STAFF REPORT FOR THE ACTION PLAN FOR THE SHASTA RIVER WATERSHED TEMPERATURE AND DISSOLVED OXYGEN TOTAL MAXIMUM DAILY LOADS

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CHAPTER 1. INTRODUCTION

1.1 Overview and Geographic Scope of TMDL

The Shasta River Total Maximum Daily Loads (TMDLs) for Temperature and Dissolved Oxygen are being established in accordance with Section 303(d) of the federal Clean Water Act (CWA). The State of California has determined that the water quality standards for the Shasta River are not being achieved due to elevated water temperature and organic enrichment/low dissolved oxygen concentrations. In accordance with CWA Section 303(d), the State of California periodically identifies those waters that are not meeting water quality standards. The United States Environmental Protection Agency (USEPA) added the Shasta River watershed to California's 303(d) List of Impaired Waters (303(d) List) in 1992 due to organic enrichment/low dissolved oxygen and in 1994 due to elevated temperature. The Shasta River watershed has continued to be identified as impaired in subsequent 303(d) listing cycles, the latest in 2002. These listings of the Shasta River watershed apply to the Shasta River from its mouth to headwaters, and include all tributaries and Lake Shastina.

Elevated water temperatures and low dissolved oxygen levels in the Shasta River and its tributaries have resulted in the impairment of designated beneficial uses of water and the non-attainment of water quality objectives. The primary adverse impacts of elevated water temperature and low dissolved oxygen in the Shasta River and its tributaries are associated with cold water fish. The cold freshwater habitat beneficial use includes the migration, spawning, reproduction, and early development of cold water fish including coho salmon (*Oncorhynchus kisutch*), Chinook salmon (*O. tshawytscha*), and steelhead trout (*O. mykiss*). The coho salmon population in this watershed is listed as threatened under the federal Endangered Species Act and the California Endangered Species Act. Elevated water temperatures and low dissolved oxygen levels may also affect recreational use, subsistence fishing, and commercial and sport fishing uses. Additionally, elevated water temperatures may be linked to impairment of the municipal and domestic water supply beneficial use of Lake Shastina.

1.2 Report Organization

The Shasta River TMDL is comprised of two distinct parts: the Staff Report and the Action Plan. This document is the Staff Report that supports and justifies the Action Plan. The content of each chapter in this Staff Report are outlined here:

- Chapter 1- Regulatory framework and watershed overview
- Chapter 2 – Temperature and dissolved oxygen conditions of the Shasta River watershed
- Chapter 3 – Factors affecting temperatures of the Shasta River watershed
- Chapter 4 – Factors affecting dissolved oxygen concentrations of the Shasta River watershed
- Chapter 5 – Analytical methods and approach
- Chapter 6 – Temperature TMDL and load allocations
- Chapter 7 – Dissolved oxygen TMDL and load allocations

- Chapter 8 - Implementation strategy
- Chapter 9 - Monitoring plan
- Chapter 10 – Reassessment
- Chapter 11 – Antidegradation analysis
- Chapter 12 – Environmental analysis
- Chapter 13 - Economic analysis
- Chapter 14 – Public participation process

The full title of the Action Plan is the *Action Plan for the Shasta River Temperature and Dissolved Oxygen Total Maximum Daily Loads*. The Action Plan, hereinafter known as the Shasta River TMDL Action Plan, includes the temperature and dissolved oxygen TMDLs and is based upon the information presented in the Staff Report. The Shasta River TMDL Action Plan is proposed as an amendment to the *Water Quality Control Plan for the North Coast Region* (Basin Plan) for adoption by the North Coast Regional Water Quality Control Board (Regional Water Board) and approval by the State Water Resources Control Board (State Water Board), Office of Administrative Law (OAL), and the United States Environmental Protection Agency (USEPA).

1.3 Regulatory Framework and Purpose

The Regional Water Board is the California State agency responsible for the protection of water quality in the Shasta River Basin. The North Coast Regional Water Board is one of nine Regional Water Boards that function as part of the California State Water Board system within the California Environmental Protection Agency. The Regional Water Board implements both the Porter-Cologne Water Quality Control Act, part of the California Water Code, and the federal Clean Water Act. Water quality standards and control measures for waters of the North Coast Region are contained in the *Water Quality Control Plan for the North Coast Region* (Basin Plan).

1.3.1 Clean Water Act Section 303(d)

Under CWA Section 303(d), states are required to develop a list of water bodies where technology based effluent limits or other legally required pollution control mechanisms are not sufficient or stringent enough to meet water quality standards applicable to such waters. The 303(d) List also identifies the pollutant/stressor causing the impairment, and establishes a prioritized schedule for addressing the water quality impairment. Placement of a water body on the 303(d) List acts as the trigger for developing a pollution control plan, called a Total Maximum Daily Load (TMDL), for each water body-pollutant/stressor combination and associated pollutant/stressor on the 303(d) List. The TMDL serves as the means to attain and maintain water quality standards for the impaired water body. The specific requirements of a TMDL are described in the United States Code of Federal Regulations (CFR) Title 40, Sections 130.2 and 130.7 (40 CFR § 130.2 and 130.7), and Section 303(d) of the CWA.

In California, the authority and responsibility to develop TMDLs rests with the Regional Water Boards. The USEPA has federal oversight authority for the CWA Section 303(d) program and may approve or disapprove TMDLs developed by the state. USEPA Region

9 is responsible for the North Coast region of California. If the USEPA disapproves a TMDL developed by the State, the USEPA is then required to establish a TMDL for the subject water body.

1.3.2 California Porter-Cologne Water Quality Control Act

In California, the Porter-Cologne Water Quality Control Act (California Water Code, Division 7, Water Quality) requires a program of implementation for a TMDL to be included into the Basin Plan (CWC § 13050(j)(3)). This program of implementation must include a description of actions necessary to achieve Basin Plan water quality objectives, a time schedule for specific actions to be taken, and a description of monitoring to determine attainment of objectives.

In March 1997 US EPA signed a consent decree addressing 17 rivers in the California North Coast, including the Shasta River (*Pacific Coast Fisherman's Association et al. v. EPA*). Under the terms of the consent decree, a court-ordered schedule for completing TMDLs for these rivers was developed. The schedule requires approval of the Shasta River TMDLs by January 2007.

1.3.3 Endangered Species Act Consultation

The USEPA and the Regional Water Board have initiated an informal consultation process with the U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration, Fisheries (NOAA Fisheries) on Klamath River Basin TMDLs, including the Shasta River. Regional Water Board and USEPA staff have used this process to provide information and updates on the TMDLs in the Klamath Basin, namely the Salmon, Scott, Shasta, Lower Lost, and Klamath River TMDLs. In addition, both NOAA Fisheries and the USFWS have participated in the Shasta River TMDL Technical Advisory Group (see Section 1.3.6) meetings.

1.3.4 What is a TMDL?

A TMDL is a planning and management tool intended to identify, quantify, and control the sources of pollution within a given watershed such that water quality objectives are achieved and the beneficial uses of water are fully protected. A TMDL is defined as the sum of the individual waste load allocations to point sources, load allocations to non-point sources and natural background loading. The amount of pollutant that a water body can receive without violating the applicable water quality objectives is the loading or assimilative capacity of the water body, and is calculated as the TMDL. Loading from all pollutant sources must not exceed the loading or assimilative capacity (TMDL) of a water body, including an appropriate margin of safety.

1.3.5 Purpose and Goals of the Shasta River TMDL Action Plan

The purpose of the Shasta River Temperature and Dissolved Oxygen TMDLs is to estimate the assimilative capacity of the system with respect to the total thermal, nutrient and oxygen-consuming loads that can be delivered to the Shasta River and its tributaries without causing an exceedance of water quality standards. The TMDLs then allocate the total loads among the identified sources of these pollutants in the watershed. Although factors other than elevated stream temperature and low dissolved oxygen in the watershed may be affecting cold water fish related beneficial uses and thus affecting salmonid populations (e.g., climate change and ocean conditions), these TMDLs focus only on stream temperature and dissolved oxygen conditions in the watershed; the impairments for which the Shasta River is listed under CWA Section 303(d).

The Action Plan component of the TMDL outlines a strategy to meet the TMDL loading allocations. The goal of the Shasta River TMDL Action Plan is to achieve the temperature and dissolved oxygen water quality objectives, and restore and protect the beneficial uses of water in the Shasta River watershed. TMDL Action Plans apply to those portions of the watershed governed by California water quality standards, and do not apply to lands under tribal jurisdiction.

1.3.6 Public Participation

The public was involved during the development of the Shasta River TMDL in several ways. Regional Water Board staff met with key stakeholder groups, including the Shasta Valley Resource Conservation District (SVRCD), Shasta River Coordinated Resource Management Planning Council, Siskiyou County Board of Supervisors, and the Klamath Basin Fisheries Task Force (KBFTF). In addition, Regional Water Board staff met with individual property owners upon request. The purpose of these meetings was to provide information on the TMDL development process and approach, to update the groups on the status of TMDL development activities, and to answer questions. Regional Water Board staff also regularly attended the public meetings of the Shasta-Scott Coho Recovery Team to assure that recommendations regarding coho salmon recovery were consistent with the TMDLs.

In January 2003, Regional Water Board staff organized the Shasta River TMDL Technical Advisory Group (TAG). The TAG was composed of individuals familiar with the water resources of the Shasta Valley including landowners and representatives of irrigation districts, municipalities, resource management agencies, tribes, and regulatory agencies. The purpose of the TAG is to advise Regional Water Board staff on issues relating to the development of the Shasta River TMDLs.

1.4 Watershed Overview

1.4.1 Area and Location

The Shasta River drains a 795 square mile basin in northern California, within Siskiyou County, and flows generally northward into the Klamath River (Figure 1.1 and Figure 1.2). The Shasta River watershed is bounded to the north by the Siskiyou Range, to the west by the Klamath Mountains, to the east by the Cascade Range, and to the south by Mt. Shasta and Mt. Eddy (SVRCD Undated). The watershed shares divides with the Scott River to the west, Butte Creek to the east, and the Trinity and Sacramento Rivers to the south.

1.4.2 Population

The population of the Shasta River basin is estimated at about 16,000. The majority of the population in this basin is centered around towns including Yreka, Weed, Montague,

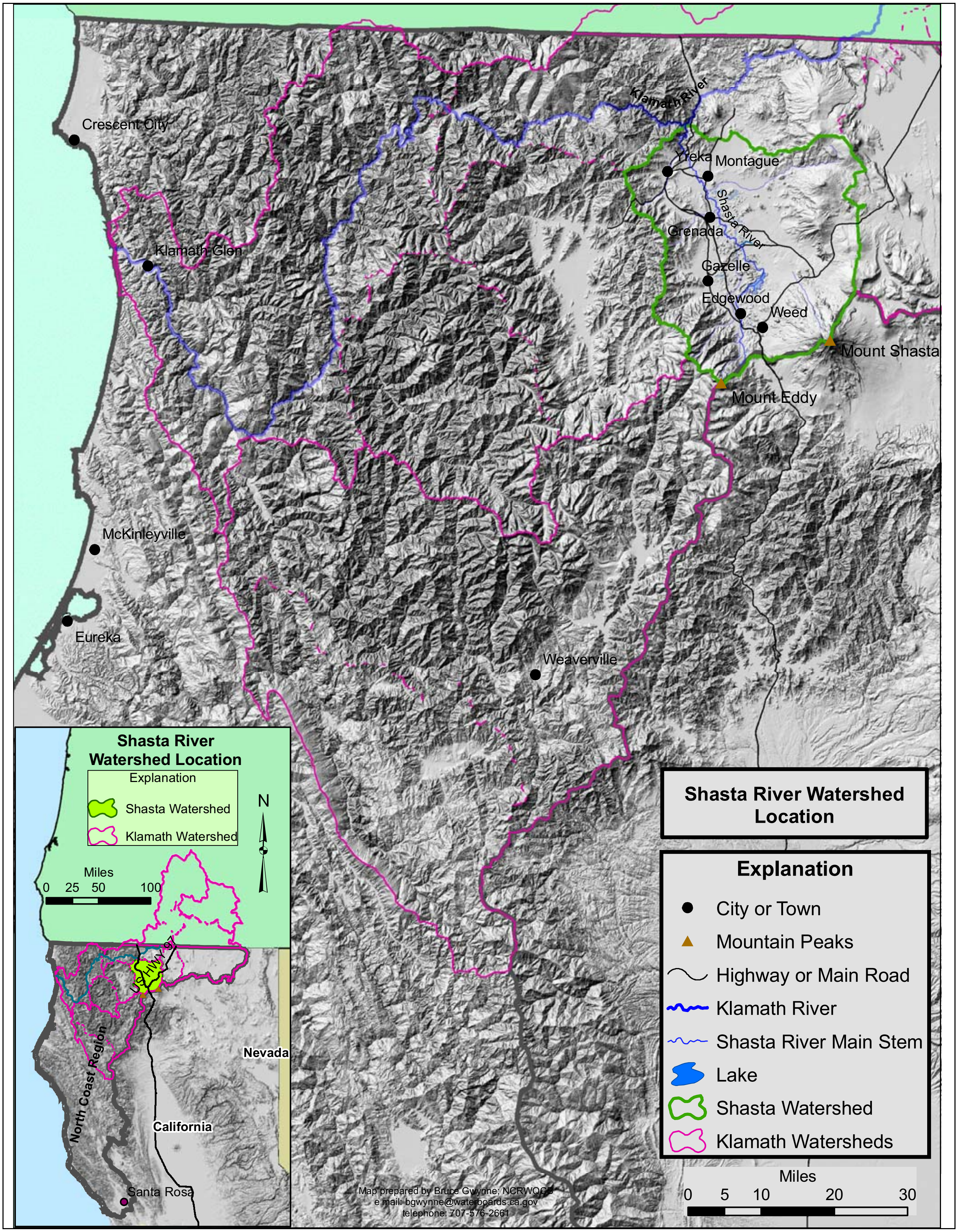


Figure 1.1: Shasta River Watershed – Location

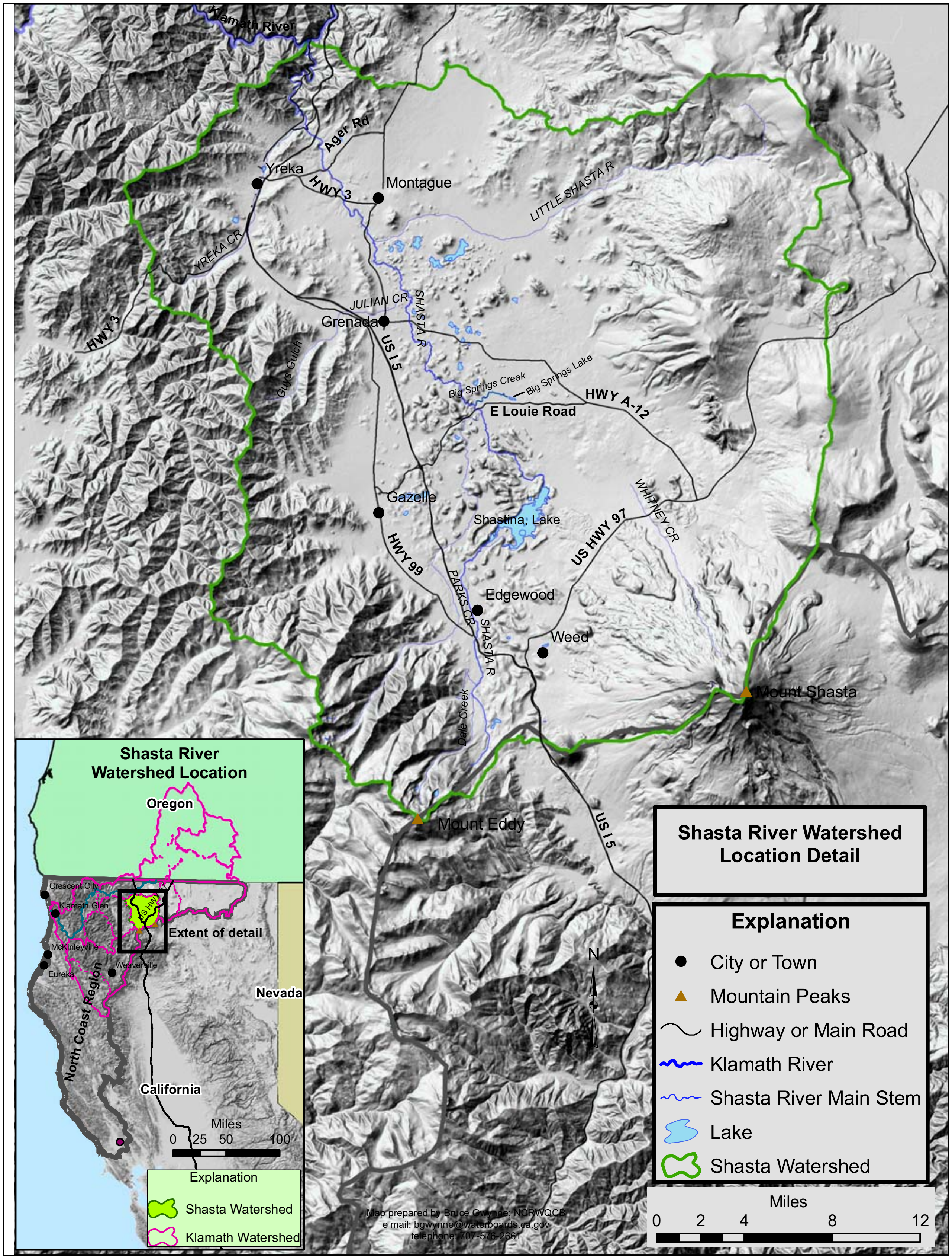


Figure 1.2: Shasta River Watershed – Location Detail

Grenada, Gazelle, and Edgewood. The largest town in the basin is Yreka, with a population of 7,290 according to 2000 census information (United States Census Bureau [USCB] Undated). This census estimated the population of Weed at 2,978 people, 1,456 people in Montague, 315 in Grenada, 136 in Gazelle, and 67 in Edgewood (USCB Undated).

1.4.3 Climate

The Shasta River basin is predominantly a low rainfall, high desert environment characterized by hot, dry summers and cool winters (Ouzel Enterprises 1991, p.1-5; SVRCD Undated). Temperatures range from above 100°F in the summer to below freezing in the winter. Typically there are about 130 frost-free days a year (SVRCD Undated).

Annual mean precipitation in the basin ranges from a low of 2.5-9 up to 85-125 inches, with much of the winter precipitation falling as snow (Figure 1.3). Average annual precipitation can reach 45 inches in the Eddy and Klamath Mountains and ranges from 85-125 inches at Mt. Shasta. Although average rainfall is high in the mountains, moist air masses are stripped of their water as they move eastward from the Pacific and climb over the Klamath Mountains (Klamath Resource Information System [KRIS] 2005). Thus, the Shasta Valley is in the rain shadow created by these mountains and receives as little as 2.5-9 inches of precipitation annually.

1.4.4 Topography

The watershed consists of two major types of topography, the low-gradient floor of the Shasta Valley, and surrounding steep mountains, punctuated by Mt. Shasta at the southern border of the Basin (Figure 1.4). The river drops about 220 feet in elevation in the valley. Throughout the valley are small hillocks that are deposited debris from a huge avalanche and debris flow that occurred more than 300,000 years ago (Crandell 1989). In the canyon section of the watershed, downstream of the valley, the Shasta River descends approximately 370 feet in approximately 7 miles to its confluence with the Klamath River. Watershed elevations range from approximately 2020 feet at the confluence with the Klamath River to a peak elevation of 14,200 feet at the summit of Mt. Shasta (KRIS 2005; SVRCD Undated).

1.4.5 Water Bodies and Hydrology

The Shasta River originates in the Scott Mountains on the north slope of Mt. Eddy as a precipitation and snow melt based stream. Mt. Shasta contributes significantly to the hydrology of the basin. With an elevation exceeding 14,000 feet, Mt. Shasta has permanent (and growing) glaciers, which provide a constant source of surface and spring flows. The melted snow percolates down through lava tubes on the mountain and pops up as springs on the Shasta Valley floor. These springs and others in the Little Shasta River watershed, along with mountain precipitation, are the source of flow in the Shasta River.

The predominantly volcanic groundwater units in the basin provide storage and recharge areas both inside and outside the basin. Due to the complexity of this extensive network of volcanic recharge/storage areas, however, the amount of groundwater in storage has not been estimated (Department of Water Resources [DWR] 2004).

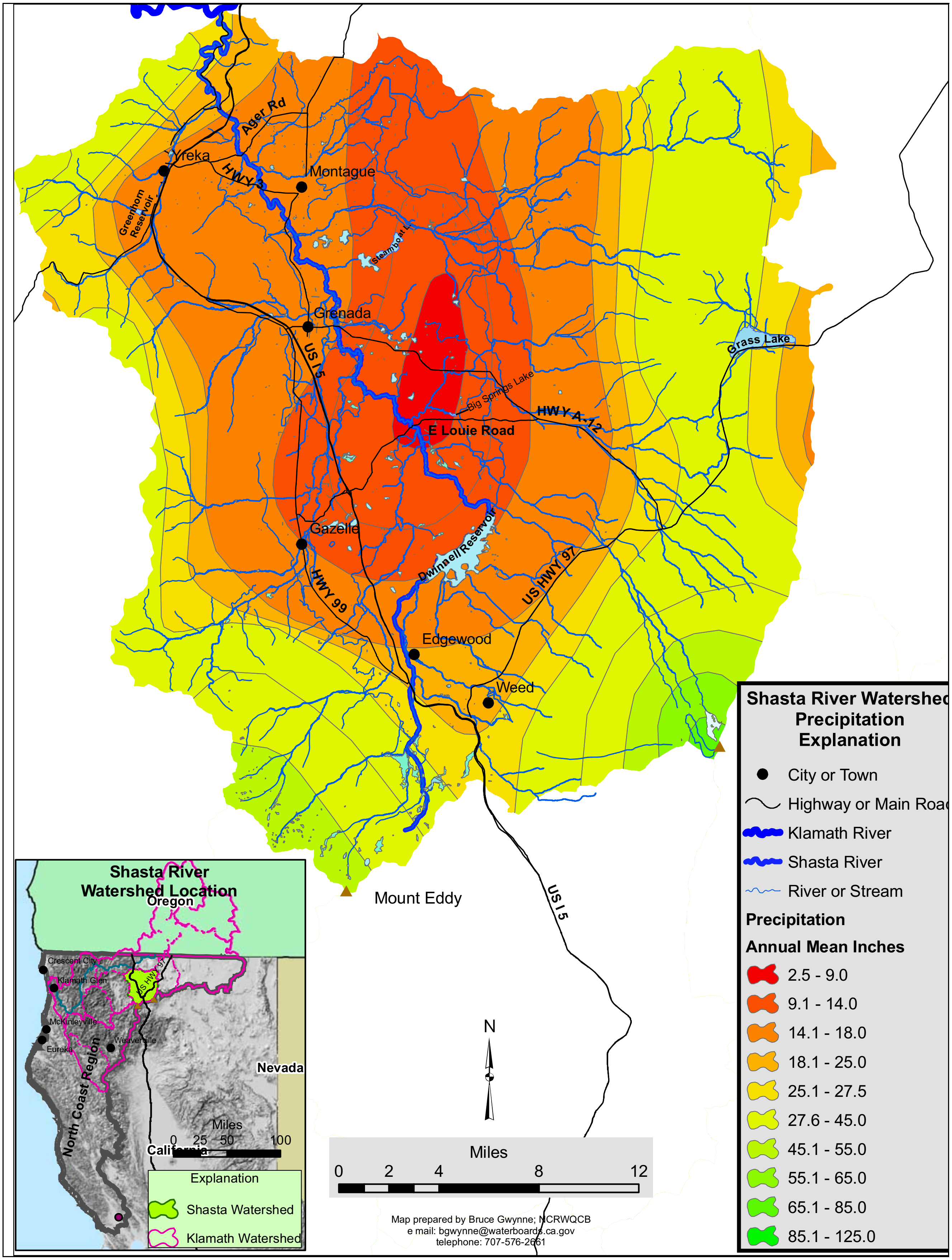


Figure 1.3: Shasta River Watershed - Rainfall

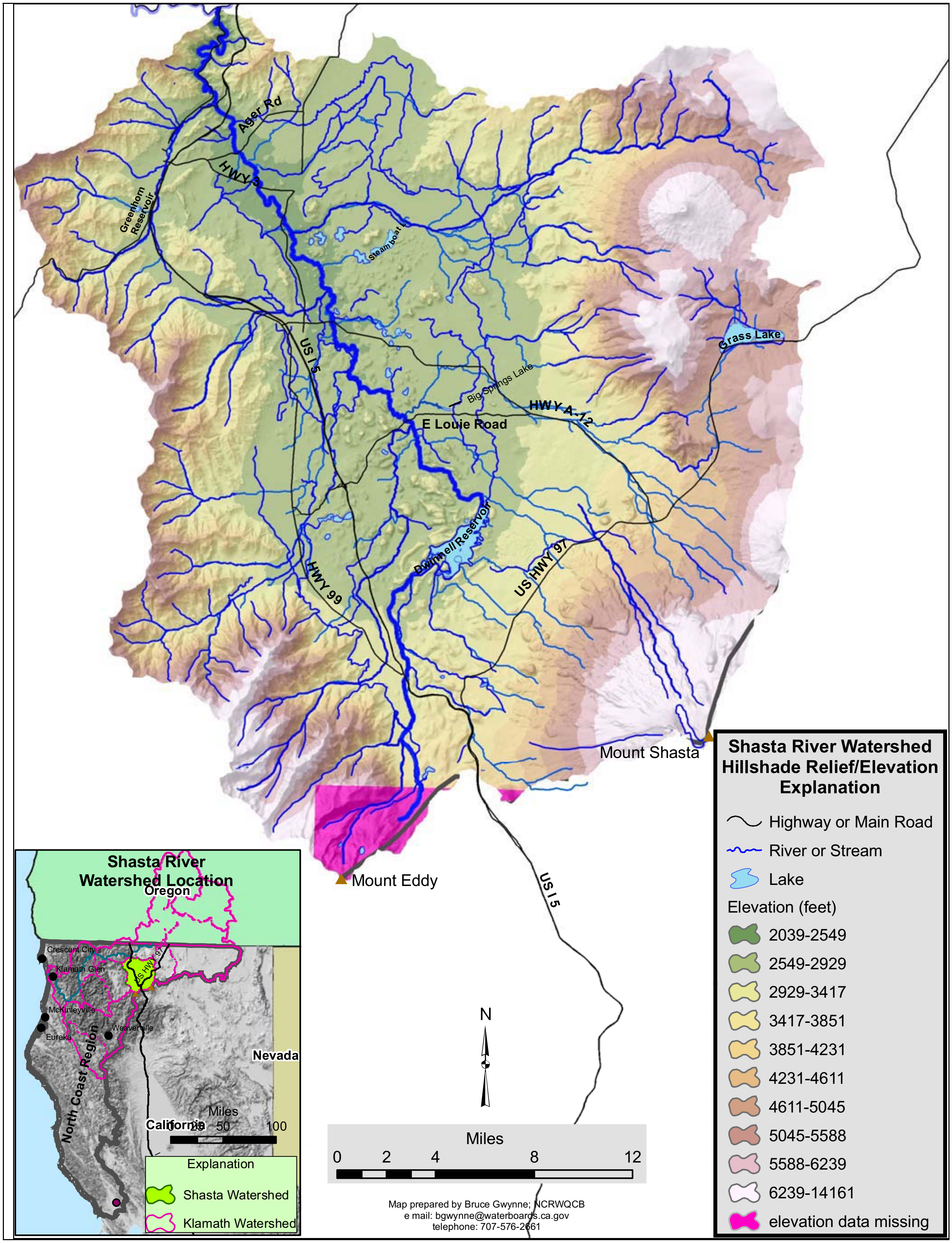


Figure 1.4: Shasta River Watershed - Elevation

From its origin in the Scott Mountains the Shasta River flows north and northwestward for approximately 60 miles before entering the Klamath River at Klamath River Mile (RM) 176.8. The river is dammed at Shasta RM 40.6 by Dwinnell Dam, which impounds Lake Shastina (also called Dwinnell Reservoir) to provide water storage for agricultural use, municipal supply for the town of Montague, and recreational use; but has no scheduled instream flow release. Shasta River Miles at select locations are identified in Figure 1.5.

Tributaries to the Shasta River include Eddy, Boles, Beaughton, Carrick, Julian, Jackson, Parks, Big Springs, Willow, and Yreka Creeks, Guys Gulch, Oregon Slough and the Little Shasta River (Figure 1.6). There are only minor tributaries in the canyon (lower 7.3 miles).

Construction of Dwinnell Dam was completed in 1928 as a water supply project for the Montague Water Conservation District (MWCD). Besides the dam and the reservoir, MWCD owns 60 miles of canals (the main canal is approximately 35 miles long) and lateral ditches to direct water into and away from Lake Shastina to farmers during the irrigation season. Although a relatively small reservoir, with a capacity of approximately 50,000 acre-feet, the reservoir only fills in above normal runoff years due to the relatively modest yield from upstream watershed areas, seasonal water use, and appreciable seepage loss (6,500 to 42,000 acre-feet per year) from the reservoir.

Relatively high precipitation in the area of the watershed above Lake Shastina creates precipitation-based flow in Dale and Eddy Creeks and the Shasta River. Spring flows from the flanks of Mount Shasta to Boles Creek, Beaughton Creek, and Carrick Creek account for much of the inflow to Lake Shastina. Flows can be flashy in Dale Creek, Eddy Creek, and the Shasta River, while flows in the spring fed creeks tend to be more stable and provide reliable base flows in wet and dry years. Parks Creek is spring fed from Mt. Eddy, and substantial flows are diverted into the Shasta River above Dwinnell Dam for storage in Lake Shastina by the MWCD. Based on United States Geologic Survey (USGS) and Department of Water Resources (DWR) Watermaster reports, the mean annual flow for the Shasta River at Edgewood Road (located upstream of Lake Shastina and including Parks Creek diversion flows) is approximately 60,000 acre-feet (Figure 1.7).

Releases of stored water to the Shasta River channel below Dwinnell Dam range from 0 to approximately 10 cubic feet per second (cfs) (approximately 20 acre feet per day) during the irrigation season. Releases to the Shasta River are delivered on an as-needed basis to provide water to several landowners downstream of Dwinnell Dam in lieu of their historic water rights that were blocked by construction of the dam (Vignola and Deas 2005).

Between Dwinnell Dam (RM 40.6) and the canyon (RM 7.3) the Shasta River meanders along the Valley floor, and is slow moving and sluggish with much of the shoreline covered by bullrush (tules) and to a lesser extent cattails (Ouzel Enterprises 1991, p.1-5). Numerous accretions from tributaries (including Big Springs, Parks, Willow, Julian, and Yreka Creeks, and Oregon Slough and the Little Shasta River), springs, and agricultural diversions, and return flows in this portion of the river contribute to a complex flow regime (Deas et al. 2003, p.i). During summer months Big Springs Creek inflow accounts for up to 50% of the flow in the river below Big Springs Creek.

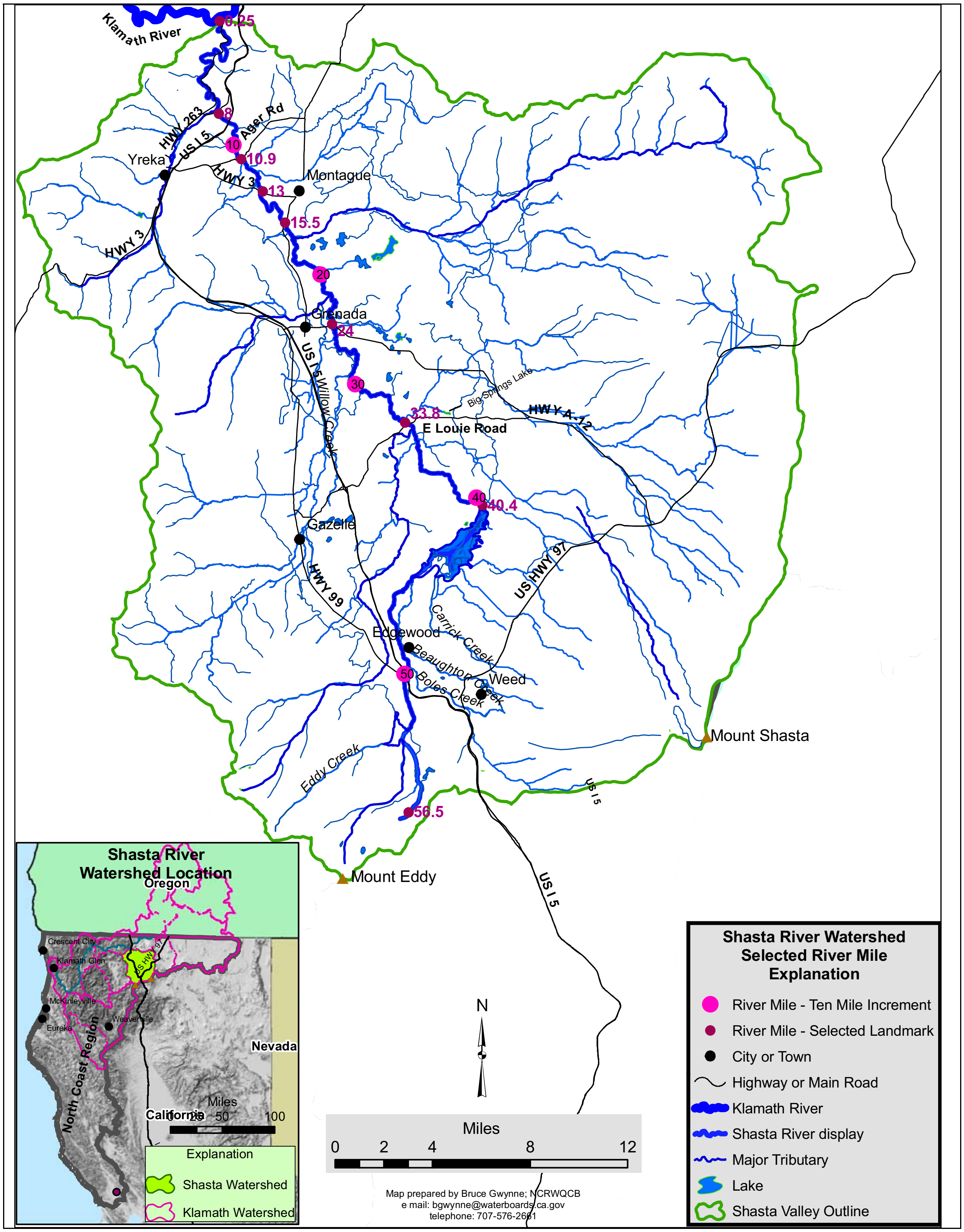


Figure 1.5: Shasta River Miles at Select Locations

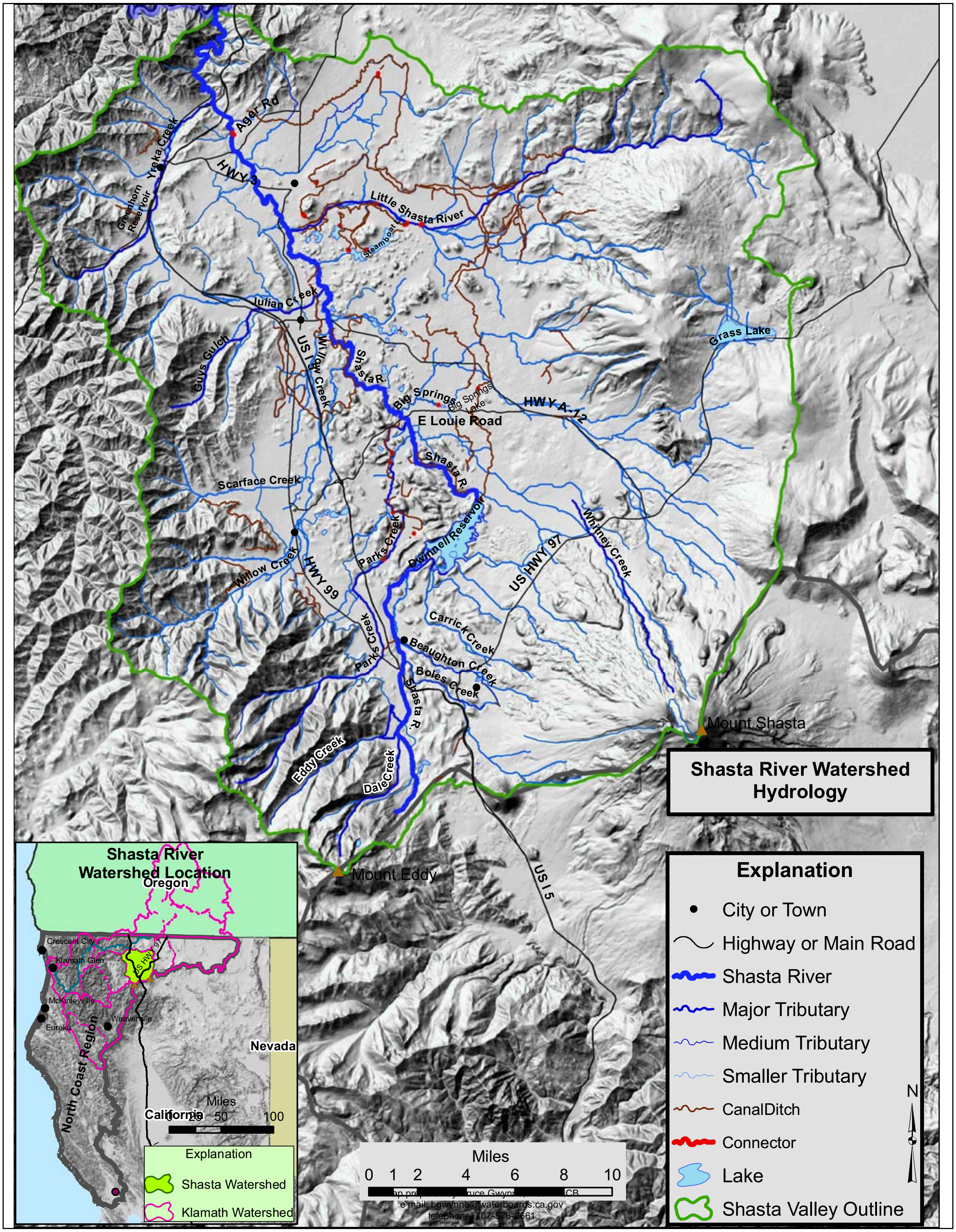


Figure 1.6: Shasta River Watershed - Waterbodies

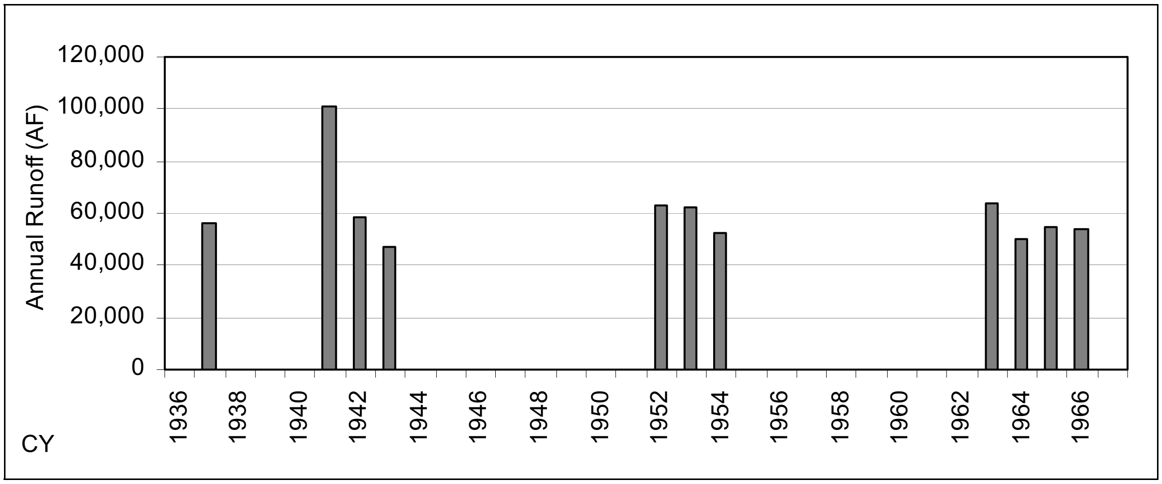


Figure 1.7: Annual Flow at Edgewood
Source: Vignola and Deas 2005. Data presented only for years with complete data record.

There are currently two real-time flow gauges on the Shasta River, both operated by USGS. One is located near Montague at RM 15.5 and is operated by USGS on behalf of DWR (station #11517000 [DWR Weir]). The other is located near the mouth (called the Yreka station, #11517500 [USGS Gage]) at RM 0.6. Flow records at the Montague station are available for 19 years during the period from 1911-1933, and 2001-2004. Flow records at the Yreka station are available from 1933 to the present.

Mean annual flow at the Yreka station for the period 1933 to 2004 is 133,000 acre-feet, with annual flows ranging from 56,000 to 264,000 acre-feet (Figure 1.8). As shown in Figure 1.8, annual Shasta River discharge responds to varying annual precipitation measured at Yreka. Flows are considerably lower during summer months compared to winter months, with typical summer season flows less than 5000 acre-feet (Figure 1.9). Finally, a review of recent Shasta River flow records shows that flows drop at the onset of the irrigation season (around April 1) and increase at the end of the irrigation season (around October 1) (Figure 1.10).

1.4.6 Geology and Soils

The Shasta River watershed spans the junction between two major geologic/geomorphic provinces. Mount Shasta and the mountains on the east side of Shasta Valley are formed of relatively young Cenozoic volcanic and intrusive rocks and are part of the Cascade Range volcanic province. The mountains on the west side of the watershed are older Franciscan rocks of the Klamath Mountains province. The valley floor between these major provinces are mostly alluvium. However, a single area stands out as unique: a gigantic landslide deposit that covers about 180 square miles. The geology of the watershed is considered below in terms of the Cascade volcanic province, the Franciscan province, and alluvial and landslide units within the valley deposits (Figure 1.11).

The mountains of the Cascade province are primarily igneous rocks that have been erupted to the surface. Some are intrusive igneous rocks that were not erupted to the surface but have been exposed by erosion. This area has undergone some uplift, but the rocks are not strongly deformed.

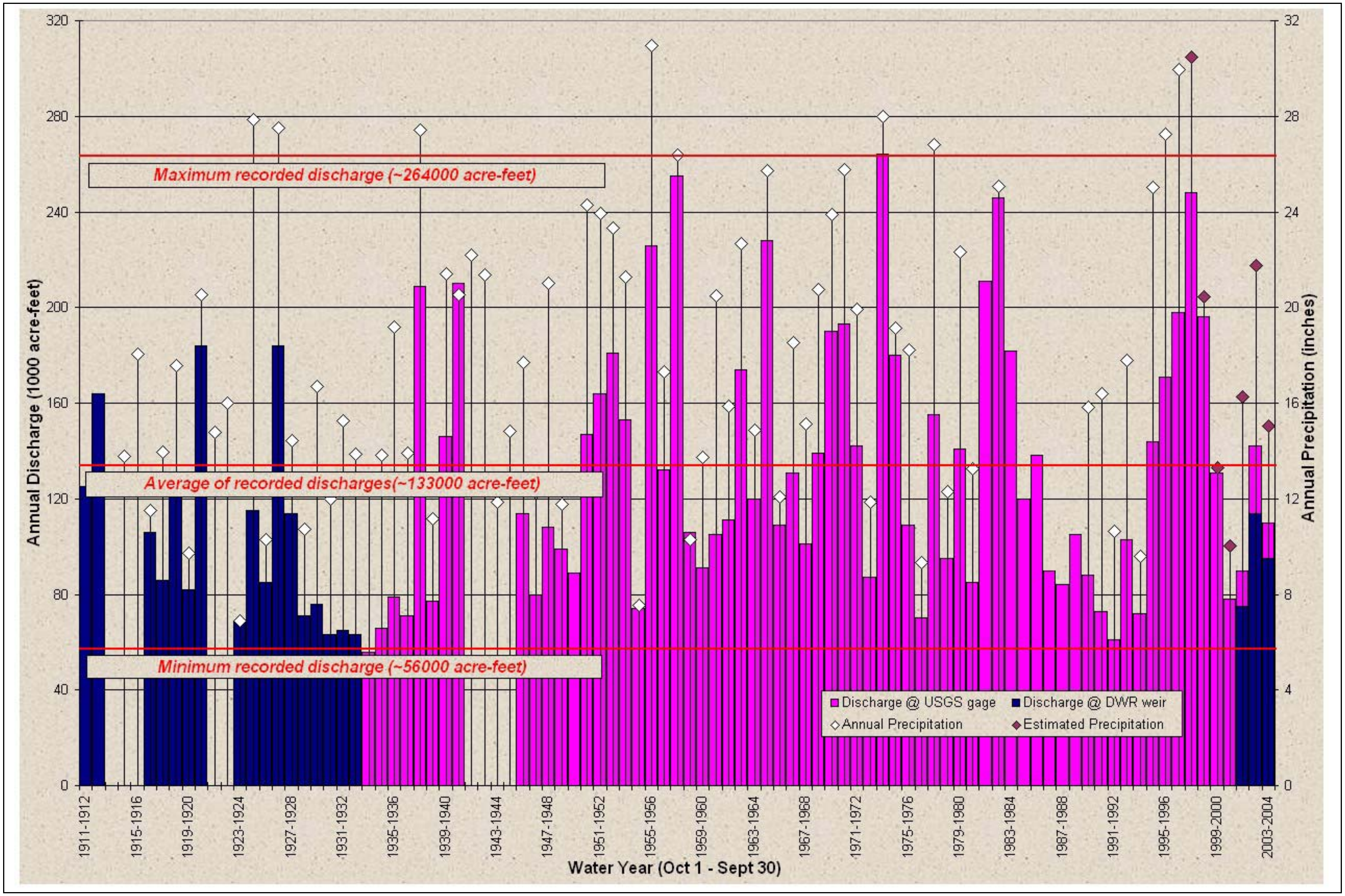


Figure 1.8: Shasta River Annual Discharge and Precipitation, 1911-2004
Note: Flow records from USGS; precipitation records from NOAA National Climatic Data Center.

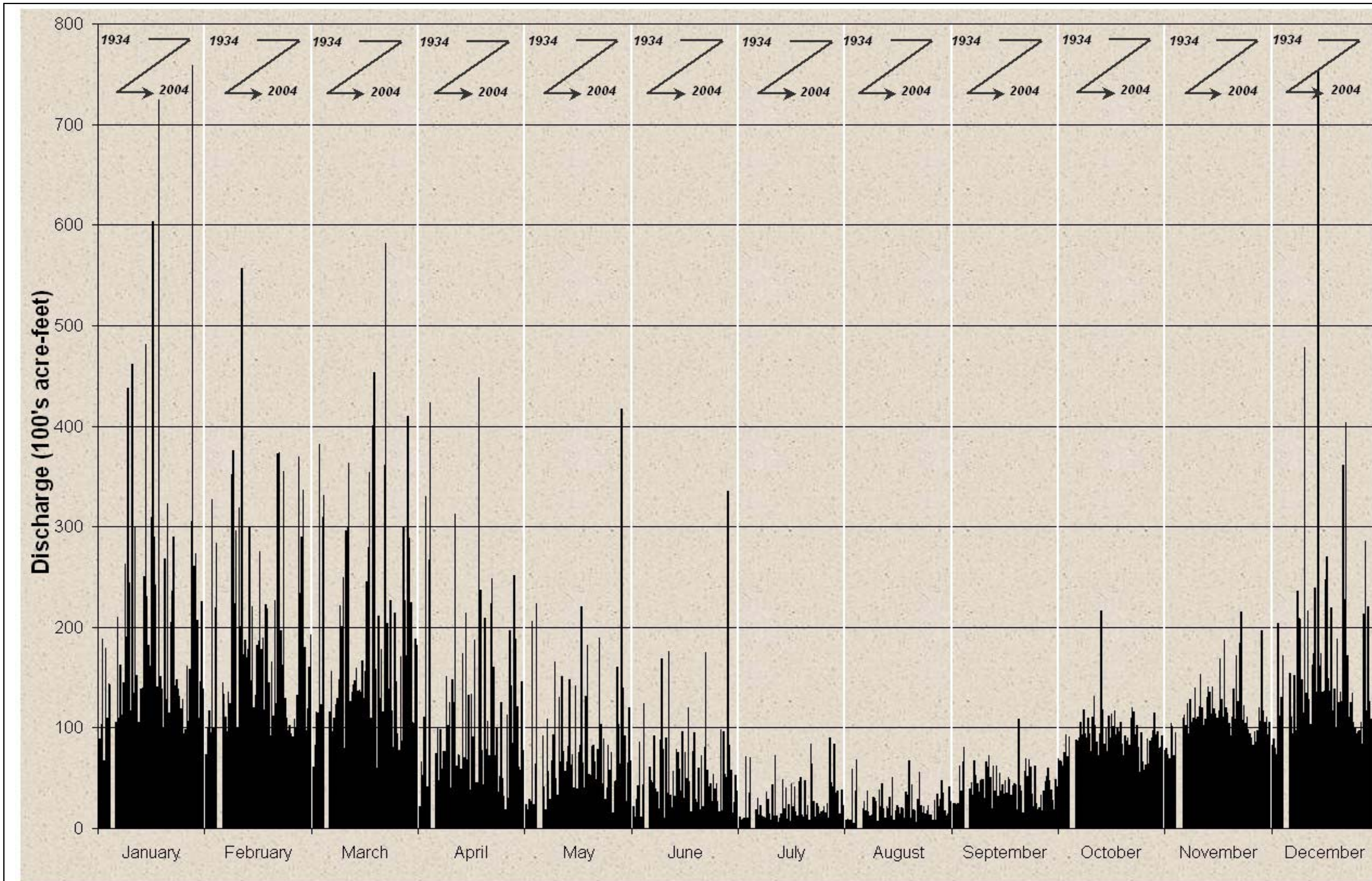


Figure 1.9: Monthly Shasta River Discharge, 1934–2004

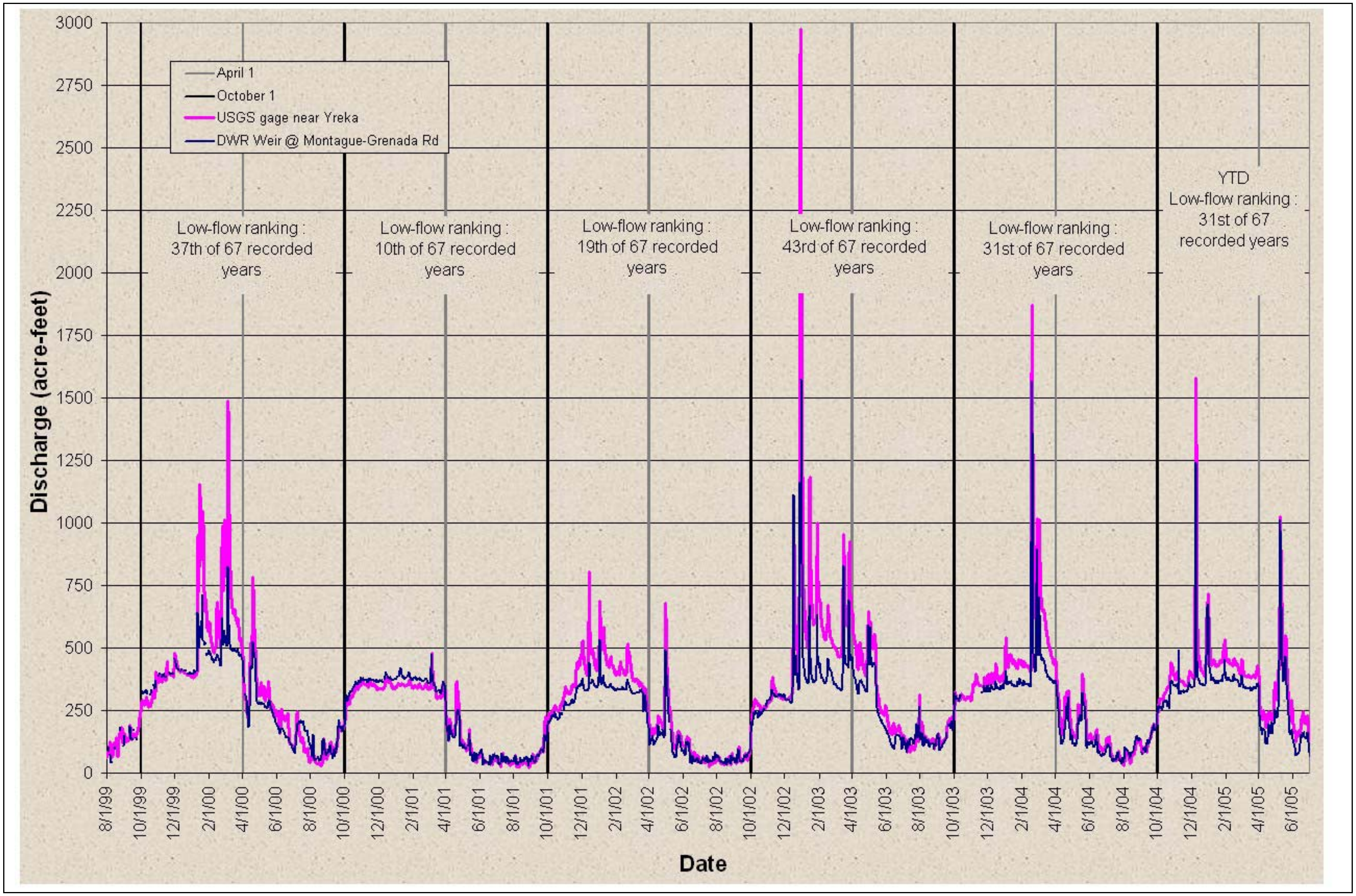


Figure 1.10: Seasonal Discharge Variation, Shasta River at DWR Weir and USGS Gage, 1999-2005

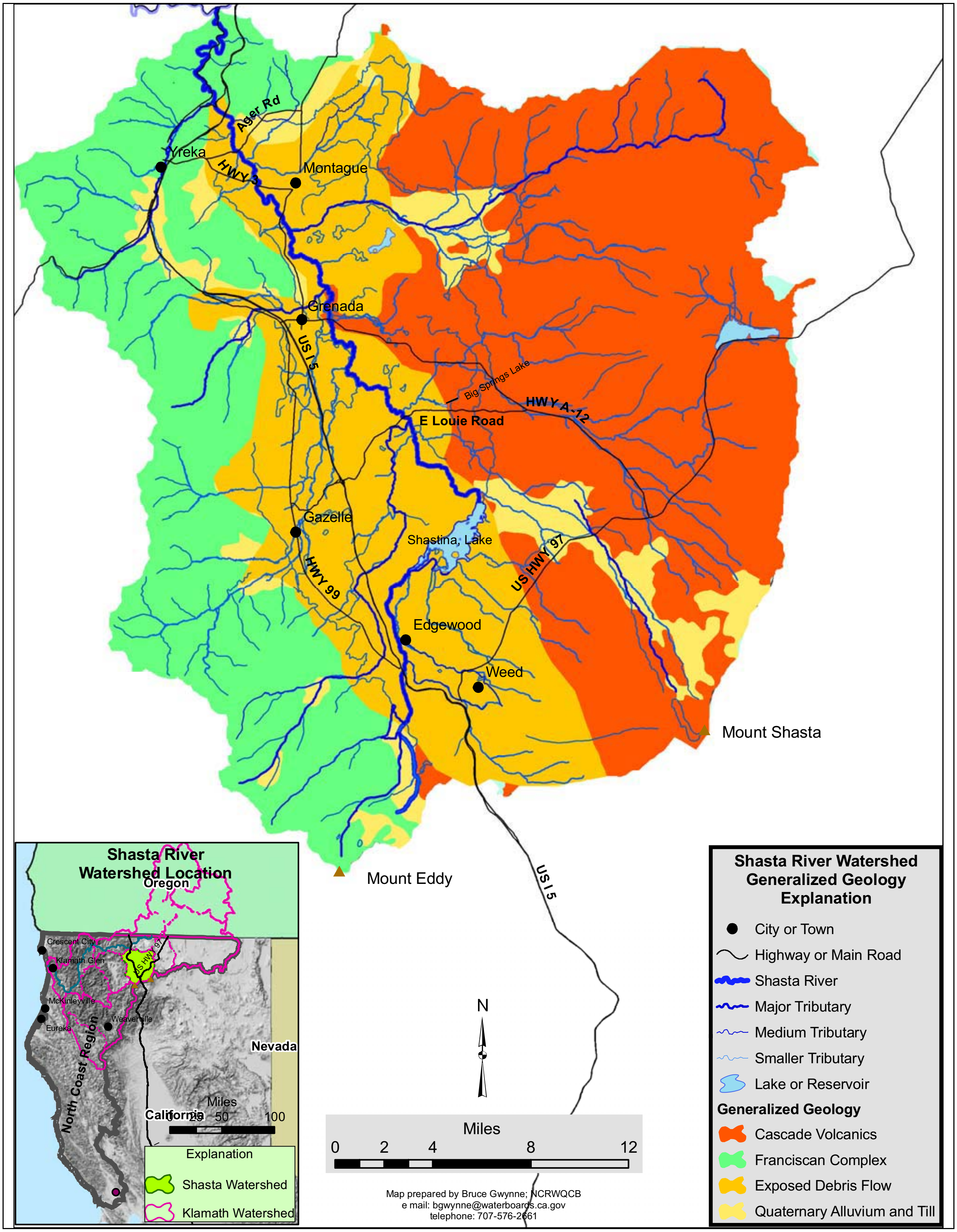


Figure 1.11: Shasta River Watershed – Geology

The mountains along the west side of the watershed are underlain by older rocks of the Franciscan Group. This suite of rocks is highly varied and includes high and medium grade metamorphic rocks, slightly metamorphosed sedimentary rocks and volcanics, granite and diorite, mafic and ultramafic rocks that are largely altered to serpentine, and small amounts of limestone. This complex has been deformed by folding, intense shearing, and thrust faulting. Deformation in the last 1-2 million years has resulted in uplift of the mountains along the west flank of the Shasta Valley.

Quaternary deposits of much of the floor of the Shasta Valley and the major tributary valleys are gravel, sand, and silt brought into the valley from the adjoining mountains by streams and mudflows. These deposits form the substrate for much of the agriculture in the valley. In the Cascades, some of the Quaternary deposits in the higher valleys are glacial deposits.

The geologic origin of deposits in a large area along the axis of Shasta Valley was not understood until 1989. This is a hummocky area having many closed depressions and little integrated drainage in many parts. It is underlain by unsorted rocky debris. Crandell (1989) interpreted this area as the deposit of a gigantic debris avalanche, or avalanches, that originated on the north slope of a mountain preceding the current Mount Shasta in Pleistocene time. This interpretation is generally accepted and explains the disrupted topography and large area of fragmental material. The deposit extends northward to the head of the Shasta Canyon, where erosion has effectively removed nearly all traces of its toe, where the Shasta River meets the Klamath.

The implication of the underlying geology of the Shasta basin is that much of the soil in the basin is of volcanic origin, and therefore can have high levels of phosphorus. These natural sources of phosphorus contribute to relatively high concentrations of inorganic phosphorus in the Shasta River.

1.4.7 Vegetation

The vegetation of the Shasta River watershed is heterogeneous and is reflective of the climatic variation that occurs in the watershed (Figure 1.12). Conifer tree species are the most common vegetation in the mountainous regions of the watershed. Herbaceous plants, including agricultural crops, dominate the valley region.

1.4.7.1 Woody Riparian Vegetation of the Shasta River

The following discussion is based upon information found in Deas et al. (1997). Woody riparian vegetation along the Shasta River varies both in its extent and location, ranging from areas completely absent of woody vegetation to areas of dense riparian forest. There are few areas along the river that can be considered a riparian "forest," characterized by a thicket of trees on both banks and extending more than one tree width from the top of the bank. However, there are locations where woody riparian vegetation forms roughly continuous rows of trees lining the river banks. In general there is little breadth (distance perpendicular to the axis of the river) to these rows of riparian vegetation. These roughly continuous rows of trees occur intermittently in places from Dwinnell Dam (RM 40.6) to south of Highway A-12 (RM 24.1) and from south of

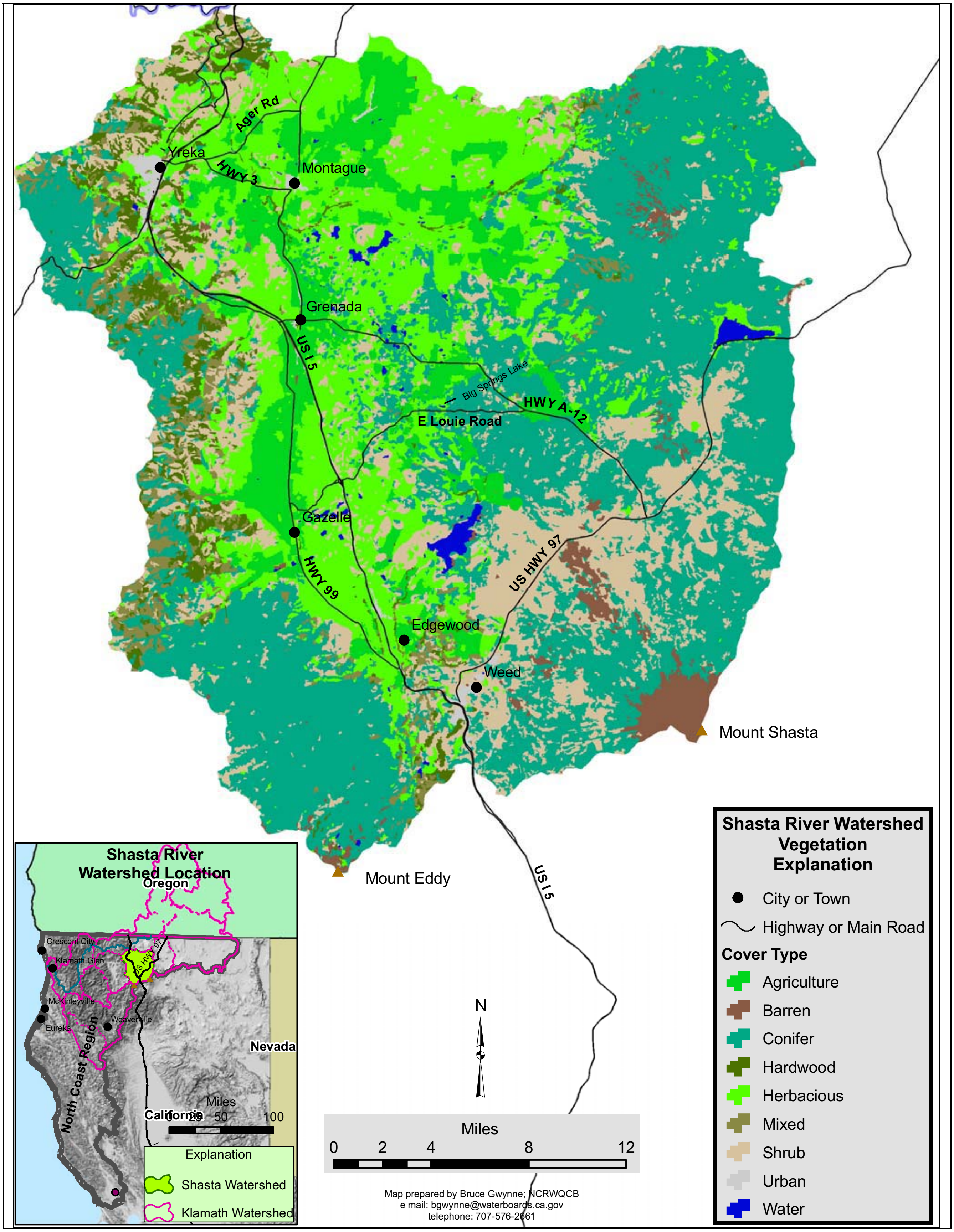


Figure 1.12: Shasta River Watershed – Vegetation and Land Use

Montague-Grenada Road near Breceda Lane (RM 16.5) to the mouth of the Shasta River (RM 0). Although other reaches of the river also have continuous vegetation, it generally occurs in intermittent areas and on one side of the bank or the other. In the area of the Shasta River between Highway A-12 to Montague-Grenada Road woody riparian vegetation is generally absent.

Table 1.1 includes a list of riparian tree species native to the Shasta Valley. In 2001, a survey of Shasta River riparian tree heights was conducted (Watercourse Engineering, Inc. 2004), and the results are summarized in Table 1.1.

Table 1.1: Tree Species and Height Statistics for Shasta River Riparian Vegetation

Common Name	**Scientific Name**	**Range of Height (ft)**	**Average Height (ft)**	**Sample Size**
While Alder	*Alnus rhombifolia*	21-35	27	3
Oregon Ash	*Fraxinus latifolia*	17-37	27	4
Black Cottonwood	*Populus trichocarpa*	32-45	39	2
Red Birch	*Betula fontanalis*	16-36	24	7
Oregon White Oak	*Quercus garryana*	55-73	64	2
Red Willow	*Salix laevigata*	-	-	-
Arroyo Willow	*Salix lasiolepsis var.bracelinea*	20-54	38	23
Pacific Willow	*Salix lasiandra*	-	-	-
Sandbar Willow	*Salix hindsiana*	13-35	22	27

In 2004 a follow-up survey of riparian vegetation was conducted (Appendix A, *Shasta River Water Quality Related Investigations-2004*) whereby riparian conditions were classified by tree density, as follows:

Description	Riparian Category
No trees	0
Less than 2 trees per 100 feet	1
Greater than 2 trees per 100 feet	2
Gallery Forest	3

Results of the 2004 survey are presented in Table 1.2.

Table 1.2: Shasta River Riparian Classification

Downstream River Mile	**Upstream River Mile**	**Length (Miles)**	**Riparian Category**
0.17	0.67	0.5	2
1	2.87	1.87	1
4.05	4.51	0.46	2
5.73	6.58	0.85	2
8.58	10.53	1.95	2
10.54	14.64	4.1	1
14.65	16.09	1.44	2
16.1	19.26	3.16	0
19.26	19.72	0.46	2
19.72	21.64	1.92	0
21.64	21.98	0.34	2
21.98	25.82	3.84	0
27.48	28.33	0.85	0
28.33	28.9	0.57	2
28.9	32.42	3.52	0
37.84	38.87	1.03	1
39.92	40.22	0.3	2

Note: Riparian Classification was identified only where river access was granted.

1.4.8 History and Land Use

Information on the history and land use of the Shasta River basin is synthesized from the following sources: DWR (1964, p.15-16), Siskiyou County Library (2000), SVRCD (2005b), and United States Department of Agriculture [USDA] (1983, p.1-4).

The Shasta Nation ancestral territory included much of the Shasta Valley. The first European exploration of Siskiyou County and the Shasta basin was in the late 1820s, when fur trappers from the Hudson's Bay Company entered the area in search of pelts. These explorers were soon followed by cattle drovers, bringing cattle from the Sacramento Valley to the Oregon settlements. With the exception of small military missions, these were the only explorers to the area until the 1849 gold rush, which established the first permanent settlers in the basin. The first discovery of gold in Siskiyou County was near the town of Yreka in 1851, and in a few months there were over 2,000 miners working in the area.

With the increased population came an increased need for food, supplies, and lumber. Many ranchers, farmers, and businessmen followed the gold rush settling in the area. By the early 1900s, farming, ranching, and timber harvest were the dominant land uses within the basin.

Today the economy of the Shasta River basin is mainly supported through agriculture and ranching, although lumber mills in the Shasta Valley also contribute to the economy. Cow-calf operations extend throughout much of the Shasta basin, supported by irrigated pasture and hay fields, as well as dry upland grazing lands. Due to local springtime flooding and a short growing season, crops grown in the Shasta Valley are limited to grass for hay and pasture, alfalfa and small grains grown for local and outside livestock feed, and a small selection of row crops.

Timber harvest and associated road building were heavy in parts of the watershed into the 1960s. Today, only limited timber harvest occurs in parts of the watershed on both US Forest Service and private lands. There are currently two active sawmills within the watershed, though much of the milled lumber is harvested outside the watershed.

Recreation has become an important industry for the area. Mount Shasta is a popular place for both downhill and cross country skiing during the winter, and for hiking and mountain climbing in the summer. Lake Shastina, mountain lakes, and streams are kept stocked with trout, and wildlife is abundant.

Though still dominated by agricultural land and open space, the Shasta Valley is experiencing increased residential development and associated urbanization. Urbanization is most evident within established urban areas such as the City of Yreka, but is also occurring in lower elevation areas through out the basin, along the Interstate 5 corridor, and around Lake Shastina. Lot splits and subdivision of agricultural land are on the rise.

1.4.9 Water Resource Management

Information on water resource management is synthesized from the following sources: California Department of Fish and Game [CDFG] (1997), DWR (1964, p.55-61), Klamath River Basin Fisheries Task Force [KRBFTF] (1991), State of California Department of Public Works [CADPW] (1932), and SVRCD (2005b).

Shasta Basin water resources have been managed for irrigation and stock watering, municipal drinking water supply, and small hydropower generation. The first hydroelectric power generation facility was built in the Shasta canyon in 1892. One small non-commercial hydro facility is in operation today.

Agricultural use of water in the Shasta River basin began with the settlement of miners in the early 1850s. By the 1940s, gold mining had diminished in the basin and agricultural development became the economic focus, resulting in increased irrigation and water use. In the early 1900s, four water service agencies were formed in the Shasta basin. The Shasta River Water Users Association (SRWA) is a corporation formed in 1912. The SRWA serves an area near the town of Montague along the west side of the Shasta Valley. The Grenada Irrigation District (GID), Montague Water Conservation District (MWCD), and Big Springs Irrigation District (BSID) formed under the California Irrigation District Act in 1921, 1925, and 1927, respectively. The GID (formerly known as the Lucerne Water District) serves the area located west of the town of Grenada. Succeeding the Big Springs Water Company (organized in 1913), the BSID serves the area north of Big Springs Lake. The MWCD, also known as the Montague Irrigation District, serves the irrigation needs of the Little Shasta Valley and the northeast part of the Shasta Valley.

The Shasta River is fully appropriated from May 1 through October 31 (SWRCB 1998). In the 1920s, surface waters of the Shasta River were subject to a statutory adjudication and on December 30, 1932 the Superior Court of California issued its judgment and decree that quantifies the amount and priority date of each surface water right on the river. Since 1934, the Department of Water Resources (DWR) Watermaster Service has managed the delivery of the adjudicated water rights using a weir located at RM 15.5. The watermaster's job is to apportion available water in order of priority of right, many are fairly far downstream in the Shasta basin. Water users along the riparian zone of the Shasta River below Dwinnell Dam and groundwater withdrawals are not subject to the adjudication. A summary of the water rights for the Shasta River basin during irrigation and non-irrigation season is presented in Table 1.3.

Winter storage of the Shasta River and Parks Creek in Lake Shastina in the amount of up to 70,000 acre-feet is appropriated to the Montague Water Conservation District during April 1 through October 1. This water is for the irrigation of approximately 10,000 acres within the boundaries of the MWCD, and use by the Town of Montague as its drinking water supply. With the exception of above normal water years when Lake Shastina is full, the only flow releases made to the Shasta River below the dam are those intended to satisfy the needs of several small users immediately downstream of the dam.

There are approximately 15 diversions on the mainstem Shasta River between Dwinnell Dam (RM 40.6) and Highway A-12 (RM 24.1) with a maximum diversion quantity totaling approximately 120 cfs. In some years major diversions in this reach are restricted during the summer to ensure that shortages do not occur downstream. There are currently approximately 27 diversions along the length of Parks Creek totaling a maximum diversion quantity of 46.2 cfs, although full diversion of this quantity of water is unlikely to be available throughout the summer.

Table 1.3: Summary of the 1932 Appropriation of Water Rights in the Shasta Basin

IRRIGATION SEASON	
Location	**Appropriation (cfs)**
Shasta River above the confluence of Big Springs Creek	111.4
Boles Creek and Tributaries	17.6
Beaughan Creek and Tributaries	10.3
Jackson Creek and Tributaries	2.8
Carrick Creek and Tributaries	11.7
Parks Creek and Tributaries	56.3
Shasta River below the confluence of Big Springs Creek and Big Springs Creek and Tributaries	184.8
Little Shasta River and Tributaries	90.0
Willow Creek and Tributaries	55.7
Yreka Creek and Tributaries	36.0
Miscellaneous Independent Springs, Gulches, and Sloughs	32.9
Total	**609.5**
NON-IRRIGATION SEASON	
Location	**Appropriation (cfs)**
Shasta River and its Tributaries	327.4

Source: CADPW 1932, p.247-314

The Big Springs Irrigation District has rights to 30 cfs from Big Springs Lake (feeding Big Springs Creek which enters the Shasta River at RM 33.71) to be used within the boundary of its district. However, since the late 1980s, the BSID has used groundwater in lieu of water diverted from Big Springs Lake.

The Grenada Irrigation District has a right to 40 cfs from the Shasta River for the period April 1 through October 1, which is diverted at RM 30.58. This water is designated for irrigation of approximately 1,700 acres within the GID. Prior downstream water rights, totaling about 80 cfs, have limited the ability of GID to take its full entitlement in some years.

In the mainstem Shasta from Highway A-12 (RM 24.1) to Yreka Creek (RM 7.7), about 16 small diversions are found with a combined maximum diversion quantity (not including diversions from Willow Creek) of approximately 27 cfs. On the Little Shasta River, current records indicate a total maximum diversion quantity of 85.6 cfs from approximately 29 diversions, although by the end of the summer most of these water users are severely restricted.

In addition to the above mentioned small diversions, the Shasta River Water Users Association has rights to 42 cfs from the Shasta River diverted at RM 17.8 during the period from April 1-Oct 1 to irrigate approximately 3,600 acres.

The City of Yreka receives water from Fall Creek (tributary to the Klamath River upstream of Iron Gate Reservoir). An underflow well in Yreka Creek occasionally supplements the Fall Creek water supply.

Management of these appropriated water rights and delivery of water to users is conducted by the California Department of Water Resources Watermaster Service, with the exception of rights on Willow Creek and Yreka Creek. In order to meet all appropriated water rights, water is reused via a complex array of ditches, and relies on return flows to the river for delivery to downstream users.

Flood irrigation is the predominant irrigation method in the basin. Records of irrigated crop area and the amount of applied water in the Shasta Valley in 2000 and 2001 are summarized in Table 1.4.

Table 1.4: Irrigated crop area and applied water in the Shasta River basin in 2000 and 2001

Crop Type	**Irrigated Crop Area (acres)**		**Applied Water (acre-feet per acre)**	
	2000	**2001**	**2000**	**2001**
Grain	3000	700	1.76	2.11
Alfalfa	7500	5800	3.07	3.56
Pasture	39,100	39,200	3.71	2.99
Onions and Garlic	400	100	3.01	3.15
Other Truck Crops	600	500	2.05	2.18
Other Deciduous crops	0	100	.00	3.29
Totals	**50,600**	**46,400**	**NA**	**NA**

NA = Not Applicable
Sources: DWR Undated a, DWR Undated b

1.4.10 Anadromous Fish of the Shasta River Watershed

Anadromous fish populations currently utilizing the Shasta River watershed include fall Chinook (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), and fall and winter steelhead trout (*Oncorhynchus mykiss*) (Hardy and Addley 2001, p.11; KRBFTF 1991, p.4-10, 4-11). The Shasta River was once one of the most productive streams of its size for anadromous fish in California (National Research Council [NRC] 2003, p. 246). Data indicate that the historic fall Chinook population within the Shasta River basin was large, and has experienced a sharp decline since the 1930s (Hardy and Addley 2001, p.11; PacifiCorp 2004, p.2-40). Available data for coho and fall and winter steelhead runs are not entirely reliable for determining long-term trends, however both species are considered to have experienced declines from historic numbers throughout the Klamath River basin (Brown and Moyle 1991, p.13-14; Brown et al. 1994; CDFG 2002, p.1; Hardy and Addley 2001, p.11; PacifiCorp 2004, p.2-40). Historically, there were summer steelhead and spring Chinook runs in the Shasta River, however those runs no longer occur in the basin (KRBFTF 1991, p.2-87 and 2-99).

1.4.10.1 <u>Fall Chinook</u>

Fall Chinook salmon are the predominant run in the Klamath River basin, and are the only Chinook run believed to currently exist in the Shasta River basin (CDFG 1997). An estimate of spawner abundance from CDFG (1965, p.372) showed that on average there were 20,000 fall Chinook per year in the Shasta River basin in the years 1959 to 1963. Fall Chinook spawning populations as measured at the Shasta River Fish Counting Facility have ranged from a high of 81,848 fish in 1930 to fewer than 750 fish in 1990-1992, excluding 1938-1955 when the weir was located 6.5 miles upstream in the Shasta River and thus did not count adults spawning downstream (Figure 1.13). Fall Chinook numbers were 1,450 and 5,203 fish, respectively, in 1993 and 1994, but increased dramatically in 1995 to 13,511 fish. In 1996 to 1999 fall Chinook numbers dropped again, ranging from 1,450 to 3,197 fish. In 2000 and 2001 fall Chinook numbers were over 11,000 fish, but declined again in 2002-2004 ranging from 6,818 to 962 fish. Preliminary information for 2005 reflect a total of 1,983 fall Chinook in the Shasta River.

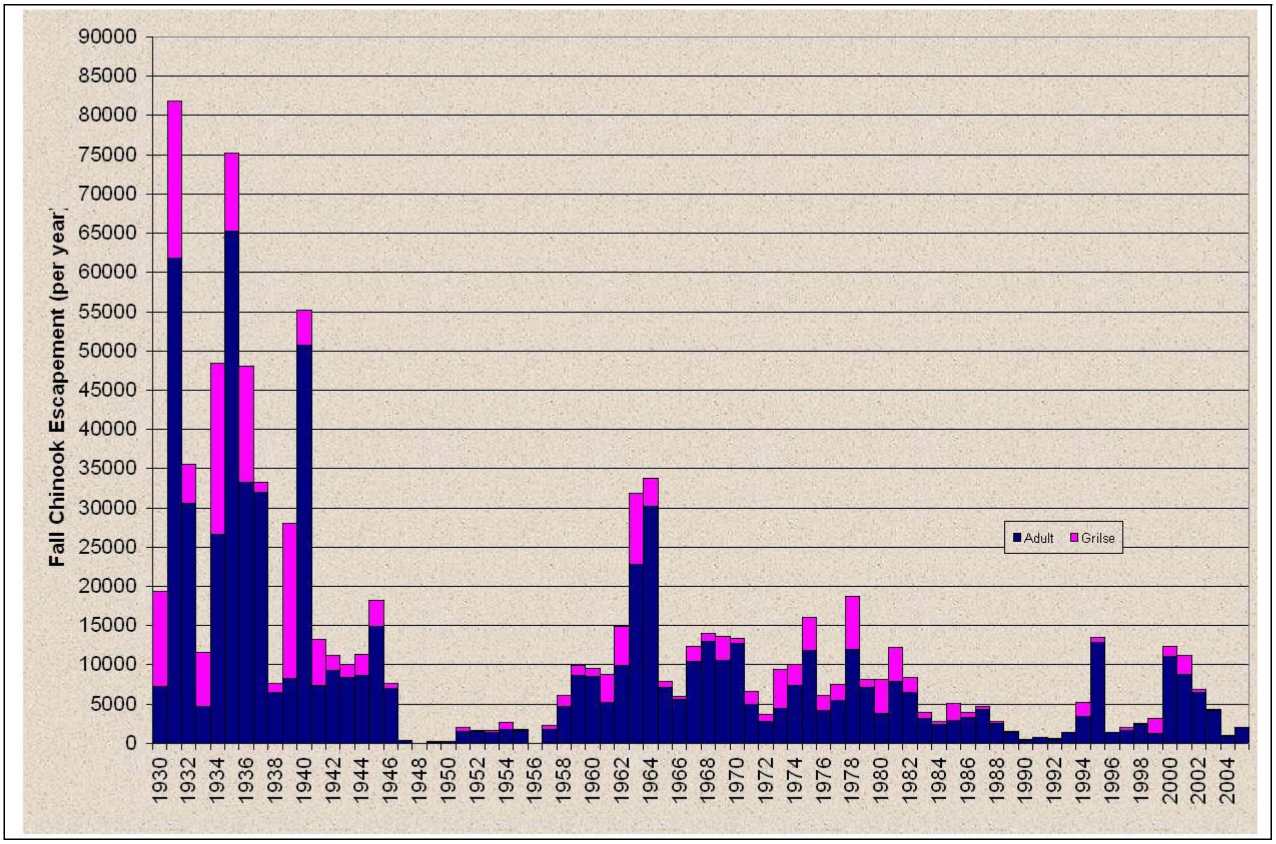


Figure 1.13: Shasta River Fall Chinook Spawning Escapement (Estimated), 1930-2005
Note: Data from 2005 are preliminary and represents total Chinook; data source does not differentiate between adults and grilse.
Source: Pacific Fishery Management Council 2005, p.185, CDFG 2004b, Hampton 2005a, p.1, and Hampton 2005b

1.4.10.2 Spring Chinook

A population of more than 100,000 spring-run Chinook was once present in the Klamath River basin (Moyle 2002, p.259). In 1931, Snyder wrote that the spring Chinook migration in the Klamath basin, while once very pronounced, "has now come to be limited as to the number of individuals, and is of relatively little economic importance (Snyder 1931, p.19)." This same decreasing trend is reflected in information from the Shasta River. CDFG (1990, as cited by Moyle 2002, p.259) states that historically spring Chinook run sizes for the Shasta River were estimated to be at least 5,000 fish. The run in the Shasta is noted as being one of the largest runs in the Klamath basin (Moyle 2002, p.259). Moyle (2002, p.259) suggests that by the early 1930s increased summer water temperatures and habitat degradation caused by the presence of Dwinnell Dam resulted in the disappearance of the spring Chinook run in the Shasta basin. In addition, the construction of Dwinnell Dam created a migration barrier for salmonids, and cut off spring Chinook and other salmonids from areas of prime habitat and cold water refuge that would have been important for spring Chinook holding throughout the summer months.

1.4.10.3 Steelhead

In 1932, an estimated 8,513 fall steelhead migrated up the Shasta River (Snyder 1933). An estimate of steelhead trout spawner abundance by CDFG (1965, p.372) recorded an average of 6,000 fall and winter steelhead in the Shasta River basin annually from 1959 to 1963. A study of angler harvest in the Shasta River in 1970 estimated a total of 172 fall steelhead (20% of the population) were harvested (Lanse 1971), which would mean an estimated population of 860 adult fall steelhead in the basin. Steelhead numbers are available from the Shasta River Fish Counting Facility, and are summarized in Figure 1.14. The Shasta River Fish Counting Facility has been operating since 1930. It is important to note, however, that the primary purpose of this facility is to count fall run Chinook, and the weir is not generally operated past November, and thus does not capture the entire run of steelhead. Therefore, these data cannot be taken as representative of entire population sizes.

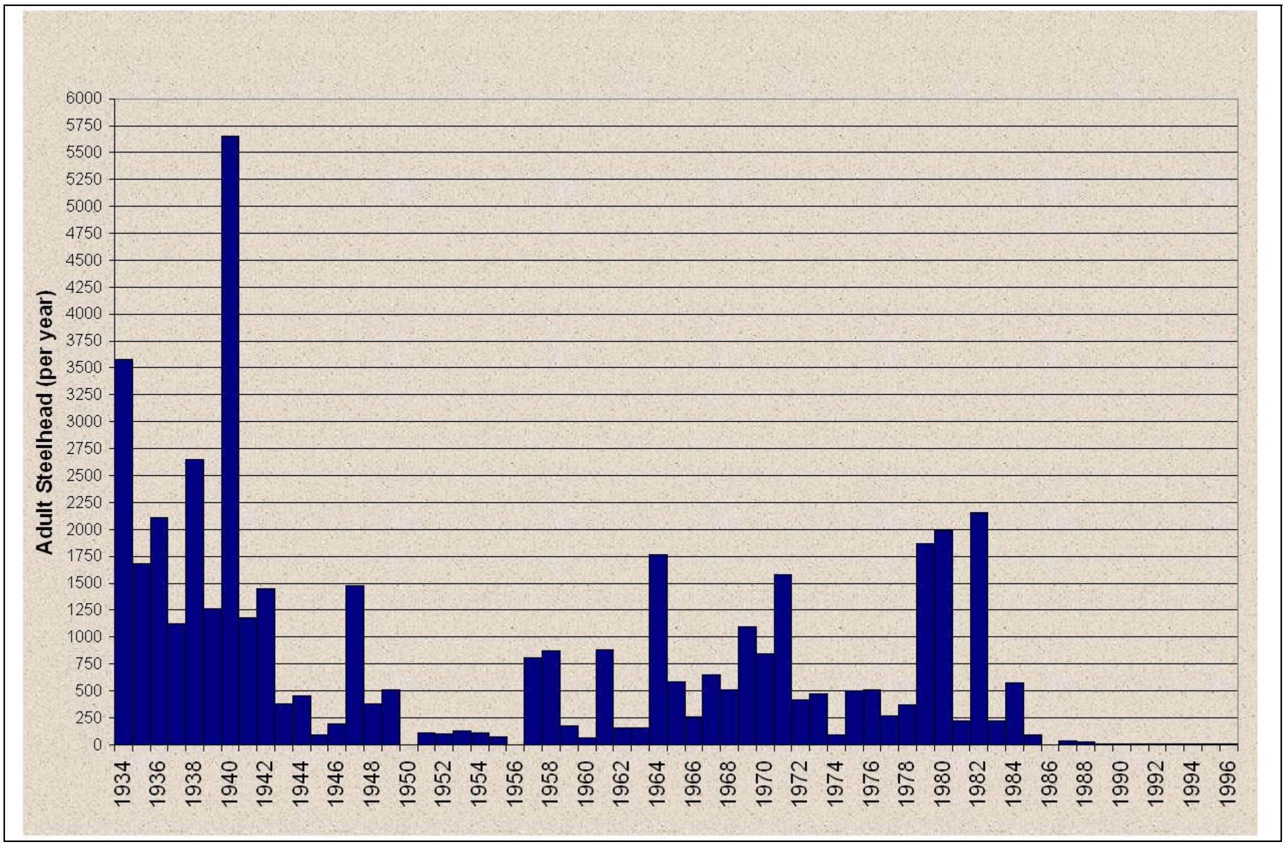


Figure 1.14: Shasta River Adult Steelhead, 1934-1996
Source: KRIS 2006

1.4.10.4 Coho

Little is known regarding the coho salmon population in the Shasta River, although it is believed that these fish follow the migration and behavior patterns of coho salmon in other areas of the Klamath River basin (CDFG 1997). It is clear from the information available that coho salmon populations statewide have undergone a dramatic decline from historic levels (Brown and Moyle 1991, p.8; Brown et al. 1994; CDFG 2002, p.1). Brown et al. (1994) state that California coho populations are probably less than 6% of what they were in the 1940s, and there has been at least a 70% decline since the 1960s. Coho salmon occupy only 61% of the Southern Oregon/Northern California Coastal Coho Salmon Evolutionarily Significant Unit streams that were previously identified as historical coho salmon streams (CDFG 2002, p.2). In 1965, CDFG estimated 800 coho spawners per year in the Shasta River basin (CDFG 1965, p.372). No other estimates of spawner abundance or population could be found for coho in the Shasta River basin, however there is information available on coho numbers from the Shasta River Fish Counting Facility managed by CDFG. It is the longest fish dataset in the Klamath basin, beginning in 1930 and continuing through the present. The primary purpose of the facility is to count fall Chinook, but steelhead and coho are also counted incidentally. Therefore, these coho numbers cannot be used as estimates of population but indicate the minimum number of coho present in the Shasta River basin during various years. Figure 1.15 presents coho numbers from the Shasta River Fish Counting Facility for the years from 1934-2005 (2005 data are preliminary).

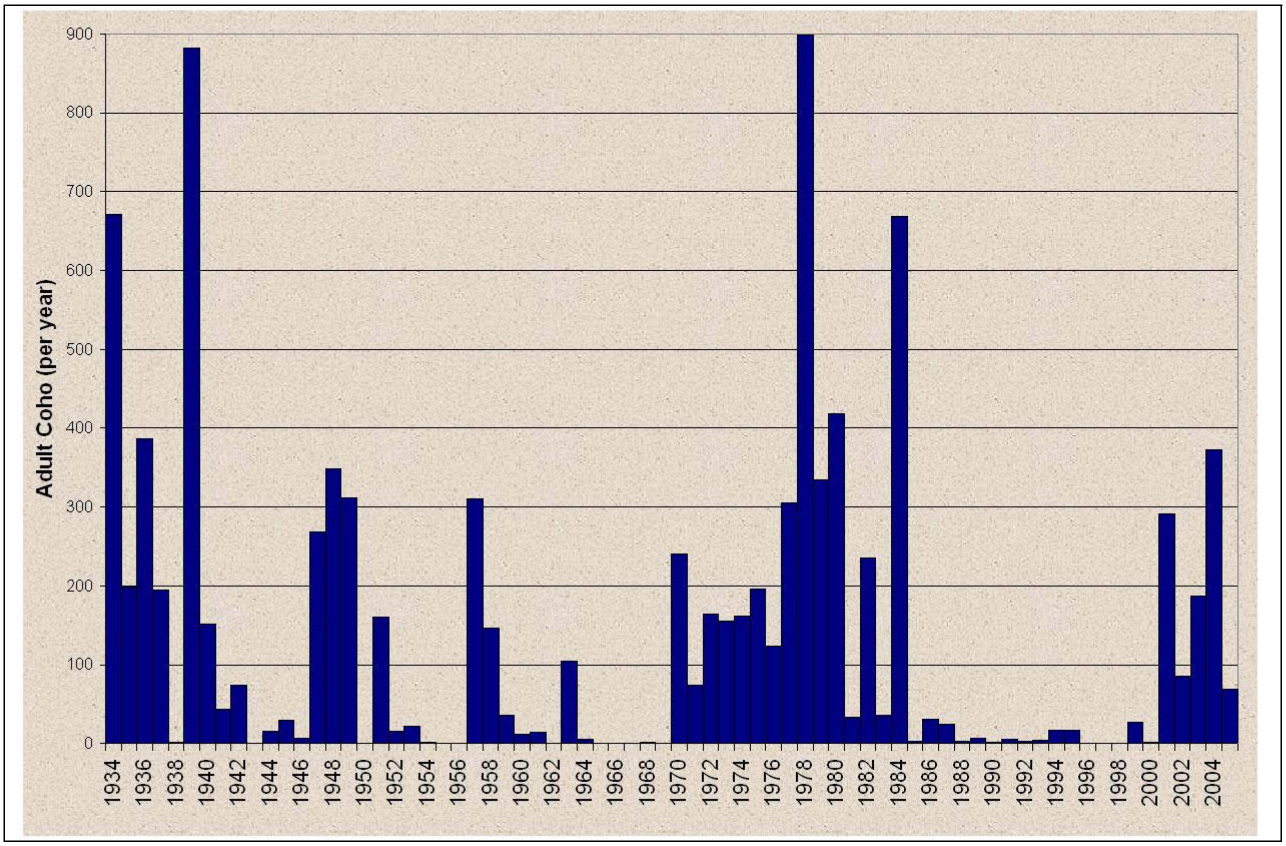


Figure 1.15: Shasta River Adult Coho, 1934-2005
Note: Data from 2005 are preliminary
Source: KRIS 2006, Hampton 2004, p.1, Hampton 2005a, p.1, and Hampton 2005b

1.4.10.5 <u>Habitat and Fish Distribution</u>

The continued survival and persistence of sustainable populations of salmonids in the Shasta River basin depends on the amount and suitability of the habitat. The construction of Dwinnell Dam in 1928 eliminated an estimated 22 percent of the total spawning habitat formerly available to salmon and steelhead (Wales 1951, as cited by CDFG 1997). A habitat survey performed by the CDFG (1965, p.372) found that there were 34 miles of habitat in the Shasta River basin suitable for Chinook and coho, and 64 miles of habitat suitable for steelhead. More current information from Hardy and Addley (2001, p.11) estimate that there are 35 miles of fall

Chinook, 38 miles of coho, and 55 miles of steelhead habitat in the basin. The authors state, however, that actual utilization of this habitat is contingent upon suitable flow conditions that may not be met during average and dry weather years due to water diversions (Hardy and Addley 2001, p.11). Others contend that stream diversions have reduced the amount of available salmon and steelhead habitat in the Shasta River basin to a subsistence level, and may have been the primary cause for the loss of the summer steelhead and spring Chinook runs in this basin (KRBFTF 1991, p.2-99). Figure 1.16 shows the distribution of migratory fish in the Shasta River watershed.

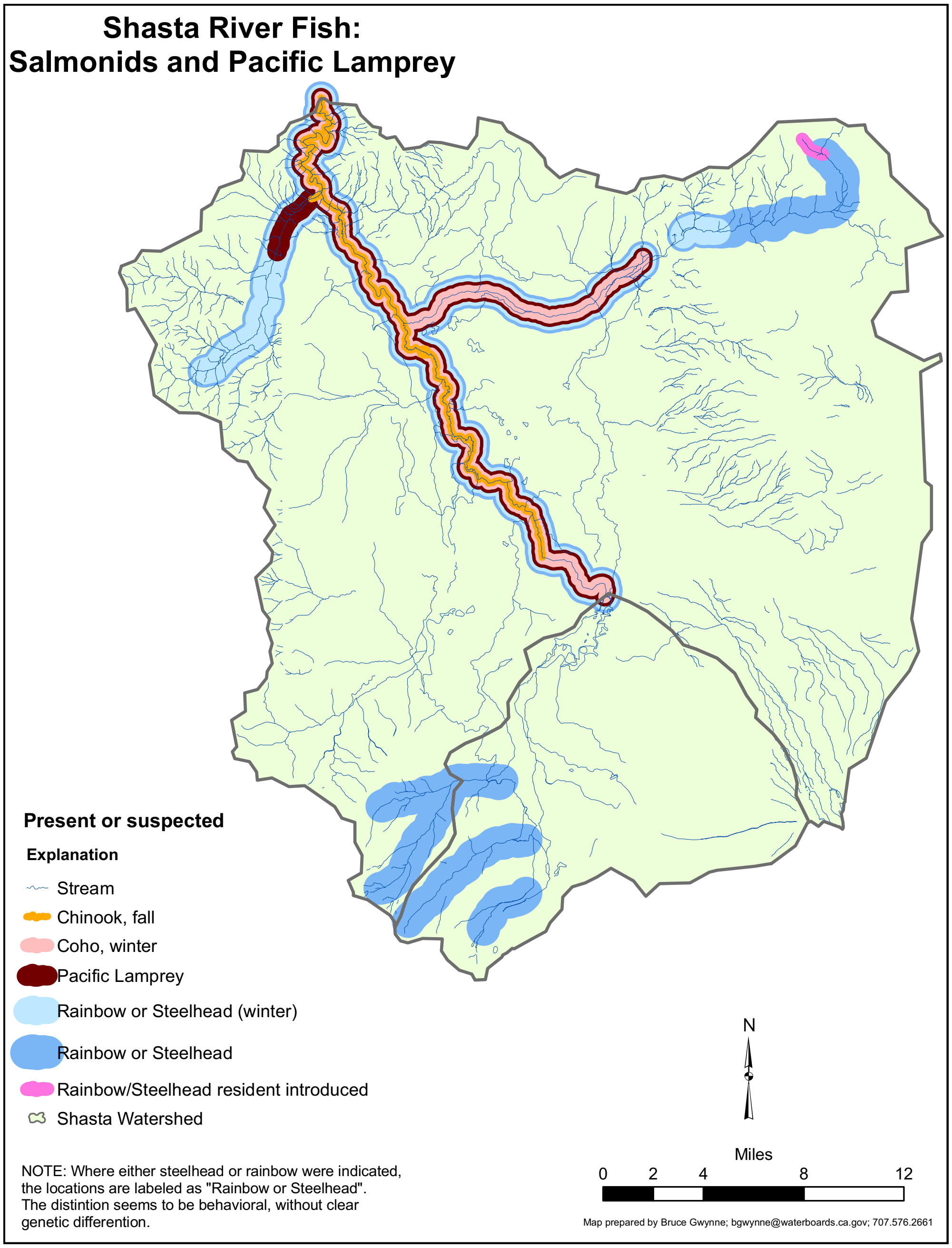


Figure 1.16: Distribution of Salmonids and Pacific Lamprey of the Shasta River watershed
Source: USFS 2005

Information in Figure 1.16 was compiled by the Klamath National Forest (United States Forest Service [USFS] 2005), and reflects the best readily available information. Locations at which fish presence is not indicated on the map do not necessarily indicate the absence of fish in these areas, as surveys may not have been conducted to determine presence/absence.

1.4.10.6 Periodicity

Considered together, the fall Chinook, coho, fall and winter steelhead are present year-round in the Shasta River basin (Figure 1.17). Many of the smaller tributaries in the Shasta basin have minimal flows during the summer, making access to and movement within in these tributaries difficult. According to CDFG, juvenile salmonids in the Shasta basin rear throughout the summer in the upper reaches of the mainstem Shasta River including Big Springs Creek, and steelhead have been observed rearing in the upper Little Shasta, and Parks Creek (Chesney 2005; Whelan, 2005c). It is important to note that the Shasta River has type II juvenile fall Chinook, which spend their first spring and summer in the stream and outmigrate in the fall (CDFG 1997, p.10; Whelan 2005a). This life history pattern results in the presence of juvenile Chinook rearing year-round in the Shasta River.

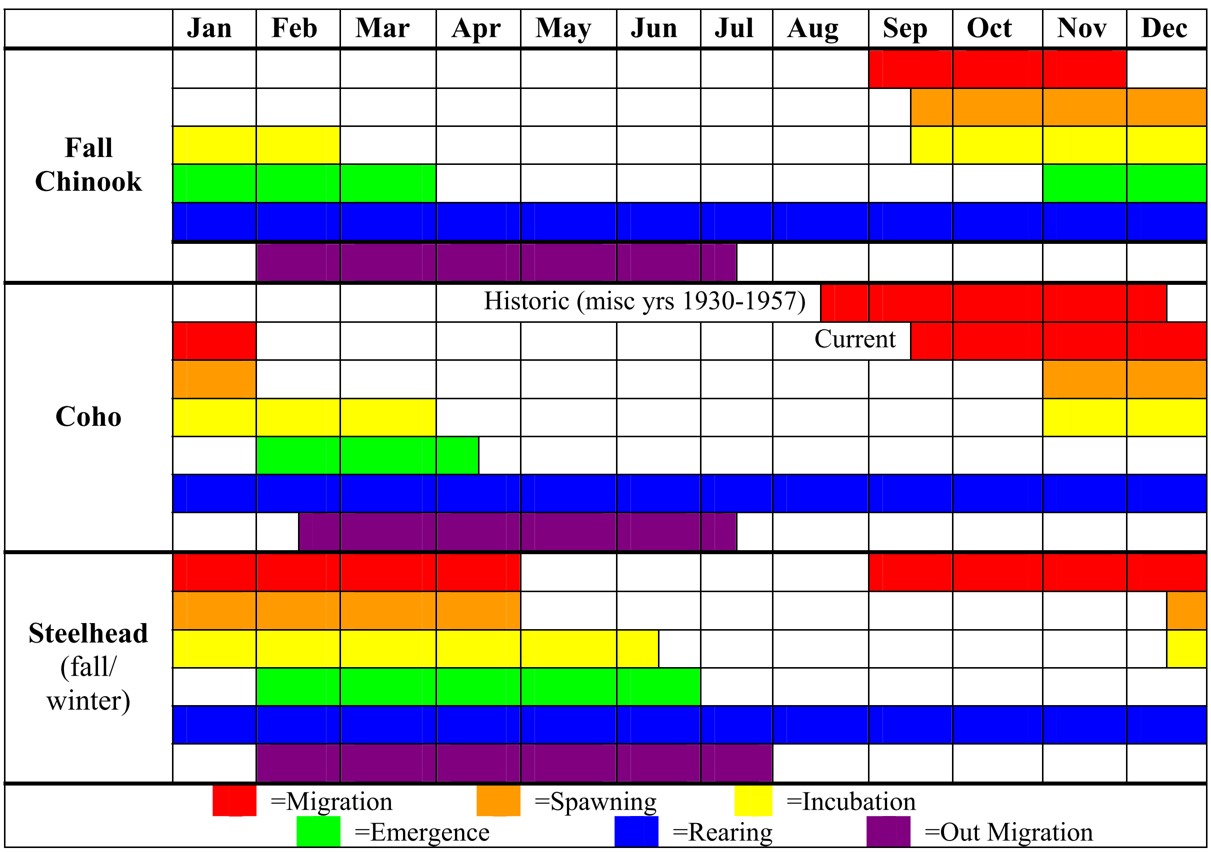


Figure 1.17: Salmonid Periodicity in the Shasta River Basin
Sources: CDFG 1997, Chesney 2000, Chesney 2002, Chesney and Yokel 2003, Chesney et al. 2004, Hampton 2002, Hampton 2003, Hampton 2004, Leidy and Leidy 1984, Shaw et al. 1997, Whelan 2005a

Periodicity information (presence of salmonids at varying life stages throughout the year) for the runs is fairly easy to interpret with the exception of data for the fall and winter run steelhead. At times references do not distinguish between fall and winter steelhead, some calling all fish winter run steelhead (see for example Leidy and Leidy 1984, Table 10), while others only refer to fall fish (see for example Hardy and Addley 2001, p.11). In other references the discussion of fall and winter run steelhead is combined (see for example KRBFTF 1991, p.4-11). Finally, some documents discuss the fall and winter steelhead separately, but then mention that there was almost no distinction between the timing of the fall and winter run into the Shasta River (see for example CDFG 1997; Shaw et al. 1997). For this reason, periodicity information for fall and winter steelhead in this document is combined into one group (Figure 1.17). Figure 1.17 shows that one or more life stage of fall Chinook, coho, and steelhead are present in the Shasta River Basin during every month of the year.

1.4.11 Non-Migratory Fish of the Shasta River Watershed

The Shasta River watershed hosts numerous populations of non-migratory fish species. Native fish persisting in the river include a variety of sculpin species, including marbled sculpin, and speckled dace. Introduced species include yellow perch, brown bullhead, bluegill, largemouth bass, mosquitofish, green sunfish, and brook and brown trout. The distribution of these non-migratory fish in the Shasta River watershed is presented in Figure 1.18, and is based on readily available data compiled by the Klamath National Forest (USFS 2005) and may not reflect all species that are present in the river, including above Dwinnell Dam. Locations at which fish presence is not indicated on the map do not necessarily indicate the absence of fish in these areas, as surveys to determine presence/absence may not have been conducted at all locations within the watershed.

The construction of Dwinnell Dam on the Shasta River in 1928 did not include any fish passage facilities and thus became a barrier to salmon and steelhead migration. However, populations of both native and introduced non-anadromous species persist in the Shasta River basin above the dam, as summarized in Table 1.5.

Table 1.5: Fishes found above Dwinnell Dam in the Shasta River Basin

Native Fish	**Introduced Fish**
Rainbow trout, *Oncorynchus mykiss*	Brown trout, *Salmo trutta*
Speckled dace, *Rhinichthys osculus*	Brook trout, *Salvelinus fontinalis*
Marbled sculpin, *Cottus klamathensis*	Brown bullhead, *Ictalurus nebulosa*
Lamprey, *Lampetra sp.*	Largemouth bass, *Micropterus salmoides*
Klamath smallscale sucker, *Catostomus rimiculus*	White crappie, *Pomoxis annularis*
-	Black crappie, *Pomoxis nigromaculatus*
-	Green sunfish, Lepom*is cyanellus*
-	Pond smelt (Wakasagi,) *Hypomesus nipponensis*
-	Golden shiner, *Notemigonus crysoleucas*
-	Tui chub, *Gila bicolor**

* It is unclear whether Tui chub were present in the river prior to Dwinnell Dam construction or whether they were introduced after construction was complete.
Source: Whelan 2005b

The California Department of Fish and Game (CDFG) regularly plants rainbow trout in Lake Shastina and along Highway 97 in Boles Creek, and brown trout brood stock is occasionally placed in Lake Shastina (CDFG 2005c; Whelan 2005b). In the past CDFG planted coho salmon in Lake Shastina, but because they did not provide any substantial angling benefit this practice was discontinued (Whelan 2005b).

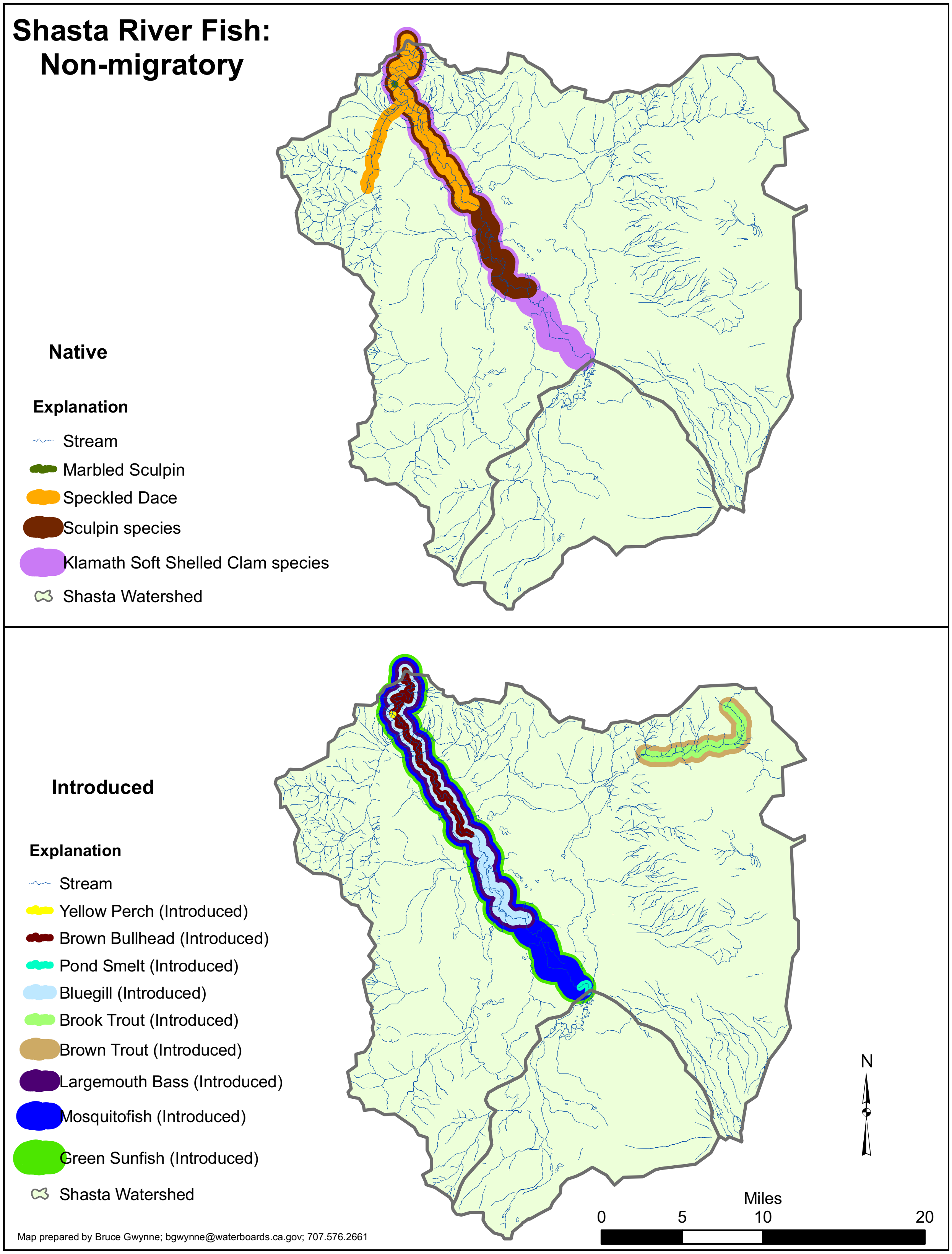


Figure 1.18: Distribution of non-migratory fish of the Shasta River watershed
Source: USFS 2005
Note: Klamath National Forest data (USFS 2005) do not include any information on these species above Dwinnell Dam, however CDFG (Whelan 2005b) have noted self-sustaining populations of brook trout in tributaries above Dwinnell Dam.

The following information on the status of some of the fish species in the Shasta River above the dam is from Whelan (2005b). The largemouth bass population appears strong and stable, while crappie numbers are lower than they have been in past years. This may be due to natural fluctuations in the crappie cycle or suppression in their numbers resulting from interactions with the strong year class of bass in the system. Information from electrofishing surveys indicate that brown trout appear to be doing well, although population size is not known. The upper reaches of various tributaries above Dwinnell Dam host self-sustaining populations of brook trout. Pond smelt are doing well and constitute a good forage base for the bass and trout. Angler data reflect stable brown bullhead numbers, while the status of the lamprey population is unknown.

1.4.12 Watershed Restoration and Water Quality Protection Efforts

Throughout the Shasta River watershed many individuals, groups, and agencies have been working to enhance and restore fish habitat and water quality. These proactive efforts have given the Shasta River watershed an advantage over other impaired watersheds with less active stakeholders. The implementation actions described in this document (Chapter 8) reflect the good work and watershed restoration efforts already underway within the Shasta River watershed.

The following sections describe some of the proactive and beneficial accomplishments of concerned citizens and agencies within the Shasta River watershed that address water quality and fisheries protection.

1.4.12.1 Shasta Valley Resource Conservation District

The Shasta Valley Resource Conservation District (SVRCD), like other resource conservation districts, is a local unit of government established to carry out natural resource management programs. The SVRCD was established in 1953 and focuses on coordinating and supporting landowner activities, both public and private. The SVRCD works to benefit agriculture while also protecting fish, wildlife, plants, and water quality. For further information please access the SVRCD website at <http://www.svrcd.org>.

1.4.12.2 Shasta River Coordinated Resource Management Planning

With fiscal and project management assistance from the SVRCD, the Shasta River Coordinated Resource Management Planning (Shasta River CRMP) group, a subcommittee of the SVRCD, has also been making significant strides in the restoration and management of the Shasta River and its tributaries. The Shasta River CRMP focuses on the diverse group of landowners and land use activities throughout the Shasta River watershed. The community-based nature of the Shasta CRMP, their accomplishments to date, their technical knowledge, their established history in the watershed, and the trust they have established with a diverse group of community members make the Shasta River CRMP an ideal group to help implement nutrient, dissolved oxygen, and temperature control practices.

1.4.12.3 Joint Projects of the Shasta Valley RCD and Shasta River CRMP

Since 1986, the SVRCD and the Shasta River CRMP together have been involved in developing and implementing many significant and beneficial water quality projects.

From 1986 until present a total of 164 projects have been implemented within the Shasta River watershed. The majority of these projects have been on private land. A total of $7.7 million dollars have been received from various funding sources including the California Department of Fish and Game, California Department of Water Resources, Klamath River Basin Fisheries Task Force, U.S. Fish and Wildlife Service, Natural Resources Conservation Service, National Marine Fisheries Service, U.S. Bureau of Reclamation, Environmental Protection Agency, North Coast Regional Water Quality Control Board, College of the Siskiyous, Fish and Game Commission, Cantara Council, and Siskiyou County Resource Advisory Committee

The following summary is based on the Shasta River restoration projects database maintained by the SVRCD and Shasta River CRMP.

- *Riparian Fencing projects* – A total of 39 riparian fencing projects are in progress or are completed in the watershed. Over 160,000 feet (30.3 miles) of fencing is in place along the banks of the Shasta River and its tributaries. This fencing protects the riparian zones from potential damage and pollutants associated with the numerous cattle ranches in the vicinity. These fences have created a buffer of non-grazed land along the Shasta, which helps protect the Shasta River's water quality and beneficial uses.
- *Riparian Planting projects* – A total of 22 riparian planting projects have been completed or are in progress in the Shasta River watershed. Multiple planting projects have been completed over the years in an effort to help protect the Shasta River. The river's banks at project locations have been repopulated with native riparian trees, which should both provide shade to help maintain lower water temperatures and also reduce sedimentation from eroding banks. Further steps have been taken to protect these newly replanted trees from the local beaver population by wrapping the lower trunks of the trees with 2" X 4" fence wire.
- *Bank Stabilization projects* – A total of 13 bioengineered bank stabilization projects are underway or completed in the Shasta River watershed. The task of bank stabilization has proven problematic as materials for willow mattresses, that prevent rapid erosion and gives time for vegetation to take root, are in very short supply. A number of trees have been planted along the Shasta River, which has greatly reduced the amount of erosion along the bank, and therefore the amount of sediment in the river.
- *Habitat Restoration projects* – A total of 7 projects aimed at restoring the riparian environment have been completed since 1986. These projects have included: the removal of garbage, the installation of boulder deflectors and general maintenance on the existing infrastructure.
- *Tailwater Management projects* – A total of 11 tailwater management projects are in progress or completed in the basin. These projects capture tailwater as it flows off a landowner's property and pump it to storage areas where it can be re-used for irrigation. By capturing and re-using this irrigation water, heated nutrient rich runoff is prevented from entering the Shasta River and its tributaries.
- *Education and Outreach projects* – A total of 9 education and outreach activities have been completed or are in progress throughout the watershed. This outreach

varies from providing ongoing support and coordination for the Shasta River CRMP to providing education and outreach to local landowners and groups throughout the basin.

- *Water Quality and Flow Monitoring projects* – A total of 13 water quality and flow monitoring projects have been conducted in the basin. In order to assess the progress made, several monitoring stations have been set up near the river to collect data. In addition to these stations, various groups and organizations have assisted in gathering data in cooperation with and independently of the Regional Water Board.
- *Fish Screening and Fish Passage projects* – A total of 4 fish passage and 13 fish screening projects are in-progress or completed in the Shasta River basin. Fish passage projects, including impoundment removal, have restored fish passage to parts of the system formerly inaccessible, while fish screens on water intake structures ensure than juvenile fish are not entrained in irrigation water.

CHAPTER 2. PROBLEM STATEMENT

2.1 Introduction

This chapter summarizes water temperatures and dissolved oxygen concentrations in the Shasta River and its tributaries, and evaluates how these water quality conditions have resulted in the non-attainment of water quality standards. Changes to stream temperature can result from increased solar heating, changes in riparian cover, changes in streamside microclimates, changes in surface flow, changes in spring and groundwater inputs, and changes in channel geometry, including aggradation and pool infilling. Factors contributing to changes in dissolved oxygen concentrations include photosynthesis and respiration of aquatic plants, respiration of aerobic organisms including bacteria that decompose organic material, concentrations of oxygen-consuming constituents, flow, velocity, and water temperature.

Increased water temperatures and low dissolved oxygen levels decrease the area and volume of suitable habitat for salmonids, decrease survival during incubation, rearing, and migration, and can be lethal. In the Shasta River basin, elevated temperatures and low dissolved oxygen contribute to the non-attainment of beneficial uses associated with the cold water fishery, specifically the salmonid fishery.

The analysis presented in this report is based on data gathered by Regional Water Board staff and data contributed by landowners and organizations working in the Shasta River watershed. As additional data become available from sources such as local groups and government agencies, the Regional Water Board can modify the TMDL and numeric targets, if necessary.

2.2 Water Quality Standards

In accordance with the federal Clean Water Act, TMDLs are set at a level necessary to achieve applicable water quality standards. California's water quality standards include designated beneficial uses, narrative or numeric water quality objectives established to protect those uses, and antidegradation policies and prohibitions. This section describes the state water quality standards applicable to the Shasta River basin.

2.2.1 Beneficial Uses

Existing and potential beneficial uses for the Shasta River are identified in the *Water Quality Control Plan for the North Coast Region* (Basin Plan) (North Coast Regional Water Quality Control Board [NCRWQCB] 2005), and are summarized in Table 2.1. The Shasta River Hydrologic Area (HA) is divided into three sections – Shasta River and Tributaries, Lake Shastina, and Lake Shastina Tributaries; each with their own designated beneficial uses.

Table 2.1: Existing and Potential Beneficial Uses in the Shasta River Hydrologic Area

Beneficial Uses	Shasta Valley Hydrologic Area		
	Shasta River and Tributaries	Lake Shastina	Lake Shastina Tributaries
Municipal and Domestic Supply (MUN)*	E	P[1]	E
Agricultural Supply (AGR)	E	E	E
Industrial Service Supply (IND)	E	P	E
Industrial Process Supply (PRO)	P	P	P
Groundwater Recharge (GWR)	E	E	E
Freshwater Replenishment (FRSH)	E	E	E
Navigation (NAV)	E	E	P
Hydropower Generation (POW)[2]	P	-	P
Water Contact Recreation (REC-1)*	E	E	E
Non-Contact Water Recreation (REC-2)	E	E	E
Commercial and Sport Fishing (COMM)*	E	-[3]	E
Warm Freshwater Habitat (WARM)	E	E	E
Cold Freshwater Habitat (COLD)*	E	E	E
Wildlife Habitat (WILD)	E	E	E
Rare, Threatened, or Endangered Species (RARE)*	E	-	-
Migration of Aquatic Organisms (MIGR)*	E	P	E
Spawning, Reproduction, and/or Early Development (SPWN)*	E	-	E
Aquaculture (AQUA)	E	P	P
Native American Cultural (CUL)[4]	-	-	-

E=Existing use, **P**=Potential Use

* Those beneficial uses affected, directly or indirectly, by elevated water temperature and/or low DO.

[1] The Basin Plan identifies MUN as a potential (P) beneficial use in Lake Shastina, however it is currently used as a municipal and domestic water supply for the town of Montague and thus is an existing use (E). This change will be considered in the next Basin Plan update.

[2] The Basin Plan identifies POW as a potential (P) beneficial use in the Shasta River and Tributaries, however hydropower generation is an existing use (E). This change will be considered in the next Basin Plan update.

[3] The Basin Plan does not list COMM as an existing (E) beneficial use in Lake Shastina, however it is currently used for sport fishing. This change will be considered in the next Basin Plan update.

[4]The Basin Plan does not list CUL as an existing (E) or potential (P) beneficial use of the Shasta River HA, however it may be listed in the future should supporting information be submitted.

2.2.2 Water Quality Objectives

The Basin Plan identifies both numeric and narrative water quality objectives for the Shasta River HA. These water quality objectives are developed to ensure protection of all beneficial uses. Table 2.2 summarizes the water quality objectives applicable to the Shasta River temperature and dissolved oxygen TMDLs.

Table 2.2: Narrative and Numeric Water Quality Objectives applicable to the Shasta River basin TMDLs

NARRATIVE OBJECTIVES	
Region-wide Objectives	
Objective	**Description**
Biostimulatory Substances	Waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses.
Temperature	The natural receiving water temperature of intrastate waters shall not be altered unless it can be demonstrated to the satisfaction of the Regional Water Board that such alteration in temperature does not adversely affect beneficial uses. At no time or place shall the temperature of any COLD or WARM intrastate water be increased more than 5°F above natural receiving water temperature.

Table 2.2 (Continued): Narrative and Numeric Water Quality Objectives applicable to the Shasta River basin TMDLs

NUMERIC OBJECTIVES				
Shasta Valley Hydrologic Area	**Dissolved Oxygen (mg/l)**		**Hydrogen Ion (pH)**	
	Minimum	**50% lower limit[1]**	**Maximum**	**Minimum**
Shasta River	7.0	9.0	8.5	7.0
Other Streams	7.0	9.0	8.5	7.0
Lake Shastina	6.0	9.0	8.5	7.0

[1] 50% lower limits represent the 50 percentile values of the monthly means for a calendar year. 50% or more of the monthly means must be greater than or equal to a lower limit.

The biostimulatory substances narrative objective refers to any substance that promotes aquatic plant growth. As demonstrated in Section 4.3.3, photosynthesis and respiration of aquatic plants in the Shasta River affect dissolved oxygen concentrations. Therefore, the biostimulatory substances objective is applicable to the dissolved oxygen TMDL. Similarly, pH is affected by the same processes that affect dissolved oxygen, most notably photosynthesis and respiration of aquatic plants.

The dissolved oxygen objective has two components, a minimum dissolved oxygen concentration and a 50% lower limit. The 50% lower limits represent the 50 percentile values of the monthly means for a calendar year. In other words, 50% or more of the monthly means must be greater than or equal to a lower limit.

In addition to narrative and numeric water quality objectives, the Basin Plan of the North Coast Region contains a provision for "controllable factors." This provision makes it a violation of the Basin Plan to discharge pollutants from controllable factors into an already impaired waterbody. The controllable factors provision is outlined below:

> Controllable water quality factors shall conform to the water quality objectives contained herein. When other factors result in the degradation of water quality beyond the levels or limits established herein as water quality objectives, then controllable factors shall not cause further degradation of water quality. Controllable water quality factors are those actions, conditions, or circumstances resulting from man's activities that may influence the quality of the waters of the State and that may be reasonably controlled (NCRWQCB 2005).

This provision requires that controllable factors must be used to prevent the further degradation of water quality in areas where the water quality objectives (including the antidegradation policies and beneficial uses) are not being met or supported. In areas where the degradation of water quality beyond the levels or limits established in the Basin Plan have already occurred, no further degradation of water quality from controllable factors is allowed by this provision.

2.2.3 Prohibitions and Policies

The Basin Plan includes prohibitions and policies applicable to the Shasta River basin, as discussed below.

2.2.3.1 Waste Discharge Prohibitions

The Regional Water Board is authorized, by Section 13243 of the Porter-Cologne Water Quality Control Act, to create Waste Discharge Prohibitions and specify conditions or locations where the discharge of all or some waste will not be permitted. The Basin Plan (NCRWQCB 2005, 4-1.00) states that point source waste discharges, except as stipulated by the Thermal Plan, Ocean Plan, and the action plans and policies contained in the Point Source Measures section of the Basin Plan, are prohibited in the Klamath River and its tributaries, including but not limited to the Trinity, Salmon, Scott, and Shasta rivers and their tributaries.

2.2.3.2 Agricultural Wastewater Management Policy

The Basin Plan also includes the Policy for Agricultural Wastewater Management, which is applicable to the Shasta River basin. In 1972 the USEPA was directed, by amendments to Public Law 92-500, to set up a permit system for dischargers that would be administered by the State of California for waters within the State. At the present time, federal regulations require permits for various types of discharges from agricultural operations including irrigation return flow from 3,000 or more acres of land when conveyed to navigable waters from one or more point sources. However, the policy also states "the state may prescribe waste discharge requirements for any point source discharger regardless of size (NCRWQCB 2005, p.4-24.00)."

2.2.3.3 Antidegradation Policies

There are two applicable antidegradation policies pertinent to water quality in the entire North Coast Region – a State policy and a federal policy. The State antidegradation policy is titled the *Statement of Policy with Respect to Maintaining High Quality Waters in California* and is commonly known as "Resolution 68-16." The federal antidegradation policy is found at 40 CFR section 131.12. Both policies are incorporated in the Basin Plan for the North Coast Region. Although there are some differences in the State and federal policies, both require that whenever surface waters are of higher quality than necessary to protect the designated beneficial uses, such existing quality shall be maintained unless otherwise provided by the policies.

The state antidegradation policy applies to groundwater and surface water whose quality meets or exceeds water quality objectives. The state policy establishes a two-step process to determine if discharges that will degrade water quality are allowed.

The federal antidegradation policy applies to surface waters that do not meet the applicable water quality objectives (i.e., impaired waters). Under the federal policy, an activity or discharge would be prohibited if the activity will lower the quality of surface water that does not meet water quality standards (i.e., the water quality is not sufficient to support designated beneficial uses) with limited exceptions set forth in federal regulations.

2.3 Temperature

Cold freshwater habitat, which includes habitat for salmonids, is the beneficial use most sensitive to elevated stream temperatures. In order to assess whether this beneficial use is fully protected in the Shasta River basin, stream temperatures are compared to temperature thresholds that are protective of salmonids. Temperature requirements of salmonids are summarized below, with an expanded discussion in Electronic Appendix A_e (*The Effects of Temperature on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function by Life Stage: Implications for Klamath Basin TMDLs*).

2.3.1 Temperature Requirements of Salmonids

Temperature is one of the most important factors affecting the success of salmonids and other aquatic life. Most aquatic organisms, including salmon and steelhead, are poikilotherms, meaning their temperature and metabolism are determined by the ambient temperature of water. Temperature therefore influences growth and feeding rates, metabolism, development of embryos and alevins, timing of life history events such as upstream migration, spawning, freshwater rearing, seaward migration, and the availability of food. Temperature changes can also cause stress and mortality (Ligon et al. 1999). Temperatures at sub-lethal levels can also effectively block migration, lead to reduced growth, stress fish, affect reproduction, inhibit smoltification, create disease problems, and alter competitive dominance (Elliott 1981; USEPA 1999). Further, the stressful impacts of water temperatures on salmonids are cumulative and positively correlated to the duration and severity of exposure. The longer the salmonid is exposed to thermal stress, the less chance it has for long-term survival (Ligon et al. 1999).

In considering the effect of temperature on salmonids, it is useful to have a measure of chronic (i.e., sub-lethal) and acute (i.e., lethal) temperature exposures. A common measure of chronic exposure is the maximum weekly average temperature (MWAT). The MWAT is the maximum seasonal or yearly value of the mathematical mean of multiple, equally spaced, daily temperatures over a running seven day consecutive period (Brungs and Jones 1977, p.10). In other words, it is the highest single value of the seven day moving average of temperature for a given time period. A common measure of acute effects is the instantaneous maximum temperature. A third metric, the maximum weekly maximum temperature (MWMT), can be used as a measure of both chronic and acute effects. The MWMT (also known as the seven-day average of the daily maximum temperatures (7-DADM)) is the maximum seasonal or yearly value of the daily maximum temperatures averaged over a running seven day consecutive period. The MWMT is useful because it describes the maximum temperatures in a stream, but is not overly influenced by the maximum temperature of a single day.

Regional Water Board staff conducted a literature review to evaluate stream temperature requirements for the various life stages of steelhead trout (*Oncorhynchus mykiss*), coho salmon (*Oncorhynchus kisutch*), and Chinook salmon (*Oncorhynchus tschawytscha)* as a means for interpreting the narrative temperature objectives in the Basin Plan (NCRWQCB 2005). This review included EPA guidance, Oregon and Washington states' standards, reports compiling and summarizing existing scientific information, and laboratory studies. Species-specific requirements were reviewed for the following life stages: migrating adults, spawning and incubation/emergence, and freshwater rearing and growth. Additionally, the effects of temperature on disease and lethality were investigated. Some of the references reviewed covered salmonids as a general class of fish, while others were species specific.

Salmonid stocks do not tend to vary much in their life history thermal needs, regardless of their geographic location. The USEPA (2001a), in their *Summary of Technical Literature Examining the Physiological Effects of Temperature on Salmonid,* makes the case that there is not enough significant genetic variation among stocks or among species of salmonids to warrant geographically-specific water temperature standards. "Many differences that had been attributed in the literature to stock differences are now considered to be statistical problems in analysis, fish behavioral responses under test conditions, or allowing insufficient time for fish to shift from field conditions to test conditions (Konecki et al. 1993; Mathur & Silver 1980, both as cited by USEPA 2001a)." USEPA states that temperature tolerance is likely controlled by multiple genes, and thus would not be easily modified through evolutionary change without a radical shift in associated physiological systems (USEPA 2001a). As a result, literature on the temperature needs of coho and Chinook salmon and steelhead trout stemming from data collected in streams outside Northern California are considered relevant to characterizing the thermal needs of salmonids which use the Shasta River.

As a result of this literature review, Regional Water Board staff selected chronic and acute temperature thresholds for evaluating Shasta River watershed temperatures. Chronic temperature thresholds were selected from the USEPA document *EPA Region 10 Guidance For Pacific Northwest State and Tribal Temperature Water Quality Standards* (2003), and are presented in Table 2.3. The Region 10 guidance is the product of a three-year interagency effort, and has been reviewed by both independent science review panels and the public. Acute lethal temperature thresholds were selected based upon best professional judgment of the literature, and are presented in Table 2.4. These freshwater temperature thresholds are applicable during the time of year when the life stage of each species is present in the Shasta River basin (see Figure 1.16). Where life history, timing, and/or species needs overlap, the lowest of each temperature metric applies.

Table 2.3: MWMT Chronic Effects Temperature Thresholds

Life Stage	**MWMT (°C)**
Adult Migration	20
Adult Migration plus Non-Core Juvenile Rearing [1]	18
Core Juvenile Rearing [2]	16
Spawning, Egg Incubation, and Fry Emergence	13

Source: USEPA 2003

[1] The Adult Migration plus Non-Core Juvenile Rearing designation is recommended by USEPA (2003) for the "protection of migrating adult and juvenile salmonids and moderate to low density salmon and trout juvenile rearing during the period of summer maximum temperatures," usually occurring in the mid to lower part of the basin. The phrase "moderate to low density" is not specifically defined.

[2] The Core Juvenile Rearing designation is recommended by USEPA (2003) for the "protection of moderate to high density summertime salmon and trout juvenile rearing" locations, usually occurring in the mid to upper reaches of the basin. The phrase "moderate to high density" is not specifically defined.

The University of California Cooperative Extension is conducting a multi-year investigation to document salmonid presence/absence and water quality conditions (including water temperature and dissolved oxygen) at juvenile salmonid rearing locations in the Shasta River. Results of the study have not been reported (Thompson 2005) and thus were not available to use in this assessment, however when the report is available it will provide additional insight regarding temperature and dissolved oxygen conditions affecting the cold freshwater habitat beneficial use.

Table 2.4: Lethal Temperature Thresholds

Lethal Threshold[1] (°C)			
Life Stage	**Steelhead**	**Chinook**	**Coho**
Adult Migration and Holding	24	25	25
Juvenile Growth and Rearing	24	25	25
Spawning, Egg Incubation, and Fry Emergence	20	20	20

[1] The lethal thresholds selected in this table are generally for chronic exposure (greater than seven days). Although salmonids may survive brief periods at these temperatures, they are good benchmarks from the literature for lethal conditions.

2.3.2 Temperature Conditions of the Mainstem Shasta River

Numerous parties have collected temperature data in the Shasta River basin, including private landowners, the Shasta River Coordinated Resource Management Planning Council, the Shasta Valley Resource Conservation District, the California Department of Fish and Game, the California Department of Water Resources, the US Fish and Wildlife Service, the US EPA, and the Regional Water Board. Shasta River temperature data records date back to the 1930s, but intensive temperature monitoring using continuous recording temperature probes began in the 1990s.

Table 2.5 and Figure 2.1 summarize mainstem Shasta River temperature conditions. Table 2.5 identifies the maximum instantaneous temperature, maximum weekly average temperature (MWAT), and maximum weekly maximum temperature (MWMT) observed at various Shasta River locations from 1994 through 2003. Figure 2.1 presents average weekly maximum temperatures for select Shasta River reaches based on recorded temperatures from the period 1994 through 2003 versus the USEPA (2003) MWMT temperature thresholds. The Highway 263 – USGS gage reach includes temperature data collected at Highway 263, near the end of Old Shasta River Road, and at the USGS flow gage; the Montague-Grenada Road – Anderson Grade Road reach includes temperature data collected at Montague-Grenada Road, Highway 3, Yreka Ager Road, I-5, upstream of Yreka Creek confluence, and at Anderson Grade Road; the Highway A12 – Little Shasta River reach includes temperature data collected at Highway A12, Freeman Road, and upstream of the Little Shasta River confluence; the Hole in the Ground – Willow Creek reach includes temperature data collected at Grenada Irrigation District pumps, East Louie Road, and upstream of the Willow Creek confluence.

The temperature associated with the top of the colored boxes in Figure 2.1 is the threshold temperature for that life stage. The time period that the various life stages occur in the Shasta River basin are depicted by the width of the colored boxes. Where the weekly maximum temperature falls above the colored life stage/threshold box, temperatures are unsuitable for the life stage. The distribution of salmonids in the Shasta River watershed is presented in Chapter 1, Figure 1.16, however locations at which fish presence is not indicated on the map do not necessarily indicate the absence of fish in these areas, as surveys may not have been conducted to determine presence/absence. Figure 2.2 presents surface water temperatures of the Shasta River on the afternoon of July 26, 2003 from thermal infrared imagery (Watershed Sciences, LLC 2004). As an evaluation of lethal temperature conditions, Figure 2.3 shows the maximum and average number of hours that temperatures exceeded lethal salmonid temperature thresholds for juvenile growth and rearing at the mouth of the Shasta River during summer months from 1996 through 2003.

Table 2.5: Mainstem Shasta River Temperature Conditions

Site	River Mile	Sample Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Summary of maximum recorded values 1994-2003	Max	Avg	Min
USGS gage	0.6	Max. Temp.				**29.4**			29.7	30.3	31.5	30.2	Max. Temp.	31.5	30.4	29.7
		MWAT				**24.3**			25.1	24.8	25.6	25.9	MWAT	25.9	25.3	24.8
		MWMT				**28.2**			28.9	29.0	29.8	29.2	MWMT	29.8	29.2	28.9
Highway 263	7.3	Max. Temp.	24.9	26.0	27.6	**24.1**	26.4	26.9	27.9	30.3			Max. Temp.	30.3	27.1	24.9
		MWAT	22.8	22.7	24.2	**22.4**	23.6	22.9	24.6	24.8			MWAT	24.8	23.7	22.7
		MWMT	24.3	24.9	26.5	**23.3**	25.7	25.4	27.0	29.0			MWMT	29.0	26.1	24.3
Yreka Cr	7.6	Max. Temp.								28.4			Max. Temp.		28.4	
		MWAT								24.4			MWAT		24.4	
		MWMT								26.9			MWMT		26.9	
Anderson-Grade Road	8.0	Max. Temp.	29.4	32.5	28.4	**26.6**	27.3	**23.7**	27.2				Max. Temp.	32.5	29.0	27.2
		MWAT	25.3	22.9	24.9	**23.9**	24.7	**21.7**	24.6				MWAT	25.3	24.5	22.9
		MWMT	27.9	29.6	27.2	**25.7**	26.7	**23.7**	26.3				MWMT	29.6	27.5	26.3
Interstate 5	8.6	Max. Temp.								**26.7**			Max. Temp.			
		MWAT								**20.7**			MWAT			
		MWMT								**26.2**			MWMT			
Yreka-Ager Road	10.9	Max. Temp.	31.1	26.1	26.4	**26.7**	25.8	26.8	27.2			27.9	Max. Temp.	31.1	27.3	25.8
		MWAT	24.8	22.1	24.0	**22.1**	23.7	22.7	23.9			24.8	MWAT	24.8	23.7	22.1
		MWMT	29.7	24.4	25.5	**25.7**	25.6	25.7	26.5			26.8	MWMT	29.7	26.3	24.4
Oregon Slough	11.8	Max. Temp.								26.8			Max. Temp.		26.8	
		MWAT								23.3			MWAT		23.3	
		MWMT								26.0			MWMT		26.0	
Highway 3	13.1	Max. Temp.		26.2	27.2	26.0	22.8	26.9	26.4			27.4	Max. Temp.	27.4	26.8	26.2
		MWAT		22.3	23.9	22.4	20.5	21.7	23.8			24.2	MWAT	24.2	23.2	21.7
		MWMT		25.0	26.4	24.6	22.4	26.0	26.1			26.8	MWMT	26.8	26.1	25.0
Montague-Grenada Road	15.5	Max. Temp.	28.3	25.0	26.8		26.2	26.4	26.8		27.5	26.5	Max. Temp.	28.3	26.7	25.0
		MWAT	24.0	21.9	23.3		23.1	22.7	23.6		22.8	23.9	MWAT	24.0	23.1	21.9
		MWMT	27.1	24.5	26.0		25.3	25.1	26.1		25.9	25.9	MWMT	27.1	25.7	24.5
Little Shasta River	16.3	Max. Temp.								26.5			Max. Temp.		26.5	
		MWAT								22.7			MWAT		22.7	
		MWMT								25.2			MWMT		25.2	
Freeman Lane	19.2	Max. Temp.										25.2	Max. Temp.		25.2	
		MWAT										22.4	MWAT		22.4	
		MWMT										24.4	MWMT		24.4	
Highway A-12	21.2	Max. Temp.	26.6	23.2	23.9	**24.2**	23.2	24.2	25.0			24.7	Max. Temp.	26.6	24.4	23.2
		MWAT	22.0	21.0	22.0	**19.3**	21.3	20.9	21.1			21.6	MWAT	22.0	21.4	20.9
		MWMT	25.1	22.0	23.3	**21.3**	22.5	23.4	24.0			24.0	MWMT	25.1	23.5	22.0
Willow Creek	25.1	Max. Temp.								22.5			Max. Temp.		22.5	
		MWAT								20.1			MWAT		20.1	
		MWMT								21.9			MWMT		21.9	
GID	30.6	Max. Temp.	**22.6**	23.6	24.6	22.9	32.5	22.8					Max. Temp.	32.5	25.3	22.8
		MWAT	**19.9**	20.1	20.4	19.0	20.0	19.2					MWAT	20.4	19.8	19.0
		MWMT	**23.2**	23.2	23.7	22.3	26.1	22.2					MWMT	26.1	23.5	22.2
East Louie Road	33.9	Max. Temp.	**23.6**	25.0	25.0		24.4	24.8	24.4				Max. Temp.	25	24.7	24.4
		MWAT	**19.6**	21.7	20.5		20.3	20.4	20.8				MWAT	21.7	20.8	20.3
		MWMT	**23.3**	24.3	23.4		23.1	23.8	23.9				MWMT	24.3	23.7	23.1
Hole in the Ground	34.8	Max. Temp.				**20.9**		20.2	23.6				Max. Temp.	23.6	21.9	20.2
		MWAT				**18.2**		17.4	20.0				MWAT	20.0	18.7	17.4
		MWMT				**19.5**		19.5	22.7				MWMT	22.7	21.1	19.5
Riverside Drive	36.0	Max. Temp.		**24.3**			25.3	26.1	25.3	27.3		23.7	Max. Temp.	27.3	25.5	23.7
		MWAT		**20.2**			20.2	20.9	22.4	22.6		20.9	MWAT	22.6	21.4	20.2
		MWMT		**23.8**			24.8	23.5	24.9	25.6		22.7	MWMT	25.6	24.3	22.7

Note: The temperatures in the grey boxes were calculated from data sets that may not have included the period of hottest summer temperatures. All temperatures are °C.

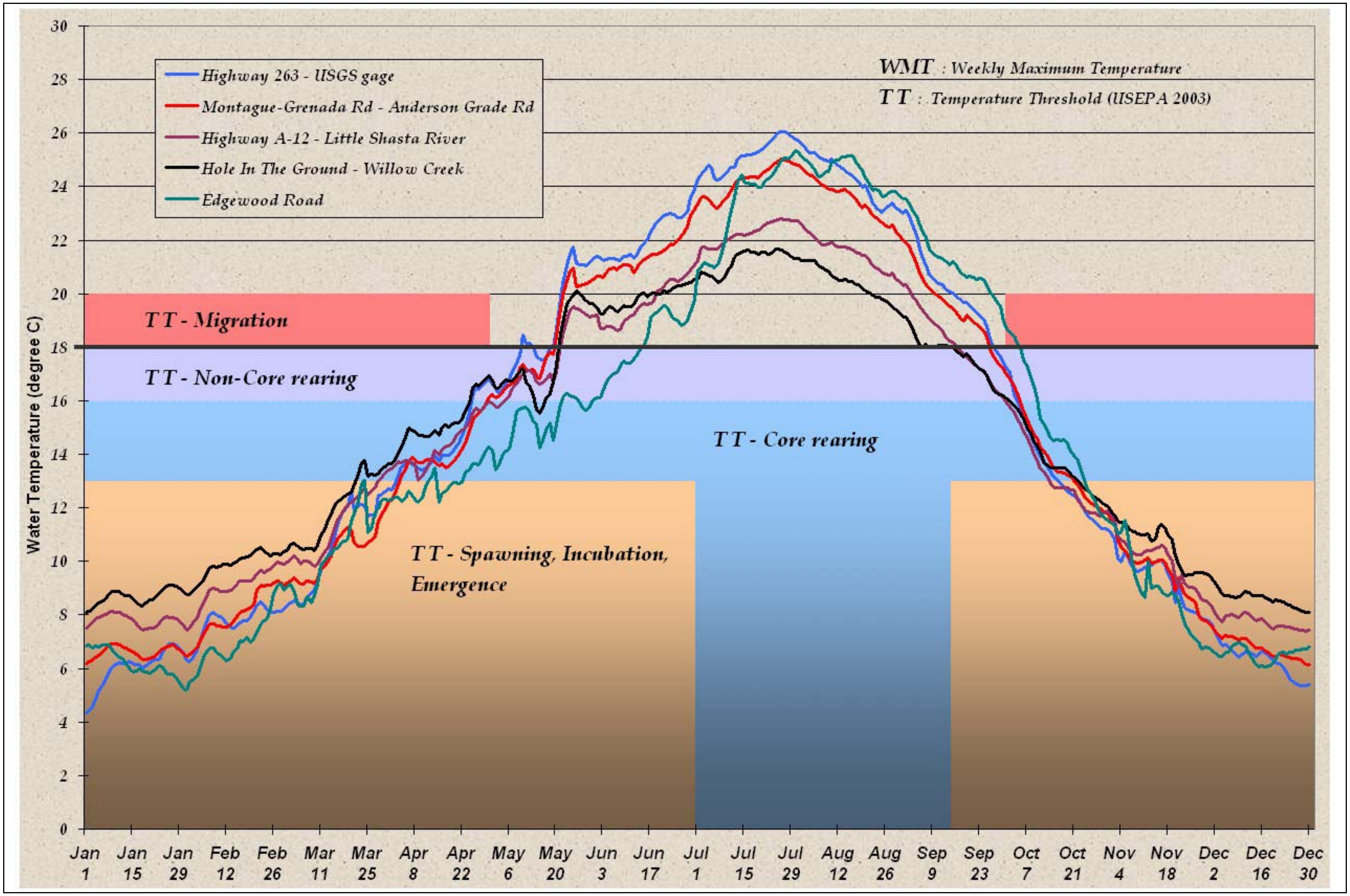


Figure 2.1: Average weekly maximum temperatures, Shasta River, 1994-2003.

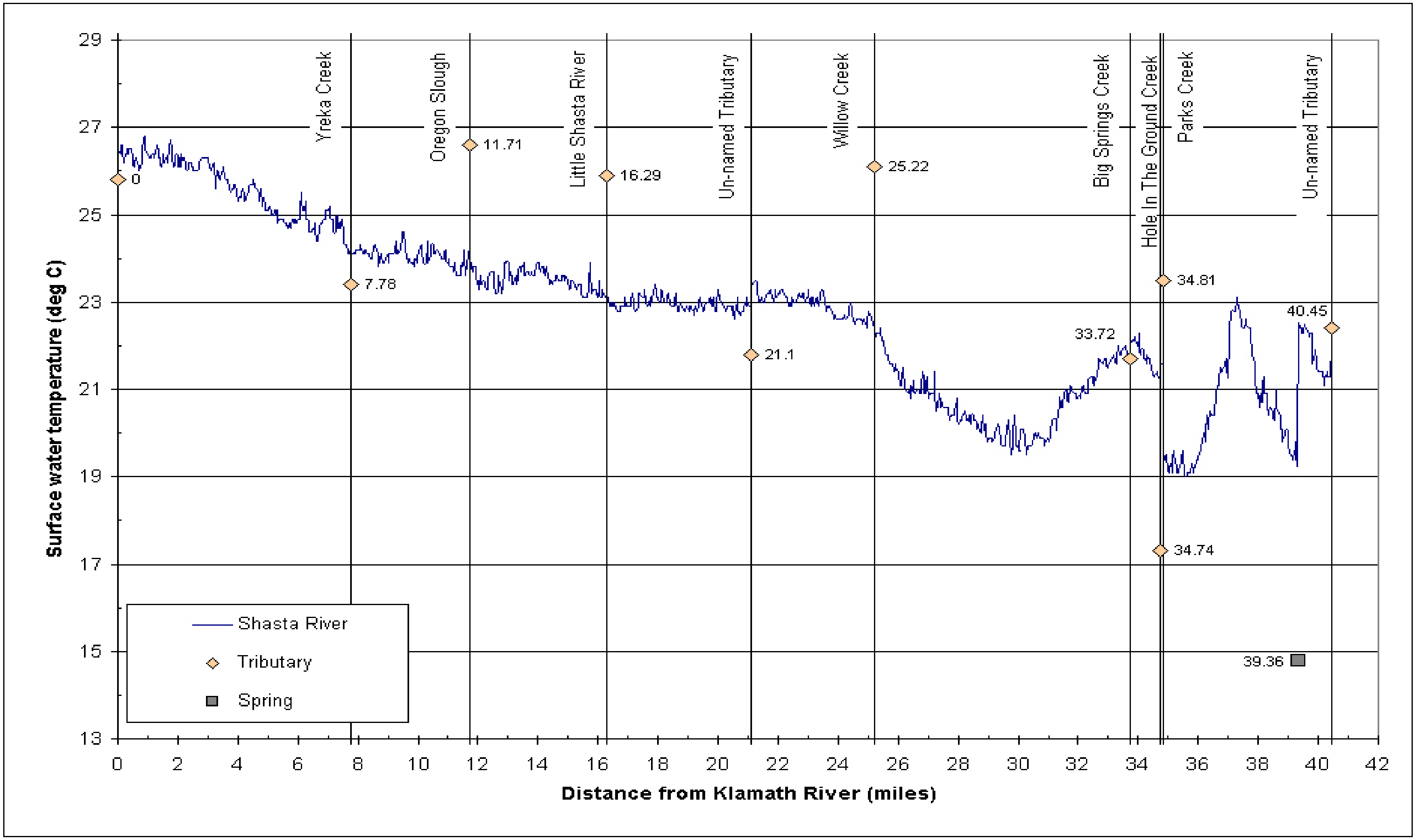


Figure 2.2: Shasta River Surface Water Temperatures - July 26, 2003
From: Watershed Sciences, LLC 2004
Note: The number next to the diamond marker for the tributaries/spring indicates the river mile at which the tributary/spring enters the mainstem Shasta River.

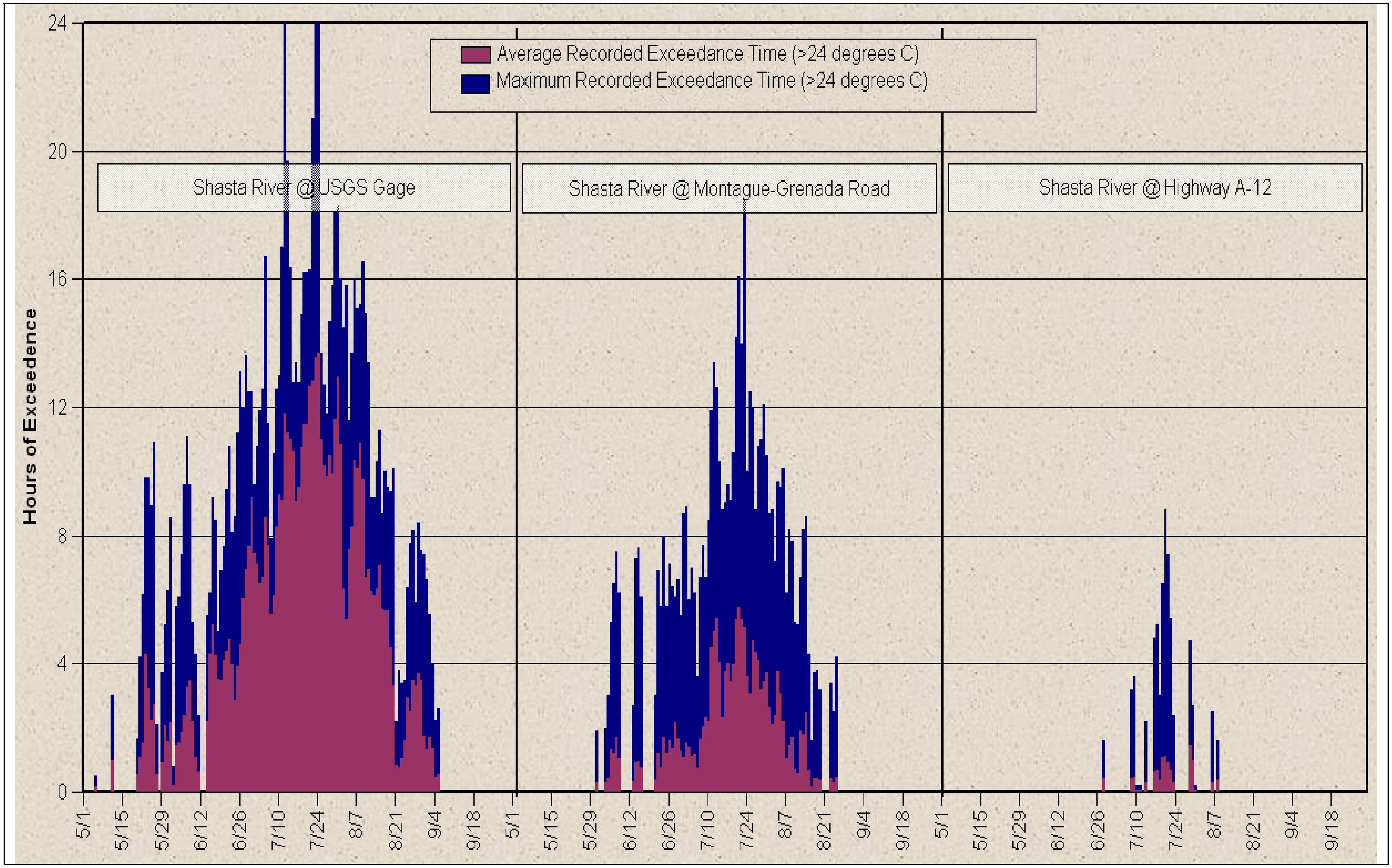


Figure 2.3: Maximum and average number of recorded hours per day Shasta River mainstem temperatures exceeded the lethal temperature threshold for juvenile rearing at the mouth, Montague-Grenada Road, and Highway A-12, 1996-2003

Daily temperature fluctuations vary throughout the Shasta River and tributaries. In the Shasta River, temperatures fluctuate up to 8°C during summer months at some locations including the mouth (i.e. the difference between the daily minimum and daily maximum temperature is 8°C). On average, Shasta River temperatures fluctuate by 4 to 5°C.

Key findings of Shasta River mainstem temperature conditions are:

- Stream temperature conditions vary throughout the Shasta River.
- Shasta River temperatures increase in the downstream direction, most notably downstream of about RM30, near Highway A12.
- On average, the difference between daily maximum and minimum Shasta River temperatures is approximately 4 to 5°C. The difference between daily maximum and minimum temperatures at the mouth approaches 8°C in summer months.
- Weekly maximum temperatures of the Shasta River meet, i.e., are below, the USEPA (2003) salmonid thresholds from approximately November 1 to mid-March.
- Shasta River temperatures are generally suitable for migration during the migration period (i.e., < MWMT of 20°C).
- Weekly maximum temperatures exceed the spawning, incubation, and emergence threshold (i.e. MWMT of 13°C) at all Shasta River reaches from April through June, and in mid-September through October.
- Weekly maximum temperatures of the Shasta River downstream of Dwinnell Dam exceed the core rearing threshold (i.e. MWMT of 16°C) from the end of April through early October, and exceed the non-core rearing threshold (i.e. MWMT of 18°C) from mid-May through September.

Instantaneous temperatures near the mouth of the Shasta River exceed lethal temperatures for juvenile rearing (i.e. >24°C) for some time every day from mid-June through August.

2.3.3 Temperature Conditions of Shasta River Tributaries

Less temperature monitoring has been conducted in the tributaries of the Shasta River. Figures 2.4 and 2.5 summarize average weekly maximum temperatures near the confluence with the Shasta River (Figure 2.4) and at upstream locations (Figure 2.5) for those tributaries with data collected between 2001 and 2003. These average weekly maximum temperatures are compared with the USEPA (2003) MWMT temperature thresholds.

Key findings of Shasta River tributary temperature conditions are:

- Temperatures of Shasta River tributaries are variable.
- Tributary temperatures near the confluence with the Shasta River are higher than temperatures at upper reaches of the tributary.
- Weekly maximum temperatures of measured tributaries near the confluence with the Shasta River tend to be comparable or warmer than Shasta River temperatures near the confluence, with the exception of Yreka Creek, which tends to be cooler than the river.
- Weekly maximum temperatures of measured tributaries near the headwaters are consistently cooler than Shasta River temperatures near the confluence.
- Weekly maximum temperatures of measured tributaries near the confluence with the Shasta River meet, i.e., are below, the USEPA (2003) salmonid thresholds from approximately November 1 to mid-March.

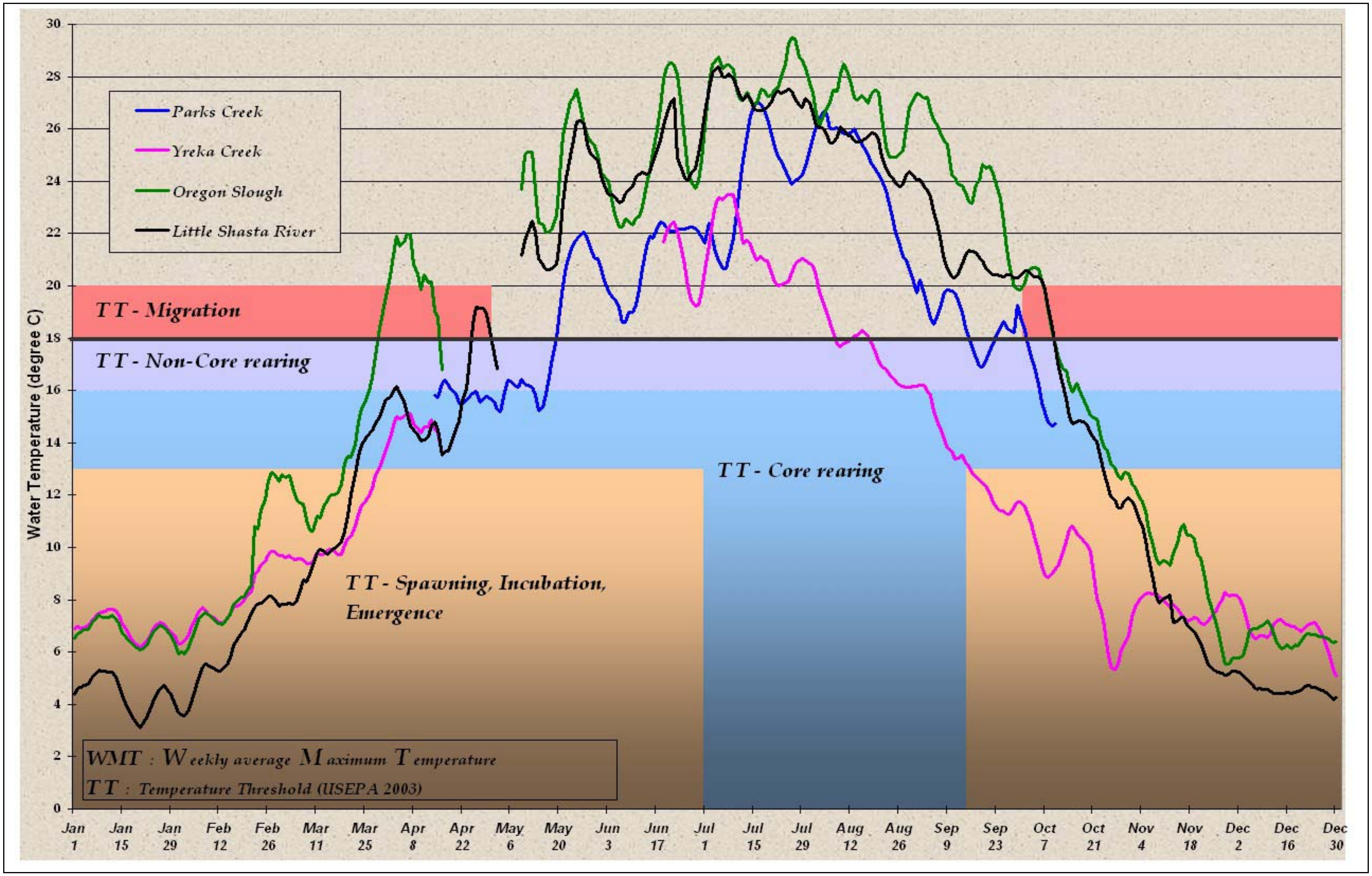


Figure 2.4: Average maximum weekly temperatures, Shasta River tributaries above confluence with Shasta River, 2001-2003
Note: Discontinuity in the data lines is due to data gaps.

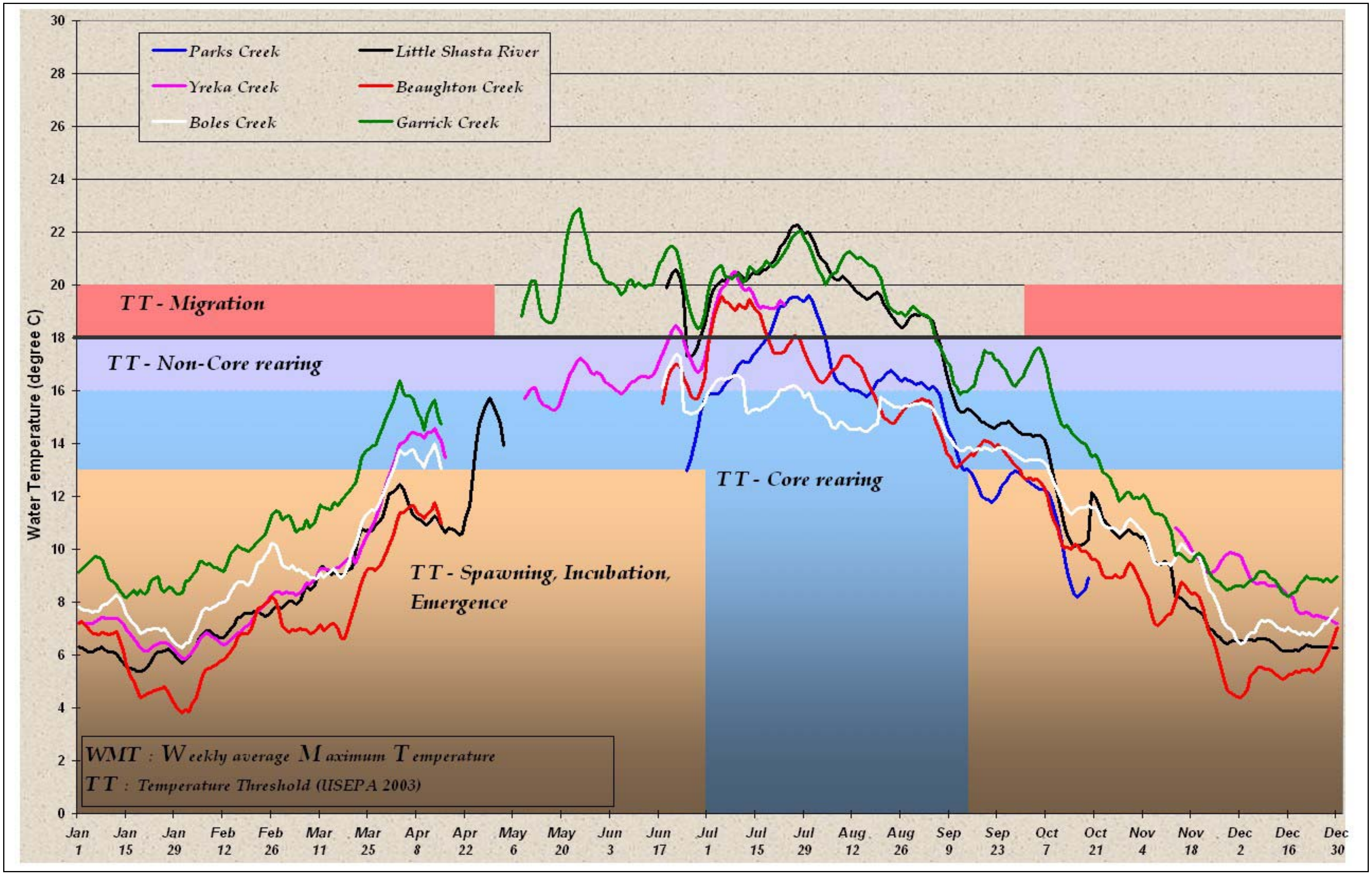


Figure 2.5: Average maximum weekly temperatures, Shasta River tributaries near headwaters, 2001-2003
Note: Discontinuity in the data lines is due to data gaps.

- Weekly maximum temperatures of measured tributaries near the confluence with the Shasta River tend to exceed the spawning, incubation, and emergence threshold (i.e., MWMT of 13°C) from mid-March through June, and mid-September through October.
- Weekly maximum temperatures of measured tributaries near the confluence with the Shasta River tend to exceed the core and non-core rearing threshold (i.e., MWMTs of 16 and 18°C, respectively) from about April through October, with some exceptions.
- Generally, weekly maximum temperatures of measured tributaries near the headwaters are below the core and non-core rearing thresholds during the summer months, except July and parts of August at some locations.

2.3.4 Temperature Conditions of Lake Shastina

Temperature profiles measured near the dam of Lake Shastina are presented in Figure 2.6. Lake Shastina tends to be thermally stratified from June through August, exhibiting warmer surface waters and colder waters at depth of the lake. Surface waters begin to warm in March, and by June stratification has set in. During summer months, surface water temperatures usually exceed 20°C, and bottom temperatures range from about 12 to 16°C. In September, stratification breaks down due to cooler air temperatures and shorter solar days. Isothermal conditions generally occur in late fall and persist through the winter months, with temperatures ranging from about 2 to 9°C. While the exact timing of these conditions varies, the general conditions are consistent. The outlet from Lake Shastina is located near the base of Dwinnell Dam.

Lake Shastina temperatures are not evaluated with respect to the USEPA (2003) thresholds because there are insufficient temperature data from Lake Shastina to calculate weekly maximum temperatures. Further, anadromous salmonids do not currently exist upstream of Dwinnell Dam, which is a barrier to migration. Note, however, that cold freshwater habitat is designated as an existing use in Lake Shastina and Lake Shastina tributaries. For a more complete discussion of temperature conditions in Lake Shastina the reader is referred to Vignola and Deas (2005).

2.4 Dissolved Oxygen

The Basin Plan includes numeric dissolved oxygen objectives for the Shasta River HA (Table 2.2). These dissolved oxygen objectives are currently undergoing revision, however at the time of this report the revisions are not complete and are not incorporated into the Basin Plan. Thus, data for the Shasta River are compared to those numeric dissolved oxygen objectives currently listed in the Basin Plan.

2.4.1 Dissolved Oxygen Requirements of Salmonids

A literature review of dissolved oxygen requirements of salmonids is presented in Electronic Appendix B_e (*The Effects of Dissolved Oxygen on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function by Life Stage*).

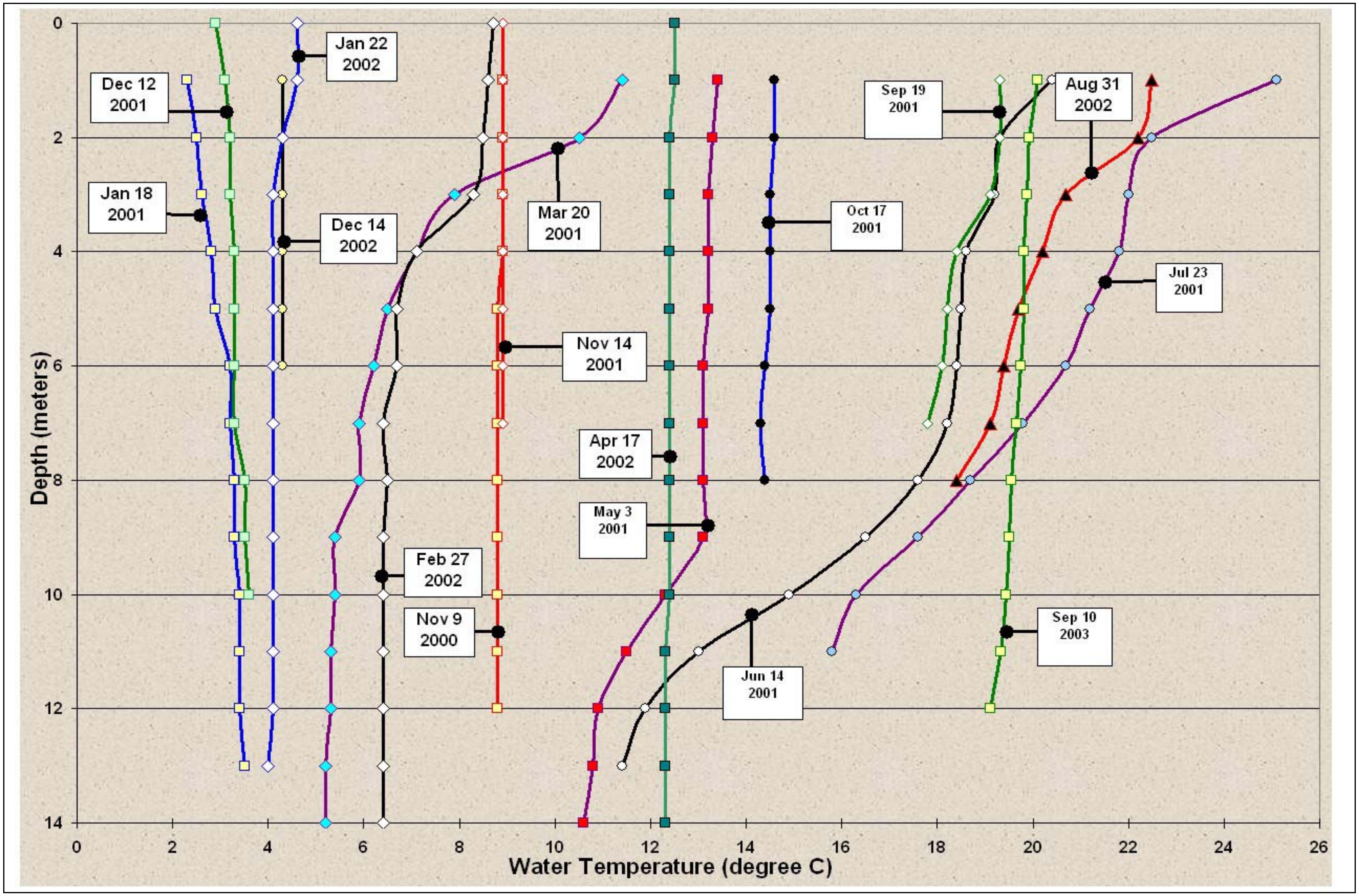


Figure 2.6: Lake Shastina temperature depth profiles, 2001-2003

2.4.1.1 Gas Bubble Disease

Gas bubble disease is not discussed in Appendix B_e, and is summarized here. High levels of total dissolved gas (TDG), including dissolved oxygen, can be harmful to salmonids and other fish and result in "gas bubble disease". This occurs when dissolved gases in their circulatory system come out of solution and form bubbles, which block the flow of blood through the capillary vessels (USEPA 1986, p.145). There are several ways TDG supersaturation can occur, including excessive algal photosynthesis, which can create supersaturated dissolved oxygen conditions (USEPA 1986, p.147). Thus, to protect salmonids and other freshwater fish, the USEPA has set criteria for TDG stating that levels should not exceed 110% of the saturation value.

Numerous studies have been conducted to determine the mortality rate of salmonids exposed to various levels of TDG. Mesa et al. (2000, p.174) conducted laboratory experiments on juvenile Chinook and steelhead. They exposed the fish to different levels of TDG and found no fish died when held at 110% TDG for up to 22 days. When fish were exposed to 120% TDG, 20% of juvenile Chinook died within 40 to 120 hours, while 20% of juvenile steelhead died within 20 to 35 hours. At TDG levels of 130%, Chinook mortality reached 20% after 3 to 6 hours, and steelhead mortality was 20% after 5 to 7 hours. Gale et al. (2001, p.3 and 21) held adult female spring Chinook at mean TDG levels ranging from 114.1% to 125.5% and found the time to first mortality ranged from 10 to 68 hours.

USEPA (1986) discusses various studies on the effects of TDG on salmonids. The following studies are all cited from the USEPA 1986 (p.148-150) water quality criteria document. Bouck et al. (1975) found TDG levels of 115% and above to be acutely lethal to most species of salmonids, and levels of 120% TDG are rapidly lethal to all salmonids. Conclusions drawn from Ebel et al. (1975) and Rulfison and Abel (1971) include the following:

- Adult and juvenile salmonids confined to shallow water (1 m) with TDG levels above 115% experience substantial levels of mortality.
- Juvenile salmonids exposed to sublethal levels of TDG supersaturation are able to recover when returned to normally saturated water, while adults do not recover and generally die.

2.4.2 Dissolved Oxygen Conditions of the Mainstem Shasta River

Measurement of dissolved oxygen concentrations of the Shasta River has been conducted by numerous parties, including private landowners, Shasta River Coordinated Resource Management Planning Council, Shasta Valley Resource Conservation District, City of Yreka, California Department of Fish and Game, California Department of Water Resources, US Fish and Wildlife Service, USEPA, and the Regional Water Board. Dissolved oxygen data records date back to the 1960s, but intensive dissolved oxygen monitoring using continuous recording dissolved oxygen probes began in the 1990s.

Figure 2.7 and Figure 2.8 summarize the available Shasta River mainstem dissolved oxygen conditions from 1994 through 2004. Figure 2.7 is a summary of all dissolved oxygen data measured from mainstem Shasta River locations, compiled into 4-week time periods, and compared to the Basin Plan minimum dissolved oxygen objective. Generally, during the fall/winter seasons (October 1 through March 30), dissolved oxygen concentrations in the Shasta River range from 7 to 19 mg/L. During the spring/summer seasons (April 1 through September 30), dissolved oxygen concentrations range from 2 to 18 mg/L. Figure 2.8 provides a closer look at the summer season data presented in Figure 2.7 by grouping the mainstem Shasta River data into river reaches, and presenting data for 2-week time periods. In addition, Figure 2.8 identifies the percentage of dissolved oxygen measurements that fall below the Basin Plan dissolved oxygen objective. Chapter 4 evaluates these dissolved oxygen data in more detail. The distribution of salmonids in the Shasta River watershed is presented in Chapter 1, Figure 1.16, however, locations at which fish presence is not indicated on the map do not necessarily indicate the absence of fish in these areas, as surveys to determine presence/absence may not have been conducted at all locations in the watershed.

Based on dissolved oxygen concentration and temperature measurements from the summer of 2003 and 2004 in the Shasta River, dissolved oxygen saturation levels were calculated. During these periods, dissolved oxygen saturation levels range from approximately 70% to 150%. The USEPA criteria for total dissolved gases is 110%. While dissolved oxygen is only one of the possible dissolved gases, the USEPA criteria for total dissolved gases is exceeded in the Shasta River at some times. However, there have been no known accounts of fish with gas bubble disease in the Shasta River watershed.

Key findings of Shasta River mainstem dissolved oxygen conditions are:

- Dissolved oxygen concentrations vary seasonally.
- Dissolved oxygen concentrations vary throughout the mainstem Shasta River.
- While Figure 2.7 presents a compilation of Shasta River mainstem dissolved oxygen measurements, the 50% lower limit of 9.0 mg/L appears to be met in at least 7 out of 12 months of the year.
- With few exceptions, mainstem Shasta River dissolved oxygen concentrations are above 7.0 mg/L during fall/winter seasons (October 1 through March 30).
- Dissolved oxygen concentrations fall below 7.0 mg/L for some period of time during the summer season (April 1 through September 30) at all mainstem Shasta River locations monitored.
- In the reach from Montague-Grenada Road to Anderson Grade Road, over 40% of dissolved oxygen measurements fall below 7.0 mg/L.
- In the Shasta River above Lake Shastina (at Edgewood Road), approximately 15% of dissolved oxygen measurements fall below 7.0 mg/L from late June through August.

2.4.3 Dissolved Oxygen Conditions of Shasta River Tributaries

Considerably less dissolved oxygen data have been collected in the tributaries to the Shasta River. Figure 2.9 summarizes dissolved oxygen concentrations in those tributaries monitored between 2001 and 2003, and identifies the percentage of dissolved oxygen measurements that fall below the Basin Plan objective. While the paucity of data limits

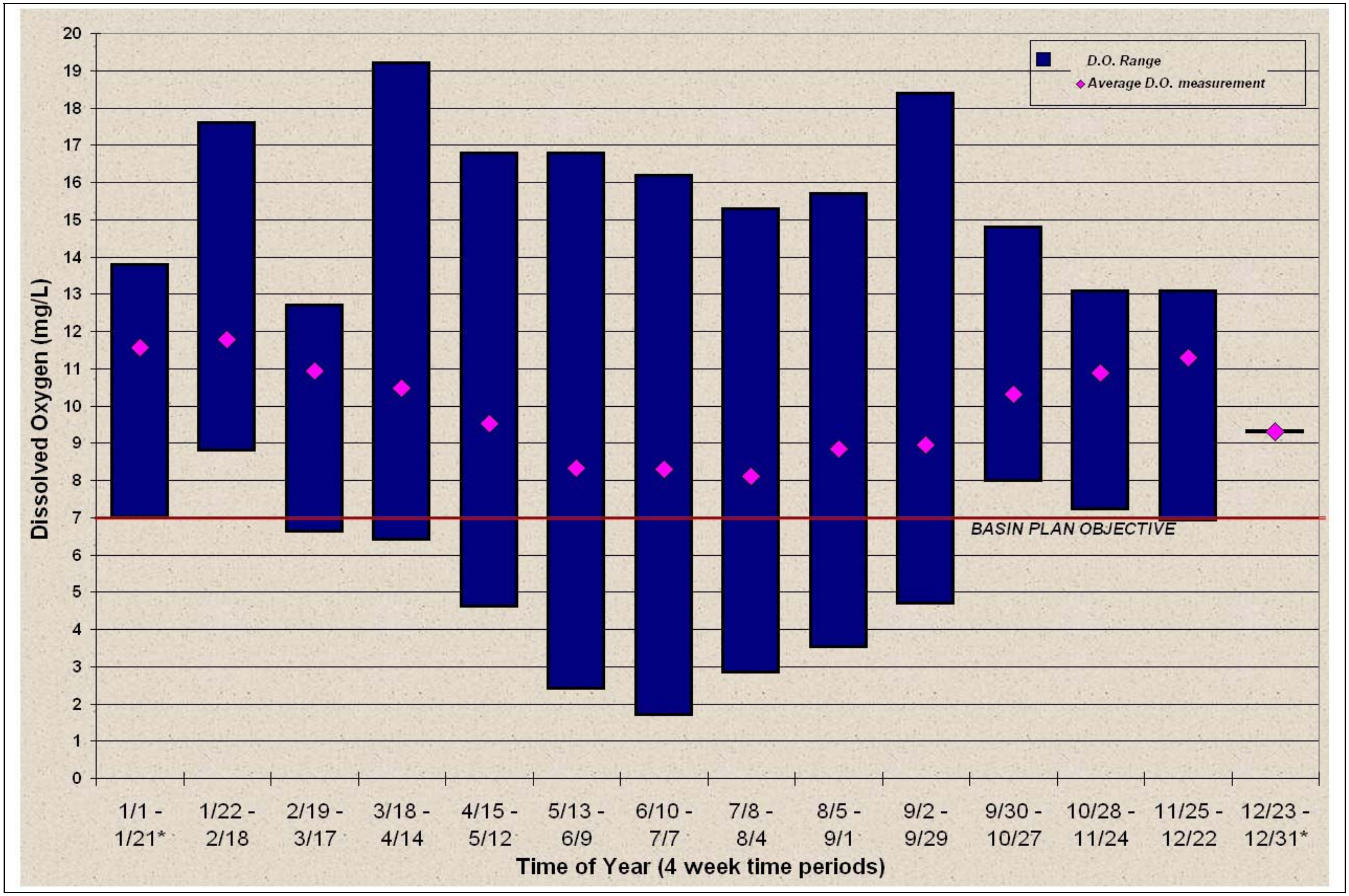


Figure 2.7: Range of recorded dissolved oxygen concentrations, composite of all Shasta River mainstem measurements, 28-day periods, 1994-2004

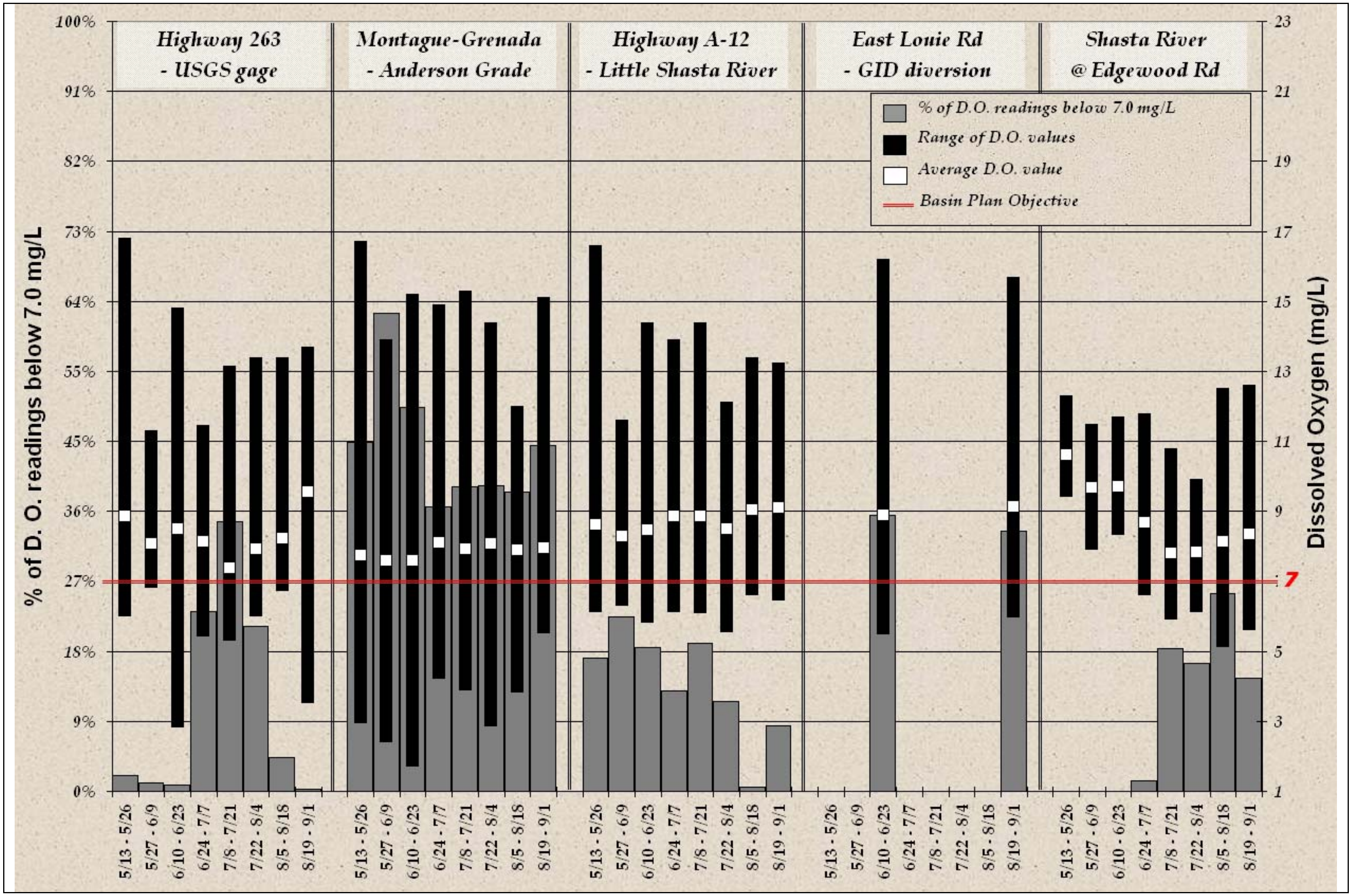


Figure 2.8: Bi-weekly dissolved oxygen concentration range, and percentage of measurements below Basin Plan dissolved oxygen objective, mainstem Shasta River reaches, May through August, 1994-2004

the ability to draw definitive conclusions, the data indicate that during the summer season, dissolved oxygen concentrations in some tributaries, particularly the Little Shasta River and Yreka Creek, fall below 7.0 mg/L for some period of time.

2.4.4 Dissolved Oxygen Conditions of Lake Shastina

Dissolved oxygen profiles measured near the dam of Lake Shastina are presented in Figure 2.10. Lake Shastina exhibits dissolved oxygen characteristics typical of a eutrophic reservoir. During summer months, when the reservoir is thermally stratified, the surface layer (epilimnion) is typically supersaturated with dissolved oxygen, while the bottom layer (hypolimnion) exhibits undersaturated conditions well below the Basin Plan dissolved oxygen objective of 6.0 mg/L. Dissolved oxygen concentrations approached zero in the hypolimnion between June and September 2001. Following fall turnover (mixing), dissolved oxygen concentrations are uniform and near saturation levels (above 6.0 mg/L). The outlet from Lake Shastina is located near the base of Dwinnell Dam. For more information on dissolved oxygen conditions in Lake Shastina, the reader is referred to Vignola and Deas (2005).

2.5 Biostimulatory Substances

The Basin Plan includes a narrative objective for "biostimulatory substances" that is applicable to the entire North Coast region:

> Waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses (NCRWQCB 2005).

In this context, biostimulatory substances refer to any substance that promotes aquatic plant growth, but generally is synonymous with the nutrients nitrogen and phosphorus. Nitrogen and phosphorus are the primary macro-nutrients that enrich freshwater aquatic systems. Nuisance is not specifically defined in the Basin Plan. In the context of the Shasta River TMDL, Regional Board staff define nuisance aquatic growth as that which contributes to violation of numeric water quality objectives (particularly dissolved oxygen and pH objectives) or adversely affects beneficial uses. Ammonia (NH_3), nitrate (NO_3^-), and ortho-phosphate (PO_4^{3-}) are the soluble fractions of nitrogen and phosphorus, and are the forms that are directly available to aquatic plants.

2.5.1 Nutrient Criteria and Trophic State Thresholds

Nutrients do not directly affect salmonids, but impact them indirectly by stimulating the growth of algae and aquatic macrophytes to nuisance levels that can adversely impact dissolved oxygen and pH levels in streams. The concentration of nutrients required to cause nuisance levels of aquatic plants varies widely from one stream to another and detailed data analysis is required to determine relationships. US EPA (2000) and Tetra Tech (2005) provide excellent summaries of the literature on these analytical methods and will not be repeated here.

USEPA (1986, p. 267) has "desired goals" for total phosphates as phosphorus for the prevention of nuisance plant growths. The "desired goal" for streams or other flowing waters not discharging directly to lakes or impoundments is 0.1 mg/L; the "desired goal" for streams at the point where they enter a lake or reservoir is 0.05 mg/L; and the "desired goal" for lakes or reservoirs is 0.025 mg/L. These desired goals are guidance levels, not

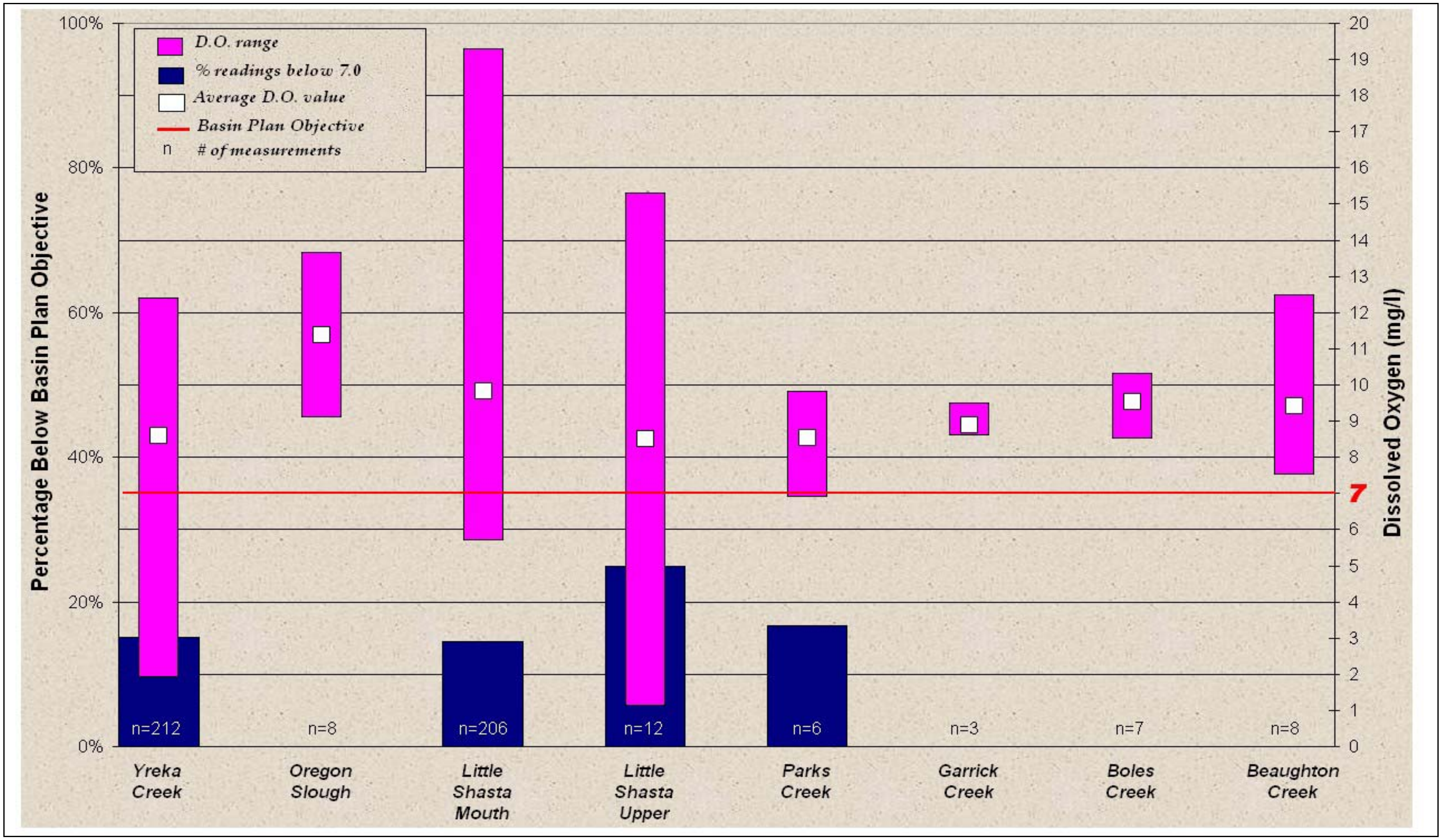


Figure 2.9: Dissolved oxygen concentrations, Shasta River tributaries, May through August, 2001-2003

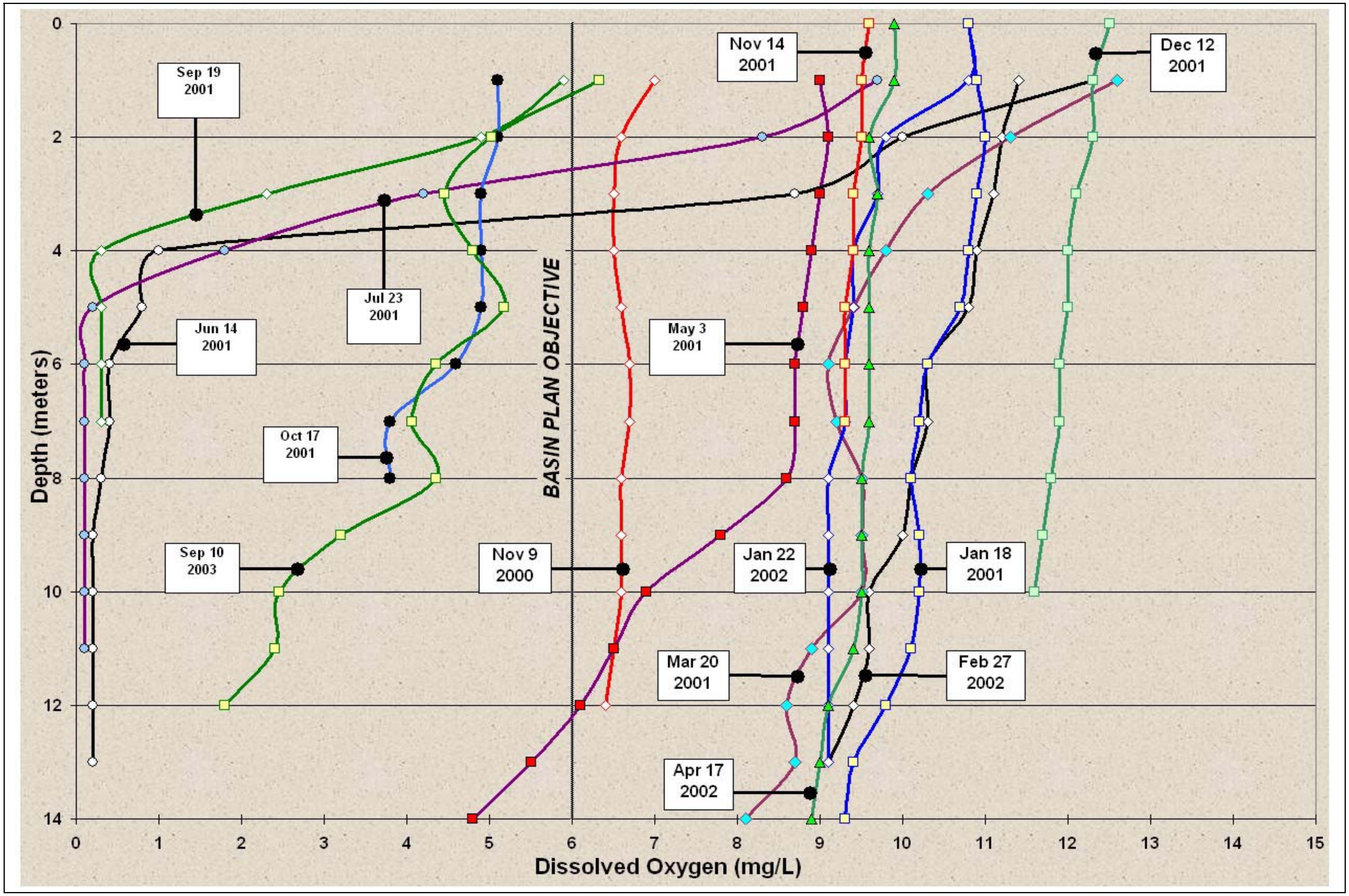


Figure 2.10: Lake Shastina dissolved oxygen depth profiles, 2001-2003

standards or criteria. USEPA (1986, p. 213) does not have a criterion or desired goal for nitrogen for prevention of nuisance plant growth; it does, however, have a criterion for nitrate nitrogen of 10 mg/L for human health protection in domestic water supplies.

In 2001, the USEPA developed recommended nutrient criteria for 13 aggregate ecoregions for rivers and streams of the United States (USEPA 2002). USEPA's recommended ecoregional nutrient criteria represent conditions of surface waters that have minimal impacts caused by human activities. The criteria are suggested baselines. California is in the process of refining these ecoregional criteria. The total phosphorus and total nitrogen criteria for ecoregion II (western forested mountains), which includes the Shasta River, are 0.01 and 0.12 mg/L, respectively.

Dodds et al. (1998) created a classification system for stream trophic state based on frequency distributions of total nitrogen, total phosphorous, and chlorophyll-a data from 200 streams in North America and New Zealand. These data were divided into three trophic state categories based on the lower, middle, and upper thirds of the distribution. USEPA (2000) states: "It should be stressed that this approach proposes trophic state categories based on the current distribution of algal biomass and nutrient concentrations which may be greatly changed from pre-human settlement levels." USEPA (2000) suggests that these distributions be used "to link nutrient concentrations and algal biomass in a very general sense." The trophic classification boundaries are presented below in Table 2.6, although they are not used to evaluate total nitrogen (TN) and total phosphorous (TP) conditions in the Shasta River.

Table 2.6: Boundaries for Trophic Classification of Streams

Parameter	**Oligotrophic-mesotrophic boundary**	**Mesotrophic-eutrophic boundary**	***Sample Size***
TN (mg/L)	0.7	1.5	1070
TP (mg/L)	0.025	0.075	1366

Source: Modified from Dodds et al. 1998

Literature values from various sources associating phosphorus and nitrogen levels in lakes and reservoirs to trophic status are presented in Table 2.7.

Table 2.7: Boundaries for Trophic Classification of Lakes and Reservoirs

Parameter	**Oligotrophic**	**Mesotrophic**	**Eutrophic**	**Hyper-eutrophic**	**Source**
Total P	<0.015	0.015-0.025	0.025-0.1	>0.1	Forsberg and Ryding (1980, as cited by Florida Lake Watch Undated)
Total N	<0.4	0.4-0.6	0.6-1.5	>1.5	Forsberg and Ryding (1980, as cited by Florida Lake Watch Undated)
Total P	<0.01	0.01-0.02	0.02-0.05 0.05-0.1*	>0.1	Environment Waikato Regional Council (Undated)
Total N	<0.2	0.2-0.3	0.3-0.5 0.5-1.5*	>1.5	Environment Waikato Regional Council (Undated)

*Supereutrophic classification
Note: All units are mg/L.

2.5.2 Shasta River Watershed Nutrient Conditions

Tables 2.8, 2.9, 2.10, and 2.11 provide a summary of nitrogen and phosphorus concentrations in the Shasta River, Lake Shastina, springs (including Bassey, Evans, Jim, Hidden Valley, and Big Springs), and key tributaries to the Shasta River, respectively.

2.5.2.1 Total Phosphorus

Total phosphorus levels in the headwaters of the watershed at the North North Fork Shasta River and Shasta River near the headwaters monitoring locations are 0.025 mg/L[1]. These values are below the USEPA 0.1 mg/L "desired goal" value to prevent nuisance growth. It is unknown how these data compare to the 0.01 mg/L USEPA criteria for ecoregion II, as the reporting limit is higher than the criteria value.

Downstream of the headwaters, Beaughton and Boles Creeks enter the Shasta River from the west and flow through the phosphorus rich volcanic soils flanking Mount Shasta. This is reflected in the high total phosphorous values in these creeks with averages of 0.192 and 0.119 mg/L respectively. These total phosphorus values are above the USEPA guidance level of 0.1 mg/L to prevent nuisance growth of aquatic plants. These values are also higher than the 0.01 mg/L USEPA criteria value for ecoregion II. As these creeks enter the Shasta River, they contribute to phosphorus loads in the river, and this is reflected in the high total phosphorous levels in the Shasta River above Dwinnell Dam.

Total phosphorus values in the Shasta River above Dwinnell are relatively high. Data from this portion of the Shasta River reflect water quality conditions entering Lake Shastina, with an average total phosphorus value of 0.09 mg/L. This total phosphorus concentration is above the USEPA "desired goal" of 0.05 mg/L for streams where they enter a lake or reservoir, and above the 0.01 mg/L criteria value for ecoregion II. Garrick Creek (aka Carrick Creek) also discharges directly into Lake Shastina, and total phosphorus values range from 0.1 to 0.29 mg/L. These values are above the USEPA guidance level of 0.05 mg/L and ecoregion II criteria value of 0.01mg/L.

The relatively high total phosphorus concentrations in Garrick Creek and the Shasta River above Dwinnell are reflected in monitoring data from Lake Shastina, where levels of total phosphorus range from 0.025 to 0.59 mg/L near the surface, with an average of 0.138 mg/L. Total phosphorus concentrations near the bottom of the reservoir range from 0.025 to 0.23 mg/L, with an average of 0.085 mg/L. These total phosphorus values

[1] In this TMDL document, all water quality samples with results below the analytical reporting limit were assumed to be half the reporting limit for this analysis. There is no commonly accepted method for statistical analysis of data below detection limits. Conventional methods include assuming the result is equal to the detection limit, half the detection limit, or zero, but these assumptions often have no theoretical basis. There are statistical methods that can be used to infer the distribution of data that are below detection limits. These require that the data be normally or log-normally distributed. The data in this analysis were neither. Since non-parametric statistics are used in this analysis, since the constituents are known to be present in the system, and since the number of data points are limited, the convention of using half the reporting limit is used here although it may lead to unquantified errors, especially when a large percentage of the data points in a set are below the reporting limit.

Table 2.8: Summary of Nitrogen and Phosphorus data for the Shasta River

Location	Metric	Ammonia as N	NO3 as N	NO2+NO3 as N	TKN	Total-N[1]	Ortho-P	Total-P
Shasta River near headwaters	Count	3	1	3	3	-	2	3
	Count (ND)	2	1	3	0	-	2	3
	Max	0.056	0.025	0.025	0.20	0.23	0.025	0.025
	Median	0.041	N/A	0.025	0.20	0.23	N/A	0.025
	Average	0.014	N/A	0.025	0.20	0.23	N/A	0.025
	Min	0.025	0.025	0.025	0.20	0.23	0.025	0.025
Shasta River above Dwinnell	Count	34	5	1	6	-	6	55
	Count (ND)	29	0	0	0	-	1	0
	Max	0.090	0.356	0.081	0.32	0.40	0.111	0.750
	Median	0.025	0.152	N/A	0.20	-	0.029	0.060
	Average	0.030	0.197	N/A	0.22	-	0.048	0.090
	Min	0.020	0.071	0.081	0.16	0.24	0.012	0.005
Shasta River below Dwinnell Dam	Count	485	65	26	165	-	124	273
	Count (ND)	319	34	14	26	-	5	4
	Max	0.700	0.730	0.240	4.00	4.24	0.422	2.010
	Median	0.075	0.122	0.025	0.49	0.52	0.131	0.239
	Average	0.025	0.025	0.087	0.50	0.59	0.140	0.190
	Min	0.005	0.020	0.025	0.10	0.13	0.005	0.020

[1]Total-N was calculated by adding the TKN and NO2+NO3 values listed in the table
Data from 1993-2003

Table 2.9: Summary of Nitrogen and Phosphorus data for Lake Shastina

Location	Metric	Ammonia as N	NO3 as N	NO2+NO3 as N	TKN	Total-N[1]	Ortho-P	Total-P
Lake Shastina (at surface)	Count	14	-	4	4	-	4	20
	Count (ND)	13	-	4	0	-	3	3
	Max	0.093	-	0.025	1.20	1.23	0.170	0.590
	Median	0.025	-	0.025	0.94	0.97	0.025	0.070
	Average	0.030	-	0.025	0.94	0.96	0.061	0.138
	Min	0.025	-	0.025	0.67	0.70	0.025	0.025
Lake Shastina (at depth)	Count	18	-	8	5	-	8	21
	Count (ND)	12	-	8	4	-	6	4
	Max	2.200	-	0.025	2.50	2.53	0.370	0.230
	Median	0.025	-	0.025	0.84	0.87	0.025	0.060
	Average	0.325	-	0.025	1.28	1.30	0.075	0.085
	Min	0.025	-	0.025	0.10	0.13	0.025	0.025

[1]Total-N was calculated by adding the TKN and NO2+NO3 values listed in the table
Data from 1993-2003

Table 2.10: Summary of Nitrogen and Phosphorus data for Springs

Metric	Ammonia as N	NO3 as N	NO2+NO3 as N	TKN	Total-N[1]	Ortho-P	Total-P
Count	8	3	12	8	-	5	8
Count (ND)	7	0	1	7	-	2	2
Max	0.088	0.290	0.260	0.69	0.95	0.160	0.220
Median	0.025	0.260	0.140	0.20	0.34	0.098	0.099
Average	0.033	0.253	0.150	0.26	0.41	0.086	0.107
Min	0.025	0.210	0.025	0.20	0.23	0.025	0.025

[1]Total-N was calculated by adding the TKN and NO2+NO3 values listed in the table
Data from 1993-2003
Note: springs monitored included Bassey, Evans, Jim, Hidden Valley, and Big Springs.

Table 2.11: Summary of Nitrogen and Phosphorus data for Key Tributaries to the Shasta River

Location	Metric	Ammonia as N	NO3 as N	NO2+NO3 as N	TKN	Total-N[1]	Ortho-P	Total-P
N. North Fork	Count	3	-	3	3	-	2	3
	Count (ND)	3	-	2	0	-	0	2
	Max	0.025	-	0.051	1	1.05	0.025	0.025
	Median	0.025	-	0.034	0.20	0.23	N/A	0.025
	Average	0.025	-	0.025	0.47	0.49	N/A	0.025
	Min	0.025	-	0.025	0.20	0.23	0.025	0.025
Beaughton Creek	Count	23	-	3	3	-	3	23
	Count (ND)	20	-	0	0	-	0	0
	Max	0.100	-	0.110	0.20	0.31	0.210	0.400
	Median	0.025	-	0.089	0.20	0.29	0.190	0.170
	Average	0.033	-	0.094	0.20	0.29	0.187	0.192
	Min	0.025	-	0.083	0.20	0.28	0.160	0.070
Boles Creek	Count	16	-	6	6	-	6	17
	Count (ND)	16	-	0	0	-	0	1
	Max	0.025	-	0.560	0.20	0.76	0.120	0.310
	Median	0.025	-	0.525	0.20	0.73	0.100	0.110
	Average	0.025	-	0.493	0.20	0.69	0.101	0.119
	Min	0.025	-	0.360	0.20	0.56	0.082	0.025
Garrick Creek	Count	16	-	-	-	-	-	28
	Count (ND)	16	-	-	-	-	-	0
	Max	0.025	-	-	-	-	-	0.290
	Median	0.025	-	-	-	-	-	0.160
	Average	0.025	-	-	-	-	-	0.169
	Min	0.025	-	-	-	-	-	0.100
Main Canal	Count	4	4	-	3	-	3	4
	Count (ND)	4	3	-	0	-	0	1
	Max	0.025	0.100	-	0.28	-	0.055	0.084
	Median	0.025	0.025	-	0.27	-	0.050	0.080
	Average	0.025	0.044	-	0.26	-	0.048	0.067
	Min	0.025	0.025	-	0.22	-	0.040	0.025
Parks creek	Count	14	1	-	4	-	2	18
	Count (ND)	14	0	-	0	-	2	3
	Max	0.025	0.098	-	0.66	-	0.025	0.260
	Median	0.025	N/A	-	0.20	-	N/A	0.010
	Average	0.025	N/A	-	0.32	-	N/A	0.046
	Min	0.025	0.098	-	0.20	-	0.025	0.005
Little Shasta	Count	24	1	4	8	-	2	36
	Count (ND)	22	1	4	0	-	0	3
	Max	0.100	0.025	0.025	0.95	0.98	0.092	0.400
	Median	0.025	N/A	0.025	0.25	0.28	N/A	0.110
	Average	0.031	N/A	0.025	0.41	0.43	N/A	0.119
	Min	0.025	0.025	0.025	0.20	0.23	0.025	0.025
Oregon Slough	Count	17	-	7	9	-	7	23
	Count (ND)	7	-	0	0	-	0	0
	Max	0.300	-	0.390	1.30	1.69	0.260	14.000
	Median	0.052	-	0.210	0.82	1.03	0.240	0.240
	Average	0.085	-	0.224	0.75	0.98	0.219	0.875
	Min	0.025	-	0.090	0.20	0.29	0.092	0.030
Yreka Creek	Count	8	-	10	72	-	50	143
	Count (ND)	7	-	0	0	-	2	2
	Max	0.076	-	1.600	0.75	2.35	1.220	1.700
	Median	0.025	-	0.860	0.20	1.06	0.050	0.103
	Average	0.031	-	0.763	0.26	1.02	0.119	0.258
	Min	0.025	-	0.098	0.10	0.20	0.010	0.010

[1]Total-N was calculated by adding the TKN and NO2+NO3 values listed in the table

Data from 1993-2003

reflect mesotrophic to hypereutrophic conditions, with the majority of data reflecting conditions which are supereutrophic or hypereutrophic. All total phosphorus data collected in Lake Shastina are above the USEPA "desired goal" for lakes and reservoirs of 0.025 mg/L, indicating levels of phosphorus that can promote nuisance aquatic growth.

Total phosphorus levels in the Shasta River below Dwinnell Dam show spatial variation, and the average total phosphorus level is 0.19 mg/L. Tributaries in this portion of the watershed have total phosphorus values ranging from 0.005 to 1.7 mg/L. The total phosphorus levels in springs are generally high with average values of 0.107 mg/L. Average levels of total phosphorus in the mainstem, tributaries, and springs below Dwinnell Dam are above the USEPA guidance value of 0.1 mg/L, and can promote nuisance aquatic growth. Additionally, average total phosphorous values are well above the recommended USEPA criteria for ecoregion II of 0.01mg/L.

Key findings regarding total phosphorus (TP) conditions are:

- Total phosphorus concentrations of the headwaters of the Shasta River are at levels that do not promote nuisance aquatic growth.
- Average and maximum total phosphorus concentrations of tributaries and the mainstem Shasta River are at levels that can promote nuisance aquatic growth.
- Average and maximum total phosphorus concentrations of Lake Shastina are generally supereutrophic or hypereutrophic, with TP concentrations at levels that can promote nuisance aquatic growth.
- Total phosphorus concentrations of springs are at levels that can promote nuisance aquatic growth.

2.5.2.2 Total Nitrogen

The headwaters of the Shasta River have total nitrogen levels indicative of some level of nutrient enrichment. Data from the Shasta River near the headwaters exceed the USEPA criteria value of 0.12 mg/L for ecoregion II (0.23 mg/L) as do total nitrogen values from the N. North Fork Shasta River (0.23 to 1.05 mg/L).

Total nitrogen levels in Boles Creek range from 0.56 mg/L to 0.76 mg/L and are higher than those in Beaughton Creek, which range from 0.28 to 0.31 mg/L. Data from the Shasta River above Dwinnell Dam reflect total nitrogen levels ranging from 0.24 to 0.40 mg/L. These tributary and mainstem values are at least twice the USEPA criteria for ecoregion II of 0.12 mg/L.

Surface measurements from Lake Shastina reflect conditions that are mesotrophic with values ranging from 0.70 to 1.23 mg/L. The average value of total nitrogen from samples collected at depth is close to the mesotrophic/eutrophic border (1.3 mg/L), and the maximum value is within the eutrophic classification range (2.53 mg/L).

In the Shasta River below Dwinnell Dam, total nitrogen values are all over the 0.12 mg/L USEPA criteria value for ecoregion II. Minimum total nitrogen levels are 0.13 mg/L and average and maximum values are far above the USEPA ecoregion II criteria (0.59 and

4.49mg/L respectively). Measured tributaries below the dam have total nitrogen values that are well above the USEPA criteria value. Average values of total nitrogen in Little Shasta, Oregon Slough and Yreka Creek are 0.43, 0.22, and 1.02 mg/L respectively. Springs in the watershed below the Dwinnell Dam have total nitrogen values ranging from 0.23 to 0.95 mg/L, which are above the 0.12 mg/L USEPA ecoregion II criteria.

Key findings regarding total nitrogen conditions are:

- Total nitrogen levels at measured locations in the Shasta River, tributaries, and springs exceed the USEPA criteria value for ecoregion II, with the exception of the Shasta River below Dwinnell Dam.
- In Lake Shastina, total nitrogen levels are generally mesotrophic to eutrophic, indicating conditions that promote aquatic growth.

2.6 Evidence of Beneficial Use Impairment

The previous three sections characterize temperature, dissolved oxygen, and nutrient conditions of the Shasta River basin. Section 2.3 demonstrates that temperature conditions regularly exceed USEPA temperature thresholds protective of salmonids. Section 2.4 demonstrates that dissolved oxygen concentrations are regularly below the Basin Plan dissolved oxygen objectives. Further, a comparison of the dissolved oxygen data presented in Section 2.4 to the dissolved oxygen requirements of salmonids presented in Electronic Appendix B_e indicates that Shasta River dissolved oxygen concentrations are often not supportive of various life stages of salmonids. Section 2.5 demonstrates that nutrient levels in the Shasta River are biostimulatory. This section summarizes prior documentation of how the temperature and dissolved oxygen conditions of the Shasta River basin are impairing the cold and warm freshwater habitat beneficial uses.

2.6.1 Cold Freshwater Habitat Impairment

As discussed in Section 1.4.10, salmonid populations of the Shasta River basin have declined sharply from historic levels. In 1985, the U.S. Department of Interior linked declining Shasta River salmonid populations to high summer stream temperatures, low summer flows, unscreened water diversions, degraded spawning gravel, and possibly hydroelectric projects (U. S. Department of Interior [USDI] 1985, pp. 5-8 to 5-16). Further, the report identified that rapid in-stream flow reductions at the onset of the spring irrigation season were possibly contributing to juvenile fall Chinook, coho, and steelhead losses, caused by stranding in pools and side channels. In 1987 and 1988, the California Department of Fish and Game (CDFG) sent memos to the Regional Water Board requesting assistance in assessing the link between water quality and the status of the Shasta River fishery. CDFG stated that in late spring during low water years, "depressed dissolved oxygen resulting from high biological oxygen demand and high temperature" in the Shasta Valley contributed to mortality of Chinook and steelhead (CDFG 1987). The 1988 memo cited "critical conditions due to dissolved oxygen concentrations, nutrient concentrations and temperature; especially during poor water years (CDFG 1988)."

A 1990-1991 Shasta River fisheries water quality project, funded by the US Fish and Wildlife Service Klamath River Basin Fisheries Task Force and the Shasta Valley Resource Conservation District, cited that fish kills in the Shasta were attributable to low dissolved oxygen levels (Ouzel Enterprises 1991, p. 2). The National Academy of Science report, "Endangered and Threatened Fishes in the Klamath River Basin: Causes of Decline and Strategies for Recovery," attributes the Shasta basin decline in salmonid production to "substantial reduction of flows by water withdrawal and the associated poor water quality," and states that high water temperature is "a major bottleneck for salmonid production" in the basin (National Research Council of the National Academies [NRC] 2003, p. 133).

In the summer of 2005, the California Department of Fish and Game documented water quality conditions in the Shasta River and a side channel located in the canyon called Salmon Heaven, and observed a number of dead fish (CDFG 2005b). On July 7th, one dead 1+ steelhead was observed in the side channel where the water temperature was 25.2°C, which is well above the juvenile rearing MWMT chronic temperature thresholds in Table 2.3, and over the juvenile lethal threshold in Table 2.4. Salmonids in this side channel were also observed swimming in the pool near the surface. Before dawn (04:42) on July 8th, dissolved oxygen concentrations were 2.17 mg/L in the downstream end of the side channel pool and 2.71 mg/L at the riffle above the pool (Basin Plan dissolved oxygen objective is a minimum of 7.0 mg/L), and stream temperatures ranged from 19.3 to 19.5 °C. On July 14th, 20 dead adult sculpin and 4 dead crayfish were observed in the side channel. No salmonids were observed. In the mid-afternoon (14:15), stream temperature in the side channel was 25°C and dissolved oxygen was 10.5 mg/L. Water temperature and dissolved oxygen levels in a spring that feeds the side channel were respectively 17.9°C and 0.5 mg/L in mid-afternoon (15:50) on the 14th.

These recent and past accounts indicate that stream temperatures and dissolved oxygen concentrations of the Shasta River basin significantly contribute to impairment of the cold freshwater beneficial use of the basin.

2.6.2 Warm Freshwater Habitat Impairment

Fish kills in Lake Shastina have been documented on numerous occasions, beginning in the 1960s. According to California Department of Fish and Game accounts (1975), fish kills were an annual summer-time occurrence in the lake during the 1960s. During that time, fish kills were attributed to low dissolved oxygen levels associated with algal blooms. The algal blooms were noted to occur due to high nutrient levels in the lake. These summer-time fish kills did not occur during the early 1970s, and CDFG (1975) notes that this may be due to improved wastewater treatment and water quality practices resulting in fewer nutrients being discharged into Lake Shastina.

The most recent documented fish kill in Lake Shastina occurred in 2001 when numerous dead Pond smelt and a few dead Tui chub, Golden shiners, and juvenile Largemouth bass were found around the edges of the lake (CDFG 2001). CDFG found no parasites or bacterial pathogens in the live fish tested, although they note that finding symptomatic fish was difficult. Water quality samples for dissolved oxygen, pH, and temperature in the lake were determined to be “okay”, but numeric water quality results were not provided (CDFG 2001).

2.6.3 Potential Municipal and Domestic Water Supply and Contact Recreation Impairment

Lake Shastina is an existing municipal and domestic water supply for the town of Montague. The lake is also used for both contact and non-contact recreation. The outflow from Lake Shastina is located near the bottom of the reservoir at Dwinnell Dam, and water is delivered to the town of Montague drinking water treatment facility via an open ditch periodically treated with a pesticide. Lake Shastina experiences regular summer algal blooms, and the algal assemblage is typical of eutrophic waters (Vignola and Deas 2005). In July 2004, Regional Water Board staff collected algal samples from Lake Shastina at two open water locations (at three depths at each location) in support of TMDL development. All of the algal samples included *Anabaena flos-aquae*, with cell densities ranging from 2 cells/mL at depth up to 994 cells/mL near the surface (NCRWQCB and University of California Davis Aquatic Ecosystems Analysis Laboratory [UCD AEAL] 2005). *Anabaena flos-aquae* is a cyanobacteria (also called blue-green algae) that produces multiple neurotoxins, including anatoxin-a (Kann 2005). The presence of neurotoxins was not analyzed as part of the Regional Water Board’s Lake Shastina study. Anatoxins are neurotoxic agents that have been implicated in numerous animal and wildlife poisonings, and one human fatality (Kann 2005).

Health risks identified by the World Health Organization (Chorus and Bartram 1999, as cited by Vignola and Deas 2005) for managing bathing waters that may contain cyanobacteria cells are:

- Low risk: <20,000 cells/ml
- Moderate risk: 100,000 cells/ml
- High risk: Cyanobacterial scum formation in contact recreation areas

While the cell counts were within the low risk category, the samples were collected at open water locations. Wind can accumulate algal blooms at shoreline locations, and cell densities can readily be increased by 1000 times or more (Brookes et al 2005, as cited by Vignola and Deas 2005).

These results represent a potential impairment to the municipal and domestic supply and contact recreation beneficial uses of Lake Shastina. This condition is not directly related to temperature and dissolved oxygen impairments; however, it is indirectly linked, as the water quality conditions that typically cause algal blooms (i.e. high nutrient concentrations and warm water temperatures) also contribute to low dissolved oxygen levels in reservoirs that are attributed to decomposition of dead algae.

CHAPTER 3. TEMPERATURE SOURCE AND LINKAGE ANALYSIS

3.1 Introduction

This chapter identifies the sources (or factors) that affect the temperature of the Shasta River and its tributaries and establishes a linkage between these sources (or factors) and stream temperature. First, the general stream heating processes applicable to any surface waterbody are described in the following section. The contributions from the identified sources (or factors) affecting Shasta River watershed temperatures are quantified in Chapter 6.

3.1.1 Stream Heating Processes

Water temperature is a measure of the total heat energy contained in a volume of water. Stream temperature is the product of a complex interaction of heat exchange processes. These processes, collectively referred to as heat fluxes, are applicable to all surface waterbodies and include heat gain from direct solar (short-wave) radiation, both gain and loss of heat through long-wave radiation, convection, conduction, advection, and heat loss from evaporation (Beschta et al. 1987; Brown 1980; Johnson 2004; Sinokrot and Stefan 1993; Theurer et al. 1984).

- Net direct solar radiation reaching a stream surface is the difference between incoming radiation and reflected radiation, reduced by the fraction of radiation that is blocked by topography and stream bank vegetation (Sinokrot and Stefan 1993). At a given location, incoming solar radiation is a function of position of the sun, which in turn is determined by latitude, day of the year, and time of day. During the summer months, when solar radiation levels are highest and stream flows are low, shade from streamside forests and vegetation can be a significant control on direct solar radiation reaching streams (Beschta et al. 1987). At a workshop convened by the State of Oregon's Independent Multidisciplinary Science Team, 21 scientists reached consensus that solar radiation is the principal energy source that causes stream heating (Independent Multidisciplinary Science Team 2000).

- Heat exchange via long-wave radiation at a stream surface is a function of the difference between air temperature and water surface temperature (Oregon Department of Environmental Quality [ODEQ] 2000; Sinokrot and Stefan 1993). Long-wave radiation emitted from the water surface can cool streams at night. Likewise, long-wave radiation emitted from the atmosphere and surrounding environment can warm a stream during the day. During the course of a 24-hour period, heat leaving and heat entering a stream via long-wave radiation generally balance (Beschta 1997; ODEQ 2000).

- Evaporative heat losses are a function of the vapor pressure gradient above the stream surface and wind conditions (Sinokrot and Stefan 1993). Evaporation tends to dissipate energy from water and thus tends to lower temperatures. The rate of evaporation increases with increasing stream temperature. Air movement (wind) and low vapor pressures (dry air) increase the rate of evaporation and accelerate stream cooling (ODEQ 2000).

- Convection describes heat transferred between the air and water via molecular and turbulent motion. Heat is transferred from areas of warmer temperature to areas of cooler temperature. The amount of heat transferred by this mechanism is generally considered low (Brown 1980; Sinokrot and Stefan 1993).

- Conduction is the means of heat transfer between the stream and its bed. In shallow streams, solar radiation may be able to warm the streambed (Brown 1980). Bedrock or cobbles on the streambed may store heat and conduct heat back to the water if the bed is warmer than the water (ODEQ 2000). Likewise, water can lose or gain heat as it passes through subsurface sediments during intra-gravel flow through gravel bars and meanders. Bed conduction is a function of the thermal conductivity of the bed and the temperature gradient within the bed (Sinokrot and Stefan 1993). A streambed that has absorbed radiant energy during the day will conduct that energy back to the stream at night.

- Advection is heat transfer through the lateral movement of water as stream flow or groundwater. Advection accounts for heat added to a stream by tributaries or groundwater. This process may warm or cool a stream depending on whether a tributary or groundwater entering the stream is warmer or cooler than the stream.

Each of the heat fluxes discussed above can be represented by mathematical equations. By adding the values of the fluxes for a particular location, the net of the heat fluxes associated with all of these processes can be calculated (Sinokrot and Stefan 1993; Theurer et al. 1984). The net heat flux represents the change in the water body's heat storage. The net change in storage may be positive, leading to higher stream temperatures, negative, leading to lower stream temperatures, or zero such that stream temperature does not change.

Of the processes described above, solar radiation is most often the dominant heat exchange process. In some cases and locations advection has a great effect on stream temperatures by diluting heat loads via mixing of colder water. Although the dominance of solar radiation is well accepted (Johnson 2003; Johnson 2004; Sinokrot and Stefan 1993; Theurer et al. 1984), some studies have indicated that air temperatures are the prime determinant of stream temperatures. These studies have based their conclusions on correlation rather than causation (Johnson 2003). Air and water temperatures are generally well correlated, however correlation does not imply causation. Heat budgets developed to track heat exchange consistently demonstrate that solar radiation is the dominant source of heat energy in stream systems (Johnson 2004; ODEQ 2002; Sinokrot and Stefan 1993).

The conclusion that solar radiation is a major source of stream temperature increases is supported by studies demonstrating both temperature increases following removal of shade-producing vegetation, and temperature decreases in response to riparian planting. Johnson and Jones (2000) documented temperature increases following shade reductions by timber harvesting and debris flows, followed by temperature reductions as riparian vegetation became re-established. In another study, shade loss caused by debris flows and high waters of the flood of 1997 led to temperature increases in some Klamath National Forest streams (De la Fuente and Elder 1998). Riparian restoration efforts by the Coos Watershed Association reduced the MWAT of Willanch Creek (located in Oregon) by 2.8 ^{o}C (6.9 ^{o}F) over a six-year period (Coos Watershed Association undated). Miner and Godwin (2003) reported similar successes following riparian planting efforts.

3.2 Sources of Information

Much of the data and information used in the development of the temperature TMDL were collected during the summers of 2002, 2003, and 2004 by Regional Water Board staff, with assistance from the U.S. Geological Survey and Watershed Sciences, LLC. These data included:

- Stream and tailwater temperature monitoring data:
- Thermal infrared remote radiometry (TIR) survey of the Shasta River and select tributaries;
- Existing flow and temperature modeling of the Shasta River developed for the SVRCD; and
- Text books and scientific literature.

3.3 Stream Heating Processes Affected by Human Activities in the Shasta River Watershed

Regional Water Board staff identified factors affecting stream temperatures of the Shasta River watershed. Human activities have affected, or have a potential to affect, each of these factors. The factors include:

- Stream shade;
- Tailwater return flows;
- Flow and surface water diversions;
- Groundwater accretion / spring inflow; and
- Lake Shastina and minor channel impoundments.

Following a discussion on the collection and use of infrared imagery in developing the temperature TMDL, the Shasta River stream heating factors are evaluated.

3.3.1 Collection and Use of Infrared Imagery

The North Coast Water Board funded a thermal infrared remote radiometry (TIR) survey of the Shasta River and select tributaries (Watershed Sciences, LLC 2004) in support of this study. On July 26 and 27, 2003, Watershed Sciences, LLC conducted aerial TIR surveys of the Shasta River from the mouth to Dwinnell Dam, Little Shasta River, Parks

Creek, and Big Springs Creek. The imagery was collected using side-by-side video and infrared cameras. The survey yielded temperature measurements of approximately ½ meter-square pixel resolution, in images that captured an area approximately 140 m – 193 m (459ft - 635ft) on the ground, depending on flight altitude. The accuracy of TIR data was better than +/- 0.5^{o}C (0.9^{o}F), based on instream temperatures directly measured at the time of the flight. Watershed Sciences subsequently processed the thermal information into longitudinal profiles, a GIS database, and other data products. A complete description of Watershed Sciences' methods, measurement accuracy, and findings is available in their 2004 report (Appendix B, *Aerial Surveys using Thermal Infrared and Color Videography: Scott River and Shasta River Sub-Basins*).

The longitudinal temperature profile of the Shasta River from the TIR survey shows that the river is thermally complex, with reaches of pronounced heating and cooling, as well as reaches with stable temperatures (Figure 3.1). The results also provide insight into factors likely to have an influence on Shasta River temperatures.

The following sections discuss the effects of stream shade, tailwater return flows, surface water diversions, and groundwater accretion / spring inflow on stream temperature, and present TIR imagery and associated data that provide supporting evidence.

3.3.2 Shade

Direct solar radiation is a significant factor influencing stream temperatures in summer months. The energy added to a stream from solar radiation far outweighs the energy lost or gained from evaporation or convection (Beschta et al. 1987; Johnson 2004; Sinokrot and Stefan 1993). Because shade limits the amount of direct solar radiation reaching the water, it provides a direct control on the amount of heat energy the water receives.

Shade is created by vegetation and topography. In addition to ridges, topographic shade includes channel banks. In small streams with deep, incised channels the shade created by the channel banks can comprise a significant portion of the total shade on the channel.

Topographic shade is minimal to non-existent in the Shasta Valley, but is more prominent in the Shasta canyon reach (Figure 1.4). The average percentage of the sky (180 degrees, horizon to horizon, regardless of aspect) that is in view from the Shasta River stream channel is 95%. USGS made this calculation using the computer program SKYVIEW, which calculates topographic shading and blocking ridges around each pixel in a 30-meter digital elevation model (Flint and Flint 2005, Table 1).

The shade provided to a water body by riparian vegetation has a dramatic, beneficial effect on stream temperatures by blocking solar radiation, reducing wind speed, altering the microclimate above the water surface (i.e. air temperature and relative humidity), and reflecting long-wave radiation. The removal of vegetation decreases shade, which increases solar radiation levels which, in turn, increases stream temperatures. Additionally, the removal of vegetation increases ambient air temperatures, can result in bank erosion, and can result in changes to the channel geometry to a wider and shallower stream channel, all of which also increase water temperatures.

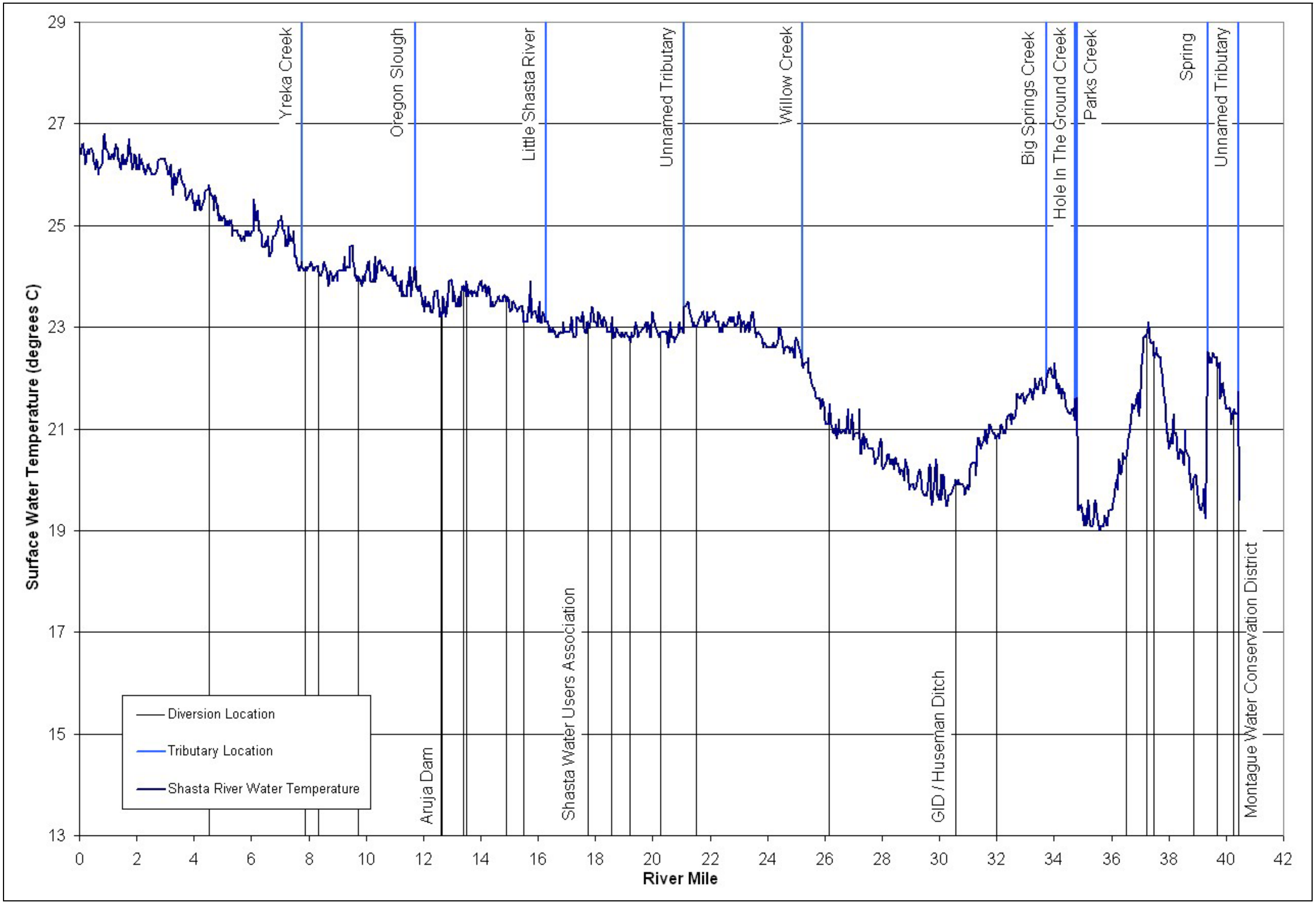


Figure 3.1: Shasta River longitudinal surface water temperature profile, and locations of tributaries and diversions, July 26, 2003

Figure 3.2 presents TIR data from the 2003 survey and is an example of the cooling effect of riparian vegetation on Shasta River temperatures. At RM 37.3 the riparian vegetation noticeably changes from sparsely vegetated to densely vegetated. In some areas the river is difficult to see because the vegetation is so thick (Figure 3.2). This change in riparian condition coincided with a 4-degree drop in temperature. Based on a review of the TIR data, there are no indications of springs or groundwater accretion in this reach, though either may be present. In contrast, Figure 3.3 presents an example of a sparsely vegetated reach of the Shasta River, where stream temperatures remain elevated and fairly constant.

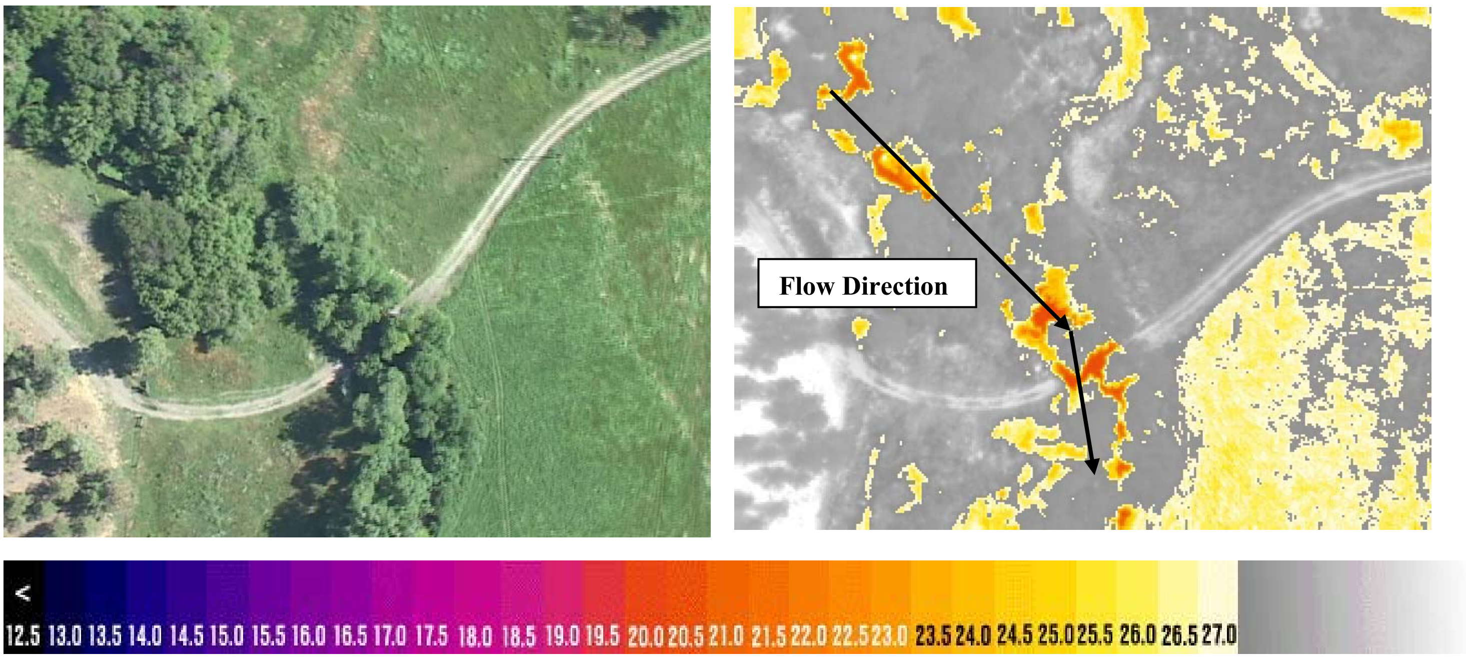


Figure 3.2: Example of dense riparian vegetation in the RM 37.3 – 34.1 cooling reach, RM 36.4
Source: Watershed Sciences 2004

Figure 3.3: Example of sparse riparian vegetation, RM 24.2
Source: Watershed Sciences 2004

In 2003 a flow and temperature model of the Shasta River was developed for the Shasta Valley Resource Conservation District with funding from the California Department of Fish and Game (Deas et al. 2003). The Tennessee Valley Authority's River Modeling System (RMS), a one-dimensional hydrodynamic and water quality model, was used. The purpose of the project was to investigate the effects of management actions on stream temperature (Deas et al. 2003).

The project used the RMS model as a tool to assess the role of riparian shade on stream temperature, among other factors. Figure 3.4 presents model results of stream temperature sensitivity to transmittance. These model simulations were run for August 28, 2001 meteorological conditions with a flow of 50 cubic feet per second (cfs). Transmittance of 100% means no solar blockage (i.e. no shade), and transmittance of 10% means solar radiation is reduced by 90%. As seen in Figure 3.4, no shading produces an average daily temperature at the mouth of 19.2 ^{o}C. Reducing solar radiation by 15, 50, and 90% translated to an average cooling of the system at the mouth of about 1.5, 3.0, and 4.0 ^{o}C, respectively (Deas et al. 2003).

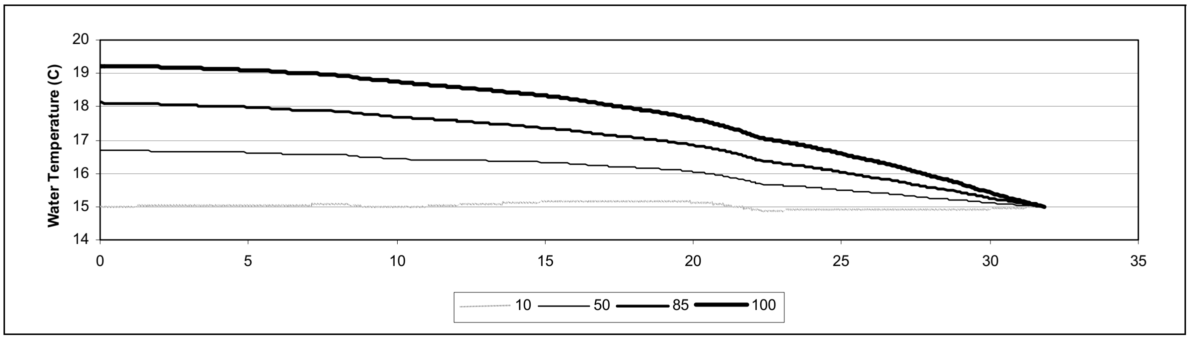
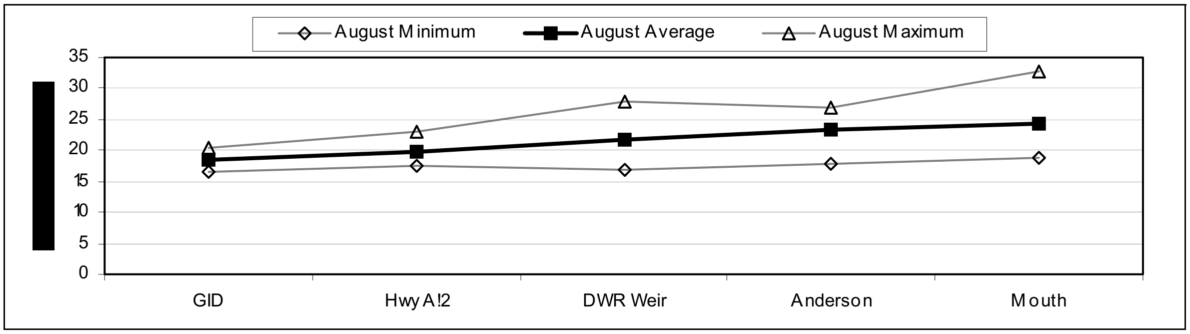


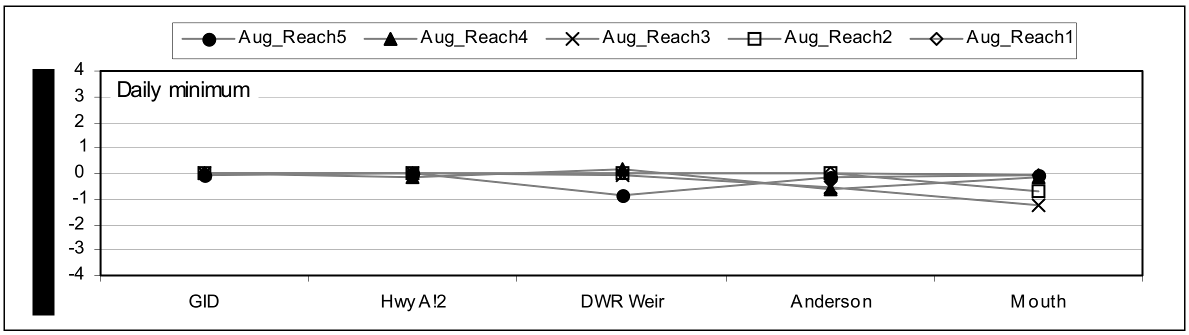
Figure 3.4: Longitudinal profile of average daily temperature for August 28, 2001 meteorological conditions for 50 cfs test case with varying transmittance (10%, 50%, 85%, 100%)
Source: Deas et al. 2003

Deas and others (2003) also evaluated the effects of riparian shading on stream temperature on a reach-by-reach basis. In these simulations shade associated with existing riparian vegetation was applied to the entire river, and then shade from mature trees (parameterized as 22 feet tall trees on each bank, based on field monitoring of Shasta River riparian tree heights) was added to each of five reaches of the modeled river, one reach at a time. The reaches are numbered 1 to 5 from downstream to upstream. The results of the August 2001 simulations are presented for select river locations in Figure 3.5. The largest reduction in daily maximum temperature was nearly 3 ^{o}C at the mouth associated with mature shade-producing riparian trees in the canyon reach.

Finally, the effects on stream temperature associated with alternate riparian vegetation restoration schemes were simulated by Deas and others (2003). When 7 foot tall bulrushes, with a transmittance value of 90%, were added to all reaches currently devoid of riparian vegetation, maximum temperature at the Mouth was reduced by nearly 1 ^{o}C compared to the baseline condition. When all reaches currently devoid of riparian vegetation were colonized by 22 foot high trees, with a transmittance of 10%, maximum temperature at the mouth was reduced by 7 ^{o}C, and the overall mean daily increase from



(A)



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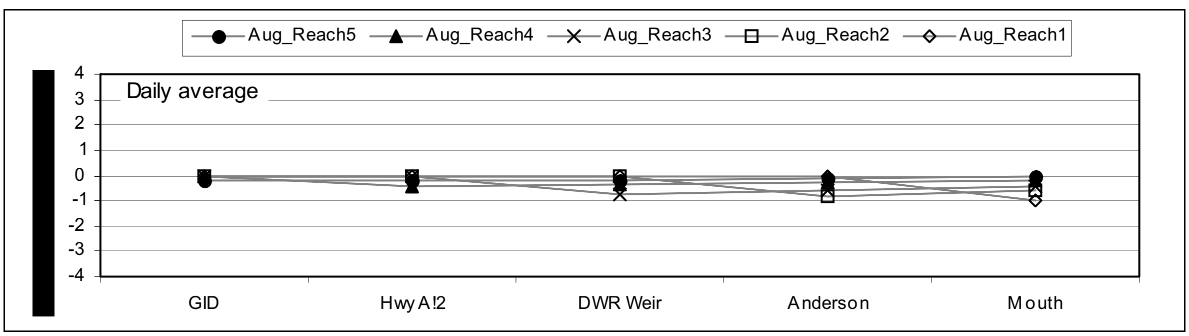

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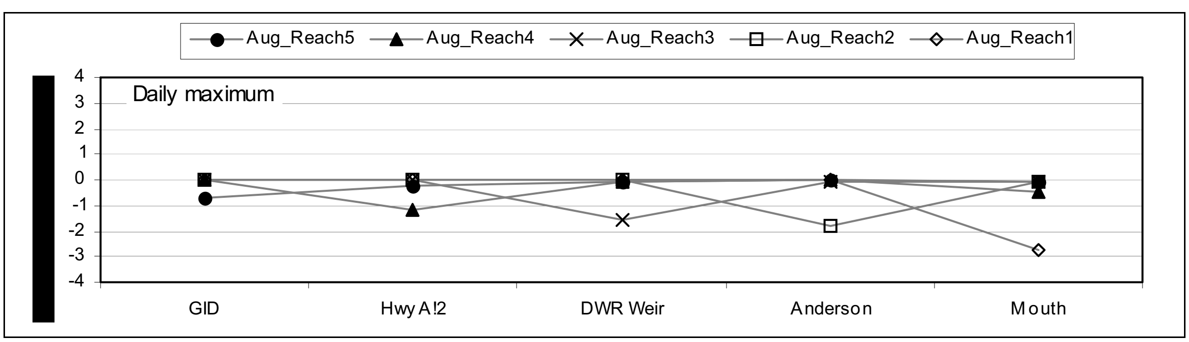


(D)

Figure 3.5: Reach by reach shading results for August. Deviations from (A) August base-case condition in (B) daily minima, (C) daily average, and (D) daily maxima of simulated water temperature at GID, Hwy 12, DWR Weir, Anderson Grade Road, and the mouth of the Shasta River.
Source: Deas et al. 2003

the top of the model reach (RM 31.8) to the mouth was less than 1 ^{o}C.

These model results indicate that reductions in solar loading associated with increases in riparian shading cause a cooling of stream temperatures in the Shasta River. While maximum temperature reductions of up to 7 ^{o}C may be possible under a condition of mature riparian tree coverage on the Shasta River, even modest improvements caused by bulrush colonization could produce a noticeable reduction in stream temperature.

Based on these model results and the Shasta River TIR survey, Regional Water Board staff identified shade as an important factor affecting stream temperatures of the Shasta River and its tributaries.

3.3.3 Tailwater Return Flows

Flood irrigation is the common irrigation practice in the Shasta Valley. When irrigation water is applied to a field in this manner, it generally flows across the field as a thin sheet or in shallow rivulets, and is prone to heating during daylight hours and cooling at night in response to air temperature. Regional Water Board staff deployed temperature monitoring devices at several locations with irrigation return flows. Upon review of the monitoring results, it was very difficult to determine when the temperature monitoring probes were exposed to irrigation return flow versus when they were exposed to the air, indicating that the temperature of the tailwater return flows were generally at equilibrium with the air temperature.

The July 26 and 27, 2003 TIR imagery shows a number of examples of locations where tailwater return flows caused an increase in Shasta River stream temperatures. The most significant example of this is on Big Springs Creek, where a tailwater return flow was 9.2 ^{o}C warmer than the creek and caused a plume of hot water that extended for hundreds of meters (Figure 3.6). Based on this information, Regional Water Board staff determined that irrigation return flows can have a significant effect on the temperature of the Shasta River and its tributaries.

3.3.4 Flow and Surface Water Diversions

Surface water diversions decrease the volume of water in the stream and thereby decrease a stream's capacity to assimilate heat. When water is removed from a stream the thermal mass and velocity of the water are decreased. Thermal mass refers to the ability of a body to resist changes in temperature. Basically, less water heats or cools faster than more water. Decreases in velocity increase the time required to travel a given distance and thus increase the time heating and cooling processes can act on the water. These principles are true for any stream.

Locations of surface water diversions from the Shasta River are identified on the longitudinal temperature profile of the Shasta River in Figure 3.1. Several of these diversions coincide with an increase in the rate of heating of the river, most notably at RM 26.2. The longitudinal temperature profile of the Shasta River is from the TIR survey conducted on July 26, 2003, and all diversions identified on Figure 3.1 may not have been diverting on this date.

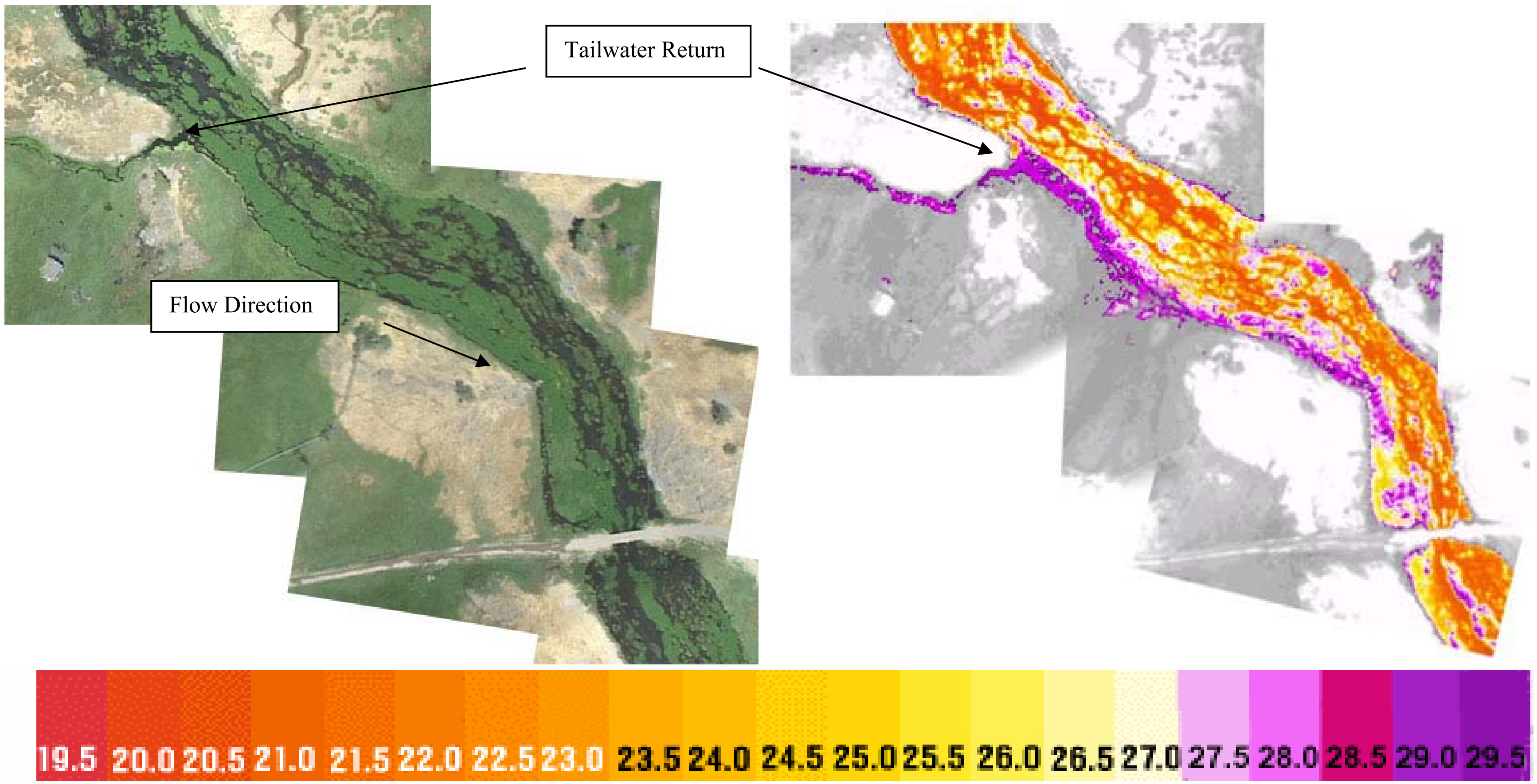


Figure 3.6 Tailwater return, Big Springs Creek
Source: Watershed Science 2004

As demonstrated in the TIR survey report (Appendix B), stream warming occurs in Parks Creek and the Little Shasta River, and portions of these tributaries completely dry up, most likely due to surface water diversion. Potential thermal refugia are lost when the mouth of a tributary that has cold water sources, such as Parks Creek, dries up.

The Shasta River flow and temperature modeling by Deas and others (2003) evaluated the effect of flow on stream temperature. Sensitivity of stream temperature to flow was modeled using 10, 50, and 100 cfs for August 28, 2001 meteorological conditions. The simulations assumed no shading. Daily average temperatures over this range of flows are shown in Figure 3.7.

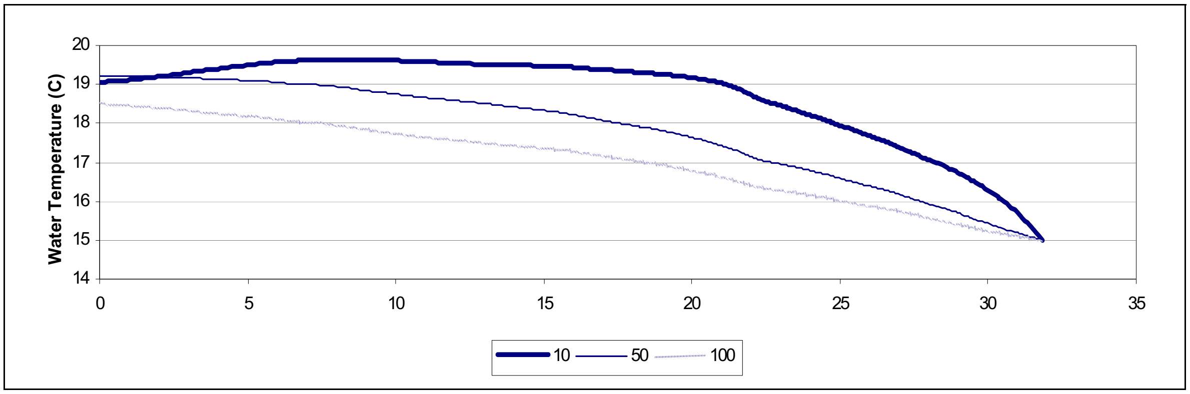
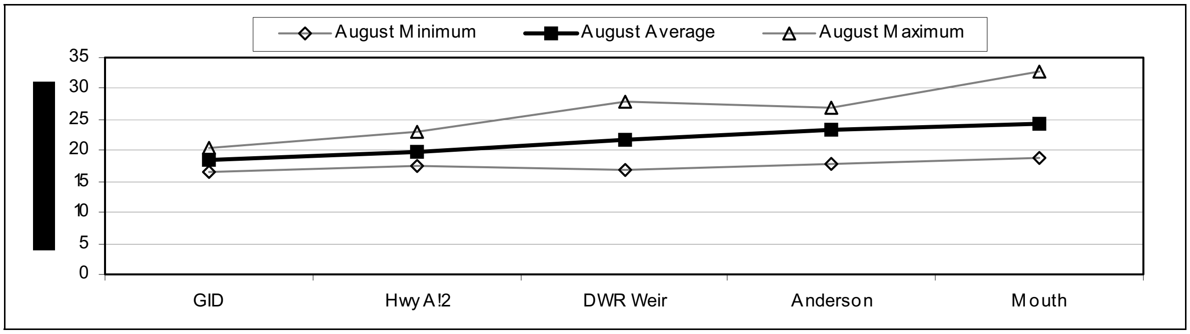


Figure 3.7: Longitudinal profile of average daily temperature by river mile for August 28, 2001 meteorological conditions for 10, 50, 100 cfs
Source: Deas et al. 2003

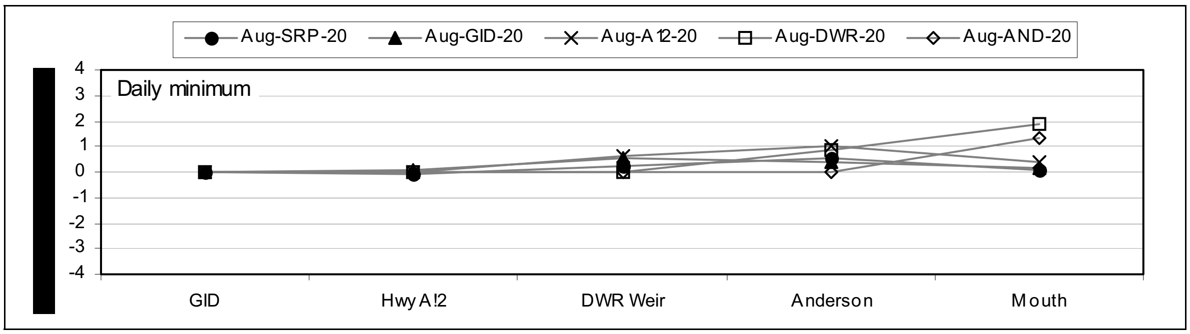
To further assess the impact of flow regime on water temperature in the Shasta River, Deas and others (2003) simulated adding water to the river base flow at the beginning of each of the five river reaches in a stepwise fashion. For example, one simulation added 20 cfs to the most upstream reach. The next simulation removed the added 20 cfs from the upstream reach and placed an additional 20 cfs at the beginning of the next reach, and so on. The temperature of the added flow for each simulation was the same as that of the baseline flow. Simulation results of adding 20 cfs in each reach in August are presented in Figure 3.8. The simulation results indicate that the farther upstream the water is added, the more miles of river experience a decrease in water temperature, corresponding with the baseline temperature of these flows.

In summary, the addition of 20 cfs reduces the maximum temperatures in the middle and lower reaches by 2 to 3 ^{o}C and increases daily minimum temperatures by up to 2 ^{o}C. It is important to note, however, that the increases in the daily minimum temperatures were associated only with 20 cfs flow increases from locations in the lower valley where baseline temperatures are warmer than at more upstream reach locations. Based on these modeling results and the TIR information, Regional Water Board staff identified flow as an important factor affecting temperatures of the Shasta River and its tributaries.

An important indirect effect of flow on stream temperature is related to soil moisture levels. Generally, soil moisture levels in the riparian zone of streams decrease with decreasing flow.



(A)



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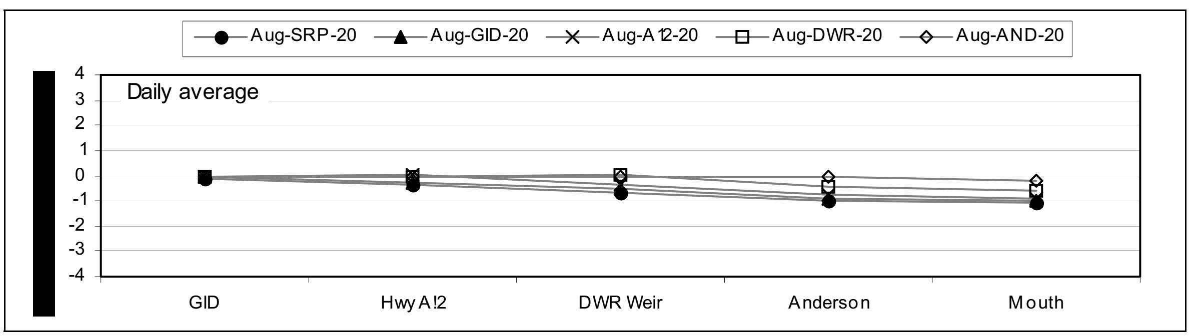
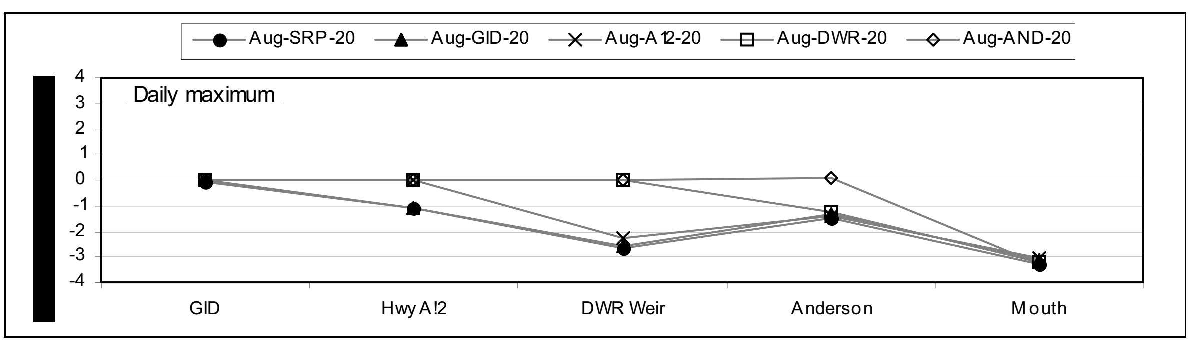


(C)



(D)

Figure 3.8: Flow regime results for 20 cfs inflows in August. Deviations from (A) August base-case condition in (B) daily minima, (C) daily average, and (D) daily maxima of simulated water temperature at GID, Hwy 12, DWR Weir, Anderson Grade Road, and the mouth of the Shasta River.
Source: Deas et al. (2003)

Soil moisture limitation is an important limiting factor for riparian vegetation establishment and growth (Kennedy et al. 2005, p 17). As surface water levels drop in a stream, the roots of riparian vegetation may not get the amount of water needed to survive. Soil moisture stress is a common cause of failure of riparian restoration efforts. This relationship between summer flow and riparian condition is important. If inadequate soil moisture levels limit or prevent riparian vegetation growth, then the opportunity for stream temperature improvements due to increase in riparian shade cannot be realized

3.3.5 Groundwater Accretion / Spring Inflows

Ground water accretion and spring inflows affect stream temperatures in a number of ways. Most importantly, groundwater accretion and spring inflows provide a stream with a cold source of water that cools the stream (advection). The effect of groundwater and spring inflows on Shasta River and tributary temperatures has not been well documented. Regional Water Board monitoring of selected springs within the Shasta River basin, however, shows that the average temperatures of spring flows range from 9 ^{o}C to 12 ^{o}C, temperatures significantly lower than the average Shasta River temperature (NCRWQCB 2004b, see Appendix C_e).

The TIR survey identified a number of springs that caused cooling of stream temperatures, including springs on Parks Creek, Big Springs Creek, and the Shasta River. Figure 3.9 provides an example of a significant cold water source, most likely a spring, which dropped the stream temperature 3.2 ^{o}C to 19.3 ^{o}C. Based on the above referenced monitoring data and the TIR survey results, Regional Water Board staff identified groundwater accretion and spring inflows as important factors lowering temperatures of the Shasta River and its tributaries.

3.3.6 Lake Shastina and Minor Impoundments

Information on the effect of Lake Shastina and minor Shasta River impoundments is synthesized from Vignola and Deas (2005) and Deas (2005a). In addition to Dwinnell Dam, the largest impoundment on the Shasta River, there are several smaller impoundments – often termed “flashboard” dams – that are used to raise the water level in the river to provide for diversion (either direct or pumping) primarily for agricultural use. Impoundments can alter the thermal regime of a river system. Differences in heat loading due to impoundments can occur because of an increase in water surface area, providing a larger surface area over which energy transfer can occur. Larger air-water interface provides additional area for solar radiation to enter the system; however, the larger surface area also allows increased fetch (allowing more wind mixing) and potentially improved cooling due to evaporation. Probably a more important characteristic of the impoundment is the increased thermal mass, which leads to moderation of the diurnal temperature signal.

Finally, impoundments generally increase river width and limit the ability of riparian shading to reduce incoming solar radiation. Similarly, the effect of topographic shading due to stream banks or bluffs is reduced when the river width is increased due to an impoundment. There are not sufficient stream temperature data within and downstream of the existing flashboard dams on the Shasta River to evaluate their effect on stream temperature. However, Regional Water Board staff suspect they cause heating of surface waters behind the impoundments, and this heating may be expressed a short distance downstream of the impoundments.

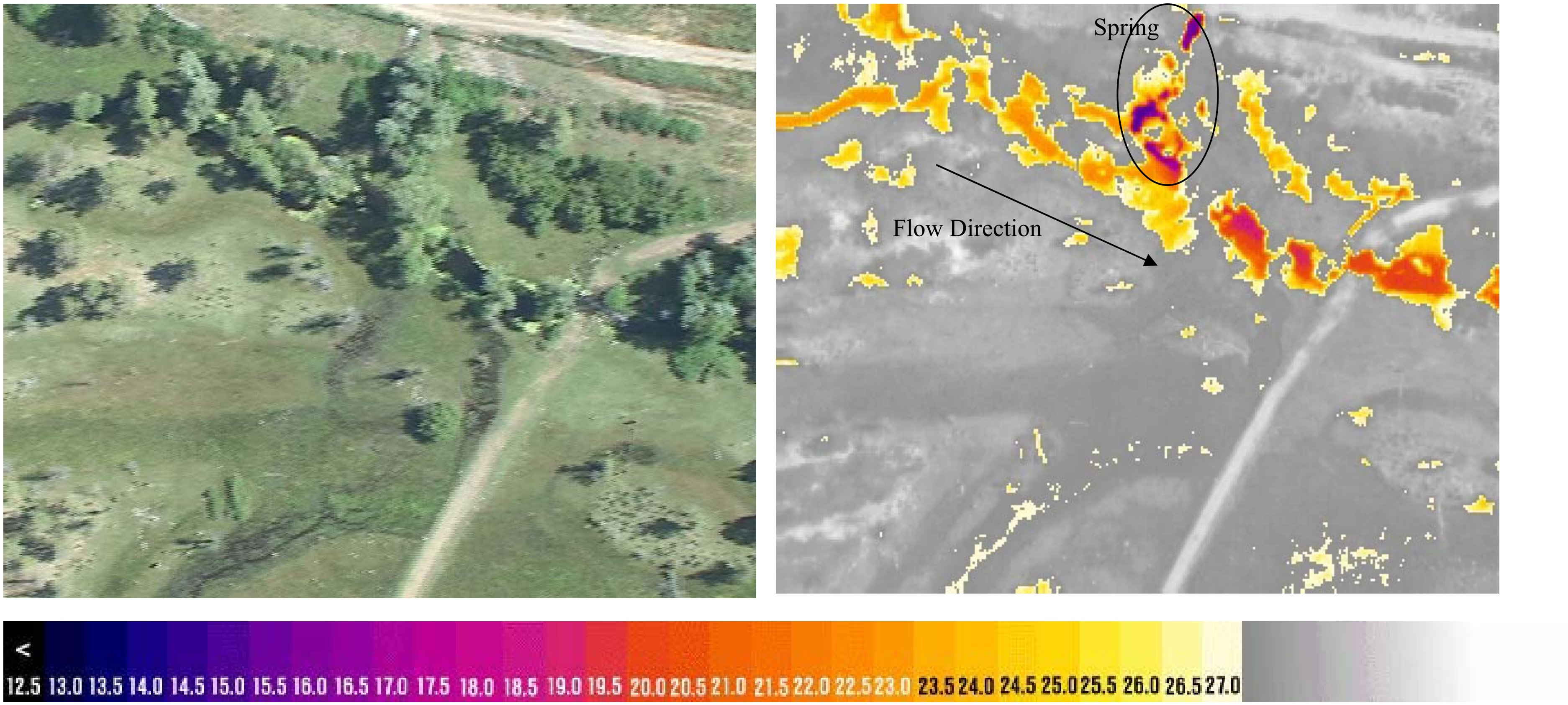


Figure 3.9: Spring entering from top of images cools the Shasta River 3.2 °C, tailwater return flow enters the river from the bottom of the picture, RM 39.0

Source: Watershed Sciences 2004

The water temperatures within Lake Shastina are summarized in Section 2.3.4. Figure 3.10 illustrates water temperatures of Shasta River inflows to Lake Shastina, surface water temperatures in Lake Shastina near the dam, and temperatures in the Shasta River below Lake Shastina for the period fall 2000 through fall 2001. As shown in Figure 3.10 the temperatures of the Shasta River above Lake Shastina are roughly similar to the surface water temperatures of Lake Shastina near the dam. Lake Shastina near the dam exhibits slightly warmer surface water temperatures in the spring of 1998. Most notably, the Shasta River below Lake Shastina is generally cooler than Lake Shastina surface water temperatures and the river temperature upstream of Lake Shastina during summer months. This is most likely due to the fact that the outflow from Lake Shastina comes from the bottom of the reservoir, where water is cooler in summer months (see Figure 2.6). The discontinuity in the water temperature trace of the Shasta River below Lake Shastina from October through November most likely represents turnover. The temperature of the Shasta River below Lake Shastina is similar to upstream locations from late fall through mid-spring when the reservoir is de-stratified. Based on this information, Regional Water Board staff identified the presence of Dwinnell Dam as an important factor affecting stream temperatures in Lake Shastina and in the Shasta River downstream of the dam.

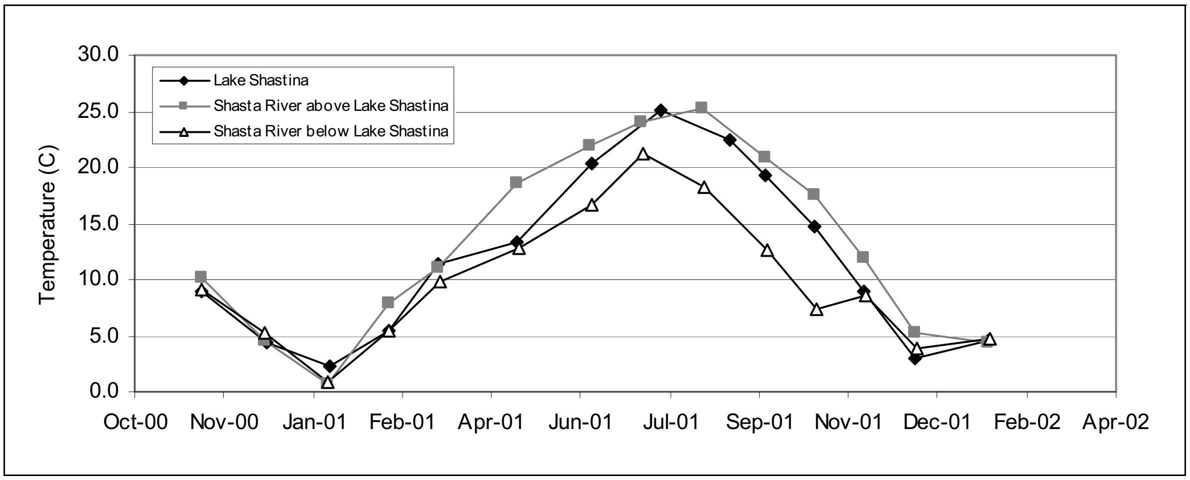


Figure 3.10: A comparison of surface water temperatures in the Shasta River above Lake Shastina, the surface water temperature of Lake Shastina near the dam, and in the Shasta River below Lake Shastina.
Source: Vignola and Deas 2005

CHAPTER 4. DISSOLVED OXYGEN SOURCE AND LINKAGE ANALYSIS

4.1 Introduction

This chapter identifies the processes that affect dissolved oxygen concentrations of the Shasta River and its tributaries and establishes a linkage between these processes and measured dissolved oxygen concentrations. First, the various processes that can affect dissolved oxygen concentrations in a surface waterbody are reviewed. Secondly, the chapter identifies the anthropogenic sources (or factors) that are affecting these processes and controlling dissolved oxygen concentrations in the Shasta River and its tributaries. The contributions from these sources are then quantified in Chapter 7.

4.1.1 Processes Affecting Dissolved Oxygen in Surface Waters

Dissolved oxygen levels in surface waters are controlled by a number of interacting processes (Figure 4.1), including:

- Photosynthesis;
- Respiration;
- Carbonaceous deoxygenation within the water column ;
- Nitrogenous deoxygenation ;
- Nitrification;
- Reaeration;
- Sediment oxygen demand; and
- Methanotrophy.

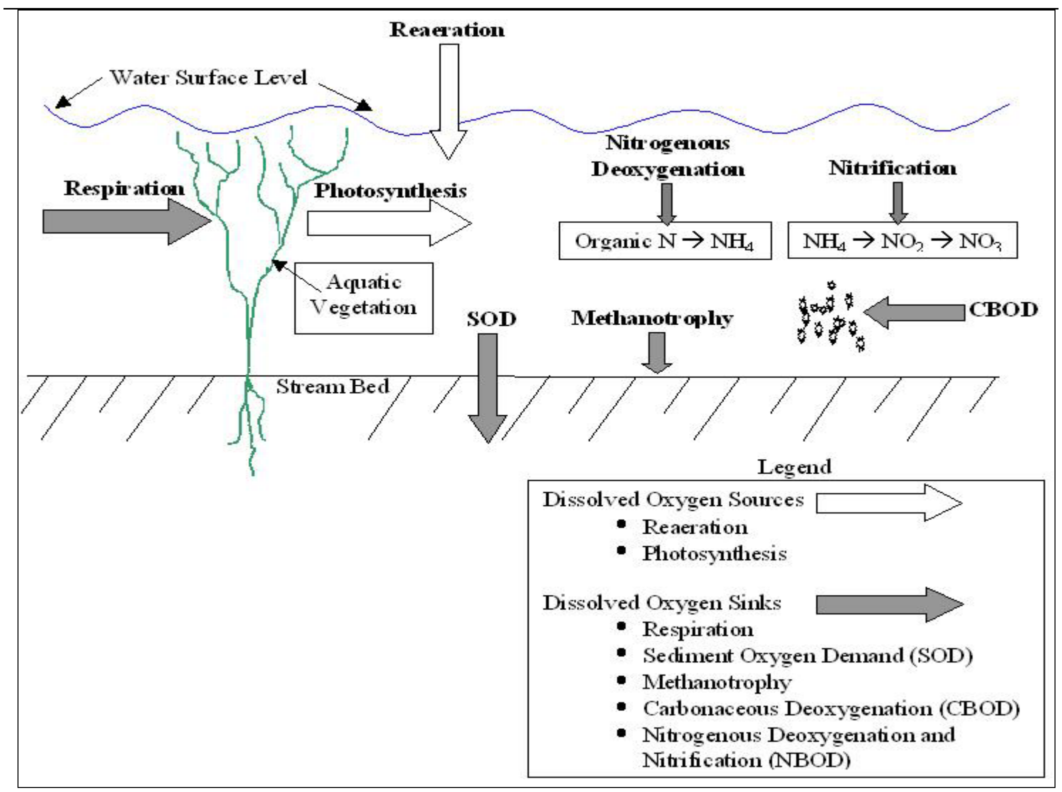


Figure 4.1: Physical, Chemical, and Biological Processes Affecting Dissolved Oxygen in Surface Water Bodies

- *Photosynthesis* is the process by which solar energy is stored as chemical energy in organic molecules. In this process, oxygen is liberated and carbon dioxide is sequestered.
- The organic matter produced by photosynthesis then serves as an energy source for nearly all other living organisms in the reverse processes of respiration and *decomposition* whereby oxygen is bonded with other elements.
- *Carbonaceous deoxygenation* is the technical term for decomposition, involving the consumption of oxygen by bacteria during the breakdown of organic material. Carbon dioxide is released as a byproduct of carbonaceous deoxygenation. When this oxidation is exerted on carbonaceous organic material that is suspended in the water column, it is measured as biochemical oxygen demand (BOD), typically measured as the amount of oxygen consumed during a five-day test period (BOD_5).
- *Nitrogenous deoxygenation* involves the conversion of organic nitrogen to ammonia (NH_4^+) by bacteria, a process that consumes oxygen.
- *Nitrification* is the process by which ammonia is oxidized to nitrite (NO^{2-}) and subsequently to nitrate (NO^{3-}); a process that also consumes oxygen.
- *Reaeration* is the process whereby atmospheric oxygen is transferred to a waterbody.
- *Sediment oxygen demand* refers to the consumption of oxygen by sediment and organisms (such as bacteria and invertebrates) through both the decomposition of organic matter and respiration by plants, bacteria, and invertebrates. Simplistically, sediment oxygen demand is carbonaceous deoxygenation and respiration occurring in the sediments.
- *Methanotrophy* is the process by which methane (CH_4) is biologically oxidized in aerobic environments, a process that consumes oxygen and forms carbon dioxide and water. Methanotrophy can occur in sediments and at the sediment-water interface. Where methanotrophy occurs, it can be measured as part of the overall sediment oxygen demand.

In addition to these processes, dissolved oxygen concentrations are affected by water temperature, salinity, and atmospheric pressure. Oxygen is soluble, or "dissolved" in water. The solubility of oxygen is a function of water temperature, salinity, and atmospheric pressure; decreasing with rising temperature and salinity, and increasing with rising atmospheric pressure. At sea level (1 atm of pressure) fresh water has a saturation dissolved oxygen concentration of about 14.6 mg/L at 0°C and 8.2 mg/L at 25°C. The connection between dissolved oxygen concentration and water temperature is important given the fact that the Shasta River is impaired by both high water temperatures and low dissolved oxygen concentrations.

4.2 Sources of Information

Much of the data and information used in the development of the dissolved oxygen TMDL was collected during the summers of 2002, 2003, and 2004 by Regional Water Board staff, with assistance from the U.S. Geological Survey and UC Davis Aquatic Ecosystems Analysis Laboratory. These data included:

- Hourly dissolved oxygen measurements at 16 sites;
- Hourly temperature measurements at 19 sites;

- Grab sample measurements of nutrients and oxygen-consuming parameters from 42 Shasta River, tributary, spring, and tailwater return sites;
- Sediment oxygen demand measurements at 18 Shasta River locations;
- Aquatic vegetation surveys of nearly 27 miles of the Shasta River and Lake Shastina;
- Light intensity measurements at 14 Shasta River sites;
- Stream bottom sediment characterization at 20 Shasta River sites;
- Riparian vegetation classification of 27 miles of the Shasta River;
- Flow measurements at 9 Shasta River locations;
- Stable isotope sample measurements from 21 Shasta River sites; and
- Text books and scientific literature.

Results of the 2002 and 2003 data collection efforts are reported in NCRWQCB (2004) and Flint and others (2005), which are included as Electronic Appendices C_e (*Shasta River Water Quality Conditions, 2002 and 2003*) and D_e (*Water-Quality Data from 2002 to 2003 and Analysis of Data Gaps for Development of Total Maximum Daily Loads in the Lower Klamath River Basin, California*). Data collected in 2004 are reported in NCRWQCB and University of California Davis, Aquatic Ecosystems Analysis Laboratory [UCD AEAL] (NCRWQCB and UCD AEAL 2005), which is included as Appendix A of this report.

4.3 Processes Affecting Dissolved Oxygen Concentrations in the Shasta River Watershed

Of the eight processes outlined in Section 4.1.1 Regional Water Board staff have identified four primary processes affecting dissolved oxygen concentrations in the Shasta River watershed. Human activities affect, or have a potential to affect, each of these processes, as discussed in Section 4.4. The four processes are:

- Sediment oxygen demand;
- Nitrification;
- Photosynthesis of aquatic plants; and
- Respiration of aquatic plants.

The effects of each of these processes on Shasta River watershed dissolved oxygen conditions are presented in the following sections. The roles of the other four processes on Shasta River watershed dissolved oxygen conditions are summarized below.

Though the data are limited, BOD_5 concentrations (a measure of carbonaceous deoxygenation in the water column) in the Shasta River indicate that carbonaceous oxygen demand exerted in the water column is only a minor component of the total oxygen demand in the Shasta River. BOD_5 concentrations in the Shasta River range from 1.0 to 15.0 mg/L, with an average of 2.1 mg/L. For comparison, biochemical oxygen demand concentrations in the Klamath River near the outlet of hyper-eutrophic Upper Klamath Lake range from approximately 5 to 25 mg/L. Also for comparison, a typical biochemical oxygen demand concentration of untreated domestic sewage in the United States is 220 mg/L (Chapra 1997, p. 358).

There is insufficient data to determine the extent to which nitrogenous deoxygenation (the conversion of organic nitrogen to ammonia) affects dissolved oxygen concentrations in the Shasta River watershed. The oxygen consumption associated with this conversion is minor compared with that of nitrification the conversion of ammonia to nitrite and nitrate, which is significant in the Shasta River watershed and is discussed in Section 4.3.2.

Reaeration plays a key role affecting dissolved oxygen concentrations in the Shasta River. The water quality model used in the development of the dissolved oxygen TMDL accounts for reaeration and is outlined in Chapters 5 and 7.

There is insufficient data to determine whether methanotrophy contributes to oxygen consumption in the Shasta River. Methane has not been measured in the Shasta River; however, Regional Water Board staff never detected odors associated with methane production in the river or at the outlet of Lake Shastina in the Main Canal. If methanotrophy does occur in the Shasta River, its contribution to oxygen demand would likely be accounted for in the sediment oxygen demand measurements.

4.3.1 Sediment Oxygen Demand

Sediment oxygen demand (SOD) rates in the Shasta River are relatively high, indicating a system with organic material that is decomposing within the sediment at a moderate rate (Flint et al. 2005, p. 38). SOD is the rate of dissolved oxygen loss from a waterbody through uptake and consumption of oxygen by biotic or abiotic reactions in surficial sediments. In most systems, such oxygen consumption is dominated by microbially-mediated decomposition processes. In other words, organic materials in the waterbody's sediments rot and decompose; that process requires oxygen, which is supplied from the overlying water. SOD can be an important part of the stream's dissolved oxygen budget, particularly in rivers with an abundance of sedimentary organic material. This sedimentary organic material may have been deposited in the channel from various sources, including bank erosion and settleable solids from irrigation return flows, as well as an accumulation of plant and algal detritus.

In August 2003, the U.S. Geological Survey measured SOD rates at six locations in two reaches of the Shasta River (Flint et al. 2005). The measurement sites were chosen because they are located in a reach of the river with measured low dissolved oxygen concentrations and observed accumulation of fine sediment and aquatic plant detritus. Other considerations for site selection included access, type of stream substrate, and the amount of macrophyte (aquatic plant) growth. Procedures for measuring SOD rates in the Shasta River and results are discussed in detail by Flint and othersl. (2005). The measured SOD_{20}[1] rates in the Shasta River range from 0.1 to 2.3 g/m^2-d with a median of 1.5 g/m^2-d [2]. A SOD_{20} rate of 1 to 2 g/m^2-d indicates a system with organic material that

[1] SOD_{20} rate is the SOD corrected to a temperature of 20°C.
[2] g/m^2-d is grams per square meter per day.

is decomposing at a moderate rate. A moderate SOD rate indicates that the decomposing organic material is neither extremely labile nor extremely refractory (Flint et al. 2005). Labile organic material is readily decomposed, while refractory organic material is more resistant to decomposition. According to Flint and coworkers (2005) the amount of dissolved oxygen that can be consumed by SOD over the course of a day is a function of stream depth and is calculated as the SOD rate in g/m^2-d divided by the stream depth in meters. Assuming an average depth of 1 meter, and applying the median Shasta River SOD rate of 1.5 g/m^2-d, then 1.5 mg O_2 is consumed per liter of water by SOD over the course of 1 day, representing a significant component of the total oxygen demand in the Shasta River. During summer months, the depth of flow in the Shasta River varies from approximately 0.1 to 1 meter in most reaches, with depths up to 3 meters in some impounded areas.

4.3.2 Nitrification

Nitrogenous deoxygenation involves the conversion of organic nitrogen to ammonia and the subsequent oxidation of ammonia. Nitrification is the oxidation of ammonia to nitrate represented by equation 4.2 in the two-step process presented below:

$$NH_4^+ + 1.5\ O_2 \rightarrow NO_2^- + H_2O + 2\ H^+ \qquad \text{(Eq. 4.1)}$$
$$NO_2^- + 0.5\ O_2 \rightarrow NO_3^- \qquad \text{(Eq. 4.2)}$$

Stoichiometrically, 3.43 and 1.14 grams of oxygen are required to transform each gram of ammonia nitrogen to nitrite nitrogen (Eq. 4.1) and nitrite nitrogen to nitrate nitrogen (Eq. 4.2), respectively. The total amount of oxidizable nitrogen is equal to the sum of organic- and ammonia-nitrogen, and is measured as Total Kjeldahl Nitrogen (TKN). The oxidation of organic- and ammonia-nitrogen consumes 4.57 grams of oxygen per gram of TKN. For water quality monitoring purposes, nitrogenous deoxygenation is estimated as 4.57 * the ambient TKN concentration (Chapra 1997, p. 424). For example, if the TKN concentration in a river is 1.0 mg/L, then 4.57 mg/L of dissolved oxygen is consumed when the organic- and ammonia-nitrogen are oxidized. If dissolved oxygen is available it will oxidize available ammonia nitrogen and nitrite nitrogen.

From 1993 through 2003, TKN concentrations in the Shasta River ranged from 0.1 to 4.0 mg/L, with an average of 0.50 mg/L (see Table 2.8 in Chapter 2). At this average TKN concentration, approximately 2.3 mg/L of oxygen would be consumed. This 2.3 mg/L of oxygen consumption occurs spread over an unknown period that is likely at least five days long, thus representing only a moderate component of the total oxygen demand exerted in the Shasta River.

4.3.3 Photosynthesis and Respiration of Aquatic Plants

During summer months (generally June through August), dissolved oxygen concentrations in the Shasta River follow a distinct diurnal pattern, with high concentrations (near or above saturation) during daylight hours and lower concentrations (near or below saturation) during nighttime hours. This dissolved oxygen signal is typical of productive river systems experiencing high photosynthesis and respiration rates of aquatic plants. Based on measured data, one of the most extreme examples of this diurnal pattern is exhibited in the Shasta River at Highway 3 between June and September 2003 (Figure 4.2).

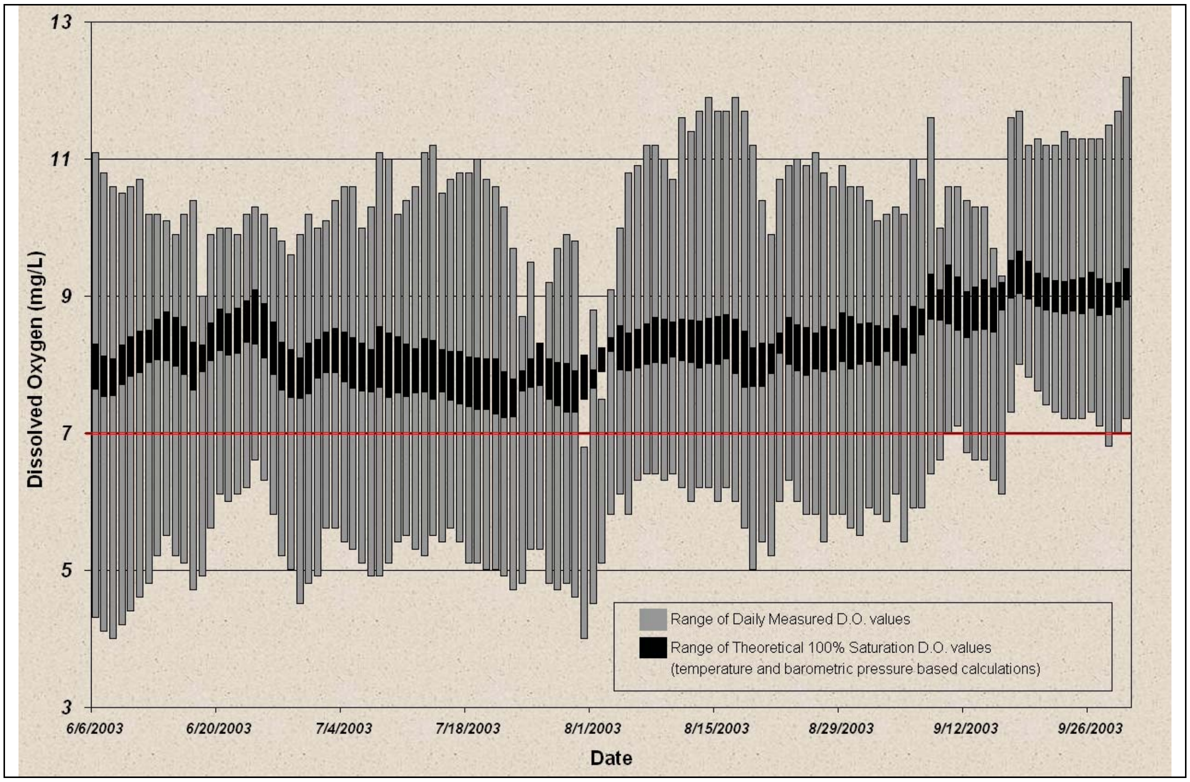


Figure 4.2: Daily measured dissolved oxygen concentration ranges versus calculated dissolved oxygen saturation concentrations, Shasta River at Highway 3, June through September 2003

Figure 4.2 shows the daily range of measured dissolved oxygen concentrations and 100-percent saturation concentrations in the Shasta River at Highway 3. The saturation dissolved oxygen concentration is calculated based upon water temperature, salinity, and atmospheric pressure. As shown in Figure 4.2 dissolved oxygen concentrations can move above (termed supersaturation) and below (under-saturation) 100-percent saturation values. Supersaturated conditions occur when the oxygen-generating factors (i.e. reaeration and photosynthesis) exceed the oxygen-consuming factors (i.e. carbonaceous and nitrogenous oxygen demand, SOD, and respiration). Conversely, under-saturated conditions occur when the oxygen-consuming factors exceed the oxygen-generating factors. USGS has reported cases of supersaturated conditions in Oregon water bodies attributed to aquatic plant growth persisting for several days or more, with saturations as high as 250 percent (Flint et al. 2005, p. 60).

Generally, during summer months, Shasta River dissolved oxygen concentrations are above the Basin Plan objective of 7.0 mg/L during daylight hours, and fall below 7.0 mg/L during nighttime and early morning hours of the day. Figure 4.3 presents the range of *hourly* dissolved oxygen concentrations during summer months in Shasta River reaches. This pattern is typical of productive river systems with prolific aquatic plant growth. Photosynthesis by aquatic plants occurs in sunlight and generates oxygen.

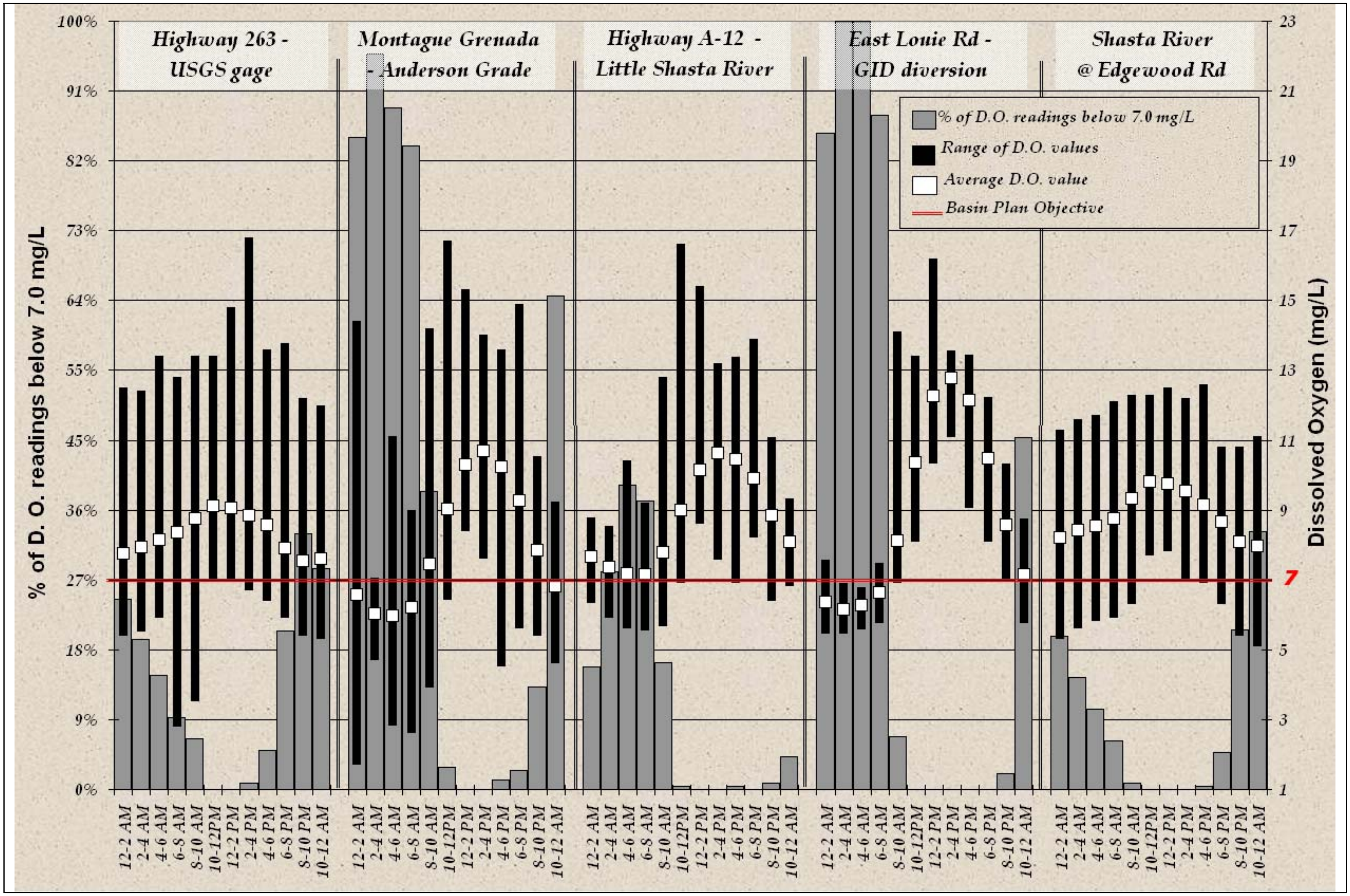


Figure 4.3. Hourly dissolved oxygen concentration ranges, mainstem Shasta River reaches, May through September 1994-2004.

Respiration by aquatic plants is constant, and consumes oxygen. During daylight hours when photosynthetic rates exceed respiration and SOD rates, there is a net increase in dissolved oxygen in the water column. During nighttime hours when aquatic plants do not photosynthesize, there is a net decrease in dissolved oxygen in the water column. Figures 4.2 and 4.3 demonstrate the dramatic effect of photosynthesis and respiration by aquatic plants on Shasta River dissolved oxygen concentrations. Section 4.3.3.1 summarizes the aquatic vegetation conditions in the Shasta River and Lake Shastina and establishes a link between aquatic vegetation productivity and measured dissolved oxygen conditions. Section 4.3.3.2 evaluates the factors that affect aquatic vegetation productivity in the Shasta River and Lake Shastina. Section 4.4 then identifies the sources (or factors) that affect photosynthetic and respiration rates of aquatic plants, sediment oxygen demand rates, and nitrification in the Shasta River and Lake Shastina.

4.3.3.1 Aquatic Vegetation Conditions of the Shasta River and Lake Shastina
High aquatic plant biomass can result in severe diurnal swings in dissolved oxygen. (USEPA 2000, p.5). In order to better understand the role of Shasta River aquatic vegetation on dissolved oxygen concentrations, Regional Water Board staff conducted a survey of the aquatic vegetation of the Shasta River in the summer of 2004, with technical assistance from UC Davis Aquatic Ecosystems Analysis Laboratory (UCD AEAL). The purpose of the aquatic vegetation survey was to characterize the spatial distribution, composition, and biomass of aquatic plants in the Shasta River and Lake Shastina. The methods and results of the aquatic vegetation survey are described in Appendix A.

The aquatic vegetation survey was conducted in the riverine reach from the mouth of the Shasta River to Dwinnell Dam and at two open water locations in Lake Shastina. Due to access limitations, the survey was conducted on 26.9 miles of the 40.6-mile reach from the mouth to Dwinnell Dam (two thirds of the river length from Dwinnell Dam to the mouth).

The types of aquatic plants in the Shasta River and Lake Shastina include: (1) benthic algae, called periphyton, which generally grow attached to rocks, gravel, and other plants; (2) vascular plants (primarily rooted), called macrophytes; and (3) suspended algae, called phytoplankton. The survey identified a total of 95 different species of aquatic plants in the Shasta River and Lake Shastina, including 75 total algal species (47 species present in the river samples and 35 species present in the Lake Shastina samples) and 20 macrophyte species.

The aquatic vegetation survey included several measures of abundance -- percent cover (a visual estimation performed in the riverine reaches dominated by macrophytes), density (measured as number of periphyton cells/cm^2 and number of phytoplankton cells/mL), ash free dry weight (AFDW), and chlorophyll a and pheophytin a concentrations for periphyton and phytoplankton.

The assemblage, distribution, and quantity of aquatic plants in the Shasta River are variable and complex. Generally, rooted macrophytes dominate the assemblage of aquatic vegetation in much of the Shasta Valley, where the river is typically slow-moving, meandering, and generally depositional. In the higher gradient reaches, most notably the canyon, periphyton is the dominant aquatic vegetation type. Due to the varying water depth in Lake Shastina, rooted macrophytes are uncommon in the shallow, near-shore zones of the lake, however the lake contains many species of phytoplankton.

Macrophytes
The rooted macrophytes of the Shasta River include two primary morphological groups: (1) emergent reeds, sedges, and rushes, which grow rooted in the shallow zones of the river at the banks, and (2) emergent and submerged broad-leaved plants, which grow in shallow as well as deep (up to approximately 10 feet) zones of the river. The dominant macrophyte species[3] in the river include *Potamogeton spp*., *Scirpus spp*., and *Elodea canadensis*. *Elodea canadensis* and *Scirpus spp*. prefer a peat channel substrate over a silt, clay, or sand substrate; *Potamogeton spp*. prefer a silt substrate over clay, sand, or gravel/pebble. Each of these dominant macrophyte species prefers a "no perceptible flow" type (see Appendix A). Free-floating macrophytes, primarily *Lemna minor*, also occur in the deeper, impounded reaches of the river.

The percent cover of macrophytes ranged from 5 to 95%, with nearly 42 percent of the river surveyed having 50% or higher total macrophytes cover. The biomass of the macrophyte-dominated reaches ranged from 8 to 309 milligrams per square centimeter (mg/cm^2), with an average of 76 mg/cm^2.

A review of the literature did not find specific macrophyte density or biomass values that are indicative of water quality conditions. However, USEPA (2000, p. 35) reports that excess macrophytes biomass, like that found at many locations on the Shasta River, can produce large diurnal fluctuations in dissolved oxygen. In addition, excessive macrophyte abundance can represent a nuisance to water recreation (Welch 1992, p. 200). On the other hand, macrophytes can provide important habitat for fish and macroinvertebrates, a benefit that must be balanced with the effects on dissolved oxygen.

Periphyton
The dominant periphyton species[4] in the river include *Cocconeis placentula and C. pediculus*, *Epithemia sorex*, and *Rhoicosphenia curvata*. These diatoms are common in flowing environments and prefer water that is both alkaline and eutrophic (Carpenter 2003, p.100; Fore and Grafe 2002). *C. placentula* prefers higher water temperatures (DeNicola 1996). *E. sorex* is often found in waters with an elevated nutrient content (Eilers 2005) and is favored in nitrogen limited water due to its ability to fix atmospheric nitrogen (Borchardt 1996; Carpenter 2003, p.100).

The biomass (AFDW) of the periphyton-dominated communities in the Shasta ranged from 2.0 to 19.1 mg/cm^2, with an average of 5.9 mg/cm^2. Periphyton chlorophyll a and pheophytin a concentrations ranged from 29.5 to 271.5 milligrams per square meter (mg/m^2) and from 22.5 to 227.4 mg/m^2, respectively. Average periphyton chlorophyll a

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[3] In this context, dominance is attributed to those macrophyte species that have the greatest percentage of cover within the river reaches surveyed.
[4] In this context, dominance is attributed to those periphyton species that have the greatest percentage of cell density ($\#/cm^2$) with respect to the total periphyton community cell density.

and pheophytin a concentrations were 153.5 and 80.7 mg/m^2, respectively. Note that units of measurement for chlorophyll a and pheophytin a differ from those for AFDW biomass (mg/m^2 and mg/cm^2, respectively).

USEPA (2000, p.31) finds that benthic chlorophyll a values for unenriched, light-limited, or scour-dominated stream systems are typically much less than 50 mg/m^2. Most of the chlorophyll a values for the Shasta River are above this value for "unenriched streams." The average of periphyton chlorophyll-a samples for the Shasta River exceeds 150 mg/m^2, which is described as the level indicative of highly enriched sites according to Lohman and others 1992 (as cited by Tetratech 2005).

Literature values for "nuisance" levels of benthic algae chlorophyll a range from 100 to 200 mg/m^2 (Dodds et al. 1998; Dodds and Welch 2000; Sosiak 2002; USEPA 2000 as cited by Tetratech 2005; Welch et al. 1988). The average value of benthic chlorophyll a in the Shasta is over 150 mg/m^2, which USEPA (2000, p.102) considers a generally agreed upon criterion to prevent nuisance conditions and impacts to aesthetic values.

Dodds and others (1998) created a classification system for stream trophic state based on frequency distributions of chlorophyll-a, total nitrogen, and total phosphorous data from 200 streams in North America and New Zealand. Table 4.1 presents their findings for classification of trophic status based on benthic chlorophyll a levels. Based on this classification scheme, the measured Shasta River benthic chlorophyll a values reflect eutrophic conditions.

Table 4.1: Boundaries for Trophic Classification of Streams

Parameter	Oligotrophic-mesotrophic boundary	Mesotrophic-eutrophic boundary	Sample size
Mean benthic chlorophyll-a (mg/m^2)	20	70	286
Maximum benthic chlorophyll-a (mg/m^2)	60	200	176

Source: Modified from Dodds et al. 1998

Phytoplankton

The dominant phytoplankton species[5] in Lake Shastina include *Anabaena flos-aquae*, *Rhodomonas minuta*, and *Tetraedron minimum*. *Anabaena flos-aquae* is a blue green algae, also called cyanobacteria, that is widespread in eutrophic lakes. Like many blue green algae, it can produce toxins that can be harmful to humans, livestock, and pets. *Tetraedron minimum* is a green algae that grows in mesotrophic or eutrophic environments, and is not commonly found in lakes, while *Rhodomonas minuta* occurs in a wide range of habitats including lakes (Sweet 2004).

The biomass of phytoplankton in Lake Shastina ranged from 33.4 to 66.4 mg/L, with an average of 52.5 mg/L. Phytoplankton chlorophyll a and pheophytin a concentrations ranged from 5.5 to 46.7 micrograms per liter (ug/L) and from 0.9 to 21.8 ug/L, respectively. Average phytoplankton chlorophyll a and pheophytin a concentrations were 27.15 and 6.1 ug/L, respectively. Literature values which associate chlorophyll levels in

[5] In this context, dominance is attributed to those phytoplankton species that have the greatest percentage of cell density (#/mL) with respect to the total phytoplankton community cell density.

lakes and reservoirs to trophic status are presented in Table 4.2. Measured chlorophyll a concentrations in Lake Shastina are within the mesotrophic to hypereutrophic classification ranges, with the majority of the values within the eutrophic-hypereutrophic classification range, and the average value indicating eutrophic conditions.

Table 4.2: Boundaries for Trophic Classification of Lakes and Reservoirs

Parameter	Oligotrophic	Mesotrophic	Eutrophic	Hyper-eutrophic	Source
Chlorophyll-a (ug/L)	<4	4-10	10-25	>25	Carlson (1977), Olem and Flock (1990, p.80-84)
Chlorophyll-a peak (ug/L)	<2	2-9	>9	-	Vignola and Deas (2005)
Tot Chlorophyll (ug/L)	<3	3-9	9-40	>40	Forsberg and Ryding (1980, as cited by Florida Lake Watch Undated)

Note: Authors cited used different chlorophyll measures

Summary

The aquatic vegetation survey documented the abundance of aquatic vegetation in the Shasta River and Lake Shastina. The Shasta River falls within the eutrophic boundary classification, and Lake Shastina falls within the eutrophic to hyper-eutrophic boundary classification. The abundance of aquatic vegetation in the Shasta River and Lake Shastina means the photosynthetic and respiration activity of the vegetation has a significant effect on the diurnal fluctuation of dissolved oxygen concentrations. In addition, when the aquatic vegetation dies and is decomposed an oxygen demand is exerted via carbonaceous deoxygenation.

4.3.3.2 Factors Affecting Aquatic Vegetation Productivity in the Shasta River

The primary factors that can limit aquatic vegetation productivity include light availability, nutrient concentrations, channel substrate composition, flow, current velocity, and temperature. This section provides a brief review of the literature with respect to these limiting factors and summarizes Shasta River conditions. Biggs (2000) provides a comprehensive review of the factors affecting periphyton growth.

Stream Temperature

Higher stream temperatures tend to enhance aquatic vegetation growth and may increase photosynthesis and respiration, resulting in greater variation in diurnal dissolved oxygen concentrations (USEPA 2000, p. 35). The maximum growth rate of aquatic vegetation occurs at a corresponding optimal stream temperature. Maximum growth rates of benthic algae often correspond with reference temperatures of 20°C (USEPA 1985, p. 293). During summer months when dissolved oxygen concentrations reach critical levels in the Shasta River, stream temperatures regularly exceed 20°C and do not limit aquatic vegetation growth.

Flow and Current Velocity

Current velocity is an important factor controlling aquatic vegetation assemblage. Generally, macrophytes are more adapted to slow moving river systems, while periphyton can withstand higher current velocities. As discussed in Section 4.3.3.1, macrophytes dominate the assemblage of aquatic vegetation in much of the Shasta Valley, where the river is characterized by slow velocity. In the higher gradient and faster velocity reaches, periphyton are dominant.

Under high current velocities, the frictional shear stress created on a periphyton mat can scour the attached algae from the substratum (Horner and Welch 1981, as cited by Welch 1992, p. 245). High current velocity can also scour rooted macrophytes. Local observers have noted that the amount of aquatic vegetation washed from the Shasta River in the fall increases when flows increase at the conclusion of the irrigation season. Removal of aquatic vegetation via scour decreases photosynthetic oxygen gain and respiratory oxygen loss to the water. In addition, when a scour-event washes the vegetative material out of the Shasta system, there may be a decrease in the oxygen demand exerted on the Shasta River, and consequently there may be an increased oxygen demand on the Klamath River.

Dwinnell Dam (located at River Mile 40.6) impounds the Shasta River, capturing all flow originating in the headwaters, as well as Parks Creek flow diverted to Lake Shastina, thereby storing water from wet periods for use in dry periods. Only in above-normal rainfall years has Lake Shastina over-topped its spillway during the winter months. Since 1956, the reservoir has reached its capacity of 50,000 acre-feet on approximately 10 occasions or an average of twice in every ten-year period (Vignola and Deas 2005). The modification of Shasta River flows, and particularly the reduction in peak flow rates caused by the dam and diversions, both limit scour of the riverbed. The implication is that fine sediments and aquatic vegetation are not scoured from the channel as much as they would be if the dam were not in place. Consequently, fine sediments and aquatic vegetation build-up in the system. This build-up of organic material contributes a significant oxygen demand on the river. One local resident observed that aquatic vegetation densities were greatly reduced for several years following relatively high rainfall in the winter 1997/1998.

Substrate Composition

Periphyton prefer cobble or gravel substrates, whereas rooted macrophytes prefer finer substrates, such as peat, silt, sand, or clay. As mentioned in Section 4.3.3.1, most of the macrophyte species found in the Shasta River prefer peat or silt substrates. As part of the aquatic vegetation survey, Regional Water Board and UC Davis staff made visual estimates of channel substrate composition (Appendix A). Shasta River substrate composition is variable. Gravel, sand, and fines predominate. The percentage of fines is greatest in the meandering, slow moving reaches of the river.

Macrophyte abundance tends to be the greatest in those reaches with the highest percentage of fine sediments. Regional Water Board staff also observed that submerged and emergent macrophytes trap fine sediment and organic material, thereby contributing to the sediment oxygen demand of the river, as well as enhancing the suitability of the substrate conditions for macrophyte establishment and proliferation. This sediment trapping capacity of macrophytes is also reported by Welch (1992, p. 200).

Light
Aquatic plants require light to grow. Light limitation can be an important control on diurnal dissolved oxygen swings in enriched rivers (USEPA 2000, p. 35). The growth rate of algae is a function of light as well as temperature and nutrient concentrations. Most models predict algal growth rates, or rates of photosynthesis, according to saturation-type relationships in which the growth rate increases linearly with light at low intensities but gradually levels off at high intensities to reach a maximum value at saturated light intensity (USEPA 1985, p. 311).

Light availability to aquatic plants in rivers is controlled by riparian canopy as well as water depth and clarity. Riparian canopy serves to block or filter incoming light. Reductions in riparian canopy therefore increase the availability of light and, conversely, increases in riparian canopy decrease light availability.

Submerged macrophytes are adapted to high light intensities. For example, photosynthetic rates (measured as ^{14}C assimilation) of *Elodea canadensis* (one of the dominant species in the Shasta River) were optimum between 75 and 100% of full sunlight (Hartman and Brown 1967, as cited by Welch 1992, p. 202). Further, incidence of nuisance growths of macrophytes in an Alabama reservoir corresponded with years of high mean daily incident light and low rainfall (less runoff and thus less turbidity) during the spring growth period (Peltier and Welch 1970, as cited by Welch 1992, p. 204).

Periphyton also respond to light availability. The species composition of periphyton can vary depending on light availability. One study found that light-adapted species had a slightly higher rate of photosynthesis at high light intensities, compared with shade-adapted species grown in artificial streams (McIntire and Phinney 1965, as cited by Welch 1992, p. 242). Further, the periphyton community grown in the lighted stream reached a saturated biomass level in two-thirds the time of the periphyton growing in the shaded stream.

A study of headwater streams in southwestern British Columbia found that the mean solar flux to stream reaches with no riparian buffer (i.e. clear-cut) was 58 times greater than the solar flux to uncut (i.e. control) riparian buffer stream reaches (Kiffney et al. 2003). Further, Kiffney et al. (2003) concluded that light was the primary constraint on accrual of periphyton biomass, with periphyton ash free dry mass in the clear-cut treatment reaches exceeding that of the control reaches by six times during the summer.

While riparian vegetation conditions are variable in the Shasta River watershed, there are many reaches with little or no riparian cover (see Section 1.4.7.1). Further, topographic shade is minimal to non-existent in the Shasta Valley, though it is more prominent in the Shasta canyon. Given these conditions, much of the Shasta River and its tributaries are exposed to ample light, which promotes prolific growths of aquatic vegetation.

Nutrient Concentrations
Aquatic vegetation requires nutrients to grow. Nuisance levels of periphyton and macrophytes can develop rapidly in response to nutrient enrichment when other factors such as light, temperature, substrate, etc. are not limiting (USEPA 2000, p. 4). Nitrogen

and phosphorus are the primary macro-nutrients that enrich freshwater aquatic systems. Ammonia (NH_4^+), nitrate (NO_3^-), and ortho-phosphate (PO_4^{3-}) are the soluble fractions of nitrogen and phosphorus and are the forms directly available to aquatic plants.

The role of nutrients in aquatic ecosystems is complex, and is confounded by other factors such as light availability, flow, and temperature. Similar nutrient concentrations may not cause similar environmental responses (such as aquatic vegetation productivity and dissolved oxygen concentrations) because of the non-nutrient factors. Despite this complexity, studies have developed quantitative relationships between nutrient concentrations and mean or maximum chlorophyll levels in periphyton (for a review see Tetra Tech 2005). These correlations tend to be waterbody-specific, and there is a lot of variability between waterbodies.

Rooted macrophytes assimilate nutrients from both the sediments and water column, though the dominant assimilation pathways are not well described for different species. Welch (1992, p. 198-208) states that rooted submerged macrophytes (the predominant type in the Shasta River) depend largely on the sediments for their nutrients. Tetra Tech (2005) notes that attempts to predict macrophytes' response to water column nutrient concentrations are fraught with difficulties, and that analysis of these effects must be done on a site-specific basis or using surrogate variables such as periphytic algae biomass.

Section 2.5 provides an overview of nutrient conditions in the Shasta River watershed as they compare to USEPA national and ecoregional criteria. Total phosphorus and total nitrogen concentrations of the Shasta River and its tributaries are biostimulatory and promote aquatic growth, reflecting nutrient overenrichment from anthropogenic sources. In Lake Shastina, total phosphorus and total nitrogen concentrations are biostimulatory, generally falling within eutrophic to hypereutrophic classification boundaries.

The concentrations of total phosphorus in the headwaters of the Shasta River (originating as snow melt from Mount Eddy) are generally below biostimulatory levels. However, total phosphorus and total nitrogen concentrations of springs and spring-fed streams are quite high and biostimulatory.

4.4 Anthropogenic Effects on Shasta River Dissolved Oxygen Conditions

Section 4.3 identified that sediment oxygen demand, nitrification, and photosynthesis and respiration of aquatic vegetation are the primary processes affecting dissolved oxygen concentrations in the Shasta River. In addition, Section 4.3.3.2 demonstrated that the conditions of light availability, nutrient concentrations, channel substrate composition, flow, current velocity, and stream temperature in the Shasta River and Lake Shastina sustain prolific growth of aquatic plants. This section identifies the anthropogenic sources or factors that promote aquatic plant growth (and thereby promote photosynthetic production and respiratory consumption of dissolved oxygen), increase sediment oxygen demand rates, and/or increase nitrification in the Shasta River watershed. In Chapter 7, the effect of these sources on dissolved oxygen concentrations in the Shasta River is quantified.

Regional Water Board staff identified five anthropogenic sources or factors affecting dissolved oxygen conditions of the Shasta River, including:

- Tailwater return flow,
- City of Yreka non point and wastewater infiltration sources,
- Lake Shastina and minor impoundments,
- Riparian shade, and
- Flow.

4.4.1 Tailwater Return Flow Quality

In this document "tailwater return flow" is defined as surface runoff of irrigation water to a surface water body, and is synonymous with "irrigation return flow." The quality of tailwater return flows in the Shasta River watershed has not been well documented. In the summer of 2003, Regional Water Board staff collected a total of 16 water samples from 13 locations with tailwater return flows to the Shasta River. Summary statistics are presented in Table 4.3. For comparison, average Shasta River concentrations are also shown in Table 4.3. The tailwater samples were collected from 13 locations in the watershed, and primarily included flow in ditches as opposed to sheet flow across a field.

Table 4.3: Summary of Shasta River tailwater return flow quality, and average water quality of the Shasta River below Dwinnell Dam

Location	Statistic	Ortho P	Total P	Ammonia as N	NO2+NO3 as N	TKN	BOD_5	TSS	TOC
Tailwater	Minimum	0.03	0.03	0.03	0.03	0.3	1.5	5	0.5
	Maximum	0.79	0.88	0.65	0.52	3.9	7.0	140	24
	Average	***0.20***	***0.26***	***0.10***	***0.10***	***1.2***	***2.7***	***16.8***	***8.2***
	Median	0.18	0.25	0.06	0.08	0.9	2.0	5	5.1
	Count	16	16	15	15	15	11	16	16
Shasta River[1]	***Average***	***0.14***	***0.19***	***0.025***	***0.087***	***0.50***	***1.5***	***5.0***	***4.3***

Notes: Units for all parameters are mg/L.
1. Shasta River data is a compilation of all Shasta River locations monitored downstream of Dwinnell Dam.

Despite the limited tailwater measurements, several important conclusions can be made about tailwater return flow quality in comparison to the average water quality of the Shasta River:

- Tailwater return flows contribute to the oxygen demand exerted on the Shasta River. The average TKN concentration of tailwater return flows is over two times that of the average Shasta River concentration during the irrigation season (1.2 and 0.5 mg/L, respectively). In other words, tailwater return flows contribute significantly to the overall nitrogenous oxygen demand of the Shasta River.
- Ammonia and nitrate (NO_3^-) are the forms of nitrogen directly available to aquatic plants. Average ammonia concentrations of tailwater return flows are four times that of the average Shasta River concentrations during the irrigation season. This contribution of ammonia to the Shasta River stimulates the growth of aquatic plants, representing a significant contribution to the total oxygen demand by increasing respiration.
- The average BOD_5 concentration of tailwater return flows is nearly two times higher than that of the average Shasta River concentration (2.7 and 1.5 mg/L, respectively).

- The carbonaceous oxygen demand associated with tailwater return flows contributes to the overall carbonaceous oxygen demand of the Shasta River and tributaries, both in the water column and in the stream sediments.
- Total suspended solids (TSS) and total organic carbon (TOC) concentrations can provide some input into potential carbonaceous oxygen demand not measured as BOD_5. The average TSS concentration of tailwater return flows is over three times that of the average Shasta River concentration (16.8 and 5.0 mg/L, respectively). Similarly, the average TOC concentration of tailwater return flows is approximately twice that of the average Shasta River concentration (8.2 and 4.3 mg/L, respectively). These results indicate tailwater return flows may contribute to the carbonaceous oxygen demand of the Shasta River.

Tailwater return flows are common in the Shasta River watershed. As mentioned in Section 1.4.9, due to the appropriated water rights in the watershed, irrigation return flows to the Shasta River are used to meet downstream water rights. There is no formal system to measure the rates of tailwater return flows within the watershed. Therefore, it is not possible to calculate exact pollutant loads associated with tailwater return flows.

In the course of conducting the 2004 aquatic vegetation survey, Regional Water Board staff observed numerous discharges of tailwater returns flows to the Shasta River from ditches draining from pasture and fields. Regional Water Board staff estimate the flow rates of observed return flows ranged from 0.5 to 5 cubic feet per second (cfs). Typically, there were deltas of settleable solids and fine sediment at these discharge locations. Regional Water Board staff observed that disruption of some of these accumulations of settled materials caused a distinct hydrogen sulfide (i.e., rotten egg) smell. In the absence of dissolved oxygen and nitrates, sulfates serve as a source of oxygen for biochemical oxidation by anaerobic bacteria. While not definitive, this observation indicates that the settled material near tailwater discharge locations contains organic material that undergoes decomposition by aerobic and anaerobic bacteria, contributing to oxygen loss from the water column.

4.4.2 City of Yreka Non Point and Wastewater Infiltration Sources

Yreka Creek flows north through the City of Yreka (Figure 1.4) and enters the Shasta River just above the Shasta canyon. Water quality monitoring of Yreka Creek has been conducted at four primary locations by the City of Yreka, with supplemental sampling by the California Department of Water Resources and NCRWQCB. From upstream to downstream these Yreka Creek monitoring locations are: (1) Oberlin Road, located on the south end of the city, (2) Highway 3, located on the north end of the city, (3) Nursery Bridge, located downstream of the City of Yreka wastewater treatment and disposal facility, and (4) Anderson Grade Road, located near the mouth of Yreka Creek. These monitoring locations were chosen in order to assess the water quality trends as the river passed through the city and passed by the wastewater treatment and disposal facility. A summary of water quality conditions of Yreka Creek at these locations is presented in Table 4.4.

Table 4.4: Yreka Creek water quality summary

Metric	Location	Ortho P	Total P	Ammonia as N	NO2+NO3 as N	NO3 as N	TKN	BOD_5	TOC	TSS
Minimum	Oberlin Road	0.025	0.005	0.025	0.098	-	0.1	-	2.4	0.5
	Highway 3	0.01	0.02	0.02	0.62	0.18	0.1	1.5	0.1	5
	Nursery Bridge	0.01	0.02	0.025	0.96	0.08	0.1	-	0.4	-
	Anderson Grade Rd.	0.02	0.02	0.025	0.86	0.31	0.1	1.5	0.3	0.5
Maximum	Oberlin Road	0.025	0.062	0.076	0.170	-	0.2	-	10	7
	Highway 3	0.03	0.63	0.77	1.23	1.25	0.3	1.5	33.8	5
	Nursery Bridge	1.17	4.25	4.28	1.48	4.73	0.7	-	36.1	-
	Anderson Grade Rd.	1.22	1.7	0.76	1.6	4.02	0.75	1.5	25.7	10
Average	Oberlin Road	NA	0.022	0.031	0.126	NA	0.18	NA	5.5	1.7
	Highway 3	0.02	0.107	0.11	0.91	0.70	0.2	NA	4.46	NA
	Nursery Bridge	0.14	0.54	0.621	NA	1.19	0.3	NA	4.53	NA
	Anderson Grade Rd.	0.21	0.47	0.105	1.11	1.65	0.3	NA	3.7	2.1
Median	Oberlin Road	NA	0.02	0.025	0.11	NA	0.2	NA	4.1	0.5
	Highway 3	0.02	0.059	0.05	0.895	0.70	0.2	NA	1.2	NA
	Nursery Bridge	0.08	0.2	0.25	NA	1.04	0.2	NA	1.6	NA
	Anderson Grade Rd.	0.15	0.23	0.06	0.87	1.49	0.3	NA	1.7	1
n	Oberlin Road	2	15	8	3	0	5	0	3	12
	Highway 3	21	66	66	4	62	21	1	21	2
	Nursery Bridge	19	63	63	2	61	19	0	19	0
	Anderson Grade Rd.	27	63	55	3	45	27	1	28	19

Units for all parameters are mg/L.
Non Detect (ND) data were calculated as ½ the reporting limit.
NA = Not Applicable. Averages and medians cannot be calculated if $n \leq 2$.
n = number of samples
Data from 1999 to 2005, collected by Regional Water Board, CDWR, and City of Yreka.

In 2000, the population of the City of Yreka was 7290 (Section 1.4.2). The City is characteristic of a small city, with land use dominated by urban single-family residential housing surrounding mixed commercial businesses. Monitoring has not been conducted in sufficient detail to determine the extent of non-point source pollution of Yreka Creek originating within the City. Water quality monitoring studies in other semi-urban cities, however, have revealed nutrients, pathogens, sediment, oil and grease, and total petroleum hydrocarbons in runoff.

The City of Yreka owns and operates wastewater collection and treatment and disposal facilities for the City's municipal wastewater, located north of the city. The wastewater treatment and disposal facility consists of secondary treatment by activated sludge, clarification, aerobic sludge digestion, chlorine disinfection, and subsurface disposal via drip irrigation to a 31-acre field. The disposal field is located adjacent to Yreka Creek, within a few feet of the creek elevation. The wastewater treatment facility is operated by the City under the terms of current waste discharge requirements (Order No. R1-2003-0047) issued by the Regional Water Board.

Cattle grazing occurs downstream of the wastewater treatment and disposal facility. In addition, the community of Hawkinsville is located downstream of the facility and is all on individual septic systems. These land uses contribute an unknown amount of pollutants to Yreka Creek.

Though the water quality data set at Oberlin Road (Table 4.4) is small, a comparison of water quality conditions in Yreka Creek at Oberlin Road versus conditions at Highway 3 can be made to assess non-point source contributions to Yreka Creek from within the City. This comparison suggests that runoff from the City may increase the total phosphorus, ammonia, and nitrite/nitrate.

A comparison of water quality conditions in Yreka Creek at Highway 3 versus conditions at the Nursery Bridge and Anderson Grade Road can be made to assess pollutant contributions to Yreka Creek from the City's wastewater collection, treatment, and disposal facilities. The average ammonia nitrogen and TKN concentrations increase by approximately 0.5 and 0.1 mg/L, respectively, from Highway 3 to the Nursery Bridge (equating to an increase in nitrogenous oxygen demand of approximately 0.46 mg/L).

Average total phosphorus and ortho-phosphate concentrations increase approximately 0.4 and 0.1 mg/L from Highway 3 to the Nursery Bridge, respectively. Ortho-phosphate concentrations increase another 0.1 mg/L approximately from the Nursery Bridge to Anderson Grade Road.

Based on these data, Regional Water Board staff identified the City of Yreka as a contributing source to the nutrient load and nitrogenous oxygen demand in Yreka Creek. The data indicate that the City's wastewater collection, treatment and disposal facilities are the primary source of both phosphorus and nitrogen loading to Yreka Creek.

4.4.3 Lake Shastina and Minor Impoundments

As discussed in Section 2.4.4, Lake Shastina regularly stratifies and becomes anoxic (near to complete absence of dissolved oxygen) in the hypolimnion (bottom layer). Nowhere else on the Shasta River has this been observed. Therefore, the presence of Dwinnell Dam and the creation of the reservoir promotes the stratification of the reservoir and the resulting low dissolved oxygen concentrations within the hypolimnion.

A comparison of available dissolved oxygen concentrations in the Shasta River above and below Lake Shastina shows that concentrations are consistently lower at the downstream location during summer months (Figure 4.4). The lower dissolved oxygen concentration in the Shasta River below Lake Shastina results primarily due to the fact that the outflow from Dwinnell Dam is discharged near the bottom of the reservoir, where anoxia is persistent in summer months. In addition, the downstream monitoring location is approximately 1.2 miles downstream of Dwinnell Dam; a reach of the river that has relatively dense riparian cover. Based on the relatively high percentage of fines and organic matter present in the channel substrate within this reach, it may have high SOD rates, which likely contribute to the measured low dissolved oxygen concentrations.

In addition to affecting dissolved oxygen levels in the Shasta River below Dwinnell Dam, Lake Shastina appears to affect dissolved oxygen concentrations in Hidden Valley Spring, which is located downstream of the dam. Dissolved oxygen levels were measured in six select springs located in the Shasta River watershed in 2003 in order to assess the nutrient contributions from springs in the watershed, and to measure physical properties of the river including dissolved oxygen. Measured dissolved oxygen concentrations were at or near saturation levels (8.0 – 13.0 mg/L for all but one of these springs). Hidden Valley Spring (located near Big Springs Road approximately 1.5 miles down-gradient of Dwinnell Dam and approximately 1000 feet from the Shasta River) had measured dissolved oxygen concentrations ranging from 1.34 to 8.38 mg/L, with an average concentration of 3.19 mg/L. Measured dissolved oxygen levels at the other springs ranged from 8.16 to 13.09 mg/L.

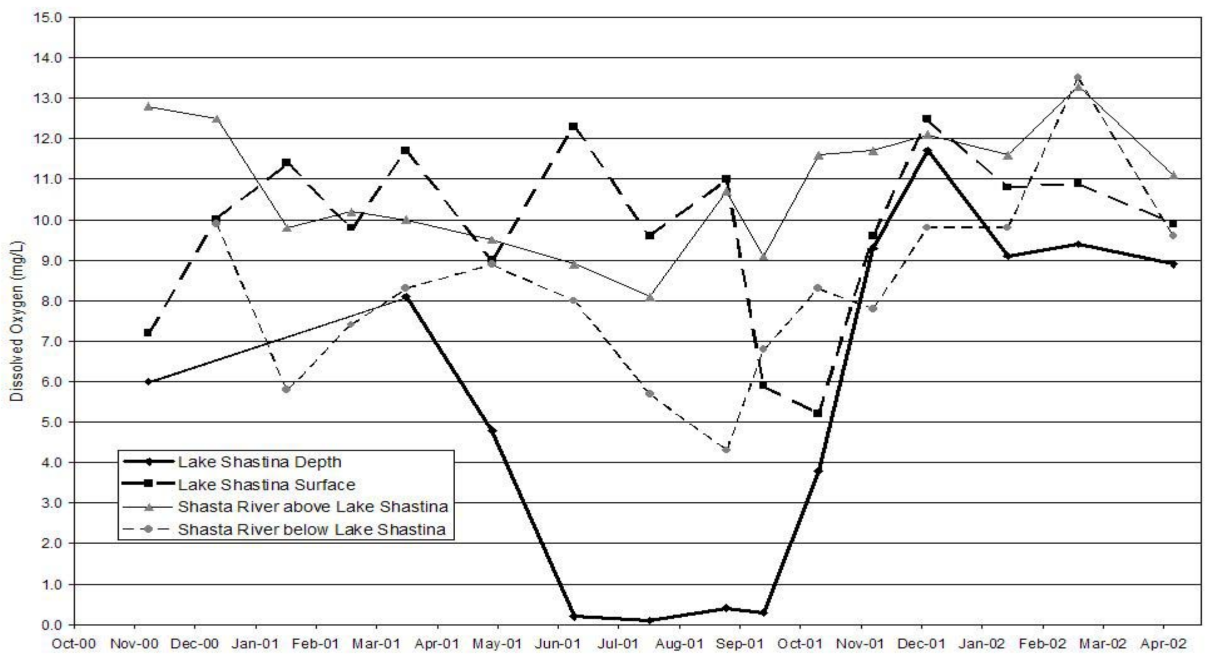


Figure 4.4: Dissolved oxygen concentrations of Lake Shastina and Shasta River, October 2000 – April 2002

Flow rates from Hidden Valley Spring vary seasonally, apparently in relation to the water surface elevation of Lake Shastina. Dwinnell Dam is leaky. Water can be heard and seen flowing from the toe of the dam. Based on available records, Lake Shastina loses from 6500 to 42,000 acre-feet annually to seepage and evaporation, with the variation largely a function of storage (Vignola and Deas 2005). Periods with more storage tend to have larger seepage losses. Given the leakiness of the dam and the change in flows from Hidden Valley Spring in relation to the storage level of the reservoir, it is likely that the spring is hydrologically connected to Lake Shastina, and that Lake Shastina is the source of low dissolved oxygen concentrations of the spring.

A comparison of the available Lake Shastina inflow and outflow water quality data indicates that annually, the lake may serve as a sink for phosphorus, and a source for nitrogen (Table 4.5). Average annual outflow concentrations of ortho-phosphate and total phosphorus are lower than average annual inflow concentrations, indicating that phosphorus is being retained in the sediments on the bottom of the reservoir.

Average annual outflow concentrations of ammonia, nitrite plus nitrate, and TKN, on the other hand, are all higher than average annual inflow concentrations. A comparison of summertime data shows that average summer outflow concentrations of ammonia, nitrite plus nitrate, and TKN are all higher than average inflow concentrations, while average outflow orthophosphate concentrations are slightly lower than average inflow concentrations (Table 4.6). This observed increase in nitrogen concentrations downstream of Lake Shastina likely stimulates the growth of aquatic plants, which in turn contributes to oxygen demand by increasing respiration. These observed nutrient dynamics do not appear to be maintained during winter months (Table 4.7).

Table 4.5: Comparison of Year-Round Lake Shastina Inflow and Outflow Data

Metric	Location	Dissolved Ammonia as N	Total Ammonia as N	Dissolved NO2+NO3 as N	TKN	Dissolved Ortho P	Total P
Minimum	Inflow	0.005	0.02	0.005	0.16	0.005	0.02
	Outflow	0.005	0.025	0.005	0.25	0.005	0.025
Maximum	Inflow	0.02	0.09	0.31	0.32	0.14	0.75
	Outflow	0.02	0.2	3.07	1.2	0.11	0.43
Average	Inflow	0.008	0.032	0.091	0.215	0.048	0.11
	Outflow	0.008	0.054	0.182	0.563	0.032	0.108
Median	Inflow	0.005	0.025	0.05	0.2	0.04	0.08
	Outflow	0.005	0.025	0.025	0.6	0.03	0.07
Count	Inflow	14	24	32	6	32	39
	Outflow	46	24	64	40	64	68

Non Detect (ND) data were calculated as half the reporting limit.
Information is from 2000-2003.

Table 4.6: Comparison of Summer (June-September) Lake Shastina Inflow and Outflow Data

Metric	Location	Dissolved Ammonia as N	Total Ammonia as N	Dissolved NO2+NO3 as N	TKN	Dissolved Ortho P	Total P
Minimum	Inflow	-	0.02	0.025	0.16	0.04	0.07
	Outflow	-	0.025	0.025	0.25	0.02	0.025
Maximum	Inflow	-	0.09	0.08	0.32	0.08	0.75
	Outflow	-	0.2	0.24	0.6	0.11	0.39
Average	Inflow	-	0.035	0.035	0.288	0.059	0.176
	Outflow	-	0.088	0.125	0.46	0.053	0.175
Median	Inflow	-	0.025	0.025	0.215	0.06	0.1
	Outflow	-	0.065	0.118	0.53	0.04	0.2
Count	Inflow	-	9	8	4	8	11
	Outflow	-	10	8	3	8	11

Non Detect (ND) data were calculated as half the reporting limit.
Information is from 2001-2003.

Table 4.7: Comparison of Winter (October-May) Lake Shastina Inflow and Outflow Data

Metric	Location	Dissolved Ammonia as N	Total Ammonia as N	Dissolved NO2+NO3 as N	TKN	Dissolved Ortho P	Total P
Minimum	Inflow	0.005	0.025	0.005	0.18	0.005	0.02
	Outflow	0.005	0.025	0.005	0.3	0.005	0.025
Maximum	Inflow	0.02	0.076	0.31	0.2	0.140	0.32
	Outflow	0.02	0.09	3.07	1.2	0.08	0.430
Average	Inflow	0.008	0.031	0.109	NA	0.044	0.084
	Outflow	0.008	0.030	0.203	0.571	0.03	0.095
Median	Inflow	0.005	0.025	0.1	NA	0.035	0.06
	Outflow	0.005	0.025	0.025	0.6	0.03	0.07
Count	Inflow	14	15	24	2	24	28
	Outflow	45	13	52	37	53	57

Non Detect (ND) data were calculated as half the reporting limit.
Information is from 2000-2003.

The regular occurrence of algal blooms in Lake Shastina during summer months indicates that nutrient levels are biostimulatory. *Anabaena flos aquae* was a dominant species present in phytoplankton samples collected in Lake Shastina in July 2004. Many cyanobacteria (or blue-green algae) are capable of sequestering atmospheric nitrogen. The presence of *Anabaena flos aquae*, a cyanobacteria, indicates that this nitrogen input pathway may occur in the reservoir.

As observed in section 4.3.3.2, the presence of Dwinnell Dam reduces scouring peak flows, thereby enhancing the accumulation of organic matter and fine sediments in the river. These materials are the preferred substrates for rooted aquatic macrophytes, so this effect expands the area of suitable habitat for macrophytes, and contributes to the respiratory oxygen demand of the river.

As discussed in Section 3.3.6, there are several small impoundments on the Shasta River – often termed “flashboard” dams – that are used to raise the water level in the river to provide for diversion (either direct or pumping) for agricultural use. These small impoundments increase the hydraulic residence time and promote change in water quality conditions. Based on results of the 2004 aquatic vegetation survey (Appendix A), macrophyte densities are highest in slow moving, depositional reaches of the Shasta River. By increasing the residence time of the river, impoundments promote settling of particulate material. The minor impoundments on the Shasta River are all relatively shallow (mean depths less than 10 feet). Limited depth provides an opportunity for light to reach the bottom of the waterbody, thereby allowing rooted macrophytes to colonize much of the impounded area.

To our knowledge, no dissolved oxygen measurements have been made at sub-daily time steps at locations immediately behind a flashboard dam on the Shasta River. However, dissolved oxygen concentrations were measured hourly during summer months in 2002, 2003, and 2004 at Highway 3, located approximately 2000 feet upstream of a flashboard dam. Based on the channel morphology and flow characteristics, this location appears to be influenced by the downstream impoundment. Dissolved oxygen levels at this location include the lowest and highest concentrations measured in the river. These dissolved oxygen conditions are likely the result of macrophyte productivity and SOD rates in this reach of the river. Macrophyte density in this reach is among the highest observed in the river, and measured SOD rates in this reach were the highest measured in 2003. In addition, this reach had among the highest percentage of fine sediments observed in 2004. These conditions demonstrate the potential effect of small impoundments on dissolved oxygen conditions of the Shasta River.

4.4.4 Riparian Shade

As discussed in Section 4.3.3.2, aquatic plant productivity is highest under increasing light availability. Therefore, theory suggests that aquatic productivity would be less in shaded reaches compared with unshaded reaches, and thus dissolved oxygen fluctuations would be less in shaded compared with unshaded reaches. Regional Water Board staff observed that aquatic vegetation abundance is lower in shaded reaches of the river, and that dissolved oxygen fluctuations appear to be greatest (i.e. higher highs and lower lows) in reaches with abundant aquatic vegetation growth.

4.4.5 Flow

Theoretically, flow could affect dissolved oxygen in several ways. First, oxygen is added to a river by reaeration. Factors affecting reaeration rates include current velocity and turbulence, water column depth, temperature, and surface films. Current velocity is positively correlated with flow. Therefore, theory suggests that reaeration rates are higher under higher flows. During summer months Shasta River flows are decreased due to surface water diversions. Therefore, it appears that decreased flows in the Shasta River contribute to lower dissolved oxygen concentrations, at least locally. Second, flow affects the depth of water in the channel. Water causes light to scatter, and the amount of photosynthetically active range of light decreases with depth. Therefore, there is less light available to aquatic plants under higher flows, resulting in less fluctuation of dissolved oxygen concentrations caused by photosynthesis and respiration. Third, flow can affect dissolved oxygen through its effects on water temperature. Larger volumes of water have a higher thermal mass and are more resistant to heating and cooling. If a large volume of water is cold it can travel downstream and retain its low temperature. As described in section 4.1.1, colder water can hold more dissolved oxygen. Through this mechanism, flow can affect dissolved oxygen.

CHAPTER 5. ANALYTICAL APPROACH AND METHODS

5.1 Introduction

Chapters 3 and 4 identify the sources and factors affecting stream temperature and dissolved oxygen concentrations in the Shasta River watershed. This chapter outlines the analytical methods used to quantify the TMDL load allocations attributed to these sources.

The Section 303(d) listings for the Shasta River address the entire Shasta River watershed. The analysis focuses on the mainstem of the Shasta River from Dwinnell Dam to the mouth for the following reasons:

- Dissolved oxygen and temperature impairments are well documented for the mainstem (see Chapter 2), and thus are more suitable for detailed analysis.
- Sources contributing to the impairments affect both the mainstem and the tributaries.
- The mainstem analysis is based on models that describe processes affecting the listed constituents. The general conclusions reached in the mainstem analysis will apply to other similar locations in the watershed.
- For temperature conditions in tributaries, detailed analysis in other similar landscapes has identified riparian shade as a key factor influencing stream temperatures, which can be influenced by human activities. Because this general conclusion is applicable to the Shasta watershed, separate temperature analysis was not performed on tributaries.
- Actions addressing temperature and dissolved oxygen apply to the mainstem and tributaries, and thus water quality improvements predicted for the mainstem can be expected in tributaries as well.

In short, actions that lead to water quality compliance in the portion of the mainstem analyzed are also expected to lead to water quality compliance in other parts of the mainstem and in the tributaries.

5.2 Analytic Approach and Model Selection

The analytical approach used to quantify allocations to the sources and factors affecting stream temperature and dissolved oxygen concentrations in the Shasta River relies on the use of computer simulation models. The processes that determine stream temperature and dissolved oxygen concentrations are inherently complex and non-linear. The degree to which one factor can impact stream temperature or dissolved oxygen concentration is dependent on the state of numerous other factors involved. For example, as outlined in Chapters 3, the temperature of the Shasta River is dependent on the interacting effects of the headwater temperature regime, surface water diversions, shade, and the temperature and quantity of tailwater return flows and tributary inflows. Further, as outlined in Chapter 4, dissolved oxygen concentrations of the Shasta River depend on water temperature, photosynthetic and respiration rates of aquatic vegetation, sediment oxygen demand rates, consumption of oxygen via nitrification and biochemical oxygen demand, and flow. Many computer simulation water quality models have been developed to depict stream temperature and dissolved oxygen conditions and dynamics. However, not all water quality models are suited for evaluating the particular factors that affect temperature and dissolved oxygen in the Shasta River watershed.

Regional Water Board staff selected the Tennessee Valley Authority's River Modeling System (RMS) as the primary analytical tool for developing the Shasta River temperature and dissolved oxygen TMDLs. In addition, a benthic algae box model was employed to evaluate the connection between nutrient concentrations and potential primary production in the Shasta River; a process not included in the RMS model. The components of the benthic algae box model are presented in Section 5.7.

The following text on model selection for the Shasta River TMDL is from the *Technical Memorandum: TVA River Modeling System: ADYN and RQUAL-RMS Model Specifications and Background* dated August 17, 2005 (Deas 2005c). This document is included as Appendix C and contains further discussion of the models considered for use in developing the Shasta River TMDLs.

> After a review of the models available in the public domain, the Tennessee Valley Authority's (TVA) River Modeling System (RMS), a one-dimensional hydrodynamic and water quality model, was chosen to model the Shasta River. This model was chosen for several reasons, including, but not limited to the fact that it is readily available in the public domain, has been widely applied to both temperature and dissolved oxygen assessments, contains detailed shading logic, allows for modeling at an hourly time step, is well documented, and is supported by TVA. Further, the model was already implemented, configured, and calibrated for flow and temperature on the Shasta River system. The primary modification was the addition of the necessary water quality modeling components applied to represent dissolved oxygen conditions for TMDL assessment.

Appendix D (*Shasta River Flow, Temperature, and Dissolved Oxygen Model Calibration Technical Report*) provides a detailed summary of the RMS model set up and calibration for the Shasta River TMDLs. This chapter provides a summary of the components and application of the model, with reference to applicable sections in Appendix D.

As identified above, the Shasta River TMDL modeling effort built upon previous flow and temperature modeling of the Shasta River conducted by Watercourse Engineering for the Shasta Valley RCD. Reports on these previous modeling efforts include Deas et al. (2003) and Watercourse Engineering, Inc. (2004). Characterization of riparian vegetation conditions was based in part on Deas et al. (1997).

5.3 River Modeling System - Model Components

RMS has two components that may be used independently or in sequence: the hydrodynamic model (ADYN) and the water quality model (RQUAL). These model components are discussed below.

5.3.1 The Hydrodynamic Component: ADYN

ADYN is a one-dimensional hydrodynamic model. The following text regarding ADYN is taken from *Shasta River Temperature and Flow Modeling Project* (Deas et al. 2003), which is included as Electronic Appendix E_e and utilizes information from the RMS User's Manual (Hauser 1995 as cited by Deas et al. 2003).

> ADYN solves the one-dimensional unsteady flow equations for conservation of mass and momentum using either a four-point implicit finite difference scheme with weighted spatial derivatives or a McCormack explicit scheme. The four-point implicit finite difference scheme was chosen for this application because the irregularity of the channel geometry rendered the explicit scheme inadequate. ADYN can model interactions with dynamic tributaries at channel junctions, multiple tributary systems with multiple internal boundary conditions along each system, and the effects of distributed or point lateral inflows. For this application the Shasta River will be modeled as one continuous reach with several distributed dynamic lateral inflows.

5.3.2 The Water Quality Component: RQUAL

The following text regarding RQUAL is adapted from Deas et al. (2003) and describes RQUAL for the current model application.

RQUAL uses the geometry, velocities and depths from the hydrodynamic model in the calculation of water quality variables. RQUAL can be used to study several water quality parameters. This application employs the temperature and dissolved oxygen modeling capabilities. RQUAL offers three options of numerical schemes used to solve the one-dimensional transport equation: a four-point-implicit finite difference scheme with weighted spatial derivatives, a McCormack explicit scheme, or a Holly-Preissman scheme. Preliminary model testing found negligible difference in results between the four-point-implicit and Holly-Preissman schemes when applied to the Shasta River. The four-point-implicit scheme was chosen for use in this application. In the coding of RQUAL, dispersion is neglected because the model was designed for application in high flow and turbulent river systems where transport is the dominant factor. Numerical dispersion serves to account for the lack of an explicit dispersion term (Hauser, pers. comm. 1995 as cited by Deas et al. 2003).

The heat budget (discussed in Section 5.3.2.1 below) used in RQUAL includes logic for bed heat exchange and riparian shading. Existing shading logic was not entirely sufficient to represent the dynamics of the Shasta River, so modifications were made. These modifications are discussed in Section 2.3 of Deas et al. (2003) and are identified in Section 5.5.2 below. In addition, a specific piece of shading logic that lowers dry bulb temperature in shade was not implemented.

It should be noted that RQUAL does not model shading by large-scale topographic features (e.g. hills, canyons, etc.). If this type of shading is considered to have a significant effect on water temperature, then modifications would be made to the model to account for it. For the Shasta River, the only potential for topographic shading of this type occurs in the canyon between the Mouth and RM 7. For this modeling effort the effect of topographic shading was not considered.

5.3.2.1 The Temperature Component of RQUAL - Heat Budget

The following discussion regarding RQUAL Heat Budget formulation is from Deas et al. (2003).

> Temperature models fall into two general classes: empirical models relating observations of stream temperature to stream properties (such as discharge, channel geometry, and streamside vegetation characteristics) and/or meteorological conditions, and models that represent the physical processes of heat exchange by means of the energy (or heat) budget. Although simple and generally convenient to use, empirical models are limited to assessing conditions within the range of data used to construct the relationship and do not provide detailed information about the effects of certain factors on stream temperature. These factors may include variations in discharge; changes in the location, size, and extent of vegetative cover; cumulative effects of upstream disturbances in riparian areas; and stream orientation effects on incoming solar radiation (La Marche, *et al*., 1997). Brown (1969) noted that one of the most effective process-based techniques for predicting river temperatures and temperature changes is the heat budget approach. The water quality component of the TVA model (RQUAL) uses the heat budget approach that quantifies pertinent factors by formulations based on physical processes.
>
> The heat budget approach quantifies the net exchange of heat at the air-water interface. TVA has extended the approach to also include heat exchange at the water-bed interface. This net change may be expressed as the sum of the major sources and sinks of thermal energy or the sum of the heat fluxes.
>
> TVA Heat Budget Formulation
>
> $$Q_n = \frac{Q_{ns} + Q_{na} + Q_{bed} - Q_b - Q_e - Q_c}{D}$$
>
> where:
>
> Q_n = the net heat flux (representing the rate of heat released from or added to storage in a particular volume) (kcal/m^3-s)
> Q_{ns} = net solar (short-wave) radiation flux adjusted for shade (kcal/m^2-s)
> Q_{na} = net atmospheric (long-wave) radiation flux (kcal/m^2-s)
> Q_{bed} = net flux of heat at the water- channel bed interface (kcal/m^2-s)
> Q_b = net flux of back (long-wave) radiation from water surface (kcal/m^2-s)
> Q_e = evaporative (latent or convective) heat flux (kcal/m^2-s)
> Q_c = conductive (sensible) heat flux (kcal/m^2-s)
> D = mean depth (m)

For detailed discussion of each of the heat budget components, the reader is referred to Section 2.2.1 through 2.3.3 of Deas et al. (2003). Deas et al. (2003) is included as Electronic Appendix E_e (*Shasta River Flow and Temperature Modeling Project*) of this report.

5.3.2.2 The Dissolved Oxygen Component of RQUAL

The RQUAL model simulates dissolved oxygen conditions in response to biochemical oxygen demand (BOD), nitrogenous biochemical oxygen demand (NBOD), sediment oxygen demand (SOD), mechanical reaeration, and photosynthesis and respiration of aquatic vegetation growing on or in the bed (as periphyton or macrophytes).

The following discussion regarding RQUAL dissolved oxygen formulation is from Geisler and Watercourse Engineering, Inc. (2005), which is included as Appendix D of this report.

Dissolved oxygen, carbonaceous biochemical oxygen demand (CBOD), and nitrogenous biochemical oxygen demand (NBOD) are represented in the RQUAL model. The time varying representation of dissolved oxygen is:

$$\Sigma[\partial O/\partial t] = K_2(O_s-O)-K_dL-K_nN+(P-R-S)/D$$

Where
- t = time (s)
- O = dissolved oxygen concentration (mg/L)
- O_s = saturation dissolved oxygen concentration (mg/l) (based on elevation and water temperature (See TVA, 2001))
- K_2 = reaeration rate based on one of several methods (see TVA, 2001), temperature corrected (1/s)
- K_d = CBOD deoxygenation rate, temperature corrected (1/s)
- L = CBOD concentration (mg/L)
- K_n = NBOD deoxygenation rate, temperature corrected (1/s)
- N = NBOD concentration (mg/L)
- P = Photosynthetic rate of macrophytes (gO_2/m^2-s)
- R = Respiration rate of macrophytes (gO_2/m^2-s)
- S = Sediment oxygen demand (gO_2/m^2-s)
- D = mean depth (m)

CBOD and NBOD are both represented as first order decay:

$$\Sigma[\partial L/\partial t] = -(K_d+K_s)/L$$

and

$$\Sigma[\partial N/\partial t] = -K_nN$$

Where
K_s = CBOD settling rate (no oxygen demand exerted) (1/s)
and t, L, N, K_d, K_n are as defined previously.

Note that the units of time represented in the above equation may differ from the model's required input values. For example, although all temporal units identified above are represented in seconds, model input decay rates are 1/day.

5.4 RMS Model Set Up and Boundary Conditions

The sections in the remainder of this chapter primarily serve as a road map referencing sections in Appendix D (Geisler and Watercourse Engineering, Inc. 2005). The following section addresses the model input parameter values and boundary conditions selected for model calibration and validation.

5.4.1 Hydrodynamics

Section 3.0 in Appendix D describes the update of the ADYN geometry input file, which included extending the model from the confluence at Parks Creek upstream to Dwinnell Dam, as well as updating the hydrographic representation of the Shasta River to reflect the most current spatial information.

Section 4.0 in Appendix D describes the water balance calculation for the updated geometry of the river. In addition, hydrodynamic input locations and types are identified.

Representation of stream flows and calibration procedures are discussed in Deas and Geisler (2004), which is included as Appendix E (*Memorandum: Shasta River flow and temperature modeling implementation, testing, and calibration*) of this report.

5.4.2 Temperature

Section 5.1.1 in Appendix D presents the temperature trace associated with the headwater condition, point inputs, and distributed inputs for the calibrated/validated model. Section 5.3 in Appendix D presents the pertinent model input parameter names, description, value, and notes regarding the rationale for value selection.

5.4.3 Dissolved Oxygen

Section 5.1.2 in Appendix D presents the dissolved oxygen trace associated with the headwater condition, point inputs, and distributed inputs for the calibrated/validated model. In addition, the CBOD and NBOD boundary conditions used for model calibration/validation are identified. Section 5.3 in Appendix D presents the pertinent model input parameter names, description, value, and notes regarding the rationale for value selection. SOD rates and macrophytic photosynthetic and respiration rates are included.

5.5 RMS Model Calibration and Validation

Section 1.1 in Appendix D identifies the calibration and two validation time periods selected.

5.5.1 Flow

The principal parameter adjusted for flow calibration was Manning's roughness coefficient, n. Section 6.1 in Appendix D presents the simulated versus measured flow for several locations along the Shasta River for the calibration and validation periods. Statistics for the final calibrated flow model are also tabulated. Daily trends are well represented; however, sub-daily deviations are apparent. Because the water balance was completed on a reach level at a daily time scale, it does not represent intra-reach diversions and return flows, and does not capture intra-day variations in diversions and return flows. As a result, modeled sub-daily flows show deviations from observed sub-daily flows.

5.5.2 Temperature

Water temperature calibration consisted primarily of modifying the evaporative heat flux coefficients, AA (m^3/mb-s) and BB (m^2/mb), for the equation $\psi = AA + BB*wind$. The thermal diffusivity of bed material, K (cm^2/hr), was also modified, but ultimately set to the default value. Section 6.2 in Appendix D presents the process of calibration for stream temperature, and presents the simulated versus measured temperature for several locations along the Shasta River for the calibration and validation periods. Statistics of the calibration and validation runs are also tabulated. Modeled temperatures in the upper reaches and valley reaches match up well with the measured phase and amplitude of the daily temperature trace. Simulated values at the mouth are generally under-predicted, particularly for the daily minimum, and may lag in phase slightly.

5.5.3 Dissolved Oxygen

Section 6.3 in Appendix D discusses the dissolved oxygen calibration process and presents the calibration and validation results. Simulated dissolved oxygen concentrations generally matched measured values well, capturing the amplitude and phasing of the dissolved oxygen signal.

5.6 RMS Sensitivity Analysis

Section 7.0 in Appendix D discusses the parameters for which sensitivity analyses were performed. The statistics associated with each of the sensitivity analyses are presented in Section 9.0 in Appendix D.

With respect to dissolved oxygen, CBOD, and NBOD decay rates were largely insensitive (meaning they had little effect on model outputs), as was the SOD rate. The driving factor for dissolved oxygen was maximum photosynthetic and respiration rate. These values were adjusted during calibration to fit the model to measured data. Reaeration rate, a calculated term within the model, played a pivotal role, particularly in the steep canyon reach where mechanical reaeration would be expected to occur.

5.7 Benthic Algae Box Model

The water quality component of RMS does not simulate the effect of nutrient concentrations on aquatic vegetation primary productivity. Therefore, in addition to applying the RMS model for developing the Shasta River TMDLs, an algae box model was applied in order to evaluate the connection between nutrient concentrations and primary production (photosynthesis and respiration of aquatic vegetation) in the Shasta

River. The Shasta River Benthic Algae Box Model (algae model) was applied by Deas (2005b) as reported in Appendix F (*Technical Memorandum: Shasta River Algae Box Model*).

5.7.1 Algae Model Components

The algae model predicts Shasta River aquatic vegetation, termed "periphyton" by Deas (2005b), biomass based on limiting factors such as light and nutrients, as well as on respiration and mortality rates. Scouring and shading were also included. The algae model is a simplification of the dynamics of the Shasta River, but nonetheless provides valuable insights into the response of periphyton biomass to nutrient concentrations in a river like the Shasta.

The mass balance equation for iteration of the Shasta River Benthic Algae Model is presented below:

$$P_{t+\Delta t} = P_t + \Delta t\left((\mu_{\max} LF - R_b - D_b - Z_b)P_t - \frac{s\,v P_t}{d} \right) \qquad \text{(Eq 4.3)}$$

Where:

Δt	= change in time (d)
P_t	= benthic algae biomass (mg/m^2) at current time step
$P_{t+\Delta t}$	= benthic algae biomass (mg/m^2) at next time step
μ_{max}	= maximum algal growth rate (1/d)
LF	= limiting factor (unitless)
R_b	= algal respiration rate (1/d)
D_b	= algal predatory and non-predatory mortality (1/d)
Z_b	= algal grazing mortality (1/d)
s	= scouring factor (unitless)
v	= water velocity (m/d)
d	= water depth (m)

Both minimum and maximum algal biomass values were employed to represent the restrictions of the physical world for algae growth that are not represented by the respiration, mortality, grazing rates or scour factor. Therefore, if Equation 4.3 produced an amount of algae that was either larger than the set maximum or smaller than the set minimum, the model substituted the maximum or minimum, respectively. The algae model application and nutrient sensitivity analysis results are presented in Section 7.2.

CHAPTER 6. TEMPERATURE TMDL

6.1 Introduction

This chapter presents the temperature TMDL for the Shasta River. The analytical approach in developing the temperature TMDL involved application of the RMS model of the Shasta River to determine a suite of conditions that result in water quality standards attainment under critical conditions. Regional Water Board staff developed a "water quality compliance" model scenario that characterizes Shasta River watershed conditions that reflects "natural receiving water temperatures" and result in water quality standards attainment.

6.2 Water Quality Compliance Scenario Conditions

The process used to develop the water quality compliance scenario involved separately evaluating the components identified in the temperature source and linkage analysis (Chapter 3) that affect Shasta River stream temperature. The components that were evaluated include riparian shade, tailwater return flow temperatures, the temperature regime of key tributaries, and flow.

The water quality compliance scenario for temperature represents baseline conditions with the following key modifications:

1. Increased riparian shade to represent site potential riparian conditions on a river-reach scale;
2. Modified temperature regime of tailwater return flows such that the return flows do not cause heating of the receiving water;
3. Modified temperature regime of key tributaries to reflect site potential shade conditions and elimination of receiving water heating by tailwater return flows; and
4. Increased Shasta River flows.

These modifications are presented below.

6.2.1 Shade

The objective of the shade modifications was to characterize riparian shade conditions that reflect site potential shade conditions. As outlined in Section 3.6 of Appendix D (Geisler and Watercourse Engineering, Inc 2005), riparian vegetation shading is represented in RMS by solar radiation transmittance. Solar radiation transmittance is defined as the amount of solar radiation that passes through the tree canopy and reaches the water surface. A value of 1.0 represents no shade and is equal to a percent transmittance of 100%, while a value of 0.0 would represent complete shade and is equal to a percent transmittance of 0%.

Regional Water Board staff developed depictions of site potential percent transmittance values by river reach based on available information about Shasta River riparian conditions. The information used in depicting site potential riparian shade conditions included:

- The Shasta River Woody Riparian Vegetation Inventory conducted by UC Davis for the Shasta Valley RCD (Deas et al. 1997);
- Riparian vegetation surveys and solar radiation measurements within the riparian corridor of the Shasta River conducted by Watercourse Engineering, Inc. in support of the Shasta River Flow and Temperature Modeling Project developed for the Shasta Valley RCD (Deas et al. 2003; Watercourse Engineering, Inc. 2004, Table 2-8);
- Riparian vegetation density characterization by Regional Water Board and UC Davis staff in 2004 (NCRWQCB and UCD AEAL 2005);
- Review of recent aerial photographs of the Shasta River, Big Springs Creek, and Parks Creek riparian corridor (Watershed Sciences, LLC 2004); and
- Assessment of soil conditions within the riparian corridor of the Shasta River based on USDA Soil Survey of Siskiyou County (USDA 1983), field observations, and anecdotal information about Shasta River riparian corridor soil conditions provided by local residents.

Based on this information, Regional Water Board staff defined reach-average percent transmittance values associated with varying riparian shade conditions (Table 6.1)

Table 6.1: Reach average percent transmittance associated with varying riparian shade conditions

Reach Average % Transmittance	Riparian Condition
10	Contiguous dense woody riparian with complete overhang across channel.
30	Contiguous dense woody riparian with near-complete overhang across channel. Or, patchy (70% of reach length) dense woody riparian with complete overhang.
50	Patchy (70% of reach length) woody riparian with near-complete overhang.
85	No woody riparian; near contiguous dense herbaceous (e.g. bulrush) growth. Or, disperse moderately dense patches of woody riparian, mixed with patches of herbaceous (e.g. bulrush) growth.
95	No woody riparian; patchy (10% or reach length) dense herbaceous (e.g. bulrush) growth.
100	No riparian vegetation provides measurable shade.

Using these reach-average percent transmittance to riparian condition relationships, Regional Water Board staff estimated *potential* riparian percent transmittance values for the Shasta River (Table 6.2). The potential riparian percent transmittance values presented in Table 6.2 account for natural riparian disturbance such as floods, wind throw, disease, landslides, and fire. These reach average percent transmittance values replaced the baseline percent transmittance values in the water quality compliance scenario. Considerations used in assigning the potential reach average percent transmittance values to the Shasta River reaches included: existing riparian vegetation condition, existing channel morphology, and soil conditions within the riparian corridor, based on the information cited above.

Table 6.2: Current and potential riparian reach-average percent transmittance values for the Shasta River

Reach	Upstream River Mile	Downstream River Mile	Reach Average Percent Transmittance[1]	
			Current	TMDL
Dwinnell Dam to Riverside Road	40.6	39.9	59	30
Riverside Road to u/s of A12	39.9	28.3	76	50
U/S of A12 to near DeSoza Lane	28.3	22.0	95	85
Near DeSoza Lane to u/s of Montague-Grenada Road	22.0	16.1	89	30
Near Montague-Grenada Road	16.1	14.6	90	10
D/S Montague-Grenada Road to Hwy 263	14.6	7.3	78	30
Hwy 263 to mouth	7.3	0	70 to 100	30 to 50[2]

[1] Daylight-hour average percent transmittance for given reach.
[2] Alternate between 30 and 50% every 10 percent of reach length.

6.2.2 Tailwater Return Flows

In the RMS model, tailwater return flows are depicted as a portion of total accretion flows within a model reach, and the model represents these accretions as distributed flows along a length of the reach (see Section 4.0 in Appendix D). For the existing condition (baseline) model runs, the temperatures assigned to these accretions, including tailwater return flows, were the temperatures of the Shasta River at Anderson Grade Road (see Section 5.1.1 of Appendix D). This decision was based on review of temperature data from 2001 and 2002, which indicated that river temperatures were approaching equilibrium temperature by the end of the Shasta Valley (i.e., near Anderson Grade). This assumes that the temperature of tailwater return flows are at equilibrium with air temperature, and the temperature time series at Anderson Grade Road was used as a surrogate.

For the water quality compliance scenario the temperatures for tailwater return flows were assigned the temperature of the Shasta River at the model node closest to the mid-point of the distributed flow reach. In other words, this assumes that the temperatures of the tailwater return flows are equal to the reach average temperature of the accretion reach. By attributing tailwater return flow temperatures in this manner, the water balance of the model was maintained, but the heat load from the tailwater return flows did not cause a change in the reach average temperature of the Shasta River.

6.2.3 Tributary Temperatures

The RMS model depicts inflows from Big Springs Creek, Parks Creek, and Yreka Creek as discrete inputs to the Shasta River. The other tributaries to the Shasta River are accounted for as a portion of total accretion flows within the appropriate river reach. The water quality compliance scenario involved modifying the temperature boundary conditions associated with the inputs from Big Springs Creek and Parks Creek to account for reductions in stream temperature that could occur given site potential riparian shade and modified heat load from tailwater return flows within these sub-watersheds. No change was applied to Yreka Creek stream temperature. The modifications assigned to Big Springs Creek and Parks Creek are presented below.

6.2.3.1 Big Springs Creek

Due to access limitations, no stream temperature data is available at the mouth of Big Springs Creek. Section 5.1.1 of Appendix D identifies the temperature boundary condition assigned to Big Springs Creek for the baseline condition, which average 17°C. For the water quality compliance scenario inflow temperatures from Big Springs Creek were set to baseline minus 4°C, for an average of 13°C.

Regional Water Board staff measured the water temperature of Big Spring proper (the spring at the eastern end of Big Springs Lake) and at the outlet of Big Spring Lake for 3-day periods in August and September 2003 (NCRWQCB 2004b). During these periods water temperature at Big Spring was constant, ranging from 11.26 to 11.31°C. The water temperature of Big Springs Lake at a depth of approximately 3 feet below water surface near the outlet of the lake ranged from 10.49°C to 12.86°C, averaging 11.7°C.

Big Springs Creek is approximately 2.3 miles long from the outlet of Big Springs Lake to its confluence with the Shasta River. The July 2003 thermal infrared (TIR) survey of Big Springs Creek showed that there are four springs that flow into Big Springs Creek within 0.4 miles downstream of the outlet of Big Springs Lake (Watershed Sciences, LLC 2004 [included as Appendix B of this report]). On the date of the TIR survey (July 27, 2003) the surface water temperature of Big Springs Creek dropped from ≈ 17.4°C near the outlet of Big Springs Lake to ≈15.6°C downstream of these springs. Further downstream of these springs, the surface temperature of Big Springs Creek increased 5.4°C within 1.2 miles, and then remained fairly constant for the remaining 0.7 miles before flowing into the Shasta River at ≈ 20.8°C. Based on these survey results, the overall rate of heating in Big Springs Creek is approximately 2.7°C/mile, with a maximum rate of heating of 4.5°C/mile. By contrast, based on July 27, 2003 TIR survey results, the rate of heating in the Shasta River in reaches not affected by surface water diversion was approximately 0.35°C/mile.

Aerial and TIR images of Big Springs Creek show there is no shade producing vegetation along Big Springs Creek, and that irrigation return flows contribute to heating of the creek. In addition aerial images show that the channel is quite wide, braided, and choked with aquatic vegetation.

Based on the information outlined above, Regional Water Board staff estimate that if riparian shade were at or near site potential conditions within the Big Springs Creek sub-watershed, and tailwater return flows did not cause heating of the receiving water, the rate of heating of Big Springs Creek could approximate 0.35°C/mile. Assuming an average temperature of 11.7°C at the outlet from Big Springs Lake, and applying the 0.35°C/mile rate of heating to the 2.3 miles of the Creek to the mouth, the resulting average temperature at the mouth would be approximately 12.5°C, rounded up to 13°C. Thirteen °C is equal to the average baseline temperature of 17°C minus 4°C. Therefore, for the water quality compliance scenario inflow temperatures from Big Springs Creek were set to baseline minus 4°C.

6.2.3.2 Parks Creek

Due to access limitations, stream temperature data at the mouth Parks Creek is limited. Section 5.1.1 of Appendix D identifies the temperature boundary condition assigned to Parks Creek for the baseline condition. For the water quality compliance scenario inflow temperatures from Parks Creek were set to baseline minus 2°C.

Based on the July 2003 TIR survey of the Shasta River, Parks Creek adds a heat load to the river that causes an increase in the surface temperature of the Shasta River of approximately 2°C just downstream of the confluence of Parks Creek (see Figure 3.1 in Chapter 3). On the day of the TIR survey the surface temperature at the mouth of Parks Creek was 26.6°C compared with a surface water temperature of the Shasta River just upstream of the confluence of 21.4°C (Watershed Sciences, LLC 2004).

Parks Creek is approximately 23 miles long. The headwaters flow from Mt. Eddy, and the creek is largely fed from snowmelt. From June through September 2003 the weekly average temperature in Parks Creek near its headwaters ranged from approximately 10°C to 17.5°C. From its headwaters Parks Creek traverses northeast through the Shasta Valley before entering the Shasta River. Aerial and TIR images show that the channel has almost no shade producing vegetation throughout the lower reaches in the Shasta Valley. In addition, the aerial and TIR images show that Parks Creek is characterized by multiple water withdraws, surface return flows, and tributary and spring seep inflows. On July 27, 2003, the day of the Parks Creek TIR survey, there was very little flow in some reaches of the creek, and the temperature of the creek appeared to respond dramatically to any mass transfers.

Based on this information it is apparent that the temperatures of Parks Creek are significantly affected by water management practices. Regional Water Board staff estimate that if riparian shade were at or near site potential conditions within the Parks Creek sub-watershed, if tailwater return flows did not cause heating of the receiving water, and if less cold water sources were diverted, the temperature regime at the mouth of Parks Creek could be reduced by at least 2°C from baseline.

6.2.4 Flow

To evaluate the effect of flow increases on Shasta River temperatures, a number of flow increase scenarios were applied. The simulations involved maintaining baseline conditions (i.e., none of the modifications outlined in Sections 6.2.1, 6.2.2, and 6.2.3 were applied), while increasing baseline flows by 50% at select locations in the Shasta River. The temperature assigned the increased flow was equal to the baseline temperature at the corresponding river location. The volume of water associated with the 50% flow increase was maintained to the mouth of the Shasta River. The Shasta River locations at which flows were increased by 50% included Dwinnell Dam, downstream of Big Springs Creek confluence, Grenada Irrigation District, Highway A12, Montague Grenada Road, and Anderson-Grade Road. The 50% flow increases were applied to these locations one at a time in a step-wise fashion. In other words, in the first simulation Dwinnell Dam flows were increased by 50% above baseline. In the second simulation the Dwinnell Dam flows reverted to the baseline flow, and flows downstream of Big Springs Creek confluence were increased by 50%, and so on.

The baseline (i.e. 100%) and 150% flows in the Shasta River at the flow increase locations are presented in Table 6.3.

Table 6.3: Average baseline and 150% flows

Shasta River Location	Average Baseline flow (cfs)	Average 150% flow (cfs)
Dwinnell Dam	5	7.5
Downstream of Big Springs Creek confluence	93	138
Grenada Irrigation District	55	82
Highway A12	73	109
Montague Grenada Road	27	40
Anderson Grade Road	22	33

Before presenting the results of the flow increase simulations, the model simulation periods are identified with a discussion regarding critical conditions.

6.3 Model Simulation Periods, Critical Conditions, and Critical Locations

As discussed in Chapter 2, the Shasta River is impaired by high temperature and low dissolved oxygen during summer months. The model simulations were run using the meteorological conditions for the model calibration and validation time periods: July 2 - 8, 2002; August 29 – September 4, 2002, and September 17 – 23, 2002. The 50% flow increase simulations were run only for the August simulation period.

Table 6.4 compares the maximum daily air temperature for the 2002 model run periods to the average of the daily maximum air temperatures for the sixteen years of record at the USGS meteorological gauging station at Brazie Ranch, located west of the Shasta River near the City of Yreka. As identified in Section 5.2 of Appendix D, Brazie Ranch is the source of meteorological data used for the Shasta River temperature and dissolved oxygen model. Table 6.4 shows that the measured daily maximum air temperatures for the model run dates in 2002 consistently exceed the 16-year average of the daily maximum air temperatures for these same dates.

Figure 1.6 in Chapter 1 shows that the Shasta River annual discharge in 2002 was well below the average annual discharge during the period of record. Further, Figure 1.8 in Chapter 1 shows that in 2002 Shasta River flows rank the 19th lowest of the 67 years for which there is a complete flow record.

Based on a review of these air temperature and flow records, Regional Water Board staff determined that the model simulation periods represent critical conditions for the Shasta River with respect to stream temperature. Finally, the August simulation period was selected for the flow scenarios as flows were lowest during this time period in 2002, and therefore, represent a critical condition.

Table 6.4: Brazie Ranch air temperature data (degrees C)

Date	2002 Daily Maximum	16-Year Average Daily Maximum
July 2	94	73
July 3	86	79
July 4	84	80
July 5	90	80
July 6	91	83
July 7	85	81
July 8	88	84
August 29	92	78
August 30	90	82
August 31	90	81
September 1	95	76
September 2	96	71
September 3	87	70
September 4	77	70
September 17	70	67
September 18	81	69
September 19	89	72
September 20	89	73
September 21	88	73
September 22	91	74
September 23	94	74

Juvenile salmonids are known or suspected to rear in the following reaches of the Shasta River: Grenada Irrigation District pumps to Highway A-12, near Breceda Lane, and in the Shasta Canyon at a side channel known as "Salmon Heaven". Based on this information, the following locations are considered temperature compliance locations, as they are at or near the downstream end of these critical summer rearing locations:

- Highway A-12 (RM 24.1),
- Montague-Grenada Road (RM 15.5), and
- "Salmon Heaven" (RM 5.6).

6.4 Model Simulation Temperature Results and Discussion

This section presents the RMS model simulation results. The temperature results of the flow increase simulations are presented in Section 6.4.1. The temperature results of the water quality compliance scenario are presented in Section 6.4.2.

6.4.1 Flow Increase Simulations

The RMS model predicts stream temperature at numerous locations in the Shasta River. Figure 6.1 identifies select model output locations. The temperature results of the six flow increase simulations and baseline condition are presented in Figure 6.2 and Table 6.5. Figure 6.2 shows the maximum and minimum temperatures in the Shasta River associated with each of the simulations. The maximum, minimum, and average water temperatures for the flow increase scenarios are presented in Table 6.5, and the increases or decreases in these temperatures compared with the baseline condition are identified.

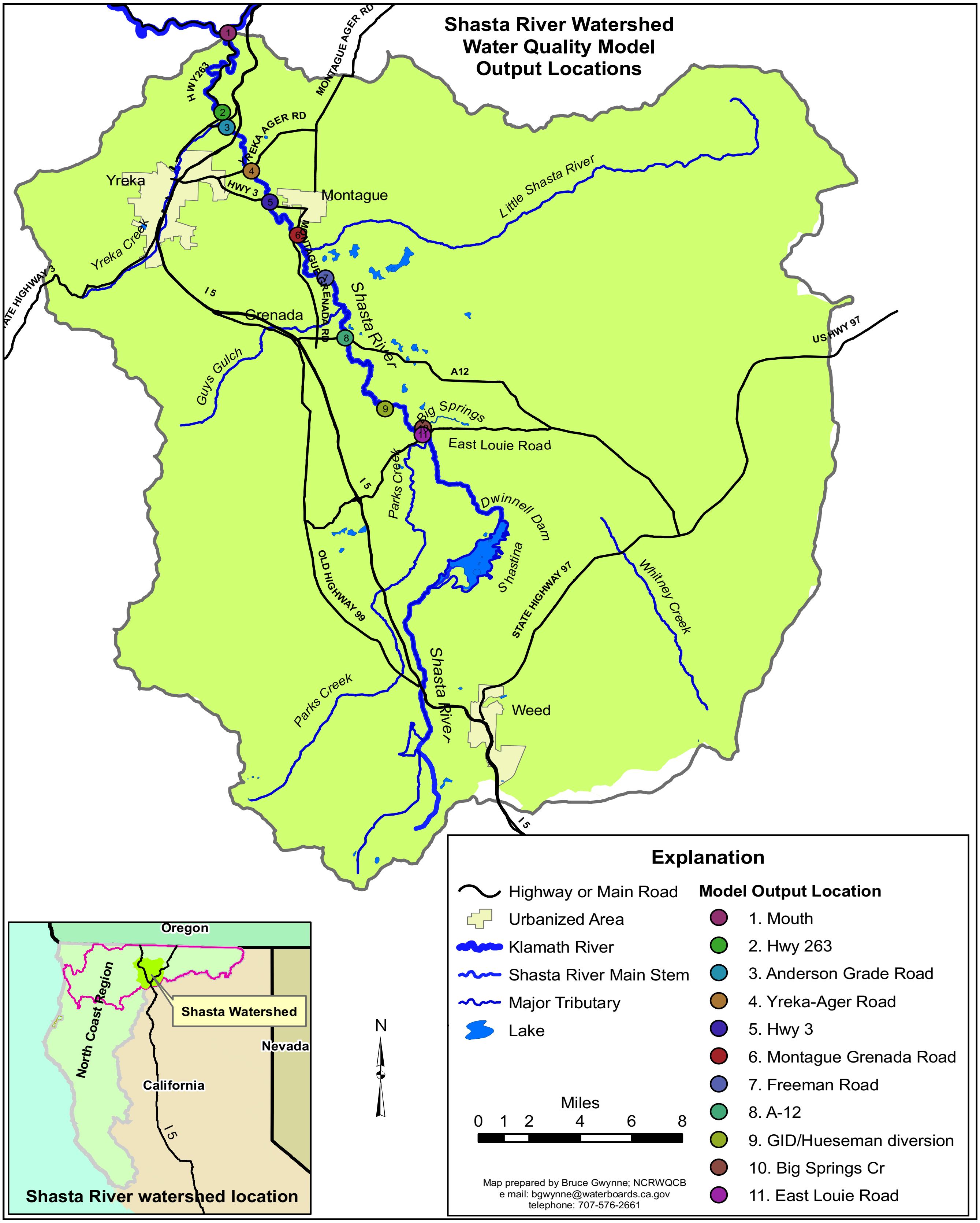
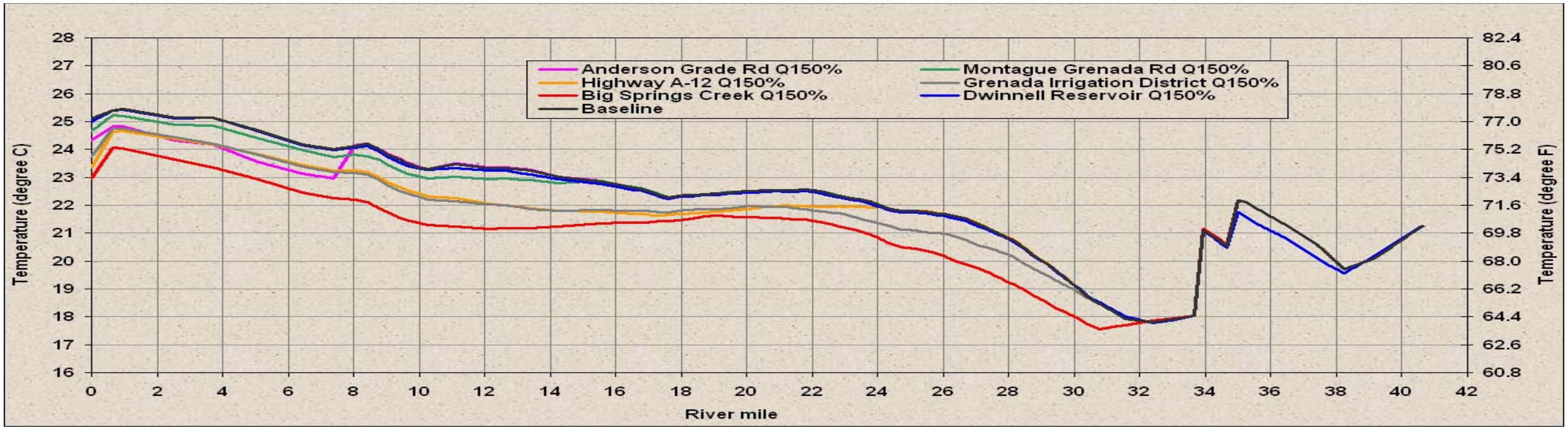


Figure 6.1: Shasta River flow, temperature, and dissolved oxygen model output locations



(A)

(B)

Figure 6.2: 50% flow increase simulations; Maximum (A) and minimum (B) temperature results

Table 6.5: 50% flow increase simulation temperature results and change from baseline

Compliance Points	River Mile	August Baseline	Maximum Modeled Temperature Values (August Baseline with increased incremental flows) Dwinnell Dam	Big Springs	GID	Highway A-12	M-G Road	A-G Road
Dwinnell Dam	42.60	21.27	21.27	21.27	21.27	21.27	21.27	21.27
Louie Road	33.93	21.09	21.09	21.16	21.16	21.16	21.16	21.16
GID	30.59	18.68	18.72	17.74	18.65	18.69	18.69	18.69
Highway A-12	24.11	22.05	21.98	20.86	21.37	21.92	22.06	22.06
Freeman Lane	19.23	22.42	22.38	21.62	21.86	21.78	22.43	22.43
M-G Road	15.52	22.85	22.75	21.36	21.84	21.77	22.88	22.88
Highway 3	13.16	23.28	23.14	21.17	21.91	21.93	22.91	23.30
Yreka Ager Road	10.91	23.48	23.33	21.25	22.13	22.25	23.03	23.50
Anderson Grade Road	8.03	24.13	24.07	22.20	23.16	23.24	23.80	24.14
Highway 263	7.30	24.19	24.16	22.46	23.39	23.44	23.97	23.12
"Salmon Heaven"	5.60	24.68	24.67	22.93	23.80	23.83	24.41	23.57
Mouth	0.66	25.46	25.43	24.03	24.75	24.66	25.21	24.82

Compliance Points	Maximum Modeled Differences in Stream Temperature compared to August Baseline (Increase or (decrease)) Dwinnell Dam	Big Springs	GID	Highway A-12	M-G Road	A-G Road
Dwinnell Dam	0.00	0.00	0.00	0.00	0.00	0.00
Louie Road	0.00	0.07	0.07	0.07	0.07	0.07
GID	0.04	(0.94)	(0.03)	0.01	0.01	0.01
Highway A-12	(0.07)	(1.19)	(0.68)	(0.13)	0.01	0.01
Freeman Lane	(0.04)	(0.80)	(0.56)	(0.64)	0.01	0.01
M-G Road	(0.10)	(1.49)	(1.01)	(1.08)	0.03	0.03
Highway 3	(0.14)	(2.11)	(1.37)	(1.35)	(0.37)	0.02
Yreka Ager Road	(0.15)	(2.23)	(1.35)	(1.23)	(0.45)	0.02
Anderson Grade Road	(0.06)	(1.93)	(0.97)	(0.89)	(0.33)	0.01
Highway 263	(0.03)	(1.73)	(0.80)	(0.75)	(0.22)	(1.07)
"Salmon Heaven"	(0.01)	(1.75)	(0.88)	(0.85)	(0.27)	(1.11)
Mouth	(0.03)	(1.43)	(0.71)	(0.80)	(0.25)	(0.64)

Compliance Points	River Mile	August Baseline	Average Modeled Temperature Values (August Baseline with increased incremental flows) Dwinnell Dam	Big Springs	GID	Highway A-12	M-G Road	A-G Road
Dwinnell Dam	42.60	17.56	17.56	17.56	17.56	17.56	17.56	17.56
Louie Road	33.93	17.60	17.62	17.60	17.60	17.59	17.60	17.59
GID	30.59	16.87	16.89	16.65	16.85	16.87	16.87	16.87
Highway A-12	24.11	18.38	18.36	17.77	18.07	18.39	18.38	18.38
Freeman Lane	19.23	18.80	18.78	18.16	18.47	18.74	18.81	18.81
M-G Road	15.52	18.95	18.95	18.39	18.69	18.91	18.96	18.96
Highway 3	13.16	18.98	18.98	18.49	18.78	18.98	19.02	18.98
Yreka Ager Road	10.91	18.94	18.95	18.56	18.82	19.00	19.01	18.94
Anderson Grade Road	8.03	18.82	18.85	18.68	18.86	19.01	18.97	18.82
Highway 263	7.30	18.77	18.80	18.70	18.86	19.00	18.94	18.77
"Salmon Heaven"	5.60	18.73	18.77	18.77	18.90	19.03	18.93	18.74
Mouth	0.66	18.69	18.73	18.90	18.89	19.06	18.88	18.74

Compliance Points	Average Modeled Differences in Stream Temperature compared to August Baseline (Increase or (decrease)) Dwinnell Dam	Big Springs	GID	Highway A-12	M-G Road	A-G Road
Dwinnell Dam	0.00	0.00	0.00	0.00	0.00	0.00
Louie Road	0.02	0.00	(0.00)	(0.00)	(0.00)	(0.00)
GID	0.02	(0.22)	(0.02)	(0.00)	(0.00)	(0.00)
Highway A-12	(0.02)	(0.61)	(0.31)	0.01	0.00	0.00
Freeman Lane	(0.03)	(0.65)	(0.33)	(0.07)	0.00	0.00
M-G Road	(0.01)	(0.57)	(0.26)	(0.04)	0.00	0.00
Highway 3	(0.01)	(0.50)	(0.21)	(0.01)	0.03	(0.00)
Yreka Ager Road	0.01	(0.39)	(0.13)	0.06	0.07	(0.00)
Anderson Grade Road	0.03	(0.14)	0.04	0.19	0.15	(0.00)
Highway 263	0.03	(0.07)	0.09	0.23	0.17	(0.00)
"Salmon Heaven"	0.04	0.04	0.17	0.30	0.20	0.01
Mouth	0.04	0.20	0.19	0.37	0.19	0.04

Compliance Points	River Mile	August Baseline	Minimum Modeled Temperature Values (August Baseline with increased incremental flows) Dwinnell Dam	Big Springs	GID	Highway A-12	M-G Road	A-G Road
Dwinnell Dam	42.60	14.14	14.14	14.14	14.14	14.14	14.14	14.14
Louie Road	33.93	13.37	13.38	13.36	13.35	13.35	13.35	13.35
GID	30.59	14.21	14.25	14.47	14.22	14.21	14.21	14.21
Highway A-12	24.11	14.86	14.88	15.29	15.02	14.91	14.86	14.86
Freeman Lane	19.23	15.04	15.05	14.79	14.86	15.22	15.04	15.04
M-G Road	15.52	14.92	14.98	14.96	15.23	15.56	14.92	14.92
Highway 3	13.16	14.90	15.00	15.33	15.45	15.77	15.10	14.87
Yreka Ager Road	10.91	14.62	14.73	15.45	15.33	15.58	14.91	14.60
Anderson Grade Road	8.03	13.72	13.89	14.91	14.61	14.77	14.26	13.69
Highway 263	7.30	13.62	13.77	14.80	14.47	14.72	14.17	14.66
"Salmon Heaven"	5.60	13.05	13.24	14.40	14.13	14.36	13.68	14.17
Mouth	0.66	12.61	12.74	14.57	13.87	14.22	13.34	13.33

Compliance Points	Minimum Modeled Differences in Stream Temperature compared to August Baseline (Increase or (decrease)) Dwinnell Dam	Big Springs	GID	Highway A-12	M-G Road	A-G Road
Dwinnell Dam	0.00	0.00	0.00	0.00	0.00	0.00
Louie Road	0.01	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)
GID	0.04	0.26	0.01	0.00	0.00	0.00
Highway A-12	0.02	0.43	0.16	0.05	0.00	0.00
Freeman Lane	0.01	(0.25)	(0.18)	0.18	0.00	0.00
M-G Road	0.06	0.04	0.31	0.64	0.00	0.00
Highway 3	0.10	0.43	0.55	0.87	0.20	(0.03)
Yreka Ager Road	0.11	0.83	0.71	0.96	0.29	(0.02)
Anderson Grade Road	0.17	1.19	0.89	1.05	0.54	(0.03)
Highway 263	0.15	1.18	0.85	1.10	0.55	1.04
"Salmon Heaven"	0.19	1.35	1.08	1.31	0.63	1.12
Mouth	0.13	1.96	1.26	1.61	0.73	0.72

The following conclusions are drawn from the flow increase simulation results:

- Maximum stream temperatures are reduced from the baseline condition at all locations downstream of the flow increase location in the river for each of the six 50% flow increase simulations.
- Minimum stream temperatures are increased from the baseline condition downstream of approximately RM 15 for each of the six 50% flow increase simulations.
- The largest reduction in maximum stream temperature is associated with the 50% flow increase downstream of the Big Springs Creek confluence.
- The temperature associated with a 50% flow increase greatly influences the temperature results.
- The Big Springs Creek 50% flow increase simulation resulted in maximum stream temperature reductions of approximately 1°C to 2°C, with the largest reduction of 2.2°C at Yreka Ager Road (RM 10.9). At River Mile 5.6, an important location for summer rearing, the maximum stream temperature is reduced by approximately 1.8°C from baseline.
- The Big Springs Creek 50% flow increase simulation resulted in minimum stream temperature increases of approximately 0.2 to 2°C.

6.4.1.1 Big Springs Creek Flow

The 50% flow increase downstream of the Big Springs Creek confluence is attributed to a 45 cfs increase in flow from the Big Springs Creek complex. Appendix G summarizes the available information pertaining to current and historic (pre-diversion) flows in the Big Springs Creek complex. The Big Springs Creek complex refers to Big Springs proper (assumed to originate at the eastern end of Big Springs Lake), Big Springs Lake, Big Springs Creek, Little Springs and the channel between Little Springs and Big Springs Creek, and may include springs that extend into the Shasta River proper. Based on the information presented in Appendix G, it is estimated that historically (pre-diversion) the Big Springs Creek complex delivered on the order of 100 to 125 cfs to the Shasta River.

The flow from Big Springs Creek in the 50% flow increase simulation averaged 112 cfs. Based on the review of Big Springs Creek complex flow records, Regional Water Board staff believe the 45 cfs flow increase from Big Springs Creek complex is within the historic (pre-diversion) flow range.

6.4.1.2 Conclusions

Regional Water Board staff chose to include the 45 cfs flow increase from the Big Springs Creek complex as part of the water quality compliance scenario. This decision was based on:

- The uniquely cold water from Big Springs.
- The significant temperature improvements in the Shasta River downstream of Big Springs Creek, which, when coupled with the other components of the water quality compliance scenario, result in attainment of the narrative water quality objective for temperature; and

- The finding that the 45 cfs flow increase from Big Springs Creek complex is within the historic (pre-diversion) flow range.

6.4.2 Water Quality Compliance Scenario

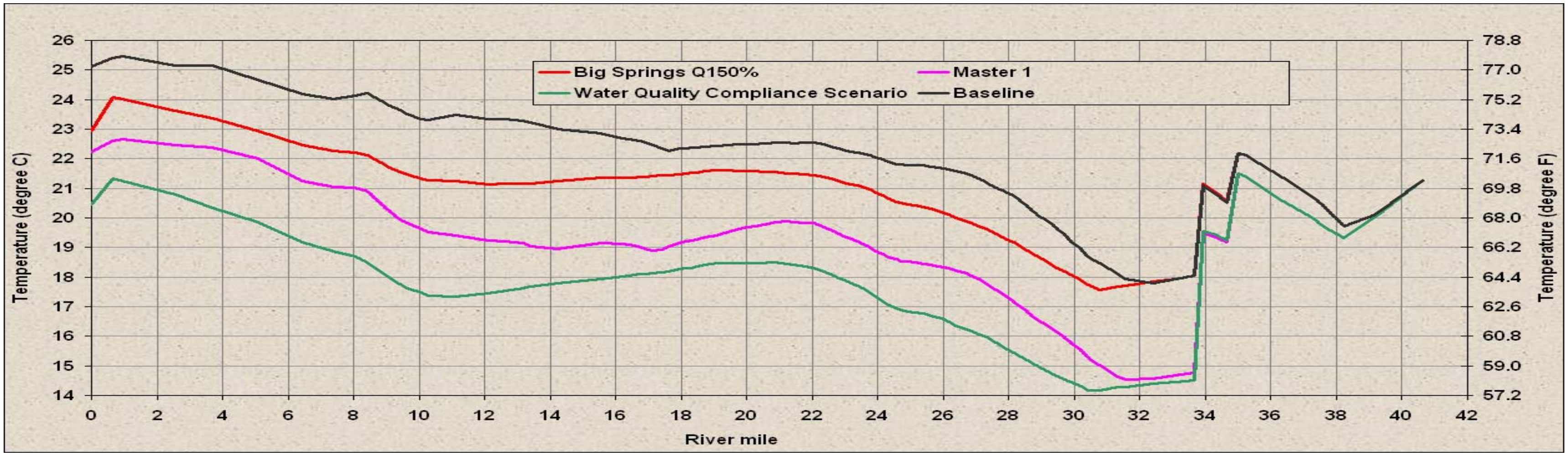
To summarize, the water quality compliance scenario included:

1. Increased riparian shade to represent site potential riparian conditions on a river-reach scale (as outlined in Section 6.2.1);
2. Modified temperature regime of tailwater return flows such that the return flows do not cause heating of the receiving water (as outlined in Section 6.2.2);
3. Big Springs Creek temperatures reduced by 4°C from baseline (as outlined in Section 6.2.3.1);
4. Parks Creek temperatures reduced by 2°C from baseline (as outlined in Section 6.2.3.2); and
5. Fifty percent increase in Shasta River flows downstream of the Big Springs Creek confluence, an increase of 45 cfs, (as outlined in Sections 6.2.4 and 6.4.1.1).

The temperature results of the water quality compliance scenario are presented in Figure 6.3 and Table 6.6. Figure 6.3 shows the maximum and minimum temperatures in the Shasta River associated with the water quality compliance scenario. For comparison, Figure 6.3 also presents the maximum and minimum temperatures for the following simulations: (1) baseline condition, (2) 50% flow increase in the Shasta River downstream of the Big Springs Creek confluence, and (3) the first four components of the water quality compliance scenario identified in the preceding paragraph (i.e. riparian shade, tailwater modifications, 4°C reduction from Big Springs Creek, and 2°C reduction from Parks Creek), identified as "Master 1". The maximum, minimum, and average water temperatures for the water quality compliance scenario are presented in Table 6.6, and the increases or decreases in these temperatures compared with the baseline condition are identified. Table 6.7 identifies the average daily maximum temperatures for the baseline, Master 1, and water quality compliance scenario at select locations.

The following conclusions are drawn from these water quality model results:

- The water quality compliance scenario results in reductions in maximum stream temperature at all Shasta River locations.
- The largest reduction in maximum stream temperature exceeds 6°C at Yreka Ager Road, compared with the baseline condition.
- The water quality compliance scenario results in reductions in the minimum stream temperature at all Shasta River locations upstream of approximately River Mile 1.
- The largest reduction in minimum stream temperature was nearly 4°C at Highway A-12, compared with the baseline condition.
- Shasta River temperatures are below juvenile salmonid growth and rearing lethal temperature thresholds (see Table 2.4) during the August simulation period (which reflects critical conditions) under the water quality compliance scenario.



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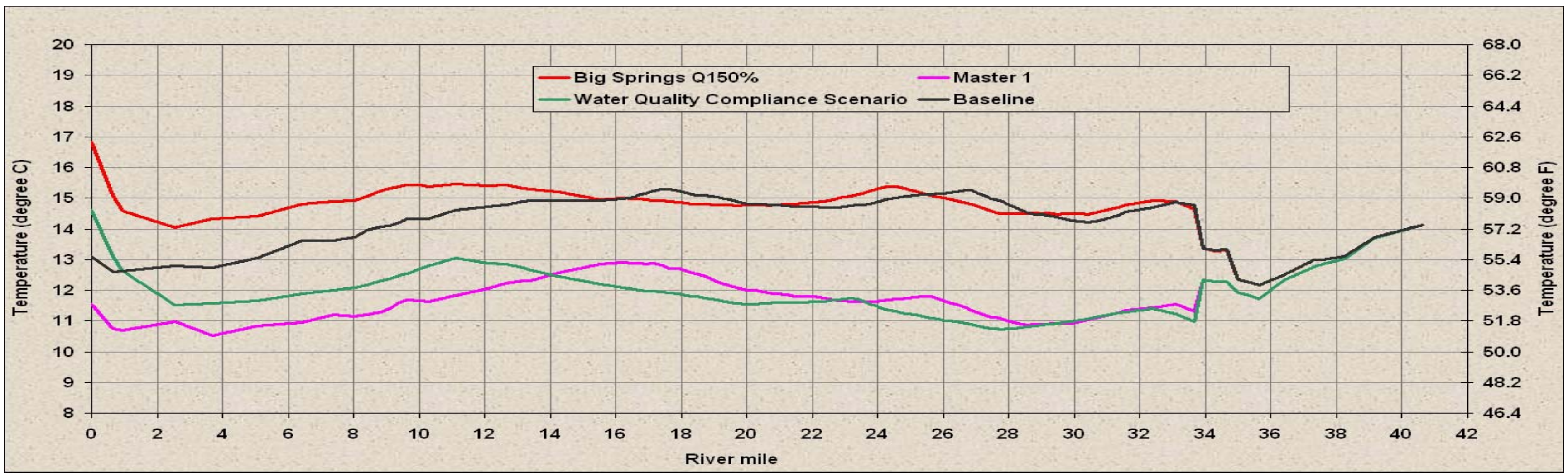


(B)

Figure 6.3: Alternate scenarios; Maximum (A) and minimum (B) temperature results

Table 6.6: Alternate scenarios, temperature results and change from baseline

Compliance Points	River Mile	Maximum Modeled Temperature Values: August Baseline	Big Springs Q150%	Master 1	Water Quality Compliance	Maximum Modeled Differences in Temp. compared to August Baseline (Increase or (decrease)): Big Springs Q150%	Master 1	Water Quality Compliance
Dwinnel Dam	42.60	21.27	21.27	21.27	21.27	0.00	0.00	0.00
Louie Road	33.93	21.09	21.16	19.48	19.56	0.07	(1.61)	(1.53)
GID	30.59	18.68	17.74	15.28	14.16	(0.94)	(3.40)	(4.52)
Highway A-12	24.11	22.05	20.86	18.87	17.34	(1.19)	(3.18)	(4.71)
Freeman Lane	19.23	22.42	21.62	19.41	18.47	(0.80)	(3.01)	(3.95)
M-G Road	15.52	22.85	21.36	19.16	17.93	(1.49)	(3.69)	(4.92)
Highway 3	13.16	23.28	21.17	19.14	17.62	(2.11)	(4.14)	(5.66)
Yreka Ager Road	10.91	23.48	21.25	19.41	17.33	(2.23)	(4.07)	(6.15)
Anderson Grade Road	8.03	24.13	22.20	21.03	18.69	(1.93)	(3.10)	(5.44)
Highway 263	7.30	24.19	22.46	21.24	19.19	(1.73)	(2.95)	(5.00)
"Salmon Heaven"	5.60	24.68	22.93	22.00	19.86	(1.75)	(2.68)	(4.82)
Mouth	0.66	25.46	24.03	22.67	21.25	(1.43)	(2.79)	(4.21)

Compliance Points	River Mile	Average Modeled Temperature Values: August Baseline	Big Springs Q150%	Master 1	Water Quality Compliance	Average Modeled Differences in Temp. compared to August Baseline (Increase or (decrease)): Big Springs Q150%	Master 1	Water Quality Compliance
Dwinnel Dam	42.60	17.49	17.49	17.49	17.47	0.00	0.00	(0.02)
Louie Road	33.93	17.59	17.60	16.40	16.38	0.00	(1.19)	(1.21)
GID	30.59	16.91	16.69	13.66	13.19	(0.22)	(3.25)	(3.73)
Highway A-12	24.11	18.44	17.83	15.17	14.28	(0.61)	(3.28)	(4.16)
Freeman Lane	19.23	18.87	18.23	16.06	15.05	(0.64)	(2.81)	(3.82)
M-G Road	15.52	19.02	18.45	16.23	15.35	(0.56)	(2.79)	(3.67)
Highway 3	13.16	19.05	18.56	16.17	15.44	(0.49)	(2.88)	(3.61)
Yreka Ager Road	10.91	19.01	18.62	16.12	15.55	(0.39)	(2.89)	(3.46)
Anderson Grade Road	8.03	18.90	18.75	16.29	15.90	(0.15)	(2.61)	(3.00)
Highway 263	7.30	18.86	18.77	16.31	15.99	(0.08)	(2.55)	(2.87)
"Salmon Heaven"	5.60	18.73	18.77	16.42	16.11	0.04	(2.31)	(2.62)
Mouth	0.66	18.77	18.96	16.53	16.49	0.19	(2.23)	(2.27)

Compliance Points	River Mile	Minimum Modeled Temperature Values: August Baseline	Big Springs Q150%	Master 1	Water Quality Compliance	Minimum Modeled Differences in Temp. compared to August Baseline (Increase or (decrease)): Big Springs Q150%	Master 1	Water Quality Compliance
Dwinnel Dam	42.60	14.14	14.14	14.14	14.14	0.00	0.00	0.00
Louie Road	33.93	13.37	13.36	12.33	11.49	(0.01)	(1.04)	(1.88)
GID	30.59	14.21	14.47	11.04	11.01	0.26	(3.17)	(3.20)
Highway A-12	24.11	14.86	15.29	11.64	10.92	0.43	(3.22)	(3.94)
Freeman Lane	19.23	15.04	14.79	12.27	11.68	(0.25)	(2.77)	(3.36)
M-G Road	15.52	14.92	14.96	12.84	12.19	0.04	(2.08)	(2.73)
Highway 3	13.16	14.90	15.33	12.30	12.73	0.43	(2.60)	(2.17)
Yreka Ager Road	10.91	14.62	15.45	11.82	12.67	0.83	(2.80)	(1.95)
Anderson Grade Road	8.03	13.72	14.91	11.14	11.68	1.19	(2.58)	(2.04)
Highway 263	7.30	13.62	14.80	10.96	11.50	1.18	(2.66)	(2.12)
"Salmon Heaven"	5.60	13.05	14.40	10.85	11.15	1.35	(2.20)	(1.90)
Mouth	0.66	12.61	14.57	10.69	12.62	1.96	(1.92)	0.01

- The 5-day average daily maximum temperatures for the water quality compliance scenario were 16.7°C, 17.5°C, and 18.9°C at Highway A-12 (RM 24.1), Montague-Grenada Road (RM 15.5) and at River Mile 5.6 (an important location for summer rearing), respectively. RM 24.1, RM 15.5, and RM 5.6 are compliance points for the temperature TMDL. The average daily maximum temperatures at these compliance points can be compared to the USEPA (2003) non-core juvenile rearing maximum weekly maximum temperature (MWMT) threshold of 18°C (see Table 2.3). Based on this comparison, the water quality compliance scenario results in maximum stream temperatures *below* the non-core juvenile rearing chronic temperature threshold at RM 24.1 and RM 15.5. The 5-day average daily maximum temperatures for the water quality compliance scenario at RM 5.6 was nearly 1°C above the threshold.
- The 5-day average daily maximum temperatures for the "Master 1" scenario were 18.1°C, 18.4°C, and 20.8°C at the temperature compliance points Highway A-12 (RM 24.1), Montague-Grenada Road (RM 15.5) and at River Mile 5.6, respectively. These temperatures are all above the USEPA (2003) non-core juvenile rearing MWMT threshold of 18°C.
- A comparison of the maximum temperatures for the water quality compliance scenario, Master 1 scenario, and baseline condition can be made to determine the relative proportions of the temperature reductions attributed to shade and tailwater management (Master 1) versus flow increase. This comparison indicates that approximately 30% of the maximum stream temperature reductions achieved by the water quality compliance scenario are attributed to the Big Springs Creek flow increase, and approximately 70% of the reductions are attributed to riparian shade increases and tailwater management.
- The water quality compliance scenario achieves compliance with the Basin Plan narrative temperature objective.

Table 6.7: 5-day average maximum temperatures for water quality compliance scenario and baseline condition

Compliance Points	RM	5-day Average Maximum Temperature		
		Baseline	Master 1	Water Quality Compliance Scenario
Highway A-12	24.11	21.07	18.1	16.71
Montague-Grenada Rd	15.52	21.53	18.4	17.49
"Salmon Heaven"	5.6	23.1	20.8	18.96

6.5 Temperature TMDL and Allocations

This section presents the temperature TMDL and load allocations. The starting point for the load allocation analysis is the equation that describes the Total Maximum Daily Load or loading capacity:

$$\text{TMDL} = \text{Loading Capacity} = \Sigma\text{WLAs} + \Sigma\text{LAs} + \text{Natural Background}$$

where Σ = the sum, WLAs = waste load allocations, and LAs = load allocations. Waste load allocations are contributions of a pollutant from point sources while load allocations are contributions from management-related non-point sources. There are no point source heat loads in the Shasta River watershed, and therefore no waste load allocations apply.

6.5.1 Development of Temperature Load Capacity and Surrogate Measures

Under the TMDL framework, and in this document, identification of the 'loading capacity' is a required step. The loading capacity represents the total loading of a pollutant that a water body can assimilate and still meet water quality objectives so as to protect beneficial uses. For the temperature TMDL the water quality objective of concern is the temperature objective, which prohibits the alteration of the natural receiving water temperature unless such alteration does not adversely affect beneficial uses. The loading capacity provides a reference for calculating the amount of pollutant load reduction needed to bring a water body into compliance with standards.

The Shasta River watershed temperature TMDL addresses the heat loads that arise from three sources:

1. Changes in riparian vegetation,
2. Tailwater return flows, and
3. Surface water flow.

The temperature loading capacity of the Shasta River and its tributaries equals the heat load associated with the potential riparian shade conditions, no net increase in receiving water temperature from tailwater return flows, and reductions in daily maximum temperatures achieved via flow increase, as detailed below.

6.5.1.1 Riparian Vegetation

In order to use the loading capacity that focuses on heat loads that arise from changes in streamside vegetation, and to be able to compare it to current conditions, a surrogate measure is proposed. EPA regulations (40 CFR §130.2(i)) allow for the use of other appropriate measures (surrogate measures) to allocate loads for conditions "when the impairment is tied to a pollutant for which a numeric criterion is not possible…(USEPA 1998)." Heat load can be measured as solar radiation transmittance (the amount of solar radiation that passes through the tree canopy and reaches the water surface, where a value of 1.0 represents no shade, and a value of 0.0 would represent complete shade). Also, solar radiation transmittance can be related to stream temperature conditions. Finally, solar radiation transmittance can be readily measured in the field. Therefore, for this temperature TMDL, the portion of the loading capacity associated with riparian shade is expressed as potential percent solar radiation transmittance for the mainstem Shasta River downstream of Dwinnell Dam, and is expressed as adjusted potential effective shade for tributaries to the Shasta River and the river upstream of Dwinnell Dam. Potential solar radiation transmittance is used for the Shasta River because the water quality model accounts for riparian shade with this metric. Adjusted potential effective shade is used for the tributaries to the Shasta River because the tributaries were not included in the water quality model and potential solar radiation transmittance values were not defined for the tributaries. Adjusted potential effective shade has been used for other temperature TMDLs in California.

6.5.1.2 Tailwater Return Flow

There is insufficient information to quantify the heat load associated with tailwater return flows in the Shasta River watershed. The loading capacity associated with tailwater return flow is no net increase in receiving water temperatures. In this document "tailwater return flow" refers to surface runoff of irrigation water to a surface water body, and is synonymous with "irrigation return flow".

6.5.1.3 Surface Water Flow

Approximately 30% of the maximum temperature reductions achieved in the water quality compliance scenario compared with the baseline condition are attributed to the 50% flow increase in the Shasta River downstream of the Big Springs Creek confluence. Regional Water Board staff have included this 45 cfs Big Springs Creek complex flow increase as part of the water quality compliance scenario because this flow increase simulation achieved the largest reductions in maximum stream temperatures compared with flow increases from other locations in the river, and results in attainment of the narrative water quality objective for temperature. Further, Regional Water Board staff estimate that the flow increase from the Big Springs Creek complex is within the historic (pre-diversion) flow range, as outlined in Section 6.4.1.1. The analysis presented in Section 6.4.1, however, demonstrates that temperature improvements are achievable due to flow increases at other locations in the Shasta River watershed. Therefore, although the loading capacity associated with flow is based on 45 cfs flow increase from the Big Springs Creek complex, Regional Water Board staff acknowledge that there are other sources of cold water in the watershed and alternative flow regimes may achieve the same temperature improvements. Additional sources of cold water in the watershed include, but are not limited to, the Parks Creek watershed, the Hole in the Ground Creek watershed, and springs within the Little Shasta River watershed.

The maximum stream temperature reductions attributed to flow increase are approximately 1.5°C, 1.2°C, and 2.1°C at RM 24.1, RM 15.5, and RM 5.6, the temperature compliance locations. Increased dedicated cold water instream surface flow[1] that results in temperature reductions of 1.5°C, 1.2°C, and 2.1°C at these compliance locations constitute the load allocation to flow.

6.5.1.4 Temperature Loading Capacity

In summary, the Shasta River watershed temperature TMDL loading capacity is equal to potential percent solar radiation transmittance for the mainstem Shasta River downstream of Dwinnell Dam, adjusted potential effective shade upstream of Dwinnell Dam and for the Shasta River tributaries, no net increase in receiving water temperature from tailwater

[1] Dedicated cold water instream flow is water remaining in the stream in a manner that the diverter, either individually or as a group, can ensure will result in water quality benefits. Temperature, length and timing are factors to consider when determining the water quality benefits of an instream flow.

return flows, and a Shasta River flow regime that results in reductions in maximum daily temperature of 1.5°C, 1.2°C, and 2.1°C at RM 24.1, RM 15.5, and RM 5.6, the temperature compliance locations. The TMDL equation becomes:

TMDL = Loading Capacity =
Potential Percent Solar Radiation Transmittance of the Shasta River
+ Adjusted potential Effective Shade of the Tributaries
+ No Net Increase in Temperature from Tailwater Return Flows
+ Flow Increases that achieved specific temperature reductions at compliance locations.

6.5.2 Temperature Load Allocations

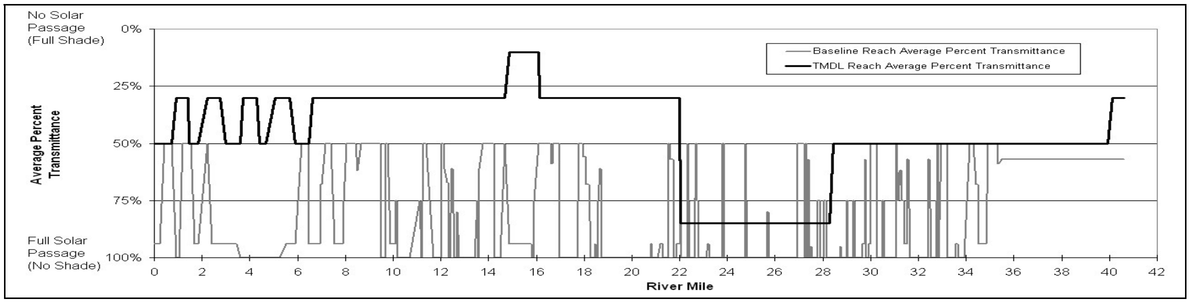
In accordance with EPA regulations, the TMDL (i.e., loading capacity) for a water body is to be allocated among the various sources of the targeted pollutant. The sum of the waste load and load allocations for the watershed is equivalent to the loading capacity for the watershed as a whole. There are no point source heat loads in the Shasta River watershed, and therefore no waste load allocations apply.

6.5.2.1 <u>Riparian Shade</u>

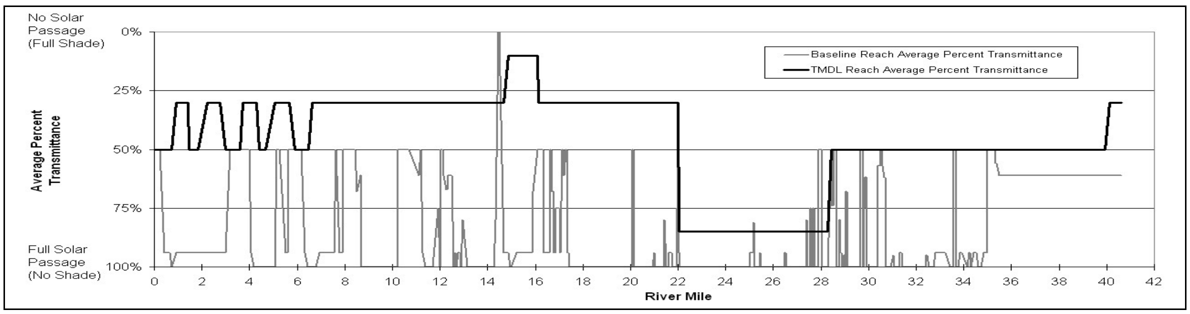
Load allocations to riparian shade are expressed differently for the Shasta River mainstem and tributaries in the Shasta River watershed temperature TMDL. For the mainstem Shasta River downstream of Dwinnell Dam the allocations are reach average potential solar radiation transmittance values. For Shasta River tributaries and upstream of Dwinnell Dam the allocations are adjusted potential effective shade.

Shasta River Potential Solar Radiation Transmittance

The potential solar radiation transmittance values for the Shasta River downstream of Dwinnell Dam were estimated by Regional Water Board staff, as outlined in Section 6.2.1. Both the potential and existing (baseline) solar radiation transmittance values for the Shasta River are presented in Figure 6.4. There is no difference assigned to the percent solar radiation transmittance between the right and left banks. The difference between existing (baseline) and potential solar radiation transmittance reflects the amount of effective shade increase (i.e. reduced solar transmittance) that is required to achieve natural receiving water temperatures in the Shasta River.



(A) Left Bank



(B) Right Bank

Figure 6.4: Existing (baseline) and potential solar radiation transmittance for the left bank (A) and right bank (B) of the Shasta River

Adjusted Potential Effective Shade of Shasta River Tributaries

This temperature TMDL analysis did not directly evaluate current or potential riparian conditions in Shasta River tributaries or the river upstream of Dwinnell Dam, nor was modeling used to calculate solar radiation heat load at streamside locations of the Shasta River tributaries. However, as discussed in Section 3.1.1, numerous studies have identified that solar radiation is the dominant heat exchange process affecting stream temperature, and that changes in solar radiation associated with riparian shade affect stream temperatures (Johnson 2004; ODEQ 2002; Sinokrot and Stefan 1993). Therefore, in order to achieve natural receiving water temperatures in the tributaries of the Shasta River and upstream of Dwinnell Dam, adjusted potential effective shade (shade resulting from topography and vegetation that reduces the heat load reaching the stream) must be achieved, and is used as a surrogate for solar energy to assess compliance. Adjusted potential effective shade is equal to 90% of site potential shade, to allow for natural riparian disturbance such as floods, wind throw, disease, landslides, and fire.

6.5.2.2 Tailwater Return Flow

The load allocation for tailwater return flows within the Shasta River watershed is no net increase in receiving water temperature.

6.5.2.3 Dedicated Cold Water Instream Flow

The load allocation for flow is reductions in the maximum daily stream temperatures of 1.5°C, 1.2°C, and 2.1°C from baseline at RM 24.1, RM 15.5, and RM 5.6, the temperature compliance locations.

6.5.2.4 Shasta River Watershed Temperature TMDL Load Allocations Summary
In summary, the temperature load allocations for the Shasta River watershed are presented in Table 6.8.

Table 6.8: Shasta River watershed temperature load allocations

Source	Allocation
Change in Riparian Vegetation	***Shasta River***: Reach average potential solar radiation transmittance, as presented in Table 6.2 and Figure 6.4. ***Tributaries***: Potential effective riparian shade = 90% of site potential shade.
Tailwater Return Flow	No net increase in receiving water temperature.
Surface Water Flow	Reductions in the maximum daily stream temperatures of 1.5°C, 1.2°C, and 2.1°C from baseline at RM 24.1, RM 15.5, and RM 5.6

6.6 Margin of Safety

The Clean Water Act Section 303(d) and the associated regulations at 40 CFR §130.7 require that TMDLs include a margin of safety that takes into account any lack of knowledge concerning the relationship between the pollutant loads and the desired receiving water quality. The margin of safety is often implicitly incorporated into conservative assumptions used in calculating loading capacities, waste load allocations, and load allocations (USEPA 1991). The margin of safety may also be incorporated explicitly as a separate component in the TMDL equation. For this TMDL analysis, conservative assumptions were made that account for uncertainties in the analysis.

- The water quality compliance scenario incorporated temperature reductions from Big Springs Creek and Parks Creek to account for improvements associated with riparian shade and tailwater management. The water quality compliance scenario did not incorporate temperature reductions from Yreka Creek and other small tributaries to the Shasta River and provides a margin of safety.
- Topographic shade was not considered in the temperature model and is likely a significant factor in the Shasta canyon, and provides a margin of safety.
- Some improvements in stream temperature that may result from reduced sedimentation are not quantified. Reduced sediment loads could lead to increased frequency and depth of pools, independent of changes in solar radiation input. These changes tend to result in lower stream temperatures overall and tends to increase the amount of lower-temperature pool habitat. These expected changes are not directly accounted for in the TMDL.
- The effects of changes to streamside riparian areas toward mature trees will tend to create microclimates that will lead to improvements in stream temperatures. These effects were not accounted for in the temperature analysis and provide a margin of safety.

CHAPTER 7. DISSOLVED OXYGEN TMDL

7.1 Introduction

This chapter presents the dissolved oxygen TMDL for the Shasta River. The analytical approach involved application of the River Modeling System (RMS) model. In addition, the Shasta River Benthic Algae Box Model (algae model) was applied in order to evaluate the effect of nutrient concentrations on primary production (photosynthesis and respiration of aquatic vegetation) in the Shasta River. The algae model application and nutrient sensitivity analysis results are presented in Section 7.2. The application and results of the RMS model are presented in Section 7.3 and 7.4. The dissolved oxygen TMDL and allocations are presented in Section 7.5.

7.2 Algae Box Model Application and Results

The Shasta River Benthic Algae Box Model was applied in order to evaluate the connection between nutrient concentrations and primary production (photosynthesis and respiration of aquatic vegetation) in the Shasta River, a dynamic not represented by RMS.

7.2.1 Model Implementation Values and Nutrient Sensitivity Results

The parameter values implemented for the algae model are tabulated in Table 7.1. These parameter values were selected to represent conditions typical of the Shasta River. The nutrient sensitivity results are summarized in Table 7.2, which tabulates annual biomass and percentage of baseline biomass associated with alternate parameter values.

For the nutrient sensitivity analysis, when the concentrations of both phosphate and nitrogen were decreased to the half-saturation constant[1] for that nutrient, the algal biomass decreased. Conversely, when the nutrient concentrations were increased to concentrations exceeding the half-saturation constant, the algal biomass increased.

The nutrient sensitivity analysis results indicate that if the modeling implementation nitrogen half-saturation constant of 0.014 mg/L is maintained, a total inorganic nitrogen (TIN - the sum of ammonia-nitrogen plus nitrate/nitrite-nitrogen) concentration of 0.02 mg/L (an order of magnitude lower than the model implementation value) would yield an average annual biomass equal to 10% of the baseline average annual biomass. A review of the Shasta River watershed nitrogen data presented in Tables 2.8, 2.9, 2.10, and 2.11 (in Chapter 2) shows that average ammonia plus nitrate/nitrite (TIN) concentrations exceed 0.1 mg/L in the Shasta River downstream of Dwinnell Dam, but are approximately 0.04 mg/L in the headwaters of the Shasta River. The analysis indicates that reductions in Shasta River TIN concentrations would likely limit the productivity of aquatic vegetation in the Shasta River.

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[1] A nutrient half-saturation coefficient is the concentration of the nutrient at which the growth rate is one half of its maximum value.

Table 7.1: Shasta River algae box model implemented parameter values

Parameter	Model Value	Units
Time step	0.041667	day
Travel time of reach	0.042	day
Reach length, l	1609	meters
River width, w	9.1	meters
River depth, d	0.6	meters
River cross-sectional area, CS	13.9	m^2
Reach volume, V	22426.9	m^3
Reach flow in and flow out, Qin and Qout	538247	m^3/day
Reach bed area, A	7357.9	m^2
Reach velocity, vel	73.2	m/day
Initial bed algae biomass, P_i	0.001	g/m^2
Minimum bed algae biomass, P_{min}	0.1	g/m^2
maximum bed algae biomass, P_{max}	20	g/m^2
Solar radiation, SR	hourly	W/m^2
Global Shade Factor, GSF	0	-
Total inorganic nitrogen inflow concentration, $[TIN]_{in}$	0.2	mg/L
Phosphate inflow concentration, $[PO4]_{in}$	0.2	mg/L
Silica inflow concentration, $[Si]_{in}$	50	mg/L
Light half saturation coefficient, K_L	0.0009	$Kcal/m^2s$
Light extinction coefficient, Le	1.48	1/meter
Nitrogen half saturation coefficient, K_N	0.014	mg/L
Phosphate half saturation coefficient, K_P	0.003	mg/L
Silica half saturation coefficient, K_S	0.03	mg/L
Maximum growth rate, G	1.2	1/day
Respiration (and excretion) rate, R	0.14	1/day
Mortality rate, D	0.14	1/day
Grazing rate, Z	0.05	1/day
Algae settling rate, v	0	m/day
Scouring factor, s	0.00001	-
Theta, .	1.040	-
Water Temperature, T	hourly	C
Reference water temperature, T_{ref}	20	C

Table 7.2: Nutrient sensitivity analysis results - annual total and annual average algae biomass

Varied Parameter(s)	Parameter(s) Value	Units	Annual Total Biomass (g/m^2)	Annual Ave Biomass (g/m^2)	% Baseline
None (Baseline Condition)	Implementation values	-	77913	8.87	100%
K_N	0.0014	mg/l	80976	9.22	104%
	0.14		7564	0.86	10%
K_P	0.0003	mg/l	77913	8.87	100%
	0.03		71489	8.14	92%
K_{Si}	0.003	mg/l	77913	8.87	100%
	0.3		77913	8.87	100%
K_N, K_P, K_{Si}	0.0014, 0.0003, 0.003	mg/l	81010	9.22	104%
	0.14, 0.03, 0.3		7564	0.86	10%
$[TIN]_{in}$	0.014	mg/l	1	0.00012	0.0014%
	0.02		7564	0.86	10%
	2		80976	9.22	104%
$[PO4]_{in}$	0.003	mg/l	1	0.00012	0.0014%
	0.02		71489	8.14	92%
	2		77913	8.87	100%
$[Si]_{in}$	5	mg/l	77913	8.87	100%
	500		77913	8.87	100%
$[TIN]_{in}$, $[PO4]_{in}$, $[Si]_{in}$	0.02, 0.02, 5.0	mg/l	7564	0.86	10%
	2.0, 2.0, 500.0		81010	9.22	104%
	1.1		67727	7.71	86.9%
	1.3		88193	10.04	113.2%
	1.4		95429	10.86	122.4%

When the modeling implementation phosphate half-saturation constant of 0.003 mg/L is maintained, a phosphate concentration of 0.02 mg/L (an order of magnitude lower than the model implementation value) would yield an average annual biomass equal to 92% of the baseline average annual biomass. A review of the Shasta River watershed phosphate data presented in Tables 2.8, 2.9, 2.10, and 2.11 (in Chapter 2), shows that average phosphate concentrations are well above 0.02 mg/L in the Shasta River above and below Lake Shastina, as well as in Shasta Valley springs (which account for much of the summer flow in the river downstream of Dwinnell). This analysis indicates that phosphate concentrations of the Shasta River watershed are biostimulatory and do not limit productivity.

7.2.2 Summary and Conclusions

Based on the algae model sensitivity analysis of nutrient half-saturation coefficients and nutrient concentrations, there are several conclusions that can be drawn from the algae model application:

- The model is mildly sensitive to phosphate half-saturation constants and concentrations;
- The model is sensitive to nitrogen half-saturation constants and concentrations;
- The concentrations of nitrogen and phosphorus in the Shasta River below Lake Shastina are biostimulatory; and
- If TIN concentrations in the Shasta River were maintained at levels comparable to those concentrations measured in the headwaters of the Shasta River, aquatic vegetation biomass would likely be reduced.

7.3 RMS Model Application

The analytical approach in developing the dissolved oxygen TMDL involved application of the RMS model to determine a suite of conditions that result in water quality standards attainment under critical conditions. Regional Water Board staff developed a "water quality compliance" model scenario that includes a suite of conditions that yields attainment of the minimum dissolved oxygen objective for the Shasta River at all times under critical conditions.

As discussed in Chapter 2, the Shasta River does not meet the dissolved oxygen objective during summer months. Therefore, as for the temperature analysis, the water quality simulations were run using the meteorological conditions for the model calibration and validation time periods: July 2 - 8, 2002; August 29 – September 4, 2002, and September 17 – 23, 2002. The determination that these time periods represent "critical conditions" is discussed in Section 6.4.

7.3.1 Water Quality Compliance Scenario Conditions

The process used to develop the water quality compliance scenario involved separately evaluating the components identified in the dissolved oxygen source and linkage analysis (Chapter 4) that affect dissolved oxygen concentrations in the Shasta River watershed. The components that were evaluated included: photosynthetic and respiration rates; sediment oxygen demand rates; dissolved oxygen and NBOD concentrations of Lake Shastina outflow, key tributaries, and tailwater return flows; riparian shade; and flow.

The water quality compliance scenario for dissolved oxygen consists of the baseline condition with the following key modifications:

1. Reduced photosynthetic and respiration rates;
2. Reduced sediment oxygen demand (SOD) rates behind minor impoundments;
3. Reduced nitrogenous oxygen demand (NBOD) input concentrations;
4. Modified dissolved oxygen concentrations at key locations;
5. Increased riparian shade, represented as decreased percent transmittance on a river reach scale, as outlined in Section 6.2.1; and
6. Increased Shasta River flow.

These modifications are discussed below, with the exception of #5, decreased percent transmittance, which is discussed in Section 6.2.1.

7.3.2 Photosynthetic and Respiration Rates

As outlined in Section 5.3.2.2, the water quality model assigns photosynthesis and respiration rates of aquatic plants in units of gO_2/m^2-s. The assigned rates are exerted on the wetted area of the channel, assuming uniform biomass and distribution.

The photosynthetic and respiration rates assigned for the water quality compliance scenario were 50% of those for the existing (baseline) condition, as shown in Table 7.3. These reductions in photosynthetic and respiration rates assume a 50% reduction in aquatic vegetation standing crop during the simulation periods. Regional Water Board staff believe that such reductions in aquatic vegetation standing crop, and associated reductions in photosynthetic and respiration rates, are achievable in the Shasta River. In the field, the mechanisms that would result in these reductions include:

- Decreased light availability to aquatic vegetation via increased riparian shade, as outlined in Section 6.2.1;
- Reduced concentrations of biostimulatory nutrients (i.e. ammonia-nitrogen, nitrate-nitrogen, and ortho-phosphate-phosphorus) in the Shasta River achieved via controls targeting NBOD reductions from Lake Shastina outflow, irrigation return flows, and Yreka Creek, as outlined in Section 7.3.4;
- Reduced fine sediment inputs from irrigation return flows that can be achieved via controls targeting NBOD reductions, as outlined in Section 7.3.4; and
- Increased flushing flows to scour the channel of accumulated fine sediments that promote the establishment and proliferation of rooted aquatic macrophytes.
- Reduced stream temperatures, as outlined in Chapter 6.

7.3.3 Sediment Oxygen Demand Rates

The water quality model assigns SOD rates in units of gO_2/m^2-s, and the assigned SOD is exerted on the wetted area of the channel. For the water quality compliance scenario SOD rates were reduced by 50% of the existing (baseline) rates at river locations influenced by minor impoundments (flashboard dams), as shown in Table 7.4. Regional Water Board staff believe SOD reductions are achievable at these locations. In practice, SOD reductions would occur as a result of the following actions:

- Removal of the minor impoundments, or re-engineering them to minimize the opportunity for sediment and organic material accumulation;
- Reduced fine sediment and organic material inputs from irrigation return flows that can be achieved via controls targeting NBOD reductions, as outlined in Section 7.3.4; and

- Reduced concentrations of biostimulatory nutrients in the Shasta River that promote aquatic vegetation growth, which in turn exert a sediment oxygen demand when the organic material is decomposed. Reductions in nutrient concentrations can be achieved via controls targeting NBOD reductions from Lake Shastina outflow, irrigation return flows, and Yreka Creek, as outlined in Section 7.3.4.

Table 7.3: Photosynthetic and respiration rates for the July, August, and September water quality compliance scenarios

River Mile	July 2-8		Aug 29-Sep 4		Sep 17-23	
	Pmax	Resp	Pmax	Resp	Pmax	Resp
	(gO_2/m^2-hr)		(gO_2/m^2-hr)		(gO_2/m^2-hr)	
40.62	1.18	0.24	1.18	0.24	1.18	0.12
39.51	1.18	0.24	1.18	0.24	1.18	0.12
39.26	1.58	0.32	1.58	0.32	1.58	0.16
25.85	1.58	0.32	1.58	0.32	1.58	0.16
25.79	1.18	0.24	1.18	0.24	1.18	0.12
24.11	1.18	0.24	1.18	0.24	1.18	0.12
24.10	0.60	0.12	0.60	0.12	0.60	0.06
22.14	0.60	0.12	0.60	0.12	0.60	0.06
22.13	1.18	0.24	1.18	0.24	1.18	0.12
16.11	1.18	0.24	1.18	0.24	1.18	0.12
15.91	1.58	0.32	1.58	0.32	1.58	0.16
14.88	1.58	0.32	1.58	0.32	1.58	0.16
14.68	0.60	0.12	0.60	0.12	0.60	0.06
13.99	0.60	0.12	0.60	0.12	0.60	0.06
13.79	1.58	0.32	1.58	0.32	1.58	0.16
13.40	1.58	0.32	1.58	0.32	1.58	0.16
13.26	1.18	0.24	1.18	0.24	1.18	0.12
12.63	1.18	0.24	1.18	0.24	1.18	0.12
12.58	1.58	0.32	1.58	0.32	1.58	0.16
12.27	1.58	0.32	1.58	0.32	1.58	0.16
12.16	1.18	0.24	1.18	0.24	1.18	0.12
11.10	1.18	0.24	1.18	0.24	1.18	0.12
10.69	1.58	0.32	1.58	0.32	1.58	0.16
10.55	1.18	0.24	1.18	0.24	1.18	0.12
6.42	1.18	0.24	1.18	0.24	1.18	0.12
6.34	0.60	0.12	0.60	0.12	0.60	0.06
4.30	0.60	0.12	0.60	0.12	0.60	0.06
4.19	1.18	0.24	1.18	0.24	1.18	0.12
4.05	1.18	0.24	1.18	0.24	1.18	0.12
3.98	0.60	0.12	0.60	0.12	0.60	0.06
0.00	0.60	0.12	0.60	0.12	0.60	0.06

Table 7.4: Sediment oxygen demand (SOD) rates for existing (baseline) and water quality compliance scenarios

River Mile	Existing scenario SOD rate (gO_2/m^2-day)	Water quality compliant scenario SOD rate (gO_2/m^2-day)
40.62	0.2	0.2
39.94	0.2	0.2
38.65	0.5	0.5
32.03	0.5	0.5
30.65	**2.0**	**1.0**
27.50	0.2	0.2
25.79	0.1	0.1
24.10	0.1	0.1
19.11	0.1	0.1
17.78	**2.0**	**1.0**
15.40	**1.5**	**0.75**
14.68	**1.5**	**0.75**
13.74	**1.5**	**0.75**
13.16	**2.0**	**1.0**
12.50	0.2	0.2
11.10	0.2	0.2
10.69	0.2	0.2
8.65	0.2	0.2
6.42	0.1	0.1
1.05	0.1	0.1
0.72	0.1	0.1
0.00	0.1	0.1

Note: SOD rates are temperature corrected in RQUAL

7.3.4 Nitrogenous Oxygen Demand Concentrations

For the water quality compliance scenario NBOD concentrations were reduced at key input locations including Dwinnell Dam, distributed flows in accreting reaches of the river that include irrigation return flows, and Yreka Creek, as shown in Table 7.5. For both the existing (baseline) and water quality compliance scenarios the boundary conditions for NBOD were based on Total Kjeldahl Nitrogen (TKN) concentrations, according to the equation: NBOD = 4.57 * TKN (Chapra 1997), as discussed in Section 5.1.2 in Appendix E. The NBOD concentrations applied at the various input locations for both the existing (baseline) and water quality compliance scenario are identified in Table 7.5.

The NBOD concentration applied to Dwinnell Dam is based on the average TKN concentration in the Shasta River just upstream of Lake Shastina. The NBOD concentration applied to Yreka Creek is based on the average TKN concentration from all Yreka Creek monitoring locations above the City of Yreka wastewater treatment and disposal facility. The NBOD concentrations for distributed flows in accreting reaches of the river (which include irrigation return flows) were assigned the same NBOD concentration as the Shasta River at the model node closest to the mid-point of the distributed flow reach. In other words, this assumes that the NBOD concentrations of the irrigation return flows are equal to the reach average NBOD concentration of the Shasta River in the accretion reach. Regional Water Board staff believe these NBOD concentration reductions are achievable in the Shasta River watershed.

Table 7.5: Nitrogenous oxygen demand (NBOD) concentrations for existing (baseline) and water quality compliance scenarios

Location	Scenario	NBOD (mg/L)	Comments
Dwinnell Dam	Existing Condition	2.74	Based on average TKN concentrations at Riverside Drive.
	Water Quality Compliance	0.91	Based on average TKN concentrations just upstream of Lake Shastina.
Big Springs Creek	Existing Condition	0.91	Based on average TKN concentrations measured in Big Springs Lake.
	Water Quality Compliance	0.91	Due to lack of data at the mouth of Big Springs Creek, the same NBOD concentration was applied.
GID to Anderson Grade Road – (Accretions - Distributed Flows)	Existing Condition	5.53	Based on average TKN concentrations from tailwater return flow dataset.
	Water Quality Compliance	Variable	The model output NBOD concentrations of the Shasta River at the mid-points of the distributed flow reaches were applied.
Yreka Creek	Existing Condition	1.33	Based on average TKN concentrations at the mouth of Yreka Creek.
	Water Quality Compliance	0.91	Based on average TKN concentrations of Yreka Creek from locations upstream of the wastewater treatment and disposal facility.

7.3.5 Dissolved Oxygen Concentrations

The same dissolved oxygen concentrations were applied to the water quality compliance scenario as the existing (baseline) scenario (as presented in Section 5.1.2 of Appendix D), with the following exceptions. The dissolved oxygen concentrations for Big Springs Creek and Parks Creek were calculated at saturation based on reduced stream temperature (and atmospheric pressure). As described in Section 6.2.3, the temperatures attributed to the water quality compliance scenario for Big Springs Creek and Parks Creek were equal to the existing (baseline) temperature regime minus 4°C and 2°C, respectively. Finally, for the water quality compliance scenario the dissolved oxygen concentrations for accretions were assigned the river concentrations associated with the model output at the mid-point of the respective accretion reach.

7.3.6 Shasta River Flow

The water quality compliance scenario included Shasta River flows based on baseline conditions with a 50% increase in flow in the Shasta Riverdownstream of the Big Springs Creek confluence. The explanation and rationale for including this flow regime in the water quality compliance scenario is discussed in Sections 6.2.4 and 6.4.1.

7.4 RMS Model Simulations - Dissolved Oxygen Results and Discussion

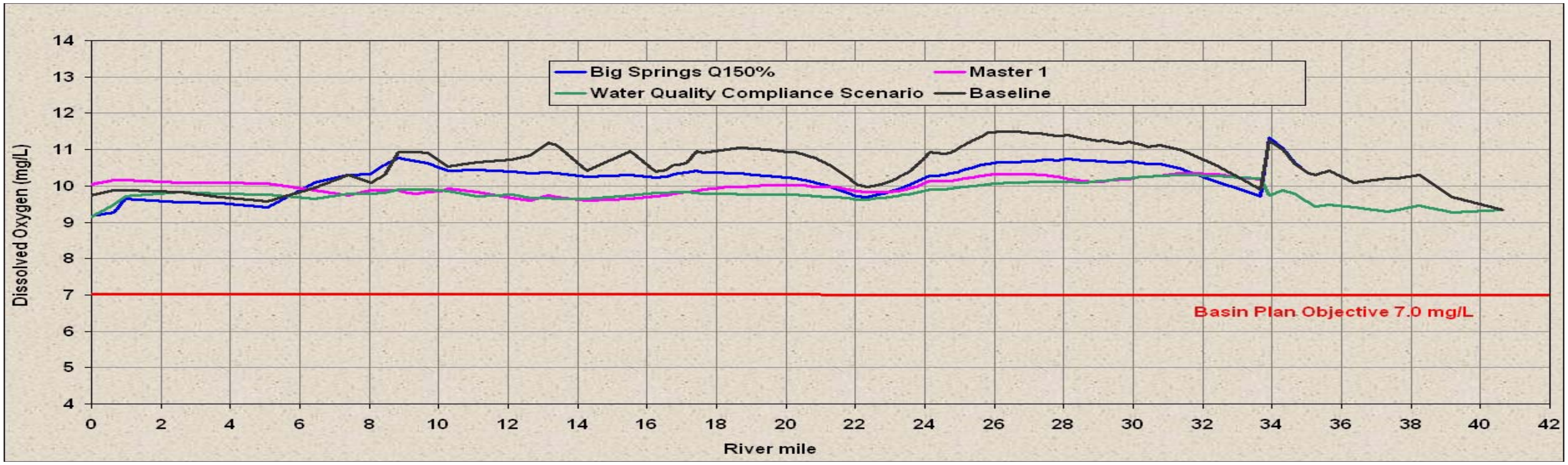
This section presents the RMS model dissolved oxygen results for the water quality compliance scenario. These results serve as the basis for dissolved oxygen TMDL allocations, as presented in Section 7.5.

7.4.1 Water Quality Compliance Scenario Dissolved Oxygen Results

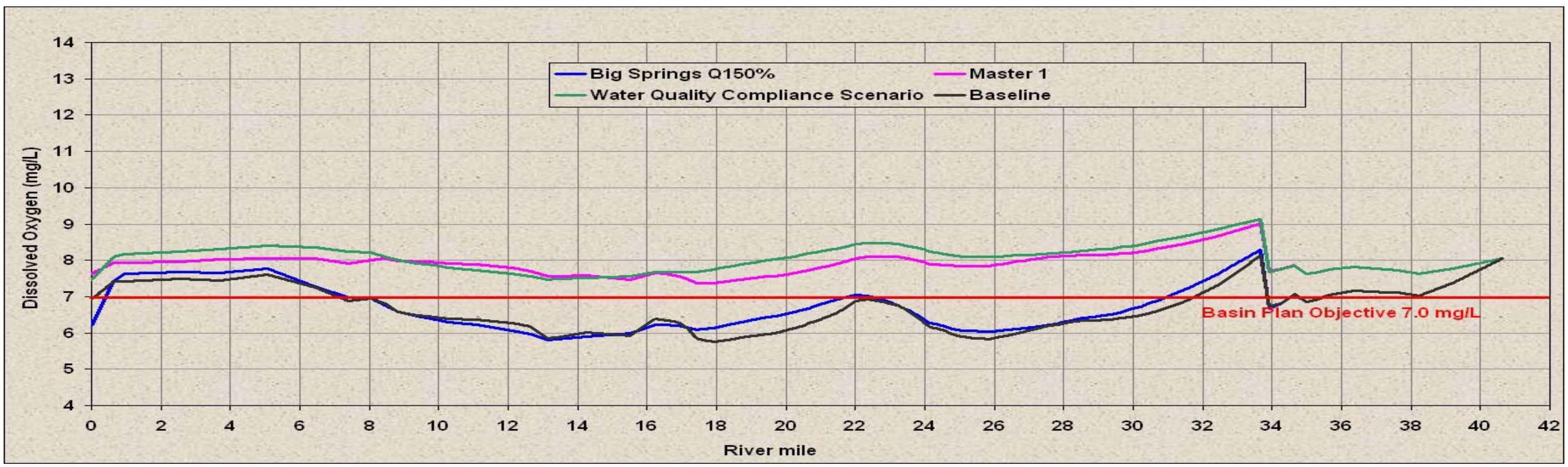
The dissolved oxygen results of the water quality compliance scenario are presented in Figure 7.1 and Table 7.6. Figure 7.1 shows the maximum and minimum dissolved oxygen concentrations in the Shasta River associated with the water quality compliance scenario. For comparison, Figure 7.1 also presents the maximum and minimum dissolved oxygen concentrations for the following simulations: (1) baseline condition, (2) 50% flow increase in the Shasta River downstream of the Big Springs Creek confluence, and (3) the first four components of the water quality compliance scenario identified in the preceding paragraph (i.e. riparian shade, tailwater modifications, 4°C reduction from Big Springs Creek, and 2°C reduction from Parks Creek), identified as “Master 1”. The maximum, minimum, and average dissolved oxygen concentrations for each of these simulations are presented in Table 7.6, and the increases or decreases in these concentrations compared with the baseline condition are identified.

The following conclusions are drawn from these water quality model results:

- Increasing flow downstream of the Big Springs Creek confluence by 50% has a modest effect on maximum and minimum dissolved oxygen concentrations in the Shasta River compared with baseline conditions. Maximum dissolved oxygen concentrations are reduced up to 0.8 mg/L. Minimum dissolved oxygen concentrations are increased up to 0.4 mg/L;
- The water quality compliance scenario results in the greatest dissolved oxygen improvements (reductions in maximum and increase in minimum concentrations) compared with the other simulations;
- The magnitude of diel dissolved oxygen concentrations is reduced throughout the Shasta River under the water quality compliance scenario;
- Dissolved oxygen concentrations are *above* the Basin Plan minimum dissolved oxygen objective of 7.0 mg/L throughout the Shasta River under the water quality compliance scenario;
- The water quality compliance scenario results in attainment of the Basin Plan minimum dissolved oxygen objective for the Shasta River.
- The water quality compliance scenario results in reduced maximum and increased minimum dissolved oxygen concentrations in the Shasta River. Though the available data indicate that the 9.0 mg/L 50% lower limit dissolved oxygen objective is being met in the Shasta River (see Section 2.4.2), implementation of the factors represented in the water quality compliance scenario will likely lead to attainment of the 9.0 mg/L 50% lower limit dissolved oxygen objective more conclusively.
- The water quality compliance scenario appears to result in attainment of the Basin Plan biostimulatory substances objective, as nutrient load reductions result in attainment of the dissolved oxygen objective and non-nuisance level growth of aquatic plants.



(A)



(B)

Figure 7.1: Alternate scenarios, maximum (A) and minimum (B) dissolved oxygen results

Table 7.6: Alternate scenarios, dissolved oxygen results and change from baseline

Compliance Points	River Mile	Maximum Modeled Dissolved Oxygen Values				Maximum Modeled Differences in D. O. compared to August Baseline (Increase or (decrease))		
		August Baseline	Big Springs Q150%	Master 1	Water Quality Compliance	Big Springs Q150%	Master 1	Water Quality Compliance
Dwinnel Dam	42.60	9.35	9.35	9.35	9.35	0.00	0.00	0.00
Louie Road	33.93	11.27	11.34	9.74	9.74	0.07	(1.53)	(1.53)
GID	30.59	11.07	10.60	10.26	10.26	(0.47)	(0.81)	(0.81)
Highway A-12	24.11	10.75	10.20	10.07	9.85	(0.55)	(0.68)	(0.90)
Freeman Lane	19.23	11.03	10.31	10.00	9.76	(0.72)	(1.03)	(1.27)
M-G Road	15.52	10.96	10.30	9.65	9.73	(0.66)	(1.31)	(1.23)
Highway 3	13.16	11.18	10.38	9.74	9.67	(0.80)	(1.44)	(1.51)
Yreka Ager Road	10.91	10.66	10.43	9.82	9.72	(0.23)	(0.84)	(0.94)
Anderson Grade Road	8.03	10.09	10.33	9.88	9.79	0.24	(0.21)	(0.30)
Highway 263	7.30	9.94	10.08	9.88	9.64	0.14	(0.06)	(0.30)
"Salmon Heaven"	5.60	9.58	9.40	10.06	9.87	(0.18)	0.48	0.29
Mouth	0.66	9.87	9.64	10.17	9.71	(0.23)	0.30	(0.16)

Compliance Points	River Mile	Average Modeled Dissolved Oxygen Values				Average Modeled Differences in D. O. compared to August Baseline (Increase or (decrease))		
		August Baseline	Big Springs Q150%	Master 1	Water Quality Compliance	Big Springs Q150%	Master 1	Water Quality Compliance
Dwinnel Dam	42.60	8.72	8.72	8.72	8.72	0.00	0.00	0.00
Louie Road	33.93	8.56	8.55	8.61	8.60	(0.01)	0.06	0.05
GID	30.59	8.16	8.19	9.05	9.19	0.03	0.88	1.02
Highway A-12	24.11	7.98	7.79	8.85	8.89	(0.18)	0.87	0.91
Freeman Lane	19.23	7.91	7.85	8.55	8.73	(0.06)	0.64	0.82
M-G Road	15.52	7.88	7.68	8.33	8.49	(0.20)	0.45	0.61
Highway 3	13.16	7.92	7.58	8.32	8.36	(0.34)	0.40	0.44
Yreka Ager Road	10.91	8.12	7.84	8.58	8.55	(0.29)	0.46	0.42
Anderson Grade Road	8.03	8.30	8.20	8.82	8.80	(0.11)	0.52	0.50
Highway 263	7.30	8.52	8.35	8.88	8.85	(0.17)	0.36	0.33
"Salmon Heaven"	5.60	8.54	8.46	8.95	8.97	(0.07)	0.42	0.43
Mouth	0.66	8.64	8.50	8.98	8.93	(0.14)	0.34	0.29

Compliance Points	River Mile	Minimum Modeled Dissolved Oxygen Values				Minimum Modeled Differences in D. O. compared to August Baseline (Increase or (decrease))		
		August Baseline	Big Springs Q150%	Master 1	Water Quality Compliance	Big Springs Q150%	Master 1	Water Quality Compliance
Dwinnel Dam	42.60	8.06	8.06	8.06	8.06	0.00	0.00	0.00
Louie Road	33.93	6.72	6.67	7.71	7.68	(0.05)	0.99	0.96
GID	30.59	6.54	6.81	8.27	8.48	0.27	1.73	1.94
Highway A-12	24.11	6.30	6.39	7.95	8.30	0.09	1.65	2.00
Freeman Lane	19.23	5.91	6.36	7.51	7.94	0.45	1.60	2.03
M-G Road	15.52	5.93	6.00	7.47	7.57	0.07	1.54	1.64
Highway 3	13.16	5.84	5.80	7.56	7.47	(0.04)	1.72	1.63
Yreka Ager Road	10.91	6.36	6.22	7.88	7.73	(0.14)	1.52	1.37
Anderson Grade Road	8.03	6.95	6.94	8.00	8.21	(0.01)	1.05	1.26
Highway 263	7.30	7.26	7.28	8.04	8.36	0.02	0.78	1.10
"Salmon Heaven"	5.60	7.61	7.77	8.04	8.40	0.16	0.43	0.79
Mouth	0.66	7.41	7.62	7.94	8.17	0.21	0.53	0.76

7.4.2 Oxygen Load Calculations

As discussed in Chapter 4, there are a number of interacting processes affecting dissolved oxygen concentrations in the Shasta River watershed. Photosynthesis and reaeration add oxygen to the water, while respiration of aquatic vegetation, sediment oxygen demand, and carbonaceous and nitrogenous oxygen demands effectively remove dissolved oxygen from the water. In other words, absent other processes being exerted on the system, photosynthesis and reaeration cause an increase in dissolved oxygen concentrations, while respiration, sediment oxygen demand, and carbonaceous and nitrogenous oxygen demand cause a decrease in dissolved oxygen concentrations in the river.

The RMS model for dissolved oxygen allowed us to evaluate how changes to these oxygen-producing and oxygen-consuming processes affect dissolved oxygen concentrations in the river. The water quality compliance scenario represents a suite of conditions that result in dissolved oxygen concentrations above the water quality objective of 7.0 mg/L at all river locations under critical conditions. The difference between the rates and concentrations of the oxygen producing and consuming processes for the existing (baseline) condition and those for the water quality compliance scenario, therefore, represents the needed changes in order to achieve water quality standards compliance for the Shasta River.

The difference in the total dissolved oxygen load of the Shasta River for a 24-hour period under the existing (baseline) condition and the water quality compliance scenario equals the reduction in total oxygen demand that is required to achieve water quality compliance. The net dissolved oxygen load of the river can be calculated using a basic dissolved oxygen budget equation:

$$O_{2net} = P + R_{aer} - (R_{esp} + S + C_{deox} + N_{deox})$$

Where,

O_{2net} = Net oxygen load in pounds/day
P = Oxygen load from photosynthesis in pounds/day
R_{aer} = Oxygen load from reaeration in pounds/day
R_{esp} = Oxygen demand from aquatic plant respiration in pounds/day
S = Oxygen demand from sediment oxygen demand in pounds/day
C_{deox} = Oxygen demand from carbonaceous deoxygenation in pounds/day
N_{deox} = Oxygen demand from nitrogenous deoxygenation in pounds/day.

This dissolved oxygen budget equation was used to calculate the 24-hour net oxygen load for the fourth day of the August simulation period for both the existing (baseline) condition and water quality compliance scenario. Several factors were considered in selecting the simulation period for which to calculate the dissolved oxygen budget, including day length, flow, and stream temperature. Daylight hours decreased (and nighttime hours increased) progressively for the July, August, and September simulation periods. Longer daylight hours yield greater oxygen production from photosynthesis. Oxygen consumption from aquatic vegetation respiration is constant and occurs around the clock. For the August simulation period there were 13 hours of daylight and 11 nighttime hours. In addition, flows were lowest in the river during the August 2002 baseline simulation period. Considering these factors in combination, the August simulation period was selected because it represents a critical condition with respect to dissolved oxygen conditions in the river. Hydrodynamic and water quality models often show some instability during the first 72 hours or so of a model simulation. Therefore, the fourth day of the August simulation period was used for calculating 24-hour net oxygen load to avoid inaccuracies that could be associated with model instability during the first 72 hours.

Tables 7.7 and 7.8 present the dissolved oxygen budget calculation results for Shasta River reaches for both the daytime and nighttime periods for the existing (baseline) condition and for the water quality compliance scenario, respectively. The total pounds of oxygen produced (i.e. the total 24-hr productivity) and the total pounds of oxygen demanded (i.e. the total 24-hr demand) are presented at the bottom of Table 7.7 and Table 7.8. In addition, the oxygen demand associated with each of the oxygen demand components (i.e. respiration, SOD, CBOD, and NBOD) are presented at the bottom of Table 7.7 and Table 7.8. Table 7.7 and Table 7.8 also present the oxygen production and oxygen demand during daylight versus nighttime hours for specified reaches of the river. Calculations of oxygen production and oxygen demand for specified reaches allow for determination of reach-scale oxygen demand reductions necessary for dissolved oxygen objective compliance.

The total net daily oxygen demand (i.e. the sum of respiratory demand, sediment oxygen demand, nitrogenous oxygen demand, and biochemical oxygen demand) on the Shasta River (from Dwinnell Dam to the mouth) for the fourth day (24-hours) of the August simulation period is 20,622 pounds/day for the existing (baseline) condition and 12,353 pounds/day for the water quality compliance scenario. Based on these calculations, the net oxygen demand of the river must be reduced by 8,269 pounds/day (i.e. 20,622 – 12,353) in order to comply with water quality standards under critical conditions.

7.5 Dissolved Oxygen TMDL and Allocations

This section presents the dissolved oxygen TMDL and load allocations. As discussed in Section 6.5, the starting point for the load allocation analysis is the equation that describes the Total Maximum Daily Load or loading capacity:

$$\text{TMDL} = \text{Loading Capacity} = \Sigma\text{WLAs} + \Sigma\text{LAs} + \text{Natural Background}$$

where Σ = the sum, WLAs = waste load allocations, and LAs = load allocations. Waste load allocations are contributions of a pollutant from point sources while load allocations are contributions from management-related non-point sources.

Table 7.7: Calculated oxygen production and demands for the August existing (baseline) condition

REACH	Reach Length (mi)	SOD (lbs/hr)	Pmax (lbs/hr)	RESP (lbs/hr)	NBOD (lbs/hr)	CBOD (lbs/hr)	Daylight Demand (lbs/day)	Daylight Productivity (lbs/day)	Total Daylight Productivity (lbs/day)	Total Daylight Productivity (lbs/mi-day)
		EXISTING (BASELINE) CONDITIONS								
		PRODUCTIVITY or (DEMAND)								
		Daylight Hours (for model time period - 13 hours)								
Dwinnell Reservoir - Riverside Drive	0.7	(0)	15	(3)	(3)	(6)	(154)	198	44	65
Riverside Drive - Parks Creek	5.0	(2)	285	(58)	(4)	(8)	(933)	3,710	2,777	555
Parks Creek - Big Springs Creek	1.3	(1)	92	(19)	(5)	(9)	(432)	1,199	767	604
Big Springs Creek - Highway A-12	9.6	(13)	1,078	(219)	(15)	(84)	(4,299)	14,016	9,716	1,016
Highway A-12 - Shasta River @ Freeman Lane	5.0	(1)	461	(93)	(28)	(25)	(1,912)	5,991	4,079	819
Shasta River @ Freeman Lane - DWR Weir	3.6	(6)	291	(59)	(4)	(4)	(948)	3,780	2,833	785
DWR Weir - Yreka-Ager Road	4.4	(6)	277	(56)	0	0	(808)	3,607	2,799	633
Yreka-Ager Road - Anderson Grade Road	3.1	(1)	252	(51)	0	0	(679)	3,282	2,603	853
Anderson Grade Road - Mouth	8.1	(1)	377	(76)	(0)	(0)	(1,006)	4,897	3,891	483

REACH	Reach Length (mi)	SOD (lbs/hr)	Pmax (lbs/hr)	RESP (lbs/hr)	NBOD (lbs/hr)	CBOD (lbs/hr)	Nighttime Demand (lbs/day)	Nighttime Productivity (lbs/day)	Total Nighttime Demand (lbs/day)	Total Nighttime Demand (lbs/mi-day)
		EXISTING (BASELINE) CONDITIONS								
		PRODUCTIVITY or (DEMAND)								
		Nighttime Hours (for model time period - 11 hours)								
Dwinnell Reservoir - Riverside Drive	0.7	(0)	0	(3)	(3)	(6)	(130)	0	(130)	(192)
Riverside Drive - Parks Creek	5.0	(2)	0	(58)	(4)	(8)	(789)	0	(789)	(158)
Parks Creek - Big Springs Creek	1.3	(1)	0	(19)	(5)	(9)	(365)	0	(365)	(288)
Big Springs Creek - Highway A-12	9.6	(13)	0	(219)	(15)	(84)	(3,638)	0	(3,638)	(381)
Highway A-12 - Shasta River @ Freeman Lane	5.0	(1)	0	(93)	(28)	(25)	(1,618)	0	(1,618)	(325)
Shasta River @ Freeman Lane - DWR Weir	3.6	(6)	0	(59)	(4)	(4)	(802)	0	(802)	(222)
DWR Weir - Yreka-Ager Road	4.4	(6)	0	(56)	0	0	(684)	0	(684)	(155)
Yreka-Ager Road - Anderson Grade Road	3.1	(1)	0	(51)	0	0	(574)	0	(574)	(188)
Anderson Grade Road - Mouth	8.1	(1)	0	(76)	(0)	(0)	(851)	0	(851)	(106)

		SHASTA RIVER PRODUCTIVITY or (DEMAND)							
		SOD (lbs/hr)	Pmax (lbs/hr)	RESP (lbs/hr)	NBOD (lbs/hr)	CBOD (lbs/hr)			
Shasta River (Daylight Hours - 13 hours)	Daily Productivity or Demand	(30)	3,129	(635)	(60)	(135)	Total 24 Hour Productivity (lbs/day)	40,680	1,001
Shasta River (Nightime Hours - 11 hours)		(30)	0	(635)	(60)	(135)	Total 24 Hour Demand (lbs/day)	(20,622)	(508)
Demand By Process	%	3.4%	0.0%	73.9%	6.9%	15.8%			

Table 7.8: Calculated oxygen production and demands for the August water quality compliance conditions

REACH	Reach Length (mi)	TMDL WATER QUALITY COMPLIANCE CONDITIONS: PRODUCTIVITY or (DEMAND) SOD (lbs/hr)	Pmax (lbs/hr)	RESP (lbs/hr)	NBOD (lbs/hr)	CBOD (lbs/hr)	Daylight Demand (lbs/day)	Daylight Productivity (lbs/day)	Total Daylight Productivity (lbs/day)	Total Daylight Productivity (lbs/mi-day)
		Daylight Hours (for model time period - 13 hours)								
Dwinnell Reservoir - Riverside Drive	0.7	(0)	8	(2)	(1)	(6)	(107)	99	(8)	(12)
Riverside Drive - Parks Creek	5.0	(2)	143	(29)	(1)	(8)	(519)	1,855	1,336	267
Parks Creek - Big Springs Creek	1.3	(1)	46	(9)	(2)	(9)	(267)	600	332	262
Big Springs Creek - Highway A-12	9.6	(8)	539	(110)	(15)	(84)	(2,815)	7,008	4,193	439
Highway A-12 - Shasta River @ Freeman Lane	5.0	(1)	230	(47)	(25)	(20)	(1,206)	2,995	1,789	359
Shasta River @ Freeman Lane - DWR Weir	3.6	(3)	145	(30)	(4)	(3)	(513)	1,890	1,377	382
DWR Weir - Yreka-Ager Road	4.4	(3)	139	(28)	0	0	(406)	1,803	1,398	316
Yreka-Ager Road - Anderson Grade Road	3.1	(1)	126	(26)	0	0	(345)	1,641	1,296	425
Anderson Grade Road - Mouth	8.1	(1)	188	(38)	(0)	(0)	(513)	2,449	1,935	240

REACH	Reach Length (mi)	TMDL WATER QUALITY COMPLIANCE CONDITIONS: PRODUCTIVITY or (DEMAND) SOD (lbs/hr)	Pmax (lbs/hr)	RESP (lbs/hr)	NBOD (lbs/hr)	CBOD (lbs/hr)	Nighttime Demand (lbs/day)	Nighttime Productivity (lbs/day)	Total Nighttime Demand (lbs/day)	Total Nighttime Demand (lbs/mi-day)
		Nighttime Hours (for model time period - 11 hours)								
Dwinnell Reservoir - Riverside Drive	0.7	(0)	0	(2)	(1)	(6)	(91)	0	(91)	(133)
Riverside Drive - Parks Creek	5.0	(2)	0	(29)	(1)	(8)	(439)	0	(439)	(88)
Parks Creek - Big Springs Creek	1.3	(1)	0	(9)	(2)	(9)	(226)	0	(226)	(178)
Big Springs Creek - Highway A-12	9.6	(8)	0	(110)	(15)	(84)	(2,382)	0	(2,382)	(249)
Highway A-12 - Shasta River @ Freeman Lane	5.0	(1)	0	(47)	(25)	(20)	(1,020)	0	(1,020)	(205)
Shasta River @ Freeman Lane - DWR Weir	3.6	(3)	0	(30)	(4)	(3)	(434)	0	(434)	(120)
DWR Weir - Yreka-Ager Road	4.4	(3)	0	(28)	0	0	(343)	0	(343)	(78)
Yreka-Ager Road - Anderson Grade Road	3.1	(1)	0	(26)	0	0	(292)	0	(292)	(96)
Anderson Grade Road - Mouth	8.1	(1)	0	(38)	(0)	(0)	(434)	0	(434)	(54)

		SHASTA RIVER PRODUCTIVITY or (DEMAND): SOD (lbs/hr)	Pmax (lbs/hr)	RESP (lbs/hr)	NBOD (lbs/hr)	CBOD (lbs/hr)			
Shasta River (Daylight Hours - 13 hours)	Daily Productivity or Demand (lbs/day)	(19)	1,565	(317)	(48)	(130)	Total 24 Hour Productivity (lbs/day)	20,340	501
Shasta River (Nightime Hours - 11 hours)		(19)	0	(317)	(48)	(130)	Total 24 Hour Demand (lbs/day)	(12,353)	(304)
Demand By Process	%	3.8%	0.0%	61.7%	9.4%	25.2%			

7.5.1 Dissolved Oxygen Loading Capacity

The loading capacity represents the total loading of a pollutant that a water body can assimilate and still meet water quality objectives so as to protect beneficial uses. For the dissolved oxygen TMDL the water quality objective of concern is the minimum dissolved oxygen objective of 7.0 mg/L for the Shasta River. There are no known point sources of oxygen-demanding constituents to the Shasta River and tributaries. Each of the components that exert an oxygen demand on the Shasta River is attributed to nonpoint sources. As outlined in Section 7.3.1, these oxygen demand components include respiration of aquatic plants, sediment oxygen demand, and nitrogenous oxygen demand (NBOD). The loading capacity for the Shasta River is, therefore, the total oxygen demand of the river under the water quality compliance scenario, as outlined in Section 7.4.1 and as presented in Table 7.8.

Therefore, the Shasta River dissolved oxygen TMDL is:

TMDL = Loading Capacity = 12,353 lbs O_2/day

7.5.2 Dissolved Oxygen Load Allocations

In accordance with EPA regulations, the TMDL (i.e., the loading capacity) for a water body is to be allocated among the various sources of the targeted pollutant. The sum of the waste load and load allocations for the watershed is equivalent to the loading capacity for the watershed as a whole. There are no known point sources of oxygen-demanding constituents to the Shasta River and tributaries, and therefore no waste load allocations apply.

For the dissolved oxygen TMDL allocations are assigned to reaches of the Shasta River, as identified in Table 7.9. Responsibility for meeting these river-reach allocations is assigned to the landowners whose operations contribute to water quality conditions within the specified reaches. These load allocations are presented on an hourly and daily basis, and equal the total hourly and total daily oxygen demand for these river reaches. The difference between the total daily oxygen demand for the existing (baseline) condition and the total daily oxygen demand for the water quality compliance scenario condition represents the reductions in total oxygen demand needed to comply with the TMDL. These river-reach oxygen demand reductions needed for dissolved oxygen compliance are also presented in Table 7.9.

In addition to the river reach load allocations, NBOD allocations are applied to Dwinnell Dam, Yreka Creek, and tailwater return flows. These allocations are assigned as NBOD concentrations, not loads, as outlined in Table 7.10. The tailwater return flow NBOD concentration allocation is equal to the average Shasta River NBOD concentration in the water quality compliance scenario. In this document “tailwater return flow” refers to surface runoff of irrigation water to a surface water body, and is synonymous with “irrigation return flow”.

Table 7.9: Shasta River dissolved oxygen TMDL river-reach load allocations and total oxygen demand reductions needed to achieve dissolved oxygen compliance

REACH	Reach Length (mi)	Hourly Demand Existing (Baseline) Conditions (lbs/hr)	Hourly Demand Water Quality Compliance (Master 1 scenario) Conditions (lbs/hr)	Reduction In Oxygen Demand Needed To Achieve Water Quality Compliance	
				(lbs/hr)	%
Dwinnell Reservoir - Riverside Drive	0.7	(12)	(8)	4	30%
Riverside Drive - Parks Creek	5.0	(72)	(40)	32	44%
Parks Creek - Big Springs Creek	1.3	(33)	(21)	13	38%
Big Springs Creek - Highway A-12	9.6	(331)	(217)	114	35%
Highway A-12 - Shasta River @ Freeman Lane	5.0	(147)	(93)	54	37%
Shasta River @ Freeman Lane - DWR Weir	3.6	(73)	(39)	33	46%
DWR Weir - Yreka-Ager Road	4.4	(62)	(31)	31	50%
Yreka-Ager Road - Anderson Grade Road	3.1	(52)	(27)	26	49%
Anderson Grade Road - Mouth	8.1	(77)	(39)	38	49%

REACH	Reach Length (mi)	24 Hour Demand Existing (Baseline) Conditions (lbs/day)	24 Hour Demand Water Quality Compliance (Master 1 scenario) Conditions (lbs/day)	Reduction In Oxygen Demand Needed To Achieve Water Quality Compliance	
				(lbs/day)	%
Dwinnell Reservoir - Riverside Drive	0.7	(285)	(198)	87	30%
Riverside Drive - Parks Creek	5.0	(1,722)	(957)	765	44%
Parks Creek - Big Springs Creek	1.3	(797)	(494)	304	38%
Big Springs Creek - Highway A-12	9.6	(7,937)	(5,197)	2,741	35%
Highway A-12 - Shasta River @ Freeman Lane	5.0	(3,529)	(2,226)	1,303	37%
Shasta River @ Freeman Lane - DWR Weir	3.6	(1,749)	(947)	803	46%
DWR Weir - Yreka-Ager Road	4.4	(1,492)	(749)	743	50%
Yreka-Ager Road - Anderson Grade Road	3.1	(1,253)	(637)	616	49%
Anderson Grade Road - Mouth	8.1	(1,857)	(948)	909	49%

Table 7.10: Nitrogenous oxygen demand (NBOD) allocations

Location	NBOD Allocation (mg/L)
Dwinnell Dam	0.91
Yreka Creek	0.91
Tailwater return flows	0.85

7.6 Margin of Safety

The Clean Water Act Section 303(d) and the associated regulations at 40 CFR §130.7 require that TMDLs include a margin of safety that takes into account any lack of knowledge concerning the relationship between the pollutant loads and the desired receiving water quality. The margin of safety is often implicitly incorporated into conservative assumptions used in calculating loading capacities, waste load allocations, and load allocations (USEPA 1991). The margin of safety may also be incorporated explicitly as a separate component in the TMDL equation. For this TMDL analysis, conservative assumptions were made that account for uncertainties in the analysis.

- The water quality compliance scenario, which is the basis for the dissolved oxygen TMDL, includes a 50% reduction of sediment oxygen demand only at locations behind minor impoundments in the Shasta River. Fine sediment and organic material load reductions from irrigation return flows that can be achieved via controls targeting NBOD reductions would result in reductions in sediment oxygen demand in the entire river, not just behind impoundments. This represents a margin of safety.
- The water quality compliance scenario does not include CBOD concentration reductions. Controls targeting NBOD reductions from irrigation return flows, Dwinnell Dam outflow, and Yreka Creek would result in reductions in CBOD concentrations, and provide a margin of safety.

CHAPTER 8. IMPLEMENTATION

Key Points

Implementation actions are the steps and measures needed to meet the dissolved oxygen and temperature TMDL, achieve water quality standards, and protect and restore the beneficial uses of water in the Shasta River watershed.

The implementation actions are structured to contain the five key elements required in a nonpoint source pollution prevention program as defined in the NPS Policy. The implementation actions also rely entirely upon existing authorities. No new authorities are proposed.

- The implementation actions are designed to build upon the on-going, proactive restoration and enhancement efforts underway in the watershed.

- The implementation plan provides actions to:
  - Increase riparian vegetation along the Shasta River and its tributaries as a mechanism to lower water temperatures and promote stream bank stability;
  - Control tailwater to prevent the discharge of nutrient enriched and elevated temperature return flow to the Shasta River and its tributaries;
  - Encourage efficient water use in the Shasta River watershed to increase dedicated cold water flow in the Shasta River;
  - Remove, re-engineer, or limit construction of minor instream impoundments or other structures capable of impeding free flow of water conveyance as a mechanism to decrease oxygen demanding sources in the Shasta River;
  - Bring the discharge of Dwinnell Dam into compliance with the dissolved oxygen TMDL;
  - Bring the Yreka wastewater treatment facility into compliance with existing Regional Water Board Orders and compliance with the dissolved oxygen TMDL;
  - Prevent the discharge of polluted urban and suburban runoff from entering Shasta River or its tributaries;
  - Address activities on U.S. Forest Service and Bureau of Land Management lands;
  - Address activities conducted as part of timber harvest activities on non-federal lands, and
  - Address discharge from State controlled roads.

This chapter describes the steps or implementation actions necessary to ensure that the purpose of the TMDL will be achieved. The proposed implementation actions are organized and grouped under primary source or land use categories. This organization mirrors that of the proposed Basin Plan amendment language and is designed to make it easier for stakeholders to find the implementation actions that apply to their specific activities. More than one section may apply.

8.1 Implementation Actions Overview

Many individuals, groups, and agencies have been working to restore and enhance water quality and fish habitat in the Shasta River watershed. Regional Water Board staff recognize that these proactive efforts have improved water quality conditions, and that continued water quality improvements will occur much faster and easier if stakeholders continue their efforts and help implement the Shasta River TMDL Action Plan. Therefore, many of the implementation actions described in this section are designed to support and monitor the results of the continued implementation of on-going watershed restoration and enhancement efforts.

For example, the Natural Resources Conservation Service (NRCS) provides aid in securing financial assistance and technical support for the implementation of beneficial management practices throughout the United States. Several programs may be available to agricultural interests in the Shasta River watershed, including an Irrigation and Water Management Program under the umbrella of the NRCS Conservation Planning Program (1997a). Also available through the NRCS is the National Agronomy Manual (NRCS 2002), with land use practices and actions designed to achieve sustainable use of different natural resources while protecting the environment.

The continued participation by the NRCS in the Shasta River watershed is valuable for water quality and TMDL-related efforts. The technical resources available to landowners and stakeholders through the NRCS are particularly useful for preventing, minimizing, and controlling oxygen consuming material (and sediment waste) discharges and high water temperatures. The Regional Water Board shall increase efforts to work cooperatively with the NRCS to provide technical support and information to willing landowners and stakeholders in the Shasta River watershed, and to coordinate educational and outreach efforts.

The Shasta Valley Resource Conservation District (Shasta RCD) has been, and continues to be a source of funding and technical assistance for stakeholders in the Shasta River watershed. For the last 10 years, the Shasta River Coordinated Resources Management and Planning Committee (CRMP) has performed work to restore anadromous fish production in the Shasta River watershed under the umbrella of the Shasta RCD. Past efforts of the Shasta RCD included funds and technical assistance for stream restoration projects, efficient irrigation water application, water diversion management, stock water conservation management practices, and other programs.

Like the NRCS, the Shasta RCD primarily provides technical, financial, and other assistance to landowners and watershed groups. The Regional Water Board shall increase efforts to work cooperatively with the Shasta RCD to provide technical support and information to willing landowners and stakeholders in the Shasta River watershed and to coordinate educational and outreach efforts.

Although the current proactive efforts to restore and enhance water quality in the Shasta River watershed can make a great difference, it is the responsibility of the Regional Water Board to develop and implement actions that will ensure attainment of the dissolved oxygen and temperature TMDLs and water quality standards. Further, the Regional Water Board must ensure that the Shasta River TMDL Action Plan is in compliance with the state Nonpoint Source Policy (NPS Policy). The policy requires that all nonpoint sources of pollution (including nutrients and other oxygen consuming waste discharges, and elevated water temperatures) be regulated through, (1) prohibitions, (2) permits in the form of waste discharge requirements (WDRs), (3) waivers of WDRs or (4) through a combination thereof.

Table 8.1: Summary of the Five Key Elements of the Policy for the Implementation and Enforcement of the Nonpoint Source Pollution Control Program

Key Element 1	The nonpoint source pollution control program's ultimate purpose shall be explicitly stated.
Key Element 2	A description of management practices and other program elements that are expected to be implemented to ensure attainment of the purpose shall be included.
Key Element 3	When it is necessary to allow time to achieve water quality requirements, a specific time schedule and milestones shall be included.
Key Element 4	Sufficient feedback mechanisms shall be included.
Key Element 5	The potential consequences for failure shall be included.

In addition, a nonpoint source pollution control implementation program must include five key elements as described in Table 8.1. The *Policy for the Implementation and Enforcement of the Nonpoint Source Pollution Control Program* was adopted by the State Water Board on May 20, 2004. The NPS Policy is available, at http://www.waterboards.ca.gov/nps/docs/oalfinalcopy052604.doc. As explained in the NPS Policy, the *Plan for California's Nonpoint Source Pollution Control Program* is to be implemented and enforced through California Water Code mandates and authorities, outreach, education, technical assistance, financial incentives, and collaborative efforts with other agencies and non-governmental organizations.

The implementation actions as presented in the Shasta River TMDL Action Plan are organized by sources (or land use activities) and include specific actions (or management measures) to be undertaken by specific responsible parties by a specific time period. Responsible parties identified under these actions include, in part, the Regional Water Board, its staff, other regulatory agencies, Shasta Valley RCD and its CRMP, municipalities and individual stakeholders. Implementation actions are summarized below.

Implementation actions for range and riparian land management sources include support for and implementation of specific grazing and riparian management practices and the development and implementation of ranch management plans in site-specific situations. The Regional Water Board will also address the removal and suppression of riparian vegetation and activities in the riparian zone as part of the Stream and Wetland System Protection Policy under development by Regional Water Board staff and their contractors.

Implementation actions for tailwater sources include support for and implementation of management practices presented in the CDFG Coho Recovery Strategy, the Shasta CRMP Shasta Watershed Restoration Plan and the Shasta RCD Draft Incidental Take Permit Application.

Implementation actions for water use and flow sources include support for and implementation of management practices for water use and conveyance efficiency and increased dedicated cold water instream flows as presented in Shasta CRMP Shasta Watershed Restoration Plan, CDFG Coho Recovery Strategy and the Draft Incidental Take Permit Program.

Implementation actions for irrigation control structures and minor impoundment sources include support for and implementation of removal or alternation of minor impoundments to lessen their impacts on water quality, where feasible, on the mainstem Shasta River.

Implementation actions for sources related to discharges from Dwinnell Dam include requiring the Montague Water Conservation District to develop and implement a plan that contains appropriate actions to reduce nitrogenous oxygen demand from the Dwinnell Dam outflow.

Implementation actions relative to the City of Yreka Wastewater Treatment Facility include Regional Water Board staff's pursuit of compliance with existing Regional Water Board Orders, including cleanup and abatement orders and monitoring and reporting programs.

Implementation actions relative to urban and suburban runoff include supporting implementation of the management measures in the state *Nonpoint Source Pollution Control Program, Urban Management Measure*s.

Implementation actions for sources related to activities on United States Forest Service (USFS) holdings include application of prescriptions as described in the appropriate National Forest Land and Resource Management Plan.

Implementation actions for sources related to activities on Bureau of Land Management (BLM) holdings include implementation of best management grazing strategies detailed in the joint management agency document *Riparian Management, TR 1737-14 1997, Grazing Management for Riparian-Wetland Areas*.

Implementation action for timber harvest activities on non-federal land will rely on the existing regulations and permitting authority, including watercourse protection measures described in the 2006 Forest Practice Rules, general waste discharge requirements and waivers thereof.

Sources associated with California Department of Transportation will be addressed through the existing permitting program (Caltrans Storm Water Program).

Consistent with the NPS Policy, the Regional Water Board will waive the requirement to file a Report of Waste Discharge under Water Code section 13269 for responsible parties identified in the Action Plan that discharge, if the responsible party chooses to participate in the on-going collaborative programs and implement recommended measures as applicable. A discharge includes land uses that may remove and/or suppress vegetation that provides shade to a water body, tailwater runoff, and the tailrace from water impoundments. Should a responsible party that discharges choose not to participate, or if the Regional Water Board's Executive Officer determines additional measures are necessary, they must submit a Report of Waste Discharge (RWD) and filing fee to the Regional Water Board immediately or in accordance with the written notice. If the implementation actions identified in Table 4 of the Action Plan fail to be implemented by the responsible party or if the implementation actions prove to be inadequate the Regional Water Board shall take additional permitting and/or enforcement actions, as necessary. The conditional waiver will not apply to any discharges for which a WDR, waiver, or prohibition is issued under a separate action of the Board. The conditional waiver expires upon Regional

Water Board adoption of a superseding regulatory action after the evaluation period specified below for each source category, or after five years, whichever occurs first.
The nonpoint source pollution control actions contained in the Shasta River TMDL Action Plan, include a variety of measures developed to achieve water quality standards, attain the TMDLs, and comply with the NPS Policy. The five key elements of the NPS Policy are included as part of the required implementation actions for each of the sources or land use activities identified in the Action Plan. This includes specific time frames and reportable milestones for attainment of water quality requirements (Key Element 3).

Other permitting tools that may be applicable include, but are not limited to:

1. The authority to require technical reports on the conditions and operation of a facility, in accordance with Water Code section 13267.
2. The authority to require monitoring reports, in accordance with Water Code section 13267.
3. The authority to inspect a facility, in accordance with Water Code section 13267.
4. The permitting of the discharge of waste, or proposed discharge of waste, to waters of the state through Waste Discharge Requirements (WDRs), in accordance with Article 4 of the Water Code. WDRs may take the form of individual or project-specific WDRs, watershed-specific WDRs, or general WDRs that are applicable to a specific activity.
5. The authority to waive the requirements for a WDR, in accordance with Water Code section 13269.
6. The permitting of a discharge of waste to waters of the United States through National Pollution Discharge Elimination System (NPDES) permits, in accordance with Section 402 of the Clean Water Act and Water Code section 13370.
7. The certification that a proposed activity, which requires a federal permit or license, complies with water quality standards, in accordance with Section 401 of the Clean Water Act.

Enforcement tools that may be applicable include, but are not limited to:

1. The authority to require a time schedule of specific actions to be taken, in accordance with Water Code section 13300.
2. The issuance of a cease and desist order, in accordance with Water Code section 13301.
3. The issuance of a cleanup and abatement order, in accordance with Water Code section 13304.
4. The authority to impose monetary liabilities or fines (administrative civil liabilities), in accordance with Water Code sections 13268 and 13350.

Additionally, enforcement actions should be consistent with the State Water Board's *Water Quality Enforcement Policy*, adopted February 19, 2002, as SWRCB Resolution No. 2002-0040, and as subsequently amended (SWRCB 2004). The Enforcement Policy has been codified in California Code of Regulations, title 23, section 2910. The Enforcement Policy promotes a fair, firm, and consistent enforcement approach appropriate to the nature and severity of a violation.

8.1.1 Prioritization of Implementation Actions

Where reaches of the Shasta River and its tributaries are providing suitable freshwater salmonid habitat, including providing connectivity of the stream system and/or refugia for coho salmon,

protection of these areas should be a priority for restoration efforts. Further discussion with landowners and stakeholders can help determine where restoration efforts are likely to yield the greatest benefit to beneficial uses. Prioritization may be scaled to a sub-watershed or a stream reach.

8.2 Ranch and Riparian Land Management

In the Shasta River watershed, grazing and range management related activities have been observed to discharge sediment and oxygen consuming materials, and to contribute to elevated water temperatures. The Basin Plan states that: "Controllable water quality factors shall conform to the water quality objectives contained [in the Basin Plan]. When other factors result in the degradation of water quality beyond the levels or limits established [in the Basin Plan] as water quality objectives, then controllable factors shall not cause further degradation of water quality. Controllable water quality factors are those actions, conditions, or circumstances resulting from man's activities that may influence the quality of waters of the State and that may be reasonably controlled" (NCRWQCB 2005, p. 3-1.00).

These impacts are especially noticeable in locations where grazing animals have unhindered access to a watercourse where nutrients in the form of animal wastes are deposited in watercourses. Animal wastes generated at considerable distances from water bodies may also be discharged via storm water runoff or tailwater return flow to nearby watercourses. Either of these grazing activities may result in lowered dissolved oxygen concentrations. Water temperature is affected when grazing animals trample, eat, and suppress vegetation that would otherwise provide shade to a watercourse, thereby causing increases in solar radiation loads. Additionally, grazing animals often discharge sediment waste through direct soil disturbance, or indirectly when grazing animals trample, eat, and suppress vegetation, thereby reducing soil stability.

8.2.1 Grazing-Related Dissolved Oxygen and Temperature Control Actions

To address these issues, the Regional Water Board staff will encourage landowners in their employment of land stewardship practices and activities that minimize, control and, preferably, prevent discharges of sediment, nutrients and other oxygen consuming materials, as well as elevated solar radiation loads of the Shasta River and tributaries. There are a number of grazing and rangeland management practices that have already been developed by local farm bureaus, the University of California Cooperative Extension, and the Field Office Technical Guides available through the NRCS (NRCS 2002). Watershed specific measures were also developed by the Shasta Valley Resource Conservation District (Shasta RCD), Shasta Valley Coordinated Resources Management and Planning Committee (Shasta CRMP), and the California Department of Fish and Game (CDFG). Several of these management practices are listed in Table 8.2. The Regional Water Board staff will support those that oversee and manage grazing and range land activities in the Shasta River watershed to implement these practices where appropriate to their ranching and other agricultural operations. Activities on federal lands are addressed separately in sections 8.9 (Forest Service) and 8.10 (BLM) of the Staff Report.

Table 8.2: Grazing, rangeland, and riparian management practices

(1) Protect sensitive areas (including streambanks, lakes, wetlands, estuaries, and riparian zones) by (a) excluding livestock, (b) providing stream crossings or hardened access to watering areas, (c) providing alternative water locations away from surface water, (d) locating salt and additional shade, if needed, away from sensitive areas, or (e) using improved grazing management (e.g. herding) to reduce the physical disturbance and direst loading of animal waste and sediment caused by livestock; and (2) Achieve the following on range, pasture and other grazing lands not addressed under (1) above: implement the range and pasture components of a Conservation Management System (CMS) as defined in the USDA NRCS Field Office Technical Guide applying the progressive planning approach of the USDA NRCS to reduce erosion. NPS Policy (MM 1E) (SWRCB 2000)
On properties owned by participants in the ITP livestock fencing shall be in place on at least 90% of that person's owned stream bank length where there is a potential to affect coho, or fencing shall be in active progress towards implementation along those streams with installation by January 1, 2008, and/or shall have CDFG approved livestock management measures in place that will provide similar protections to the streambanks and riparian zone. Livestock riparian exclusion fencing built after 3-30-05 needing to comply with the permit must be approved by SVRCD, will be expected to have a setback of at least 35 feet from normal high water line, and shall be maintained in good working order as long as the permit is in place and livestock are present. Draft Shasta ITP (Minimization Measures B) (SVRCD 2005b)
SVRCD will work with landowners and DFG on appropriate methodology and riparian species selection on a site by site basis. Draft Shasta ITP (Minimization Measures C) (SVRCD 2005b)
Grazing along the steam corridor may occur as a mechanism of riparian management and will be coordinated with the SVRCD, the landowners and CDFG staff. Draft Shasta ITP (Table 1-1) (SVRCD 2005b)
Planting of riparian vegetation along stream banks will be coordinated with the SVRCD, the landowners and CDFG staff. Draft Shasta ITP (Table 1-1) (Table 1-1) (SVRCD 2005b)
Address factors that contribute to high temperatures. Coho Recovery Strategy (HM-5a, b) (CDFG 2004b)
Promote coho salmon recovery by minimizing diversion entrainment, protecting riparian vegetation, and encouraging effective land use practices. Coho Recovery Strategy (P-1 through P-7).(CDFG 2004b)
Increase riparian vegetation. Coho Recovery Strategy (HM-4a-d) (CDFG 2004b)
Continue program of riparian fencing and native tree planting. Shasta Watershed Restoration Plan (Shasta CRMP 1997)

The Shasta CRMP provides a multi-interest effort to cooperatively seek solutions, to help manage local resources, and to solve related problems (Shasta CRMP 2005). It completed the *Shasta Watershed Restoration Plan* (Shasta Restoration Plan) in 1997, which addresses multiple watershed issues including nutrient sources and other oxygen consuming materials that influence dissolved oxygen concentrations and elevated solar radiation loads to waters of the Shasta River system.

The Shasta Restoration Plan identifies the following recommended actions for ranch and riparian land management: 1) Continue program of riparian fencing for livestock control; 2) increase shade; 3) reduce fine sediment in spawning gravel; 4) continue native tree planting; and 5) focus erosion controls on methods that will be both effective and result in ongoing vegetative bank protection. The community-based nature of the Shasta CRMP, its accomplishments to date, history in the watershed, and the trust established with a diverse group of landowners and stakeholders make the Shasta CRMP highly suited to implement dissolved oxygen and temperature control strategies and practices. Because of its unique standing in the watershed, the Shasta CRMP is also in the valuable position of being able to effectively encourage and assist landowners in developing and implementing management practices that prevent, minimize, and control discharges.

First, the Regional Water Board and staff shall increase efforts to work cooperatively with the Shasta CRMP to provide technical support and information to willing individuals, landowners, and community members in the Shasta River watershed and to coordinate educational and outreach efforts.

Second, the Regional Water Board will coordinate with the Shasta CRMP to: (1) implement the strategic actions specified in the Shasta Restoration Plan, and (2) assist landowners in developing and implementing management practices that are adequate and effective at preventing, minimizing, and controlling discharges of nutrients and other oxygen consuming wastes, and elevated solar radiation loads. Such actions should address many of the sources of nutrients and oxygen consuming wastes and elevated water temperatures in the watershed. By implementing these restoration measures, the Shasta CRMP will greatly aid in the attainment of dissolved oxygen and temperature water quality standards in the Shasta River watershed. Additionally, implementing the strategic actions will likely result in a higher priority ranking for the Shasta CRMP when applying for grant funding from the Regional and State Water Boards.

Regional Water Board staff will coordinate with the Shasta CRMP to develop appropriate methods to monitor the Plan's implementation and effectiveness. Regional Water Board staff will provide annual updates to the Regional Water Board on the status of the program's effectiveness in achieving compliance with the TMDL, Basin Plan, and the NPS Policy.

Additionally, the Regional Water Board shall take appropriate permitting actions as necessary to address the removal and suppression of vegetation that provides shade to a water body in the Shasta River watershed. Such actions may include, but are not limited to, prohibitions, waste discharge requirements (WDRs) or waivers of WDRs for grazing and rangeland activities, farming activities near water bodies, stream bank stabilization activities, and other land uses that may remove and/or suppress vegetation that provides shade to a water body. Should prohibitions, waivers or WDRs be developed, they may apply to the entire North Coast Region or just to the Shasta River watershed.

8.2.2 Ranch Management Plans for Grazing Activities

Should voluntary efforts fail to be adequate and effective at preventing, minimizing, and controlling discharges of sediment, nutrients and other dissolved oxygen consuming materials, and elevated solar radiation loads, or a responsible party chooses to not participate in voluntary efforts, the Regional Water Board may require the appropriate responsible parties to develop, submit, and implement a ranch management plan. Any landowner is potentially subject to this requirement if livestock grazing activities on their property are discharging, or threatening to discharge oxygen consuming materials and/or are resulting in elevated solar radiation loads to a water body in the Shasta River watershed. The Regional Water Board's Executive Officer will require a ranch management plan and monitoring on an as-needed, site-specific basis, as determined by Regional Water Board staff.

Staff shall consider the following criteria when determining whether a ranch management plan is appropriate: 1) grazing activities that are the greatest threat to water quality, specifically the impacts of the discharge or threatened discharge to dissolved oxygen loads and/or the potential to increase water temperatures that affect the beneficial uses of the Shasta River and its tributaries; and 2) significance of the discharge, including such factors as volume, percent delivery, and the feasibility and reasonableness of control.

The ranch management plan shall describe in detail:

1. Locations discharging and/or with the potential to discharge nutrients and other oxygen consuming materials, and elevated solar radiation loads to watercourses which are caused by livestock grazing.
2. How and when identified sites are to be controlled and monitored, and management practices that will be implemented to prevent and reduce future discharges of nutrients and other oxygen consuming materials, and elevated solar radiation loads to the Shasta River and its tributaries.

For stakeholders with mixed-use property management activities, such as range management and irrigated agriculture, the ranch management plan shall consider and include all aspects of such mixed land use management strategies. Should a landowner/discharger be required to develop, submit, and implement a ranch management plan and conduct effectiveness monitoring, the landowner/discharger will be notified in writing of the requirements. It is likely the landowner/discharger will first be asked to submit any pertinent information on grazing-caused discharges and management practices previously collected and completed by the landowner/discharger. Following analysis of this information, the Executive Officer shall determine if further information, in the form of a ranch management plan, is required. A ranch management plan will likely not be required if the landowner/discharger has already developed and is implementing grazing practices that are determined to be adequate and effective at preventing, minimizing, and controlling discharges of oxygen consuming material and elevated solar radiation loads. Additionally, the Executive Officer shall specify in writing the required contents of a ranch management plan.

The Shasta CRMP's role may entail assisting applicable stakeholders in developing individual or group ranch management plans. Ranch management plans shall include methods, activities, and systems to assure that oxygen consuming materials, organic compounds, and other oxygen demanding substances that may contribute to lowered dissolved oxygen levels are not discharged to affected watercourses. Where appropriate, a ranch management plan shall also address actions to reduce solar radiation loads to affected watercourses. The ranch management plan shall also illustrate compliance, as applicable, with the *Plan for California's Nonpoint Source Pollution Control Program, Section 1. Agricultural Management Measures, Subsections 1A-1F* (SWRCB 2000), Regional Water Board directives, the Basin Plan, and also with the Management Measures in the Nonpoint Source Pollution Control Plan.

8.2.3 Stream and Wetland System Protection Policy

The Regional Water Board shall also address the removal and suppression of vegetation that provides shade to a water body through the up-coming Stream and Wetland System Protection Policy. During the 2004 Triennial Review of the Basin Plan, the Regional Water Board determined that the development of a riparian protection policy was a high priority. This policy will be comprehensive and region-wide and will address, in part, the importance of shade on instream water temperatures. This policy will also be developed to comply with the five key elements of the NPS Policy. As the Stream and Wetland System Protection Policy will potentially propose new rules and regulations in the form of riparian setbacks, buffer widths, or other specific measures, the policy will take the form of a Basin Plan amendment with associated public noticing, review and comment period, and other environmental review requirements. As a result of Regional Water Board action on the Stream and Wetland System Protection Policy, modifications of measures recommended in the Shasta River TMDL Action Plan may be required for consistency with this policy. Regional Water Board staff, and their contractors, are currently developing the policy under a grant from the U.S. EPA. A draft of the policy is scheduled for public review in the Spring of 2007 with adoption by the Regional Water Board scheduled for Fall of 2007.

Permitting Action Development Schedule: The Regional Water Board shall develop and take appropriate permitting and enforcement actions to address the removal and suppression of vegetation that provides shade to a water body in the Shasta River watershed as more information becomes available on where discharges are occurring. Such actions may include, but are not limited to, general waste discharge requirements (WDRs) or waivers of WDRs for grazing and rangeland activities, farming activities near water bodies, stream bank stabilization activities, and other land uses that may remove and/or suppress vegetation that provides shade to a water body. Should prohibitions or general WDRs be developed, they may apply to the entire North Coast Region or just to the Shasta River watershed.

Compliance Schedule: Within ten years of EPA approval of the TMDL, all identified discharges associated with riparian land use activities shall be in compliance with water quality standards, the TMDLs and the NPS Policy.

8.3 Tailwater Return Flow

The Temperature TMDL (Chapter 6) determined that tailwater flowing over land exposed to solar radiation can increase significantly in temperature before discharging to nearby watercourses. Results from the Dissolved Oxygen Source Analysis (Chapter 4), also show that tailwater return flows are contributing factors to low dissolved oxygen concentrations in waters of the Shasta River. Tailwater associated with field flooding (sheet) irrigation methods are known to accumulate, transport, and discharge oxygen consuming materials including, among others, excess nitrogenous and phosphorous bearing compounds. This enriched tailwater contributes to the elevated nitrogenous oxygen demand (NBOD) rates in receiving waters where it is discharged and, as such, is a controllable water quality factor.

Additionally, sediment enriched tailwater return flows also appear to contribute to elevated sediment oxygen demand (SOD) rates in the Shasta River (Chapter 7). Elevated SOD results in reduced dissolved oxygen concentrations that are harmfully impacting the beneficial uses of water, particularly the salmonid populations of the Shasta River system.

Proper tailwater management is a major factor in achieving compliance with Basin Plan objectives and the TMDL. Therefore, it was determined that there should be no net increase in stream temperature from tailwater return flows. The water quality compliance scenario of the dissolved oxygen TMDL (Chapter 7), calculated that a 50% reduction in photosynthetic and respiration rates from existing baseline conditions is achievable, when assuming a 50% reduction in the standing crop of aquatic vegetation. Hence, by reducing fine sediment sources to the river system the production of aquatic plants may also be reduced.

8.3.1 Implementation Actions

A number of tailwater management practices are presented in the NPS Program, CDFG Coho Recovery Strategy, the Shasta CRMP Shasta Restoration Plan, and the Shasta RCD Draft Incidental Take Permit Application. Practices include the reuse of tailwater, constructing off-stream retention ponds for percolating tailwater through the ground, and a community based approach to managing tailwater among groups of water users. Tailwater management practices are summarized below in Table 8.3.

Table 8.3: Tailwater Return Flow Management Measures

Develop and implement comprehensive nutrient management plans for areas where nutrient runoff is a problem affecting coastal waters and/or water bodies listed as impaired by nutrients. Such plans would include a plant tissue analysis to determine crop nutrient needs; crop nutrient budget; identification of the types, amounts, and timing of nutrients necessary to produce a crop based on realistic crop yield expectations; identification of hazards to the site and adjacent environment; soil sampling and tests to determine crop nutrient needs; and proper calibration of nutrient equipment. When manure from confined animal facilities is to be used as a soil amendment and/or is disposed of on land, the plan shall discuss steps to assure that subsequent irrigation of that land does not leach excess nutrients to surface or ground water. NPS Program (MM 1C) (SWRCB 2000)
Capture of additional tailwater from on-site or neighboring fields. Draft Shasta ITP (Table 1-1) (SVRCD 2005b)
The Shasta RCD will assist landowners/sub-permittees in designing and implementing tailwater capture systems that intercept and reuse runoff from on-site and off-site properties in accordance with standards outlined by the Natural Resources Conservation Service NRCS. Draft Shasta ITP (Table 1-1) (SVRCD 2005b)
Conduct assessments of tailwater return flows, promote opportunities to eliminate, minimize, reclaim and reuse, where feasible. Coho Recovery Strategy (WUE-7a-c) (CDFG 2004b)
Manage tailwater return flows so that entrained constituents, such as fertilizers, fine sediment and suspended organic particles, and other oxygen consuming materials are not discharged to nearby watercourses. This could include modifications to irrigation systems that reuse tailwater by constructing off-stream retention basins, active (pumping) and or passive (gravity) tailwater recapture/redistribution systems. (U.C. Davis 1998; NRCS 1997b)
Seek ways to reduce irrigation tailwater, or capture for reuse. Shasta Watershed Restoration Plan (Shasta CRMP 1997)

Implementing these management practices can assist in moderating and/or reducing water temperatures and decreasing substances that reduce oxygen levels in the Shasta River system. Parties responsible for tailwater discharge from irrigated lands, which may include landowners, lessees, and land managers, should implement the management practices described above. Regional Water Board staff will evaluate the effectiveness of these actions and develop recommendations, which may include parts or all of the management measures in Table 8.3, to determine the most effective regulatory vehicle to bring tailwater discharges into compliance with the TMDL and the Basin Plan. Information gathered during the evaluation phase will be used to formulate final recommendation(s) for the Regional Water Board’s consideration. This evaluation phase shall be completed within one year of U.S. EPA approval of the TMDL.

Based on Regional Water Board staff recommendation(s) derived from the evaluation phase for tailwater management, the Regional Water Board shall adopt as appropriate, prohibitions, WDRs, waivers of WDRs, or any combination, thereof.

8.3.2 Tailwater Management Plan

Should voluntary efforts fail to be adequate and effective at preventing, or reducing water temperatures and decreasing substances that reduce oxygen levels in the Shasta River system, or a responsible party chooses to not participate in voluntary efforts, the Regional Water Board may require the appropriate responsible parties to develop, submit, and implement a tailwater management plan. The Regional Water Board's Executive Officer will require a tailwater management plan and monitoring on an as-needed, site-specific basis, as determined by Regional Water Board staff. The plan may include various elements such as discharge and receiving water sampling, monitoring, and reassessment. Additional management practices to assure that tailwater discharges to receiving waters comply with the TMDL and the Basin Plan may also be based on results from the tailwater management program.

<u>Permitting Action Development Schedule:</u> Within one year of the date the TMDL Action Plan takes effect, the Executive Officer shall provide a recommendation to the Regional Water Board on the most effective and appropriate permitting action(s) to address discharge from tailwater sources.
<u>Permitting Action Adoption Schedule:</u> Within five years of EPA approval of the TMDL, the Regional Water Board shall adopt a permitting mechanism to ensure tailwater discharges are in compliance with water quality standards, the TMDLs and the NPS Policy.
<u>Compliance Schedule:</u> Within ten years of EPA approval of the TMDL, all discharge of tailwater shall be in compliance with water quality standards, the TMDLs and the NPS Policy.

8.4 Water Use and Flow

Natural flows of the Shasta River system, in addition to seasonal snowmelt, are augmented by ground water accretion or as surface spring inflows. Surface water derived from a number of the larger springs, particularly those feeding certain reaches of Parks and Big Springs Creeks and the mainstem Shasta River, provided a source of cold water that noticeably decreases surface water temperature downstream from the springs. Additionally, the cumulative volumes of water discharged by these springs, if not diverted, would increase the overall volume of water in downstream watercourses, thus, increasing the thermal mass and velocity of the water. A significant source of cold groundwater to the Shasta River is that of Big Springs.

The TMDLs for both water temperature and dissolved oxygen show that decreased flows in the Shasta River mainstem and select tributaries are detrimentally affecting the beneficial uses of the cold water fishery. Surface water diversions in the Shasta River watershed has one of the most significant effects on stream temperatures and dissolved oxygen levels. Flow is diverted from natural sources for irrigation, stock watering, and domestic use.

The SWRCB, Division of Water Rights is the agency with authority to oversee and regulate water rights. Currently, the Division of Water Rights does not accept applications to appropriate surface water from the Shasta River because the stream system is listed on the Declaration of Fully Appropriated Streams. (SWRCB WR Order 98-08.) Surface water diversions in the Shasta watershed were subject to a statutory adjudication that resulted in a judgment and decree approved by the Superior Court of the State of California, in Siskiyou County in 1932 (Siskiyou County Superior Court, 1932). Water rights are apportioned by quantity, and priority date. Senior right holders have earlier priority and may divert their entire share before those that are junior. The watermaster manages the water allocation on a day-to-day basis in accordance with the decree. At the time the watershed was adjudicated, there were approximately 40,000 acres of irrigated agriculture. Today there are 50,000 acres under irrigation. Riparian rights and groundwater pumping are not subject to the decree. Also, the decree contains no requirements for the protection of instream beneficial uses or consideration of the public trust doctrine.

8.4.1 Implementation Actions

A number of actions relative to water use and increasing instream flow were developed and presented by CDFG in the Shasta RCD Draft Incidental Take Permit Application and Coho Recovery Strategy. The Shasta CRMP also developed measures to address instream flow in the Shasta Restoration Plan. A summary of the instream flow and water use measures are presented in Table 8.4. These programs, when implemented, will help attain the TMDL and meet the water quality objectives in the Basin Plan. A brief overview of each program is discussed below.

Table 8.4: Instream Flow Management Measures

Promote effective irrigation while reducing pollutant delivery to surface and ground waters. Pursuant to this measure, irrigation water would be applied uniformly based on an accurate measurement of cropwater needs and the volume of irrigation water applied, considering limitations raised by such issues as water rights, pollutant concentrations, water delivery restrictions, salt control, wetland, water supply and frost/freeze temperature management. Additional precautions would apply when chemicals are applied through irrigation. . Additional precautions would apply when chemicals are applied through irrigation. NPS Policy (MM 1F) (SWRCB 2000)
All persons covered by the permit and diverting water from within the Shasta River watershed will be expected to support ongoing watermaster services (either by DWR or by some other entity) should DWR cease to provide service) and pay their proportionate coast of that service to provide watermaster service in the Shasta Valley between April 1 and October 1 when instream flows are likely to be most critical to coho. Individual proportional costs for this activity are expected to continue to be collected by the County of Siskiyou via annual property taxes. Those participants exercising riparian rights and not subject to watermaster control will cooperate with the watermaster in assuring they are within their legal rights and will inform the watermaster of any changes in the quantities of water they will be diverting. Draft Shasta ITP (Avoidance Measures III. A. i.) (SVRCD 2005b)
DFG, DWR, and the SVRCD shall develop and implement a management plan to coordinate and monitor irrigation season start up so as to minimize rapid deductions in instream flows. A draft Ramped Diversion Plan will be submitted to DFG by January 1, 2007 with a finalized plan submitted by January 1, 2008. Draft Shasta ITP (Avoidance Measures III. A. ii.) (SVRCD 2005b)
All persons covered by the ITP shall endorse continued efforts by DWR or other private watermaster organizations, to assure that flows year round shall not be allowed to fall below 20 cfs at the Shasta River near Montague (SRM) gage, a quantity that has been historically the watermaster's minimum target for flow at that location, nor that flows at A-12 shall fall below 45 cfs at any time during the summer, a quantity that will assure that substantial cold water refugia areas are retained upstream of the point. Draft Shasta ITP (Avoidance Measures III. A. iii.) (SVRCD 2005b)
The SVRCD will develop a dry and critically dry year plan to assure that stranding, or elimination of needed cold water refugia areas does not occur during extremely dry years. The dry year plan will be developed by SVRCD and will insure that previously described flows at 50 cfs at A-12 and 20 cfs at Montague-Grenada road are achieved. A draft Dry Year Plan will be completed by the SCRCD one year from the issuance of the permit. Draft Shasta ITP (Avoidance Measures III. F) (SVRCD 2005b)
The SVRCD will work with those entities seeking coverage under the ITP to assist them in their efforts to upgrade overall irrigation efficiency. Potential projects that may be implemented to improve flows include upgrade of water delivery systems to reduce waste, upgrade of water application systems, monitoring crop water requirements vs. soil moisture, etc. Draft Shasta ITP (Minimization Measures V. A. i.) (SVRCD 2005b)

Table 8.4 (continued): Instream Flow Management Measures

Encourage the Shasta CRMP to develop a dry year water plan for the Shasta River watershed. Coho Recovery Strategy (WM-1a) (CDFG 2004b)
Add additional oversight and more people to verify water use and better manage water in current watermaster service areas. Coho Recovery Strategy (WM-2a) (CDFG 2004b)
Institute a cooperative agreement between diverters to stage/stagger their irrigation starts and completions (ramped flows) to gradually change flows over several days. Coho Recovery Strategy (WM-3a) (CDFG 2004b)
CRMP, CDFG, and voluntary landowner participation: agree to pull diversions for a limited time period to produce a pulsed flow downstream. Coho Recovery Strategy (WM-4a) (CDFG 2004b)
Determine unused diversion rights and approach those diverters about providing flows for instream use without affecting the water rights of others. Coho Recovery Strategy (WM-5c) (CDFG 2004b)
For critical streams/reaches, diverters could rotate irrigations so diversions do not coincide when increased flows are critical for fish. Coho Recovery Strategy (WM-6a(CDFG 2004b).
Provide headgates and measuring devices for diversions located in riparian areas Coho Recovery Strategy (WM-7a) (CDFG 2004b)
Study and forecast correlation of stream flow with other parameters to predict weekly flow rates. Can be based on snow surveys, precipitation, aquifer condition, etc. Coho Recovery Strategy (WM-8b) (CDFG 2004b)
Seek funding to conduct instream flow studies to determine flow-habitat relationships. Coho Recovery Strategy (WM-9) (CDFG 2004b)
Provide a structured process for willing participants to donate, sell, or lease water rights to provide improved stream flow. Coho Recovery Strategy (WA-1b, c, d & WA-7a, b, c) (CDFG 2004b)
Acquire water rights that shall be dedicated to instream flow. Coho Recovery Strategy (WA-7) (CDFG 2004b)
Support preparation of a water balance study. Apply study results to water management, augmentations, and Habitat enhancement recommendations. Coho Recovery Strategy (WM-1b) (CDFG 2004b)
Study feasibility of building storage reservoirs to capture excess winter runoff (solely) for the benefit of coho salmon, not for irrigation augmentation. Coho Recovery Strategy (WA-2a & WA-3b) (CDFG 2004b)
Identify and prioritize benefits and/or detriments to lining/piping surface ditch systems; promote ongoing diversion ditch maintenance. Coho Recovery Strategy (WUE-3; WUE-4) (CDFG 2004b)
Promote and/or retain water efficient irrigation practices. Coho Recovery Strategy (WUE-5a-e) (CDFG 2004b)
Prepare a comprehensive groundwater study to determine the current status of groundwater in the Shasta Valley and its relationship to surface flows. Coho Recovery Strategy (WM-10a) (CDFG 2004b)
Continue pulsed flow program to flush salmonids downstream during lethal water temperature conditions. Shasta Watershed Restoration Plan (I B-2) (SRCRMP 1997)
Support creation of dedicated instream flows for fish and wildlife. Shasta Watershed Restoration Plan (I B-2) (Shasta CRMP 1997)
Contemplate the impacts of readjudication of both surface and ground water. Shasta Watershed Restoration Plan (I B-9) (Shasta CRMP 1997)
Continue pulse flows until water quality is improved. Shasta Watershed Restoration Plan (III B-3.e) (Shasta CRMP1997)
Seek funding for purchase of water for instream flows from willing sellers. Shasta Watershed Restoration Plan (III B-6) (Shasta CRMP 1997)
Where other means of adequate protection (for fish) are unlikely, support the purchase of key (property) areas from voluntary sellers whose sale would protect remaining land uses in the Shasta Valley. Shasta Watershed Restoration Plan (III B-7) (Shasta CRMP 1997)

8.4.2 Incidental Take Permit Program

Section 1602 of the California Endangered Species Act prohibits the unauthorized take[1] of threatened species, including coho salmon. "The CDFG may authorize take of a listed species by issuing a permit, known as an 'Incidental Take Permit,' if the take is incidental to otherwise lawful activity, such as a permitted agricultural diversion, and any take is minimized and fully mitigated" (CDFG 2005a, p. 1). Parties whose activities may result in a take of coho salmon can comply with Section 1602 by individually applying for an Incidental Take Permit. To ease possible burdens on landowners conducting certain activities in the Shasta River watershed, the CDFG is currently working with the Shasta RCD on a watershed-wide permitting approach to implementing the Incidental Take Permit Program (SVRCD 2005b). The primary activity covered by the Incidental Take Permit in the Shasta River watershed is surface water diversions associated with irrigated agriculture. Other activities include livestock management, fishery restoration projects, streambed and bank alterations, and vehicular impacts. Under the Watershed-Wide Incidental Take Permit, the Shasta RCD will be the permit holder allowing individual landowners to enroll in the program as sub-permittees. The sub-permittees will work directly with the Shasta RCD, avoid a CDFG fee, and be protected from enforcement action under the Endangered Species Act.

In order to fully avoid, minimize, and mitigate for incidental take of coho salmon under the Watershed-Wide Incidental Take Permit, the Shasta RCD developed avoidance, minimization, and mitigation measures, along with a plan to monitor effectiveness and compliance. For more information and details on these measures, see the Draft Incidental Take Permit Application (SVRCD 2005b) available from the Shasta RCD.

The Shasta RCD has submitted its application in March 2005 to CDFG for their Watershed-Wide Incidental Take Permit for Coho Salmon. CDFG is currently reviewing the application. Changes to the scope of the permit and the avoidance, minimization, and mitigation measures may occur.

The Shasta RCD draft application for an Incidental Take Permit for coho salmon requires prospective sub-permittees in the program to participate in watermastering control and oversight (SVRCD 2005b). Non-participation in watermastering services results in exclusion of sub-permittees from the Incidental Take Permit program and, therefore, makes them subject to regulation and enforcement actions by the CDFG if a take of coho salmon is deemed likely from the water diverter's improper use of their water allocations. The Regional Water Board recognizes that not all agricultural and other water users with water rights diversions included in the Shasta River Decree may choose to, or are obligated to participate in the Shasta RCD Incidental Take Permit program. Therefore, to achieve strict and efficient use and conservation of diverted water, all water users with decreed rights to water in the Shasta Valley, including all waters upstream of Dwinnell Dam, are encouraged by the Regional Water Board to participate as sub-permittees in the Coho Salmon Incidental Take Permit Program upon final approval by the CDFG and adoption by the Shasta RCD.

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[2] Take means to hunt, pursue, catch, capture, or kill, or attempt to hunt, purse, catch, capture, or kill.

8.4.3 Coho Recovery Strategy

The CDFG has also developed a statewide *Recovery Strategy for California Coho Salmon* (Coho Recovery Strategy), which includes descriptions of the Shasta River watershed and recommendations for the recovery of coho salmon that are specific to both the Shasta River and Shasta River watersheds (CDFG 2004b). Implementation actions in the Coho Recovery Strategy are mostly of a general nature, but in many instances, they address individual streams and reaches, and near-stream and upslope areas when deemed critical to the recovery of coho salmon habitat.

Many of the recovery recommendations, or "tasks" detailed in the Coho Recovery Strategy focus on issues and actions pertinent to the efforts of the TMDL. Several management measures, all of which can be adapted to increasing instream flows in the Shasta River and its tributaries, include water conservation. Other management measures recommend the leasing, purchasing, or donations of water rights from willing water rights holders in the Shasta River watershed. All water diverters in the Shasta River watershed should participate in this program. The Regional Water Board shall work with the CDFG and aid, where appropriate, in the implementation of necessary tasks, actions, and recovery recommendations as specified in the Coho Recovery Strategy. The first step in this process will likely be the creation of an inter-agency working group. Regional Water Board staff also intends to work with CDFG staff in the development of the Watershed-Wide Incidental Take Permit, especially in relation to criteria for the management of grazing practices, riparian shade and other streamside activities, irrigated agriculture and other water use activities affecting the beneficial uses of water.

8.4.4 Shasta River Coordinated Resource Management and Planning Committee

In addition to the programs described above, a number of water efficient conservation practices are recommended in the Shasta CRMP Shasta Watershed Restoration Plan. The Shasta Restoration Plan provides water users throughout the Shasta River watershed with water management practices that would assist efforts in assuring adequate instream flows.
Financial aid and staffing assistance with the above tasks may be available through the SWRCB, DWR, CDFG, NRCS, U.C. Cooperative Extension, the Shasta RCD, Shasta CRMP, USEPA, and/or other organizations.

Implementation of water conservation measures may not be effective in benefiting water quality because other water right holders may divert more water if more water is left available in the stream. In addition, an appropriative water right holder risks forfeiture for non-use if water is not used for a period of five years. The law of forfeiture applies to appropriative water rights, including those that were adjudicated, but will not affect riparian rights. The goal of water conservation is to increase stream flows to protect instream beneficial use. There are numerous legal tools available to water diverters to ensure that conserved water is applied to instream beneficial uses and will not be lost to forfeiture. Water made available through the implementation of conservation measures must be dedicated to beneficial use in order to be effective under this Plan. Dedicated means that the diverter, either individually or as a group, can demonstrate that the measure contains assurances that it will result in water quality benefits.

For example, under Water Code section 1707, any person entitled to use water, whether based on an appropriative, riparian, or other water right, may petition the State Water Board to change the purpose of use to the preservation and enhancement of wetlands habitat, fish and wildlife resources, or recreation. The State Water Board may approve the petition if the change does not increase the amount of the original entitlement, does not unreasonably affect any legal user of water, and meets other requirements of the Water Code. The Action Plan also encourages water conservation and other flow measures on a watershed-wide scale to be the most effective, such as coordinating pulse flows as contemplated in the CDFG Coho Recovery Strategy. The Plan allows for creative solutions to dedicate these flow measures, including collaborative agreements. Any agreement should clearly delineate how measures ensure benefits to water quality.

If the measures summarized in Table 8.4 fail to be implemented or effective, the Regional Water Board will consider other actions for flow related impacts on water quality. The SWRCB Division of Water Rights is the agency primarily responsible for water right administration. Regional Water Board action consists primarily of various recommendations for state action. It may be appropriate for the State Water Board to consider various options in the water rights context to respond to the over-allocation, including but not limited to, seeking modifications of the decree, proceedings under the public trust doctrine, and/or proceedings under the waste and unreasonable use provisions of the California Constitution and the California Water Code. The doctrine of reasonable use “limits all rights to the use of water to quantities necessary for beneficial use, but prohibits waste or unreasonable use or unreasonable methods of use or diversion” (SWRCB 1990). The Regional Water Board may request that the SWRCB consider riparian rights and groundwater use in reviewing the adjudications and other proceedings.

Implementation Schedule
Effective prior to the date the TMDL Action Plan is adopted, water diverters should participate in the CDFG's Coho Recovery Strategy (CDFG 2004b) and Incidental Take Permit Program (CDFG 2005a)

The Regional Water Board shall work with CDFG to establish monitoring and reporting elements of these programs in order to gauge their effectiveness. Water diverters should participate in and implement flow-related measures outlined in the Shasta CRMP Shasta Watershed Restoration Plan. The Regional Water Board shall work with the Shasta CRMP to establish monitoring and reporting elements in order to gauge the Plan's implementation and effectiveness.

Reporting Schedule:
Within two years, and again within four years, of EPA approval of the TMDL water diverters shall report to the Regional Water Board, either individually or through the Shasta Valley RCD and its CRMP, on the measures taken to increase the dedicated cold water instream flow in the Shasta River by 45 cfs or alternative flow regime that achieves the same temperature reductions from May 15 to October 15.

Within five years of EPA approval of the TMDL, water diverters shall provide a final report to the Regional Water Board, either individually or through the Shasta Valley RCD and its CRMP, on documenting dedicated cold water instream flow in the Shasta River in relation to the 45 cfs goal or alternative flow regime that achieves the same temperature reductions from May 15 to October 15.

Dedicated cold water instream flow is defined as water remaining in the stream in a manner that that the diverter, either individually or as a group, can ensure will result in water quality benefits. Temperature, length and timing are factors to consider when determining the water quality benefits of an instream flow.

If after five years, the Regional Water Board Executive Officer finds that the above-measures have failed to be implemented or are otherwise ineffective, the Regional Water Board may recommend that the SWRCB consider seeking modifications to the decree, conducting proceedings under the public trust doctrine, and/or conducting proceedings under the waste and unreasonable use provisions of the California Constitution and the California Water Code.

8.5 Irrigation Control Structures and Impoundments

Since approximately 1915, extensive irrigation water control structures have been built in many watercourses in the Shasta Valley by private landowners and/or cooperatively controlled water and irrigation districts (KRBFTF 1991). These structures consist of weirs, dams, and other minor impoundments (collectively referred to as minor impoundments), of varying construction across the Shasta River and several tributaries that impound water to achieve an irrigation head for direct and/or indirect diversion to adjacent fields. A number of these impoundments are controlled by flashboard dams and other instream structures.

Some of the known effects that minor impoundments on the Shasta River have on the beneficial uses of water include a lack of and/or insufficient riparian vegetation along natural streambanks and/or man-made structures, such as levees and the banks of the impoundments themselves. Insufficient riparian shade increases solar radiation loads. In particular, instream impoundments, by virtue of providing larger surface storage areas and shallow depths, allows increased solar radiation to reach the waters surface, which cumulatively add to increased water temperatures. Other effects include areas of localized erosion, largely caused by the lack of root strength from insufficient or non-existent streamside vegetation. Impoundments have also been shown to increase sediment oxygen demand (SOD) rates beyond what would naturally occur without the impoundments. Accumulations of fine sediment and organic particles provide favorable conditions for the growth of aquatic macrophytes that, in turn, can trap and store additional fine sediment. These conditions are well suited for the growth of microbial communities that contribute to the relatively high sediment oxygen demand rates in select reaches of the Shasta River system affected by impounded water.

The Dissolved Oxygen TMDL (Chapter 7) determined that water quality compliance for dissolved oxygen concentrations could be achieved if the sediment oxygen demand rates were reduced by 50% from the existing rates (referred to as baseline) at river locations influenced by minor impoundments. Water quality compliance in the Basin Plan for waters of the Shasta Valley, excluding Lake Shastina, is a minimum dissolved oxygen concentration of 7.0 mg/L (NCRWQCB 2005).

8.5.1 Implementation Actions for Irrigation Control Structures and Minor Impoundments

The Shasta RCD and the Shasta CRMP, working cooperatively with other organizations and private parties, removed one impoundment that, since it was installed in 1889, impeded juvenile and adult salmon migration. Negotiations are ongoing for the removal and/or modification of two additional impoundments upstream from the completed project. Further upstream there are also three additional impoundments that are considered candidates for removal or modification (Shasta RCD 2005b). To assist in efforts toward achieving the TMDLs for temperature, dissolved oxygen, Basin Plan objectives and, especially the health of the cold water fishery, all stakeholders should initiate or renew efforts to arrive at viable solutions for modifying and/or removing the remaining impoundments.

In addition, to reduce solar radiation loads and sediment oxygen demand rates in the Shasta River system known to be affected by artificially impounded water, it is recommended that the various irrigations districts, individual irrigators, and other stakeholders that own, operate, manage, or anticipate construction of instream impoundments shall comply with the following measure.

Options may include, but are not limited to:

- Permanently removing impoundments in the Shasta River mainstem as a mechanism to provide for flushing flows capable of scouring fine sediment from the stream-river channel on which aquatic plants grow. Impacts to water quality to consider that may result from impoundment removal may include the short-term effects of flushing flows, instream increases in sediment routing and redistribution, bank erosion, and habitat restructuring (including possible riparian and aquatic floral and faunal alterations) to downstream reaches.

- Re-engineering existing impoundments to decrease their surface area. The same concerns expressed for impoundment removal, above, regarding water quality impacts will also warrant investigation if impoundment alterations are considered as a management practice.
- Not undertaking the construction of new impoundments unless they can be shown to have positive effects to the beneficial uses of water relative to water quality compliance and the support of beneficial uses, including the salmonid fishery, in the Shasta River watershed.

Implementation Schedule Within one year of TMDL approval by the U.S. EPA, individual landowners and/or landowner groups, irrigation districts, and any other entities responsible for owning, operating, and/or otherwise managing minor impoundments, such as flashboard dams, or other structures capable of blocking, impounding, or otherwise impeding the free flow of water in the Shasta River system shall report to the Regional Water Board methods and management practices they shall implement that will reduce sediment oxygen demand rates by 50% from baseline behind all minor impoundments.

The Regional Water Board has concluded, and strongly advocates that minor impoundments can be effectively removed and/or altered, and that new minor impoundments do not have to be constructed within those reaches of the Shasta River system without undue economic impacts to those stakeholders now dependent on their use. If it is determined that impoundment alteration or removal is a viable option, then doing so should be considered to advance the Shasta River system toward water quality compliance with the TMDL and the Basin Plan.

8.6 Lake Shastina and Dwinnell Dam

8.6.1 Dwinnell Dam

Dwinnell Dam impounds the waters of the Shasta River at approximately river mile 40, forming Lake Shastina (AKA Dwinnell Reservoir). This facility diverts water from Lake Shastina providing irrigation water for the Montague Water Conservation District (MWCD), and providing drinking water supply for the town of Mongatue..

As discussed in sections 2.4.4 and 4.4.3, during summer months dissolved oxygen concentrations in the deeper hypolimnion of Lake Shastina are below the Basin Plan objective of 7.0 mg/L, approaching anoxia at times. Further, there is known leakage from the toe of the impoundment and analysis indicates the reservoir is hydrologically connected to the Shasta River and down-gradient springs. Finally, section 2.5.2 and 4.4.3 demonstrates that concentrations of nitrogen and phosphorus in the outflow from Dwinnell Dam exceed USEPA criteria, are biostimulatory, and contribute to downstream oxygen demand. Given these findings the following action is proposed for the MWCD, the party responsible for controlling discharges from the dam: report to the Regional Water Board on a plan to bring the discharge(s) from Dwinnell Dam into compliance with the TMDLs, the Basin Plan, and the NPS Policy.

Implementation Schedule
Within 2 years of EPA approval of the TMDL the MWCD shall report to the Regional Water Board on a plan to bring the discharge(s) from Dwinnell Dam into compliance with the TMDLs, the Basin Plan, and the NPS Policy.

8.6.2 Lake Shastina

In addition to having dissolved oxygen concentrations below the Basin Plan objective during summer months, there is evidence that nitrogen concentrations in the outflow from Lake Shastina are higher than inflow concentrations (see section 4.4.3), indicating that the reservoir itself, or surrounding land uses, contributes nitrogen loads to the system.

To more fully characterize the water quality of Lake Shastina and source contributions from near- and upslope management practices, the Montague Water Conservation District, City of Weed, County of Siskiyou, Caltrans, and the Community of Lake Shastina shall take the following actions:

- Initiate, complete, and submit to the Regional Water Board Executive Officer for approval the results of a study characterizing water quality conditions and factors affecting water quality conditions in Lake Shastina.
- Develop a plan for addressing factors affecting water quality conditions in Lake Shastina
- The study and plan shall include: (1) a description of goals and objectives (NPS Policy Key Element 1), (2) data collection methods and procedures, (3) the general locations of data collection sites, (4) data analysis methods and procedures, (5) quality control and quality assurance protocols, (6) the parties responsible for data collection, data analysis, and reporting, (7) timelines and due dates for data collection, data analysis, and reporting, (8) financial resources to be used, (9) provisions for adaptive change to the investigation based on additional data and results, as they are available, and 10) appropriate actions, based on the investigation's results, to reduce nutrients and other oxygen demanding substances and to meet dissolved oxygen objectives in Lake Shastina.

Implementation Schedule
Within 2 years from EPA approval of the TMDL the Montague Water Conservation District, City of Weed, County of Siskiyou, Caltrans, and the Community of Lake Shastina shall complete the required study and plan. Within 5 years of EPA approval of the TMDL the responsible parties shall begin implementing the plan.

8.7 City of Yreka Wastewater Treatment Facility

The City of Yreka owns and operates wastewater treatment and disposal facilities (Yreka WWTF) for municipal wastewater, WDID No. 1A840730SIS, for the community of Yreka. Waste Discharge Requirements Order No. R1-2003-0047 (Order No. R1-2003-0047) issued by the Regional Water Board regulates waste treatment and disposal from the Yreka WWTF. There are four percolation ponds and a 31-acre subsurface infiltration disposal field east of State Route 263 (formerly old U.S. Highway 99) and immediately adjacent to Yreka Creek. The percolation ponds and the disposal field are constructed on the site of dredge tailings from historic gold mining (NCRWQCB 2004a). Provisions in Order No. 96-69 prohibit any direct surface and subsurface seepage discharges of raw and/or treated effluent and biostimulatory substances to Yreka Creek during any stage of operations at the Yreka WWTF. Table 8.5 shows parameters and limits for representative samples from wastewater effluent necessary for compliance with Order No. R1-2003-0047.

Table 8.5: Representative Upper Limits Samples for WDR Order No. 96-69 of Wastewater Effluent from the Yreka Wastewater Treatment Facility

	30-day Unit	7-day Average[1]	Daily Average[2]	Constituent Maximum
BOD [20^{O}C (68^{O}F), 5-day]	mg/l	30	45	60
Suspended solids	mg/l	30	45	60
Settleable Solids	ml/l	0.1	---	0.2
Coliform organisms (Total)	mpn/100 ml	23[3]	---	230
Hydrogen Ion	pH	Not less than 6.5 nor greater than 8.5; within this range, the discharge shall not cause the pH of receiving waters to be changed at any time more than 05 pH units from which occurs naturally		

[1]The arithmetic mean of the values for effluent samples collected in 30 consecutive days.
[2]The arithmetic mean of the values for effluent samples collected in 7 consecutive days
[3]Median

Additionally, eight Basin Plan water quality objectives for the receiving waters of Yreka Creek were emphasized in the Order, including the following three most pertinent to the TMDL:

- Waste discharges must not cause the dissolved oxygen concentrations to be depressed below 7.0 mg/l.
- During critical spawning and egg incubation periods the dissolved oxygen concentration from discharges shall not be depressed below 9 mg/l.
- The discharge must not contain concentrations of biostimulants that promote objectionable aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses of the receiving waters.

Bacteria, algae, and higher aquatic macrophytes require a variety of nutrients for growth and reproduction; some of the nutrients may be released during the decomposition of these plants, which may then act as biostimulatory oxygen--consuming materials, particularly nitrogenous and phosphorous compounds. Discharges of these oxygen consuming materials beyond that necessary to maintain natural populations of aquatic vegetation and bacteria often negatively affect dissolved oxygen concentrations beneficial to resident and anadromous salmonids, and adversely affect general stream health.

In 1997 and 1998, during field inspections and routine monitoring report reviews, the Regional Water Board determined that waste discharges were occurring from the lower percolation ponds to a cutoff trench that discharges directly to Yreka Creek. Subsequent laboratory sample analysis confirmed that levels of phosphorous, nitrogen, and ammonia in the percolation ponds, the cutoff trench drainage, and Yreka Creek below the percolation facilities were elevated compared to sample points upstream from the Yreka WWTF. Subsequently, Cease and Desist Order (CAO) No. 98-103 was adopted by the Regional Water Board during September 1998, requiring elimination of waste discharges to Yreka Creek. In May, 2003, the CAO No. 98-103 was rescinded and replaced with WDID Order No. R1-2003-0048 to reflect and include improvements and upgrades to the Yreka WWTF. A major addition to the Yreka WWTF was the construction of the 31-acre subsurface infiltration field, just north of the percolation ponds. Monitoring and Reporting Program No. R1-2003-0047 was then issued in May 2003 to encompass changes to the operation of the WWTF.

After Order No. R1-2003-48 was in effect, Regional Water Board staff observed, and sample analyses indicated, that during the wet weather seasons of 2003 and 2004 waste effluents containing elevated levels of oxygen--consuming materials and other biostimulatory discharges were, in all likelihood, reaching Yreka Creek after the 31-acre infiltration field was taken out of service. Consequently CAO No. R1-2004-0037 was issued, directing the Yreka WWTF to comply with the WDRs in Order No. 96-69. To date there is no record of abatement of oxygen consuming material and other discharges that may affect dissolved oxygen concentrations to Yreka Creek from the Yreka WWTF.

In order to prevent, minimize, and control discharges of oxygen consuming material and other biostimulatory waste that may cause dissolved oxygen excursions from narrative and numeric requirements to Yreka Creek and or/the TMDL for the Shasta River, whichever is more protective of the beneficial uses of water, the Regional Water Board staff shall pursue aggressive compliance with Order No 96-69, and CAO No.R1-2004-0037. To ensure timely submittal of sampling and analytical results from the operators of the Yreka WWTF, the Regional Water Board staff shall also continue vigorous oversight and enforcement of Monitoring and Reporting Program No. R1-2003-0047.

Implementation Schedule
Regional Water Board staff is presently actively involved, and will continue to assist the City of Yreka's WWTF to achieve compliance with Order No. 96-69, CAO No. R1-2004-0037, and Monitoring and Reporting Program No. R1-2003-0047.

8.8 Urban and Suburban Runoff

Concerns have been expressed regarding urban and suburban polluted nonpoint source stormwater discharges to various watercourses in the Shasta Valley watershed from sources within and/or under the sphere of influence of urban population centers. The three largest urban and/or industrial population concentrations include the cities of Yreka, Weed, and the Lake Shastina Development. To date, these cities and developments have not characterized nonpoint source pollutant discharges (SVRCD 2005a). Municipal, industrial, and residential properties are often sources of a number of nonpoint source pollutants that are carried in stormwater via roads, drainage ditches, stormwater systems, and other runoff conveyances to nearby watercourses. Runoff from these sources often contains nutrient and bacterial products from lawn and garden fertilizers, detergents, pet wastes, and faulty septic systems. Other pollutants from urban and residential areas may include pesticides, herbicides, antifreeze, heavy metals, and petroleum products. Yreka Creek and other tributaries to the Shasta River, the mainstem Shasta River and, ultimately, the Klamath River are the potential receiving waters of many of these pollutants from upstream urban and suburban sources.

The SWRCB's *Plan for California's Nonpoint Source Pollution Control Program, Urban Management Measures, §3.1-§3.6- urban sources of nonpoint pollution* (SWRCB 2000), provides guidance for the implementation of watershed management measures for the characterization, reduction, and/or control of polluted runoff to nearby watercourses. These measures are summarized in Table 8.6. In addition to addressing sediment generating nonpoint pollution sources, many of these management measures, though general in nature, have been shown to be effective in reducing discharges of nutrients, other oxygen consuming constituents, and biostimulatory materials to local waterbodies.

Table 8.6 Urban and Suburban Runoff Management Measures from NPS Program

Develop a watershed protection program to 1. Avoid conversion, to the extent practicable, of areas that are particularly susceptible to erosion and sediment loss; 2. Preserve area that provide important water quality benefits and/or are necessary to maintain riparian and aquatic biota; 3. Protect to the extent practicable the natural integrity of water bodies and natural drainage systems associated with site development – including roads, highways and bridges; 4. Limit increases of impervious surfaces; and 5. Provide education and outreach to address NPS pollution.
Plan, design and develop sites to: 1. Protect areas that provide important water quality benefits necessary to maintain riparian and aquatic biota, and/or are particularly susceptible to erosion or sediment loss; 2. Limit increase in impervious areas; 3. Limit land disturbance activities such as clearing and grading and cut and fill to reduce sediment loss; and, 4. Limit disturbance of natural drainage features and vegetation.
By design or performance: 1. After construction has been completed and the site is permanently stabilized, reduce the average total suspended solids (TSS) loading by 80 percent (for purposes of this measure, an 80 percent TSS reduction is to be determined on an average annual basis; or 2. Reduce the post-development loading of TSS so that the average annual TSS loadings are no greater than pre-development loadings. 3. To the extent practicable, maintain post-development peak runoff rate and average volume at levels similar to pre-development levels.
1. Reduce erosion and to the extent practicable, retain sediment on site during and after construction; and, 2. Prepare and implement, prior to land disturbance, an effective, approved erosion and sediment control plan or similar administrative document that specifies erosion and sediment control provisions.
1. Limit application, generation, and migration of toxic substances; 2. Ensure the proper storage and disposal of toxic materials; 3. Apply nutrients at rates necessary to establish and maintain vegetation without causing nutrient runoff to surface waters; and, 4. Prepare and implement, prior to the use or storage of toxic material on site, an effective, approved chemical control plan or similar administrative document that contains chemical control provisions (e.g. minimize use of toxic materials; ensure proper containment if toxic materials are to be used /stored on site).
Develop and implement watershed management programs to reduce runoff pollutant concentrations and volumes from existing development: 1. Identify priority local and/or regional watershed pollutant reduction opportunities (e.g. improve existing urban runoff control structures); 2. Specify a schedule for implementing appropriate controls: 3. Limit destruction of natural conveyance systems; and, 4. Where appropriate, preserve, enhance, or establish buffers along surface waters and their tributaries.

The Regional Water Board staff will rely on supporting implementation of the management measures in the SWRCB's *Nonpoint Source Pollution Control Program, Urban Management*

*Measure*s. In order to prevent, minimize, and control discharges to watercourses within the Shasta River hydrologic system that may contain nutrients, oxygen consuming material, and other biostimulatory waste capable of depressing dissolved oxygen levels below water quality narrative and numeric requirements, Regional Water Board staff will coordinate with the appropriate parties and will support the following actions and/or recommendations to achieve compliance with the TMDL, the Basin Plan and the NPS Policy:

Implementation Schedule
Effective the date that the TMDL Action Plan is adopted, the Regional Water Board staff shall coordinate with stakeholders within the cities of Yreka, Weed, Lake Shastina development, and other stakeholders to assure that appropriate management practices are initiated to control polluted runoff to waters of the Shasta Valley watershed from facilities within their spheres of influence.

Parties responsible for the control and cleanup of pollutant discharges described above, shall submit to the Regional Water Board for review, management plans describing proposed actions, including timelines, to eliminate and/or control applicable pollutant discharges to waters of the Shasta Valley.

8.9 United States Forest Service

Portions of two national forests, the Klamath and the Shasta-Trinity National Forests, are located within the Shasta River watershed. The USFS administers the Klamath National Forests Land & Resource Management Plan (Klamath Management Plan [USFS 1995a]) for the Klamath National Forest, and the Shasta-Trinity National Forests Land and Resource Management Plan (Shasta-Trinity Management Plan [USFS 1995b]) for the Shasta-Trinity National Forest. The Klamath Management Plan applies to 48,677 acres including the mountainous regions of the Shasta River watershed west of Yreka and scattered lands in the eastern side of the watershed. The Shasta-Trinity National Management Plan applies to 71,211 acres of non-contiguous land in the southern and southeast mountainous regions of the Shasta Valley, primarily the forested slopes descending from the north side of Mount Shasta. Both Forest Management Plans incorporated direction from the Northwest Forest Plan (i.e. the Aquatic Conservation Strategy) and all amendments. The Forest Management Plans are the guiding management documents for both forests and provide guidance for the implementation of best management practices (BMPs) deemed to be protective of the environment while allowing resource extraction.

To date, there have been no watershed analyses by the USFS for the Parks-Willow, Upper Shasta River, and Whitney-Herd Peak watersheds located partly within the Shasta-Trinity National Forest. However, portions of the Klamath National Forest, including Little Shasta River and Grass Lake watersheds, are covered in the Goosenest Adaptive Management Area Ecosystem Analysis (USFS 1996). That analysis functions as a watershed analysis.

As such, oxygen--consuming material reductions and water temperature control strategies for USFS lands within the Shasta River watershed have not been fully formulated. In the absence of watershed specific oxygen consuming material controls, and water temperature reduction actions, the USFS implements BMPs for the protection of water quality contained in the guidance document, *Water Quality Management for Forest System Lands in California, Best*

Management Practices (Guidance Document). The practices and programs in the Best Management Practices Program comply with section 208 and 319 of the Federal Clean Water. The Forest Service Best Management Practices Program arose from a formal Management Agency Agreement in 1981 between the USFS and the SWRCB, designating the USFS as a Water Quality Management Agency for USFS lands in California (USFS-SWRCB 1981).

8.9.1 Dissolved Oxygen and Temperature Related Efforts

The Aquatic Conservation Strategy, referred to above, also elucidates the *Standards and Guidelines for Riparian Reserves* that, for the most part, provide variable width reduced-harvest buffers around fish bearing streams, other wildlife sensitive streams, unstable slopes, and other sensitive features.

The USFS defines Riparian Reserves as Forest land allocations intended to protect riparian areas. Riparian Reserves are also defined as lands around fish bearing streams, other wildlife sensitive streams, lakes, wetlands, unstable areas, and potentially unstable areas, and other sensitive features where special standards and guidelines direct land use (USFS 1994). After each USFS management district performs a watershed analysis, decision-makers can then tailor the riparian reserve buffers of the Aquatic Conservation Strategy to conform to local conditions. Watershed analyses have not been fully completed for USFS holdings in the Shasta Valley and, in this situation, Riparian Reserve buffer widths conform to the general Interim Riparian Reserve Buffer Widths designated in the Aquatic Conservation Strategy. Specifically, Table 8.7 identifies the Riparian Reserve type and associated buffer widths that would apply to USFS land in the Shasta Valley. Any land management activity occurring within the Riparian Reserves would have to be consistent with the Aquatic Conservation Strategy and applicable Standards and Guidelines for Riparian Reserves.

Table 8.7 Recommended Interim Riparian Reserve Widths for Klamath National Forest and Shasta-Trinity National Forest Lands in the Shasta River Watershed[1]

RIPARIAN RESERVE TYPE	**Riparian Reserve Widths**
Fish-bearing streams.	Include the stream and: area on each side from active channel edges to the top of inner gorge, or outer edge of 100 year flood plain, or to outer edge of riparian vegetation, or height of two site potential trees[2], or 300 feet slope distance, whichever is greatest.
Perennial, nonfish bearing streams	Include the stream and: area on each side from active channel edges to the top of inner gorge, or outer edge of 100 year flood plain, or outer edge of riparian vegetation, or height of one site potential tree[2], or 150 feet slope distance, whichever is greatest.
Lakes and natural ponds	Include the body of water and: area to the outer edge of riparian vegetation, or extent of seasonally saturated soil, or extent of unstable and potentially unstable areas, or height of one site potential tree[2], or 300 feet slope distance, whichever is greatest.
Constructed ponds, reservoirs and wetlands >1-acre in size	Include the body of water or wetland and: area to outer edges of riparian vegetation, or to seasonally saturated soil, or the extent of unstable and potentially unstable areas, or distance of one site potential tree, or 150 feet slope distance from wetland edge >1 acre, or the maximum pool elevation of constructed ponds, reservoirs, whichever is greatest.

Table 8.7 Recommended Interim Riparian Reserve Widths for Klamath National Forest and Shasta-Trinity National Forest Lands in the Shasta River Watershed[1]

RIPARIAN RESERVE TYPE	Riparian Reserve Widths
Seasonally flowing or intermittent streams[3] wetlands <1-acre in size, and unstable or potentially unstable areas	At a minimum include: extent of unstable and potentially unstable areas (includes earthflows), stream channel and extend to top of inner gorge, stream channel or wetland and area from the edges of the stream channel or wetland to outer edges of riparian vegetation, and extension from edges of stream channel to height of one site potential tree[2], or 100 feet slope distance, whichever is greatest.

[1]Information from the Land and Resource Management Plans for the Klamath and Shasta-Trinity National Forests, Klamath National Forest LRMP (USFS 1995a), Shasta-Trinity National Forest LRMP (USFS 1995b).
[2]Site potential tree, depending on site class, is an average maximum height of the tallest dominant tree, ≥ 200 years old.
[3] Intermittent stream defined as any nonpermanent flowing drainage feature with a definable channel having evidence of annual scour or deposition, includes ephemeral streams meeting these physical criteria.

Regional Water Board staff determined that application of the Interim Riparian Reserves management practices in the Klamath and Shasta-Trinity National Forests appear to adequately protect the beneficial uses of water from temperature related effects of timber harvest operations. The Riparian Reserve buffers will, over time, increase the riparian canopy, which will decrease solar radiation loads and lower water temperatures. The buffers will also allow the unfettered growth of riparian vegetation toward a late-seral community. The buffers of undisturbed riparian vegetation would also provide a “filtration strip” that can trap and filter nutrients and other oxygen-consuming constituents, preventing such discharges to adjacent water bodies.

8.9.2 Rangeland and Grazing Related Efforts

The extent and impacts of past and present grazing activities on USFS land to watercourses within the Shasta Valley is considered minor but warrant consideration to meet all aspects of the TMDL. The USFS implements rangeland management and grazing strategies designed to lessen impacts to water quality as described in Water Quality Management for Forest System Lands in California, Best Management Practices, 2000 and in grazing allotment management plans. A number of the best management practices for activities in riparian corridors, paraphrased from both documents, include deferred and rotational livestock grazing; controlling overall livestock numbers, season of use and distribution, and riparian exclusionary fencing as a fallback measure if other efforts fail to prohibit livestock from damaging riparian areas (USFS 2000). Grazing management measures are summarized in Table 8.8.

Table 8.8 Grazing Standards and Guidelines for Shasta-Trinity and Klamath National Forests[1]

Adjust grazing practices to eliminate impacts that retard or prevent attainment of Aquatic Conservation Strategy objectives. If adjusting practices is not effective, eliminate grazing
Locate new livestock handling and/or management facilities outside Riparian Reserves. For existing livestock handling facilities inside the Riparian Reserve, ensure that Aquatic Conservation Strategy objectives are met. Where these objectives cannot be met, require relocation or removal of such facilities.
Limit livestock trailing, bedding, watering, loading, and other handling efforts to those areas and times that will ensure Aquatic Conservation Strategy objectives are met.

[1]From Shasta - Trinity LRMP

8.9.3 Implementation Actions

In order to prevent, minimize, and control discharges of oxygen consuming material and nutrient waste discharges and high water temperatures on federal land from USFS activities, in particular rangeland and grazing activities, and silvicultural activities in the Shasta River watershed, the USFS should consistently implement rangeland management and grazing strategies as described in the individual Forest Management Plans, *Water Quality Management for Forest System Lands in California, Best Management Practices, 2000* and in grazing allotment management plans. The Regional Water Board staff will continue its involvement with the USFS to periodically reassess the mutually agreed upon goals of the Management Agency Agreement between the SWRCB and the USFS.

Additionally, the Regional Water Board shall work with the USFS to draft and finalize a Memorandum of Understanding (MOU). The MOU shall be drafted and ready for consideration by the appropriate decision-making body(ies) of the USFS within two years of the date the TMDL Action Plan takes effect.

The MOU shall include the following contents:

Contents specifically related to elevated water temperatures:

- A commitment by the USFS to continue to implement its Standards and Guidelines for Riparian Reserves per the Shasta-Trinity and Klamath Forest Management Plans.
- A monitoring plan to ensure that the Standards and Guidelines for Riparian Reserves are effective at preventing or minimizing effects on natural shade.
- A commitment by the USFS to implement the monitoring plan and conduct adaptive management.

Contents related to grazing activities affecting both dissolved oxygen concentrations and water temperatures:

- A date for the completion of a description of existing grazing management practices and riparian monitoring activities implemented on grazing allotments in the Shasta River watershed.
- A commitment by the USFS and the Regional Water Board to determine if existing management practices and monitoring activities are adequate and effective at preventing, reducing, and controlling discharges of biostimulatory waste and elevated water temperatures.
- A commitment by the USFS to develop revised management practices and monitoring activities should existing measures be inadequate or ineffective, subject to the approval of the Regional Water Board's Executive Officer.
- A commitment by the USFS to implement adequate and effective grazing management practices and monitoring activities and to conduct adaptive management.

In developing the MOU, the Regional Water Board shall work with the USFS to develop time lines that take into consideration USFS resources.

The Regional Water Board shall continue to implement *Order No. R1-2004-015, Categorical Waiver for Discharges Related to Timber Activities on Federal Lands Managed by the United States Department of Agriculture*[2]. When the waiver expires on March 24, 2009, the Regional Water Board maintains the option of renewing the order. If it is determined that the prescriptions of the MAA are implemented and effective at controlling discharges of oxygen consuming waste and elevated solar radiation loads, Regional Water Board staff may recommend that an ownership-wide (in lieu of project-specific) waiver of WDRs be considered as part of an adaptive management approach to TMDL implementation.

<u>Development of Permitting Action Schedule:</u> Regional Water Board to work with the USFS to draft and finalize a Memorandum of Understanding (MOU). The MOU shall include, in part, buffer width requirements and other management practices as detailed in Tables 8.7 and 8.8.
<u>Adoption of Permitting Action Schedule</u>: The MOU shall be drafted and ready for consideration by the Regional Water Board and the appropriate decision-making body of the USFS within two years of EPA approval of the TMDL.
<u>Compliance Schedule:</u>
1) Regional Water Board continued involvement with the USFS to periodically reassess the mutually agreed upon goals of the Management Agency Agreement (SWRCB and USFS 1981).
2) Compliance with the Categorical Waiver for Timber Activities on Federal Lands.
3) Continued annual/periodic meetings between the USFS and the Regional Water Board assuring that MPs are fully implemented as per the guidance presented in *Water Quality Management for Forest System Lands in California, Best Management Practices* (USFS 2000).

8.10 United States Bureau of Land Management

The United States Bureau of Land Management (BLM) manages approximately 11,691 acres of public land in the Shasta River watershed, which consists mostly of dry foothills with ephemeral streams scattered along the western and eastern areas of the watershed. The primary land use on BLM lands in the Shasta River watershed is cattle grazing, although timber harvest, road use, recreational, and other activities are present or may occur in the future. Grazing activities include grazing allotments. Given the ecological characteristics and the dispersed nature of BLM land in the Shasta watershed, cattle grazing is expected to have a minor impact to water quality. To lessen impacts to water quality from grazing activities, BLM implements best management grazing strategies that are detailed in a joint management agency document titled: *Riparian Management, TR 1737-14 1997, Grazing Management for Riparian-Wetland Areas, USDI-BLM, USDA-FS* . Specific grazing management practices for Northwestern California, including all of the Shasta River watershed, were later submitted in a BLM document, *Record of*

[2] In order to regulate the discharge of waste from timber harvest activities on federal lands, the Regional Water Board adopted the Categorical Waiver for Discharges Related to Timber Activities on Federal Lands Managed by the United States Department of Agriculture (Order R1-2004-0015) in 2004. Timber activities on federal lands must meet several conditions to qualify for the Categorical Waiver. These conditions include, among other provisions, conducting an environmental review of the project pursuant to the National Environmental Protection Act (NEPA), the maintenance of a water quality program consistent with the Basin Plan, and a verification system acceptable to the Regional Water Board, including, but not limited to, inspection, surveillance, enforcement, and monitoring of management practices.

Decision, Northwestern California, Standards for Rangeland Health and Guidelines for Livestock Grazing Management (BLM 1999). This document also recognizes that riparian standards and guidelines in the Northwest Forest Plan are extended to all anadromous watersheds beyond the range of the northern spotted owl, which includes all of the Shasta Valley. The Secretary of the USDI approved the Northwest CA ROD in July 2000 (BLM 2000). Management measures for riparian areas are summarized in Table 8.9.

Table 8.9 BLM Grazing Management Measures

Grazing management must provide an adequate cover and height of vegetation on the banks and overflow zones to promote natural stream function (sediment filtering, bank building, flood energy dissipation, aquifer recharge and water storage)[1].
Control the timing of grazing to prevent damage to streambanks when they are most vulnerable to tramplin[1]g.
Ensure sufficient vegetation during periods of high flow to protect streambanks, dissipate energy, and trap sediment[1].
Techniques that restrict livestock from riparian areas, including fencing or fence relocation, barriers such as thickets or brush wind rows, water gaps in erosion-resistant stream reaches, hardened crossings or water access, and relocation of bed grounds and management facilities[1].

[1]'From Riparian Management, TR 1737-14 1997, Grazing Management for Riparian-Wetland Areas, USDI-BLM, USDA-FS

Additionally, in order to prevent, minimize, and control biostimulatory, nutrient, and other oxygen depleting material discharges and elevated water temperatures from activities on BLM lands in the Shasta River watershed, the Regional Water Board shall work with the BLM to draft and finalize a Memorandum of Understanding (MOU). The MOU shall be drafted and ready for consideration by the appropriate decision-making body(ies) of the BLM within two years of the date the Shasta River TMDL Action Plan takes effect. The MOU shall include the following contents:

Contents Specifically Related to Elevated Water Temperatures:

- A commitment by the BLM to continue to implement the riparian area requirements.
- A monitoring plan to ensure that the riparian area requirements are effective at reducing high water temperatures.
- A commitment by the BLM to implement the monitoring plan and conduct adaptive management.

Contents Related to Grazing Activities Affecting Both Dissolved Oxygen Concentrations and Water Temperatures:

- A date for the completion of description of existing grazing management practices and riparian monitoring activities implemented in grazing allotments in the Shasta River watershed if different than the Northwest CA ROD.
- A commitment by the BLM and the Regional Water Board to determine if existing management practices and monitoring activities are adequate and effective at preventing, reducing, and controlling discharges of biostimulatory waste discharges and elevated water temperatures.
- A commitment by the BLM to develop revised management practices and monitoring activities should existing measures be inadequate or ineffective, subject to the approval of the Regional Water Board's Executive Officer.

- A commitment by the BLM to implement adequate and effective grazing management practices and monitoring activities and to conduct adaptive management.

In developing the MOU, the Regional Water Board shall work with the BLM to develop time lines that take into consideration BLM resources.

Through the development, review, and implementation of the MOU, Regional Water Board staff shall determine the appropriate permitting or enforcement actions necessary to prevent, minimize, and control biostimulatory, nutrient, and other oxygen demanding material discharges and elevated water temperatures from BLM lands in the Shasta River watershed. Such actions include, but are not limited to, WDRs, waivers of WDRs, cleanup and abatement orders, or other appropriate permitting or enforcement action(s).

Should the BLM choose not to participate in the development, finalization, and implementation of a MOU, Regional Water Board staff shall initiate appropriate permitting or enforcement actions on activities on BLM land within the Shasta River watershed for consideration by the Board on an as-needed basis.

Development of Permitting Action Schedule: Regional Water Board to work with the BLM to draft and finalize a Memorandum of Understanding (MOU) concerning management practices specific to BLM land in the Shasta River watershed that complies with the Shasta TMDL. The MOU shall include, in part, riparian area requirements and other management practices as detailed in Table 8.9 Adoption of Permitting Action Schedule: The MOU shall be drafted and ready for consideration by the Regional Water Board and the appropriate decision-making body of the BLM within two years of EPA approval of the TMDL Compliance Schedule: Begin annual/periodic meetings between the BLM and the Regional Water Board assuring that measures are fully implemented as per the guidance presented in Continued annual/periodic meetings between the USFS and the Regional Water Board assuring that MPs are fully implemented as per the guidance presented in *Water Quality Management for Forest System Lands in California, Best Management Practices* (USFS 2000).

8.11 Timber Harvest Activities on Non-federal Lands

Past timber harvest activities have often been shown to contribute to elevated solar radiation loads to many North Coast watercourses. Because timber harvest activities in the Shasta watershed are limited, a watershed-specific source analysis for solar radiation loads to watercourses from timber harvest activities in the Shasta River watershed was not conducted for the TMDL. The Regional Water Board shall rely on applicable current regulations, existing permitting and enforcement tools, and other ongoing staff involvement, summarized in Table 8.10. As such, no new regulations or actions are being proposed in association with this TMDL. Existing regulations and permitting tools include:

- Z'Berg-Nejedly Forest Practice Act and the California Environmental Quality Act (CEQA)

- Management Agency Agreement between the CDF and the State Water Resources Control Board to oversee water quality protection on timber operations on non-federal lands in California.
- Watercourse protection measures as required in the 2006 Forest Practice Rules.
- Senate Bill 810, enacted in 2003, provides that a Timber Harvest Plan (THP) may not be approved if the Regional Water Board finds that the proposed timber operations will result in discharges to a water body impaired by sediment and/or is in violation of the Basin Plan.
- Regional Water Board Timber Harvest General Waste Discharge Requirements (Order No. R1-2004-0030) and Categorical Waiver of Report of Waste Discharge (Order No. R1-2004-016) for timber activities on non-federal lands. Both the Categorical Waiver and the General Waste Discharge Requirements programs use the CDF timber harvest, functional equivalent review process for THPs and Non-industrial Timber Management Plans (NTMP) to ensure compliance with the CEQA.
- Active and continuous oversight by Regional Water Board staff of the timber harvest review and inspection process.
- Habitat Conservation Plans and Sustained Yield Plan review.
- CDF and Board of Forestry meetings and review.

Table 8.10 Examples of Select Management Measures for Timber Harvest Activities on Non-federal Lands from the 2006 California Forest Practice Rules

Every timber operation shall be planned and conducted to prevent deleterious interference with watershed conditions that primarily limit the values set forth in "the rules" (e.g. sediment load increase where sediment is the limiting factor, thermal load increase where water temperature is the primary limiting factor, etc). Section 916.9, 936.9 (a)
Comply with the terms of a Total Maximum Daily Load that has been adopted to address factors that may be affected by timber operations, if a TMDL has been adopted, or not result in any measurable sediment load increase to watercourses of lakes. Section 916.9, 936.9 (a) (1)
Not result in any measurable steam flow reduction during critical low water periods except as part of an approved water drafting plan. Section 916.9, 936.9 (a) (4)
Protect maintain and restore the quality and quantity of vegetative canopy needed to: (a) provide shade to the watercourse or lake, (b) minimize daily and seasonal temperature fluctuations, (c) maintain daily and seasonal temperature within the preferred range for anadromous salmonids. Section 916.9, 936.9 (a) (6)
Any timber operations or silvicultural prescriptions within 150 feet of any Class I watercourse or lake transition line or 100 feet of any Class II watercourse or lake transition line shall have protection, maintenance, or restoration of beneficial uses of water or the populations and habitat of anadromous salmonids or listed aquatic or riparian-associated species as significant objectives. Section 916.9, 936.9 (c)
The minimum WLPZ width for Class I waters shall be 150 feet from the watercourse or lake transition line. Section 916.9, 936.9 (f)
Within a WLPZ for Class I waters, at least 85 percent overstory canopy shall be retained within 75 feet of the watercourse or lake transition line. Section 916.9, 936.9 (g)

8.11 8.12 **California Department of Transportation**

The primary mission of Caltrans is to provide the people of California with a safe, and efficient intermodal transportation system. This mission involves planning, designing, constructing, and maintaining large-scale transportation facilities, such as freeways, highways, interchanges, bridges, and tunnels.

The California Department of Transportation (Caltrans) has jurisdiction over three state highways in the Shasta River watershed: State Route 3, State Route 263, and State Route 97.

There is also a major segment of U.S. Interstate Highway 5, which Caltrans is responsible for maintaining and that is within the watershed (Siskiyou County 2005). State roads and highways are known to be possible sources of anthropogenic waste discharges, including fine sediment, road oils, pesticide and herbicide residues, oxygen-consuming materials from weed, tree and shrub cuttings and other substances due to improper road location, surfacing, drainage design and chemical applications during routine highway maintenance activities.

Caltrans has sampled stormwater runoff from their facilities (facilities are highways, maintenance yards, and construction sites) that included ammonia, nitrates and nitrites, phosphorous compounds, and fecal and total coliform. The analytical results were reported as averages, which were then compared to the most stringent water quality objectives in the nine Regional Water Board's Basin Plans. Sample results did show some exceedences of the most stringent numeric and narrative targets in the Basin Plans but the results were not ascribed to a particular Regional Water Board's watershed (Caltrans 2003).

Discharges of waste from Caltrans' facilities are regulated by the State Water Board under the National Pollutant Discharge Elimination System (NPDES) Permit, Statewide Storm Water Permit, and Waste Discharge Requirements (WDRs) for the State of California, Department of Transportation (Caltrans) (Order No. 99-06-DWQ and NPDES No. CAS000003), which was adopted on July 15, 1999. This permit, and the program to implement the permit, are generally known as the Caltrans Storm Water Program.

The overall goal of the Storm Water Program is to integrate appropriate storm water control activities into ongoing activities, thus making control of storm water pollution a part of Caltrans' normal business practices. As described by Caltrans (Caltrans 2003), components of the Storm Water Program include:

- Storm Water Management Plan (SWMP). Caltrans developed the SWMP to describe the procedures and practices used to reduce the discharge of pollutants to storm drainage systems and receiving waters.
- Annual Report and Regional Workplans. The Annual Report describes the activities that Caltrans has undertaken in the previous fiscal year to implement the SWMP. The Regional Workplans describe the activities that Caltrans Districts will undertake in the next fiscal year to implement the SWMP.
- Monitoring and Best Management Practice (BMP) Development. The purpose is to identify pollutants of concern in storm water runoff from Caltrans facilities and to describe how Caltrans identifies, evaluates, and approves BMPs.
- Public Education.
- Guidance for Design, Construction and Maintenance Activities. Guidance documents have been developed to implement storm water BMPs in the design, construction and maintenance of highway facilities.

In order to address possible discharges of chemical, nutrient and other oxygen demanding substances, sediment, and also operations that may increase solar radiation loads to watercourses that may result from Caltrans' activities on roads and other facilities, Regional Water Board staff shall periodically evaluate the effectiveness of the Caltrans Storm Water Program. The purpose for evaluating the Caltrans Storm Water Program is to determine if it is adequate and effective at preventing, minimizing, and controlling any of the aforementioned discharges in the North Coast Region, including the Shasta River watershed. The evaluation shall be completed within two years of the date the TMDL Action Plan takes effect. If Regional Water Board staff find that the Caltrans Storm Water Program is inadequate, Regional Water Board and State Water Board staff shall develop specific requirements for State Water Board consideration to be incorporated into the Caltrans Storm Water Program at the soonest opportunity, or the Regional Water Board shall take other appropriate permitting or enforcement actions.

<u>Implementation Schedule</u> Regional Water Board staff shall complete an initial evaluation of the Caltrans Stormwater Program within two years of the date the TMDL Action Plan takes effect. After the initial two year evaluation is completed, the Regional Water Board staff shall continue periodic reviews of the Caltrans Storm Water Program to assure ongoing compliance with the Shasta River TMDL.

CHAPTER 9. MONITORING

Key Points

- There are several different types of monitoring, including implementation monitoring, upslope-near stream effectiveness monitoring, instream effectiveness monitoring, and compliance and trend monitoring.
- Monitoring may be required in conjunction with existing and/or proposed human activities that will likely result in elevated water temperatures, or discharges of biostimulatory substances, nutrients, or other material that detrimentally lowers dissolved oxygen concentrations.
- Regional Water Board staff shall coordinate development of a compliance and trend monitoring plan within two years of the date the Shasta River TMDL Action Plan takes effect.
- Monitoring requirements are specifically incorporated into the proposed Memoranda of Understanding with the U.S. Forest Service and U.S. Bureau of Land Management.

The purpose of this chapter is to describe the types of monitoring applicable to the Shasta River watershed and describe the monitoring requirements of the TMDL Action Plan.

9.1 Types of Monitoring

Monitoring can take several different forms, have different objectives, and yet be called, ubiquitously, monitoring. Consistent nomenclature is necessary for clarity. It is the intention of this section to describe the different types of monitoring.

9.1.1 Implementation Monitoring

Implementation monitoring assesses whether activities and control practices were carried out as planned. This type of monitoring can be as simple as photographic documentation, provided that the photographs are adequate to represent and substantiate the implementation of control practices. Implementation monitoring is a cost-effective type of monitoring because its purpose is to demonstrate that pollutant source control practices were properly installed and operated. On its own, however, implementation monitoring cannot directly link management activities to water quality, as no water quality measurements are made.

9.1.2 Instream and Upslope-Near Stream Effectiveness Monitoring

Upslope-near stream effectiveness monitoring is intended to determine if control practices are effective at keeping the pollutant from being discharged to a water body. In other words, it is "...used to evaluate whether the specified activities had the desired effect (Solomon 1989, as cited by MacDonald et al. 1991, p. 7)."

Instream effectiveness monitoring may be conducted upstream and downstream of the area of concern or before, during, and after the implementation of control practices. Development of an instream effectiveness monitoring program is site-specific and may include, where appropriate, partnerships between landowners and state and federal agencies. Both instream and upslope effectiveness monitoring can be as simple as photographic documentation. Photo-documentation would be especially useful to detect changes in riparian vegetation cover, instream aquatic plant abundance, etc., as it may affect light transmittance, hence, indirectly water temperature, provided that the photographs are adequate to represent and substantiate that the control practices are effective.

9.1.3 Compliance and Trend Monitoring

Compliance and trend monitoring is intended to determine, on a watershed scale, if water quality objectives are being met, if TMDLs are being met, and if beneficial uses are being protected from the adverse effects of one or more pollutants.

Different sources refer to this type of monitoring as either compliance monitoring or trend monitoring. For example, MacDonald et al. (1991, p.7) state that compliance monitoring is "…the monitoring used to determine whether specified water quality criteria are being met." The California Department of Forestry (CDF) and the Regional Water Boards across the State have developed general water quality monitoring conditions that use trend monitoring for monitoring typically applied at a watershed scale, focusing on the combined effects of all watershed management activities for multiple years. Examples of Trend Monitoring objectives include " . . . [determining] whether Basin Plan water quality standards are achieved and maintained over time (Fitzgerald 2004)." In reality, monitoring for compliance with water quality objectives, TMDLs, and beneficial uses will produce data that is useful for analyzing trends in water quality. Therefore, Regional Water Board staff calls this monitoring requirement "Compliance & Trend Monitoring."

The comprehensiveness of compliance monitoring will vary depending on the site, local conditions, land ownership patterns, and the extent of land management activities in an area. Regarding nutrients and oxygen-consuming constituents, for example, compliance monitoring may involve the use of seasonal grab sample monitoring, and dissolved oxygen measurements at hourly or sub-hourly intervals at select instream locations. Temperature monitoring, as mentioned above, may consist of relevant photo-documentation depicting changes, beneficial or otherwise, to riparian and/or instream vegetation components, grab sampling, periodic time-step recording using remote temperature data loggers, or other appropriate methods and approaches selected by the stakeholder and approved by the Regional Water Board's Executive Officer.

9.2 Monitoring Requirements

Each of the above types of monitoring is important for determining the overall success of the TMDL Action Plan in achieving dissolved oxygen and temperature water quality standards. Therefore, monitoring shall be conducted upon the request of the Regional Water Board's Executive Officer in conjunction with existing and/or proposed human activities that will likely result in nutrient and oxygen-consuming constituent waste discharges and/or elevated water temperatures within the Shasta River watershed. Monitoring may involve implementation, upslope-near stream effectiveness, instream effectiveness, and/or compliance and trend monitoring. The authority for such requirements is contained in Section 13267 of the California Water Code, which states that the Regional Water Board may require any discharger, suspected discharger, or future discharger to furnish monitoring program reports.

The Executive Officer will base the decision to require monitoring on site-specific conditions, the size and location of the discharger's ownership, and/or the type and intensity of land uses being conducted or proposed by the discharger. The decision will also be based on the control practices selected by the discharger. For example, if a discharger selects proven, established control practices, then instream effectiveness monitoring is less likely to be required. Conversely, if a discharger selects control practices that are not proven and are not known to provide protection against discharges, then there is a higher likelihood that instream effectiveness monitoring will be required. If monitoring is required, the Executive Officer may direct the stakeholder to develop a monitoring plan and may describe specific monitoring requirements to include in the plan. Such requirements may include:

- parameter(s) to monitor (e.g., nutrients such as ortho-phosphate, total phosphorus, ammonia, nitrite plus nitrate, total Kjeldahl nitrogen, as well as measures of oxygen-consuming constituents such as biochemical oxygen demand, chemical oxygen demand, and/or total organic carbon, water temperature, percent shade, etc.);
- procedure (e.g., visual observations, photo-documentation, grab samples, near-constant sampling, etc.);
- technique (e.g., sample upstream and downstream of areas of concern, sample before, during, and after the implementation of a control practice, etc.);
- location(s) (e.g., TMDL compliance monitoring points or tailwater return flow locations);
- frequency (i.e., how often will a sample be collected);
- duration (i.e., how long will the sampling occur);
- quality control and quality assurance protocols, and/or;
- reporting requirements.

9.2.1 Monitoring Requirements Specific to Ranch Management Plans

Implementation monitoring and upslope effectiveness monitoring will also likely be required of those landowners/stakeholders who are required to develop and implement a Ranch Management Plan as described in Chapter 8 Implementation, and upslope and/or near-stream effectiveness monitoring in such instances will generally involve photographic documentation over time (i.e., photo-point monitoring). Some examples where photo-point monitoring would be valuable include structural controls and management practices that exclude cattle and cattle wastes from watercourses, tailwater discharge sites, riparian vegetation conditions, bank stabilization projects, and stormwater control practices and facilities.

9.2.2 Compliance and Trend Monitoring Requirements

Compliance and trend monitoring is a valuable and necessary element of any strategy to restore and attain water quality standards. The data gathered from compliance and trend monitoring provides dischargers and the Regional Water Board with the information needed to determine if the requirements of the TMDL Action Plan are improving the quality and quantity of instream salmonid habitat and, thus, if the TMDL Action Plan as a whole is effective at achieving water quality objectives, achieving the TMDLs, and protecting the beneficial uses.

In order to gather adequate instream monitoring data and draw valid conclusions, it is necessary for instream monitoring to be well planned for and thought out. Therefore, Regional Water Board staff shall develop a compliance and trend monitoring plan designed to provide feedback on the effectiveness of the TMDL Action Plan. The plan will likely include a detailed description of monitoring objectives, the parameters to be monitored, monitoring procedures and techniques, the locations of trend monitoring stations, monitoring frequency and duration, quality control and quality assurance protocols, benchmark conditions where available, measurable milestones, and specific due dates for monitoring and data analysis. Regional Water Board staff shall complete the monitoring plan within one year from the date that the U.S. EPA approves the TMDL Action Plan.

Due to the complexity and expense of compliance and trend monitoring, Regional Water Board staff shall attempt to work cooperatively with other agencies and organizations to develop the plan and conduct monitoring. In particular, Regional Water Board staff shall attempt to coordinate efforts with the Shasta Valley Resource Conservation District (SVRCD) and the Shasta River Coordinated Resources Management and Planning Committee (Shasta CRMP). The Shasta CRMP, as described in the Shasta Watershed Restoration Plan (Shasta CRMP 1997), is engaged in a pro-active monitoring effort designed to establish baseline information in the Shasta River watershed by describing current conditions both quantitatively and qualitatively so that restoration needs can be identified and projects prioritized.

Schedule: Within two year from the date that the US EPA approves the TMDL Action Plan, Regional Water Board staff shall complete a compliance and trend monitoring plan.

9.2.3 Monitoring Requirements Specific to the U.S. Forest Service and U.S. Bureau of Land Management

Monitoring requirements are specifically addressed and incorporated into the proposed Memorandum of Understanding for the U.S. Forest Service (Section 8.9.3) and U.S. Bureau of Land Management (Section 8.10). For both of these agencies, the requirements are primarily for implementation and upslope-near stream effectiveness monitoring.

CHAPTER 10. REASSESSMENT

Key Points

- The TMDL has a duration of 40 years to achieve water quality objectives.

- Regional Water Board staff will report back to the Regional Water Board at least yearly on status and progress. The annual review will occur in a public forum designed to include all stakeholders including downriver communities, tribes, sport and commercial fishermen.

- The Regional Water Board is likely to reassess the Shasta River TMDL Action Plan every three years during the Basin Planning Triennial Review process.

- For activities that rely on encouragement as a first step, a formal assessment of effectiveness of these efforts will be completed within 5 years from the date of U.S. EPA approval of this TMDL.

- The Regional Water Board will conduct a more extensive and focused reassessment after the Shasta River TMDL Action Plan has been in effect for ten years, or sooner, if the Regional Water Board determines it necessary.

This chapter describes the process the Regional Water Board will take to review, reassess, and possibly revise the TMDL Action Plan for the Shasta River watershed.

It is estimated that the water quality objectives addressed by this TMDL can be achieved within 40 years of approval of this TMDL Action Plan. Many actions can be completed early in the life of the TMDL, and can have immediate beneficial impacts on water quality. These include, for example, reductions in tailwater return flows resulting from water reuse. Other actions may be initiated in the near-term, but may not show effects on water quality for some time. These include, for example, restoration of riparian shade. While activities that enable shade to develop may be short-term, the development of shade has a long timeframe associated with the growth of woody vegetation. This key element of achieving TMDL water quality objectives controls the time estimated for TMDL actions to result in meeting water quality objectives.

Regional Water Board staff will report back to the Regional Board at least yearly on the status and progress of implementation activities, and on whether current efforts are reasonably expected to achieve water quality standards in the life of the TMDL. The Regional Water Board is likely to reassess the TMDL Action Plan every three years during the Basin Planning Triennial Review process. For activities that rely on encouragement as a first step, a formal assessment of effectiveness of these efforts will be completed within 5 years from the date of U.S. EPA approval of this TMDL. A more extensive and focused reassessment will occur after the TMDL Action Plan has been in effect for ten years.

During the reassessment, the Regional Water Board is likely to consider how effective the TMDL Action Plan is at meeting the dissolved oxygen and temperature TMDLs, achieving dissolved oxygen and temperature water quality objectives, and protecting the beneficial uses of the Shasta River watershed. In order to help determine the effectiveness of the TMDL Action Plan, the Regional Water Board and staff will ask a series of questions. These questions are listed below in Table 10.1, along with possible approaches to answering the questions, and steps to take if revision is found to be necessary.

Although the Regional Water Board and staff will attempt to answer the questions listed in Table 10.1 while conducting the reassessment, it is important to note that the questions and possible revisions are not requirements of the Regional Water Board. It may not be feasible to fully assess the TMDL Action Plan due to limited resources or data. For example, the amount of time and funding required to conduct a new dissolved oxygen or temperature source analysis may not be available during reassessment.

Table 10.1: Reassessment Considerations

Topic	Questions to Ask During Reassessment	How to Answer the Question	Steps to Take if Revision is Necessary
Problem Statement	Are dissolved oxygen and temperature water quality objectives still not being met? Are the beneficial uses associated with cold water fish still negatively impacted by low dissolved oxygen concentrations and high water temperatures? Are nutrient and other oxygen consuming material waste discharges and elevated water temperatures still the cause of the reduction in quality and quantity of instream habitat capable of supporting salmonids and other beneficial uses? Are there other beneficial uses adversely affected by depressed dissolved oxygen concentrations and high water temperatures?	Review compliance and trend monitoring data, and any other valid, instream water quality and salmonid data. Review scientific research, data, and literature published since 2005.	If the answers are all no, the Shasta River may be considered high quality waters. Delisting the River from the 303(d) List will likely be appropriate. Consider amending the Basin Plan to revise, lessen, and perhaps eliminate dissolved oxygen and temperature control requirements. Consider amending the Basin Plan to relax dissolved oxygen and temperature control requirements. If any answer is yes, consider amending the Basin Plan to increase and tighten dissolved oxygen and temperature control requirements. Consider requiring Grazing, Riparian, and Water Use Management Plans from more dischargers.
Desired Conditions	Are the desired conditions no longer appropriate? Are there any parameters that should be added, revised, or removed?	Review scientific research, data, and literature published since 2005.	If the answer is yes, consider amending the Basin Plan to update the desired conditions.
Desired Conditions	Are the monitoring and sampling requirements still accurate and understandable?	Review scientific research, data, and literature published since 2005. Consider monitoring experiences.	If the answer is no, consider developing a monitoring and sampling guidance document that is separate but supplemental to the TMDL Action Plan.
Dissolved Oxygen Source Analysis	Are the sources identified in the dissolved oxygen source analysis still accurate?	Review Grazing, Riparian, and Water Use Management Plans, Memoranda of Understanding, and waste discharge requirements. Review scientific research, data, and literature published since 2005. Conduct a new dissolved oxygen source analysis.	If the answer is no, consider amending the Basin Plan to update the dissolved oxygen source analysis. Consider revising the TMDL and load allocations.
Temperature Source Analysis	Are the sources identified in the temperature source analysis still accurate?	Review timber harvest plans (private and US Forest Service), Ranch , Riparian, and Water Management Plans, Memoranda of Understanding, and waste discharge requirements. Review scientific research, data, and literature published since 2005. Conduct a new temperature source analysis.	If the answer is no, consider amending the Basin Plan to update the temperature source analysis. Consider revising the TMDL and load allocations.
TMDL	Are the TMDLs accurate?	Review scientific research, data, and literature published since 2005. Conduct new source analyses.	If the answer is no, consider amending the Basin Plan to update the TMDL(s). Consider revising the load allocations.
Load Allocations	Are the load allocations accurate?	Review scientific research, data, and literature published since 2005. Conduct new source analyses	If the answer is no, consider amending the Basin Plan to update the load allocations.

Table 10.1: Reassessment Considerations

Topic	Questions to Ask During Reassessment	How to Answer the Question	Steps to Take if Revision is Necessary
		and rework the TMDL calculations.	
Implementation	Are the requirements clear and easily understandable by the regulated dischargers?	Consult with dischargers. Consult with other agencies involved with the TMDL Action Plan.	If the answer is no, consider developing a guidance document. Consider amending the Basin Plan to revise unclear or confusing language.
Implementation – Water Temperature	Are sources of elevated water temperatures effectively being prevented, minimized, and controlled?	Review Grazing, Riparian, and Water Use Management Plans, timber harvest plans, waste discharge requirements, and monitoring data.	If the answer is no, consider requiring more landowners/dischargers develop and implement Riparian, Grazing, and Water Use Management Plans. Consider increasing the number of waste discharge requirements and/or enforcement actions on activities that remove shade-producing vegetation. Consider amending the Basin Plan to add a prohibition against the removal and/or suppression of vegetation that provides shade to a water body in the Shasta River watershed.
Implementation – Discharges Contributing to Low Dissolved Oxygen Concentrations	Are existing nutrient and other oxygen consuming waste discharges effectively being prevented, minimized, and controlled?	Review Grazing, Riparian, and Water Use Management Plansand instream monitoring data.	If the answer is no, consider requiring more landowners/dischargers to develop and implement Grazing, Riparian, and Water Use Management Plans. Consider amending the Basin Plan to increase and tighten dissolved oxygen control requirements.
Implementation – Water Use	Has/is the State Water Resources Control Board studying the surface water issues, particularly watercourse flows vs. appropriations, in the watershed? Has/is the State Water Board taking the findings of the study into consideration and acting accordingly to protect water quality standards?	Consult with the State Water Resources Control Board.	If the answer is no, consider increasing Regional Board efforts to ensure such actions are taken. Consider funding appropriate studies from water quality funds.
Implementation – Grazing Activities	Are nutrient and other oxygen consuming waste discharges and elevated water temperatures caused by grazing activities being prevented, minimized, and controlled?	Review Grazing, Riparian, and Water Use Management Plans and instream monitoring data.	If the answer is no, consider requiring more landowners/dischargers to develop and implement Grazing, Riparian, and Water Use Management Plans. Consider amending the Basin Plan to increase grazing related implementation actions.
Implementation – Bank Stabilization	Are bank stabilization projects causing elevated water temperatures?	Review 401 Certification permits issued since 2005. Review instream monitoring data.	If the answer is yes, consider waste discharge requirements for such activities.
Implementation – Shasta Valley Resource	Have implementation practices subscribed to by sub-permittees in the Shasta RCD's Coho Incidental Take Permit been effective at	Review the terms, conditions, and management practices agreed to by sub-permittees participating in the Coho Incidental Take Permit program. Review	If the answer is no, enter into negotiations with the CDF&G (the CEQA lead agency for the Incidental Take Permit) and the Shasta Valley RCD to review

Table 10.1: Reassessment Considerations

Topic	Questions to Ask During Reassessment	How to Answer the Question	Steps to Take if Revision is Necessary
Conservation District	preventing, minimizing, and controlling nutrient and other oxygen consuming waste discharges and elevated water temperatures in a manner beneficial to the viability of the cold water fish of the Shasta River watershed?	available compliance and trend monitoring data. Conduct dissolved oxygen and temperature source analyses.	reasons for compliance failures and/or inadequacies to protect water quality. Jointly improve existing, or synthesize new management practices that assure dissolved oxygen and temperature TMDL allocations are attainable. Review monitoring and reporting program(s) of incidental take sub-permittees to assess if program specifics are still topical.
Implementation – Shasta Valley CRMP	Have the strategic actions described in the Shasta Restoration Plan (Shasta CRMP 1997) been effective at preventing, minimizing, and controlling nutrient and other oxygen consuming waste discharges and elevated water temperatures?	Review the Shasta CRMP's effectiveness monitoring data. Review available compliance and trend monitoring data. Conduct dissolved oxygen and temperature source analyses.	If the answer is no, consider revising strategic actions. Consider requiring landowners/dischargers to implement nutrient and other oxygen consuming waste, and temperature control practices.
Implementation – Urban and Suburban Nonpoint source Pollution:	Is there sufficient information to ascertain if urban and suburban sources of nonpoint source stormwater pollution containing nutrients and other oxygen demanding substances from the Lake Shastina Development and the City of Yreka are not negatively impacting the water quality of local watercourses and the Shasta River?	Review available nonpoint source pollution control strategies and plans, if any, implemented by the Lake Shastina development and the City of Yreka.	If the answer is no, consider requiring the submission of Stormwater Pollution Prevention Control Plans containing nonpoint source pollution control strategies having accurate monitoring and reporting protocols.
Monitoring	Is there enough information available to determine if nutrient and other oxygen-consuming constituent waste discharges and sources of elevated water temperatures are being controlled?	Review submitted and available monitoring data.	If the answer is no, consider requiring additional monitoring and the submission of monitoring reports and data.
Monitoring - Compliance & Trend	Is there enough information available to determine if the quality and quantity of instream salmonid habitat is improving?	Review submitted and available monitoring data associated with instream effectiveness monitoring and compliance and trend monitoring.	If the answer is no, consider requiring additional compliance and trend monitoring and the submission of monitoring reports and data. Consider funding additional monitoring stations.

CHAPTER 11. ANTIDEGRADATION ANALYSIS

Key Points

- The state and federal antidegradation policies require, in part, that where surface waters are of higher quality than necessary to protect beneficial uses, the high quality of those waters must be maintained unless otherwise provided by the policies.
- The federal antidegradation policy prohibits any activity or discharge that would lower the quality of surface water that does not meet water quality standards with limited exceptions as set forth in the federal regulations.
- The Shasta River TMDL Action Plan is based, in part, on the principles contained in the state and federal antidegradation policies.
- The Shasta River TMDL Action Plan will result in water quality improvement; therefore, state and federal antidegradation analyses are not required.

This chapter briefly describes the state and federal antidegradation policies and how they apply to the Shasta River TMDL Action Plan.

11.1 State and Federal Antidegradation Policies

The state and federal antidegradation policies are independently enforceable requirements. The state antidegradation policy is titled the *Statement of Policy with Respect to Maintaining High Quality Waters in California*, codified in 23 CCR §2900, and is commonly known as "Resolution 68-16." The federal antidegradation policy is found at 40 CFR §131.12. Both polices have been incorporated into the Basin Plan.

Although there are some differences, where the state and federal policies overlap they are consistent with each other. Both the state and federal antidegradation policies require that where surface waters are of higher quality than necessary to protect the designated beneficial uses, the high quality of those waters be maintained unless otherwise provided by the policies. Both policies require that certain findings be made before any adverse change to water quality can be permitted. The State Water Board has concluded that Resolution No. 68-16 incorporates the federal Antidegradation Policy (see State Water Board Order No. WQ 2001-16, p. 19, fn 83).

The state antidegradation policy applies to groundwater and surface water whose quality meets or exceeds water quality objectives. The state policy establishes a two-step process to determine if discharges that will degrade water quality are allowed. The first step requires that where a discharge will degrade high quality water, the discharge may be allowed if any change in water quality:

1. Will be consistent with the maximum benefit to the people of the state,
2. Will not unreasonably affect present and anticipated beneficial uses of such water, and
3. Will not result in water quality less than that prescribed (e.g., by water quality objectives).

The second step is that any activities that result in discharge to high quality waters are required to use the best practicable treatment or control necessary to avoid a pollution or nuisance and to maintain the highest water quality consistent with the maximum benefit to the people of the state. The state antidegradation policy further establishes that if the discharge, even after treatment, unreasonably affects beneficial uses or does not comply with applicable provisions of Basin Plans, the discharge would be prohibited.

The federal antidegradation policy applies to surface water regardless of the quality of the water. In allowing an activity to degrade or lower water quality, the federal antidegradation policy requires states to ensure that:

1. The activity is necessary to accommodate important economic or social development in the area,
2. Water quality is adequate to protect and maintain existing beneficial uses fully, and
3. The highest statutory and regulatory requirements and best management practices for pollution control are achieved.

The federal antidegradation policy also applies to surface waters that do not meet the applicable water quality objectives (i.e., impaired waters). Under the federal policy, an activity or discharge would be prohibited if the activity will lower the quality of surface water that does not meet water quality standards (i.e., the water quality is not sufficient to support designated beneficial uses) with limited exceptions set forth in federal regulations.

Both the state and federal antidegradation policies acknowledge that minor or repeated activities, even if individually small, can result in violation of antidegradation policies through cumulative effects, especially, for example, when the waste is a cumulative, persistent, or bioaccumulative pollutant.

11.2 Applicability to the Shasta River TMDL Action Plan

The proposed Shasta River TMDL Action Plan is based in part on the principles contained in the state and federal antidegradation policies. The recommended alternative – adoption of the proposed Shasta River TMDL Action Plan– will not delete or limit beneficial use designations and will not relax any water quality standard. This proposal will result in water quality improvements; therefore, state and federal antidegradation analyses are not required.

CHAPTER 12. ENVIRONMENTAL ANALYSIS

Key Points

- For the purposes of the California Environmental Quality Act (CEQA), the proposed project consists of:
  - Adoption of the Shasta River TMDL Action Plan as a Basin Plan amendment.
- The project is categorically exempt from the provisions of CEQA that require an initial study, environmental impact report, and a negative declaration.
- Other relevant provisions of CEQA and State Water Board regulations require that amendments to a Basin Plan comply with the functionally equivalent substitute environmental process, including:
  - Holding a scoping meeting, and preparation of:
    1. a substitute environmental document,
    2. alternatives to the project,
    3. a CEQA Checklist,
    4. an analysis of individual and cumulative environmental impacts, and
    5. mitigation measures.
- A properly noticed CEQA Scoping Meeting was held on June 28, 2005, in Yreka, CA.
- This Staff Report serves as the substitute environmental document.
- Three alternatives are considered:
  - Alternative 1: No Action.
  - Alternative 2: Shasta River TMDL Action Plan as proposed.
  - Alternative 3: WDR-based Implementation Actions.
- Regional Water Board staff recommend Alternative #2.
- The CEQA Checklist is included as Appendix H.
- This chapter serves as the analysis of environmental impacts.
- The adoption of the proposed Shasta River TMDL Action Plan will <u>not</u> have a significant individual nor cumulative impact on the environment because the term “significant impact” is defined to include only adverse impacts. The environmental changes that will result from the proposed project are beneficial, not adverse.
- A description and analysis of mitigation measures is not required because there are no significant adverse impacts to be mitigated.

For the purposes of the California Environmental Quality Act (CEQA), the project consists of adoption of the proposed Shasta River TMDL Action Plan as a Basin Plan amendment.

The adoption of the proposed Shasta River TMDL Action Plan will not have a "significant impact on the environment," because that term is defined to include only adverse impacts (14 CCR §15382). The environmental changes that will result from the proposed project are beneficial, not adverse. These statements are supported by the CEQA Checklist (Appendix H) and by the information presented in this Staff Report.

12.1 Functionally Equivalent Substitute Environmental Document

As discussed previously in this Staff Report, the Basin Plan amendment process has been certified by the Secretary for Resources as functionally equivalent to, and therefore exempt from, the CEQA requirement for preparation of an environmental impact report (EIR) or negative declaration and initial study (14 CCR §15251(g)). A substitute environmental document that is functionally equivalent to an EIR or negative declaration must be prepared, and must include a description of the proposed project and either a description of alternatives with mitigation measures to avoid significant adverse impacts or a statement showing that the project would have no significant adverse impacts. This entire Staff Report serves as the functionally equivalent substitute environmental document.

Other relevant portions of CEQA continue to apply, and State Water Board regulations require amendments to a Basin Plan to comply with a substitute environmental process. As part of this process, a Basin Plan amendment must include:

- Solicitation of public input, including holding a scoping meeting to assess the potential environmental scope of the CEQA analysis, and preparation of:
- A substitute environmental document;
- Alternatives to the project;
- A CEQA Checklist;
- An analysis of individual and cumulative environmental impacts;
- Mitigation measures.

The project has met these requirements. More information on these requirements is included in the following sections.

12.2 Scoping Meeting

The CEQA Scoping Meeting was held on June 28, 2005, in Yreka, California. A public notice of the meeting was sent out on May 13, 2005. Triplicate notices were inserted in newspapers throughout the North Coast Region beginning the week of May 15, 2005. In preparation for the Scoping Meeting, a plain English summary of the proposal was made available to interested parties and was posted on the North Coast Regional Water Board website.

Many of the comments received at the CEQA Scoping meeting concerned technical aspects of the initial proposal rather than the scope of the environmental review. The comments received at the CEQA Scoping Meeting that concerned the scope of the environmental review are summarized in Table 12.1 below. These comments, and others, helped to shape the scope of the environmental review and specific aspects of the resulting proposal.

12.3 Alternatives and Staff Recommendation

This section identifies and analyzes reasonable alternatives to the recommended approach that address different ways to reduce nutrient and other oxygen consuming constituent waste discharges and elevated water temperatures in the Shasta River watershed. An analysis of reasonable alternatives is required by CEQA. Every conceivable alternative need not be considered – only those that would meet the project objectives and are reasonable. "The range of potential alternatives to the proposed project shall include those that could feasibly accomplish most of the basic objectives of the project and could avoid or substantially lessen one or more of the significant effects (14 CCR §15126.6(a))."

Table 12.1: Comments and Responses from the CEQA Scoping Meeting

Scoping Factor	Comment	Response
Aesthetics	No Comments.	N/A
Agricultural Resources	Proposed project could result in conversion of farmland, to non-agricultural uses because the requirements will be so stringent that rural landowners will have to sell land for development.	No specific information was presented to demonstrate that the proposal was overly stringent. The information presented in this Staff Report indicates that the proposed implementation actions are not overly stringent. The proposal is authorized and required by existing state and federal laws. The Regional Water Board will work with landowners to develop inventories and help fund projects for cooperative landowners. The public will have time to come up with acceptable implementation alternatives. Landowner income and ability, as well as the source of problems will all be factored into specific time tables and practices to control low dissolved oxygen, nutrient and other oxygen-consuming constituent inputs and impacts to water temperatures.
Air Quality	No Comments.	N/A
Biological Resources	No Comments.	N/A
Cultural Resources	No Comments.	N/A
Geology and Soils	No Comments.	N/A
Hazards and Hazardous Materials	No Comments.	N/A
Hydrology and Water Quality	Increasing riparian vegetation may reduce instream water flows.	While this may be true in the short term, in the long term, increasing riparian vegetation can raise the water table thus increasing groundwater inputs. Additionally, staff is discussing the restoration of vegetation to natural levels only.

Table 12.1: Comments and Responses from the CEQA Scoping Meeting

Scoping Factor	Comment	Response
Land Use and Planning	Look at the effects of duplication of programs.	Duplication of efforts and overlap of regulatory programs is addressed in this Staff Report.
Mineral Resources	No Comments.	N/A
Noise	No Comments.	N/A
Population & Housing	No Comments.	N/A
Public Services	No Comments.	N/A
Recreation	No Comments.	N/A
Transportation and Traffic	No Comments.	N/A
Utilities and Service Systems	No Comments.	N/A

Factors that can be used to determine the feasibility of alternatives include: economic, social, environmental, legal, and technical. The analysis of alternatives must "include sufficient information about each alternative to allow meaningful evaluation, analysis, and comparison with the proposed project" (14 CCR §15126.6(d)).

In order to meet the project objectives, the selected alternative must provide the tools necessary to effectively control factors leading to low dissolved oxygen levels and elevated water temperatures across the Shasta River watershed so that the TMDLs are achieved, beneficial uses are protected, temperature and dissolved oxygen-related water quality objectives are attained, and water quality is preserved, enhanced, and restored. Each alternative is analyzed to determine potential consequences and how that alternative would or would not achieve the stated goals.

The following alternatives were considered:

Alternative 1	No Action.
Alternative 2	Shasta River TMDL Action Plan as proposed.
Alternative 3	WDR-based Implementation Actions.

12.3.1 Alternative 1: No Action

The no action alternative retains the existing Basin Plan language and does not result in the proposed Basin Plan amendment.

Currently, the Shasta River watershed is not meeting water quality objectives as set out in the Basin Plan for the North Coast Region. Section 303(d) of the federal Clean Water Act requires that a list be developed of all impaired or threatened waters within each state. The Shasta River watershed is listed as impaired on the 303(d) list, as described in Chapters 1 and 2 of this Staff Report. The watershed is not only listed as impaired on the federal 303(d) list, but the listings have been confirmed by monitoring and data evaluation. Section 303(d) also requires that each state establish a total maximum daily load (TMDL) for any water body designated as water quality limited. A TMDL is the maximum amount of a pollutant that a water body can contain and still achieve water quality standards. When TMDLs are adopted into the Basin Plan, they must contain implementation strategies that establish how water bodies will attain and maintain water quality objectives and support designated beneficial uses.

The Regional Water Board has entered into an agreement with the U.S. EPA to complete a full TMDL action plan by a court ordered consent decree due date.[1] As part of this agreement, the U.S. EPA provides funding to the Regional Water Board. Under the no action alternative, a full and complete TMDL action plan would not be adopted and the U.S. EPA would be forced to establish the technical TMDLs for dissolved oxygen and temperature by the consent decree due date. Technical TMDLs established by the U.S. EPA lack implementation strategies, monitoring plans, reassessment strategies, antidegradation analyses, environmental analyses, and economic analyses. Without a comprehensive TMDL action plan, and an implementation strategy in particular, achievement of the TMDLs, attainment of water quality standards, and protection of the beneficial uses of the Shasta River is not likely to occur.

The no action alternative is technically feasible and does not require any change to the Basin Plan. This alternative, however, has already been demonstrated to be ineffective at controlling low dissolved oxygen levels, discharges of nutrients and other oxygen-consuming constituents, and increased water temperatures in the Shasta River watershed. Selecting the no action alternative would not result in any increased regulatory or economic burden to dischargers; however, the economic impacts of not addressing water quality impairments would be continued. The consequences of selecting this alternative may be the continued degradation of water quality and adverse impacts, both individual and cumulative, to beneficial uses with the attendant direct and indirect costs, such as the increased costs for water treatment, reduced commercial, recreational and subsistence fisheries, and degradation of recreational waters.

12.3.2 Alternative 2: Shasta River TMDL Action Plan

This alternative consists of amending the Basin Plan to add the Shasta River TMDL Action Plan as proposed.

The Regional Water Board identified low levels of dissolved oxygen and elevated water temperatures as water quality problems in the Shasta River watershed, and the watershed is listed as impaired on the federal Clean Water Act Section 303(d) list. The Regional Water Board is obligated to complete TMDLs in the Shasta River watershed to comply with a completion schedule agreed to with the U.S. EPA under the terms of a court ordered consent decree arising from the lawsuit of Pacific Coast Federation of Fishermen's Associations v. Marcus, as described in the previous section. To meet this schedule, the Shasta River TMDLs must be completed and adopted into the Basin Plan in 2006.

The goal of the proposed Basin Plan amendment is to establish the TMDL and describe the implementation actions necessary to achieve the TMDLs and attain water quality standards, including protecting the beneficial uses of water. The amendment does this by addressing the dissolved oxygen and temperature impairments in the Shasta River watershed specifically through implementation actions. The proposed implementation actions describe the steps that are necessary to prevent, minimize, and control total thermal, nutrient, and oxygen-consuming loads, and related factors such as flow that reduce assimilative capacity. The implementation actions are tailored for individual sources and land uses. Several of the implementation actions outline a process for coordination among stakeholders while others describe additional study needs. Other implementation actions focus on use of permitting and enforcement tools.

[1] Pacific Coast Federation of Fishermen's Associations, et al. v. Marcus, No. 95-4474 MHP, 11 March 1997.

The Shasta River TMDL Action Plan must be adopted in order to preserve, enhance, and restore the Shasta River watershed, support beneficial uses, and achieve and maintain water quality objectives. The result will be a proactive strategy to address low dissolved levels and excess water temperatures resulting from land use activities conducted in the watershed.

12.3.3 Alternative 3: WDR-Based Implementation Actions

This alternative consists of amending the Basin Plan to add the TMDLs as proposed (i.e., the dissolved oxygen and temperature source analyses, TMDLs, load allocations, and margins of safety), and a suite of implementation actions that would vary from those currently proposed. Specifically, the implementation actions would be more regulatory in nature and rely on formal permit mechanisms to prevent, reduce, and control factors leading to low dissolved oxygen levels and elevated water temperatures in the Shasta River watershed. The goals of such an alternate TMDL Action Plan would be the same: to achieve the TMDLs and attain water quality standards, including protecting the beneficial uses of water. This alternative would also meet consent decree deadlines.

As stated above, many of the implementation actions under this alternative would be similar but more regulatory in nature than currently proposed in Alternative #2. For example, permits in the form of waste discharge requirements (WDRs) or waivers of WDRs would be developed to address discharges of nutrients and oxygen-consuming constituents and sources of elevated water temperatures. Activities that remove or suppress vegetation that provide shade to a waterbody, and grazing activities would be regulated under WDRs or waivers of WDRs. It is possible that fine sediment sources originating from activities such as road construction, maintenance and grading activities would be added to this list of activities requiring WDRs or waivers in the future.

This alternative would meet the objectives of the project by ensuring that human activities that contribute to low dissolved oxygen levels and elevated water temperatures in the Shasta River watershed are prevented, reduced, and controlled so as to meet the TMDLs and attain water quality standards. WDRs and waivers of WDRs would allow for specific requirements on an individual landowner basis or a general land use basis, and would also include specific time lines and monitoring requirements. This alternative would also likely increase the compliance cost to landowners/dischargers, as WDRs require the submission of an annual fee to the State. The environmental analysis is similar to Alternative 2 because these same actions are contemplated in both alternatives, though with different timing and degree of certainty.

12.3.4 Staff Recommendation

Regional Water Board staff recommend Alternative #2 and the adoption of the Shasta River TMDL Action Plan.

12.4 CEQA Checklist

Following the CEQA Scoping Meeting, and the preparation of a specific proposal (the project), the CEQA Checklist was prepared. The CEQA Checklist is attached to this Staff Report as Appendix H.

12.5 Analysis of Environmental Impacts

The project does not consist of any activities that would adversely affect dissolved oxygen levels or water temperature. The project establishes a Shasta River TMDL Action Plan to control total thermal, nutrient, and oxygen-consuming loads, and related factors such as flow that reduce assimilative capacity. The proposed requirements will be incorporated into permitting requirements and authorities. The proposed project will not have an adverse impact, individual or cumulative, to the environment. The proposed project will, however, have a significant beneficial impact on the environment because it will improve water temperatures and dissolved oxygen levels in the Shasta River Basin.

Both voluntary and regulatory actions taken to improve water quality (as listed in Chapter 8) could potentially have temporary construction impacts to water quality. At a minimum, best management practices (BMPs) would be put in place to minimize water quality impacts. Depending on the activity, a permit and/or specific environmental (CEQA) review might be necessary prior to implementation. These projects will be evaluated on a case-by-case basis by the implementing agency. Management measures exist to minimize impacts to less than significant in most cases. An example of a potential impact that could be mitigated with management measures could be removal of a minor surface water impoundment. In this case, the short-term water quality impacts would be addressed by BMP implementation during structure removal. In this scenario as well as others, the temporary water quality impacts would be outweighed by the long-term benefits of water quality improvement.

The adoption of the proposed Shasta River TMDL Action Plan will <u>not</u> have a significant impact on the environment because the term "significant impact" is defined as an adverse impact with "… a substantial, or potentially substantial, adverse change in any of the physical conditions within the area affected by the project, including land, air, water, minerals, flora, fauna, ambient noise, and objects of historic or aesthetic significance (14 CCR §15382)." The environmental changes that will result from the proposed project are beneficial, not adverse.

12.6 Mitigation Measures

As described above, adoption of the proposed Shasta River TMDL Action Plan will have a beneficial impact on the environment because it will improve dissolved oxygen levels and lower the temperature of waters of the state in the Shasta River watershed. The environmental changes that will result from the proposed project are beneficial, not adverse. A description and analysis of mitigation measures is not required because there are no significant adverse impacts, individual or cumulative, to be mitigated.

CHAPTER 13. ECONOMIC ANALYSIS

Key Points

- The proposed Shasta River TMDL Action Plan will provide significant economical benefits at a reasonable cost.
- Economic benefits relate to:
    - Improving fishing, including commercial, subsistence, and cultural fishing;
    - Improving recreation;
    - Establishing properly functioning ecosystems;
    - Improving fish and wildlife habitat;
    - Improving land values; and
    - Improving water conveyance and storage facilities.
- Costs may be related to the following implementation measures:
    - Temperature and vegetation implementation actions;
    - Tailwater return flow control;
    - Water use implementation actions;
    - Agricultural implementation actions, such as those for grazing; and
    - Dwinnell Dam and Lake Shastina pollutant control study(ies).
- This economic analysis is limited in scope to new requirements imposed by this proposal. Landowners and dischargers are already bound by various existing regulatory requirements that involve water quality and natural resource protection, and the economic impacts associated with existing obligations are not included in this analysis.
- The costs and benefits will not be uniformly distributed throughout the watershed, or even across properties with similar land uses.
- Potential sources of financing for implementation measures include private financing as well as public monies available through grants and other public funding programs.
- Regional Water Board staff conclude the estimated costs of the proposed Shasta River TMDL Action Plan are reasonable considering economic benefits and legal obligations to protect water quality and beneficial uses.

This chapter includes an analysis of the potential economic benefits and costs that may result from the adoption and implementation of the proposed Shasta River TMDL Action Plan. Benefits relate to both economic and non-economic values that will be improved by recovery of the watershed, high water quality, and supported beneficial uses. The costs relate primarily to implementation of preventative and remediation measures necessary to achieve the TMDLs.

Regional Water Board staff conclude that the estimated costs of the proposed Shasta River TMDL Action Plan are justified, not only because of the economic benefits that would be achieved, but also because of the legal obligations under which the Regional Water Board must act to protect water quality, beneficial uses, and the general public interest in fulfilling these obligations.

13.1 Legal Framework

In amending the Basin Plan, the Regional Water Board must analyze the reasonably foreseeable methods of compliance with proposed performance standards and treatment requirements (Pub. Resources Code §21000 et seq.). This analysis must include economic factors, but does not require a cost-benefit analysis.

Additionally, in accordance with the Porter-Cologne Water Quality Control Act, it is the policy of the state to protect the quality of all waters of the state. Waters of the state include "any surface water or groundwater, including saline waters, within the boundaries of the state (CWC §13050)." When adopting the Porter-Cologne Act, the Legislature declared that all values of the water should be considered, but then went on to provide only broad, non-specific direction for considering economics in the regulation of water quality.

> The Legislature further finds and declares that activities and factors which may affect the quality of the waters of the state shall be regulated to attain the highest water quality which is reasonable, considering all demands being made and to be made on those waters and the total values involved, beneficial and detrimental, economic and social, tangible and intangible (CWC §13000).

The Porter-Cologne Act directed regulatory agencies to pursue the highest water quality that is reasonable, and *one* of the factors used to determine what is reasonable is economics. It is clear, though, that economic factors cannot be used to justify a result that would be inconsistent with the federal Clean Water Act or the Porter-Cologne Act. The Regional Water Board is obligated to restore and protect water quality and beneficial uses.

13.2 Scope of the Economic Analysis

13.2.1 Existing Requirements

Landowners and dischargers are bound by various existing regulatory requirements that involve water quality and natural resource protection. The cost of complying with existing obligations and/or requirements should not be attributed to the proposed Shasta River TMDL Action Plan. Therefore, the scope of the economic analysis is limited to the implementation of the Shasta River TMDL Action Plan as proposed.

Applicable existing requirements include:

- Existing Basin Plan requirements (such as the federal and state antidegradation policies, prohibitions, and the existing water quality objectives for temperature, dissolved oxygen, sediment, settleable material, suspended material, and turbidity).
- State nonpoint source program requirements.
- Porter-Cologne Act requirements (such as the requirement of Section 13260 for every person who discharges a waste that impacts water quality to file a report of waste discharge with the Regional Water Board, and the cleanup and abatement requirements of Section 13304).
- The California Department of Forestry and Fire Protection or USFS requirements for timber harvest activities.
- The federal and state endangered and threatened species requirements.
- Obligations imposed by other local, state and federal natural resource agencies.

Every segment of riparian control fencing and surface drainage and reuse systems, for example, cannot be attributed to the proposed Shasta River TMDL Action Plan; some are necessary for compliance with other regulatory programs. Some costs to control total thermal, nutrient and oxygen-consuming loads, and related factors such as flow that reduce assimilative capacity are related to actions necessary to avoid a violation of the prohibitions in the Basin Plan and to avoid a taking under federal and state Endangered Species Acts or to fully mitigate impacts of authorized takes. Other costs may be incurred as a result of compliance with the Clean Water Act, other related statutes and regulations, or local land use ordinances. Conversely, compliance with the proposed Shasta River TMDL Action Plan will help dischargers comply with the other regulatory requirements.

13.2.2 Geographic Scope

The costs and benefits will not be uniformly distributed throughout the Shasta River watershed. The implementation actions proposed by the Shasta River TMDL Action Plan (see Chapter 8 of this Staff Report) are not uniformly required across the Shasta River watershed or even across properties with similar land uses. Instead, many of the implementation actions will be required of landowners on an as-needed, site-specific basis or are activities that are ongoing and are encouraged by the Regional Water Board. While this flexibility adds greatly to the effectiveness of the Shasta River TMDL Action Plan, it is one factor preventing this economic analysis from totaling benefits and cost on a watershed scale.

Additionally, more intensive land use activities will face greater costs than less intensive land use activities. Activities in proximity to surface water bodies will require greater care and assume higher costs than activities on lands that do not deliver to a surface water body.

13.2.3 Sediment Linkage to Dissolved Oxygen Impairment

As discussed in Chapters 4, the Shasta River watershed is not listed for sediment on the USEPA 303(d) list. However, Regional Water Board staff believes that fine sediment and organic material inputs to the Shasta River and tributaries promote the establishment and productivity of aquatic macrophytes. Aquatic macrophytes and periphyton contribute significantly to depressed dissolved oxygen concentrations. Fine sediment and organic material in the Shasta River promote the anchorage, growth, and production of aquatic plants. By reducing fine sediment sources to the river system, the production of aquatic plants may also be reduced. The luxuriant growth of the submerged macrophytes may also be stimulated, in part, by the oxygen consuming fine sediment and organic materials discharged in enriched tailwater return flows in addition to organic material from their own senescence and death. Runoff from livestock wastes and fertilizer may be other sources of oxygen consuming fine sediment and organic material to the Shasta River. Warm water temperatures, high nutrient concentrations, and ample light availability also contribute to aquatic plant productivity.

13.3 Benefits

This section presents the estimated benefits of the proposed Action Plan. These benefits relate to both economic and non-economic values that will be achieved by recovery of the watershed, high water quality, and supported beneficial uses. Benefits also include avoiding costs associated with the impacts of current and expected fine sediment waste discharges and elevated temperatures and low dissolved oxygen levels if they are not prevented and controlled. Existing temperature and dissolved oxygen impairments of beneficial uses negatively impact the cold water salmonid fishery (including the essential habitat of these fish), the fishing industry, water supplies, parks and the recreation industry, and others. The loss of topsoil from stream bank erosion and topsoil runoff from farming, grazing, and horticulture is another economic impact to agricultural industries.

The United Nations Environmental Programme, Division of Technology, Industry and Economics (UNEP 1999), summarized the results of many studies related to economic impacts of eutrophication of water bodies in the United States. The report stated that most of the studies focused on the benefits of improved water quality. The document pointed to a common theme among the studies, that improvements in water quality resulted in a range of benefits from improved recreation benefits and higher property values, to improved fish populations and lowered health risks.

Ribaudo (1989), an economist with the U.S. Department of Agriculture, studied water quality benefits related to prevention of soil erosion under the U.S.D.A. Conservation Reserve Program. He concluded that if sediment could be prevented from entering streams, the benefits to downstream landowners and water users would include actual benefits and avoided costs, such as lowered water treatment costs, reduced sediment removal costs, reduced flood damage, less damage to equipment that uses water, and increased recreational fishing.

Although many of the economic benefits of the proposed Shasta River TMDL Action Plan are foreseeable and describable, there is inadequate information to fully quantify some of these benefits. What information is available on benefits related to fishing, recreation, properly functioning ecosystems, , remediation activities, residential land prices, and water conveyance and storage facilities are described in the following sections. These sections are organized alphabetically, and are not listed in order of importance or size of economic benefit.

13.3.1 Fishing – Commercial, Subsistence, & Cultural

Commercial commodity fishing has been adversely affected by the decline in fisheries stocks in recent years. Salmon, especially, have economic value to commercial, recreational, and cultural fishing activities. The financial losses of commercial fisheries are due to many factors beyond habitat impaired by the impact of elevated water temperature and low dissolved oxygen (including ocean harvest, water diversions, and other habitat impairments), so the amount of the loss attributed to low dissolved oxygen and high water temperatures in the Shasta River watershed has not been determined. However, the Coho Recovery Strategy extrapolates coho recovery benefits and concludes that the economic benefits of recovery would be greater than the costs:

> Benefits associated with non-use values include intrinsic, or existence values which are derived from the knowledge that coho salmon populations exist, and bequest values which confer value to the resource for the benefit of future generations. Based on studies that examined streams in Colorado and salmon restoration in the Columbia River Basin, the San Joaquin River, and the Elwha River, the extrapolated value of California coho salmon recovery could be significantly larger than the fiscal or socioeconomic costs of recovery (CDFG 2004c).

In addition to the impact on the commercial fishery, fishing plays an important role in Native American cultures in the Klamath River to which the Shasta River is tributary. Improved habitat resulting from increased dissolved oxygen and lowered water temperatures will result in improved opportunities for cultural and subsistence fishing. Although these benefits are not quantified, the economic and cultural impact on the tribes of the Klamath Basin due to loss of salmonids fisheries is significant. The economic costs due to changes in traditional diets were explored in a recent study:

> Whereas historic fish consumption for the Karuk Tribe is estimated at 450 pounds per person per year, fish consumption for the Tribe based on the tribal fish catch in 2003 is estimated at less than 5 pounds per person per year. . . .The central thesis of this report is that Karuk people face significant and costly health consequences as a result of denied access to many of their traditional foods. Not only does a traditional diet prevent the onset of conditions such as obesity, diabetes, heart disease, kidney trouble and hypertension, a traditional

> diet of salmon and other foods is one of the best treatments for such conditions (Norgaard 2004).

The Coho Recovery Strategy also discussed this issue, but could not quantify it:

> Coho salmon recovery will have significant costs, but will also provide economic benefits. Benefits associated with Yurok and Hoopa Valley tribes' Federally reserved fishing rights, increased commercial land and water use activities, multiple species benefits, and improved water quality and watershed health will be realized, but they are not quantified. Coho salmon recovery will also result in benefits to recreational and commercial fishing and related industries, which are also not quantified in this document (CDFG 2004c).

13.3.2 Properly Functioning Ecosystems

Another large, but intangible, benefit can be ascribed to properly functioning ecosystems at various scales – local planning watershed, watershed, regional, etc. The National Academy of Sciences (NAS) states, "We now think of the natural environment, and the ecosystems of which it consists, as natural capital – a form of capital asset that, along with physical, human, social, and intellectual capital, is one of society's important assets (NAS 2004)." Some functions are most beneficial if they remain part of an integrated ecosystem rather than as individual components. Some of the valuable functions of intact ecosystems are nutrient recycling, regulation of climate and atmospheric gases, maintenance of biodiversity, water supply, flood risk reduction, etc. Not all of these services, of course, are impacted by high water temperature or low dissolved oxygen levels. The National Academy of Sciences has recently reviewed the studies associated with valuation of ecosystem services. They discuss several non-market valuation methods for both use and nonuse benefits. These analyses are beyond the scope of what is required for this economic analysis, but the concept of ecosystem services, apart from direct measurable goods and services, is among the intangible benefits of controlling low dissolved oxygen levels, and high water temperatures.

13.3.3 Recreation

Recreation does more than just supply leisure activity – recreation can have a significant economic impact. "Recreation and tourism are California's largest industries. California's rivers draw more of these users than any other location, except for its beaches (California State Lands Commission 1993)." "The demand for water-based recreation has been increasing as our population expands and the desire for outdoor recreation grows, particularly near urban areas and in national parks and other unique sites (Koteen et al. 2002)." Recreation and leisure activities provide economic value to those offering travel services. Services and amenities proximate to the recreation locations, such as equipment rental, hotels, campgrounds, restaurants, sale of supplies, park fees, etc.

The impact of water quality on recreation varies depending on the type of recreational activity. Some activities are more sensitive to nutrient and temperature related water quality impairments than others. A study by Koteen et al. (2002) showed that rafters, for example, are more interested in water quantity than sediment loads and are less willing to pay for improved water quality than are other recreational users such as swimmers, shoreline campers, fishermen, and sightseers. Koteen et al. (2002) summarized the value of water for particular recreational activities. They compared the mean increase in benefit to households in 1998 dollars for a specific change in water uses – such as from non-boatable to boatable; boatable to fishable; fishable to swimmable, etc. – in various geographic areas and nationwide. For example, a nationwide study showed a mean increase in benefit to households in 1998 dollars for a water quality change that allowed a change in recreation activity from boatable to fishable to be $79.60 for a change from fishable to swimmable to be $88.68. The report also summarized a 1982 study in 119 counties in Idaho, Oregon, and Washington that calculated the mean annual recreation benefits of swimming ($54,630), camping ($48,957), fishing ($98,303), and boating ($66,515). The 1982 values are based on the travel costs per number of visits to each recreational site in a year by nearby populations. They also summarized the marginal values of increasing water flow by type of activity, with fishing offering the highest marginal values per acre-foot for higher flows.

Recreational salmonid fishing will increase if fish stocks recover. Recreational fishing also creates jobs. As more fish are available, recreational fishing will be more attractive. Stedman and Hanson (2005) reported: "During 1991 it was estimated that 2.7 million people spent more than $1.5 billion fishing in California. The state's recreational fishery generated more than $900 million in earnings by supporting 40,000 jobs and contributed more than $90 million in state sales tax." Some studies suggest that recreational fishing rivals or exceeds commercial fishing in its economic value. Recreational fishing also supports direct and indirect economic value. "Dollars pumped into California's economy from river recreation include not only the direct value of licenses for fishing, registration of boats, equipment purchased, and hiring of guides or rafts, but also the value of lodging or campsites, money generated by travel to and from the rivers, and the maintenance and repair of river-related equipment (California State Lands Commission 1993)."

The impact of reducing nutrient loads and improving water temperatures, flow, and dissolved oxygen levels on recreational uses (and the associated economic benefit) will vary, depending on the activity and location. Recreational fishing appears to be highly sensitive to water quality improvements – not only because of the nature of the recreational water contact (i.e., it is more desirable to fish in clean water), but also because of the impact of poor water quality on fish stocks.

13.3.4 Remediation - Habitat Restoration

Remediation costs can be expected to decrease if the total thermal, nutrient and oxygen-consuming loads, and related factors such as flow that reduce assimilative capacity, are prevented. Remediation of fish habitat after impairment occurs can be expensive. The need for expensive restoration and remediation will be reduced, if not eliminated, if adverse impacts to temperature and dissolved oxygen levels can be reduced.

Prevention is far less expensive than remediation after degradation occurs. An enforcement case, which took place in 2003 - 2004 in the North Coast Region, illustrates the costs associated with remediation and enforcement. In this case, a local flood control agency removed all riparian canopy in two creeks while performing maintenance activities. The County District Attorney's office charged the Agency with two misdemeanors under a violation of Water Code Section 13387(a)(2) for conducting vegetation removal projects in the two creeks in a manner contrary to a permit issued by the Regional Water Quality Control Board.

The incidents at the two creeks raised concerns from the public, Regional Water Board staff, and other local environmental officials after extensive vegetation was removed from the creek beds and banks during the agency's flood control operations. The flood control agency responded with plans to revegetate the impacted area and other corrective actions. The County Superior Court authorized a conditional dismissal requiring the Agency to take corrective actions resulting from alleged unlawful streambed clearing operations. The settlement required the Agency to complete revegetation work at the impacted creeks and to enhance the creeks in areas not directly impacted by the vegetation clearing activities. The Agency was also required to enact interim guidelines for flood control activities and to work with state and federal agencies on a long-term maintenance program to provide effective flood control while minimizing environmental impacts. Additionally, the Agency must now solicit input from local cities and post notices near work sites to advise neighbors of impending creek clearing activity. The settlement also requires the Agency to develop watershed education programs for local high schools and provide technical assistance to the local high schools' creek habitat enhancement projects. The criminal case provides for a final dismissal of the criminal charges in three years if the Agency complies with conditions geared towards restoring the affected creeks and improving environmental education programs.

13.3.5 Residential Land Prices

Improvement of water quality has a positive economic impact on property values, even if property owners do not consume the water. Koteen et al. (2002) and others have summarized studies concerning the change in residential property prices near water bodies as related to changes in water clarity. "The studies examined the change in property price for each foot of lake frontage given a 1-foot improvement in water clarity." The studies found price increases ranging from $2.34 per foot of lakefront property in Minnesota to $16-28 in Maine. Conversely, the authors include a study showing a decrease in property value related to a decrease in water clarity in Florida. The precise property value changes discussed in the report cannot, of course, be applied directly or quantitatively to the Shasta River watershed; the authors caution, "The value is unique for each situation, such as location and current clarity." The tendency, though, for property values to increase when water quality is increased is borne out by other studies.

13.3.6 Water Conveyance and Storage Facilities

Excess water-borne sediment and other pollutants are deposited in slow moving areas, such as reservoirs and irrigation canals. This will reduce the life of these facilities. Higher sediment loads and nutrients increase maintenance costs of irrigation canals and reservoirs. The capacity of reservoirs is reduced. The costs avoided by reducing sediment and improving dissolved oxygen levels are difficult to quantify, but dams are expensive and this economic benefit is likely large overall.

13.4 Costs

This section presents the estimated costs of the proposed Action Plan. These costs relate to the economic impacts of compliance and remediation. See Section 13.2 for a discussion of the costs that can be ascribed to this proposal compared to the costs that are imposed by existing regulatory requirements.

The costs of the proposed Shasta River TMDL Action Plan will not be uniformly distributed throughout the Shasta River watershed. The proposed implementation actions (see Chapter 8 of this Staff Report) are not uniformly required across the Shasta River watershed or even across properties with similar land uses. Instead, the extent of the implementation action necessary is not known and may change based on the success of implementation. Additionally, there are various ways to address a given impairment and not all the management measures listed may be needed. Also, some of the actions called for in the Shasta River TMDL Action Plan (such as control fencing) are already in place or completed. Finally, many of the implementation actions will be required of landowners on an as-needed, site-specific basis or are activities that are on going and are simply encouraged by the Regional Water Board. While this flexibility should greatly improve the effectiveness of the Shasta River TMDL Action Plan, it is a factor that prevents this economic analysis from totaling benefits and cost on a watershed scale. Therefore, estimated costs are expressed on a unit scale (e.g., per acre, per linear foot of fence).

13.4.1 Methodology

The cost analysis was conducted to provide approximate estimates of the cost to implement the proposed Shasta River TMDL Action Plan. An economist on staff with the State Water Board assisted in developing this analysis (see Horner 2005 for more information). Costs of management measures that are likely to be required to achieve the actions specified in the TMDL were estimated using the Natural Resource Conservation Service (NRCS) Program Costs derived from the ProTracts cost dataset. ProTracts is a national dataset maintained by NRCS to assist local NRCS Districts in setting cost shares for implementing conservation practices. Cost estimates are provided at the county level and the data used for this analysis are specific to Siskiyou County. These cost estimates may not represent the total cost of implementing a management practice, but they do provide a reasonable approximation of costs that can be adjusted if necessary. The NRCS Program Costs database is updated on a monthly basis.

Management measures that are likely to achieve proposed implementation actions are varied and numerous. An early step in this analysis was to select the management measures from the NRCS Program Costs database that are the most appropriate and the most likely to be used to control total thermal, nutrient, and oxygen- consuming loads.

Table 13.1 lists the NRCS Program Costs best management practice categories. The management measures that were selected are in bold text.

Table 13.1: NRCS Program Costs

BEST MANAGEMENT PRACTICES			
CODE	**NAME**	**CODE**	**NAME**
322	**Channel Vegetation**	548	Grazing Land Mechanical Treatment
327	Conservation Cover	**550**	**Range Planting**
328	**Conservation Crop Rotation**	**554**	**Drainage Water Management**
329	**Residue Management, No-Till/Strip Till**	555	Rock Barrier
330	**Contour Farming**	**560**	**Access Roads**
332	**Contour Buffer Strips**	561	Heavy Use Area Protection
340	**Cover Crop**	562	Recreation Area Improvement
342	**Critical Area Planting**	566	Recreation Land Grading and Shaping
344	**Residue Management, Seasonal**	568	Recreation Trail and Walkway
350	**Sediment Basin**	**570**	**Runoff Management System**
382	**Fence**	572	Spoil Spreading
386	**Field Border**	**574**	**Spring Development**
390	Riparian Herbaceous Cover	575	Animal Trails and Walkways
391	**Riparian Forest Buffer**	**580**	**Streambank and Shoreline Protection**
393	**Filter Strip**	582	Open Channel
410	Grade Stabilization Structure	584	Channel Stabilization
412	**Grassed Waterway**	585	Stripcropping
422	Hedgerow Planting	600	Terrace
423	Hillside Ditch	601	Vegetative Barriers
450	**Anionic Polyacrylamide (PAM) Erosion Control**	**607**	**Surface Drainage, Field Ditch**
468	**Lined Waterway or Outlet**	**612**	**Tree/Shrub Establishment**
484	Mulching	**614**	**Watering Facility**
490	Forest Site Preparation	**638**	**Water and Sediment Control Basin**
511	Forage Harvest Management	655	Forest Trails and Landings
512	Pasture and Hay Planting	666	Forest Stand Improvement

13.4.2 Estimated Costs for Shasta River TMDL Action Plan

Estimates of the costs of the Shasta River TMDL Action Plan, should it be adopted and implemented as proposed, are listed in Table 13.2. The table is organized in the same order as the proposed implementation actions in Chapter 8. This information is based on the economic analysis conducted by an economist on staff with the State Water Board (Horner 2005).

As discussed above, a single management measure will likely not be implemented over the entire extent of a given land use or across the entire Shasta River watershed. It is up to the landowner/discharger to decide which implementation actions and management measures are most appropriate to control sediment and water temperature on his or her property. Also, some of the management measures have already been implemented or are required by other regulatory programs.

Table 13.2: Estimated Costs for the Implementation of the Shasta River TMDL Action Plan

Estimated Costs for Livestock Access Limitation Practices		
Fencing	$3.25 per running foot of fence	Per NRCS Program Cost database.
Installation of Remote Water Supply (Tanks)	$1.75 per gallon of tank capacity	Per NRCS Program Cost database.
Estimated Costs for Temperature and Vegetation Implementation Actions		
Planting Trees	$180 per acre.	Per NRCS Program Cost database.
Maintaining Trees	$800 per acre.	Per NRCS Program Cost database.
Estimated Costs for Water Use Implementation Actions		
Contain Facility Wastewater and Runoff	$20 per acre foot	Per NRCS Program Cost database.
Lining Water Delivery Ditches	$206.25 per irrigated acre	Per NRCS Program Cost database.
Install Surface Drainage and Reuse Systems	$41.25 per irrigated acre	Per NRCS Program Cost database.
Install Cropland Filter Strips	$1.11 per irrigated acre	Per NRCS Program Cost database.
Install Stock water Conveyances	$2.00 to $5 per linear foot	Per NRCS Program Cost database.
Well Construction	$35 per linear foot	Per NRCS Program Cost database.
Install Remote Water Supply	$1.00 per gallon of trough capacity	Per NRCS Program Cost database.
Estimated Costs for Flood Control and Bank Stabilization Implementation Actions		
Planting Trees	$180 per acre.	Per NRCS Program Cost database.
Maintaining Trees	$800 per acre* (*includes installation and a one time maintenance)	Per NRCS Program Cost database.
Estimated Costs for Grazing Implementation Actions		
Fencing	$3.25 per running foot of fence	Per NRCS Program Cost database.
Development of a Ranch Management Plan	Level Ground: $8.50 to $12.50 per acre Steep Ground: $12.50 to $18.50 per acre	Based on the estimated cost for a consultant to prepare the plan at a rate of $200 to $300 per day. A plan for 100 acres of flat ground would take about 4 days to prepare and a plan for 100 acres of steep ground would take about 6 days to prepare. Miscellaneous expenses (e.g., gas) are also included (Fitzgerald, 2005)[1].
Estimated Costs for Dwinnell Dam and Lake Shastina Studies		
Study design, and implementation, including monitoring,	$150,000 to $200,000	Per personnel communication with Dr. Deas

[1] Note: Costs for developing this type of plan are highly variable. Therefore, these costs should be considered rough estimates based on costs for developing a similar type of plan in the Scott River watershed.

13.5 Sources of Funding

Potential sources of funding for implementing required management measures or actions include monies from private and public sources. Public financing includes, but is not limited to grant funds, as described below, single-purpose appropriations from federal, state, and/or local legislative bodies, and bond indebtedness and loans from government institutions.

Every year there are different sources of public financing through grant and funding programs administered, at least in part, by the Regional Water Board and the State Water Board. These programs vary over time depending upon federal and state budgets and ballot propositions approved by voters. An up-to-date list and description of funding programs can be viewed at the State Water Board's website at: <http://www.waterboards.ca.gov/funding/index.html>. At the time of this writing there are several Regional and State Water Board grant funding programs pertinent to the proposed Action Plan for the Shasta River Temperature and Dissolved Oxygen TMDLs. The programs currently available are listed below.

- The Federal 319(h) Clean Water Act Program.

This is an annual federally funded nonpoint source pollution control program that is focused on controlling activities that impair beneficial uses and on limiting pollutant effects caused by those activities. Project proposals that address TMDL implementation and those that address problems in impaired waters are favored in the selection process. There is also a focus on implementing management activities that lead to reduction and/or prevention of pollutants that threaten or impair surface and groundwaters. Eligible applicants include nonprofit organizations, local government agencies including special districts, tribes, and educational institutions. State or federal agencies may qualify if they are collaborating with local entities and are involved in watershed management or proposing a statewide project. Approximately $4.5 - 5.5 million are available per year. For 2005-2006, the 319(h) Program has been added to the Consolidated Programs; however, it is available on an annual basis where the other programs in the consolidated list (below) are funded by bonds and are not necessarily going to be eligible in the future. Eligible 319(h) project types include:

- Implementation of measures and practices that reduce or prevent nonpoint source pollution to ground and surface waters.

- Projects consistent with Total Maximum Daily Loads, local watershed-based plans, and the California Nonpoint Source Program Plan.

At the time of this writing, the State Board in coordination with the nine Regional Water Boards, US Environmental Protection Agency (EPA), as well as other agencies, are working to implement the 2005-06 Consolidated Grants Program. The current Consolidated Grants Program integrates and coordinates related grant programs for Watershed Protection, Water Management, Agricultural Water Quality, Drinking Water, Urban Storm Water, and Non-Point Source Pollution Control. Approximately $143 million will be made available from six interrelated grant programs administered by the State Water Board's Division of Financial Assistance. Consolidation of these grants reduces application efforts and better integrates program goals with partner agencies, which include the US EPA, CALFED, Coastal Commission, Coastal Conservancy, Department of Water Resources, Department of Fish and Game, Resources Agency, and other related agencies. The 2005-06 Consolidated Grants are funded utilizing Proposition 40, Proposition 50, and federal appropriations. The six consolidated programs are as follows:

1. Proposition 40 – Non-Point Source Pollution Control Program
2. Proposition 50 - Coastal Nonpoint Source Pollution Control Program
3. Federal Clean Water Act Section 319 (h) – Non-point Source Implementation Program
4. Propositions 40 and 50 – Agricultural Water Quality Grant Program
5. Proposition 40 – Urban Storm Water Program
6. Proposition 40 – Integrated Watershed Management Program

CHAPTER 14. PUBLIC PARTICIPATION

Key Points

- The public has had many opportunities to comment on and participate in the development of this Draft Shasta River TMDL Action Plan and Staff Report.
- The Shasta River TMDL Technical Advisory Group (TAG) has provided input and advice to Regional Water Board staff. Staff have responded to many questions and comments raised by the TAG.
- A public Scoping Meeting was held to solicit public comment on the scope of the environmental review.
- Status updates and presentations on the Shasta River TMDL have been made to the Regional Water Board and members of the public.
- There will be many more opportunities for public input and comment on the Shasta River TMDL Action Plan.

This chapter describes some of the opportunities that have been made available to the public for comment on and participation in the development of the Shasta River TMDL Action Plan.

14.1 Shasta River TMDL Technical Advisory Group

The Shasta River Dissolved Oxygen and Temperature TMDL Technical Advisory Group (TAG) was formed to provide input and advice to staff of the Regional Water Board during development of the technical TMDLs for dissolved oxygen and temperature in the Shasta River watershed. Although forming a TAG was not a requirement of the Basin Plan amendment process, the existence of the TAG engaged members of the community and helped to produce a more robust TMDL.

Members of the TAG included representatives from the California Department of Fish & Game, the California Department of Water Resources, the County of Siskiyou, the Siskiyou County Farm Bureau, the Natural Resources Conservation Service, the Shasta River Coordinated Resource Management Planning Council, the Shasta Valley Resource Conservation District, the City of Yreka, the City of Montague, several Shasta Valley irrigation districts, the National Oceanic & Atmospheric Administration, the United States Fish & Wildlife Service, the University of California Cooperative Extension, several members of the local communities, and contractors working on behalf of the Regional Water Board to assist with the development of certain sections of the TMDL.

Seven meetings were held over the course of the TMDL development period, which began in earnest in early 2002. Meetings were held on February 3, 2003, May 7, 2003, August 18, 2003, May 13, 2004, November 22, 2004, April 18, 2005, and November 3, 2005. During this time, Regional Water Board staff presented the following documents for TAG review and comment:

- Shasta River Dissolved Oxygen TMDL Monitoring Plan (May 2003 [NCRWQCB 2003])
- Shasta River Water Quality Conditions, 2002 and 2003 (May 2004 [Appendix C_e]).
- Shasta River Water Quality Related Investigations – 2004 (April 2005 [Appendix A]).
- Water-Quality Data from 2002 to 2003 and Analysis of Data Gaps for Development of Total Maximum Daily Loads in the Lower Klamath River Basin, California (USGS report, 2005 [Appendix D_e])
- Lake Shastina Limnology (Report prepared by Watercourse Engineering, April 2005 [Vignola and Deas 2005])

Throughout the TAG process, Regional Water Board staff attempted to respond to questions and concerns raised by the TAG. Several examples of staff responses to TAG suggestions are as follows:

Temperature:

- In response to concerns that temperature probes may be inaccurate, RWB staff deployed duplicate probes at select monitoring locations in 2003.

Dissolved Oxygen

- In response to concerns about the field and analytical methods used in the Shasta River dissolved oxygen monitoring program conducted by USGS, extensive additional quality assurance review and analysis was completed, resulting in a clearer depiction of the uses and limitations of dissolved oxygen data collected in 2002 in particular.
- In response to concerns that the dissolved oxygen objective for the Shasta River is unattainable at upper reaches of the Shasta River under ambient stream temperatures, Regional Water Board staff prepared a memo addressing these concerns and provided it to all TAG members.
- Regional Water Board staff conducted monitoring of Big Springs and Big Springs Lake in response to a request to conduct such monitoring to adequately characterize water quality conditions from springs.
- In response to concerns that nutrient concentrations may have daily variation and that daily grab samples may not reflect this variation, RWB staff sampled at select locations three times within a 24-hour period for one sample event in July 2003.

14.2 Scoping Meeting

The purpose of the Scoping Meeting was to solicit public comments to help staff assess the potential environmental scope of the environmental analysis. Holding a scoping meeting is a requirement of the California Environmental Quality Act (CEQA). The Scoping Meeting was held on June 28, 2005, in Yreka, California. Many of the comments received at the CEQA Scoping meeting concerned technical aspects of the ongoing analysis rather than the scope of the environmental review. The comments received at the CEQA Scoping Meeting that concerned the scope of the environmental review are summarized in Chapter 12. These comments, and others, helped to shape the scope of the environmental review and specific aspects of the analysis.

14.3 Presentations to the Regional Water Board

Periodically, Regional Water Board staff presented updates and status reports to the Regional Water Board and interested members of the public on the Shasta River TMDL and related efforts in the Klamath River Basin. Presentations were made on February 10, 2004 in Santa Rosa, on May 4, 2005 in Weaverville, and on August 10, 2005 in Santa Rosa. The presentations were opportunities for the public and Board members to hear status updates and background information. At each of these meeting, the public also had the opportunity to give comment before the Board. All such comments are part of the public record.

14.4 Other Activities

On October 1, 2002, Regional Water Board staff presented the TMDL program and schedule for Klamath River Basin TMDL development to the Siskiyou County Board of Supervisors. Regional Board staff made a presentation to the Siskiyou County Board of Supervisors on October 12, 2005. Regional Water Board staff have maintained regular contact with County staff regarding the status of TMDL development throughout the process.

On April 24, 2002, Regional Water Board staff made a presentation to the Shasta River Coordinated Resource Management Planning Council to introduce the TMDL process in the Klamath River Basin. On September 12, 2002, Regional Water Board staff presented the TMDL program and schedule for the Shasta River TMDLs to the Shasta Valley Resource Conservation District Board in Yreka. On May 12, 2004, Regional Water Board staff presented results of the Shasta River thermal infrared study to the Shasta Valley Resource Conservation District Board.

On January 9, 2003, Regional Water Board staff made a presentation to the Statewide Coho Recovery Team convened by the California Department of Fish and Game. Regional Water Board staff also attended, as members of the public, a series of meetings of the Scott-Shasta Recovery Team, a separate effort associated with the statewide Coho Recovery Team aimed specifically at developing elements of recovery plans for these watersheds. This coordination identified areas of overlap between the TMDL and Coho Recovery efforts, aligned Coho Recovery recommendations to minimize conflict with TMDL goals, and provided an opportunity for ongoing discussion with individuals and organizations also involved in the TMDL process.

Regional Water Board staff have given regular updates on the status of TMDL activities in the Klamath Basin to the Klamath Basin Fisheries Task Force and its subgroups. Presentations were made to the full Task Force on June 24, 2004, June 15, 2005, and October 19, 2005, and to the Task Force's Technical Working Group on December 7, 2004. A presentation to the Task Force was held on February 9, 2006.

The USEPA and the Regional Water Board have initiated an informal consultation process with the U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration, Fisheries (NOAA Fisheries) on Klamath River TMDLs. Regional Water Board and USEPA staff have used this process to provide information and updates on the TMDLs in the Klamath River Basin, namely the Salmon, Scott, Shasta, Lower Lost, and Klamath River TMDLs. In addition, both NOAA Fisheries and the USFWS have attended the Shasta River TMDL Technical Advisory Group meetings.

The USEPA has held regular meetings with representatives of tribes in the Klamath River Basin watershed in California and the Regional Water Board to provide updates on the TMDL process, as part of USEPA's tribal trust responsibilities. These meetings have been held approximately quarterly for the last several years.

In addition, there has been and continues to be informal contact with many individuals and organizations active in the Shasta River watershed.

14.5 Peer Review

Prior to development of the Public Review Draft of the Shasta River TMDL Staff Report, the draft report was reviewed by Dr. Charles Coutant as part of a formal state-mandated peer-review process. Dr. Coutant's comments on the peer-review draft are presented in Appendix I.

14.6 Public Draft and Opportunities for Public Input

Throughout the Basin Plan amendment process, there are opportunities for public participation and comment, including at the CEQA scoping meeting, at the Regional Water Board and associated workshops prior to the Regional Water Board hearing for the proposed TMDL Basin Plan amendment, at the Regional Water Board hearing to consider adoption of the TMDL Basin Plan amendment, before the State Water Board, and during public forum at any Regional Water Board meeting. The following opportunities and their estimated dates remain for public comment on the proposed Shasta River TMDL Basin Plan amendment. Please note that the following dates may change.

The Shasta TMDL and Action Plan were partially released for public comment on February 7, 2006. The full document was available on February 22, 2006. Following public testimony on the *Action Plan for the Shasta River Watershed Temperature and Dissolved Oxygen Total Maximum Daily Load* at the May 17, 2006 hearing in Fortuna, the Regional Water Board directed staff to prepare a revised set of documents, including the Action Plan (or Basin Plan Amendment), Resolution R1-2006-0052, and the Staff Report, that clearly delineated the changes made to the draft document as a result of the public hearing process. The documents have now been revised and were reposted on the Regional Water Board web site on May 26, 2006.

Public Comment Period .... February 7, 2006-April 3, 2006

Public Informational Workshop .... March 8, 2006
before the Regional Water Board in Santa Rosa, CA

Public Informational Workshop (Arcata) .... March 14, 2006

Public Informational Workshop (Yreka) .... March 15, 2006

Public Hearing .... May 17, 2006
before the Regional Water Board in Fortuna, CA

Second Public Hearing.. June 28, 2006
before the Regional Water Board in Santa Rosa, CA

Public Workshop and Hearing ....To Be Determined
before the State Water Resources Control Board in Sacramento, CA

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California Regional Water Quality Control Board
North Coast Region

and

Aquatic Ecosystems Analysis Laboratory
John Muir Institute of the Environment
University of California, Davis

Shasta River Water Quality Related Investigations - 2004

April 2005

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Introduction

Staff of the North Coast Regional Water Quality Control Board (Regional Water Board) are in the process of developing temperature and dissolved oxygen Total Maximum Daily Loads (TMDLs) for the Shasta River. In July and August 2004, Regional Water Board and UC Davis Aquatic Ecosystems Analysis Laboratory staff monitored various water quality, physical, and biological attributes of the Shasta River to gain a more complete understanding of water quality dynamics of the Shasta River. The results are being used to support TMDL development analyses.

This report presents the monitoring methodologies and results.

2004 Monitoring Plan and Methods

The components of the Shasta River 2004 Monitoring Plan included: (1) aquatic vegetation surveys, (2) stream sediment characterization, (3) riparian density characterization, (4) light intensity measurements, (5) water quality monitoring, and (6) stable isotope analysis of suspended material and macrophytes. The geographic scope of this monitoring was those portions of the Shasta River from Lake Shastina to the mouth at locations where Regional Water Board staff had access to the river from property owners. The monitoring occurred from July 26 to August 6, 2004.

Aquatic Vegetation Surveys

Purpose and Background: Dissolved oxygen levels in the Shasta River reflect a pronounced diurnal fluctuation (NCRWQCB 2004), apparently driven by photosynthesis and respiration of aquatic plants. The purpose of the aquatic vegetation surveys was to characterize the spatial distribution, composition, and biomass of aquatic plants in the Shasta River and Lake Shastina. Information from the surveys has been used to better understand the role of aquatic plants on dissolved oxygen levels in the Shasta River, and has been incorporated in the Shasta River water quality model (Tennessee Valley Authority RQUAL and ADYN) being developed in support of the Shasta River TMDLs.

Methods: The types of aquatic plants in the Shasta include (1) benthic algae, called periphyton, attached to substrate or other plants, (2) rooted vascular plants, called macrophytes, and (3) suspended algae, called phytoplankton. The objective of the surveys was to characterize the type, composition, and biomass of aquatic plants at a reach-scale. In this case a "reach" is defined as a length of river with similar plant types and species of similar cover and density. The length of a reach was determined on-site by visual inspection and cataloguing of the plant species presence and cover. Where Regional Water Board staff had been granted access to the river by the property owner, we walked the riverbank or floated the river, and catalogued the plants present. The upstream and downstream boundaries of the reaches were noted on USGS topo maps in the field. In some cases, but not all, coordinates were logged using Global Positioning System.

The percent cover of macrophytes was made by visual estimation. Teams of two to five Regional Water Board and UC Davis staff individually estimated the percent cover for a given reach, and then reached a unanimous decision of the percent cover. Due to significant small-scale variability, no percent cover estimates were made of the periphyton communities.

The macrophytes were identified to the species level by UC Davis staff using dichotomous keys from the Jepson Manual of Higher Plants of California (Hickman 1993). Notes on native versus exotic status were taken from the same source. Periphyton and phytoplankton samples were identified to species by Aquatic Analysts of White Salmon, Washington according to Standard Methods 10200.D.2 (APHA 1992).

The methods for collecting and determining the biomass (ash free dry mass [AFDM] and Chlorophyll and Pheophyton a [Chl a and Pheo a]) of the aquatic plants varied depending on the nature of the plant community (i.e. periphyton-dominated, macrophyte-dominated, or phytoplankton-dominated) at a given river location, as detailed below.

For the ***periphyton-dominated communities***, algae samples were collected at locations with microhabitats of similar depth (1 to 2 feet) and flow velocity (1 to 2 feet per second) and free from riparian and topographic shading. These site-selection criteria and sample methodology were also employed for periphyton surveys conducted in summer 2004 on the Klamath River. The periphyton samples were collected according to Standard Methods 10300 B.2.a (APHA 1995). Three rocks were collected from the sites for sampling of periphyton composition (speciation and enumeration) and abundance (AFDM, Chl a and Pheo a). Prior to processing, unattached debris was rinsed from each rock. An area corresponding to the size of a standard microscope slide (1 inch by 3 inch) was marked, scraped from a rock, and placed into a Nalgene bottle with Lugol's solution for preservation. A second rock was scraped from an equivalent area and placed in a Nalgene bottle preserved with $MgCO_3$ for chlorophyll a and pheophyton a analysis, according to Standard Methods 10200 H.3 (APHA 1995). The third rock was scraped as above and placed in a Nalgene bottle for analysis of AFDM, according to Standard Methods 10300 C.5 (APHA 1995). Samples were placed in a cooler with ice. Speciation and biomass of periphyton samples were analyzed by Aquatic Analysts.

For the ***macrophyte-dominated communities,*** samples were also collected at locations with microhabitats of similar depth (1 to 2 feet) and flow velocity (1 to 2 feet per second) and free from riparian and topographic shading. Samples of the dominant macrophyte species occurring at a site were collected from the area inside a milk crate (11 inches by 11 inches) and placed in a Ziploc bag on ice for subsequent confirmation of species identification and analysis of AFDM according to Standard Methods 10400 D.3.a.3 (APHA 1995) and chlorophyll a according to Standard Methods 10400 D.3.b (APHA 1995). The University of California at Davis' Aquatic Ecosystems Analysis Laboratory conducted analyses of the macrophyte samples.

For the ***phytoplankton-dominated communities*** samples were collected using a Kemmerer sampler at three depths (surface, mid, and near-bottom) consistent with

Standard Methods 10200 B.2.a (APHA 1995). Samples for species composition analysis were placed in a Nalgene bottle and preserved with Lugol's solution. Samples for chlorophyll a analysis (Standard Methods 10200 H.3) were placed in a Nalgene bottle preserved with $MgCO_3$. Samples for ash free dry weight analysis (Standard Methods 10300 C.5) were placed in a Nalgene bottle. All samples were placed in a cooler with ice. Aquatic Analysts processed the phytoplankton samples.

Stream Bottom Sediment Size Characterization

Purpose and Background: Sediment oxygen demand (SOD) measurements and analysis of sediment composition (% organic content and % finer than 63 microns) were conducted at six locations on the Shasta River in July 2003. The purpose of the bottom sediment characterization in 2004 was to characterize sediment composition in order to extrapolate the 2003 results of the SOD measurements to other reaches of the river.

Methods: Visual estimates of the percent composition by particle-size classes (i.e., cobbles, gravel, sand, and fines) were made at various locations within the Shasta River where access was granted. The visual estimates of the composition of the stream bottom sediments were made based on the size and texture of the substrate. Observations about the nature of the fine sediments were noted.

Riparian Vegetation Characterization

Purpose and Background: A riparian vegetation survey was conducted in 2001 for building input data sets for the flow and temperature model (Tennessee Valley Authority RQUAL and ADYN models) developed by Watercourse Engineering, Inc. for the Shasta River Resource Conservation District. Characterization of riparian conditions was made at additional locations in 2004 to supplement those done in 2001, using the same methods used in 2001.

Method: Descriptions of riparian conditions were noted according to the following descriptors: 0 = no trees, 1 = less than 2 trees per 100 feet, 3 = greater than 2 trees per 100 feet.

Light Intensity Measurements

Purpose and Background: In the water quality model being developed for the dissolved oxygen TMDL (Tennessee Valley Authority RQUAL and ADYN models), dissolved oxygen concentrations are governed in large part by the photosynthetic rate of macrophytes. One input factor that controls the photosynthetic rate is a light extinction coefficient. Light intensity measurements were made in the Shasta River to calculate appropriate light extinction coefficients. The light extinction coefficient is a measure of the amount of light penetrating the water surface.

Method: Light intensity measurements were made at the water surface and at 1-foot increments below the surface using a LI-COR Radiation Sensor according to manufacturer's directions.

Water Quality Monitoring

Purpose and Background: Measurements of temperature, dissolved oxygen, pH, and specific conductance were made to supplement measurements conducted by Regional Water Board staff in 2002 and 2003. Further, measurements of dissolved oxygen at 15-minute intervals were used to calculate photosynthetic and respiration rates.

Method: Discreet measurements of temperature, dissolved oxygen, pH, and specific conductance were made at each aquatic plant sample location using YSI 600XL datasondes. Measurements of these parameters were also made at 15-minute intervals at six locations from July 30 to August 5, 2004 using YSI 6600 datasondes.

Stable Isotope Analysis

Purpose and Background: The heavy isotopes of carbon and nitrogen are useful as biological tracers. Primary producers (i.e. green plants) take up the isotopes in the concentration in which they are found in the environment and incorporate them into their tissue. In streams and rivers with access to the open ocean, typical sources of the heavy isotope ^{15}N include marine derived material (e.g. anadromous fish including salmon), or anthropogenic sources (human or animal waste or synthetic fertilizers), both of which are naturally enriched in the heavy isotope. Therefore, water samples containing algae, and samples of aquatic macrophytes growing in the river were collected to determine the presence of anthropogenic sources of nitrogen in the Shasta River system.

Method: The methods and results of the stable isotope analysis are presented in **Appendix B**.

Results

Regional Water Board and UC Davis Aquatic Ecosystems Analysis Laboratory staff surveyed approximately 2/3 of the length of the Shasta River from Dwinnell Dam to the mouth. Those reaches surveyed and the associated sample points for the various components of the Monitoring Plan are summarized in **Tables 1 and 2** and shown on **Figures 1a, 1b, and 1c**.

Aquatic Vegetation Survey Results

The results of the aquatic vegetation surveys are presented in **Tables 3 to 8**. The benthic and suspended algae species (i.e. periphyton and phytoplankton) identified in the Shasta River and Lake Shastina are presented in **Table 3**. The algae species composition and associated density and biovolume at each sample point are summarized in **Table 4**. Algal biomass results are presented in **Table 5**. The macrophyte species identified in the Shasta River are presented in **Table 6**. The total percent cover of macrophytes per reach is presented in **Table 7**, along with the macrophyte species composition per reach. Finally, the biomass of the macrophyte samples is shown in **Table 8**. **Figures 1a, 1b,**

and 1c identify the river reaches distinguished by varying macrophyte species assemblages and cover. **Appendix A** describes the general life history and habitat affinities of the aquatic macrophytes of the Shasta River.

Stream Bottom Sediment Size Characterization Results

Visual estimates of the percent composition of stream bottom sediments by particle-size class are presented in **Table 9**. Regional Water Board staff have developed estimates of SOD rates at those locations where sediment composition observations were made, based on the 2003 SOD measurement results (NCRWQCB 2004) and published SOD rates (Bowie *et. al.* 1985). These SOD estimates and the 2003 SOD measurement results are included in **Table 9**.

Riparian Vegetation Classification Results

The characterization of riparian classes (# of trees per 100 feet) is presented in **Table 10** and **Figure 2**.

Light Intensity Measurements

Light extinction coefficients for locations in the Shasta River are presented in **Figure 3**.

Water Quality Monitoring

Dissolved oxygen and pH measurement results taken at 15-minute intervals at six Shasta River locations from July 30 to August 5, 2004 are presented in **Figures 4 a – f**. Temperature and specific conductance measurement results taken at 15-minute intervals at six Shasta River locations from July 30 to August 5, 2004 are presented in **Figures 5 a – f**.

Stable Isotopes

Results of the stable isotope analysis are presented in **Appendix B.**

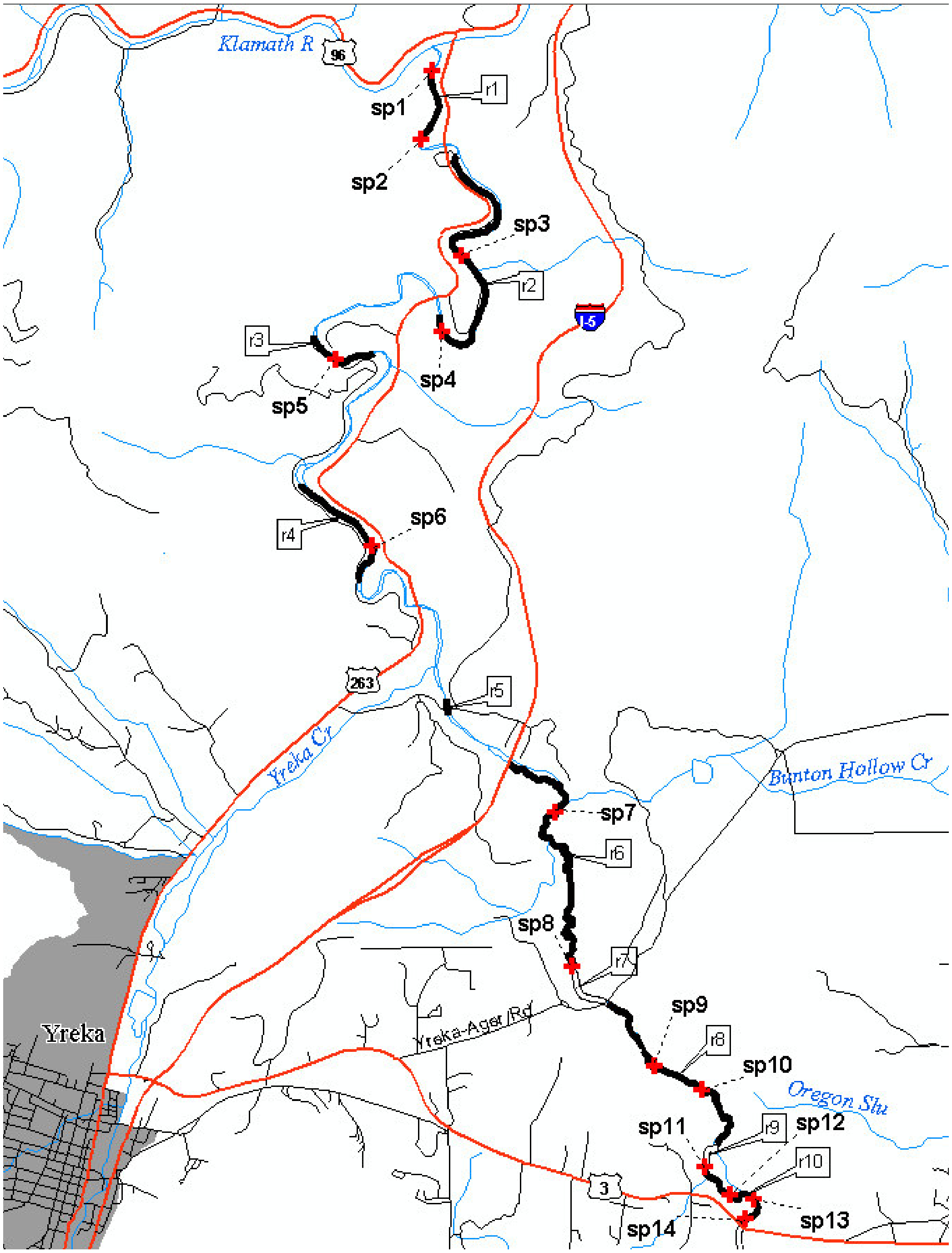


Figure 1a. Shasta River survey reaches and sample points – mouth to Highway 3.

This figure shows the reaches of the Shasta River from the mouth to Highway 3 that were surveyed. "r" = Reach; "sp" = Sample Point. The reaches are defined by the macrophyte species growing within the reach, and by the density of those macrophyte species. The sample points correspond to locations where macrophyte or algae samples were collected, where water quality measurements were taken, where light measurements were made, and/or where stream bottom sediment size characterizations were estimated.

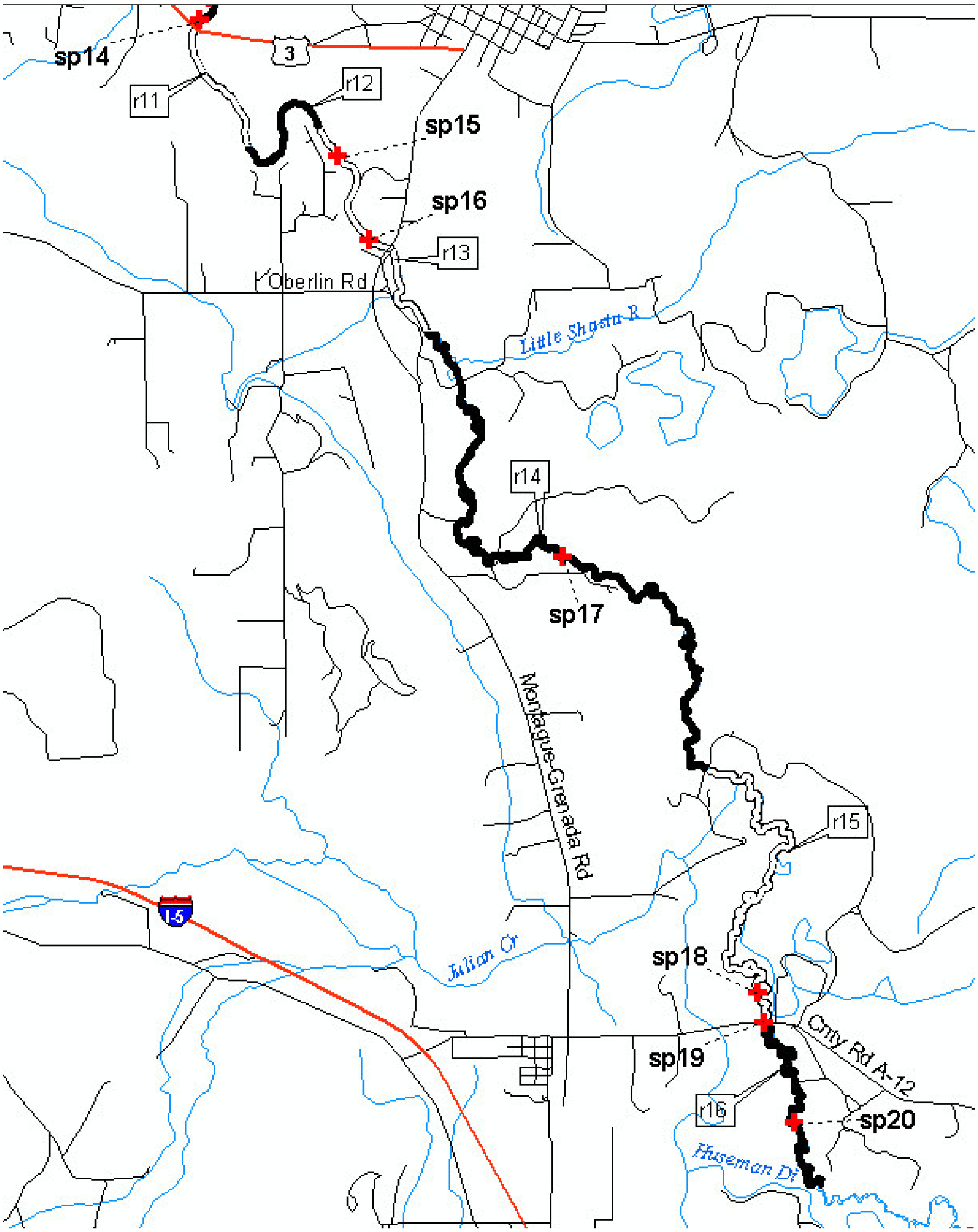


Figure 1b. Shasta River survey reaches and sample points – Highway 3 to Highway A12.

This figure shows the reaches of the Shasta River from the mouth to Highway 3 that were surveyed. "r" = Reach; "sp" = Sample Point. The reaches are defined by the macrophyte species growing within the reach, and by the density of those macrophyte species. The sample points correspond to locations where macrophyte or algae samples were collected, where water quality measurements were taken, where light measurements were made, and/or where stream bottom sediment size characterizations were estimated.

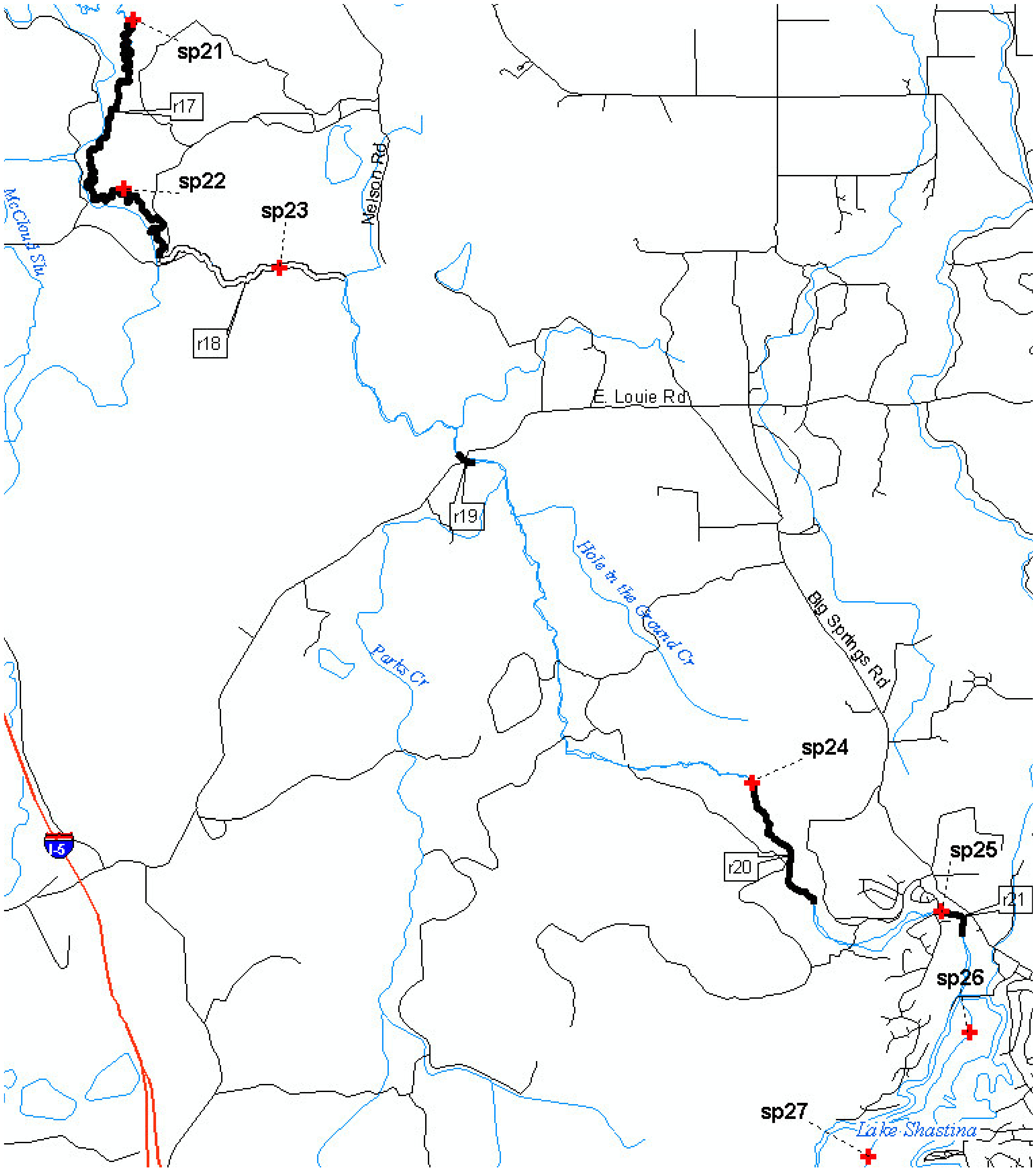


Figure 1c. Shasta River survey reaches and sample points – Highway A12 to Lake Shastina.

This figure shows the reaches of the Shasta River from the mouth to Highway 3 that were surveyed. "r" = Reach; "sp" = Sample Point. The reaches are defined by the macrophyte species growing within the reach, and by the density of those macrophyte species. The sample points correspond to locations where macrophyte or algae samples were collected, where water quality measurements were taken, where light measurements were made, and/or where stream bottom sediment size characterizations were estimated.

Table 1. Shasta River Reach Locations

	Downstream			Upstream			Length
Reach #	River Mile	Latitude	Longitude	River Mile	Latitude	Longitude	Miles
1	0.17	41.82907	-122.59406	0.67	41.82253	-122.59572	0.5
2	1	41.82131	-122.59149	2.87	41.80709	-122.59372	1.87
3	4.05	41.80537	-122.60862	4.51	41.80381	-122.60149	0.46
4	5.73	41.79217	-122.61022	6.58	41.78361	-122.60351	0.85
5	8.01	41.77265	-122.59309	8.06	41.77195	-122.59291	0.05
6	8.58	41.76743	-122.58577	10.53	41.74985	-122.57828	1.95
7	10.54	41.74971	-122.57820	10.91	41.74619	-122.57432	0.37
8	10.92	41.74610	-122.57416	12.26	41.73360	-122.56129	1.34
9	12.27	41.73348	-122.56139	12.62	41.72968	-122.56084	0.35
10	12.63	41.72955	-122.56076	13.1	41.72648	-122.55833	0.47
11	13.11	41.72635	-122.55839	13.87	41.71711	-122.55296	0.76
12	13.88	41.71698	-122.55287	14.64	41.71846	-122.54546	0.76
13	14.65	41.71832	-122.54539	16.09	41.70248	-122.53437	1.44
14	16.1	41.70236	-122.53426	21.14	41.66806	-122.50532	5.04
15	21.15	41.66800	-122.50514	24.09	41.64840	-122.49943	2.94
16	24.1	41.64827	-122.49949	25.82	41.63538	-122.49394	1.72
17	27.48	41.63148	-122.47807	30.57	41.60932	-122.47508	3.09
18	30.58	41.60920	-122.47500	32.03	41.60749	-122.45266	1.45
19	33.88	41.59108	-122.43857	33.98	41.59035	-122.43700	0.1
20	37.8	41.56129	-122.40413	38.87	41.54945	-122.39558	1.07
21	39.92	41.54873	-122.38061	40.22	41.54642	-122.37742	0.3

Notes: Refer to river reaches shown in Figures 1a, 1b, and 1c.
River miles are based on the 1:24 K hydrography developed by David Lamphear of the Institute for Forest and Watershed Management.

Table 2. Shasta River Sample Points and Analyses Performed

Sample Point	River Mile	Latitude	Longitude	Periphyton	Macrophyte	Phytoplankton	Water Isotopes	Macrophyte Isotopes	Light Intensity	Sediment Composition
1	0.17	41.82907	-122.59406				X			
2	0.67	41.82253	-122.59572	X					X	X
3	1.97	41.81232	-122.59095		X			X	X	
4	2.77	41.80568	-122.59338	X	X			X		X
5	4.26	41.80320	-122.60598		X					
6	6.33	41.78671	-122.60168	X						X
7	9.18	41.76305	-122.58015		X			X		X
8	10.56	41.74943	-122.57821		X			X		X
9	11.45	41.74048	-122.56863		X			X		X
10	11.78	41.73841	-122.56300						X	
11	12.45	41.73151	-122.56267	X						X
12	12.70	41.72903	-122.55961							
13	12.89	41.72870	-122.55689						X	X
14	13.06	41.72691	-122.55784		X		X	X	X	X
15	14.83	41.71620	-122.54350		X			X	X	X
16	15.39	41.70964	-122.54027	X			X		X	X
17	18.88	41.68466	-122.52021		X			X		X
18	23.90	41.65044	-122.50005		X		X	X	X	X
19	24.11	41.64813	-122.49947	X						
20	25.20	41.64027	-122.49638		X			X		X
21	27.49	41.63134	-122.47804		X		X	X	X	
22	29.71	41.61580	-122.47944				X		X	X
23	31.58	41.60841	-122.46046		X			X	X	X
24	37.88	41.56071	-122.40302	X	X		X	X	X	X
25	39.95	41.54870	-122.38003				X			X
26		41.53615	-122.37824			X			X	
27		41.52337	-122.39329			X			X	

Notes: Refer to river reaches and sample points shown in Figures 1a, 1b, and 1c.
River miles are based on the 1:24 K hydrography developed by David Lamphear of the Institute for Forest and Watershed Management.

Table 3. Shasta River and Lake Shastina Algal Species List

Species Code	Species Name
ABFA	Anabaena flos-aquae
ACMN	Achnanthes minutissima
AFPR	Amphora perpusilla
CAVM	Caloneis ventricosa minuta
CCMG	Cyclotella meneghiniana
CHXX	Chlamydomonas sp.
COPC	Cocconeis placentula
COPD	Cocconeis pediculus
CXER	Cryptomonas erosa
EPSX	Epithemia sorex
GFAN	Gomphonema angustatum
NVCV	Navicula cryptocephala veneta
NZAM	Nitzschia amphibia
NZCM	Nitzschia communis
NZDS	Nitzschia dissipata
NZFR	Nitzschia frustulum
OSXX	Oscillatoria sp.
RDMN	Rhodomonas minuta
RHCU	Rhoicosphenia curvata
RPMS	Rhopalodia musculus
SCQD	Scenedesmus quadricauda
SNRD	Synedra radians
STAM	Stephanodiscus astraea minutula
TEMN	Tetraedron minimum

Only those species with greater than 0.5% density are presented in Table 1.
Many of the algae species identified in the samples are common to mesotrophic to eutrophic waters (Sweet 2004).

Table 4. Shasta River and Lake Shastina Algae Species Composition, Density, and Biovolume by Sample Location

Shasta River Locations

Sample Point	Total Density (# / cm2)	Total Biovolume (um3 / cm2)	Species code (percent density)															
			ACMN	AFPR	CAVM	CCMG	COPC	COPD	EPSX	GFAN	NVCV	NZAM	NZCM	NZDS	NZFR	OSXX	RHCU	RPMS
2	420724	330919497	8.8%				16.7%	8.8%	22.5%								11.8%	
4	49697	33736551					34.5%	4.8%	29.8%						7.1%		7.1%	
6	126288	38327170					33.0%	19.0%					12.0%		8.0%		9.0%	
11	1897236	1892140144				1.9%	38.1%	2.9%	21.0%								15.2%	
16	106817	70312298		3.3%	4.3%		44.6%										21.7%	6.5%
19	101902	28541419					31.2%				3.2%			5.4%		5.4%	47.3%	
24	180339	62962692		12.6%			13.4%		9.2%	7.6%							21.8%	
22	283749	121939714					81.1%	1.9%		2.8%					0.9%		8.5%	
Yreka Cr @ AG Rd	709907	117009444		10.1%							14.3%	17.6%		16.0%	9.2%			

Lake Shastina Samples

Sample Point	Total Density (# / mL)	Total Biovolume (um3 / mL)	Species Code (percent density)								
			ABFA	CHXX	CXER	RDMN	SCQD	SNRD	RHCU	STAM	TEMN
26 (0 m)	3458	1695955	25.2%		7.0%	29.6%	6.1%				17.4%
26 (2 m)	2553	1625504	20.0%		5.8%	25.0%	6.7%				27.5%
26 (12 m)	9	5951	20.0%		20.0%					20.0%	40.0%
27 (0 m)	2988	1296019	18.9%	7.5%	14.2%	26.4%					20.8%
27 (2 m)	2472	1840360	40.2%		7.2%	8.2%	11.3%				13.4%
27 (7 m)	619	261800	15.6%					8.9%	6.7%	11.1%	22.2%

Notes: Algae species names and associated codes are listed in Table 3.
Only the most abundant species (i.e. greatest % density) are presented, which explains why the % density at a given site is < 100.

Table 5. Shasta River and Lake Shastina Algal Biomass

Shasta River - (Mainstem)	Sample Point	Chlorophyll a (ug/cm2)	Pheophytin a (ug/cm2)	AFDW (mg/cm2)
	2	25.79	5.74	2.97
	4	2.95	2.25	1.98
	6	5.7	4.7	3.33
	11	27.15	22.74	19.10
	16	6.79	5.19	5.97
	19	15.3	6.7	3.32
	24	23.8	9.2	4.81
	Yreka Cr @ Anderson Grade Rd	33.9	8.0	6.38

Lake Shastina	Sample Point	Chlorophyll a (ug/L)	Pheophytin a (ug/L)	AFDW (mg/L)
	26 (0 m)	46.70	8.20	66.40
	26 (2 m)	40.90	2.00	61.00
	26 (7 m)	35.0	1.9	54.40
	27 (0 m)	26.30	21.80	50.40
	27 (2 m)	5.50	0.90	33.40
	27 (7 m)	8.5	1.8	49.40

AFDW is the weight lost after ignition (dry wgt - ash wgt), divided by the sample area. It provides a rough estimate of the organic material in the sample.

Table 6. Shasta River Macrophyte Species List

Species Code	Species Name
AZME	Azola mexicana
BEER	Berula erecta
CEDE	Ceratophyllum demersum
ELCA	Elodea canadensis
EQXX	Equisetum spp
LEMI	Lemna minor
MYSI	Myriophyllum sibiricum
POCR	Potamogeton crispus
POIL	Potamogeton illinoensis
POPE	Potamogeton pectinatus
RAAQ	Ranunculus aquatilus
SCXX	Scirpus spp
SPEM	Sparganium emersum
TYLA	Typha latifolia
UNID	unidentified succulent
VECA	Veronica catenata
XXXX	other

Table 7. Shasta River Macrophytes: Percent Cover and Species Composition by Reach

Shasta River - (Mainstem)	Reach	Total Cover in Reach (%)	Species code (percent of macrophyte species composition)																
			AZME	BEER	CEDE	ELCA	EQXX	LEMI	MYSI	POCR	POIL	POPE	RAAQ	SCXX	SPEM	TYLA	UNID	VECA	XXXX
	1		Reach not surveyed for macrophyte assemblages																
	2	40				15%						15%		55%		15%			
	3	5				10%			5%	15%	15%	15%		10%	15%	15%			
	4	5				2%			1%			2%		95%					
	5	15									80%	20%							
	6	50	2%		5%	15%		3%	10%	10%	15%	20%		5%	10%			5%	
	7	95	5%			2%		5%	3%		18%	25%		13%	12%	10%		7%	
	8		Reach not surveyed for macrophyte assemblages																
	9	25			3%	2%			3%		40%	20%	10%	8%	2%				
	10	70				1%		10%	1%	3%	60%	5%	1%	14%	5%	1%		5%	
	11	30				1%		10%	1%	3%	60%	5%	1%	14%	5%	1%		5%	
	12	90									25%	60%						10%	5%
	13	10				5%			10%		30%	40%						10%	5%
	14	70			4%	20%	1%		5%			25%		15%	10%	10%		10%	
	15	15				20%		5%				35%		20%	5%	10%		5%	
	16	10				60%						20%		15%					5%
	17	40	4%	5%	18%	23%		5%	13%			13%		10%		5%		4%	
	18	85	2%	15%	10%	10%		3%	5%		10%	30%		10%		5%			
	19	70	Species assemblage was not identified																
	20	75	2%	25%	15%	10%		3%	10%			15%					15%		5%
	21	35	5%		15%			10%				70%							

Note: Macrophyte species names and associated codes listed in Table 6.

Table 8. Shasta River Macrophyte Biomass

Sample Point	Dry sample (g)	Chlorophyll-a (ug/g dry material)	Phaeophytin-a (ug/g dry material)	AFDM (g/m2)
3	28	29	98	383
4	37			750
5	38			823
7	22	70	232	413
8	28			505
9	42			761
14	20	27	90	369
15	30			621
17	74	82	275	1594
18	15			117
20	4	18	62	77
21	21			340
23	59	110	384	748
24	171	46	157	3088

Table 9. Stream Bottom Sediment Composition and Sediment Oxygen Demand Rate Estimates

Sample Point / Location	SOD_{20} Rate[1] (g/m2/d)	Percent Composition[2] Fines	Sands	Gravel	Cobble	Boulder	Bedrock	Notes
2	0.1	5	5	5	10	10	45	Fines largely of organic origin.
4	0.1	5	10	15	15	5	15	Fines largely of organic origin.
6	0.1	5	10	10	5	40	20	Fines largely of organic origin.
7	0.2	10	20	60	10	0	0	
7	0.2	20	20	50	10	0	0	
9	0.2	15	15	25	25	20	0	
11	0.2	15	20	30	25	10	0	
13	2.0*	35	40	25	0	0	0	Fines largely of organic origin.
14	1.5*	20	20	30	20	10	0	
15	1.5	35	30	25	10	0	0	Fines blanket channel bottom.
16	1.5*	20	20	30	25	5	0	Fines largely of organic origin.
U/S of SWUA diversion	2.0	40	30	20	10	0	0	Fines largely of organic origin.
17	0.1	5	90	5	0	0	0	
18	0.1	5	25	70	0	0	0	
20	0.1	5	40	25	20	10	0	
22	0.2	30	60	10	0	0	0	Fines:50% clay, 50% organic
U/S of GID diversion	2.0	30	40	20	10	0	0	Fines largely of organic origin.
23	0.5	20	50	30	0	0	0	
24	0.5	20	20	30	30	0	0	Fines--floculant organic material
25	0.2	5	0	10	75	10	0	

Notes:

1. SOD_{20} (g/m^2/d) is the SOD rate corrected for temperature of 20 C. See explanation in text

2 Percent substrate composition are visual estimates made by Regional Water Board and UC Davis staff.

* Measured SOD rates (NCRWQCB 2004).

Table 10. Shasta River Riparian Classification

Reach Location	Downstream River Mile	Upstream River Mile	Length Miles	Riparian Category
Near mouth at USGS gage	0.17	0.67	0.5	2
D/S of Pioneer Bridge	1	2.87	1.87	1
End of Old Shasta River Rd	4.05	4.51	0.46	2
D/S of Hwy263	5.73	6.58	0.85	2
U/S of I5	8.58	10.53	1.95	2
D/S of Y-A Rd to d/s of M-G Rd	10.54	14.64	4.1	1
D/S and U/S of M-G Rd; M-G Rd is at RM 15.50	14.65	16.09	1.44	2
U/S M-G Rd to Freeman Rd	16.1	19.26	3.16	0
Short reach u/s of Freeman Road	19.26	19.72	0.46	2
U/S Freeman Rd to near DeSoza	19.72	21.64	1.92	0
Near DeSoza Lane	21.64	21.98	0.34	2
D/S and U/S of A12; A12 is at RM 24.11	21.98	25.82	3.84	0
U/S of A12	27.48	28.33	0.85	0
Short reach d/s of GID	28.33	28.9	0.57	2
D/S and U/S of GID; GID is at RM 30.58	28.9	32.42	3.52	0
Approx 2 miles d/s of Dwinnell Dam	37.84	38.87	1.03	1
Upstream of Riverside Road	39.92	40.22	0.3	2

Notes:

Riparian Category:	Criteria:
0	No trees
1	Less than 2 trees per 100 feet
2	Greater than 2 trees per 100 feet
3	Gallery forest

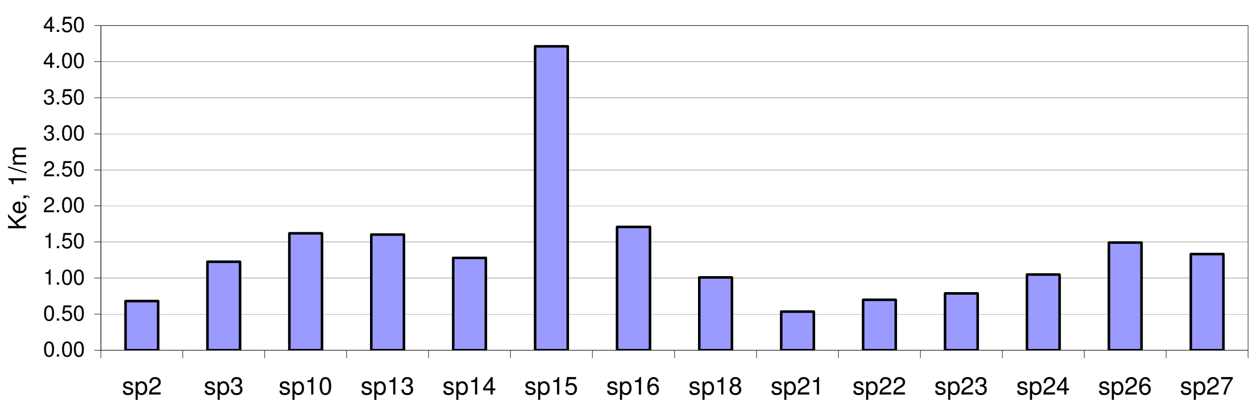
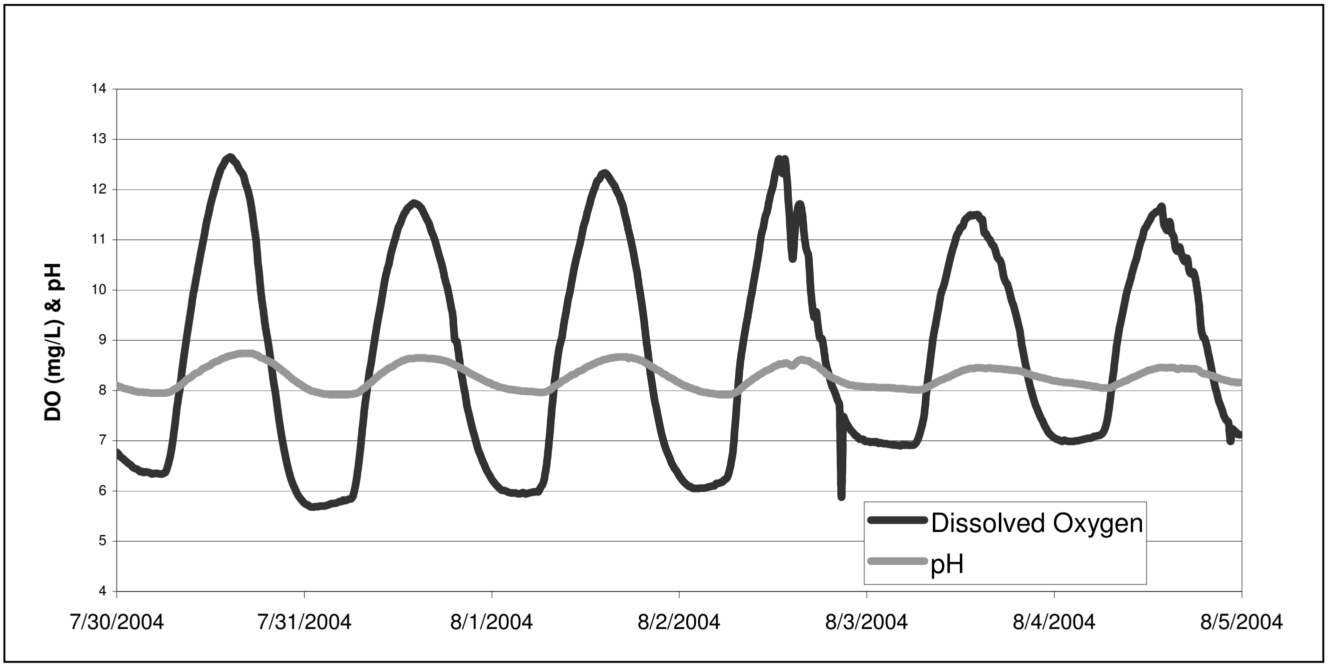


Figure 2. Light extinction coefficients for locations in the Shasta River.

(a)



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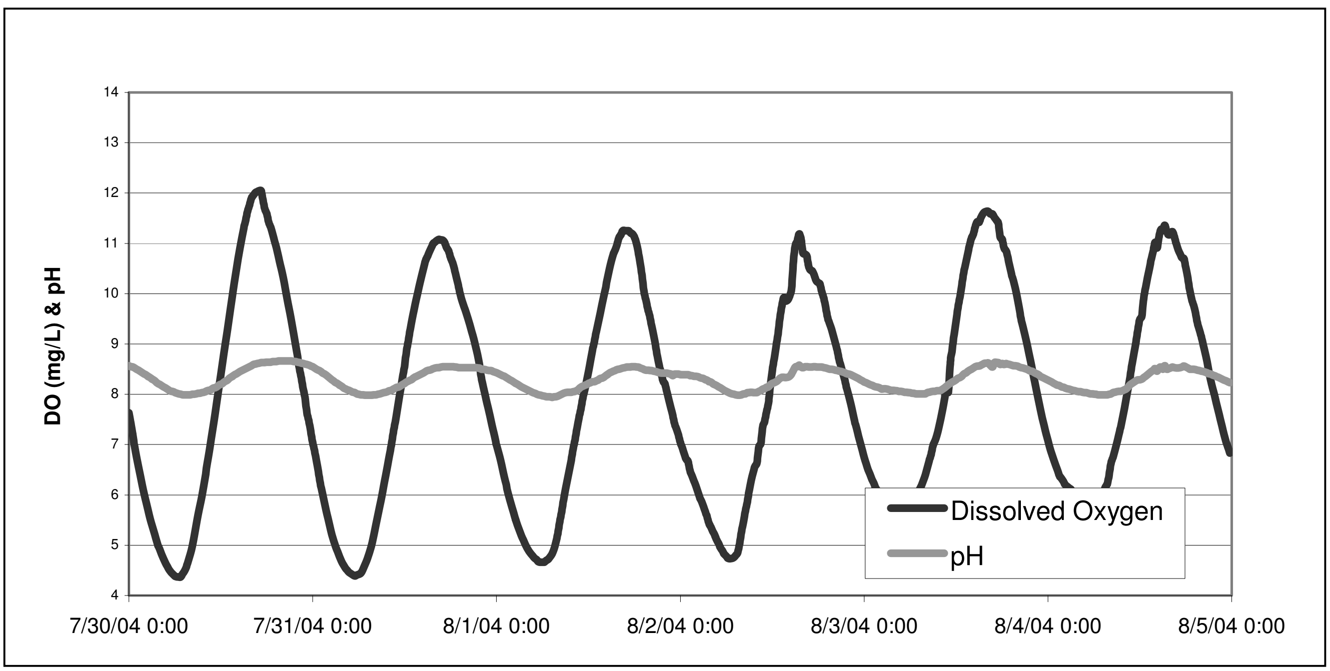
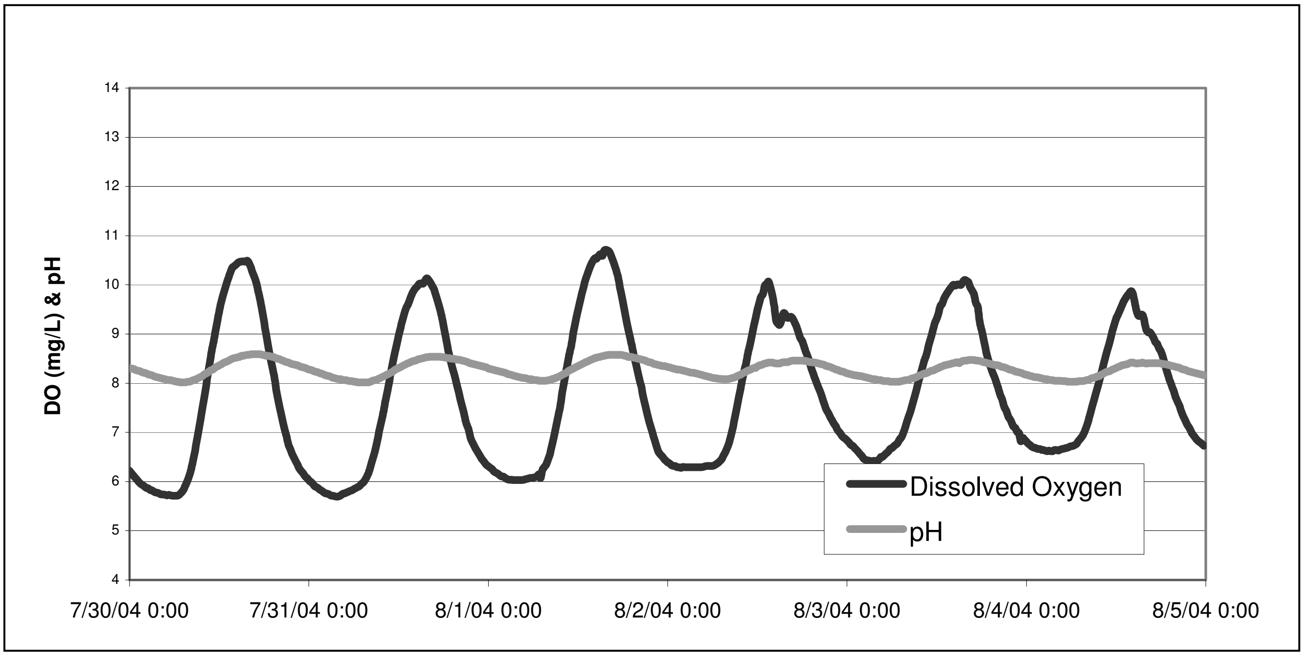


Figure 3. Shasta River dissolved oxygen and pH measurements from July 30 to August 5, 2004: (a) Yreka-Ager Road, (b) Highway 3.

(c)



(d)

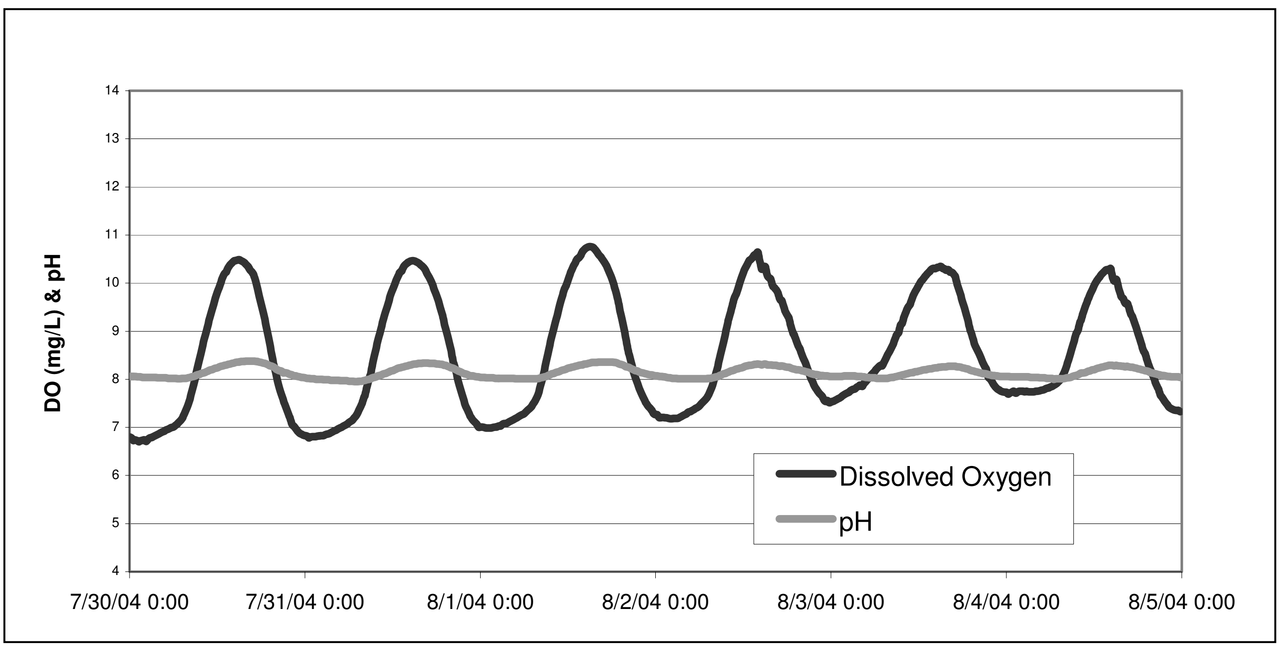
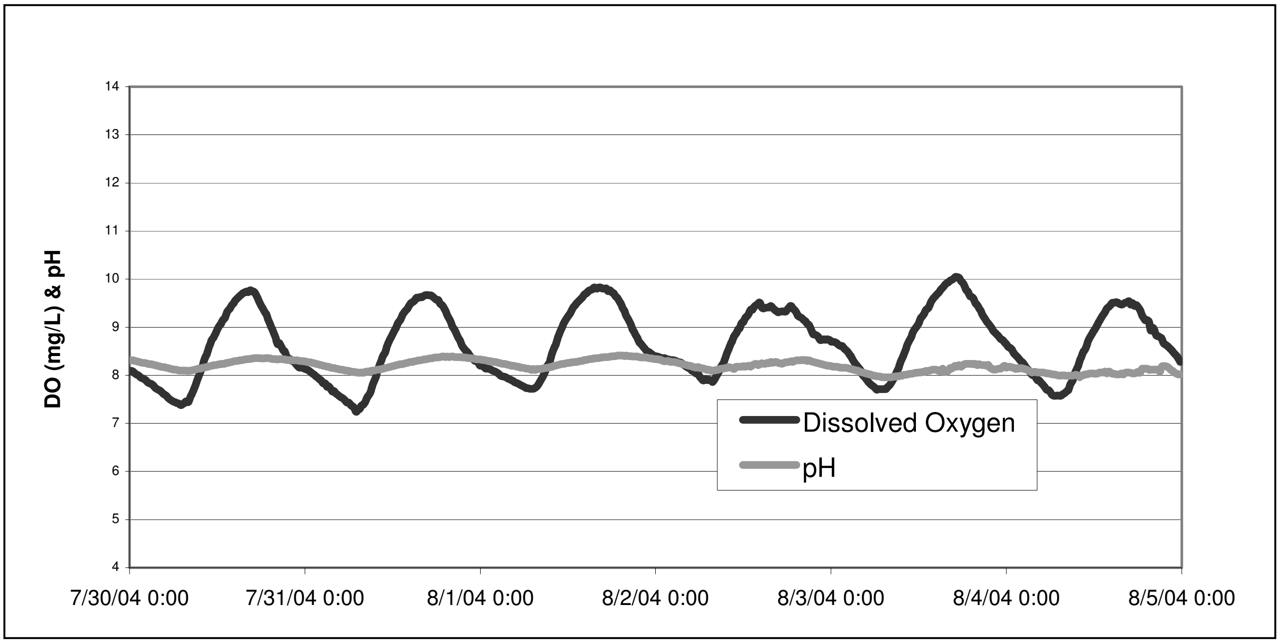


Figure 3. Shasta River dissolved oxygen and pH measurements from July 30 to August 5, 2004: (c) Montague-Grenada Road, (d) Freeman Road.

(e)



(f)

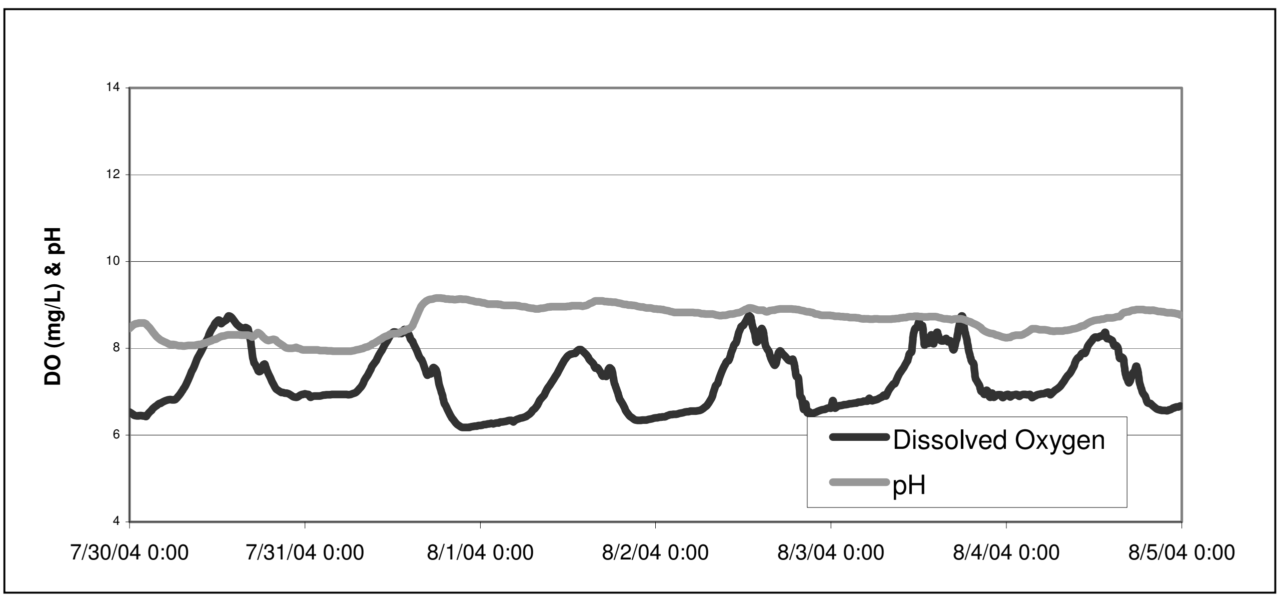
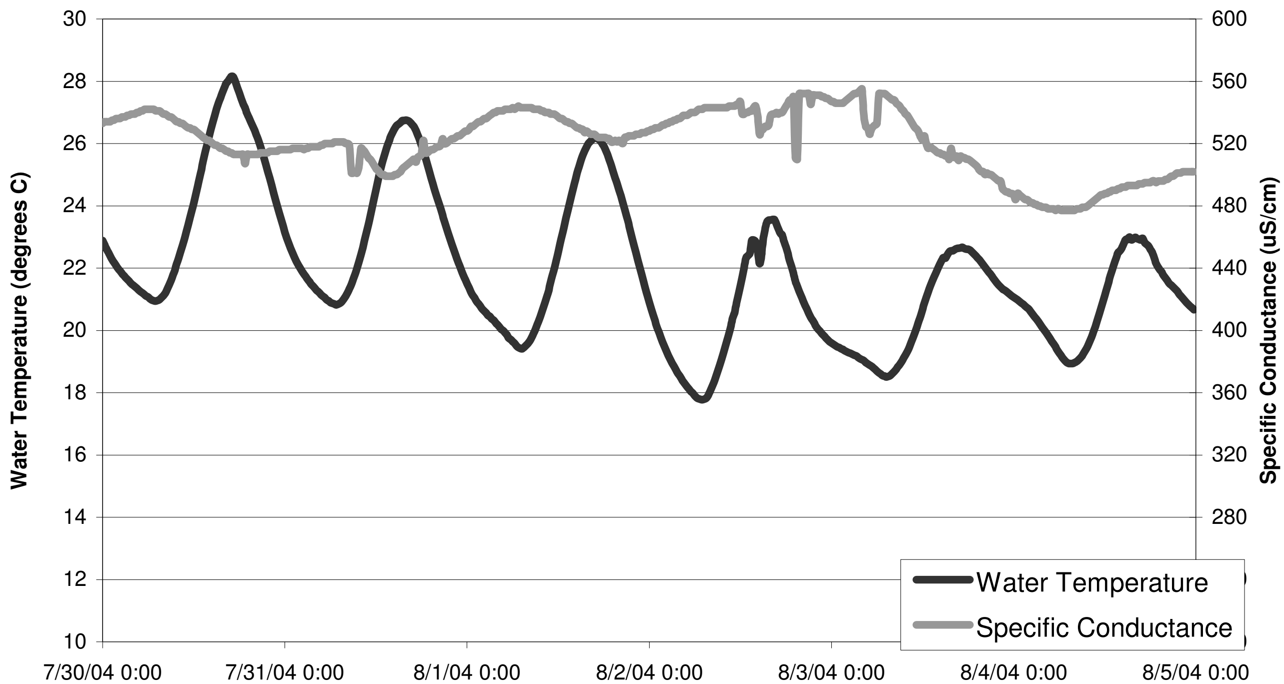


Figure 3. Shasta River dissolved oxygen and pH measurements from July 30 to August 5, 2004: (e) Highway A12, (f) Riverside Road.

(a)



(b)

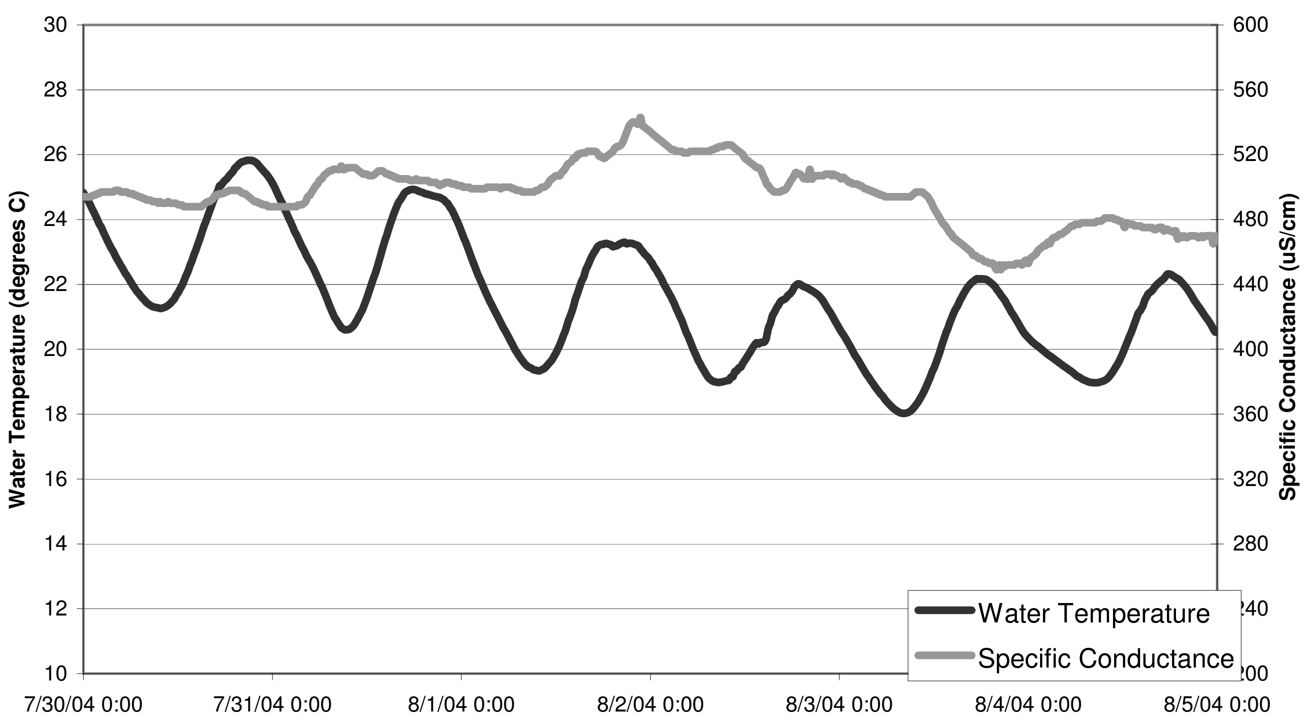
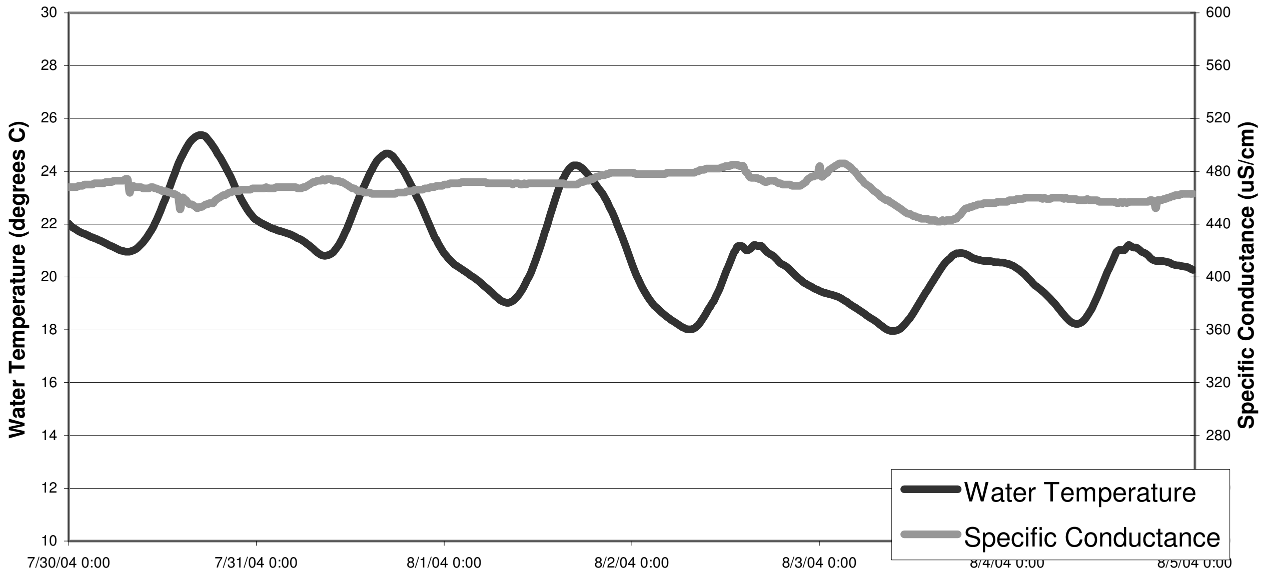


Figure 4. Shasta River temperature and specific conductance measurements from July 30 to August 5, 2004: (a) Yreka-Ager Road, (b) Highway 3.

(c)



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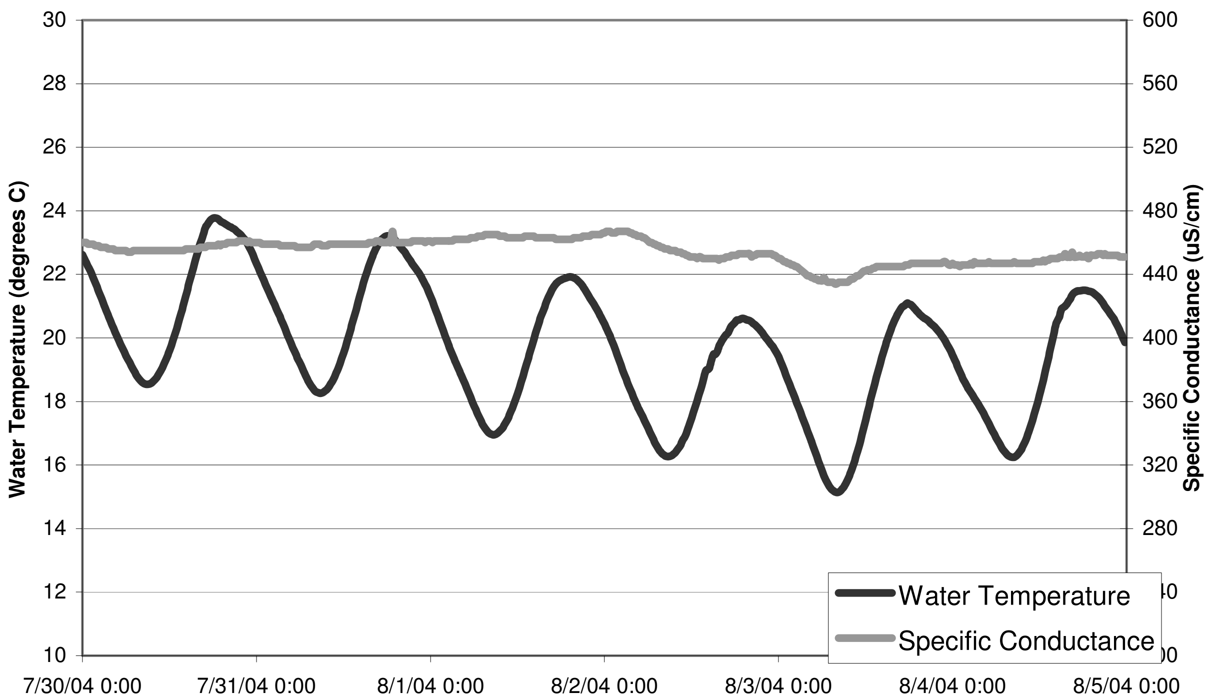
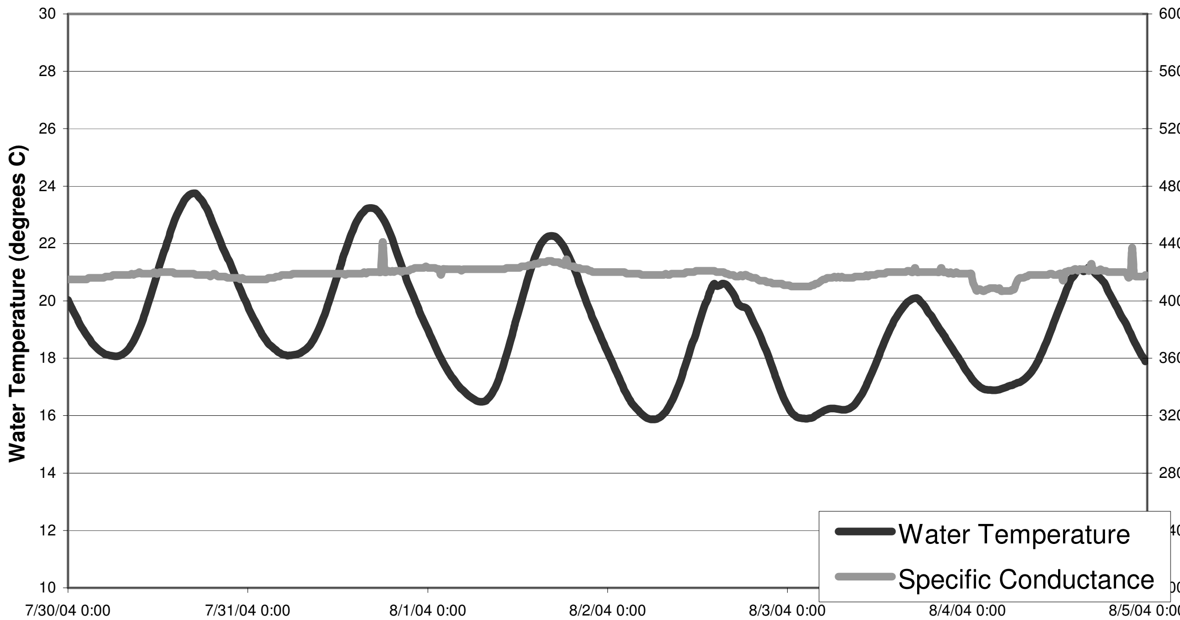


Figure 4. Shasta River temperature and specific conductance measurements from July 30 to August 5, 2004: (c) Montague-Grenada Road, (d) Freeman Road.

(e)



(f)

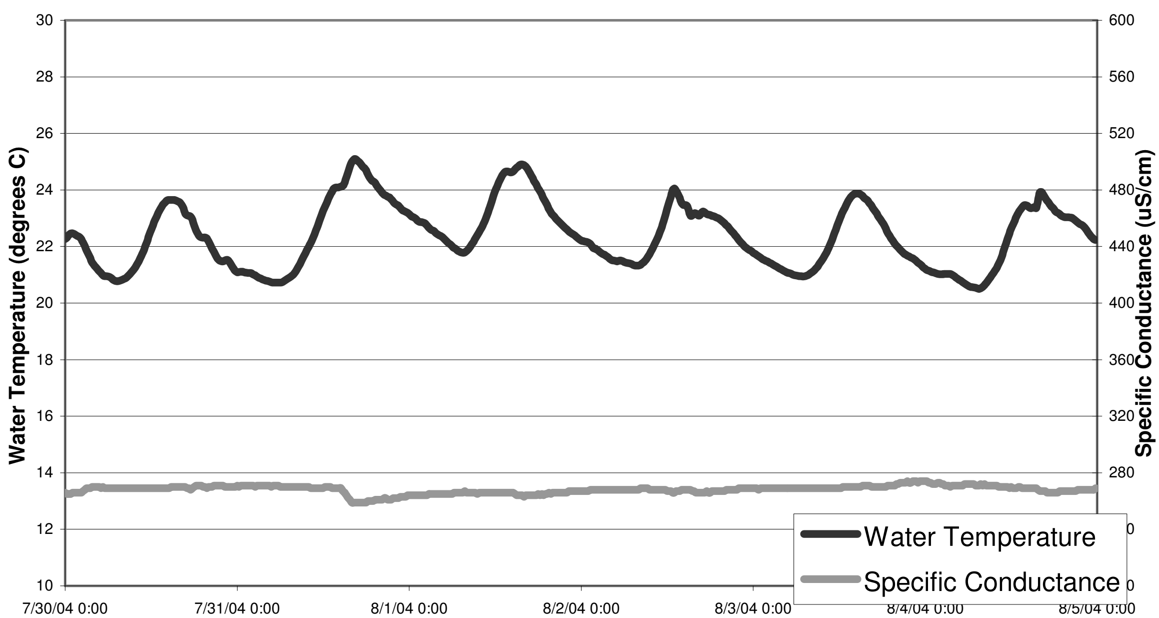


Figure 4. Shasta River temperature and specific conductance measurements from July 30 to August 5, 2004: (e) Highway A12, (f) Riverside Road.

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Appendix A - Aquatic Macrophytes of the Shasta River

The aquatic macrophytes of the Shasta River can be divided into the groups listed below. These morphological groups are taken directly from the Dawson et al. (1999). Following a brief discussion of their general life histories and habitat affinities, each species is described individually.

- Emergent broad-leaved herbaceous
  - *Berula erecta (BEER)*
  - *Solanum dulcamara*
  - *Veronica anagalis-aquaticus*
  - *V. catenata (VECA)*
- Emergent reeds, sedges, rushes
  - *Equisetum* spp. *(EQXX)*
  - *Juncus* spp.
  - *Scirpus acutus*
  - *Scirpus americanus*
  - *Sparganium emersum* ssp. *Emersum (SPEM)*
  - *Typha latifolia (TYLA)*
- Floating-leaved (rooted)
  - *Potamogeton crispus (POCR)*
  - *Potamogeton illinoensis (POIL)*
  - *Potamogeton pectinatus (POPE)*
- Free-floating
  - *Azolla mexicana (AZME)*
  - *Lemna minor (LEMI)*
- Amphibious
  - *Mimulus guttatus*
- Submerged broad-leaved
  - *Elodea canadensis (ELCA)*
- Submerged linear-leaved or fine-leaved
  - *Ceratophyllum demersum (CEDE)*
  - *Myriophyllum sibiricum (MYSI)*
  - *Ranunculus aquatilus (RAAQ)*

Characteristic Habitats of Aquatic Macrophytes

Substrate types and flow types are listed in order of relative importance as habitat for the aquatic macrophytes morphological group (adapted from Dawson, 1999):

Group	Sediment type:	Flow type:
Emergent broad-leaved herbaceous *Berula erecta* *Solanum dulcamara* *Veronica anagalis-aquaticus* *V. catenata*	1. Silt 2. Clay 3. Gravel/Pebble 4. Sand	1. Upwelling 2. Ripple 3. No flow
Emergent reeds, sedges, rushes *Equisetum* spp. *Scirpus acutus* *Juncus* spp. *S. americanus* *Typha latifolia* *Sparganium emersum* ssp. *Emersum*	1. Peat 2. Silt 3. Clay 4. Sand	1. No perceptible flow 2. Smooth 3. No flow
Floating-leaved (rooted) *Potamogeton crispus* *P. illinoensis* *P. pectinatus*	1. Silt 2. Clay 3. Sand 4. Gravel/Pebble	1. No perceptible flow 2. Smooth 3. Unbroken standing waves
Free-floating *Azolla mexicana* *Lemna minor*	1. Silt 2. Clay 3. Gravel/Pebble	1. No perceptible flow 2. Smooth 3. No flow
Amphibious *Mimulus guttatus*	1. Peat 2. Clay 3. Silt 4. Gravel/Pebble	1. Upwelling 2. No perceptible flow 3. Rippled
Submerged broad-leaved *Elodea canadensis*	1. Peat 2. Silt 3. Sand 4. Clay	1. No perceptible flow 2. Smooth 3. Rippled
Submerged linear-leaved or fine-leaved *Ceratophyllum demersum* *Myriophyllum sibiricum* *Ranunculus aquatilus*	1. Sand 2. Gravel/Pebble 3. Silt 4. Clay	1. Upwelling 2. Smooth 3. No perceptible flow

Berula erecta (BEER) (Apiaceae – dicot)

"Water parsnip" "Water cress"

CA native. Africa, Eurasia.

This bushy broadleaf was only found in the upper reaches surveyed. In the Hidden Valley area, there were many individuals. It is quite distinctive. The entire plant is considered toxic and has been implicated in cases of livestock poisoning.

The flowers are small and white in secondary umbels (entire inflorescence is an umbel of umbels) on round-stemmed, several-branched stalks.

Solanum dulcamara (Solanaceae)

"Nightshade"

Native to northern Eurasia. Invader in CA central coast, Modoc Plateau, Canada, and Eastern US.

This plant was widespread but uncommon in the upper Shasta River. It did not occur in the canyon. It grows with about 2/3 of its mass outside of the wet edge of the stream. It did not seem to occur away from the stream edge.

Berries and flowers are very distinctive on Nightshade. Berries are poisonous.

Veronica anagalis-aquatica, Veronica catenata (VECA), and hybrids (7) (Scrophulariaceae – dicot)

"Water Speedwell" "Chain Speedwell"

Native to Europe. Invader throughout CA excluding the Mojave, Modoc, and Sonoran regions; naturalized widely in North and South America.

This plant most often grows near the banks of the stream. It has both submersed and above-water leaves. The submersed leaves tend to be smaller and lighter in color. Flowers are about 3/8 of an inch in diameter, white with pink centers to lavender in color.

There are two species of this genus in the Shasta River. *V. catenata (VECA)* and *V anagalis-aquatica* have been seen to hybridize freely, resulting in individuals indistinguishable from either species as well as individuals that fall in between the two species in appearance.

The plant was present in most of the valley reaches of the river, not present in the canyon.

An example that looks more like *V. anagalis-aquatica*.

An example of *V. catenata (VECA)*.

Note the smaller number of flowers and buds. Though this photo shows a much darker color plant than the other photos, that color difference is not indicative. The only easily-observed, consistent difference is in the number of flowers.

The photo below illustrates the variation in color of the submersed portion of the plant. Though this is a rare case, *Veronica* does occasionally form mats that obstruct flow.

Equisetum arvense (Equisetaceae – pteridophyte)

"Field Horsetail"

CA native. Distribution throughout CA excluding the Mojave and Sonoran regions; North America; also Europe, Asia.

E. arvense grows near water, typically in dense clumps. It is rarely over 2 feet tall. We only found it in one place in the Shasta River, around river mile 20.

Fertile stems are usually well below 1.5 feet tall and tan or brown in color. They grow in the earlier part of the growing season and wilt soon after.

The green stems are generally infertile, though some will carry an inflorescence. They develop later in the growing season; usually after the fertile stems have wilted.

Juncus spp. (Juncaceae – monocot)

"Rush"

Likely that all species present in Shasta River are native to CA. There are few invader species of this genus in CA and none of them typically grow in the region studied. *Juncus* is distributed worldwide, but predominantly the northern hemisphere.

There are dozens of species of *Juncus* in Northern California. The plant generally grows less than 3 feet tall in clumps such as in the photo above. The stems are round, usually somewhat blue-green in color and are not hollow. There are no flat-bladed leaves or sharp edges as in grasses and sedges. *Juncus* species are typically associated with wetlands and streamsides. There are a few species that will grow directly in the stream, but most often their roots are only periodically inundated.

Juncus was rare throughout the valley and canyon.

Sparganium emersum ssp. Emersum *(SPEM)* (9) (Typhaceae – monocot)

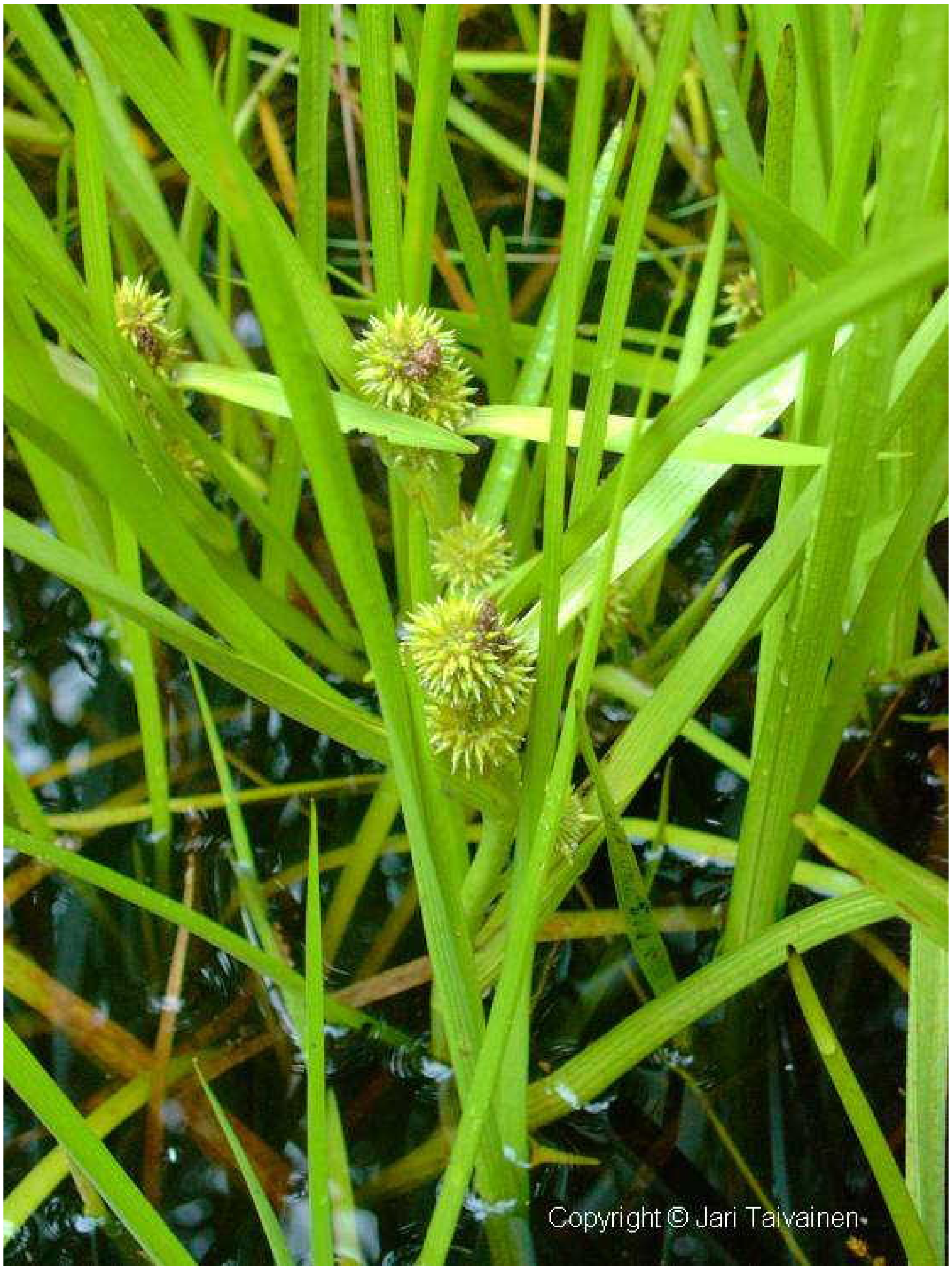
"Bur-reed"

CA native. Found throughout most of northern CA; to Alaska, Canada.

This reed grows along the edges of the stream, "feet in the water", or in very shallow areas. It usually occurs in large strips that come a foot or more into the channel and extend several feet onto dry land. The plant is generally about 2.5 to 3 feet tall. It is a much lighter green than the two other large reeds present in the Shasta River.

Sparganium grew mostly in the middle reaches of the river, only in one area of the canyon and not at all in the upper reaches.

The blades of the leaves are widely triangular, almost flat with a keel, and often twisted. The inflorescences are carried on round-stemmed stalks that zigzag at each node.



The spiny fruit are round and about the size of a quarter (or smaller) in diameter; they are carried close to the stem.

There were instances of a *Sparganium* that was growing completely submerged, often in swift-flowing water. This plant never had inflorescences, therefore we were unable to identify if it was just more *S. emersum emersum (SPEM)* that had managed to root deeper in the stream channel during low water, or if it was another *Sparganium* species.

Scirpus acutus var. *occidentalis* (11) and *S. americanus* (10) (Cyperaceae – monocot)

"Bulrush"

CA native (temperate North America), *americanus* found in South America as well

Both of these species grow along the banks. They grow in water as deep as a foot, or out of the water entirely, but always very close to the wet edge of the stream.

This photo shows flowers of *S. acutus.* *S. americanus* has very similar flowers.

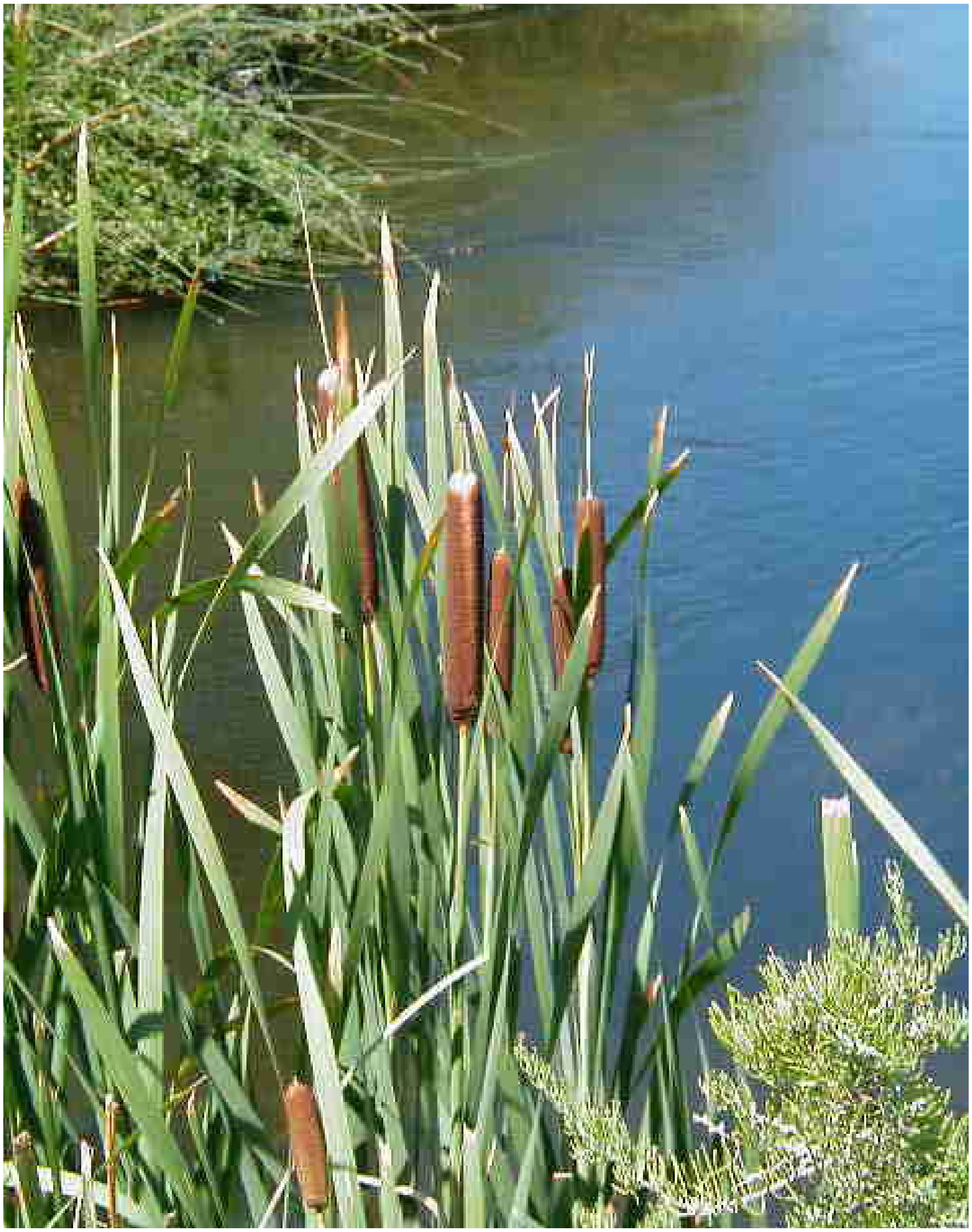
Scirpus is grey-green in color and has small, feathery, terminal inflorescences. There are two species of Bulrush in the Shasta River; *S. acutus* and *S. americanus. S. acutus* has round stems. *S. americanus* has triangular stems, with concave sides. Of the two, *acutus* is generally the larger, and was much more common; only a few examples of *americanus* were found.

Scirpus is abundant in the Shasta River. It grows in canyon as well as valley reaches.

Typha latifolia (TYLA) (12) (Typhaceae – monocot)

"Broad-leaved Cattail"

CA native. Found throughout temperate regions of North and Central America, Eurasia, and Africa.



As with *Sparganium*, the leaves are basal and tend to twist. The stems of the inflorescence are round, about a quarter inch diameter and straight. Found in most of the same places as *Scirpus*, but not as abundant.

Potamogeton crispus (POCR) (3) (Potamogetonaceae - monocot)

"Crispate-leaved Pondweed"

Native to Eurasia. Found worldwide.

This plant was rare in the Shasta River. It generally was found mixed in with *P. illinoensis (POIL).* It is easy to distinguish from *illinoensis* by its much smaller, much wavier leaves.

Potamogeton illinoensis (POIL) (1) (Potamogetonaceae - monocot)

"Shining Pondweed"

CA native. Present in most of CA, to Baja CA, British Colombia, Texas, Caribbean and Central America.

The leaves of this plant are typically about 4 to 5 inches long with a slightly translucent quality (especially the submerged leaves) and prominent veins running lengthwise. The leaves tend to be slightly wavy but not curled and not as wrinkled along the edges as *Potamogeton crispus (POCR)*.

This plant is common in the Shasta River and grows in both valley and canyon reaches.

The inflorescence of this plant is held above the water. It is generally 1 to 1.5 inches in length and about 3/8 to half of an inch in diameter. Club-like, greenish to brownish in color.

This plant is generally seen in large to huge clumps, growing in water that is between 1.5 and 5 feet deep. It often chokes the entire stream width, slowing the water significantly. The photo above shows a section of the stream that is filled with *P. illinoensis (POCR)*; the red color on the surface of the water is from the tiny, free-floating plant *Azola mexicana (AZME)*, which gathers (similar to *Lemna minor (LEMI)*) against obstructions in the surface flow of the stream – in this case the floating leaves and inflorescences of the *P. illinoensis (POIL)*.

Potamogeton pectinatus (POPE) (4) (Potamogetonaceae - monocot)

"Fennel-leaf Pondweed"

CA native. Found worldwide excluding South America

This Potamogeton has leaves that are threadlike and look very similar to the stems. The stems are branched low on the plant but not branched above. Inflorescences are carried on the ends of stems and are typically interrupted as shown above.

This is the most common plant in the Shasta River. It grows abundantly in most reaches and is present almost every reach.

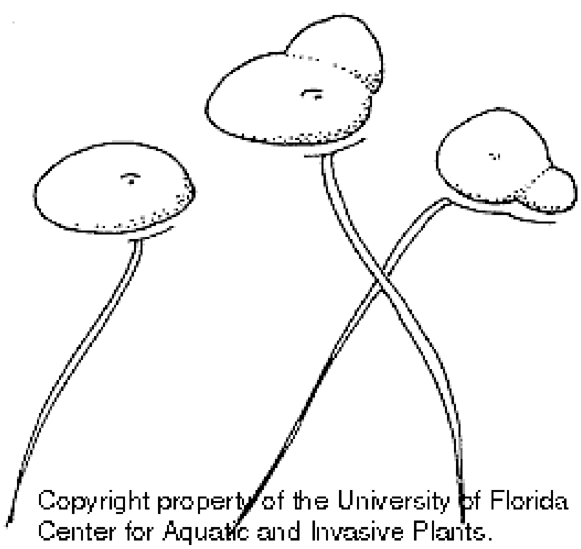
This photo shows a typical clump of *P. pectinatus (POPE)*. This plant can grow to significantly restrict flow in the stream, similar to *P. illinoensis (POIL).* Notice the variation in color, ranging from light green to reddish brown. No part of this plant rises above the surface of the water.

Lemna minor (LEMI) (8) (Lemnaceae – monocot)

"Duckweed"

CA native. Found worldwide.

In this photo, *Lemna* is the green, the *Azolla* is red.



The total length of one *Lemna minor (LEMI)* is about a half an inch at most.

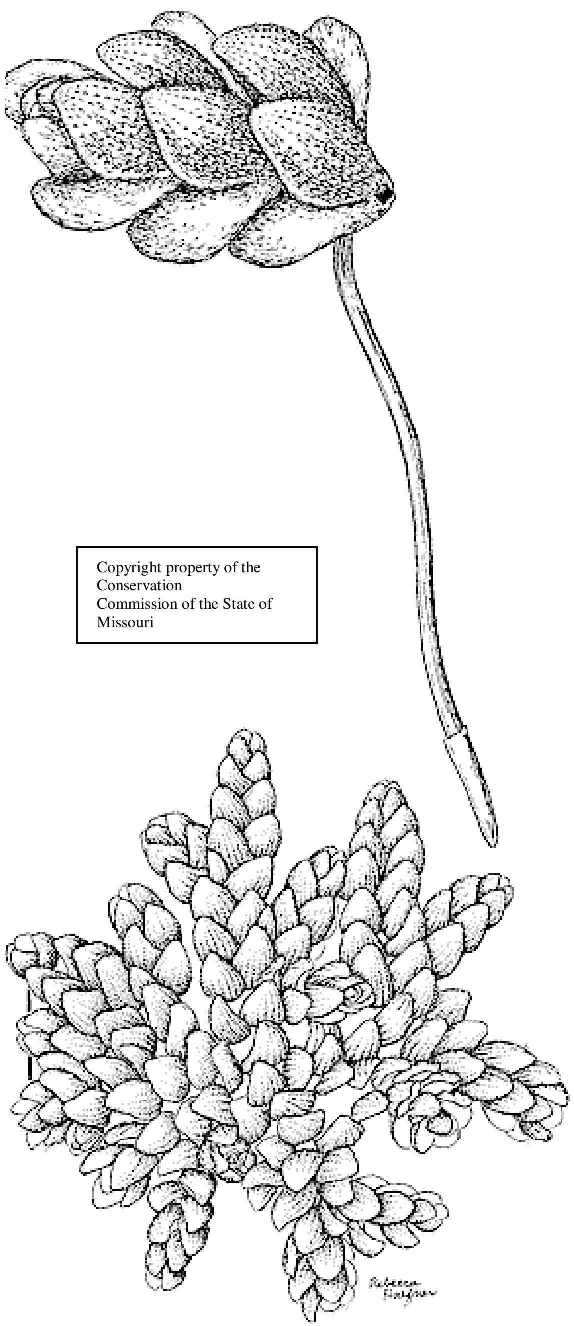
Lemna grows only in slower waters. It is present in most of the valley reaches, never in the canyon. It is not particularly abundant.

Azolla mexicana (AZME) (Azollaceae – pteridophyte)

"Mexican Mosquito Fern"

CA native. Sacramento Valley, northern Sierra Nevada. Presence in Shasta River seems to be a recent event, as it is not listed in the Jepson Manual as growing in the region. Found to British Columbia, central U.S. and South America.

Azolla is rare in the Shasta River, and tends to be mixed in with *Lemna*



Looks similar to *Lemna minor (LEMI)* at a distance, but it is more fern-like, slightly larger (up to ¾ of an inch long, and turns rusty-red in the full sunlight.

Grows in large colonies, obscuring the water surface completely.

Spore reproduction.

Mimulus guttatus (Scrophulariaceae – dicot)

“Seep-spring monkeyflower” “Common monkeyflower”

CA native. To Alaska, western Canada, Rocky Mtns, northern Mexico.

This flower is quite variable and may hybridize with several other *Mimulus* species. It is also quite variable in habitat. We found it growing in floating mats in the natural spring in Hidden Valley. Some individuals in the mat were not rooted to the substrate at all, but some were rooted lightly. In contrast, we also found some individuals growing in the soil of a very wet meadow below the spring. It is noted, however, that the plant grows only near springs. We found no examples of this species growing along the main river.

Elodea Canadensis (ELCA) (2) (Hydrocharitaceae – monocot)

“Common Waterweed” “American Waterweed” “Canadian Waterweed” “Oxygen Weed”

CA Native. Found throughout most of CA, to B.C., eastern U.S. Naturalized in Europe.

The leaves of this plant are generally less than a quarter of an inch wide at the base, and about a quarter of an inch long. They come off the stem in whorls of 3 at very regular intervals along the stem, gradually getting much denser (vertically) at the tips of stems.

This plant rarely blooms, but when it does have flowers (between July and September), they will be small (3/8 of an inch across) with 3 white petals, on the end of long, thread-like stalks. These flowers will be held at but not above the surface of the water. An example of a flower is shown in the photo to the left, in the lower right hand portion of the plant.

The photo above shows typical stems of the plant. It is the only plant with small leaves and long stems of this sort in the study area. *Myriophylum* and *Ceratophylum* could possibly be mistaken for this plant, but their leaves are very “dissected”, meaning they are fans of threadlike material instead of small triangles as in *Elodea*.

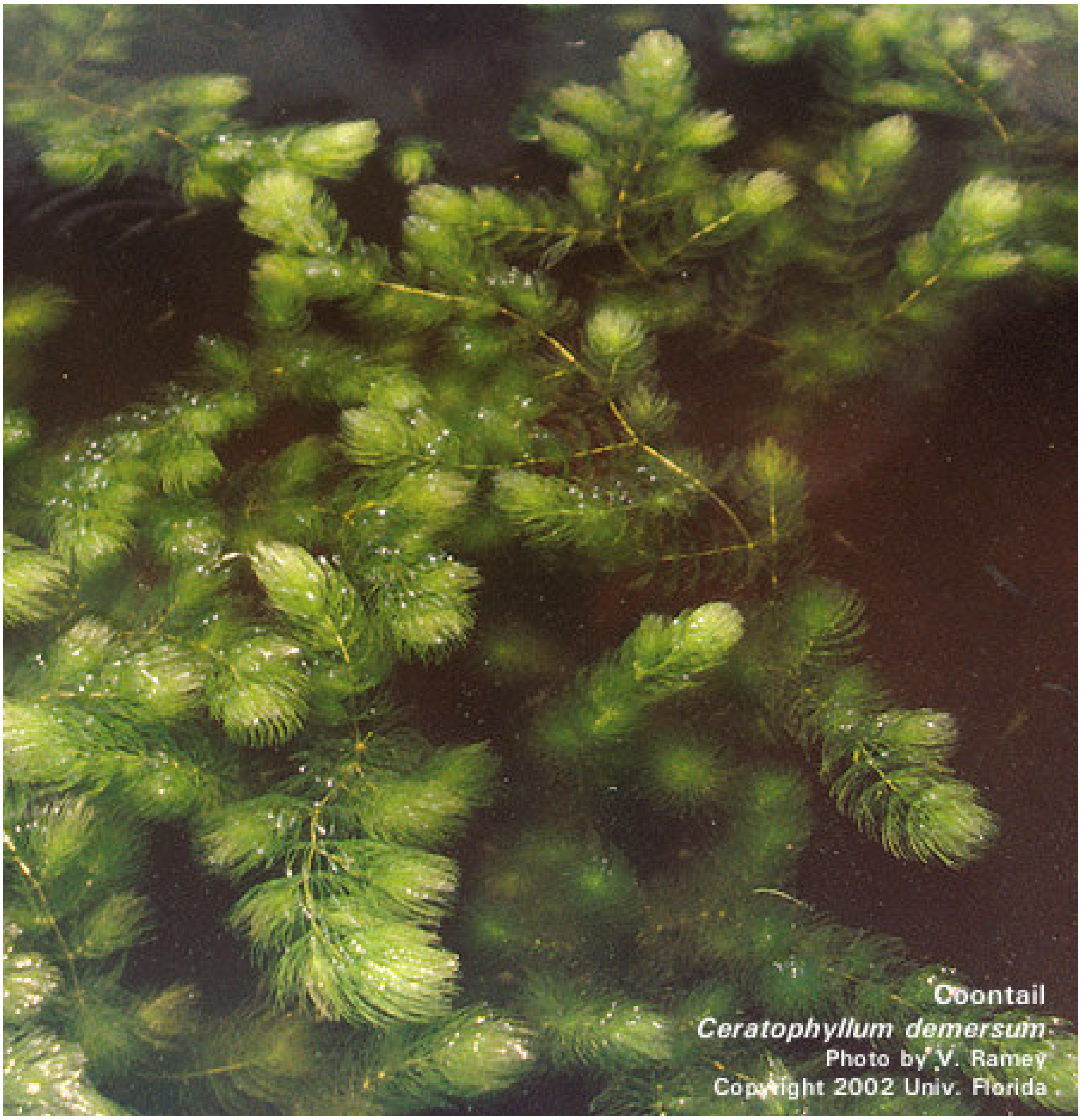
Elodea Canadensis (ELCA) never protrudes from the water. It can be found in large clumps and mixed with other submerged plants. It generally grows in shallow water to a depth of 3 feet at most. The photo above shows a typical clump. There is a small amount of *Potamogeton pectinatus (POPE)* mixed in with the *Elodea*.

This plant is very common in many reaches in both canyon and valley.

Ceratophyllum demersum (CEDE) (6) (Ceratophyllaceae – dicot)

"Coontail" "Hornwort"

CA native. Found worldwide.



Grows in dense clumps. Usually does not grow in huge mats. The photo above shows an individual that is somewhat lighter in color than is typical in the Shasta River.

Note the much denser leaves at the ends of stems.

Ceratophylum demersum (CEDE) grows only in the valley reaches and was more common in the upper reaches of the valley. It is not very abundant.

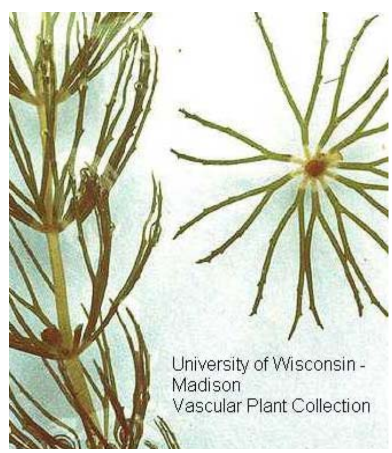
Myriophylum sibiricum (MYSI) (6) (Haloragaceae – dicot)

"Northern Water Milfoil"

CA native. Found throughout most of northern CA, in the Mojave River; to British Columbia, eastern U.S. Also found in Eurasia.

This plant has a gestalt similar to *Ceratophyllum* "Coontail", but on closer examination it has leaves that are *pinnate* (a central rib with many ribs coming off of it from two sides, like a feather) rather than branched.

Myriophyllum sibiricum (MYSI)



Ceratophyllum demersum (CEDE)

Also, note that the leaves of the Milfoil are not toothed, whereas the Coontail leaves have small teeth along one edge.

Myriophyllum sibiricum (MYSI) leaves do not become more dense towards the ends of the stems. *Elodea Canadensis (ELCA)* and *Ceratophyllum demersum (CEDE)* both become denser towards the ends of the stems.

Myriophylum sibiricum (MYSI) was present in canyon and valley reaches, but it was not very abundant.

Ranunculus aquatilus (RAAQ) (5) (Ranunculaceae – dicot)

"White Water-Buttercup"

CA native. Found throughout CA excluding the Channel Islands. Also found in the Great Basin. To Alaska, eastern North America, Mexico.

Another fine-leaved plant, but it is far less dense. The leaves come off of the stem in an alternating pattern instead of in whorls. The flowers are terminal on stalks instead of axillary.

Clumps of *Ranunculus* have a characteristic look due to the bare white stalks of the inflorescences, which carry one flower each.

It was only found in 3 valley reaches around river mile 12.5. It was not very abundant in any of them.

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Appendix B

Stable Isotope Analysis of Suspended Material and Macrophytes in the Shasta River

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BACKGROUND

The nucleus of an atom consists of protons and neutrons surrounded by a cloud of electrons. Each element (e.g. carbon and nitrogen) has a specific and fixed number of protons in the nucleus, although the number of neutrons can vary. For example, carbon can have six, seven, or eight neutrons. Each proton and neutron has an atomic mass of one, and the sum of the protons and neutrons in the nucleus constitute the atomic mass of the element. Elements can vary in their atomic mass, which is the result of the addition of neutrons to the nucleus. Atoms of the same atomic number but different atomic mass are called **isotopes**. Thus, the naturally occurring isotopes of carbon are carbon-12 (6 protons + 6 neutrons), carbon-13 (6 protons + 7 neutrons), and carbon-14 (6 protons + 8 neutrons), which are abbreviated as ^{12}C, ^{13}C, and ^{14}C, respectively. ^{14}C undergoes radioactive decay and is called a radiogenic or "unstable" isotope. The radioactive decay of ^{14}C is the basis for radiocarbon (carbon-14) dating. ^{12}C and ^{13}C do not undergo radioactive decay and are called stable isotopes.

Most elements (including Carbon, Hydrogen, Oxygen, Nitrogen, and Sulfur) have two or more stable isotopes. Heavy isotopes of carbon and nitrogen are the most useful as biological tracers. Each has a heavy isotope (^{13}C and ^{15}N) with a natural abundance of ~1% and a light isotope (^{l2}C and ^{14}N) that makes up the remainder of the mass of the element (**Table 1**).

Table 1. Average Terrestrial Abundances of the Stable Isotopes of Carbon and Nitrogen

Element	Isotope	Abundance (%)
Carbon	^{12}C	98.89
	^{13}C	1.11
Nitrogen	^{14}N	99.63
	^{15}N	0.37

Primary producers (green plants) take up the isotopes in the concentration in which they are found in the environment and incorporate them into their tissue. When living organisms consume and metabolize the green plants that contain the two isotopes of nitrogen, they tend to excrete the lighter isotope and retain the heavier isotope in their bodies, a process called fractionation. As tissue is passed up the food chain, it tends to concentrate the heavier isotope leaving a tracer in the tissue. Isotopes of nitrogen are particularly useful in freshwater ecosystems for nitrogen source identification. In streams and rivers with access to the open ocean, typical sources of ^{15}N include marine derived material (e.g. anadromous fish including salmon), or anthropogenic sources (human or animal waste or synthetic fertilizers), both of which are naturally enriched in the heavy isotope. If evaluated in conjunction with isotopes of oxygen, the exact source of nitrogen to an ecosystem can be determined. Analysis of isotopes of oxygen was beyond the scope of this study. However, if nitrogen is examined alone, the presence of an anthropogenic input can be detected. If primary producers (i.e. algal cells or macrophytes) are sampled, and they have a high concentration of the heavy isotope of nitrogen, there is a high probability that there are inputs of the heavy isotope to the system. Because of the rapid uptake of nitrogen by primary producers, any ^{15}N signal detected in primary producers would be the result of inputs occurring around the time of sampling. If salmon can be eliminated as a source, the most likely candidate is some type of anthropogenic input. Consequently, water samples containing algae, and samples of aquatic macrophytes growing in the river were collected to determine the presence of anthropogenic sources of nitrogen in the Shasta River system.

ANALYTICAL METHODOLOGY

Water samples were collected in high density polyethelene containers and stored on dry ice in the field. Samples of macrophytes were collected and stored in Ziploc bags on dry ice. The samples were transported to the Aquatic Ecosystem Analysis Laboratory at the University of California at Davis and stored at –30^{o}C until analysis. Samples for natural abundance stable isotope analyses were dried at 55°C for ≥ 48 h. For samples collected on filters (i.e., seston and biofilm), entire filters were triturated, encapsulated, and analyzed. All isotopic analyses were performed at the stable isotope facility at the University of California at Davis (http://stableisotopefacility.ucdavis.edu) using a Europa Scientific Hydra 20/20 isotope ratio mass spectrometer with an analytical precision of ± 0.1‰ for carbon and ± 0.2‰ for nitrogen. Standard notation for reporting stable isotope data is the delta (δ) value. This notation is used to reflect the ratio of the heavier to lighter isotope expressed as the per mil (‰) deviation from arbitrary standards (PeeDee Belemnite carbonate for δ^{13} C and atmospheric N for δ^{15} N) according to the equation $\delta^{15}N$ or $\delta^{13}C$ ‰ = $[((R_{sample} / R_{standard}) -1) \times 1000]$ where R is $^{15}N/^{14}N$ or $^{13}C/^{12}C$.

RESULTS AND DISCUSSION

Macrophytes

Each plant sample was analyzed for total N, total C, $\delta^{15}N$, and $\delta^{13}C$ based on 3 subsamples for each site. *Elodea canadensis* is prominent in the Shasta River and was present in most of the plant samples collected. For each sample where *Elodea* was present, it was analyzed separately for the same parameters, with 3 subsamples of just *Elodea*.

Figure 1 suggests a relatively strong relationship between river mile from Lake Shastina and $\delta^{15}N$ in the *Elodea canadensis* samples, with an increase in the level of ^{15}N from about 6.0 near the outlet of Lake Shastina to about 10.0 near the mouth of the Shasta River. By comparison, ^{15}N values from the Navarro River, a relatively prisitine north coast river, with no external inputs of heavy (enriched) nitrogen ranged from 0 (atmospheric N) to +3 ‰ (Johnson, unpublished data). Cabana and Rasmussen (1996) reported that $\delta^{15}N$ values from primary consumers from pristine systems averaged 3.3 ‰. Primary consumers are expected to be 3.3-3.4 ‰ above the primary producers (Steffy and Kilham 2004), meaning that in pristine systems algae and macrophytes would have a $\delta^{15}N$ value of 0 ‰. All macrophytes sampled in the Shasta River below Lake Shastina were enriched in the heavy isotope. Natural sources of the heavy isotope are relatively limited. In watersheds that connect directly with the ocean, migrating salmon can provide a large natural source of ^{15}N. However, these samples were collected in July and August when no salmonid migration was taking place. Therefore, additions of marine-derived nitrogen to the system can be ruled out, and the most probable source was anthropogenic. Anthropogenic inputs from sewage to aquatic ecosystems have resulted in organisms enriched in the heavy nitrogen isotope (e.g., Lake et al. 2001, Steffy and Kilham 2004, Wainright et al. 1996)

There is also a distinct increase in the level of ^{15}N in all Shasta River macrophytes sampled from the outlet of Lake Shastina to the Klamath (**Figure 2**). The spikes in ^{15}N levels indicate local inputs of ^{15}N –enriched water. Although statistically there appears to be a negative relationship between river mile and $\delta^{15}N$, the relationship is anchored by the very high values of $\delta^{15}N$ located nearer the confluence of the Shasta with the Klamath. The majority of the macrophytes had $\delta^{15}N$ levels between 5 and 7 ‰, but there are a few locations with somewhat higher levels (above 8 ‰) throughout the entire length studied. All of these values suggest that anthropogenic sources of N account for a large fraction of the N being sequestered and incorporated by stream macrophytes.

Figure 1. Stable nitrogen isotope vs. river mile for *Elodea canadensis*. River mile 0 is the confluence with the Klamath River.

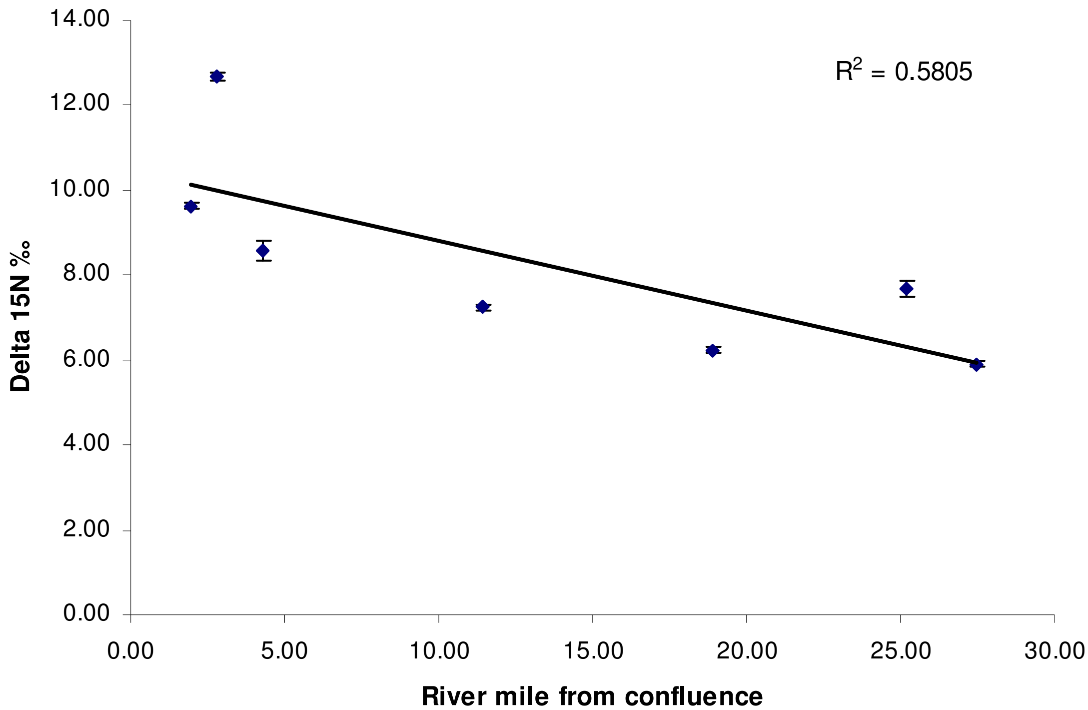
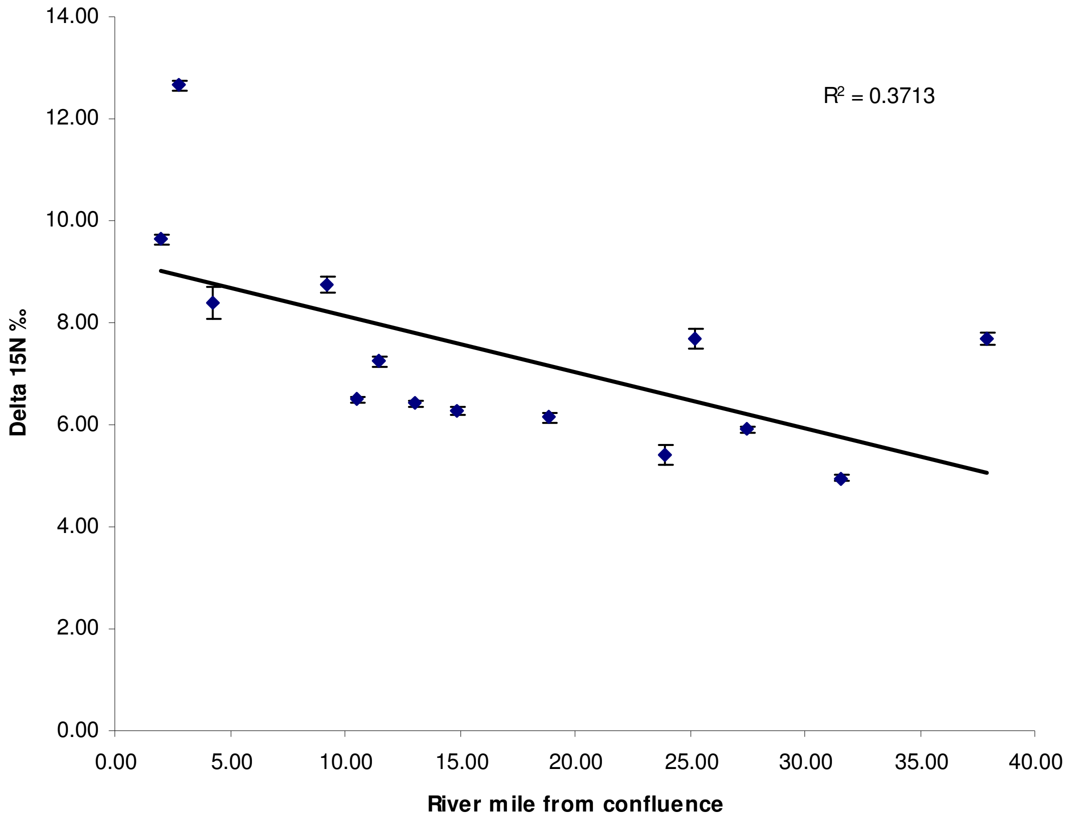


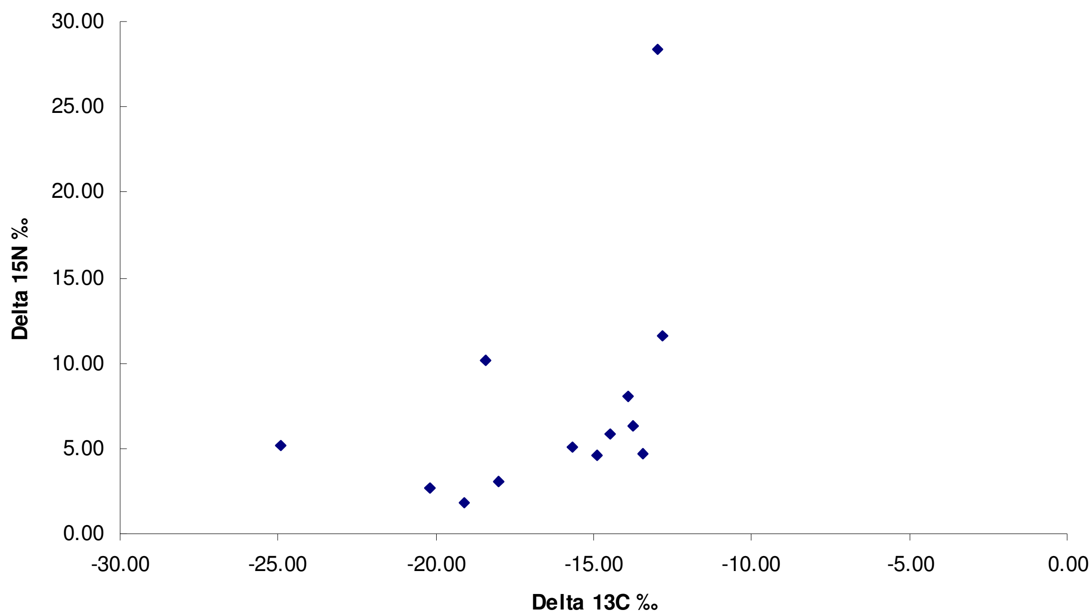
Figure 2. Stable nitrogen isotope vs. river mile for all macrophytes collected from the Shasta River. River mile 0 is the confluence with the Klamath River.



Suspended organic material

Suspended organic material was examined for stable isotope signatures in the same way as the macrophytes. Data are presented in two ways, a plot of the $\delta^{13}C$ vs. $\delta^{15}N$ (**Figure 3**) and $\delta^{15}N$ vs. river mile (**Figures 4 and 5**). **Figures 4 and 5** are similar to the plot for macrophytes except that samples were not collected at all of the same locations. The $\delta^{13}C$ values in Figure 3 provide an indication of the carbon source for material suspended in the water column. Generally, if the carbon source is the same for all samples in a river system, the values will be located similarly along the horizontal axis ($\delta^{13}C$). There is substantial scatter along the horizontal axis indicating that the carbon source for the material in the Shasta River is not similar. Although difficult to interpret, the carbon sources are probably both allochthonous (originating with organic matter falling into the river) and autochthonous (carbon fixed from carbon dioxide by green plants growing in the water or autotrophic bacteria). Although there is a trend for those samples that are slightly higher (less negative) in $\delta^{13}C$ to have somewhat greater $\delta^{15}N$ values, the relationship is not strong and is driven by a single sample with an extreme $\delta^{15}N$ value. It is not certain why the sample has that large of a $\delta^{15}N$ value, although the sample was collected in Yreka Creek at Oberlin Road within the city limits. The values of $\delta^{13}C$ are within a normal range for rivers on the North Coast of California. For example, in the Navarro River, $\delta^{13}C$ values ranged from -33 to -18 (Kiernan and Johnson, unpublished data).

Figure 3. Plot of $\delta^{13}C$ and $\delta^{15}N$ from samples collected from the Shasta River, Parks Creek, and Yreka Creek. Values of $\delta^{13}C$ allow a determination of the carbon source to the food web, and the $\delta^{15}N$ provides information on the source of nitrogen to the system and the trophic position.



Figures 4 and 5 are plots of suspended organic material $\delta^{15}N$ against river mile. **Figure 4** contains all points sampled, and **Figure 5** is the same plot without the single outlier at river mile 27.49. As with the plots for macrophytes, there is a strong trend for an increase in $\delta^{15}N$ as water moves downstream. $\delta^{15}N$ values are lower for suspended material compared to macrophytes, with values from just under 3 to 8 ‰. The outlier in Figure 4 was omitted from the plot in Figure 5 to examine the relationship without the outlier. The value of the outlier is not exceptionally high, but was not similar to other samples from that location or any location upstream. This value could be the result of a sample contaminated with organisms from a higher trophic position (e.g., part of an insect), waste material from cows, or analytical error. All samples in the analysis were submitted together and it is unlikely that a single sample in the middle of the analysis would provide spurious results. If the results reflect actual values for the suspended material collected at the site, it is not certain where the material originated. Since the suspended organic matter moves downstream it is probable that this sample reflects conditions at some point upstream, but the exact location is unknown. These high values for $\delta^{15}N$ confirm the conclusions drawn from the macrophyte stable isotope data that the sites are likely impacted by anthropogenic inputs of nitrogen.

Unless further analyses are performed, it is not possible to determine the exact source of the nitrogen, but the most probable sources are organic enrichment due to inputs of animal or human waste or synthetic fertilizers. Studies elsewhere that found values of $\delta^{15}N$ in primary producers (algae and macrophytes) between 9 ‰ and 12 ‰ were in areas with suspected inputs of sewage from leaking septic tanks (Steffy and Kilham 2004). Their conclusion was that the values were elevated above areas with sewers due to the leaking of nitrogen from on-site septic systems. Likewise, Lake et al. (2001) found that increased shoreline development around 17 freshwater sites lead to elevated $\delta^{15}N$ levels. They concluded that these elevated levels were probably due to increased human wastewater discharges to these small lakes. Animal waste (e.g., cattle, hogs, poultry) can similarly cause elevated $\delta^{15}N$ levels. Finally, synthetic nitrogen fertilizers are high in $\delta^{15}N$ and will also result in elevated $\delta^{15}N$ levels in surface waters if they are allowed to runoff into the stream.

Figure 4. Suspended organic material stable nitrogen isotope values plotted against river mile for the Shasta River. River mile 0 is the confluence with the Klamath River. All sample points are included in the analysis.

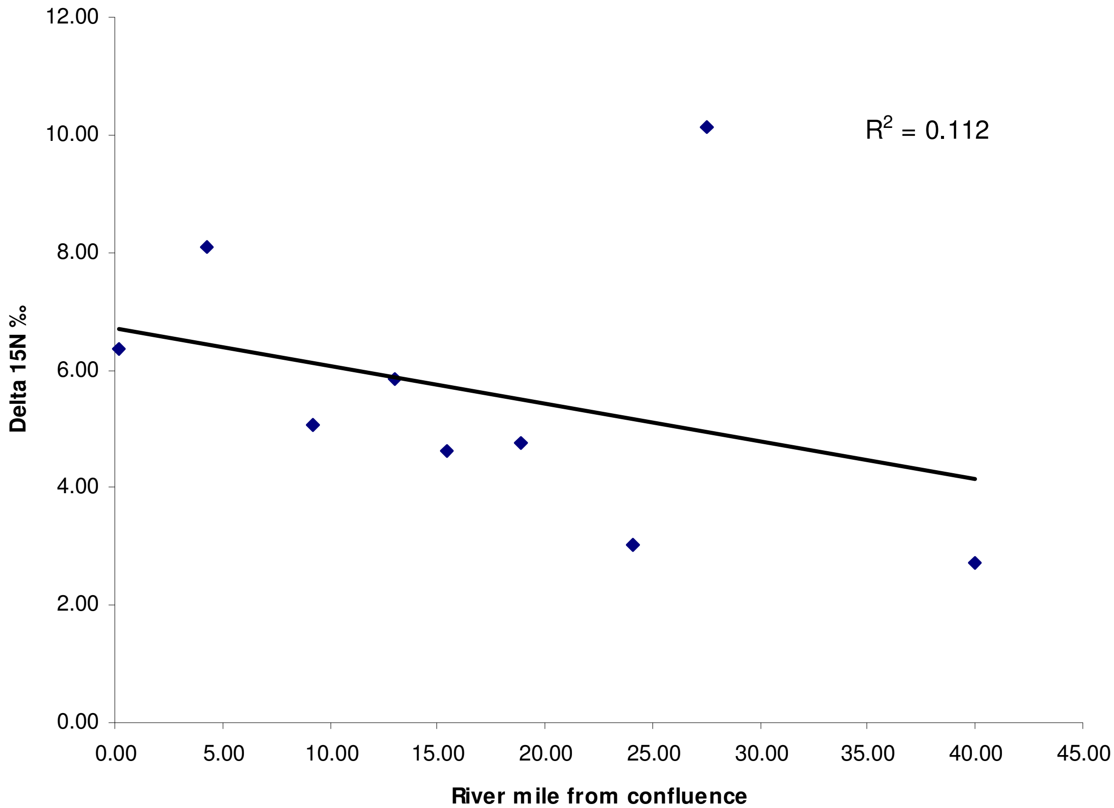
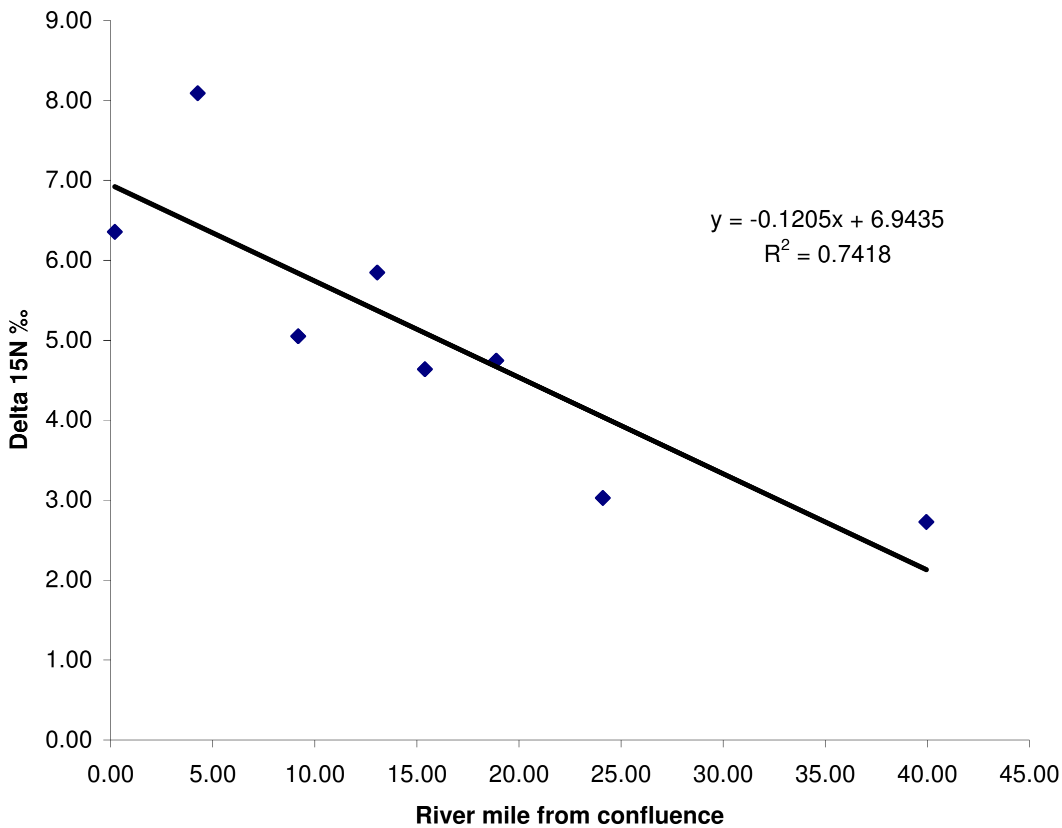


Figure 5. Suspended organic material stable nitrogen isotope values plotted against river mile for the Shasta River. River mile 0 is the confluence with the Klamath River. The single outlier point at river mile 27.49 is omitted from the plot.



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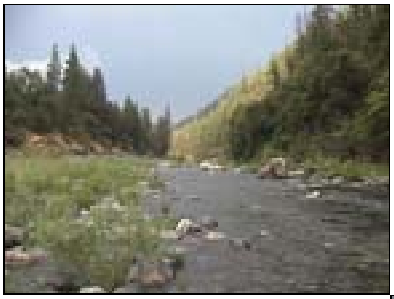
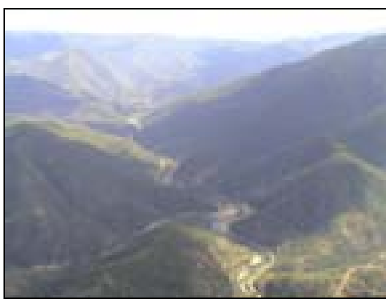
Aerial Surveys using Thermal Infrared and Color Videography

Scott River and Shasta River Sub-Basins

February 26, 2004





Report to:

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Final Report

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Introduction

In July 2003, Watershed Sciences, LLC (WS, LLC) conducted airborne thermal infrared remote (TIR) sensing surveys on selected streams in the Scott and Shasta River sub-basins in Northern California. The overriding objective of the survey(s) was to collect TIR and color video imagery in order to characterize spatial temperature patterns in the basin. The imagery and derived data sets are intended to support ongoing total maximum daily load (TMDL) studies and related stream temperature modeling efforts through the California North Coast Regional Water Quality Control Board (NCRWQCB) and the Department of Environmental Science and Policy at the University of California at Davis.

Water temperatures vary naturally along the stream gradient due to topography, channel morphology, substrate composition, riparian vegetation, ground water exchanges, and tributary influences. Stream temperatures are also affected by human activities within the watershed. TIR images provide information about spatial stream temperature variability and can illustrate changes in the interacting processes that determine stream temperature. In most cases, these processes are extremely difficult to detect and quantify using traditional ground based monitoring techniques.

It is the aim of this report to: 1) document methods used to collect and process the TIR images, 2) present spatial temperature patterns and 3) present hypotheses of hydrologic processes influencing spatial temperature patterns based on first-look inspection of the imagery. Thermal infrared and associated true color video images are included in the report in order to illustrate significant thermal features. An associated ArcView 3.2 GIS[1] database includes all of the images collected during the survey and is structured to allow analysis at finer scales.

Methods

Data Collection

Images were collected with TIR (8-12μ) and visible-band cameras attached to a gyro-stabilized mount on the underside of a helicopter. The two sensors were aligned to present the same ground area, and the helicopter was flown longitudinally along the stream channel with the sensors looking straight down. Thermal infrared images were recorded directly from the sensor to an on-board computer in a format in which each pixel contained a measured radiance value. The recorded images maintained the full 12-bit dynamic range of the sensor. The individual images were referenced with time and position data provided by a global positioning system (GPS).

A consistent altitude above ground level was maintained in order to preserve the scale of the imagery throughout the survey. The ground width and spatial resolution

[1] Geographic Information System

presented by the TIR image vary based on the flight altitudes. The flight altitude is selected prior to the flight based on the channel width and morphology. During the flight, images were collected sequentially with 40% or better vertical overlap. The flight was conducted in the mid-afternoon in order to capture heat of the day conditions.

For each survey, WS, LLC deployed in-stream data loggers prior to the survey in order to ground truth (i.e. verify the accuracy of) the TIR data. The in-stream data loggers were ideally located at regular intervals (*10 miles or less*) along the survey route. Due to access limitations in some areas, WS, LLC data were supplemented with additional in-stream monitoring sites provided by the NCRWQCB, the USFS and Fruit Growers Supply, Inc. Meteorological data including air temperature and relative humidity were recorded using a portable weather station (*Onset Computer Corp.*) located in Happy Camp, CA and fixed monitoring stations located in the Scott River Sub-Basin (*operated by: USFS – Callahan and NCRWQCB*) and the Shasta River Sub-Basin (*operated by: CA Dept. of Forestry - Weed*).

Data Processing

Measured radiance values contained in the raw TIR images were converted to temperatures based on the emissivity of water, atmospheric transmission effects, ambient background reflections, and the calibration characteristics of the sensor, including the temperature and transmission of the external optics. The atmospheric transmission value was modeled based on the air temperatures and relative humidity recorded at the time of the survey. The radiant temperatures were then compared to the kinetic temperatures measured by the in-stream data loggers. The in-stream data were assessed at the time the image was acquired, with radiant values representing the median of ten points sampled from the image at the data logger location. Calibration parameters were fine-tuned to provide the most accurate fit between the radiant and kinetic temperatures.

Once the TIR images were calibrated, they were integrated into a GIS in which an analyst interpreted and sampled stream temperatures. Sampling consisted of querying radiant temperatures (pixel values) from the center of the stream channel and saving the median value of a ten-point sample to a GIS database file (Figure 1). The temperatures of detectable surface inflows (i.e. surface springs, tributaries) were also sampled at their mouth. In addition, data processing focused on interpreting spatial variations in surface temperatures observed in the images. The images were assigned river miles based on a 1:24k (*Beta Version*) routed GIS stream coverage provided through Humboldt State University using the dynamic segmentation features of the Arc/Info software. This coverage was the best routed stream layer available for the basin. Never-the-less, it is important to note that measures assigned to the images from this coverage are relative distances along the mapped stream line and may not match distances derived from other sources or ground based surveys. When comparing locations from other sources, it may be necessary to re-assign measures to the data (*images*) based on a common source.

The median temperatures for each sampled image of each surveyed stream were plotted versus the corresponding river mile to develop a longitudinal temperature profile. The profile illustrates how stream temperatures vary spatially along the stream gradient. The location and median temperature of all sampled surface water inflows (e.g. tributaries, surface springs, etc.) are included on the plot to illustrate how these inflows influence the main stem temperature patterns. Where applicable, tributaries or other features that were detected in the imagery, but were not sampled due to their small size (*relative to pixel size*) or the inability to see the stream through riparian vegetation are included on the profile to facilitate the interpretation of the spatial patterns.

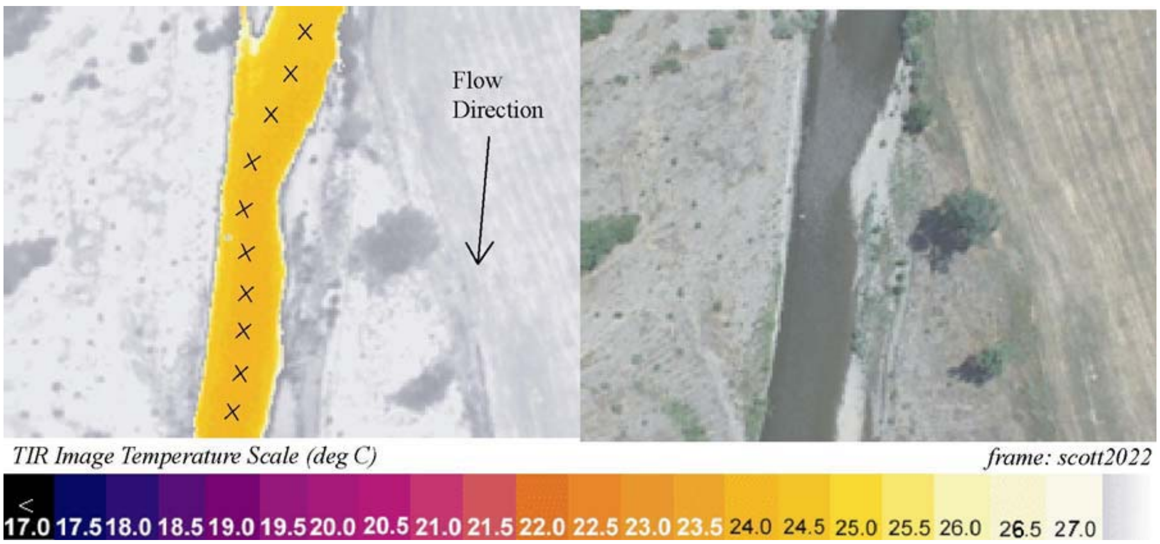


Figure 1 – TIR/color video image pair showing how temperatures are sampled from the TIR images. The black *X's* on the TIR image show typical sampling locations near the center of the stream channel. The recorded temperature for this image is the median of the sample points.

During the analysis, the images were stored in a format (Arc/Info GRID) where each cell (or pixel) contained a calibrated radiant temperature value to $1/10^{th}$ of degree Celsius. For visual analysis and presenting in reports, the GRID(s) were converted to a pseudo color image in *jpeg* format by applying a specific color to represent a range of temperatures. In this case, the color map was segmented into 0.5°C increments through the full range of water temperatures observed during the analysis. Radiant temperatures in the image that were more than 1.0°C above the warmest water temperature (including tributaries) were assigned shades of gray with white representing the warmest temperatures. Using this color scheme, the converted raster images represent the full range of temperature values in the GRID images, but effectively differentiate the range of water temperatures. Figure 1 provides an example of the converted pseudo-color image. In this example, the water surface temperature is mapped in shades of orange while the terrain and vegetation temperatures are mapped in shades of gray. By applying two different color maps, the scheme provides a better means of visualizing changes in stream temperatures than could be achieved by stretching a single color map over the full image.

TIR Image Characteristics and Limitations

Since water is essentially opaque to TIR wavelengths, the sensor is only measuring water surface temperature. Thermal infrared data accurately represents bulk water temperatures where the water column is thoroughly mixed. However, thermal stratification can form in reaches that have little or no mixing. Thermal stratification in a free flowing river is inherently unstable due to variations in channel shape, bed composition, and in-stream objects (i.e. rocks, trees, debris, etc.) that cause turbulent flow. In the TIR images, indicators of thermal stratification include cool water mixing behind in-stream objects and/or abrupt transitions in stream temperatures. Occurrences of thermal stratification interpreted during analysis are identified in the results section for each survey. None-the-less, one should recognize the inherent limitations of measuring only surface temperatures. Thermal stratification is not detected in all situations and small, sub-surface seeps may be mixed into the water column without creating a detectable signature at the water surface. Consequently, these fine scale thermal processes may be missed unless these processes directly influence broader scale temperature patterns. In this case, cooling along the stream gradient (*or even lack of heating*) is an indicator of these processes, but should be verified with additional analysis or field surveys.

Thermal infrared radiation received at the sensor is a combination of energy emitted from the water's surface, reflected from the water's surface, and absorbed and re-radiated by the intervening atmosphere. Water is a good emitter of TIR radiation and has relatively low reflectivity (approximately 4 to 6% of the energy received at the sensor is due to ambient reflections). During image calibration, a correction is included to account for average background reflections. However, variable water surface conditions (i.e. riffle versus pool), slight changes in viewing aspect, and variable background reflection temperatures (i.e. sky versus trees) can result in differences in the calculated radiant temperatures within the same image or between consecutive images. The apparent temperature variability is generally less than 0.6^oC (Torgersen et al. 2001). However, the occurrence of reflections as an artifact (or noise) in the TIR images is a consideration during image interpretation and analysis. In general, apparent stream temperature changes of $< 0.6^oC$ are not considered significant unless associated with a point source.

The accuracy of the radiant temperature values derived from the TIR images are a combination of the radiometric accuracy of the sensor, instrument noise, transmission of energy through the atmosphere, ambient reflections, and slight variations in the way the water surface radiates TIR energy (i.e. emissivity). Past TIR surveys conducted in the Pacific Northwest have shown that an average accuracy of $\pm 0.5^oC$ is readily achievable by applying the methods used in this study (Torgersen et al. 2001, Faux et al 2001). This methodology uses ground truth sensors located in the stream to adjust the atmospheric transmission model in order to achieve more accurate radiant temperatures. The adjusted calibration is verified against independent sensors to measure overall accuracy and variability. Regardless of methods, a level of variability still exists in the imagery due to instrument noise and variations in conditions at the stream survey (*discussed in the previous paragraph*). The variability of the instrumentation is difficult to separate from other sources. However, the scanned array sensor used on earlier studies exhibited a characteristic noise level of about ±0.4°C that manifested itself as "speckling" in the imagery. The focal plane array sensor used during these studies presents a very clean image without the speckling observed in the older sensors. The new sensor is 10 times more sensitive and reflective differences at the water surface are more apparent in this imagery (*these patterns used to be lost in the noise*). In addition, slight changes in apparent temperature are noted on the edges of the images with the more accurate radiant temperatures in the center. Based on these factors, temperature variations within ±0.5°C should be considered within the noise levels characteristic of TIR remote sensing. The exception to this rule is if the difference has a spatial pattern that is typical of a specific thermal process (i.e. tributary mixing zone, etc.).

In stream segments with flat surface conditions (i.e. pools) and relatively low mixing rates, observed variations in spatial temperature patterns can be the result of differences in the instantaneous heating rate at the water's surface. In the TIR images, indicators of differential surface heating include seemingly cooler radiant temperatures in shaded areas compared to surfaces exposed to direct sunlight. Shape and magnitude distinguish spatial temperature patterns caused by tributary or spring inflows from those resulting from differential surface heating. Unlike thermal stratification, surface temperatures represent bulk water conditions when the stream is mixed. Temperature sampling along the center of the stream channel (Figure 1) minimizes variability due to differences in surface heating rates. None-the-less, differences in surface heating combined with ambient reflection can confound interpretation of thermal features especially near the riverbank

A small stream width logically translates to fewer pixels "in" the stream and greater integration with non-water features such as rocks and vegetation. Consequently, a narrow channel (relative to the pixel size) can result in higher inaccuracies in the measured radiant temperatures (Torgersen et. al. 2001). In some cases, small tributaries were detected in the images, but not sampled due to the inability to obtain a reliable temperature sample. [2]

Scott River Sub-Basin

Overview

TIR remote sensing surveys in Scott River Sub-Basin were flown on July 25-26, 2003 (Figure 2). Table 1 summarizes the survey times, extents, and image resolution for each surveyed stream. The Scott River was surveyed at a flight altitude that provided a wider image footprint to better capture the wider channel widths and side/off channel features characteristic of the main stem Tributaries were surveyed at lower flight altitudes to provide slightly higher spatial resolution and better visibility through riparian vegetation. Kidder Creek/Big Slough was surveyed at two different altitudes. The lower altitude was used to record radiant temperatures in the stream, but did not provide an

[2] Features that are detected in the imagery, but not sampled for temperature are noted in the comment attribute of the flight point coverage.

image width sufficient enough to capture the multiple channels of the slough. The higher altitude results in a wider image footprint (*lower pixel resolution*) and provides an alternate image set for understanding the surface hydrology within the surveyed segment.

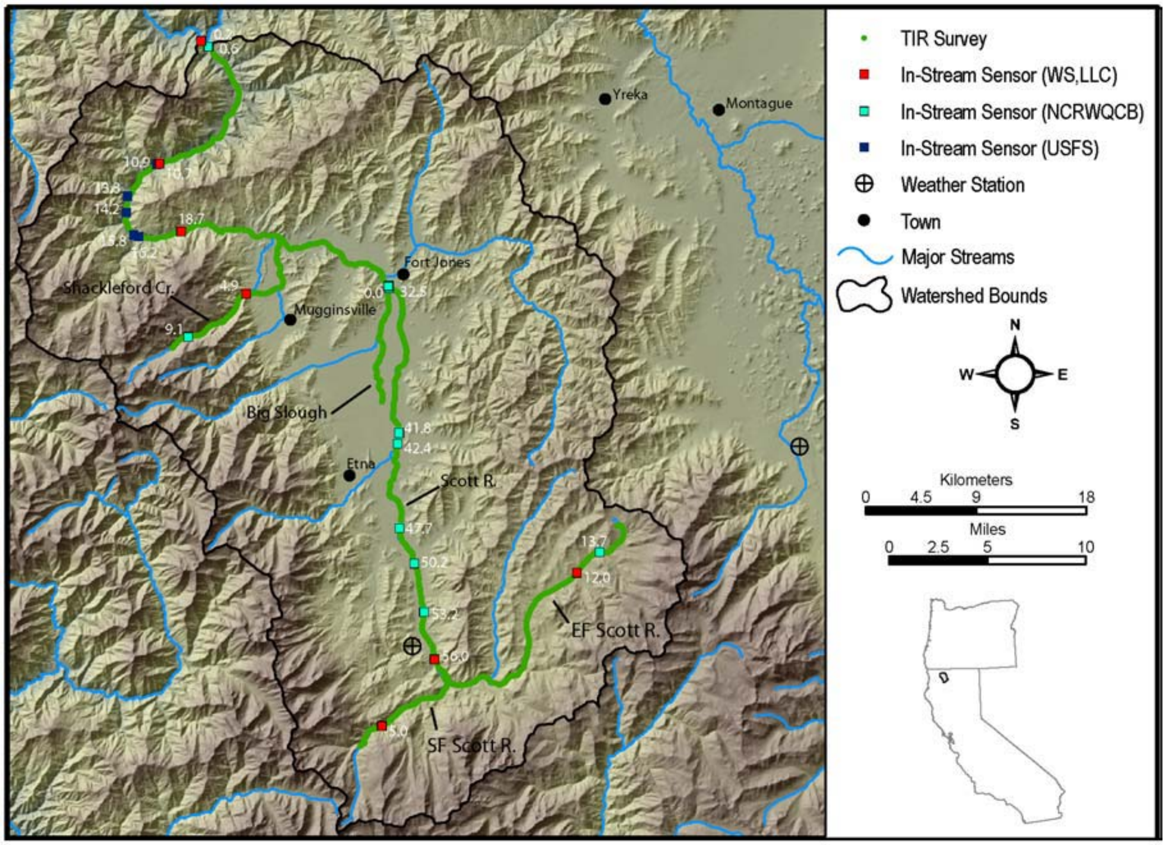


Figure 2 – Map showing the streams surveyed in the Scott River Sub-Basin using TIR and color video on July 25-26, 2003. The map also shows the location of the in-stream sensors used to ground truth the imagery, labeled by river mile.

Table 1 – Summary of river segments surveyed with TIR and color video in the Scott River Sub-Basin on July 25-26, 2003.

Stream	Survey Date	Survey Time (24 hr)	Survey Extent	River Miles	Image Width Meter (ft)	TIR Image Pixel Size Meter (ft)
Scott R.	25-Jul	14:00-15:20	Mouth to East Fork	57.0	193 (635)	0.6 (2.0)
East Fork Scott R.	25-Jul	15:21-15:39	Mouth to Mountain House Cr.	16.1	161 (529)	0.5 (1.7)
Kidder Cr/Big Slough	25-Jul	16:20-16:31	Mouth to rm 10.5	10.5	161 (529)	0.5 (1.7)
Kidder Cr/Big Slough	25-Jul	16:33-16:42	rm 10.5 to mouth	10.5	268 (881)	0.9 (2.8)
Shackelford Cr.	26-Jul	13:49-14:14	Mouth to Back Meadows Cr.	10.1	140 (459)	0.5 (1.4)
South Fork Scott R.	26-Jul	14:31-14:42	Mouth to Jackson Cr.	6.8	161 (529)	0.5 (1.7)

Results

Weather Conditions

Weather conditions for the times of the surveys are summarized in Table 2. Sky conditions were generally clear each survey day and overall conditions were considered good for the TIR surveys. Although air temperatures exceeded 90°F each survey day, air temperatures were generally cooler than those observed the previous week (Figure 3). During the survey dates, scattered thunderstorms formed in the region during the late afternoon and the shift in weather conditions between 16:00 and 17:00 at the Callahan station on the 25th is presumably due to a passing thunderstorm. These thunderstorms were localized and did not impact the TIR surveys.

Table 2 – Meteorological conditions recorded at three different monitoring stations in the survey area for dates and times of the TIR surveys.

	Callahan Station, CA			Scott River (mile 13.1)				Scott River (mile 32.5)			
Time	Air Temp °F	Air Temp °C	RH %	Air Temp °F	Air Temp °C	RH %	Wind Speed (m/s)	Air Temp °F	Air Temp °C	RH %	Wind Speed (m/s)
July 25, 2003											
13:00	87.0	30.6	49	82.9	28.3	49	0.9	79.7	26.5	63	0.9
14:00	88.0	31.1	42	86.2	30.1	39	1.3	82.9	28.3	55	1.3
15:00	94.0	34.4	25	88.5	31.4	36	2.7	86.7	30.4	50	0.4
16:00	95.0	35.0	25	90.3	32.4	31	0.9	87.4	30.8	40	0.9
17:00	66.0	18.9	97	93.0	33.9	20	1.8	89.2	31.8	33	1.8
18:00	65.0	18.3	100	91.0	32.8	24	1.8	88.3	31.3	42	1.8
July 26, 2003											
13:00	92.0	33.3	24	84.2	29.0	38	1.8	85.5	29.7	42	0.4
14:00	93.0	33.9	22	88.0	31.1	30	1.8	88.9	31.6	38	0.9
15:00	95.0	35.0	20	90.1	32.3	26	1.8	90.0	32.2	36	0.9
16:00	95.0	35.0	18	91.2	32.9	27	1.8	91.0	32.8	33	0.4
17:00	93.0	33.9	20	90.9	32.7	29	1.3	89.4	31.9	42	0.9
18:00	87.0	30.6	28	90.7	32.6	29	0.4	86.7	30.4	39	0
July 27, 2003											
13:00	93.0	33.9	22	88.2	31.2	27	0.4	87.4	30.8	37	0.4
14:00	96.0	35.6	19	91.9	33.3	21	0.4	92.5	33.6	28	0
15:00	99.0	37.2	15	94.5	34.7	20	0.9	93.6	34.2	21	0.4
16:00	99.0	37.2	15	94.3	34.6	22	0.9	93.0	33.9	23	0.9
17:00	99.0	37.2	16	95.2	35.1	21	0.9	92.5	33.6	32	0.9
18:00	90.0	32.2	22	95.7	35.4	15	0.9	85.6	29.8	37	0

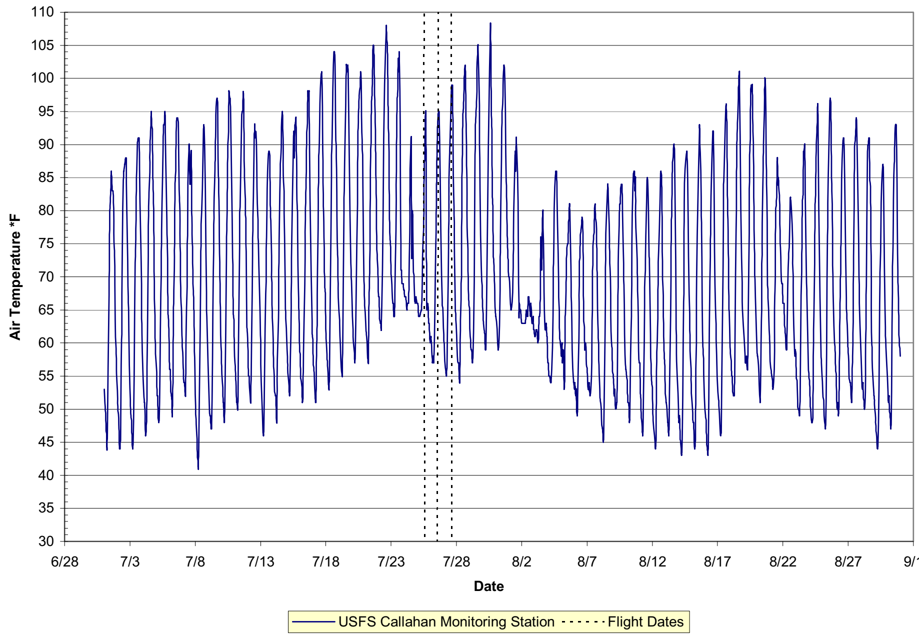


Figure 3 – Continuous air temperatures measured at the USFS Callahan Monitoring Station in the Scott River sub-basin (*source: http://cdec.water.ca.gov/*).

Flow Levels

River flow levels were not specifically measured as part of the TIR survey. However, since surveys were generally targeted to capture summer low flow conditions, relative flow conditions at the time of the survey can facilitate analysis stream temperatures (Figure 4). As shown, mean daily flow levels in the Scott River (*at Fort Jones, CA*) were on average 90 cfs for the two days of the Scott River surveys. These flows were higher than those measured in the previous week, but considerably lower than those observed in early August. The increased flows near the time of the survey were presumably due to the contribution of thunderstorms.

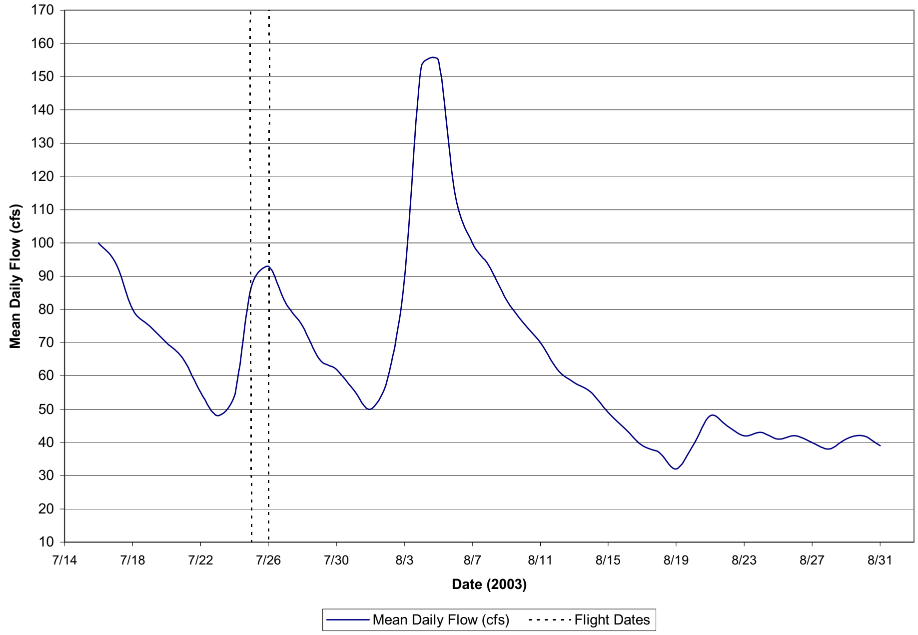


Figure 4 – Mean daily flow levels in the Scott River measured at Ft. Jones, CA (*river mile 34*) and the dates of the of the TIR surveys in the basin.

Thermal Accuracy

Overall, the average absolute differences between the kinetic temperatures recorded by the in-stream data loggers and the radiant temperatures derived from the TIR images were within the desired accuracy (< 0.5^{o}C) on each survey segment (Table 3). With the exception of the upper site on Shackelford Creek, range of differences between radiant and kinetic measurements was ±0.6^{o}C. This range is also consistent with TIR surveys conducted in the Pacific Northwest over the past five years (Torgersen, 2001).

On the Scott River, radiant temperatures were checked against in-stream measurements taken by Watershed Sciences at the time of the survey and further verified with data provided by the NCRWQCB. However, analysis of the longitudinal temperature patterns derived from the TIR imagery illustrated an anomalous[3] jump in radiant temperatures between river miles 12.2 and 17.4. This reach was bracketed by in-stream sensors at river miles 10.7 and 18.7, which verified the consistency and accuracy of radiant temperatures both upstream and downstream of the jump. The US Forest Service provided additional in-stream measurements at 4 sites between river mile 12.2 and 17.4 and these data quantified a consistent bias in radiant temperatures of +2.1^{o}C. Since the bias appeared consistent, the TIR imagery within the anomalous reach was recalibrated to remove the bias. The recalibrated reach is delineated on the spatial temperature profiles presented later in this report.

[3] Review of the raw data and flight notes did not reveal any evidence about the source of the anomaly and it was not observed on any other surveys conducted in the basin or on any other streams surveyed during 2003.

Table 3 – Comparison of ground-truth water temperatures (Kinetic) with the radiant temperatures for streams in the Scott River Sub-Basin.

Image	Source/ Owner	Time 24 hr	River Mile	Kinetic °C	Radiant °C	Difference °C
Scott River (average 0.3°C)						
scott0012	WS, LLC	14:00	0.2	26.6	26.1	0.5
scott0029	NCRWQCB	14:00	0.6	25.6	26.2	0.6
scott0384	WS, LLC	14:12	10.7	23.8	23.9	0.1
scott0389	USFS	14:13	10.9	23.0	24.0	1.0
scott0481	USFS	14:16	13.3	23.4	23.8	-0.4
scott0517	USFS	14:17	14.2	23.1	23.1	0.0
scott0608	USFS	14:21	15.8	22.7	22.6	0.1
scott0621	USFS	14:21	16.2	23.5	23.9	-0.4
scott0715	WS, LLC	14:24	18.7	23.3	23.4	-0.1
scott1281	NCRWQCB	14:44	32.5	26.1	26.2	-0.1
Scott1282	NCRWQCB	14:44	32.5	25.1	25.4	-0.3
Scott1282	NCRWQCB	14:44	32.5	26.1	25.7	0.4
scott1665	NCRWQCB	14:58	41.8	23.8	24.0	-0.2
scott1692	NCRWQCB	14:58	42.4	23.9	24.1	-0.2
scott1692	NCRWQCB	14:58	42.4	23.9	24.1	-0.2
scott1692	NCRWQCB	14:58	42.4	23.6	24.1	-0.5
scott1942	NCRWQCB	15:08	47.7	24.5	24.4	0.1
scott2036	NCRWQCB	15:12	50.3	23.3	23.6	-0.3
scott2036	NCRWQCB	15:12	50.3	23.3	23.6	-0.3
scott2157	NCRWQCB	15:16	53.2	24.7	25.0	-0.3
scott2262	WS, LLC	15:19	56.0	23.3	23.4	-0.1
East Fork Scott River (average 0.5°C)						
scott2712	WS, LLC	15:34	12.0	23.8	24.3	-0.5
scott2763	NCRWQCB	15:36	13.7	20.2	19.8	0.4
Kidder Creek (average 0.2°C)						
kidd0008	NCRWQCB	16:20	0.0	26.8	26.5	0.3
kidd0605	NCRWQCB	16:42	0.0	26.8	26.9	-0.1
Shackelford Creek (average 0.6°C)						
shaq0031	WS, LLC	13:50	n/a	22.8	22.4	0.4
shaq0382	WS, LLC	14:04	4.9	17.7	18.1	-0.4
shaq0382	WS, LLC	14:04	4.9	17.4	17.7	-0.3
shaq0633	NCRWQCB	14:13	9.1	15.7	14.6	1.1
South Fork Scott River (average 0.3°C)						
sfs0063	WS, LLC	14:30	n/a	23.0	22.6	0.4
sfs0336	WS, LLC	14:39	5.0	17.9	18.1	-0.2

Temporal Differences

Figure 5 shows in-stream temperature variations at 2 locations in the Scott River Basin. The figure is intended to provide a sense of how stream temperatures changed during the time frame of the flight. On the Scott River, at river mile 18.7, the survey was conducted prior to the daily maximum stream temperature of 24.7°C at 16:35. At this point, the stream temperature rose 1.2°C (from 23.0°C to 24.2°C) during the time of the survey. On the South Fork Scott River at river mile 5.0, the sensor was retrieved before recording the daily maximum stream temperature. During the survey at that point, the stream temperature rose only 0.15°C.

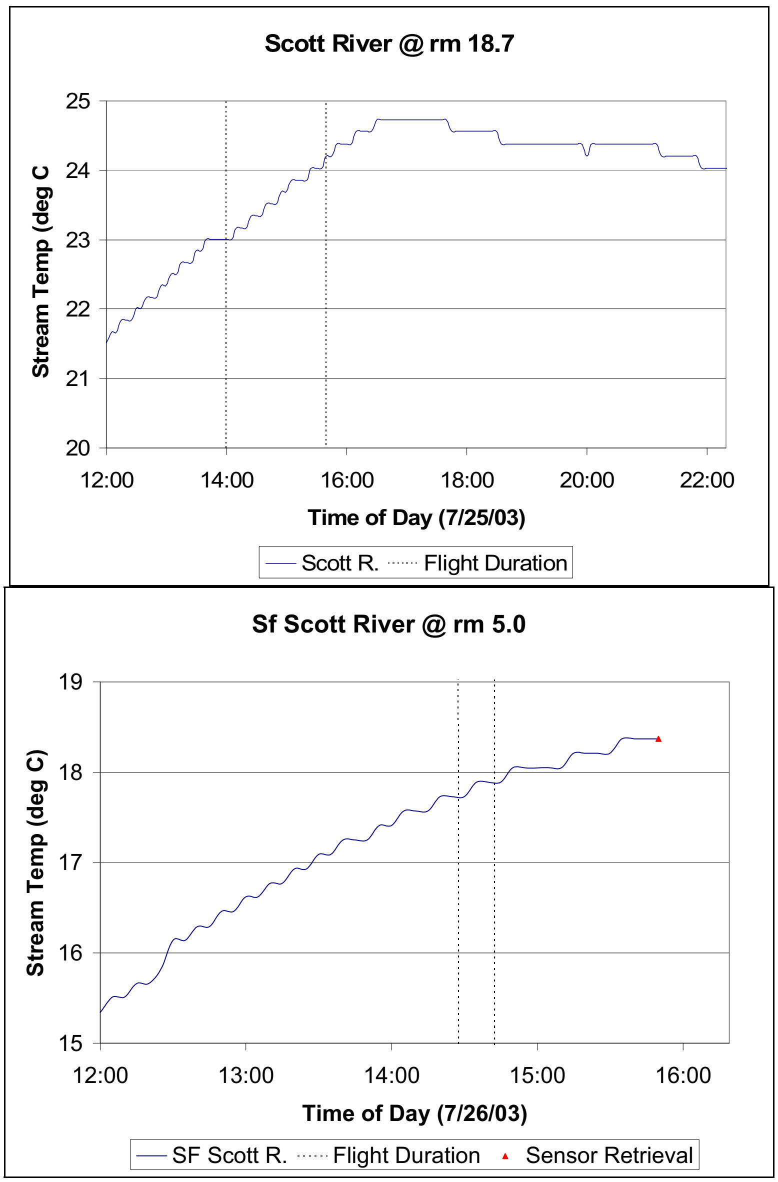


Figure 5 – Stream temperature variation and time of TIR remote sensing flight at a single location on both the Scott and South Fork Scott River surveys.

Scott River

Median radiant temperatures were plotted versus river mile for the Scott River (Figure 6). The plot illustrates the location of surface water inflows (tributaries, springs, seeps), labeled by river mile. The corresponding name and temperature of the surface inflows are summarized in Table 4.

The Scott River is bordered by mine tailings from the confluence of the East and South Forks (rm 57.0) downstream to river mile 51.6. Although radiant water temperatures increased through this reach, numerous (*9 sampled*) cool water springs and seeps were detected that contributed to localized spatial thermal variability. The detection of cool seeps indicates the general occurrence of shallow sub-surface exchanges through this reach that may buffer heating processes. Relatively rapid longitudinal heating (≈3^{o}C) was observed between river miles 54.3 and 53.5. While the factors driving this increase are not directly apparent, the observed pattern suggests the general absence of sub-surface discharge and a possible losing reach. The increase was followed by one of the larger spring/seep complexes, detected at river mile 52.3 (Figure 7).

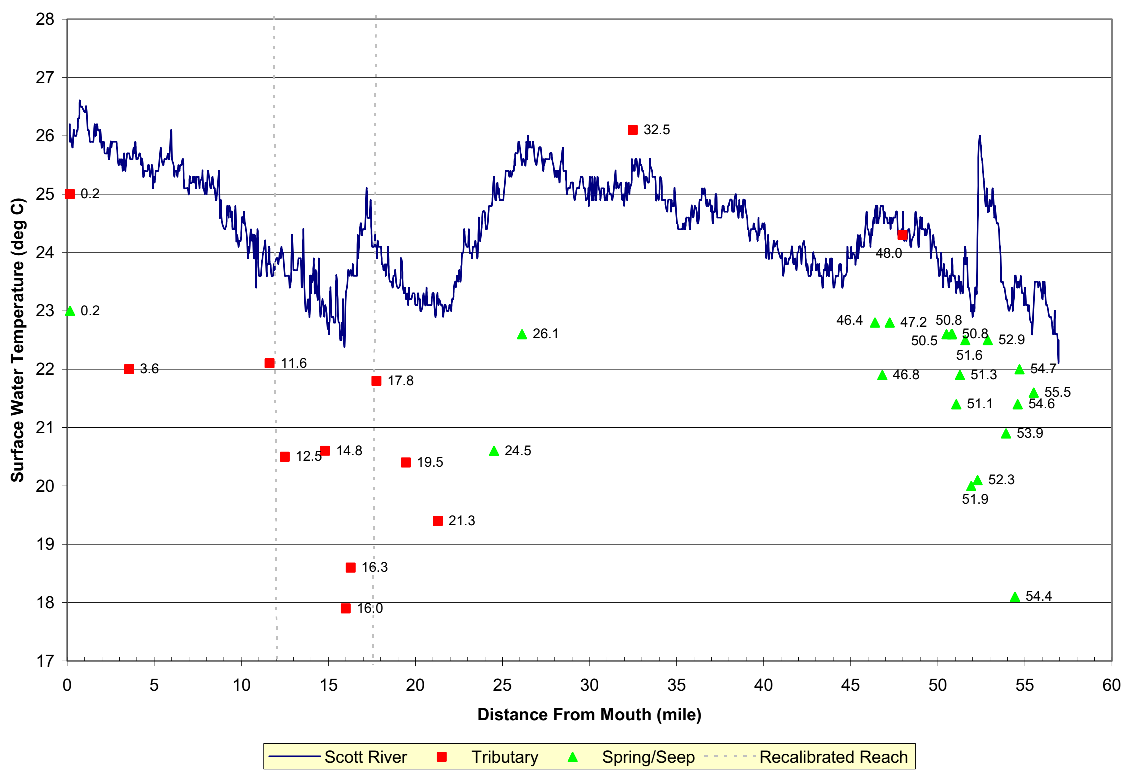


Figure 6 – Median radiant temperature versus river mile for the Scott River measured on July 25, 2003. Surface inflows sampled during the analysis are labeled by river mile.

Table 4 – Tributary temperatures for the Scott River (*LB – left bank, RB – right bank looking downstream*).

Name	Image	km	mile	Tributary °C	Scott River °C	Difference °C
Tributary						
Klamath River (RB)	scott0011	0.2	0.2	25.0	26.2	-1.2
Mill Creek (RB)	scott0127	5.7	3.6	22.0	25.7	-3.7
Tompkins Creek (RB)	scott0419	18.7	11.6	22.1	23.8	-1.7
Unnamed Tributary (RB)	scott0451	20.1	12.5	20.5	23.6	-3.1
Kelsey Creek (LB)	scott0569	23.9	14.8	20.6	23.1	-2.5
Canyon Creek (LB)	scott0615	25.8	16.0	17.9	23.3	-5.4
Boulder Creek (LB)	scott0623	26.2	16.3	18.6	23.7	-5.1
Unnamed Tributary (LB)	scott0676	28.6	17.8	21.8	24.1	-2.3
Isinglass (LB)	scott0739	31.3	19.5	20.4	23.2	-2.8
Unnamed Tributary (LB)	scott0836	34.3	21.3	19.4	23.2	-3.8
Kidder Creek (LB)	scott1282	52.3	32.5	26.1	25.4	0.7
French Creek (LB)	scott1949	77.2	48.0	24.3	24.4	-0.1
Spring/Seep						
Spring (RB)	scott0013	0.3	0.2	23.0	25.9	-2.9
Spring/Seep (LB)	scott0956	39.4	24.5	20.6	25.3	-4.7
Spring/Seep (LB)	scott1018	42.1	26.1	22.6	25.5	-2.9
Spring/Seep (LB)	scott1875	74.7	46.4	22.8	24.7	-1.9
Spring (LB)	scott1897	75.4	46.8	21.9	24.8	-2.9
Spring/Seep (RB)	scott1919	76.0	47.2	22.8	24.6	-1.8
Spring (LB)	scott2047	81.3	50.5	22.6	23.7	-1.1
Spring (RB)	scott2056	81.7	50.8	22.6	23.6	-1.0
Spring/Seep (LB)	scott2058	81.8	50.8	22.6	23.9	-1.3
Spring (RB)	scott2064	82.2	51.1	21.4	23.3	-1.9
Spring (LB)	scott2074	82.5	51.3	21.9	23.4	-1.5
Spring Complex (LB)	scott2088	83.0	51.6	22.5	24.1	-1.6
Spring (LB)	scott2104	83.6	51.9	20.0	23.1	-3.1
Spring (LB)	scott2121	84.2	52.3	20.1	24.4	-4.3
Spring (RB)	scott2145	85.1	52.9	22.5	24.8	-2.3
Spring (RB)	scott2184	86.8	53.9	20.9	23.2	-2.3
Spring (LB)	scott2200	87.6	54.4	18.1	23.6	-5.5
Spring (RB)	scott2206	87.9	54.6	21.4	23.4	-2.0
Spring/Seep (RB)	scott2210	88.0	54.7	22.0	23.4	-1.4
Spring (RB)	scott2246	89.3	55.5	21.6	23.1	-1.5

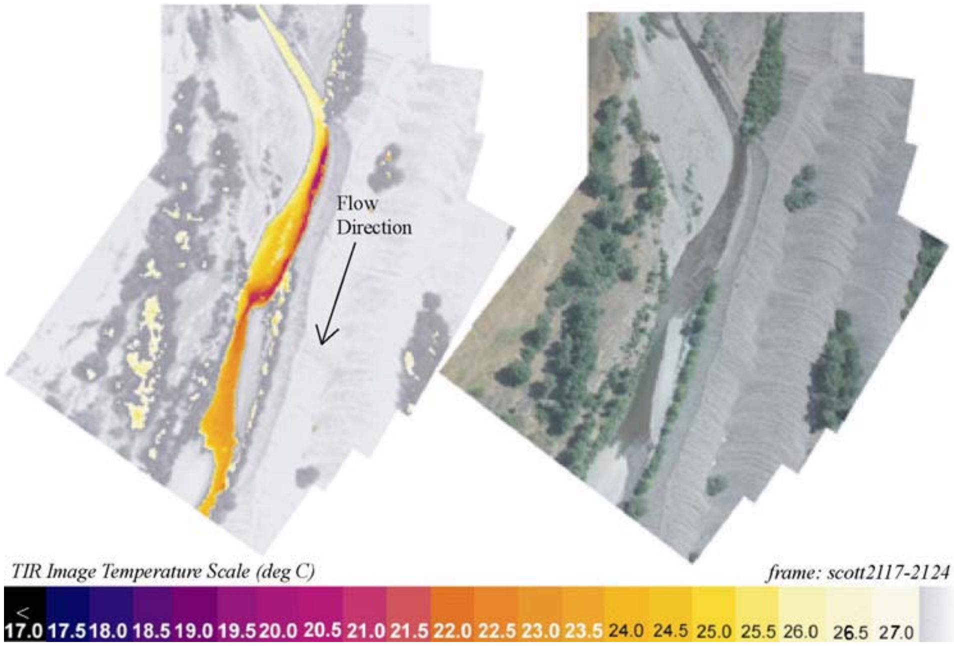


Figure 7 – TIR/color image mosaic showing a sub-surface discharge which appears to emerge from mine tailing along the left bank and decreases water temperatures in the Scott River by ≈3.0°C at river mile 52.3.

Moving downstream of the mine tailings, the longitudinal profile shows a general increase between river miles 52.0 and 46.4 with stream temperatures reaching a local maximum of ≈24.8°C (river mile 46.7). A total of 8 spring/seeps were sampled through this reach. These inflows were observed as seeps emerging from within the channel floodplain and were generally smaller than those observed in the mine tailing reach (Figure 8). Although individually, the seeps appear to have little direct influence on bulk water temperatures, the detection of these areas indicates some level of hyporheic exchange which may collectively buffer stream temperature increases and localized cool water areas at finer scales.

The longitudinal profile shows that stream temperatures decreased by ≈1.5°C between river miles 46.4 and 44.0 before warming steadily downstream to river mile 26.6. This warming trend extends through most of the Scott Valley with a local maximum of ≈25.9°C observed ≈1.2 miles upstream of the mapped Shackelford Creek confluence. Kidder Creek/Big Slough was the only surface inflow detected through this reach and it was slightly warmer than the main stem.

At the time of the flight, stream temperatures decreased by ≈3.0°C between river miles 26.6 and 22.1. This reach generally corresponds to a geomorphic transition from the Scott Valley to a more confined, higher gradient channel that is characteristic of the lower river. Two springs inflows were detected through this reach, which contributed to the cooling trend. Shackelford Creek is a major tributary that joins the Scott River at river mile 24.8. However, Shackelford Creek was not sampled, since no surface water was visible in the creek channel at the confluence of the Scott River.

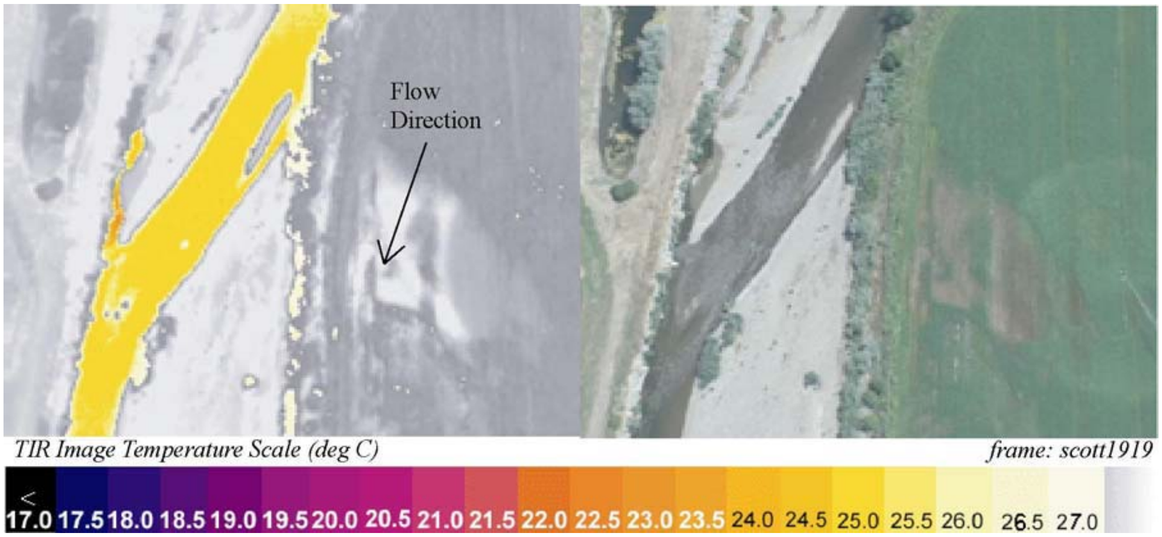


Figure 8 – TIR/color image pair showing an example of a cool water seep detected at river mile 47.2 in the Scott River.

Stream temperatures showed an overall warming trend in the lower 26 river miles. At river miles 16.3 and 16.0 respectively, Boulder Creek and Canyon Creek contributed cooler water to the Scott River and disrupted the general warming trend by lowering main stem temperatures by about 2.0^{o}C to ≈22.6^{o}C. Downstream of Canyon Creek, stream temperatures resumed an overall warming trend reaching ≈26.5^{o}C at its confluence with the Klamath River. Of the 11 tributary inflows that were sampled during the analysis, nine entered the river in the lower 26 miles and all contributed water that was cooler than the main stem.

In order to provide additional context for interpreting spatial temperature patterns, median radiant temperatures were plotted in relation to the in-stream temperatures at the time of the survey and to the recorded daily maximum temperatures (Figure 9). Maximum values were only available for the WS, LLC sensors. As shown, radiant temperatures were consistent (±0.6^{o}C) at the time of the survey. At the uppermost ground truth site, the stream temperature at flight time matched the daily maximum temperature. At the lower three sites (i.e. downstream of river mile 19), the daily maximum temperatures were 1.1-1.4^{o}C warmer than at flight time, but the general shape of the profile remained consistent.

Figure 6 and Figure 9 both delineate the survey segment that was recalibrated to remove an anomalous temperature bias from the TIR images. Both figures illustrate that with the bias removed the spatial temperature patterns were consistent with prevailing trends upstream and downstream of the recalibrated area. Figure 9 additionally shows the location and temperature of in-stream sensors used to assess the radiant temperatures in this reach. Although the upstream end of this bias was well defined, the downstream end was less obvious and caution should be taken when interpreting temperature patterns at the downstream transition (e.g. river miles 12.0 to 12.5).

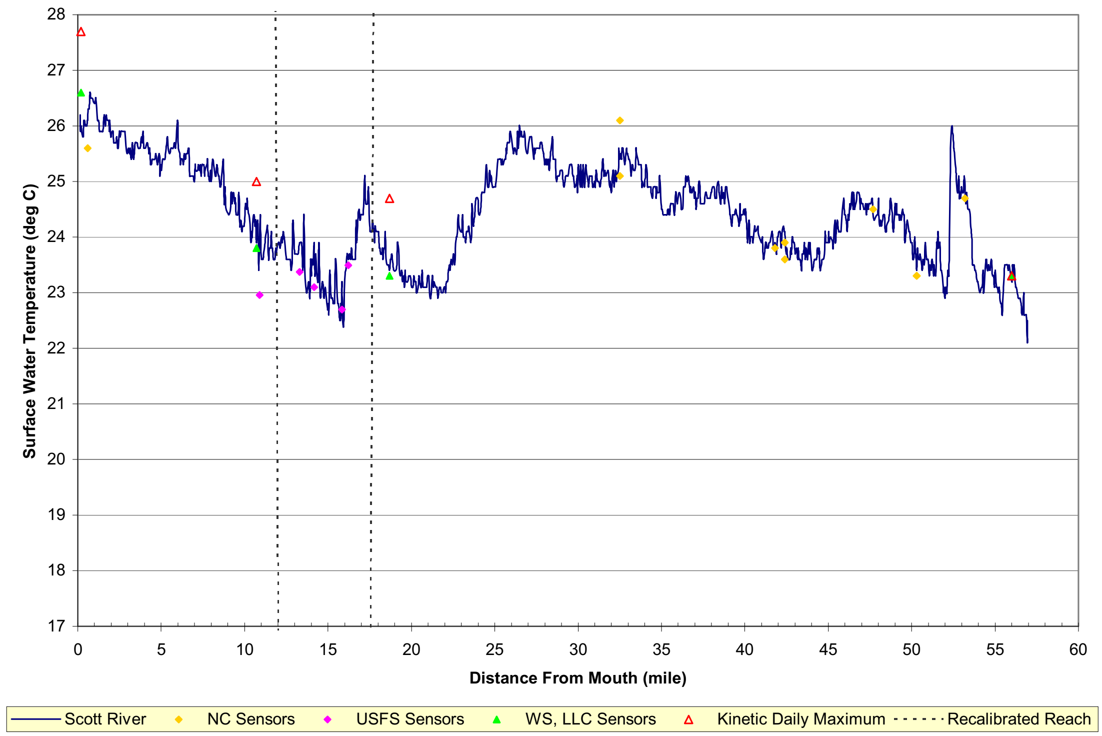


Figure 9 – Median stream temperatures versus river mile for the Scott River. The plot also shows the recorded kinetic temperatures at the time of the survey and the maximum daily stream temperatures at the ground truth locations.

East Fork Scott River

Median channel temperatures derived from the TIR images were plotted versus river mile for the East Fork Scott River (Figure 10). The location and name of sampled tributaries are illustrated on the plot by river mile and are listed in Table 5.

The East Fork Scott River was small (*channel width relative to pixel size*) upstream of the Crater Creek confluence at river mile 14.4 and, in some locations, difficult to detect through the riparian vegetation. The inflow of Crater Creek lowers water temperatures in the East Fork to ≈18.1°C, however stream temperatures warmed rapidly downstream of the confluence reaching ≈23.6°C by river mile 12.6. Over the next 1.6 miles, stream temperatures varied between 23.0°C and 24.4°C. Three springs sampled within this reach contributed to the observed spatial thermal variability, but did not contribute sufficient flow to reduce bulk temperatures in the East Fork below 23.0°C. Downstream of the spring at river mile 10.9, stream temperatures warmed again reaching ≈25.1°C by river mile 10.3. From river mile 10.3 to the South Fork confluence, stream temperatures remained above 24.0°C with only local spatial variability observed along the thermal profile. Four spring/seep discharges and five tributaries were sampled in the lower 10 stream miles which contributed (at least in part) to the observed variability. Big Mill Creek at river mile 2.8 contributed flow that was ≈2.9°C cooler and its contribution lowered East Fork water temperatures by ≈1.5°C.

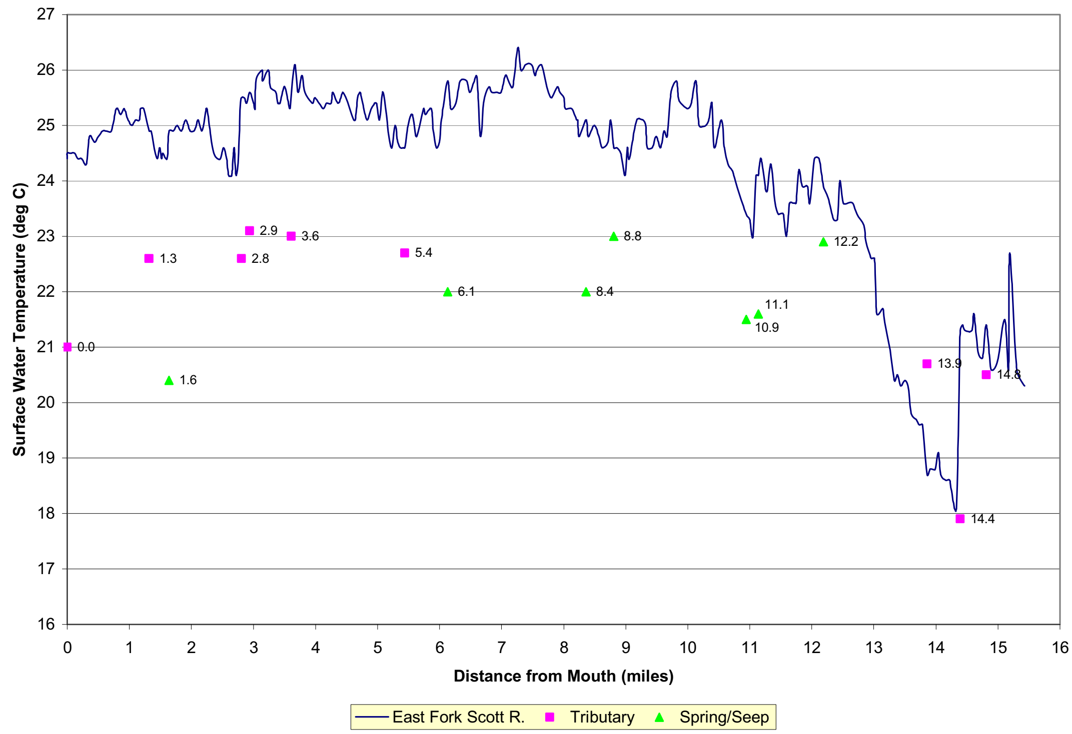


Figure 10 – Median channel temperatures versus river mile for the East Fork Scott River.

Table 5 - Tributary temperatures for the East Fork Scott River.

Name	Image	km	mile	Tributary °C	EF Scott R. °C	Difference °C
Tributary						
South Fork Scott River (LB)	scott2298	0.0	0.0	21.0	24.4	-3.4
Unnamed Tributary (LB)	scott2343	2.1	1.3	22.6	24.9	-2.3
Big Mill Creek (LB)	scott2401	4.5	2.8	22.6	25.5	-2.9
Spring/Seep (LB)	scott2408	4.7	2.9	23.1	25.6	-2.5
Mule Creek (LB)	scott2437	5.8	3.6	23.0	25.6	-2.6
Grouse Creek (LB)	scott2501	8.8	5.4	22.7	24.6	-1.9
Houston Creek (LB)	scott2769	22.3	13.9	20.7	18.7	2.0
Crater Creek (LB)	scott2784	23.2	14.4	17.9	21.3	-3.4
Unnamed Tributary (LB)	scott2799	23.8	14.8	20.5	21.4	-0.9
Spring/Seep						
Spring (LB)	scott2357	2.6	1.6	20.4	24.9	-4.5
Spring (RB)	scott2524	9.9	6.1	22.0	25.8	-3.8
Spring (RB)	scott2594	13.5	8.4	22.0	25.1	-3.1
Spring (LB)	scott2610	14.2	8.8	23.0	24.6	-1.6
Spring (RB)	scott2676	17.6	10.9	21.5	23.4	-1.9
Spring (RB)	scott2683	17.9	11.1	21.6	24.1	-2.5
Spring (LB)	scott2717	19.6	12.2	22.9	23.9	-1.0

(LB – left bank, RB – right bank looking downstream)

South Fork Scott River

Median channel temperatures derived from the TIR images were plotted versus river mile for the East Fork Scott River (Figure 11). The location and name of sampled tributaries are illustrated on the plot by river mile and are listed in Table 6. As shown in the profile, stream temperatures increased steadily gaining 3.8°C over the length of the survey. Five inflows were sampled during the analysis including three springs. At its mouth, the South Fork was observed as a cooling source to the Scott River.

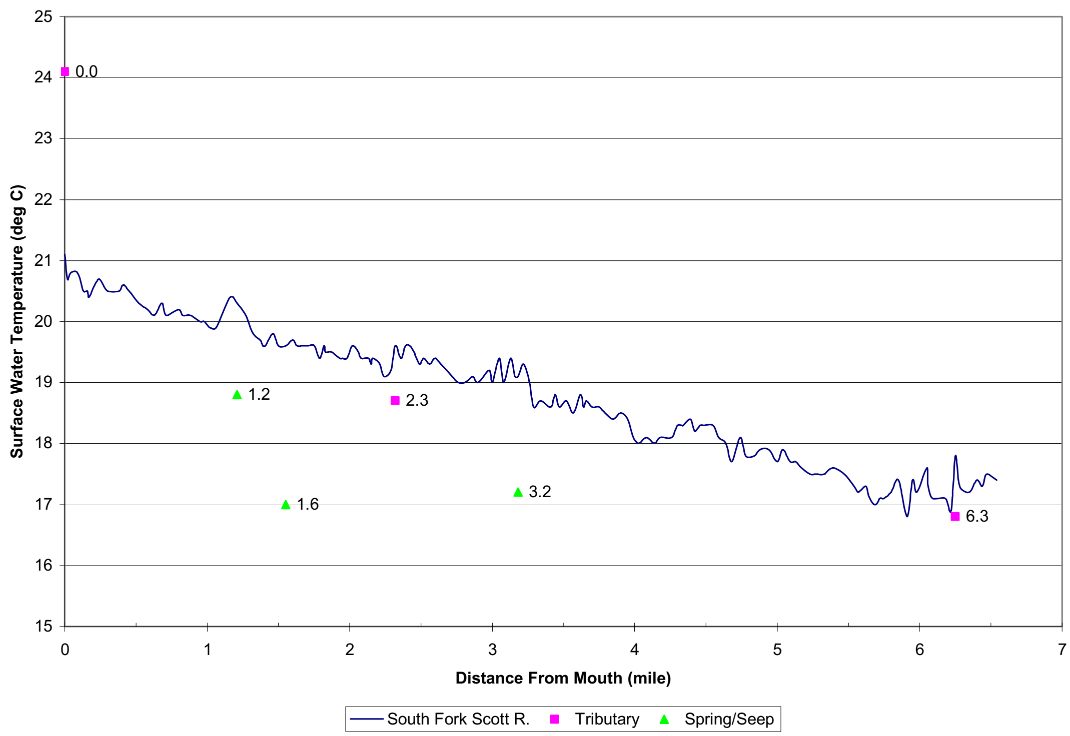


Figure 11 – Median channel temperatures versus river mile for the South Fork Scott River.

Table 6 - Tributary temperatures for the South Fork Scott River

Name	Image	km	mile	Tributary °C	SF Scott R. °C	Difference °C
Tributary						
East Fork Scott R. (RB)	sfs0108	0.0	0.0	24.1	21.1	3.0
Boulder Creek (RB)	sfs0217	3.7	2.3	18.7	19.6	-0.9
Jackson Creek (LB)	sfs0395	10.1	6.3	16.8	17.8	-1.0
Spring						
Spring (LB)	sfs0160	1.9	1.2	18.8	20.3	-1.5
Spring (RB)	sfs0174	2.5	1.6	17.0	19.6	-2.6
Spring (RB)	sfs0258	5.1	3.2	17.2	19.1	-1.9

(*LB – left bank, RB – right bank looking downstream*)

Shackelford Creek

Median channel temperatures were plotted versus river mile for Shackelford Creek (Figure 12). The location and name of sampled tributaries, springs, and other surface inflow are illustrated on the plot by river mile and are listed in Table 7. The Shackelford Creek channel contained no detectable surface water through two segments, which are delineated on the profile. The profile also identifies the locations of flow diversions detected in the imagery.

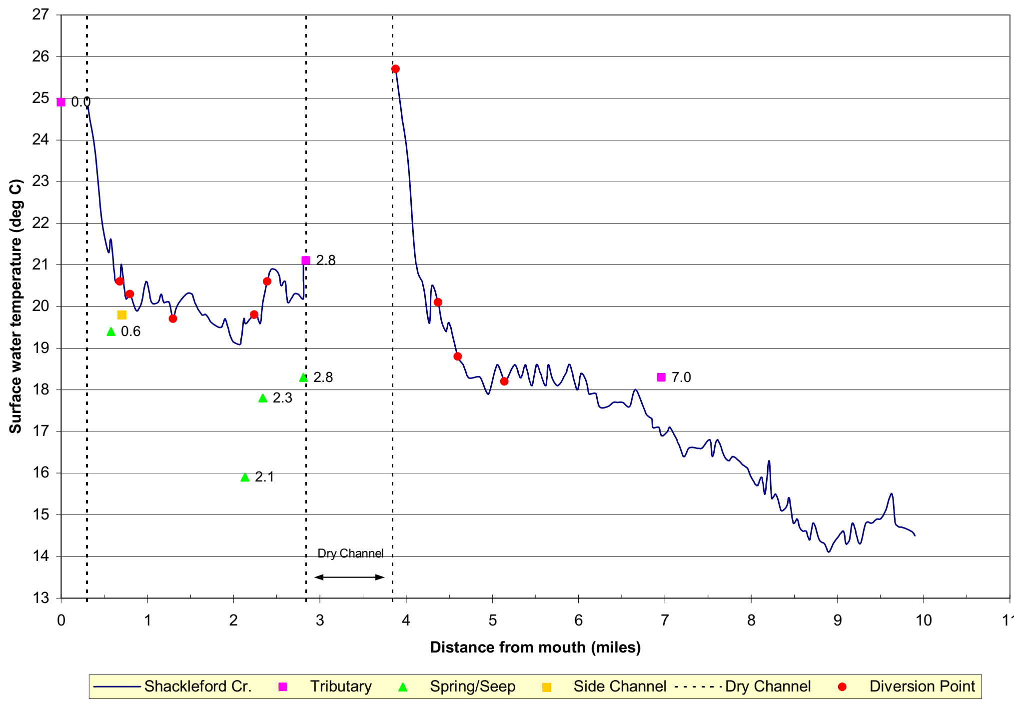


Figure 12 – Median channel temperatures versus river mile for Shackelford Creek. The plot shows the location of surface water inflows labeled by river mile.

Table 7 - Tributary temperatures for Shackelford Creek.

Name	Image	km	mile	Tributary °C	Shackelford Cr. °C	Difference °C
Tributary						
Scott River	shaq0076	0.0	0.0	24.9	n/a	n/a
Mill Cr. (RB)	shaq0285	4.6	2.8	21.1	21.2	-0.1
Big Meadows Cr. (LB)	shaq0537	11.2	7.0	18.3	16.9	1.4
Spring/Seep						
Spring/Seep (RB)	shaq0103	0.9	0.6	19.4	21.6	-2.2
Spring (LB)	shaq0183	3.4	2.1	15.9	19.6	-3.7
Spring (RB)	shaq0196	3.8	2.3	17.8	20.1	-2.3
Seep (LB)	shaq0284	4.5	2.8	18.3	21.1	-2.8
Side Channel						
Side Channel (LB)	shaq0111	1.1	0.7	19.8	21.0	-1.2

(*LB – left bank, RB – right bank looking downstream*)

At the upstream end of the survey (river mile 9.9), water temperatures in Shackelford Creek were cool with measured radiant temperatures ≈14.5°C and remained relatively cool to river mile 9.0 before warming steadily to 18.2°C at river mile 6.0. While the confluences of several small tributaries were detected through this reach, only Big Meadows Creek at river mile 7.0 was visible enough to obtain a radiant temperature sample. Water temperatures remained ≈18.2°C over the next mile before exhibiting rapid longitudinal heating from river mile 5.0 to river mile 3.9. This segment of rapid longitudinal heating corresponds spatially to the point where Shackelford Creek transitions from its canyon to the Quartz Valley. In addition, four diversion dams were identified between river miles 5.1 and 3.9. Reduced flow volumes (from the diversions) combined with decreased stream gradient (*and hence velocity*) were seemingly the overriding factors driving the rapid longitudinal heating. The diversion at river mile 3.9 removes most of the remaining surface flow and the channel goes dry just downstream.

Downstream of river mile 3.9, the Shackelford Creek channel remains dry to river mile 2.8 where the inflow from Mill Creek reintroduces surface flow. At the confluence, radiant water temperatures in Mill Creek were approximately ≈21.1°C. Several small cool water seeps were detected near the confluence suggesting a level of shallow, sub-surface exchange (Figure 13). The in-channel seeps combined with a larger spring inflow at river mile 2.1 (Figure 14) contributing to the slight cooling trend observed between river miles 2.8 and 2.1. Rapid longitudinal heating was observed from river mile 0.9 to where the channel was dry at river mile 0.3. A series of five flow diversions were detected between river miles 2.5 and 0.7. As with the reach upstream of Mill Creek, the rapid longitudinal heating in the lower stream mile was presumably due to the reduced flow volumes.

Recall that the ground truth process revealed that radiant temperatures were approximately 1.1°C cooler than kinetic temperatures measured at river mile 9.1 (Table 3). In order to assess how this difference may impact interpretation of the spatial temperature patterns, the kinetic temperatures at flight time were plotted in relation to the longitudinal temperature profile (Figure 15). The plot shows that, while the radiant temperature profile may show a slightly higher magnitude, both the radiant and kinetic temperatures show warming between the two ground truth points. Available information was not sufficient to determine if the in-stream sensor or the radiant temperatures provide a truer representation of bulk temperatures at this location.

Figure 13 – TIR/color video image showing the confluence of Mill Creek (21.1°C) and the dry channel of Shackelford Creek at river mile 2.8. Small cool water seeps are visible in the TIR images suggesting at least some level of sub-surface exchange in the channel.

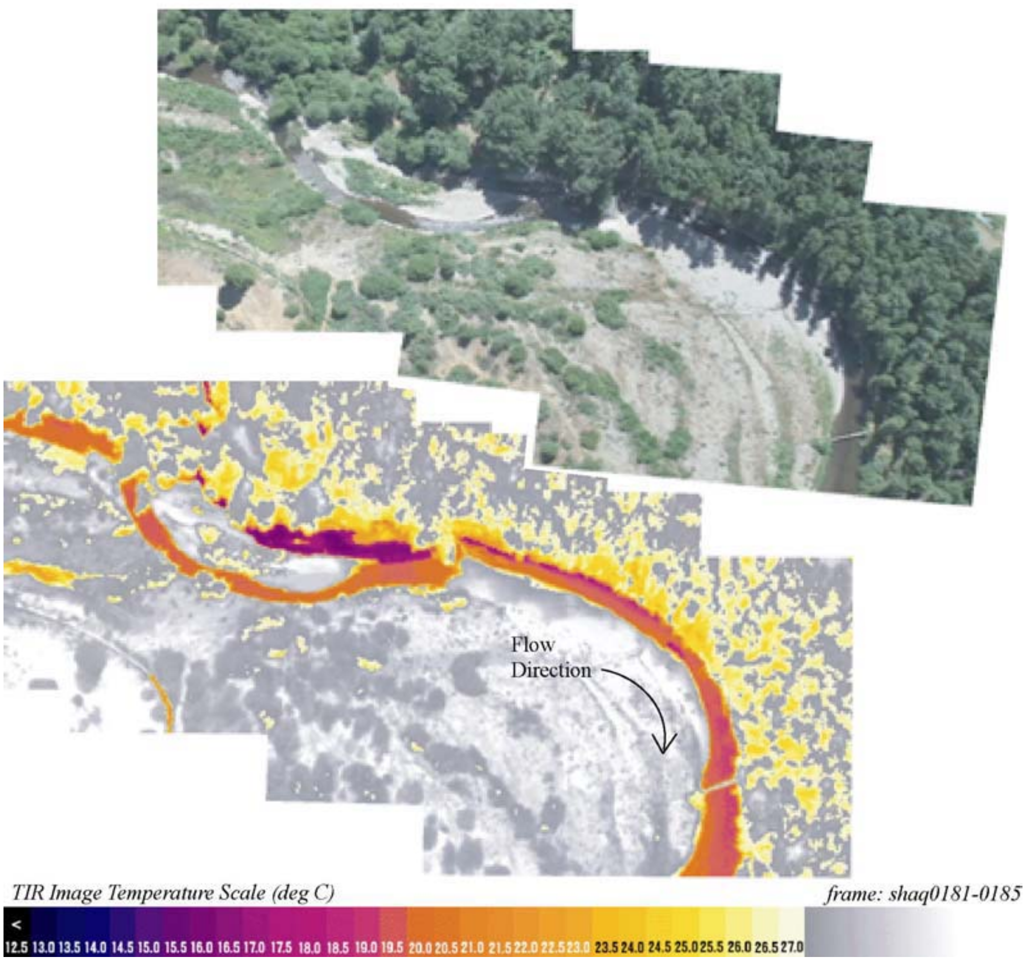


Figure 14 – TIR/color video image showing a spring inflow along the left bank of Shackelford Creek at river mile 2.1.

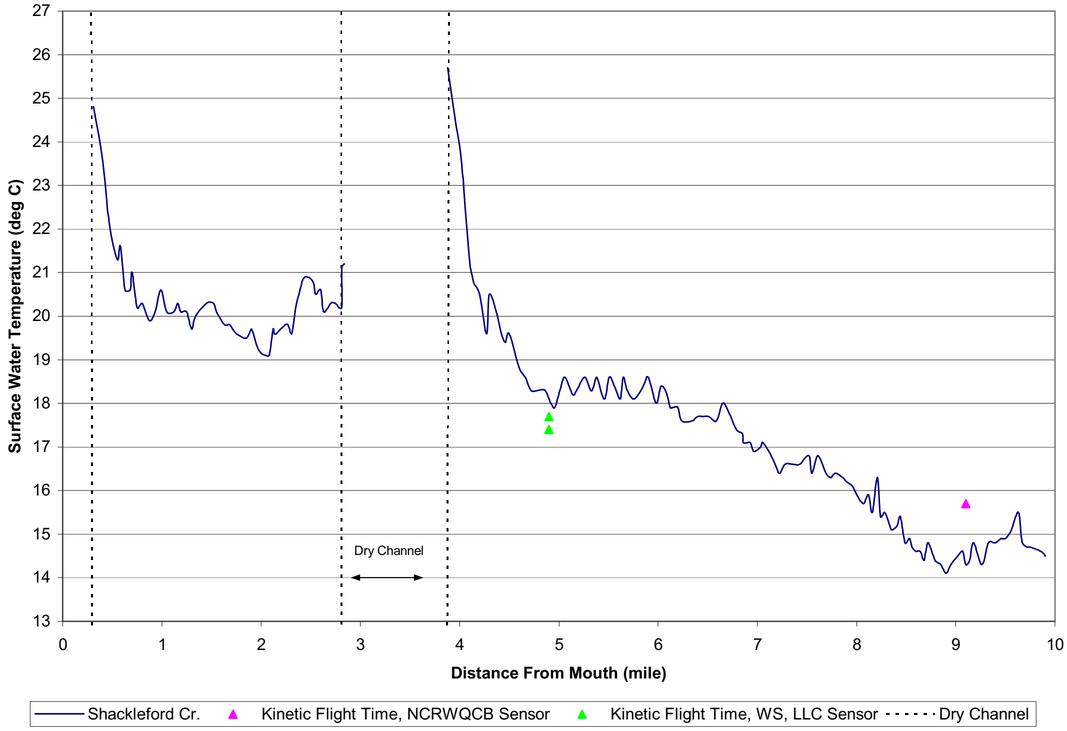


Figure 15 – Median channel temperatures versus river mile for Shackelford Creek. The plot also shows measured in-stream temperatures at the time of the flight.

Kidder Creek/Big Slough

Kidder Creek was surveyed from its mouth to the confluence with Big Slough and then continued on Big Slough to its confluence with Patterson Creek. Median channel temperatures were plotted versus river mile for both survey segments (Figure 16). The location and name of sampled tributaries are illustrated on the plot by river mile and are listed in Table 8.

Surface temperatures were above 25.4^{o}C over the full 3.6 miles of Kidder Creek and exhibited a slight warming trend (+1.2^{o}C) in the downstream direction. Spatial temperature patterns showed relatively little local thermal variability (*outside of characteristic noise levels*) and no distinct surface inflows were sampled during the analysis.

Big Slough similarly exhibited warm radiant temperatures, but showed considerably more spatial thermal variability upstream of river mile 6.0. Upstream of river mile 6.0, radiant water temperatures in Big Slough showed more dramatic swings with a maximum surface temperature of 33.0^{o}C recorded at river mile 6.9. Interpretation of the imagery indicated that areas of Big Slough were thermally stratified. The stratified areas typically occurred behind impoundments and on wide stream bends and can be identified by warmer, but localized (often unstable), surface temperatures. Images with thermally stratified reaches are identified in the associated database. Stability in surface temperatures downstream of river mile 6.0 suggests a possible change in the conditions (i.e. mixing rates, flow levels) that allowed the formation of stratified areas.

Kidder Creek and Big Slough meandered through the relatively low gradient valley and had multiple channels (both active and inactive) over much of the surveyed length. Consequently, side channels and off channel features were often outside the image footprint. In order to capture these features, the Kidder Creek and Big Slough survey was repeated at a higher altitude (i.e. wider image footprint). The higher altitude flight was not sampled for temperature, but the images are included in the database and provide an addition spatial reference for assessing spatial temperature patterns in Kidder Creek and Big Slough.

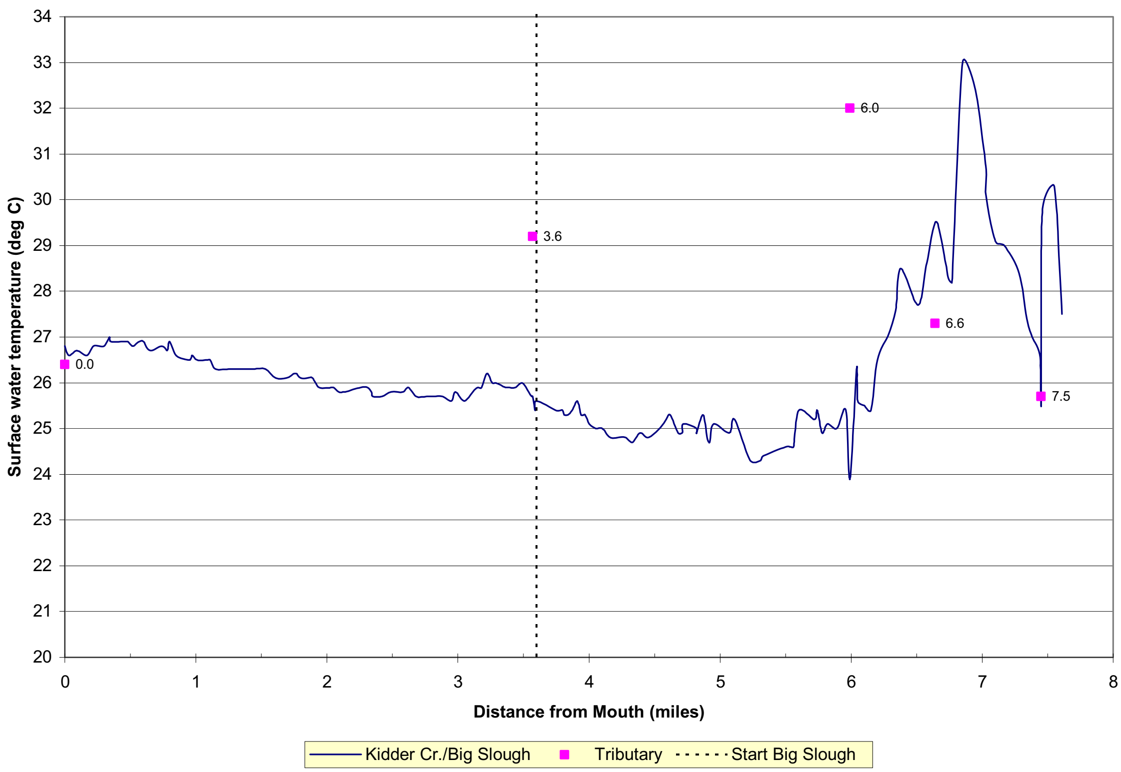


Figure 16 – Median channel temperatures versus river mile for Kidder Creek and Big Slough. The plot shows the location of surface water inflows labeled by river mile.

Table 8 - Tributary temperatures for Kidder Creek and Big Slough.

Tributary Name	Image	km	mile	Tributary °C	Kidder Cr. Big Slough °C	Difference °C
Scott River (RB)	kidd0007	0.0	0.0	26.4	26.8	-0.4
Kidder Creek (LB)	kidd0151	5.8	3.6	29.2	25.7	3.5
Unnamed Tributary (LB)	kidd0244	9.6	6.0	32.0	23.9	8.1
Unnamed Tributary (LB)	kidd0266	10.7	6.6	27.3	29.5	-2.2
Unnamed Tributary (LB)	kidd0297	12.0	7.5	25.7	25.6	0.1

LB = left bank; RB = right bank.

Discussion

Airborne thermal infrared remote sensing has provided a measure of spatial temperature patterns for selected streams in the Scott River Basin. The results showed temperatures in the Scott River varied at different spatial scales along the stream gradient. At the upstream end of the survey, spatial temperature patterns were characterized by springs and seeps, which were detected at numerous locations within the mine tailings. Temperatures downstream exhibited reach scale patterns of both warming and cooling. This report provides some hypotheses and observations on the observed reach scale patterns, but more in-depth analysis is needed to develop a complete picture of thermal processes in the basin.

Shackelford Creek and the South and East Fork Scott Rivers each showed unique spatial temperature patterns. The TIR and associated true color images provide a basis for further analysis of channel conditions and temperature dynamics in these streams. Shackelford Creek in particular showed a wide range of temperatures over the 10-mile survey extent.

Shasta River Sub-Basin

Overview

TIR remote sensing surveys in the Shasta River Sub-Basin were flown on July 26-27, 2003 (Figure 17). Table 9 summarizes the survey times, extents, and image resolutions for each surveyed stream. The Shasta River was surveyed at a flight altitude that provided a wider image footprint to better capture the wider channel widths and side/off channel features characteristic of the main stem Tributaries were surveyed at lower flight altitudes to provide slightly higher spatial resolution and better visibility through riparian vegetation.

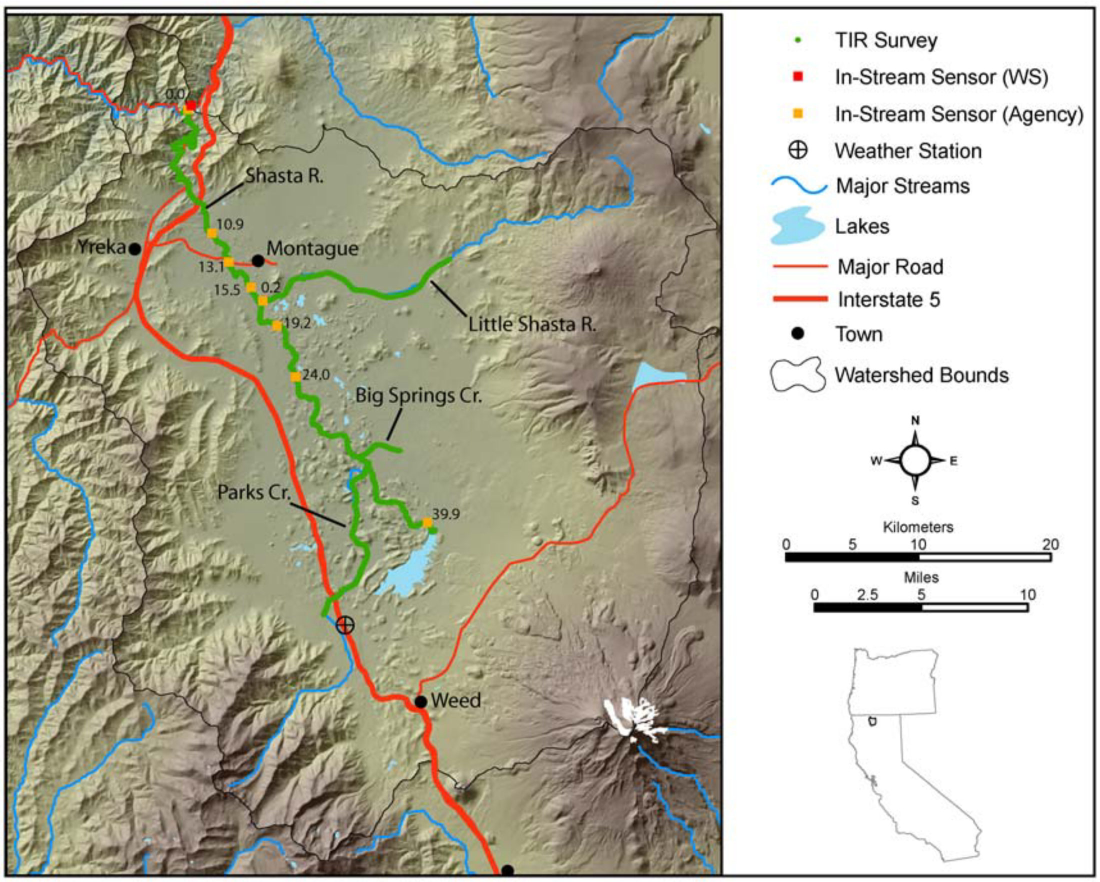


Figure 17 – Map showing the streams surveyed in the Shasta River Sub-Basin using TIR and color video on July 26-27, 2003. The map also shows the location of the in-stream sensors used to ground truth the imagery, labeled by river mile.

Table 9 – Summary of river segments surveyed with TIR and color video in the Shasta River Sub-Basin on July 26-27, 2003.

Stream	Survey Date	Survey Time (24 hr)	Survey Extent	River Miles	Image Width Meter (ft)	TIR Image Pixel Size Meter (ft)
Shasta R.	26-Jul	15:40-16:52	Mouth to Dwinnel Dam	40.5	150 (494)	0.48 (1.54)
Little Shasta R.	27-Jul	13:39-13:59	Mouth to Main Canal	12.6	150 (494)	0.48 (1.54)
Parks Cr.	27-Jul	14:06-14:27	Mouth to I-5 Bridge	10.0	128 (423)	0.41 (1.32)
Big Spring Cr.	27-Jul	14:33-14:36	Mouth to Big Springs Lake	2.6	171 (564)	0.54 (1.76)

Results

Weather Conditions

Weather conditions for the times of the surveys are summarized in Table 2.

Thermal Accuracy

Table 10 summarizes the differences between the kinetic temperatures recorded by the in-stream data loggers and the radiant temperatures derived from the TIR images. On average, radiant temperatures were within the desired accuracy (< 0.5^{o}C) for streams with in-stream monitoring sites. Due to access limitations, no in-stream sensors were deployed in Big Springs Creek or Parks Creek. As a result, no data are available to assess the radiant temperature accuracy on these streams. However, flights on these streams occurred within ½ hour of the Little Shasta survey. Due to the proximity of time and distance, the calibration parameters used to correct the TIR images on the Little Shasta River were considered applicable to Big Springs and Parks Creek.

On the Shasta River, radiant temperatures were ≈0.9^{o}C warmer than measured in-stream temperatures at the upper-most monitoring site (river mile 39.9). The factors contributing to this difference were not apparent from the imagery. At the three closest downstream monitoring sites (i.e. river miles 15.5, 19.2, and 24.0), radiant temperatures were slightly cooler than kinetic. The impacts, if any, which these differences have on observed spatial temperature patterns, are addressed during the discussion of the longitudinal profiles.

Table 10 – Comparison of ground-truth water temperatures (Kinetic) with the radiant temperatures for streams in the Shasta River Sub-Basin.

Image	Time 24 hr.	River Mile	Kinetic °C	Radiant °C	Difference °C
Shasta River (average 0.4)					
shas0041	15:41	0.0	26.1	26.6	-0.5
shas0622	16:01	10.9	24.2	24.2	0
shas0795	16:07	13.1	23.7	23.7	0
shas0925	16:11	15.5	23.6	23.2	0.4
shas1105	16:17	19.2	23.2	22.8	0.4
shas1315	16:24	24.0	23.3	22.7	0.6
shas2052	16:51	39.9	20.9	21.8	-0.9
Little Shasta River (average 0.4)					
lshasta0045	13:33	n/a	25.4	25.9	0.5
lshasta0052	13:39	n/a	23.0	22.6	-0.4
lshasta0071	13:40	0.24	27.4	27.6	0.2

Temporal Differences

Figure 18 shows an in-stream temperature variation at the mouth of the Shasta River for the date of the Shasta River survey. The figure is intended to provide a sense of how stream temperatures changed during the time frame of the flight. The survey began prior to, but continued into, the time of the daily maximum stream temperature of 26.4°C, which occurred from 16:00 to 18:10. Temporal data for other monitoring sites and streams were only available for the time of the survey.

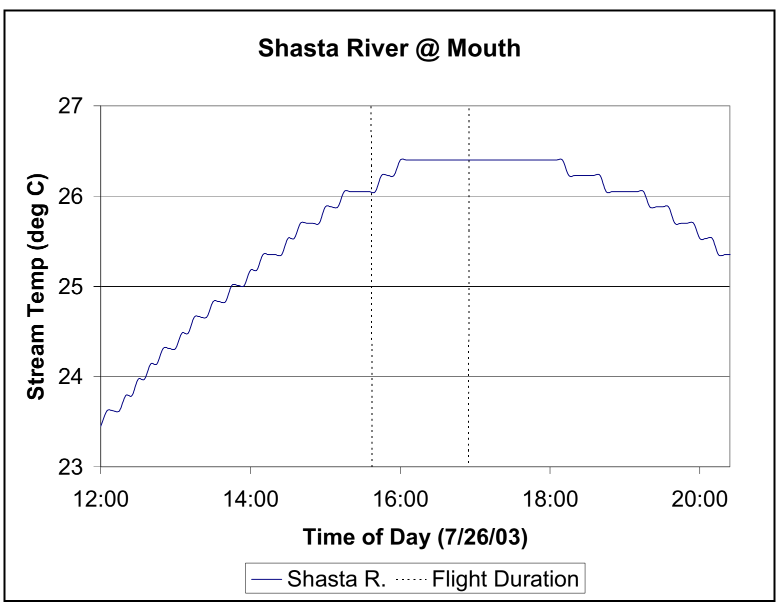


Figure 18 – Stream temperature variation and time of TIR remote sensing flight at a single location on the Shasta River Survey on 7/26, 2003.

Shasta River

Median radiant temperatures were plotted versus river mile for the Shasta River (Figure 19). The plot illustrates the location of surface water inflows (tributaries, springs, seeps) labeled by river mile. The corresponding name and temperature of the surface inflows are summarized in Table 11. Due to the length of the survey, the median radiant temperatures were also plotted in relation to the kinetic temperatures at the time of the survey (Figure 20). This plot provides additional context for examining the differences between kinetic and radiant temperatures and for understanding how these differences may alter the interpretation of the observed spatial temperature patterns.

Figure 19 – Median radiant temperature versus river mile for the Shasta River measured on July 26, 2003. Surface inflows sampled during the analysis are labeled by river mile and listed in Table 11.

Table 11 – Tributary temperatures for the Shasta River.

Name	Image	km	mile	Tributary °C	Shasta R. °C	Difference °C
Tributary						
Klamath R (RB)	shas0036	0.0	0.0	25.8	26.5	-0.7
Yreka Cr (LB)	shas0477	12.5	7.8	23.4	24.2	-0.8
Oregon Slough (RB)	shas0688	18.9	11.7	26.6	24.2	2.4
Little Shasta R (RB)	shas0968	26.2	16.3	25.9	23.1	2.8
Unnamed Tributary (LB)	shas1182	34.0	21.1	21.8	23.4	-1.6
Willow Cr (LB)	shas1354	40.6	25.2	26.1	22.3	3.8
Big Springs Cr (RB)	shas1759	54.3	33.7	21.7	21.9	-0.2
Hole in The Ground Cr (RB)	shas1804	55.9	34.7	17.3	21.6	-4.3
Parks Cr (LB)	shas1807	56.0	34.8	23.5	21.6	1.9
Unnamed (RB)	shas2079	65.1	40.5	22.4	21.7	0.7
Spring						
Spring (LB)	shas2029	63.3	39.4	14.8	22.5	-7.7

(*LB – left bank, RB – right bank looking downstream*).

Figure 20 – Median stream temperatures versus river mile for the Shasta River. The plot also shows the kinetic temperatures at the time of the survey and the maximum daily stream temperature at the ground truth locations.

At the upstream end of the survey, water temperatures in the Shasta River were shaped in part by surface inflows. At river mile 39.4, a spring lowered stream temperatures in the Shasta River from 22.5°C to 19.3°C. Stream temperatures warmed rapidly downstream of the spring before exhibiting an overall cooling trend of 4.0°C between river miles 37.2 and 35.8. The source of the apparent cooling was not directly apparent from the imagery. However, the sharp decrease in water temperatures over a relatively short distance suggests a cooling influence. Moving downstream, Parks Creek was a source of warm water at river mile 34.8 and increased main stem temperatures by 1.7°C. The warm inflow came from the southern channel of Parks Creek while the northern channel did not contain enough flow to obtain a radiant temperature sample.

Downstream of Parks Creek, water temperatures in the Shasta River showed definitive reach scale thermal patterns, but no longer exhibited dramatic response to detected inflows (i.e. tributaries, springs, etc). Local variability along the longitudinal profile was generally characteristic of the ±0.5°C noise common to TIR remote sensing. A slight cooling trend was observed between river mile 33.7 and 30.3. The general cooling trend was observed downstream of the confluence with Big Spring Creek - although radiant temperatures at the mouth of Big Spring Creek did not vary significantly from those in the Shasta River. Longitudinal heating was observed between river miles 30.3 and 23.5 and again between river mile 16.4 and the Klamath River confluence. A consistent water temperature of 23.0oC was observed between river miles 23.5 and 16.4 Given the warm air temperatures (≈36oC) and general exposure of the stream surface to direct solar loading, a constant water temperatures or cooling through a given stream segment suggests a buffering or cooling source within that reach.

Little Shasta River

Median channel temperatures derived from the TIR images were plotted versus river mile for the Little Shasta River (Figure 21). Visual inspection of the topographic base maps (DRGs) showed numerous mapped surface inflows throughout the surveyed segment. However, analysis of the imagery showed these inflows contained little or no surface water at the time of the survey. Consequently, no surface inflows (tributaries, springs, seeps, irrigation returns, etc.) were sampled. Similarly there was very little visible surface flow in the Little Shasta River throughout much of the survey extent. Discontinuities in the amount of visible surface water naturally resulted in irregular sampling intervals. This was especially true upstream of river mile 6.0.

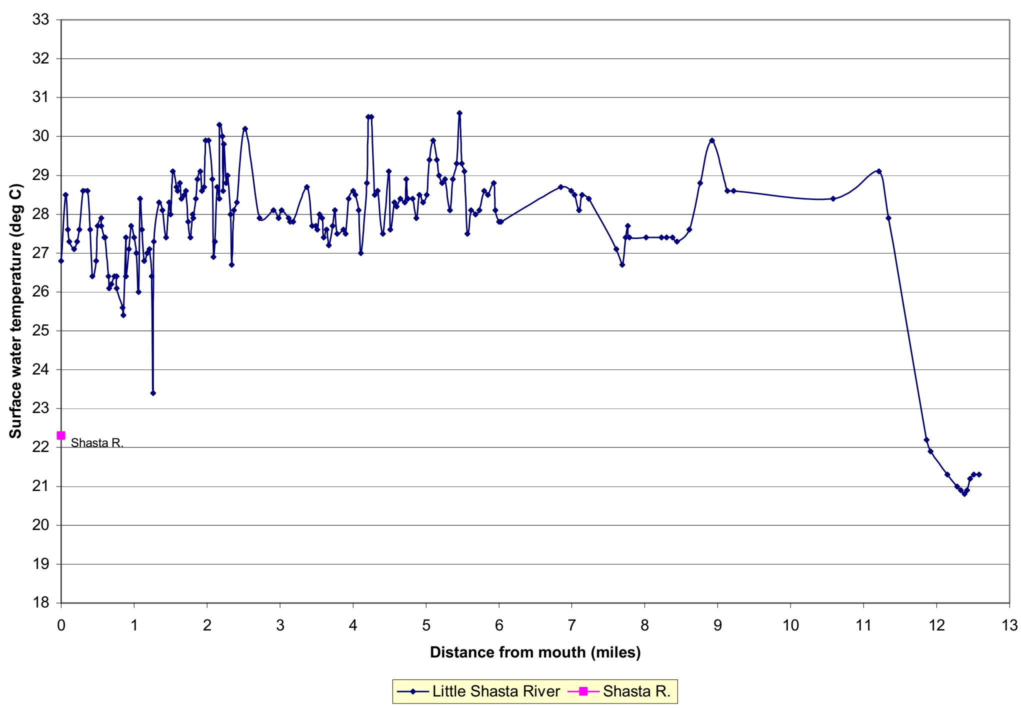


Figure 21 – Median channel temperatures versus river mile for the Little Shasta River (7/27/03)

The average median water temperature in the Little Shasta River was 28.0°C between river mile 11.3 and the mouth. Radiant temperatures varied considerably between sample points with apparent changes of up to 3.0°C observed within 0.2 river miles. This level of variability is not unusual for streams with very low surface flows because temperatures generally respond dramatically to relatively small inputs. However, on the Little Shasta River, the TIR images revealed very few indicators of sub-surface exchanges (seeps or springs) or obvious surface inputs that may result in a high degree of local thermal variability. Under very low flow or poorly mixed conditions, variability in surface temperature may also be the result of differential surface heating and/or locally stratified segments. These factors probably contributed significantly to the observed spatial temperature patterns observed on the Little Shasta River (Figure 22).

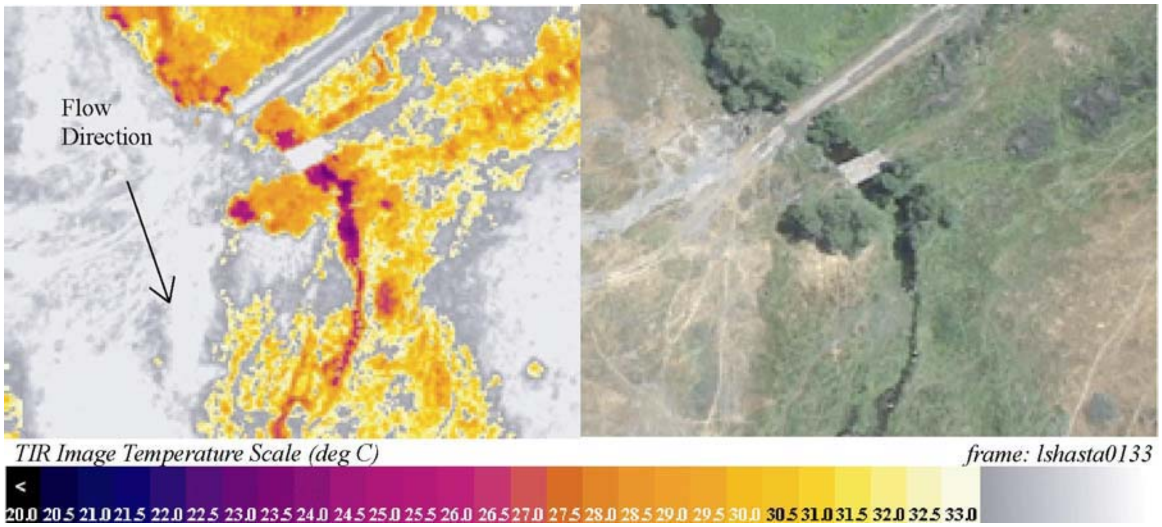


Figure 22 – TIR/color video image showing an example of the localized surface temperature variability on Little Shasta River at river mile 1.3. Median surface temperature upstream of the bridge were 25.7°C while surface temperatures of 23.3°C were recorded in the shaded area downstream of the bridge. The difference suggest differential surface heating in the shaded areas or thermal stratification upstream of the bridge.

Parks Creek

Visual inspection of the topographic base map shows that Parks Creek is characterized by multiple water withdraws, surface returns, and tributary inflows as it progresses through the Shasta Valley East of Interstate 5. At the confluence of the Shasta River, the survey started along the Northern channel of Parks Creek and continued along the mapped line for approximately 10 stream miles past the Interstate 5 crossing. Along this route, the airborne imagery also showed the interconnectedness and variability of the surface hydrology associated with Parks Creek (Figure 23). As with the other surveys, median channel temperatures derived from the TIR images were plotted versus river mile for Parks Creek (Figure 24). The location of sampled tributaries and other surface inflows are illustrated on the plot by river mile and are listed in Table 12.

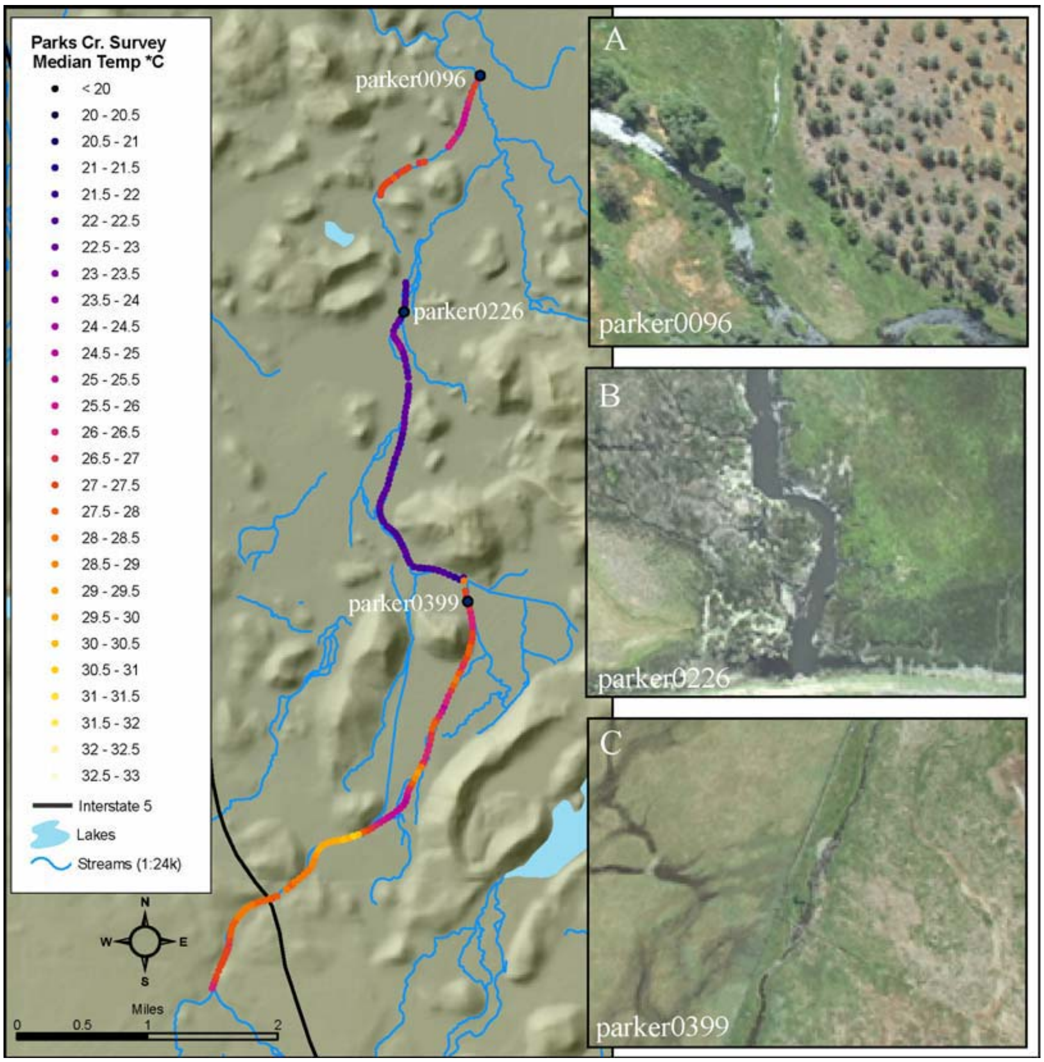


Figure 23 – A series of three true color video images illustrating changes in channel characteristics over the 10-mile survey length of Parks Creek. Image A shows the mouth of Parks Creek, illustrating the narrow channel width compared with the Shasta River. Image B shows Parks Creek at river mile 2.6, with a wider channel than is seen upstream at river mile 5.7 (Image C).

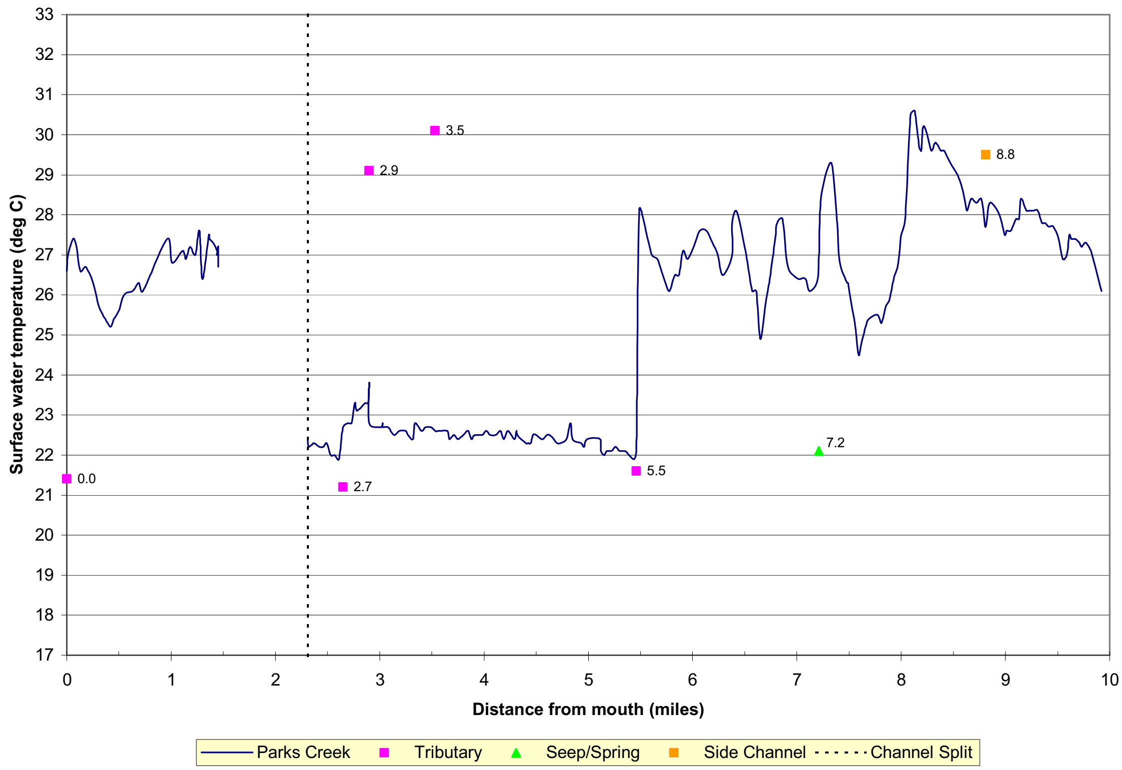


Figure 24 – Median channel temperatures versus river mile for Parks Creek.

Table 12 - Tributary temperatures for Parks Creek.

Name	Image	km	mile	Tributary °C	Parks Cr. °C	Difference °C
Tributary						
Shasta River (RB)	parker0096	0.0	0.0	21.4	26.6	-5.2
Unnamed (RB)	parker0230	4.3	2.7	21.2	22.7	-1.5
Unnamed (LB)	parker0243	4.7	2.9	29.1	23.8	5.3
Unnamed (LB)	parker0270	5.7	3.5	30.1	22.6	7.5
Unnamed (RB)	parker0390	8.8	5.5	21.6	22.1	-0.5
Seep/Spring						
Seep (LB)	parker0461	11.6	7.2	22.1	26.8	-4.7
Side Channel						
Side Channel (RB)	parker0533	14.2	8.8	29.5	27.7	1.8

(*LB – left bank, RB – right bank looking downstream*)

Between river miles 9.9 and 5.5, water temperatures were generally warm, ranging from 24.6°C to 30.6°C. Parks Creek appeared to have very little surface flow through this reach and water temperatures appeared to respond dramatically to any mass transfers (inputs or losses). For example, a decrease in surface temperatures of ≈3.2°C was observed immediately downstream of an apparent cool water seep at river mile 7.2. The seep contributed cooler water locally to the stream, but water temperatures heated rapidly again in the absence of the cooling process. At river mile 5.5, Parks Creek is joined by a canal carrying cooler water (≈21.6°C). The inflow of the canal dictated the temperature of Parks Creek. In contrast to the upper reach, stream temperatures showed little local variability from river mile 5.5 to river mile 2.9, with an overall increase of only 0.9°C. The stream channel had almost no riparian vegetation through this reach and the overall lack of heating through this reach suggests other possible buffering sources. Downstream of rive mile 2.4, Parks Creek splits into two channels. In the Northern channel (*the one followed by the survey*) the stream disperses into several channels for the first 0.9 miles with no clearly discernable main channel. While the channels were visible in the TIR imagery, the thermal signature appeared due to saturated vegetation with no detectable surface water. Consequently, no radiant temperature samples could be acquired in this reach.

Big Springs Creek

Median channel temperatures were plotted versus river mile for Big Springs Creek (Figure 25). The location of sampled tributaries, springs, and other surface inflow are illustrated on the plot by river mile and are listed in Table 13.

The imagery showed considerable vegetation in the stream channel over the full extent, but surface water was clearly visible. Although the in-channel vegetation created interesting thermal patterns in the TIR images, radiant temperatures were only sampled from the surface water. True to its name, Big Springs Creek contained four springs detected within 0.4 miles downstream of the outlet of Big Springs Lake. The spring influences reduced water temperatures in Big Springs Creek to ≈15.6°C at river mile 1.9. Downstream of the springs, temperatures increased rapidly reaching 21.0°C at river mile 0.7 before remaining consistent (21.0°C; ±0.5°C) to the confluence of the Shasta River.

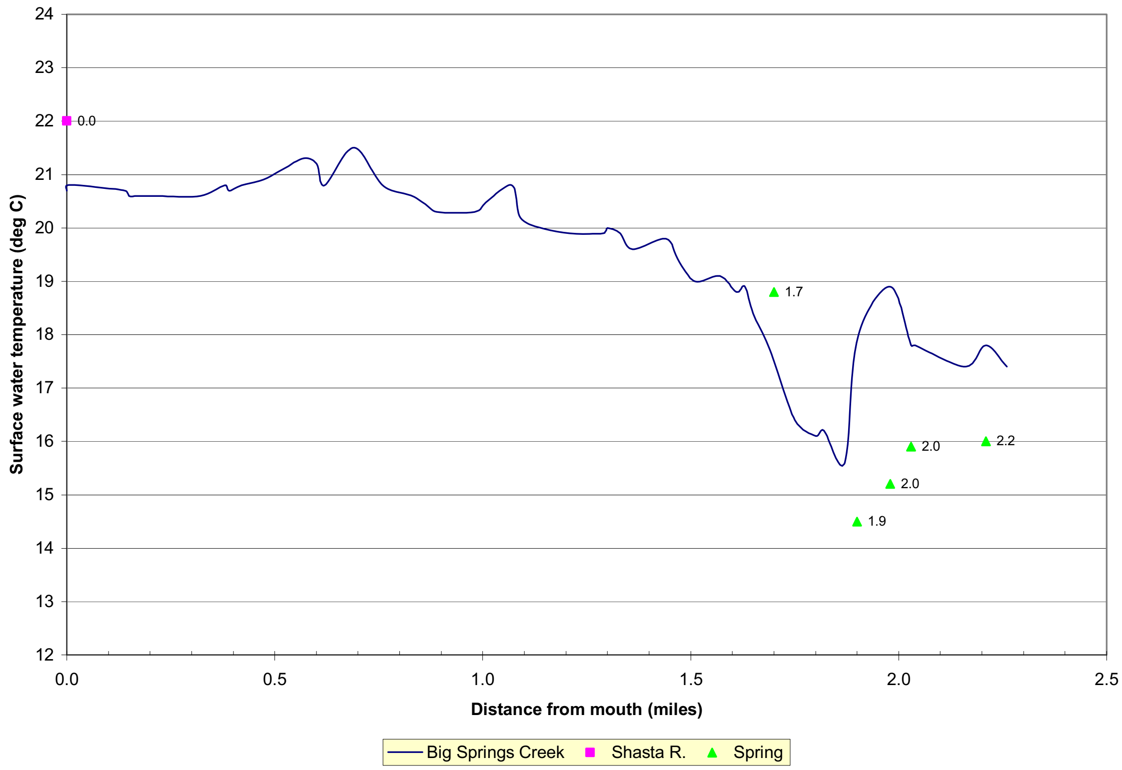


Figure 25 – Median channel temperatures versus river mile for Big Springs Creek. The plot shows the location of surface water inflows labeled by river mile.

Table 13 - Tributary temperatures for Big Springs Creek (7/27/03).

Name	Image	km	mile	Shasta R. °C	Tributary °C	Difference °C
Shasta River (LB)	big0007	0.0	0.0	22.0	20.7	1.3
Spring						
Spring (LB)	big0075	2.7	1.7	18.8	17.5	1.3
Spring (RB)	big0084	3.1	1.9	14.5	17.9	-3.4
Spring (RB)	big0086	3.2	2.0	15.2	18.9	-3.7
Spring (LB)	big0088	3.3	2.0	15.9	17.8	-1.9
Spring (RB)	big0093	3.6	2.2	16.0	17.8	-1.8

(*LB – left bank, RB – right bank looking downstream*)

Discussion

Thermal infrared remote sensing surveys were successfully conducted on selected streams in the Shasta River Basin. Longitudinal temperature profiles were developed for each surveyed stream that illustrates broad scale spatial temperature patterns. Downstream of the Parks Creek confluence, the shape of the Shasta River profile is defined by variations in longitudinal heating rates with one reach showing little or no heating and another showing a general cooling trend. More comprehensive analysis is required to determine the combination of factors contributing to the variations in heating (or cooling) rates along the stream gradient.

Analysis of the imagery showed that Parks Creek and the Little Shasta River had relatively little surface water. The spatial temperature patterns of both streams were generally characteristic of low volume streams with a high degree of local spatial variability in reaches with little apparent surface water. In Parks Creek, the amount of visible surface water varied longitudinally based primarily on mass transfers in the channel, while the Little Shasta River had very little visible surface water throughout the full survey extent. On these streams, further analysis may put a greater emphasis on the true color images for assessing channel and surface water characteristics.

Follow-on

This report presents the longitudinal temperature profiles and provides some hypotheses on the processes influencing spatial temperature patterns. Theses hypotheses are considered a starting point for more rigorous spatial analysis and fieldwork. Individual TIR and color video image frames are organized in an ArcView database to allow viewing of the temperature patterns and channel characteristics at finer spatial scales. The following is a list of potential uses for these data in follow-on analysis (based on Faux et. al. 2001 and Torgersen et. al. 1999):

1. The patterns provide a spatial context for analysis of seasonal temperature data from in-stream data loggers and for future deployment and distribution of in-stream monitoring stations. How does the temperature profile relate to seasonal temperature extremes? Are local temperature minimums consistent throughout the summer and among years?

2. The database provides a method to develop detailed maps and to combine the information with other spatial data sets. Additional data sets may include factors that influence heating rates such as stream gradient, elevation and aspect, vegetation, and land-use. In viewing the temperature patterns in relation to other spatial factors, correlations are often apparent that provide a more comprehensive understanding of the factors driving temperature patterns at different spatial scales.

3. What is the temperature pattern within critical reach and sub-reach areas? Are there thermal refugia within these reaches that are used by coldwater fish species during the summer months? Do cool water tributaries represent potential thermal refugia? What is the availability/extent of the cool water habitat represented by these sources?

4. The TIR and visible band images provided with the database can be aggregated to form image mosaics. These mosaics are powerful tools for planning fieldwork and for presentations.

5. Stream temperature profiles provide a spatially continuous data set for the calibration of reach and basin scale stream temperature models.

6. Digitized color video images provide a means to evaluate in-stream habitat and riparian/floodplain conditions at the time of the survey.

Bibliography

Faux, R.N., H. Lachowsky, P. Maus, C.E. Torgersen, and M.S. Boyd. 2001. **New approaches for monitoring stream temperature: Airborne thermal infrared remote sensing**. Inventory and Monitoring Project Report -- Integration of Remote Sensing. Remote Sensing Applications Laboratory, USDA Forest Service, Salt Lake City, Utah.

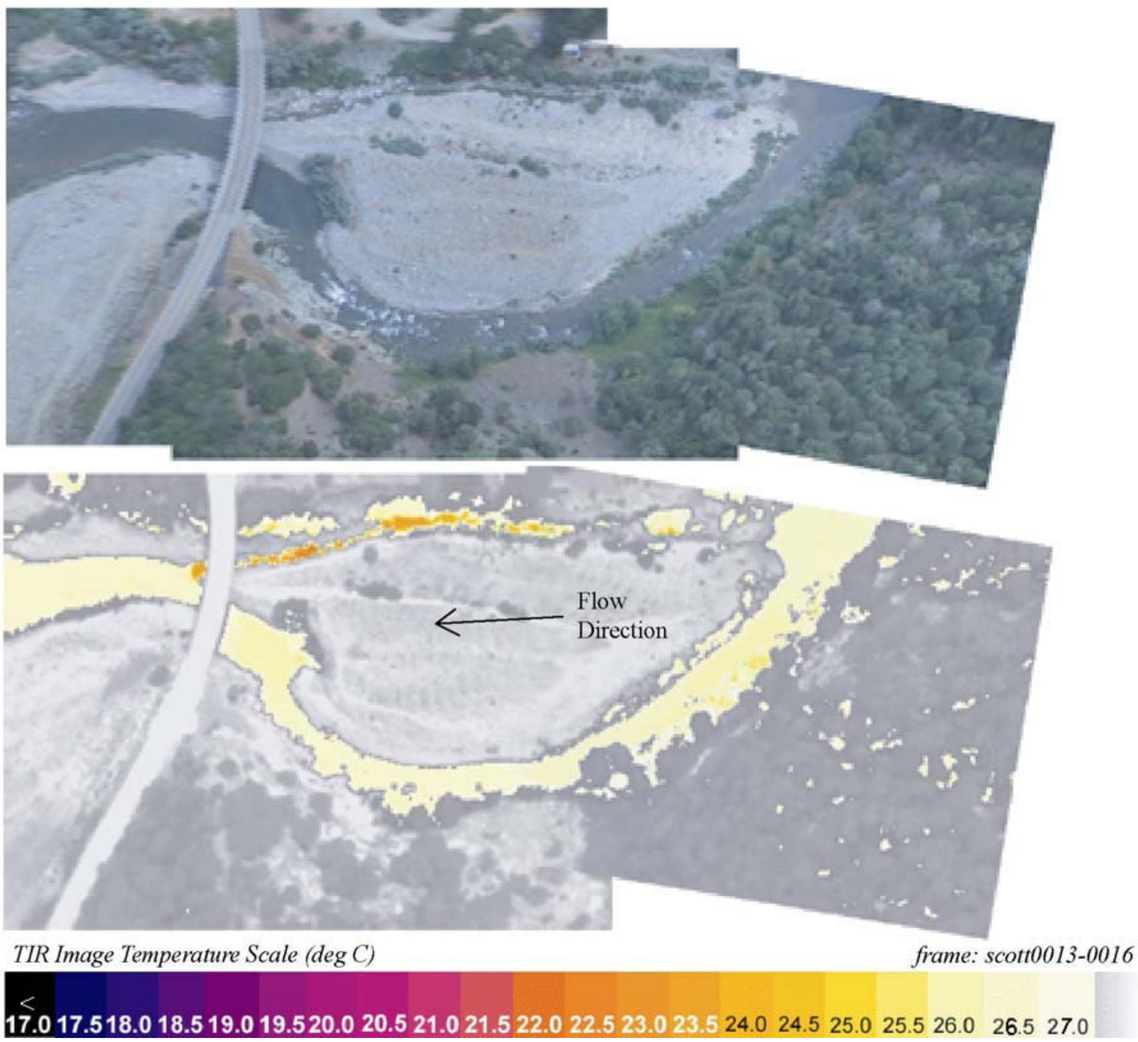
Torgersen, C., R. Faux, and B. McIntosh. 1999. **Aerial survey of the Upper McKenzie River: Thermal infrared and color videography**. Report to the USDA, Forest Service, McKenzie River Ranger District.

Torgersen, C.E., R. Faux, B.A. McIntosh, N. Poage, and D.J. Norton. 2001. Airborne thermal remote sensing for water temperature assessment in rivers and streams. *Remote Sensing of Environment* 76(3): 386-398.

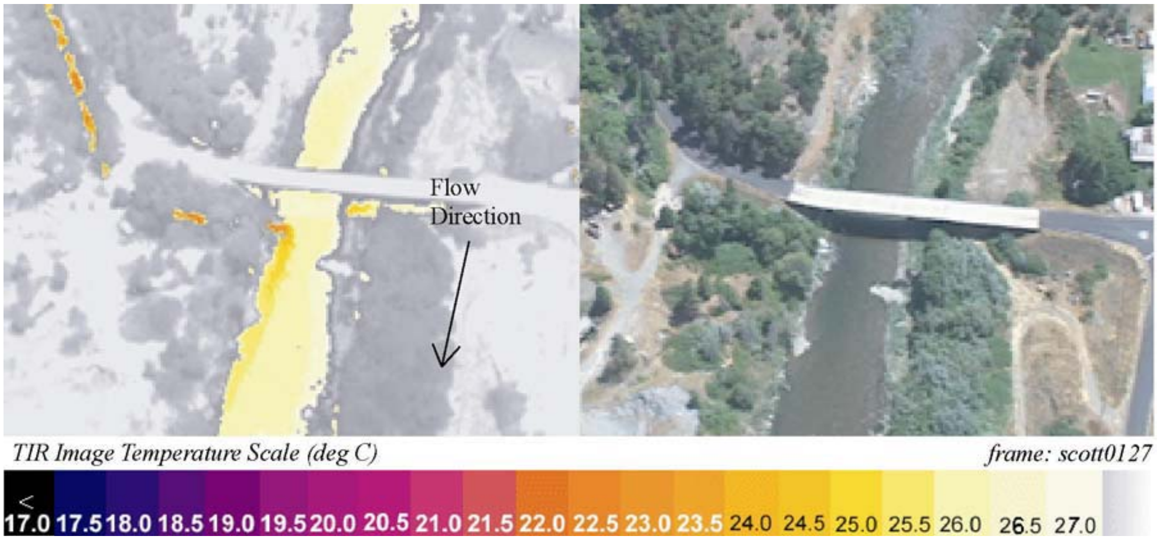
Appendix A - Selected Images

The following images were selected to show interesting features along each of the surveyed streams. References to right or left bank are considered looking downstream.

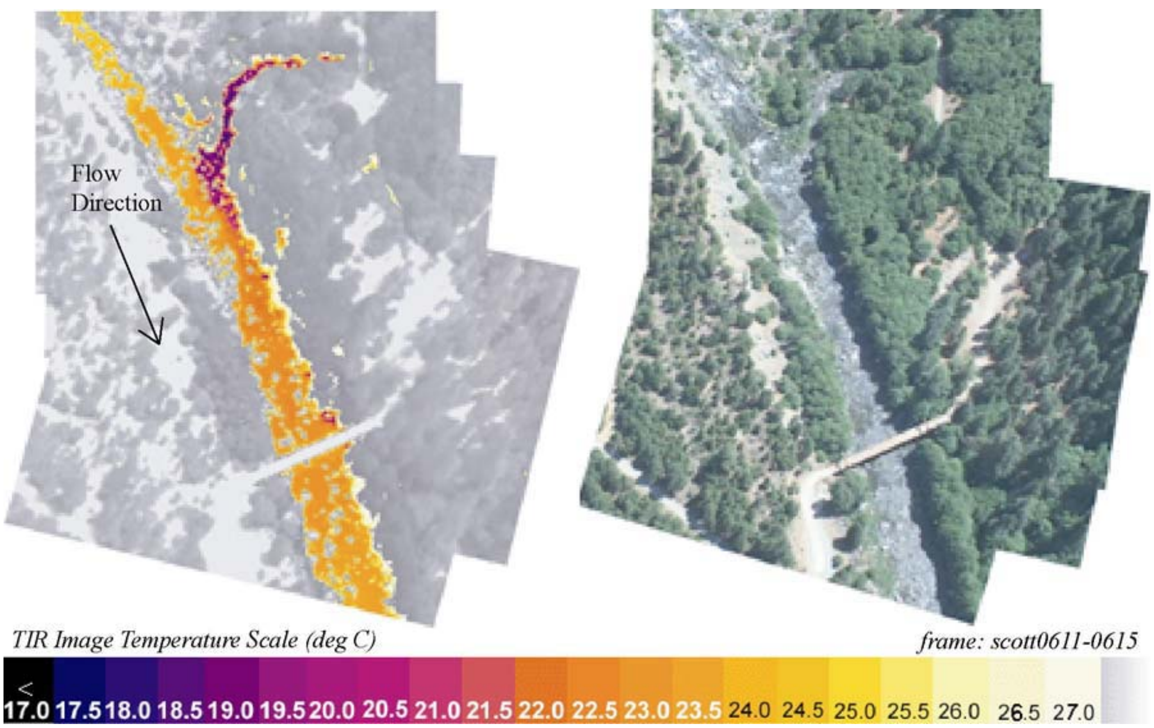
Scott River



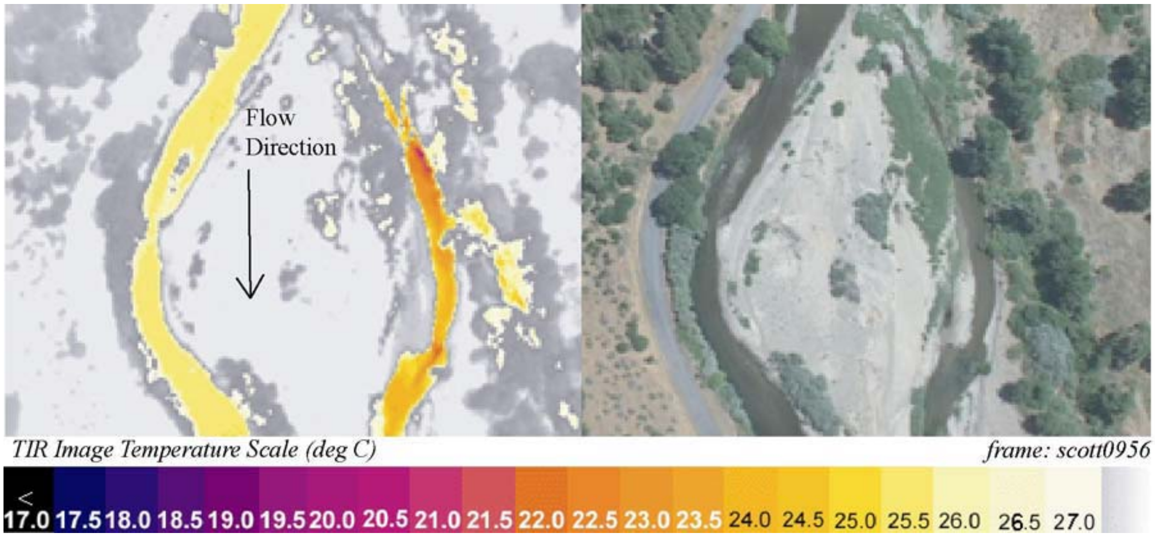
TIR/color video image pair showing a spring (22.1°C) in the side channel on the right bank of the Scott River (25.9°C) at river mile 0.2.



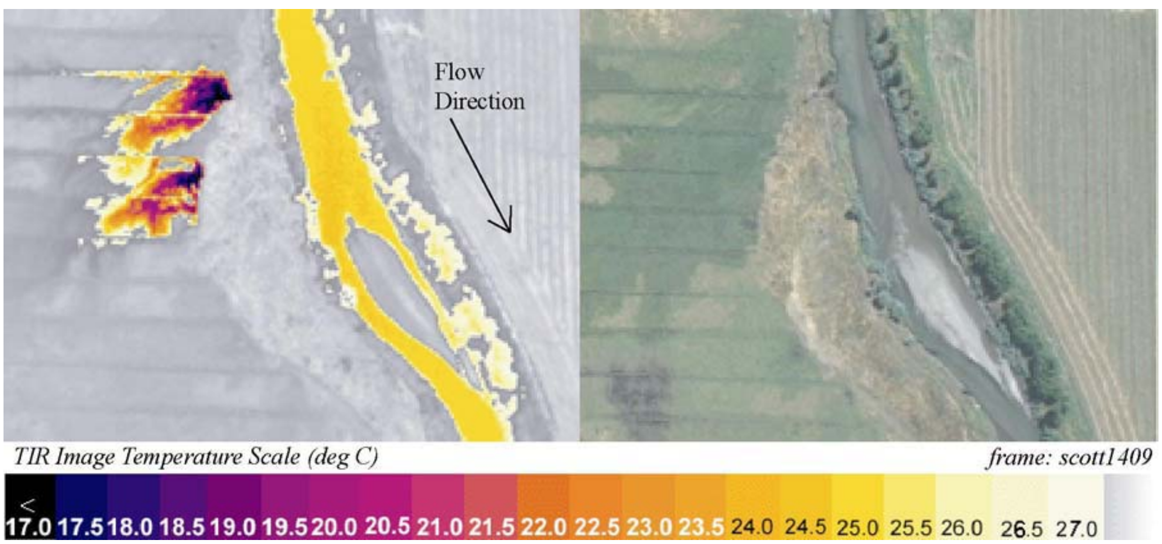
TIR/color video image pair showing Mill Creek (20.9 °C) on the right bank of the Scott River (25.6 °C) at river mile 3.6.



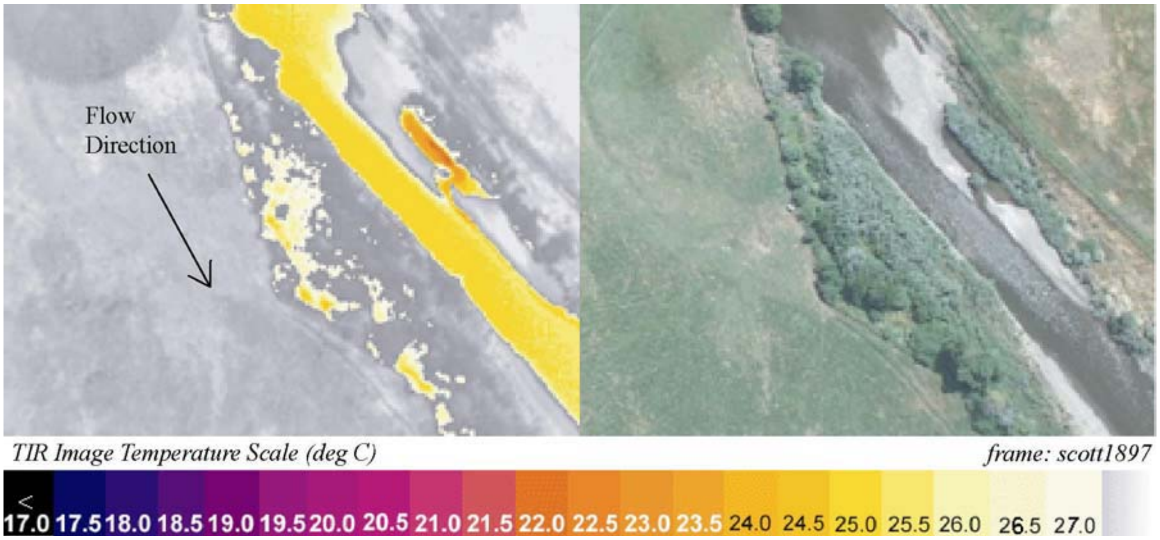
TIR/color video image pair showing Canyon Creek (17.9 °C) on the left bank of the Scott River (22.6 °C) at river mile 15.9.



TIR/color video image pair showing a spring/seep emerging from within the left bank channel of the Scott River (25.3 °C) at river mile 24.5.

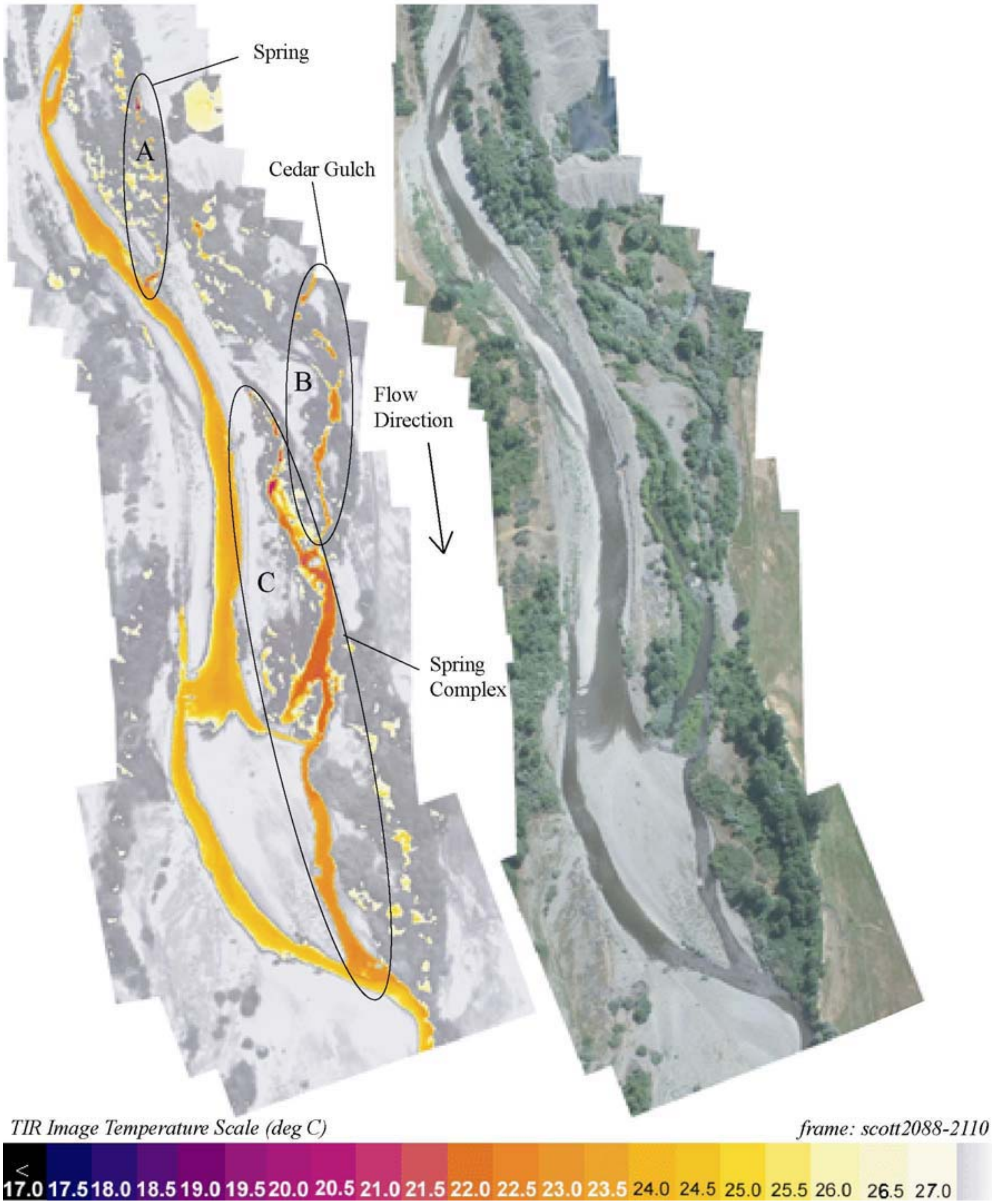


TIR/color video image pair showing a thermal signature in a field near right bank of the Scott River (24.5 °C) at river mile 36.5. This thermal signature is presumed due to transpiring vegetation from irrigation or recent rain.

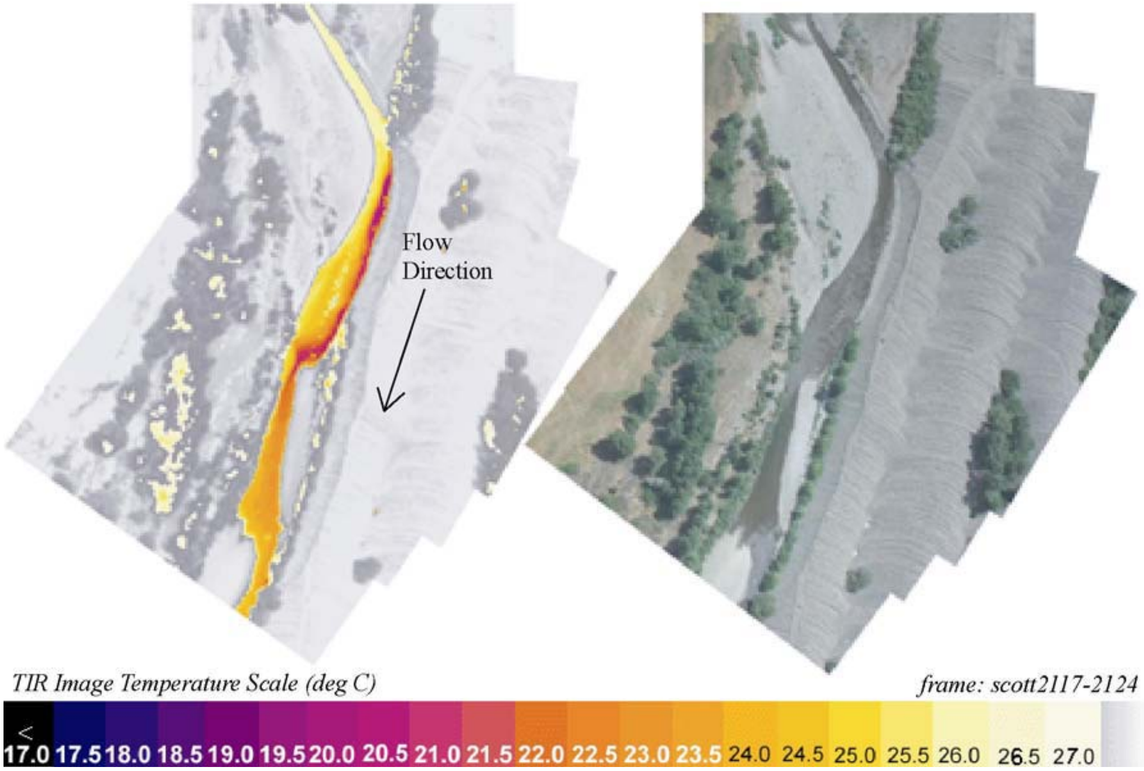


TIR/color video image pair showing a spring/seep (21.9 ^{o}C) on the left bank of the Scott River (24.8^{o}C) at river mile 46.8.

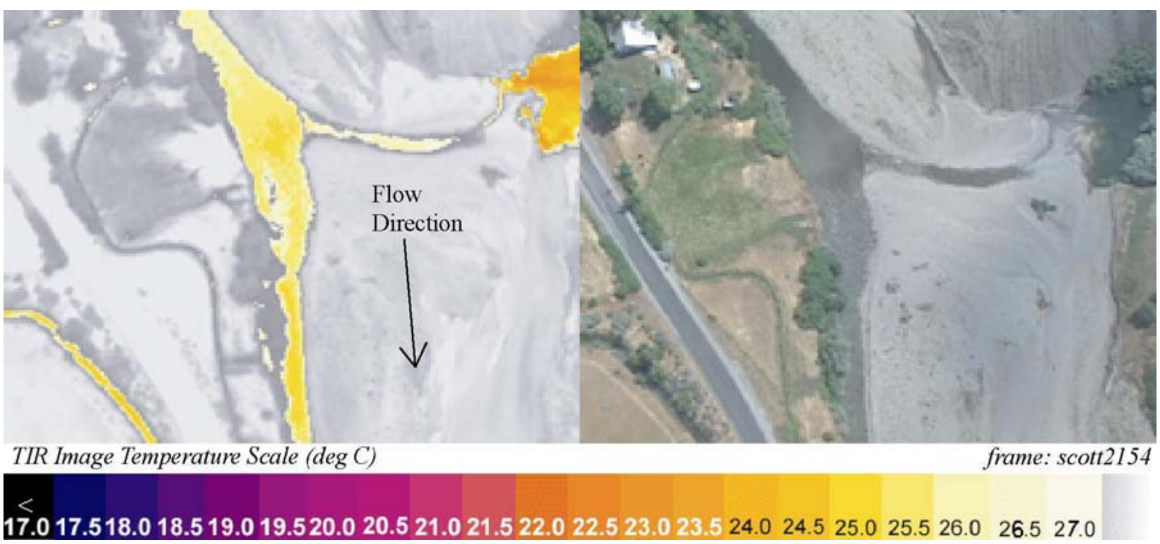
TIR/color video image pair showing a warm side channel on the left bank (bottom portion) and a spring/seep (21.4 °C) on the right bank (top portion) of the Scott River (23.4 °C) at river mile 51.0.



TIR/color video image pair showing a spring complex (C) (22.5 °C) on the left bank of the Scott River (24.1 °C). Cedar Gulch (B) can be seen on the left bank of the Scott River; however, because it's confluence with the Scott cannot be determined, it was not sampled. There is also a spring (A) (20.0 °C) on the left bank of the Scott upstream of Cedar Gulch, at river mile 52.0.

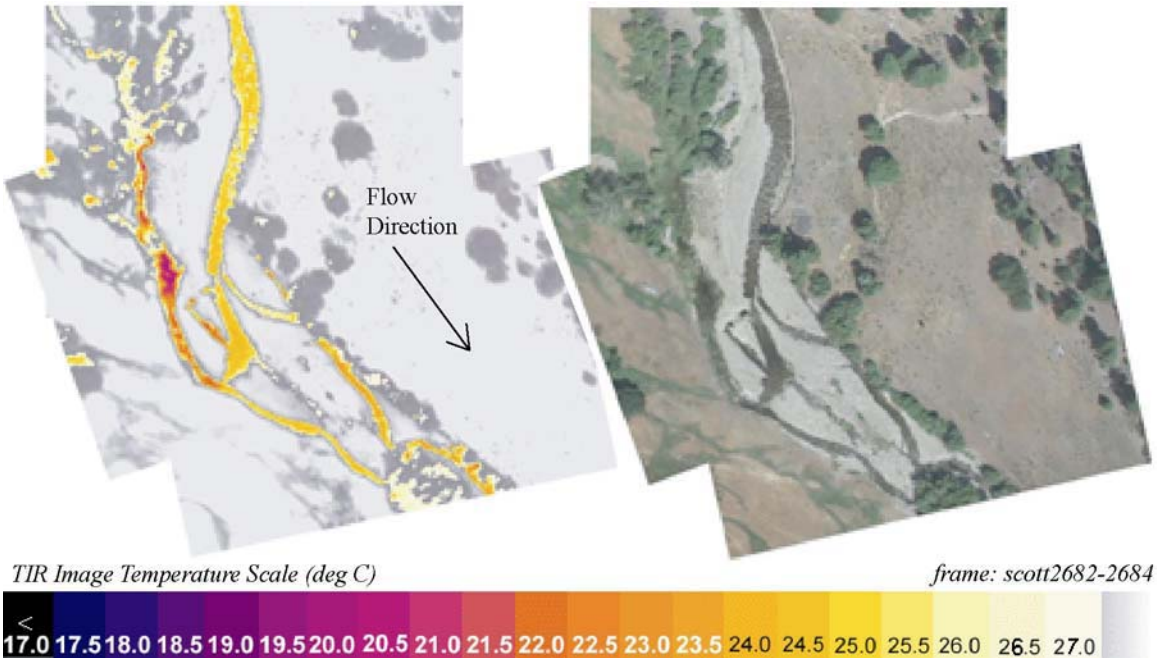


TIR/color video image pair showing a spring (20.1 °C) emerging from mine tailings along the left bank of the Scott River at river mile 52.3. As a result of this spring, the main stem temperature drops from 25.8 °C to 23.4 °C.

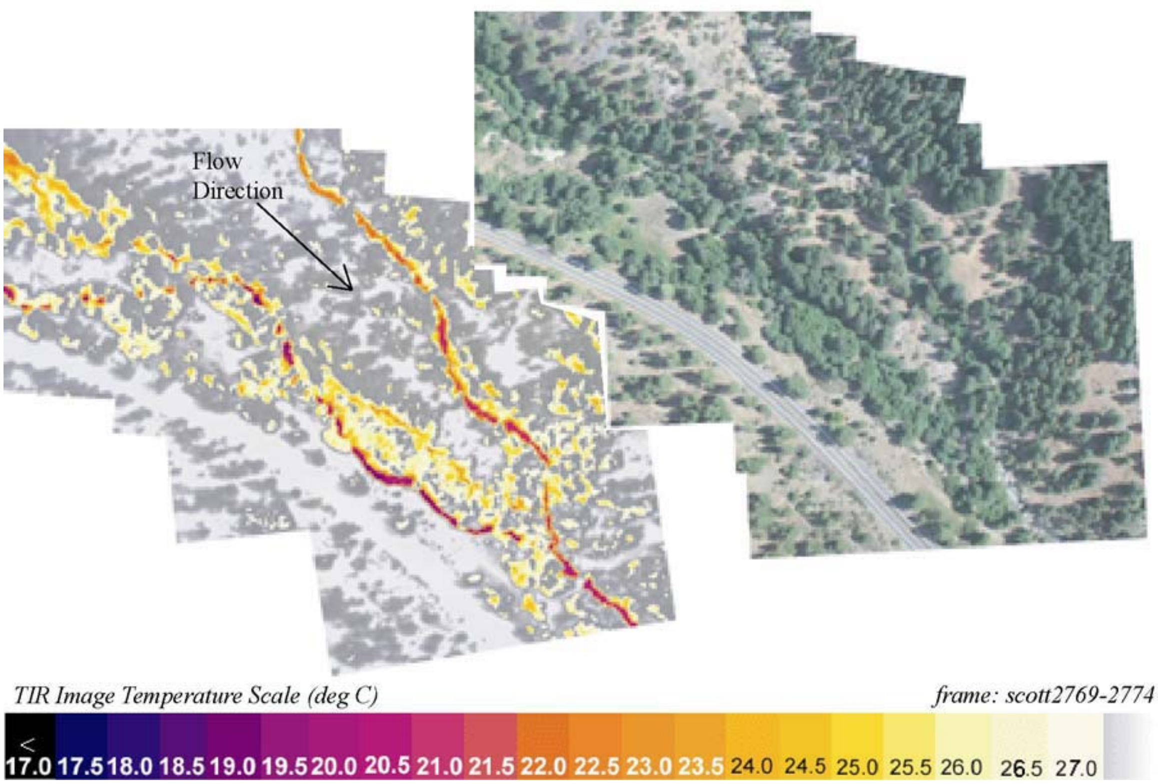


TIR/color video image pair showing cool surface water in the mine tailings near the Scott River (25.3 °C) at river mile 53.1.

East Fork Scott River

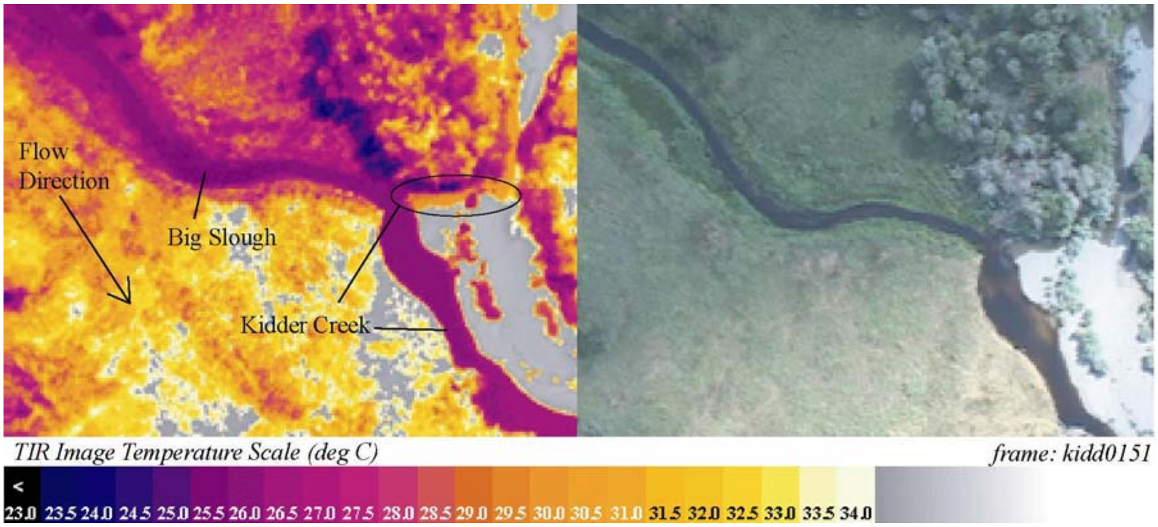


TIR/color video image pair showing a spring (21.6 °C) along the right bank of the EF Scott River (24.1 °C) at river mile 11.1.

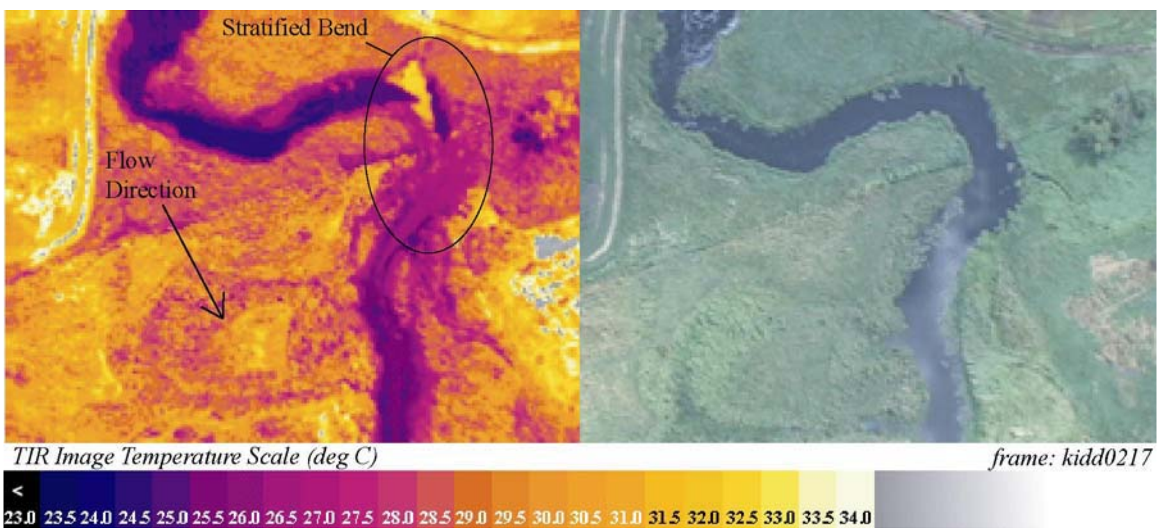


TIR/color video image pair showing Houston Creek (20.7 °C) on the left bank of the EF Scott River (18.7 °C) at river mile 13.9.

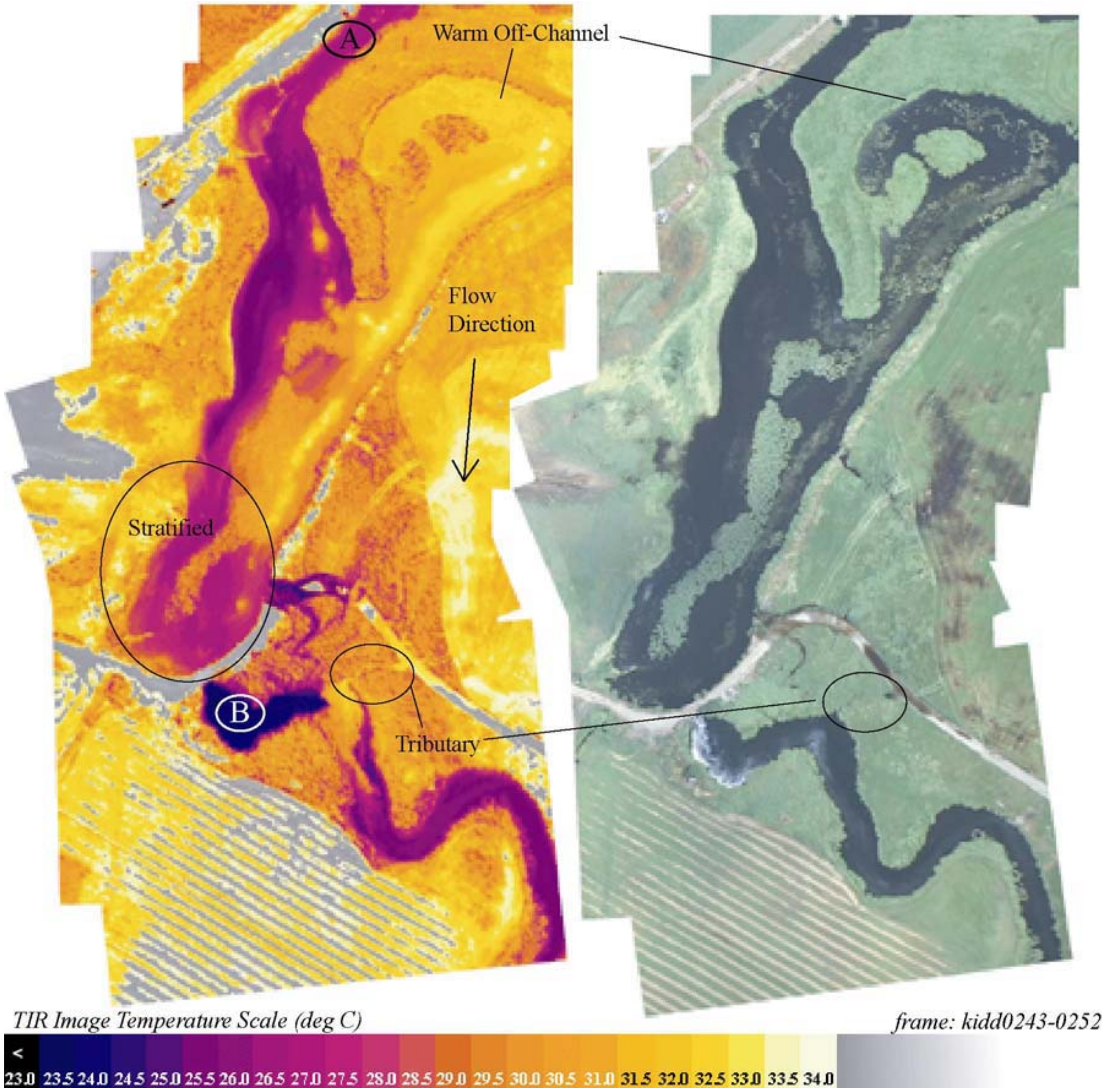
Kidder Creek/Big Slough



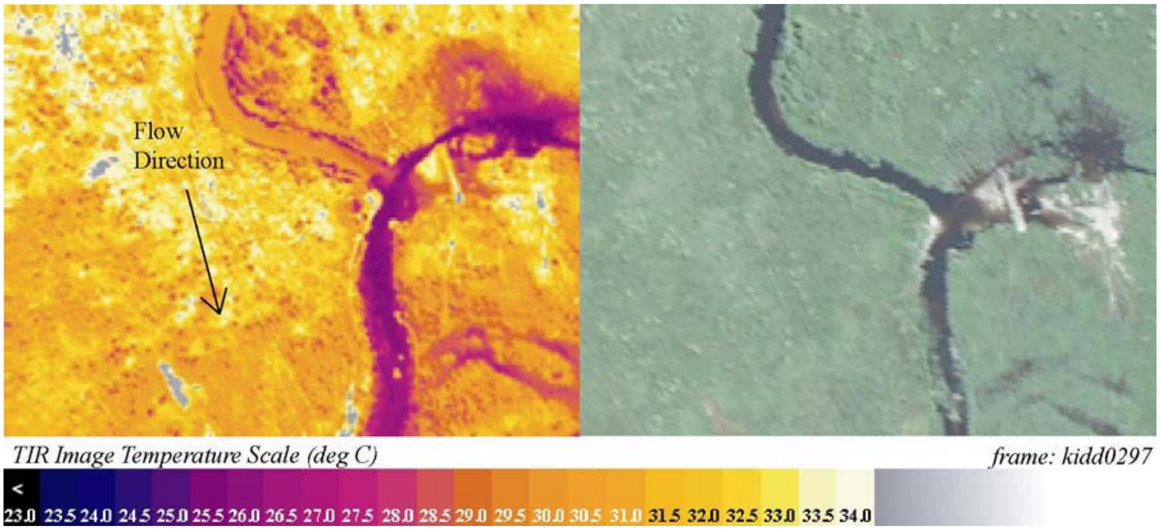
TIR/color video image pair showing the confluence of Big Slough (25.7^{o}C) and Kidder Creek (29.2^{o}C) at river mile 3.6 of Kidder Creek.



TIR/color video image pair showing a region of Big Slough (25.2^{o}C) at river mile 5.1. The surface temperature pattern around the bend indicates a thermally stratified condition.

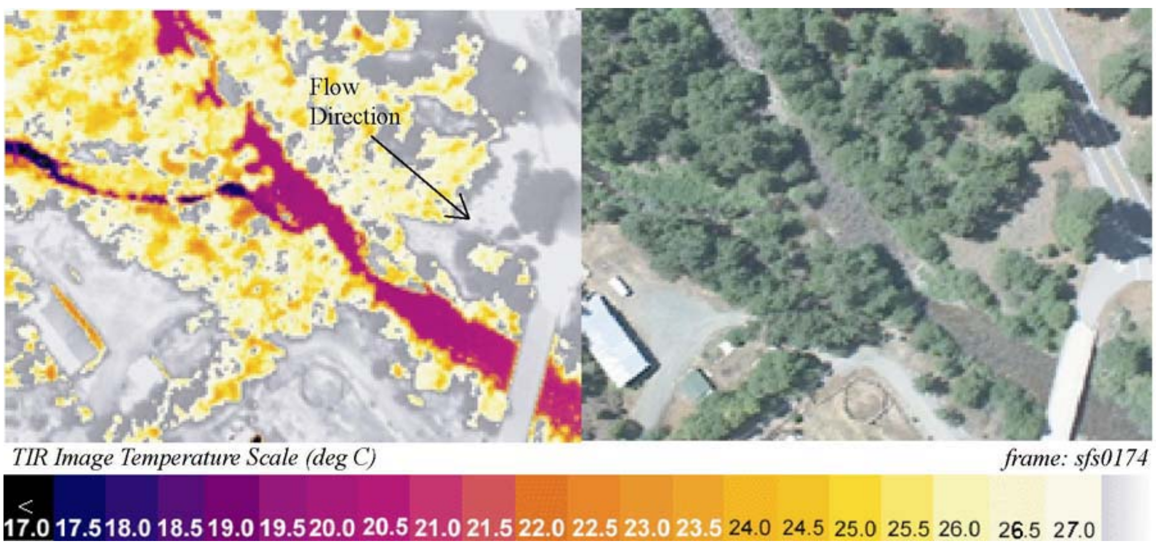


TIR/color video image pair showing a stratified stretch of Big Slough with an unnamed warm tributary (32.0°C) on the left bank, in the bottom half of the image. The temperature at point A is 25.4°C while the temperature directly downstream of the bridge (B) is 23.9°C (river mile 6.0).

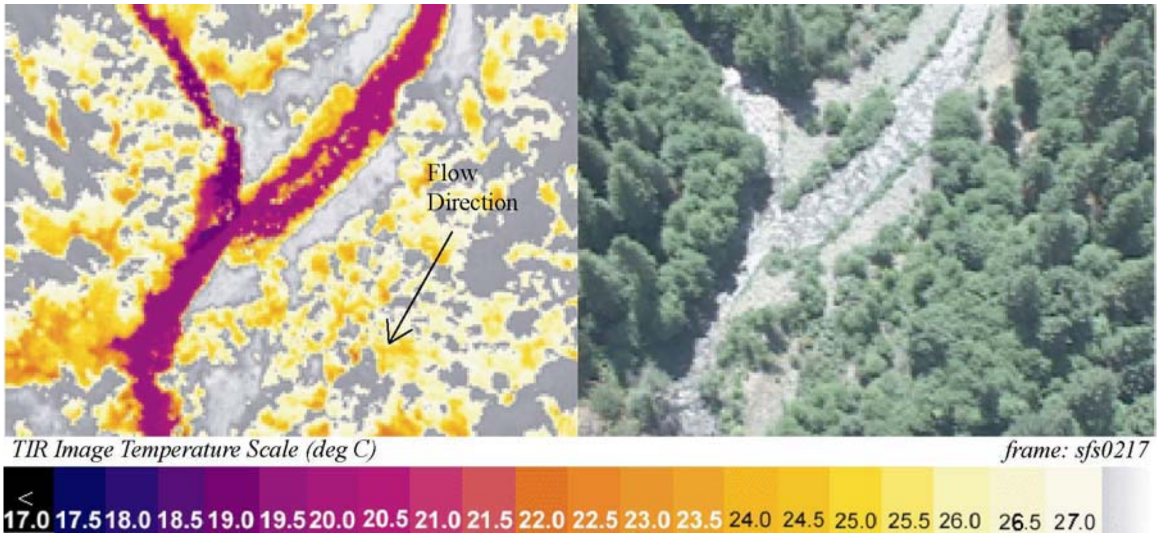


TIR/color video image pair showing a transition in Big Slough from a stratified state to a mixed condition moving downstream at river mile 7.5.

South Fork Scott River

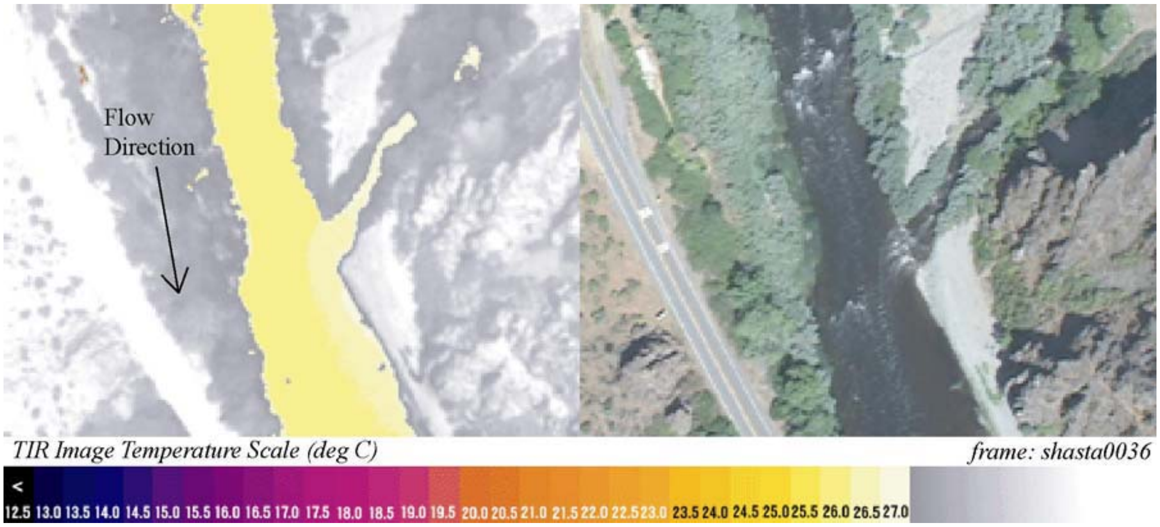


TIR/color video image pair showing a spring (17.0 ^{o}C) on the right bank of the SF Scott River (19.6 ^{o}C) at river mile 1.6.

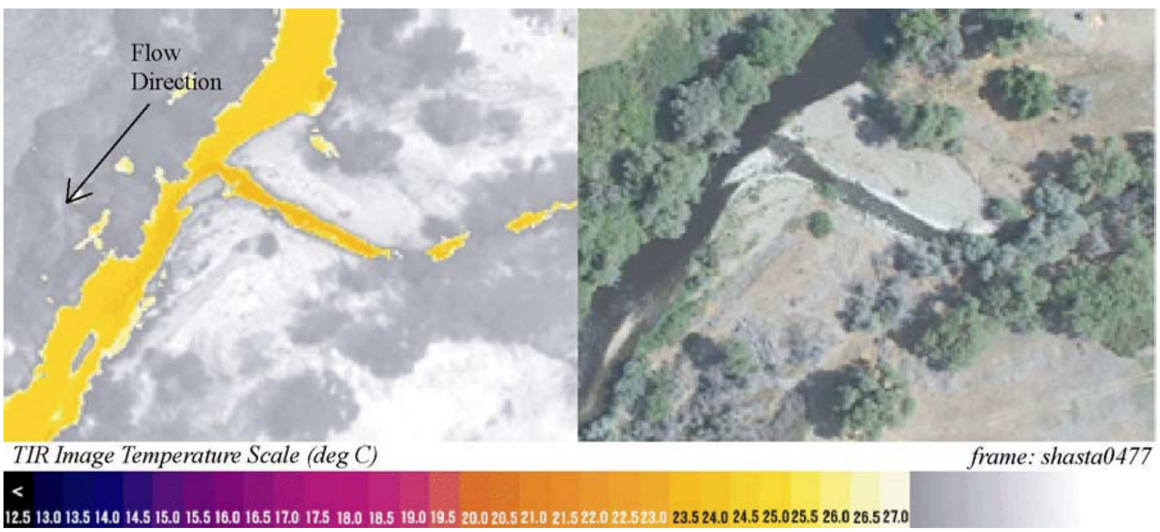


TIR/color video image pair showing the confluence of Boulder Creek (18.7 °C) on the right bank of the SF Scott River (19.6 °C) at river mile 2.3.

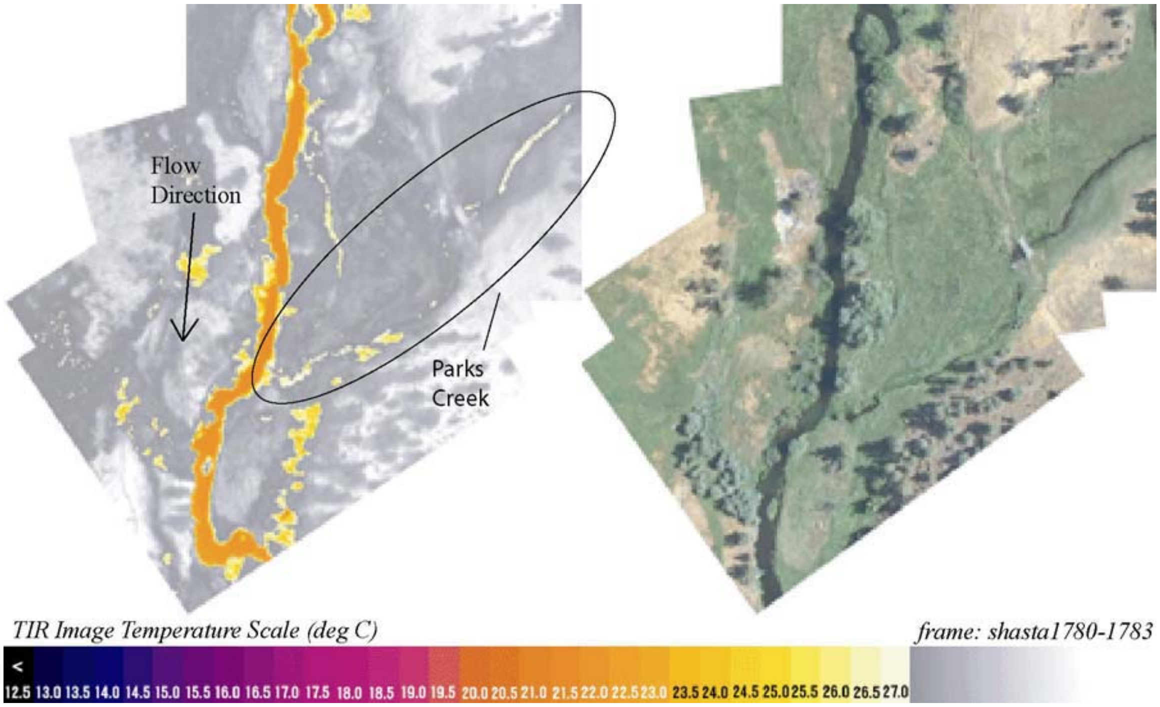
Shasta River



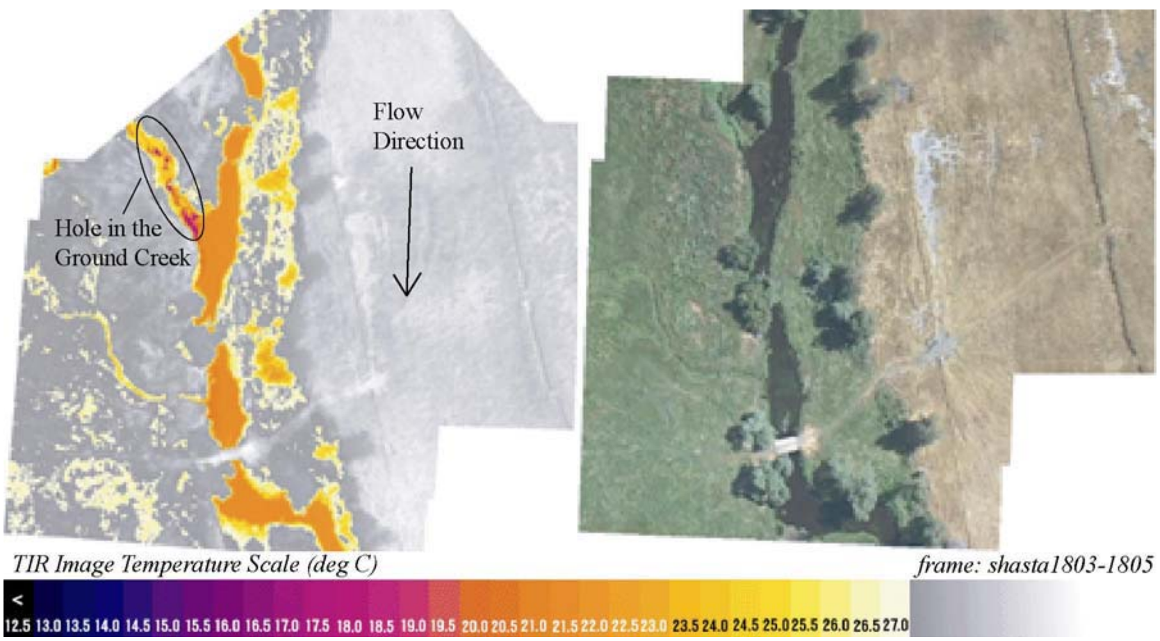
TIR/color video image pair showing the confluence of the Klamath River (25.8°C) and the Shasta River (26.5°C).



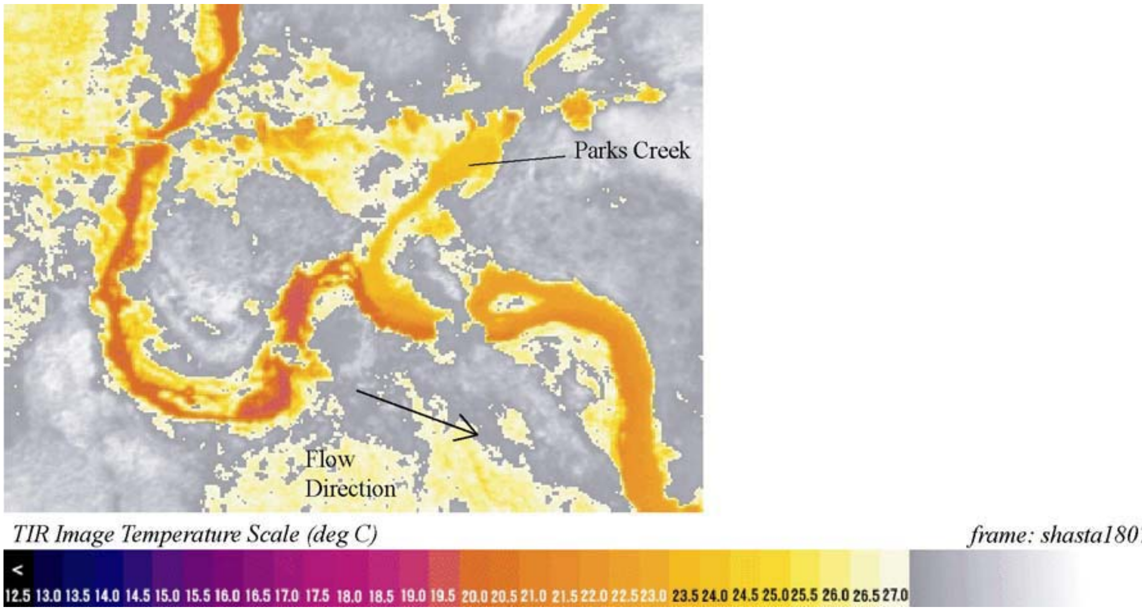
TIR/color video image pair showing Yreka Creek (23.4°C) on the left bank of the Shasta River (24.2°C) at river mile 7.8.



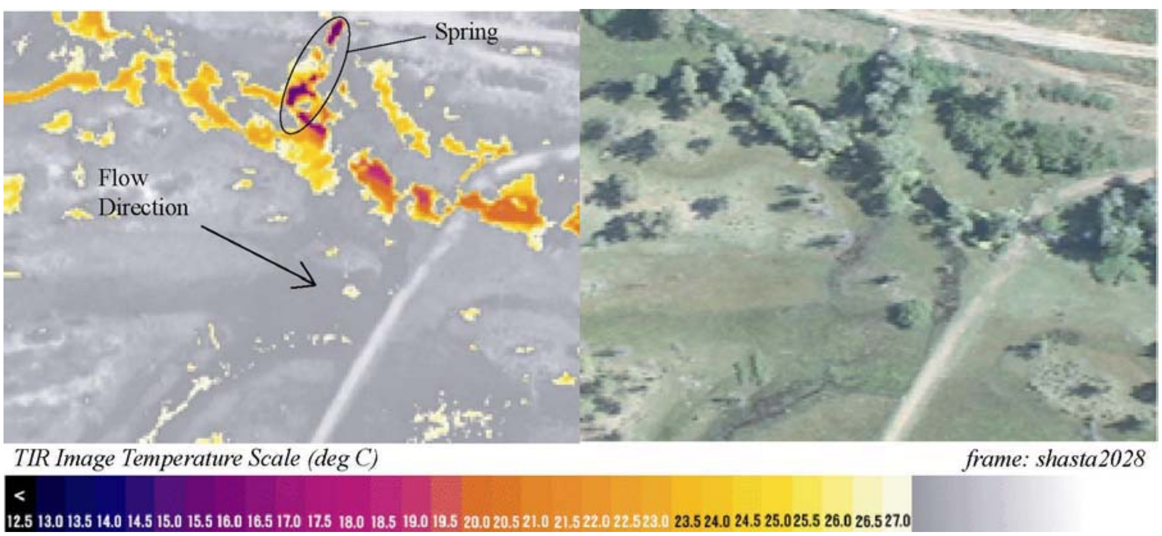
TIR/color video image pair showing the downstream confluence of Parks Creek (north channel) to the left bank of the Shasta River (21.7°C) at river mile 34.2. However, due to the lack of visibility at the mouth of Parks Creek, it was not sampled in this image.



TIR/color video image pair showing the confluence of Hole in the Ground Creek (17.3°C) to the right bank of the Shasta River (21.6°C) at river mile 34.7.

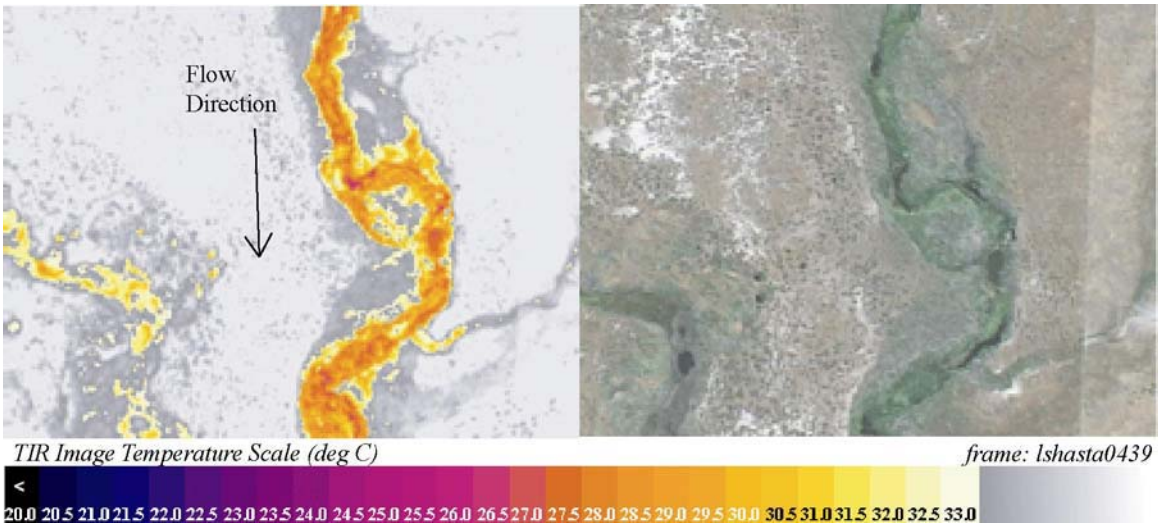


TIR/color video image pair showing the upstream confluence of Parks Creek (23.5°C) to the left bank of the Shasta River (21.6°C) at river mile 34.8.



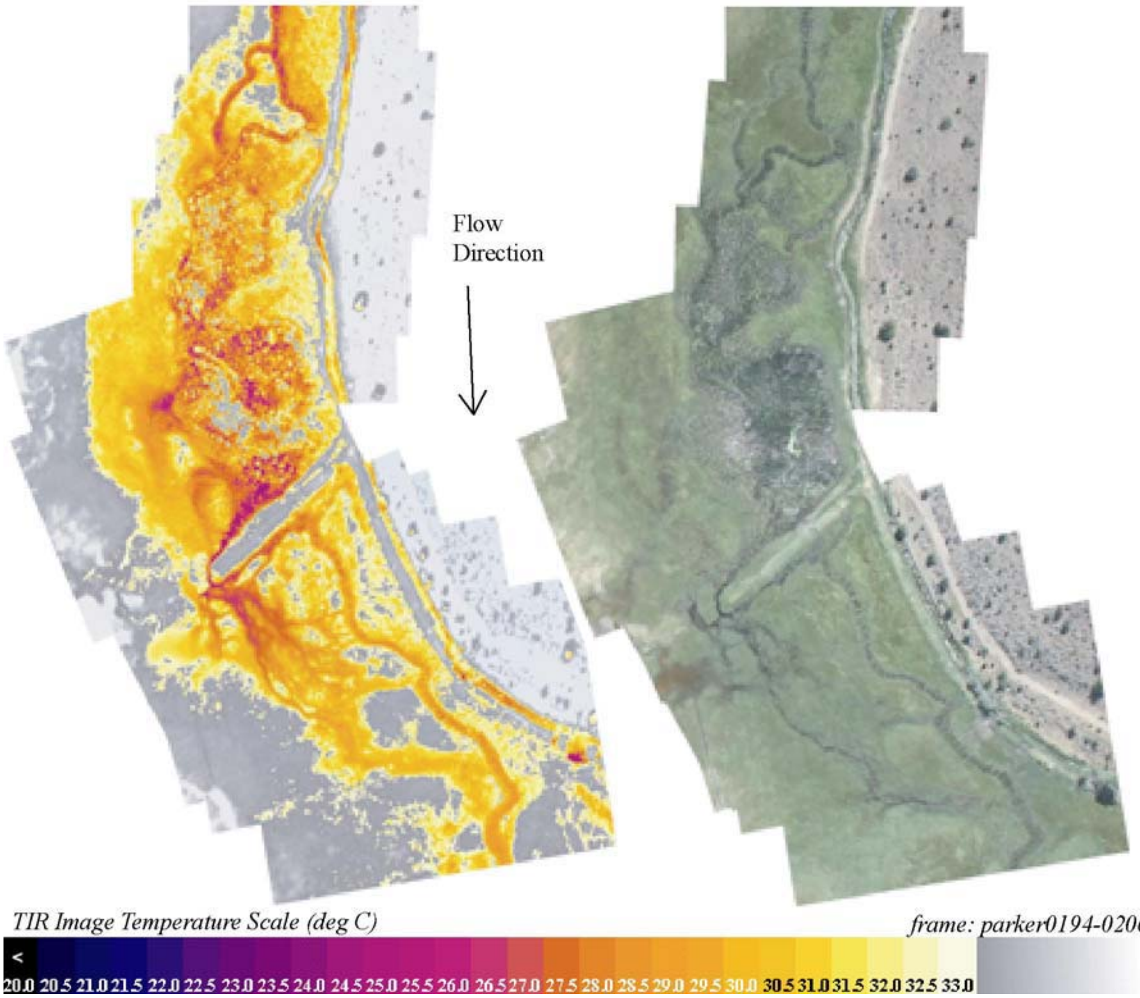
TIR/color video image pair showing a spring (14.8°C) on the left bank of the Shasta River (22.3°C) at river mile 39.3.

Little Shasta River

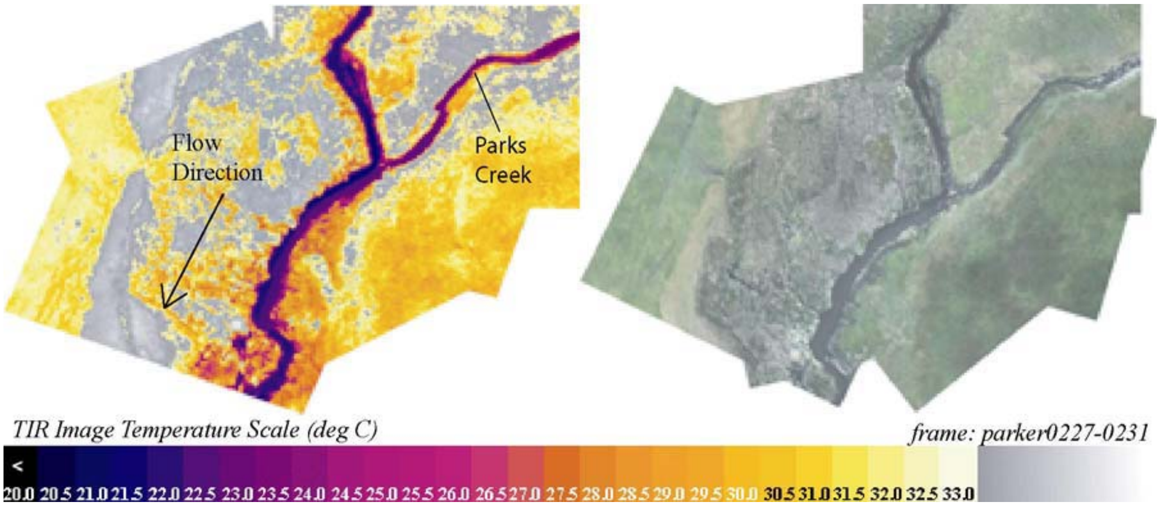


TIR/color video image pair showing a region of Little Shasta River at river mile 8.0 which is typical of the conditions of Little Shasta River through much of its length.

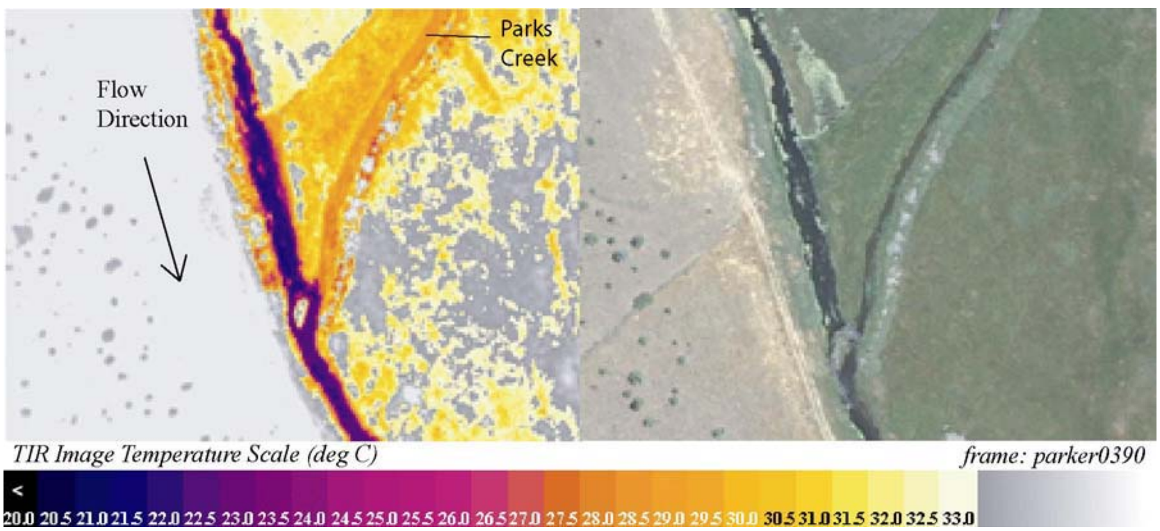
Parks Creek



TIR/color video image pair showing a largely undefined channel at river mile 2.2 of Parks Creek (26.7^{o}C).



TIR/color video image pair showing an unnamed tributary (21.2°C) on the right bank of Parks Creek (22.7°C) at river mile 2.6.



TIR/color video image pair showing an unnamed tributary (21.6°C) on the right bank of Parks Creek (28.1°C) at river mile 5.5.

TECHNICAL MEMORANDUM: TVA River Modeling System: ADYN and RQUAL – RMS Model Specifications and Background

TO: Matt St John, North Coast Regional Water Quality Control Board

FROM: Mike Deas, Watercourse Engineering, Inc.

COPIES: Josh Viers, University of California, Davis

Michael Johnson, University of California, Davis

RE: Shasta River TMDLs – Water Quality Model Selection and Specifications

DATE: August 17, 2005

1. Introduction

Assessment of water quality conditions in support of the Shasta River TMDL analysis included consideration of a modeling approach consistent with the 303(d) listed parameters – temperature and dissolved oxygen.

2. Review of Models

Previous modeling efforts on the Shasta River were limited to flow and temperature representation. Outlined herein are the existing models, as well as selected models, that could be applicable to river systems.

2.1. Existing Models

Previous modeling efforts of flow and temperature were modeled in the Shasta River were completed by U.C. Davis (1998) and Abbott (2002). The former work was completed using the RMA-2 and RMA-11 models to represent hydrodynamics and water temperature, respectively. The work by Abbott applied the Tennessee Valley Authority models (TVA) ADYN and RQUAL to represent hydrodynamics and water temperature, respectively. The ADYN shade routine was modified to accommodate river aspect and different shading attributes on river left and river right, as well as longitudinal variations. The TVA models were applied within the River Management System (RMS) framework that assists with executing the model and assessing output through a graphical user interface.

2.2. Applicable Models

2.2.1. CE-QUAL-ICM (Eutrophication model)

CE-QUAL-ICM is a water quality model historically used to assess eutrophication. ICM stands for "integrated compartment model," which is analogous to the finite volume numerical method. The model computes constituent concentrations resulting from transport and transformations in well-mixed cells that can be arranged in arbitrary one-, two-, or three-dimensional configurations.

2.2.2. CE-QUAL-RIV1

CE-QUAL-RIV1 is a one-dimensional (laterally and vertically averaged) hydrodynamic and water quality model. CE-QUAL-RIV1 consists of two parts, a hydrodynamic code (RIV1H) and a water quality code (RIV1Q). The hydrodynamic code is applied first to predict water transport and its results are written to a file, which is then read by the quality model. It can be used to predict one-dimensional hydraulic and water quality variations in streams and rivers with highly unsteady flows, although it can also be used for prediction under steady flow conditions.

RIV1H predicts flows, depths, velocities, water surface elevations, and other hydraulic characteristics. The hydrodynamic model solves the St. Venant equations as the governing flow equations using the widely accepted four-point implicit finite difference numerical scheme.

RIV1Q can predict variations in each of 12 state variables: temperature, carbonaceous biochemical oxygen demand (CBOD), organic nitrogen, ammonia nitrogen, nitrate + nitrite nitrogen, dissolved oxygen, organic phosphorus, dissolved phosphates, algae, dissolved iron, dissolved manganese, and coliform bacteria. In addition, the impacts of macrophytes can be simulated. Numerical accuracy for the advection of sharp gradients is preserved in the water quality code through the use of the explicit two-point, fourth-order accurate, Holly-Preissman scheme.

2.2.3. CE-QUAL-W2

CE-QUAL-W2 is a water quality and hydrodynamic model in 2D (longitudinal-vertical) for rivers, estuaries, lakes, reservoirs and river basin systems. W2 models basic eutrophication processes such as temperature-nutrient-algae-dissolved oxygen-organic matter and sediment relationships. Model represents, longitudinal-vertical hydrodynamics (laterally averaged) and water quality in stratified and non-stratified systems, multiple algae, epiphyton/periphyton, CBOD, and generic water quality groups, internal dynamic pipe/culvert model, hydraulic structures (weirs, spillways) algorithms including for submerged and 2-way flow over submerged hydraulic structures, dynamic shading algorithm based on topographic and vegetative cover. Recent versions allow this model to be applied to river basins, wherein both reservoir and river reaches can be represented.

2.2.4. QUAL2E/QUAL2K

QUAL2K (or Q2K) is a river and stream water quality model that is intended to represent a modernized version of the QUAL2E. It is a one-dimensional, steady-flow stream model (laterally and vertically averaged). Water temperature and quality can be modeled on a diurnal basis (i.e., sub-daily), and point and non-point loads can be represented.

2.2.5. RMA-2/RMA-11

RMA-2 and RMA-11 are a set of hydrodynamic and water quality models, respectively. RMA-2 is a two dimensional depth averaged finite element hydrodynamic numerical model (and can be applied in one-dimension with depth and laterally averaged conditions). It computes water surface elevations and horizontal velocity components for subcritical, free-surface flow in two dimensional flow fields. RMA-2 computes a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. Friction is calculated with the Manning's or Chezy equation, and eddy viscosity coefficients are used to define turbulence characteristics. Both steady and unsteady state (dynamic) problems can be analyzed.

RMA-11 is a finite element water quality model for simulation of one- two- or three-dimensional estuaries, bays, lakes and rivers. It is also capable of simulating one and two dimensional approximations to systems either separately or in combined form. It is designed to accept input of velocities and depths, either from an ASCII data file or from binary results files produced by RMA-2. Results in the form of velocities and depth from the hydrodynamic models are used in the solution of the advection diffusion constituent transport equations.

2.2.6. WASP

The Water Quality Analysis Simulation Program (WASP6) is an enhancement of the original WASP. This model helps users interpret and predict water quality responses to natural phenomena and manmade pollution for various pollution management decisions. WASP6 is a dynamic compartment-modeling program for analyzing river and stream water quality. WASP also can be linked with hydrodynamic and sediment transport models that can provide flows, depths velocities, temperature, salinity and sediment fluxes

2.2.7. Tennessee Valley Authority Models: ADYN and RQUAL

ADYN and RQUAL are a set of one-dimensional, finite difference hydrodynamic and water quality models, respectively. ADYN computes hydrodynamic attributes for, free-surface flow in open channels using the conservation of mass and momentum equations. The model can assess unsteady flow regimes in complex channels (e.g, water or wave travel times, routing, flow reversal, interaction with dynamic tributaries, multiple point or distributed inflows/outflows, variable geometry and roughness elements).

The water quality model RQUAL, solves the mass transport equation; however, the diffusion term is not incorporated in this version of RQUAL. The water quality model represents temperature, biochemical oxygen demand, nitrogenous oxygen demand, dissolved oxygen and primary production. The model includes riparian shading, but has been modified from the original form to provide more flexibility in representing variable shade quality and tree height distribution in river reaches.

2.2.8. Model Comparison

The attributes of the TVA models are compared with other identified models in the table below.

Model Attribute	TVA	QUAL2K	WASP	CE-QUAL-ICM	CE-QUAL-W2	RMA2/ RMA11	CE-RIV1
One-dimensional	1	1	1,2,3	1,2,3	2	1,2	1
Hydrodynamic Model	Yes	No	Exter.[a]	Exter.[a]	Yes	Yes	Yes
Water Quality							
- Temperature	Yes	Yes	Yes	Yes	Yes	Yes	Yes
- Dissolved Oxygen	Yes[b]	Yes	Yes	Yes	Yes	Yes	Yes
Boundary Conditions (P: Point, NP: Nonpoint)	P,NP	P, NP	P, NP	P, NP	P, NP	P, NP	P, NP
Actively Supported	Yes	Yes	Yes	Yes[c]	Yes	Yes	Yes[c]
Vertical stratification	No	No	Yes[d]	Yes[d]	Yes	No	No
Lateral variability	No	No	Yes	Yes	No[e]	Yes	No
Other pollutants[e]	limited	limited[f]	Yes	Yes	limited[f]	limited[f]	limited[f]
Wetting and drying[g]	No	No	Yes[g]	Yes[g]	No[g]	Yes	No
Pre-processor	Yes	Yes	Yes	No	Yes	Yes	No
Post-processor	Yes	Yes	Yes	No	No	Yes	No
Open source code	Yes	Yes	Yes	Yes	Yes	Yes	Yes

[a] hydrodynamic models are external.

[b] nitrogenous biochemical oxygen demand, biochemical oxygen demand, sediment oxygen demand, reaeration, and macrophyte respiration and photosynthesis are specified boundary conditions or represented processes to assess dissolved oxygen conditions. Nutrient fate and transport, algae uptake and excretion, and other sources and sinks of nutrients are not modeled processes in TVA. Mike, for my own info, what models include these processes?

[c] CE-QUAL-ICM and CE-RIV1 are supported by the U.S. Army Corps of Engineers, but at a lesser level than the more popular models listed – more on a case-by-case application than general support.

[d] requires 3-dimensional hydrodynamic modeling.

[e] branching networks and control structures can be used to represent lateral variability for certain systems.

[f] All identified models have open source codes and modifications can be made to the models to represent other constituents and processes as necessary.

[g] wetting and drying refers to the ability of the model system to drop computational elements, segments, or nodes when water levels drop (drying) and re-activates them when water levels rise (wetting). For WASP and CE-QUAL-ICM wetting and drying can be accommodated if the selected hydrodynamic model allows such simulation. CE-QUAL-W2 cannot truly "dry" but because there are multiple layers rising and falling water levels and changing channel geometry can be represented.

2.3. Model Selection

After a review of the models available in the public domain, the Tennessee Valley Authority's (TVA) River Modeling System (RMS), a one-dimensional hydrodynamic and water quality model, was chosen to model the Shasta River. This model was chosen for several reasons, including, but not limited to the fact that it is readily available in the public domain, has been widely applied to both temperature and dissolved oxygen assessments, contains detailed shading logic, allows for modeling at an hourly time step, is well documented, and is supported by TVA. Further, the model was already implemented, configured, and calibrated for flow and temperature on the Shasta River system. The primary modification was the addition of the necessary water quality modeling components applied to represent dissolved oxygen conditions for TMDL assessment.

3. Tennessee Valley Authority Models

3.1. Background

ADYN and RQUAL are a set of one-dimensional, finite difference hydrodynamic and water quality models, respectively. ADYN computes water surface elevations and horizontal velocity components for subcritical, free-surface flow in open channels. ADYN solves the conservation of mass and momentum equations (St Venant equations) using one of two numerical schemes: a four point implicit finite difference scheme with weighted spatial derivatives or a McCormack explicit scheme. The model can assess unsteady flow regimes in complex channels (e.g, water or wave travel times, routing, flow reversal, interaction with dynamic tributaries, multiple point or distributed inflows/outflows, variable geometry and roughness elements).

The water quality model RQUAL, solves the mass transport equation with the same numerical scheme used in the flow model. The diffusion term is not incorporated in this version of RQUAL. The water quality model represents temperature, biochemical oxygen demand, nitrogenous oxygen demand, dissolved oxygen, sediment oxygen demand, reaeration, and primary production (photosynthesis and respiration). Details of model formulation, application, and governing equations are presented in Hauser (1995). The original model code includes riparian shading, but has been modified by Abbott (2002) to provide more flexibility in representing variable shade quality and tree height distribution in river reaches.

Both ADYN and RQUAL can be operated from within a graphical user interface – called the River Management System (RMS) – that allows the user to prepare input files and run the model. There is an additional software package called AGPM-1D, which is a post-processor for ADYN and RQUAL, allowing the user to examine the output as time series, longitudinal profiles, as well as animation features. These software packages cost less than $500.00 and are available from Loginetics Inc.

3.2. Model Meta Data

NAME: Tennessee Valley Authority River Modeling System (ADYN and RQUAL Module)

ORGANIZATION/PERSON HOLDING AND DISTRIBUTING THE MODEL:
Tennessee Valley Authority, Resources Group, Engineering Services
TVA Engineering Lab,
129 Pine Road, Norris, Tennessee, 37828
Phone: 423-632-1888
Fax: 423-632-1840

TYPE OF MODELING OR APPLICATION:

ADYN:

- River and resource hydraulics
- One-dimensional, longitudinal, unsteady flow
- Hydraulics of floods and man-made transients (e.g., hydropower releases)
- Effects of dynamic tributary systems, local inflow sources
- Assessment of wetted areas for environmental flow assessments
- Governing Equation: St. Venant Equations
- Numerical solution: (a) four point implicit finite difference, or (b) McCormack explicit scheme

RQUAL

- Water quality fate and transport
- One-dimensional, longitudinal, dynamic representation
- Waste load allocation
- Effects of location, magnitude, and timing of interventions seeking to improve water quality
- Dilution and degradation of wastes
- Effects of thermal loadings and atmospheric heat exchange on stream temperature
- Effects of natural or artificial reaeration, diurnal photosynthesis and respiration by benthic algae/macrophytes, waste loads, tributary inflows, and variable flow regimes on the dissolved oxygen regime
- Governing Equation: Mass transport equation (advection-diffusion equation with diffusion neglected)
- Numerical solution: (a) four point implicit finite difference, or (b) McCormack explicit scheme

NUMBER OF MODEL DIMENSIONS: One (laterally and depth averaged)

MODEL LIMITATIONS: When linked to "RQUAL", does not currently model water quality in dynamic tributaries (not applied in Shasta River analysis)

MODEL MODIFICATIONS: The model was modified by Abbott (2002) to include the ability to model riparian shading based on stream aspect, as well as different shading attributes for tree height and solar radiation transmissivity that can vary for each bank.

MODEL LANGUAGE: FORTRAN

MODEL PLATFORM: PC (personal computer)

<u>INTERFACE AND PRE-/POST-PROCESSORS</u>:
The River Management System (RMS) includes an interface to display both ADYN and RQUAL output and statistics using the ADPLT and RQPLT post processor programs.

EXPERIENCE: Used extensively by the Tennessee Valley Authority

CURRENT VERSION:

- ADYN: 4.xx
- RQUAL: 4.xx

INPUT REQUIREMENTS:
ADYN:

- River geometry
- River and local tributary hydrology (water surface elevation and flow rate at boundaries)

RQUAL:

- River geometry (consistent with ADYN)
- Meteorological conditions
- River and local tributary water quality, including sediment oxygen demand and benthic algae/macrophyte photosynthesis and respiration distribution, as well as riparian shading attributes.
- Processes include:
  - Temperature
  - Dissolved oxygen
  - Nitrogenous biochemical oxygen demand
  - Biochemical oxygen demand
  - Benthic algae/Macrophyte photosynthesis and respiration
  - Sediment oxygen demand
  - Reaeration

OUTPUT (available at all nodal locations):
ADYN

- Discharge and water surface elevation
- Water velocity
- Water depth
- Wetted area
- Travel times
- Water volume
- Froude number

RQUAL

- Water temperature
- Dissolved oxygen

3.3. TVA Model Applications

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SHASTA RIVER FLOW, TEMPERATURE, AND DISSOLVED OXYGEN MODEL CALIBRATION TECHNICAL REPORT

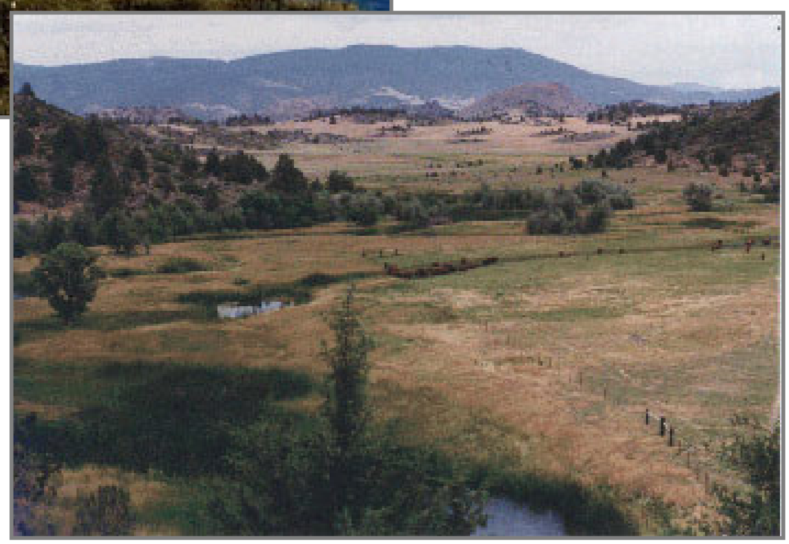

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Table of Contents

1.0 Introduction

The Shasta River flow, temperature, and dissolved oxygen modeling report is the second technical document that supports the development and implementation of the TVA River Management System (RMS). The RMS consists of two primary components: ADYN, a one-dimensional (vertically and depth averaged), hydrodynamic river model which produces velocities and depths for a prescribes river geometry (channel cross section and bed slope); and RQUAL, a one-dimensional water quality model that simulated temperature and dissolved oxygen for specified flow (velocity and depth from the ADYN model), biochemical oxygen demand (BOD), nitrogenous biochemical oxygen demand (NBOD), sediment oxygen demand (SOD), benthic algae photosynthesis and respiration (P and R), and meteorological conditions. The model is primarily designed to assess fate and transport of heat energy (i.e., temperature) and dissolved oxygen for specified conditions (e.g., CBOD, NBOD, SOD, P and R). The RMS does not explicitly simulate fate and transport of nutrients, the uptake of nutrients, or nutrient byproducts of benthic algae or other primary production.

This document addresses model updates relating to new geometric information (based on the 1:24 K hydrography developed by David Lamphear of the Institute for Forest and Watershed Management, Humboldt State University) and associated updates to the hydrodynamic and water quality files; the latest calibration for temperature and dissolved oxygen associated with these updates and modifications; and sensitivity analysis using the final calibrated model. These topics are presented in 7 inter-related tasks and associated subtasks – the major tasks including

- data analysis
- model selection
- geometry conversion
- re-formatting the hydrodynamic ADYN file
- formatting the water quality RQUAL files
- calibration and validation
- sensitivity analysis

Throughout this project the model effort has undergone multiple refinements and improvements. In addition to the hydrography information identified above, there has been additional water quality data available to assist in model calibration, and application of the model has provided further opportunity to interpret input data and more carefully refine model parameters. The final product is a calibrated flow, temperature, and water quality model for the Shasta River from Dwinnell Dam to the confluence with the Klamath River that forms a useful tool in assessing water quality conditions and potential impacts of modifications to flow, modifications to potential oxygen demands, and temperature control management activities. As with all numerical models of complex natural systems, responsible application of the models includes understanding and considering the limitations of both the available data and model representations when making resource management decisions.

This document is intended to supplement the technical memorandum Shasta River Modeling Status Report dated 9-13-04 (Deas and Geisler, 2004) and relies on previous work in the basin as presented in the Shasta River Flow and Temperature Modeling Project reports (Watercourse 2004a, 2004b).

1.1 Task 1. Data Analysis and Selection of Calibration/ Validation Periods

The year 2002 was selected for this modeling effort based on the relatively large quantity of available flow and water temperature data. Although water quality information is limited in 2002 as compared to 2003 and 2004, there are limited flow and water temperature data in 2003 and 2004. During the 2002 field season, hourly river stage data was collected using pressure transducers at eight locations along the Shasta River (Table 1). Based on rating curves developed for each of the sites, hourly flow was calculated for these locations. Onset Hobo and Stowaway loggers were used to collect hourly temperature data at eleven sites along the river (Table 2).

Table 1. Locations of pressure transducers[1]

Location	River Mile
Mouth (USGS Gage)	0.6
Anderson-Grade Road	8.0
Yreka-Ager Road	10.9
DWR Weir	15.5
Freeman Road	19.2
A12	24.1
Grenada (GID)	30.6
Louie Road	33.9

Table 2. Location of temperature loggers

Location	RM
Mouth of Shasta	0.0
Hwy 263	7.3
Anderson Grade	8.0
Yreka-Agar Rd	10.9
Hwy A-3	13.1
DWR Weir	15.5
Hwy A-12	24.1
GID	30.6
Louie Rd	33.9
Parks Creek	34.9
Shasta above Parks Creek	35.9

Meteorological data was purchased from the Western Regional Climate Center, which compiles meteorological data from Brazie Ranch. The Brazie Ranch station, which is maintained by the California Department of Forestry, is located two to 3 miles south-east

[1] Note, all the river miles have been converted to the most recent mapping (the so-called Lamphear mapping) which adds approximately 4 miles to the older mapping of 36 miles (identified in Abbott, 2002) from the mouth to the dam, for a new length of 40.6 miles.

of Yreka at latitude 41°41'07" and longitude 122° 35'39", and an elevation of approximately 3020 feet. The data from this station that were used in the RMS included hourly records of wind speed, air temperature, relative percent humidity, and solar radiation.

The periods of calibration and validation of the model were selected based on availability of flow, water temperature, and meteorological data. Flow data was particularly important. Equipment failure resulted in discontinuities in the available data. Flow data availability for all locations are outlined in Table 3. There are notable gaps in June, July, and August, but sufficient data available for model implementation.

Table 3. Available measured flow data for 2002

Start Date	Start Time	End Date	End Time	Notes
5/21/02	14:00	6/03/02	16:00	for all entries, up to 3 hours at a time may be missing from data
6/19/02	15:00	7/09/02	19:00	
8/21/02	16.00	8/31/02	14:00	
8/31/02	15:00	9/06/02	12:00	data gaps in Mouth and A12
9/16/02	15:00	10/05/02	6:00	
10/09/02	2:00	10/15/02	10:00	

Temperature data were available throughout much of the period, but certain data gaps were noted. Available periods of measured temperature data, complete at all sites for 2002 are:

- 4/18/2002 to 6/04/2002
- 7/02/2002 to 10/15/2002

Available periods of measured meteorological data for 2002 are:

- 1/01/2002 to 5/14/2002
- 6/04/2002 to 12/31/2002

Thus, the periods of full and complete flow, temperature, and meteorological measured data include:

- 8/21/2002 to 9/04/2002
- 9/16/02 to 9/30/2002
- 10/09/2002 to 10/15/2002.

Because the complete periods of measured data for temperature, flow, and meteorology were limited by the available temperature information at Louie Road, temperature for

Louie Road was estimated for the period 6/04/2002 to 10/02/2002 using an equilibrium temperature model developed by Watercourse Engineering (Watercourse, 2002).
Three weeklong periods were modeled for flow and temperature, and dissolved oxygen:

- 9/17/2002 to 9/23/2002
- 7/02/2002 to 7/08/2002
- 8/29/2002 to 9/04/2002

The period from 9/17/2002 to 9/23/2002 was used for calibration of the model, and the other two periods were modeled using the same input parameters, for the purpose of validation.

Availability of water quality data was not given priority when considering the selection of modeling periods, primarily due to the paucity of available data. Characterizing flow and temperature conditions was considered of primary importance due to much greater data availability and characterizing flow and temperature is critical to representing water quality processes (due to decay rates and temperature dependence). Hourly DO data for 2002 is available, but is not continuous. The USGS collected hourly data at 4 locations: Edgewood Road (RM 47.7), Montague-Grenada Road (RM 15.57), Highway 3 (RM 13.11), and the Mouth (RM 0.6). The USFWS also collected hourly data at the mouth in 2002. Edgewood Road is located above Lake Shastina, outside of the model study area. Available dissolved oxygen data are further outlined below.

2.0 Task 2. Model Selection

The Tennessee Valley Authority's River Modeling System version 4 was selected for application to the Shasta River by Abbott (2002) and the application extended for this study. This model includes a hydrodynamic model (ADYN) and a water quality model (RQUAL). ADYN is a one-dimensional, longitudinal, unsteady flow model that simulates water-surface elevation at defined nodes along the river. The RQUAL model is also a one-dimensional, longitudinal model that simulates temperature, dissolved oxygen, CBOD, and NBOD at defined nodes along the river. RQUAL uses outputs from ADYN as well as user-input meteorology and water quality coefficients.

3.0 Task 3. Geometry Conversion

Several modifications were made during the study to update and extend the original application by Abbott (2002). The first modification was to extend the model from the confluence at Parks Creek upstream to Dwinnell Dam. Using the spatial description provided by Abbott (2002) the model was extended from RM 31.83 to 36.38. Initial testing indicated that this modification did not significantly affect model performance. The second modification was initiated when the Regional Board decided to use a different spatial description (mapping) of the Shasta River (NCRWQCB). The Lamphear hydrography was developed by the Humboldt State University's Institute for Forest and Watershed Management. The Regional Water Board suggested the Lamphear hydrography is a more detailed description of the river course than that used in previous models of the Shasta River, and that the increase in model geometry detail would allow a finer scale resolution of dissolved oxygen dynamics. The total river length determined from the Lamphear hydrography is 4 miles longer than the previous description – providing appreciably more detail in the highly meandering reaches that run from above Hwy A-12 to the DWR weir. The entire hydrodynamic file was thus updated, along with the shade file and the water quality control file.

3.1 Task 3a: Converting to the Lamphear Hydrography for Measured Cross-sectional Geometry Locations

The ADYN hydrodynamic file requires input of cross-sectional geometry and elevation at each node in order to define the river. The additional length of the Lamphear hydrography was not uniformly distributed throughout the river from Dwinnell Dam to the confluence with the Klamath River. As such, a linear extrapolation from the previous mapping to the Lamphear hydrography was not possible. Previously measured geometry information (principally top width, depth, right bank height, and left bank height at 24 locations along the river) were identified in the Lamphear hydrography river mapping by matching the longitude and latitude and assigning the Lamphear hydrography river mile to that location (Table 4). To confirm that the Lamphear hydrography locations were consistent with approximate location of measured data, visual inspection of the old points on old river mappings and new points on new river mappings were made (Figure 1). Some points were subsequently adjusted to reflect the location of the cross-sectional measurement. For example, when the location in the original mapping was at a notable location, such as a hair-pin bend in the river, then it was placed at the hair-pin bend in the new mapping, by visual inspection. The cross-sectional geometries measured at the 24 points were then assigned to the Lamphear hydrography river mile and intermediate points were linearly interpolated between the measured data (Table 5). Any points upstream of the first measured location and downstream of the last measured location were assigned the value of the first and last, respectively. The linear interpolation was consistent with Abbott (2002) in constructing the previous input geometry.

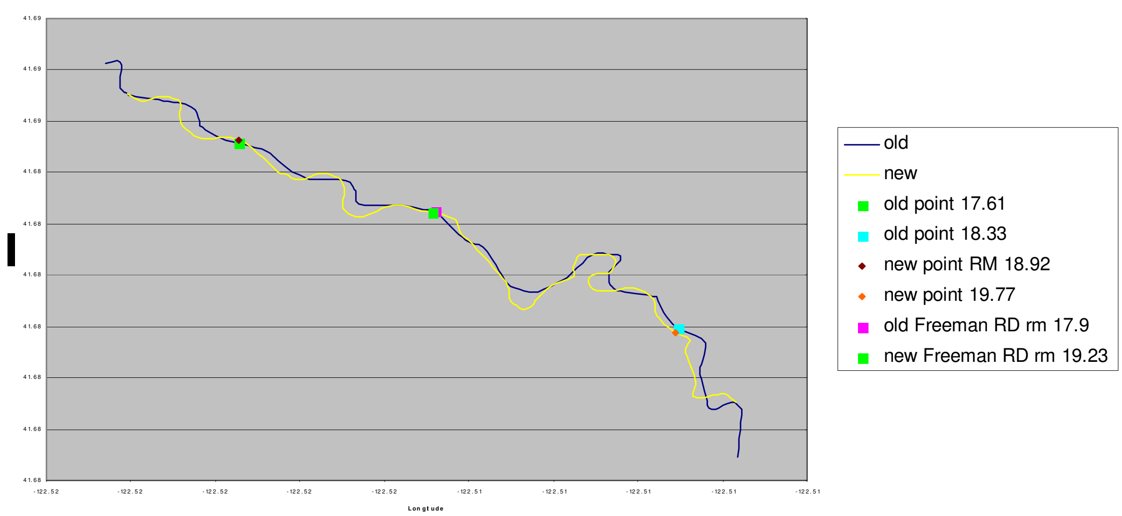


Figure 1. Comparison of old (Abbott, 2002) and new mapping from RM 18.92-19.77

Table 4. Locations of cross-sectional geometry in old (Abbott, 2002) and new river mile and longitude and latitude

Abbott's	Longitude	Latitude	Lamphear	Longitude	Latitude
2.34	-122.58880	41.80703	2.390	-122.58893	41.80704
3.14	-122.59678	41.81083	3.180	-122.59672	41.81070
3.92	-122.60814	41.80615	3.990	-122.60823	41.80618
5.50	-122.60977	41.79336	5.600	-122.61039	41.79384
6.27	-122.60195	41.78539	6.420	-122.60195	41.78545
7.07	-122.59689	41.78138	7.290	-122.59680	41.78142
7.85	-122.59271	41.77200	8.060	-122.59291	41.77195
8.56	-122.58140	41.76672	8.860	-122.58136	41.76597
9.22	-122.57933	41.75989	9.550	-122.57922	41.76000
9.93	-122.57854	41.75051	10.480	-122.57871	41.75033
10.60	-122.57117	41.74369	11.170	-122.57136	41.74368
14.72	-122.53742	41.70831	15.570	-122.53769	41.70829
15.43	-122.53141	41.70039	16.400	-122.53163	41.69973
16.19	-122.53000	41.69281	17.140	-122.52998	41.69283
16.88	-122.52908	41.68586	17.970	-122.52918	41.68587
17.61	-122.51944	41.68458	18.920	-122.51946	41.68464
18.33	-122.50904	41.68095	19.770	-122.50910	41.68087
21.95	-122.49798	41.64677	24.380	-122.49799	41.64631
22.45	-122.49552	41.64210	24.930	-122.49564	41.64239
24.97	-122.47882	41.62649	28.180	-122.47870	41.62645
25.97	-122.48253	41.61502	29.400	-122.48263	41.61502
26.47	-122.47710	41.61398	30.010	-122.47722	41.61392
26.98	-122.47343	41.60969	30.680	-122.47339	41.60974
27.95	-122.45782	41.60869	31.720	-122.45786	41.60855

3.2 Task 3b: Converting locations of estimated elevation to the Lamphear Hydrography

Elevations were converted from the original to the Lamphear hydrography using the same approach used to convert cross-sectional geometry. Abbott (2002) had taken elevation values from a USGS 1:24 K map at 26 locations. As above, locations in the Lamphear hydrography river mapping were matched by longitude and latitude and corrected, when appropriate, by visual inspection (Table 6 & Figure 2). Intermediate points were calculated using linear interpolation.

Table 5. River mile locations for bed elevations along the Shasta River

Abbott (2002) River Miles	Bed Elev. from USGS map (m)	Lamphear 2004 River Miles
0.05	620.00	0.05
0.87	630.00	0.89
1.78	640.00	1.81
2.53	650.00	2.58
3.44	660.00	3.51
4.34	670.00	4.42
4.90	680.00	4.97
5.38	690.00	5.47
6.03	700.00	6.20
6.48	710.00	6.66
7.02	720.00	7.24
8.35	730.00	8.61
11.35	740.00	11.95
12.30	745.00	13.08
14.99	750.00	15.88
16.36	755.00	17.33
19.29	760.00	20.88
21.83	765.00	24.14
25.10	770.00	28.32
30.04	780.00	33.86
32.02	790.00	36.07
32.33	795.00	36.41
33.21	800.00	37.40
34.84	810.00	39.11
35.55	820.00	39.82
36.06	830.00	40.35

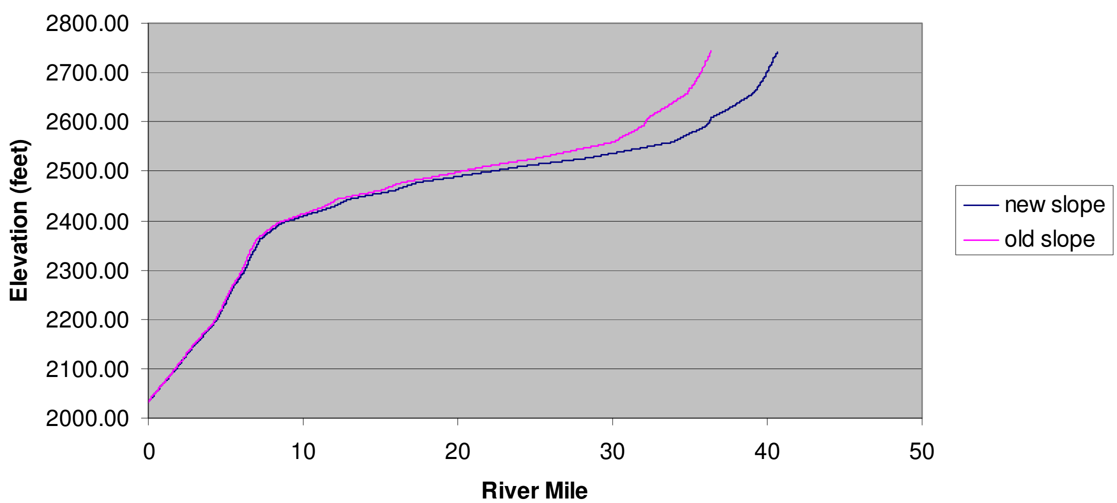


Figure 2. Shasta River slope with old (Abbott, 2002) and new geometry

3.3 Task 3c: Comparing cross-sections

The input geometry requires a cross-section at each node defined by

- a specified number of points,
- the distance of each point from the first designated point in the cross section, and
- the elevation at each point.

Cross-sections for the Lamphear hydrography were defined as in Abbott (2002). Specifically the cross-sections were assumed to be defined by five points with the third point centered from left to right bank and having the greatest depth (Figure 3). The river bank slopes (above the water surface) were assumed to be 1:1, and were extended upwards approximately 5 feet above the highest survey point to allow assessment of high flows (e.g., flows that would result in a water surface elevation above approximately 2144 ft msl in Figure 3). The channel bed and approximate river width was represented using the three interior points, with the lowest (middle) point representing a thalweg. Figure 4 shows the cross sectional area of flow and stage for a typical and a low flow condition. This "v-shaped" configuration was recommended by M. Bender (pers. comm.) to more effectively represent low flow conditions.

The elevation of the center point was taken to be the interpolated elevation calculated from the Shasta River bed elevation identified in Task 3b. The elevations of the two inner points were taken to be the bed elevation (at the center point) plus the measured depth. The elevations of the right and left banks were taken to be the two inner point elevations plus the right and left bank heights, respectively.

The Regional Board also made cross-sectional measurements in 2004. Comparisons of the Board's measured cross-sections generally showed good agreement, as indicated by the comparison of the model cross section and measured data at RM 2.77 (Figure 3). Because high flows (e.g., winter flood) were not modeled, over bank conditions were not an issue.

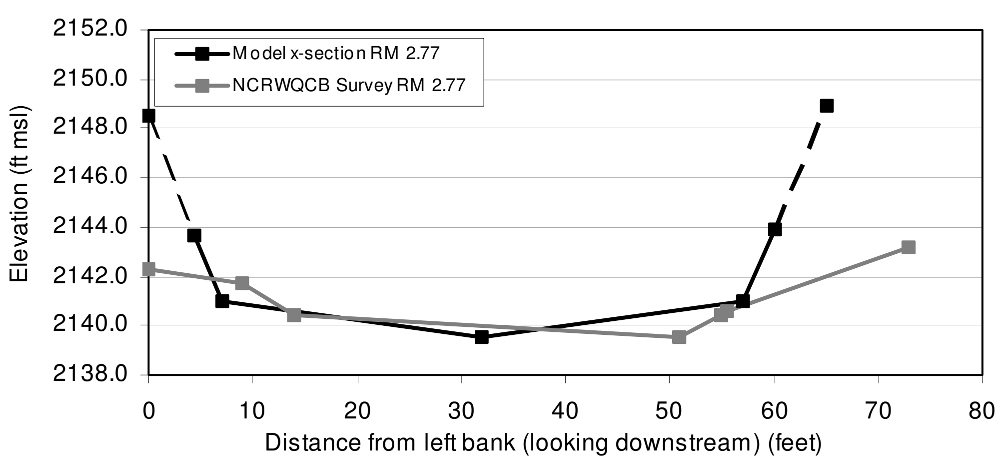
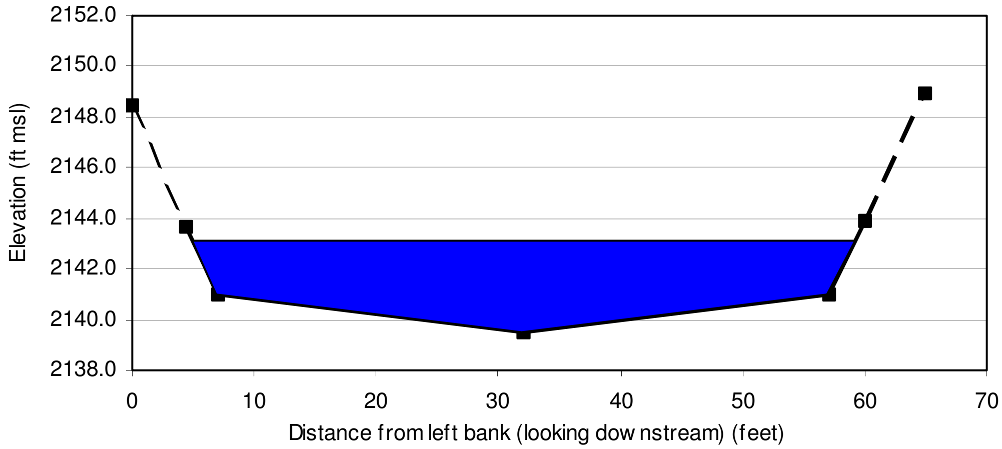
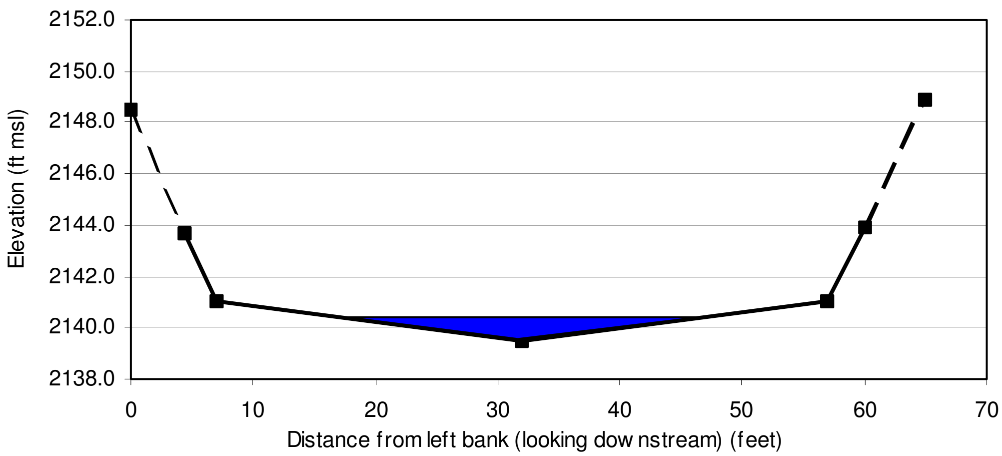


Figure 3. Sample RMS cross-section representation at RM 2.77 and measured cross section



(a)



(b)

Figure 4. Cross sectional flow area and stage for (a) typical and (b) low flow conditions for representative cross -section

3.4 Task 3d: Updating Model Node Locations in the Lamphear Hydrography

Information was available at increments of 0.01 miles in the Lamphear hydrography. This translates to 4168 points describing the river from Dwinnell Dam to the confluence with the Klamath River. In the previous model (Abbott, 2002) 438 nodes were used to describe the river. One limitation of the River Modeling System hydrodynamic model is that maximum number of nodes is 999. Thus, the total number of available points in the Lamphear hydrography had to be reduced by approximately one-quarter without losing significant overall river length. To minimize impact on river length, nodes were primarily removed from the straighter portions of the river, as shown in Figures 6 & Figure 7. Distance between nodes was never greater than seven times the distance between previous or subsequent pairs of nodes, in order to aid the ADYN numerical calculations. The final modeled river length was 39.05 miles, a reduction of 1.57 miles, or 3.9 %.

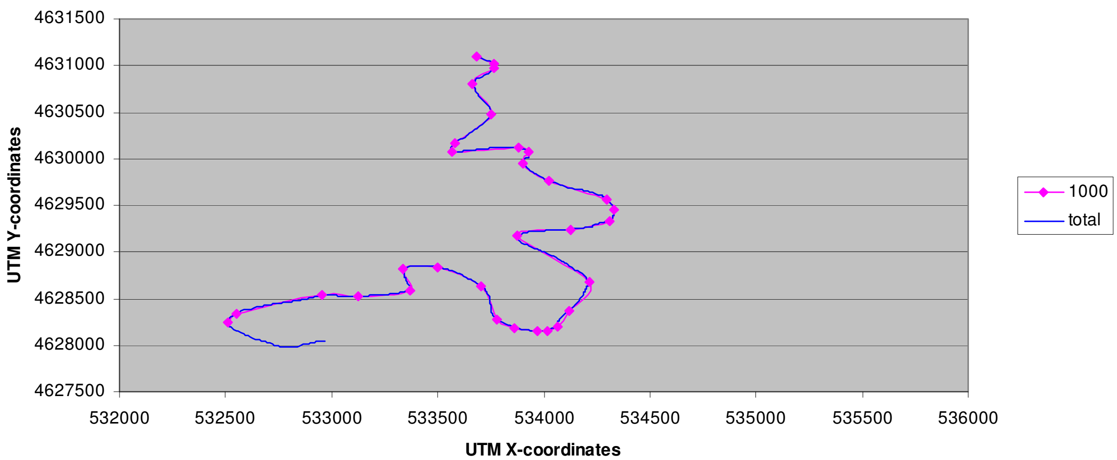


Figure 5. Nodes assigned to RM 0-5

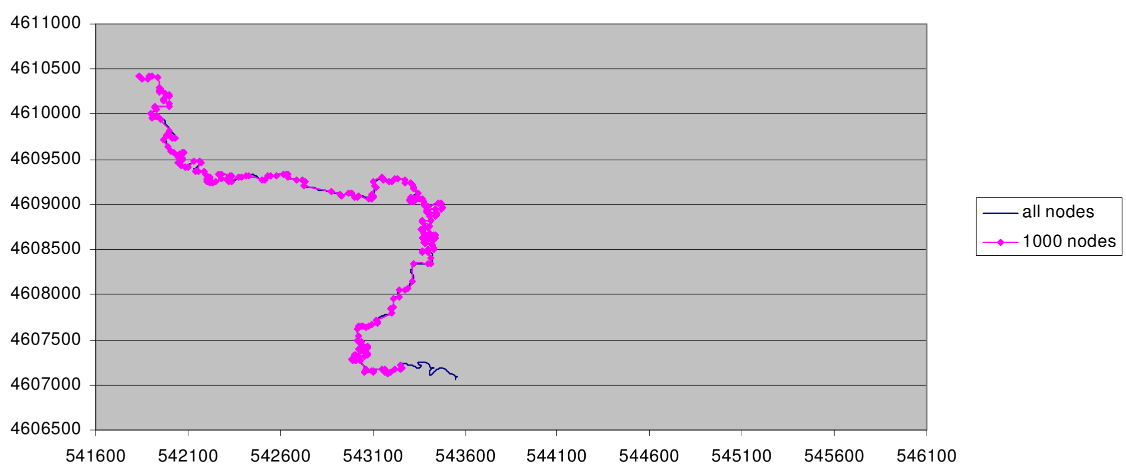


Figure 6. Nodes assigned to RM 25-30

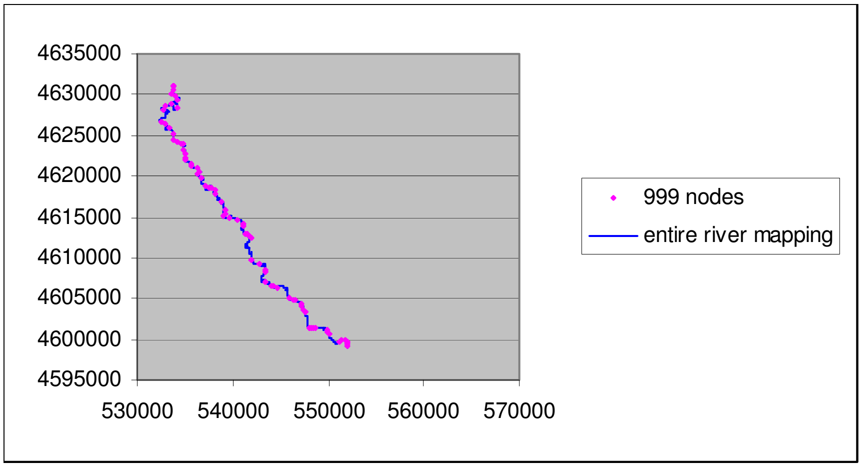


Figure 7. 999 nodes mapped along river

3.5 Task 3e: Calculating new river azimuths

New azimuths between model nodes representing the orientation of the river as it traverses the region from Dwinnell Dam to the confluence with the Klamath River were also calculated for the new river geometry. The method applied for calculating azimuths (in radians based on zero degrees being north) from longitude and latitude was:

$dy = lat_2 - lat_1$

$dx = long_2 - long_1$

if $dx > 0$, then radians from north = $\Pi/2 - atan(dy/dx)$

otherwise, radians from north = $3\Pi/2 - atan(dy/dx)$

where lat_1, $long_1$ and lat_2, $long_2$ refer to the latitude and longitude of adjacent model nodes.

3.6 Task 3f: Converting shading file

Riparian vegetation shading is represented in the model using various attributes, including tree height and solar radiation transmittance. These shade attributes are assigned for each node and can vary for the left and right river banks. Solar radiation transmittance is defined as the amount of solar radiation that passes through the tree canopy and reaches the water surface. A value of 1.0 represents no shade, a value of 0.0 would represent complete shade.

To transform the original shade file to the Lamphear hydrography, the percentage of total river length for each nodal interval was calculated for the original and new mapping and the transmittance was re-mapped by matching the transmittance value at the original percentage of total length to the same percentage of total length in the new mapping. The original shading file was also altered to limit transmittance of solar radiation to 50 percent, by a simple linear mapping. This was based on additional information on riparian transmittance. Lowney (2000) provides a discussion of riparian transmittance:

"Most of the solar radiation reaching the canopy is absorbed, the remainder is either reflected (scattered backward) or transmitted (scattered forward) towards the water surface. Monteith and Unsworth (1990) suggest that for a deep canopy of foliage, leaves absorb approximately 80 percent of incident radiation, reflect 10 percent, and transmit 10 percent. Attenuation of solar radiation by the forest canopy decays exponentially, strongly dependent on the leaf area index (LAI) – the plan area of leaves per unit ground area, and an extinction coefficient that characterizes orientation of individual leaves. Forest canopies are generally more efficient in absorbing solar radiation than other vegetative surfaces due to their increased surface irregularity and canopy density. Moreover, it is reasonable to assume that a well established riparian forest, particularly a diverse community will absorb more solar radiation than a single row of trees."

Lowney also identified an assumed transmittance rate, based on field measurements, of approximately 10 percent for full riparian forests, but higher values– between 15 and 25 percent – for riparian bands and strips. These values are consistent with Abbott (2002) for fully shaded reaches. However, additional discussions with Lowney (C. Lowney, pers. comm.) and others (Watercourse, 2002b) indicate that transmittance rates may be larger due to variability in the existence of woody riparian vegetation, incomplete tree canopy, the distance the trees are from the bank, relative health of the riparian vegetation, and other factors. Thus, maximum transmittance was set to 50 percent for calibration as a conservative estimate. Certain scenarios and applications may examine higher rates of solar radiation attenuation assuming high quality riparian vegetation conditions.

The shading file (.ris), constructed by Abbott (2002) was initially extended to Dwinnell Reservoir by assigning the shading input at the highest previous point (approximately Parks Creek at RM 31.83 in original geometry) to all upstream nodes up to Dwinnell Dam (RM 36.38 in original geometry). This assumption was maintained when the original geometry was mapped to the Lamphear hydrography, i.e., shading was maintained constant from approximately Parks Creek up to Dwinnell Dam – an assumption that is supported by both Deas et al (1997) and CWRCB (2005). Abbott (2002) provides detailed descriptions of the shading logic, input files, and other information.

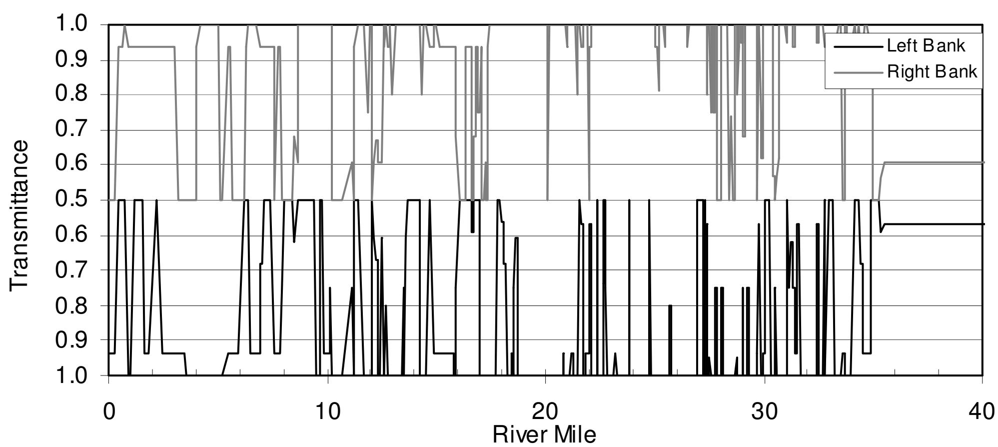


Figure 8. Longitudinal distribution of shade conditions on the Shasta River (tree height assumed 22 feet where present)

4.0 Task 4: Re-formatting the Hydrodynamic ADYN file

The TVA hydrodynamic model (ADYN) requires input of river geometry, boundary conditions for flow, and initial conditions for flow. The updated geometry was input as described above; however, the upstream inflow to the model domain as well as tributaries and other inputs and outputs was required.

The river was modeled as a single reach with 11 lateral inputs (or outflows). To develop the flow boundary conditions, the river was divided into sub-reaches based on the locations of flow measurement, major diversions, and tributaries. Major diversions and tributaries were modeled as point sources and the rest of the river was represented as sub-reaches with distributed accretions or depletions. The accretions/depletions were calculated using a water balance based on daily averages of measured flows over the reach:

(daily average flow at x_i)-(daily average flow at x_{i+1}) = accretion (+) or depletion (-)

where x_i represents the upstream end of the reach and x_{i+1} is the downstream end of the reach.

Where major diversions or tributaries with known flows fall within the reach, i.e., between locations x_i and x_{i+1}, they are included as point sources or sinks in the calculation of accretions and depletions:

(daily average flow at x_i)-(daily average flow at x_{i+1}) – spring inflow + diversion =

accretion (+) or depletion (-)

These accretions and depletions are entered for all days in the simulation. This approach is useful when manipulating specific sub-reaches, as in increasing flows in a single sub-reach or modifying water quality in a particular sub-reach. The various tributaries, diversions, and accretion/depletions are outlined in Table 6.

Initial conditions were developed by running the model with identical daily boundary conditions for 8 days to create a steady state condition. This steady streamflow condition forms the initial conditions for model simulations, and are presented in Task 6.

5.0 Task 5: Formatting the Water Quality RQUAL files

5.1 Task 5a: Boundary condition file (.rib)*

Boundary conditions for RQUAL consist of a headwater condition, point inputs, and distributed inputs. Generally, temperature and DO data vary hourly, while CBOD, and NBOD are maintained constant. The locations, river mile, and boundary condition type are shown in Table 6. Hwy A-12 and DWR weir are included as benchmarks.

Table 6. Hydrodynamic input locations and types

Name	Abbreviation	River Mile	Boundary Condition Type
Dwinnell Dam	DWIN	40.62	Headwater
Riverside Drive	RIV	39.94	Point
Parks Creek	PKS	34.94	Point
Big Springs	BIGS	33.71	Point
Grenada Irrigation District (GID)	GID	30.59	Diversion
GID to Hwy A-12	G-A12	27.35	Distributed
	A12*	24.11	n/a
Hwy A-12 to Freeman Lane	A-SRF	21.60	Distributed
Shasta Water Users Association	SWUA	17.85	Diversion
Freeman Lane to DWR Weir	S-DWR	17.32	Distributed
	DWR*	15.52	n/a
DWR Weir to Yreka Ager Rd	DWR-Y	13.26	Distributed
Yreka Ager Rd to Anderson Grade	Y-AND	9.58	Distributed
Yreka Creek	YREKA	7.88	Point

* These boundary condition locations are included in the model input files for testing, but not used in the calibration or production simulations

5.1.1 Temperature

The water quality component of the TVA model (RQUAL) uses the heat budget approach that quantifies pertinent factors by formulations based on physical processes.
The heat budget approach quantifies the net exchange of heat at the air-water interface. TVA has extended the approach to also include heat exchange at the water-bed interface. This net change may be expressed as the sum of the major sources and sinks of thermal energy or the sum of the heat fluxes.
TVA Heat Budget Formulation

$$Q_n = \frac{Q_{ns} + Q_{na} + Q_{bed} - Q_b - Q_e - Q_c}{D}$$

where:

Q_n = the net heat flux (representing the rate of heat released from or added to storage in a particular volume) ($kcal/m^3s$)
Q_{ns} = net solar (short-wave) radiation flux adjusted for shade ($kcal/m^2s$)
Q_{na} = net atmospheric (long-wave) radiation flux ($kcal/m^2s$)
Q_{bed} = net flux of heat at the water- channel bed interface ($kcal/m^2s$)
Q_b = net flux of back (long-wave) radiation from water surface ($kcal/m^2s$)
Q_e = evaporative (latent or convective) heat flux ($kcal/m^2s$)
Q_c = conductive (sensible) heat flux ($kcal/m^2s$)
D = mean depth (m).

For a more complete discussion of the heat budget terms, the reader is referred to Abbott (2002).

In addition to heat exchange at the air-water and bed-water interface, heat energy can enter and leave the river system via inputs (e.g., tributaries) and outputs (e.g., diversions).

Temperature boundary conditions can be entered for both point sources and distributed sources. For the point sources, values are input at the designated river mile. For the distributed sources, temperature values are input over the same reach as the distributed flow is applied. Outflows are assumed to leave the river at the temperature of the river at the identified location.

Because available temperature measurements at Parks Creek and Shasta above Parks were limited, hourly temperature measurements at Louie Road were used as input for the upstream boundary condition (Dwinnell Dam), Riverside Drive, and Parks Creek. Temperature was input for each hour of the simulation.

Absent water temperature data from Big Springs Creek, several water temperatures data sets were explored. Initially data from the Shasta River at Grenada Irrigation District was applied after Abbott (2002). However, review of this temperature signal indicated that the diurnal phase was lagged, peaking late in the evening, compared with other locations on the river. Sensitivity testing with the model indicated that this lag may have been associated with impoundment of the river at the GID diversion. Subsequently, data from the Shasta River at Hwy A-12 were applied as the boundary condition at Big Spring Creek because there was not a lag at Highway A-12. Further investigation of Regional Board data indicated that the lag in diurnal temperatures occurs above the GID impoundment (Figure 9), suggesting that the springs complex associated with Big Springs or other springs, and possibly water resources development (e.g., irrigation schedules and operations) lead to this signal. Thus, temperatures from GID were ultimately used as the boundary conditions at Big Spring Creek. Because there is a lack of site specific data for Big Springs Creek (for flow, water temperature and other parameters) it is important to consider this boundary condition when assessing alternatives that alter Big Springs inflow temperature.

Temperatures for all accretions between GID and Anderson Grade were assigned the temperature at Anderson Grade. This decision was based on review of temperature data from 2001 and 2002 which indicated that temperatures were approaching equilibrium temperature by the end of the Shasta Valley (i.e., near Anderson Grade). Lacking any time series data for return flows, it was assumed that irrigation return flows would be near equilibrium temperature, and thus Anderson Grade time series data was used as a surrogate. Temperature boundary conditions are shown in Figure 10.

5.1.2 Dissolved Oxygen, NBOD, CBOD

Dissolved oxygen, carbonaceous biochemical oxygen demand (CBOD), and nitrogenous biochemical oxygen demand (NBOD) are represented are represented in the RQUAL model. The time varying representation of dissolved oxygen is represented as

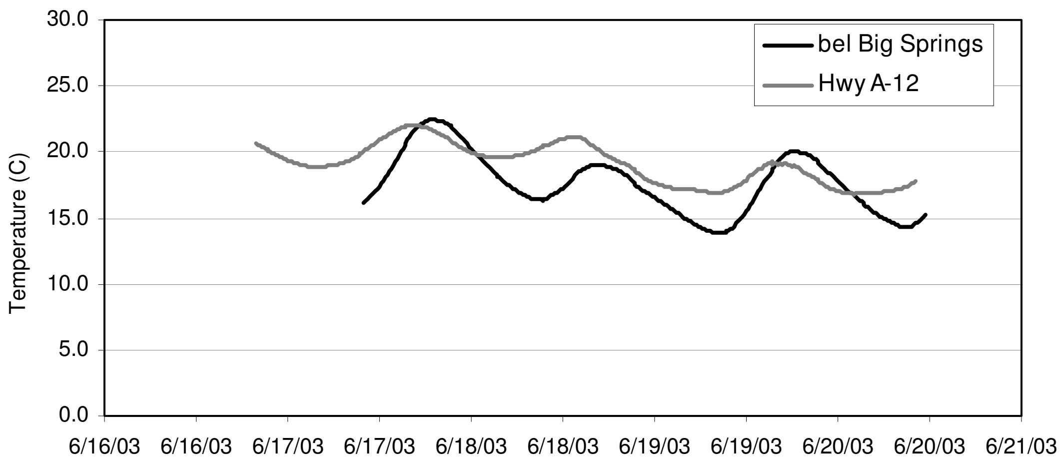
$$\Sigma[\partial O/\partial t] = K_2(O_s\text{-}O)\text{-}K_dL\text{-}K_nN+(P\text{-}R\text{-}S)/D$$

Where

t = time (s)

O = dissolve oxygen concentration (mg/l)

O_s = saturation dissolve oxygen concentration (mg/l) (based on elevation and water temperature (See TVA, 2001))
K_2 = reaeration rate based on one of several methods (see TVA, 2001), temperature corrected (1/s)
K_d = CBOD deoxygenation rate, temperature corrected (1/s)
L = CBOD concentration (mg/l)
K_n = NBOD deoxygenation rate, temperature corrected (1/s)
N = NBOD concentration (mg/l)
P = Photosynthetic rate of macrophytes ($gO_2/m^2/s$)
R = Respiration rate of macrophytes ($gO_2/m^2/s$)
S = Sediment oxygen demand ($gO_2/m^2/s$)
D = mean depth (m)



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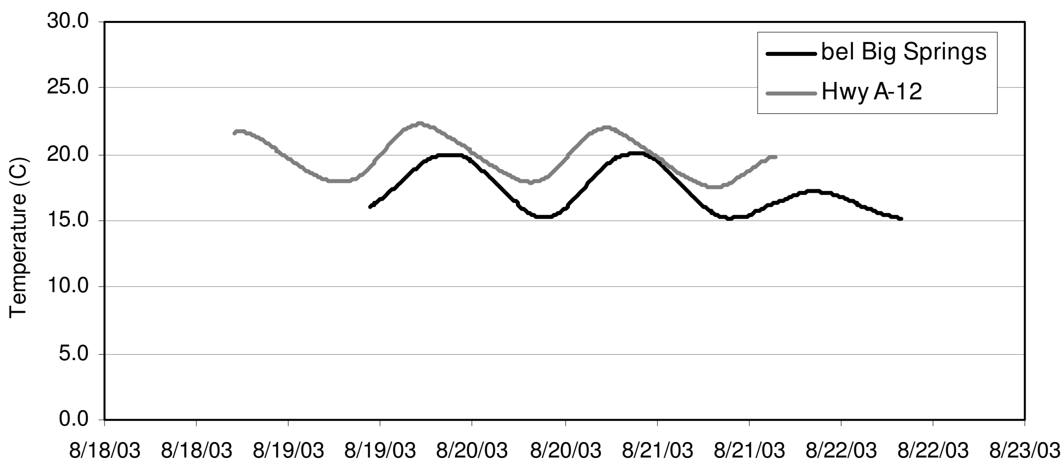
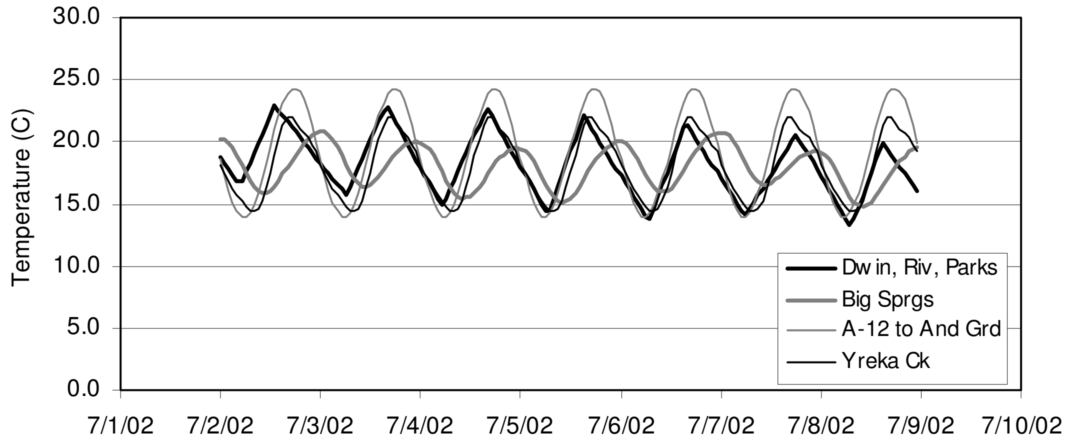


(b)

Figure 9. Observed water temperature for the Shasta River at Highway A-12 and below Big Springs Creek (CRWQCB, 2004)



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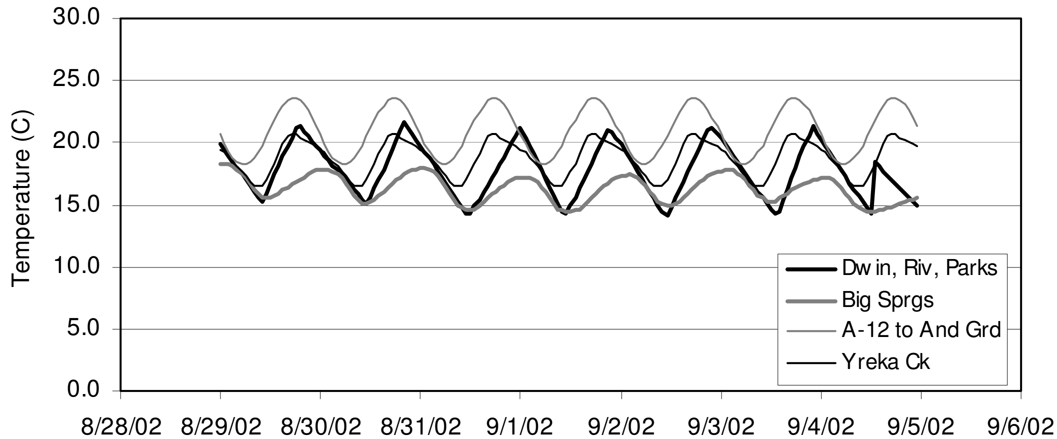

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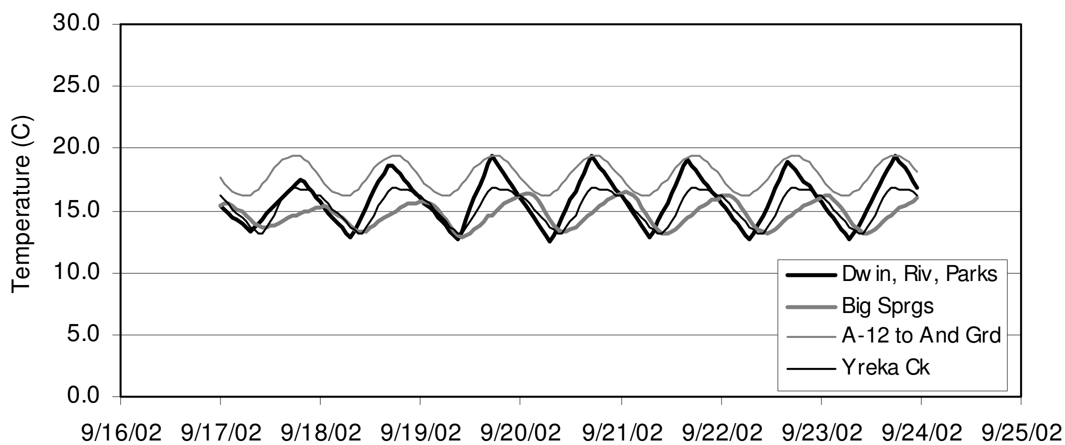


(c)

Figure 10. Water temperature boundary conditions for the July, August-September, and September calibration periods

CBOD and NBOD are both represented as firth order decay:

$$\Sigma[\partial L/\partial t] = -(K_d+K_s)/L$$

and

$$\Sigma[\partial N/\partial t] = -K_nN$$

Where

K_s = CBOD settling rate (no oxygen demand exerted) (1/s)
and t, L, N, K_d, K_n are defined previously.

Note, the units of time represented in the above equation may differ from the model required input values. For example, although all temporal units identified above are represented in seconds, model input decay rates are 1/day.

Sediment oxygen demand and macrophyte photosynthesis and respiration are discussed separately under initial conditions and water quality coefficients, below, because they are specified by the user and are not simulated state variables.

Dissolved oxygen, CBOD, and NBOD boundary conditions were applied at the same locations as temperature.

Dissolved Oxygen

Dissolved oxygen data was unavailable at all boundary conditions for the calibration and validation periods. Thus, all DO boundary conditions were estimated using saturation concentration based on water temperature and atmospheric pressure (based on the elevation of the Shasta Valley):

$$\text{saturated DO (mg/L)} = \exp((-139.34411)+(1.575701\text{x}10^5/T)-(6.642308\text{ x}10^7/T^2)+(1.2438\text{ x}10^{10}/T^3)-(8.621949\text{ x}10^{11}/T^4))$$

where water temperature, T, is in degrees Kelvin. Boundary conditions are represented graphically in Figure 11.

CBOD

Based on NCRWQCB data CBOD boundary conditions were generally non-detect (less than 2 mg/L). There were 3 values of $CBOD_5$ above the detection limit: 3.5 mg/L at Yreka-Ager Road on August 19, 2003, 3.4 mg/L at Riverside Drive on August 19, 2003, and 15.0 at Riverside Drive on August 20, 2003. Boundary conditions were estimated at 3.5 mg/L because all boundary condition locations either lacked data or were below the assumed detection limit. The model requires CBODu, and Hauser (2002) notes that $CBOD_u$ is usually 1.5 to 3 time $CBOD_5$. CBODu was assumed equal to 5 mg/l for this application for all boundary conditions for all simulation periods.

NBOD

There was appreciably more nitrogen information to estimate NBOD boundary conditions. Chapra (1997) estimates NBOD based on total Kjedahl nitrogen (TKN):

$$\text{NBOD (mg/L)} = 4.57*\text{TKN (mgN/L)}$$

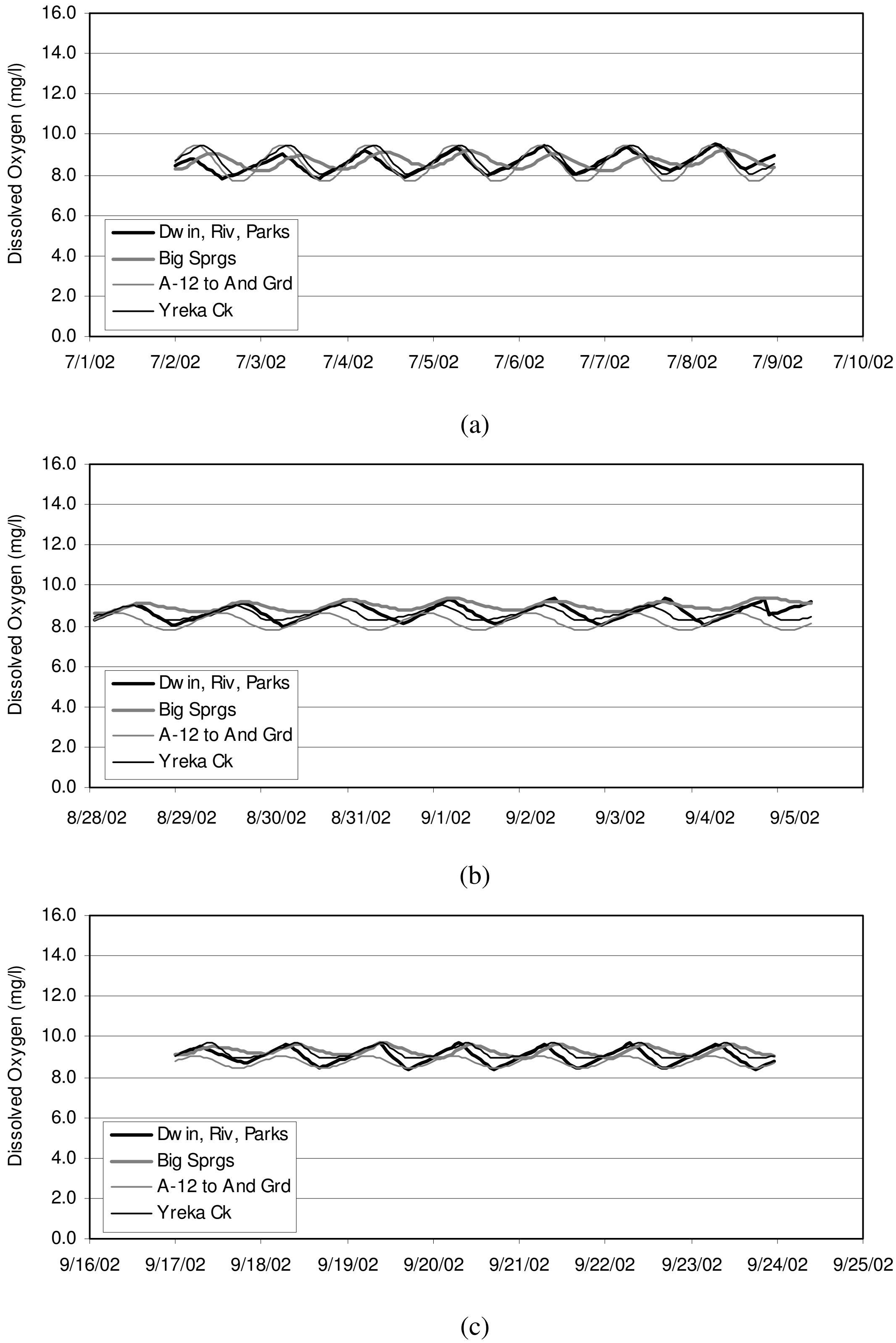


Figure 11. Dissolved oxygen boundary conditions for the July, August-September, and September calibration periods

The boundary conditions for NBOD were based on TKN values (Table 7). The NBOD values used for boundary conditions were 2.74 mg/l for Dwinnell Dam, Riverside Drive and Parks Creek; 0.91 mg/l for Big Springs Creek; 5.53 mg/l for accretions between Highway A-12 and Anderson Grade (based on limited tailwater return flows data), and 1.33 mg/l for Yreka Creek (Figure 12).

Table 7. Available CBOD and TKN data

Location	Metric	BOD_5 (mg/L)	TKN (mg N/L)
Dwinnell Dam[a]	Minimum	ND	ND
	Maximum	15.0	1.2
	Average	5.35	0.57
	Median	2.45	0.60
	Count	4	39
Big Springs[b]	Minimum	ND	ND
	Maximum	ND	ND
	Average	NA	NA
	Median	NA	NA
	Count	3	3
Tailwater Return Flow / Distributed Flow[c]	Minimum	1.5	0.3
	Maximum	7.0	3.9
	Average	2.7	1.2
	Median	2.0	0.9
	Count	11	15
Yreka Creek[d]	Minimum	ND	ND
	Maximum	ND	0.75
	Average	NA	0.29
	Median	NA	0.20
	Count	2	28

ND = Non Detect
NA = Not Applicable
[a] Dwinnell Dam outflow data collected from 1995 through 2003 by CRWQCB and DWR at Riverside Drive.
[b] Big Springs data collected in 2003 at Big Springs Lake outflow by CRWQCB.
[c] Tailwater return flow data collected in 2003 by CRWQCB.
[d] Yreka Creek data collected from 1999 though April 2005 by City of Yreka, CRWQCB, and DWR at Anderson Grade Road and Nursery Bridge.

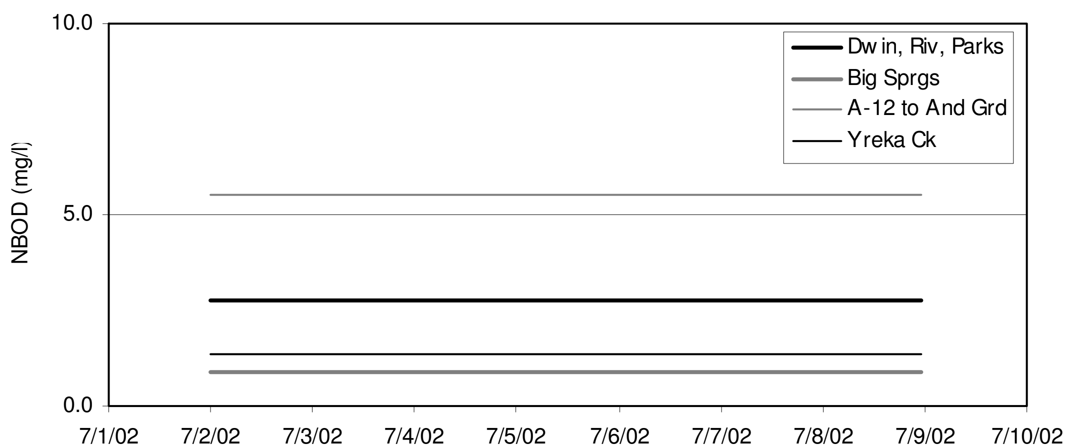


Figure 12. NBOD boundary conditions for the July, August-September, and September calibration periods (same for all periods, only July presented)

5.2 Task 5b: Meteorology file (*.rim)

The meteorology input requires cloud cover, dry bulb temperature, dew point temperature, barometric pressure, wind speed, and short wave solar radiation. The raw data from Brazie Ranch provided dry bulb temperature, wind speed, solar radiation, and relative humidity for the calculation of dew point temperature. Dew point temperature was calculated after Chapra (1997) as:

$$DPT\ (C) = 237.3B/(1-B)$$

where

$B = \ln(e/6.108)/17.27$

e = vapor pressure (mb) = $RH^*e_s/100$

where

RH = relative humidity (%)

e_s = saturation vapor pressure (mb) = $e_s = 6.108 \exp[17.27T/(T+237.3)]$

T = Air temp (C)

Cloud cover was set to zero for the modeled periods, which is a typical condition for late spring through early fall periods. Barometric pressure was estimated based on local elevation to be constant at 930.41mb.

5.3 Task 5c: Water quality coefficients and initial conditions file (*.ric)

The model requires a wide range of water quality coefficients as well as initial conditions, e.g., numerical solution scheme for RQUAL; initial conditions for temperature, DO, CBOD, and NBOD; water quality coefficients and rate constants; and river azimuths. Outlined herein are final model parameter and coefficient values, specification of sediment oxygen demand rates (CRWRCB, 2004c), determination of maximum photosynthetic and respiration rates (CRWRCB, 2005) associated with primary production, and initial conditions. Initial conditions are constant for the entire river. Model results for the first day or so should be discarded because they retain the characteristics of the initial conditions.

5.3.1 Rates, Constants, Coefficients and Other Model Parameters

Pertinent model input parameter names, description, value, and pertinent notes are presented in Table 8.

Table 8. Input parameters for .ric file

Coefficient	Description	Value	Notes & Reference
PRT	print interval for standard output file (hrs)	1.0	hours
IPLT	flag to create plot file	1	1 = yes
THET	spatial derivative weighting factor for 4-point implicit scheme	0.55	range is 0.5-0.6. (p. 114 of User Guide)
TSI	model testing coefficient	1.0	recommended value p. 97 of User Guide
PLT	plot file interval (hrs)	1.0	
NSCH	numerical solution scheme	H	Holly-Priessman scheme for shallow or deep water
PDC	Holly-Priessman numerical scheme limit on C	0.01	recommended by User Guide for stability
PDCX	Holly-Priessman numerical scheme limit on dC/dx	-1	recommended by User Guide for stability
IRS	flag for shading file Abbott (2002)	1	1 = include shading
PHI	latitude of river (decimal degrees)	41.875	Abbott (2002) p. 68
ALON	longitude of river (decimal degrees)	122.630	Abbott (2002) p. 68
TFOG	time of morning fog lift	6.00	Abbott (2002) p. 68
BW	bank width (ft) from river edge to barrier at above river mile	0.0	Abbott (2002) p. 155
AA	coefficient in wind speed function (m^3/mb/s) for evaporative cooling (ψ = aa + bb*wind)	1.0E-9	Calibrated value range = 0E-9 to 4E-9 p. 102 of User Guide
BB	coefficient in wind speed function (m^2/mb) for evaporative cooling (ψ = aa + bb*wind)	1.5E-9	Calibrated value range = 1E-9 to 3E-9 p. 102 of User Guide
XL	effective channel bed thickness of upper layer for bed heat conduction (cm)	10	recommended value p. 102 of User Guide
XL2	effective channel bed thickness of deep layer (cm)	50	recommended value p. 102 of User Guide
DIF	thermal diffusivity of bed material (cm^2/hr)	27.7	recommended value and chosen based on calibration. (range 25 to 50)
CV	bed heat storage capacity (cal/cm^3°C)	0.68	recommended value p. 102 of User Guide
BETW	fraction of solar radiation absorbed in surface 0.6 m of water	0.4	recommended value p. 102 of User Guide
BEDALB	albedo of bed material	0.25	recommended value p. 103 of User Guide
SHDBT	fraction of drybulb/dewpoint depression by which dry bulb is cooler over shaded water	0.5	recommended value p. 103 of User Guide
THR	temperature correction coefficient for reaeration	1.024	Chapra (1997) p.41, User Guide p. 104
THB	temperature correction coefficient for CBOD decay	1.047	Chapra (1997) p.41, User Guide p. 104
BK20	deoxygenation rate at 20°C for CBOD (1/day)	0.2	Chapra (1997) p. 357-358
THN	temperature correction coefficient for NBOD decay	1.09	User Guide p. 104
NK20	deoxygenation rate at 20°C for NBOD (1/day)	0.2	Chapra (1997) p. 424-425 RANGE 0.1-0.5 day^{-1}. For shallow streams, can be > 1
THS	temperature correction coefficient for SOD	1.065	user guide p. 104 Chapra (1997) p.41 gives 1.08,
EXCO	light extinction coefficient (1/m)	0.1	range 0.05-0.3; 0.05 clean water; 0.3 turbid water; (user's guide p.104).
HMAC	average weed height from bottom of channel (ft)	1.0	range of weed height 1-3 feet (User Guide, p. 104)
THPR	temperature correction coefficient for macrophyte photosynthesis and respiration	1.08	user guide p. 104
IK2E	flag for reaeration equation choice	3	see p. 104 User Guide. Owens formulation was chosen because it was developed for shallow rivers.
BS20	CBOD settling rate (1/day)	0.656	Calculated as $K_s = v_s$/depth assume v_s = 0.3 m/d (Chapra (1997) p. 358 provides a range of 0.1-0.5 m/d). Avg depth of river : 1.5 ft

Table 8 (cont.) Input parameters for .ric file

Coefficient	Description	Value	Notes & Reference
SFAC	factor to multiply all SK20 in reach to test sensitivity	1.0	p.108 User Guide
PFAC	factor to multiply all PMAX20 in reach to test sensitivity	1.0	p.109 User Guide
PMAX20	photosynthetic rate for attached algae (gO_2/m^2/hour)	See below	See below
RFAC	factor to multiply all RESP20 in reach to test sensitivity	1.0	p.110 User Guide
RESP20	attached algae respiration rate (gO_2/m^2/hour)	See below	See below
User Guide refers to Hauser, G.E. and G.A. Schohl, 2002			

5.3.2 Sediment Oxygen Demand

To represent the spatial variability in sediments that may yield oxygen demand, the sediment oxygen demand rate at 20°C (SK20) was based on USGS (2004) studies and qualitative field mapping of sediments completed by the North Coast Regional Water Quality Control Board. The results are provided in Table 9. These rates are temperature corrected in RQUAL.

Table 9. Spatial Distribution of sediment oxygen demand (input parameter SK20)

River Mile	SOD rate (gO_2/m^2/day)
40.62	0.2
39.94	0.2
38.65	0.5
32.03	0.5
30.65	2.0
27.50	0.2
25.79	0.1
24.10	0.1
19.11	0.1
17.78	2.0
15.40	1.5
14.68	1.5
13.74	1.5
13.16	2.0
12.50	0.2
11.10	0.2
10.69	0.2
8.65	0.2
6.42	0.1
1.05	0.1
0.72	0.1
0.00	0.1

Based on field work and qualitative distribution of sediments completed by the North Coast Regional Water Quality Board

5.3.3 Photosynthetic and Respiration Rates

Extensive sampling and observation of the types and quantities of attached algae and macrophytes in the Shasta River were undertaken in 2004 by the CRWQCB (2005). However, light and dark bottle tests were not performed, so explicit values for photosynthetic rate were not available. The qualitative information provided by the NCRWQCB (Table 10) provided a mapping of rates along the river based on the following algal densities:

- 0-10% low coverage
- 11-60% medium coverage
- 61-100% high coverage

Table 10. Qualitative reach description of benthic algae cover and relative coverage

Reach	% Benthic Cover	River Mile		Relative Coverage
(NCRWQCB descriptor)		From	To	
Riverside	35	39.27	40.47	med
Hidden Valley	75	32.06	39.27	high
E. Louie Road	70	30.57	32.06	high
u/s GID	85	25.85	30.57	high
d/s GID	40	24.11	25.85	med
15 - u/s A12	10	22.14	24.11	low
14 - A12 to DeSoza	15	16.08	22.14	med
De Soza to Brecada	70	14.74	16.08	high
Brecada to u/s Big Bend	10	13.8	14.74	low
Big Bend	90	13.31	13.8	high
d/s Big Bend to u/s Hwy3	30	12.63	13.31	med
u/s Hwy3 to impoundment	70	12.24	12.63	high
d/s impoundment - short reach	20	11.73	12.24	med
d/s impoundment to Y-A Rd	15	10.9	11.73	med
Y-A Rd to riparian	95	10.56	10.9	high
riparian to 263	50	6.36	10.56	med
263 to d/s Pioneer Bridge	5	4.23	6.36	low
d/s Pioneer Bridge to u/s gage	25	4.05	4.23	med
gage to mouth	5	0	4.05	low

Mapping the Results to the Algae Study

Maximum photosynthesis rates, P_{max}, for each section of the river were derived from calibration. Photosynthesis by most freshwater benthic algae is a non-linear function of light intensity. At low irradiances, photosynthetic rate increases linearly with increasing light, and appears to be limited primarily by the number of photons captured by photosynthetic pigments. At mid-level irradiances, photosynthesis begins to level off as light becomes saturating. The maximum rate of photosynthesis, whether reached asymptotically (no photoinhibition) or as a peak (photoinhibition), is referred to as Pmax.

Three sites, representing the three levels of relative coverage, were chosen primarily on the basis of available dissolved oxygen observations. These sites included Shasta near

Mouth, Shasta at Hwy3, and DWR Weir, representing low, medium, and high levels of observe coverage. During calibration, P_{max} was adjusted to best fit available data at each site. For simplicity, only one value of P_{max} was derived for each of the three sites. The sites and derived values of P_{max} are presented in Table 11.

Table 11. Calibrated P_{max} values

Location	RMI	Calibrated ($g\ O_2/m^2/hour$)
DWR	15.52	3.15
Hwy3	13.2	2.36
Mouth	0.66	1.20

These calibrated values of P_{max} were then applied to the entire river according to the distribution of benthic algae coverage observed by NCRWQCB. This distribution is presented in Table 12 and shown in Figure 13 in the following section.

RQUAL model does not explicitly model algal growth. Rather the user specifies standing crop that can vary in space and per simulation period (e.g., the standing crop can vary among the July, August, and September period). Respiration was assumed to equal 20 percent of P_{max} for July and August when standing crop is close to the seasonal high. However, for late September, the respiration was reduced by 50 percent to represent a smaller standing crop in the fall period. P_{max} and respiration (at 20^oC, RQUAL corrects for temperature) inputs for each of the three periods simulated are provided in Table 13, below.

5.4 Task 5d: Shade file (.ris)

The shade file is an addition to the RQUAL program (Abbott, 2002). It allows for varied solar transmittance along the length of the river in response to riparian vegetation, and was modified for this recent modeling effort as described previously. The input for tree height was 22 feet at all nodes where vegetation was identified as present (Deas et al, 1997), which is the average tree height (Abbott, 2002). The longitudinal distribution of shade conditions on the Shasta River is presented in Figure 8 in Section 3.6.

Table 12. Calibrated P_{max} values assigned to NCRWQCB reaches

Reach	Benthic Cover	River Mile		Relative Coverage	P_{max} $gO_2/m^2/hour$
(NCRWQCB Descriptor)	%	From	To		Calibrated
Riverside	35	39.27	40.47	med	2.36
Hidden Valley	75	32.06	39.27	high	3.15
E. Louie Road	70	30.57	32.06	high	3.15
u/s GID	85	25.85	30.57	high	3.15
d/s GID	40	24.11	25.85	med	2.36
15 - u/s A12	10	22.14	24.11	low	1.20
14 - A12 to DeSoza	15	16.08	22.14	med	2.36
De Soza to Brecada	70	14.74	16.08	high	3.15
Brecada to u/s Big Bend	10	13.8	14.74	low	1.20
Big Bend	90	13.31	13.8	high	3.15
d/s Big Bend to u/s Hwy3	30	12.63	13.31	med	2.36
u/s Hwy3 to impoundment	70	12.24	12.63	high	3.15
d/s impoundment - short reach	20	11.73	12.24	med	2.36
d/s impoundment to Y-A Rd	15	10.9	11.73	med	2.36
Y-A Rd to riparian	95	10.56	10.9	high	3.15
riparian to 263	50	6.36	10.56	med	2.36
263 to d/s Pioneer Bridge	5	4.23	6.36	low	1.20
d/s Pioneer Bridge to u/s USGS gage	25	4.05	4.23	med	2.36
USGS gage to mouth	5	0	4.05	low	1.20

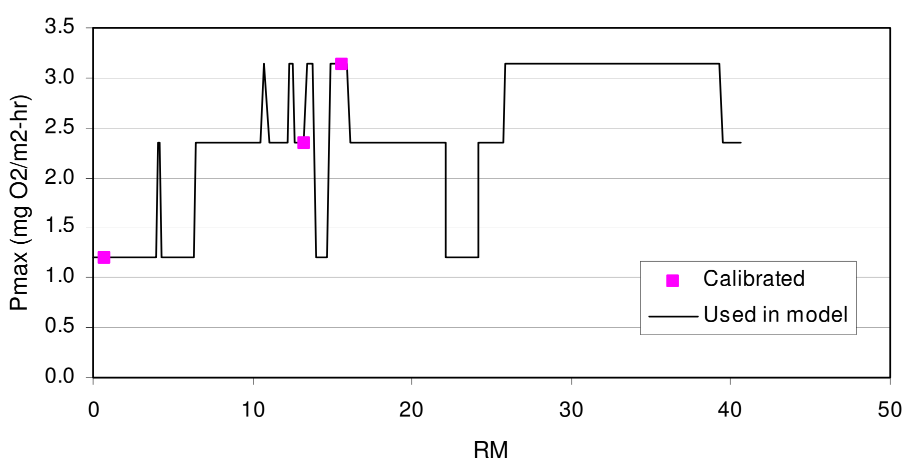


Figure 13. Calibrated values of Pmax distributed by observed coverage along the Shasta River by river mile (RM)

Table 13. The spatial distribution of Pmax and respiration values for the July, August, and September simulation periods

River Mile	July 2-8		Aug 29-Sep 4		Sep 17-23	
	PMAX20	RESP20	PMAX20	RESP20	PMAX20	RESP20
40.62	2.36	0.48	2.36	0.48	2.36	0.24
39.51	2.36	0.48	2.36	0.48	2.36	0.24
39.26	3.15	0.64	3.15	0.64	3.15	0.32
25.85	3.15	0.64	3.15	0.64	3.15	0.32
25.79	2.36	0.48	2.36	0.48	2.36	0.24
24.11	2.36	0.48	2.36	0.48	2.36	0.24
24.10	1.20	0.24	1.20	0.24	1.20	0.12
22.14	1.20	0.24	1.20	0.24	1.20	0.12
22.13	2.36	0.48	2.36	0.48	2.36	0.24
16.11	2.36	0.48	2.36	0.48	2.36	0.24
15.91	3.15	0.64	3.15	0.64	3.15	0.32
14.88	3.15	0.64	3.15	0.64	3.15	0.32
14.68	1.20	0.24	1.20	0.24	1.20	0.12
13.99	1.20	0.24	1.20	0.24	1.20	0.12
13.79	3.15	0.64	3.15	0.64	3.15	0.32
13.40	3.15	0.64	3.15	0.64	3.15	0.32
13.26	2.36	0.48	2.36	0.48	2.36	0.24
12.63	2.36	0.48	2.36	0.48	2.36	0.24
12.58	3.15	0.64	3.15	0.64	3.15	0.32
12.27	3.15	0.64	3.15	0.64	3.15	0.32
12.16	2.36	0.48	2.36	0.48	2.36	0.24
11.10	2.36	0.48	2.36	0.48	2.36	0.24
10.69	3.15	0.64	3.15	0.64	3.15	0.32
10.55	2.36	0.48	2.36	0.48	2.36	0.24
6.42	2.36	0.48	2.36	0.48	2.36	0.24
6.34	1.20	0.24	1.20	0.24	1.20	0.12
4.30	1.20	0.24	1.20	0.24	1.20	0.12
4.19	2.36	0.48	2.36	0.48	2.36	0.24
4.05	2.36	0.48	2.36	0.48	2.36	0.24
3.98	1.20	0.24	1.20	0.24	1.20	0.12
0.00	1.20	0.24	1.20	0.24	1.20	0.12

6.0 Task 6: Calibration and Validation

Model calibration and validation for flow, temperature, and dissolved oxygen was completed for several discrete periods of time. The calibration period was 9/17/2002-9/23-2002 and the validations periods were 7/02/2002-7/08/2002 and 8/29/2002-9/04/2002. Model parameters were set during calibration and these values were retained during validation.

6.1 Flow

Representation of stream flows, as well as calibration procedures, are discussed in detail in the previous modeling memo (Deas and Geisler, 2004). The principal parameter adjusted for flow calibration was Manning's roughness coefficient, n[2]. Figures Figure 14 through Figure 17, below, include simulated versus measured flow for several locations along the Shasta River for the calibration period. Daily trends are well represented; however, sub-daily deviations are apparent. These deviations are due to the daily water balance completed on a reach basis and do not account for intra-reach operations (diversions and return flows). Sub-daily deviations (e.g., hourly) are due to the averaging to daily values in completing the water balance exercise. Statistical summaries for each location are provided in Table 14 through Table 16. The root mean squared error (RMSE) for all locations is less than 3.0 cfs, with a mean absolute error (MAE) of less than 2.25 cfs.

Validation results for the 7/02/02-7/08/02 and 8/29/02-9/04/02 period are shown in Figure 18 through Figure 21 and Table 15, and Figure 22 through Figure 25 and Table 16, respectively. For the June period the RMSE and MAE is less than 4.5 cfs and 3.54 cfs, respectively. Late August and early September period flow statistics for RMSE and MAE were 2.78 cfs and 2.32 cfs, respectively.

In all cases model performance at the mouth showed the larges error statistics. Presumably the accumulation of uncertainty in return flows and diversions (both in space and time) in the downstream direction contribute to model performance. Overall these deviations are on the order of uncertainty associated with flow measurement in a system such as the Shasta River (USGS, 2005).

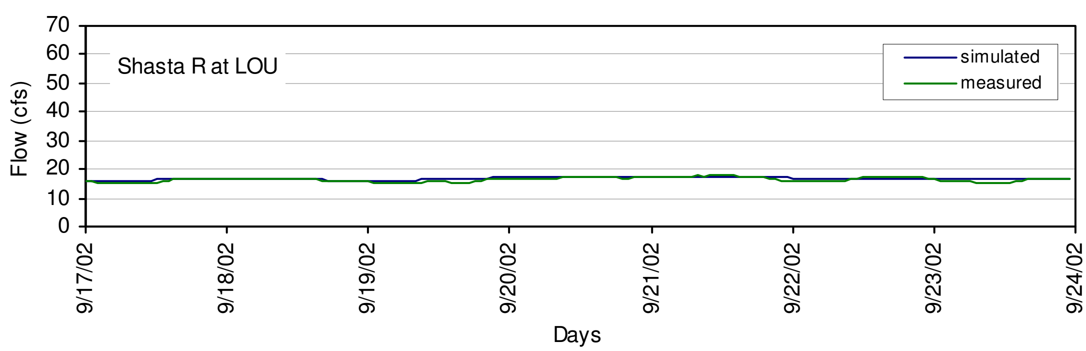


Figure 14. Flow at Louie Road from 9/17/02 – 9/23/02

[2] Shen and Julien (1993) present a wide range of Manning roughness coefficients various levels of particle size distributions (sand, gravels, cobbles), levels of vegetation, sinuosity, and channel gradient. Values generally range from 0.01 to 0.20 for various combinations of the above factors.

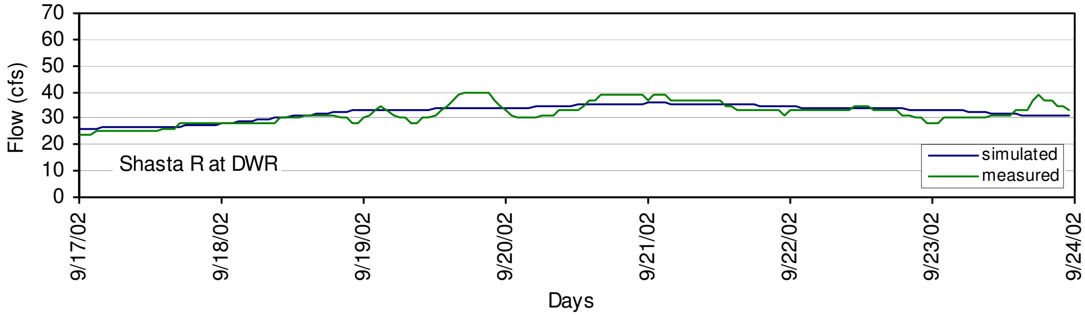


Figure 15. Flow at DWR Weir from 9/17/02 – 9/23/02

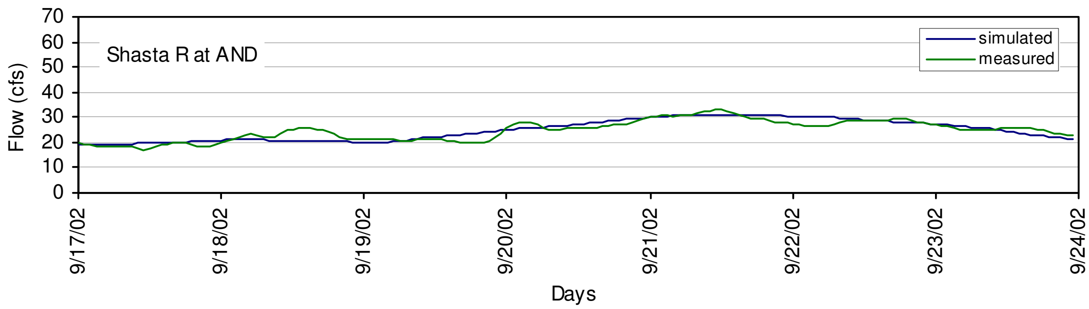


Figure 16. Flow at Anderson Grade from 9/17/02 – 9/23/02

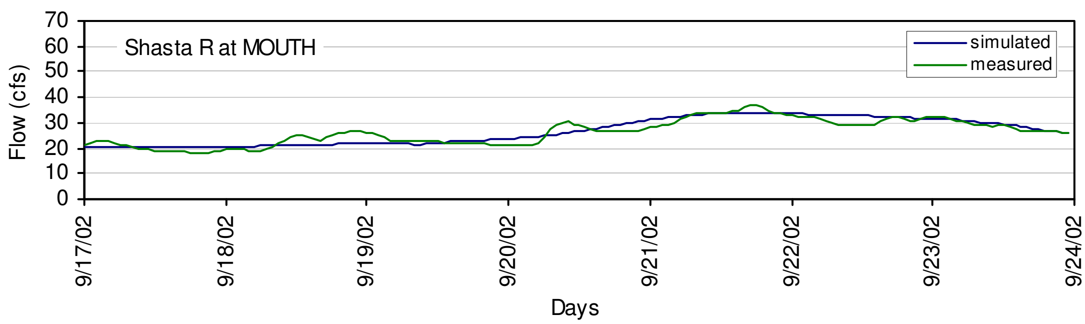


Figure 17. Flow at the Mouth from 9/17/02 – 9/23/02

Table 14. Statistics for final calibrated flow model for 9/17/02-9/23/02 with n = 0.05

Statistic (values in cfs)	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.39	0.43	0.14	0.14
Mean absolute error (MAE)	0.51	2.22	1.53	1.70
Root mean squared error (RMSE)	0.63	2.75	1.92	2.12
number of hours in sample	168	168	168	168

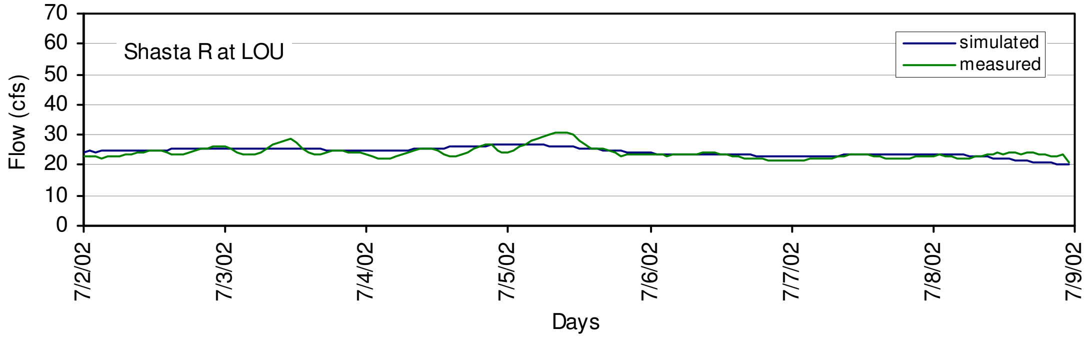


Figure 18. Flow at the Louie Road from 7/02/02 – 7/08/02

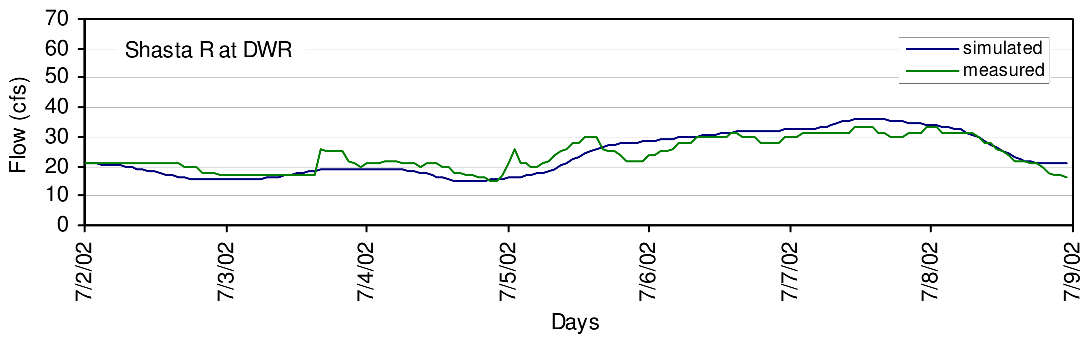


Figure 19. Flow at the DWR Weir from 7/02/02 – 7/08/02

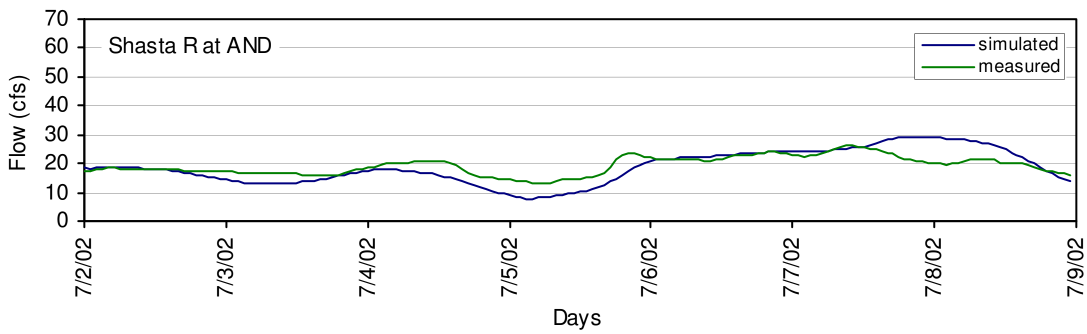


Figure 20. Flow at Anderson Grade from 7/02/02 – 7/08/02

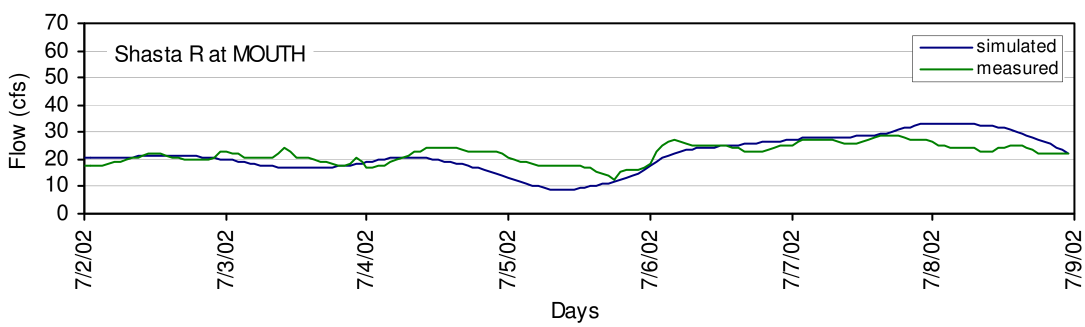


Figure 21. Flow at the Mouth from 7/02/02 – 7/08/02

Table 15. Statistics for flow model for validation period 7/02/02-7/08/02

Statistic (values in cfs)	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.24	-0.15	-0.54	-0.40
Mean absolute error (MAE)	1.20	2.62	2.84	3.54
Root mean squared error (RMSE)	1.55	3.19	3.71	4.50
number of hours in sample	168	168	168	168

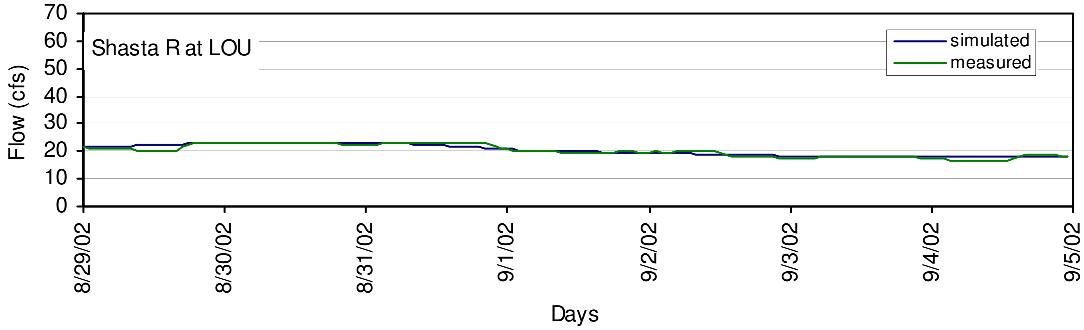


Figure 22. Flow at Louie Road from 8/29/02-9/04/02

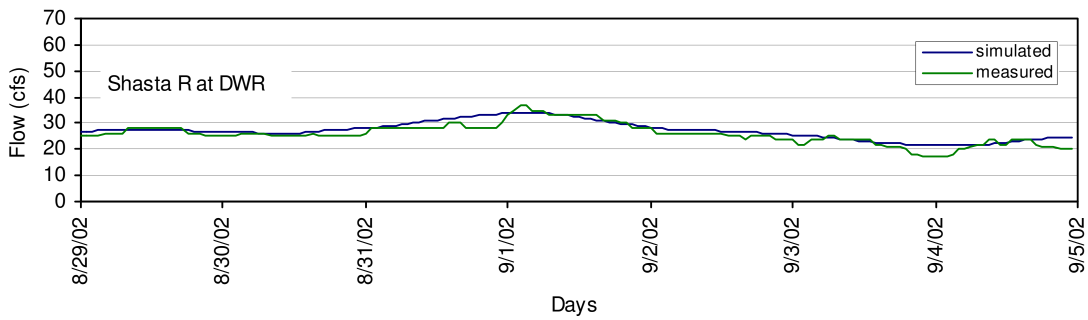


Figure 23. Flow at DWR Weir from 8/29/02-9/04/02

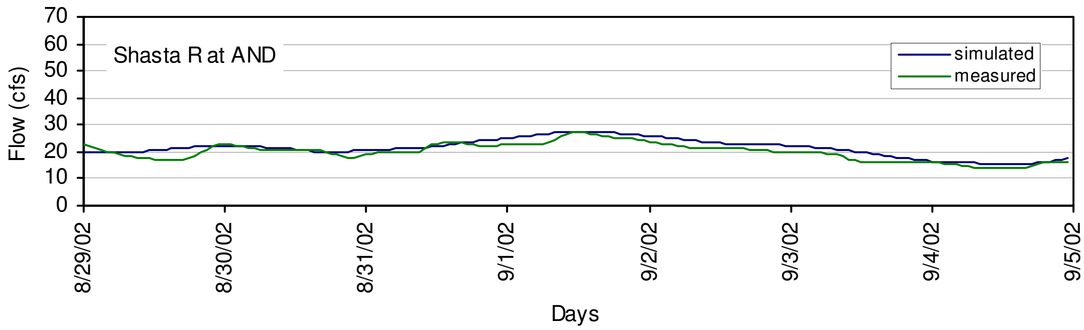


Figure 24. Flow at Anderson Grade from 8/29/02-9/04/02

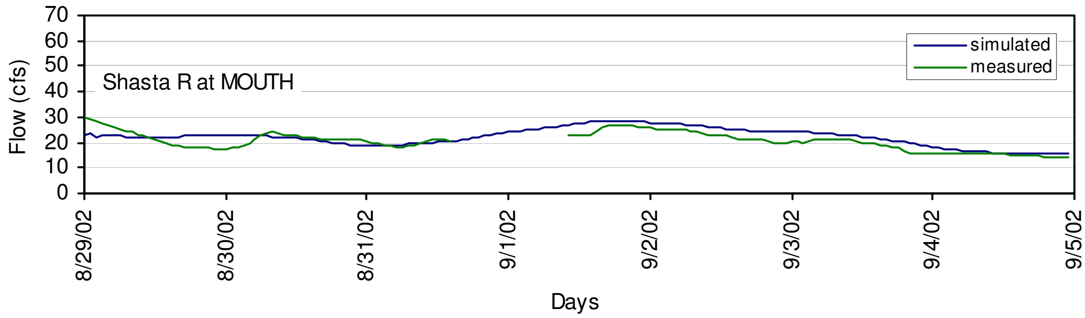


Figure 25. Flow at the Mouth from 8/29/02-9/04/02

Table 16. Statistics for flow model for validation period 8/29/02-9/04/02

Statistic (values in cfs)	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.23	1.26	1.44	1.40
Mean absolute error (MAE)	0.63	1.66	1.67	2.32
Root mean squared error (RMSE)	0.81	2.11	1.95	2.79
number of hours in sample	168	168	168	168

6.2 Water Temperature

Water temperature calibration consisted primarily of modifying the evaporative heat flux coefficients, AA (m^3/mb/s) and BB (m^2/mb) for the equation $\psi = AA + BB*wind$. The thermal diffusivity of bed material, K (cm^2/hr) was also modified, but ultimately set to the default value (Hauser, 2002).

Table 17. Final values for calibrated model

Coefficient	Value
AA	1E-9 m^3/mb/s
BB	1.5E-9 m^2/mb
n	0.05
K (DIF)	27.7 cm^2/hr

6.2.1 Instabilities in temperature

The original calibration based on previous geometry (Abbott, 2002) and different model parameters, resulted in modest instabilities (oscillations) in the temperature results during calibration (Figure 26). The RQUAL numerical solution in previous work was performed using a 4-point implicit scheme which can be subject to such instabilities. Increasing the spatial derivative weighting factor (theta) from 0.50 to 0.55 in was sufficient to dampen the oscillations in all simulations (Figure 27).

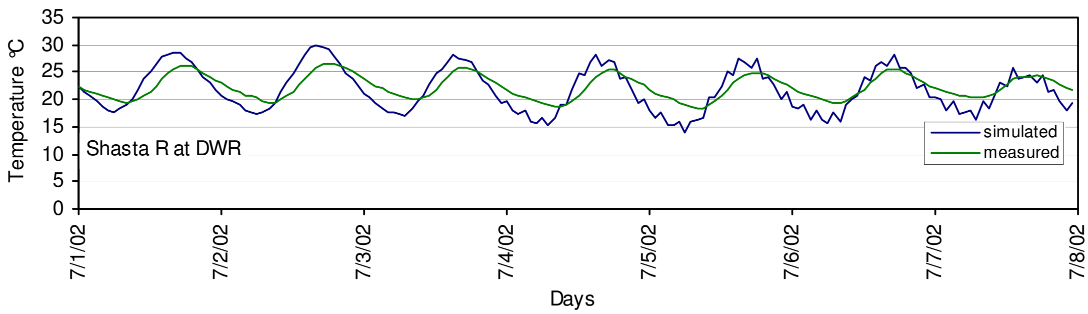


Figure 26. Temperature at DWR Weir for validation period 7/02/2002 – 7/08/2002 with theta = 0.5

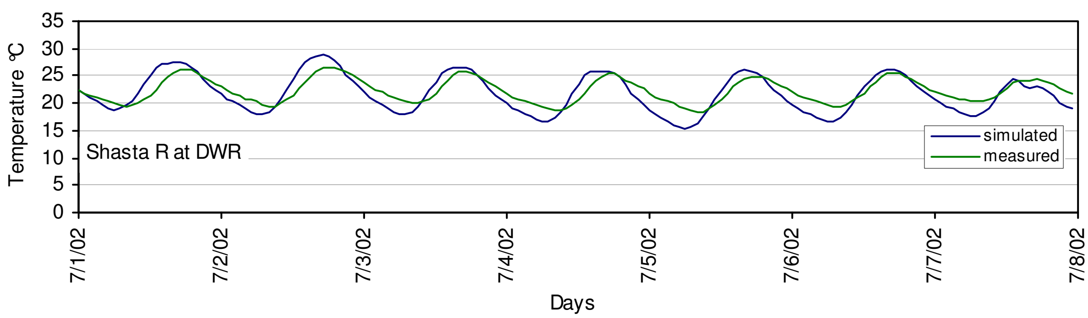


Figure 27. Temperature at DWR Weir for validation period 7/02/2002 – 7/08/2002 with theta = 0.55

These instabilities could not be resolved with theta values within the documented range of values (0.5-0.6) with the updated geometry (Lamphear) and increased number of nodes. Thus, the Holly-Priessman scheme was chosen as an alternate.

6.2.2 Results

Statistics for all calibration files for temperature calibration in Appendix 1.

Figure 28 through Figure 31 and Table 21 include simulated versus measured temperature for several locations along the Shasta River for the calibration period. Results for the validation periods are presented in Figure 32 through Figure 39 and Tables 22 and 23. Throughout the river model simulated Tw agrees well with measured data, including phase and amplitude. Model simulated temperature effectively captures the thermal dynamics of the Shasta River under a variety of summer and early-fall hydrologic and meteorological conditions in the Shasta River. Modeled temperatures in the upper reaches and valley reaches match the measured phase and amplitude of the daily temperature trace well – for all periods the RMSE and MAE for all sites above Yreka Creek are generally less than $2^{o}C$. Simulated values at the mouth are generally under-predicted, particularly for the daily minimum, and may lag in phase slightly. For the location near the mouth of the Shasta River RMSE range from $1.93^{o}C$ to $3.59^{o}C$, and MAE range from $1.58^{o}C$ to $3.3^{o}C$. One factor potentially influencing predicted temperatures at the mouth might be the fact that during summer and fall periods considerably different meteorological conditions occur in the canyon reach. Although the Shasta River canyon may provide a modest amount of topographic shading, the rocky canyon creates a hot, arid reach, with the canyon walls re-radiating heat well into the evening hours. Local meteorological data may improve model prediction capabilities in the lower portion of this reach if deemed necessary.

Another factor affecting water temperature conditions include water resources management actions in the valley reach by local landowners and irrigation districts. Diversions and return flows are largely unquantified, making short-term operations difficult to simulate. Of particular interest are the modes of return flow to the Shasta River, including direct surface inputs from canals or ditches, non-point surface and subsurface runoff from fields and irrigation activities adjacent to the river. These waters enter the river at various times and temperatures.

Finally, stream geometry plays a vital critical role in water temperature response. The Shasta River is a small stream, making it prone to rapid response to meteorological conditions. As the river falls to very low levels in the summer, it is difficult to predict its depth and width based on available information. A considerable effort has gone into constructing a geometry that is responsive to flow conditions, but in certain reaches data are limited.

Given the data limitations and challenges of addressing this small river system, overall model performance is good, providing critical insight into temperature dynamics along the river main stem from Dwinnell Reservoir to the confluence with the Klamath River.

These temperature results were used during model calibration for dissolved oxygen, and subsequently application of the model.

Table 18. Statistics for final calibrated temperature model for period 9/17/02-9/23/02

Statistic (values in °C)	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.09	0.02	-0.47	-0.71
Mean absolute error (MAE)	0.59	0.69	1.29	1.58
Root mean squared error (RMSE)	0.73	0.90	1.56	1.93
number of hours in sample	168	168	168	168

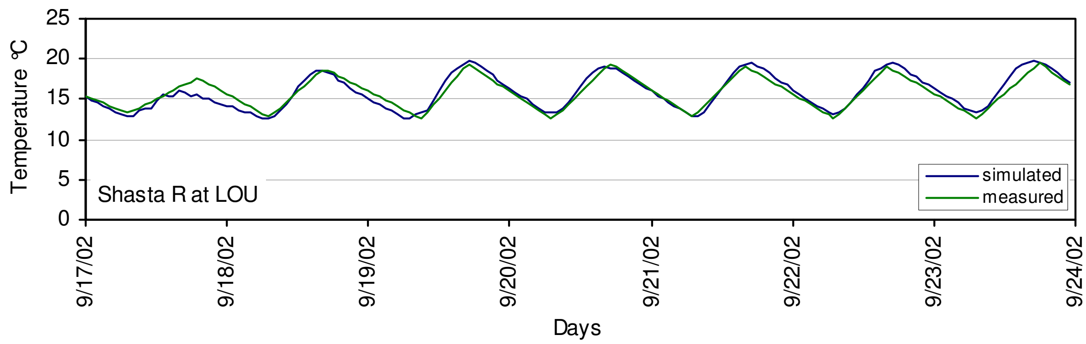


Figure 28. Temperature at Louie Road for 9/17/02 – 9/23/02

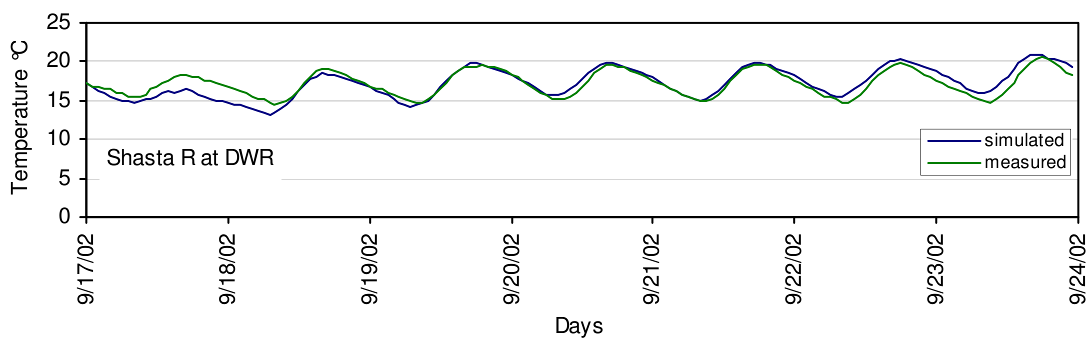


Figure 29. Temperature at DWR Weir for 9/17/02 – 9/23/02

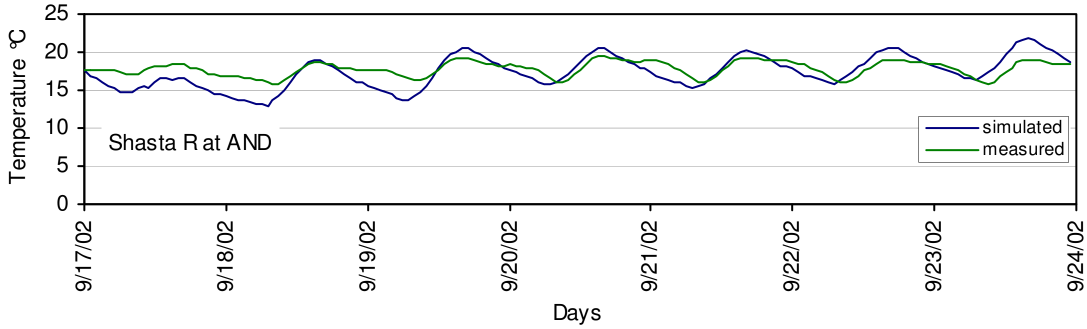


Figure 30. Temperature at Anderson Grade for 9/17/02 – 9/23/02

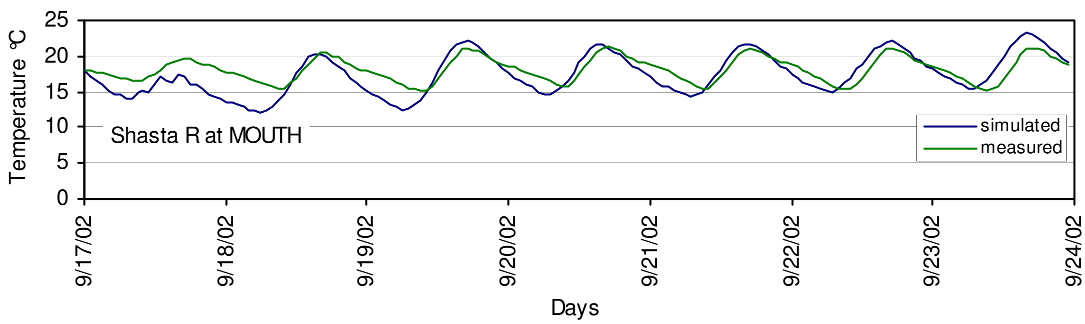


Figure 31. Temperature at the Mouth for 9/17/02 – 9/23/02

Table 19. Statistics for temperature model for validation period 7/02/02-7/08/02

Statistic (values in °C)	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.84	-0.62	-1.33	-1.40
Mean absolute error (MAE)	1.15	1.09	1.57	1.94
Root mean squared error (RMSE)	1.41	1.36	2.02	2.38
number of hours in sample	168	168	168	168

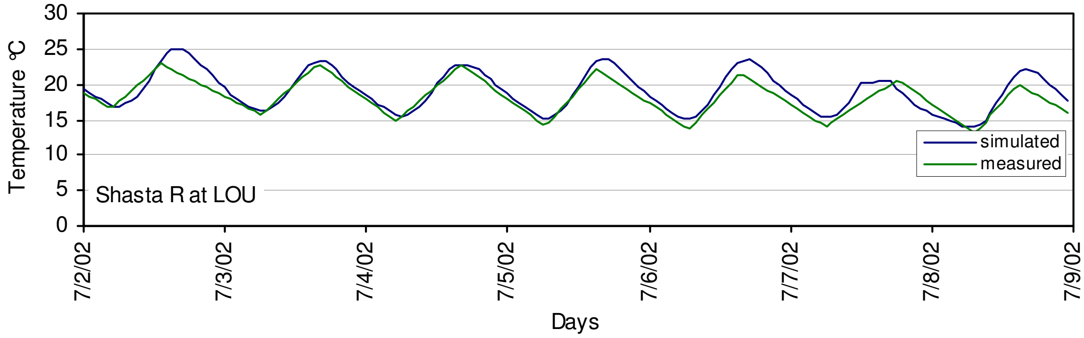


Figure 32. Temperature at Louie Road for period 7/02/02 – 7/08/02

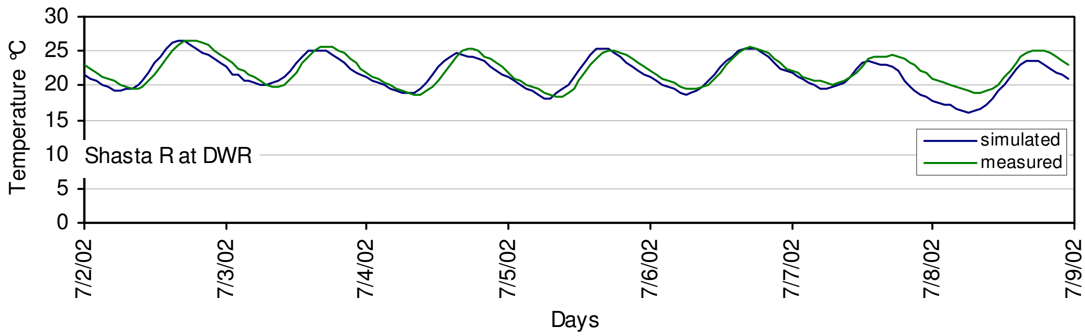


Figure 33. Temperature at DWR Weir for period 7/02/02 – 7/08/02

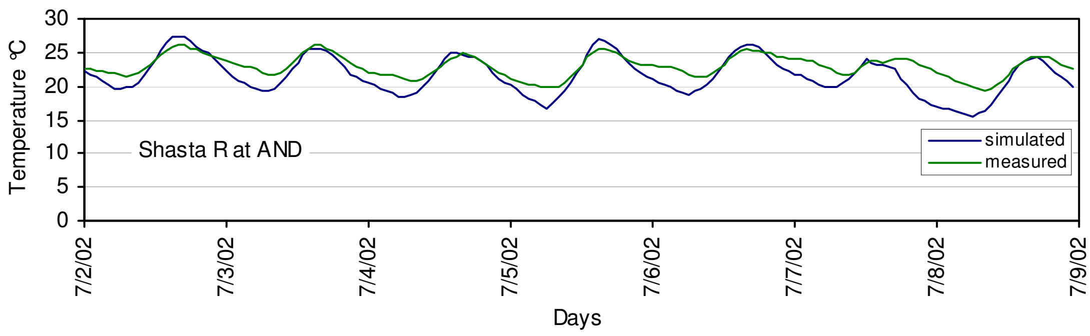


Figure 34. Temperature at Anderson Grade for period 7/02/02 – 7/08/02

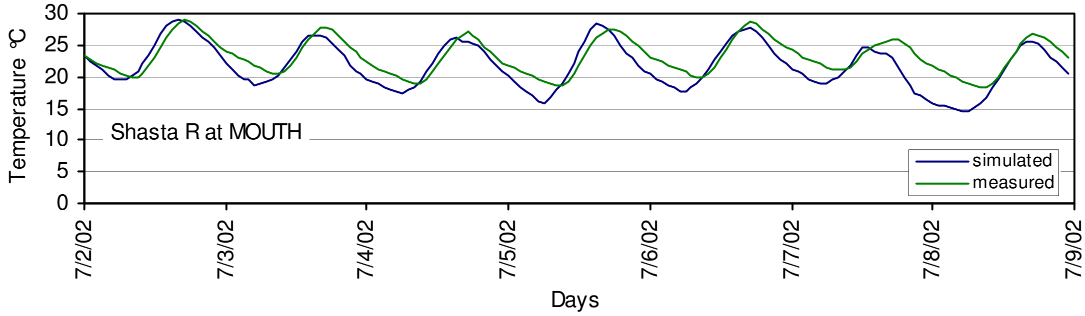


Figure 35. Temperature at the Mouth for period 7/02/02 – 7/08/02

Table 20. Statistics for temperature model for validation period 8/29/02-9/04/02

Statistic (values in °C)	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.27	-0.34	-1.29	-3.30
Mean absolute error (MAE)	1.76	0.97	1.64	3.30
Root mean squared error (RMSE)	2.16	1.34	2.10	3.59
number of hours in sample	168	168	168	168

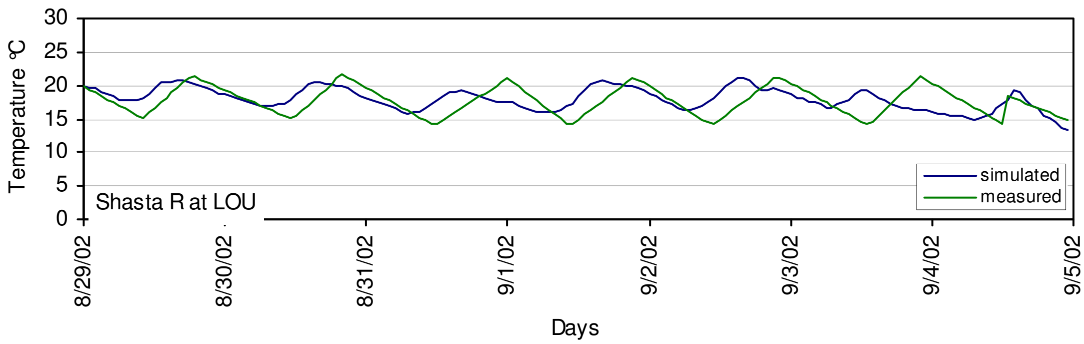


Figure 36. Temperature at Louie Road for period 8/29/02-9/04/02

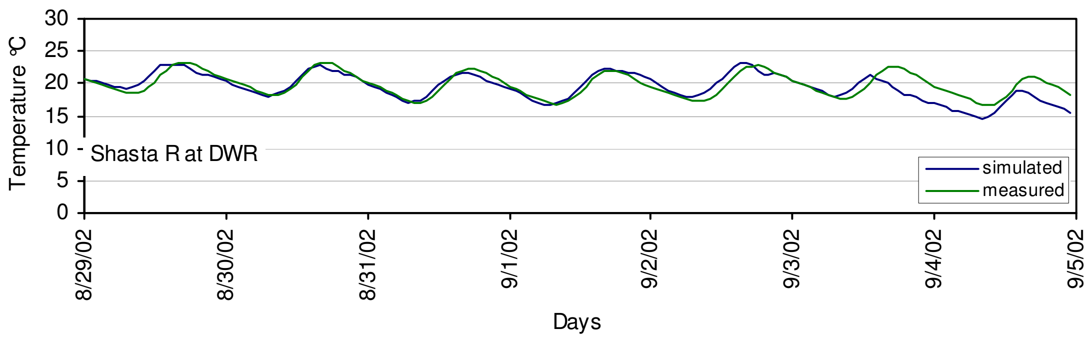


Figure 37. Temperature at DWR Weir for period 8/29/02-9/04/02

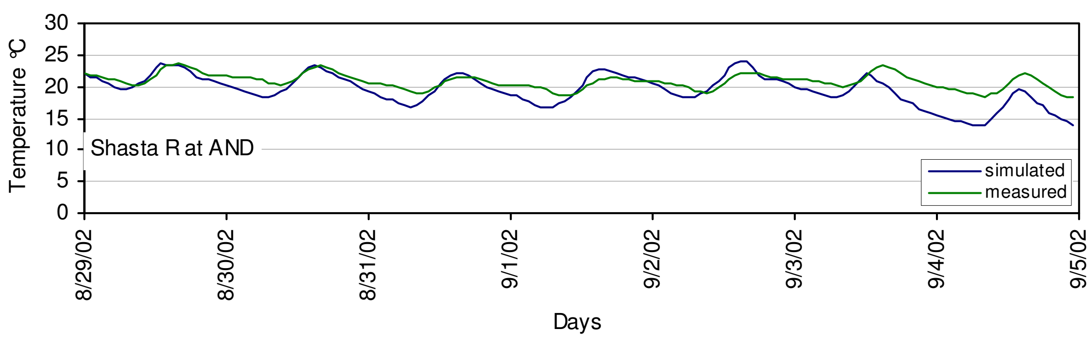


Figure 38. Temperature at Anderson Grade for period 8/29/02-9/04/02

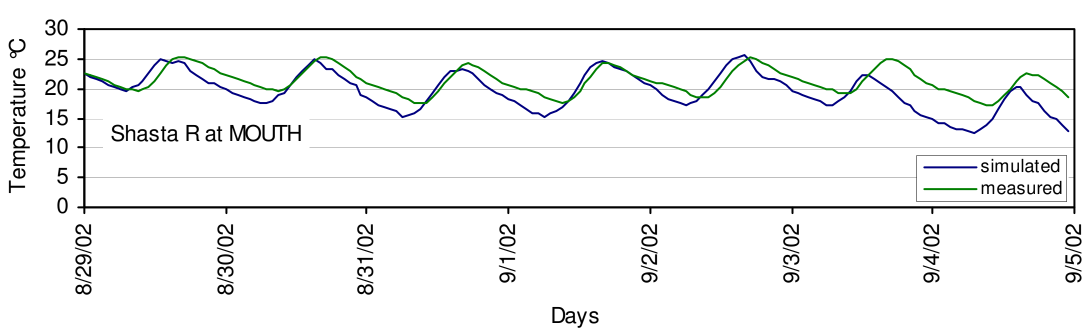


Figure 39. Temperature at the Mouth for period 8/29/02-9/04/02

6.3 Dissolved Oxygen

Water quality calibration consisted of modifying parameters to reproduce dissolved oxygen. The RQUAL model simulates dissolved oxygen conditions in response to biochemical oxygen demand (BOD), nitrogenous biochemical oxygen demand (NBOD), sediment oxygen demand (SOD), mechanical reaeration, and photosynthesis and respiration of algae growing on or in the bed (as macrophytes or periphyton). Specification of CBOD, NBOD, SOD, reaeration, photosynthesis and respiration, and riparian shading for the Shasta River were presented in previous sections of the report.

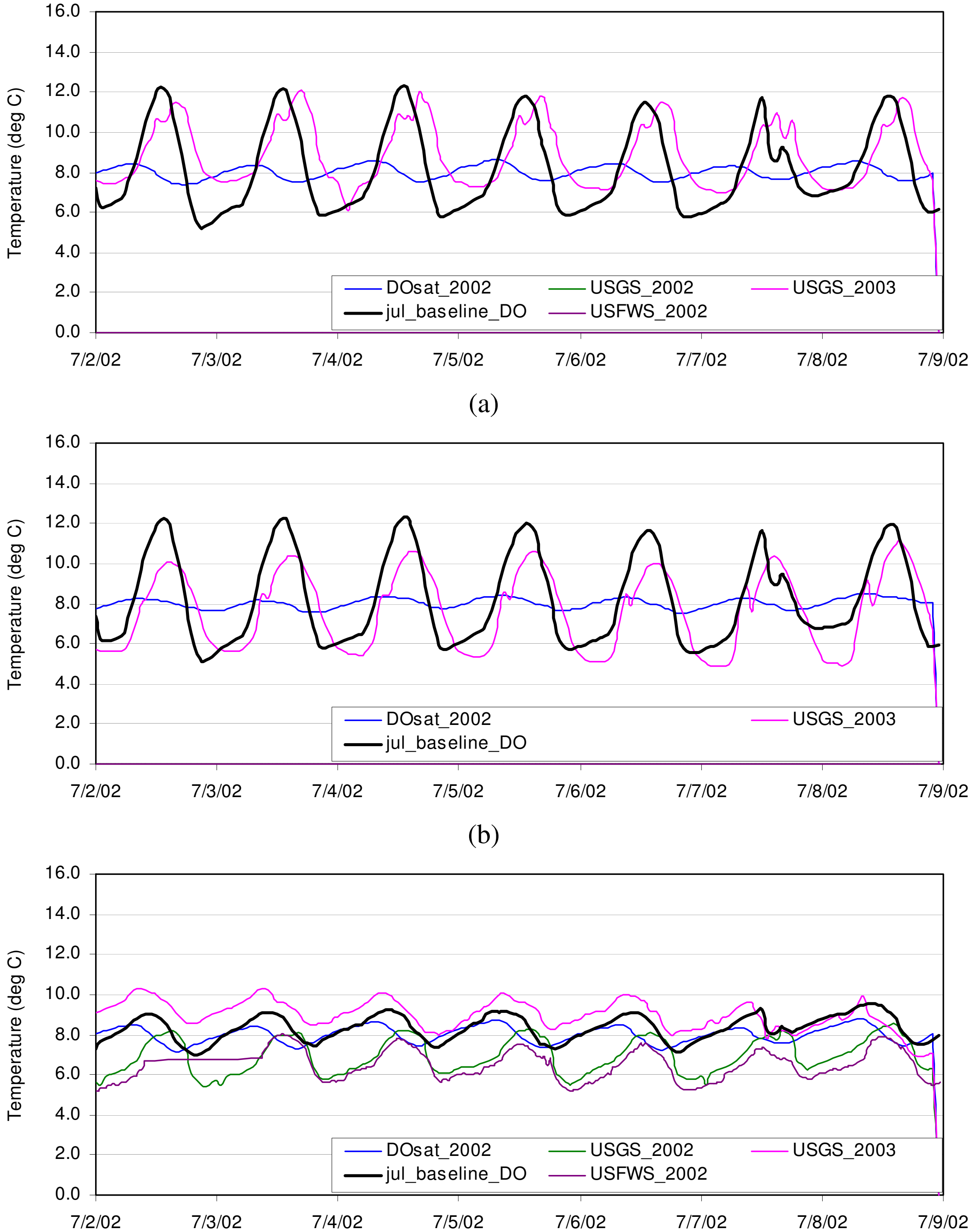
Model coefficients, rates, and parameters that are associated with these processes can have a direct influence on simulated dissolved oxygen conditions. For example CBOD, NBOD, and SOD decay rates can influence the rate of oxygen demand placed on the system. Likewise, reaeration formulations (rate) can influence the amount of reoxygenation or deoxygenation across the air water interface due to mechanical reaeration. Finally, photosynthesis and respiration by aquatic plants have direct implications on oxygen concentrations in the water column during daytime and nighttime periods. Dissolved oxygen for the Shasta River was calibrated using data for the periods 9/17/02 – 9/23/02 at Montague-Grenada Road, Highway 3, and the mouth. Data were unavailable from upstream locations. Although a wide range of parameters were explored during calibration (see available parameters in Table 8), the model was most responsive to photosynthetic and respiration rates. The calculated rates listed in Table 21 were applied in the calibration process.

One of the primary challenges during dissolved oxygen calibration was working with limited data sets and there is uncertainty associated with data sets (see USGS, 2005). As a result, 2003 data was used to augment available data and assist in assessing model performance. The basic assumption is that flow, meteorological, and aquatic/benthic conditions were roughly similar between the two years.

Calibrated model parameters provided in Table 8 and for macrophyte maximum photosynthetic rate and respiration are shown in Table 24. The results are presented for Montague Grenada Road (DWR Weir), Highway 3, and the mouth in Figure 40 through **Error! Reference source not found.**, representing July, late August, and September time periods, respectively.
Overall, the model performance is quite good, replicating the phase and amplitude of dissolved oxygen conditions in the river. For July, daily maximum values at Highway 3 are overestimated by approximately 1.5 mg/l, while minimum daily values are well represented. There is a slight phase shift at Highway 3 and DWR Weir in July as well. Late August and September are well represented. For all of the periods, field data at the mouth confound comparison with simulated values. 2003 data is included as an additional source of insight. In theory, the canyon should provide mechanical reaeration through the steep riverine reach. Simulated results agree well with saturation dissolved oxygen values and 2003 USGS data. The USFWS and USGS data, although within agreement of less than 1.0 mg/l in late July, deviate remarkably in September. Given that the there were identified data issues with the USGS data in 2002 (USGS, 2005), efforts were not taken to match these data sets. Due to the limited calibration data from the year in questions, calibration statistics are not included for dissolved oxygen.

Table 21. Calibrated model parameters for photosynthetic rate (Pmax) and respiration rate

River Mile	Respiration (gO2/m2/hour)	Pmax (gO2/m2/hour)
40.62	0.24	2.36
39.26	0.24	2.36
39.19	0.31	3.15
25.86	0.31	3.15
25.79	0.24	2.36
24.11	0.24	2.36
24.10	0.24	2.36
22.14	0.24	2.36
22.13	0.24	2.36
16.11	0.24	2.36
15.91	0.31	3.15
14.88	0.31	3.15
14.68	0.24	2.36
13.79	0.24	2.36
13.74	0.31	3.15
13.40	0.31	3.15
13.26	0.24	2.36
12.63	0.24	2.36
12.58	0.31	3.15
12.27	0.31	3.15
12.16	0.24	2.36
11.10	0.24	2.36
10.69	0.31	3.15
10.55	0.31	3.15
10.49	0.24	2.36
6.34	0.24	2.36
6.17	0.24	2.36
4.30	0.24	2.36
4.19	0.24	2.36
4.05	0.24	2.36
3.98	0.24	2.36
0.0	0.24	2.36



(a)

(b)

(c)

Figure 40. Simulated versus measured dissolved oxygen at (a) DWR Weir, (b) Highway 3, and (c) Mouth: 7/02/02-7/08/02

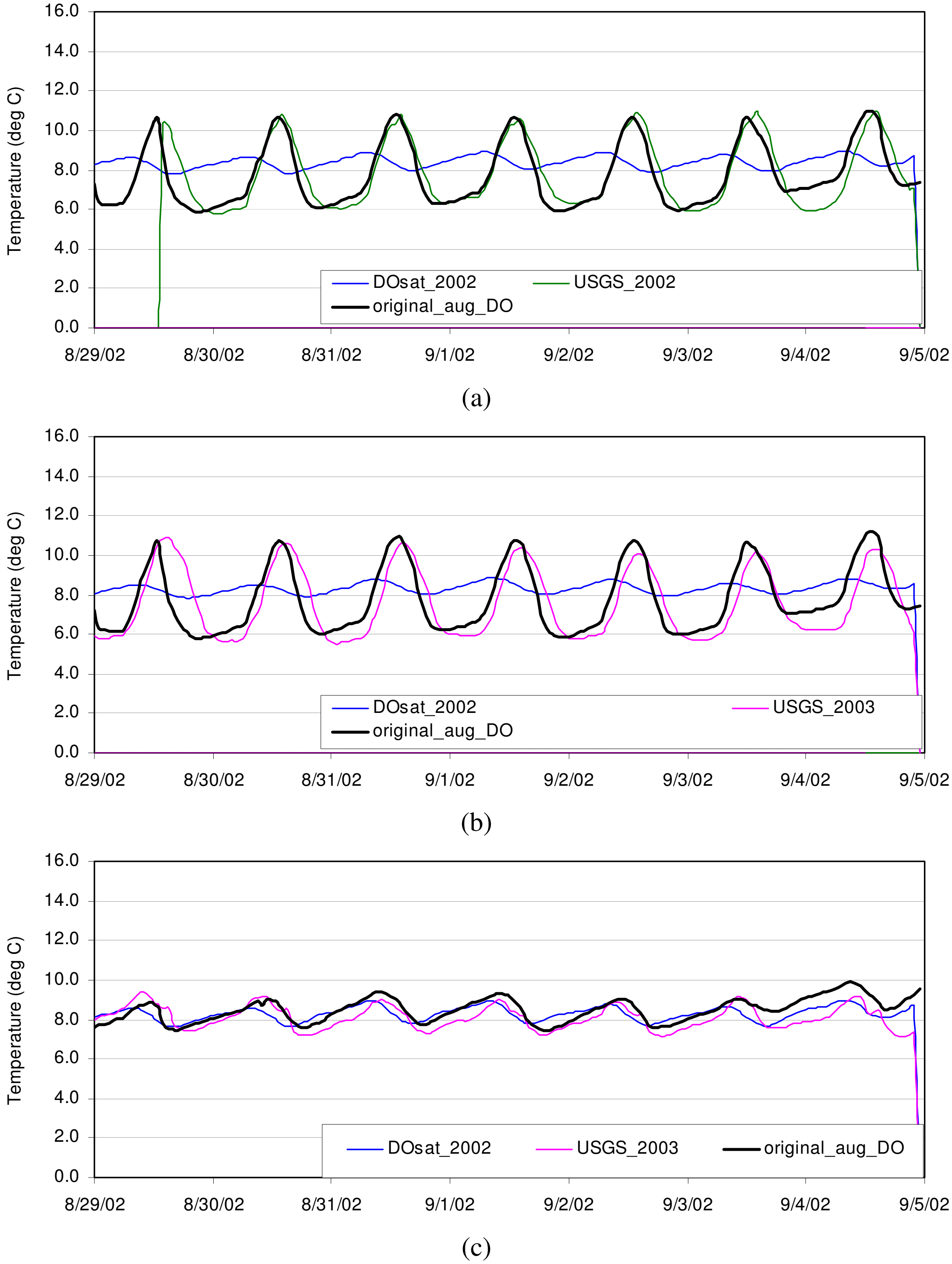


Figure 41. Simulated versus measured dissolved oxygen at (a) DWR Weir, (b) Highway 3, and (c) Mouth: 8/29/02-9/5/02

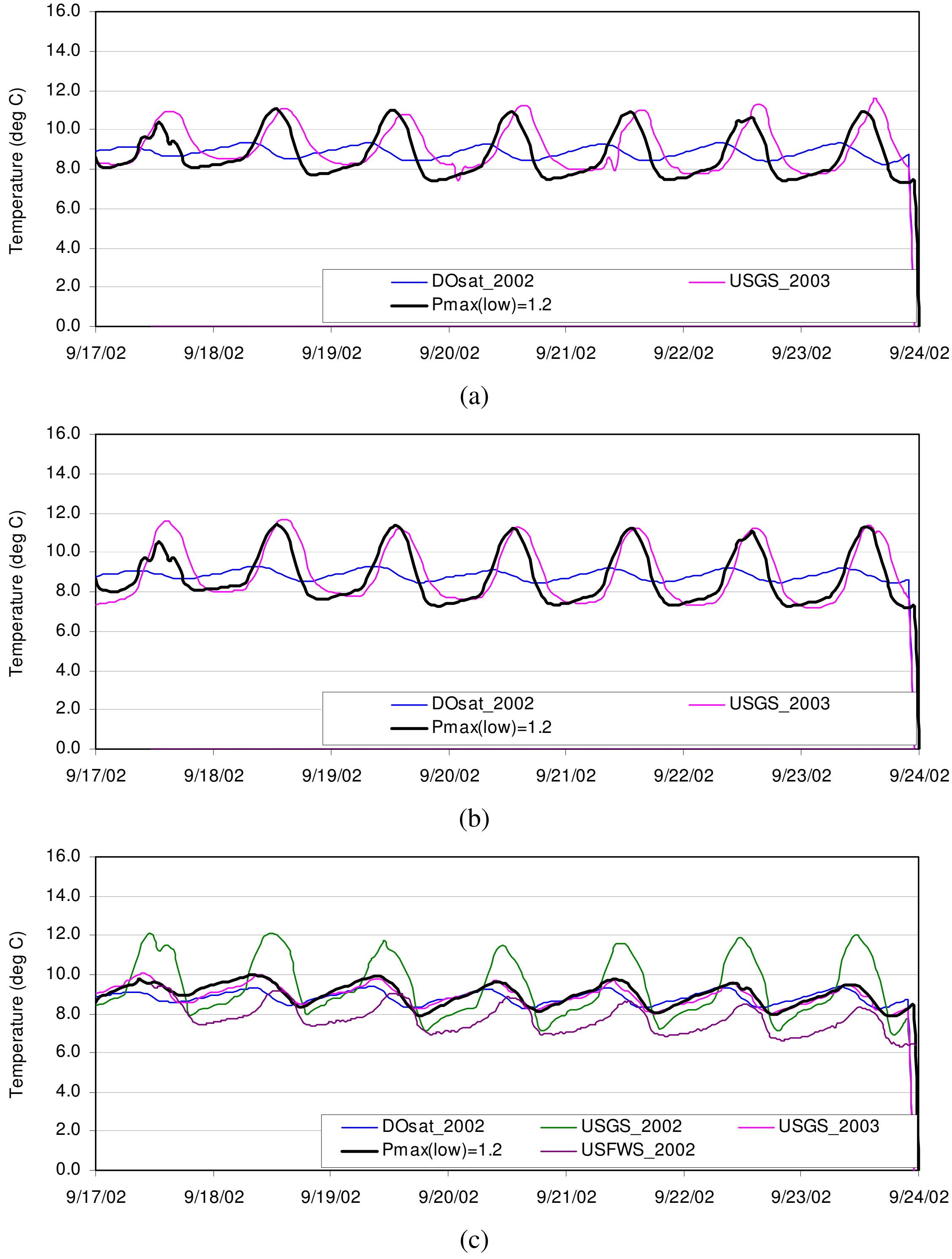


Figure 42. Simulated versus measured dissolved oxygen at (a) DWR Weir, (b) Highway 3, and (c) Mouth: 9/17/02-9/24/05

7.0 Sensitivity Analysis

Previous applications of the TVA RMS to the Shasta River included sensitivity analysis. Watercourse Engineering (2004b) and Abbott (2002) examined the impact of variable flow regimes and temperature boundary conditions on the transit time, depth, and thermal response of the river. An extensive effort was completed on examining the effects of various transmittance rates and tree heights, as well as the implications of variable flow regimes and spatial extent of riparian vegetation shading. The reader is referred to Watercourse Engineering (2004b) and Abbott (2002) for additional details.

Additional sensitivity analyses were completed under this project to identify the sensitivity of flow to Manning roughness, evaporative heat flux values, CBOD decay rate, NBOD decay rate, and selected SOD values. In sum, the model was modestly sensitive to manning roughness, primarily because the travel time through the system is relatively short (e.g., on the order of one day). As is typical in water temperature simulations, the model was sensitive to the evaporative heat flux coefficients used in the heat budget formulation. With respect to dissolved oxygen, CBOD, and NBOD decay rates were largely insensitive, as was the SOD rate. The driving factor for dissolved oxygen was maximum photosynthetic and respiration rate. These values were adjusted during calibration to fit the model to measured data. Reaeration rate, a calculated term within the model, played a pivotal role, particularly in the steep canyon reach where mechanical reaeration would be expected to occur. The results of these analyses are included in the Appendix. The results of these analyses assisted in calibration of the model and should assist decision makers in model interpretation.

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Cindy Lowney, Consultant

9.0 Appendix: Sensitivity Analysis Results

9.1 Manning Roughness

Flow simulation was tested for sensitivity with respect to the Manning roughness coefficient. The coefficient was varied from 0.04 to 0.055 in increments of 0.005. Statistical summaries of model performance under the various roughness values are shown in Table 22 through Figure 25. Results indicate that the model performed similarly in all cases. The relatively short transit time through the model domain, coupled with the representation of accretions and depletions on a reach basis (based on the daily water balance) results in the model being generally insensitive to the Manning roughness coefficient.

Table 22. Statistics for final calibrated flow model for 9/17/02-9/23/02 with n = 0.05

	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.39	0.43	0.14	0.14
Mean absolute error (MAE)	0.51	2.22	1.53	1.70
Root mean squared error (RMSE)	0.63	2.75	1.92	2.12
number of hours in sample	168	168	168	168

Table 23. Statistics for flow model for 9/17/02-9/23/02 with n = 0.055

	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.38	0.41	0.13	0.12
Mean absolute error (MAE)	0.51	2.22	1.52	1.71
Root mean squared error (RMSE)	0.63	2.75	1.91	2.14
number of hours in sample	168	168	168	168

Table 24. Statistics for flow model for 9/17/02-9/23/02 with n = 0.045

	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.39	0.44	0.16	0.17
Mean absolute error (MAE)	0.51	2.22	1.53	1.70
Root mean squared error (RMSE)	0.64	2.74	1.91	2.11
number of hours in sample	168	168	168	168

Table 25. Statistics for flow model for 9/17/02-9/23/02 with n = 0.04

	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.39	0.43	0.14	0.14
Mean absolute error (MAE)	0.51	2.22	1.53	1.70
Root mean squared error (RMSE)	0.63	2.75	1.92	2.12
number of hours in sample	168	168	168	168

9.2 Evaporative Heat Flux Coefficients and Bed Conduction

Evaporative heat flux parameters aa and bb (coefficients in the wind speed function for evaporative cooling (ψ = aa + bb*wind)) were varied for various values and combinations. Recall, the selected values for aa and bb were 1.0×10^{-9} m^3/mb/s and 1.5×10^{-9} m^2/mb, respectively. The results, presented in Appendix A, indicate that the model is sensitive to evaporative heat flux coefficients in the range of applicable values.

Sensitivity of temperature to calibrated aa and bb values for various bed thermal diffusivity values (DIF, represented by K). The calibrated value of K was 27 cm^2/hr and values of 25 cm^2/hr and 30 cm^2/hr were assessed. Results showed modest sensitivity.

Finally, sensitivity of temperature to calibrated aa, bb, and K values for Manning roughness values of 0.045 to 0.055 were examined. Results, tabulated in Table 26, generally showed modest sensitivity.

Table 26. Summary of tables presenting sensitivity results

Table	aa ($\times 10^{-9}$ m^3/mb/s)	bb ($\times 10^{-9}$ m^2/mb)	K (cm^2/hr)	n
Table 27	0.5	1.5	27.7	0.05
Table 28	0.0	1.0	27.7	0.05
Table 29	1.0	1.5	27.7	0.05
Table 30	1.0	1.0	27.7	0.05
Table 31	0.5	1.0	27.7	0.05
Table 32	1.0	2.0	27.7	0.05
Table 33	2.0	2.0	27.7	0.05
Table 34	0.5	1.5	30.0	0.05
Table 35	0.5	1.5	25.0	0.05
Table 36	0.5	1.5	27.7	0.055
Table 37	0.5	1.5	27.7	0.045

Table 27. aa=0.5 bb= 1.5 (suggested values from User Guide)

	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.33	0.32	-0.11	-0.30
Mean absolute error (MAE)	0.69	1.00	1.46	1.72
Root mean squared error (RMSE)	0.83	1.17	1.75	2.08
number of hours in sample	168	168	168	168

Table 28. aa=0.0 bb= 1.0

	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.90	2.61	1.29	1.42
Mean absolute error (MAE)	1.04	1.71	2.13	2.48
Root mean squared error (RMSE)	1.20	1.87	2.42	2.85
number of hours in sample	168	168	168	168

Table 29. aa=1.0 bb= 1.5

	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.10	-0.09	-0.64	-0.93
Mean absolute error (MAE)	0.59	0.77	1.41	1.72
Root mean squared error (RMSE)	0.73	0.99	1.73	2.11
number of hours in sample	168	168	168	168

Table 30. aa=1.0 bb= 1.0

	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.38	0.38	-0.01	-0.16
Mean absolute error (MAE)	0.68	0.96	1.42	1.69
Root mean squared error (RMSE)	0.81	1.09	1.68	2.01
number of hours in sample	168	168	168	168

Table 31. aa=0.5 bb= 1.0

	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.63	0.83	0.60	0.57
Mean absolute error (MAE)	0.84	1.30	1.67	1.93
Root mean squared error (RMSE)	0.98	1.43	1.94	2.27
number of hours in sample	168	168	168	168

Table 32. aa=1.0 bb= 2.0

	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	-0.15	-0.50	-1.19	-1.56
Mean absolute error (MAE)	0.58	0.82	1.58	1.93
Root mean squared error (RMSE)	0.76	1.09	1.95	2.40
number of hours in sample	168	168	168	168

Table 33. aa=2.0 bb= 2.0

	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	-0.54	-1.16	-2.00	-2.45
Mean absolute error (MAE)	0.68	1.19	2.08	2.53
Root mean squared error (RMSE)	0.89	1.40	2.45	2.97
number of hours in sample	168	168	168	168

Table 34. aa=1.0 bb= 1.5 K=30.0

	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.11	-0.08	-0.64	-0.92
Mean absolute error (MAE)	0.59	0.76	1.42	1.73
Root mean squared error (RMSE)	0.73	0.98	1.73	2.11
number of hours in sample	168	168	168	168

Table 35. aa=1.0 bb= 1.5 K=25.0

	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.09	-0.10	-0.66	-0.94
Mean absolute error (MAE)	0.59	0.78	1.41	1.71
Root mean squared error (RMSE)	0.73	1.01	1.74	2.11
number of hours in sample	168	168	168	168

Table 36. aa=1.0 bb= 1.5 K=27.7 n = 0.055

	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.11	-0.08	-0.63	-0.91
Mean absolute error (MAE)	0.59	0.77	1.44	1.68
Root mean squared error (RMSE)	0.72	0.99	1.75	2.07
number of hours in sample	168	168	168	168

Table 37. aa=1.0 bb= 1.5 K=27.7 n = 0.045

	Louie Rd. (RM 33.92)	DWR (RM 15.5)	Anderson Grade (RM 8.03)	Mouth (USGS gage) (RM 0.62)
Mean Bias	0.09	-0.10	-0.67	-0.95
Mean absolute error (MAE)	0.60	0.77	1.40	1.76
Root mean squared error (RMSE)	0.74	1.00	1.73	2.15
number of hours in sample	168	168	168	168

9.3 Maximum Photosynthetic and Respiration Rate

To assess sensitivity to photosynthetic rates a suite of simulations were completed varying P_{max} ±0.25 percent globally (see Figure 13 and Table 13 for baseline values) while holding R constant. Four locations were examined: Louie Road, DWR Weir, Anderson Grade, and the mouth. The impacts on hourly dissolved oxygen for the August 28 through September 4, 2002 period are shown in Figure 43 through Figure 50. When maximum photosynthetic rate is decreased 25 percent (PFAC = 0.75), daily maximum dissolved oxygen values are decreased by approximately 1.0 mg/l at all locations except the mouth, where presumably mechanical reaeration and lower overall standing crop results in a smaller response (well under 0.5 mg/l). Increasing maximum photosynthetic rate by 25 percent (PFAC = 1.25) results in the daily maximum dissolved oxygen values increasing by approximately 1.0 mg/l at all locations except the mouth, where presumably mechanical reaeration and lower overall standing crop results in a smaller response (approximately 0.5 mg/l). in both cases the Anderson Grade site shows a smaller response than the DWR Weir and Louie Road locations. Overall dissolved oxygen is sensitive when maximum specified photosynthetic rates are increased or decreased 25 percent.

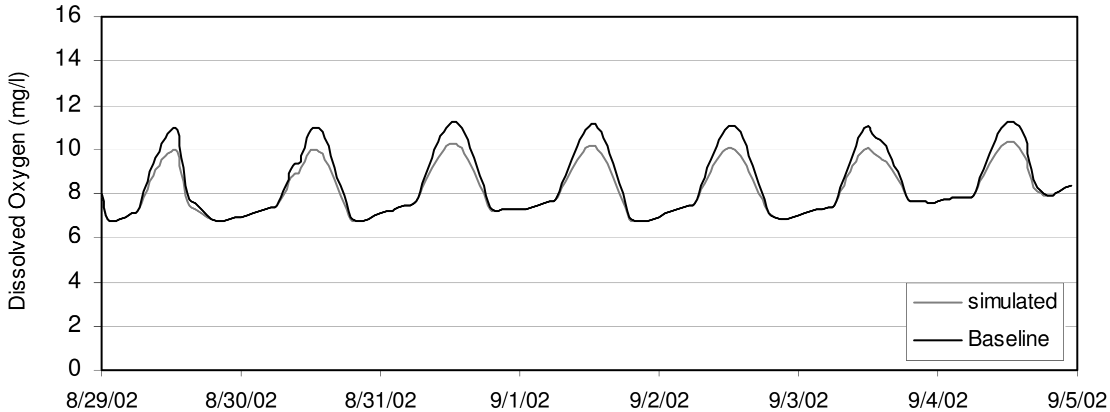

Figure 43. Dissolved oxygen at Louie Rd, PFAC = 0.75: 8/29/02 to 9/5/02

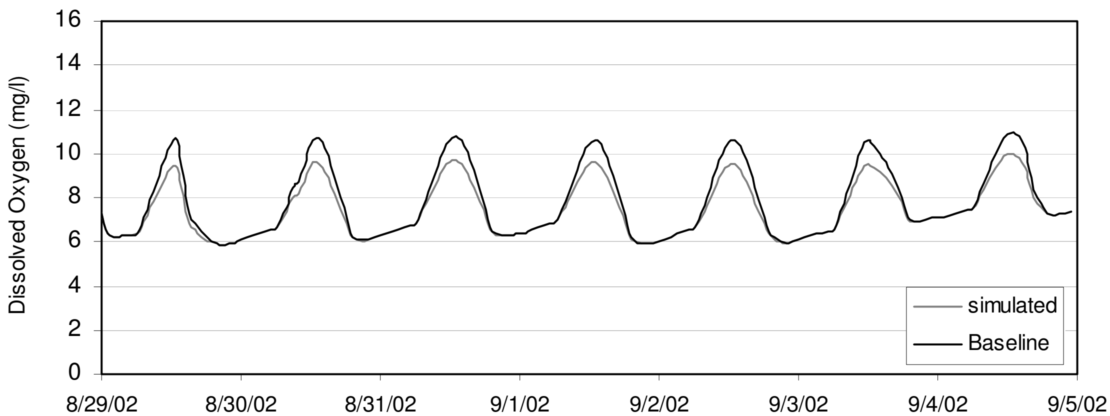

Figure 44. Dissolved oxygen at DWR Weir, PFAC = 0.75: 8/29/02 to 9/5/02

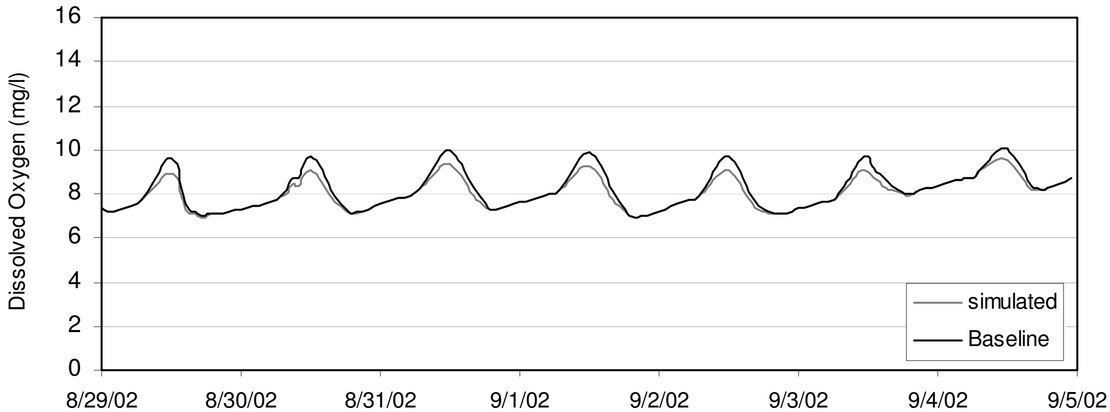

Figure 45. Dissolved oxygen at Anderson Rd, PFAC = 0.75: 8/29/02 to 9/5/02

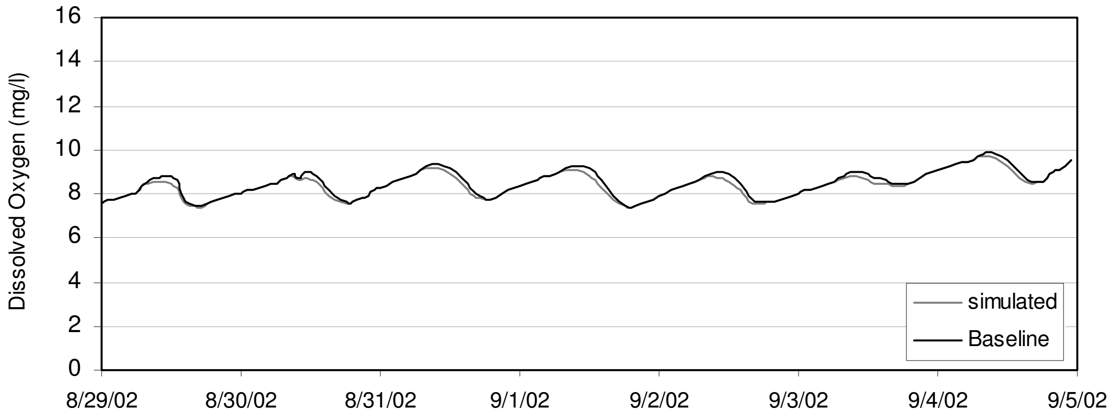

Figure 46. Dissolved oxygen at Mouth, PFAC = 0.75: 8/29/02 to 9/5/02

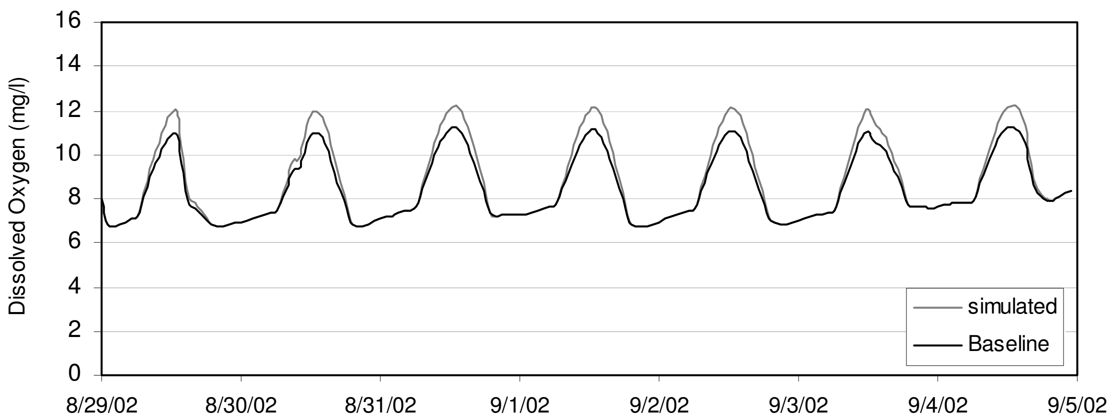

Figure 47. Dissolved oxygen at Louie Rd, PFAC = 1.25: 8/29/02 to 9/5/02

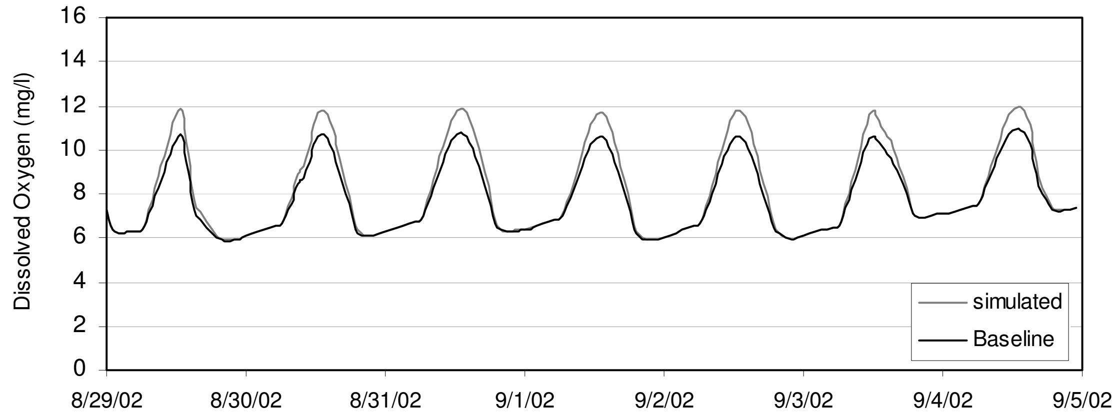

Figure 48. Dissolved oxygen at DWR Weir, PFAC = 1.25: 8/29/02 to 9/5/02

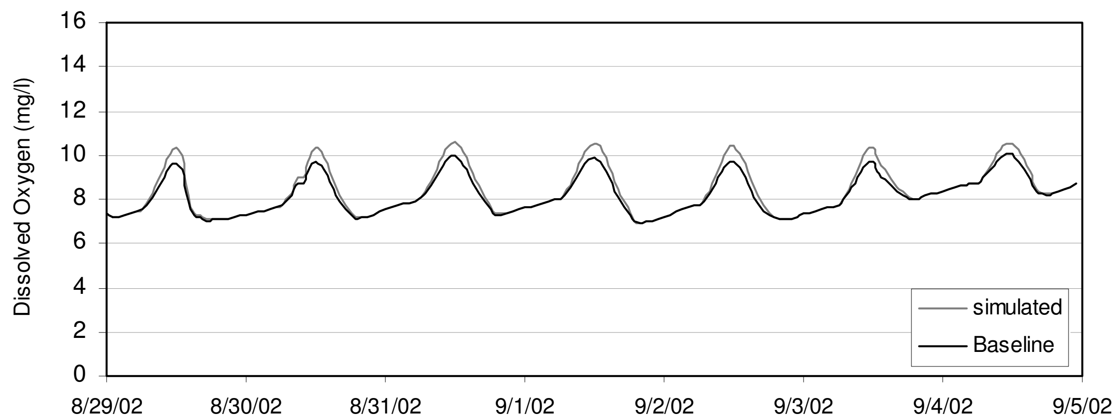

Figure 49. Dissolved oxygen at Anderson Rd, PFAC = 1.25: 8/29/02 to 9/5/02

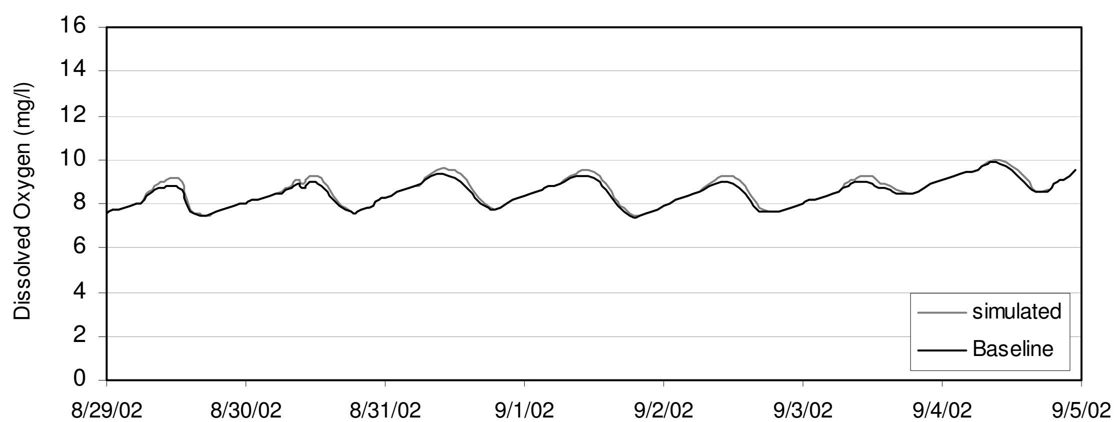

Figure 50. Dissolved oxygen at Mouth, PFAC = 1.25: 8/29/02 to 9/5/02

9.4 CBOD, NBOD, and SOD

The sensitivity of decay coefficients for CBOD and NBOD, as well as SOD rates were assessed using the calibrated model for the period August 29 to September 4. Four locations were examined: Louie Road, DWR Weir, Anderson Grade, and the mouth.

CBOD rates were varied ±0.1 units from the baseline value of 0.2/d, yielding a range of values from 0.1/d to 0.3/d. Due to low CBOD concentrations in the system, less than 3.5 mg/l on average, the model was insensitive to this range of decay rates with differences of less than 0.1 mg/l at all locations (less than 0.1 mg/l increase with lower decay rates, and less than 0.1 mg/l decrease with higher decay rates).

NBOD rates were increased +0.2 units from a baseline of 0.2 /d. The response was less than a 0.1 mg/l decrease in DO at all locations. As with CBOD, the system has low overall NBOD concentrations, with a system wide average around 2 mg/l. Thus, the impacts of increased decay rates are modest.

SOD was changed to from variable demands ranging from 0.1 g/m^2 d to 2.0 g/m^2 d throughout the entire river reach. This had a locally larger effect with DO decreasing by up to approximately 0.2 mg/l at the Anderson Grade location, but overall the impact was modest.

In sum, the impact of sensitivity due to these oxygen demands was small. The low constituent concentrations and overall low SOD values play a role in this insensitivity. However, this does not mean that there are locations where conditions may illustrate a larger impact or that under different hydrologic or loading conditions that the system may show a larger sensitivity.

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MEMO

DATE: September 13, 2004

TO: Joshua Viers, John Muir Institute of the Environment, University of California, Davis

COPIES: Matt St. John, North Coast Regional Water Quality Control Board
Mike Johnson, University of California, Davis

FROM: Mike Deas, Watercourse Engineering, Inc.
Limor Geisler, University of California, Davis

RE: Completion of the Shasta River Flow and Temperature Modeling Phase

Please find enclosed the report presenting the Shasta River flow and temperature modeling implementation, testing, and calibration.

Introduction

This document is a review of the Shasta River modeling project status as of August, 2004. The implementation, calibration, and validation of the model with respect to hydrodynamics and temperature are complete. Three seven day periods were modeled for flow and temperature:

- 7/02/2002 to 7/08/2002
- 8/29/2002 to 9/04/2002
- 9/17/2002 to 9/23/2002

The period from 9/17/2002 to 9/23/2002 was used for calibration of the model, and the other two periods were modeled using the same input parameters, for the purpose of validation. These periods approximately represent early-summer, mid-summer, and late-summer/early-fall conditions in the Shasta River and include a sufficient range of flows and water temperatures to test the model.

Task 1. Calibration

Task 1.1 Available Data Review

The periods of calibration and validation of the model were chosen based on availability of data. Presented in Table 1 and Table 2 are the available field observations for flow, temperature, and meteorological data.

Table 1. Available measured flow data for 2002

Start Date	Start Time	End Date	End Time	Notes
5/21/02	14:00	6/03/02	16:00	for all entries, up to 3 hours at a time may be missing from data
6/19/02	15:00	7/09/02	19:00	
8/21/02	16.00	8/31/02	14:00	
8/31/02	15:00	9/06/02	12:00	data gaps in Mouth and A12
9/16/02	15:00	10/05/02	6:00	
10/09/02	2:00	10/15/02	10:00	

Table 2. Available measured temperature data at Louie Road from 2002

File Name	Start Date	End Date
10603	5/20/2002	6/03/2002
10614	6/04/2002	6/14/2002
10703	6/15/2002	6/23/2002
20904	8/06/2002	9/04/2002
2002930	9/05/2002	9/30/2002

Available periods of measured temperature data, complete at all sites for 2002, not including Louie Road, are:

- 4/18/2002 to 6/04/2002
- 7/02/2002 to 10/15/2002

Available periods of measured meteorological data for 2002 are:

- 1/01/2002 to 5/14/2002
- 6/04/2002 to 12/31/2002

Thus, the periods of full and complete measured data are:

- 8/21/2002 to 9/04/2002
- 9/16/02 to 9/30/2002
- 10/09/2002 to 10/15/2002.

Louie Road data was a limiting condition in the early-summer, thus temperature for this location was calculated for the summer period, as outlined below.

Task 1.2 Temperature at Louie Road

In order to derive Louie Road water temperature data for the period 6/04/2002 to 10/02/2002, a heat budget model was used to simulate expected water temperatures. This model calculates heat flux, and consequent changes in water temperature, on an hourly basis at the air-water interface of a pond of specified dimensions. The model assumes that the pond is fully mixed in the vertical and horizontal directions. Given a pond size, an initial pond temperature, and hourly meteorological data the model is used to simulate water temperature in changing meteorological conditions.

Water temperatures for June through October 2002 were synthesized using a temperature equilibrium model calibrated to existing data (derived from graphs of Louie Road water temperature from summer 2002). Hourly Louie Road water temperatures were approximated by the temperature of water coming into equilibrium with local atmospheric conditions that change through the day but are assumed constant over discrete one-hour periods.

The temperature model used, Watercourse Equilibrium Temperature Model (Watercourse, 2002), solved equations of heat transfer to estimate total heat energy transmitted from the atmosphere to a body of water, and consequent temperature gain or loss, within a specified time period. The governing equation was a simplification of the advection-diffusion equation found in Equation (1).

$$\frac{dT_w}{dt} = S = \frac{q_n A}{C_p \rho V} \qquad (1)$$

Where:

T_w=	water temperature (°C)
t=	time step (in this case, 1 hour = 3600s)
S=	sources and sinks ($°Cs^{-1}$)
q_n=	net heat flux (Wm^{-2})
A=	area of pond surface (m^2)
C_p=	specific heat of water at 15°C (4185.5 $Jkg^{-1}°C^{-1}$ where a J = 1 W-s)
ρ=	calculated density of water (kgm^{-3})
V=	volume of pond (m^3)

The model was calibrated to observed temperatures at Louie Road for May through September 2002. Two parameters, water depth and an evaporation coefficient, were adjusted to allow the model to simulate observed temperatures. Water depth affected the relative diurnal range of water temperatures, altering the extent of daytime heating, nighttime cooling and the heat storage capacity of the simulated water body. The evaporation coefficient was used to adjust the average daily temperature of the water body.

Meteorological conditions were assumed to be the same as conditions observed at Brazie Ranch. In the heat budget calculations, the model used cloud cover, dry bulb temperature, wet bulb temperature, average barometric pressure, wind speed and shortwave solar radiation. Cloud cover, wet bulb temperature, and average barometric pressure were not reported at Brazie Ranch. Values for these parameters were either assumed or calculated from other meteorological data. Cloud cover was assumed to be zero throughout the period of interest. Average barometric pressure was assumed constant and calculated as a function of elevation. Wet bulb temperature was estimated from dry bulb temperature, average barometric pressure, and relative humidity.

Task 1.3 Calibrating Coefficients

During calibration, the input coefficients calibrated were: Manning's roughness coefficient (n), the wind speed evaporative cooling coefficients (here, aa, m^3/mb/s and bb, m^2/mb for the equation ψ = aa + bb*wind), and the thermal diffusivity of bed material (K, cm^2/hr). Sensitivity analysis was performed by assessing the maximum and minimum of the range of default values for the parameters; the model was sensitive to changes in the thermal diffusivity of the bed material and the wind speed evaporative cooling coefficients. The values chosen based on the calibration are presented in Table 3. (Extensive documentation of the calibration phase will be available as an appendix of the final document.)

Table 3. Best values based on calibration of period 9/17/2002 - 9/23/2002

Coefficient	Value
aa	2.5E-9 m^3/mb/s
bb	1.0E-9 m^2/mb
n	0.05
K	50.0 cm^2/hr

Task 1.4 Extending the Model to Dwinnell Reservoir

The existing model was extended to Dwinnell Reservoir. It should be noted that the river azimuths were also recalculated for input into the control inputs file (*.ric) file in order to correspond to the instructions in the user's guide. The river azimuths used in all previous simulations, including calibration, were offset by 180 degrees. In all subsequent simulations, re-calibrated river azimuths are used. However, there is a negligible difference in results between simulations run using the old and corrected river azimuths. The shading file (*.ris), provided by Abbott (2002), was extended to Dwinnell Reservoir by estimating the shading input at the previous most upstream previous node (RM 31.83) was the same as the new nodes extending to RM 36.38. (Previously, Abbott's shading file was altered to allow no less than 50% transmittance of solar radiation, by a simple linear mapping. This was justified based on the little actual shade available on the Shasta River.) The estimated boundary condition for flow was set at 5 cfs to provide a continuous wetted channel between the dam and Parks Creek. The water temperature at Dwinnell Dam was set equal to that at Louie Road. Differences between the original and extended models are presented in Table 4 and Table 5. Extending the model to Dwinnell did not significantly affect the results of the simulations.

Table 4. Notes on differences in hydrodynamics files (*.aii): original and extended models

Lateral Inflow Number	Lateral Inflow	Location on River	River Mile for Flow Input in *.aii File (Original Version)	River Mile for Flow Input in *.aii File (Extended Version)	Notes	Flow Calculations for Original File	Flow Calculations for Extended File
	USBC	36.38	---	---	---	0.6*LOU	5 cfs
1	Shasta Above Parks	31.8	---	31.83-31.70	point source	---	0.6*LOU-5 cfs
2	PKS	31.0	31.04-30.98	31.04-30.98	point source	0.4*LOU	0.4*LOU
3	BIG SPRINGS	29.9	29.90-29.79	29.90-29.79	point source	GID-LOU+40(GID DIV)	GID-LOU+40(GID DIV)
4	GID/HUSEMAN DIVERSION	26.9	26.92-26.87	26.92-26.87	point source	-40	-40
5	GID->A12	26.9-21.9	26.92-21.95	26.92-21.95	distributed	A12-GID	A12-GID
6	A12->SRF	21.9-17.9	21.89-17.88	21.89-17.88	distributed	SRF-A12	SRF-A12
7	SWUA DIVERSION	16.8	16.81-16.76	16.81-16.76	point source	-42	-42
8	SRF->DWR	17.9-14.7	17.79-14.66	17.79-14.66	distributed	DWR-SRF+42(SWUA DIV)	DWR-SRF+42(SWUA DIV)
9	DWR->YAR	14.7-10.3	14.57-10.31	14.57-10.31	distributed	YAR-DWR	YAR-DWR
10	YAR->AND	10.3-7.9	10.23-7.90	10.23-7.90	distributed	AND-YAR	AND-YAR
11	AND->MOUTH (note: Yreka Creek is at RM 7.6)	7.9-0.0	7.65-7.56	7.65-7.56	point source	MOUTH-AND	MOUTH-AND

USBC-Upstream Boundary Condition
PKS-Parks Creek (RM 31.0)
GID-Grenada Irrigation District (RM 26.9)
A12-Highway A12 (RM 21.9)
SRF- Shasta River At Freeman Lane (RM 17.9)
SWUA- Shasta Water Users Association (RM 16.8)
DWR- Monteque-Grenada Road (DWR Weir) (RM 14.7)
YAR- Yreka Ager Road (RM 10.3)
AND- Anderson Grade (RM 7.9)

Table 5. Notes on differences in temperature input (*.rib) between original and extended models. Note, in the new, extended version, the sub-reaches with distributed flow inputs have the temperature input in the center of the sub-reach.

Lateral Inflow Number	Location	Notes	Original Input Location	Input Location for Extended File
1	Shasta Above Parks	point source		31.83
2	PKS	point source	31.04	31.04
3	BIG SPRINGS	point source	29.90	29.90
4	GID/HUSEMAN DIVERSION	point source	26.92	26.92
5	GID-A12	distributed	26.87	24.42
6	A12-SRF	distributed	21.82	19.89
7	SWUA DIVERSION	point source	17.76	16.81
8	SRF-DWR	distributed	16.81	16.19
9	DWR-YAR	distributed	14.44	12.40
10	YAR-AND	distributed	10.17	9.05
11	AND-MOUTH (this input is at Yreka Creek)	point source	7.65	7.65

Task 1.5 Instabilities in Temperature

In the final stages of calibration and validation, the results of temperature showed instabilities (oscillations), which had been somewhat visible in the results of the calibration period. An example of this instability is shown in Figure 1.

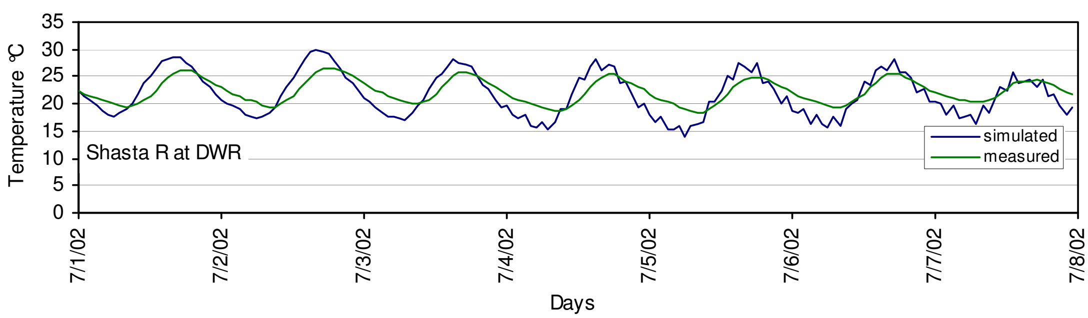

Figure 1. Temperature at DWR Weir for validation period 7/02/2002 – 7/08/2002 with theta = 0.5

The RQUAL numerical solution is performed using a 4-point implicit scheme which is subject to these instabilities. Increasing the theta value from 0.50 to 0.55 in the RQUAL file was sufficient to dampen the oscillations in all simulations. The range for theta, as given in the User's Guide p. 114, is 0.5-0.6.

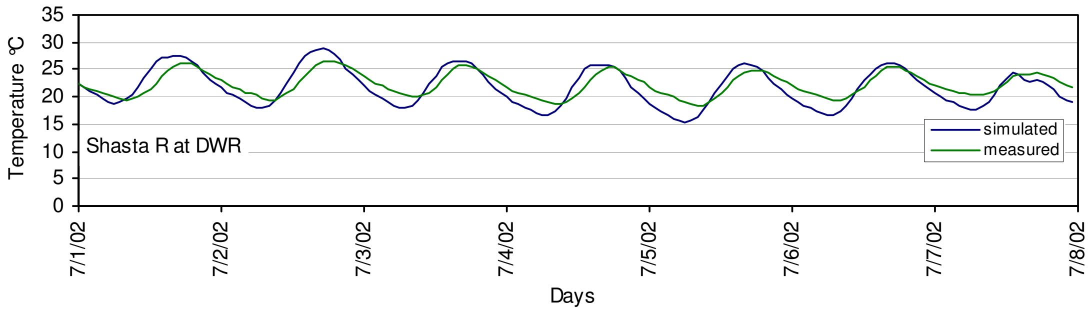

Figure 2. Temperature at DWR Weir for validation period 7/02/2002 – 7/08/2002 with theta = 0.55

Task 1.6 Geometry at Mouth

Near the mouth of the Shasta River, the simulated temperatures were at times underestimated and diverged somewhat from field observations,. An attempt was made to assess the sub-reach geometry from RM 7.9 to 0.0 to determine the sensitivity of the model results to river geometry. Narrowing the geometry near the mouth did not change the results of the simulation, i.e., the model was insensitive to river width in this sub-reach. Some possible explanations for the model performance in this reach may include local meteorological conditions in this step, rocky canyon, as well as a more complete assessment of the geometry over the entire reach versus just in the vicinity of the confluence with the Klamath River.

Task 2. Validation and Final Results

Validation was performed by running two alternate seven-day periods with the same coefficient inputs as the calibrated model. Input flow, temperature and meteorological data measured during the period modeled were used for the simulations. No alterations were made to the model in implementing the simulations for the purpose of validation.

The boundary condition for temperature at Dwinnell Dam and Parks Creek was assumed to equal the temperature at Louie Road. Model boundary conditions for Big Springs was assumed to equal the temperature measured at Highway A12. GID is closer to Big Springs, but the *measured* temperature at GID was consistently out of phase with the *measured* temperatures all the other locations.

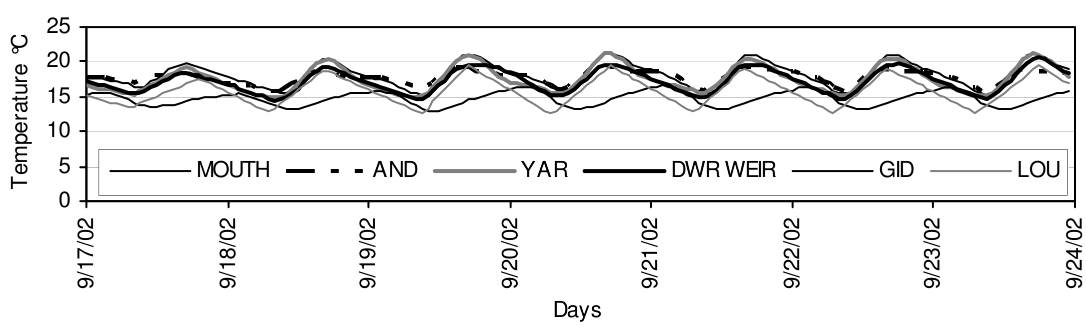

Figure 3 compares measured data at several Shasta River locations and clearly indicates

that temperatures observed below the GID Dam are out of phase with other observations. This was not an anomalous condition identified only in 2002: it has consistently been identified well back in the 1990's.

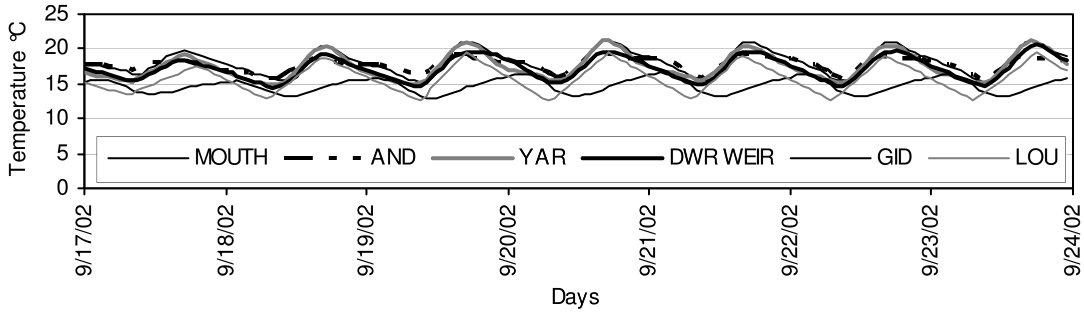

Figure 3. Measured temperature at five locations for the period 9/17/2002 – 9/24/2002

It is postulated that the presence of the reservoir behind the GID Dam increases retention time, increases depth, and reduces velocity. These impounded conditions result in a thermal lag when compared to a free-flowing river reach. The phase shift in water temperature below the diversion dam is mostly eliminated by Highway A12 because meteorological conditions quickly restore the thermal signature of the river.

The model simulated temperature at GID does not match the phase of the observed temperatures because the impoundment is not explicitly represented in the model. To test the hypothesis that the impoundment is modifying the local thermal regime, the model was applied to this reach with a fictitiously elevated Manning coefficient within the impounded reach. Setting this bed roughness coefficient to 0.3 (an order of magnitude greater than calibration values), resulted in deeper slower flows. When the model was altered to include a high Manning's coefficient simulated temperature at GID matched field observations in phase (Figure 4). The discrepancy between the two traces is due to using A-12 temperatures as the Big Springs inflow temperature – A-12 is probably warmer than actual Big Springs inflow temperatures due to the heating that occurs between the two locations as water travels downstream. Even with the increased roughness in the GID impoundment reach, the model also simulates the return to meteorologically dominated temperatures measured at A12 (Figure 5).

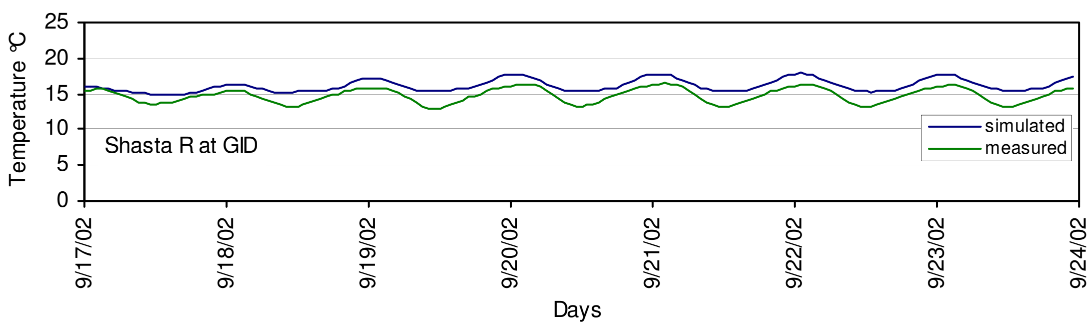

Figure 4. Temperature at Grenada Irrigation District from 9/17/2002 – 9/23/2002 modeled with Manning's n = 0.3 from RM 22-29 and n = 0.05 at all other locations—all other conditions are identical to the calibrated model for this period, as described in this report

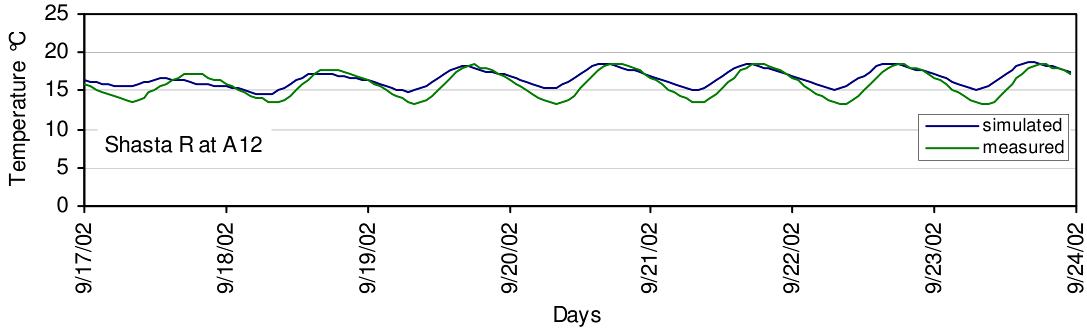

Figure 5. Temperature at Highway A12 from 9/17/2002 – 9/23/2002 modeled with Manning's n = 0.3 from RM 22-29 and n = 0.05 at all other locations—all other conditions are identical to the calibrated model for this period, as described in this report

At the Mouth, another lag between measured and modeled temperature appears. This is likely due to meteorological conditions in the canyon near the mouth that differ from the meteorological input used for the model, which is measured at Brazie Ranch. In this sub-reach it is postulated that the rocky canyon walls emit long-wave radiation well into the evening, heating the river later in the day and increasing the lag in temperature.

The results for the calibrated simulation for the period 9/17/2002 - 9/23/2002 and simulations for the validation periods 8/29/2002 – 9/04/2002 and 7/02/2002 – 7/08/2002 are presented in Table 7 through Table 12 and Figure 6 through Figure 35. Note that results in the form of summary statistics and graphs are available at 11 locations for temperature and 8 locations for flow; the locations presented below are representative. The mean absolute error is consistently less than 10 percent of the actual value for flow and temperature; i.e., within 1 to 2 °C and 1 to 3 cfs.

Work In Progress

- **Task 1. Review of available water quality data and identification of additional data needs.** This task has been substantially completed; however, ongoing model testing and assessment of benthic algae and organic sediment distributions are pending results of field studies from the North Coast Regional Water Quality Control Board.
- **Task 2. Implementation and calibration of the water quality portion of the Shasta River model.** Implementation of the water quality portion of RQUAL is complete, i.e, the model is up and running with the desired water quality parameters, but as yet uncalibrated. Comparison of water quality output with limited measured data for 2002 is underway.

Future Work

- Task 3. Formulation and testing of the algae-nutrient sub-model
- Task 4. Status Meeting (**Completed**)

- Task 5. Formulation of preliminary alternatives (**Scheduled for early October**)
- Task 6. Updating the model based on 2004 field data (**Ongoing**)
- Task 7. Identify and formulate final alternatives for assessment
- Task 8. Assessment of final alternatives
- Task 9. Reporting

A revised timeline is outlined in Table 6.

Table 6. Revised timeline for the Shasta River Flow and Water Quality Modeling Project

Task	Description	Scheduled Completion
Task 1	Review of available water quality data and identification of additional data needs.	Mid- to Late-September
Task 2	Implementation of the water quality portion of RQUAL	Mid- to Late-September
Task 3	Formulation and testing of the algae-nutrient sub-model	Mid- to Late-September
Task 4	Status Meeting	Completed
Task 5	Formulation of preliminary alternatives	Late-September to early-October
Task 6	Updating the model based on 2004 field data	September/October
Task 7	Identify and formulate final alternatives for assessment	October
Task 8	Assessment of final alternatives	November-December
Task 9	Reporting	TBD

Table 7. Summary hourly flow statistics for best calibration, 9/17/2002 - 9/23/2002

	Louie Road	A12	DWR	Anderson Grade	Mouth
Mean Bias	0.05	-0.20	-0.13	-0.26	-0.21
Mean absolute error (MAE)	0.48	1.21	1.99	1.56	1.64
Root mean squared error (RMSE)	0.58	1.42	2.68	1.92	2.05
N (number of hours)	168	168	168	168	168

Table 8. Summary hourly temperature statistics for best calibration, 9/17/2002 - 9/23/2002

	Louie Road	A12	DWR	Anderson Grade	Mouth
Mean Bias	0.13	0.70	0.03	-0.30	-0.55
Mean absolute error (MAE)	0.44	0.92	1.04	1.04	1.50
Root mean squared error (RMSE)	0.58	1.12	1.21	1.21	1.73
N (number of hours)	168	168	168	168	168

Table 9. Summary hourly flow statistics for validation period 8/29/2002 – 9/04/2002

	Louie Road	A12	DWR	Anderson Grade	Mouth
Mean Bias	-0.25	-0.62	0.57	0.77	0.65
Mean absolute error (MAE)	0.67	3.34	1.47	1.19	1.83
Root mean squared error (RMSE)	0.89	4.67	1.87	1.46	2.36
N (number of hours)	168	168	168	168	149

Table 10. Summary hourly temperature statistics for validation period 8/29/2002 – 9/04/2002

	Louie Road	A12	DWR	Anderson Grade	Mouth
Mean Bias	0.30	0.97	-0.02	-0.54	-0.93
Mean absolute error (MAE)	1.10	1.31	1.28	1.24	1.89
Root mean squared error (RMSE)	1.36	1.60	1.54	1.53	2.28
N (number of hours)	168	168	168	168	168

Table 11. Summary hourly flow statistics for validation period 7/02/2002 – 7/08/2002

	Louie Road	A12	DWR	Anderson Grade	Mouth
Mean Bias	-0.32	0.80	-0.61	-0.94	-0.75
Mean absolute error (MAE)	1.22	4.86	2.35	2.41	3.14
Root mean squared error (RMSE)	1.68	6.50	2.87	3.08	4.04
N (number of hours)	168	168	168	168	168

Table 12. Summary hourly temperature statistics for validation period 7/02/2002 – 7/08/2002

	Louie Road	A12	DWR	Anderson Grade	Mouth
Mean Bias	0.07	0.06	-1.36	-1.99	-2.21
Mean absolute error (MAE)	0.24	1.15	2.01	2.04	2.65
Root mean squared error (RMSE)	0.32	1.35	2.36	2.47	3.13
N (number of hours)	168	152	168	168	168

Graphs of Calibrated Period and Validation Periods

Calibration Period (9/17/2002 – 9/23/2002):

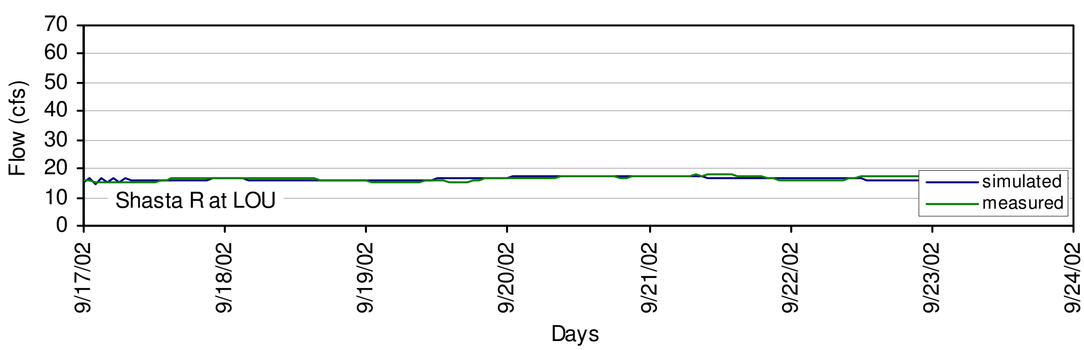

Figure 6. Flow at Louie Road for 9/17/2002 – 9/23/2002

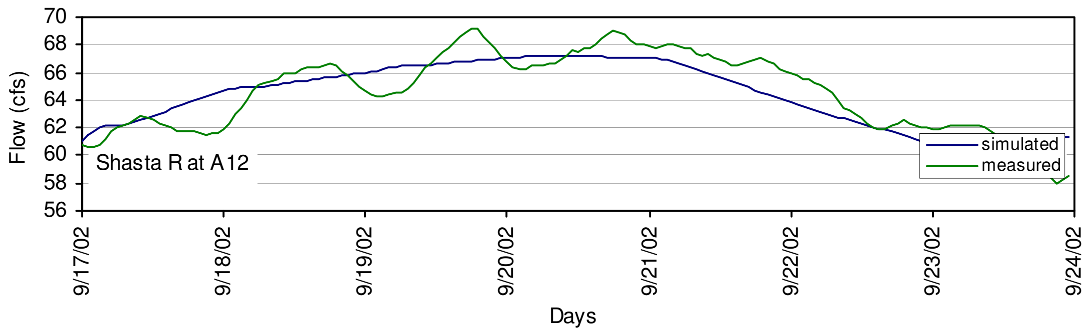

Figure 7. Flow at Highway A12 for 9/17/2002 – 9/23/2002

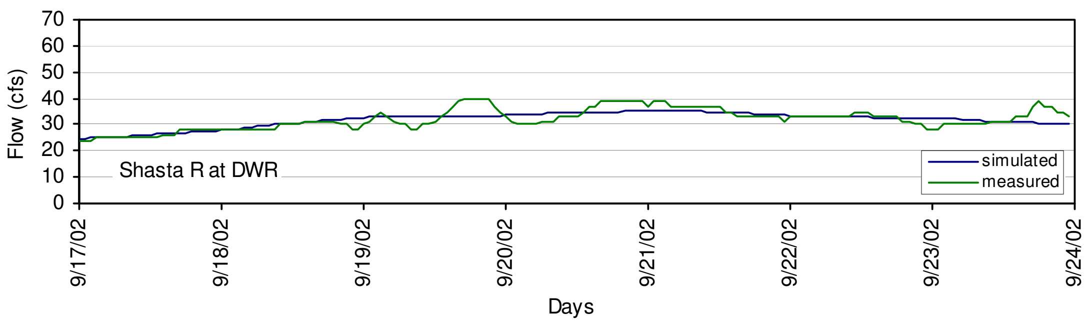

Figure 8. Flow at DWR Weir for 9/17/2002 – 9/23/2002

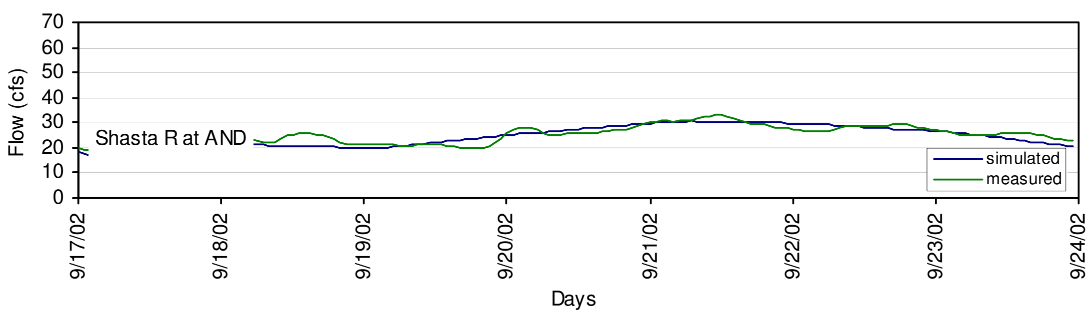

Figure 9. Flow at Anderson Grade for 9/17/2002 – 9/23/2002

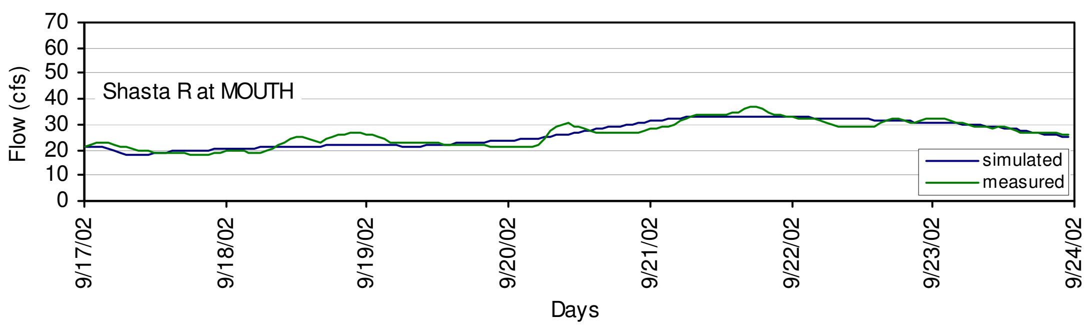

Figure 10. Flow at the Mouth for 9/17/2002 – 9/23/2002

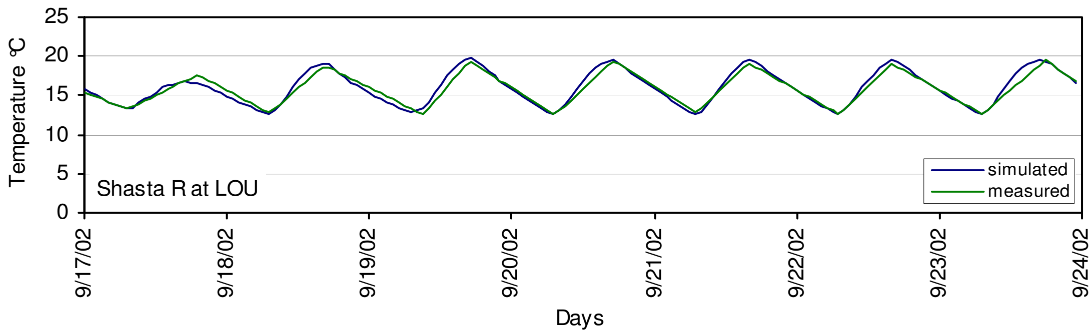

Figure 11. Temperature at Louie Road for 9/17/2002 – 9/23/2002

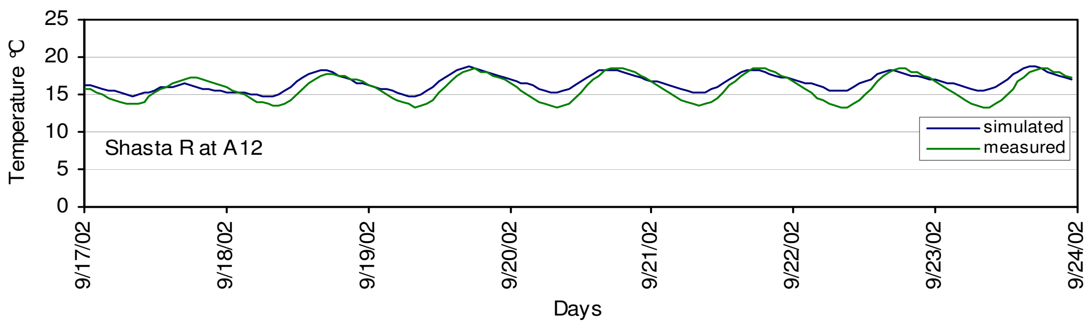

Figure 12. Temperature at Highway A12 for 9/17/2002 – 9/23/2002

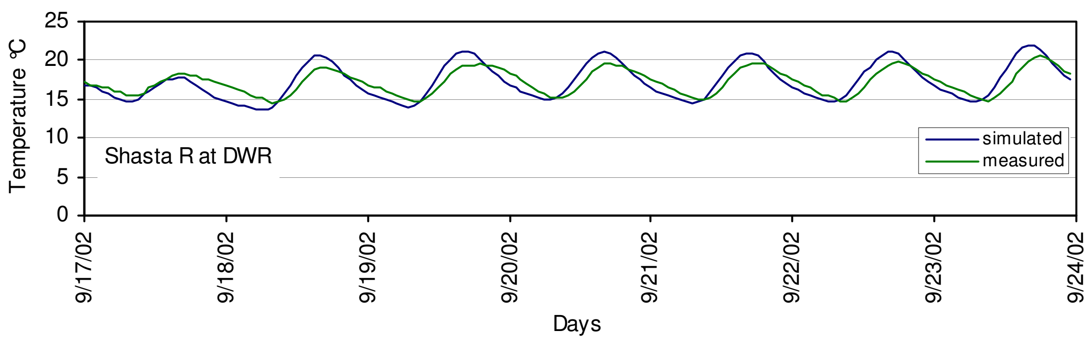

Figure 13. Temperature at DWR Weir for 9/17/2002 – 9/23/2002

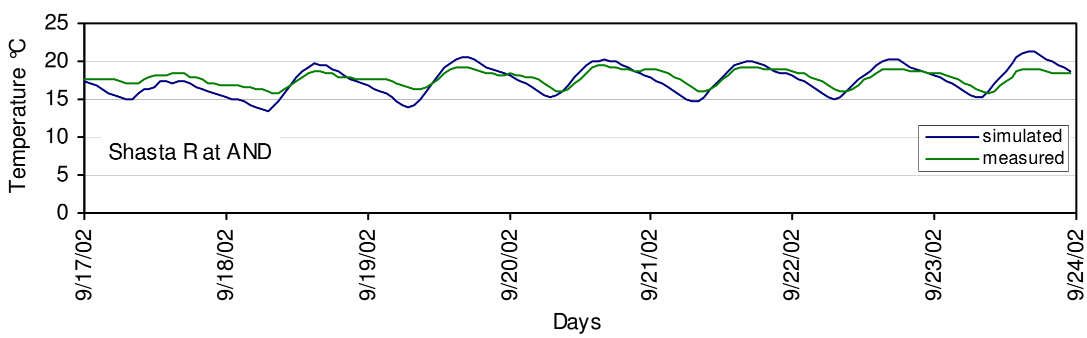

Figure 14. Temperature at Anderson Grade for 9/17/2002 – 9/23/2002

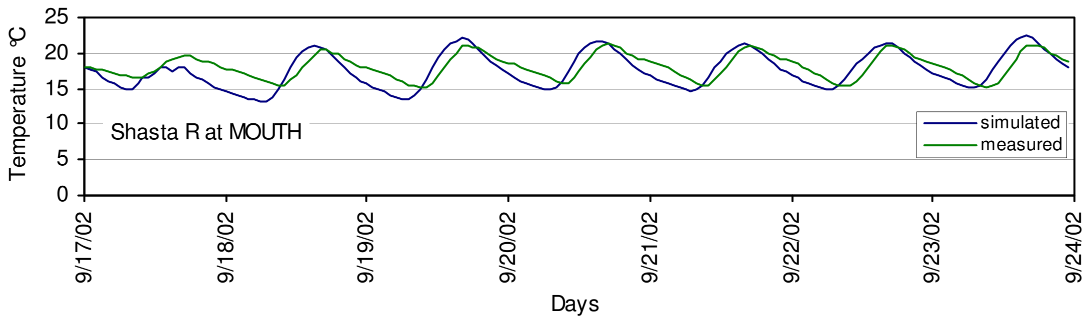

Figure 15. Temperature at the Mouth for 9/17/2002 – 9/23/2002

Validation Period (8/29/2002 – 9/04/2002):

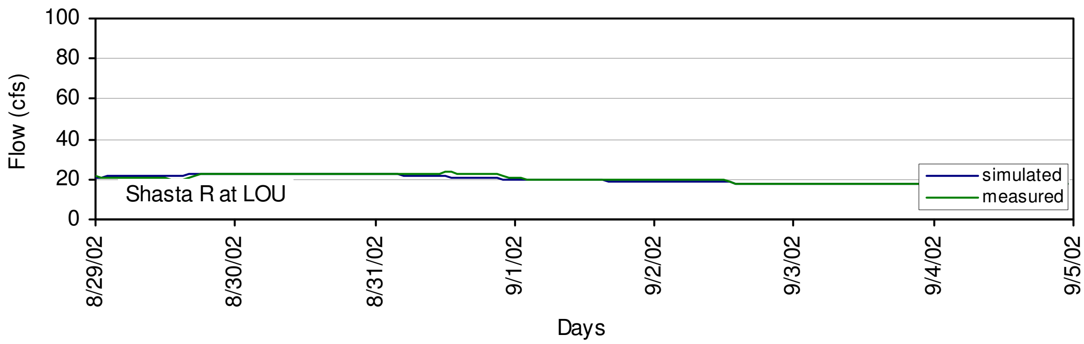

Figure 16. Flow at Louie Road for 8/29/2002 – 9/04/2002

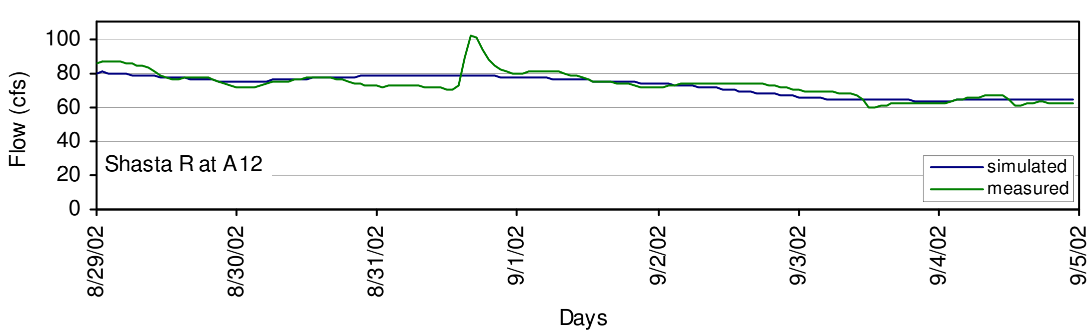

Figure 17. Flow at Highway A12 for 8/29/2002 – 9/04/2002

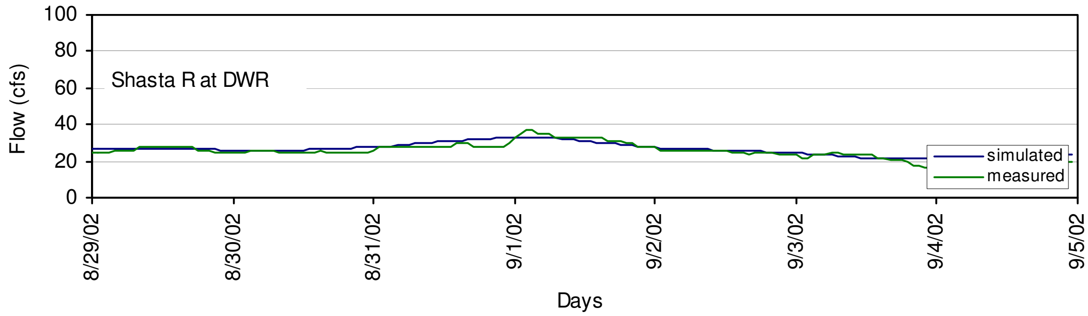

Figure 18. Flow at DWR Weir for 8/29/2002 – 9/04/2002

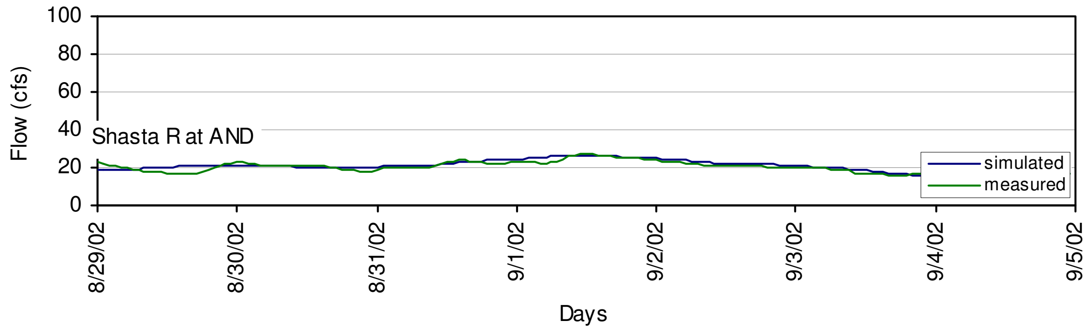

Figure 19. Flow at Anderson Grade for 8/29/2002 – 9/04/2002

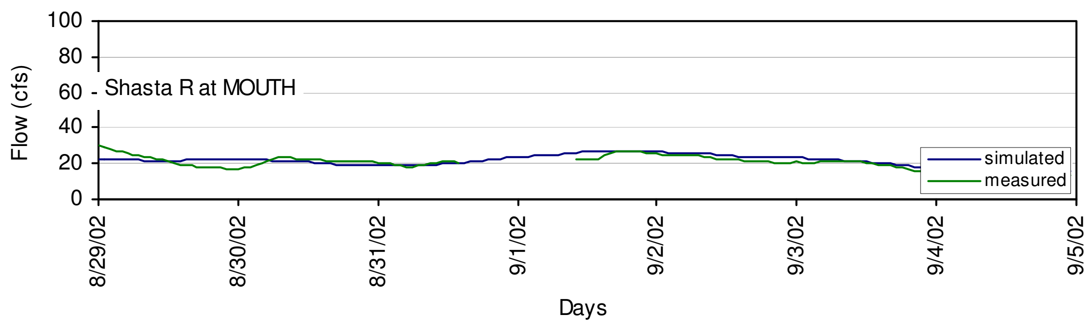

Figure 20. Flow at the Mouth for 8/29/2002 – 9/04/2002

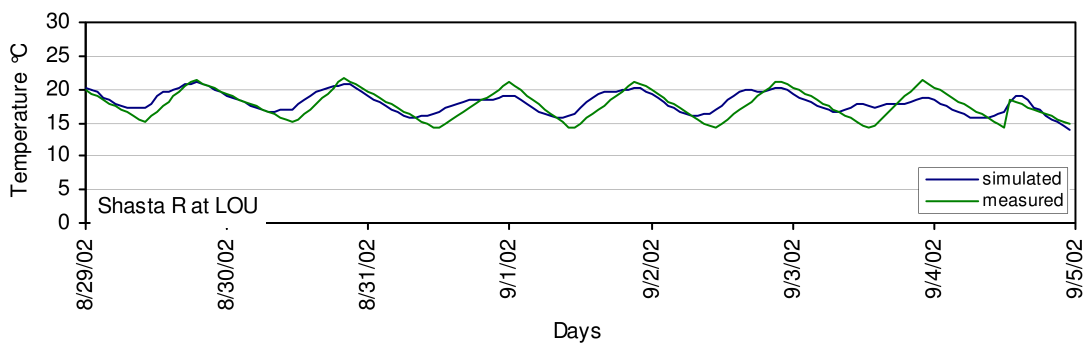

Figure 21. Temperature at Louie Road for 8/29/2002 – 9/04/2002

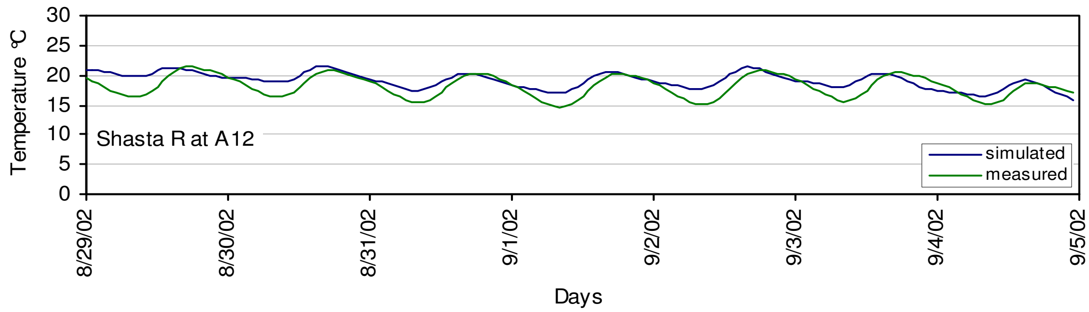

Figure 22. Temperature at Highway A12 for 8/29/2002 – 9/04/2002

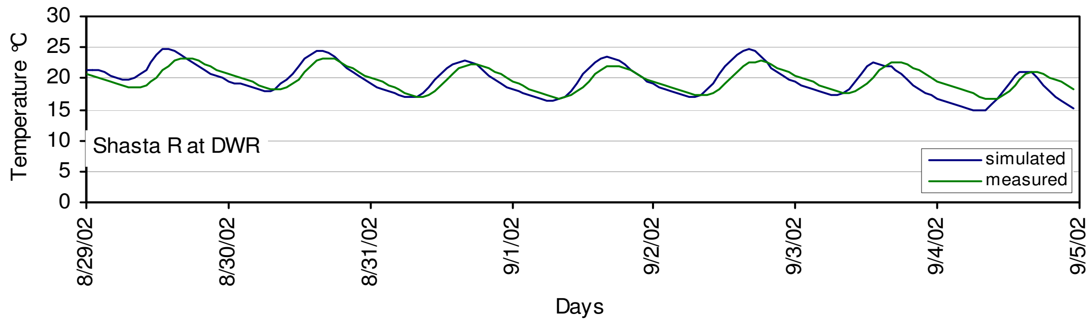

Figure 23. Temperature at DWR Weir for 8/29/2002 – 9/04/2002

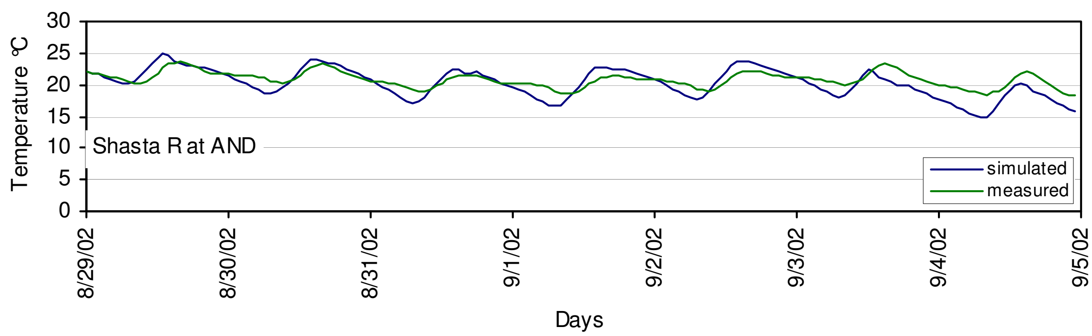

Figure 24. Temperature at Anderson Grade for 8/29/2002 – 9/04/2002

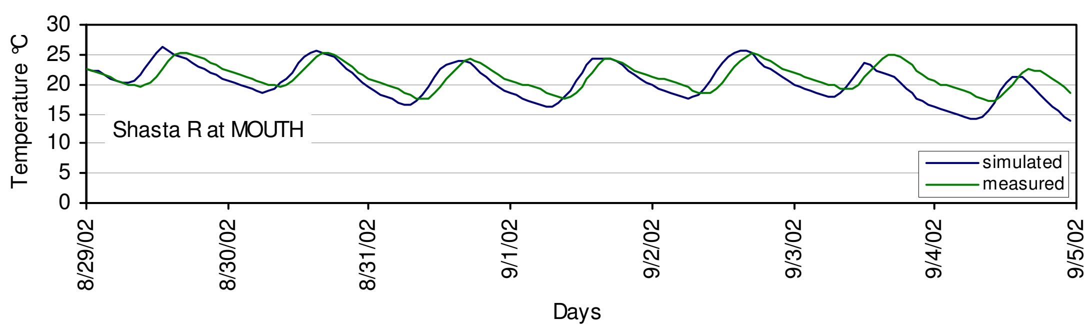

Figure 25. Temperature at the Mouth for 8/29/2002 – 9/04/2002

Validation Period (7/02/2002 – 7/08/2002):

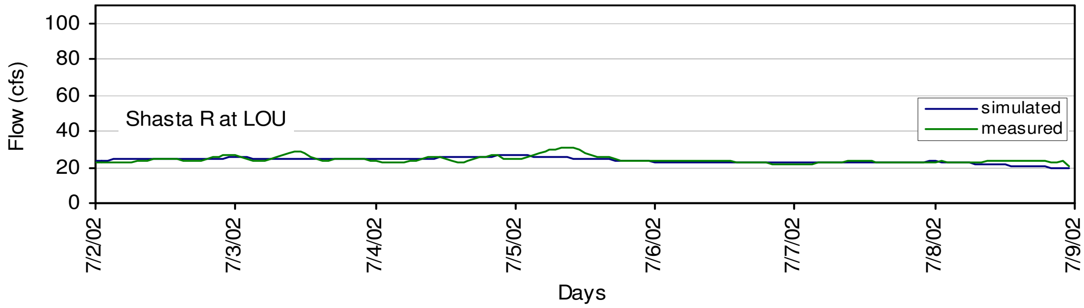

Figure 26. Flow at Louie Road for 7/02/2002 – 7/08/2002

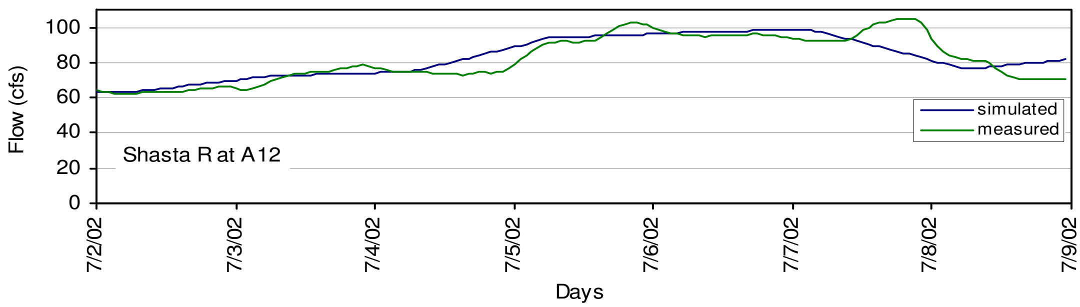

Figure 27. Flow at Highway A12 for 7/02/2002 – 7/08/2002

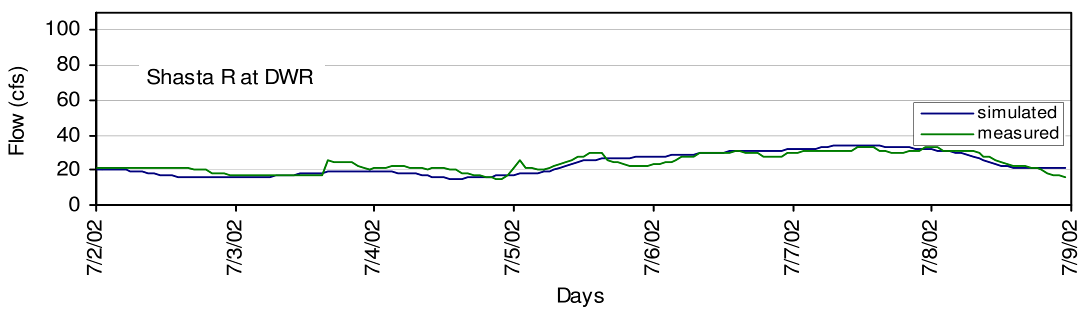

Figure 28. Flow at DWR Weir for 7/02/2002 – 7/08/2002

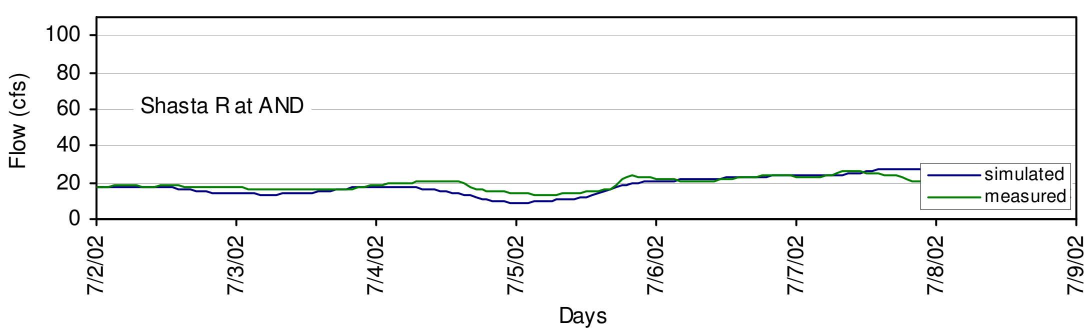

Figure 29. Flow at Anderson Grade for 7/02/2002 – 7/08/2002

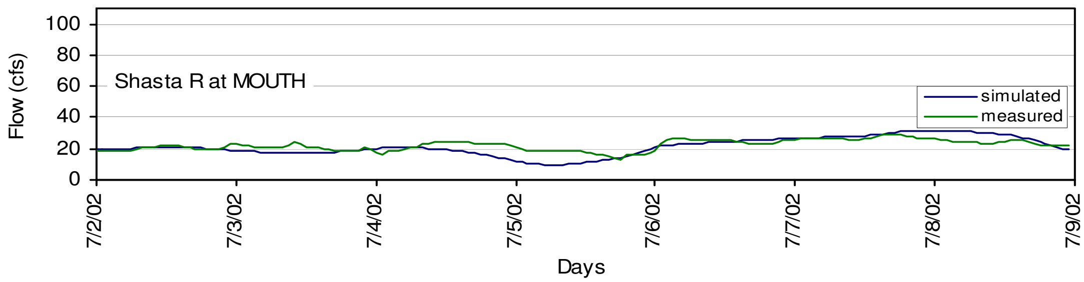

Figure 30. Flow at the Mouth for 7/02/2002 – 7/08/2002

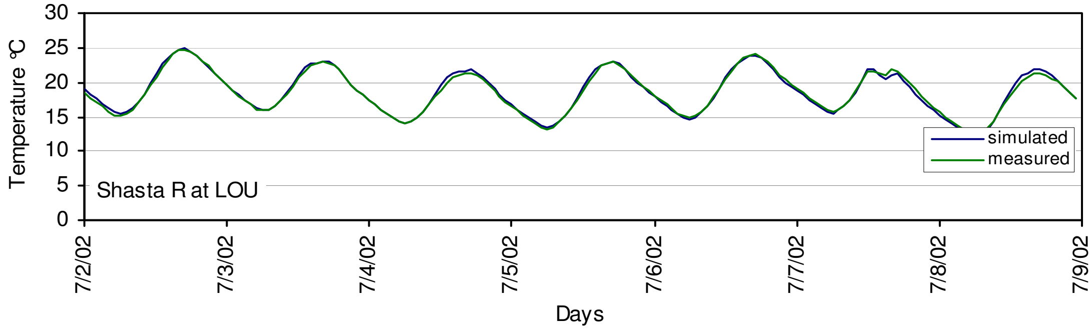

Figure 31. Temperature at Louie Road for 7/02/2002 – 7/08/2002

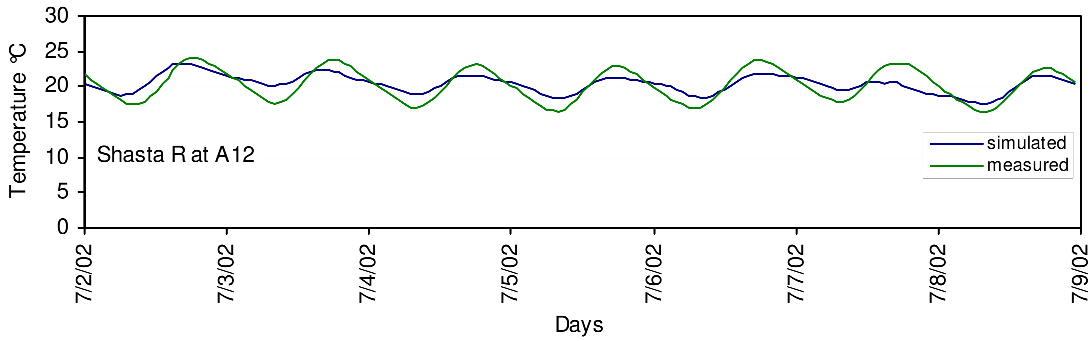

Figure 32. Temperature Highway A12 for 7/02/2002 – 7/08/2002

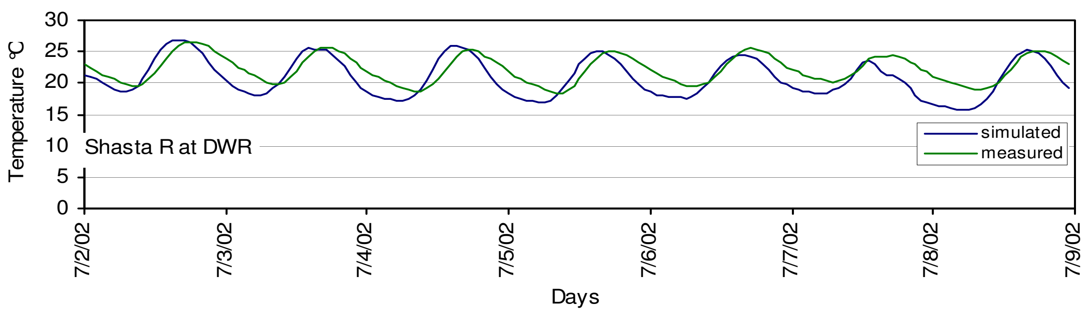

Figure 33. Temperature DWR Weir for 7/02/2002 – 7/08/2002

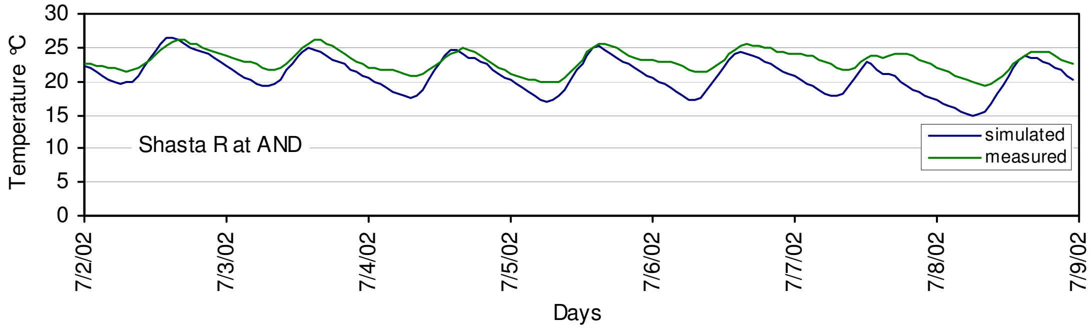

Figure 34. Temperature Anderson Grade for 7/02/2002 – 7/08/2002

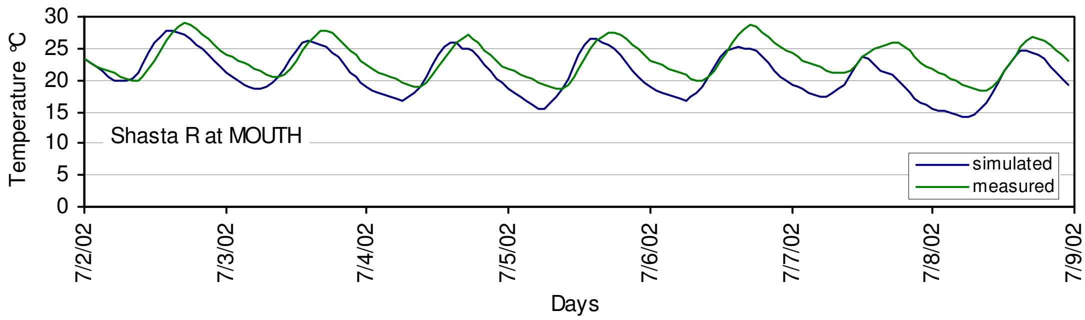

Figure 35. Temperature the Mouth for 7/02/2002 – 7/08/2002

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TECHNICAL MEMORANDUM: SHASTA RIVER ALGAE BOX MODEL

TO: Matt St John, North Coast Regional Water Quality Control Board

FROM: Mike Deas, Watercourse Engineering, Inc.

COPIES: Josh Viers, University of California, Davis

Michael Johnson, University of California, Davis

RE: Shasta River Periphyton Analysis

DATE: August 16, 2005

Introduction

While modeling the Shasta River, it was determined that exploring the connection between nutrient levels in the river and potential primary production might lead to more accurately modeled dissolved oxygen. Therefore, an existing model used to predict phytoplankton biomass was altered and employed to determine the periphyton biomass in Shasta River based on limiting factors such as light and nutrients, as well as on respiration and mortality rates. Scouring and shading were also included. Such models are simplifications of natural systems, nonetheless, can provide insight into potential system dynamics. Given the limited available information on the Shasta River, the model is applied herein as a screening tool to determine potential cause and effect relationships for variable water quality conditions.

Model Approach

Existing Model

The existing mass balance model was a volume-based model that calculated the concentration of algae in the water of the reach, called phytoplankton. Equation (1) represents the original differential equation representing the algal growth over time.

$$V\frac{dP}{dt} = V(\mu - R_P - D_P)P - A\nu_s P + Q_{in}P_{in} - Q_{out}P \qquad (1)$$

Where:

V = volume (m^3)

P = phytoplankton biomass (μg/l)

μ = algal growth rate (1/d)

R_P = algal respiration rate (1/d)

D_P = algal predatory and non-predatory mortality (1/d)

A = bed area (m^2)

v_s = algal settling rate (m/d)

Q_{in} = inflow rate (m^3/d)

P_{in} = inflow algal concentration ((μg/l)

Q_{out} = outflow rate (m^3/d)

A forward difference approximation was employed to use the equation in an iterative form, creating Equation (2), presented below. $P_{t+\Delta t}$ represents the phytoplankton concentration at the future time, P_t represents the phytoplankton concentration at the current time, and Δt is the time interval; thus a simple marching scheme can be implemented to solve for $P_{t+\Delta t}$.

$$P_{t+\Delta t} = P_t + \left(\frac{\Delta t}{V}\right)\left(V(\mu - R_P - D_P)P_t - A v_s P_t + Q_{in} P_{in} - Q_{out} P_t\right) \quad (2)$$

Where:

Δt = change in time (d)

Shasta River Benthic Algae Model

To modify the existing algae model to a benthic algae model, several changes were made. The state variable was changed from phytoplankton, measured in volumetric concentration to benthic algae, measured in biomass per area. Limiting factors were calculated and, along with the maximum growth rate, used to create an apparent growth rate. A grazing coefficient was added along with the respiration and mortality coefficients. The settling component of the equation, $A v_s P_t$, was removed, as benthic algae cannot settle. The inflow algae concentration component was removed. Altering the outflow algae concentration component created a scouring term. The final mass balance equation for iteration of the Shasta River Benthic Algae Model is presented below (Equation (3)).

$$P_{t+\Delta t} = P_t + \Delta t\left((\mu_{\max} LF - R_b - D_b - Z_b)P_t - \frac{s v P_t}{d}\right) \quad (3)$$

Where:

Δt = change in time (d)

P_t = benthic algae biomass (mg/m^2) at current time step

$P_{t+\Delta t}$ = benthic algae biomass (mg/m^2) at next time step

μ_{max} = maximum algal growth rate (1/d)

LF = limiting factor (unitless)

R_b = algal respiration rate (1/d)

D_b = algal predatory and non-predatory mortality (1/d)

Z_b = algal grazing mortality (1/d)

s = scouring factor (unitless)

ν = water velocity (m/d)

d = water depth (m)

However, both minimum and maximum algal biomass values were employed to represent the restrictions of the physical world for algae growth that are not represented by the respiration, mortality, grazing rates or scour factor. Therefore, if Equation 3 produced an amount of algae that was either larger than the set maximum or smaller than the set minimum, the model substituted the maximum or minimum, respectively.

Scouring of benthic algae

A component of the benthic algae biomass calculation is scouring. Scouring occurs when benthic algae is removed from the bed of the river due to the force of the water flowing above it. Scouring will increase with the velocity of the water. Therefore, when the biomass equation was rewritten for an area-based calculation, not a volumetric calculation, the water velocity was retained in the scouring equation. Also a scouring factor was added, represented the percentage of benthic algae that is removed from the river bed by the water flow.

Limiting Factors

To more accurately calculate the algae biomass, the maximum growth rate for algae, taken from the literature, must be tempered with limiting factors. These factors take into account the limitations on growth due to available light, available nutrients, and the effect of temperature on algae growth. The apparent growth rate is represented as shown in Equation (4).

$$\mu = \mu_{max} f(T) f(L,P,N,C,Si) \qquad (4)$$

μ = phytoplankton growth rate (1/day)

μ_{max} = maximum phytoplankton growth rate (1/day)

$f(T)$ = temperature correction (unitless)

L = light limitation (unitless)

P = phosphorous limitation (unitless)

N = nitrogen limitation (unitless)

C = carbon limitation (unitless)

Si = silica limitation (unitless)

The function $f(L,P,N,C,Si)$ represents one of several methods used to characterize algal growth limitation due to several interacting factors, and will be outlined further below.

Temperature

A Van't Hoff Arrhenius formulation is used to accommodate growth rates at temperatures other than 20°C.

$$G_T = G_{max}(\theta)^{T-20} \tag{5}$$

Where:

G_T	= temperature adjusted growth rate (1/day)
G_{max}	= maximum growth rate at 20°C (1/day)
θ	= temperature adjustment factor (1.047)
T	= ambient water temperature (°C)

Light

Algae utilize available underwater light for photosynthesis and the subsequent metabolic processes and cell growth. Solar radiation can be used to represent available light.

Light limitation fraction can be represented as

$$f(L) = (1-GSF)I/(K_L + I) \tag{6}$$

Where:

$f(L)$	= light limitation fraction ($0 \leq f(L) \leq 1$)
I	= light intensity (W/m^2, solar radiation)
GSF	= global shade factor, unitless
K_L	= light half saturation constant (8.37 W/m^2)

For the Shasta River algae model, both a global shade factor and hourly solar radiation were used to determine hourly light limitation fraction. If the global shade factor was equal to zero, there was no shade. If the global shade fraction was equal to one, there was complete darkness. When combined with the measured hourly solar radiation, the global shade fraction is a very flexible tool for evaluating the effects of cloud cover or vegetative cover on algal biomass. Because hourly solar radiation data was used, at night and in the early morning $f(L)$ equals 0.

Nutrients

The nutrients represented in the model include phosphorous, nitrogen, and silica. Carbon is assumed to be plentiful in the river system and does not limit algal production. Nutrient concentrations for the Shasta River algae model can be input as hourly concentrations, and therefore the limiting factors for each nutrient are calculated hourly as well. The equations for calculating the limitations of growth due to nutrients are as follows.

$$f(P) = \frac{PO_4^{3-}}{K_P + PO_4^{3-}} \quad (7)$$

$$f(N) = \frac{(NH_4^+ + NO_3^-)}{K_N + (NH_4^+ + NO_3^-)} \quad (8)$$

$$f(Si) = \frac{Si}{K_{Si} + Si} \quad (9)$$

Where:

$f(P)$	= phosphorous limitation fractions (unitless)
PO_4^{3-}	= orthophosphate concentration (mg/l)
K_P	= phosphorous half saturation constant (mg/l)
$f(N)$	= nitrogen limitation fractions (unitless)
NH_4^+	= ammonia concentration (mg/l)
NO_3^-	= nitrate concentration (mg/l)
K_N	= nitrogen half saturation constant (mg/l)
$f(Si)$	= silica limitation fractions (unitless)
S_i	= silica concentration (mg/l)
K_{Si}	= silica half saturation constant (mg/l)

Combined Limiting Factors – f(L,P,N,Si)

The combined limiting factors for light and nutrients can be determined using several methods, including multiplicative, minimum, harmonic mean, and arithmetic mean.

Multiplicative

$$f(L,P,N,Si) = f(L) \cdot f(P) \cdot f(N) \cdot f(Si) \quad (10)$$

Minimum

$$f(L,P,N,Si) = minimum[f(L),f(P),f(N),f(Si)] \quad (11)$$

Harmonic Mean

$$f(L,P,N,Si) = \frac{n}{\left(\frac{1}{f(L)} + \frac{1}{f(P)} + \frac{1}{f(N)} + \frac{1}{f(Si)}\right)} \tag{12}$$

Arithmetic Mean

$$f(L,P,N,Si) = \frac{\left(f(L) + f(P) + f(N) + f(Si)\right)}{4} \tag{13}$$

Comparison of these methods illustrates that the multiplicative formulation is the most limiting, while the arithmetic mean is the least limiting. However, because the light limiting factor can be equal to zero during the night and the early morning, only the multiplicative and minimum methods represent the correct combined limiting factors when using hourly solar radiation data. For the Shasta River algae model, the minimum combined limiting factor method was used.

Model Implementation

Presented in Table 1 are typical values for parameters necessary for the benthic algae model.

Table 1. Typical parameter values necessary for algal mass balance

	Parameter Values[a]							
	Growth Rate (1/d)	Respiration (1/d)	Mortality (1/d)	Grazing (1/d)	K_L (W/m^2 d)	K_N (mg/l)	K_P (mg/l)	K_{Si} (mg/l)
Total Phytoplankton	1.0-3.0	0.05 to 0.15	0.003 to 0.17	0.01 to 0.07	8.37 to 25.12	0.01 to 0.40	0.0005 to 0.03	0.03 to 0.10

[a] Values represent predominately freshwater systems

Those values used to implement the Shasta River algae model are presented in Table 2. The hourly solar radiation data used in model implementation is 2000 solar radiation from Brazie Ranch (with small data gaps filled using linear interpolation and large data gaps filled using 2000 meteorological data from Klamath Falls (Oregon AgriMet station KFLO, supported by U.S. Bureau of Reclamation) solar radiation). The hourly water temperature data used 2000 water temperature data for the mouth of the Shasta River complied for the Klamath River modeling project. The light extinction coefficient was provided from existing Shasta River field data.

The travel time and reach dimensions were approximate estimates of typical Shasta River conditions. A rectangular cross-section shape was assumed for the fictitious reach. While the model is built to accommodate hourly flow and nutrient data, as the reach was fictitious, it was determined that constant flow (and therefore constant velocity in the reach) and constant nutrient concentrations would allow for a better understanding of the model's functions. The resulting algae biomass from model implementation is presented in Figure 1.

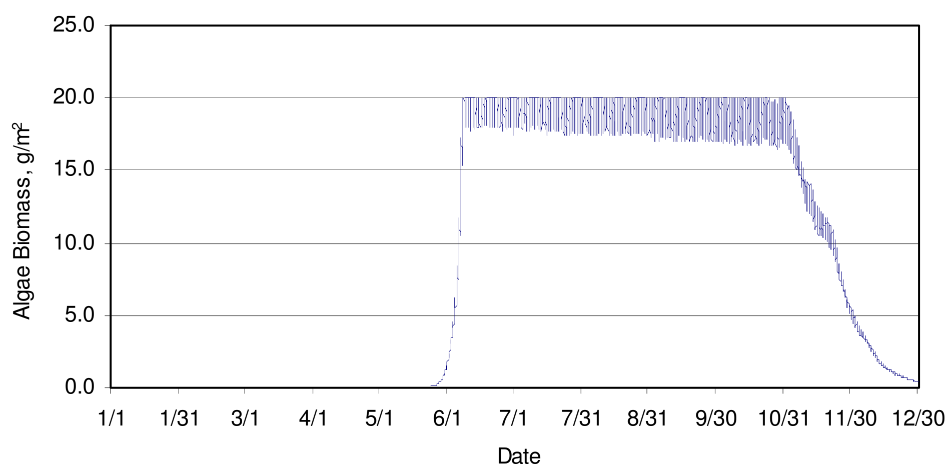


Figure 1. Algal biomass with model implementation parameters

Table 2. Model parameter values for implementation

Parameter	Model Value	Units
Time step	0.041667	day
Travel time of reach	0.042	day
Reach length, l	1609	meters
River width, w	9.1	meters
River depth, d	0.6	meters
River cross-sectional area, CS	13.9	m^2
Reach volume, V	22426.9	m^3
Reach flow in and flow out, Qin and Qout	538247	m^3/day
Reach bed area, A	7357.9	m^2
Reach velocity, vel	73.2	m/day
Initial bed algae biomass, P_i	0.001	g/m^2
Minimum bed algae biomass, P_{min}	0.1	g/m^2
maximum bed algae biomass, P_{max}	20	g/m^2
Solar radiation, SR	hourly	W/m^2
Global Shade Factor, GSF	0	-
Total inorganic nitrogen inflow concentration, $[TIN]_{in}$	0.2	mg/l
Phosphate inflow concentration, $[PO4]_{in}$	0.2	mg/l
Silica inflow concentration, $[Si]_{in}$	50	mg/l
Light half saturation coefficient, K_L	0.0009	Kcal/m^2s
Light extinction coefficient, Le	1.48	1/meter
Nitrogen half saturation coefficient, K_N	0.014	mg/l
Phosphate half saturation coefficient, K_P	0.003	mg/l
Silica half saturation coefficient, K_S	0.03	mg/l
Maximum growth rate, G	1.2	1/day
Respiration (and excretion) rate, R	0.14	1/day
Mortality rate, D	0.14	1/day
Grazing rate, Z	0.05	1/day
Algae settling rate, v	0	m/day
Scouring factor, s	0.00001	-
Theta, θ	1.040	-
Water Temperature, T	hourly	C
Reference water temperature, T_{ref}	20	C

Sensitivity Analysis

A test of sensitivity was performed on the model to determine what parameters, if any, to which the model is sensitive. The sensitivity analysis was restricted to nutrient half-saturation coefficients, nutrient concentrations, the light extinction coefficient, the depth of the river (changing the depth altered the flow rate in the model since the flow rate is determined from the dimensions of the river reach and the travel time), the maximum growth rate, the global shading factor, the initial algal biomass per area, and the maximum and minimum algal biomass per area. Based on the sensitivity analysis, there are several conclusions that can be drawn about the model.

The model is not sensitive to silica half-saturation constants or concentrations. The model is mildly sensitive to phosphate half-saturation constants and concentrations, and is sensitive to nitrogen half-saturation and concentrations.

For both phosphate and nitrogen, when the concentration of nutrient approached the half-saturation for that nutrient, the algal biomass was decreased, and vice versa, if the nutrient concentration retreated from the half-saturation constant, the algal biomass increased. Maintaining the modeling implementation nitrogen half-saturation constant of 0.014 mg/l, a nitrogen concentration of 0.02 mg/l (an order of magnitude lower than the model implementation value) created only 10% of the model implementation biomass. If the nitrogen concentration was lowered to equal the half-saturation concentration, essentially no algae was produced during the year. The same was true for lowering the phosphate concentration to equal the half-saturation constant. However, lowering the phosphate concentration one order of magnitude to 0.02 mg/l only lowered the biomass to 92% of the model implementation biomass. Increasing the nitrogen concentration by an order of magnitude or decreasing the half-saturation constant by an order of magnitude both increased the algal biomass to 104 % of the model implementation biomass. Increasing the phosphate concentration by an order of magnitude or decreasing the half-saturation constant by an order of magnitude both had no effect on the annual biomass. Increasing the half-saturation constant for phosphate produced the same 92% biomass as decreasing the phosphate concentration to 0.02 mg/l.

Combinations of increasing or decreasing all of the half-saturation or concentrations of nutrients together did affect the results in a none-additive manner. When the half-saturation constants were all lowered an order of magnitude, there was an increase in the biomass of 104%, but the annual cumulative biomass is slightly larger than when only the nitrogen half-saturation constant is lower. Increasing all of the half-saturation constants by an order of magnitude produced the same result as only increasing the nitrogen half-saturation constant.

All nutrient sensitivity results are presented in Table 3 and Figure 2 through Figure 7, and Figure 15 through Figure 32.

There was a linear relationship between the light extinction coefficient, Le, and the annual average algal biomass, P_{ave}. Increasing Le decreased P_{ave} slightly, but still well within the same order of magnitude, as shown in Table 3, Figure 8 , and Figure 33 through Figure 36. The yearly graphs show that increasing the Le slightly decreases the amount of algae produced in the latter portion of the growing season. The relationship between river depth, d, and P_{ave} was similar to the Le vs P_{ave} relationship as P_{ave} decreased with increasing d and the size of change in P_{ave} was not very large, as shown in Table 3 and Figure 9. Also, the same changes in the production at the end of the growing season occurred for increased d as they did for increased Le, as shown in Figure 37 through Figure 40. The similar relationships for Le and d were expected as the amount of light reaching the bottle of a river bed decreases with increases in either d or Le.

There was also a linear relationship between maximum algal growth rate, G, and P_{ave}. Increases in G produced increases in P_{ave}. However, incremental increases in G did not increase the order of magnitude of P_{ave}, as shown in Table 3 and Figure 10. As shown in Figure 41 through Figure 44, increasing G increased the length of the growing season by starting the algae bloom earlier in the year.

The global shade factor, GSF, decreased P when increased, but it did not indicate a linear relationship. Rather, it appeared that the decrease in P_{ave} was smaller with increased GSF until GSF reached 0.5 (or 50% shade) and then the increases in GSF produced larger decreases in P_{ave} until there is approximately 60% of the model implementation biomass when GSF equals 0.9. The sensitivity analysis results for varying GSF can be seen Table 3 and Figure 11.As seen in Figure 45 through Figure 48, increasing GSF shortened the length of the growing season by both delaying the start of the algae bloom and curtailing the period of time in which the algae would flourish until there is no growing season for a GSF of 0.9.

Increases in the minimum algal biomass per area, P_{min}, produced very small increases in P_{ave}. There was little change to P_{ave} even when P_{min} was increased by an order of magnitude. This indicates that this model implementation rarely produced an algal biomass per area of less than 1 g/m^2. Sensitivity analysis results for P_{min} are presented in Table 3 and Figure 12. There were no overall seasonal changes in the timing of growth or the length of the growing season, as presented in Figure 49 through Figure 52.

Increases in the maximum algae biomass per area, P_{max} created large increases of P_{ave} in a linear relationship to each other. The sensitivity of P_{max} was tested to the large range presented in Table 3 to determine if there was a maximum algal biomass per area that the model would achieve on its own. The value for P_{max} that was found to allow the model to always use the calculated algal biomass per area was very large. The large value underlines both the inherent problems in modeling a processes as complex as algal growth in a river as well as the necessity of using parameters such as P_{max} and P_{min} in assisting the model to calculate results feasible to the physical world. Sensitivity analysis results for P_{max} are presented in Table 3 and Figure 13. Illustrated in Figure 53 through Figure 57 is the change in both maximum algal biomass per area and the start of the growing season. As P_{max} increased, the start of the growing season was delayed very slightly, until, with the largest value of P_{max} shown, the growth season has been delayed by several months but ends normally, so is quite short.

Increasing the initial algal biomass per area, P_i, produced small increases in P_{ave}. As can be seen in Table 3, increasing P_i by three orders of magnitude only increased P_{ave} to 110.3% of the implementation value. Further investigation into P_i and its effect on P_{ave}

showed that the values of P asymptotically approached 10.89 g/m^2 until P_i reached 20, and then remained a constant 10.89 g/m^2 with further increases in P_i. However, this maximum value is directly related to the maximum algal biomass per area, P_{max}, which is specified by the user of the model, in this case specified to be 20 g /m2. Changing P_{max} would alter both the constant maximum P_{ave} that is asymptotically approached as well as the maximum P_i at which the constant P_{ave} would be achieved. Graphically, increases in P_i produced both an unstable algal population in the middle of winter which decreases to normal levels until the start of the regular growing season, and a hastening of the start of the growing season. Sensitivity analysis results for P_i are presented in Table 3, Figure 14, and Figure 58 through Figure 63.

Table 3. Annual total and annual average algae biomass sensitivity analysis results

Varied Parameter(s)	Parameter(s) Value	Units	Annual Total Biomass	Annual Ave Biomass	% Baseline
None (Baseline Condition)	Implementation values	-	77913	8.87	100%
K_N	0.0014	mg/l	80976	9.22	104%
	0.14		7564	0.86	10%
K_P	0.0003	mg/l	77913	8.87	100%
	0.03		71489	8.14	92%
K_{Si}	0.003	mg/l	77913	8.87	100%
	0.3		77913	8.87	100%
K_N, K_P, K_{Si}	0.0014, 0.0003, 0.003	mg/l	81010	9.22	104%
	0.14, 0.03, 0.3		7564	0.86	10%
$[TIN]_{in}$	0.014	mg/l	1	0.00012	0.0014%
	0.02		7564	0.86	10%
	2		80976	9.22	104%
$[PO4]_{in}$	0.003	mg/l	1	0.00012	0.0014%
	0.02		71489	8.14	92%
	2		77913	8.87	100%
$[Si]_{in}$	5	mg/l	77913	8.87	100%
	500		77913	8.87	100%
$[TIN]_{in}$, $[PO4]_{in}$, $[Si]_{in}$	0.02, 0.02, 5.0	mg/l	7564	0.86	10%
	2.0, 2.0, 500.0		81010	9.22	104%
Le	1.40	1/m	78390	8.92	101%
	1.44		78149	8.90	100%
	1.52		77683	8.84	100%
	1.56		77454	8.82	99%
d	0.15 (0.5)	m (ft)	88277	10.05	113%
	0.31 (1.0)		84307	9.60	108%
	0.92 (3.0)		73433	8.36	94%
	1.22 (4.0)		68195	7.76	87.5%
G	1.0	1/day	55527	6.32	71.3%
	1.1		67727	7.71	86.9%
	1.3		88193	10.04	113.2%
	1.4		95429	10.86	122.4%
GSF	0.1	-	76926	8.76	98.8%
	0.5		70736	8.05	90.8%
	0.7		64543	7.35	82.9%
	0.9		45184	5.14	57.9%
P_{min}	0.0	g/m^2	77590	8.83	99.6%
	0.2		78841	8.98	101.2%
	0.5		80039	9.11	102.7%
	1.0		80820	9.20	103.7%
P_{max}	30	g/m^2	116100	13.22	149.0%
	40		154114	17.54	197.7%
	50		191943	21.85	246.3%
	100		379504	43.20	487.0%
	1.00E+27		4.34E+22	4.94E+18	5.57E+17
P_i	0	g/m^2	77913	8.87	100.0%
	0.002		78485	8.94	100.8%
	0.005		79717	9.08	102.4%
	0.010		80535	9.17	103.4%
	0.100		83189	9.47	106.8%
	1.000		85953	9.78	110.3%

Parameter variation and Annual Average Algal Biomass Graphs

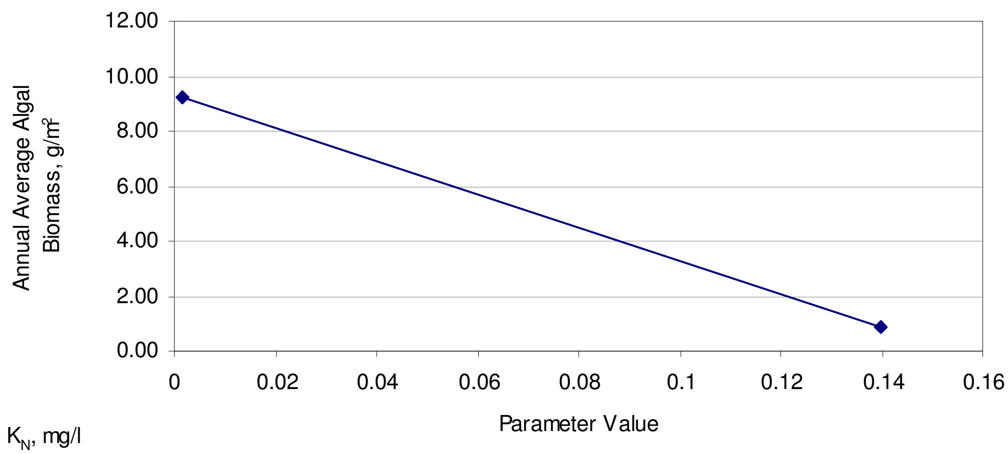


Figure 2. Annual average algal biomass when K_N was varied.

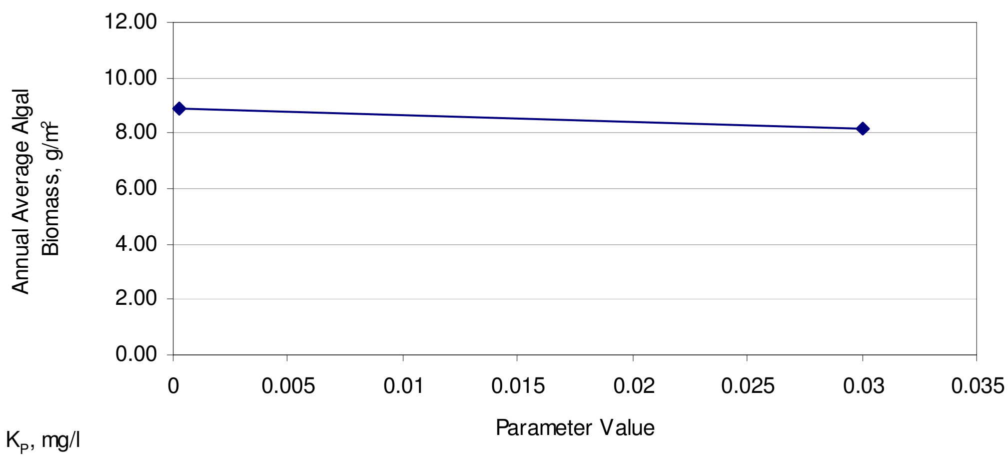


Figure 3. Annual average algal biomass when K_P was varied.

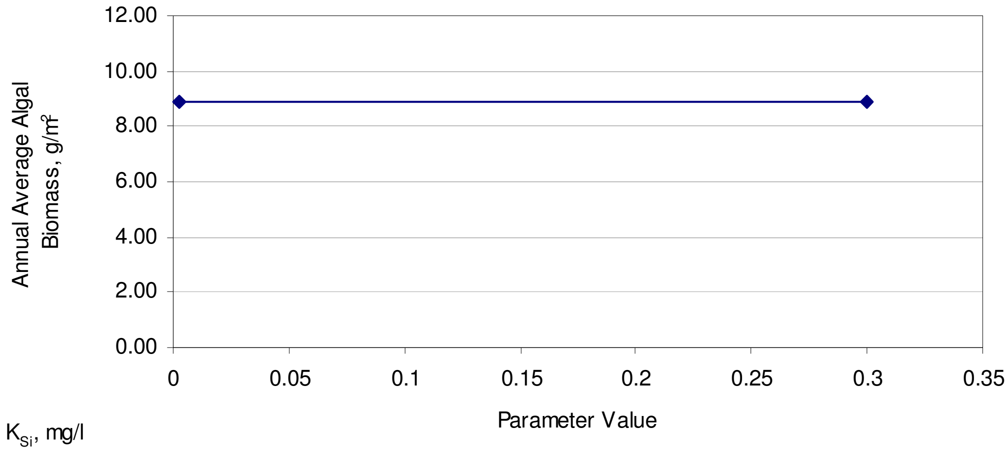


Figure 4. Annual average algal biomass when K_{Si} was varied.

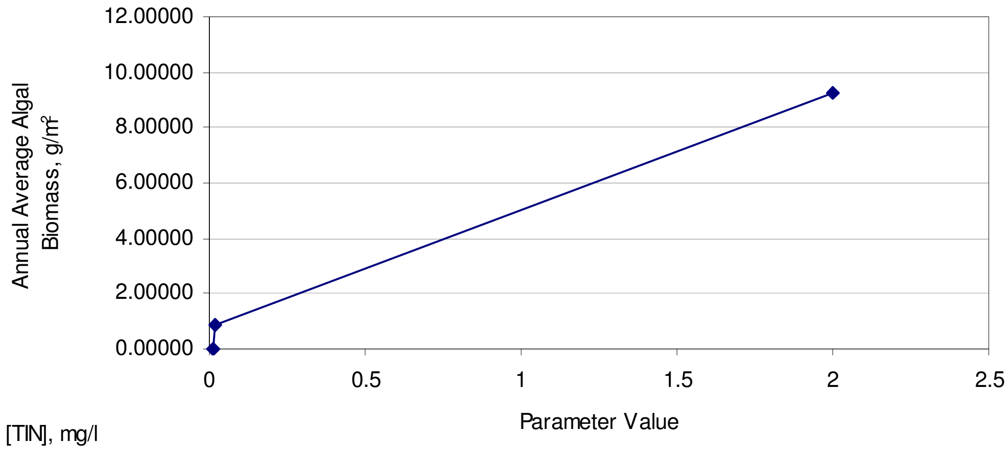


Figure 5. Annual average algal biomass when [TIN] was varied.

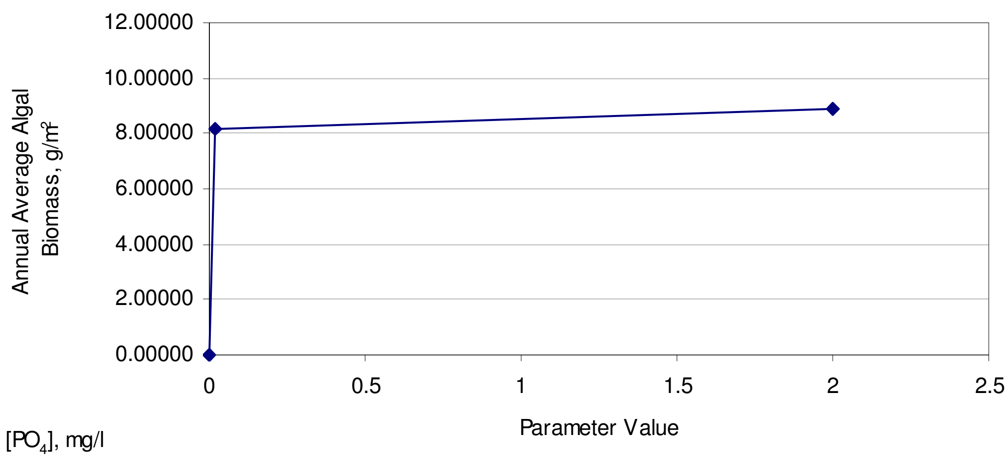


Figure 6. Annual average algal biomass when $[PO_4]$ was varied.

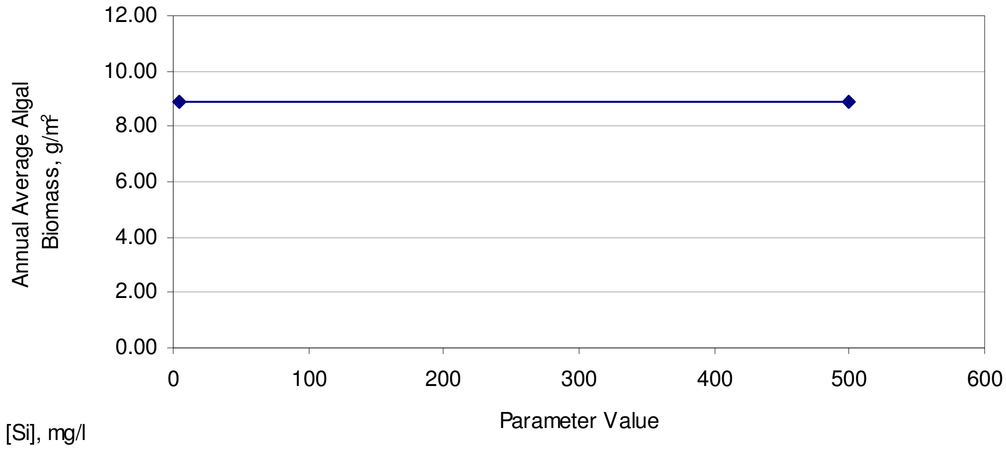


Figure 7. Annual average algal biomass when [Si] was varied.

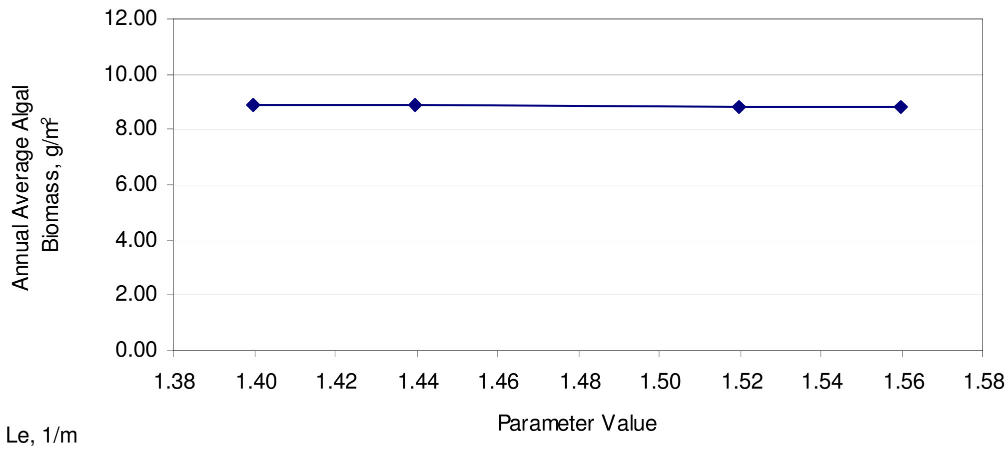


Figure 8. Annual average algal biomass when Le was varied.

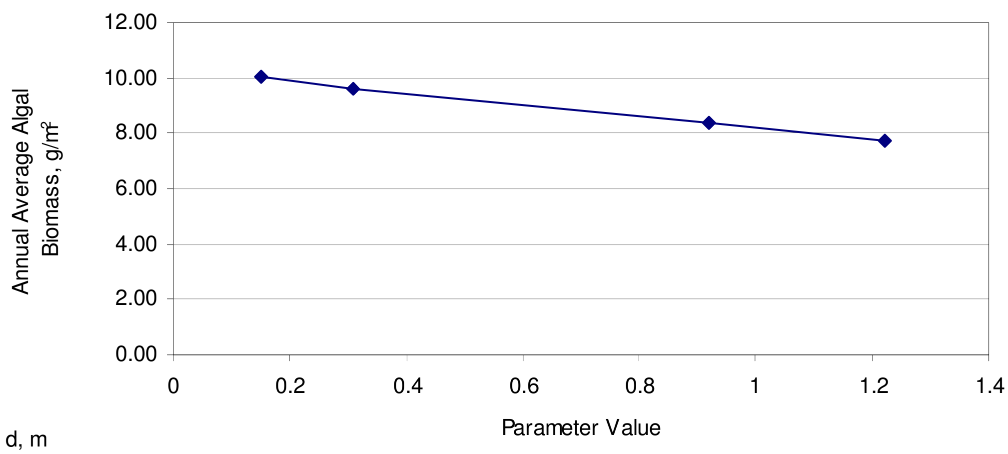


Figure 9. Annual average algal biomass when d was varied.

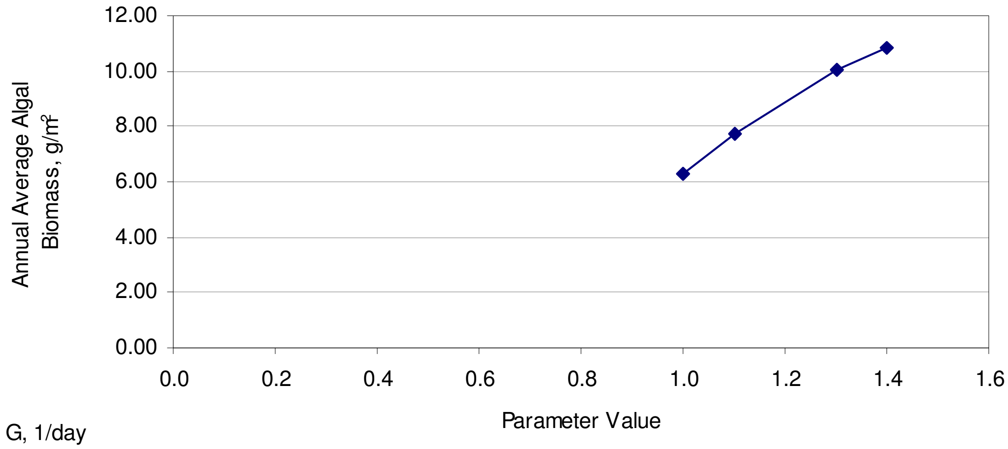


Figure 10. Annual average algal biomass when G was varied.

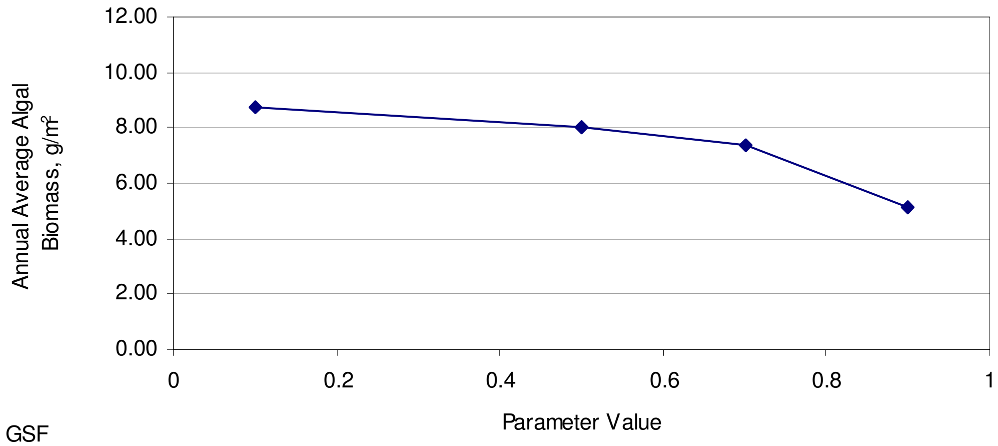


Figure 11. Annual average algal biomass when GSF was varied.

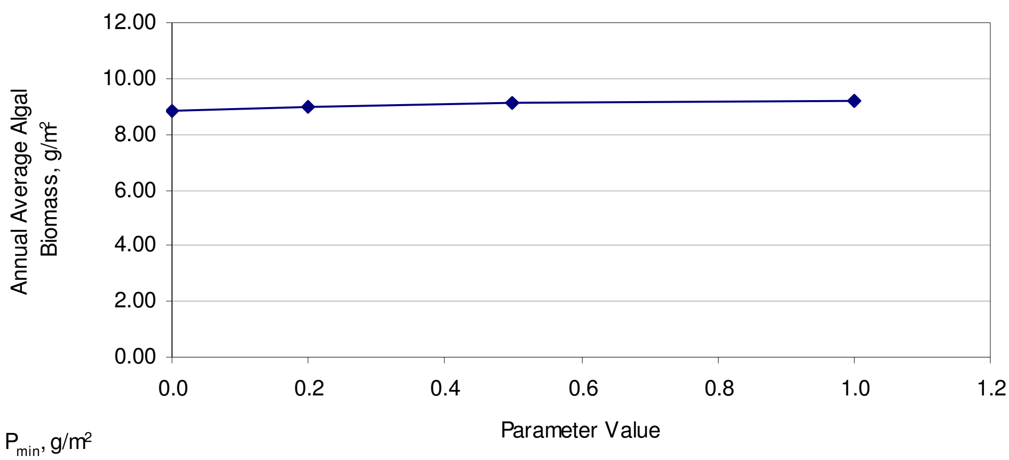
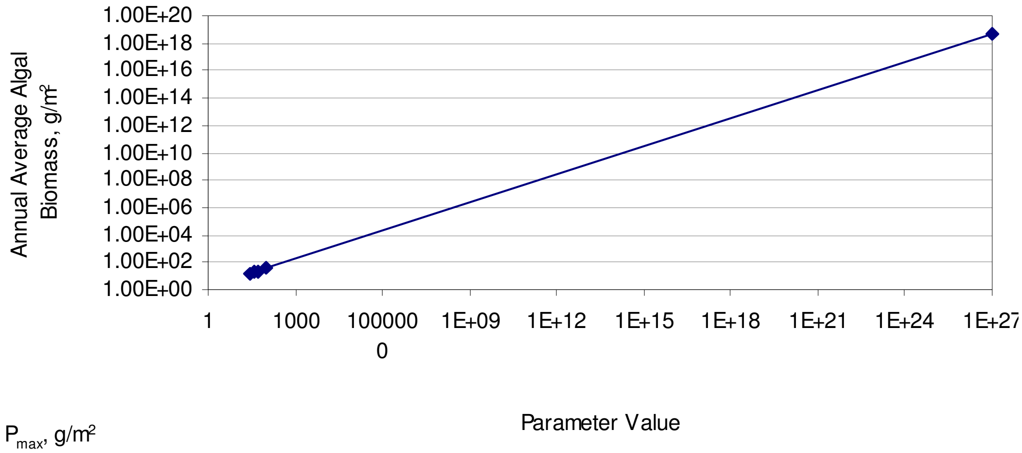
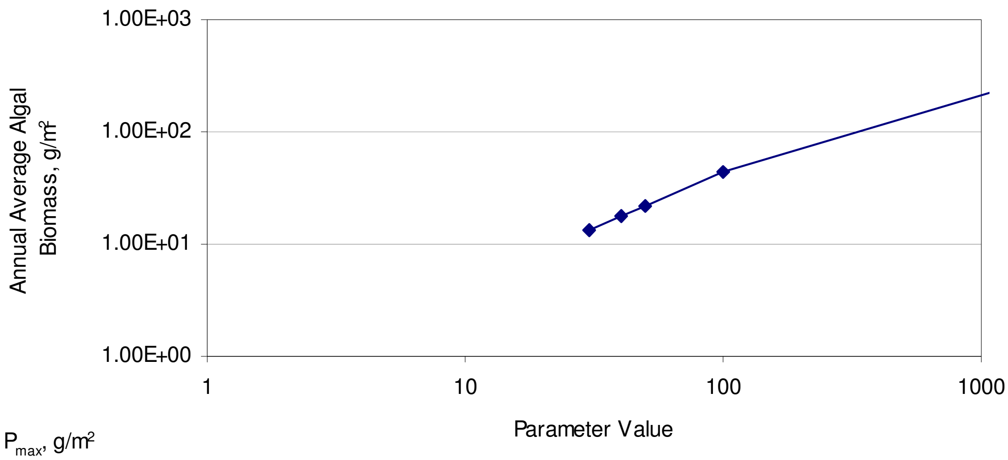


Figure 12. Annual average algal biomass when P_{Min} was varied.



(a)



(b)

Figure 13. Annual average algal biomass when P_{Max} was varied: (a) all values of P_{Max}; (b) smaller values of P_{Max}

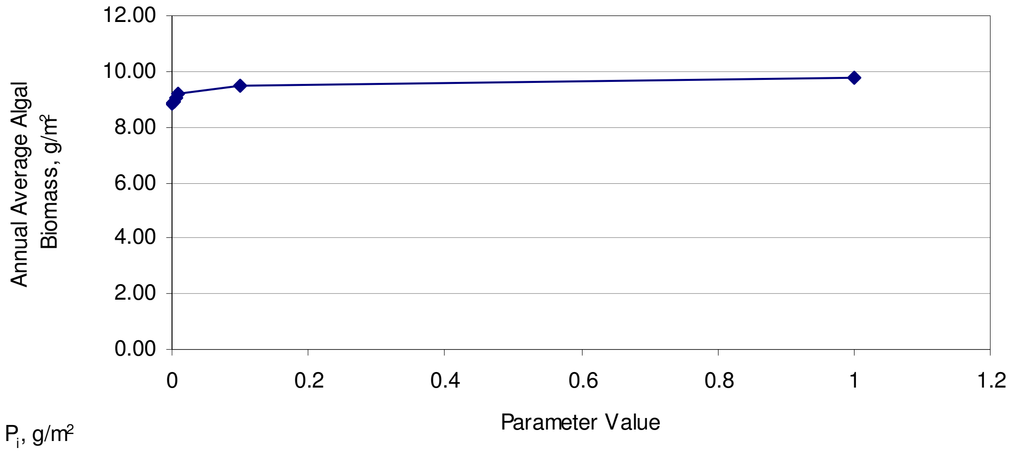


Figure 14. Annual average algal biomass when P_i was varied.

Algal Biomass graphical results for sensitivity analysis

Altering nutrient half-saturation coefficients

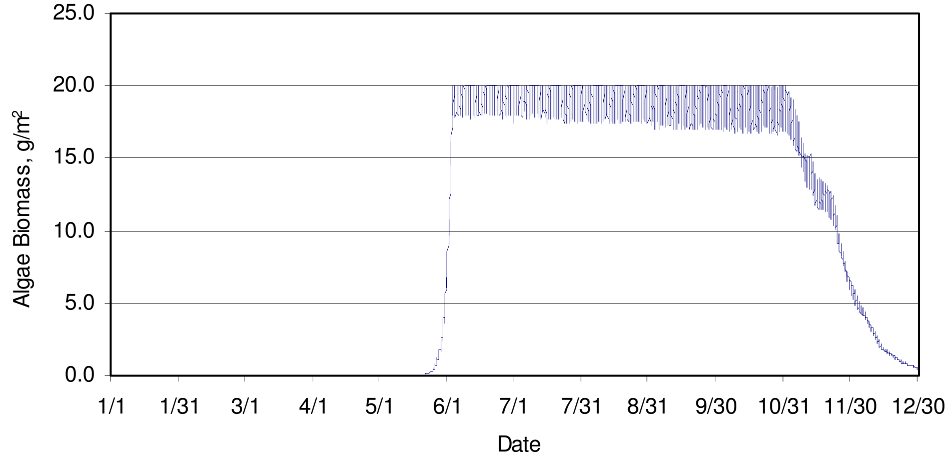


Figure 15. Algal biomass with Nitrogen half saturation coefficient equal to 0.0014 mg/l

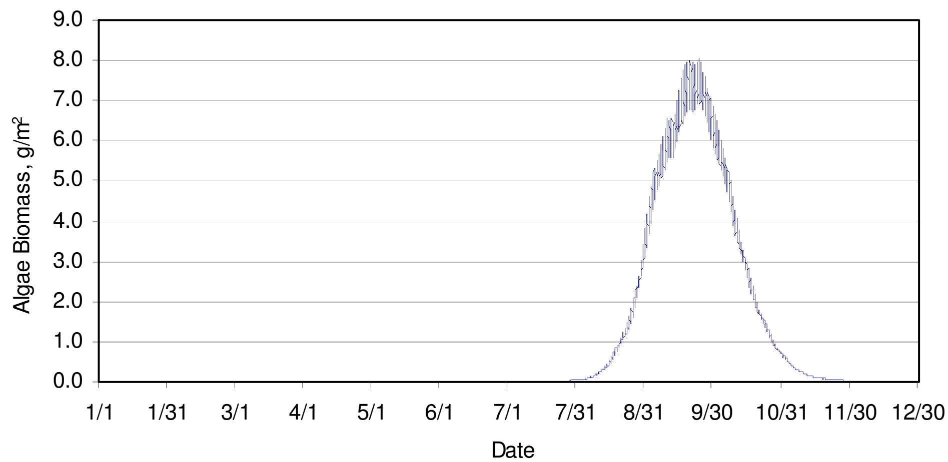


Figure 16. Algal biomass with nitrogen half saturation coefficient equal to 0.14 mg/l

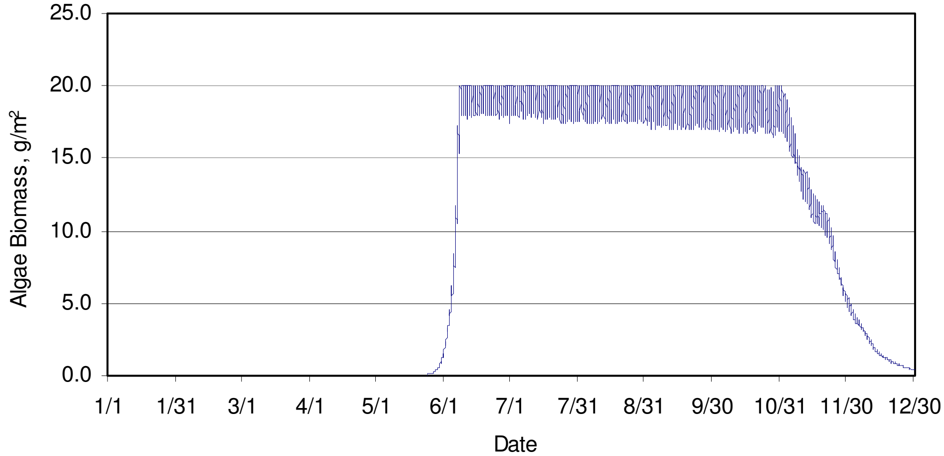


Figure 17. Algal biomass with phosphorus half saturation coefficient equal to 0.0003 mg/l

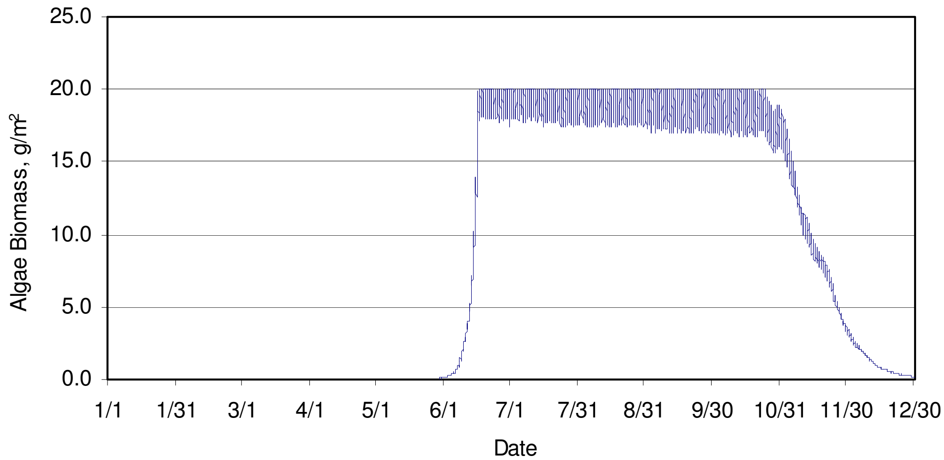


Figure 18. Algal biomass with phosphorus half saturation coefficient equal to 0.03 mg/l

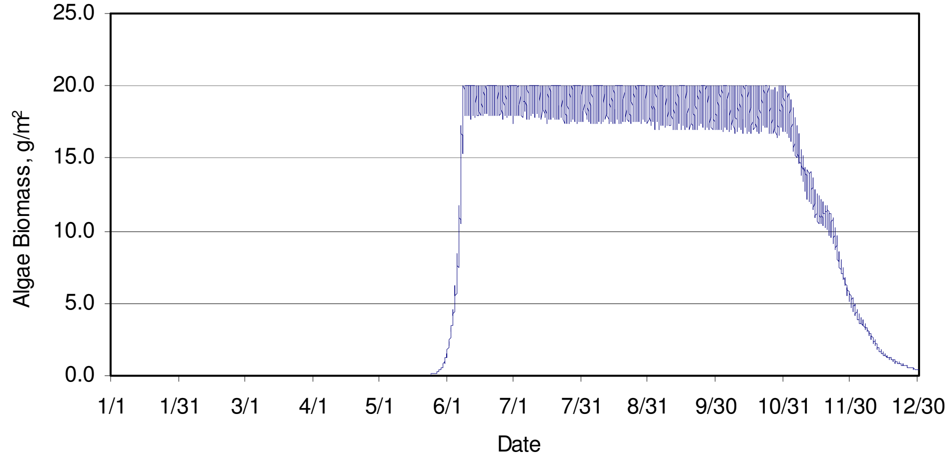


Figure 19. Algal biomass with silica half saturation coefficient equal to 0.003 mg/l

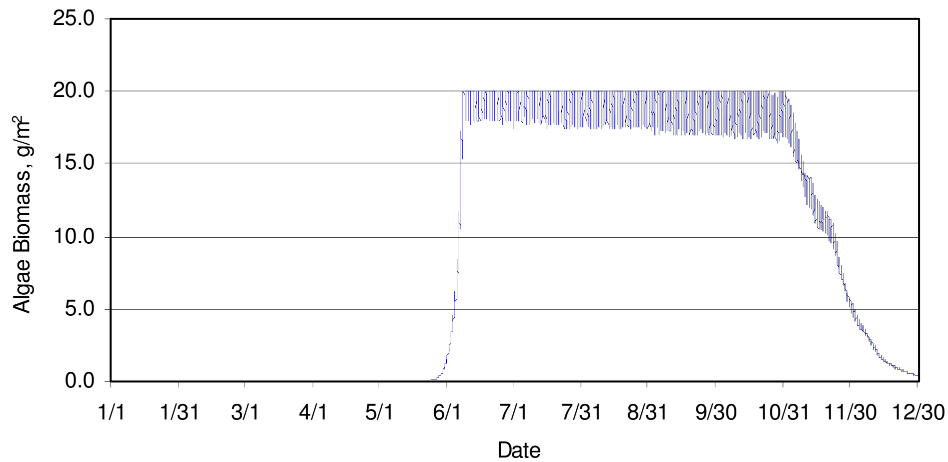


Figure 20. Algal biomass with silica half saturation coefficient equal to 0.3 mg/l

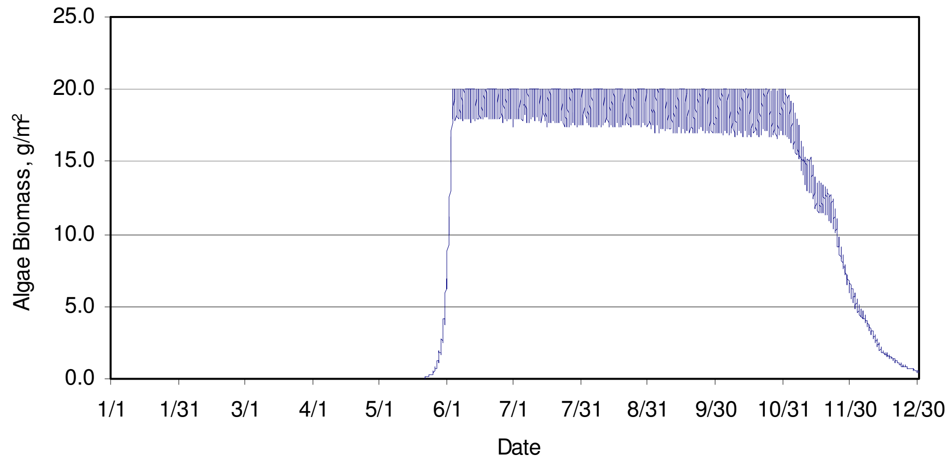


Figure 21. Algal biomass with K_N equal to 0.0014 mg/l, K_P equal to 0.0003 mg/l and K_S equal to 0.003 mg/l

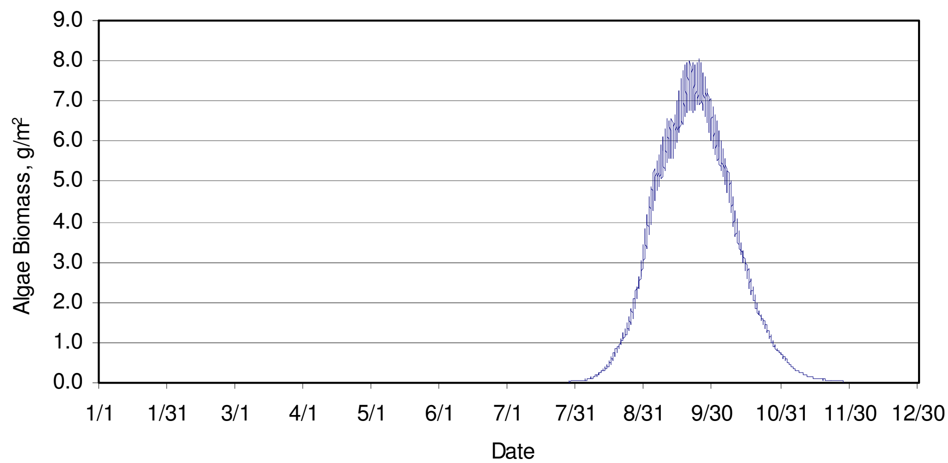


Figure 22. Algal biomass with K_N equal to 0.14 mg/l, K_P equal to 0.03mg/l and K_S equal to 0.3 mg/l

Altering nutrient concentrations

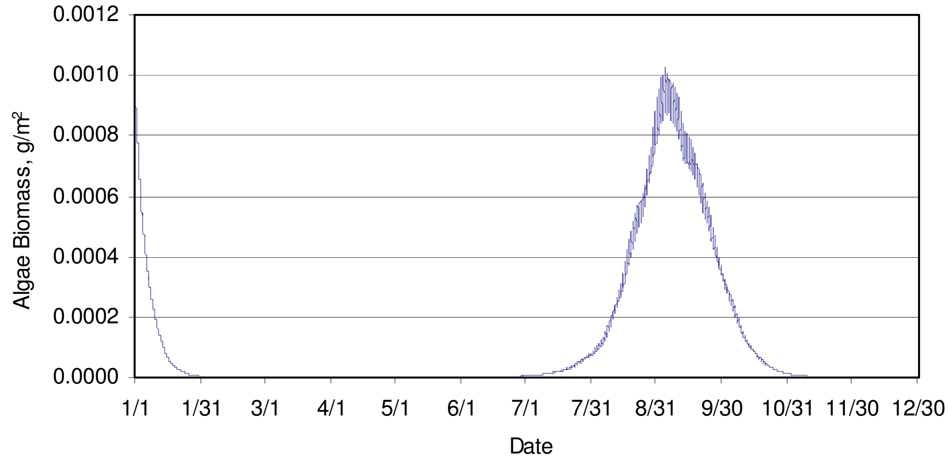


Figure 23. Algal biomass with total inorganic nitrogen concentration equal to 0.014 mg/l

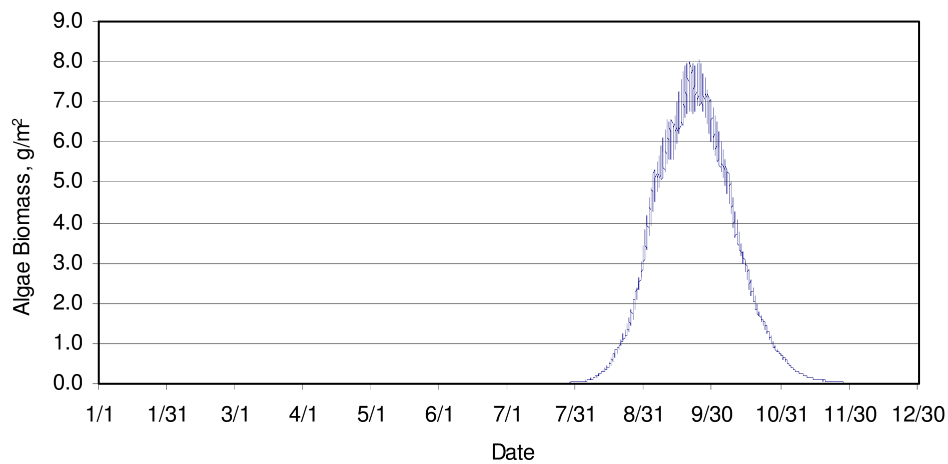


Figure 24. Algal biomass with total inorganic nitrogen concentration equal to 0.02 mg/l

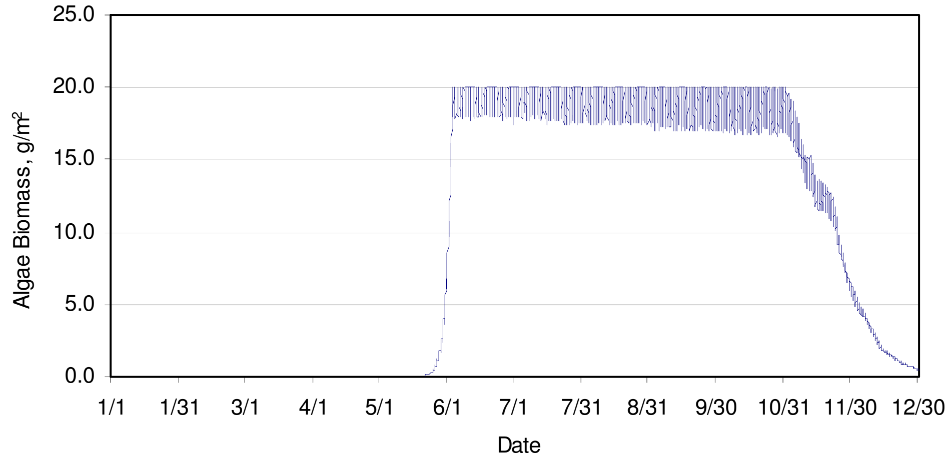


Figure 25. Algal biomass with total inorganic nitrogen concentration equal to 2.0 mg/l

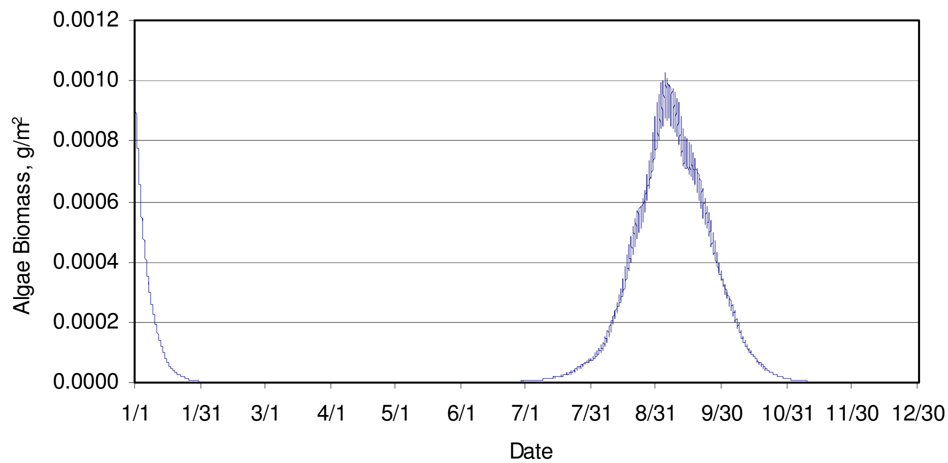


Figure 26. Algal biomass with phosphate concentration equal to 0.003 mg/l

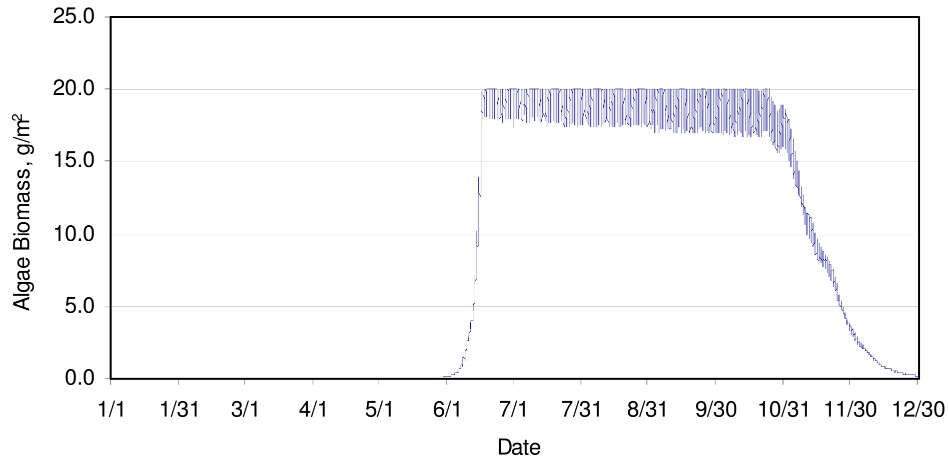


Figure 27. Algal biomass with phosphate concentration equal to 0.02 mg/l

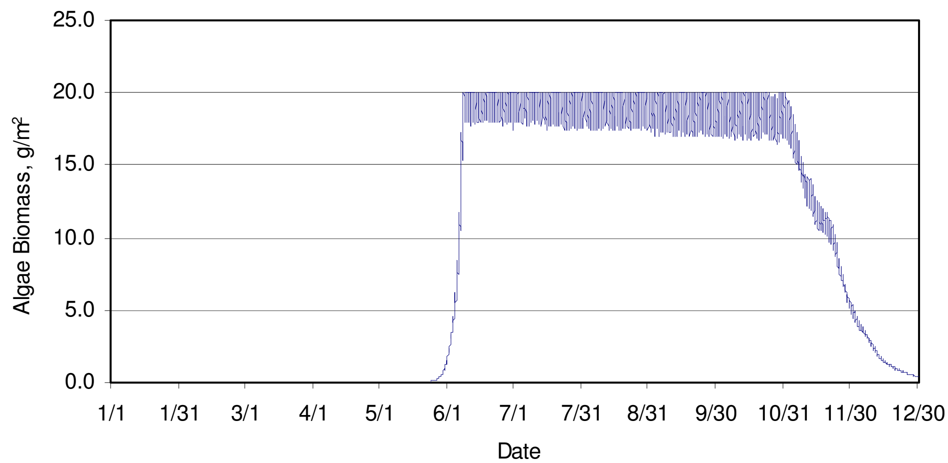


Figure 28. Algal biomass with phosphate concentration equal to 2.0 mg/l

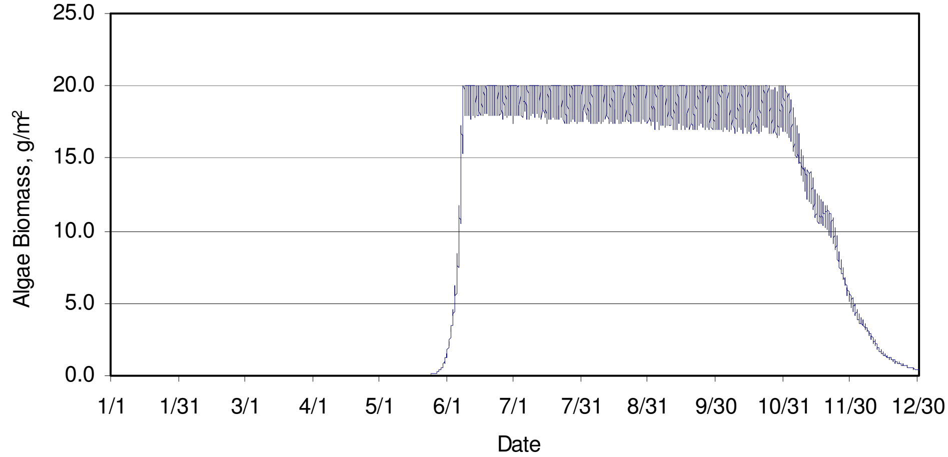


Figure 29. Algal biomass with silica concentration equal to 5.0 mg/l

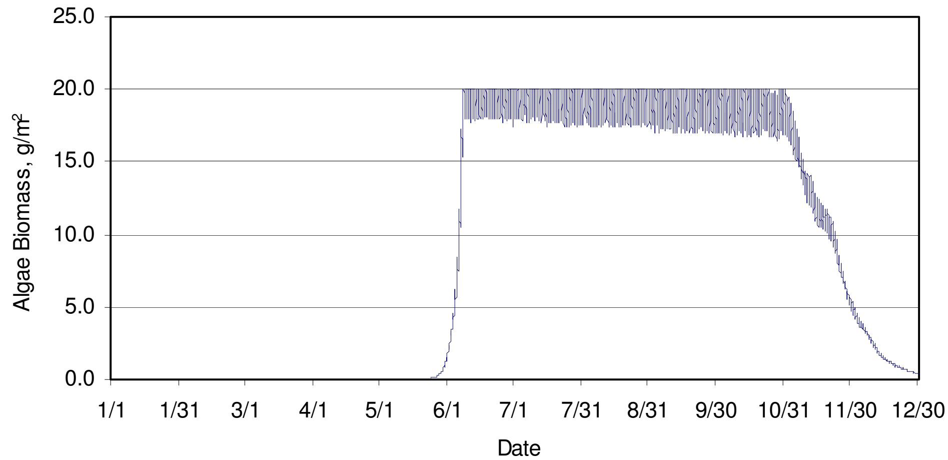


Figure 30. Algal biomass with silica concentration equal to 500.0 mg/l

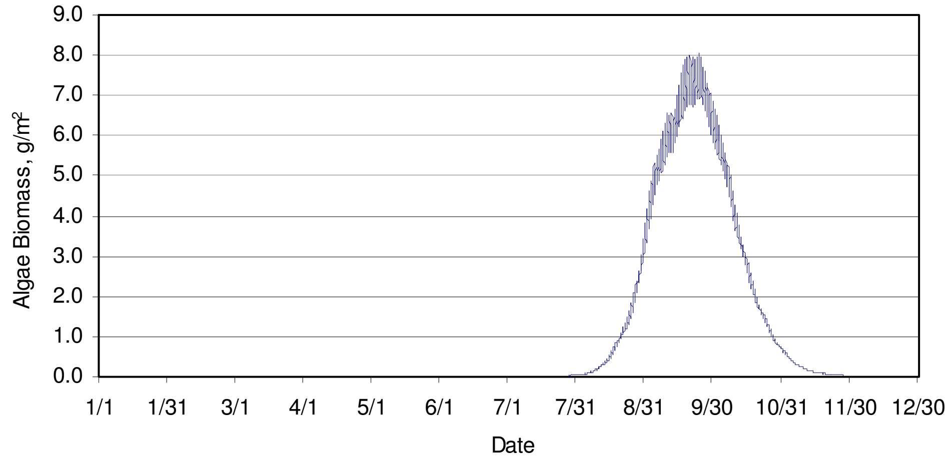


Figure 31. Algal biomass with TIN concentration equal to 0.02 mg/l, phosphate concentration equal to 0.02 mg/l, and silica concentration equal to 5.0 mg/l

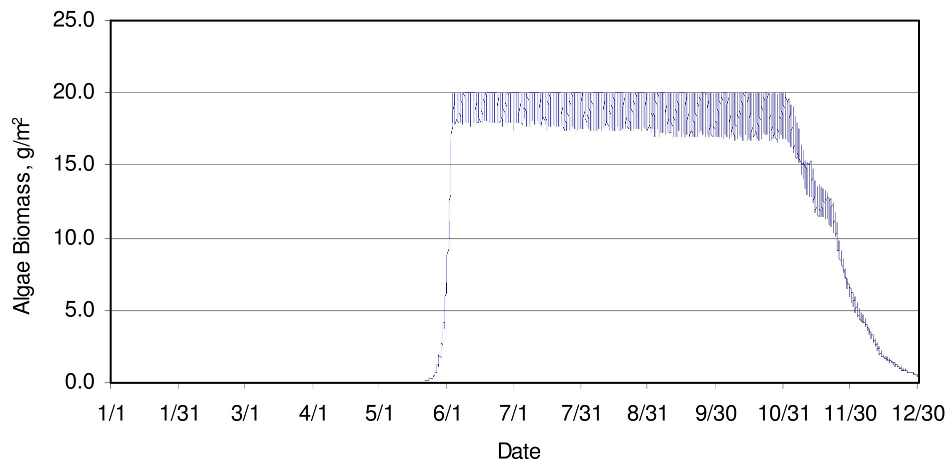


Figure 32. Algal biomass with TIN concentration equal to 2.0 mg/l, phosphate concentration equal to 2.0 mg/l, and silica concentration equal to 500.0 mg/l

Altering the light extinction coefficient

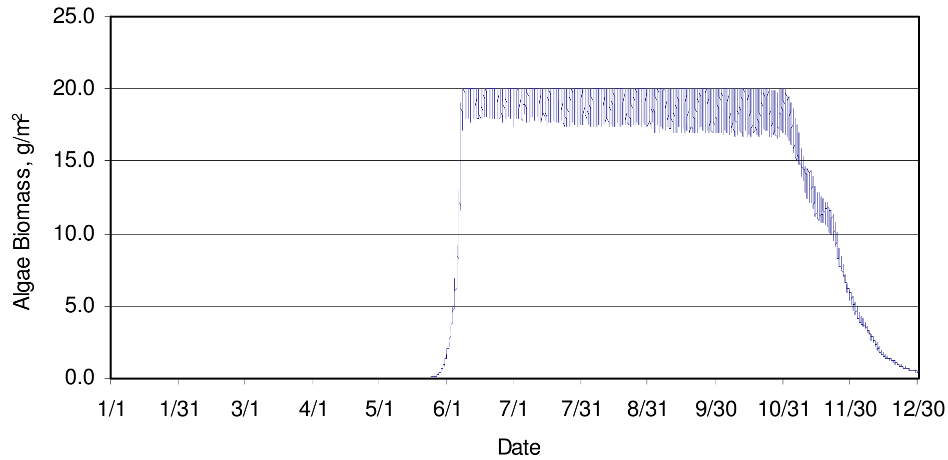


Figure 33. Algal biomass with light extinction coefficient equal to 1.40

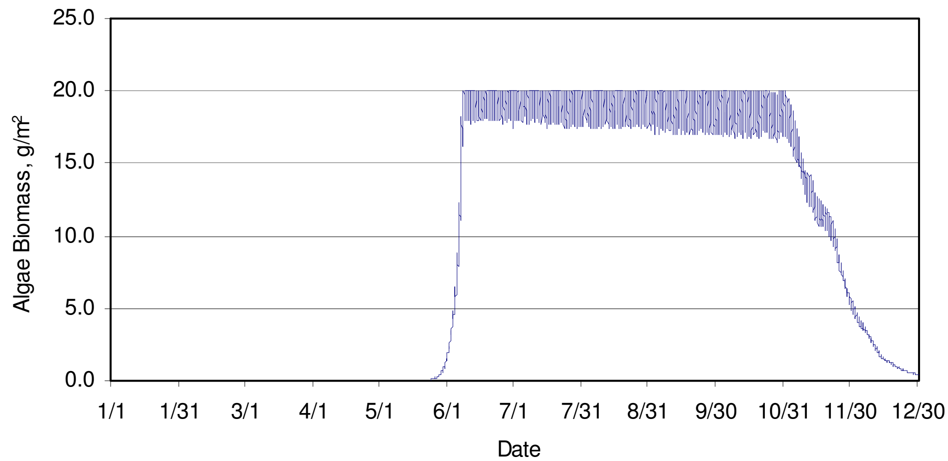


Figure 34. Algal biomass with light extinction coefficient equal to 1.44

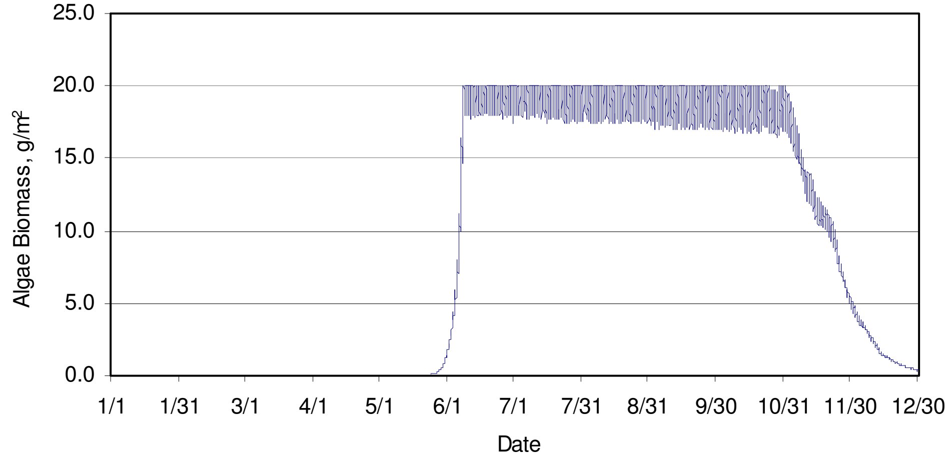


Figure 35. Algal biomass with light extinction coefficient equal to 1.52

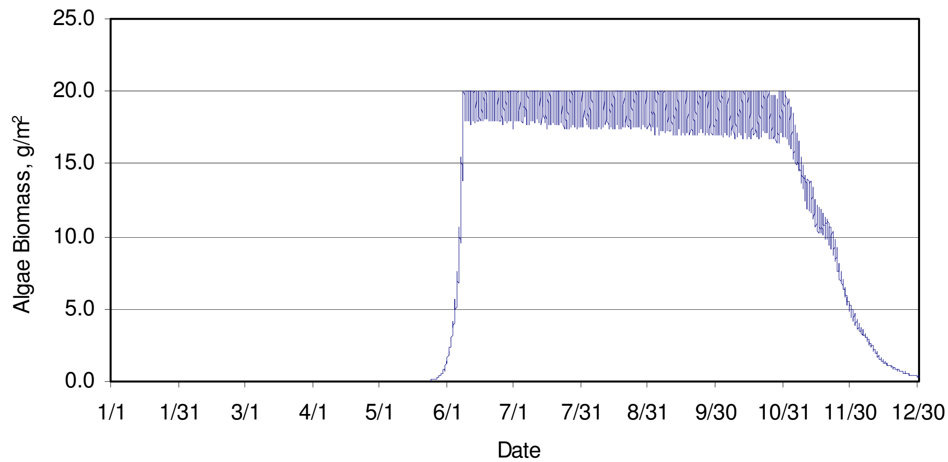


Figure 36. Algal biomass with light extinction coefficient equal to 1.56

Altering depth

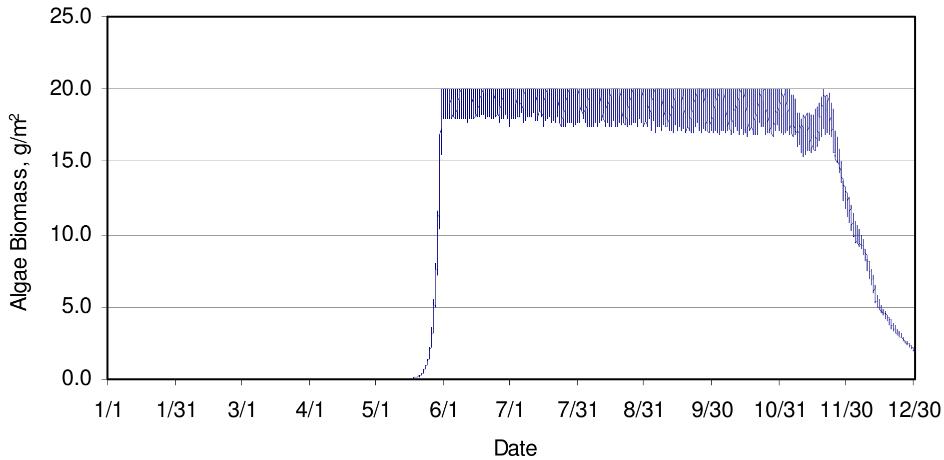


Figure 37. Algal biomass with depth equal to 0.2 meters

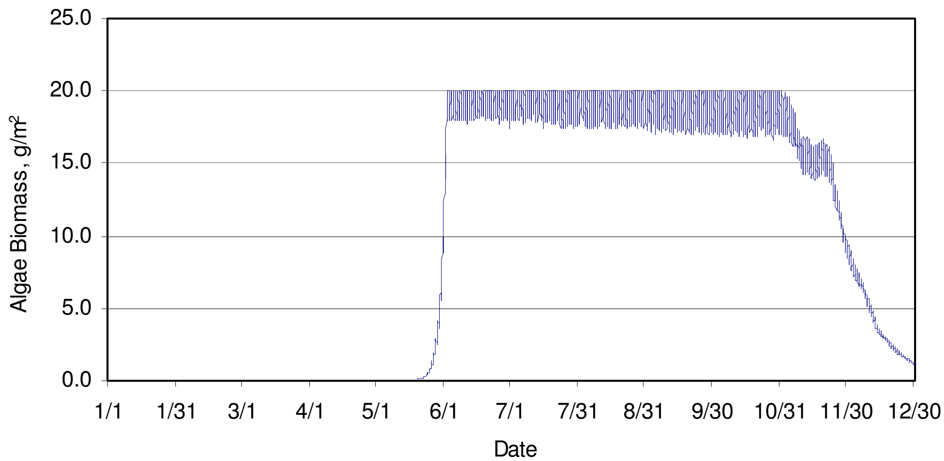


Figure 38. Algal biomass with depth equal to 0.3 meters

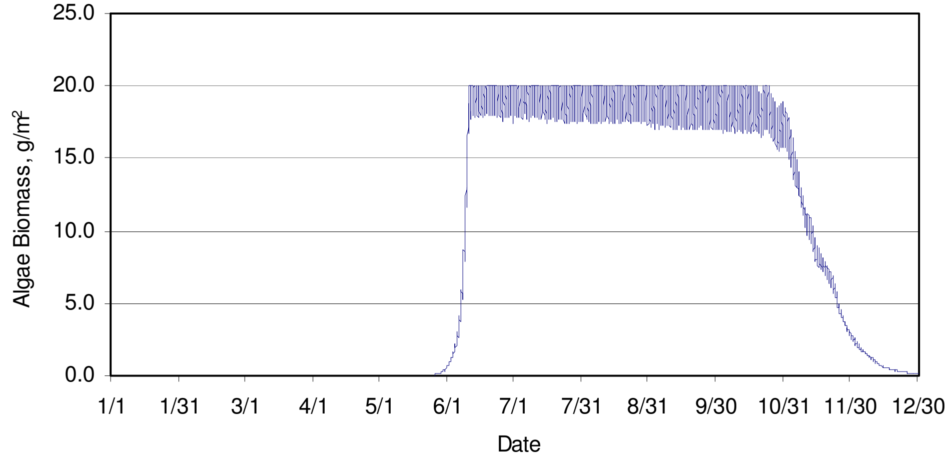


Figure 39. Algal biomass with depth equal to 0.9 meters

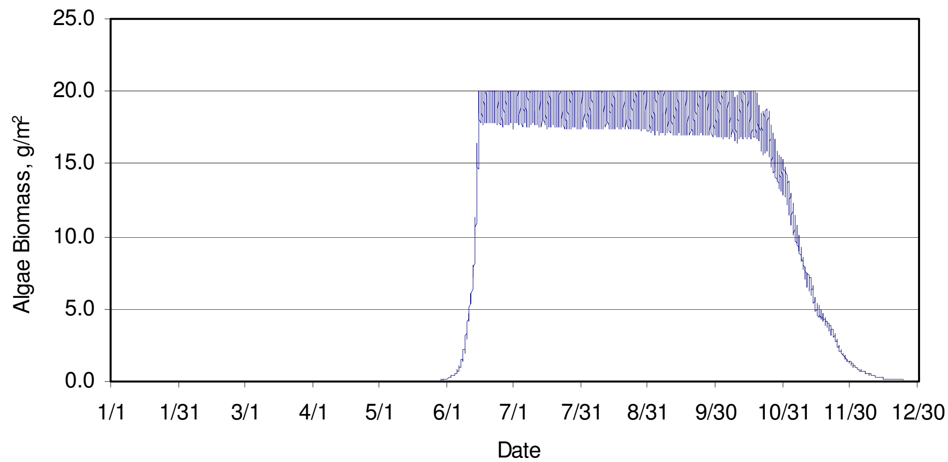


Figure 40. Algal biomass with depth equal to 1.2 meters

Altering maximum algal growth rate

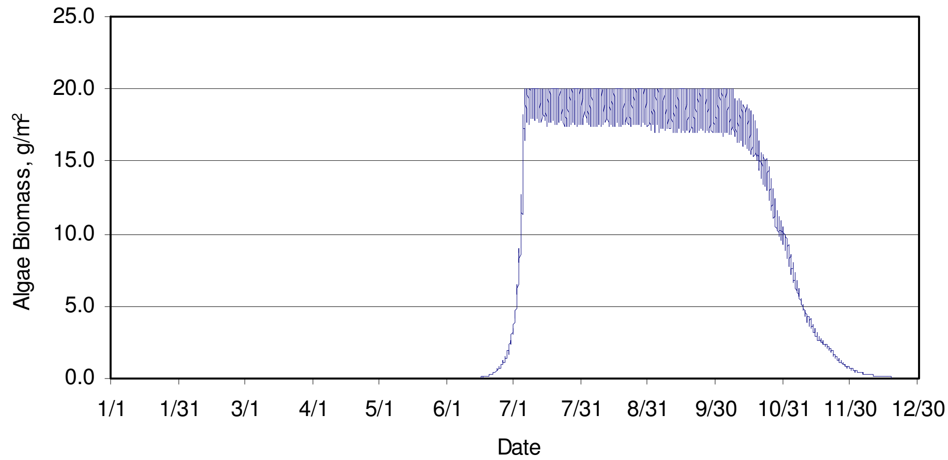


Figure 41. Algal biomass with maximum algal growth rate equal to 1.0 1/day

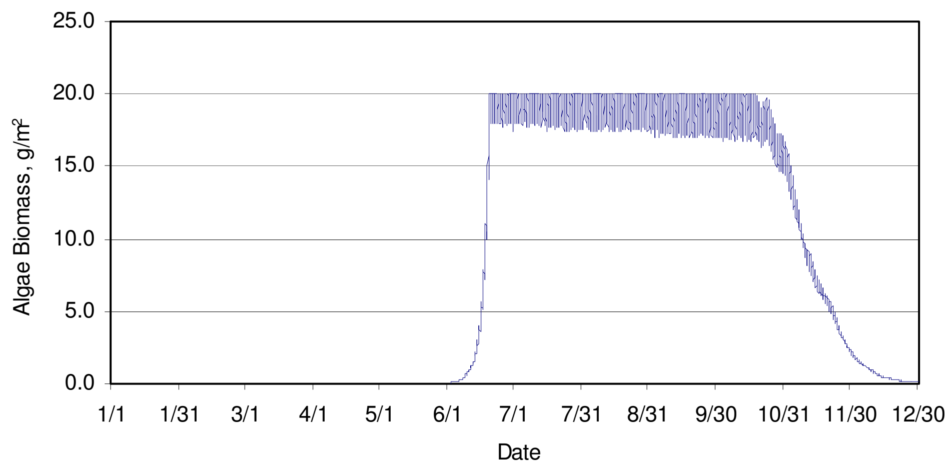


Figure 42. Algal biomass with maximum algal growth rate equal to 1.1 1/day

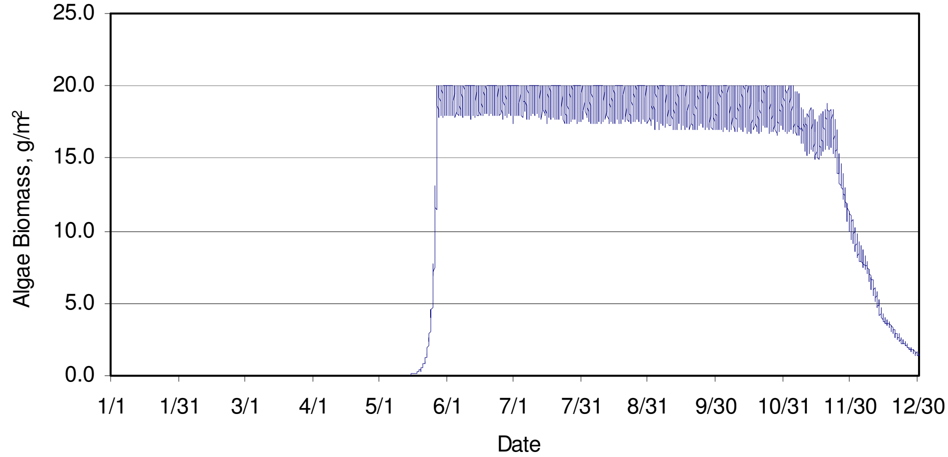


Figure 43. Algal biomass with maximum algal growth rate equal to 1.3 1/day

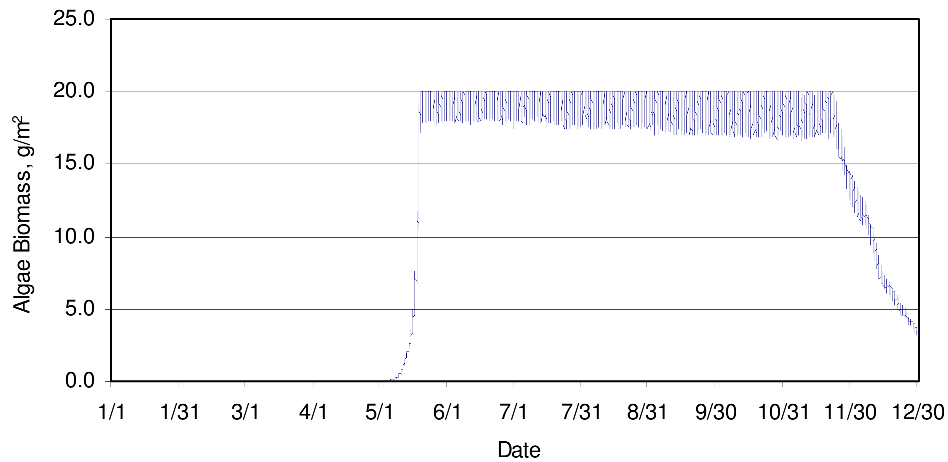


Figure 44. Algal biomass with maximum algal growth rate equal to 1.4 1/day

Altering Global Shade Factor

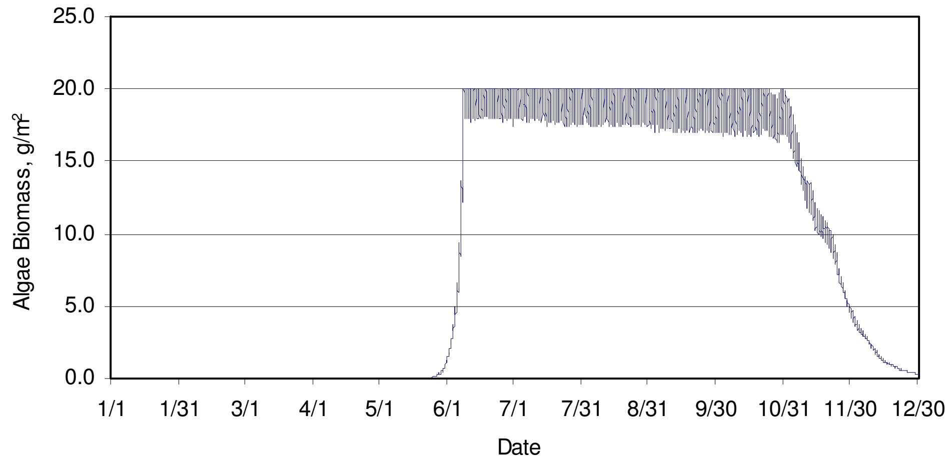


Figure 45. Algal biomass with global shade factor equal to 0.1

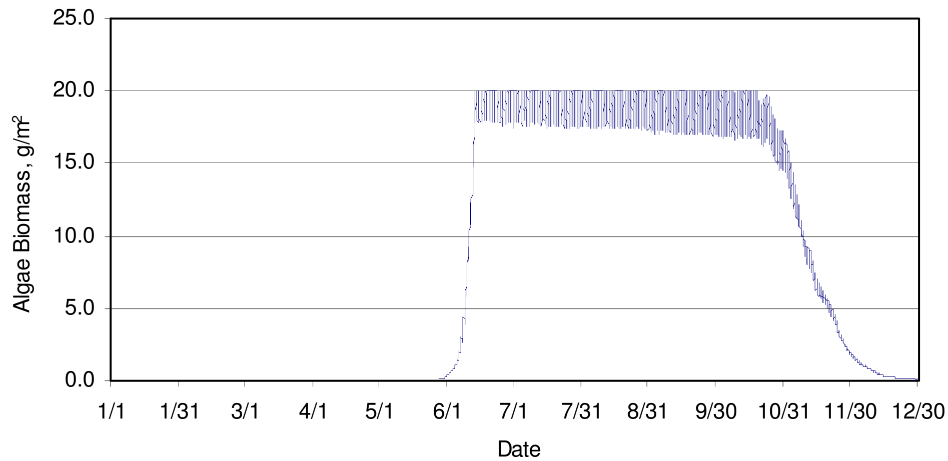


Figure 46. Algal biomass with global shade factor equal to 0.5

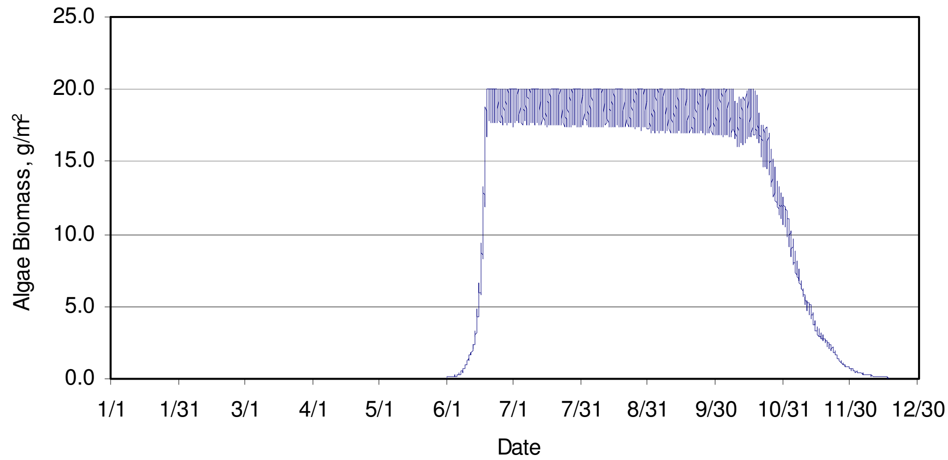


Figure 47. Algal biomass with global shade factor equal to 0.7

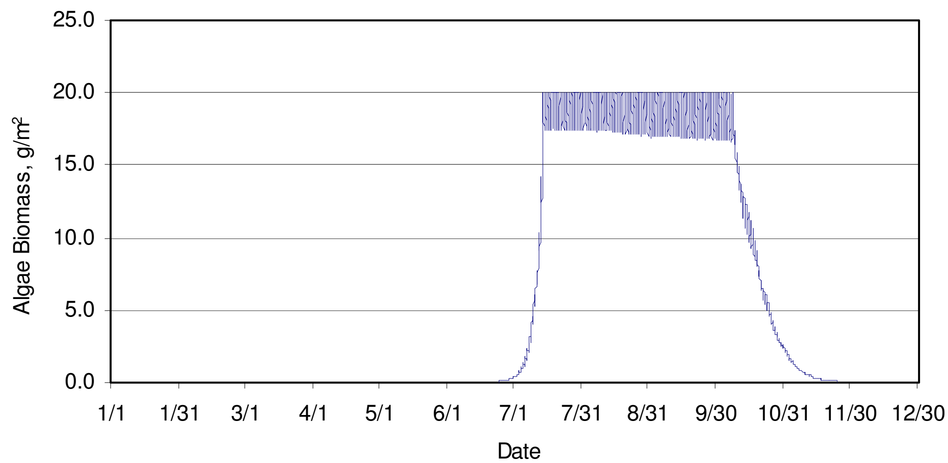


Figure 48. Algal biomass with global shade factor equal to 0.9

Altering Minimum Algal Biomass

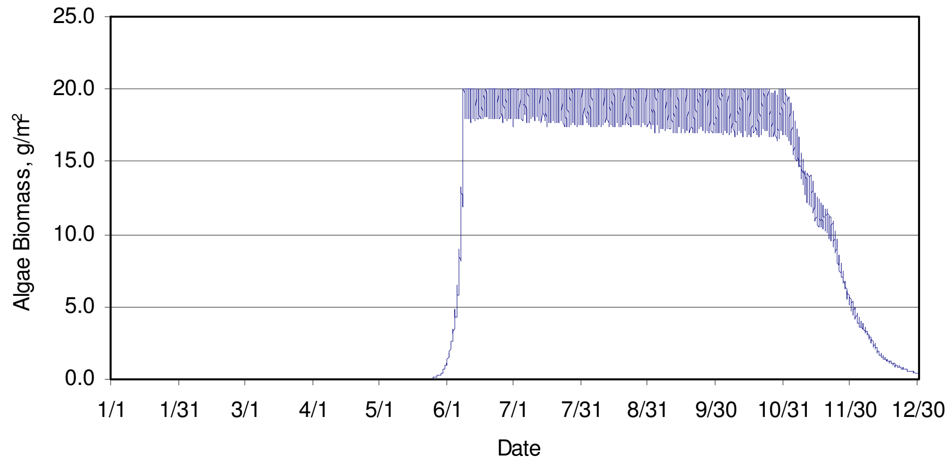


Figure 49. Algal biomass with minimum algal biomass equal to 0.0 g/m^2

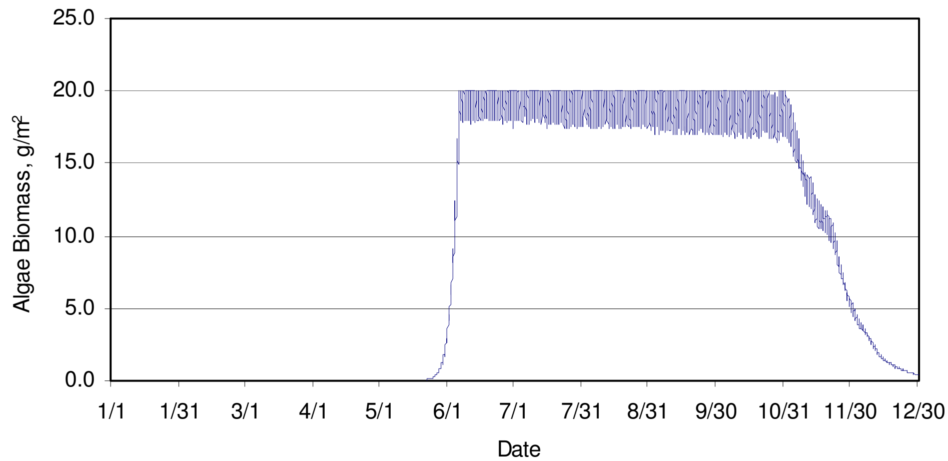


Figure 50. Algal biomass with minimum algal biomass equal to 0.2 g/m^2

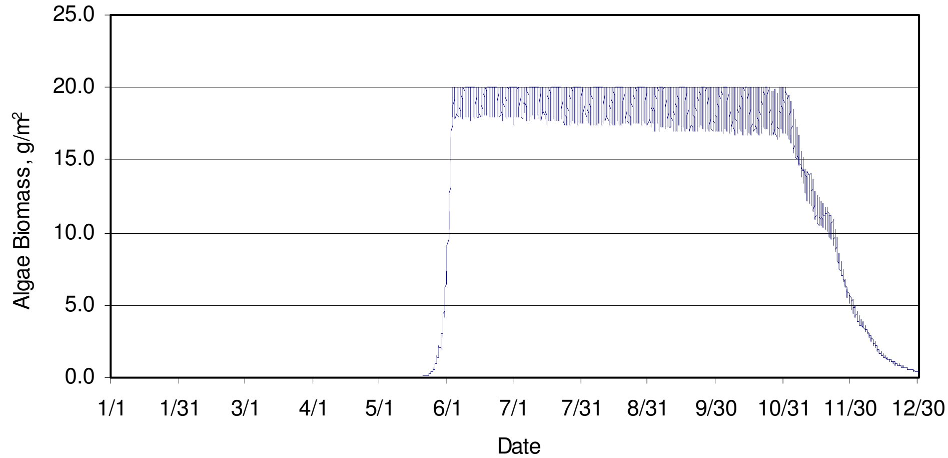


Figure 51. Algal biomass with minimum algal biomass equal to 0.5 g/m^2

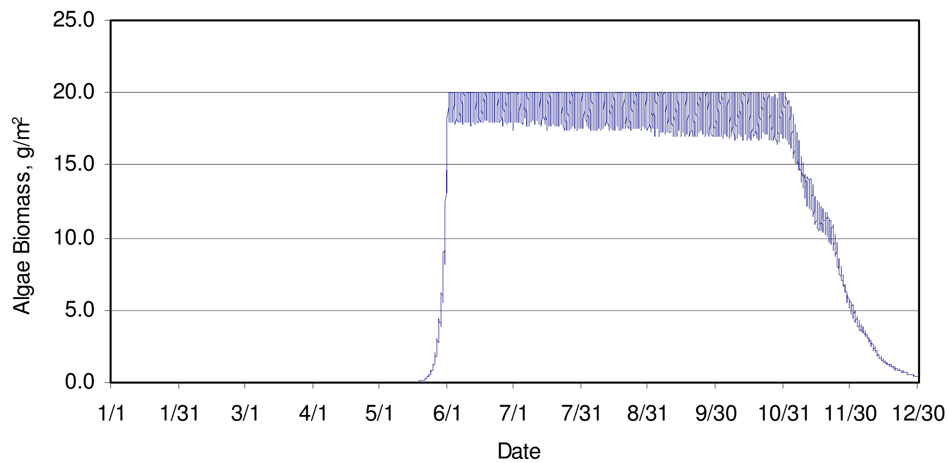


Figure 52. Algal biomass with minimum algal biomass equal to 1.0 g/m^2

Altering Maximum Algal Biomass

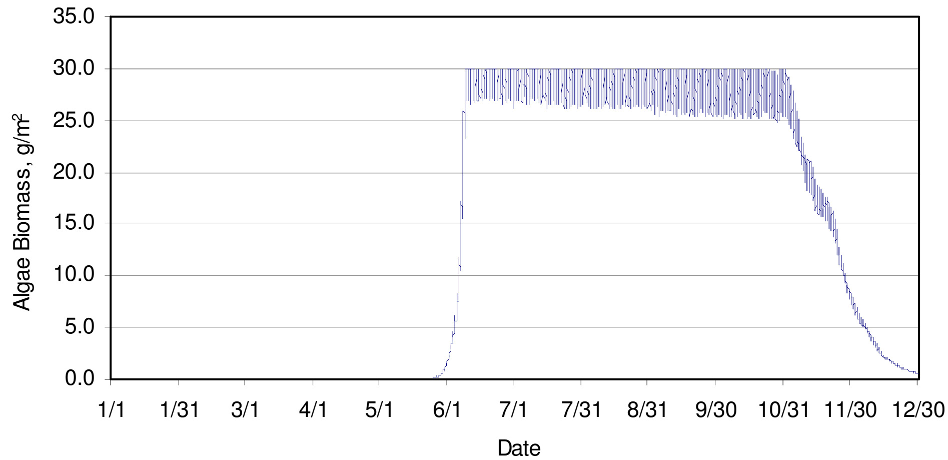


Figure 53. Algal biomass with maximum algal biomass equal to 30.0 g/m^2

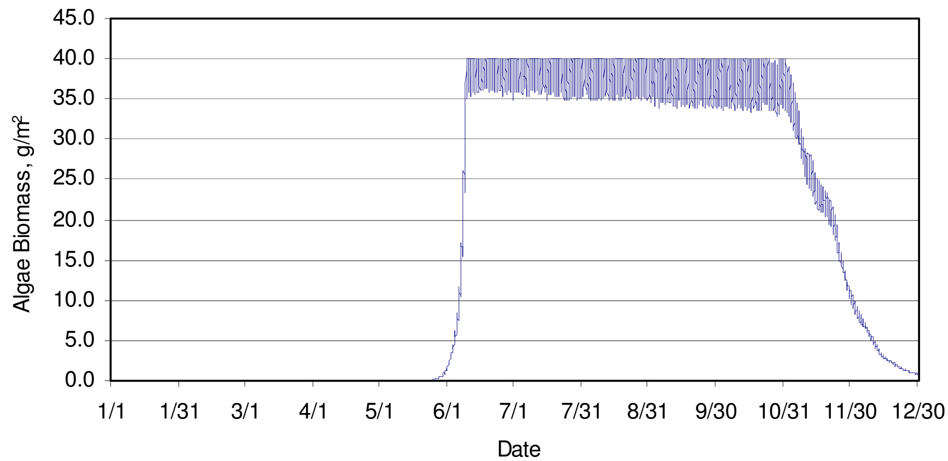


Figure 54. Algal biomass with maximum algal biomass equal to 40.0 g/m^2

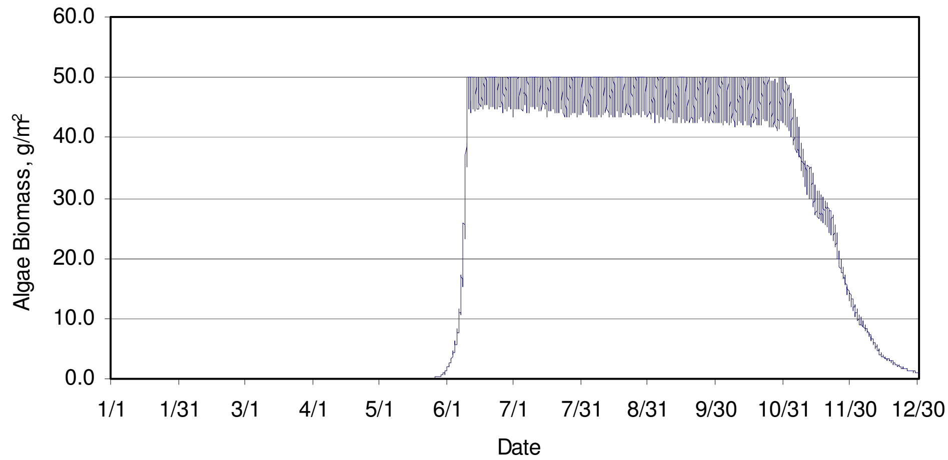


Figure 55. Algal biomass with maximum algal biomass equal to 50.0 g/m^2

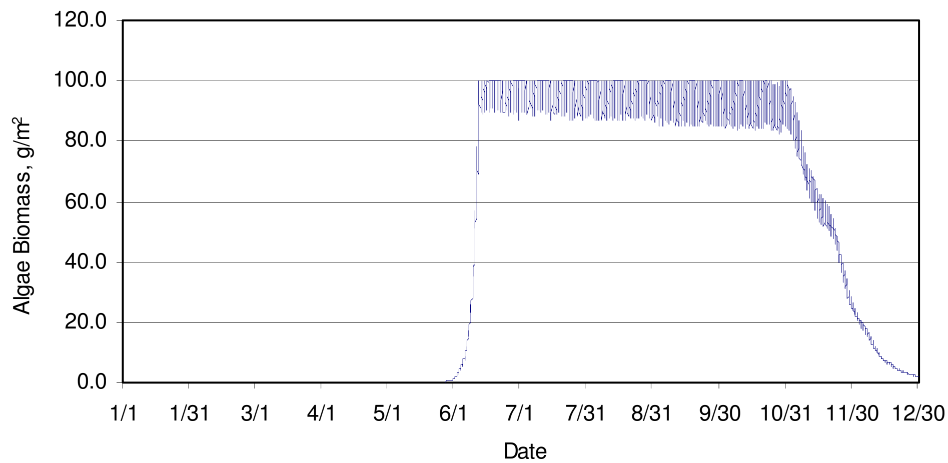


Figure 56. Algal biomass with maximum algal biomass equal to 100.0 g/m^2

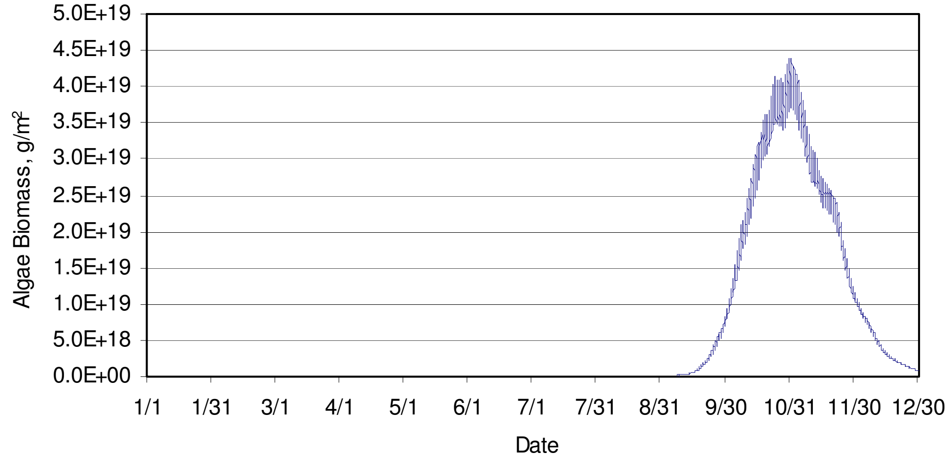


Figure 57. Algal biomass with maximum algal biomass equal to 1 x 10^{27} g/m^2

Altering Initial Algal Biomass

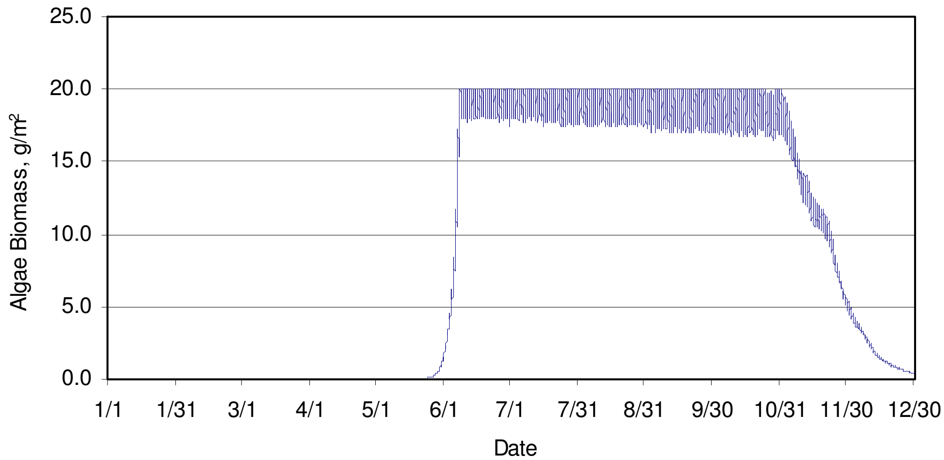


Figure 58. Algal biomass with initial algal biomass equal to 0.000 g/m^2

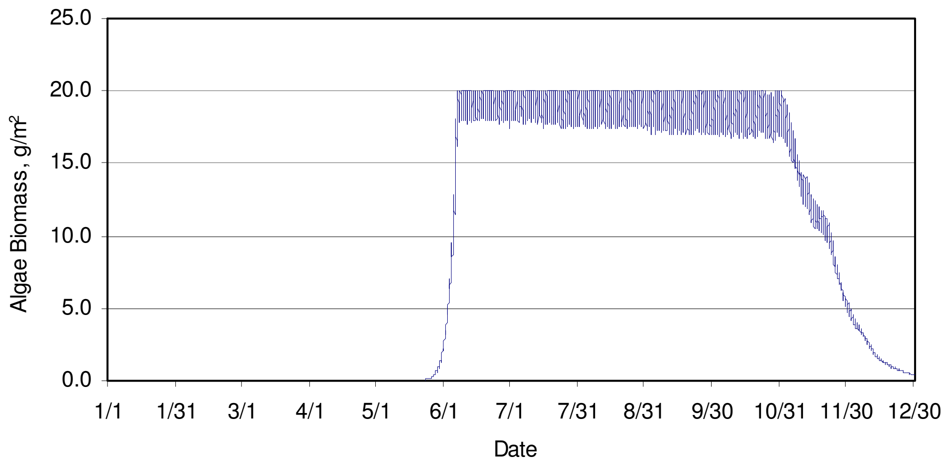


Figure 59. Algal biomass with initial algal biomass equal to 0.002 g/m^2

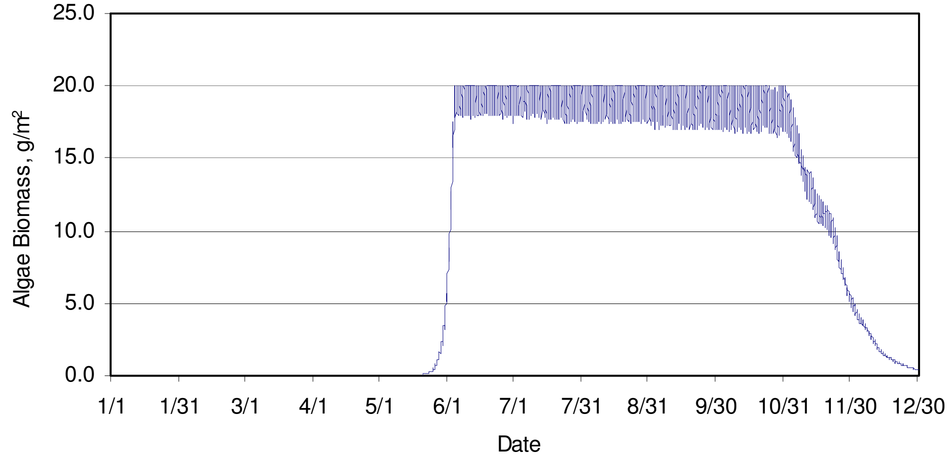


Figure 60. Algal biomass with initial algal biomass equal to 0.005 g/m^2

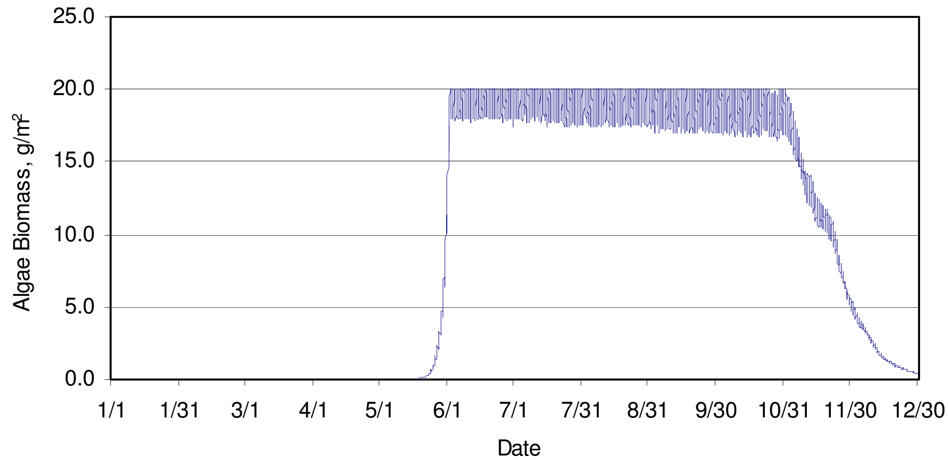


Figure 61. Algal biomass with initial algal biomass equal to 0.010 g/m^2

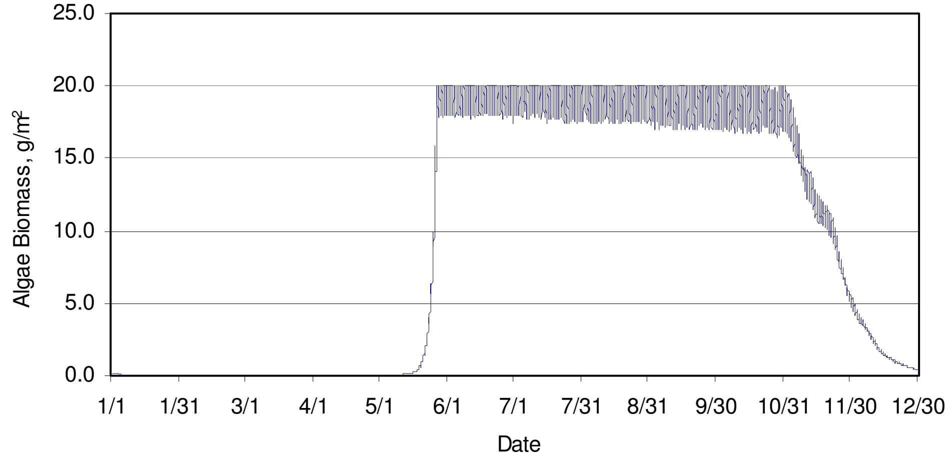


Figure 62. Algal biomass with initial algal biomass equal to 0.100 g/m^2

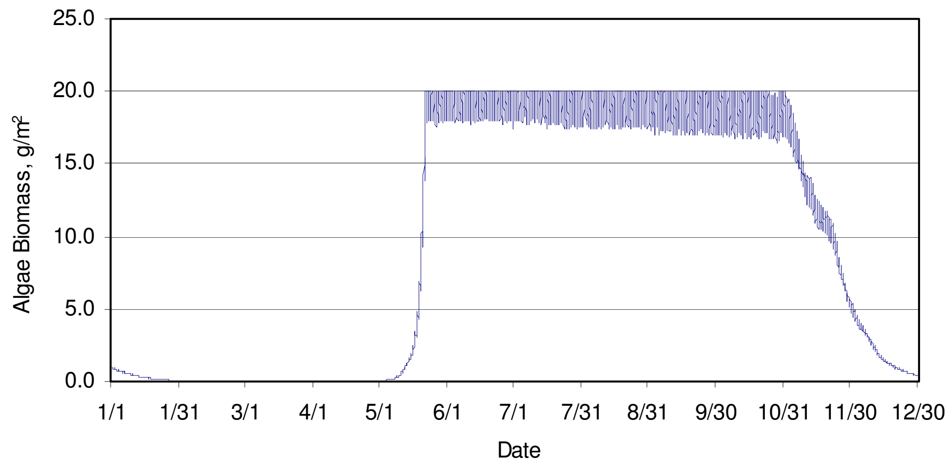


Figure 63. Algal biomass with initial algal biomass equal to 1.000 g/m^2

TECHNICAL MEMORANDUM

TO: Matt St John, North Coast Regional Water Quality Control Board

FROM: Mike Deas, Watercourse Engineering, Inc.

COPIES: Josh Viers, University of California, Davis
Michael Johnson, University of California, Davis

RE: Big Springs Creek and Spring Complex – Estimated Quantification

DATE: February 1, 2006

Summary

Review of available information suggests that Big Springs Creek water rights are on the order of 55 cubic feet per second (cfs), however, not all of these rights are met in all years. In addition, Big Springs Creek contributions to the Shasta River are estimated to be on the order of 60 cfs, but vary seasonally. It is estimated that Big Springs Creek historically (pre-diversion) delivered on the order of 100 to 125 cfs to the Shasta River.

Big Springs Creek and Spring Complex: Estimate of Shasta River Contributions

Glacial melting on Mount Shasta and mountain precipitation are principal sources of groundwater recharge in the Shasta Valley. A portion of this recharge reaches the Shasta River through spring discharge in the vicinity of Big Springs (DWR, 1991). The Big Springs Creek complex, for purposes of this discussion, includes Big Springs proper (assumed to originate at the eastern end of Big Springs Lake), Big Springs Lake, Big Springs Creek, Little Springs and the channel between Little Springs and Big Springs Creek (Figure 2). Examining historic Shasta River flow and temperature data from locations downstream and upstream of the Big Springs Creek confluence, it is postulated that the springs complex may also extend into the Shasta River proper. The extent and quantification of the springs complex is incomplete. Nonetheless, there is sufficient information to identify the potential range of contributions from the Big Springs Creek complex to the Shasta River.

Big Springs Lake and Little Springs Water Rights

Quantification of water rights at Big Springs Lake and Little Springs is well documented (

Table 1). Documented water rights to Big Springs Lake total approximately 47.5 cfs and rights to Little Springs total approximately 7.6 cfs. Although the combination of water rights for Big Springs Lake and Little Springs is on the order of 55 cfs, review of historic Watermaster Service records indicates that the water diversions from Big Springs Lake averages approximately 40 cubic feet per second (cfs) during the irrigation season.

Table 1. Big Springs Lake and Little Springs water rights (source: Water Master Service Records, DWR)

Entity		Big Springs Lake	Little Springs
Big Springs Irrigation District [A]		30	-
Newton [B]		7.5	-
Busk [C]		10	3.1
Louie		-	4.5
	Total	47.5	7.6

[A] Big Springs Irrigation District abandoned their surface water right and now meets district demand from groundwater wells, possibly due to frequent curtailment by the Watermaster.

[B] Previously Brahs et al

[C] Previously Louie

Big Springs Irrigation District (BSID) no longer pumps water from Big Springs Lake, but rather has drilled water supply wells upgradient, and pumps from groundwater. Review of Watermaster Service records indicates that BSID stopped withdrawing water directly from the lake around 1983.

In addition, there are numerous other smaller wells and springs utilized for irrigation in this area that could reasonably be presumed to be drawing on water that would otherwise contribute to the Big Springs complex. These include the Basey wells (or Pacy Wells), periodically used by the Montague Water Conservation District to supplement water from Dwinnell Reservoir and the subject of court action by the users of Big Springs Lake.
An agreement was reached in 1986 between E.J. Louie, A.H. Newton, Jr., and the Montague Water Conservation District, wherein the parties "agreed that when the flows of Big Springs recede from 17.5 cfs to 10.0 cfs, Montague Water Conservation District would do the following:

- Turn off the Basey pumps until the flow of Big Sprigns was 17.5 cfs or pay A.H. Newton, Jr. the additional power costs to use his own pumps.
- If flows of Big Springs fall below 10.0 cfs, Montague Water Conservation District will shut off the Basey pumps until flows return to above 10.0 cfs." (Shasta Valley Watermaster Service Records, 1987)

Review of Watermaster Service Records suggests that the first season this agreement was implemented was in 1987.

Contributions to the Shasta River

Using water rights information, coupled with measured Shasta River flows above and below Big Springs Creek, an estimate of the contributions of the total potential springs complex to Shasta River flow can be made.

Available Flow Measurements

Shasta River flow measurements made during the late spring through summer period in 2002 at Louie Road (above Big Springs Creek) and at the Grenada Irrigation District (GID) diversion dam (below Big Springs Creek) indicated that the net accretion between these two locations ranged from approximately 55 cfs to over 80 cfs (Watercourse, 2004a, 2004b). This data was augmented with a combination of direct measurements within Big Springs Creek, Little Springs Creek, and Shasta River locations immediately above and below Big Springs Creek by the California Department of Public Works in

1922 and 1923 during the Shasta River Adjudication Proceedings (California, 1925) prior to the Shasta River adjudication. These latter data are the most detailed measurements of flows in the vicinity of Big Springs Creek. Although conditions may have changed over the last 80 years, the 2002 measurements largely corroborate the earlier measurements.

Big Springs Creek Inflows

As reported in the water supply and use report to support adjudication proceedings, it was not possible to obtain satisfactory discharge records in the creek proper due to extensive aquatic vegetation (California, 1925). Thus, measurements within Big Springs Creek were augmented through daily stream flow measurement carried out in the Shasta River upstream and downstream of Big Springs Creek to estimate the tributary input. The exact locations of these flow measurements are not known, but are presumed to be fairly close to the creek because the objective of the work was to capture creek inflows to the Shasta River. The results of these efforts for 1922 and 1923 are shown in Figure 1.

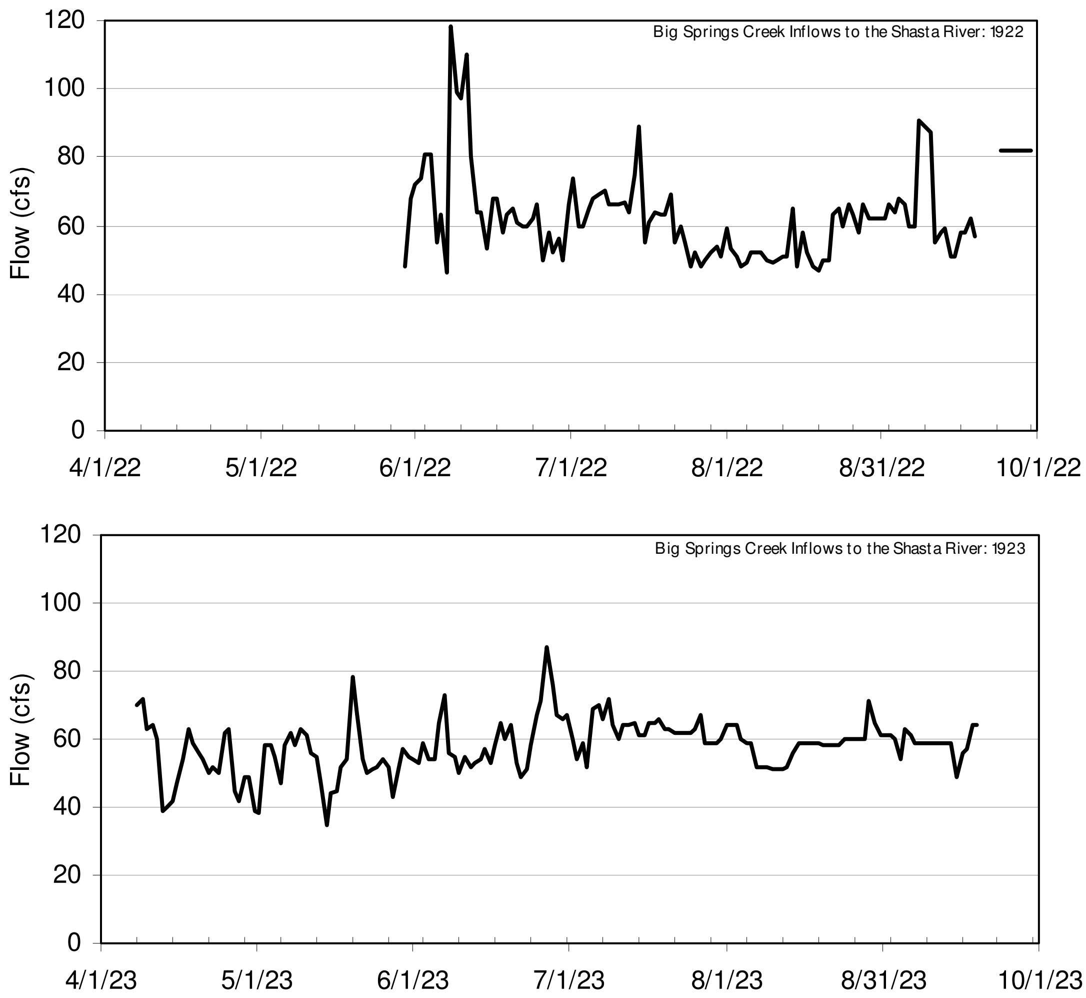


Figure 1. Daily Big Springs Creek inflow to the Shasta River: 1922 (top) and 1923 (bottom) (California, 1925)

There are several aspects of Figure 1 that are illustrative. One attribute that is unlike most streams in California during the summer period is the generally stable nature of Big Springs Creek. Summary statistics (Table 2) indicate that the mean flow was consistently on the order of 60 cfs, and that although the maximum and minimum values varied considerably, the standard deviation was small. This is consistent with the 2002 flow observations.

Table 2. Summary statistics for daily flow in Big Springs Creek above the confluence with the Shasta River

Statistic	1922 (cfs)	1923 (cfs)
Mean	63.4	58.0
Maximum	118	87
Minimum	46	35
Standard Deviation	13.2	7.7

A second attribute, related to the first, is that the flow does not exhibit a typical seasonal reduction through the summer period, rather the spring signal is persistent through the summer and into early fall. In the 1923 record there appears to be an increase in flow as the summer season progresses: an observation that is noted in the Watermaster Service records.

Also apparent in the record is a notable amount of variation in Big Springs Creek inflow to the Shasta River. Daily records of diversions and irrigation practices were not available for this report. However, it is reasonable to assume that variations in cropping patterns, land use, and other practices could yield short term variability in creek flows.

A summary of individual daily measurements from the 1922-23 season (California, 1925) is presented in Table 3. These estimates may not determine if there are additional spring flow contributions to the Shasta River directly from the Big Springs complex. Nonetheless, the results suggest that Big Springs Creek historically (pre-diversion) delivered on the order of 100 to 125 cfs to the Shasta River.

Table 3. Summary of flows observed on individual days during the 1922 and 1923 irrigation seasons (California, 1925)

Date	Big Spring Creek Gage #1	Big Sp. Water Cons. Diversion Gage #3	Louie Bros Main Chanal Diversion Gage #40	Louie Bros Small Canal Diversion	Stallcup & Sons Diversions Gage #3	Total Diversion From Big Springs	Little Spring Creek Diversion	Total Flow of Big Spring Creek & Little Spring Creek
5-24-1922	112.2	0	1.4	0	0	1.4	0	113.6
6-05-1922	80.5	28.2	5.4	3	7.4	44	0	124.5
6-21-1922	79.9	28.1	7.4	2.8	7.4	45.7	0	125.5
10-12-1922	108.5	0	0	0	0	0	2.2	110.7
10-12-1922	104.4	0	0	0	0	0	2.2	106.6
10-17-1922	118.5	0	0	0	0	0	4	122.5
10-17-1922	96.5	0	0	0	0	0	4	100.5
10-21-1922	114	0	0	0	0	0	3.8	117.8
10-21-1922	99.9	0	0	0	0	0	3.8	103.7
11-04-1922	117.3	0	0	0	0	0	4.8	122.1
5-04-1923	58.2	31.8	7.6	2	7.2	48.6	7.8	114.4
5-07-1923	54.6	31.6	7.6	2	7.2	48.4	7.8	110.8
5-07-1923	61.1	31.6	7.6	2	7.2	48.4	7.8	117.1
6-04-1923	54.1	34.2	5.4	2	7.2	48.8	7.6	110.5
Average								114.3

*Note: values may not add up due to rounding and transcription errors due to old records

Factors that may affect this estimate include, but are not limited to:

- the relatively short data record
- additional pumping that may affect the inflow to Big Springs Lake (not only pumping early in the 20th century at the time of the flow measurements, but approximately 80 years of water resources development in the region, e.g., Basey wells)
- applied water irrigation efficiency
- annual variability in base flow within the Shasta River as well as springs inflow
- other water diversions and inflows (unassociated with the Big Springs Complex) between Louie Road and GID
- meteorological conditions
- variations in land use and applied water from Big Springs Lake and Little Springs

Current quantification of flows in and around the Big Springs complex would provide much needed detail in this unique reach of the Shasta River.

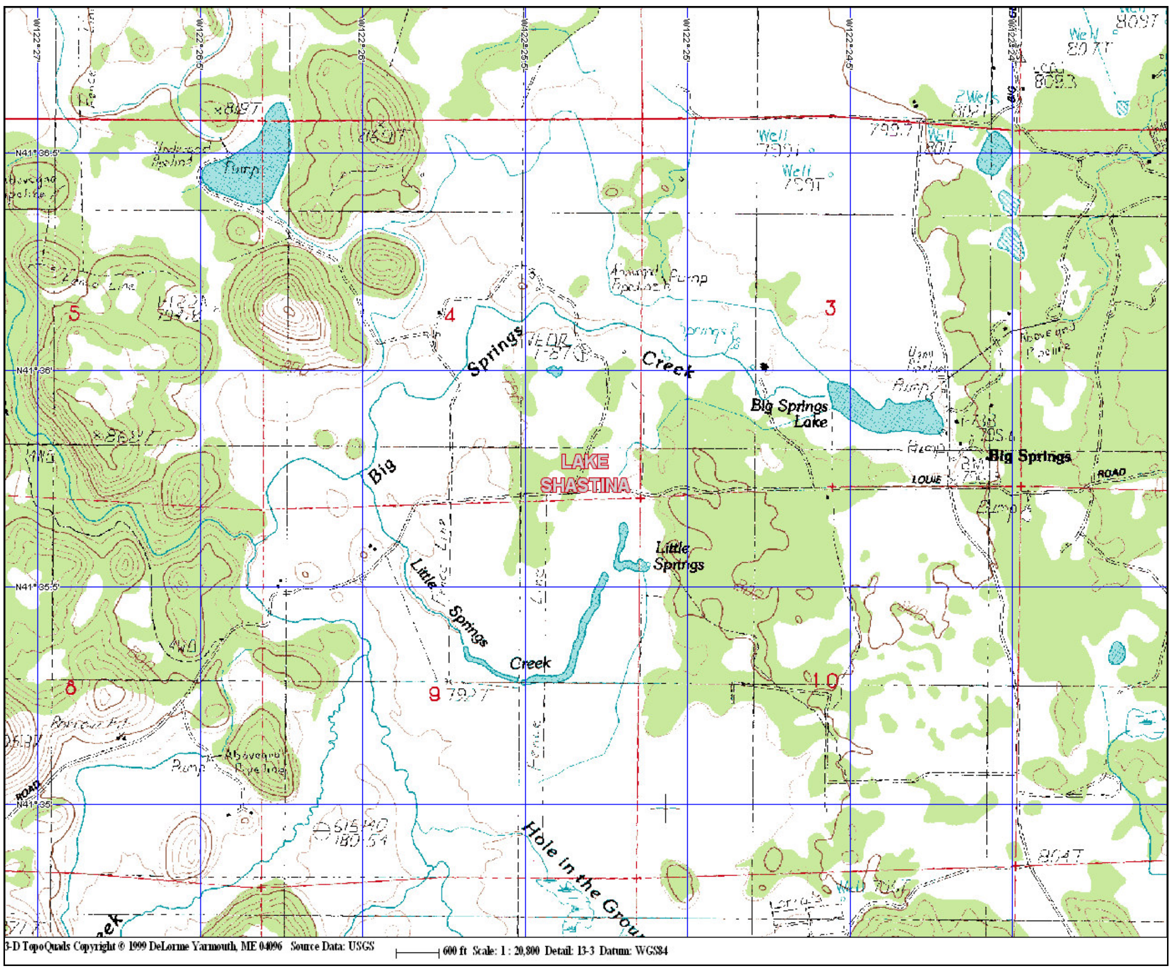


Figure 2. Big Springs Area

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Watercourse Engineering, Inc. (Watercourse). 2004b. *Shasta River Flow and Temperature Modeling Project*. Sponsored by the Shasta Valley Resource Conservation District with funding from the California Department of Fish and Game, California Coastal Salmon Restoration Program. November.

CEQA CHECKLIST

Project Title:
Action Plan for the Shasta River Watershed Water Temperature and Dissolved Oxygen TMDLs.

Project Proponent:
State of California
North Coast Regional Water Quality Control Board
5550 Skylane Boulevard, Suite A
Santa Rosa, California 95403

Project Contact:
David Leland
707-576-2220

Project Description:
Adoption of two amendments to the *Water Quality Control Plan for the North Coast Region* (the Basin Plan) as follows:

- Introduction to Total Maximum Daily Loads
- Action Plan for the Shasta River Watershed Water Temperature and Dissolved Oxygen Total Maximum Daily Loads (Shasta River TMDL Action Plan)

Environmental Factors Potentially Affected (Explanation Attached):

	Aesthetics	X	Agriculture Resources		Air Quality
	Biological Resources		Cultural Resources		Geology /Soils
	Hazards & Hazardous Materials		Hydrology / Water Quality		Land Use / Planning
	Mineral Resources		Noise		Population / Housing
	Public Services		Recreation		Transportation/Traffic
	Utilities / Service Systems		Mandatory Findings of Significance		

Evaluation of Environmental Impacts:

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
I. AESTHETICS – Would the project:				
a) Have a substantial adverse effect on a scenic vista?				**X**
b) Substantially damage scenic resources, including, but not limited to, trees, rock outcroppings, and historic buildings within a state scenic highway?				**X**
c) Substantially degrade the existing visual character or quality of the site and its surroundings?				**X**
d) Create a new source of substantial light or glare that would adversely affect day or nighttime views in the area?				**X**
II. AGRICULTURE RESOURCES –Would the project:				
a) Convert Prime Farmland, Unique Farmland, or Farmland of Statewide Importance (Farmland), as shown on the maps prepared pursuant to the Farmland Mapping and Monitoring Program of the California Resources Agency, to non-agricultural use?			**X**	
b) Conflict with existing zoning for agricultural use, or a Williamson Act contract?				**X**
c) Involve other changes in the existing environment, which, due to their location or nature, could result in conversion of Farmland, to non-agricultural use?			**X**	

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
III. AIR QUALITY – Would the project:				
a) Conflict with or obstruct implementation of the applicable air quality plan?				**X**
b) Violate any air quality standard or contribute substantially to an existing or projected air quality violation?				**X**
c) Result in a cumulatively considerable net increase of any criteria pollutant for which the project region is non-attainment under an applicable federal or state ambient air quality standard?				**X**
d) Expose sensitive receptors to substantial pollutant concentrations?				**X**
e) Create objectionable odors affecting a substantial number of people?				**X**
IV. BIOLOGICAL RESOURCES – Would the project:				
a) Have a substantial adverse effect, either directly or through habitat modifications, on any species identified as a candidate, sensitive, or special status species in local or regional plans, policies, or regulations, or by the California Department of Fish and Game or U.S. Fish and Wildlife Service?				**X**
b) Have a substantial adverse effect on any riparian habitat or other sensitive natural community identified in local or regional plans, policies, and regulations or by the California Department of Fish and Game or US Fish and Wildlife Service?				**X**

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
c) Have a substantial adverse effect on federally protected wetlands as defined by Section 404 of the Clean Water Act through direct removal, filling, hydrological interruption, or other means?				**X**
d) Interfere substantially with the movement of any native resident or migratory fish or wildlife species or with established native resident or migratory wildlife corridors, or impede the use of native wildlife nursery sites?				**X**
e) Conflict with any local policies or ordinances protecting biological resources, such as a tree preservation policy or ordinance?				**X**
f) Conflict with the provisions of an adopted Habitat Conservation Plan, Natural Community Conservation Plan, or other approved local, regional, or state habitat conservation plan?				**X**
V. CULTURAL RESOURCES – Would the project:				
a) Cause a substantial adverse change in the significance of a historical resource as defined in §15064.5?				**X**
b) Cause a substantial adverse change in the significance of an archaeological resource pursuant to §15064.5?				**X**
c) Directly or indirectly destroy a unique paleontological resource or site or unique geologic feature?				**X**
d) Disturb any human remains, including those interred outside of formal cemeteries?				**X**

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
VI. GEOLOGY AND SOILS – Would the project:				
a) Expose people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving:				**X**
i) Rupture of a known earthquake fault, as delineated on the most recent Alquist-Priolo Earthquake Fault Zoning Map issued by the State Geologist for the area or based on other substantial evidence of a known fault? Refer to Division of Mines and Geology Special Publication 42.				**X**
ii) Strong seismic ground shaking?				**X**
iii) Seismic-related ground failure, including liquefaction?				**X**
iv) Landslides?				**X**
b) Result in substantial soil erosion or the loss of topsoil?				**X**
c) Be located on a geologic unit or soil that is unstable, or that would become unstable as a result of the project, and potentially result in on- or off-site landslide, lateral spreading, subsidence, liquefaction or collapse?				**X**
d) Be located on expansive soil, as defined in Table 18-1-B of the Uniform Building Code (1994), creating substantial risks to life or property?				**X**
e) Have soils incapable of adequately supporting the use of septic tanks or alternative wastewater disposal systems where sewers are not available for the disposal of wastewater?				**X**

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
VII. HAZARDS AND HAZARDOUS MATERIALS – Would the project:				
a) Create a significant hazard to the public or the environment through the routine transport, use, or disposal of hazardous materials?				**X**
b) Create a significant hazard to the public or the environment through reasonably foreseeable upset and accident conditions involving the release of hazardous materials into the environment?				**X**
c) Emit hazardous emissions or handle hazardous or acutely hazardous materials, substances, or waste within one-quarter mile of an existing or proposed school?				**X**
d) Be located on a site which is included on a list of hazardous materials sites compiled pursuant to Government Code § 65962.5 and, as a result, would it create a significant hazard to the public or the environment?				**X**
e) For a project located within an airport land use plan or, where such a plan has not been adopted, within two miles of a public airport or public use airport, would the project result in a safety hazard for people residing or working in the project area?				**X**
f) For a project within the vicinity of a private airstrip, would the project result in a safety hazard for people residing or working in the project area?				**X**
g) Impair implementation of or physically interfere with an adopted emergency response plan or emergency evacuation plan?				**X**

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
h) Expose people or structures to a significant risk of loss, injury or death involving wildland fires, including where wildlands are adjacent to urbanized areas or where residences are intermixed with wildlands?				**X**
VIII. HYDROLOGY AND WATER QUALITY – Would the project:				
a) Violate any water quality standards or waste discharge requirements?				**X**
b) Substantially deplete groundwater supplies or interfere substantially with groundwater recharge such that there would be a net deficit in aquifer volume or a lowering of the local groundwater table level (e.g., the production rate of pre-existing nearby wells would drop to a level which would not support existing land uses or planned uses for which permits have been granted)?				**X**
c) Substantially alter the existing drainage pattern of the site or area, including through the alteration of the course of a stream or river, in a manner that would result in substantial erosion or siltation on- or off-site?				**X**
d) Substantially alter the existing drainage pattern of the site or area, including through the alteration of the course of a stream or river, or substantially increase the rate or amount of surface runoff in a manner that would result in flooding on- or off-site?				**X**

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
e) Create or contribute runoff water which would exceed the capacity of existing or planned stormwater drainage systems or provide substantial additional sources of polluted runoff?				**X**
f) Otherwise substantially degrade water quality?				**X**
g) Place housing within a 100-year flood hazard area as mapped on a federal Flood Hazard Boundary or Flood Insurance Rate Map or other flood hazard delineation map?				**X**
h) Place within a 100-year flood hazard area structures that would impede or redirect flood flows?				**X**
i) Expose people or structures to a significant risk of loss, injury or death involving flooding, including flooding as a result of the failure of a levee or dam?				**X**
j) Inundation by seiche, tsunami, or mudflow?				**X**
IX. LAND USE AND PLANNING – Would the project:				
a) Physically divide an established community?				**X**
b) Conflict with any applicable land use plan, policy, or regulation of an agency with jurisdiction over the project (including, but not limited to the general plan, specific plan, local coastal program, or zoning ordinance) adopted for the purpose of avoiding or mitigating an environmental effect?				**X**

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
c) Conflict with any applicable habitat conservation plan or natural community conservation plan?				**X**
X. MINERAL RESOURCES – Would the project:				
a) Result in the loss of availability of a known mineral resource that would be of value to the region and the residents of the state?				**X**
b) Result in the loss of availability of a locally-important mineral resource recovery site delineated on a local general plan, specific plan or other land use plan?				**X**
XI. NOISE – Would the project result in:				
a) Exposure of persons to or generation of noise levels in excess of standards established in the local general plan or noise ordinance, or applicable standards of other agencies?				**X**
b) Exposure of persons to or generation of excessive groundborne vibration or groundborne noise levels?				**X**
c) A substantial permanent increase in ambient noise levels in the project vicinity above levels existing without the project?				**X**
d) A substantial temporary or periodic increase in ambient noise levels in the project vicinity above levels existing without the project?				**X**

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
e) For a project located within an airport land use plan or, where such a plan has not been adopted, within two miles of a public airport or public use airport, would the project expose people residing or working in the project area to excessive noise levels?				**X**
f) For a project within the vicinity of a private airstrip, would the project expose people residing or working in the project area to excessive noise levels?				**X**
XII. POPULATION AND HOUSING – Would the project:				
a) Induce substantial population growth in an area, either directly (for example, by proposing new homes and businesses) or indirectly (for example, through extension of roads or other infrastructure)?				**X**
b) Displace substantial numbers of existing housing, necessitating the construction of replacement housing elsewhere?				**X**
c) Displace substantial numbers of people, necessitating the construction of replacement housing elsewhere?				**X**
XIII. PUBLIC SERVICES – Would the project:				
a) Result in substantial adverse physical impacts associated with the provision of new or physically altered governmental facilities, need for new or physically altered governmental facilities, the construction of which could cause significant environmental impacts, in order to maintain acceptable service ratios, response times or other performance objectives for any of the public services:				**X**

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
i) Fire protection?				**X**
ii) Police protection?				**X**
iii) Schools?				**X**
iv)Parks?				**X**
v) Other public facilities?				**X**
XIV. RECREATION				
a) Would the project increase the use of existing neighborhood and regional parks or other recreational facilities such that substantial physical deterioration of the facility would occur or be accelerated?				**X**
b) Does the project include recreational facilities or require the construction or expansion of recreational facilities that might have an adverse physical effect on the environment?				**X**
XV. TRANSPORTATION/TRAFFIC – Would the project:				
a) Cause an increase in traffic that is substantial in relation to the existing traffic load and capacity of the street system (i.e., result in a substantial increase in either the number of vehicle trips, the volume to capacity ratio on roads, or congestion at intersections)?				**X**
b) Exceed, either individually or cumulatively, a level of service standard established by the county congestion management agency for designated roads or highways?				**X**
c) Result in a change in air traffic patterns, including either an increase in traffic levels or a change in location that results in substantial safety risks?				**X**

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
d) Substantially increase hazards due to a design feature (e.g., sharp curves or dangerous intersections) or incompatible uses (e.g., farm equipment)?				**X**
e) Result in inadequate emergency access?				**X**
f) Result in inadequate parking capacity?				**X**
g) Conflict with adopted policies, plans, or programs supporting alternative transportation (e.g., bus turnouts, bicycle racks)?				**X**
XVI. UTILITIES AND SERVICE SYSTEMS – Would the project:				
a) Exceed wastewater treatment requirements of the applicable Regional Water Quality Control Board?				**X**
b) Require or result in the construction of new water or wastewater treatment facilities or expansion of existing facilities, the construction of which could cause significant environmental effects?				**X**
c) Require or result in the construction of new storm water drainage facilities or expansion of existing facilities, the construction of which could cause significant environmental effects?				**X**

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
XVII. MANDATORY FINDINGS OF SIGNIFICANCE				
a) Does the project have the potential to degrade the quality of the environment, substantially reduce the habitat of a fish or wildlife species, cause a fish or wildlife population to drop below self-sustaining levels, threaten to eliminate a plant or animal community, reduce the number or restrict the range of a rare or endangered plant or animal or eliminate important examples of the major periods of California history or prehistory?				**X**
b) Does the project have impacts that are individually limited, but cumulatively considerable?				**X**
c) Does the project have environmental effects that will cause substantial adverse effects on human beings, either directly or indirectly?				**X**

Explanation of Environmental Impacts:

AESTHETICS

There is nothing in the proposed TMDL and Action Plan that will impact designated scenic vistas or highways, or have a demonstrable negative aesthetic affect, or result in increase glare.

AGRICULTURAL RESOURCES

The proposed TMDL and Action Plan may result in small reductions in agricultural land use along streams. Riparian buffers are crucial to the restoration of water temperatures and they also reduce sediment inputs. The width of the riparian buffer will vary by location and, in some locations, the buffer may be extended into land currently used for agricultural production. The proposed TMDL and Action Plan will not change the agricultural character of the watershed. The proposal will not result in conversion of the land to development. Riparian protection areas will maintain or increase the biological resources, and will have a beneficial impact on runoff to surface water. The proposal does not conflict with existing zoning for agricultural use, or Williamson Act contracts. The proposal does not involve other changes in the existing environment, which, due to their location or nature, could result in conversion of farmland to non-agricultural use.

AIR QUALITY

The proposed TMDL and Action Plan will not adversely affect air quality, result in increase exposure to sensitive species through the air pathway, or result in changes in temperature, humidity, precipitation, winds, cloudiness, or other atmospheric conditions.

BIOLOGICAL RESOURCES

The proposed TMDL and Action Plan is not expected to adversely affect plants and animals, including rare, threatened, or endangered species. The proposal does not have the potential to degrade the quality of the environment, substantially reduce fish or wildlife habitat, cause fish or wildlife population to drop below self-sustaining levels, or threaten to eliminate a plant or animal community.

CULTURAL RESOURCES

The proposed TMDL and Action Plan will have no direct or indirect impact on any cultural resources.

GEOLOGY AND SOILS

The proposed TMDL and Action Plan will not affect any geologic or soil conditions. This is a beneficial, not adverse, impact.

HAZARDS AND HAZARDOUS MATERIALS

The proposal will not impact these areas.

HYDROLOGY AND WATER QUALITY

This project is intended to improve the quality of discharges to surface waters of the Shasta River watershed and positively alter surface water quality by controlling total thermal, nutrient, and oxygen-consuming constituent loads. Water temperature will decrease as the amount of riparian shading increases, tailwater return flows do not cause heating of receiving waters, Shasta River flows are increased, and excess fine sediment is reduced allowing formation of deeper pools in response to implementation of the Action Plan. Dissolved oxygen levels will increase as aquatic plant respiration rates are reduced, sediment oxygen demand rates are reduced, and nitrogenous oxygen demand concentrations are reduced in response to increased riparian shade, and reduced nutrient, oxygen-consuming constituent, and fine sediment loads from tailwater return flows, stormwater runoff, and the City of Yreka's wastewater treatment disposal facility. A decrease in water temperature and an improvement in dissolved oxygen levels would be a beneficial impact to the designated beneficial uses of the Shasta River watershed.

The Action Plan encourages water users to develop and implement water conservation practices in the Shasta River watershed. Water conservation may result in an increase in groundwater inputs to streams and will not have a negative environmental impact. In addition, minor water impoundments may be permanently removed which could result in short-term detrimental impacts to water quality during structure removal. These potential short-term detrimental impacts would be acceptable in turn for the long-term beneficial impact to water quality, including improvements in stream temperature and dissolved oxygen levels.

LAND USE AND PLANNING

The proposal will not conflict with any applicable land use plans.

MINERAL RESOURCES

The proposal will not result in the loss of a mineral resource.

NOISE

The proposal will not result in an increase in existing noise levels or cause exposure of people to severe noise levels.

POPULATION AND HOUSING

The proposal will not affect induce substantial population growth population growth. The proposal will not affect development patterns or displace substantial numbers of people.

PUBLIC SERVICES

The proposal will not result in any adverse impacts to fire, police, schools, parks, or other public facilities.

RECREATION

The implementation of the proposed TMDL and Action Plan will not increase the use of neighborhood parks or recreational facilities. The proposal will not require construction or expansion of recreational facilities.

TRANSPORTATION AND TRAFFIC

The proposed TMDL and Action Plan will not impact existing transportation or traffic circulation patterns.

UTILITIES AND SERVICE SYSTEMS

The proposed TMDL and Action Plan will not impact existing transportation or traffic circulation patterns.

DETERMINATION On the basis of this initial evaluation:

X	I find that the proposed Water Quality Control Plan amendment will not have a significant adverse effect on the environment.
	I find that the proposed Water Quality Control Plan amendment could have a significant adverse effect on the environment. However, there are feasible alternatives and/or feasible mitigation measures that would substantially lessen any significant adverse impact. These alternatives are discussed in the attached written report.
	I find the proposed Water Quality Control Plan amendment may have a significant effect on the environment. There are no feasible alternatives and/or feasible mitigation

	measures available which would substantially lessen any significant adverse impacts. See the attached written report for a discussion of this determination.

Signature	***Date***
Catherine Kuhlman Executive Officer, California Regional Water Quality Control Board, North Coast Region ***Printed Name/Title***	

Charles C. Coutant, Ph. D.
Aquatic Ecologist

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Oak Ridge, TN 37830
865-483-5976
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November 14, 2005

Ms Lauren R. Clyde
Sanitary Engineering Associate
California Regional Water Quality Control Board
North Coast Region
5550 Skylane Boulevard, Suite A
Santa Rosa, CA 95403

Dear Ms Clyde:

It is my pleasure to respond to your invitation of October 12, 2005 to review the scientific basis of the Shasta River TMDL Action Plan and Staff Report. I understand that it is my responsibility under Health and Safety Code Section 57004 to provide my opinion about "whether the scientific portion of the proposed rule is based upon sound scientific knowledge, methods, and practices." The rule in this case is the Action Plan for the Shasta River Temperature and Dissolved Oxygen Total Maximum Daily Loads. I have read all of the material supplied to me. This letter briefly summarizes my findings for the specific questions posed. More detailed comments, suggestions, and edits are appended.

In my view, the methods used by the Board and its consultants to demonstrate the linkage between water quality conditions, stream habitat, and impacts to beneficial uses are based on sound scientific knowledge, methods, and practices. The excellent literature reviews clearly show the thermal and dissolved oxygen conditions that should prevail if the beneficial use of year-round salmonid fish habitat is to be sustained and improved. Appropriate field sampling of temperature, dissolved oxygen and factors affecting them has been carried out to document recent water quality in the Shasta River and major tributaries, although it could have been improved by further sampling of the inflows, including irrigation return water. Use of thermal infrared imagery has provided a perspective on thermal conditions along the river not obtainable otherwise. State-of-the-art modeling (with generally appropriate calibration and validation; but see comments about including all relevant factors) has been used to synthesize the data and provide a dynamic view of likely causes and effects and a way to test alternative influences and mitigating actions. The overall analytical structure of the project is scientifically sound. (Question 1)

Aquatic plant productivity is convincingly linked to DO and its extremely wide daily fluctuations. The effect is both direct and through nutrient-rich sediment that fosters macrophyte growth and sediment oxygen demand, largely caused by accumulated aquatic plant debris. There seems to be some confusion in the text about whether this is a sediment TMDL rather than a DO TMDL (see footer on draft amendment and first key point of Chapter 8). (Question 2.a)

The RMS models are generally appropriate for the task at hand and seem sufficiently calibrated and validated for the Shasta River conditions. I am acquainted with the TVA's RMS models (others have used them in our lab and I know the developers and their applications of the models). I also am generally familiar with some alternative models. I have some concern that factors like hyporheic flows in the upper reaches, which show cooling in the TIR data, may not have been adequately incorporated. Remaining factors like shade may have been overemphasized in the thermal model as a result. I was also surprised that reaeration was not effectively incorporated in defining remedial actions for DO (reaeration was the main factor manipulated in TVA's use of the models, resulting in construction of reaeration weirs). (Question 2.b)

The analyses convincingly demonstrate that carbonaceous and nitrogenous oxygen demand load coupled with nutrient-stimulated aquatic plant photosynthesis and respiration rates are dominant causes of the DO problems. Reducing these loads and rates will, in the long term, likely meet the DO objectives. I am not convinced that this long-term action (probably decades) will be sufficient for your objectives. Enhanced reaeration may be necessary to maintain adequate night-time DO, as in TVA's system, and rid the daytime of excess oxygen. These load reductions will not reduce river temperature, however. (Question 2.c)

The DO source and linkage analysis sufficiently establishes a link between channel substrate conditions (silty, organic-rich sediment that is thick behind flash dams) and the establishment and proliferation of aquatic plants. I was surprised, however, that this linkage was not capitalized upon more for corrective actions. I would suggest more active and periodic flushing with managed flows to scour fine sediments on which aquatic plants thrive. The flash dams seem particularly well linked to plant-enhancing substrates, and finding alternatives to these dams would seem advantageous (e.g., through pumping irrigation water from the gravel-bed aquifer instead of from shallow impoundments). Such actions seem needed in the implementation chapter. (Question 2.d)

The expression of DO load allocations under the compliance scenario as total daily oxygen demand seems to have been based on sound scientific knowledge, methods and practices with the exception of a realistic expectation for the timing of compliance. As noted above, simply selecting modeled inputs that would make the system comply is quite different from expecting these inputs to change in any reasonably short time frame. The goals of reducing nutrients and oxygen demanding loads from plant detritus and irrigation returns, as well as increasing shade from mature trees to reduce temperatures, are very long-term. A companion compliance action scenario for the shorter term may be needed if the goals are to be realized in our lifetimes. (Question 2.e)

The analyses demonstrate, and the photographs visualize, that the high degree of solar radiation transmittance is a major factor in causing warm stream temperatures in summer. I suspect, however, that this factor has been somewhat overused as a surrogate for other influences that are not well incorporated in measurements and the models. Because shade development is such a long-term remediation, additional focus on factors with nearer-term implications may be useful. Hyporheic flow seems to be operating in parts of the river to cool or ameliorate heating, yet it is not included in the model (there is some distributed inflow, but I did not see the corresponding distributed outflow, although I may have missed it). The heat input from irrigation returns was not well characterized, as the studies noted. I know from personal experience that when it is difficult to obtain information on many thermal factors, it is relatively easy to tinker with the shade component to calibrate and validate the temperature model. All-in-all, it seems unsatisfactory to do all the work that the studies represent only to conclude that the preferred remedial action is to plant trees that will take 50 years to have the desired effect. (Question 2.f)

I am not an expert in doing solar transmittance measurements and projections, but the information presented seems logical and may represent sound scientific practice. I gathered from comments about access that some landowners may not be cooperative when it comes to planting trees or fencing riparian areas from cattle. As noted above, development of shade is a long-term proposition, and the thermal TMDL won't be met for quite some time if this is the main remedial action. (Question 2.g)

In my detailed comments, I have highlighted some fairly major issues for you to consider. These include (in order of my notes on the chapters): fish passage issues at Dwinnel Dam (and perhaps at flash dams) in the demise or reduction in salmon populations, whether the salmonids would normally occupy the mainstem Shasta River in summer based on life-cycle strategy and behavioral preferences, claiming thermal exceedences when life functions are not occurring (e.g., incubation in summer), lack of consideration of percent saturation in discussions of DO (high values can lead to gas bubble disease), seasonal nutrient releases from Lake Shastina, possible methane releases from Lake Shastina in summer (adding to downstream oxygen demand), hyporheic (subsurface) flow affecting temperatures, temperature influences of Lake Shastina discharges (current and potential management opportunities), the need for more scouring flows to remove fine sediments and lower SOD, better quantitative characterization of irrigation return flows and use of them for TMDL actions, more study of and possible reduction in number of flash dams, doubts about the N-15 evidence, possible exaggerated influence of shade when bottom effects (e.g., hyorheic flows) are turned off in the model, flow effects seem to be modeled strangely, not considering reaeration in setting the actions.

I noted that in several places the TMDLs were referred to as "sediment and temperature" rather than DO and temperature. The text and appendix material makes a good case that nutrient-rich sediment is a major factor for both habitat for macrophytes and nutrients to make them grow (and cause DO problems), but the focus should still be on a DO TMDL along with temperature.

In summary, I found the analytical approach sound and quite thorough, and the analyses to be of generally high quality. I had questions and suggestions that you may want to consider. I was somewhat disappointed with the bottom line for temperature for it included mostly action to increase shade while just assuming that warm inputs can be eliminated by edict, which seems impractical. Relying on shade will be a very long-term remediation, one that the salmonid populations may not live to see. For DO, I agree with focus on nutrient-rich sediments (both input and accumulation) and their stimulatory effects on macrophytes, but suggest that there may be other useful control measures such as managed flushing flows and finding alternatives to the flash dams for irrigation water supply. I surely concur with the need for monitoring and periodic revisiting of the issues by the Board.

Thank you for the opportunity to review your extensive work.

Sincerely,

Charles C. Coutant, Ph.D.
Aquatic Ecologist

Cc: Matt St. John

Via e-mail and hard copy
Attachment: Detailed Peer Review Comments

Detailed Peer Review Comments on Shasta River TMDL
C. C. Coutant

Note that major issues are highlighted in **bold**.

CHAPTER 1: INTRODUCTION

Page 2, next to last paragraph: Might note which EPA Region is responsible.

Page 3. 1.3.1: The coordination among subbasins is good. Is it the intent to make the respective TMDLs somewhat similar?

Page 4, 1.3.4: The Technical Advisory Group was a good idea for early information and buy-in.

Page 4, 1.4.1: According to my map, the Siskiyou Range is more northwest of the Shasta basin. What is the red outline on the inset in Figure 1.1 (This needs to be identified, as it could be confused with the Shasta basin, which is the green. I found later that this must be the outline of the Klamath River basin in California, but it should be identified.). I found that going to my road atlas gave me a better picture of the topographic setting of the Shasta basin than does the inset, for it included the mountain ranges and colored topographic information. You might consider using such a map. The ranges and mountains could be labeled (see note for 1.4.4).

Page 4, 1.4.2: Gazelle and Edgewood communities are not located on Figure 1.1. As a general editorial rule, any place mentioned in the text ought to be identified on a map.

Page 6, 1.4.4 and 1.4.5: Mt. Shasta and Mt. Eddy are noted many times in the text but not labeled on figures. It would be good to do so.

Page 9, 3d paragraph: Many creeks named in text are not labeled on the figure.

Page 9, 4th paragraph: The MWCD canal seems to be shown on Figure 1.4 but is not labeled. Other canals seem to be shown, too, but not labeled. It would help for comparisons of river and canal flows if they were given in the same units.

Page 18, Table 1.2: Good survey, but no river mile labels are shown on maps to go along with the river miles in this table. Although one can get a general scale from the bottom paragraph of page 16, a separate map with river mile designations would help.

Page 20, 3d paragraph: Big Springs Lake is in text but not labeled on figures.

Page 20, 4th paragraph: Note use of cfs here whereas the earlier figures were acre-feet. Common units (or easy conversions) would help. Change who to whom in last line.

Page 23, 4th paragraph: Have to note that flood irrigation is a wonderful heating mechanism for return flows. Hope that this is covered in rest of document. (I was subsequently disappointed that it wasn't really covered well, and that the return flows were usually not measured for temperature or other important variables.)

Page 23, Table 1.4: What does "acres per 1000" mean under Irrigated Crop Area? Do you mean thousands of acres?

Page 25, top paragraph: Spring Chinook salmon likely migrated upstream past the present Dwinnell Dam in cool, spring conditions to cool summer refuges in the mountains (getting to the cold mountain streams to oversummer is what allows a spring run). Considering the season of spring Chinook migration (river still cool) one suspects that **blockage by the dam was more important than temperatures from the reservoir for the demise of spring Chinook. If so, then fish passage should be an issue, too.**

Blockage is mentioned on page 29. The blockage issue detracts from the justification for a thermal TMDL for the mainstem.

Page 27, Figure 1.13: Fall Chinook do not normally rear over the summer elsewhere. They have a typical strategy of migrating out of the rivers in their first spring, as underyearlings. Many of us salmon biologists consider this life-history strategy to be an adaptation to avoiding normally warm summer water temperatures (see my 1999 report for EPA Region 10 on Perspectives on Temperature in Pacific Northwest Fresh Waters). Is there evidence to back up this figure showing year-around rearing of fall Chinook in the Shasta? The basinwide figure may be misleading with respect to the mainstem TMDL. None of these species would be expected to be found in the mainstem in summer. They typically move out of the mainstem to the ocean (fall Chinook) or up into cooler tributaries, like the steelhead seasonal movements you show in Figure 1,12. **This could be a big factor in justifying your temperature TMDL, which is focused on the low-flow summer months.**

Page 27, bottom paragraph: “brown bull” should be brown bullhead; “blue gill” and “mosquito fish” should each be one word (bluegill, mosquitofish). Also in Figure 1.14.

Page 29, Table 1.5: Note that the species name for Tui chub needs to be italicized.

Page 29, first paragraph under table: Rainbow should not be capitalized, nor should Largemouth and Brown in the next paragraph.

Page 30, line 2: underway is usually one word.

Page 31, 3d line from bottom: restore should be restored.

Pages 30-31. These summaries are excellent and show that the local folks are concerned and active in environmental restoration. Kudos to them! But why do the study reports in the appendices note that the study teams often could not obtain access? Physically no way or landowner objections?

CHAPTER 2: PROBLEM STATEMENT

Page 1, 2nd paragraph: gestation should be incubation.

Page 2, Table 2.1: Why is Lake Shastina not used for sport fishing? Surely, there is spawning, reproduction, and/or early development of fish and other aquatic life in Lake Shastina. Do you refer only to salmonids? If so, this should be stated.

Page 4, 2nd paragraph: **This paragraph sets up the regulation of irrigation return water as part of the TMDL for both temperature and DO. It seems inconsistent with later decisions not to include them as point sources.** The monitoring and modeling studies noted the deficiency in getting data from them.

Page 5, top paragraph: I know this is intended to be general, but it is a bit too general. Temperature is not always a stress (although too warm or too cold temperatures can be). There are always temperatures, so we can’t do without them. The intent seems to be to comment on too-warm temperatures for salmonids.

Page 5, line 7-8: This sentence doesn’t sound right. Better to say: A MWAT can be selected that allows for optimum growth rate of salmonids during peak temperatures in summer (Armour 1991). However, this may not be desirable, because, by definition, it means that water is so cool the rest of the year that growth rates are sub-optimal.

Page 5, line 8-9: It may be common, but the instantaneous maximum temperature is never a good measure of acute effects, unless it is extraordinarily high. A temperature of 90F (32C) is clearly acutely lethal to salmonids (death would occur very quickly), but an instantaneous temperature of 77F (25C) is not acutely lethal unless there are days of exposure. There are many good references to the time-temperature relationships of salmonids (e.g., Brett's publications) that are cited in the thermal literature review given in eh appendices.

Page 5, second paragraph as a whole: This paragraph is ok if it is simply describing the various measures available, without value judgments. All have recognized drawbacks.

Page 5, bottom paragraph (extending to top of page 6): I hope they measure presence/absence of the salmonids, too. **This seems to be a key question—whether the juvenile salmonids would actually be in the mainstem in summer**. See note above.

Page 6, Table 2.3: Despite the references, I think 16C for core juvenile rearing is low unless one is intending to maintain optimum conditions all the time (probably unreasonable). The optimum growth temperature for Chinook is above this according to research by Brett. It is still a useful goal.

Page 6, Table 2.3 footnote 2: defines should be defined.

Page 6, Table 2.4: This table probably should be footnoted to say that the lethal threshold is for a long-time exposure (usually taken as a week). It's not a sharp cutoff. These temperatures can be experienced briefly and fish survive and do well. That's why instantaneous temperature is a poor measure of acute lethality. Nonetheless, these are good benchmarks for lethal conditions.

Page 7, Table 2.5: This table needs a better legend to indicate it is about *maximum* temperatures in three measures, peak temperature ("temp."), weekly average ("WAT"), and maximum weekly ("WMT") (assuming I'm correct). The last three columns should be identified as the summary for the 1994-2003 period of record. Any idea how representative the monitoring stations really are of the total streamflow?

Page 9, bullets: (see notes from Figure 2.3, below). I was surprised to not find any mention or data on daily temperature fluctuations here. Daily maximums mean a whole lot different things if the daily range is small or large. Same for DO later on. This is especially strange since so much is made later on about fluctuations.

Page 10, Figure 2.2: This is a good figure, but note that the bottoms of the river mile numbers are cut off and the tributary names are difficult to read or incomplete.

Page 11, Figure 2.3: This figure is misleading, if not technically incorrect. Although it is dramatic, it **is unrealistic to show exceedences for spawning, incubation, and emergence of salmonids in summer months when these life stages do not occur**, especially at the station from which the data are taken (lower mainstem). Thus, the red bars are inappropriate at least from the middle of June (the likely end of any trout emergence) through the end of August (when some salmon might begin to spawn). My timing may be a little off for the Shasta fish, but the principle remains. Note same problem with 5th and 7th bullets on page 9. It's true the threshold is exceeded, but the functions are not occurring then. For the last bullet, I have a similar concern, for what evidence is there that juveniles are rearing there in summer, and adults migrating and holding then? In many salmon streams, the mid-June through August period is pretty devoid of salmonids. Your use of these data would be stronger if presence were clearly supported.

Page 12, tributary findings: Again, I'd be careful making too much about high temperatures in summer when salmonids are often not there doing their thing.

Page 12, and Figure 2.6 (Lake Shastina): It would be useful for downstream conditions to know at what depth water is discharged from Lake Shastina (this is mentioned in the appendices, but it would be good to have it here, too). It is a deep discharge with low DO.

Page 17, Figure 2.7: The legend needs to say what the text does, that this is a composite of all mainstem DO measurements.

Page 16: **I was surprised that no mention was made of percent saturation in the DO section.** A DO value of 19 mg/l is 135% saturation even at a cold 2C, a saturation level that is bad for salmonids because of gas bubble disease (the EPA criterion for total dissolved gas is 110%). Saturation at 20C is only 9.2 mg/L; at 20C, the EPA criterion of 110% saturation occurs at 10.2 mg/L. Although DO is only one part of total dissolved gas, there have been fish kills elsewhere from superoxygenation of waters by photosynthesis. If one takes from Figure 2.1 that water temperature is above 20C in the mainstem Shasta River from mid May to end of September (roughly) then from Figure 2.8 roughly 40% of the time the DO may be at lethally HIGH levels for salmonids. **In my opinion, this fact absolutely must be considered in the dissolved oxygen TMDL and is a reason for minimizing the daily fluctuations.** As with temperature, the daily cycling is important (see anecdote on page 28) and should be presented (percent saturation will vary with both DO content and temperature). The ill effects of high percentages of saturation are a further justification for doing a TMDL.

Page 18, Figure 2.8: This figure needs a better legend to describe the axes and what is being shown. The figure is informative, but takes long to figure out.

Pages 23-24, tables 2.8 -2.11 If the point was to show that P and N are high essentially everywhere below Lake Shastina, the data support that point well.

Page 25-26, Lake Shastina P: Is there any information on the seasonal cycling of P in the reservoir, particularly the sequestration in the sediments? Typically, plankton in a eutrophic reservoir will scavenge P and deposit it in the sediments during non-summer months. With stratification, the anoxia of the hypolimnion releases P into the water column again. Reservoirs that do not stratify and do not go hypoxic in summer become traps for P, which limits their biological productivity and the productivity of downstream waters (e.g., Lake Koocanusa in Montana and British Columbia and the Kootenai River). On the other hand, **deep discharges from a stratified reservoir in summer can release a lot of P into the downstream river**. If the P can be permanently sequestered in the bottom of Lake Shastina, then the P levels downstream might be lowered. Could be worth investigating.

Page 26, last full paragtraph, 4th line: spelling of border.

Page 27, 4th bullet: measure should be measured (monitored?)

Page 27, paragraph 2.6: The cautions noted above should probably be acknowledged here. It is inappropriate to say that USEPA temperature thresholds are exceeded at times when the salmonid life history events for those thresholds are not occurring.

Dissolved oxygen concentrations are also regularly ABOVE the EPA-defined lethal levels for salmonids (gas supersaturation).

Page 28, 3d paragraph: I'd be wary of making too much of this anecdote, especially since it involves a side channel fed by a spring with a (presumably) natural flow with a DO of 0.05 mg/L. Surface aeration and photosynthesis presumably raise DO in the side channel as water moves downstream. This tells the reader little in support of DO problems in the mainstem river. I don't dispute that temperature and DO are a problem, just that this is not very good evidence for it.

Page 29, 3d paragraph: I see here that the discharge is from the bottom of Lake Shastina. This virtually insures a high P load to downstream from the reservoir in summer. This P load may be more manageable than some of the other sources noted in the TMDL action plan.

Also, hypolimnetic discharges often have high loads of **dissolved methane**. Methane contributes to the oxygen demand of released waters, and may be more important as a source of oxygen demand than bottom sediments. Several reservoirs where this is a problem are installing aerating weirs downstream of the dam outlet to get the dissolved methane to transfer to the air and to help oxygenate the water. I have not seen methane mentioned in the TMDL document.

CHAPTER 3. TEMPERATURE SOURCE AND LINKAGE ANALYSIS

Page 1, first bullet: Solar exposure is the main source of heating, to be sure, but the base temperature from groundwater, springs, hyporheic flow, etc. sets the starting point.

Page 1, second bullet: This "balance" may not be true if the water is cold at start and the air temperature is quite warm, as often is the case in the region. This goes beyond the correlation noted on page 2, last full paragraph.

Page 4, Figure 3.1: This figure is nearly identical, but better, than Figure 2.2.

Page 5, next to last paragraph: Riparian vegetation is not likely to actually cool the stream water, but to prevent it from heating. There may not be any noticeable groundwater accretion, but I suspect there is a lot of **hyporheic flow**. If there is sub-channel flow, the emerging water would be cool and would provide the cooling seen in the TIR imagery. RM 24.2 is actually a bit of a warming reach.

Page 6, Figure 3.2: The arrow on the right-hand image is pointing to the warm open field, which is confusing. Better to align the arrow with the stream.

Page 7, First paragraph after Figure 3.4: I'm surprised that the shading from mature trees did not make any more than 1C difference in average daily temperature. Is the last sentence correct? If so, it weakens the case (given later) for controlling temperature with shade.

Page 9, 3.2.3: Figure 3.6 is not clear about supporting the point made. The figure needs labels. Where is the irrigation return? Which way is the river flowing? The thermal pattern looks about the same all along the right-hand image.

Page 9, last full paragraph: I don't see how an increase in flow would increase the daily minimum temperature unless there is a lot of groundwater (or hyporheic flow) that is swamped by the increased (and warmer?) surface flow. The paragraph ends with the statement that flow management is important, but the preceding sentence suggests lower flow is better. The modeling seems to show that higher flow reduces daily fluctuations caused by both solar heating and cool subsurface water.

Page 11, 3.2.5: **Hyporheic flow seems like a major omission.** Hyporheic flow is not groundwater accretion but subsurface flow in the gravel channel. This larger streamflow buffers against solar heating and actually cools the surface flow as the deep water from earlier months returns to the surface. The TIR imagery (Figure 3.1) suggests several zones of hyporheic flow where there is gradual cooling (e.g., miles 31-34, 35-37). This points out a potential problem with using a model. If the model doesn't include something like hyporheic flow, it will not show up as an influence in the model runs. Stream models all have shading, so prominently that tinkering with the shade factor is used as a calibration tool for stream temperature models. But unless the model was developed for gravel-bed rivers (unlikely that the TVA one was) it will not even acknowledge hyporheic flow as a mechanism.

I think the existing model can be gerry-rigged to handle hyporheic flow. The model includes distributed lateral inflow (which is inflow not attributed to a specific tributary and which is distributed across a reach) that can be used to handle groundwater inputs. (A single spring input would just be handled just like a trib.) This distributed flow is assigned its own water quality values (temp, DO, CBOD, and NBOD). For hyporheic flow, if you have some idea of the rate of flux in and out of the gravel, you could treat the flux into the gravel as withdrawal from the stream (water of ambient quality) and replace it downstream with distributed inflow representing the flux out of gravel (with water quality of the hyporheic flow). Being able to model the hyporheic flow as a separate entity would be better, but this method should maintain the overall water balance and produce the water quality interactions between the stream and the hyporheic flow of interest. You seem to be using this distributed lateral inflow logic for the irrigation return flows.

Page 14, middle of the second paragraph: **I suggest you need more information on the cool deepwater discharges from Lake Shastina.** Such discharges are, as stated, usually cool and can have a large beneficial cooling effect on the temperature of the downstream river if managed well. Many reservoir tailwaters support trout fisheries throughout the country (even in the South) precisely because of these cool hypolimnetic discharges. This chapter skims over this topic all too lightly, in my view, especially since there are temperature management opportunities there.

CHAPTER 4: DISSOLVED OXYGEN SOURCE AND LINKAGE ANALYSIS

Page 1, Figure 4.1: Unless it is meant to be included in CBOD, I do not see oxidation of methane from hypolimnetic releases from Lake Shastina.

Page 2, bottom paragraph, first line: end parenthesis is missing.

Page 3, Figure 4.2: The legend needs improvement. Isn't this figure the daily measured dissolved oxygen range compared to the respective calculated saturation values (based on temperature and barometric pressure)? This and Figure 4.3 on the next page are fine figures that clearly make the point.

Page 5, first full paragraph: Don't you think comparing the river BOD to untreated sewage is an unfair comparison that does not serve your point well? Wouldn't it be better to compare with another river, perhaps an organically polluted one? **What**

about methane oxidation in Lake Shastina tailwaters in summer? I'd like to see this explored, especially since it is important below other eutrophic reservoirs with hypolimnetic discharges (accounting for a large proportion of the oxygen demand).

Page 6, end of second paragraph of 4.2.3: Incomplete sentence.

Page 8, end of first full paragraph: Just a side note that juvenile fall Chinook salmon feed on the chironomids in (or emerging from) the macrophytes.

Page 9, Phytoplankton: What about phytoplankton released from Lake Shastina into the Shasta River? Lake phytoplankton are often just organic detritus once placed in a riverine habitat. That organic release is probably important in the reach below the dam, as it often is below eutrophic reservoirs. At least it ought to be ruled out as a major source of BOD.

Page 10, first full paragraph: This is weak, especially so since so much of the TMDL rests on the macrophytes. If possible, I'd beef this up.

Page 11, top paragraph: This paragraph is right on target. **Scouring flows are needed more often in the Shasta River.** This may need to be an explicit management tool as well as reliance on a once-every-10-years natural occurrence of flood flows. Short bursts of high flow over a few days may be sufficient, and not interrupt most irrigation storage. Managed flood flows may be more likely to have the desired effect than other management measures, such as nutrient reduction. Certainly warrants more consideration. It is the fine, macrophyte-enhancing sediments noted in 4.4.3 that would be washed out.

Pages 11-12, section 4.4.4 Light: These comparative relationships are quite true, but riparian shading takes many years to accomplish from scratch. While the riparian zone is building, other measures will likely be needed, such as more scour of plant material and fine sediments.

Pages 13-16, the Algae model: As far as I can tell, this is a good model and it has produced useful results. While the nutrients are stimulatory, the sentence on page 15 just below the table is important. However, I would not say "in the absence of other water quality improvements" but rather …in the absence of other water quality, water quantity, and habitat improvements…not enable dissolved oxygen standards for the river to be met.

Pages 16-18, Return Flows (quality **and quantity**): The section is probably a fair assessment of what we know, but it is a shame that these flows are not better characterized. The number of samples seems inadequate in both time and space. The return flows contribute actual fine sediment that fosters habitat for macrophytes and exerts SOD, they contribute suspended solids that are settled by macrophytes (more SOD), and they are nutrient rich (more macrophytes and algae). It would seem essential to determine the quantity as well as the quality, that is, what percentage of the Shasta River flow is made up of irrigation return water. Are there no mandatory settling basins before water is returned? Other river basins have them. Requiring such settling basins might be more effective than some other control measures for oxygen-reducing substances/features. **This seems like a major factor that needs more attention.**

Page 18, City of Yreka: Although the second paragraph of this section notes that the City of Yreka contributes to the nutrient load and nitrogenous oxygen demand in Yreka Creek, this is given no quantitative perspective. Is this loading a significant proportion of that to the Shasta River below Yreka Creek? This ought to be relatively straightforward to determine based on relative flows and concentrations. Certainly the City would want these comparisons made solidly before it embarks on any nutrient control measures.

Page 19, bottom paragraph: **This discussion of Lake Shastina discharges is exceedingly weak. Low dissolved oxygen in the tailwaters below eutrophic reservoirs is a nationwide problem that is well recognized and subject to extensive and expensive corrective measures.** TVA reservoirs are examples. There was even a famous court case in which EPA would have had to declare reservoir discharges as point sources of pollution because of the low DO and high nutrient loads (EPA has not had to do so as a regulatory matter, but the facts about DO and nutrients remain). With this background, it is simply not sufficient to say "…differences in dissolved oxygen concentrations above and below Lake Shastina <u>may also be due to</u> the fact that the outlflow …is discharged near the bottom of the reservoir… [underlining mine]. This should have been one of the first features for study in a tailwater river with low DO in summer.

In addition to the immediate low DO in the discharge, **methane is often a major dissolved constituent of hypolimnetic water and an important source of oxygen depletion in the tailwater and on downstream** (I noted this earlier). Unless there is good aeration in the tailwater (natural or induced), methane will remain in solution as the river passes downstream and its oxidation can be a large part of the oxygen demand. I don't know if this is the case for the Shasta R., but it ought to be explored. An aerating weir may be needed below the dam, as at several TVA dams.

[In re-reading these comments after having read the appendices, it seems that the Lake Shastina discharges are not a large part of the river flow. Perhaps my emphasis is less important than it might be if Lake Shastina had a strong outlet to the river. Nevertheless, I'll keep the comments here in hopes that the treatment of the discharges and the management opportunities they may offer are strengthened.]

Page 20, Figure 4.4: This figure has several problems. First, the legend should say dissolved, not dissolve. The four lines cannot be distinguished from the key (the key shows only one broken line). The symbols are too small and are difficult to resolve. The line that goes to lowest DO has several thicknesses along its length. Needs work.

Page 20, springs: The spring issue is interesting. You say in line 4 of the first paragraph that nutrient measurements were made. I seem to have missed where these concentrations and their volumes relative to the river are given. The nutrient load may be more important than the DO levels.

Page 22, second paragraph, line 6: …influenced by… In line 10 do you really mean to say that SOD levels were the lowest? I would have expected high macrophyte density and *high* SOD levels to go together.

It would appear that **further investigation of the small impoundments would be needed and desirable to quantify the effects of the aggregate of such dams on the Shasta R.** The appendix gave more information, but it still is just a sampling. Alternative ways to get irrigation water are available (such as pumping from onshore wells drawing from the hyporheic flow) that do not entail damming up sediment and creating wonderful macrophyte habitats. Reducing macrophyte habitats by reducing such dams could be more effective than long-term nutrient controls. Removing the dams would also help promote scour, discussed earlier.

Page 23, flow: It seems to me that effective reaeration is more likely reduced by increased flow. At higher flows, there is less surface area per volume of cross section. Also, the water is moving faster, so an initial low DO is carried farther downstream before being influenced by reaeration. The same thing happens with temperature—stream temperatures equilibrate fairly rapidly at low flows but excess heat (or cold) is carried farther downstream at higher flows. I guess I'll learn more in Chapter 7.

Page 23, last 3 lines: **The statement that N-15 wouldn't have come from salmon in July and August doesn't comport with the large literature on salmon-transported, marine-derived stable isotopes.** Salmon carcasses are scavenged by aquatic insects, mammals, fungi, bacteria, all of which rapidly transfer the marine-derived nutrients to the surrounding ecosystem. The salmon nutrients don't wash out within the season. They wind up in lots of places, including macrophytes and periphyton that make suspended organic matter. I would certainly not use this isotope information as evidence of anthropogenic nitrogen enrichment. There are no doubt anthropogenic sources of N, but the isotope information would not be critical evidence in this regard.

CHAPTER 5: METHODS

Page 4, Temperature component: I had a few questions about TVA's River Modeling System (RMS), so I contacted Ming Chen Shiao of TVA for more information. The RMS has been used mainly in dam tailwater systems. It was developed mainly for quick tailwater water quality assessment and built with components that have most impact on the temperature and DO in dam tailwaters. He characterized it as somewhat crude in conceptual design but useful for TVA's assessments of the cold temperatures and low DOs below TVA dams. The RQUAL component includes logic for bed heat exchange, mainly to keep water temperature from dropping too much in early morning hours. This heat exchange is simple conduction that does not take into account hyporheic flows (flows in and out of the sediment).

If bed heat exchange is turned off for this application (as said on the bottom of page 3) and the riparian shade logic is retained, **it seems as though the riparian shade aspect (or other aspects of the air-water interface heat budget) would be exaggerated to counteract cooling from the inactivated bed effects.** Won't this artificially inflate the expected benefits of managing shade?

Page 5, Oxygen component: With respect to the oxygen component of RQUAL, Ming said that methane oxidation would be considered part of the empirical CBOD. Methane oxidation could be included as an added explicit step, if desired (3.56 mg/L of oxygen is required to oxidize 1 mg/L of methane). The problem with lumping everything in with CBOD is that it gives no clues as to what might be corrected to improve DO. RQUAL makes all CBOD a fifth (?) order decay, which is lumping a lot of different Cs into one package. Ming suggests another model, CEQUAL-W2, would be better for differentiating Cs and getting at the source of the problems.

Three edits in this section: (1) first indented paragraph: "are represented" is written twice; (2) third "where" item: should be dissolved; (3) on next page, fifth line:

shouldn't "firth" be fifth? Also, note in this section liter is abbreviated with a small letter l, whereas earlier in the text liter is a capital L, as in mg/l vs. mg/L. A detail, perhaps.

Page 6, paragraph 5.5, line 3: address should be addresses.

Page 7, 5.6.1, Flow: This may be naïve, but with so much of the case for DO problems hinging on the diurnal curve being so exaggerated (supersaturation to below standards and back) isn't it somewhat important to have the "sub-daily deviations" correct in the model? Aren't the intra-reach operations (diversions and return flows) features that are potentially controllable under the TMDL? Controllable doesn't necessarily mean elimination, just management to help the temperature/DO problems. To me, it doesn't make good sense to excuse away or otherwise eliminate the very features that can be managed for water quality improvement.

CHAPTER 6: TEMPERATURE TMDL

Page 2, second paragraph: Was any consideration given to landowner preferences regarding riparian shading? Locally, we have river reaches with homeowner developments and there is strong movement to making lawns right to the river's edge. The potential for increasing shade there is low unless it is tall, mature trees (these can be encouraged with some success).

Page 2, table 6.2: This table would be more interesting and informative if it had both current and potential values for the reaches side by side.

Page 3, Big Springs Creek: This looks like a good strategy. One would expect the heating rate of the cold spring water to be higher than for the warmer Shasta River water, from air contact alone.

Page 4, first paragraph of 6.3.2.3: I don't understand how the irrigation return flows can be assumed to be at thermal equilibrium. In my experience, surface return flows are very warm in summer because of solar heating in the fields and ditches (and settling basins when they occur). Even given this detail, **I'm surprised that one of the more controllable features for temperature can be smoothed over with such broad model assumptions.** Infiltration galleries are available for return flows, which allow the return flow to percolate through the gravel bed of the river floodplain and get cooled geothermally as the water returns to the surface (or hyporheic) flow.

Page 5, Critical conditions: In terms of temperatures, it is a good high-temp/low flow year, but the issue still remains whether the salmonids you wish to protect would be there at that time. Fall Chinook juveniles have usually moved out by then; adults have yet to arrive, I suspect. Resident rainbow, yearling steelhead, and yearling or older coho would likely have gone into cooler tribs anyway. I think you will have a much more defensible case for criticality of you make it on both physical and biological bases.

Page 7, Figure 6.1: The colors on the model output locations are hard to see against the heavy green background. Also, some colors are difficult to differentiate (e.g., 2 & 3, 10 & 11).

Page 17, second paragraph: **I don't see how river flow can be changed on a reach-by-reach basis.** This stepwise analysis eliminates the influences of upstream flows and essentially treats the reach as a pond, no? Temperature is greatly affected by transit

time in relation to local heat balance dynamics (available time to come to equilibrium). Unless I can find out why this incremental approach is valid, I have to look at the results with a great deal of skepticism.
I understand better from the appendix, but my concerns remain.

Pages 18-19, Tables 6.5 to 6.8: I found these tables very difficult to read. The color helped.

Page 20, top paragraph: Is it realistic to think that the outflow of a group of springs can be increased? Or is this being done by reducing withdrawals?

Page 23, bottom paragraph, first line: insert to after attributed.

Page 24, last paragraph: That was a lot of work to simply say, “make more shade.” And it won’t happen quickly, for it takes many years to get a tree to shade a river. I’m sure it is a result the landowners will like, but will the salmon? I just have the feeling that a more explicit model (or better use of the capabilities this model has) might have pinpointed other avenues for temperature reduction.

CHAPTER 7: DISSOLVED OXYGEN TMDL

Page 2, general: I still wonder how much methane oxidation from the Lake Shastina outfall influences the downstream DO. TVA has installed aeration weirs downstream of several dams that are very effective in both reducing (volatilizing) methane and adding oxygen. I will include a clipping from the local newspaper that came as I was reviewing this section. Aeration weirs below dams with deep discharges are so effective they might be considered for the Lake Shastina tailwater. Such weirs create rapid improvement as opposed to long-term effects of shading and nutrient removal. Aerating weirs might also be considered for larger irrigation returns (it pays to think of implementation as the analyses are being done).

Page 3, Table 7.1: Either the legend or table should show the units, as do tables 7.2 and 7.3.

Pages 5-13, figures: These figures look good and certainly show the improvement you want. But I have to wonder how realistic and timely it is to reduce the rates of oxygen depletion/production stated on page 2 with just controlling the factors you have identified.

Page 15, second full paragraph through the end of the page: These are results-oriented statements that are true only to the extent that the model has included all the relevant and important factors, especially the ones that might be manipulated to achieve the desired water quality. The results show the change required, but not how to get there (that is, what specifically needs to be done). This criticism is strongly brought home when you get to the last paragraph, where you explicitly ***remove reaeration*** from the equation. **Why you would remove the very factor that has most aided DO improvement for rivers elsewhere baffles me.** Altering flows is not the only way to affect reaeration. You use the TVA model but then don’t use it for what the TVA found it to be most beneficial—improving DO. True, TVA was faced with the major task of boosting an initial low DO in the dam discharges, but I suspect you are, too, with Lake Shastina releases (at least to some degree). But the weirs reduce the oxygen load from methane as well as adding oxygen.

Page 17, Table 7.4: Shifting units are confusing. What are the unlabeled lower right boxes (per mile?)?

CHAPTER 8: IMPLEMENTATION

Page 1, first bullet, second line: **Why does this say "sediment and temperature related water quality objectives" when I thought it was temperature and DO?** A cut and paste error? Admittedly, much of the implementation for DO will be through controlling input of nutrient-rich sediment and the buildup of sediment in the channel that fosters aquatic macrophytes. But the TMDL is for DO, no? Note the same sediment problem in the footer for the Draft Amendment Language. I sense some confusion of objectives.

General Comment: I did not go into this chapter in detail. You know the social system there and what would have to be done (and the authorities for doing it). Some of my comments on the science suggest other areas for implementation that may be as effective or possibly more effective. I like the general approach of working with other agencies and groups, including landowners. If done cooperatively, you can generate a lot of enthusiasm for making corrective actions and even get the local landowners to take much of the initiative; if done dogmatically and authoritatively, you could have much resistance.

CHAPTER 9: MONITORING

Page 1, Key points: good.

Page 1, last paragraph, first line: are should be is

Page 2, top: Such photographic documentation monitoring is not effective for temperature and DO, but may be effective for vegetative cover (shading), macrophyte abundance or elimination of irrigation return flows, for example.

Page 2, second line of 6.1.3: states should be state

Page 2, end of 6.1.3: Don't forget temperature. Something like this might be added: Temperature monitoring would require measurements at hourly or sub-hoourly intervals at selected instream locations.

Page 3, top paragraph: Temperature is so easy to monitor, why hold back? The use of the term "discharger" seems inconsistent with the previous determination that there were no point source discharges on the Shasta River. I agree that irrigation return flows are discharges and should be monitored (at least the large ones).

Page 3, first bullet: Isn't DO itself to be measured at all? Seems incredible that it wouldn't be.

Page 3, first full paragraph: I agree with the plan to have the RWB design a monitoring plan specific for giving feedback on this TMDL. I suspect that the actions planned will not yield results in the near term, but take a long time. Alternative near-term actions will probably be needed.

Page 3, first full paragraph, next to last line: data should be date

Page 3, bottom paragraph: Why not use the USGS monitoring system?

General: Some of the monitoring words seem pretty generic and lifted from other situations (e.g., using "discharger" when this TMDL background says there aren't any).

CHAPTER 10: REASSESSMENT

This all seems pretty logical and thorough. There may be items from my other comments that might apply.

DRAFT AMENDMENT LANGUAGE

Throughout: The footer says "Sediment and Temperature" TMDLs. Isn't this for temperature and DO? Note earlier comment on Chapter 8.

Page 1, 3d paragraph: What permit actions might be taken? It could be useful to indicate some, probably not here but somewhere else (Chapter 8 on implementation?).

Page 1, first paragraph of Problem Statement: **If the 110% supersaturation criterion for gas bubble disease is invoked then the daily high levels of DO are above what ought to be basin objectives. This would seem to offer an additional justificaton for a DO TMDL.**

Page 2, III.B: As a novice for the Shasta, I'm surprised that there are no point sources (irrigation return flows seem like point sources to me).

Page 3, Table 1: Since the text refers to totals, it would be helpful to total the columns. How and where these numbers are calculated might be indicated.

Page 5, IV.A: I'm surprised air temperature is not listed.

Page 6, top paragraph: I'm sorry to see you use the words "natural receiving water temperatures" for these are notoriously hard to define. It is better, as the temperature TMDL does, to set a temperature goal appropriate for the beneficial uses to be protected.

Page 7, two paragraphs below the figure: How realistic is it to mandate that irrigation return flows not contribute to heating of the river? If there are return flows in summer, there will be heating. This seems to me to be the ostrich with its head in the sand.

Page 7, 3d paragraph below figure: Falling back totally on shade for the load allocation has problems, as noted above. In the model, shade is easily tinkered with to account for the real influences on water temperature such as subsurface flows and small tributaries (return flows). Shade can take decades to implement, thus essentially giving up on any improvement in the near future. I'm not sure the science as reflected in the work done for this TMDL would support going to just shade.

Page 8, second paragraph: I really question whether the sensitive life stages are actually in the mainstem Shasta River all year. The statement says "basin" but the TMDL is applied to the mainstem. This is a point of vulnerability for someone wishing to challenge the TMDL.

Pages 8-12, Table 2: I would support essentially all of these actions, but have noted above others that might be considered.

Page 13, Monitoring: I would try to establish a RWB or RWB contractor monitoring system as well as relying on the discharger.

Page 14, top paragraph: This paragraph refers just to sediment, as was done before. Isn't the TMDL for temperature and DO? Was this a copy & paste mistake or is sediment the only thing really considered important?

State of California
North Coast Regional Water Quality Control Board

PUBLIC COMMENTS & RESPONSES

for the

Action Plan and Staff Report for the Shasta River Temperature and Dissolved Oxygen Total Maximum Daily Loads

May 26~~3~~, 2006

Appendix J

State Water Resources Control Board
North Coast Region
5550 Skylane Boulevard, Suite A
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TABLE OF CONTENTS

RESPONSE TO PUBLIC COMMENTS

Shasta River Watershed
Temperature and Dissolved Oxygen
Total Maximum Daily Loads

Prepared by:
Staff of the
North Coast Regional Water Quality Control Board
May 3, 2006

The Response to Public Comments document for the Shasta River watershed TMDLs is divided into two response sections; comments categorized by general topic, where appropriate, and responses and individual comments and responses.

Section 1 – Categorized Comments and Responses

Regional Water Board staff reviewed all of the written comments submitted during the comment period and all comments presented orally at the three public workshops. These comments were then partitioned into categories based on comment topic. Comments are arranged within each category and include the commenters name or affiliation. Responses are provided for each comment; however, several comments may be addressed under one response if the comments were similar enough in scope. For oral comments presented at the workshops, the workshop name will appear and then the commenters name will be given before their comment. The categories are listed below with their page number.

Comment Categories

Section 2 – Individual Comments and Responses

Comments submitted from certain agencies or individuals were addressed separately from the categorized comments above. For these, the comments from each letter or oral presentation were extracted and given an individual response. The entire submitted text was not included. Again, there may be one response for multiple comments if staff found this to be more appropriate. The individual commenters are listed below with their page number.

Section 1 – Categorized Comments and Responses

1. Beneficial Uses

Yreka Public Workshop comment:
Jack Cowley: The only thing that concerns me is that there is minimum emphasis on agriculture and we want to make sure that is a beneficial use.

California Cattlemen's Association comment:
It is important to remember as you progress with the Shasta TMDL that Agriculture is identified as a beneficial use for the Shasta River.

Response: The Basin Plan designates "agricultural supply" as a beneficial use of waters. Agricultural supply is defined in the Basin Plan (page 2-1.00) as "Uses of water for farming, horticulture, or ranching including, but not limited to, irrigation, stock watering, or support of vegetation for range grazing". The beneficial use relates to the quality of water for use, not the quantity available for use or the presence of the agricultural activity itself.

Yreka Public Workshop comment:
John Giorgi: Why did you have some beneficial uses at the top when they are all supposed to be equal?

Response: The organization of the beneficial uses as presented at the workshop was for information purposes only. All beneficial uses are important.

John Spencer comment:
The TMDL must identify the applicable non-degradation provision of the Basin Plan and the Implementation Plan must lay out a clear path to compliance, i.e. a clear path to eliminating discharge of polluted agricultural wastewater whether or not this discharge is downstream irrigation water.

Response: The Staff Report (Chapter 11) contains an antidegradation analysis. The Action Plan, Table 4, has been revised to more clearly describe the path to bring tailwater return flows (e.g. polluted agricultural wastewater) into compliance with the Basin Plan water quality standards, the TMDL, and the Nonpoint Source (NPS) Policy.

Shasta River Coordinated Resources Management and Planning committee (CRMP) comment:
Hydropower generation is an existing use in the Shasta River, not a potential use as stated in Chapter 2, page 2.

Response: Thank you for your comment. Table 2-1 in the Basin Plan indicates that the hydropower generation is a potential beneficial use. The existing use of water for hydropower generation will be noted and forwarded to the appropriate Regional Water Board staff to be addressed as part of the Basin Plan triennial review.

Klamath River Keeper comment:
The TMDL fails to identify past beneficial uses, which must be restored in order to comply with the Porter-Cologne Act. That Act clearly calls for such consideration. In the past the Shasta River produced annual runs of up to 500,000 salmon. Furthermore, the Shasta was a stronghold of Spring Chinook salmon, which are currently on the brink of extinction in the Klamath River Basin. Porter-Cologne requires that you develop an Action Plan, which aims at restoring the historic conditions that supported those beneficial uses.

Response: The TMDL staff report identifies the Beneficial Uses of the Shasta River Basin, which include a suite of beneficial uses associated with coldwater fish, including salmonid species. Fish population information is summarized in Section 1.4.10, and includes a discussion of spring Chinook. Porter-Cologne requires the Action Plan to restore water temperature and dissolved oxygen in the Shasta River Basin to levels that are fully protective of the Beneficial Uses. The most sensitive existing Beneficial Uses in the Shasta River Basin include those associated with the support of salmonid populations and the TMDLs are established at levels to restore them.

California Cattlemen's Association comment:
CCA and local members would like to be engaged in further development of the TMDL, and subsequent policies, specifically the Wetland and Riparian Protection Policy.

Response: The Regional Water Board staff support CCA participation in this TMDL and any future Basin Plan amendments.

2. Water Temperature Objectives

EPA comment:
On page 6-17 of the Staff Report, EPA recommends that the final Shasta TMDL state explicitly that meeting the narrative objective of no alteration of natural receiving water temperature will also meet the 5˚F objective in the basin plan.

Response: The narrative temperature objective in the Basin Plan calls for natural receiving water temperatures unless it can be demonstrated to the satisfaction of the Regional Water Board that such alteration does not adversely affect beneficial uses. The water quality compliance scenario results in a temperature condition that staff believes does not adversely affect the most sensitive beneficial uses, specifically those associated with cold water fish. Since the TMDLs address all of the significant sources of temperature impairment in the Shasta River watershed, i.e., streamside shade, tailwater return flows, minor impoundments, and flows, we believe that the Shasta temperature TMDL, when achieved, will meet the 5 F objective in the Basin Plan.

State Water Resources Control Board (SWRCB) comment:
In the Basin Plan language, Page 1, Part I, first paragraph: "Water temperature conditions are regularly too high…" Because the temperature objectives in the Basin Plan are narrative and the TMDL is interpreting the narrative in order to protect beneficial uses, staff recommend you say …"because they exceed temperature protective of salmonids…" or just leave out "too high" and say, "Water temperature conditions regularly exceed temperature thresholds protective of salmonids." Would be much more clear and concise.

Response: The Action Plan language has been revised.

3. DO Objectives

EPA comment:
On page 2-3 and Chapter 7 of the Staff Report, EPA recommends that the Regional Board revise the paragraph on the dissolved oxygen 50% lower limit. Figure 2.7 implies that the 9.0 mg/l monthly mean standard is likely met given a limited review of the data in the months of September - April. Improving summer conditions by meeting the 7.0 mg/l (based on the TMDL analysis) will then more conclusively attain the 9.0 mg/l. If the Regional Board agrees, then a statement regarding how attainment of the 7.0 mg/l standard meets the 9.0 mg/l objective is needed in chapter 7. EPA recommends that the Regional Board work with EPA to assure all the basin plan standards for dissolved oxygen are addressed in the final TMDL.

Response: The text has been revised in sections 2.2.2, 2.4.2, and 7.4.1 of the Staff Report to address this comment.

4. Biostimulatory Objectives

EPA comment:
Table 2-2 identifies the biostimulatory substances narrative objective as "applicable to the TMDL." EPA recommends that the final staff report clarify what is meant by "applicable." The document should clearly explain how the TMDLs address the biostimulatory objective.

Response: Modifications have been made to Sections 2.2.2 and 7.4.1 of the Staff Report.

5. Water Temperature Modeling

Eureka Public Workshop comment:
Michael Hentz: Groundwater levels – has there been any measurements as to the height of the water table? Has it been decreasing? How does groundwater affect temperature and how has it been depleted over time?

Response: Groundwater measurements were not made as part of the TMDL analysis.

Eureka Public Workshop comment:
Felice Pace: The modeling that you presented, you only presented one set of manipulations, you could have done other things, but you had a specific suggestion. But are we talking about the different allocation to get us to compliance, and it doesn't by the way, because at the bottom, it doesn't reach compliance.

Response: The water quality model was used to evaluate the components identified in the temperature and dissolved oxygen source and linkage analysis chapters. These components were evaluated discretely in order to better understand their effects, and were then combined to form the basis for the water quality compliance scenario, as described in sections 6.2 and 7.3. The narrative temperature objective in the Basin Plan calls for natural receiving water temperatures unless it can be demonstrated to the satisfaction of the Regional Water Board that such alteration does not adversely affect beneficial uses. The water quality compliance scenario results in a temperature condition that staff believe does not adversely affect the most sensitive beneficial uses, specifically those associated with cold water fish.

Yreka Public Workshop comment:
Dave Webb: Is the model run going to become the official baseline for comparison into the future or is there another baseline?

Response: TMDLs must result in attainment of water quality standards throughout the year, including under critical conditions [40 CFR 130.7(c)]. For the Shasta River, temperature and dissolved oxygen objectives are not being met during the summer months. The temperature and dissolved oxygen load allocations were developed based on the water quality compliance scenario, which was run for the period August 29 – September 4, 2002.

Yreka Public Workshop comment:
Steve Orloff: When modeling the effect of return flow how did you estimate the volume of that return flow?

Response: Please see the responses to Dr. Daniel Drake in the Individual Comments and Responses section of this document.

Yreka Public Workshop comment:
Siskiyou County Supervisor Jim Cook: The coldwater flows that you based the models on: I want to make sure you capture the comments of Mr. Louie about the temperature. This is not anecdotal – there is actual data. I'm sure he will get the data for us – and there is data there. I'd like that to be capture on your board.

Response: We look forward to receiving the data from Mr. Louie. See also responses to Dr. Drake and to responses to Comment Category 7 – Water Temperature, Flow and Allocations.

Yreka Public Workshop comment:
Jim De Pree: It's still unclear to me that in the technical TMDL that you may have done other modeling scenarios. How many of those other scenarios were looked at. I feel like the 50% increase is the only way to achieve the targets. How did that increased flow move down the system?

Response: Various water quality modeling scenarios were applied in evaluating the components identified in the temperature and dissolved oxygen source and linkage analysis chapters. The water quality compliance scenario represent the synthesis of these discrete model scenario applications. In regards to the 50% flow increase, please see response to Comment Category 7 – Water Temperature, Flow and Allocations.

Yreka Public Workshop comment:
Jim De Pree: You have a lot of documentation on the models but it's not in plain language. If we're going to look at different ways to meet those objectives, we don't want to get boxed into the idea that flow is the only way to meet those objectives. If you're allowing for diversion below Big Springs Creek for ag purposes but not out of the Big Springs complex – how does that mesh with the priority of water rights? You have an inequitable situation there.

Response: We agree that the modeling analysis is complex and highly technical. Please see the response to Comment Category 7 – Water Temperature, Flow and Allocations. We recognize that the issue of flow increases is complex with respect to water rights. Regional Water Board staff are engaging State Water Resources Control Board Division of Water Rights staff and attorneys in order to better understand the constraints and opportunities that our TMDL analysis has identified.

Yreka Public Workshop comment:
Jim De Pree: Some people may have been diverting and some might not be diverting. So using a model run on these particular conditions when there is associated error, should they even be used in the TMDL for devising implementation? Shouldn't those more be hypotheses to be tested as the TMDL in implemented?

Response: Please see the response to Comment Category 7 – Water Temperature, Flow and Allocations. In addition, the TMDL identifies the need for more monitoring of system hydrodynamics, and this information will be used in assessing the adequacy of the TMDL.

Yreka Public Workshop comment:
Jim De Pree: You need to make that more clear in the Action Plan. I don't understand potential shade. Is that required amount at every point? Is there an allowance for windstorms etc.?

Response: Please see section 6.5.2.1. The potential solar radiation transmittance values for the Shasta River were estimated by staff, and do account for natural disturbance. Adjusted potential effective riparian shade equal to 90% of site potential shade is applied to Shasta River tributaries, and accounts for natural riparian disturbance.

Yreka Public Workshop comment:
Jim De Pree: In the mainstem – are you going to require the potential in the tributaries and the mainstem?

Response: Yes; see previous response.

Yreka Public Workshop comment:
Jim De Pree: But in a reach you have several different property owners and who has to be below – how is it divided? I assume that the temperatures at the river miles is what you are ultimately trying to reach. In the model – when you use the accretions, you look at subsurface flow or groundwater or tailwater. Do you have to allocate what you think might be the percentage from each of those sources to account for any increase in flow from those sources. And if you found that 90% of that water that you're gaining is from subsurface flow, would that make a difference in model results?

Response: Please see responses to Dr. Drake's letter as well as response to Comment Category 7 – Water Temperature, Flow and Allocations.

Siskiyou County Supervisor Marcia Armstrong comment:
The Temperature TMDL says that the 50.0% flow increases from the Big Springs Complex is "achievable" (Chapter 6, pp. 17). We are somewhat unclear as to how such increases will be achieved, how the modeling was done to accomplish these particular numbers, and what underlying assumptions were made in calibrating the model.

Response: Please see response to Comment Category 7 – Water Temperature, Flow and Allocations.

Siskiyou County Supervisor Marcia Armstrong comment:
Volcanic activity appears to be a reason behind the constant year-round temperature in the Big Springs area, 58 degrees in Big Springs and 56 degrees in Little Springs. These temperatures are higher than what should be expected from the melt of snowpack on Mount Shasta and likely reflect a geothermal heating of these spring waters, which would be part of the natural conditions of Shasta Valley. It would seem that the Shasta River would naturally have temperatures above 18 degree Celsius, or 64.4 degrees Fahrenheit, the rearing threshold for Salmonids, for water traveling approximately 18 miles or more down stream during the summer period.

Response: Regional Water Board Staff have found no evidence that volcanic activity influences the temperatures of Big Springs. Our own temperature measurements of Big Springs show the groundwater emerging at a temperature of 11.3 deg C (52.3 deg C) . This temperature is in fact lower than ground water temperatures measured at other locations throughout the north coast. For instance, Regional Water Board staff measured Scott Valley groundwater temperatures of 13-14 deg C (56-58 deg F). These temperatures reflect the temperature of the earth that the groundwater passes through. The only thing thermally unique about the Shasta River is the large volume of cold water sources. Please also see response to Dr. Daniel Drake, comment 27 in the Individual Comments and Responses section of this document.

Siskiyou County Supervisor Marcia Armstrong comment:
The modeling approach that was utilized only takes in consideration one climatic year, and that seems like a risky proposition when this single sampling period becomes the baseline for the Action Plan/Basin Plan.

Response: TMDLs must result in attainment of water quality standards throughout the year, including under critical conditions [40 CFR 130.7(c)]. For the Shasta River, temperature and dissolved oxygen objectives are not being met during the summer months. The temperature and dissolved oxygen load allocations were developed based on the water quality compliance scenario, which was run for the period August 29 – September 4, 2002. As detailed in section 6.3 of the Staff Report, both air temperature and flow conditions represented critical conditions during this time period. Results of the water quality compliance scenario demonstrate that when the TMDL is fully implemented, water quality standards can be achieved under critical conditions.

Siskiyou County Supervisor Marcia Armstrong comment:
Unfortunately the information and data are presented in a highly technical methodology. If we do not understand the data, then it becomes likely that we have the potential to end up in a “box canyon” with the North Coast Regional Water Quality Board (NCRWQCB) taking actions that we have no chance to prevent. We need to be able to run additional scenario modeling, using the particular model that was configured for the Shasta Valley TMDL. We feel it is appropriate to have the NCRWQCB empower the Shasta Valley Resource Conservation District (RCD)/CRMP to be able to undertake this task.

Response: We agree that the information and analysis is complex and highly technical. The Regional Water Board will make the Shasta River water quality model available to the Shasta Valley RCD/CRMP. A training will be provided by Dr. Deas of Watercourse Engineering for Shasta Valley RCD/CRMP staff on use of the Shasta River water quality model, paid for by Regional Water Board TMDL funds. Regional Water Board staff are in the process of detailing the specifics of this training with Dr. Deas.

Santa Rosa Public Workshop comment:
Siskiyou County Supervisor Jim Cook: Setting hard and fast requirements using modeling approach with limited data and only one climactic year seems to us to be a little bit too risky. We wonder why an adaptive approach is not a better way to firm up the basis for those requirements.

Response: See response to similar comment by Supervisor Armstrong above. See also response to the California Cattlemen's Association comment in Comment Category 7 – Scientific Support.

Shasta CRMP comment:
The Environmental Analysis states that "the public will have time to come up with alternatives". Devising and assessing alternatives will require functional access to the temperature and dissolved oxygen model as modified by RWQCB. The Shasta Valley RCD invested over $300,000 in the development of components of that model, and feels it is appropriate for RWQ to provide training to the RCD on the model in its current form so that we can do at least limited modeling of alternatives on our own.

Response: See response to similar comment by Supervisor Armstrong above.

Shasta CRMP comment:
We are not sure the temperature model outputs are as yet wholly reliable as it is being used by RWQ. Data from June, 1998, when Dwinnell Reservoir was releasing 400 cfs (MWCD estimate) of cold water from the bottom of the reservoir from June 1-14 with corresponding maximum water temperatures of 68-72 F at R.M. 15.4 suggests that additional examination of model assumptions is in order. Runoff in 2006 appears likely to provide similar opportunities for field observations of the river with supplemented by Dwinnell flows into the late spring when air temperatures have the potential to affect water temperatures significantly. Perhaps RWQ should take advantage of that opportunity to further test model outputs.

Response: Regional Water Board staff agree that additional water quality modeling could be completed to gain additional insights into the temperature dynamics of the Shasta River. We look forward to working closely with Shasta Valley RCD/CRMP staff in additional modeling efforts.

Shasta CRMP comment:
There was no assessment of the impacts of the loss of aquatic plants on other aquatic organisms which form the food base for the cold water fish being targeted, nor were possible loss of habitat issues, since in many areas rooted aquatic plants seem to be providing the only cover for the fish present. This may be of greatest concern upstream of RM 24 where the highest reductions in aquatic plants per mile are targeted, yet this is where human impacts should be lowest due to limited tailwater return and greatest amounts of springwater inflows. These factors suggest that additional considerations should be given to this before it is proposed as a blanket implementation method.

Response: The Shasta River is highly productive. Regional Water Board staff, including fishery biologists, believe that there would be ample food and cover to fully support the cold freshwater habitat beneficial use under TMDL compliant conditions. The total oxygen demand reductions for the reach upstream of Highway A-12 (River Mile 24.1) to Big Springs Creek is among the highest for the designated river reaches, as summarized in Table 7.9. As the commenter notes, this reduction is largely due to reduced respiration associated with reduced aquatic plant growth under water quality compliant conditions. Photosynthesis and respiration rates of aquatic plants for the water quality model were developed based on the July/August 2004 aquatic vegetation survey results (see Appendix A of Staff Report), as outlined in section 5.3.3 of Appendix D in the Staff Report). The amount of aquatic plant cover was comparatively high within this reach. Also, the channel width tends to be wider in this reach, compared to other reaches. The resulting reduction in total oxygen demand is based largely on these two factors. Regional Water Board staff believe that the reductions attributed to the Big Springs Creek to Highway A-12 reach can be met given implementation of the Action Plan, and point out that actions taken in upstream reaches will benefit downstream reaches.

6. Scientific Support

Rancho Hills Community Association comment:
From the information provided, it seems the recommendations lack the supporting science or quantity of data, therefore, the results are questionable and require further investigation. The state-hired consultant even suggests that more data is needed and we believe this recommendation should be given full consideration by your board before any action plan is approved.

Dan Drake comment:
It seems absolutely imperative that before this draft can be accepted, an evaluation of these interrelated factors on the functioning of the coldwater fisheries is necessary, not just a mechanistic or modeled response for temperature or oxygen levels. Much real world data and historical as well as local knowledge has not been included in this draft. The risk of not making an integrated evaluation is the risk of the fishery itself. Why isn’t a more integrated and thorough evaluation conducted on the functioning of the coldwater fisheries?

Tom Wetter comment:
I appreciate that the NCRWQB has a difficult and necessary job to do. But, in considering solutions and sources of funding, I ask the NCRWQB staff and directors to take a step back and clearly identify the core issues and problems and do the work called for by your consultants. By default, the residents of Siskiyou County will be the implementers of the solution. Please make certain we're working on the right problem with the right solution before you issue a call to action.

Montague Water Conservation District comment:
The District has concerns and questions in regards to the data collected for the development of the TMDL. The District feels this is a weak foundation to build an action plan on.

California Cattlemen's Association comment:
It is recommended that further research be conducted to support the outlined activities, and any regulatory actions be based upon sound reliable data.

Response: Regional Water Board staff has completed a thorough technical analysis and is confident that their conclusions are scientifically supported. Staff collected quality data for the TMDLs for over 2 years before developing the technical analysis. The staff used appropriate models to develop the load allocations and the technical work was peer review by Dr. Charles Coutant, an aquatic ecologist. He writes in his technical review, "In summary, I found the analytical approach sound and quite thorough, and the analyses to be of generally high quality." Therefore, staff believe the TMDLs are based on sound science. Further, other agencies such as the California Department of Fish and Game (DFG or CDFG) and NOAA Fisheries support the findings of the TMDLs. They have identified the same impairments and have established the same linkage to sources of pollution in the Shasta River watershed. Additionally, the EPA, in their comment letter, supported the level of science that serves as the basis for the Action Plan.

However, the Regional Water Board is continually in the process of updating the technical analysis whenever new information is discovered. The TMDL process allows for adaptive management as described in a report to Congress by the National Academy of Sciences entitled "Assessing the TMDL Approach to Water Quality Management (2001)". TMDLs do not have to be based on 'complete science' before implementing actions. The authors of the report recommend an approach called 'adaptive implementation' and describe it as "a process of taking actions of limited scope commensurate with available data and information to continuously improve our understanding of a problem and its solutions, while at the same time making progress toward attaining a water quality standard."

The report further explains:

> By definition, science is this process of continuing inquiry. Thus, calls to make policy decisions based on 'the science,' or calls to wait until 'the science is complete,' reflect a misunderstanding of science. Decisions to pursue some

> actions must be made, based on a preponderance of the evidence, but there may be a need to continue to apply science as a process (data collection and tools of analysis) in order to minimize the likelihood of future errors. The immediate actions alone should not be expected to completely eliminate the impairment.

USEPA's Region 9 *Guidance for Developing TMDLs in California* also allows for a 'phased approach' to the TMDL technical analysis. "This 'phased approach' to TMDLs enables States to adopt TMDLs and begin implementation while collecting additional information needed to review and, if necessary, revise TMDL elements based on new information"(EPA, 2000).

The RWB will work with the stakeholders to apply 'adaptive implementation' or a 'phased approach' and refine the analysis as more data becomes available. Adaptive management is needed to ensure that the TMDL program is not halted because of a lack of data and information, but rather progresses while better data are collected and analyzed with the intent of improving upon initial TMDL plans.

7. Water Temperature, Flow and Allocations

General Comment Regarding Analysis of Flow and Water Temperature:
A number of commenters (Siskiyou Supervisor Marcia Armstrong, Dave Webb, and Tim Louie) raised questions about how the flow increase component of the water quality compliance scenario was represented in the model, and how these model results were incorporated into the temperature allocations for the temperature TMDL.

Response: The Tennessee Valley Authority's River Modeling System model (RMS) was applied for the Shasta River in developing the temperature and dissolved oxygen TMDLs. For TMDL development the Shasta River RMS model was calibrated for the period from 9/17/2002 to 9/23/2002 and validated for the periods from 7/02/2002 to 7/08/2002 and from 8/29/2002 to 9/04/2002 (see calibration and validation results in section 5.5 of Appendix D of the Staff Report). Calibration procedures are detailed in section 6.0 of Appendix D of the Staff Report. The water quality compliance scenario was run for the period from 8/29/2002 to 9/04/2002.

Flow input locations and types for the Shasta RMS model are identified in Table 6 of Appendix D of the Staff Report. The Shasta River has many ungaged diversions, spring flows, irrigation return flows, and tributaries. In the absence of gaged flow records for all flows, some flow inputs (spring flows, irrigation return flows, and tributaries) and outputs (diversions) were accounted for together as accretions and depletions in the Shasta RMS model. Due to access limitations, flow measurements of Big Springs Creek and the Shasta River within the vicinity of the creek were unavailable for application in the current (for TMDL development) and previous (for Shasta River RCD) model efforts. However, accretion flows in the Shasta River reach from downstream of Parks Creek to the Grenada Irrigation District pumps (GID) were determined based on a water balance, including measured flows at Shasta River above Parks Creek, Parks Creek inflow, and

Shasta River at GID, taking into account the GID diversion (see section 4.1.3 of Appendix E of the Staff Report). All of the accretion flow within this reach was assigned as an input from Big Springs Creek (as described in section 5.1 of Appendix D in the Staff Report). The accretion flow in this reach is referred to as the Big Springs Creek "complex" in the Staff Report, and this "complex" includes Big Springs proper (assumed to originate at the eastern end of Big Springs Lake), Big Springs Lake, Big Springs Creek, Little Springs and the channel between Little Springs and Big Springs Creek. Further, based on examination of historic Shasta River flow and temperature data from locations downstream and upstream of the Big Springs Creek confluence, it is postulated that the "complex" may also extend into the Shasta River proper (Appendix G of Staff Report).

The water quality compliance scenario included a 50% increase in flow in the Shasta River at the location just downstream of Big Springs Creek. The average flow at this location under the baseline and water quality compliance scenario conditions was 93 and 138 cubic feet per second (cfs), respectively. This increase was due to an increased Big Springs Creek complex flow input of 45 cfs, from 74 cfs to 119 cfs. For the water quality compliance model scenario this increased flow of 45 cfs served as "dedicated" instream flow, moving all of the way down the river to the mouth.

Shasta River flow measurements made during the late spring through summer period in 2002 at Louie Road (above Big Springs Creek) and at the Grenada Irrigation District (GID) diversion dam (below Big Springs Creek) indicated that the net accretion between these two locations ranged from approximately 55 cfs to over 80 cfs (Watercourse, 2004a, 2004b as reported in Appendix G of Staff Report). These flows are within the range of flows of Big Springs Creek (52 and 70 cfs) described by one commenter. As reported in Appendix G of the Staff Report, the California Department of Public Works measured flows within the Big Springs Creek complex in 1922 and 1923 during the Shasta River adjudication proceedings. Measured flows at the mouth of Big Springs Creek ranged from 35 to 118 cfs, with mean flows of 63 and 58 cfs in the 1922 and 1923 irrigation seasons, respectively. Based on measured flows in Big Springs Creek (Gage #21 located below the confluence of Little Spring Creek and below all diversion points in 1922-1923) and gaged diversion flows, the average total flow from Big Springs Creek including Little Springs Creek was reported to be 114.3 cfs during the 1922 and 1923 irrigation seasons (California (1925), as reported in Appendix G of Staff Report). Documented water rights to Big Springs Lake total approximately 47.5 cfs and rights to Little Springs total approximately 7.6 cfs (for additional details see Appendix G of Staff Report).

Based on the information outlined above, Regional Water Board staff estimate that pre-diversion flows from the Big Springs Creek complex were on the order of 100 to 125 cfs. In section 6.4.1.2 of the Public Review Draft Staff Report it was stated that the "50% flow increase from Big Springs Creek is achievable". The intended meaning of this statement is that Regional Water Board staff estimate that the flows represented in the water quality compliance scenario are within the historic (pre-diversion) flow range.

Big Springs Creek complex was selected for the 50% flow increase component of the water quality compliance scenario because it is a unique source of cold water. As discussed in the revised text in section 6.2.3.1, the temperature of Big Springs proper is quite constant at approximately 11.3°C (52.3°F); this is cold water.

The results of the water quality compliance scenario are presented in Figure 6.3 of the Staff Report, along with results of the Master 1 and Big Springs Q150% scenarios. The conditions of these scenarios are detailed in section 6.4.2 of the Staff Report. The effect of the flow increase component of the water quality compliance scenario can be determined by comparing the water quality compliance scenario results to those of the Master 1 scenario; the additional reduction in maximum stream temperature achieved in the water quality compliance scenario compared with the Master 1 scenario is attributed to the average increased flow of 45 cfs from the Big Springs Creek complex. As shown in Figure 1 below, the flow increase component of the water quality compliance scenario accounts for approximately 1.5°C, 1.2°C, and 2.1°C decrease in maximum stream temperatures at river miles (RM) 24.1, 15.5, and 5.6. These river miles are temperature compliance points, and are important locations for summer rearing of juvenile salmonids, as discussion in section 6.3 of the Staff Report.

US EPA regulations require that all sources or factors affecting a water quality impairment are allocated the appropriate responsibility for improving water quality conditions. In this case, our analysis demonstrates that flow alteration affects natural receiving water temperatures. Therefore, the Shasta River temperature TMDL includes a load allocation for flow: reduction in the maximum daily stream temperatures of 1.5°C, 1.2°C, and 2.1°C from baseline at RM 24.1, 15.5, and 5.6. The following is cited from US EPA's comment letter regarding the Public Review Draft Staff Report and Basin Plan Language:

> "EPA also supports the Regional Board's determination that the narrative temperature objective necessitates the consideration of all factors that influence natural stream temperature - including flow alterations. The TMDL appropriately included an analysis of the relationship of flow alterations in determining natural stream temperatures. TMDL submittals must demonstrate that all significant sources be considered in order to be approvable by EPA. The inclusion of the influence of flow on temperature is consistent with previous EPA temperature TMDLs in the North Coast."

We interpret the term 'sources' to refer to source categories or classes of sources.
The temperature load allocation for flow does not specify a flow regime necessary to achieve the stream temperature reductions. While the water quality compliance scenario was based on a 50% flow increase in the Shasta River due to an average flow increase of 45 cfs from the Big Springs Creek complex, Regional Water Board staff recognize (and acknowledge in section 6.5.1.3 of the Staff Report) that there are other opportunities to increase flows that may achieve the same temperature improvements. Several commenters indicated, and we agree, that Parks Creek has significant cold spring water inflows, and could provide temperature benefits to the Shasta River. There are other

sources of cold water, and the Action Plan includes a goal of increasing the dedicated cold water instream flow in the Shasta River by 45 cfs. Dedicated cold water instream flow is defined in the glossary as "water remaining in the stream in a manner that that the diverter, either individually or as a group, can ensure will result in water quality benefits. Temperature, length and timing are factors to consider when determining the water quality benefits of an instream flow."

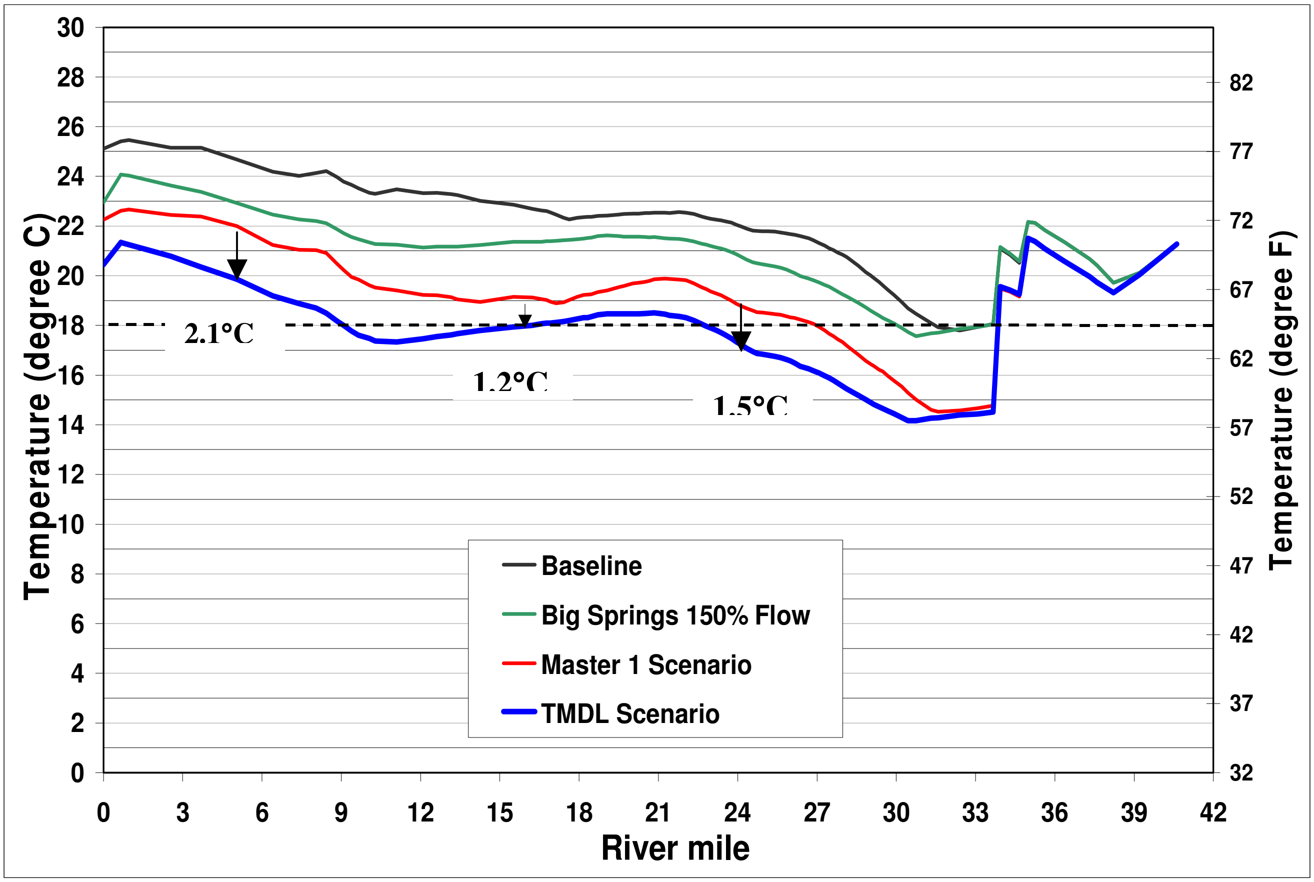

Figure 1. Temperature load allocations for flow.

8. Dissolved Oxygen Allocations

Siskiyou County Supervisor Marcia Armstrong comment:
It is not clear whether the 50.0% reduction in respiration rates as assigned to the Shasta River reaches in Table 3 (BPL, pp. 7) is achievable.

Response: Based on our best professional judgment, Regional Water Board staff believe 50% reduction in respiration rates is achievable given full implementation of the Action Plan. The factors staff believe will contribute to 50% reduction in respiration rates are outlined in section 7.3.2. We acknowledge uncertainty in quantifying the contribution of the various factors in achieving this reduction.

9. Volunteerism and Timelines

Eureka Public Workshop comments:
Felice Pace: we've had plenty of experience to evaluate volunteerism and we need to rethink timelines for evaluation in the TMDL.

Michelle Marta: your data describes a crisis and I'm alarmed at the amount of time allocated for implementation and returning with studies and I urge you to accelerate your evaluations and implementations so that we can get this river out of crisis.

Pacific Coast Federation of Fishermen's Associations comments:
Include numeric goals and fish-friendly timelines for achieving water quality standards.

Voluntary actions over the past 30 years have not alleviated the current degraded water quality conditions of the Shasta River. "Tier 2" "regulatory-based encouragement" should be followed by "Tier 3" "effluent limitations" in a reasonable time for fish to respond, as well as for people to respond to the requirements—say five years. Please outline steps and requirements that will meet water quality objectives in a timely manner.

Tim McKay comment:
I believe the NCRWQCB needs to work on more action in its Action Plan for implementing the clean-up provisions of the TMDL. The causes of impairment in the Shasta, Scott and other tributaries are well documented, and were well documented decades ago. Why is it that a small minority of people in the Klamath~Trinity region can be allowed to take actions that can have such a large impact on so many other people?

Santa Rosa Public Workshop comment:
Daniel Myers: In other words, what we mostly have heard about (in the Action Plan) are things that are not specific that are not discernable, they rely up on a 2 year period, a 5 year period, a 40 year period, and reexamination. I don't think that's what TMDL action plans are supposed to be like.

Sandy Bar Nursery and Ranch comment:
Thirty years of voluntary pollution clean-up has failed; it is time for real regulation.

John Spencer comment:
The TMDL Action Plan should review the 30-year history of the "voluntary" approach to meeting water quality standards in the Shasta River Basin including past 319 and restoration grants, successes and failures. Based on this analysis the Action Plan should stress "regulatory-based encouragement" for a maximum of 5 years followed by "effluent limitations" if the "encouragement" is not effective in meeting applicable standards.

State Water Resources Control Board comment:
In the BP language, Part V. Implementation is lacking a specific time frame for certain events, i.e. page 8 last paragraph. How long is the time period for notice of failure of voluntary actions if that scenario does happen? It's not clear when the various

implementation actions are to take place, or when they are to be initiated. Some sort of timeline is needed so the regulated community can know what is expected.

In the BP language, Page 14, Part VIII, the first sentence is unclear. "The Regional Water Board shall take enforcement actions for violations of the Shasta River TMDL Action Plan where elements of the TMDL Action Plan are made enforceable restrictions in a specific permit or order, as appropriate." Should be more specific on how items in the implementation plan will be made enforceable per the Policy for Implementation and Enforcement of the Nonpoint Source Pollution Control Program which emphasizes that any discharge must be regulated using waste discharge requirements, waivers, or prohibitions as appropriate. Staff recommends adding language to be clear that discharges will be regulated.

Klamath RiverKeeper comment:
The Draft TMDL relies heavily on voluntary action by landowners in order to address pollution impairments. Klamath RiverKeeper supports voluntary restoration. However, the NCWQCB is a regulatory agency. The Board should not and cannot legally avoid its obligation to fulfill its regulatory mandate. Therefore, voluntary approaches should be kept in perspective and utilized properly.

Jane Turnbull comment:
Fifty years of damaging activities will take some major changes in patterns of use, if the river is to be returned to health. Reparation cannot be accomplished by means of incremental changes. I hope that you and your board members will make the tough decisions that will be needed to remedy this vital waterway.

Response: Many commenters raised objections to the voluntary nature of the actions identified in the Action Plan and recommended that the Regional Water Board include more specificity in its timeline for when discharges will be regulated. The *Policy for the Implementation and Enforcement of the Nonpoint Source Pollution Control Program* requires all current and proposed nonpoint source discharges to be regulated under waste discharge requirements (WDRs), waivers of WDRs, a basin plan prohibition, or some combination of these administrative tools. All nonpoint source pollution control programs must contain the five key elements listed in the California Code of Regulations, title 23, section 2915. These include (1) the clear purpose to achieve and maintain water quality, (2) a description of the management practices to be implemented and a way to determine progress, (3) a time schedule with quantifiable milestones, (4) feedback mechanisms to determine whether the program is meeting its stated purpose, and (5) a clear consequence for failure to achieve the stated purpose. As detailed below, the Action Plan contains discrete time limits at which point the Regional Water Board will review the implementation and effectiveness of the recommended actions. If a solution to impairment is being implemented by another regulatory entity or a non-regulatory action of another entity, the Regional Water Board may certify that such action will correct the impairment, in lieu of adopting a redundant program. The Regional Water Board cannot rely on such programs until it makes certain findings supported by substantial evidence, including that the program will be adequate to correct the impairment. The Regional Water Board must allow sometime in order to make this determination. If the information shows that parties are not implementing measures to improve water quality in all source categories listed in Table 4 of the Action, or if parties are not providing information to determine whether measures are being implemented, the Regional Water Board will adopt a different approach.

Each source category includes a time schedule that contains a deadline at which point the Regional Water Board will review the success of the measures. For example, for tailwater discharges, Regional Water Board staff will review the adequacy of voluntary actions within one year from EPA adoption and within five years, adopt a WDR, waiver, prohibition, or combination thereof that may be based on a third-party program or not. For range and riparian activities, the Action Plan allows two years to monitor implementation and effectiveness of recommended actions, and specifies that the Regional Water Board will adopt a WDR, waiver or prohibition either regionwide or by watershed within ten years. It is not appropriate to set a closer date for Regional Water Board adoption of a WDR, waiver or prohibition in this source category because the regulation may be adopted on a state or regional level in a broader policy. Low flows are not discharges subject to Regional Water Board permitting authority; however, the Regional Water Board will monitor the effectiveness of various actions to dedicate cold instream flows to the Shasta River and its tributaries and may make recommendations to the State Water Board based on the success of these programs. It is appropriate to rely on third-party and other regulatory programs in this source category given that the Regional Water Board authority is limited. In the interim, a conditional waiver has been added to the Action Plan that waives the requirement for dischargers to file a Report of Waste Discharge (RWD) so long as they are participating in the recommended actions and programs. This provides an incentive to implement voluntary action. Those not participating must file a RWD immediately.

10. Ranch and Riparian Implementation

Edward Jones comment:
You say that it is harmful to fish to have livestock in or near the water. This is also untrue. I have seen cows, horses, and deer in the water and steelhead and salmon would be swimming around and between their legs.

Response: Adverse impacts to fish from livestock has been well documented in the Shasta Watershed Restoration Plan, the California Department of Fish and Game Coho Recovery Strategy, and the draft Shasta Valley Resource Conservation District master incidental take permit application for Coho Salmon cited in the Staff Report. Impacts include direct damage to redds from livestock hoofs, to increases in nutrient concentrations from livestock waste.

Eureka Public Workshop comments:
Unidentified: How will you reduce aquatic plants?

Debbie Duckworth: Will the reduction in plants in channel leave open the door for an invasive plant to become established?

Response: See response to Yreka Public Workshop comment below.

Yreka Public Workshop comment:
Don Meamber: Grazing the riparian corridors could control the invasive weeds such as in the horrible photo you showed at the public meeting of the "white top."

Response: Reduction in aquatic vegetation will be achieved by limiting light availability through increased riparian shade, decreasing nutrient concentrations from tailwater return flow restrictions, and by decreasing water temperatures through a combination of measures. See Section 4.3.3.2 (Factors Affecting Aquatic Vegetation Productivity in the Shasta River) in the Staff Report for a more complete discussion.

The TMDL does not require the elimination of aquatic vegetation. Total elimination would likely result in the creation of a situation that would be conducive for invasive plant introduction and establishment. Rather, the TMDL requires a reduction in aquatic vegetation to a more "natural" condition by such measures as described above.

Regional Water Board staff concurs that well planned and timed grazing activities in riparian areas can be a viable measure to control invasive species.

Yreka Public Workshop comment:
Tim Louie: The problem when you fence the cattle out is that the weeds are going to start to grow. You need to make a study on that.

Response: The existing Shasta Watershed Restoration Plan, the California Department of Fish and Game Coho Recovery Strategy, and the draft Shasta Valley Resource Conservation District Master Incidental Take Permit Application for Coho Salmon all recommend exclusion of cattle from riparian areas. Regional Water Board staff is not recommending total exclusion of grazing from these areas, but rather implementing practices that will allow riparian shade producing vegetation to get established and grow to natural site potential.

Pacific Coast Federation of Fishermen's Associations comment:
Shade is not an adequate treatment to reduce water temperatures—it may help, but only in the very long term. The fish cannot survive long enough to realize the benefits of shade.

Response: Regional Water Board staff recognize that the development of adequate riparian shade is a long term (+40 year) action. As such the Action Plan was crafted to require a multi-faceted approach. Shade is only one component of the required implementation actions; increase in stream flow and reduction in oxygen demand are also crucial parts of the recovery strategy.

Santa Rosa Public Workshop comment:
Siskiyou County Supervisor Jim Cook: Because of the long lag time for shade to affect temperature it might be helpful to investigate gravel supplementation as a way to encourage lower temperatures, which that does happen, and improve spawning conditions.

Response: Regional Water Board staff is unaware of any water temperature reduction strategy in use in California that uses gravel supplementation to lower water temperature. Staff would be interested in reviewing information germane to this issue. The Action Plan does not prevent the implementation of additional measures designed to protect beneficial uses.

Santa Rosa Public Workshop comment:
Siskiyou County Supervisor Jim Cook: And while shading is important, an important component to the stream temperature, which we found out using Dr. Deas' models, assigning a blanket value of 90% to the site seems to be not particularly helpful.

Response: A blanket value of 90% shade is not the load allocation for shade. The temperature TMDL riparian shade allocation for the Shasta River is reach average potential solar radiation transmittance; the temperature TMDL riparian shade allocation for Class I and II tributaries is equal to 90% of the site potential solar radiation riparian shade, which allows for natural disturbance to the riparian vegetation from such events as windthrow, flooding, bank erosion, fire, and disease.

Santa Rosa Public Workshop comment:
Siskiyou County Supervisor Jim Cook: Regarding the wetland and riparian protection policy that is mentioned in the implementation plan but has not been developed yet. You're going to approve this, we're going to say, by golly we're going to do all these things, and in a year or two we're going to find out what (the riparian protection policy) actually meant, and we're very concerned about that.

Response: The wetland and riparian protection policy will go through a full California Environmental Quality Act (CEQA) review process, including scoping meetings, public workshops and board hearing(s). The interested public will be kept fully informed and Regional Water Board staff will actively solicit public comments throughout the entire process.

Yreka Public Workshop comment:
Tim Louie: The riparian vegetation along Big Springs Creek has remained the same for many years. Altering the riparian zone of the creek will be difficult and unpractical. The stream is wide and there is little fall over the approximate 3-mile course to the Shasta River.

Response: Comment noted**.** Increasing riparian vegetation along Shasta River tributaries, including along Big Springs, is an important component of the temperature TMDL. As such, staff would be interested to know what riparian enhancement practices had been applied to the riparian zone along Big Springs Creek in the past that lead to this "static" condition. This kind of information will be useful in developing a fuller understanding of the site specific conditions along the riparian zones in the Shasta River. The Action Plan incorporates adaptive management principles to allow for implementation of additional measures and alternative approaches if the current proposal proves ineffective.

Yreka Public Workshop comment:
Don Meamber: Grazing the riparian areas will probably help remove the nutrients as long as the livestock don't do more damage. I've always felt a single wire temporary electric fence at the bank edge would eliminate the damage if the livestock are there for a short period, with a more permanent fence further back, like I have, to keep them out the remainder of the time. Most ranchers probably wouldn't feel they have the time to be bothered stringing an electric fence each season like this.

Response: Comment noted.

11. Tailwater Implementation

Yreka Public Workshop comment:
John Giorgi: I'm concerned about tailwater recovery when it goes back into the streams. If you are required to treat this water that's a heavy burden when the water may have come 10-15 miles back up the road, and all you're using is tailwater from your neighbors place because you don't have a water right, and you're next to the river. Therefore you're responsible for cooling the water that you didn't take out. And my understanding is to return water at the same quality it came out and again your nitrates and DO is going to change. So I hope you consider this. The other thing is incidental take. We have streams in the Shasta Valley that don't have record of fish going up them and will these streams have the same regulation because they are a tributary to the Shasta? I'm referring to fencing and creating a terrible weed base. I'm talking about water hemlock, which is poisonous to livestock. Who will determine the price if we have an incidental take on fish?

Response: The Action Plan outlines several measures for consideration applicable to tailwater management, including recycling and reuse where possible. The Action Plan,

Table 4, describes the path to bring tailwater return flows into compliance with the Basin Plan water quality standards, the TMDL, and the NPS Policy.

The TMDL Action Plan, Table 4, describes steps that may be necessary in working with the Shasta RCD's Coho Incidental Take Permit and CDFG's Coho Recovery Strategy regarding the restoration potential of various watercourses in the Shasta Valley, including the potential for the incidental take of salmonids. The CDF&G has the expertise to determine watercourses that do, or have the potential to provide fish habitat. When the habitat and restoration potential, based on site conditions, of a watercourse is ascertained, actions necessary to comply with the TMDL and Basin Plan will take into consideration economic impacts to landowners, and the management measures necessary to control minimize adverse environmental affects from the unwanted proliferation of weedy plants.

Yreka Public Workshop comment:
Siskiyou County Supervisor Jim Cook: In two years you're going to give a report on tailwater. The CRMP has been working on tailwater projects for a number of years, the easy ones are done, the more difficult ones haven't been done mostly because of the cost but also the engineering. You're basically creating a dam to create a lake to pump water back into the system. So I'm concerned that in two years, you can stand there and say well, I think they might be doing an engineering study, we're being set up for disaster. I think it needs to be extended to five years. In five years, we might get the engineering done. It's a function of money. Two years is not enough. The riparian protection policy and three tiered irrigation policy have not been done yet they are included in this Implementation Plan. You should make the statement that "other policies may be applied on top of this" instead of these policies will be applied, so you are not committing us to a policy before we know what it is.

Response: The TMDL Action Plan for irrigation water management does not specify a three tiered management approach. However, tailwater management does call for a "tiered approach" if prohibitions, WDRs, Waivers of WDRs, or any combination of the latter are selected for tailwater management. The Action Plan requires the Regional Water Board's Executive Officer to report to the Regional Water Board one year after EPA approval of the TMDL on the status of an evaluation plan for tailwater management. After the evaluation phase, the Action Plan, Table 4, provides for an adaptive approach that relies on cooperation between irrigators, the Shasta RCD and Shasta Valley CRMP, CDFG, and the Regional Water Board to implement management measures that best comply with the TMDL, the Basin Plan water quality standards, and the State's NPS policy (SWRCB 2004). When the latter is completed then the determination is made to either issue WDRs, Waivers of WDRs, prohibitions, or any combination of the latter.

Pacific Coast Federation of Fishermen's Associations comment:
Agricultural return flows need to be treated before being returned to the river for downstream use. Technology is available to do this with vegetative filters and settling or wetlands ponds.

Response: The TMDL Action Plan expressly encourages the use of appropriate technology for tailwater management, including vegetation filtrations strips, wetland "polishing"ponds, and upslope settling basins.

EPA comment:
EPA recommends that the allocations by river reach be supplemented by additional water quality allocations for tailwater return flows. EPA's review of the Shasta TMDL indicates that a more explicit statement of what modeled inputs of agricultural return flows is possible, albeit with qualifications. The analysis indicates to EPA that NBOD reductions from agricultural sources are likely needed in order to attain the dissolved oxygen standard.

Response: NBOD reductions from tailwater return flows are included in the water quality compliance scenario. The text of section 7.5.2 of the Staff Report and the Action Plan has been modified to add a specific NBOD concentration-based allocation for tailwater return flows.

EPA comment:
EPA also suggests that the implementation plan would be strengthened by adding a reasonable level of monitoring and reporting on tailwater return flows. The TMDL should clearly indicate how tailwater-related nutrient load will be monitored and assessed in the future.

Response: The Implementation Plan, Chapter 8, and Action Plan, Table 4, will require a comprehensive monitoring and reporting program after tailwater sources, usage, and discharges are evaluated and a management plan is formulated. Chapter 9, Monitoring of the Staff Report, and Chapter 10, Reassessment, tasks the Regional Water Board to develop a compliance and trend monitoring plan within one year, and reassessment occur with five years, respectively, of the date of EPA approval. The EPA will have the opportunity to fully review proposals for monitoring and reassessment planning before they are enacted in the watershed.

Marcia Armstrong comments:
The current action plan notes that projects referencing tail water return flows must be accomplished within two years by the impacted landowner. Oftentimes the engineering backlog prevents a timely design concept, and the potential for non-compliance arises as the tail water projects are not built within the stipulated time frame. We would ask that serious consideration be given to extend this compliance timeline to five years.

The Basin Plan talks about adherence to a certain tiered tail water management program (BPL, pp. 10). This particular program has yet to be developed. There needs to be appropriate language that allows some review and approval process as these policies or regulations are defined.

Response: The Basin Plan Language for the Action Plan does not call for strict adherence to a tiered approach to tailwater management; however, it does state that a tiered approach *may* be instituted for compliance if prohibitions, WDRs, or Waivers of WDRs, or any combination of the latter are instituted for tailwater management. Prior to tailwater implementation actions and management, an informational gathering phase is required where the regulated community will have opportunity to comment and offer management options best suited to site specific conditions. It will then be determined if a timeline greater than 5 years is necessary.

Santa Rosa Public Workshop comment:
Palma Risler of USEPA: It would be in line with other nutrient TMDLs in California if your staff would look again at monitoring recommendations for irrigated AG return flow quality. As it stands now I think that there was an evaluation phase in a year, but in many other nutrient TMDLs in California, the parties, the dischargers, come to the agencies with some reasonable monitoring that they have collected. Now (I don't know) whether or not irrigated AG is monitoring tailwater already through the Coho Incidental Take Permit. I didn't see it in there, maybe it is, but if we could again make it more explicit that the dischargers should report to the board so the evaluation phase is clearer: what is to be expected in the evaluation phase? Are they to collect what type of information? And they should produce that for the board and for your staff. I would think that your staff could best characterize what they think is the most important parameters to monitor for. Because without that how will they measure the success and the need for any additional programs?

Response: Any existing (and future) monitoring data collected by dischargers and/or other parties that are scientifically defensible would be considered appropriate to assess tailwater compliance with TMDL and Basin Plan targets.

The Coho Incidental Take Permit has not yet been approved and, in its current draft, there are no provisions for irrigated agriculture to institute tailwater monitoring.

The Implementation Plan, Chapter 8, and Action Plan, Table 4, will require a comprehensive monitoring and reporting program after tailwater sources, usage, and discharges are evaluated and a management plan is formulated. The Staff Report in Chapter 9, Monitoring, and Chapter 10, Reassessment, tasks the Regional Water Board to develop a compliance and trend monitoring plan within one year, and reassessment occurs with five years, respectively, of the date of EPA approval. During all steps in the process, Regional Water Board staff will seek to involve dischargers and other parties involved to prioritize and then select appropriate sampling locations, constituents, and field and laboratory analytical methodologies.

Santa Rosa Public Workshop comment:
Siskiyou County Supervisor Jim Cook: Making targets, especially tailwater that are reached specific where inputs are supposed to not degrade the water where they're

joining, effectively imposes a higher standard on persons upstream and we think it might be better that you have identical standards for them all.

Response: Actions necessary for similar types of land use activities to achieve water quality compliance are expected to be similar regardless of the location of the activity in the watershed.

Sandy Bar Nursery and Ranch comment:
Please adopt a plan that will require irrigators to clean-up irrigation water before returning it to the Shasta River. The technology exists; all that is needed is an agency with the guts to require clean up of polluted agricultural wastewater.

Reponse: The TMDL Action Plan, if implemented, should provide for a reasonable time frame and appropriate management measures, methods, and technology to allow irrigation return water to be discharged to receiving waters in compliance with the TMDL and the Basin Plan.

John Spencer comment:
The TMDL should fully lay out the technology available to eliminate agricultural return flow pollution and include a time-line for all those responsible for polluted discharge to come into compliance.

Response: The TMDL Action Plan, Table 4, encourages the use of appropriate technology to bring tailwater discharges into compliance with the TMDL, the Basin Plan, and the Nonpoint source Policy. The Regional Water Board's Executive Office may require, depending on site conditions, dischargers and other responsible parties to develop and implement tailwater management plan(s) to prevent discharges of pollution that elevate water temperatures and decrease dissolved oxygen concentrations in nearby watercourses.

Shasta CRMP comment:
The tailwater goal of no net increase in receiving water temperature may or may not be achievable, but no time frame is identified—is this intended to be at any time, or averaged over the course of a 24-hour period?

Zero tolerance for tailwater seems inconsistent with shared resources uses.

Response: The Action Plan calls for tailwater returns to be at or below river temperatures. This would apply any time.

Don Meamber comment:
All parties involved up here feel that "zero net increase" is too unrealistic of a regulation to enforce. It is an ideal goal but an achievable percentage increase would be more realistic.

Response: Thank you for your comment.

Klamath River Keeper comment:
The Action Plan should refer to the following Basin Plan provision: “Controllable water quality factors shall conform to the water quality objectives contained herein. When other factors result in degradation of water quality beyond the levels or limits established herein as water quality objectives, then controllable factors shall not cause further degradation of water quality. Controllable water quality factors are those actions, conditions or circumstances resulting from man's (sic) activities that may influence the quality of the waters of the State and that may be reasonably controlled.” Because the Basin is in violation of the nutrient standard, this controllable source MUST be controlled in order to comply with the Basin Plan provision quoted above. The Basin Plan should lay out the steps by which the Board is going to require compliance, i.e. adequate treatment of all ag return flows so that they are not further degrading those parameters currently out of compliance.

Response: The Action Plan and Basin Plan Language for the Shasta River will be incorporated into an amendment to the present North Coast Water Quality Control Plan. As such, the Basin Plan Amendment when approved by the Regional Water Board and adopted by the State Water Board, will assure that proper steps are enacted for the treatment and compliance of all agricultural return flows that are protective of the beneficial uses of water.

California Cattlemen’s Association comment:
CCA has some general concerns with Chapter 9, Monitoring. Specifically, monitoring “shall be conducted upon the request of the Regional Water Board’s Executive Officer in conjunction with existing or proposed human activities that will likely result in increased dissolved oxygen and reduced water temperature in the Shasta River Watershed…The Executive Officer will base the decision to require monitoring on site-specific conditions, the size and location of the discharger’s ownership and/or the type and intensity of land uses being conducted or proposed by the discharger.” CCA strongly recommends that any additional steps taken beyond the voluntary tiered approach be based upon a reasonable need or evident problem, not assumptions or theory.

Response: As presently written, Chapter 9, Monitoring Plan, takes into consideration the management practices of individual landowners and dischargers. If ranch and other land managers choose voluntary land use practices that are proven to be effective at controlling discharges of pollutants from entering watercourses, then a “reasonable need or evident problem" is less likely to occur, thus, also making it less likely that monitoring may be required.

12. Flow and Water Use

Flow and water use comments have been divided into five categories and the comments within each category are given a single response that addresses all comments. At the end of this section, there are also comments that were responded to individually.

Flow and Water Use Comment Group 1 – Shasta River Adjudication

Save our Shasta and Scott Valley comment:
If in the judgment of staff the plan is not successful, it specifically calls for modification to the water decree. This is totally unacceptable.

Eureka Public Workshop comments:
Denver Nelson: isn't the Shasta River fully appropriated, and are you suggesting that you are taking water rights and giving them to the environment.

Unidentified: The adjudication didn't take into consideration public trust flows because it was done in 1930's before the case law came down. It's possible that water rights can be arranged. There's another comment about groundwater, and they are not covered in the adjudication, and you do not need a water right to pump groundwater. It also doesn't address riparian rights, I took a look at the decree, and at the time, there was 40,000 acres of agriculture and now there are 50,000 so there has been an increase in diversions.

Yreka Public Workshop comment:
Blair Hart: And for that to be done and to have those milestones met (Big Springs Creek flow increases and temperature targets), those temperature reductions are not doable in the first five years. And you have down that if this isn't done in five years, there is a possibility of re-adjudication and that just scared the thunder out of everyone.

Pacific Coast Federation of Fishermen's Associations comment:
Problems with the Shasta River Adjudication must be identified and addressed in the TMDL Action Plan.

Siskiyou County Supervisor Marcia Armstrong comment:
We are very concerned that if the public draft of the Shasta River TMDL was adopted in its present form, it would have the potential to (sooner or later) re-open water adjudication (Basin Plan Language (BPL), p. 11, Flow). The current beneficial use of water for agriculture, municipal and domestic use would be diminished to such an extent that open space would be lost to development or that litigation for property takings would occur.

Santa Rosa Public Workshop comments:
Siskiyou County Supervisor Jim Cook: We are very concerned about this reopening of the water adjudication which it seems that if the current beneficial uses for water: agricultural, municipal, domestic, are diminished that's what would happen and open space would be lost to development and that's a great concern in our county or litigations for taking might occur.

Daniel Myers: The draft Scott Action Plan initially addressed the role of the Water Resources Control Board to participate in the restoration of stream flows. I think that they have to be a partner in any successful TMDL. I don't think you can leave water flows and the involvement of the State Water Resources Control Board out of it, I think you need to shake them a little bit and say, "You're part of this, participate."

Steve Orloff comments:
Even if the Action Plan does not specifically require an increase in flow from Big Springs, the wording implies that is does and creates a great deal of anxiety. I believe that the language in the plan relating to increased flow should be removed.

These areas should be investigated before reduced agricultural water use to augment flows is included in a TMDL Action Plan.

Klamath Siskiyou Wildlands Center comment:
KS Wild supports the adoption of a Shasta River plan that will reevaluate the Shasta River Watershed Adjudication so as to protect beneficial uses that rely on clean and abundant water.

Sandy Bar Ranch and Nursery comments:
Call on the Department of Fish and Game and Water Resources Board to enforce those provisions of the California Constitution that require water users to maintain habitat for fisheries and other beneficial uses.

Inform the State Water Resources Board that the Shasta River Water Adjudication is not adequate to protect beneficial uses and must be fixed. Completed in the1920s, the Shasta River Adjudication did not address riparian rights. Landowners along the river can - and do - remove all the water they want even when this damages fisheries and other beneficial uses.

John Spencer and Klamath RiverKeeper comments:
The modeling also clearly shows the connection between flows and water quality. Yet the staff (as in the Scott) has skirted around the problems with the adjudication.

Thus the EO and staff have a positive obligation to identify in the course of preparing TMDLs provisions of adjudications and DFG codes that are being violated when those violations contribute to violation of water quality standards. Such is the case in the Shasta, Scott and Mainstem Klamath. The TMDL must identify the problems with the

Shasta River Adjudication, elucidate how these problems have impacted water quality and lay out a path in the Implementation Plan to resolve these issues.

Shasta CRMP comments:
The implementation report and the Basin Plan language vaguely describe a 5 year review at which time all aspects of water use will be examined if adequate progress has not been made, including re-adjudication. The lack of detail here suggests a broad process is being envisioned.

By failing to describe any process (for the 5 year review), the appearance is created of a process in which both those persons who have been actively addressing water quality impacts and those who have not will be treated identically (i.e. punished) via (a very inflexible) re-adjudication process. That is hardly the way to encourage participation. A tiered approach should be laid out, with a mechanism for a person to create a "safe harbor" for himself through proactive efforts.

Concerning the 5-year progress report and possibility of review of the adjudication, no guidance is given to allow a person to gauge whether or not adequate process is possible or has occurred.

Shasta CRMP comment:
The legal assessment did not address the very complex problems in securing 40 cfs for instream flows (in the Shasta) from a combination of surface and groundwater users, nor the multiple jurisdictions that would need to be collaboratively involved.

Tim McKay comment:
I believe that the NCRWQCB must clearly explain the importance of the Shasta River in the historical context of beneficial uses in the Klamath-Trinity Basin. This analysis should address how the state has exercised its affirmative duty to protect public trust fishery resources.

Response to Comment Group 1: Many parties submitted comments addressing the Regional Water Board's approach to the problems with the Shasta River adjudication. Comments range from expressing severe reservations over the consequences of opening the decree, to expressing the serious need to reopen the adjudication to protect water quality. The response below should correct some misunderstandings evident in several of the comments, as well as describe how the Action Plan adequately balances this issue in light of legal and practical constraints.

Surface water diversions in the Shasta watershed were subject to a statutory adjudication that resulted in a judgment and decree approved by the Superior Court of the State of California, in Siskiyou County in 1932. The court recognized at that time that the water supply of the stream system is inadequate for all agricultural needs throughout the irrigation system. At the time the watershed was adjudicated, there were approximately 40,000 acres of irrigated agriculture. Today there are 50,000 acres under irrigation, presumably from additional diversions under riparian rights and groundwater pumping, which are not subject to the decree. This increased use exacerbates an already over-allocated system. The decree contains no requirements for the protection of instream beneficial uses.

The Staff Report makes clear that the State Water Board, Division of Water Rights is the agency with authority to oversee and regulate water rights. The Regional Water Board's ability to request that the State Board consider various water right actions is the extent of the Regional Water Board jurisdiction in this matter. The Regional Water Board cannot compel any action and has no guarantee that the State Water Board will address the issue. The State Board shall consider the Basin Plan in acting on applications to appropriate water under Water Code section 1258. The Basin Plan allows the Division sufficient flexibility in carrying out Basin Plan objectives in any water right proceeding. If the State Water Board were to consider taking an action that affects water rights, based on a Regional Water Board recommendation or for some other reason, there would be extensive opportunities for public participation at that time. Water rights comments such as takings and affirmative public trust duty are more appropriately addressed if and when the water rights issues are focused in a hearing at the state level.

The TMDL Action Plan requests water diverters to participate in, and implement applicable flow-related measures that result in dedicated cold instream surface flow in the Shasta River and tributaries. The Regional Water Board expects a progress report after two years, and will reassess the success of these measures after five years. There are several reasons to support this approach. First, applicable flow-related measures implemented via the CRMP or DFG programs are collaboratively based, and could therefore involve all diverters including riparian and groundwater users. All water users contribute to low flow problems and therefore should participate in solutions, not just those subject to the decree. Second, the collaborative nature of the programs will allow flexibility for more efficient results without procedural burdens. Reopening an adjudication, or any public trust or waste and unreasonable use hearing before the State Water Board will be costly and time-consuming. Investing those resources in solutions now could yield better results. Finally, the collaborative approach allows parties to generate and implement the solution in a more creative way, assuming that parties take advantage of the opportunity. That being said, it would be inappropriate to rely on the collaborative approach if it fails to yield measurable results. For this reason, progress reports and a five-year evaluation period are incorporated into the Basin Plan.

Some comments requested more definition on how the Regional Water Board will assess the progress in this area in its five-year evaluation. The following language has been added to the Action Plan:

"Within five years, water diverters shall report to the Regional Water Board, either individually or through the Shasta Valley RCD and its CRMP on the measures taken to increase dedicated cold water instream flow in the Shasta River by 45 cfs or alternative flow regime that achieves the same temperature reductions."

"Dedicated cold water instream flow" is defined in the glossary as "water remaining in the stream in a manner that that the diverter, either individually or as a group, can ensure will result in water quality benefits. Temperature, length and timing are factors to consider when determining the water quality benefits of an instream flow."

This language has been added to express the target by which the Regional Water Board will gage progress toward increasing cold flows into the Shasta River. It does not mean that 45 cfs must be in the river within five years. The Regional Water Board will consider all evidence that indicates what efforts water diverters have made to reach this target. Individual water diverters should document implementation of any steps and measures that they have taken and should be prepared to submit this information to the Regional Water Board.

Flow and Water Use Comment Group 2 – Technical Issues

Yreka Public Workshop comment:
Blair Hart: I think a big reason people are here, is the 50% increased flow out of Big Springs and it had me alarmed. It is something that is physically undoable, the water is not there.

Eureka Public Workshop comment:
Unidentified: Where are we going to get the extra water in Big Springs Creek?

Siskiyou County Supervisor Marcia Armstrong comment:
It appears that the amount of increased flow necessary for the water compliance scenario (150.0% at Big Springs) **would not** allow for the diversion of water further downstream in accordance with the water rights adjudication. In order to obtain the benefits of the colder water of the Big Springs Complex, that water would seemingly have to flow "un-impaired" past the check points on the Shasta River.

Santa Rosa Public Workshop comments:
Siskiyou County Supervisor Jim Cook: We're not quite sure what to do with this cornerstone approach of increasing the flows of the Big Springs to 40 cfs. At the present time there's only 25 cfs in gross surface diversions from that system some of which returns as tail water and that's making the net diversion even less, so stretch it as you might you just aren't going to turn 25 cfs into 40 cfs.

We believe (your staff) provided little guidance on alternatives (to Big Springs Creek flow increases). Park Creek in particular, which was mentioned during this but we didn't find it in the documents, which joins the Shasta in almost the same area as the Big Springs Creek has significant cold spring water in flows. And could potentially provide similar benefits but no similar singling out occurred there, so it seems that the water users from Big Springs were targeted simply because the data was available there while other areas were ignored. We understand you can only get cold water from where you find cold water but we're reasonably convinced that Big Springs is not the only place it can be found.

As far as the modeling goes, well the Action Plan says that 50% flow increase from the Big Springs complex is achievable. What we don't understand and we might be able to get that information is: how is that achievable? And how is it modeled to be achievable?

Patrick Griffin comment:
If all the water currently being used from the Big Springs complex was allowed to flow to the Shasta River, it would increase flows by about 25 cfs and dry up a considerable mount of agricultural land. Where is the rest of the water going to come from?

Tim Louie comment:
I am concerned about the amount of water claimed to be available based on some historic documentation in the 1922/1923 years. The flow in Big Springs Creek has remained constant at approximately 52 cfs after the dam is put in place. It doesn't seem to matter how much water is taken from the lake, the flow below the dam stays constant.

Steve Orloff comments:
There is insufficient information relating to whether or not increasing flow would even have a significant impact on temperature. The analysis done by Dan Drake, comparing two years with significantly different flow rate showed no difference in temperature. According to the presentation in Yreka and the figures in the document, increasing flow at best would only account for one-third of the desired effect on temperature and would have no effect on DO or other water quality parameters.

It is doubtful that the desired increase in flow of 50 cfs could be acquired from Big Springs. If the desired quantity of water cannot be obtained from Big Springs, will the next step be to acquire more water form other irrigators? An even greater quality of water would likely be required from another area where the source was warmer.

Shasta CRMP comments:
We don't know what to do with the cornerstone approach chosen of increasing flows at Big Springs by 40 cfs. At present, there are only ~25 cfs in gross surface diversion from that system, some of which returns as tailwater, making the net diversion even less. Stretch it as you might, it will never equal the 40 additional cfs identified.

It seems as if water users from Big Springs are being targeted simply because data was available, while other areas were ignored. We understand that you can only get cold water where you find it, but Big Springs is not the only place it is found.

Response to Comment Group 2: Please see response to Comment Category 7 – Water Temperature, Flow and Allocations.

Flow and Water Use Comment Group 3 – Flexibility

Yreka Public Workshop comments:
Siskiyou County Supervisor Jim Cook: I'd like verification on that. If you don't use flows, that puts more stress on the other activities. That infers that there is a trade off, and if we can beef up the trees, we won't have to improve flows. That's my inference – can I find that in the document? Since you're cooling the water, and flows don't matter.

Siskiyou County Supervisor Jim Cook: I think you gave us an out. I infer that shade, tailwater and flows are three things we need to do. But from what you're saying is that we don't need the flows if we can compensate. Is it there right now?

Siskiyou County Supervisor Jim Cook: Just a clarification again – is there something you could put in that the flow model you used is nothing more than a what if scenario and is nothing more than a tool to see what can be doable.

Siskiyou County Supervisor Marcia Armstrong comment:
We would like to ensure that the "potential alternatives" for mitigation are not mandated for implementation. For example, the proposal to increase the flows to 150.0% at Big Springs may have a distant historic basis, but reality may dictate that this alternative may not be currently attainable. A realistic mix of increased riparian shade, higher flow rates, reduction of nitrogen levels, and the recognition of storm water impacts could be used to achieve the end result, but the flexibility to use all alternatives is critical.

John Spencer and Klamath RiverKeeper comment:
Staff appears ready to propose shade as the solution to the temperature impairment. The shade solution is problematic due to soil conditions but even if it were to work staff says it would take upward of 60 years to achieve the temperature standard. We can't afford to wait 30 years for compliance!

Because the shade alternative is problematic and will only solve the temperature problem over the long-term, the Implementation Plan should focus on increasing Big Springs flows as the most effective, quickest and (in all likelihood) the most cost effective method to address water temperature pollution.

Shasta CRMP comment:
The implementation report and the Basin Plan language vaguely describe a 5 year review at which time all aspects of water use will be examined if adequate progress has not been made, including re-adjudication. The lack of detail here suggests a broad process is being envisioned. This presents several problems. First, given ordinary design and engineering hurdles, tree growth rates, lack of planting stock at present, and time for securing any permits required, realistically little will be substantially different in 5 years.

Response to Comment Group 3: Several commenters requested clarification on the degree of flexibility in substituting measures from one source category to another, so long as it cools the water. This overstates the issue of flexibility. To be clear, the Regional

Water Board expects to see implementation of actions in each applicable source area as defined in Table 4. Actions to increase shade are fully independent from actions to improve tailwater quality, or actions designed to increase flow. A responsible party cannot offset flow related measures by planting additional shade trees because full planting is expected already to be necessary to meet the assigned load allocation for shade. This is especially true due to the long duration until water quality benefits can be realized from shade plantings. That said, the Action Plan has incorporated sufficient flexibility in its iterative approach that would allow for implementation of additional measures that are effective at decreasing temperature and increasing DO that could lessen the need for other measures. All recommended measures should be implemented unless and until the TMDL targets are met and water quality in the Shasta River is no longer impaired. The following text has been added to the Action Plan to clarify that implementation actions are independent of one another: "Action items are fully independent from each other and require 100% implementation within each Source or Land Use category."

Flow and Water Use Comment Group 4 – Jurisdiction

Yreka Public Workshop comments:
Blair Hart: Does staff have a full understanding of what the Shasta CRMP is? I'm very concerned that you're adding on to what DFG has proposed for the ITP. The Shasta River CRMP does not have authority to do anything.

Siskiyou County Supervisor Jim Cook: It seems you had usurped DFG's fiduciary responsibility to do an IFIM. They're going to undertake that in the next 5 years. That will be the water quality standard. I was afraid you had set the standard without any input from DFG. So that needs to be clarified.

Pacific Coast Federation of Fishermen's Associations comment:
Emergency responses to adverse flow conditions (drought years) should be outlined.

Steve Orloff comment:
Alternative measures in lieu of increasing summer flows should be evaluated and perhaps mentioned in the plan. It is doubtful that historic summer flows in the Shasta River prior to the construction of Dwinnell Dam were as high as current flows. Dams usually moderate flows – decrease winter and early spring flows and increase summer flows. Increasing summer slows may eliminate cold water refugia and be harmful to fish. Studies are needed to determine whether salmonid fisheries habitat could be improved by creating side channels to better take advantage of cold water accretions. In additions, more studies are need the to assess the potential benefits of flushing flows or pulse lows to reduce sediment oxygen demand.

Response to Comment Group 4: Blair Hart commented that the Regional Water Board may not understand the extent of the CRMP authority and expressed concerns, along with others, about consistency with DFG, specifically in the area of flows. These comments stem from the Plan's approach to largely rely on the ongoing efforts of the Shasta Management Plan of the CRMP, and DFG's ITP and Coho Recovery Strategy.

The Shasta Valley Resource Conservation District (Shasta RCD) formed in 1953 is a non-profit public agency organized under Division 9 of the California Public Resources Code. The Shasta RCD is authorized to provide conservation work within it boundaries and cooperate with other public agencies or districts, private entities, or private individuals to accomplish its goals and work for the benefit of the public (Shasta Valley Resource Conservation District Long Range Plan 2001-2005). The Shasta RCD formed the Shasta River Coordinated Resources Management and Planning Committee (CRMP) in 1991 with the goal of examining and understanding local factors effecting anadromous fisheries in the Shasta River watershed. The landowners who founded the Shasta CRMP recognized that many of the water quality problems that affect salmon were the result of the cumulative impacts of agricultural practices along streams in the Shasta Basin. Since that time the Shasta CRMP has directed many projects designed to help agricultural producers to include elements of salmon and steelhead conservation in their ongoing ranch activities. These projects include erosion control, installation of fish screens, outmigrant assisting pulsed flows, tree planting, livestock exclusion fencing, and irrigation tailwater recovery. (Shasta Watershed Restoration Plan.)

Regional Water Board staff recognize that the RCD and CRMP cannot compel actions from unwilling participants. This cooperative framework allows for more creative problem solving and efficiencies in administration. This TMDL finds that the RCD through the CRMP could be an effective way to implement measures necessary to protect water quality. Dischargers can choose to not participate in the process, and if so, will have to pursue a different approach, either through a different watershed group or individually with the Regional Water Board. The Regional Water Board would prefer to avoid developing redundant programs, and instead lend support to a process that is ongoing and shows promise toward meeting water quality goals if implemented. Its success, however, will be determined by how actively engaged the parties become in the process. The Regional Water Board intends to work with closely with the RCD to develop sufficient monitoring in order to gage the effectiveness of the Program.

This collaborative approach is not intended to interfere with the IFIM study planned by DFG. The IFIM (Instream Flow Incremental Methodology) is a flow assessment tool in the management of freshwater environments. It is not a water quality standard; rather, it is a tool to be used in the context of endangered species regulation. When DFG completes the study, the Regional Water Board may consider the results and modify its Basin Plan if appropriate.

Other parties raised specific ideas that are appropriately addressed in the context of these on-going programs. The suggestion to create an emergency response program for drought years appears already contemplated in the Coho Recovery Strategy. This applies similarly to parties providing comments on refugia and the roll it plays for fish protection. Parties are encouraged to fully participate in these programs to develop the best most comprehensive solutions.

Flow and Water Use Comment Group 5 – Flow Measures

Yreka Public Workshop comment:
Don Meamber: On implementation, this is instream flow type statement. It says explore if there are unused appropriative rights to water not belonging to a particular landowner can remain in the river, not to be used by other diverters downstream.' I think if you have an appropriative right, you still have that right even if you are not using it. I think you mean unused appropriative rights or water not belonging to a landowner.

Siskiyou County Supervisor Marcia Armstrong comment:
We have been told by the NCRWB staff that diversions can occur, but we are unable to determine how that would be implemented based on the data in the current staff report and Action Plan. The concept of fairness and water rights priority does not allow for junior rights holders to divert water when more senior holders would give up water under this scenario.

Don Meamber comment:
In Chapter 8, pg. 13, last bullet: Not sure what was meant in the sentence about the unused appropriative water rights, which I brought up at the public hearing. Did the RWB staff mean as a permanent in stream flow, or for short periods of time? If someone failed to use that right for 5 years, he could lose it unless he was notifying Water Rights Board in the every 3 yr. (I believe) reports that he was substituting reclaimed water, etc. without losing his right. A lost right could be considered instream flow, I imagine. I don't believe the riparian or adjudicated rights are lost by disuse.

Response to Comment Group 5: The following paragraph has been added to Chapter 8 to better describe water right legal issues as it relates to dedicated cold instream flow measures:

Implementation of water conservation measures may not be effective in benefiting water quality because other water right holders may divert more water if more water is left available in the stream. In addition, an appropriative water right holder risks forfeiture for non-use if water is not used for a period of five years. The law of forfeiture applies to appropriative water rights, including those that were adjudicated, but will not affect riparian rights. There are numerous legal tools available to water diverters to ensure that conserved water is applied to instream beneficial uses and will not be lost to forfeiture. Water made available through the implementation of conservation measures must be dedicated to beneficial use in order to be effective under this Plan. Dedicated means that the diverter, either individually or as a group, can demonstrate that the measure contains assurances that it will result in water quality benefits.

For example, under Water Code section 1707, any person entitled to use water, whether based on an appropriative, riparian or other water right, may petition the State Water Board to change the purpose of use to the preservation and enhancement of wetlands habitat, fish and wildlife resources, or recreation. The State Water Board may approve the petition if the change does not increase the amount of the original entitlement, does not unreasonably affect any legal user of water, and meets other requirements of the Water Code. The Plan also encourages water conservation and other flow measures on a watershed-wide scale to be the most effective, such as coordinating pulse flows as contemplated in the DFG Coho Recovery Strategy. The Plan allows for creative solutions to dedicate these flow measures, including collaborative agreements. Any agreement should clearly delineate how measures ensure benefits to water quality.

Flow and Water Use Individual Comments

Yreka Public Workshop comment:
Blair Hart: One of things we have been discovering is what we don't know or understand about it. We have shot ourselves in the foot by converting the sprinkler irrigation from flood – it's been documented.

Response: Comment noted. Regional Water Board staff defer to knowledge of local experts on the appropriate means and methods to achieve water conservation.

John Spencer comment:
Staff is ignoring the Basin Plan at 4-34.00, which specifically instructs the Executive Officer to "investigate the violation or threatened violation of those rules and regulations of other agencies which have been adopted to protect the quality of the waters of the region."

Response: The language cited in this comment is directed specifically toward discharges of herbicide wastes from silviculture applications. It is not clear what violation or threatened violation the commenter is requesting the Regional Water Board to investigate. Enforcement actions are discretionary and dependent on staff resources and priorities. The Basin Plan Amendment clearly preserves the Regional Water Board's enforcement authority for violations actions affecting water quality of the Shasta River and its tributaries. The commenter is encouraged to write to the Regional Water Board staff to better describe the alleged violation.

Don Meamber comments:
In Chapter 8, pg. 18, Table 8.5, 3rd Recommendation, 'stagger of irrigation starts', temperature. The large X means it is important? This doesn't seem right, because we are at that point now and the water and air temperature are both normally cool this time of year, so even if the landowners dried up the river for a few days, the water should stay cool. The large X for habitat makes more sense.

In Chapter 8, pg. 21, last bullet, 'Flows required to clean spawning gravels.' We get some high water most winters, yet not enough to clean spawning gravels adequately. Maybe the valley does not have enough downgrade to create velocity to move the fine sediment out of the gravel.

Response: Comment noted.

California Cattlemen's Association comment:
CCA has some specific concerns with Chapter 8, Implementation. Under the key points section there should also be cooperation with the North Coast Regional Water Board staff, with BLM, Non-governmental organizations, landowners, and the local agricultural commissioner. CCA does not agree with "no net increase in irrigation return flow," and 50% reduction of sediment oxygen demand behind minor impoundments." CCA is willing to work with the Regional Board and local landowners to find environmentally and economically feasible options with alternatives.

Response: See response to comments on tailwater implementation above regarding tailwater issues. Regarding cooperation, Regional Water Board looks forward to working with CCA and many other agencies and organizations during implementation of the TMDL.

13. Minor Impoundments

Yreka Public Workshop comment:
*Don Meamber***:** Dissolved oxygen at Montague Grenada Road was the lowest – is this because the DWR has a weir that is there year round – it is collecting sediment. Is this increasing oxygen demand at this location?

Response: We assume the commenter is referring to Figure 2.8, which presents a summary of summer time dissolved oxygen conditions within reaches of the Shasta River, based on data collected from 1994 through 2004. The information presented for the Montague-Grenada Road to Anderson Grade Road reach includes measurements from Montague Grenada Road, Highway 3, Yreka Ager Road, I-5, upstream of Yreka Creek confluence, and at Anderson Grade Road. The dissolved oxygen measurements made at Montague Grenada Road are from a location immediately downstream of the DWR weir, and therefore do not necessarily reflect sediment oxygen demand occurring behind the weir.

Don Meamber comment:
The DWR needs to remove the check dam weir used at my place. The fines never get flushed there because there are no flashboards to remove to open up the river there, like the irrigators' dams. Fish passage is a problem at low flow as well. The USGS has measured the Shasta flow for years at the mouth without a dam.

Response: Required actions associated with "Irrigation Control Structures, Flashboard Dams, and other Minor Impoundments" identified in the revised Action Plan apply to all minor impoundments in the Shasta River watershed, including the DWR weir at Montague Grenada Road.

14. Lake Shastina

Lake Shastina CSD comment:
The Plan states repeatedly in the document that the most important timeframe is mid to late summer. At this time of the year, the quantity of water in the River immediately below the Dam is so minute, how can this impact the rivers or fish? It is believed that what is going down the river at that time is mostly used for irrigational reasons.

Response: Regardless of the quantity of water in the Shasta River, the time of year, or the relative portion of stream flow used for irrigation, the water quality objectives must be achieved and all beneficial uses protected, including for fisheries. If more water is required to restore the designated beneficial uses, then more water of suitable quality should be made available.

Lake Shastina CSD comment:
If one reviews the incoming flows prior to the construction of the Dam, it may be questionable what the TMDL would have been or if there would have even been year round flows. Since the construction of Dwinnell Dam, there have been 75 salmon runs. It is not believed that over these years, and quite possibly prior to the construction of the Dam, the TMDL has changed all that much. If they have, it is not certain as to if the change created a positive or negative impact on the salmon.

Response: Comment noted. See response above regarding requirement to comply with water quality objectives and beneficial uses. The TMDL analysis indicates that the current discharge from Dwinnell Dam is not in compliance with water quality objectives nor is it protective of beneficial uses. The TMDL addresses the effects of the dam on water quality. The TMDL doesn't address other effects of the dam and its operations on loss of migration, spawning and rearing habitat, or changes in the hydrologic continuity, for example.

Lake Shastina Community Services District (CSD) comment:
There are several other factors that have greater impacts (than the Dam)
1. 30 years back, commercial boats had to stay miles off the coast, creating something equivalent to a safe fish reserve. Results, less fish were taken.
2. 30 years back, commercial boats caught enough fish to feed a population of 'y'; today they take enough fish to feed a population of 'x', a substantial difference. Results, more fish are now taken.
3. 30 years back, scientific equipment such as fish finders and electronic tracking equipment was not on every boat to locate fish. Results, less fish were taken.
4. Over the past 30 years, it is believed the number of sport anglers on the Klamath River and on the West Coast has increased drastically. Results, more fish being taken.
5. Over the past 30 years, due to the quantity of drift boats and guides, it is believed the success of sport anglers has increased substantially. Results, more fish being taken.

6. Over the past 30 years, it is possible the quantity of seals has increased. Results, more fish being taken.
Recognizing the above, in conjunction with the NCRWQCB's issue with TMDL year after year, how are these fish surviving? Maybe things are not as bad as is being implied. They are definitely not bad enough to imply to people that they may lose their water rights and thus their livelihood, or dams need to be removed.

Response: The threatened status of salmon fisheries has been thoroughly documented in a number of scientific studies as documented in the Staff Report. See, for example, the National Research Council Report, Endangered and Threatened Fishes in the Klamath River Basin. See also sections 1.4.10 and 2.6.1 of the Staff Report for additional information. The TMDL does not mandate either the loss of water rights or the removal of Dwinnell Dam.

Lake Shastina CSD comment:
How does this Plan affect real estate disclosure laws (around Lake Shastina)?

Response: The Shasta River watershed was listed as impaired for temperature in 1992 and for dissolved oxygen in 1994. The TMDL Action Plan is the proposed mechanism to bring the waters in the Shasta River watershed into compliance with existing water quality law. If actions are identified for Lake Shastina homeowners, these could require disclosure similar to any other legal disclosure requirement of a regulation that may affect a homeowner once the Action Plan is adopted into the Basin Plan.

Lake Shastina CSD comment:
Is it known what the water temperature was below Dwinnell Reservoir before the Dam was constructed? Is it known if the temperature of the water coming out of the springs in the bottom of the Lake is equal to the temperature at Big Springs? Remember that approximately 90 plus years ago, Big Springs was a field of small springs one could ride a horse across. Did this marsh increase temperature due to shallow waters? Does one know if the water production from this marsh was higher or lower and by what percent? If the temperature was higher and volume less, again before man installed the pipes, how did these fish survive over these many years?

Response: Unfortunately there is no known water quality data available from prior to the Dam's construction (circa 1928) either for the springs in the bottom of the lake or for the Big Springs "marsh", so comparisons to this timeframe must be based on application of engineering and scientific knowledge and tools.. Available information on fish populations indicates that the Shasta River watershed produced much larger numbers of salmon in the early part of the 20th century than it does today (see the Staff Report section 1.4.10) and that water quality conditions today do not reflect conditions supportive of cold water fish requirements, thus indicating at least one explanation for the change in productivity.

Save our Shasta and Scott Valley Comment:
The Montague Water Conservation District is being directed to prepare a "nitrogenous oxygen demand" study. There is no further discussion as to what another wasteful study hopes to accomplish.

Response: Discharges of water from Dwinnell Dam are not in compliance with water quality objectives in the Basin Plan. The intent of the study is to inform both the Montague Water Conservation District and the Regional Water Board on the condition of the discharge from the Dam and possible solutions to bring the discharge into compliance with water quality standards.

Yreka Public Workshop comment:
Stan Sears: Why is water district responsible for water quality conditions in Lake Shastina and how is reducing nitrogen levels by 67% possible?

Response: The Montague Water Conservation District is not exclusively responsible for water quality conditions in Lake Shastina. Anyone who discharges into Lake Shastina, including Caltrans, the County of Siskiyou, homeowners, homeowner associations, the City of Weed, and other upstream landowners are responsible for the water quality conditions of the Lake. This clarification was made to Table 4 of the TMDL Action Plan. Nevertheless, the Montague Water Conservation District, as owner and operator of the dam and its associated facilities is responsible for the quality of water discharged from the lake.

Yreka Public Workshop comment:
Stan Sears: Who's gonna pay for it [reducing nitrogen levels in Shastina], and what is the estimate of the cost of that?

Response: The Montague Water Conservation District, as owner and operator of the dam and its associated facilities is responsible for the quality of water discharged from the lake, and is therefore responsible for bringing that discharge into compliance with Basin Plan water quality objectives. All responsible parties will be responsible for reducing nitrogen levels in the Lake.

Yreka Public Workshop comment:
Don Meamber: What does coordinating groundwater storage with the operation of Lake Shastina mean?

Response: Regional Water Board staff believes this comment is related to a measure cited in the Staff Report (Table 8.4) that summarizes some of the avoidance, minimization and mitigation measures contained in the CDFG Coho Recovery Strategy. These measures were included in the Table as representative of the extent of measures proposed under the draft ITP. Further information should be obtained from either CDFG as the lead agency or from the Shasta River RCD as the permit applicant.

Yreka Public Workshop comments:
Rex Houghton: You showed temperatures and you referred to water above Lake Shastina, are we going to have to make the water coming out of Lake Shastina cleaner than it is coming in?

Harry Sampson: I'd like to go back to the discussion of nitrogen in and out of Shastina. You said it was necessary to decrease by 67%. This is a mathematical thing. It doesn't work out.

Response: The TMDL requires that water discharging from Dwinnell Dam be in compliance with water quality standards. The outflow currently is in conformance with the temperature objective (supportive of beneficial uses) because the water comes from the bottom of the reservoir and is cold. However, the outfall does not currently meet the water quality objective for dissolved oxygen, nor does it comply with the TMDL load allocation for nitrogenous oxygen demand (NBOD). The TMDL allocation for Dwinnell Dam is an NBOD concentration of 0.91 mg/L, which reflects the average NBOD concentration in the Shasta River where it flows into the lake. As a result of physical processes in the reservoir (e.g. stratification), the NBOD at the bottom of the reservoir is substantially increased. The average NBOD concentration immediately downstream of Dwinnell Dam is 2.74 mg/L. The TMDL load allocation requires that the NBOD outflow concentration be equivalent to the average inflow concentration to the reservoir. Reducing the average NBOD concentration from 2.74 mg/L to 0.91 mg/L constitutes a 67% reduction. This is more fully described in the Staff Report (see Sections 2.4.4, 4.4.3 and 7.5.2).

Siskiyou County Supervisor Marcia Armstrong comment:
The Montague Water Conservation Board is charged with the responsibility for initiating an investigative study of Lake Shastina for potential reductions in the nitrogenous oxygen demanding substances. The cost of the study could be financially prohibitive to such a small water agency. Every effort needs to be made to assist the Montague Water Conservation Board with the financial resources to fund this critical component of the Basin Plan.

Response: Comment noted. Regional Water Board staff is aware that possible cost of the required study would be a considerable expense for the district. Staff will aid the district in the identifying appropriate grant programs to help fund the study costs.

Siskiyou County Supervisor Marcia Armstrong comment:
Any entity contributing to the nitrogenous levels should also be named as a responsible party for the study (on nitrogenous demanding substances) and any other potential remediation/mitigation.

Response: Comment noted. Additional responsible parties, as appropriate, are included in the revised TMDL Action Plan, Table 4.

Tom Wetter comment:
The underlying data used in the development of Shasta River TMDL Action plan is a report known as the Lake Shastina Limnology Study (Circa 2005), completed by Watercourse Engineering Inc., of Davis California. The reports author's concluded that there wasn't sufficient data to actually formulate effective mitigation strategies. The report actually calls for additional study and a systematic assessment of the reservoir. In all, there are ten specific areas of study identified in the report that the experts from Watercourse Engineering say need to be completed before a realistic action plan can be developed and implemented.

Response: Comment noted. Regional Water Board staff concurs that additional study is likely required before an effective plan can be developed. The TMDL Action Plan was developed to incorporate a time schedule for the development and implementation of a study, rather than requiring immediate implementation of a design solution.

Montague Water Conservation District comment:
Table 4 of the TMDL implementation actions lists the MWCD and other appropriate stakeholder as responsible parties for implementing an investigation into ways to reduce nitrogenous oxygen demanding substances contributing to low DO. The District feels that "Appropriate Stakeholders" as a responsible party is vague at best. The District would like to see specific organizations listed that have influence on the water quality in Lake Shastina. Lake Shastina Property Owners Association. Juniper Valley Homeowners Associations, the City of Weed and Siskiyou County for their control of the lake's recreational usage and being the responsible party for areas above the Lake. The California Department of Fish and Game should also share responsibility as they have participated in enhancement activities for fish habitat.

Response: Comment noted. Additional responsible parties, as appropriate, are included in the revised TMDL Action Plan, Table 4.

Montague Water Conservation District comment:
The wording in the TMDL states that: effecting the beneficial uses of water in Lake Shastina and waters of the Shasta River downstream from Dwinnell Reservoir." It was mentioned at the meeting of March 15th by Matt St. John that RWQCB was not expecting to have the entire Lake meet their requirement, just the waters being released into the Shasta River below the Dam. The District would like this clarified in the documentation.

Response: The revised Action Plan identifies the Montague Water Conservation District (MWCD) as the responsible party for Dwinnell Dam and requires MWCD to report to the Regional Water Board, within 2 years of EPA approval of the TMDL, on a plan to bring the discharge from Dwinnell Dam into compliance with the TMDLs, the Basin Plan and the NPS Policy. In this case, the discharge refers to water flowing or seeping from the Dam. In addition, the revised Action Plan identifies MWCD as one of six responsible parties required to complete a study of water quality conditions and factors affecting water quality conditions in Lake Shastina, and to a plan for addressing factors affecting water quality conditions within 2 years of EPA approval of the TMDL.

Montague Water Conservation District comment:
The mention of reducing the nitrogenous oxygen demanding substances released from Dwinnell Dam raises the question, since the water released into the Shasta River during the summer months is done so to satisfy the prior rights established prior to the construction of the Dam, could alleviating that water entirely by pipelining it to the appropriate right holder satisfy the requirements set forth by RWQCB?

Response: It is not appropriate to solve a water quality problem by eliminating the water body in question.

Montague Water Conservation District comment:
The implementation action states, "Based on the results of the investigation, the RWQCB shall determine appropriate implementation actions necessary to reduce the nitrogenous oxygen concentrations in Lake Shastina and affected areas downstream from Dwinnell Dam." The District would like the wording to state the RWQCB would suggest various alternatives in which the MWCD will then decide the appropriate implementation action necessary for the District.

Response: The Porter-Cologne Water Quality Control Act prohibits the Regional Water Board from requiring the "manner of compliance". The typical process involves the development of a study, including a proposed solution, by the discharger, which is then reviewed by Regional Water Board staff. The Regional Water Board staff would work with the MWCD in the development of an appropriate plan.

Montague Water Conservation District comment:
One of the many questions is since the water released from Dwinnell Reservoir is for prior right use, how much of the actual lake water reaches past these points, and if any does, how does this affect the water downstream from these reaches is it is of minimal quantities?

Response: Discharges of water from Dwinnell Dam are not in compliance with water quality objectives in the Basin Plan. The Montague Water Conservation District, as owner and operator of the dam and its associated facilities, is responsible for the quality of water discharged from the lake, and for bringing the discharge into compliance with applicable water quality standards.

Klamath Siskiyou Wildlands Center comment:
KS Wild supports the adoption of a Shasta River plan that includes mitigation and pollution reduction efforts for the chronic toxic algae problem in the Dwinnell Reservoir.

Sandy Bar Nursery and Ranch comment:
Adopt a plan that will clean up Dwinnell Reservoir (aka Lake Shastina). Dwinnell Reservoir is part of the Shasta River and needs to be included in the clean-up plan. The reservoir is a breeding ground for toxic algae that has killed pets and can kill children.

Response: The TMDL Action Plan, Table 4, includes a time schedule for development and implementation of a study to address the NBOD, which acts as a stimulant for algae growth.

Klamath River Keeper Comment:
You have failed to adequately address Dwinnell Reservoir. Dwinnell Reservoir is part of the Shasta River and it lies astride its course. The Reservoir itself is therefore part of the impaired listing. Therefore you are obligated to identify those actions, which are needed to restore water quality in Lake Shastina to compliance with Basin Plan standards. Your proposal to defer dealing with the problems of Dwinnell Reservoir is unacceptable, illegal and a violation of the TMDL Consent Degree.

Response: The Action Plan identifies a clear set of requirements for parties responsible or potentially responsible for discharges to the lake and for operation of the lake to identify their discharges and bring those discharges into compliance with Basin Plan water quality standards.

Montague Water Conservation District comment:
The time it may take to go through the appropriate steps such as funding, identifying, engineering, and implementing will take many more years than allowed in the draft. Therefore, a five year guideline may not be adequate enough to satisfy what the RWQCB is asking for and would like wording pertaining to extension periods if found necessary for completion of any work already being done or ultimately extending the periods of time for completion.

Response: Comment noted. Any responsible party may petition the Regional Water Board for extension of due dates.

15. Yreka Treatment Plant

City of Yreka comment:
As an operator of the Yreka Wastewater Plant, I am concerned that you are looking at the nitrates from the sampling site called Anderson Grade Bridge, and not considering the fact that we are not the only nitrate contributors to the Creek. There are cattle around and

in the Creek twenty yards upstream of the aforementioned sampling site. I am requesting that you look at the Plant's monthly effluent samples to determine the Plant's nitrate reduction instead of the Anderson Grade sampling site since this would be a more accurate count of the Plant's contribution to the Creek. I am submitting this statement in view of the fact that at the last meeting, Board staff was calling for a 32% reduction in nitrates from our Plant, and it would not be fair to hold the Plant responsible for the pollutants in the Creek for which we have no control over. We further request that the language in the Basin Plan, Chapter 4, Page 4-17, Paragraph 2, and Page 4-18, Paragraph, 1, be revised accordingly.

California Cattlemen's Association Comment:
Annually tens of thousands of acres within California are converted from rangeland to other uses. It is mutually recognized that there is increased residential development and associated urbanization, particularly within Shasta Valley. Therefore, CCA encourages the Shasta TMDL to place further emphasis on urban factors contributing to the water quality impairments, including an emphasis on the City of Yreka's wastewater treatment and disposal facility.

Response: For clarification, the document "Basin Plan" referred to in the comment is the *Public Review Draft Staff Report for the Action Plan for Shasta River Watershed* (Staff Report). Neither Chapter 8 (Implementation) of the Staff Report, nor the TMDL Action Plan requires a 32% reduction in nitrates to Yreka Creek from the Sewage Treatment Plant. The technical analysis identifies that the NBOD concentration at the mouth of Yreka Creek must be 0.91 mg/L, representing an average reduction in the NBOD concentration entering the Shasta River from Yreka Creek of 32%. As discussed in section 4.3.2 of the Staff Report, recall that NBOD (nitrogenous oxygen demand) is a measure of the amount of oxygen consumed from the conversion of organic nitrogen to ammonia (NH_4^+) and the oxidation of ammonia to nitrite (NO_2^-) and subsequently to nitrate (NO_3^-). The total amount of oxidizable nitrogen is equal to the sum of organic-nitrogen and ammonia-nitrogen, and is measured as Total Kjeldahl Nitrogen (TKN). The oxidation of organic-nitrogen and ammonia-nitrogen consumes 4.57 grams of oxygen per gram of TKN, and therefore, NBOD is estimated as 4.57 times the ambient TKN concentration. Therefore, an NBOD concentration of 0.91 mg/L corresponds to a TKN concentration of 0.2 mg/L.

There are several potential sources of elevated NBOD loads in the Yreka Creek watershed in addition to the Yreka wastewater treatment plant, including grazing and other uses affecting the riparian zone, and urban stormwater runoff. The wastewater treatment plant is expected to be responsible for discharges from the plant. The Action Plan identifies the existing permitting mechanisms, Monitoring and Reporting Program Order No. R1-2003-0047 and Cleanup and Abatement Order No. R1-2004-037, as the vehicles for achieving compliance. Other sources noted in the comment are addressed in other actions identified in the Action Plan, which include actions for range and riparian land management.

16. Stormwater Runoff

Yreka Public Workshop comments:
Siskiyou County Supervisor Jim Cook: Should the text in Lake Shastina not include the other communities that input stormwater so they can be identified as a source and part of the impairment of Shastina? Essentially, so they can share some of the responsibility for meeting the load allocation for Shastina?

I think the text should include something about other communities that input water into that facility. The communities being Lake Shastina, Weed, and Edgewood. Caltrans may have an input as well.

Response: The community of Lake Shastina, city of Weed, and other populated areas with urban and suburban runoff, as well as CalTrans, are identified in the TMDL Action Plan to improve on existing and/or develop future management actions to minimize, control, and, preferably, prevent discharges of nutrients and other oxygen consuming materials, sediment, and elevated water temperature waste discharges to the Shasta River and its tributaries, including Lake Shastina. The City of Montague and Edgewood have been added as responsible parties under the "urban and suburban runoff source" in Table 4 of the Action Plan. The TMDL Action Plan also specifies that measures also apply to all suburban communities with stormwater discharges and other runoff related events that may contribute to dissolved oxygen depleting, and water temperature elevating waste discharges to Lake Shastina.

Santa Rosa Public Workshop comment:
Siskiyou County Supervisor Jim Cook: There are storm drains in Yreka that discharge directly into Yreka Creek and we think those might be more of a point source pollution, however in this report they are not identified as that.

Response: Typically the term "point source" is used in reference to those discharges subject to federal Clean Water Act (CWA) permitting. Traditionally, the CWA had contained an exception for discharges of storm water runoff. Changes in federal regulations modified the point-source permit program to include certain specific types of stormwater discharges. Currently, the point source program requires permitting for stormwater runoff discharges from certain categories of industry, from construction projects that create land disturbance in excess of 1 acre (excluding agriculture), and from large and medium municipal storm drain systems. Other categories of stormwater discharges can be regulated by point-source permits when the state permitting authority can show that the discharge is a significant source of pollutants to waters of the US. At this time, Yreka does not meet the definition of a regulated municipal point source discharge.

17. CEQA Issues

Shasta CRMP comments:
The example approach utilized to meet the requirement of demonstrating that TMDL targets were achievable relied in part on the dedication of 40 cfs from Big Springs. Since this water is presumably not being delivered via Big Springs currently, presumably there will need to be reductions in up gradient water use. The CEQA checklist did not indicate that roughly 3-4000 currently irrigated acres would need to be effectively abandoned for agricultural uses.

The CEQA checklist does not acknowledge that a re-adjudication will almost certainly have major impacts and costs.

Response: The TMDL does not mandate either the abandonment of irrigated fields nor re-adjudication of existing water rights. Rather, the TMDL and its associated Action Plan request that diverters implement applicable measures that allow additional flow to be dedicated to instream flows to provide for full support of beneficial uses of water. This can be accomplished in a number of ways including increased irrigation conveyance and use efficiency, purchase of water rights from willing sellers, or alteration of other land management activities. The Regional Water Board would consider requesting the State Water Board to re-open the water right adjudication on the Shasta River only if, after five years, the irrigating community can not show good faith efforts and meaningful progress toward increasing dedicated cold water flows. If the State Water Board determined that a water right action was necessary and in the public interest, it would have to satisfy its own CEQA requirements at the time with opportunity for public comment and participation.

18. Economics

Yreka Public Workshop Comment:
Tim Louie and Patrick Griffin: In Chapter 13.3, references are made to the economic benefit resulting from camping, fishing and boating. Not sure that would apply here. Most of the Shasta River system is privately owned. Most of the river frontage is agricultural land not housing developments. There is limited BLM ownership in the lower Shasta River.

Response: The section of the economic analysis that looks at benefits to outdoor recreation is referring to the current land owned by BLM and also the potential for the Shasta River to support more recreational uses in the future as water quality is improved.

Yreka Public Workshop Comment:
Tim Louie, Patrick Griffin and Shasta CRMP:
The economic analysis failed to acknowledge the very complex problems in securing the above 40 cfs for instream flows (in the Shasta). Under the circumstances, claims put

forward through the (technical) analyses that TMDL targets are achievable without significant impacts are disingenuous at best. Diverting 40 cfs of water from agricultural use to the river for temperature enhancement will decrease agricultural production by about 4,000 acres, which results in approximately $1,000,000 lost revenue per year. I believe the economic impact cannot be mitigated. Is the Board considering the value and economic benefit of agriculture production made possible by these waters? Will the landowners served by the water in Big Springs have a choice of how to lower water temperatures or will the water be taken? Improvements to water delivery could help save some of the water – perhaps that's something you could focus on without taking it from the users.

Response: The economic analysis has considered potential costs to agriculture but has concluded that the benefits of restoring the Beneficial Uses of the Shasta River outweighs the costs. The Action Plan requires water users in the Shasta River Basin to collectively increase dedicated instream cold water flows in the Shasta River by 45 cfs. The means for accomplishing this is at the discretion of the responsible parties. The TMDL does not require any agricultural land to be taken out of production. See also response to Comment Category 7 – Water Temperature, Flow and Allocations for a more detailed explanation of compliance with the requirement to increase flows by 45 cfs.

Yreka Public Workshop Comment:
Tim Louie; Patrick Griffin:
In Chapter 13.2, TMDL implementation will require compliance with the Non-Point source program. Those costs are not considered even though they are significant.

Response: Compliance with the Non-Point Source Program is required regardless of the TMDL analysis results and Action Plan.

Yreka Public Workshop Comment:
Tim Louie; Patrick Griffin:
The costs of containing wastewater are listed as $20/acre. I am not sure that is adequate. The topography of the Shasta Valley will make zero tolerance for wastewater a serious and costly element of this plan.

Response: Comment noted. Costs listed were noted as estimates. Please note that the Action Plan seeks to improve irrigation return flows to a quality equal to river water quality, and doesn't rely on elimination of return flows. Certainly, recycling of return flows would constitute a means for compliance, but is not the only option available.

Yreka Public Workshop comment:
Tim Louie: Cost of establishing vegetation is underestimated, a one-time maintenance cost is not adequate – some of the soils are going to be difficult to get trees established in and I think you've addressed that.

Response: Staff concurs and notes that the costs outlined in Chapter 13 are estimates.

Montague Water Conservation District comment:
The District would like to know the cost estimates of (the nitrogenous oxygen demand study) and if possible an estimate on the implementation of various outcomes. Along with these explanations, we would also like to have listed the various resources/grants available to help defer the bulk of the cost.

Response: Staff is not aware of a specific funding source that is available for this type of project; however, the following websites should be helpful to the District:

http://getgrants.ca.gov/

http://www.grants.gov/

http://www.swrcb.ca.gov/funding/

http://www.umbc.edu/economics/grad_699_abstracts/a_otis_proposal.pdf

Shasta Valley RCD comment:
It is suggested that a good addition to the TMDL documents would be a discussion of possible sources of funding for agencies, non-profits and landowners, etc., who wish to undertake projects or monitoring of conservation efforts.

Response:
In addition to the websites listed above in response to the MWCD comment, the following websites should be helpful:

NRCS
http://www.nrcs.usda.gov/programs
and
http://www.nrcs.usda.gov/programs/WSRehab

Grants.gov
http://www.grants.gov/NaturalResources

US Dept. of Ag.
http://www.rurdev.usda.gov/ca/index.htm

EPA
http://yosemite.epa.gov/r9/fsfc.nsf/fundingsources?ReadForm
and
http://yosemite.epa.gov/r9/fsfc.nsf/58cc78776e5e186b8825641b006a9bd8/d52443c8332833368825642900696104!OpenDocument
and
http://www.epa.gov/region9/funding/index.html

The Rural Community Assistance Corporation
http://www.rcac.org

19. Process Issues

Montague Water Conservation District comment:
The district is interested in meeting with the staff of the California Water Quality Board and discussing the concerns of the TMDL recommendations.

Response: In response to this request, Regional Water Board staff met with the Montague Water Conservation District on April 12, 2006.

Rancho Hills Community Association comment:
Since the Shasta River runs through our development, it seems reasonable that some notification to our association regarding these hearings would have been justified. We would appreciate being notified in the future.

Tom Connick comment:
It's unfortunate as an adjudicated water rights landowner in Siskiyou County that I was not and have not been contacted directly about the 2/22/2006 Draft Action Plan for the Shasta River Watershed.

Tom Wetter comments:
First, statements contained in your documents use "Quality Management" and "Business Plan Development" terms and describe processes used to identify and involve stakeholders. However, for these phrases to become more than just slogans for your organization, a real effort must be made to involve, notify, and communicate with all of the stakeholders.

For the Shasta River TMDL Action Plan, the first report I saw in the newspaper was an article in the March 21st edition of the Siskiyou Daily News. According to your Department, the public comment period started on February 7th 2006. Again, access to the plan document (some nine inches thick) has been extremely limited. In response to the public outcry, the comment period was extended to April 3rd. The process used by NCRWQB to develop the Shasta River TMDL Action Plan seems to limit public input and comment by design.

Shasta Valley RCD comments:
Documents as posted on the RWQCB website are not accessible for people on dial-up Internet connections. Even with a 10-day extension in time for review, we do not feel that adequate review has been done.

A 30-day review is quite short for reviewing documents as lengthy as published for any TMDL study and implementation plan. A longer review period should be allowed for subsequent TMDL efforts.

Response: The Basin Plan amendment process must adhere to legal requirements put forth in the California Water Code regarding adequate noticing of hearings, workshops and the public comment period. The TMDL load allocations from the technical analysis and the Action Plan are the parts of the TMDL proposed for adoption as an amendment to the Regional Water Board Basin Plan. All the legal requirements for public participation were met for the Shasta TMDL process. The public had ample time to review the public draft and provide comments. The public comment period began on February 7, 2006 and ended on April 3, 2006. The notice for the public comment period was mailed to those who expressed interest in receiving it in January. Although not a legal requirement, it was also noticed in three newspapers in early February, including the 'Siskiyou Daily News'; circulated where the commenters reside. The first five chapters of the TMDL Staff Report were posted on the Regional Water Board website on February 7, 2006. Chapters 6 and 7 were posted on February 10, 2006 and the rest of the Staff Report and the Basin Plan amendment language (TMDL Action Plan) were posted on February 22; meeting the legal requirement for at least a 30-day comment period. The public hearing scheduled for May 17, 2006 was noticed on March 28, 2006 and published in the Siskiyou Daily News meeting the 45-day noticing requirements. Chapter 14 of the staff report further describes the public participation process for the Shasta TMDLs.

If interested parties did not receive the notice in the mail before the comment period started, it is because they did not notify staff that they wished to be included on the mailing list. Regional Water Board staff made numerous and continual efforts to include interested parties in the TMDL process and to provide opportunities for public input, including commenting on the public draft TMDLs. The Regional Water Board will include all those who expressed an interest during the public comment in future notices and mail-outs.

Santa Rosa Public Workshop comment:
Siskiyou County Supervisor Jim Cook: … there were no meetings with the local technical advisory group and the board staff to go over the current draft (of the Basin Plan language) before it was released. There was no opportunity for the staff to fine tune the wording for better understanding by the people that are most likely to be affected, based on discussions that might and should have taken place.

We would like to have you provide time for technical advisory group review and discussion of this document. We'd like you to provide for public distribution electronic and/or hard copies of the document with any clarifying revisions identified as needed by that technical advisory group. And then schedule a final public workshop in Yreka area, and finally then and only then schedule the final public comments to the board with the time for the board and the staff reflection for those comments to be taken into action.

Shasta Valley RCD comment:
Another concern is the lack of input by a local stakeholders group (TAG) before the TMDL documents were made public.

Shasta CRMP comments:
… there was no meeting with the local technical advisory group and RWQ staff to go over the current findings before they were released. No opportunity for RWQ staff to fine tune wording for better understanding by the people most likely to be affected based on discussions that might and should have taken place. Provide time for a TAG review and discussion of the document.

Schedule a final public workshop in the Yreka area, and finally then and only then, schedule final public comments to the board with time (i.e. a month) for board and staff reflection on those comments before taking action.

Response: The above commenters called for another Technical Advisory Group (TAG) meeting before the public comment period ends. Although, as explained above, the Regional Water Board staff have met all of the legal requirements for public participation, staff have scheduled two additional meetings before the Regional Water Board adoption hearing on May 17 to review the revised Action Plan and supporting Staff Report. These meetings will be held on May 4 in Orleans and May 5 in Yreka. Further, if and when the Regional Water Board adopts the amendment, the public can provide additional comments on the adopted draft before the State Water Resources Control Board (State Board), the Regional Water Board's parent agency, holds their adoption hearing.

Shasta Valley RCD comment:
It is suggested that the Basin Plan language be provided in a Word format for easy review and comment/language change documentation. In trying to make suggestions for language change, we had to scan the document (with many associated mistakes) and then work off of this poor copy, as time was short to complete this effort and have the document ready to submit by the April 3rd deadline.

Response: Staff will consider using Word format for future online posting. Adobe Acrobat was used to create a pdf file of the TMDL documents. It is possible to select, cut and paste text from a pdf document to a Word document, although we agree that posting in the Word format is more convenient for editing.

Shasta CRMP comment:
And maybe the greatest problem in the near term--those who did not have access to a high speed internet connection were effectively disenfranchised from any opportunity to get and review the document; given its 96 mb size.

Santa Rosa Public Workshop comment:
Siskiyou County Supervisor Jim Cook: **…**the greatest problem in the near term for those of us that don't have access to high speed internet connections. We're effectively disenfranchised from any opportunity to get and review the document because of its size.

We would like to see the electronic or hard copy form so that we can distribute it effectively.

Save our Shasta and Scott Valley comment:
In order to meet deadlines, the TMDL process for the Shasta Valley has severely limited the public from providing meaningful input. The electronic version available shortly prior to the public meeting was unreadable and hard copies are only now available.

Shasta Valley RCD comment:
Documents as posted on the RWQCB website are not accessible for people on dial-up Internet connections. Even with a 10-day extension in time for review, we do not feel that adequate review has been done.

Response: The chapters were posted individually in order to make it easier to download. However, the above commenters have indicated that people with a 'dial-up' Internet connection were not able to download some of the chapters due to their size. The Regional Water Board staff apologize for this inconvenience, but note that 'DSL' internet connections are available in Siskiyou County. Using a connection at least as fast as 'DSL' allows easy access to posted information on the Regional Water Board website. The Siskiyou County Library has a 'T1' internet connection, which is faster than 'DSL', and the library allows users to make copies for 10 cents a page. In addition, the newspaper notices announcing the availability of the public draft on February 7 included the phone numbers of Regional Water Board staff. The Regional Water Board website where the document was posted also included the phone numbers of Regional Water Board staff. Staff were available to help stakeholders in obtaining the Shasta TMDL documents. If staff had received a request by phone, email, fax, or in person, arrangements would have been made to ensure that all those interested were able to receive a copy of the TMDLs and the Basin Plan language. However, no requests in any form were received and the first staff heard of downloading problems was at the March 8, 2006 Regional Board Workshop in Santa Rosa. Regional Water Board staff provided Mr. Jim Cook with a hard copy and CD containing the Action Plan and Staff Report at the March 8, 2006 workshop. On March 9, 2006, Regional Water Board staff sent by overnight delivery service 25 CDs containing the Action Plan and Staff Report, in response to a request from the Shasta Valley RCD.

Santa Rosa Public Workshop comment:
Siskiyou County Supervisor Jim Cook: The (TMDL) document was posted on two separate days and that served to confuse people. Those who could download it right away had no clear indication that there were major components that were arriving some time later, the next day or slightly later and that information needed to be downloaded, there was no indication that that was happening.

Shasta CRMP comment:
And the document itself, posted on two separate days served to confuse people—those who downloaded it right away had no clear indication that major components would be

arriving sometime later and would absolutely need to be captured also, or that the draft basin plan language was to be found elsewhere.

Response: The above commenters expressed concern that people downloading the document from the Regional Water Board website on February 7 were not aware that Chapters 1-5 of the staff report did not make up the entire document. However, on the website where these chapters were available, it was made clear that this was not the entire document and that the remainder of the document would be posted no later than February 22, 2006. There were over 30 days to review the document and provide comment from the time all Shasta TMDL documents were posted on February 22, 2006.

Shasta CRMP comments:
During the Yreka Workshop, staff frequently stressed the desire to adaptively respond to additional information over time, yet there doesn't seem to be provision for that in the draft basin plan language.

Response: Many of the actions in the Action Plan require that staff give an update to the Regional Water Board on how implementation of and compliance with the TMDLs is progressing. At that time, the Board may direct staff to amend the Basin Plan in response to implementation or compliance issues that may have arisen. Staff can amend the Action Plan as appropriate in the form of a Basin Plan amendment that will undergo the same public process as the Shasta TMDLs. See also Section VIII of the Action Plan for "Reassessment and Adaptive Management" for additional information.

Tom Connick comment:
Will independent scientific peer review support the data and conclusions presented in this report?

Response: Prior to development of the Public Review Draft of the Shasta River TMDL staff report, Dr. Charles Coutant reviewed the draft report as part of a formal state-mandated peer-review process. Dr. Coutant's comments on the peer-review draft are presented in Appendix I of the Staff Report.

Klamath River Keeper comment:
It is instructive that - in spite of your and your staff's many *"mea culpa's"* concerning your failure to implement your own Environmental Justice Policy during development of the Shasta, Scott and Lost River TMDLs you have yet to hold one TMDL meeting in a Klamath River community.

Response: Although Eureka is not on the Klamath River; the Regional Water Board did hold a public workshop there, in response to a previous request from the commenter. At that time, both Regional Water Board staff and the commenter believed that this adjustment was responsive to the concerns expressed by the commenter. Since that time, the commenter has expressed further concerns regarding the need for meetings in communities on the river, and the Regional Water Board is making arrangements to do this for subsequent meeting sequences for this and other Klamath Basin TMDLs. Staff acknowledge the need to hold TMDL meetings closer to those communities affected by water quality in the Klamath River and its tributaries. Staff encourage members of the Klamath communities to comment on the Shasta or other TMDLs.

California Cattlemen's Association comment:
CCA agrees with the general concept and voluntary approach taken by the North Coast Water Board (Regional Board) to address the impairments of the Shasta River and tributaries.

Response: Comment noted.

20. Miscellaneous

Edward Jones comment:
In regards to the temperature and dissolved oxygen being a factor in the small salmon and steelhead runs in the Shasta River, this is just not true. The fish are accustomed and adapted to this water. Having lived here 73 years I have seen big runs of salmon some years, and small runs other years. I just about lived down at the Shasta River swimming, the water was very warm but the small salmon and steelhead hatch would be swimming right with us. The low oxygen and the high temperatures have always been present in the Shasta River, I guess back then the young fish had not been told they were dead due to these conditions.

Response: While it is true that a certain percentage of fish can tolerate adverse conditions for a limited amount of time, there is ample evidence of the overall decline of Shasta River salmonid populations. Chapter 1, Section 1.4.10 details the well-documented legacy of population declines. Chapter 2 details the life stage requirements of various salmonid species with respect to water quality and clearly demonstrates that existing water quality conditions in the Shasta River and to a lesser extent in its tributaries are not supportive of biological requirements of these salmonid species. The TMDLs are aimed at restoring water quality and supporting beneficial uses, including those related to salmonid populations.

Eureka Public Workshop comment:
Denver Nelson: for a lot of the summer, there isn't any flow at the mouth of the Shasta into the Klamath.

Response: The Shasta River is important both because it provides rearing and spawning habitat for juvenile salmonids within the Shasta River drainage as well as well as because it discharges to the Klamath River. TMDL analysis results indicate that restoring water temperatures in the Shasta River would have a significant effect on temperatures of the Shasta River at its confluence with the Klamath River, and this effect would be further enhanced by increases in contributions of cold water from upstream parts of the watershed. In addition, the watershed remains a crucial part of the recovery of salmonid populations in the Klamath Basin.

Eureka Public Workshop comment:
Tim McKay: I would like that if in your implementation plan and monitoring that you could identify your institutional barriers to achieving your affirmative duty to protect the resources under the public trust.

Response: The Regional Water Board must work with and coordinate with a variety of local, state, and federal agencies with authority or responsibilities that overlap with those of the Regional Water Board. Coordinating with these other agencies is an ongoing challenge for both the TMDL process and for water quality regulation in general. For example, the Regional Water Board is working to improve communication between the Division of Water Rights and the Division of Water Quality at the State Water Board to better coordinate the agencies' actions.

Yreka Public Workshop comment:
Rex Houghton: We've been working with DFG with the ITP – are we going to jump through the same hoops?

Response: The Regional Water Board staff are committed to working with the Department of Fish and Game (DFG) to dovetail the ITP with the Shasta River TMDL Action Plan, as is noted in the Action Plan and the Staff Report

Yreka Public Workshop comment:
Dom Meamber: Dr. Coutant said in his review that 16 C is too low for juvenile coho growth.

Response: Dr. Coutant suggested 16 C is low for juvenile core rearing, but that it is "a useful goal". Regional Water Board staff chose to include 16 C as a chronic effects temperature threshold for core juvenile rearing, based on US EPA (2003) guidance, as discussed in section 2.3.1 of the Staff Report.

Tom Connick comment:
One can only hope that the assumptions and conclusions reached in this report are being applied equally and as rapidly throughout, and to every watershed in the entire state, not just the ones with the smallest populations.

Response: There are two main driving forces behind the Regional Water Board's development of the Shasta TMDLs. First is the Shasta's inclusion on the 303(d) list of impaired waters, which triggered TMDL development. The Shasta River is listed for water temperature and dissolved oxygen. The second is a the Consent Decree entered into in 1997 between the USEPA and a group of plaintiffs. The Consent Decree required a schedule for completion of TMDLs for listed waters in the North Coast region including the Shasta River. The Consent Decree requires completion of TMDLs for 18 watersheds in the region by the end of 2007. The Shasta is thus one of the last watersheds for which TMDLs are being completed as part of the Consent Decree.

Pacific Coast Federation of Fishermen's Associations comment:
Inadequate enforcement of Basin Plan standards by other agencies should be addressed by the NCWQCB.

Response: The Regional Water Board staff is committed to working with other agencies to enforce Basin Plan standards.

Marcia Armstrong comment:
We feel that the Temperature TMDL does not take into consideration the potential for adaptive genetics within the salmonid fish stocks. The statement is also made that USEPA feels that "temperature change is linked to multiple genes, and thus would not be easily modified through evolutionary change without a radical shift in associated physiological systems." To the extent that differing locations for runs of anadromous fish stocks are identified as significant units of those species' populations, we feel that the salmonid species of fish in the Shasta River Basin have demonstrated their capacity for genetic adaptation. In addition, hatchery fish stocks are said to be different from wild fish stocks even when hatchery fish are bred from wild fish. It is not then too far to go to recognize that there could be fish in the Shasta River system that are different from those fish studied to determine temperature thresholds. Therefore, we feel that the question of temperature thresholds applicable to Shasta River stocks is still an open question."

Tom Connick comment:
The idea that one-size salmonid fishery standard fits all is expedient, but no very scientific or realistic. Salmonids by nature return to specific streams because they are categorically different and unique.

Tom Connick comment:
Were the benchmarks presented site specific to this particular watershed with its unique hydraulics, geological and volcanic activity?

Response: As the commenters note, USEPA Region 10 investigated the potential for variation in temperature requirements among stocks or species of salmonids (*Issue Paper 5: Summary of Technical Literature Examining the Physiological Effects of Temperature on Salmonids,* USEPA 2001a). USEPA concludes that there is not enough significant genetic variation among stocks or among species of salmonids to warrant geographically-specific water temperature standards.

The EPA statement quoted by the commenter above explains why differences in temperature tolerances are not likely; "temperature change is linked to multiple genes, and thus would not be easily modified through evolutionary change without a radical shift in associated physiological systems." So while the genes may be different, there most likely aren't enough different genes to affect the fundamental biological makeup that generally determines temperature tolerance. While it is true that hatchery fish genetics differ from wild fish, it has not been proven that these genetic differences result in differing temperature tolerances. Likewise, while Evolutionarily Significant Unit's are based on genetic differences between salmonid populations, they are not presumed to relate to temperature tolerance.

The same EPA document quoted above goes on to suggest that the salmonids' shared fundamental biological makeup is a product of evolution. Salmonid species in the Pacific Northwest all share the same ocean, where they spend most of their lives. Pacific Ocean temperatures do not vary much up and down the coast, and generally do not exceed the scientifically proven optimal temperatures for salmonids in freshwater.

The USEPA used the technical document cited to support their guidance document for developing water temperature standards in the Pacific Northwest (*EPA Region 10 Guidance for Pacific Northwest State and Tribal Water Quality Standards, [USEPA 2003]*). The 2003 guidance document presents temperature criteria for various salmonid lifestages. USEPA created this guidance to assist states and tribes in adopting temperature water quality standards that would be approved by USEPA and consistent with the Clean Water Act and National Environmental Policy Act. Staff feel confident that the USEPA numeric temperature criteria for salmonids used in this TMDL document are scientifically supported and reflect the best available data on temperature thresholds.

In conclusion, Regional Water Board staff recognize that salmonids species in the Pacific Northwest may have slight differences in temperature tolerance, but more data are needed to quantify these differences. Currently, enough data exist to determine that Shasta River temperatures are not supportive of salmonid species; in fact, they occasionally exceed scientifically proven lethal levels. If there is information that reflects different thermal tolerances of salmonids of the Shasta River Basin, Regional Water Board staff would welcome the opportunity to review this information.

Siskiyou Supervisor Marcia Armstrong comment: This TMDL appears to conclude that only a "naturally loaded TMDL" can satisfy the water quality objectives, rather than allowing for "non-point loading."

Response: The TMDL does not require the elimination of non-point source loadings. The loading capacity includes allocations to non-point sources.

Patrick Griffin comment:
13.4.2 states; "It is up to the landowner/discharger to decide which implementation actions and management measures are most appropriate to control sediment and water temperature on his or her property." Will the landowners and water users in the Shasta Valley actually have that choice?

Response: The landowner will have their choice in methods for addressing water quality on their property. The Regional Water Board does not prescribe management measures for controlling impacts to water temperature and dissolved oxygen in the Shasta River watershed. This is most appropriately developed by the landowners because they can make prudent judgments based on site-specific conditions on their land. The Staff Report does provide examples of measures for controlling impacts to water quality, however the landowner is not confined to these measures. The landowner is responsible for water quality impacts originating on their property. As stated in the Action Plan, the Regional Water Board will periodically assess the progress of this approach and decide whether more prescriptive measures are necessary.

Jim Henderson comment:
Please do everything you can to protect the Shasta River. It can be one of the greatest sources of cold water inputs to the mainstem Klamath River. Keep it cold and keep it clean. The salmon are counting on it. Salmon as you know are an elastic species but we as managers of their habitat need to keep the door open for their return. Cleaning up the Shasta to near pre-Euro contact is crucial and when combined with some CA dam removals will go a long way towards bringing the salmon back.

Response: Comment noted. The Regional Water Board recognizes the importance of the Shasta River Basin in providing crucial rearing and spawning salmonid habitat. The contribution of the Shasta River to the heat budget of the Klamath River will be more closely assessed in the technical analysis for the Klamath River TMDLs.

John Spencer comment:
Pleased be advised that we live on the Shasta River at Shelly Bridge and have spent years trying to be good stewards of the river. This river is too precious to exploit or pollute. However this is being done by ranches both upstream and my neighbor who takes water out day and night for example, with an 8-inch pipe even when the water is just a trickle. Rivers are too precious to be destroyed by the greed of those who exploit the river for their own selfish needs. It need not be that way. They can keep the river clean and cool whereas all concerned especially the fish and wildlife, may continue to sustain life instead of destruction.

Response: Comment noted. The technical analysis for the Shasta River Temperature TMDL recognizes the importance of flow in controlling water temperature.

Shasta CRMP comments:
The plan poorly addresses present and future suburb and rural residential impacts on water quality or stream shading. This becomes significant to the extent that agricultural land will likely be converted to rural residential, where land manipulation processes are no longer driven by agricultural return on investment economics.

Response: The TMDL Action Plan does not envision or require the conversion of agricultural land to suburbs and rural residential development. The TMDL does, however, require landowners to address their impacts to water quality through the implementation of appropriate management measures.

Don Meamber comment:
Concerning the gravel problem; I was talking to Dave Webb about the subject a couple years ago. I wondered if one of the old monster gold mining dredges could be put to work cleaning the bottom of the river. I was talking to a contractor recently who is putting in another tailwater pipeline for me now just N. of the River. He used to own and operate a stationary dredger in Scott Valley. He thought it might work to pick up the material off the bottom, screen the gravel and drop it back into the river and scatter the silt and sand back onto the stream bank. This might be an alternative to importing gravel and maybe less expensive. I know DFG has problems getting rocks or gravel to streams bed without damaging the banks in the process.

Response: Comment noted. The issue of spawning gravel conditions and abundance was not addressed as part of the TMDL analysis.

Save our Shasta and Scott Valley comment:
The Shasta Valley like the Scott has a unique history of major accomplishments through voluntary actions and hard work. If this plan is adopted in its present form, then the North Coast Board risks the undermining of all of these cooperative efforts.

Response: That would be unfortunate, especially since the TMDL Action Plan is crafted around and supports ongoing efforts by landowners and other interested stakeholders to restore and protect water quality. Regional Water Board staff believes that the proposed Action Plan provides landowners with a “feasible and reasonable” approach to bringing their discharges into compliance with water quality standards. The Regional Water Board hopes to continue working with landowners to implement projects that protect water quality in the Shasta River Basin.

General Comment Regarding Limited Time Scale of Analysis:
A number of commenters raised concern that the Shasta River model was applied for too short a time period, and was not appropriate to base the Action Plan on the results of this application.

Response: TMDLs must result in attainment of water quality standards throughout the year, including under critical conditions [40 CFR 130.7(c)]. For the Shasta River, temperature and dissolved oxygen objectives are not being met during the summer months. The temperature and dissolved oxygen load allocations were developed based on the water quality compliance scenario, which was run for the period August 29 – September 4, 2002. As detailed in section 6.3 of the Staff Report, both air temperature and flow conditions represented critical conditions during this time period. Results of the water quality compliance scenario demonstrate that when the TMDL is fully implemented, water quality standards can be achieved under critical conditions.

Section 2 – Individual Comments and Responses

1. Margaret J. Boland and J. Sharon Heywood – US Forest Service Comments

Comments:
Staff Report Pg. 8-5 – "Proposed implementation actions for sources related to activities on United States Forest Service holdings include application of the Interim Riparian Reserves management practices described in the Northwest Forest Plan Aquatic Conservation (ACS) Strategy, and rangeland management and grazing strategies detailed in the joint management agency document: Riparian Area Management 1997."

As an alternative to citing the Northwest Forest Plan we recommend that the Shasta-Trinity and Klamath Land and Resource Management Plans (LRMPs) be referenced. Both LRMPs have incorporated the Aquatic Conservation Strategy including direction for Interim Riparian Reserves, Key Watersheds and the nine ACS objectives. The LRMPs incorporate the Forest Service Best Management Practice guidance document as Forest-wide Standard and Guidelines (See Klamath LRMP page 4-19 and Shasta-Trinity LRMP page 4-25.) Referencing the Forest Plans would provide a stronger link between the TMDL Action Plan and activities on lands managed by the Forest Service.

Response: Citations have been revised to reflect the reference to the Shasta-Trinity and Klamath Land and Resource Management Plans.

Comment:
The citation for the Shasta-Trinity Forest LRMP is: United States Forest Service (USFS). 1995. Shasta-Trinity National Forest Land and Resource Management Plan, Shasta-Trinity National Forest, Pacific Southwest Region. The citation for the Klamath Forest LRMP is: United States Forest Service (USFS). 1995. Klamath National Forest Land and Resource Management Plan, Klamath National Forest, Pacific Southwest Region.

Response: The staff report, including reference section will be revised to use the correct citation.

Comments:
We would like clarification as to which document is being referred to as “Riparian Area Management 1997”. We could not find a document that fit this description in the References chapter. We believe that this reference refers to ‘Riparian Management, TR 1737-14 1997, Grazing Management for Riparian-Wetland Areas, USDI-BLM, USDA-FS.” This document is a good technical reference but it does not set range management direction for the Forest Service. As an alternative to referencing this document we recommend that the TMDL Action Plan reference each Forest’s respective LRMP and tier to existing management direction for range management. For example, the Shasta-Trinity NF LRMP contains goals and standards and guidelines for range management. Examples of this information follow:

Shasta-Trinity LRMP, pg. 4-5 – Forest Goals for Range Management
21. a. Manage rangeland vegetation to provide for healthy ecosystems and to make forage available on a sustainable basis for use by livestock and wildlife.
21. b. Manage livestock grazing activities to meet desired ecosystem conditions to the extent that such activities do not adversely affect the attainment of the Aquatic Conservation Strategy or Riparian Reserves. Similar goals can be found on page 4-9 of the Klamath LRMP.

Shasta-Trinity National Forest LRMP, pg. 4-6 – Forest Goals for Water
39. Maintain or improve water quality and quantity to meet fish habitat requirements and domestic use needs.
40. Maintain water quality to meet or exceed applicable standards and regulations. Klamath Forest Water Quality goals are similar, and can be found on page 4-5 of the Klamath LRMP.

Standards and Guidelines (S&Gs) for Range are found on page 4-22 and 23 of the Shasta-Trinity National Forest LRMP and page 4-63 through 4-68 of the Klamath National Forest LRMP. These S&Gs lay the foundation for management of grazing activities on Federal Lands.

Because all range management activities tier to the Shasta-Trinity and Klamath National Forest LRMPs we believe that citing these documents under proposed implementation actions (instead of Range Area Management 1997) will more accurately meet the intent of implementation actions for the TMDL Action Plan.

Response: The Staff Report and Action Plan will be revised to cite the grazing measures as contained in the Shasta-Trinity National Forest and Klamath National Forest LRMPs. The reference will also be corrected

Comment:
Pg. 8-29 (first paragraph) – “The Pacific Northwest Forest Plan, including the Aquatic Conservation Strategy, is applicable to both these national forests. The USFS also

administers the Klamath National Forest Land & Resource Management Plan (KLRMP) and the Shasta-Trinity National Forest Plan."

It would be good to note that both Forest LRMPs have incorporated direction from the Northwest Forest Plan (i.e. the Aquatic Conservation Strategy) and all amendments. The LRMPs are the guiding management documents for both forests.

Response: Comment noted. Staff Report will be revised to clarify this incorporation.

Comment:
Pg. 8-29 (second paragraph) – "To date, there have been no watershed analyses by the USFS for their management areas in the Shasta Valley…"

This is a correct statement for the 5th Field Watersheds located partly within the Shasta-Trinity National Forest. These watersheds include Parks-Willow, Upper Shasta River and Whitney-Herd Peak. However, portions of the Klamath National Forest, including Little Shasta River and Grass Lake watersheds, are covered in the Goosenest Adaptive Management Area Ecosystem Analysis (USFS, 1996, Goosenest Adaptive Management Area Ecosystem Analysis, Goosenest Ranger District). That analysis functions as a watershed analysis.

Response: This clarification will be made in the staff report.

Comment:
Pg. 8-29 (second paragraph) – "…the USFS implements best management practices (BMPs) for the protection of water quality contained in the guidance document, Water Quality Management for Forest System Lands in California, Best Management Practices (guidance Document), referred to by the USFS as the Forest Service 208 Report."

We recommend that the wording "Forest Service 208 Report" be dropped. This term isn't commonly used to reference the BMP program. Retain the reference "Water Quality Management for Forest System Lands in California, Best Management Practices".

Pg. 8-29 (second paragraph) – "The Forest Service 208 Report arose from a formal Management Agency Agreement …"

Replace '208 Report' with 'Best Management Practices Program'.

Response: The phrase "Forest Service 208 Report" will be replaced with Best Management Practices Program.

Comment:
Pg. 8-29 (third paragraph) – “The Aquatic Conservation Strategy, referred to above, also elucidates the Standards and Guidelines for Riparian Reserves that, for the most part, provide variable width no-harvest and reduced harvest buffers around fish-bearing streams.”

Drop the phrase “no-harvest”. Harvest could be prescribed on a site-specific basis in order to meet the Aquatic Conservation Strategy under the LRMPs (and Northwest Forest Plan).

Response: The phrase “no harvest” will be deleted from the Staff Report to maintain consistency with the approved Aquatic Conservation Strategy under the LRMPs (and Northwest Forest Plan).

Comment:
Pg. 8-29 (last paragraph, first sentence) – “The USFS defines “Riparian Reserves” as forestland allocations…….”

Change “forestland allocations” to “Forest land allocations” in order to indicate that these are land use determinations, in keeping with provisions of the National Forest Management Act.

Response: Change will be reflected in the Staff Report.

Comment:
Pg. 8-29 (last paragraph, third sentence) – “After each USFS management district performs a watershed analysis, decision-makers can then tailor the riparian reserve buffers of the Aquatic Conservation Strategy to conform to local conditions.”

This sentence is confusing because the Forest Plans (per the Northwest Forest Plan) required a watershed analysis if there is to be a change in the interim widths. To add clarity, replace “riparian reserve buffers” with “riparian reserve buffer widths”. Refer to language in the Scott River TMDL Staff Report (Section 5.1.11.2) which is more accurate than the subject wording.

Response: “Riparian reserve buffers” will be replaced with “riparian reserve buffer widths” to maintain consistency with the approved Aquatic Conservation Strategy under the LRMPs (and Northwest Forest Plan).

Comment:
Pg. 8-29 (last paragraph, next-to-last sentence) – “Specifically, Table 8.7 identifies the riparian type and Riparian Reserve buffer widths that would apply to USFS land in the Shasta Valley.”

This statement is not accurate because of several inaccuracies in Table 8.7:

1. The source for the table is incorrect. We couldn't find the page cited in the footnote.

2. The third column ("Buffer Widths") should be deleted. The height of site potential trees is determined for a specific area during a project environmental analysis process. The widths shown in this column apparently were taken from a project well outside the watershed, because site-potential trees on the drier east side forest types, typical of those in the Shasta River watershed, are smaller than 150 feet, regardless of species.

3. Remove the footnote stating that one site potential tree is for Douglas fir, since the **number** of site potential tree heights is Forest direction, while the **heigh**t is determined on a site or project scale.

4. The "Wetlands <1 acre in size" width should not be N/A, as this would confuse the reader. Incorporate the intent of the actual directive, which says that "The wetland and area from the edge of the wetland to the outer edges of the riparian vegetation" comprise the interim riparian reserve width.

Response: Table 8.7 has been revised to correct inaccuracies and maintain consistency with the approved Aquatic Conservation Strategy under the LRMPs (and Northwest Forest Plan).

Comment:
Pg. 8-29 (last paragraph, last sentence) – "Within the Riparian Reserve buffers, timber may not be harvested and additional management practices and restrictions are required pertaining to livestock grazing, mineral extraction, and recreation."

Replace this sentence with "any land management activity occurring within the Riparian Reserves would have to be consistent with the Aquatic Conservation Strategy and applicable Standards and Guidelines for Riparian Reserves."

Response: Revision will be made to maintain consistency with the approved Aquatic Conservation Strategy under the LRMPs (and Northwest Forest Plan).

Comment:
Pg. 8-30 (second paragraph) – "…the USFS implements rangeland management and grazing strategies designed to lessen impacts to water quality that are detailed in the joint management agency document: Riparian Area Management 1997 (USDA/USDI 1997), and also in the Forest Service 208 Report (USDA 2000)."

Consider rewording first sentence as follows: the USFS implements rangeland management and grazing strategies designed to lessen impacts to water quality as described in Water Quality Management for Forest System Lands in California, Best Management Practices, 2000 and in grazing allotment management plans.

Remove the reference to Riparian Area Management 1997. See also the comment for page 8-5 (third comment bullet) and the comment for Pg. 8-30 (last paragraph).

Response: Suggested revision will be incorporated into Staff Report and citation corrected.

Comment:
Pg. 8-30 (last paragraph) – "… the USFS shall consistently implement the best management practices included in Riparian Area Management 1997, and Water Quality Management for Forest System Lands in California, Best Management Practices (USFS 2000)."

Drop Riparian Area Management 1997 reference and replace with respective Forest LRMPs.

Response: See response above. Citation will be corrected.

Comment:
Pg. 8-31 – "Additionally, the Regional Water Board shall work with the USFS to draft and finalize a Memorandum of Understanding (MOU). The MOU shall be drafted and ready for consideration by the appropriate decision-making body(ies) of the USFS within two years of the date the TMDL Action Plan takes effect."

The Forest Service supports the development of an MOU with the North Coast Water Quality Control Board. We also appreciate that the TMDL Action Plan acknowledges the need to take into consideration USFS resources available to carry out actions developed in the MOU.

Response: Comment noted.

Comment:
Pg. 8-31 – "Contents specifically related to elevated water temperatures:

1. A commitment by the USFS to continue to implement the Riparian Reserve buffers width requirements.
2. A monitoring plan to ensure that the Riparian Reserve buffer widths are effective at reducing high water temperatures.
3. A commitment by the USFS to implement the monitoring plan and conduct adaptive management."

For #1: Text correction, should read: ‘implement **its** Standards and Guidelines for Riparian Reserves per the Shasta-Trinity and Klamath LRMPs.

For #2: Text correction, should read: “a monitoring plan to ensure that the Standards and Guidelines for Riparian Reserves are effective at preventing or minimizing effects on natural shade.”

For #’s 2 and 3. The MOU requires “a monitoring plan to ensure that the Standards and Guidelines for Riparian Reserve management are effective” and “a commitment by the USFS to implement the monitoring plan and conduct adaptive management.” Our understanding is that the details of this monitoring plan will be worked out during preparation of the MOU and that consideration will be given to the availability of USFS resources to carry out preparation of the plan and monitoring activities.

Response: Revisions to 1 and 2 as recommended will be made to the Staff Report. The proposed MOU will include specifics of the monitoring plan.

Comment:
Pg. 8-31 – “Contents related to grazing activities affecting both dissolved oxygen concentrations and water temperatures:

1. A date for the completion of a description of existing grazing management practices and riparian monitoring activities implemented on grazing allotments in the Shasta Valley.

2. A commitment by the USFS and the Regional Water Board to determine if existing management practices and monitoring activities are adequate and effective at preventing, reducing, and controlling discharges of biostimulatory waste discharges and elevated water temperatures.

3. A commitment by the USFS to develop revised management practices and monitoring activities should such measures be inadequate or ineffective, subject to the approval of the Regional Water Board’s Executive Officer.

4. A commitment by the USFS to implement adequate and effective grazing management practices and monitoring activities and to conduct adaptive management.”

#1: Does this requirement pertain to Forest Service Allotments in the Shasta Valley only or was it intended to include all Forest Service grazing allotments in the Shasta River Watershed?

Response: The requirement pertains to the Shasta River watershed rather than just to the Shasta Valley. Clarification will be made to the Staff Report.

Comment:
#'s 2, 3 and 4 in previous comment: Currently range management activities on the Shasta-Trinity and Klamath National Forests are directed by the LRMPs, and management plans for each grazing allotment. Range management activities are also monitored under the Best Management Practices Evaluation Program. The BMP Evaluation Program provides for an annual assessment of BMP effectiveness for all management activities monitored. We would like to see the MOU incorporate to the extent possible the BMP monitoring program. The existing program should, with minor modifications, satisfy the requirements of #'s 2, 3 and 4. This existing coordination along with other coordination activities is noted in the TMDL Action Plan on page 8-32 under 'Implementation Schedule'.

Response: It is Regional Water Board staff intent that the existing BMP monitoring program would be the basis for the monitoring as defined in the MOU. An appendix measures were added to the revised Action Plan to clarify grazing measures.

Comment:
#2 in previous comment: There is a typo; "discharges" is repeated.

Response: Typo will be deleted.

Comment:
#3 in previous comment: Replace "should such measures be inadequate" to "should **existing** measures be inadequate". This clarifies which measures you are referring to.

Response: This clarification will be made to the Staff Report.

Comment:
There are 3 current grazing allotments on the Klamath National Forest in the Shasta River Watershed (Horse Thief, Ball Mountain, and Deer Mountain Allotments). Currently there are no grazing allotments on the lands in the Shasta River Watershed administered by the Shasta-Trinity National Forest. The Bear Creek Allotment, located in the headwaters of the North Fork Sacramento River and Upper Trinity River Watershed is the closest active Shasta-Trinity Forest allotment to the Shasta River Watershed.

Response: Comment noted.

Comment:
Pg. 8-32 (Implementation Schedule, #3) – 'MPs' should read 'BMPs'.

Response: Typo will be corrected

Comment:
Action Plan Pg. 13 – Table 4: "Shasta River Dissolved Oxygen and Temperature TMDL Implementation Actions – Activities on Federal Lands.

1. The USFS shall consistently implement the best management practices included in Riparian Area Management 1997 (USDA/USDI 1997), and Water Quality Management for Forest System Lands in California, Best Management Practices (USFS 2000).

2. The Regional Water Board staff will continue its involvement with the USFS to periodically reassess the mutually agreed upon goals of the Management Agency Agreement between the State Water Resources Control Board and the USFS.

3. Additionally, the Regional Water Board shall work with the USFS to draft and finalize a Memorandum of Understanding (MOU). The MOU shall be drafted and ready for consideration by the appropriate decision-making body of the USFS within two years of the date the TMDL Action Plan takes effect. The MOU shall include buffer width requirements and other management practices as detailed in the Implementation chapter of the TMDL."

#1. As noted previously, consider replacing Riparian Area Management 1997 reference with LRMP reference for both Forests. You might consider language used in the Action Plan for the Scott River TMDL in Table 4 under USFS and BLM: "The following items shall be addressed during the MOU development:…………8. A commitment by the USFS/BLM to continue to implement the Riparian Reserve buffer width requirements."

Response: See response above. The Riparian Area Management 1997 reference will be replaced with LRMP reference for both Forests.

Comment:
#3 in previous comment: See our previous comments (on pages 1 through 6 of this attachment) relating to problematic language in the Implementation chapter, which are to be the details of USFS Action #3.

Response: Revisions will be made to both the Staff Report and the Action Plan to ensure consistency of language.

2. Dr. Dan Drake – UC Cooperative Extension Comments

Dr. Drake's comments on issues related to the technical analysis of flow reflect the need to distinguish inflows based on the quality of the water. Additional language has been added to the staff report to clarify this distinction. The water quality compliance condition requires 45 cfs of water from Big Springs Creek (a cold source), or an equivalent flow increase of dedicated cold water that results in the same temperature conditions at the temperature compliance points.

Comment 1:
Figure 3.1 shows surface water temperatures for the river and indicates the location of diversions. I identified 27 diversions on that figure. Water temperatures did increase downstream of 3 of those 27 diversion. However, temperature was cooler after 4 diversions. At 5 diversions the temperature stayed about the same, and at 15 diversions the temperature rose only slightly. If reduced flow increases temperature dramatically (i.e. there is a valid practical observable relationship in this river system) then why wasn't there a consistent increase in surface temperature downstream of diversions?

Response: The temperatures presented in Figure 3.1 reflect the net effect of all the heat exchange processes that affect the river temperature. These heat exchange processes are described in section 3.1.1. It is clear from the available information that cold tributaries, groundwater inputs, and riparian shade have a cooling effect in some reaches. The combination of these and other processes determines the temperature of the river. We maintain that the laws of thermodynamics indicate that the thermal mass of water in a waterbody is a major factor influencing the response of a stream to heat exchange processes. In other words, a larger volume of water heats and cools more slowly in response to heat exchange processes compared with a smaller volume of water. We also point out that the temperatures presented in Figure 3.1 are based on a thermal infrared remote radiometry (TIR) survey of the Shasta River conducted on July 26, 2003. While Figure 3.1 identifies all known locations where there are surface water diversion, it is not known whether (and is unlikely that) diversions were occurring at each of the diversion locations on the date of the survey.

Comment 2:
I address the flow study conducted by Mike Deas and published in 2003, summarized in Figure 3.7. This study uses a model specific for the Shasta River that evaluates solely the impact of various flows with everything else held constant. The study shows that a 10-fold increase in flow (the example in the study from 10 cfs to 100 cfs) impacted average water temperature only 4 degrees at the mouth. This is a very large increase in flow for a small impact. A 5-fold increase in flow was hardly even detected at the mouth by the model. If a 5 or 10 fold increase had such a minimal impact what impact if any could a more achievable increase in flow have on temperature?

Response: Figure 3.7 represents the changes in temperature solely associated with different flow volumes. The information presented in Figure 3.7 was developed assuming that the increased volumes are at ambient river temperature. Thus, the results only quantify the change in the rate of heating and cooling due to increased thermal mass and decreased travel time. The TMDL water quality compliance scenario assumes that the increase in flows will be achieved by increase in sources of cold water. The modeling results presented in Figure 3.7 do not quantify the effects of increases of cold water. Nevertheless, although the change in flow volume has a modest effect on the river temperature at the mouth, the increase in volume alone results in an additional six miles of river habitat thermally sufficient for salmonid rearing. An addition of six miles of habitat is not trivial.

Comment 3:
Using public information collected and available from the Department of Water Resources, I looked at flow and water temperatures at the Montague Grenada Road weir. Using data from 1998, a very good water year, I found the average daily flow from mid June to September was 180 cfs. During that same time the water temperature average was 21.9 ºC. Average flow in 2000 was much reduced at 60 cfs at the same location with the same collection procedure by DWR. According to the hypothesis suggested by the draft report, the reduced flows should have seen much warmer water temperature. However, the measured average was nearly identical at 21.7 ºC. Actually, a 0.2 ºC decrease with a 3-fold decrease in average flow rate. The same pattern was seen at the mouth of the Shasta with temperature differences of 0.3C between the years with very different flows. A similar pattern was seen at both locations focusing on just the warmest months of July and August.

The analysis above considered average temperature. I also looked at the number of days over a threshold temperature of 20 ºC. I found, despite the huge difference in flows, the number of days with temperatures over that threshold were about the same (70 and 74). This analysis shows almost no impact with a 3-fold difference in flow rate. Again, what possible impact could a more achievable increase in flow have on water temperature? These data are readily available and published in documents on the web. A Google search will quickly find these data. Yet it was not included at all in the draft document. Why was this information not included to show the impact of flow (or lack of impact) on temperature?

Response: The argument presented further illustrates the need to distinguish between additions of any water versus the addition of cold water. The argument presented leads to more questions than conclusions. For instance, were differences in cold water inputs proportional to the overall increase in flow between the two years? Groundwater discharges are often relatively constant from year to year. Without additional information describing the source and condition of the additional flow, conclusions about the effects of the differences in flow cannot be made.

Comment 4:
I refer to Figure 1.8. Prior to completion of the dam, there are 7 years of data showing total annual discharge at the DWR weir (1911 to 1922). That discharge was about 80,000 acre-feet. There are also 3 values for total discharge from the same location in 2002, 2003 and 2004 indicating about the same total annual discharge of about 80,000 acre feet. Why is that important? How does that relate to reduced flows and warmer temperatures?

We know that dams and particularly Shastina fill in the winter and that they reduce high winter flows. So, if the high winter flows are reduced and we are discharging the same total amount, then flows after the winter have to be higher to discharge nearly the same total annual flow. In this case the summer flows have to be higher than they were before the dam was built. This is not discussed and recommendations to increase flows would only make even greater summer flows than historical.

This concept is supported by anecdotal historical records that suggest the Shasta River may have dried up in some years or been extremely small in late summer (see History, Condition and Prospects of the Indian Tribes of the United States. Journal of the expedition of Colonel Redick McKee, U.S. Indian Agent, through North-western California, Performed in the summer and fall of 1851. By George Gibbs; plus personal communication with Montague resident). The river never dries up or has extremely low flows now with the dam.

Response: Regional Water Board staff agree that reservoirs, including Shastina, store water from wet periods for use in dry periods. The comment points again to the need to distinguish inflows based on the quality (i.e. temperature) of the water. Most of the water released from Lake Shastina is used for irrigation, some of which is lost to evapotranspiration, while some percolates and becomes groundwater, and some other amount enters the river as irrigation tailwater (a.k.a. tailwater return flow). Because irrigation tailwater generally enters the river hot during the day, the increase in river flow is accompanied by an increase in heat load. If the percolated irrigation water enters the river as cold groundwater, then the augmentation of flow may have a beneficial effect on stream temperatures (as the commenter points out in Comment 15). Changes from irrigated tailwater returning as surface water to cooler groundwater inputs may present opportunities for water quality enhancement.

In addition, please note that some areas of current cold water discharge are not impounded by or diverted to Lake Shastina.

Comment 5:
My last point related to flows relates to pool stratification and cool water refugia for fish. In nearby Modoc County, pool stratification has been measured. The stratification is enhanced during periods of the hottest temperatures providing safer places for fish. The Shasta doesn’t have stratification but it does have cool water refugia due to springs. Stratification in pools has been found elsewhere in California, north coast streams, the Sierra Nevada and Southern California. The researchers on the north coast concluded that cool water refugia occur when stream pools are isolated from main channel flows and/or streamflow levels fall below some threshold level. That means higher flows could actually reduce or eliminate the refugia. Would higher flows reduce or eliminate the cool water refugia that we have on the Shasta. Do we already have higher flows than historical and could encouraging still higher summer flows exacerbate a possible lack of cold-water

refugia? There needs to be some consideration of the potential effect of increased flow on cold water refugia. This information needs to be included in the analysis.

Response: The commenter claims that higher flows could reduce or eliminate Shasta River thermal refugia. Thermal refugia are important habitat especially when ambient water temperatures are inhospitable for fish. However, the temperature analysis demonstrates that the water quality compliance scenario results in miles of thermally suitable habitat that don't currently exist. If monitoring data indicate the re-introduction of dedicated cold water has a deleterious impact on beneficial uses, then revisions to the plan can be made consistent with an adaptive management approach.

Comment 6:
There is no comment 6

Comment 7:
This section (Chapter 4) was much more difficult to understand than the temperature section. Efforts to improve the understanding and readability would be beneficial.

Response: Regional Water Board staff agree that the processes affecting dissolved oxygen in the Shasta River are complex and explanation of these processes is highly technical.

Comment 8:
Page 4-3 identifies 4 primary factors affecting the DO. In looking at Figure 4.3 it appears that the reach below A12 has improved DO levels compared to reaches upstream and downstream. Yet the reach below A12 has all the features (high light intensity, fine sediments, macrophytes, and slow moving water for example) that you indicate contribute to low DO. Then how are the improved DO levels at this reach of the river explained?

Response: Figure 4.3 summarizes hourly dissolved oxygen conditions for reaches of the Shasta River. The dissolved oxygen data for a given reach presented in Figure 4.3 is a compilation of measurements within the designated reach. While the reaches were selected to reflect observed differences in temperature and dissolved oxygen conditions between reaches, the differences are most reflective of the specific locations at which the data was collected and the amount of measurement data at these locations. The Highway A-12 to Little Shasta River Reach included dissolved oxygen data collected just below A-12 for 3 to 5 day periods in June, July, August, September, and October 2003 and at Freeman Road for 3 to 5 day periods in June, July, and August 2003. In contrast, the Montague- Grenada Road to Anderson Grade Road reach included dissolved oxygen collected at Montague-Grenada Road for all summer months in 2002 and 2003, at Highway 3 for all summer months in 2003, and at Yreka Ager Road for 3 to 5 day periods in June, July, August and October 2003. With this information in mind, Regional Water Board staff agree that the DO conditions in the Highway A-12 to Little Shasta

River reach are different from those in the upstream and downstream reaches, but the differences do not necessarily represent “improvements”. As discussed in Chapters 4 and 7 of the Staff Report, most of the oxygen demand in the Shasta River is attributed to aquatic plant respiration. Based on the aquatic vegetation survey of the Shasta River conducted in 2004 (NCRWQCB 2005) there is not a lot of aquatic vegetation cover or biomass in the Shasta River at Highway A-12 and at Freeman Road. Regional Water Board staff believe these aquatic vegetation conditions explain the difference in the dissolved oxygen conditions compared with the upstream and downstream reaches, as presented in Figure 4.3.

Comment 9:
Pg 4-10 chlorophyll a values in the Shasta are compared to other streams. Are they appropriate streams for comparison? One of the 3 references is not listed (Lohman et al. 1992), and another is not available for us to review (Tetratech 2005). I was not able to find the USEPA report either. So, I have no way to evaluate the material. Therefore I recommend more text describing why it is an appropriate comparison.

Response: The referenced citations in section 4.3.3.1 include benthic chlorophyll a values that are generally representative of stream trophic status. All references cited in the Shasta River TMDL documents are part of the administrative record and are available for review.

Comment 10:
On Pgs 4-14 and 7-1 various nutrient concentrations in the Shasta are compared to values from the headwaters. The headwaters originate in totally different soils, have much higher gradients and are not an appropriate comparison. The valley sections of the Shasta are a reflection of the volcanic soils it flows through. Other comparisons could be more appropriate to help evaluate the nutrient levels in the Shasta River.

Response: Regional Water Board staff agree that nutrient concentrations are affected by geology and soil characteristics. Section 2.5.2 discusses the variability of nutrient conditions in the Shasta River watershed, and notes that phosphorus concentrations in tributaries that flow through volcanic soils (e.g. Beaughton and Boles Creeks), as well as springs which flow from lava tubes originating near Mount Shasta, have comparatively higher phosphorus levels.

Comment 11:
Pg. 4-15 discusses a tailwater return flow water quality study. The study is not adequately described. It states primarily ditches were sampled and we don’t even know if those ditches enter the river. Ditch values do not necessarily reflect overland or sheet flow water quality. Lastly, the term “flows in ditches” is used once but from then on it becomes tail water return flows. All of the attributes assigned to these ditch samples are

supposed to reflect tailwater return flows. Values from ditches do not necessarily reflect the water that actually enters the river as tailwater; especially overland sheet flows.

Response: As a TAG participant, the commenter may recall that Regional Water Board staff identified water quality sampling of tailwater return flows as an important objective of the dissolved oxygen TMDL monitoring plan, and staff requested permission of landowners to conduct such sampling. Regional Water Board staff collected tailwater return flow samples at those locations for which we were granted access in the summer of 2003. The results of these samples were first reported in the report "Shasta River Water Quality Conditions 2002 & 2003" (NCRWQCB 2004b). At the request of landowners the locations of the tailwater return flow samples were not identified. All of the samples reported as tailwater return flow were collected at locations where the water returned to the river at a downstream location as a surface flow, including flow in ditches. In the TMDL documents "tailwater return flow" refers to surface runoff of irrigation water to a surface water body, and is synonymous with "irrigation return flow".

Comment 12:
Tailwater returns are continued onto Pg 4-16 where it is stated that tailwater return flows are common. Are they really that common? How common is common? What is the volume of return flows compared to the river volume?

Response: As stated in section 4.4.1, "The quality of tailwater return flows in the Shasta River watershed has not been well documented." The same can be said for the volume of tailwater return flows. As mentioned in the response to Comment 11, Regional Water Board staff collected water samples of tailwater return flows at locations for which we were granted access in the summer of 2003. A review by Regional Water Board staff of the Thermal Infrared Radiometry imagery and associated data products collected by Watershed Sciences LLC, on July 27, 2003 (Watershed Sciences 2004, included as Appendix B of the Staff Report), indicated tailwater return flows to the Shasta River at 19 locations on the date of the survey. During the aquatic vegetation survey conducted in July/August 2004, Regional Water Board staff walked or floated nearly 27 miles of the Shasta River from Dwinnell Dam to the mouth. While documentation and measurement of tailwater return flow locations and volume were not study objectives, Regional Water Board staff estimate tailwater return flows occur at a minimum of 19 locations on the Shasta River at rates ranging from 0.25 to 2 cubic feet per second.

Regional Water Board staff believe that more monitoring of tailwater return flows in the Shasta River watershed is needed in order to better characterize the quality and quantity of this discharge. We encourage the accurate measurement and reporting of the quality and quantity of all tailwater return flows in the Shasta River watershed. We believe that qualified organizations such as UC Cooperative Extension, could and should play a valuable and positive role in linking agricultural practices and conditions with water quality compliance in the Shasta River watershed.

Comment 13:
Were nutrient concentrations obtained from these "ditch water" samples used in modeling for tailwater return flows? Were nutrient concentrations obtained from these "ditch water" samples used for accretions to the river? Were any attempts made to adjust accretions for the source of the accretion, for example tributary source, overland flows, ditch returns, and/or subsurface flows? The volumes and quality of each of these sources could, and are likely to be very different. Any results of computer modeling that includes accretions would be highly suspect if the volume and quality of water were not segregated to account for the source of the accretion. It is my knowledge that all of the water quality modeling used aggregated volume and quality for accretions.

Response: The hydrodynamic and water quality input conditions (a.k.a. boundary conditions) for the Shasta River model are presented in section 4.0 and 5.1 in Appendix D of the Staff Report. The water quality concentrations assigned to distributed accretion flows were based on average concentrations of tailwater return flow samples collected by Regional Water Board staff in the summer of 2003. In the absence of detailed information and data, aggregating based on overall accretions to meet conservation of mass constraints is a routine modeling technique.

It is important to recognize that a water quality model is a tool for understanding the water quality dynamics of a waterbody. Any model is limited by the amount of data available to describe the boundary conditions in the model. The locations and quantity of hydrodynamic inputs (i.e. tributaries, groundwater accretions, spring inflows, and tailwater return flows) in the Shasta River watershed are not well documented. As identified in our response to Comment 12, additional data on the quality of tailwater return flows is also needed. The Shasta River water quality model relied upon all available hydrodynamic and water quality data. Regional Water Board staff point out that the model generally calibrated/validated well. However, we believe that the model could be improved with additional hydrodynamic and water quality data to better define the model boundary conditions. We believe that qualified organizations such as UC Cooperative Extension could and should play a valuable and positive role in collecting and interpreting this type of information. Additional information gained through future monitoring/study will be considered with respect to those actions identified in the Action Plan addressing tailwater return flows.

Comment 14:
There are considerable mis-statements and misleading statements related to SOD that are germane to interpretation, conclusions and implementation related to SOD (and dissolved oxygen):

Comment 14 i:
Six locations were not really sampled (as stated on pg 4-4). The first two "locations" near the Montague-Grenada road were about 500 meters apart. "Locations" 3 and 4 were 50 to 100 meters apart. And, "locations" 5 and 6 were 25 to 50 meters apart. When the river is about 40 miles long this does not truly represent 6 different locations. The samples

basically reflect two or maybe 3 locations: near the Montague-Grenada road, and near the Aruja dam (perhaps above and below conditions). Further note these are selected sites for expected high SOD, not representative or random sites to represent the river.

Response: The intent in selecting the SOD measurement locations was to quantify the variability of SOD rates in those reaches with assumed high SOD rates, and was not intended to be representative of variability throughout the river, as the commenter implies. Further, our documentation regarding the SOD measurements has consistently stated that SOD measurements were made at six locations within two short reaches of the Shasta River. Results of the sediment oxygen demand (SOD) measurements were first reported in the report "Shasta River Water Quality Conditions 2002 & 2003" (NCRWQCB 2004b), and reported in a USGS publication (Flint et al. 2005). Page 6 of the NCRWQCB report states: "SOD rates were measured and sediment characteristics classified in the Shasta River upstream and downstream of Montague-Grenada Road and at four locations near the Highway 3 bridge." On page 76 of the NCRWQCB report (in its Appendix 2: Sediment Oxygen Demand Study of the Shasta River – Methodology) it states: "The rate of SOD was measured at six sites in two reaches of the Shasta River (Table 10). These sites were chosen because they are located in a reach of the Shasta River that is known to have dissolved oxygen problems and to accumulate some amount of fine sediment and plant detritus." The text in section 4.3.1 has been modified slightly for clarity.

Comment 14 ii:
The draft text states "…the measured SOD_{20} rates in the Shasta River range from 0.1 to 2.3 $g/m^2/d$…". Based on i. above these samples cannot represent the range in values for the Shasta River. They represent values obtained from expected high SOD locations. In addition, the range is not really from 0.1 to 2.3. Those values are the range of replications or subsamples (2 to 3 replications were taken at each "location") rather than a true range between locations. Thus that range better represents the variation in values.

Response: As the commenter correctly quotes, section 4.3.1 reports the ***measured*** SOD_{20} rates of the Shasta River. The SOD_{20} rates applied for model calibration/validation and the water quality compliance scenario are presented in Table 7.4 of the Staff Report. It is critical to note that SOD_{20} rates of 1.5 to 2.0 are only applied to locations influenced by minor impoundments in the Shasta River. Significantly lower SOD_{20} rates are applied to all other areas of the river.

Comment 14 iii:
The values (Flint et al 2005) show remarkably high variation from replication to replication (e.g. 0.1, 0.7 and 1.5 for 3 replicates at one "location"). Often this amount of variation is due to poor experimental conditions or factors calling into question the validity of the measurements. It is stated that care was taken to avoid disrupting sediment (which would provide inaccurate SOD values). However, no quality control validation was provided to evaluate the effectiveness of the "care" to eliminate or reduce sediment

disruption. From personal experience it is extremely difficult to do anything in some areas of the Shasta River without disrupting the sediment. The high variation in the results (15 fold variation between replications) is strong evidence that errors in the data are present, making them unusable (in contrast to best available).

Response: The commenter is correct that measurement of SOD has inherent challenges, because there is variability in the oxygen demand exerted in the sediments of a dynamic river system. The Regional Water Board contracted with the USGS to conduct the SOD measurements at considerable expense, because the USGS has extensive experience in performing these measurements, and staff believed that careful representation of SOD rates was a very important component of the water quality model. Regional Water Board staff disagree that replicate variation represents error, as the commenter suggests. Finally, we believe the measured SOD_{20} rates do reflect the best available information for the Shasta River, and we would welcome submittal for review of information the commenter believes is superior.

Comment 14 iv:
The draft TDML document makes several points that SOD was related to fine sediments. However, the reference (Flint et al 2003) did not conduct a cause and effect analysis. They estimated the correlation between SOD and organic-matter content and particle size. Furthermore, they did not even find a correlation between those factors (as stated in Flint et al 2003).

Response: Again, we refer to Table 7.4. SOD_{20} rates of 1.5 to 2.0, rates representative of a reach with organic material decomposing at a moderate rate, were only applied to those areas of the Shasta River immediately upstream of minor impoundments, and are consistent with rates reported in the literature from other river systems with high organic loading. All other reaches of the river were assigned considerably lower SOD_{20} rates.

Comment 14v:
Table 7.4 reports SOD rates based on a model to the level of hundredths of a river mile. Modeled values are shown 20 miles from the only sites with actual field data (and those data were not representative samples but selected as high). No field data (except for the 2 or 3 selected locations) or validation of the model was presented. And, the model results were used to set parameters and for compliance, not as a tool to understand relationships (the purpose of a model).

Response: Table 7.4 does not report SOD rates “based on a model”; it reports the SOD rates applied to different locations of the Shasta River as input parameters to the model. The RMS model does not predict SOD rates, and model results were not used to set parameters for compliance. The RMS model applied the SOD rates assigned by Regional Water Board staff.

Comment 15:
The analysis is incomplete in estimating the overall impact of flood irrigation and overland flows associated with flood irrigation on river temperature, nutrients and dissolved oxygen. The conclusions to reduce or eliminate tailwater returns may have consequences not discussed in the draft. Overland flows entering the river may represent only a small portion of the total accretions to the river associated with the practice of flood irrigation. A far greater quantity of significantly better quality water may be entering the river through subsurface flows. This has been observed in several river systems (see for example Torgersen, et al 1995. Thermal refugia and Chinook salmon habitat in Oregon. In: Proc. 15^{th} Biennial Workshop on Color Photography and Videography in Resource Assessment, May 1995, Terre Haute, Indiana. Am. Soc. Photogrammetry and Remote Sensing, and work by Tamzen Stringham, John Buckhouse and Bill Krueger, Oregon State University). Reductions or elimination of tailwater return flows may substantially reduce subsurface flows and their positive influence on water quality (both temperature and D.O.) of the Shasta River. Further analysis is needed to determine the net effect of changing tailwater return flows.

Response: As defined in section 4.4.1, in the TMDL documents “tailwater return flow” refers to surface runoff of irrigation water to a surface water body, and is synonymous with “irrigation return flow”. Regional Water Board staff agree that allowing irrigation water to percolate into the soil is desired, as pollutants can be filtered and trapped within the soil column, and residence times of subsurface flow can help cool the water. See also response to Comment 27.

Comment 16:
As mentioned in #10 and 12 above, it is unclear in the analysis whether the nutrient concentrations determined from the “ditch water” samples were used in analysis of tailwater impacts and responses. Based on the information presented in the draft, those samples should not be used to represent sheet flows or tailwater return in general.

Response: See response to Comments 11 and 13.

Comment 17:
The reduction in warming attributed to a change in transmittance from 100 to 10 percent is a total of about 4 ºC a very small change for a dramatic and unrealistic level of transmittance. This weakens the relationship between shading and reduced warming and any potential to significantly reduce warming.

Response: We assume the commenter is referring to Figure 3.4, which as cited is referenced from Deas et al. (2003). The Deas et al. (2003) work was conducted under contract with the Shasta Valley RCD to evaluate the relationships between flow and shade and stream temperature in the Shasta River. The temperature and dissolved oxygen modeling applied for Shasta River TMDL development built upon this earlier modeling work. Findings of the earlier modeling work were used to further evaluate the factors affecting Shasta River temperature and dissolved oxygen conditions, but the earlier findings were not used directly in calculating the TMDLs. We also disagree with the commenter's assertion that 4°C is a very small temperature change.

Comment 18:
The shade/water temperature relationship is also not strengthened by the shading model results (Deas et al 2003) as cited on pg 3.8. In this study again an unrealistic simulation of 22-foot tall trees on each bank in the canyon resulted in maximum daily water temperatures 3 ºC lower, but almost no change in daily average.

Response: As described in our response to Comment 17, the model results of Deas et. al. 2003 are used to identify the potential factors affecting Shasta River temperatures, but were not used directly in calculating the TMDLs. With this said, we believe 22-foot tall trees are a reasonable assumption for some reaches of the Shasta River, as trees of this height have been measured in places on the river. In addition, evaluating daily average temperatures is less appropriate than evaluating maximum daily temperatures with respect to salmonid temperature requirements.

Comment 19:
The study using 7 foot tall bulrushes (reported on pg 3-8) had only 1 ºC effect on maximum temperatures, but bulrushes are problematic due to their trapping of sediment, which according to the draft report encourages macrophyte rooting, growth and resultant dissolved oxygen problems.

Response: See response Comment 17.

Comment 20:
Considering these comments, there is extremely weak support for statements in the middle paragraph of pg 3-8 that claims riparian shading causes a cooling of stream temperatures and bulrush colonization could produce a noticeable reduction. It should also be noted that even the weak shade/temperature relationship does not support a cooling of water. It would support, however weakly, a reduction in warming.

Response: See response to Comment 17.

Comment 21:
Documented procedures for determining reach-average percent transmittance values (Table 6.2) are inadequate for evaluation. The only stated procedure is that existing vegetation, channel morphology and soil conditions were considered. What soil conditions were considered? How were those soil conditions determined? The Siskiyou County Soil survey is adequate for this level of detail. How did channel morphology affect potential transmittance values? Based on my experience, the level of riparian

vegetation suggested as reach-average potential is unrealistic based on local conditions. Many soil conditions are saturated clay soils that have site potential for sedges and similar vegetation adapted to those conditions. Many of these sites and other sites on the Shasta River will not support large trees required to reach the transmittance levels stated in Table 6.2.

Response: As stated in section 6.2.1, "Regional Water Board staff developed depictions of site potential percent transmittance values by river reach *based on available information* about Shasta River riparian conditions." The information used is described in section 6.2.1, and included anecdotal information about Shasta River riparian corridor soil conditions provided by local residents. Regional Water Board staff recognize there is site-specific variability in potential percent transmittance not described in the reach averages presented in Table 6.2. Regional Water Board staff responsible for implementing the Shasta River TMDL will evaluate such site-specific information if provided by a land owner, lessee, or their representative.

Comment 22:
What is the quantitative impact on fine sediment deposition from increased riparian vegetation such as bulrush (which will slow water and trap more sediment)? How would increased fine sediment deposition impact macrophyte population and growth and its impact on dissolved oxygen levels?

Response: The TMDL analysis has not quantified deposition of fine sediments from flow through emergent macrophytes such as bulrush. The Action Plan includes actions to reduce fine sediment delivery to the Shasta River and its tributaries, which would make the commenter's concern moot.

Comment 23:
What is the impact on flow due to water use by riparian vegetation needed to achieve the proposed potential average-reach level transmittance?

Response: The overall effect of riparian vegetation on stream flows is unknown. Mature riparian trees transpire water; however, the presence of mature riparian trees and riparian grasses, rushes, and sedges has also been shown to increase groundwater retention in areas where natural riparian vegetation has been restored, leading to increases in summerflow.

Comment 24. Considering that the CDFG documents cited here (pg 1-29) and elsewhere in the document are basically unavailable, it would be extremely helpful and is critical for stakeholder review to have at least the cited pages reproduced in a reference section.

Response: All references cited the TMDL documents, including those in sections 1.4.10 and 1.4.11 of the Staff Report, are part of the administrative record for the TMDL document. The administrative record for the TMDL is available for public review. Many of the references (with the obvious exception of the personal communications) used in the fisheries section of this report are available on the internet through a simple key word search.

Comment 25. After living in this area for over 20 years, talking with landowners, fishermen and others, conducting scientific trials on local salmonids and hearing presentations by CDFG personnel, I have never heard anyone mention type II juvenile fall Chinook. To include them without the opportunity to even look at the single (CDFG, 1997) reference (what can we review about a personal communication?) is absolutely biased.

Response: The document, A Biological Needs Assessment For Anadromous Fish in the Shasta River (CDFG 1997, p.10), discusses the possibility of Type II or Type III Chinook in the Shasta River. The personal communication between Regional Water Board staff and California Department of Fish and Game staff (Whelan 2005a) cites details of a phone conversation in which CDFG staff commented on a draft version of the periodicity information for Chinook salmon in the Shasta River basin. The major comment from the CDFG staff during the phone call was to explain that there are Type II Chinook present in the Shasta River, and thus this fact should be reflected in the text and periodicity figure (Figure 1.17).

The 1997 CDFG biological needs assessment document is available on the internet, and can be found either using a search for the title, or by going to the following URL and looking for the title of the document: <http://krisweb.com/biblio/biblio_klamath.htm>. The 2005 personal communication (Whelan 2005a) is part of the administrative record for the Shasta TDML document.

Comment 26. What role do coldwater refugia play in fish development and the beneficial use of the Shasta as a coldwater fishery on the Shasta? What would be the consequence of reductions or elimination of those refugia? What impact would proposed increases in flow have on coldwater refugia? Why is this not discussed at all related to recommended changes in flow?

Response: Please see response to Comment 5.

Comment 27. At public meetings an analogy with a water glass was used to explain the theoretical effect of shade and flow on water temperature. Careful consideration of both model and real-world data suggests that within the natural limits of the Shasta River system, even with flow increases the water in the "glass" is so small in relation to the hot environment of this area and water temperatures will closely reflect air temperatures. Therefore, water temperatures in the Shasta are elevated compared to other more typical salmonid areas. Similarly, even with reduced solar transmittance, water temperatures are elevated compared to some salmonid rearing areas. However, Shasta River water temperatures are not that different from water temperatures associated with salmonids in warmer areas such as central and southern California. In these systems, and in the Shasta River, cold-water refugia associated with seeps, spring inflows, and perennially flowing cool headwaters reaches are likely key (Dr. Lisa Thompson, UC Davis, pers. comm.). It is important to keep in mind the purpose of the TMDL is not to modify water temperature or dissolved oxygen; it is to strengthen the beneficial use of cold-water fisheries. Maintaining or enhancing refugia may be more important than anything else. Similarly, establishing shade at the level required to significantly lower water temperatures may so drastically alter the food cycle as to harm coldwater fisheries. Additionally, riparian vegetation at the required levels may also use significant amounts of water and reduces velocity (with concomitant increased warming), lead to more fine sediment deposition, macrophyte recruitment and even larger dissolved oxygen fluctuations. These would be countered to some degree by reduced light and that impact on macrophytes. Overall it seems like the advocates for increased flow, more shade, fewer diversions, dam removal or whatever have lost sight of the objective. It seems absolutely imperative that before this draft can be accepted, an evaluation of these interrelated factors on the functioning of the coldwater fisheries is necessary, not just a mechanistic or modeled response for temperature or oxygen levels. Much real world data and historical as well as local knowledge has not been included in this draft. The risk of not making an integrated evaluation is the risk of the fishery itself. Why isn't a more integrated and thorough evaluation conducted on the functioning of the coldwater fisheries?

Response: The commenter's speculation that the Shasta River is uniquely warm because of it's environmental setting does not agree with the modeling results presented in the temperature analysis, nor is it supported by temperature data from this and other north coast anadromous streams. In fact, the Shasta River watershed is unique in the North Coast in having a mountain exceeding 14,000 feet in height with permanent snow, and in having cold water sources that discharge at high levels throughout the year, including during the late summer and fall.

The current importance of thermal refugia speaks to the degree of impairment in a river that once supported Chinook runs as high as 80,000, including spring Chinook. The commenter's speculation about unintended negative consequences of water quality restoration is noted.

3. Quartz Valley Indian Reservation and Karuk Tribe Comments

Quartz Valley Indian Reservation Summary of Comments:

Overall, the technical analysis in the Shasta Dissolved Oxygen (D.O.) and Temperature TMDL uses sound logic, has good supporting graphics, and uses standard models that have been previously used in the basin. The models are transparent and their assumptions are clearly stated and for the most part well supported. The Shasta TMDL recognizes that increasing flows is an important action needed to remediate water temperature problems, which is both scientifically accurate and commendable.

There are several ways in which the technical portion of the TMDL could be improved. First, there is no discussion of pH in the TMDL, despite the fact that pH values in the mainstem often exceed *Basin Plan* objectives (NCRWCB 2001), are high enough to be stressful to salmonids, and have similar causes as the dissolved oxygen issue. Second, the TMDL repeatedly refers to nutrient sources (such as from tailwater returns and Dwinnell Reservoir) as problems because of contributions to nitrogenous biological oxygen demand (NBOD), when NBOD is in fact only a small part of the oxygen demand in the Shasta River. The real problem with those nutrient sources, which the TMDL repeatedly overlooks, is the total amount of nitrogen (in all forms) contained in those nutrients sources and its stimulation of aquatic plant growth. This occurs throughout the Staff Report and the *Basin Plan* amendment language, and should be corrected.

A more holistic watershed focus is another way in which the TMDL could be improved. Partially due to the model-centric focus of the TMDL, the Shasta River is treated as a 40 mile trunk without functional tributaries. Flow data from the *Appropriation of Water Rights in the Shasta Basin* (CADPW, 1932) contained in the TMDL show that all tributaries had surface flow and were functional parts of the Shasta River, but there is no mention of restoring connectivity. Pollution from reaches of streams like upper Parks Creek are not recognized because they are not part of the model, although Parks Creek connected to the Shasta River during major storms. Water quality issues within Lake Shastina (aka Dwinnell Reservoir) are described, but the benefit of removing the dam for abating temperature and nutrient pollution is not discussed. It should be noted here that NRC (2004) recommends consideration of removal of Dwinnell Dam.

A summary of our comments regarding implementation is included below as Table 1 (patterned after Table 4 of the Basin Plan amendment language). The water quality compliance scenario in temperature TMDL includes a 50% increase in flow from Big Springs Creek. We strongly support that decision; however the TMDL implementation does not lay out a clear path for how such a substantial increase in flow could be achieved. The RWB proposes to take no action to increase flows to improve water quality for five years, which seems like a long wait given the stock status of Klamath River salmon (Kier Associates, 2006); we think two years would be a more reasonable amount of time. Implementation relies heavily on voluntary measures, although adjacent language stressing the Regional Water Board's (RWB) ability to follow up with enforcement is reassuring. The Action Plan proposes good ideas for how to manage tailwater return flows, riparian areas, and rangelands. The discussion of urban and suburban runoff does not contain any language regarding planning or design, an oversight that should be corrected.

The Shasta TMDL does not set a clear monitoring program, leaving it until a year after TMDL approval. It would seem wise to encourage continuation of specific on-going monitoring efforts of relevant parameters before the more comprehensive plan is drafted.

Karuk Tribe Summary of Comments:

Overall, the technical analysis in the Shasta Dissolved Oxygen (D.O.) and Temperature TMDL uses sound logic, has good supporting graphics, and uses standard models that have been previously used in the basin. The models are transparent and their assumptions are clearly stated and for the most part well supported. The Shasta TMDL recognizes that increasing flows is an important action needed to remediate water temperature problems, which is both scientifically accurate and commendable.

There are several ways in which the technical portion of the TMDL could be improved. The TMDL repeatedly refers to nutrient sources (such as from tailwater returns and Dwinnell Reservoir) as problems because of contributions to nitrogenous biological oxygen demand (NBOD), when NBOD is in fact only a small part of the oxygen demand in the Shasta River. The real problem with those nutrient sources, which the TMDL repeatedly overlooks, is the total amount of nitrogen (in all forms) contained in those nutrients sources and its stimulation of aquatic plant growth. This occurs throughout the Staff Report and the *Basin Plan* amendment language, and should be corrected.

A more holistic watershed focus is another way in which the TMDL could be improved. Partially due to the model-centric focus of the TMDL, the Shasta River is treated as a 40 mile trunk without functional tributaries. Flow data from the *Appropriation of Water Rights in the Shasta Basin* (CADPW, 1932) contained in the TMDL show that all tributaries had surface flow and were functional parts of the Shasta River, but there is no mention of restoring connectivity. Pollution from reaches of streams like upper Parks Creek are not recognized because they are not part of the model, although Parks Creek connected to the Shasta River during major storms. Water quality issues within Lake Shastina (aka Dwinnell Reservoir) are described, but the benefit of removing the dam for abating temperature and nutrient pollution is not discussed. It should be noted here that NRC (2004) recommends consideration of removal of Dwinnell Dam.

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The Shasta TMDL does not set a clear monitoring program, leaving it until a year after TMDL approval. It would seem wise to encourage continuation of specific on-going monitoring efforts of relevant parameters before the more comprehensive plan is drafted.

Response: Responses to each of the summary comments provided by the Quartz Valley Indian Reservation and the Karuk Tribe are provided in responses to the detailed comments below.

Detailed Comments for Quartz Valley Indian Reservation and Karuk Tribe:

Comment:
1.4.10 Anadromous Fish of the Shasta River Watershed (Comment only submitted by QVIR)
The section on fisheries (1.4.10) is thorough and there are useful charts that summarize data on fall chinook, coho and steelhead trout. Although data on steelhead and coho are sparse, the Shasta TMDL should state explicitly that life history requirements of these species make them more vulnerable to water quality problems. Consequently, coho and steelhead populations are likely to have declined more than fall Chinook salmon, which do not require extended freshwater rearing.

Response: Text has been added to section 1.4.10.6 of the Staff Report pointing out that one or more life stage of fall Chinook, coho, and steelhead are present in the Shasta River Basin during every month of the year. Section 2.3.2 identifies that Shasta River temperatures exceed salmonid spawning, incubation, emergence and rearing thresholds during most summer months.

Comment:
Although the TMDL makes no mention of it, Pacific salmon populations are effected changing ocean productivity and patterns of precipitation. The Pacific Decadal Oscillation (PDO) cycle causes major shifts in ocean productivity and conditions seem to shift from favorable for salmon to unfavorable approximately every 25 years. Good ocean conditions for salmon off the California and Oregon Coast prevailed from 1900-1925 and 1950-1975 and switched to favorable again in 1995 (Hare et al., 1999). The good ocean cycle is usually associated with increased rain and snow fall. Poor ocean cycles from 1925-1950 and 1976-1995 were associated with dry on-land cycles.

The Chinook salmon population of the Shasta River is showing a long term decline (Figure 1) that does not bode well for long term survival. The population is failing to rebound despite recent average and above average rainfall years and mostly favorable ocean conditions. Collison et al. (2003) point out that PDO conditions will switch back to negative ocean and dry on land sometime between 2015 and 2025 and that, if freshwater habitat conditions have not improved by that time, stock losses are likely to occur. Shasta stocks ranged from 533-726 from 1990-1992 during the last dry climatic cycle, a critically low level (Gilpin and Soule, 1990). The final Shasta TMDL should cite the findings of Hare et al. (1999) and use it as a reason for urgency of to move forward on a TMDL Implementation Plan.

Response: Thank you for your comment. Dr. Coutant made a similar comment during our peer review process. Regional Water Board staff agree with the importance of initiating actions in the TMDL Action Plan in a timely manner. Table 4 of the Action Plan addresses all identified factors affecting the temperature and dissolved oxygen impairments. All actions are to be addressed concurrently and must be initiated upon EPA approval of the TMDL. Regional Water Board staff acknowledge that some implementation actions (i.e. dedicated cold water instream flow) will have more immediate benefits than others.

Comment: (Comment only submitted by QVIR)
The Shasta TMDL does not address the October 1 deadline for shutting off stock water and increasing stream flows for fish passage. Snyder (1931) noted that fall Chinook salmon entered the Shasta River in September. Fish now delay their migration until after October 1 because of lack of sufficient flow and associated warm water temperatures (Figure 2). This delayed pattern of entry into the Shasta River is manifest in both wet and dry years (Figure 3). Fall chinook forced to sit for weeks in stressful Klamath River conditions likely have reduced fecundity. This intensive selection pressure likely selects for later run timing. For discussion of similar impacts caused by Iron Gate Dam on mainstem spawning Klamath River fall chinook, see Kier Associates (2006).

Response: Comment noted. The revised TMDL Action Plan includes a goal of increasing cold water intream flows in the Shasta River by 45 cfs from May 15 to October 15.

Comment: (Comment only submitted by QVIR)
1.4.10.5 Habitat and Fish Distribution
The distribution map (Figure 1.16) showing very limited range for steelhead likely is conservative, with steelhead very likely occurring in Parks Creek at least during high flow years. A map showing gradient would be useful to judge the former range of coho salmon, spring chinook and steelhead. Expanding habitat toward historical range under TMDL Implementation would substantially improve prospects of long term Pacific salmon species population viability and stability.

The fish distribution map indicates that Big Springs is not currently salmonid habitat yet the California Department of Water Resources (1981) *Klamath and Shasta River Spawning Gravel Enhancement Study* showed a huge concentration of fall chinook spawning Big Springs Creek. This is a tangible indication that Big Springs Creek was a major refugia for Pacific salmon in the early 1980's before reduction of flows due to ground water pumping. Figure 4 shows riparian destruction in lower Big Springs Creek and the adjacent reaches of the Shasta River that would also degrade fish habitat and lead to thermal pollution (Kier Associates, 1999).

Response:
Regional Water Board have reviewed the California Department of Water Resources (1981) *Klamath and Shasta River Spawning Gravel Enhancement Study, and* agree that fall Chinook have been present in Big Springs Creek. However, as stated in Section 1.4.10.5 of the Staff Report, Figure 1.16 is based on information from the USFS (Klamath National Forest). Locations where fish are not marked as "present or suspected" in Figure 1.16 may reflect areas that were not surveyed by the USFWS for salmonid presence/absence. Thus although a particular area is not marked as having fish present, it does not indicate that salmonids and lamprey are absent from these areas.

Comment:
2.2.2 Water Quality Objectives: (Comment only submitted by QVIR)
Table 2.2 "Narrative and Numeric Water Quality Objectives applicable to the Shasta River basin TMDLs" should also include the *Basin Plan* water quality objectives for pH in the Shasta River. While the Shasta River is not officially listed as pH impaired, summer pH values in mainstem Shasta River are extremely high (>9.5), and are unequivocally related to nutrients and D.O.

The lack of analysis of pH in TMDL is troubling, and deserves correction, for several reasons. First, pH directly affects salmonids, with pH levels above 8.5 being stressful and pH 9.6 being lethal (Wilkie and Wood 1995). For a more complete review of the effects of pH on salmonids, see Kier Associates (2005a). Second, ammonia toxicity increases with pH (U.S. EPA 1999). Third, high maximum pH and high diurnal ranges of pH are often symptomatic of nutrient enrichment and excessive growth of aquatic plants, which makes pH a highly useful index of photosynthesis. As described in Chapter 4, the primary cause of the low dissolved oxygen problems in the Shasta River is excessive respiration by aquatic plants. Analysis of pH data is a valuable tool to help understand the spatial and temporal dynamics of D.O. and nutrient impairment.

The mouth of the Shasta River has been monitored with automated water quality probes since 2000. Data from 2000-2004 show that maximum pH typically exceeds the *Basin Plan* objective of 8.5 for most days from June through September (Figure 5). TMDL Appendices A and C contains continuous pH data from other sites in the Shasta River. Goldman and Horne (1983) note that at pH of over 9.5 that all ammonium ions would be converted to dissolved ammonia, which is highly toxic to salmonids. These pulses of extreme pH occurred in seasons of downstream juvenile migration (June 2002) and during periods when adult Chinook salmon may be holding (September 2001) downstream of the mouth of the Shasta in the Klamath River.

Response: Table 2.2 has been revised to include pH. Regional Water Board staff agree that the processes and factors that effect dissolved oxygen, and to a lesser extent temperature, also effect pH. In particular, photosynthesis of aquatic plants alters pH levels. In addition, Regional Water Board staff recognize that pH levels in the Shasta River regularly exceed the Basin Plan objective for pH of 8.5. Though not specifically analyzed as part of these TMDLs, Regional Water Board staff anticipate that implementation of the temperature and dissolved oxygen TMDLs will result in improvements to pH. In particular, reduced photosynthetic rates by 50% would result in reduced pH levels. Future monitoring to assess the effectiveness of the temperature and dissolved oxygen TMDLs should include pH.

Comment: (Comment only submitted by QVIR)
2.3.1 Temperature Requirements of Salmonids
It is our opinion that this section presents the best available science, including from U.S. Environmental Protection Agency (2003).

Response: Thank you for your comment, it has been noted.

Comment:
2.3.2 Temperature Conditions of the Mainstem Shasta River
This section presents colorful and useful graphics (i.e. Figure 2.1) that show the seasonal variability versus life history requirements, duration of stressful conditions and the temperature profile of the river from Dwinnell Dam to the convergence with the Klamath River.

The TMDL states on page 2-12 that "Weekly maximum temperatures exceed the spawning, incubation, and emergence threshold (i.e. MWMT of 13°C) at all Shasta River reaches from April through June, and during the second half of September." An examination of Figure 2.1 shows that to be incorrect because temperatures are above 13°C until mid-October, not September. This should be corrected.

Response: The text in section 2.3.2 has been changed to acknowledge that Shasta River temperatures exceed the spawning, incubation, and emergence threshold into October.

Comment:
2.5 Biostimulatory Substances: (Comment only submitted by QVIR)
pH should also be specifically mentioned in this sentence on page 2-24, "In this context for the Shasta River TMDL, Regional Board staff define nuisance aquatic growth as that which contributes to violation of numeric water quality objectives (particularly dissolved oxygen) or adversely affects beneficial uses."

Response: The text in section 2.5 has been changed, identifying pH as an indicator of nuisance aquatic growth conditions.

Comment: (Comment only submitted by QVIR)
2.5.1 Nutrient Criteria and Trophic State Thresholds
This section of the TMDL should mention that site-specific data analyses are required to set meaningful nutrient criteria (Tetra Tech, 2004).

We recommend that this section start with this paragraph:

> "Nutrients do not directly affect salmonids, but impact them indirectly by stimulating the growth of algae and aquatic macrophytes to nuisance levels that can adversely impact dissolved oxygen and pH levels in streams. The concentration of nutrients required to cause nuisance levels of periphyton varies widely from one stream to another. Detailed data analysis is required to determine relationships. U.S. EPA (2000) and Tetra Tech (2004) provide excellent summaries of the literature on these analytical methods and will not be repeated here. Such analyses have not yet been conducted on the Shasta River, so in this section we discuss national (USEPA 1986), regional (USEPA 2002), and international (Dodds et al. 1998) literature."

Response: The text in section 2.5.1 has been modified, incorporating portions of the recommended text.

Comment: (Comment only submitted by QVIR)
The Dodds et al. (1998) reference is relied upon far too heavily, perhaps even misapplied, in this section of the TMDL. The trophic categories in Dodds et al. (1998) were derived from looking at the distribution of nutrient concentrations in many streams and then arbitrarily dividing them up into three statistically equal categories; they are not based on any type of ecological functionality.

EPA (2000) provides the following cautionary note about Dodds et al. (1998):

> "It should be stressed that this approach proposes trophic state categories based on the current distribution of algal biomass and nutrient concentrations which may be greatly changed from pre-human settlement levels."

In other words, it is likely that the population of streams used by Dodds et al. (1998) are skewed towards more impaired streams, thus the nutrient concentrations for the trophic boundaries are skewed high. In particular, the 0.7 mg/L total nitrogen value presented by Dodds et al (1998) as the oligotrophic-mesotrophic boundary is highly suspect. Note that USEPA's (2002) recommended ecoregional nutrient criteria for total nitrogen is 0.12 mg/L, more than 5 times lower than the 0.7 mg/L from Dodds et al. (1998). Based on analysis of nutrient, pH, D.O., and periphyton data in the Klamath, Trinity, and Salmon Rivers, Kier Associates (2005a) recommended a total nitrogen criteria of 0.2 mg/L for the lower Klamath River.

As noted above, the nutrient concentration required to cause impairment in a stream varies widely according to many factors, thus the more specific the analysis the better. Thus, we cannot see any justification for the TMDL to use the numbers presented Dodds et al. (1998) derived from across North America and New Zealand, rather than the

USEPA (2002) criteria derived from data in Nutrient Ecoregion II (Western Forested Mountains) of the western United States. We recommend that both Dodds et al. (1998) and USEPA (2002) remain in the literature review presented in 2.5.1, but that when analyzing Shasta River nutrient data in section 2.5.2 (Shasta River Watershed Nutrient Conditions), the USEPA (2002) recommended criteria should be used instead.

Response:
The commenter raises important points. An expanded discussion on Dodds et al. (1998) has been added to section 2.5.1, which includes comments from USEPA (2000) about the limitations of these trophic state categories. Regional Water Board staff agree that the methods used to create the trophic categories in Dodds et al. (1998) limit the utility of this information. Thus TP and TN levels in section 2.5.2 are evaluated against the USEPA (1986) national criteria and USEPA (2000) Ecoregion II critieria.

Comment:
<u>2.5.2 Shasta River Watershed Nutrient Conditions</u>
<u>2.5.2.1 Total Phosphorus</u>
On page 2-28, the following statement is made:

> "Downstream of the headwaters, Beaughton and Boles Creeks enter the Shasta River from the west and flow through the phosphorus rich volcanic soils flanking Mount Shasta. This is reflected in the high total phosphorous values in these creeks with averages of 0.192 and 0.119 mg/L respectively."

The land use map (Figure 1.12) clearly indicates that the watersheds of Beaughton and Boles Creek contain an urbanized area around Weed that may also be a substantial contributor to phosphorus concentrations. Development is widely recognized to increase nutrient concentrations in streams (U.S. EPA, 2000). While we agree that the high phosphorus concentrations in Beaughton and Boles Creek are likely due in part to natural geology, they are also likely exacerbated by land use, and this should be acknowledged in the TMDL.

Response: The commenter is correct that Beaughton and Boles Creek flow through an urbanized area, and it is well documented that urbanized areas contribute to nutrient loading in streams. Appropriately, the Action Plan includes actions associated with nutrient controls in urban and suburban runoff.

Comment:
<u>2.5.2.2 Total Nitrogen</u>
As noted above in comments on Section 2.5.1, Shasta River nutrient data should not be compared to Dodds et al. (1998), but to USEPA (2002).

Response: Regional Water Board staff agree that the methods used to create the trophic categories in Dodds et al. (1998) limit the utility of this information. Thus TP and TN levels in section 2.5.2 are only evaluated against the USEPA (1986) national criteria and USEPA (2000) Ecoregion II criteria.

Comment:
In regard to Beaughton and Boles Creek, page 2-29 of the TMDL states "Although total phosphorus levels are high in these tributaries, total nitrogen levels are generally low." We disagree with this assertion; nitrogen concentrations in Boles Creek are high. The TMDL should also recognize that the form of nitrogen is also important (as inorganic forms of nitrogen such as ammonia and nitrate are available to immediately stimulate plant growth). While total nitrogen at Boles does lie slightly below Dodds et al.'s oligotrophic-mesotrophic boundary, nitrate plus nitrite concentrations are very high. We suggest the following revision. Replace "Data from Boles creek generally reflect oligotrophic conditions, with average total nitrogen measuring 0.69 mg/L." with "Data from Boles creek indicate that total nitrogen there are higher than Beaughton Creek, with average total nitrogen measuring 0.69 mg/L, far above USEPA (2002) recommended nutrient criteria of 0.12 mg/L. Additionally, inorganic forms of nitrogen were high, with nitrate plus nitrite nitrogen ranging from 0.360 to 0.560 and an average of 0.493."

Response: The text in section 2.5.2.2 has been modified, incorporating the suggested language.

Comment:
The statement "Total nitrogen values in springs are generally within the mesotrophic boundary" (p 2-30) is inconsistent with the rest of the nutrient discussion. The statement should be changed to "Total nitrogen values in springs are several times higher than the USEPA (2002) recommended ecoregional criteria."

Response: The text in section 2.5.2.2 has been modified to reflect this point.

Comment:
Little evidence is provided to support the statement that "Maximum total nitrogen levels in the mainstem Shasta River increase in a downstream direction." Table 2.8 provides total nitrogen data on the Shasta River near the headwaters, Shasta River above Dwinnell, and then lumps all mainstem sites below that as "Shasta River below Dwinnell Dam." To support that statement, the sites below Dwinnell Dam should be analyzed individually. Appendix B of the TMDL contains USGS and RWB data from 2002-2003 indicating that the patterns at sites below Dwinnell Dam are complex and that analysis of the data is confounded due to the use of a laboratory with inadequate detection limits for Kjeldahl nitrogen.

Response: The text in section 2.5.2.2 has been modified to reflect this point.

Comment:
2.6.3 Potential Municipal and Domestic Water Supply and Contact Recreation Impairment
Discussions of Dwinnell Reservoir in Section 2.5.2 note increased nutrients as compared to reaches of the Shasta River above, but do not mention the role of the nitrogen-fixing blue green algae *Anabaena flos-aquae* as one of the sources of nutrient pollution (though it is later in the document in Chapter 4). *Anabaena flos-aquae* is correctly noted in the text to be a producer of anatoxins.

Response: This point the commenter makes is addressed in section 4.4.3.

Comment:
3.1.1 Stream Heating Processes
This section presents a good description of how the Shasta River warms.

Response: Thank you for your comment.

Comment:
3.3 Stream Heating Processes Affected by Human Activities in the Shasta River Watershed
3.3.2 Shade
On page 3-6, there is discussion of a reach at river mile 37.3 shown in Figure 3.2 where the riparian vegetation noticeably changes from sparsely vegetated to densely vegetated, coincident with a 4 degree drop in temperature. It seems unlikely that riparian vegetation would rapidly cool temperatures by 4 degrees C. As Dr. Coutant points out in the peer-review (Appendix I) another possibility is that hyporheic exchange cooled the water. For details, see our comments under 3.3.7, a new section that we request be added to the TMDL.

Response: Regional Water Board staff agree the 4 ^{o}C reduction in temperature may be due to more factors than just the increase in shade. However, we believe that hyporheic exchange is an unlikely explanation, given our experiences in the Scott River where heat losses due to hyporheic processes were modeled. A more likely explanation is groundwater accretion. Regardless, the drop in temperature does, in fact, coincide with the presence of dense vegetation. The text in section 3.3.2 has been modified to reflect these points.

Comment:
3.3.3 Tailwater Return Flows
The attribution of warming in Big Springs Creek to diversion and agricultural return water is correct, although less than optimally illustrated by the TIR image presented (Figure 3.6). Page 3-8 states that "…Big Springs Creek, where a tailwater return flow was 9.2^{o}C warmer than the creek and caused a plume of hot water that extended for

hundreds of meters (Figure 3.6)." We have examined this figure closely, and do not see the effect described. We are unable to determine if the effect does not exist, or if it is problem with image quality.

Response: The plume of hot water shown in Figure 3.6 is not obvious for two reasons. First, the arrows in the picture are not pointing to the correct tailwater discharge. Secondly, the tailwater is so hot that it shows up grey in the image and is hard to distinguish from the surrounding grasses. Figure 3.6 has been revised to make the tailwater plume more visible.

Comment:
3.3.4 Flow and Surface Water Diversions
The Shasta TMDL does not present the thermal evidence (Watershed Sciences 2004) that flow depletion is causing stream warming in tributaries Parks Creek and the Little Shasta River. Data and TIR images show temperature oscillations in Parks Creek and the Little Shasta River that indicate these streams warm as their flows are depleted (Figure 6). Kier Associates (2005b) described a similar effect on Shackleford Creek in the Scott River. Diversion also completely dries up reaches that would otherwise be suitable habitat for salmonids (Figure 7). Changing patterns of diversion on lower Parks Creek would provide a cold water reach connected to the mainstem Shasta River that could serve as a refugia for juvenile salmonids.

Response: Regional Water Board staff agree that flow depletion contributes to stream warming in Parks Creek and the Little Shasta River, and the text in section 3.3.4 has been modified to reflect this.

Comment:
U.S. EPA (2003) points out the need to protect and restore well distributed refugia when other factors confound meeting temperature requirements of salmonids in mainstem environments. Hydrologic connectivity of Parks Creek is also needed for spawning gravel recruitment in the Shasta River below Dwinnell Dam. Kier Associates (1999) noted that: "Without a change in winter flow regimes to allow increased gravel supply from Parks Creek to enter the Shasta River, long-term depletion of spawning gravels for salmon and steelhead is inevitable."

Response: Regional Water Board staff agree with these statements.

Comment:
3.3.5 Groundwater Accretion / Spring Inflows
This section of the TMDL contains good discussions of why groundwater accretions and spring inflows are important to water temperatures in the Shasta River; however, it does not note that groundwater accretions and spring inflows are not included in the TMDL's water quality model.

Table 6 in Appendix D shows the "Hydrodynamic input locations and types" (e.g. the locations of types of inflows and outflows included in the models). The only specific inputs included were Parks Creek (rm 34.94), Big Springs (rm 33.71), and Yreka Creek (rm 7.88). Other inflows are included as distributed inflows. As noted in Appendix D, temperatures for "all accretions between GID and Anderson Grade" (that reach covers most of the mainstem Shasta below Dwinnell Dam) were assigned the temperature of the Shasta River at Anderson Grade. In other words, it appears as though all springs and groundwater accretions, such as the spring shown in figure 3.9, were assigned Shasta River water temperatures. This seems problematic as the springs are much cooler than the Shasta River water.

Response: A water quality model is a tool for understanding the water quality dynamics of a waterbody. Any model is limited by the amount of data available to describe the boundary conditions in the model. The locations and amount of groundwater accretions and spring inflows in the Shasta River watershed are not well documented. The Shasta River water quality model used the available hydrodynamic and water quality data. Regional Water Board staff point out that the model generally calibrated/validated well. Regional Water Board staff agree that the model could be improved with additional hydrodynamic and water quality data to better define the model boundary conditions. See also response to Comment Category 7- Water Temperature, Flow and Allocations.

Comment:
<u>3.3.7 Hyporheic function</u>
We propose that a short section on hyporheic function be added here.

Connection of surface water to these sub-surface waters is recognized as having a potential cooling influence (Poole and Berman, 2001; U.S. EPA 2003). It is important to note that this is a different mechanism than springs or groundwater accretion. It is not "new" cool water that dilutes the warm river water, but rather that warm river water enters the sand/gravels of the hyporheic zone and then re-emerges cooler, with no net effect on the amount of water in the stream. While magnitude and distribution of this effect in the Shasta River is unknown, it may be significant (and likely the cause of the cooling described in section 3.3.2 and shown in Figure 3.2). As Dr. Coutant mentioned in his review, the model could potentially simulate this effect:

> "For hyporheic flow, if you have some idea of the rate of flux in and out of the gravel, you could treat the flux into the gravel as withdrawal from the stream (water of ambient quality) and replace it downstream with distributed inflow representing the flux out of gravel (with water quality of the hyporheic flow)"

As noted by Dr. Coutant, failing to include this mechanism in the model may result in an over-estimation of the effect of shade. We recognize that the Regional Water Board will be reticent to conduct additional modeling work at this stage of TMDL development, but as research in the Shasta River continues this should be conducted in the future.

A major problem in the Shasta River that may have disrupted hyporheic function is the mining of hundreds of thousands of yards of gravel from the Shasta River when highway Interstate 5 was built (Kier Associates 1991). Virtually all alluvium was removed and replenishment is blocked by Dwinnell Dam and by de-watering of tributaries that formerly contributed both water and gravel to the mainstem (Kier Associates, 1999). Restoring connectivity of tributaries with the mainstem could increase spawning gravel supply and ultimately recreate some hyporheic function as well.

Response: Regional Water Board staff agree that there is an element of hyporheic function in most streams, including the Shasta River, and has a potential cooling influence. In addition, we agree that there is currently not a lot of gravel in the Shasta River, particularly downstream of Dwinnell Dam. The Shasta River water quality model does not specifically account for hyporheic function. Regional Water Board staff believe incorporation of this factor would be a valuable component of future modeling efforts on the Shasta River.

Comment:
<u>3.3.8 Timber harvest</u>
We propose that a short section on timber harvest be added here.

Timber harvest activity in upper Parks Creek (Figure 7) is likely having similar effects as in the Scott River, described by Kier Associates (2005b). Logging in rain-on-snow prone watersheds leads to increased sediment yield and peak discharge that in turn widen stream channels and contribute to increased water temperature. Although the introduction of the *Shasta TMDL* mentions logging as an historic activity, it appears active in upper Parks Creek. Lingering cumulative effects, such as high road densities, skid roads and early seral forests, are likely triggering increase sediment yield, increased flood flows and decreased summer base flows. Kier Associates (2005b) pointed out that dry upland forest sites may require decades for recovery due to slow tree regeneration, causing an extended window of cumulative watershed effects related to flow.

Response: The revised Shasta River TMDL Action Plan addresses timber harvest activities on both federal and non-federal lands.

Comment:
<u>4.3 Processes Affecting Dissolved Oxygen Concentrations in the Shasta River Watershed</u>
The third paragraph of section 4.3 on page 4-3 (beginning with "Though…") should be revised. Characterizing Shasta River biological oxygen demand (BOD_5) as "relatively low" in comparison to raw sewage and hyper-eutrophic Upper Klamath Lake is not at all appropriate. As coldwater salmonid habitat they are much higher than optimal. We do

agree that Shasta BOD_5 concentrations are low in the sense that they are not the major factor driving D.O. dynamics in the Shasta River. We suggest that paragraph should be replaced with the following revision:

> "Though the data are limited, BOD5 concentrations (a measure of carbonaceous deoxygenation in the water column) in the Shasta River indicate that carbonaceous oxygen demand exerted in the water column is only a minor component of the total oxygen demand in the Shasta River. BOD_5 concentrations in the Shasta River range from 1.0 to 15.0 mg/L, with an average of 2.1 mg/L. For comparison, biochemical oxygen demand concentrations in the Klamath River near the outlet of hyper-eutrophic Upper Klamath Lake range from approximately 5 to 25 mg/L. Also for comparison, a typical biochemical oxygen demand concentration of untreated domestic sewage in the United States is 220 mg/L (Chapra 1997, p. 358)."

Response: The text in section 4.3 has been modified in response to this comment.

Comment:
4.3.3.2 Factors Affecting Aquatic Vegetation Productivity in the Shasta River
Biggs (2000) is the best reference regarding periphyton growth, and should be cited in this section. The following sentence should be added to the end of the first paragraph of this section on page 4-11: "Biggs (2000) provides a comprehensive review of the factors affecting periphyton growth."

Response: The text in section 4.3.3.2 has been modified to include the suggested reference.

Comment: (Comment only submitted by QVIR)
Flow and Current Velocity
The statement on page 4-12 "In addition, when a scour-event washes the vegetative material out of the Shasta system, there is a decrease in the oxygen demand exerted on the river" should be followed by a mention of how this might affect the Klamath River. We suggest the following: "However; it should be noted that this material could potentially have negative consequences downstream in the mainstem Klamath River, depending upon the time of year and if it settled out or kept moving out to the Pacific Ocean."

Response: The text in section 4.3.3.2 has been modified, acknowledging potential increased oxygen demand on the Klamath River from scour of aquatic vegetation in the Shasta River.

Comment: (Comment only submitted by QVIR)

Nutrient Concentrations

The last paragraph in this section (beginning with "Section 2.5 provides an overview of trophic status boundaries associated with nutrients…") contains numerous references to trophic boundaries based (apparently) on the Dodds et al. (1998) reference. As explained above in comments on section 2.5.1s, the trophic boundaries presented in Dodds et al. are arbitrary and do not have much relevance to the Shasta River, so this section should be revised to reference ecoregional criteria from USEPA (2002) instead of Dodds et al.

Response:

Regional Water Board staff agree that the methods used to create the trophic categories in Dodds et al. (1998) limit the utility of this information. Thus in section 4.3.3.2, TP and TN levels are now only evaluated against the USEPA (1986) national criteria and USEPA (2000) Ecoregion II criteria.

Comment:

4.4 Anthropogenic Effects on Shasta River Dissolved Oxygen Conditions

4.4.1 Tailwater Return Flow Quality

The most important mechanism by which tailwater returns affect D.O. is not included in the bullets on page 4-15, an omission which deserves correction. Tailwater returns are increasing nitrogen levels in the Shasta River, which can increase growth of aquatic plants. As shown in Chapter 7, respiration of aquatic plants, stimulated by high nutrient levels, is by far the largest contributor to dissolved oxygen demand in the Shasta River. While it is worthwhile to mention that tailwater returns do increase nitrogenous oxygen demand of the Shasta River, the most significant effect of tailwater on oxygen demand is to increase total nitrogen levels and stimulate aquatic plant growth. We recommend that a new second bullet be added:

> "The average total nitrogen concentration of tailwater return flows is over two times that of the average Shasta River concentration during the irrigation season (*XX and XX [fill in the appropriate values]* mg/L, respectively). This increase in nitrogen stimulates the growth of aquatic plants, substantially contributing to oxygen demand by increasing respiration."

Also, table 4.3 should also include total nitrogen calculated from individual samples as NO3+NO2 + TKN.

Response: The text in section 4.4.1 has been modified to acknowledge that the average concentration of ammonia in tailwater return flows is four times that of the average Shasta River ammonia concentration, thereby contributing to respiratory oxygen demand.

Comment:
<u>4.4.3 Lake Shastina and Minor Impoundments</u>
This section does not mention two of Lake Shastina's most important effects on oxygen demand in the Shasta River:

> 1. Shastina reduces peak flows, allowing organic matter and fine sediments to accumulate in the channel, contributing to oxygen demand via macrophyte respiration, and
> 2. Shastina increases nitrogen concentrations, stimulating aquatic plant growth and hence contributing to oxygen demand via macrophyte respiration.

We recommend the following text be added in a new paragraph at the bottom of page 4-19 (after "…may occur in the Reservoir"):

> "As discussed above in section 4.3.3.2, Lake Shastina substantially reduces scouring peak flows. This allows organic matter and fine sediments to accumulate in the channel. These are the preferred substrates for aquatic macrophytes, so this effect expands the area of suitable habitat for macrophytes, increasing the amount of macrophyte photosynthesis and respiration in the Shasta River."

We recommend the following text be added in a new paragraph near the bottom of page 4-19 (above "The regular occurrence of algal blooms…"):

> This increase in total nitrogen concentrations fuels the growth of aquatic plants, which in turn contributes to oxygen demand by increasing aquatic plant photosynthesis and respiration.

Also, because not all blue green algae can fix nitrogen (i.e. *Microcystis aeruginosa* cannot), the statement "Blue green algae are capable of sequestering atmospheric nitrogen." should be changed to "Like many blue green algae, *Anabaena flos-aquae* is capable of sequestering atmospheric nitrogen, resulting in the potential for additional nutrient pollution."

Response: The text in section 4.4.3 has been modified in response to these comments.

Comment:
<u>4.4.5 Flow</u>
This section does not mention a third important way in which flow affects dissolved oxygen. We recommend that the following text be added to the last sentence in this section (after "…caused by photosynthesis and respiration.") on page 4-21:

> Third, flow can affect dissolved oxygen through its effects on water temperature. For instance, larger volumes of water have a higher thermal mass are more resistant to heating and cooling. So if a large volume of

> water is cool (i.e. from a spring-fed creek such as Big Springs) it can travel downstream and retain its low temperature. Low temperatures allow water to water hold more dissolved oxygen. Through this mechanism, flow can affect dissolved oxygen.

Response: The text in section 4.4.5 has been modified to reflect the role that flow can play on dissolved oxygen through its effect on temperature.

Comment:
5.2 Analytic Approach and Model Selection
For reasons discussed above in our comments on section 4.4.5, the following sentence should have "water temperature, " inserted after "sediment oxygen demand rates, ":

> Further, as outlined in Chapter 4, dissolved oxygen concentrations of the Shasta River depend on photosynthetic and respiration rates of aquatic vegetation, sediment oxygen demand rates, consumption of oxygen via nitrification and biochemical oxygen demand, and flow.

Response: The text in section 5.2 has been modified, adding "water temperature".

Comment:
5.6 RMS Sensitivity Analysis
We recommend the following addition to the section (extracted from Appendix D, with some edits):

> With respect to dissolved oxygen, CBOD, and NBOD decay rates were largely insensitive (meaning they had little effect on model outputs), as was the SOD rate. The driving factor for dissolved oxygen was maximum photosynthetic and respiration rate. These values were adjusted during calibration to fit the model to measured data. Reaeration rate, a calculated term within the model, played a pivotal role, particularly in the steep canyon reach where mechanical reaeration would be expected to occur.

Response: The text in section 5.6 has been modified with the suggested addition.

Comment: (Comment only submitted by QVIR)
Overall, this chapter appears to be based on sound analyses. We applaud the Regional Water Board for including flow increases from Big Springs in its Water Quality Compliance Scenario, as flow depletion is a long recognized problem in the Shasta River Basin, and good evidence is provided as to how this flow increase would affect water quality.

6.2 Water Quality Compliance Scenario Conditions

6.2.3 Tributary Temperatures
6.2.3.1 Big Springs Creek
The discussion of how 4^{O}C lower than baseline was chosen for the Water Quality Compliance Scenario should be explained more clearly (we cannot make sense of it in its current form).

Response: The text in section 6.2.3.1 has been modified to clarify Regional Water Board staff's approach to selecting the boundary condition temperature of Big Springs Creek for the water quality compliance scenario.

Comment:
6.6 Margin of Safety
On page 6-19, the following statement is made:

> Some improvements in stream temperature that may result from reduced sedimentation are not quantified. Reduced sediment loads could lead to increased frequency and depth of pools, independent of changes in solar radiation input. These changes tend to result in lower stream temperatures overall and tends to increase the amount of lower-temperature pool habitat. These expected changes are not directly accounted for in the TMDL.

While it is true that reducing sediment loads would likely decrease stream temperatures (and it should be noted that increased rates of hyporheic exchange are another mechanism by which this would occur), it is not clear what basis the Regional Water Board has for stating that sediment load are going to decrease. If this statement is to remain in the TMDL, it should be specified *why* sediment loads are going to decrease, otherwise this is not a margin of safety, it is theoretical statement.

Response: The Shasta River TMDL Action Plan includes actions for those activities that have the potential to contribute sediment loads, including range and riparian land management, tailwater return flows, urban and suburban stormwater runoff, and timber harvest activities on federal and nonfederal lands. Regional Water Board staff believe that when implemented these actions would reduce sediment loads, particularly reducing inputs of fine sediments.

Comment:
7.2 Algae Box Model Application and Results
7.2.2 Summary and Conclusions (Comment only submitted by QVIR)
We agree with the statement on page 7-4 that "If TIN concentrations in the Shasta River were maintained at levels comparable to those concentrations measured in the headwaters of the Shasta River, aquatic vegetation biomass would likely be reduced."

7.3 RMS Model Application

7.3.2 Photosynthetic and Respiration Rates
On page 7-5, the TMDL states:

> The photosynthetic and respiration rates assigned for the water quality compliance scenario were 50% of those for the existing (baseline) condition, as shown in Table 7.3. These reductions in photosynthetic and respiration rates assume a 50% reduction in aquatic vegetation standing crop during the simulation periods. Regional Water Board staff believe that such reductions in aquatic vegetation standing crop, and associated reductions in photosynthetic and respiration rates, are achievable in the Shasta River.

No reason is stated for why a 50% reduction in photosynthetic and respiration rates was chosen. With no reason provided, the decisions seems arbitrary. The TMDL then states: "In practice, the mechanisms that would result in these reductions include:

- Decreased light availability to aquatic vegetation via increased riparian shade, as outlined in Section 6.2.1;
- Reduced concentrations of biostimulatory nutrients in the Shasta River achieved via controls targeting NBOD reductions from Lake Shastina outflow, irrigation return flows, and Yreka Creek, as outlined in Section 7.3.3;
- Reduced fine sediment inputs from irrigation return flows that can be achieved via controls targeting NBOD reductions, as outlined in Section 7.3.3; and
- Increased flushing flows to scour the channel of accumulated fine sediments that promote the establishment and proliferation of rooted aquatic macrophytes.
- Reduced stream temperatures, as outlined in Chapter 6."

While we agree that these mechanisms would indeed reduce the photosynthetic/respiration rates, it is unknown how much each of these factors would need to change in order to result in a 50% reduction in the photosynthetic/respiration rates. The quantitative relationships between each of these factors and the photosynthetic/respiration rates is not known. This uncertainty should be acknowledged in the text.

Response: The assumed reduction in photosynthetic/respiration rates by 50% is based on Regional Water Board's best professional judgement. We acknowledge uncertainty in quantifying the contribution of the various factors in achieving this reduction.

Comment:
As we have stated above several times, it is not NBOD that causes dissolved oxygen problems in the Shasta River, it is total nitrogen. As shown in table 7.7, NBOD is only 7.9% of the oxygen load for the baseline condition; respiration of aquatic plants is 73.9%.

Therefore, "NBOD" in the bullet points above should be replaced with "NBOD and total nitrogen"

Response: Regional Water Board staff agree that respiration of aquatic plants accounts for much greater proportion of the total oxygen demand compared with nitrogenous oxygen demand. The second bullet in section 7.3.2 states that reduced respiration rates will be achieved in part by reducing the concentrations of biostimulatory nutrients, and this includes ammonia and nitrate. As described in section 5.3.2.2, the RMS model simulates dissolved oxygen conditions in response to biochemical oxygen demand (BOD), nitrogenous biochemical oxygen demand (NBOD), sediment oxygen demand (SOD), mechanical reaeration, and photosynthesis and respiration of aquatic vegetation growing on or in the bed (as periphyton or macrophytes). The water quality compliance scenario includes these parameters that effect dissolved oxygen, including NBOD. As discussed in section 7.3.4, NBOD boundary conditions were based on Total Kjeldahl Nitrogen concentrations, which is a measure of organic nitrogen plus ammonia-nitrogen. In addition, we note that Section 5.7 describes that the RMS model does not simulate the effect of nutrient concentrations on aquatic plant productivity. In other words, the RMS model does not "grow" aquatic plants in response to ambient conditions including nutrient concentrations, and therefore photosynthetic and respiration rates do not change in response to nutrient concentrations. Therefore, a separate analysis of the connection between nutrient concentrations and aquatic plant production was conducted using an algae box model, as presented in section 7.2. Finally, Regional Water Board staff point out that the implementation actions in the Action Plan address "fine sediment, nutrients, and other oxygen consuming materials", which includes all forms of nitrogen and phosphorus.

Comment:
While it is important to acknowledge scientific uncertainty, we also believe that since the factors causing D.O. problems are known, there is no need to wait until we have 100% certainty on the magnitude of land/water use changes that are required to bring the Shasta River into compliance with the water quality objectives. The best strategy is to continue with restoration efforts, and then evaluate progress along the way.

Response: Regional Water Board staff agree. The Action Plan requires monitoring, adaptive management, and evaluation of progress towards meeting water quality standards.

Comment:
Chapter 8:
The RWB has an obligation to make sure that the water quality objectives are met, and beneficial uses restored and protected, particularly because the final *Shasta TMDL Action Plan* will be amended to the *Basin Plan* (NCRWQCB, 2001). If there are multiple ways to meet the objectives, we support giving landowners the flexibility to decide how they want to meet those objectives. For example, <u>if</u> other regulatory and policy processes such

as the *Shasta Incidental Take Permit* (SRCD, In Draft), *Coho Recovery Plan* (CDFG, 2004), and Timber Harvest Plans will result in the attainment of water quality objectives, then further regulation by the RWB is not necessary.

Duplicative and overlapping regulation benefits no one. Unfortunately, these other processes often rely on voluntary measures that neither guarantee that water quality problems will be remedied nor that TMDL objectives will be achieved. <u>When other policy approaches and voluntary landowner actions fail to achieve the TMDL objectives, then the RWB must use its considerable regulatory and enforcement authority to take necessary actions to ensure results.</u>

Response: See response to Comment Category 9 – Volunteerism and Timelines.

Comment:
The implementation actions requested in these comments are summarized below as Table 1 (a revised version of Table 4 from the proposed Shasta TMDL Basin Plan amendment language).

<u>8.1.1 Prioritization of Implementation Actions</u>
Page 8-6 states "Where reaches of the Shasta River and its tributaries are providing suitable freshwater salmonid habitat, protection of these areas should be a priority for restoration efforts." While this is a step in the right direction, it could be improved by specifically mentioning coho salmon, coldwater refugia needs and connectivity.

Response: Comment noted. This additional clarifying language will be added to page 8-6 of the Staff Report.

Comment:
The Shasta TMDL should follow the approach of Bradbury et al. (1995), which is to identify the most intact habitat patches and to begin restoration by making sure that these areas are protected and enhanced as a top priority. In the Shasta River basin, these would be the stream reaches with coho salmon or those that provide coldwater refugia for other Pacific salmon species. The *Shasta TMDL* needs to add specific reference to lower Parks Creek and the need to restore riparian there and change diversion to provide a refugia and to improve spawning gravel supply to the mainstem Shasta River.

Response: Temperature allocations for riparian shade apply to the Shasta River and its Class I and II tributaries. Regional Water Board staff agree that attaining site potential riparian shade conditions in lower Parks Creek is an integral component of the TMDL. We note that water quality standards must be achieved at all locations of the Shasta River watershed at all times.

Comment:
8.3 Tailwater
We recognize that tailwater returns are a substantial contributor to water quality problems, and we support the recommendations in this section.

Response: Support for recommended measures noted.

Comment:
8.4 Water Use and Flow
The water quality compliance scenario in Chapter 6 includes a 50% increase in flow from Big Springs Creek. We strongly support that decision; however the TMDL implementation does not lay out a clear path for how such a substantial increase in flow could be achieved. To be realistic, it will also have associated cost factors for assisting water conservation to offset the current demand for groundwater. Some language should likely be added to reflect this long term need.

The RWB proposes to take no firm action to increase flows to improve water quality for five years, which seems like a long wait given the stock status of Klamath River salmon (Kier Associates, 2006). We support the RWB in taking action, and think that two years would be a more reasonable amount of time to wait. (The following portion of this comment was submitted only by QVIR.) A quote from the *Long Range Plan for Klamath River Basin Fishery Restoration Program* (Kier Associates, 1991) gives a sense of long term perspective:

> "In the year 2000, if adequate progress towards improving flow conditions for salmonids has not been made …. then investigate the option of reallocation of water rights under the public trust doctrine for protection of fish habitat."

Response: While it is true that the water quality compliance schedule used a parameter of 50% increase in flow from Big Springs, it was simply one of a multitude of possibilities for increasing cold water flow in the Shasta River. To clarify concerns raised by a number of commenters, revisions to the TMDL Action Plan, Table 4, have been made to clarify the need for irrigators to develop and implement measures to increase dedicated cold water flows, and to report on the progress being made within two years and again at four years after TMDL approval. Costs are adequately addressed in chapter 13 of the Staff Report.

Comment:
While many of the ideas proposed in the *Coho Recovery Plan* are positive, they are also voluntary. It is important for the Regional Water Board to remember that it has a responsibility to protect public trust resources and ensure results. If voluntary measures work, that would be great, but they are often insufficient and further action is required.

Response: See response to Comment Category 9 – Volunteerism and Timelines.

Comment:
Chapter 8 states that: "Other management measures recommend the leasing, purchasing, or donations of water rights from willing water rights holders in the Shasta River watershed."
While purchasing or donations could provide long-term benefits to fish and water quality, leases would be unwise because they provide no long-term benefits. A major hurdle for success, if water rights are acquired, is that riparian water users are likely to exploit any water not used by those contributing water. The original Shasta River adjudication (CDPW, 1932) recognized that problem and it still has not been remedied. today. Before water rights are purchased, restrictions on water withdrawal under riparian rights must be disallowed, which likely requires another adjudication. Legality of some water rights also needs to be explored because ground water diversions that are linked to surface flow depletion require an Appropriative Water Right and diversions from the underflow of Big Springs have not obtained such rights (Kier Associates, 1999). The TMDL should also note that water rights holders may designate temporarily their water right to instream flow under California law SB-301, without penalty of losing that right at a future date (Kier Associates, 1999).

Response: Two paragraphs have been added to Chapter 8 of the Staff Report to better describe water right legal issues as it relates to dedicated cold in stream flow measures. See Response 5 for the full text. For issues with the Shasta River adjudication, see response to Flow and Water Use Comment Group 1 – Shasta River Adjudication.

Comment:
<u>8.5 Irrigation Control Structures and Impoundments</u>
<u>8.5.1 Implementation Actions for Irrigation Control Structures and Minor Impoundments</u>
The reference "(Great Northern Corp. 2001)" should be added after "1996" to the statement "The Shasta CRMP, working with cooperative landowners, has removed one impoundment in 1996, the farthest downstream…"

Response: Reference will be added to Section 8.5.1 of the Staff Report.

Comment:
<u>8.6 Lake Shastina</u>
This statement on page 8-25 has several problems and needs correction:

> "Additionally, nutrient inflows (Chapter 4) from natural sources to the reservoir appear to be significant, but nutrient loads from the outflow of Shastina exceed inflow loads, on an annual basis, suggesting that Lake Shastina is an additional source capable of generating its own nitrogenous oxygen demanding substances."

First, the TMDL does not contain any data/analysis regarding Lake Shastina nutrients loads (loads are mass per time, e.g. kg/year), only concentrations (e.g. mg/L). The sentence should be corrected by replacing "loads" with "concentration" (or if the Regional Water Board does have information about loads, it should be presented). Second, as we have stated above several times, it is not NBOD that causes dissolved oxygen problems in the Shasta River, it is total nitrogen. Therefore, "nitrogenous oxygen demanding substances" in the sentence above should be replaced with "nitrogen, affecting dissolved oxygen conditions downstream by increasing nitrogenous oxygen demanding substances and stimulating growth of aquatic plants."

The statement on page 8-25 that "10) appropriate actions, based on the investigation's results, to reduce nitrogenous oxygen demand, thereby, increasing dissolved oxygen concentrations in Lake Shastina and, thus, discharges from Dwinnell Dam to the Shasta River." we recommend that "nitrogenous oxygen demand," should be replaced by "total nitrogen and nitrogenous oxygen demand"

Two other statements on the same page should be similarly revised by replacing "nitrogenous oxygen demand" with "total nitrogen and nitrogenous oxygen demand":

> "Initiate, complete, and submit to the Regional Water Board the results of an investigation characterizing, quantifying, and analyzing the sources of nitrogenous oxygen demanding substances contributing to low dissolved oxygen levels affecting the beneficial uses of water in Lake Shastina and to waters of the Shasta River downstream from Dwinnell Dam.
>
> Based on the results of the investigation, the Regional Water Board shall determine appropriate implementation actions necessary to reduce the nitrogenous oxygen demand that is lowering dissolved oxygen concentrations in Lake Shastina and affected areas downstream from Dwinnell Dam."

Response: The text in section 8.6 has been modified significantly, and the revised Action Plan includes new requirements pertaining to Dwinnell Dam and Lake Shastina water quality. These revisions make the above comments moot.

Comment: (Comment only submitted by QVIR)
Lake Shastina has substantially changed the hydrology of the Shasta River, decreasing peak stormflows and reducing the frequency of high flows that can scour fine sediments and aquatic plants. For this reason, we request that the following language be added to this section "The Regional Water Board shall study the possibility of using pulse flows from Lake Shastina to clean out accumulated organic matter and macrophytes from the Shasta River. The study will also consider the effects of such pulse flows on the Klamath River downstream."

Response: The Action Plan includes actions to reduce fine sediment and organic matter in the Shasta River. Should these actions not be sufficient to meet water quality standards, the Regional Water Board will consider additional actions, including use of pulse flows from Lake Shastina, during TMDL implementation.

Comment:
8.8 Urban and Suburban Runoff
This section neglects to mention planning and design as important means to manage urban and suburban runoff. Runoff pollution is much easier to minimize and manage if stormwater is considered during the design phase. We recommended the addition of the following language:

> "New developments should be designed to minimize stormwater runoff and maximum infiltration by minimizing impervious surface area, minimizing hydrologic connection between impervious surfaces and watercourses, and constructing stormwater retention basins. Existing developments should be retrofitted to minimize stormwater runoff."

Response: While this language was not incorporated exactly as suggested, Table 4 of the Action Plan has been revised to include a number of appendices that list examples of measures to be undertaken to aid in compliance with water quality standards, the TMDL and the NPS Policy.

Comment:
8.10 United States Bureau of Land Management (Comment only submitted by QVIR)
This section should specifically reference staff for enforcement. BLM lands in the Shasta River canyon include extremely important Chinook salmon spawning habitat and juvenile salmon and steelhead rearing habitat. Grazing in violation of BLM policies has taken place illegally in the past and may recur if occasional enforcement presence is not in evidence. Illegal residences on BLM land off Hudson Road have not been removed and residents are harvesting firewood from the riparian zone on public land.

Response: Comment noted. The TMDL Action Plan has been revised to make it clear that Regional Water Board will take appropriate enforcement actions for all sources of waste discharge into Shasta River waters regardless of responsible party. See section VI (Enforcement) of the revised Action Plan for additional information.

Comment:
If the RWB staff are not prepared to present a monitoring plan with the *Shasta River TMDL*, they should at least specifically mention on-going monitoring that should be continued for long term trend monitoring. The CRMP gauge at Montague-Grenada Road, USFWS multi-channel data recorder, USGS flow monitoring and annual deployment of automated temperature sensing probes. The TMDL should specifically

reference need to store and share data in a way that supports TMDL implementation and adaptive management. (The following portion of this comment was submitted only by QVIR.) The Klamath Resource Information System (TCRCD, 2003) is available for use by the community and the major expense of populating the database has been paid by previous grants. Cooperative efforts between the RWB, Tribes, agencies and stakeholders would not cost much if each partner dedicated a few days of staff time a year.

Response: As stated in section 9.2.2 of the Staff Report, Regional Water Board staff will complete a compliance and trend monitoring plan for Shasta River TMDL implementation within one year from the date that US EPA approves the TMDL. In the meantime, we fully support continuation of on-going water quality monitoring efforts in the Shasta River watershed. Regional Water Board staff agree that cooperative efforts between all stakeholders conducting monitoring in the watershed is essential to attaining and maintaining water quality standards.

Comment:
The Shasta TMDL comes at a time when Klamath River fall Chinook salmon stocks are collapsing, due to water quality problems and consequent disease epidemics (Kier Associates, 2006). Unlike other mountains throughout the West, snowpack on Mt Shasta is increasing with the onset of global warming, making the Shasta River an even more important tributary for Klamath Basin salmonids. NRC (2004) calls for restoring the Shasta River as a necessity in ensuring the salmon survival. The switch in the PDO looms. Speedy implementation is needed.

Response: Comment noted.

Comment: See “Recommended Alternative Action” column below.

Table 4. Proposed TMDL Implementation Actions and Recommended Alternative Actions

Source or Land Use Activity	Responsible Parties	Action Proposed in Public Draft TMDL	Recommended Alternative Action
Range and Riparian Land Management	• **Parties Conducting Grazing Activities.** • Parties Responsible for Vegetation that Shades Water Bodies. • Parties Responsible for Bank Stabilization Activities. • Regional Water Board.	**Landowners should employ land stewardship practices and activities that minimize, control, and, preferably, prevent discharges of fine sediment, nutrients and other oxygen consuming materials, as well as elevated solar radiation loads from affecting waters of the Shasta River and tributaries.** Those that oversee and manage grazing and range land activities in the Shasta River watershed should implement grazing and rangeland management practices listed in Table 8.1 of the TMDL Implementation Plan, and in the Shasta Restoration Plan. The Shasta CRMP should, (1) implement the strategic actions specified in the Strategic Action Plan, and (2) assist landowners in developing and implementing management practices that are adequate and effective at preventing, minimizing, and controlling discharges of nutrients and other oxygen consuming wastes, and elevated water temperatures. The Regional Water Board will work cooperatively with the Shasta CRMP to provide technical support and information to willing individuals, landowners, and community members in the Shasta River watershed, coordinate educational and outreach efforts, and monitor the implementation and effectiveness of the Shasta	Proposed action is sufficient.

Table 4. Proposed TMDL Implementation Actions and Recommended Alternative Actions

Source or Land Use Activity	Responsible Parties	Action Proposed in Public Draft TMDL	Recommended Alternative Action
		Watershed Restoration Plan. Should voluntary efforts fail to be implemented or effective at preventing, minimizing, and controlling discharges of sediment, nutrients and other dissolved oxygen consuming materials, and increasing solar radiation loads, the Regional Water Board's Executive Officer shall require the appropriate responsible parties to develop, submit, and implement a RRWMP on an as-needed, site-specific basis. Any landowner may be subject to this requirement if livestock grazing activities on their property are discharging, or threatening to discharge oxygen consuming materials and/or elevated solar radiation loads to a water body in the Shasta River watershed. The RRWMP shall describe in detail: Locations discharging and/or with the potential to discharge nutrients and other oxygen consuming materials, and increased solar radiation loads to watercourses which are caused by livestock grazing, How and when those sites are to be controlled and monitored, and management practices that will prevent and reduce, future discharges of nutrient and other oxygen consuming materials, and increases in solar radiation loads.	

Table 4. Proposed TMDL Implementation Actions and Recommended Alternative Actions

Source or Land Use Activity	Responsible Parties	Action Proposed in Public Draft TMDL	Recommended Alternative Action
		Group and/or individual RRWMPs shall be implemented upon review, comment, and approval by Regional Water Board staff and their Executive Officer for compliance with Regional Board directives, the Basin Plan, and also with the management measures in the Nonpoint Source PCP. The Regional Water Board shall address the removal and suppression of vegetation that provides shade to a water body through its Wetland and Riparian Protection Policy, a comprehensive, region-wide riparian policy that will address the importance of shade on instream water temperatures and will potentially propose riparian setbacks and buffer widths. The Policy will likely propose new rules and regulations, and will therefore take the form of an amendment to the Basin Plan. Other actions under this section may be modified for consistency with this policy, once adopted. With funding already available through a grant from the U.S. EPA, Regional Water Board staff are scheduled to develop this Policy by the end of 2007. Permitting and Enforcement: The Regional Water Board shall take appropriate permitting and enforcement actions if necessary to address the removal and suppression of vegetation that provides shade to a water body in the Shasta River watershed. Such actions may include, but	

Table 4. Proposed TMDL Implementation Actions and Recommended Alternative Actions

Source or Land Use Activity	Responsible Parties	Action Proposed in Public Draft TMDL	Recommended Alternative Action
		are not limited to, general waste discharge requirements (WDRs) or waivers of WDRs for grazing and rangeland activities, farming activities near water bodies, stream bank stabilization activities, and other land uses that may remove and/or suppress vegetation that provides shade to a water body. Should prohibitions or general WDRs be developed, they may apply to the entire North Coast Region or just to the Shasta River watershed. If necessary, Regional Water Board staff shall propose to the Board appropriate enforcement actions for human activities that result in the removal or suppression of vegetation that provides shade to a water body in the Shasta River watershed. Such actions may include, but are not limited to, cleanup and abatement orders, cease and desist orders, and administrative civil liabilities (fines) in accordance with California Water Code sections 13304, 13301, and 3350, respectively. Enforcement actions for violations of the California Water Code shall be taken when and where appropriate. Enforcement activities should be consistent with the State Water Board's *Water Quality Enforcement Policy* (SWRCB Resolution No. 2002-0040), adopted February 19, 2002, and as it may be amended from time to time. This enforcement policy promotes a fair, firm, and	

Table 4. Proposed TMDL Implementation Actions and Recommended Alternative Actions

Source or Land Use Activity	Responsible Parties	Action Proposed in Public Draft TMDL	Recommended Alternative Action
		consistent enforcement approach appropriate to the nature and severity of a violation. Within two years of the date that the TMDL Action Plan takes effect the Regional Water Board's Executive Officer shall report to the Board on the status of the preparation and development of appropriate permitting actions. Enforcement implementation is ongoing and effective the date that the TMDL Action Plan is adopted.	
Tailwater Return Flows	• Parties Responsible for Tailwater Management and Use • Shasta CRMP • Shasta RCD • CDFG • Regional Water Board	Parties responsible for tailwater discharges from irrigated lands, which may include landowners, lessees, and land managers, should implement the management practices presented in the CDF&G's Coho Recovery Strategy, the Shasta CRMP's Shasta Watershed Restoration Plan and the Shasta RCD's Incidental Take Permit Application. Regional Water Board staff will evaluate the effectiveness of these voluntary actions and develop recommendations for the most effective	Proposed action is sufficient.

Table 4. Proposed TMDL Implementation Actions and Recommended Alternative Actions

Source or Land Use Activity	Responsible Parties	Action Proposed in Public Draft TMDL	Recommended Alternative Action
		regulatory vehicle to bring tailwater discharges into compliance with the TMDL and the Basin Plan. Information gathered during the evaluation phase will be used to formulate final recommendation(s) to the Regional Water Board. This evaluation phase shall be completed within 12 months after the TMDL is approved by the U.S. EPA. Based on Regional Water Board staff recommendation(s) derived from the evaluation phase for tailwater management, the Regional Water Board shall adopt prohibitions, Waste Discharge Requirements, Waivers of Waste Discharge Requirements, or any combination, thereof, as appropriate. To assure compliance if prohibitions, WDRs, Waivers of WDRs, or any combination of the latter are adopted, a tiered tailwater management program may be instituted for tailwater management that may include various elements such as discharge and receiving water sampling, monitoring, and reassessment. Additional management practices to assure that tailwater discharges to receiving waters comply with the TMDL and the Basin Plan may also be based on results from the tailwater management program.	

Table 4. Proposed TMDL Implementation Actions and Recommended Alternative Actions

Source or Land Use Activity	**Responsible Parties**	**Action Proposed in Public Draft TMDL**	**Recommended Alternative Action**
Water Use and Flow	• Water Rights Holders and other Stakeholders • Shasta Coordinated Resource Management and Planning Committee (Shasta CRMP) • Shasta Valley Resource Conservation District (Shasta RCD) • California Department of Fish and Game (CDFG) • Regional Water Board	Water diverters should participate in the CDFG's Coho Recovery Strategy (CDFG 2004a) and Incidental Take Permit Program (CDFG 2004b). The Regional Board shall work with DFG to establish monitoring and reporting elements of these programs in order to gage their effectiveness. Water diverters should participate in and implement flow-related measures outlined in the Shasta CRMP's Shasta Watershed Restoration Plan. The Regional Board shall work with the Shasta CRMP to establish monitoring and reporting elements in order to gage the Plan's implementation and effectiveness. If after five years, the Regional Board Executive Officer finds that the above-measures have failed to be implemented or are otherwise ineffective, the Regional Board may recommend that the SWRCB consider seeking modifications to the decree, conducting proceedings under the public trust doctrine, and/or conducting proceedings under the waste and unreasonable use provisions of the California Constitution and the California Water Code.	Water diverters should participate in the CDFG's Coho Recovery Strategy (CDFG 2004a) and Incidental Take Permit Program (CDFG 2004b). The Regional Board shall work with DFG to establish monitoring and reporting elements of these programs in order to gage their effectiveness. Water diverters should participate in and implement flow-related measures outlined in the Shasta CRMP's Shasta Watershed Restoration Plan. The Regional Board shall work with the Shasta CRMP to establish monitoring and reporting elements in order to gage the Plan's implementation and effectiveness. **The Regional Water Board shall actively encourage the purchase of water rights for the purpose of maintaining adequate streamflows.** **Recommend revisiting adjudication to stop riparian appropriation of water purchased for instream flows and fish.** **(The previous two paragraphs were only submitted by QVIR.)** If after **two** years, the Regional Board Executive Officer finds that the above-measures have failed to be implemented or are otherwise ineffective, the Regional Board will recommend that the SWRCB consider seeking modifications to the decree, conducting proceedings under the public trust doctrine, and/or conducting proceedings under the

Table 4. Proposed TMDL Implementation Actions and Recommended Alternative Actions

Source or Land Use Activity	**Responsible Parties**	**Action Proposed in Public Draft TMDL**	**Recommended Alternative Action**
			waste and unreasonable use provisions of the California Constitution and the California Water Code.
Irrigation Control Structures, Weirs, Flashboard Dams, and other Minor Impoundments (Collectively referred to as minor impoundments)	• Individual Irrigators • Irrigation districts • Other Stakeholders owning, operating, managing, or anticipating construction of minor impoundments	Irrigations districts, individual irrigators, and other stakeholders that own, operate, manage, or anticipate construction of instream impoundments such as flashboard dams, or other structures capable of blocking, impounding, or otherwise impeding the free flow of water in the Shasta River system shall comply with the following measure: Within one year of TMDL approval by the U.S. EPA, report to the Regional Water Board methods and management practices they shall implement that will reduce sediment oxygen demand rates by 50% from baseline behind all minor impoundments. Options may include, but are not limited to: 1) permanently removing impoundments in the Shasta River mainstem as a mechanism to provide for flushing flows capable of scouring fine sediment from the stream-river channel on which aquatic plants grow; 2) re-engineering existing impoundments to decrease their surface area; and 3) not undertaking the construction of new impoundments unless they can be shown to have positive effects to the beneficial uses of water relative to water quality compliance and the	Proposed action is sufficient.

Table 4. Proposed TMDL Implementation Actions and Recommended Alternative Actions

Source or Land Use Activity	Responsible Parties	Action Proposed in Public Draft TMDL	Recommended Alternative Action
		support of beneficial uses, including the salmonid fishery, in the Shasta Valley.	
Lake Shastina	• Montague Water Conservation District (NWCD) • Other Appropriate Stakeholders • Regional Water Board	The Montague Water Conservation District shall take the following actions: Initiate within two years, complete and submit to the Regional Water Board within five years, the results of an investigation characterizing, quantifying, and analyzing the sources of, and ways to reduce, nitrogenous oxygen demanding substances contributing to low dissolved oxygen levels affecting the beneficial uses of water in Lake Shastina and to waters of the Shasta River downstream from Dwinnell Dam. Based on the results of the investigation, the Regional Water Board shall determine appropriate implementation actions necessary to reduce the nitrogenous oxygen demand that is lowering dissolved oxygen concentrations in Lake Shastina and affected areas downstream from Dwinnell Dam.	The Montague Water Conservation District shall take the following actions: Initiate within two years, complete and submit to the Regional Water Board within five years, the results of an investigation characterizing, quantifying, and analyzing the sources of, and ways to reduce, **nutrients and** nitrogenous oxygen demanding substances contributing to low dissolved oxygen levels affecting the beneficial uses of water in Lake Shastina and to waters of the Shasta River downstream from Dwinnell Dam. Based on the results of the investigation, the Regional Water Board shall determine appropriate implementation actions necessary to reduce the **nutrients and** nitrogenous oxygen demand that is lowering dissolved oxygen concentrations in Lake Shastina and affected areas downstream from Dwinnell Dam. (The following portion of this comment was submitted only by QVIR.) **The Regional Water Board shall study the possibility of using pulse flows from Lake Shastina to clean out accumulated organic matter and macrophytes from the Shasta River.**

Table 4. Proposed TMDL Implementation Actions and Recommended Alternative Actions

Source or Land Use Activity	Responsible Parties	Action Proposed in Public Draft TMDL	Recommended Alternative Action
City of Yreka Wastewater Treatment Facility (Yreka WWTF)	• City of Yreka • Regional Water Board	The Regional Water Board staff shall pursue aggressive compliance with Order No 96-69, and CAO No.R1-2004-0037. To ensure timely submittal of sampling and analytical results from the operators of the Yreka WWTF, the Regional Water Board staff shall also continue vigorous oversight and enforcement of Monitoring and Reporting Program No. R1-2003-0047.	Proposed action is sufficient.
Urban and Suburban Runoff	• Cities of Yreka, Weed, the Lake Shastina Development • Other Stakeholders • Regional Water Board	The cities of Yreka, Weed, the Lake Shastina Development and other stakeholders should identify possible pollutants, their sources, and volumes of polluted runoff from urban and suburban sources within their spheres of influence that may discharge, directly or indirectly, to waters of the Shasta Valley watershed. Cities and other stakeholders responsible for urban and suburban runoff should implement the following measures: Seasonal scheduling of construction activities to prevent unnecessary waste loads in stormwater runoff. Seasonal scheduling for the application to lawns and gardens, municipal facilities, and agricultural areas of fertilizers, pesticides and herbicides, and other oxygen consuming materials that may contribute to dissolved oxygen impairments to watercourses in the Shasta River hydrologic system from cities, towns, developments and other	The cities of Yreka, Weed, the Lake Shastina Development and other stakeholders should identify possible pollutants, their sources, and volumes of polluted runoff from urban and suburban sources within their spheres of influence that may discharge, directly or indirectly, to waters of the Shasta Valley watershed. Cities and other stakeholders responsible for urban and suburban runoff should implement the following measures: Seasonal scheduling of construction activities to prevent unnecessary waste loads in stormwater runoff. Seasonal scheduling for the application to lawns and gardens, municipal facilities, and agricultural areas of fertilizers, pesticides and herbicides, and other oxygen consuming materials that may contribute to dissolved oxygen impairments to watercourses in the Shasta River hydrologic system from cities, towns, developments and other

Table 4. Proposed TMDL Implementation Actions and Recommended Alternative Actions

Source or Land Use Activity	Responsible Parties	Action Proposed in Public Draft TMDL	Recommended Alternative Action
		concentrations of urban and suburban populations. When, and if, pollutant sources are identified that discharge, or threaten to discharge, oxygen consuming materials, fine sediment, and other polluting constituents to nearby watercourses from existing runoff control facilities, the Regional Water Board will work cooperatively with responsible parties to ascribe appropriate management measures and reasonable time schedules to control and eliminate said pollutant discharges.	concentrations of urban and suburban populations. **New developments should be designed to minimize stormwater runoff and maximum infiltration by minimizing impervious surface area, minimizing hydrologic connection between impervious surfaces and watercourses, and constructing stormwater retention basins. Existing developments should be retrofitted to minimize stormwater runoff.** When, and if, pollutant sources are identified that discharge, or threaten to discharge, **nutrients,** oxygen consuming materials, fine sediment, and other polluting constituents to nearby watercourses from existing runoff control facilities, the Regional Water Board will work cooperatively with responsible parties to ascribe appropriate management measures and reasonable time schedules to control and eliminate said pollutant discharges.

Table 4. Proposed TMDL Implementation Actions and Recommended Alternative Actions

Source or Land Use Activity	**Responsible Parties**	**Action Proposed in Public Draft TMDL**	**Recommended Alternative Action**
Activities on Federal Lands	• U.S. Forest Service (USFS) • Regional Water Board	The USFS shall consistently implement the best management practices included in *Riparian Area Management 1997* (USDA/USDI 1997), and *Water Quality Management for Forest System Lands in California, Best Management Practices* (USFS 2000). The Regional Water Board staff will continue its involvement with the USFS to periodically reassess the mutually agreed upon goals of the Management Agency Agreement between the SWRCB and the USFS. Additionally, the Regional Water Board shall work with the USFS to draft and finalize a Memorandum of Understanding (MOU). The MOU shall be drafted and ready for consideration by the appropriate decision-making body of the USFS within two years of the date the TMDL Action Plan takes effect. The MOU shall include buffer width requirements and other management practices as detailed in the Implementation chapter of the TMDL.	Proposed action is sufficient.

Table 4. Proposed TMDL Implementation Actions and Recommended Alternative Actions

Source or Land Use Activity	Responsible Parties	Action Proposed in Public Draft TMDL	Recommended Alternative Action
	• U.S. Bureau of Land Management • Regional Water Board	BLM shall implement best management grazing strategies that are detailed in a joint management agency document titled: *Riparian Area Management 1997* (USDA/USDI 1997). The Regional Water Board shall work with the BLM to draft and finalize a Memorandum of Understanding (MOU). The MOU shall be drafted and ready for consideration by the appropriate decision-making body of the BLM within two years of the date the Shasta River TMDL Action Plan takes effect. The MOU shall include buffer width requirements and other management practices as detailed in the Implementation chapter of the TMDL.	Proposed action is sufficient.
Timber Harvest Activities on Non-federal Lands	• **California Department of Forestry (CDF)** • **Regional Water Board**	[discussed in chapter 8 but not in Basin Plan amendment language]	**The Regional Water Board shall rely on applicable current regulations, existing permitting and enforcement tools, and other ongoing staff involvement, summarized in the listed below, associated with timber harvest activities. As such, no new regulations or actions are being proposed in association with this TMDL:** **- Z'Berg-Nejedly Forest Practice Act and the California Environmental Quality Act (CEQA)** **-Management Agency Agreement between the CDF and the State Water Resources Control Board to oversee water quality protection on timber operations on non-federal lands in California.** **- Senate Bill 810, enacted in 2003, provides that**

Table 4. Proposed TMDL Implementation Actions and Recommended Alternative Actions

Source or Land Use Activity	Responsible Parties	Action Proposed in Public Draft TMDL	Recommended Alternative Action
			a Timber Harvest Plan (THP) may not be approved if the Regional Water Board finds that the proposed timber operations will result in discharges to a water body impaired by sediment and/or is in violation of the Basin Plan. - Regional Water Board Timber Harvest General Waste Discharge Requirements (Order No. R1-2004-0030) and Categorical Waiver of Report of Waste Discharge (Order No. R1-2004-106) for timber activities on private lands. Both the Categorical Waiver and the General Waste Discharge Requirements programs use the CDF timber harvest, functional equivalent review process for THPs and Non-industrial Timber Management Plans (NTMP) to ensure compliance with the CEQA. - Active and continuous oversight by Regional Water Board staff of the timber harvest review and inspection process. - Habitat Conservation Plans and Sustained Yield Plan review. - U.S. Forest Service activities (discussed in Section 8.1.17) and CDF and Board of Forestry meetings and review.
Caltrans Activities	• California Department of Transportation (Caltrans) • Regional Water Board.	Regional Water Board staff shall complete an initial evaluation of the Caltrans Stormwater Program within two years of the date the TMDL Action Plan takes effect. After the initial two-year evaluation is completed, the Regional Water Board staff shall continue periodic reviews of the Caltrans Storm Water Program to assure ongoing	Proposed action is sufficient.

Table 4. Proposed TMDL Implementation Actions and Recommended Alternative Actions

Source or Land Use Activity	Responsible Parties	Action Proposed in Public Draft TMDL	Recommended Alternative Action
		compliance with the Shasta River TMDL.	

Response: Table 4 in the Action Plan has been completely revised. Please see the revised version.

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Appendix A: Quartz Valley Indian Reservation Comments

Typographic/grammar errors and other less significant comments

General comment
Many of the tables and charts in this document are formatted as images, not text/lines. This makes them harder to read (fuzzy and pixilated) and makes it impossible to copy/paste data from tables into spreadsheets. If possible, the Regional Water Board should try in future TMDLs to properly format the tables and charts.

Page 2-25
This statement is based on a total of 6 data points: "Total phosphorus levels are low in the headwaters of the watershed at the North North Fork Shasta River and Shasta River near the headwaters monitoring locations, with values of 0.025 mg/L"
Hence, a qualifying statement is necessary (also note that the word North is repeated). We suggest the following: "Existing limited data (6 samples) indicate that total phosphorus levels are low in the headwaters of the watershed at the North Fork Shasta River and Shasta River near the headwaters monitoring locations, with values of 0.025 mg/L"

Page 2-28
This statement is based on a total of 6 data points: "Total phosphorus concentrations of the headwaters of the Shasta River are generally oligotrophic, with TP concentrations at levels that do not promote nuisance aquatic growth."
Hence, a qualifying statement is necessary. We suggest the following: "Existing limited data (6 samples) indicate that total phosphorus concentrations of the headwaters of the Shasta River are generally oligotrophic, with TP concentrations at levels that do not promote nuisance aquatic growth."

Page 2-29
This statement is based on a total of 6 data points: "Existing limited data (6 samples) indicate that" to the beginning of "The headwaters of the Shasta River generally have low total nitrogen levels, indicative of conditions that do not promote aquatic plant growth."
Hence, a qualifying statement is necessary. We suggest the following: "Existing limited data (6 samples) indicate that the headwaters of the Shasta River generally have low total nitrogen levels, indicative of conditions that do not promote aquatic plant growth."

Page 3-9
In Figure 3.5, the Y-scale on graph is too large. It would be more legible if scale was from +1 to -4, rather than current scale of +4 to -4. If this would be easy to do, it should be redone.

Page 3-16
There is a bunch of irrelevant words on this page (delete).

Page 4-2
The statement that "The organic matter thus produced then serves as an energy source for bacteria and animals in the reverse process of *respiration*…" should be revised to include the fact that plants also respire (could be fixed by adding "plants, " before "bacteria").

Page 4-5
The statement “At this average TKN concentration, approximately 2.3 mg/L of oxygen is consumed, representing a moderate component of the total oxygen demand exerted in the Shasta River.” should be revised to read “At this average TKN concentration, approximately 2.3 mg/L of oxygen would be consumed. This 2.3 mg/L of oxygen consumption occurs spread over an unknown period that is likely at least five days long, thus representing only a moderate component of the total oxygen demand exerted in the Shasta River.”

Page 4-6
This statement on page 4-6 is ambiguous as to whether the conditions occurred in the Shasta River or elsewhere: “USGS reports document cases of supersaturated conditions attributed to aquatic plant growth persisting for several days or more, with saturations as high as 250 percent (Flint et al. 2005, p. 60).” We recommend changing it to:
“USGS reports from Oregon document cases of supersaturated conditions attributed to aquatic plant growth persisting for several days or more, with saturations as high as 250 percent (Flint et al. 2005, p. 60).”

Page 8-7
On this page there are several mentions of the Scott River that should instead be the Shasta River. It appears as though this language was ported over from the Scott TMDL. Also, there is mention of the “Strategic Action Plan”, another relic from the Scott River TMDL.

Page 8-8
Change “timewith” to “time with”

Page 8-9
“Grazing on federal land is addressed separately in sections 8.8 (Forest Service) and 8.9 (BLM) of the Staff Report.” This apparently references an outdated numbering system; it should be sections 8.9 and 8.10.

Page 8-11
This language is contained twice in the same paragraph. One should be deleted.

> “Irrigation water would be applied uniformly based on an accurate measurement of cropwater needs and the volume of irrigation water applied, considering limitations raised by such issues as water rights, pollutant concentrations, water delivery restrictions, salt control, wetland, water supply and frost/freeze temperature management. Additional precautions would apply when chemicals are applied through irrigation.”

Page 8-13
This statement is out of place, and it is unclear what the point is:

> “The Dissolved Oxygen TMDL (Chapter 7), using the water quality compliance scenario of the RMS model, shows that photosynthetic and respiration rates approaches 50% of existing baseline conditions when assuming a 50% reduction in the standing crop of aquatic plants.”

This does not make any sense. The photosynthetic/respiration rates are essentially the same things (just different units) as the standing crop.

Page 8-18
Change "dry wet water plan" to "dry year water plan"
Change "dissolver" to "dissolved"

Page 8-34
Change "Contol" to "Control"
Change "Dsicharge" to "Discharge"
Change "nd" to "nd"

Response: The appropriate changes have been made.

4. Greg Frantz and Michael Buckman – State Water Resources Control Board Comments

Comments:
Would be helpful to know when items are defined in the glossary via bolding or * indication.

Page 1, Part I, first paragraph: "Water temperature conditions are regularly too high…" Because the temperature objectives in the Basin Plan are narrative and the TMDL is interpreting the narrative in order to protect beneficial uses, staff recommend you say …"because they exceed temperature protective of salmonids…" or just leave out "too high" and say, "Water temperature conditions regularly exceed temperature thresholds protective of salmonids." Would be much more clear and concise.

Page 2, Part III. Section B: Last paragraph: "The Shasta River Watershed"…,no net increase in receiving water temperature". Could add clarity to the regulation to leave off the "no" because you define this to be a net increase of zero later.

Page 2. Part III, Section B: Was not clear how the Maximum daily temperatures of 1.5°C, 1.2°C, and 2.1°C were derived in the Staff report. Since these are regulatory numbers, it's important to show in the staff report how they were determined. The Maximum daily temperatures of 1.5°C, 1.2°C, and 2.1°C were also sited Page 3 Part III, Section C before table 1. And again sited in table 2 on page 5.

Page 3. Part III, Section B: "TMDL=…+ no Net increase in Temp…" Just a suggestion, to leave off the "no" because the actual equation includes the Net Increase which you explain to be a zero net increase in temperature from tailwater return flows in Section C.

Page 4, Figure 1: It appears that both right and left banks have the same TMDLs for average percent transmittance although the baseline values are different. Please standardize the y-axes on these two graphs so the reader can readily see this.

Page 5, Table 2: Under "Change in Riparian Vegetation" there's a reference to Tables 6.2 and 6.4, which do not appear in the amendment language (they're found in the staff report). This reference should be removed. The amendment language has to stand on its own. If tables are necessary add them to the amendment. Also, Table 6.4 does not seem to apply here, since it refers to Brazie Ranch air temperatures, and the context in the amendment language refers to Shasta River solar radiation transmittance.

Page 5, Part III Section C should be Section D. Also, there's reference to a "water quality compliance model scenario," which is not explained. Please add explanation.

Page 5 Part IV, Section A. Consider adding carbonaceous deoxygenation, nitrogenous deoxygenation, and reaeration to the glossary of terms.

Page 6. Part IV, Section C: The value of 0.91 mg/L for NBOD is not explained. Where does this number come from? Could not find TKN in Appendix E to calculate .91mg/L. It says to refer to 5.1.2 in Appendix E but I could not find that section…possibly left out or in wrong location.

In Table 4 numerous acronyms are used before defining their meaning such as CRMP (p8) RRWMP (p9) PCP (p9) RCD (p10) WWTF (p12) BLM (p13) etc

Page 8, In Table 4, Paragraph 2. It appears that 8.2 is suppose to be referred to instead of table 8.1.

Part V. Implementation is lacking a specific time frame for certain events, i.e. page 8 last paragraph. How long is the time period for notice of failure of voluntary actions if that scenario does happen? It's not clear when the various implementation actions are to take place, or when they are to be initiated. Some sort of timeline is needed so the regulated community can know what is expected.

Page 13. Part VI. First paragraph "…nitrates and nitrates…" Should read "nitrates and nitrites" ?

Table 4: On page 9, the second and third paragraphs do not resolve. Something has clearly been left out.

Page 14, Part VIII. The first sentence is unclear. "The Regional Water Board shall take enforcement actions for violations of the Shasta River TMDL Action Plan where elements of the TMDL Action Plan are made (thru?) enforceable restrictions in a specific permit or order, as appropriate. Should be more specific on how items in the implementation plan will be made enforceable per the Policy for Implementation and Enforcement of the Nonpoint Source Pollution Control Program which emphasizes that any discharge must be regulated using waste discharge requirements, waivers, or prohibitions as appropriate. Staff recommends adding language to be clear that discharges will be regulated.

Page 15, Part IX. Tailwater Return Flow should all be bold and not just Tailwater.

Part IX, Glossary: We recommend you include a definition for "nitrification" or NBOD, since these terms are used in the amendment language. If these terms are the same as nitrogenous oxygen demand, which does appear in the glossary, then only this latter terms should be used in the amendment language.

Staff Report:

Chapter II. Page 8. Table 2.5 Has no unit of measure.

All equations, units, and conversion factors have to be shown in the staff report.

Response: All of the suggested edits/revisions have been incorporated into the revised Staff Report and Basin Plan Amendment.

5. Jim Cook – Siskiyou County Supervisor Comments

Supervisor Cook's comment document is included here in its entirety. This is the format in which it was received by Regional Water Board staff.

(Begin comment document):

Note: This document was recreated by scanning hard copies of the posted .pdf basin plan language. It contains many minor spelling and optical character recognition (ocr) errors which I have not attempted to correct in the interests of time. Changes are indicated by strikethrough where text was deleted, and by blue print where text was inserted.

North Coast Regional Water Quality Control Board

2122/2006 Draft

[Add a new sub-section to the Water Quality Control Plan for the North Coast Region implementation chapter (Chapter 4) with the following Action Plan for the Shasta River. This section will be added after the "Action Plan for the Scott River Watershed Sediment and Temperature TMDL." In addition to adding the following language, several editorial revisions will be made, including appropriate changes to the Title Page, Table of Contents, Summary of Basin Plan Amendments (Appendix 1), page numbers, table and figure numbers, footnote numbers, and headers and footers to reflect the new language. The final locations of tables and figures in relation to the text may also be changed to accommodate the existing formatting of the Basin Plan.]

ACTION PLAN FOR THE SHASTA RIVER WATERSHED TEMPERATURE AND DISSOLVED OXYGEN TOTAL MAXIMYMDAILY1.0ADS 1

The Shasta River watershed (CalWater Hydrolog–ic Area 105.50), which includes all tributaries and Lake Shastina, comprises approximately 508,734 acres (795 mi) in Siskiyou County. The Shasta River is tributary to the Klamath River. This *Action Plan for the Shasta River Temperature and Dissolved Oxygen Total Maximum Daily Loads,* hereinafter known as the Shasta River TMDL Action Plan, includes temperature and dissolved oxygen total maximum daily loads (TMDLs) and describes the implementation actions that presently appear necessary to achieve the TMDLs and attain water quality standards in the Shasta River watershed. The goal of the Shasta River TMDL Action Plan is to achieve the TMDLs, and thereby achieve dissolved oxygen and temperature related water quality standards, including the protection of the beneficial uses of water in the Shasta River watershed.

The Shasta River TMDL Action Plan sets out the loads and directs conditions to be considered and incorporated into regulatory and non-regulatory actions in the Shasta River watershed. The Shasta River TMDL Action Plan is not directly and independently enforceable, except as incorporated into appropriate permitting or enforcement orders. The ability to make timely progress shall be dependent, at least in part by funding availability. (Need further discussion on this.)

The Regional Water Board shall take enforcement actions for violations of the Shasta River

TMDL Action Plan where elements of the TMDL Action Plan are made enforceable restrictions in a specific permit or order, as appropriate. Nothing in this TMDL Action Plan precludes actions to enforce any directly applicable prohibition found elsewhere in the Basin Plan or to require cleanup and abatement of existing sources of pollution where appropriate.

~~See VIII., Enforcement, on pp. 14~~

A glossary defining key terms is located at Part IX of this Action Plan. **I. Problem Statement**

The Shasta River watershed was listed as impaired for organic enrichment/dissolved oxygen in 1992, and as impaired for temperature in 1994, pursuant to Section 303(d) of the Clean Water Act. These listings were confirmed in the TMDL analysis. Dissolved oxygen concentrations are regularly too low to comply with the Basin Plan dissolved oxygen objectives. Water temperature conditions are regularly too high and exceed temperature thresholds protective of salmonids.

Low dissolved oxygen concentrations and elevated water temperatures in the Shasta River, its tributaries, and Lake Shastina have resulted in degraded water quality conditions that do not meet applicable water quality objectives and that impair designated beneficial uses. The designated beneficial uses that are not fully supported include: cold freshwater habitat (COLD); rare, threatened, and endangered species (RARE); migration of aquatic organisms (MIGR); and spawning, reproduction, and/or early development of fish (SPWN), commercial and sport fishing (COMM); and contact and non-contact water recreation (REC-1 and REC-2).. The designated beneficial uses associated with the cold freshwater salmonid fishery (COMM, COLD, RARE, MIGR, SPWN, CUL) are the designated beneficial uses most sensitive to the dissolved oxygen and water temperature impairments.

The Klamath River, to which the Shasta River is tributary, is also listed as impaired for low dissolved oxygen, high water temperature, and high nutrient levels. The Klamath River has additional beneficial uses that are not designated for the Shasta River that may be adversely affected by inputs from the Shasta River. These beneficial uses include the Native American cultural use (CUL) that supports cultural and traditional rights of indigenous people, such as ceremonial uses, and the subsistence fishing use (FISH).

Adopted by the North Coast Regional Water Quality Control Board on (insert date}. Adopted by the State Water Resources Control Board on (insert date}. Approved by the State Office of Administrative Law on (insert date}. Approved by the United States Environmental Protection Aoencv on !insert datel.

II. Watershed Restoration Efforts

Throughout the Shasta River watershed, many individuals, groups, and agencies have been working to enhance and restore fish habitat and water quality. These groups include, but are not limited to, the Shasta Valley Resource Conservation District, the Shasta River Coordinated Resources Management Program, private timber companies, the Natural Resource Conservation Service, Siskiyou County and the Five Counties Salmon Conservation Program, the California Department of Fish and Game, the California Department of Water Resources, the United States Forest Service, and the Klamath River Basin Fisheries Task Force. The past and present efforts of these stakeholders have improved water quality conditions in the Shasta River and its tributaries.

III. Tefmper!1oerature

A. Shasta River Temperature Source Analysis

The Shasta River temperature source analysis identifies the sources (or factors) that affect the temperature of the Shasta River watershed. Five primary factors have been identified as affecting stream temperatures in the Shasta River watershed. ~~Human activities have affected, or have a potential to affect, each of tl1ese factors.~~ The factors include:

. ~~Reduced~~ Sstream shade ~~from agricultural practices including grazing and livestock activities~~;
. Tailwater return flows;
. Flow regulation and modification;
. Groundwater accretion ~~/~~ / spring inflow; and
. Lake Shastina and minor channel impoundments.

In addition, microclimate alterations resulting from near-stream vegetation removal may increase temperatures, where microclimates exist. Further, changes in channel geometry from natural conditions can also negatively affect water temperatures. Higher summer flows than historical may be affecting cold water refugia and functions of the cold water fishery. However, these factors have not been quantified for the Shasta River temperature TMDL.

B. Shasta River Temperature TMDL

The "loading capacity" refers to the total loading of a pollutant that a water body can assimilate and still meet water quality objectives so as to protect beneficial uses. For the temperature TMDL the water quality objective of concern is the temperature objective, which prohibits the alteration of the natural receiving water temperature unless such alteration does not adversely affect beneficial uses. The loading capacity provides a reference for calculating the amount of pollutant load reduction needed to bring a water body into compliance with standards. The starting point for the load allocation analysis is the equation that describes the Total Maximum Daily Load or loading capacity:

TMDL = Loading Capacity = 1:.WLAs + 1:.LAs + Natural Background

where 1:. = the sum, WLAs = waste load allocations, and LAs = load allocations. Waste load allocations are contributions of a pollutant from point sources, while load allocations are contributions from management-related non-point sources. There are no point source heat loads in the Shasta River watershed, and therefore no waste load allocations apply.

The Shasta River watershed temperature TMDL loading capacity is equal to the potential achievable percent solar radiation transmittance for the mainstem Shasta River, potential achievable effective riparian shade for the Shasta River tributaries, no net increase over a 24-hour time period in receiving water temperature from tailwater return flows, and an appropriate instream flow regime. An appropriate combination of these factors is ~~that~~ projected to results~~s~~ in a reductions~~s~~ in maximum daily temperature ~~of~~ down to 18~~1~~.0~~.SOC~~℃~~, 1._C, and 2.1℃~~ for compliance at~~points at~~ river mile~~s~~ 24.1~~, 15.5, and 5.6, respectively~~. Downstream of river mile 24.1 all protective measures as described above shall be employed and temperature targets established as adequate information accrues to allow that to be done.

~~The Shasta River watershed temperature TMDL: loading capacity is equal to ____% of the potential percent solar radiation transmittance for the mainstem Shasta River, _____% of the potential effective riparian shade for the Shasta River Tributaries, no net increase (should we agree \that this is the objective considering the above changes?) in receiving water temperature from tailwater return flows, and a combination of water management, shade, and other actions that result in maintaining temperatures of 18 degrees Celsius for compliance points at river miles 24.1, 15.5, and 5.6. (Do we want to engage DFG and comment about having compliance points? Will DFG be able to delete these points? We could delete points 15.5 and 5.6, or we could suggest language that calls for studies on compliance points and a decision to be made later.) Comment: As written the loading capacity only permits the natural background and makes no provision for agriculture as a beneficial use. If this change is accepted, the formula at the top of BPL pp. 3 should be changed accordingly.~~

TMDL = Loading Capacity =
Potential Percent Solar Radiation Transmittance of the Shasta River
+ Potential Effective Shade of the Tributaries
+ No Net Increase in Temperature from Tailwater Return Flows
+ Instream Flow IRegime ncreases that Achieved Specific Temperature Reductions at Compliance Locations.

C. Shasta River Temperature Load Allocations

In accordance with the Clean Water Act, the Shasta River temperature TMDL is allocated to sources of elevated water temperature in the watershed. As there are no known point source heat loads to the Shasta River watershed, the TMDL is allocated among the non-point source heat loads in the watershed. The non-point sources include (1) solar heat load (Le., sunlight) at streamside (riparian) locations in the watershed, (2) heat load from tail water return flows, and (3) heat load from surface water flow reductions.

In order to quantify the part of the TMDL focused on solar heat loads that arise from changes in streamside vegetation, and to be able to compare it to current conditions, two surrogate measures are used: (1) potential percent solar radiation transmittance at locations along the mainstem Shasta River, and (2) adjusted potential effective riparian shade at locations along tributary streams (see Glossary). Landowners and operators in the mainstem Shasta River are allocated loads equal to potential percent solar radiation transmittance, as depicted in Figure 1 and tabulated in Table 1. Landowners and operators in tributaries are allocated loads equal to adjusted potential effective riparian shade, which is equal to 90%achievable of site potential shade, to allowing for natural riparian disturbances such as floods, wind throw, disease, landslides, and fire.

riparian shade, which is equal to ____% of site potential shade, to allow for...landslides, and fire and for a load allocation to agriculture as a beneficial use.

The load allocation for tailwater return flow sources within the Shasta River watershed is a zero net increase in receiving water temperature over a 24-hour time period..
watershed is a ___degree net increase in receiving water temperature.

The load allocation for flow is projected to result in a reductions in the maximum daily stream temperatures to 18.0of 1.5°C , 1.2°C, and 2.1°C from baseline at RM 24.1, RM 15.5, and RM 5.6, the temperature complianceat locations for the TMDLriver mile 24.1.

Table 2 summarizes the temperature load allocations for the Shasta River watershed.

__

__**Table 1.** Solar heat load allocations for the mainstem Shasta River, expressed as the potential

~~Table 1, and Table 2, pp. 5: Comment: These tables and the paragraph should be corrected to correspond to the above changes in shade.~~

River Reach	Upstream River Mile	Downstream River Mile	Potential Reach Average Percent Transmittance[1]
Dwinnell Dam to Riverside Road	40.6	39.9	30
Riverside Road to uIs of A 12	39.9	28.3	50
VIS of A12 to near DeSoza Lane	28.3	22.0	85
Near DeSoza Lane to *uls* of Montague-Grenada Road	22.0	16.1	30
Near Montague-Grenada Road	16.1	14.6	10
D/S Montague-Grenada Road to Hwv 263	14.6	7.3	30
Hwv 263 to mouth	7.3	0	30 to 50"

[1]Daylight-hour average percent transmittance for given reach.
2 Alternate between 30 and *500k* every 10 percent of reach length.

Figure 1: Existing (baseline) and potential_solar radiation transmittance for the left bank (A) and right bank (8) of the Shasta River

No Solar Passage (Full Shade)

Note—graphic deleted due to ocr problem scanning document. problems

Source	Allocation
Change in Riparian Veaetation	*Shasta River*. Reach average potential solar radiation transmittance, as presented in Table 62 and Figure 6.4. *Tributaries:* Potential effective rioarian shade = 90% of site ootential shade.
Irrigation Return Flow	No net increase in receiving water temperature.
Surface Water Flow	Reductions in the maximum daily stream temperatures of 1.5°C, 1.C, and 2.1°C from baseline at RM 24.1, RM 15.5, and RM 5.6

C. Shasta River Temperature Margin of Safety, Seasonal Variations, and Critical Conditions

The temperature TMOL TMDL includes an implicit margin of safety, based on conservative assumptions and uncertainties. The water quality compliance model scenario incorporated temperature reductions from Big Springs Creek and Parks Creek to account for improvements associated with riparian shade and tailwater management, but did not incorporate temperature reductions from Yreka Creek and other small tributaries to the Shasta River, and provides a margin of safety. Topographic shade was not considered in the temperature model and is likely a non-negligible factor in the Shasta canyon, and provides a margin of safety. Some improvements in stream temperature that may result from reduced sedimentation are not quantified. Reduced sediment loads could lead to increased frequency and depth of pools, independent of changes in solar radiation input. These changes tend to result in lower stream temperatures overall and tends to increase the amount of lower-temperature pool habitat. These expected changes are not directly accounted for in the TMOLTMDL. Finally, the effects of changes to streamside riparian areas toward mature trees will tend to create microclimates that will lead to improvements in stream temperatures. These effects were not accounted for in the temperature analysis and provide a margin of safety.

Comment: "C" should probably be changed to D. Also, it's not clear how a margin of safety is or would be applied. Are the temperature reductions higher than need be in order to provide a margin of safety? And for what purpose is there a margin of safety? Is it for the beneficial use or for the those parties allocated a temperature loading?

To account for annual and seasonal variability, the Shasta River temperature TMOL TMDL analysis evaluated temperatures and thermal processes during mid- to late-summer, considered the most critical time period for the most sensitive beneficial uses (i.e., the hottest time of the year corresponding with the lowest surface water flows). The critical period accounts for seasonal variation and provides an implicit margin of safety because at this point the air temperature is elevated, the flow is below average, and the most sensitive beneficial use - salmonid juvenile rearing - is present. Sensitive life stages exist in Shasta River watershed throughout the year, but summer water temperatures represent the most critical conditions with respect to temperature and the most sensitive beneficial uses.

IV. Dissolved OxvaenOxygen

A. Shasta River Dissolved Oxygen Source Analysis

Dissolved oxygen levels in surface waters are controlled by a number of interacting processes including: photosynthesis, respiration, carbonaceous deoxygenation, nitrogenous deoxygenation and nitrification, reaeration, sediment oxygen demand, water temperature, salinity, and atmospheric pressure. The primary processes affecting dissolved oxygen concentrations in the Shasta River watershed are photosynthesis and respiration of aquatic plants, nitrification (termed ~~NBOO~~NBOD), and sediment oxygen demand (SOD). The following anthropogenic sources or factors, in no special order, adversely affect dissolved oxygen conditions in the Shasta River:

. T-ailwater return flows;
. City of Yreka nonpoint and wastewater infiltration sources;
. Lake Shastina and minor impoundments;
. ~~Agricultural practices including grazing and livestock activities that r~~Reduced riparian shade; and
. Flow regulation and modification.

B. Shasta River Dissolved Oxygen TMDL

The dissolved oxygen "loading capacity" of the Shasta River is the total net daily oxygen demand that results in attainment of the dissolved oxygen objectives. For the dissolved oxygen TMDL the water quality objective of concern is the minimum dissolved oxygen objective of 7.0 mg/L for the Shasta River. There are no known point sources of oxygen-demanding constituents to the Shasta River and tributaries. Each of the components that exert an oxygen demand on the Shasta River is attributed to nonpoint sources, and includes respiration of aquatic plants, sediment oxygen demand (SOD), and nitrification (NBOD).

The dissolved oxygen loading capacity of the Shasta River is 12,353 pounds of oxygen demand per day, and is expressed as the following Shasta River dissolved oxygen TMDL equation:

TMDL = Loading Capacity = 12,353 lbs 02/day

C. Shasta River Dissolved Oxygen Load Allocations

In accordance with the ~~Crean~~ Clean Water Act, the Shasta River dissolved oxygen TMDL is allocated to the sources of oxygen demand in the watershed. There are no known point sources of oxygen-demanding constituents in the Shasta River watershed, and therefore the waste load allocation is set to zero. Therefore, the TMDL includes oxygen demand from natural and non-point anthropogenic sources. The load allocations are assigned to reaches of the Shasta River as identified in Table 3, and account for the total net daily oxygen demand for the designated river reaches. Responsibility for meeting these river-reach allocations are assigned to the landowners whose operations contribute to water quality conditions within the specified reaches. In addition to these river reach load allocations, allocations are applied to several river inputs that require NBOD reductions in order to meet water quality compliance, including Dwinnell Dam outflow and Yreka Creek. These allocations are assigned as NBOD concentrations and equal 0.91 mg/L for both Dwinnell Dam outflow and Yreka Creek.

In order to meet the dissolved oxygen TMDL and load allocations, it is necessary to reduce oxygen demand and/or increase oxygen input. ~~the following needs to occur: . Fifty percent reduction in respiration rates of instream aquatic plants;~~
~~. Fifty percent reduction in SOD rates behind minor impoundments;~~
~~. Reduced NBOD input concentrations; and~~
~~. Increased surface water flow.~~

~~(are the fifty percent reductions reasonable or calculated properly?)~~

D. Shasta River Dissolved Oxygen Margin of Safety, Seasonal Variations, and Critical Conditions

The TMDL includes an implicit margin of safety to account for uncertainties in the analysis. The margin of safety is included because the TMDL is based on conservative assumptions in the TMDL analysis. The water quality compliance model scenario, which is the basis for the dissolved oxygen TMDL, includes a 50% reduction of sediment oxygen demand only at locations behind minor impoundments in the Shasta River. Fine sediment and organic material load reductions from irrigation return flows that can be achieved via controls targeting NBOD reductions would result in reductions in sediment oxygen demand in the entire river, not just behind impoundments. This represents a margin of safety. In addition, the water quality compliance model scenario does not include biochemical oxygen demand (CooDCBOD) concentration reductions. Controls targeting NBOD reductions from irrigation return flows, Dwinnell Dam outflow, and Yreka Creek would result in reductions in CHaD CBOD concentrations, and provides a margin of safety.

The dissolved oxygen analysis was conducted for a critical period of mid- to late-summer. The critical period accounts for seasonal variation and provides an implicit margin of safety, because at this point the air temperature is above average, the flow is below average, and the most sensitive beneficial use - salmonid juvenile rearing - is present. Sensitive life stages exist in the Shasta River watershed throughout the year, but summer conditions represent the most critical conditions with respect to dissolved oxygen. This critical period also corresponds to the time of greatest photoperiod and water temperature, both of which reduce the concentration of dissolved oxygen. To account for the possibility that excursions below the TMDL may occur during periods of time other than the mid- to late summer critical period, the TMDL is established as a year-round load.

Table 3: Shasta River TMDL river reach load allocations and total oxygen demand reductions needed to achieve water quality compliance

Note—graphic deleted due to ~~ocr~~ problem ~~s~~scanning

~~also corresponds to the time of greatest photoperiod and water temperature, both of which reduce the concentration of dissolved oxygen. To account for the possibility that excursions below the TMDl may occur during periods of time other than the mid- to late summer critical period, the TMDl is established as a yearround load.~~

V. ImpR,lernmeontation

Specific implementation actions that the Regional Water Board shall pursue to achieve the TMDLs and meet the dissolved oxygen and temperature related water quality standards in the Shasta River and tributaries are
described in Table 4. Table 4 is organized by topic and/or source, impairment most affected, and responsible party(ies) considered appropriate to implement ~~TMDl~~ TMDL actions. Individual landowners and responsible parties may find that more than, one implementation action is applicable to their circumstances. The implementation actions are designed to encourage and build upon on-going, proactive restoration and enhancement efforts in the watershed. Additionally, the implementation actions described in Table 4 ~~are~~ may be necessary to comply with the Plan or California's Nonpoint Source Pollution Control Program (NPS Policy).[2] If the implementation actions identified in Table 4 fail to be implemented by the responsible party or if the implementation actions prove to be inadequate the Regional Water Board shall take additional permitting and/or enforcement actions, as necessary.

Table 4 Shasta River Dissolved Oxygen and Temperature ~~TMDl~~ TMDL Implementation Actions

Source or land Use Activitv	Responsible Parties	Actions to Address Dissolved Oxygen and Water T-ernmperature
		landowners should employ land stewardship practices and activities that reduce discharges of fine sediment, nitrogen and phosphorus and reduce solar radiation transmittance from affecting waters of the Shasta River and tributaries affecting the Shasta River. ~~activities that minimize, control, and, preferably, prevent discharges of fine sediment, nutrients and other oxygen consuming materials, as well as elevated solar radiation loads from affecting waters of the Shasta River and tributaries.~~ Those that oversee and manage grazing and range land activities in the Shasta River watershed should implement

grazing and rangeland mmanagement practices listed in Table 8.1 2 of the TMDl TMDL Implementation Plan, and in the Shasta Watershed Restoration Plan.
And these changes to 8.2.

Manage grazing to provide adequate pasture residual vegetation for filtering of sediment and nutrients.

Use multiple pastures including upland pastures together to provide rest and pasture re-growth to attain residual vegetation.

Use number of cattle, sizes and grazing time that permits riparian vegetation to reach site potential.

Avoid grazing cattle with young calves near riparian areas.

Avoid providing hay raise on other property to cattle located on riparian areas.

Obtain and use hay from riparian field crops at other locations.

Harrow or otherwise mechanically breakdown cattle manure to facilitate natural incorporation into the soil prior to increasing rainfall or irrigation that results in overland flows.

Manage stock watering and livestock movement so that incursions into riparian areas and stream channels do not reduce the likelihood to attain site vegetation potential.

Use exclusionary fencing or other permanent structures when other management practices fail to achieve desired riparian goals due to livestock.

Stream crossings. Provide a stabilized area to control access for both livestock and machinery.

Herding and riding of livestock. If other grazing strategies fail to allow riparian vegetation to attain site potential, forcibly herd livestock.

Comment: Table 8.2 is the table with the listed management practices. Also, the "current edition" of the Shasta Watershed Restoration Plan should be referenced.

Range and Riparian land Management	. Parties Conducting Grazing Activities. . Parties Responsible for Vegetation that Shades Water Bodies. . Parties Responsible for Bank Stabilization Activities. . Regional Water Board.	The Shasta CRMP should, (1) implement the strategic actions specified in the <u>Shasta Watershed Restoration Plan</u> ~~Strategic Action Plan,~~ ~~Comment: The Strategic Action Plan should be replaced with the Shasta Watershed Restoration Plan.~~ and (2) assist landowners in developing and implementing management practices that are adequate and effective at preventing, minimizing, and controlling discharges of nutrients and other oxygen consuming wastes, and elevated water temperatures. The Regional Water Board will work cooperatively with the Shasta CRMP to provide technical support and information to willing individuals, landowners, and community members in the Shasta River watershed, coordinate educational and outreach efforts, and monitor the implementation and effectiveness of the Shasta Watershed Restoration Plan. The RWB staff shall convene a meeting of Responsible Parties to develop standards to be used to gage adequacy, timing and effectiveness of voluntary actions. ~~Should voluntary efforts fail to be implemented or effective at preventing, minimizing, and controlling discharges of sediment, nutrients and other dissolved oxygen consuming materials, and increasing solar radiation loads, the Regional Water Board's Executive Officer shall reQuire the aoorooriate~~

2 The *Policy for the Implementation and Enforcement* of *the Nonpoint Source Pollution Control Program* (N PS Policv).

Table 4 Shasta River Dissolved Oxygen and Temperature TMDL Implementation Actions

Source or Land Use Activity	Responsible Parties	Actions to Address Dissolved Oxygen and Water Temperature
		~~responsible parties to develop, submit, and implement a RRWMP on an as-needed, site-specific basis. Any landowner may be subject to this requirement if livestock grazing activities on their property are discharging, or threatening to discharge *oxygen* consuming materials and/or elevated solar radiation loads to a water body in the Shasta River watershed.~~ Should the rate of implementation of voluntary efforts fail to be adequate or effective at preventing, minimizing, and/or controlling both discharges of sediment, nutrients and other dissolved oxygen consuming materials and solar radiation loads, the Regional Water Board's Executive Officer shall require the appropriate responsible parties to develop, submit~~-~~, and implement a Ranch Riparian Water Management Plan (RRWMP) on an as-needed, site-specific basis. Any landowner may be subject to this requirement if activities on their property result in discharging, or threatening to discharge ~~oxygen consuming materials~~nitrogen and phosphorus and/or result in failure to take adequate measures to decrease solar radiation loading to the Shasta River and tributaries that are affecting the Shasta River. ~~a water body in the Shasta River watershed.~~ The RRWMP shall describe in detail: ~~The RRWMP shall describe in .detail:~~

	"	Locations discharging and/or with the potential to discharge nutrients and other oxygen consuming materials, and increased solar radiation ~~loads to watercourses which are~~ ~~caused by livestock grazing,~~ to watercourses, which are caused by management activities. How and when those sites are to be controlled and monitored, and management practices that will prevent and reduce, future discharges of nutrient and other oxygen ~~c~~consuming materials, and increases in solar radiation loads. Group and/or individual RRWMPs shall be implemented upon review, comment, and approval by Regional Water Board staff and their Executive Officer for compliance with Regional Board directives, the Basin Plan.~~, and also with the management~~ ~~measures in the Nonpoint Source PCP.~~ ~~Pollution Control Program (PCP)~~.	
		~~The Regional Water Board shall address the removal and~~ ~~suppression of vegetation that provides shade to a water body~~ ~~through its Wetland and Riparian Protection Policy, a~~ ~~comprehensive, region-wide riparian policy that will address~~ ~~the importance of shade on instream water temperatures and~~ ~~will potentially propose riparian setbacks and buffer widths.~~ ~~The Policy will likely propose new rules and regulations, and~~ ~~will therefore take the form of an amendment to the Basin~~ ~~Plan. Other actions under this section may be modified for~~ ~~consistency with this policy, once adopted. With funding~~	

		~~already available through a grant from the U.S. EPA, Regional Water Board staff are scheduled to develop this Policy by the end of 2007.~~ Permitting and Enforcement: Should the rate of implementation of voluntary efforts fail to be timely, adequate, or effective, the Regional Water Board shall~~.~~ ~~The Regional Water Board shall~~ take appropriate permitting and enforcement actions if necessary to address the removal and suppression of vegetation that provides shade to a water body in the Shasta River watershed. Such actions may include, but are not limited to, general waste discharge requirements (WDRs) or waivers of WDRs *for* grazing and rangeland activities, farming activities near water bodies, stream bank stabilization activities, and other land uses that may remove and/or suppress vegetation that provides shade to a water body. Should prohibitions or general WDRs be developed, they may apply to the entire North Coast Region or just to the Shasta River watershed.

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Table 4 Shasta River Dissolved Oxygen and Temperature TMDl Implementation Actions

Source or land Use Activity	Responsible Parties	Actions to Address Dissolved Oxygen and Water Temperature
		If necessary, Regional Water Board staff shall propose to the _Board appropriate enforcement actions *for* human activities _that result in the removal or suppression of vegetation that provides shade to a water body in the Shasta River watershed. _Such actions may include, but are not limited to, cleanup and _abatement orders, cease and desist orders, and administrative civil liabilities (fines) in accordnce with California Water Code _sections 13304, 13301, and 3350, respectively. _~~Enforcement actions for violations of the California Water Code shall be taken when and where appropriate. Enforcement activities should be consistent with the State Water Board's Water Quality Enforcement Policy (SWRCB Resolution No. 2002-0040), adopted February 19, 2002, and as it may be amended from time to time. This enforcement policy promotes a fair, firm, and consistent enforcement approach appropriate to the nature and severity of a violation. Within two years of the date that the TMDl Action Plan takes effect the Regional Water Board's Executive Officer shall report to the Board on the status of the preparation and development of appropriate permitting actions. Enforcement implementation is ongoing and effective the date~~

		that the TMDl Action Plan is adopted. Following the two year review of voluntary actions, the Regional Water Board's Executive Officer shall report to the Board on the status of those efforts and, if necessary, initiate the preparation and development of appropriate permitting actions.
Tailwater Return Flows	. Parties Responsible for Tailwater Management and Use · Shasta CRMP . Shasta RCD . CDFG · Regional Water Board	Parties responsible *for* tailwater discharges from irrigated lands, affecting temperature and dissolved oxygen of the Shasta River, which may include landowners, lessees, and land managers, should implement the management practices presented in the CDF&G's Coho Recovery Strategy, the Shasta CRMP's Shasta Watershed Restoration Plan and the Shasta RCD's Incidental Take Permit Application or permit once adopted. Regional Water Board staff will evaluate the effectiveness of these voluntary actions and develop recommendations Regional Water Board staff will evaluate the effectiveness of these voluntary actions and, if the actions are found not to be timely, adequate, or effective, will develop recommendations for the most effective regulatory vehicle to bring tailwater

		discharges into compliance with the ~~TMDl~~ TMDL and the Basin Plan. Information gathered during the evaluation phase will be used to formulate final recommendation(s) to the Regional Water Board. This evaluation phase shall be completed within ~~12~~36 months after the ~~TMDl~~ TMDLis approved by the U.S. EPA. Based on Regional Water Board staff recommendation(s) derived from the evaluation phase for tailwater management, the Regional Water Board ~~shall~~ may adopt prohibitions, Waste Discharge Requirements, Waivers of Waste Discharge Requirements, or any combination, thereof, as appropriate. To assure compliance, if prohibitions, WDRs, Waivers of WDRs, or any combination of the latter are adopted, a ~~tiered~~ tailwater management evaluation program may be instituted that ~~define a "tiered tailwater management program".~~ ~~may be instituted for tailwater management that~~ may include various elements such as discharge and receiving water sampling, monitoring, and reassessment.

Table 4 Shasta River Dissolved Oxygen and Temperature TMDL Implementation Actions

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Source or Land Use Activity	Responsible Parties	Actions to Address Dissolved Oxygen and Water Temperature
		Additional management practices to assure that tailwater discharges to receiving waters comply with the TMDL and the Basin Plan may also be based on results from the tailwater management evalu program. manaaement croaram.
Water Use and Flow	· Water Rights Holders and other Stakeholders . Shasta Coordinated Resource Management and Planning Committee (Shasta CRMP) . Shasta Valley Resource Conservation District (Shasta RCD) · California Department of Fish and Game (CDFG) · Regional Water Board	Water diverters should participate in the CDFG's Coho Recovery Strategy (CDFG 20048) and Incidental Take Permit Program (CDFG 2004b). The Regional Board shall work with DFG to establish monitoring and reporting elements of these programs in order to gage their effectiveness. Water diverters should participate in and implement flow-related measures outlined in the Shasta CRMP's Shasta Watershed Restoration Plan. The Regional Board shall work with the Shasta CRMP to establish monitoring and reporting elements in order to gage the Plan's implementation and effectiveness. If after five years, the Regional Board Executive Officer finds that the above-measures have failed to be implemented or are otherwise ineffective, the Regional Board may recommend that the SWRCB consider seeking modifications to the decree, conducting proceedings under the public trust doctrine, and/or conducting proceedings under the waste and unreasonable use provisions of the California Constitution and the California Water Code. Those water related measures contained in the CDFG's Coho Recovery Strategy and Incidental Take Permit and application and in the Shasta CRMP's Shasta Watershed Restoration Plan will all contribute to achieving TMDL Goals, and participation in those programs is highly encouraged. Those water related measures are expected to form the core of anticipated voluntary efforts under Water

Use and Flow. The RWB shall work with the CRMP, RCD, and DFG to establish monitoring and reporting elements in order to gauge the effectiveness of those voluntary efforts. Those elements shall ~~bu~~ be used to evaluate those efforts of those formal participants and those not formally participating.

In order to accomplish water quality objectives any mix of legal actions is acceptable as long as specified results can be achieved. RWB shall assist SVRCD and CRMP in the use of the SVWQ model to investigate over time the effectiveness of proposed measures. After 5 years, RWB staff will evaluate the effectiveness of these vol~~o~~untary actions to determine if persons in the Shasta Valley are making reasonable progress ~~towaree~~ toward achieving water quality objectives considering the combined effect of all actions viewed as a whole.

An additional review shall occur at ~~(~~10 years. ~~review placemarker. Is there language about a 10 year review somewhere?)~~

At 20 years, if ~~either adequate~~ progress ~~along those paths chosen by the community or the opportunities for progress remaining on those paths are clearly~~is still not sufficient to accomplish water quality objectives, then water rights holders must, within 2 years, complete a good-faith effort to develop approaches and timelines to secure additional gains in water quality. An evaluation will be performed including a reevaluation of the target objectives and technical analysis. ~~Failing that, RWB staff may develop such a plan.~~

Enforcement actions for violations of the California Water Code shall be taken when and where appropriate. Enforcement activities should be consistent with the State Water Board's *Water Quality Enforcement Policy* (SWRCB Resolution No. 2002-0040), adopted February 19, 2002, and as it may be amended from time to time. This enforcement policy promotes a fair, firm, and consistent enforcement approach appropriate to the nature and severity of a violation.

Irrigation Control Structures, Weirs, Flashboard Dams, and other Minor Impoundments (Collectively referred to as minor impoundments)	. Individual Irrigators . Irrigation districts . Other Stakeholders owning, operating, managing, or anticipating construction of minor impoundments	Irrigations districts, individual irrigators, and other stakeholders that own, operate, manage, or anticipate construction of instream impoundments such as flashboard dams, or other structures capable of blocking, impounding, or otherwise impeding the free flow of water in the Shasta River system shall comply with the following measure: Within one year of TMDL approval by the U.S. EPA, Regional Board S assess and establish baseline sediment oxygen demand levels. Follov owners and operators of those structures shall identify methods and m practices to be used to reduce sediment oxygen demand. Options may include, but are not limited to: 1) removing impoundments Shasta River mainstem as a mechanism to provide for flushing flows c scouring fine sediment from the stream-river channel on which aquatic grow; 2) re-engineering existing impoundments to decrease their surfa and 3) not undertaking the construction of new impoundments that will beneficial uses of water relative to water quality compliance and the su beneficial uses, including the salmonid fishery, in the Shasta Valley.
Lake Shastina	Montague Water	~~. - jct s~~

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Table 4 Shasta River Dissolved Oxygen and Temperature TMDlImplementation Actions

Source or Land Use Activity	Responsible Parties	Actions to Address Dissolved Oxygen and Water Temperature
	Conservation District (MWCD) City of Weed and the Lake Shastina CSD County of Siskiyou . Rancho Hills Community Association Lake Shastina .Property Owners Association Other Appropriate Stakeholders Regional Water Board	The Montague Water Conservation District in cooperation with the City of Weed and the Lake Shastina CSD shall develop within 1 year a timeline and approach to characterize, quantify, and analyze the sources of, and ways to reduce, nitrogenous oxygen demanding substances contributing to low dissolved oxygen levels affecting the beneficial uses of water in Lake Shastina and to waters of the Shasta River downstream from Dwinnell Dam. Based on the results of the investigation, the Regional Water Board shall determine appropriate implementation actions necessary to reduce the nitrogenous oxygen demand that is lowering dissolved oxygen concentrations in lake Shastina and affected areas downstream from Dwinnell Dam.
City of Yreka Wastewater Treatment Facility (Yreka WWTF)	.City of Yreka Regional Water .Board	The Regional Water Board staff shall pursue aggressive compliance with Order No 96-69, and CAO No.R1-2004-0037. To ensure timely submittal of sampl.ing and analytical results from the operators of the Yreka WWTF, the Regional Water Board staff shall also continue vigorous oversight and enforcement of Monitoring and Reporting Program No. R1-2003-0047.
		The cities of Yreka, Weed, the Lake Shastina Development and other stakeholders should identify possible pollutants, their sources, and volumes of polluted runoff from urban and suburban sources within their spheres of influence that may discharge, directly or indirectly, to waters of the Shasta Valley watershed. Cities and other stakeholders responsible for urban and

Urban and Suburban Runoff	· Cities of Yreka, Weed, Montague, The Lake Shastina Development . Other Stakeholders · Regional Water Board	suburban runoff should implement the-following measures: Seasonal scheduling of construction activities to prevent unnecessary waste loads in stormwater runoff. Seasonal scheduling for the application to lawns and gardens, municipal facilities, and agricultural areas of fertilizers, pesticides and herbicides, and other oxygen consuming materials that may contribute to dissolved oxygen impairments to watercourses in the Shasta River hydrologic system from cities, towns, developments and other concentrations of urban and suburban populations. When, and it, pollutant sources are identified that discharge, or threaten to discharge, oxygen consuming materials, fine sediment, and other polluting constituents to nearby watercourses from existing runoff control facilities, the Regional Water Board will work cooperatively with responsible parties to ascribe appropriate management measures and reasonable time schedules to control and eliminate said pollutant discharges.

Table 4 Shasta River Dissolved Oxygen and Temperature TMDL Implementation Actions

Source or Land Use Activitv	Responsible Parties	Actions to Address Dissolved Oxygen and Water Temperature
Activities on Federal Lands	.U.S. Forest Service (USFS) . Regional Water Board	The USFS shall consistently implement the best management practices included in *Riparian Area Management* 1997 (USDNUSDI1997), and *Water Quality Management for Forest System Lands in California, Best Management Practices* (USFS 2000). The Regional Water Board staff will continue its involvement with the USFS to periodically reassess the mutually agreed upon goals of the Management Agency Agreement between the SWRCB and the USFS. Additionally, the Regional Water Board shall work with the USFS to draft and finalize a Memorandum of Understanding (MOU). The MOU shall be drafted and ready for consideration by the appropriate decision-making body of the USFS within two years of the date the TMDL Action Plan takes effect. The MOO shall include buffer width requirements and other management practices as detailed in the Implementation chapter of the TMDL.
	.U.S. Bureau of Land	BLM shall implement best management grazing strategies that are detailed in a joint management agency document titled: *Riparian Area Management* 1997 (USDNUSDI 1997). The Regional Water Board shall work with the BLM

	Management Regional Water · Board	to draft and finalize a Memorandum of Understanding (MOU). The MOU shall be drafted and ready for consideration by the appropriate decision-making body of the BLM within two years of the date the Shasta River TMDL Action Plan takes effect. The MOU shall include buffer width requirements and other management practices as detailed in the Implementation chapter of the TMDL.
Caltrans Activities	· California Department of Transportation (Caltrans) · Regional Water Board.	Regional Water Board staff shall complete an initial evaluation of the Caltrans Storm water Program within two years of the date the TMDL Action Plan takes effect. After the initial two- year evaluation is completed, the Regional Water Board staff shall continue periodic reviews of the Caltrans Storm Water Program to assure ongoing compliance with the Shasta River TMDL.

VI. Monitoring

Monitoring is important for determining the success of the TMDL Action Plan in achieving dissolved oxygen and temperature water quality standards. Monitoring shall be conducted upon the request of the Regional Water Board's Executive Officer in conjunction with existing and/or proposed human activities that will likely result in increased dissolved oxygen and reduced water temperatures in the Shasta River watershed. Monitoring may involve implementation, upslope effectiveness, photo documentation, instream and near-stream effectiveness (e.g. riparian buffer establishment affecting nutrient discharges), and*lor* compliance and trend monitoring (e.g. temperature and dissolved oxygen, Potential Percent Solar Radiation Transmittance, time predicated dissolved oxygen sampling, nutrients, sediment oxygen demand, nitrates and nitrates, and any other parameters reflective of improvements toward achieving the TMDL). Monitoring of sampling parameters, frequency, numeric and

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narrative objectives, and other appropriate metrics shall be based on locations consistent with those reaches representative of the TMDL. See the Glossary in Part IX of this Action Plan for definitions of these terms. The authority for such requirements is contained in Section 13267 of the California Water Code, which states that the Regional Water Board may require any discharger, suspected discharger, or future discharger to furnish, with input from the Regional Water Board, monitoring program reports.

The Executive Officer will base the decision to require monitoring on site-specific conditions, the size and location of the discharger's ownership, and/or the type and intensity of land uses being conducted or proposed by the discharger. If monitoring is required, the Executive Officer may direct the discharger to develop a monitoring plan and may describe specific monitoring requirements to include in the plan.

VII. Reassessment and AdaDtive Manaaement

The Regional Water Board will review, reassess, and possibly revise the Shasta River TMDL Action Plan. Reassessment is likely to occur every three years during the Basin Planning Triennial Review process. Regional Water Board staff will report to the Regional Water Board at least yearly on the status and progress of implementation activities, and on whether current efforts are reasonably calculated and on track to achieve water quality standards within 40 years. For activities that rely on encouragement as a first step, a formal assessment of effectiveness of these efforts will be completed within 5 years from the date of U.S. EPA approval. A more extensive reassessment will occur after a date that is 10 years from the date the TMDL Action Plan is effective, or sooner, if the Regional Water Board determines it necessary. During reassessment, the Regional Water Board is likely to consider how effective the requirements of the TMDL Action Plan are at meeting the TMDLs, achieving dissolved oxygen and temperature water quality objectives, and protecting the beneficial uses of water in the Shasta River watershed.

~~VIII. Enforcem_nt~~

~~The Regional Water Board shall take enforcement actions for violations of the Shasta River TMDL Action Plan where elements of the TMDL Action Plan are made enforceable restrictions in a specific permit or order, as appropriate. Nothing in this TMDL Action Plan precludes actions to enforce any directly applicable prohibition found elsewhere in the Basin Plan or to require cleanup and abatement of existing sources of pollution where appropriate.~~

IX. Glossary

Biochemical Oxygen Demand:
An analytical method used as an indicator for the concentration of biodegradable organic matter present in a sample of water. It measures the rate of uptake of oxygen by micro-organisms in the sample of water over a given period of time, and can be used to infer the general quality of the water and its degree of pollution.

Chemical Oxygen Demand:
An analytical method commonly used to indirectly measure the amount of organic compounds in water. Most generally used to determine the amount of organic pollutants found in surface water (e.g., lakes and rivers), making it a useful measure of water quality.

Compliance and Trend Monitoring:
Monitoring intended to determine, on a watershed scale, if water quality standards are being met, and to track progress towards meeting water quality standards.

Effective Shade:
The percentage of direct beam solar radiation attenuated and scattered before reaching the ground or stream surface from the natural potential vegetation conditions.

Groundwater Accretion:
The gradual increase in surface flow in a stream resulting from the influx of groundwater.

Implementation Monitoring:
Monitoring used to assess whether activities and control practices were carried out as planned. This type of monitoring can be as simple as photographic documentation, provided that the photographs are adequate to represent and substantiate the implementation of control practices.

Instream Effectiveness Monitoring:
Monitoring of instream conditions to assess whether pollution control practices are effective at keeping waste from being discharged to a water body. Instream effectiveness monitoring may be conducted upstream and downstream of the discharge point or before, during, and after the implementation of pollution control practices.

Irrigation Return Flows: Same as Tailwater Return Flow.

Natural Potential Vegetation Conditions:
The most advanced seral stage that nature is capable of developing and making actual at a site in the absence of human interference. Seral stages are the series of plant communities that develop during ecological succession from bare ground to the climax community (e.g., fully mature, old-growth).

Nitrogenous Oxygen Demand:
The conversion of organic nitrogen to ammonia by bacteria, a process that consumes oxygen.

Potential Effective Riparian Shade:
That shade resulting from topography and vegetation that reduces the heat load reaching the stream. *The difference between existing (baseline) and potential solar radiation transmittance reflects the amount of effective riparian shade increase (i.e. reduced solar transmittance) that is required to achieve natural receiving water temperatures.*

Potential Percent Solar Radiation Transmittance:
Potential percent solar radiation transmittance is the amount of solar radiation that passes through the tree canopy and reaches the water surface when vegetation is at the site's potential, where a value of 1.0 represents no shade, and a value of 0.0 would represent complete shade.

Road:
Any vehicle pathway, including, but not limited to: paved roads, dirt roads, gravel roads, public roads and highways, private roads, rural residential roads and driveways, permanent roads, temporary roads, seasonal roads, inactive roads,

trunk roads, spur roads, ranch roads, timber roads, skid trails, and landings which are located on or adjacent to a road.

Salmonids:
Fish species in the family *Salmonidae,* including but not limited to, salmon, trout, and char.

Sediment:
Any inorganic or organic earthen material, including, but not limited to: soil, silt, sand, clay, peat, and rock.

Sediment Oxygen Demand:
Sediment oxygen demand refers to the consumption of oxygen by sediment and organisms (such as bacteria and invertebrates) through both the decomposition of organic matter and respiration by plants, bacteria, and invertebrates.

Solar Radiation Transmittance:
Solar radiation transmittance is defined as the amount of solar radiation that passes through the tree canopy and reaches the water surface. A value of 1.0 represents no shade; a value of 0.0 would represent complete shade, as measured by ?????

Tailwater Return Flow:
Water applied to a field for irrigation at rates that exceed soil infiltration and evaporation rates, resulting in runoff of irrigation water to a surface water body. Same as Irrigation Return Flows.
(end comment document)

Response: Regional Water Board staff thank you for your thoughtful input into preparation of the TMDL Action Plan. Many changes have been made to the Public Review Draft Action Plan. A number of your comments have been incorporated. The following identifies those comments that we did not incorporate in the revised Action Plan, with reference to the section in which the comment was made:

III. Temperature A. Shasta River Temperature Source Analysis - We did not delete the sentence “Human activities have affected, or have a potential to affect, each of these factors”, because this is a finding of the TMDL analysis.
III. Temperature A. Shasta River Temperature TMDL - We did not change the temperature allocation for flow, because identifying maximum temperature reductions at each of the temperature compliance locations achieved from increased dedicated cold water instream surface flow is an integral goal of the TMDL.
Table 2 - We did not delete Table 2, because it presents the temperature load allocations for each source category.

Table 4 – Range and Riparian Land Management - We did not delete the "minimize, control, and preferably prevent discharge" language, as this is a cornerstone of the TMDL implementation approach.
Table 4 – Range and Riparian Land Management - We did not delete the language regarding the Executive Officer reporting to the Regional Water Board on the status of the preparation and development of appropriate permitting actions within 2 years of EPA approval of the TMDL, because this action is required for compliance with the State Board's Policy for the Implementation and Enforcement of the Nonpoint Source Pollution Control Program.
Table 4 – Water Use and Flow – We did not include 10-year and 20-year milestones for review of the effectiveness of measures to increase dedicated cold water instream surface water flow because it would be inappropriate to rely on the collaborative efforts if such efforts fail to yield measurable results. Progress reports and a five-year evaluation period are appropriately incorporated into the Basin Plan to determine the adequacy of the collaborative approach and to provide an incentive for parties to participate.
VIII. Enforcement – We did not delete this section, because enforcement is part of the regulatory framework.

State of California
North Coast Regional Water Quality Control Board

PUBLIC COMMENTS & RESPONSES

for the

Action Plan and Staff Report for the Shasta River
Temperature and Dissolved Oxygen Total Maximum Daily Loads

June 28, 2006

Appendix K

State Water Resources Control Board
North Coast Region
5550 Skylane Boulevard, Suite A
Santa Rosa, California 95403
707-576-2220

TABLE OF CONTENTS

RESPONSE TO PUBLIC COMMENTS

Shasta River Watershed
Temperature and Dissolved Oxygen
Total Maximum Daily Loads

Prepared by:
Staff of the
North Coast Regional Water Quality Control Board
June 28, 2006

This is the second of two 'Response to Public Comment' documents prepared by the North Coast Regional Water Quality Control Board (Regional Water Board) staff. The first document was prepared for the initial public review period that ended on March 24, 2006 and is included in the Staff Report for the Action Plan for the Shasta TMDLs as Appendix J. This second document, included as Appendix K to the staff report, was prepared to respond to comments made during a second public comment period, which ended June 18, 2006.

The second comment period was provided as a result of the May 17, 2006 Regional Water Board hearing on the *Action Plan for the Shasta River Watershed Temperature and Dissolved Oxygen Total Maximum Daily Loads* in Fortuna, California. At the close of the hearing, the Regional Water Board directed staff to prepare a "clean" set of documents, including the Action Plan (or Basin Plan Amendment), Resolution R1-2006-0052, and the Staff Report, that would reflect all previously highlighted revisions as well as those detailed on the errata sheet distributed during the board meeting. New revisions generated during the public hearing process and staff's editorial review were highlighted for review in each document. The documents were reposted on the Regional Water Board web site on May 26, 2006.

The Regional Water Board closed the public hearing portion on all issues/items except those included in the revised or amended language, and directed that only written public comment on the highlighted revisions to the documents would be accepted. Comments were due on June 18, 2006, ten days prior to the June 28, 2006 Regional Water Board meeting. Regional Water Board staff reviewed all of the written comments submitted during the second comment period. These comments were then partitioned into categories based on comment topic. In this document, comments are arranged within each category and include the commenters name or affiliation. Responses are provided for each comment; however, several comments may be addressed under one response if the comments were similar enough in scope. The comment categories are listed below with their page number.

Regional Water Board staff addressed all comments submitted even though some comments were outside the scope outlined by the Board at the May 17 public hearing or were resubmittals from the first comment period. The resubmittals were included in this document as well, however, since they were already provided a response in the first 'Response to Public Comment' document (Appendix J), the response in this document simply references Appendix J.

Comments that addressed flow issues were separated into the 13 categories shown below on the left hand side. For these comments, the Regional Water Board staff chose to address all comments with a single response; provided after comment category 13 – Adjudication, Riparian and Groundwater Rights. This response addresses all 13 comment categories that deal with flow as it relates to water temperature and dissolved oxygen in the Shasta River watershed.

Comment Categories

Section 1 - Flow Issues

1. Lack of Water as Form of Pollution

California Farm Bureau Federation comment:
In particular, Farm Bureau concurs that diversions of water are not pollutants, and are not subject to regulation through the CWA TMDL process.

Shasta Valley Resource Conservation District comment:
The North Coast Regional Water Board (RWB) staff defines low flows as a form of pollution in the draft Resolution. The addition of this language to the resolution appears to reflect an effort by the RWB staff to regulate water rights through water quality laws. This language is of concern to the extent it suggests that action taken by the Regional Board is designed to foster the reallocation of water away from existing beneficial uses by water diverters in the watershed, and allocate this water to other uses. The implementation of this staff recommendation could result in land being withdrawn from agricultural use and subdivided into small parcels, which would bring many adverse consequences. We believe that maintaining the separation between water quality and water quantity regulations is the correct interpretation. We request that you delete Paragraph 9 from the Board Resolution.

Siskiyou Board of Supervisors comment:
The North Coast Regional Water Board (RWB) staff defines low flows as a form of pollution in the draft Resolution. The addition of this language to the resolution appears to reflect an effort by the RWB staff to regulate water rights through water quality laws and as a possible attempt to change water rights law in a potentially impermissible manner. Siskiyou County does not believe that the Clean Water Act, nor the Porter-Cologne Act, supports the RWB staff's interpretation and text addition. We ask that the specific sections of these Acts be cited showing the specific authority the RWB staff believes supports the statements that "lack of water is a form of pollution", that "water quality includes water quantity", and that the RWB can address "low flows in its Basin Plan for the Division of Water Rights' and the State Water Board's consideration." Absent such authority, the RWB should not proceed in accordance with the staff recommendation in such a manner. Furthermore, even if there is some legal basis for such an approach, it is our position that it is not sound public policy to so proceed and disturb years of accepted practice and invite protracted litigation which does not serve any interests well.

Save Our Scott and Shasta comment:
One revision that is of concern to S.O.S.S. is a new finding in Resolution R1-2006-0052. That new finding, at paragraph 9, provides as follows:
"Lack of water is a form of pollution, a term defined by the Clean Water Act as the "man-induced alteration of the chemical, physical, biological, and radiological integrity of water." Water quality includes water quantity and no artificial distinction can be made between them. California combines water rights and water quality functions of the state government into one

agency for this very reason. Jurisdiction over the administration of water rights lies with the Division of Water Rights and the State Water Board, however, the Regional Water Board finds it entirely appropriate to address low flows in its Basin Plan for the Division of Water Rights' and State Water Board's consideration."

Save Our Scott and Shasta comment:
The diversion of water is not the discharge of a "pollutant." Accordingly, the federal Environmental Protection Agency has explained that TMDLs are not an appropriate vehicle for mandating changes in diversions. EPA has explained that low flow is not a pollutant, and that the Clean Water Act does not require TMDLs for waters affected by low flows. Low flows are relevant to TMDLs, but not in the way the Regional Board is addressing them. Instead, low flows are to be considered when calculating the total pollutant load. The preamble to EPA's proposed TMDL regulations, published in the Federal Register on July 13, 2001, at 65 F.R. 43586 explains EPA's interpretation of the Clean Water Act:

> EPA does not believe that flow, or lack of flow, is a pollutant as defined by CWA Section 502(6). . .. [I]t does not believe Section 303(d)(1)(C) requires that States must establish TMDLs for such waters. This is because EPA interprets Section 303(d)(1)(C) to require that TMDLs be established for "pollutants" and does not believe "low flow" is a pollutant. Section 303(d)(1)(C) provides that States shall establish TMDLs "for those pollutants" which the Administrator identifies as suitable for such calculation. . . . However, low flow is not a pollutant. It is not one of the items specifically mentioned in the list of pollutants Congress included in at section 506(6) of the CWA. Nor does it fit within the meaning of any of those terms . . .. Section 303(d) is a mechanism that requires an accounting and allocation of pollutants introduced into impaired waters (whether from point or nonpoint sources). If low flow in a river, even if man-induced, exacerbates or amplifies the impairing effect of a pollutant in that river by increasing its concentration, that factor is to be accounted for and dealt with in the TMDL by calculating and allocating the total pollutant load in light of, among other things, seasonal variations in flow.

65 Federal Register 43592-93. Accordingly, in determining the permissible amount of pollutant loading in the Shasta River, the Regional Board should calculate and allocate the total load "in light of" the existing flows.

The Regional Board should follow a different approach, one consistent with the true scope of the TMDL process and its own lack of jurisdiction to determine water rights. It should carefully avoid any implication that this proceeding will preordain what quantity of water will ultimately be dedicated to what beneficial uses. In order to make the finding in paragraph 9 a more complete statement of the law, the Regional Board should expressly acknowledge that low flow is not a pollutant, and that the TMDL process is not the appropriate regulatory forum within which to address low flows. It should expressly disavow any intention to predetermine though the TMDL process the balance to be struck among competing beneficial uses of the water in the Shasta River. In the Action Plan, the Regional Board should state that increasing flows will not be addressed as a part of

TMDL implementation, because low flow is not a pollutant, and that it is not developing a TMDL for low flows. The Action Plan itself should be amended to remove measures designed to increase flows. Instead, it should state that any such measures, if appropriate, should be developed and implemented through other processes.

Brett Lutz comment:
I am writing to strongly support proposed changes to the Shasta TMDL, Draft Resolution NO.1- 2006- 0052, especially item 9, which points out that lack of water should be considered a form of pollution, based on wording in the Clean Water Act.

Don Morrill comment:
I appreciate the Northcoast Regional Water Quality Control Board making changes to language to the effect that the Shasta River is an important part of the Klamath River system. To reduce flows in this stream is a form of water pollution.

Mark Pringle comment:
Language that recognizes the Shasta as an important part of the whole Klamath River and recognizes that reduced flows are a form of water pollution is essential in restoring fisheries.

Tim McKay comment:
Project analysis must discuss relationships between flows and the ability to achieve necessary temperature reductions in the Shasta River.

2. <u>45 cfs as Specific Number in Action Plan</u>

Klamath RiverKeeper comment:
Most importantly, you need to retain the provision calling for increasing flows in the Shasta River by 150% in order to drop the river temperature 2-4 degrees. Adopting this provision will provide the incentive for all Shasta River water users to work together to conserve. It will likely also avoid the divisive water adjudication war which will surely ensue if you eliminate this provision. Restoring Shasta flows to what they were only about a decade ago will make the Shasta River once again hospitable for salmon and steelhead and it will happen immediately not in 60 years.

George Sexton comment:
Please adopt a clean-up plan with enforceable standards and which will increase flows in the Shasta River by 150% in order to drop the river temperature 2-4 degrees. THIS WILL MAKE THE RIVER ONCE AGAIN HOSPITABLE FOR SALMON AND STEELHEAD.

Humboldt Board of Supervisors comment:
The Board of Supervisors strongly supports the proposed changes to the Shasta River Watershed Temperature and Dissolved Oxygen Total Maximum Daily Loads (TMDL) Plan. The Board supports the proposed changes in the Plan and the linkage between flows and water temperature, and recommends an additional 45 cfs of cold water to go to the river over the life of the TMDL.

Mark Pringle comment:
I want to thank the NCRWQCB for including language that recognizes the important link between water flow/temperature and healthy fish populations. The Shasta TMDL describes a linkage between flows and water temperature and recommends that the RCD's come up with an additional 45 cfs of cold water to go to the river over the life of the TMDL.

Rudy Ramp comment:
The Shasta TMDL describes a linkage between flows and water temperature and recommends that the RCD's come up with an additional 45 cfs of cold water to go to the river over the life of the TMDL. Since the science is clear that riparian shade cannot do the job of reducing temperature without additional cold water flows, I do not want to see this recommendation removed or amended.

Sierra Club comment:
We support the inclusion of the 45 cfs goal for minimum instream flow during the critical fishery period.

Shasta Valley Resource Conservation District comment:
The Shasta Valley RCD continues to oppose the 45 cfs instream flow requirement to potentially achieve temperature reductions in the Shasta River. Since the text of the Action Plan acknowledges that any combination of measures, including increased flows, to achieve the reduction in water temperature will be acceptable, it is inappropriate to require a specific flow number.

Siskiyou Board of Supervisors comment:
In addition, Siskiyou County continues to oppose the 45 cfs dedicated instream flow requirement to potentially achieve temperature reductions in the Shasta River. Again, RWB staff is trying to assert water rights actions via the TMDL process under a federal law that has no water rights authority implied. Since the text of the Action Plan acknowledges that any combination of measures, including flows, will be acceptable, it is inappropriate to identify a specific flow number.

Coast Action Group comment:
There is sufficient comment in the file on flow needs and the flow relationship with conditions related to the other noted pollutants that points to the necessity to for the Regional Board (and SWRCB) to enforce minimum flow standards . Flow maintenance (45 cfs recommended) as part of the Action/Implementation Plan must be accomplished to remedy the noted conditions. The absence an acceptable number, as a numeric target, would make policy assuring movement towards WQS unenforceable. Lack of such numeric target, related to flow maintenance, and supporting analysis would make the TMDL and Action Implementation Plan non-compliant with the necessary legal mandates under both the CWA and State Water Code.

There is concern that the 45 cfs target minimum flow implementation will impact only certain diverters. The Division of Water Rights (SWRCB) will have to take charge of any allocation analysis (if needed) and spread the impact of reallocation over all diverters/users. There are reasonable opportunity and feasible methods to make sufficient cold water available to support the 45 cfs minimum flow requirement. The SWRCB and Division of Water Rights must address the issue of wasteful practices, and diversion license condition enforcement in allocation analysis.

The water quality compliance scenario in Chapter 6 includes a 50% increase in flow from Big Springs Creek. We strongly support that decision. However the TMDL Action/Implementation Plan must provide description of actions taken to provide for such substantial increases in flow. As discussed above, increased flows are a necessary mandate of this TMDL. There are reasonable and available solutions to solving the flow problem. Consideration should be given to associated cost factors for assisting water conservation to offset the current demand for groundwater.

3. Water Use and Flow Reporting Timeframe

Shasta Valley Resource Conservation District comment:
As one of the entities named as a responsible party in the achievement of the TMDL requirements, the Shasta Valley RCD feels that the short timelines attached to the Action Plan guarantees failure. It is our hope that we can proceed cooperatively with the Regional Water Board to achieve the water quality objectives. Such short timelines may mean that the goals we are trying to reach are effectively unattainable. We suggest that the Water Board staff consider using a 10 year timeline with an expanded adaptive management strategy.

Siskiyou Board of Supervisors comment:
Finally, the excessive optimism shown in the short timelines attached to the flow related provisions of this Action Plan guarantees failure and assures that, rather than proceeding cooperatively with the RWB to achieve water quality objectives, we will, instead, find ourselves proceeding down the path followed by much of the rest of California, losing more Williamson Act agricultural land and open space and with it the hope of restoring and protecting water quality. We will then find ourselves presiding over more and more 2-1/2 acre parcel subdivisions relying on ever larger quantities of ground and surface water having a grossly negative effect on achieving TMDL goals. After review of this Amendment, we suggest RWB staff use a 10 year timeline with an expanded management strategy.

California Trout comment:
Our final recommendation speaks to the time allotted to achieve certain goals, most notably flow and temperature standards. Five years is mentioned in the Action Plan as a trigger to assess actions and if flow measures "have failed to be implemented or are otherwise ineffective" a recommendation to the State Water Board may be made to seek modifications of water rights. We note the many qualifiers involved to make this happen but can see the sensitivity of the issues. We recommend that 10 years be the criteria before above actions

take place. This 10-year timeline also matches the newly revised timeline for the Department of Fish and Games Incidental Take Permit.

Pacific Coast Federation of Fisherman's Associations comment:
Specific actions to achieve the minimum flows for fish are not delineated, yet immediate steps are needed now to preserve remaining salmonid stocks. We are presently experiencing relatively favorable conditions for salmonids in the ocean and in a wet on-land cycle that will likely reverse sometime between 2015 and 2025 in what is known as the Pacific Decadal Oscillation (PDO) cycle. That coho salmon and fall chinook salmon populations are at such low levels or showing serious declines during the positive cycle of the PDO is not a good sign. In order to restore Shasta River chinook and coho salmon stocks, low flow and water quality problems must be remedied by 2015 or whenever the PDO switches to less favorable conditions for salmon stocks or further extinctions are likely to occur. A population that is already severely stressed even under relatively good oceans conditions will disappear when, as is inevitable, those cyclical conditions shift for the worse.

Coast Action Group comment:
The RB proposes to take no action to increase flows to improve water quality for five years. This is a long time, given the stock status of Klamath River salmon. Affecting this change should take no longer than two years. Described actions to increase flows must have timelines – that will achieve the goal of lowering instream temperature 5 degrees – in a reasonable period of time. Five years for action to occur is too long. Two years would be a more reasonable time period.

National Oceanic and Atmospheric Administration comment:
In the Public Comments and Responses document dated May 26, 2006, beginning on page 18, the State Board comments that the implementation plan lacks specific time frames and that the regulated community needs some sort of timeline to know what is expected. We agree and recommend the State Board set a timeline to fulfill their duties in the basin.

National Oceanic and Atmospheric Administration comment:
NMFS also suggests that the specific implementation plan actions to be achieved by the Shasta River TMDL over five year or longer periods should include milestone goals and annual reporting of progress. This will help encourage local stakeholder participation to achieve goals that seem attainable, and also allow for adjustments in implementation to be made along the way. This would encourage water users to meet TMDL goals, rather than assume they may be ignored because the goals seem distant or unattainable.

National Oceanic and Atmospheric Administration (NMFS) comment:
Further, the Regional Board should require those studies needed to address flow issues in the basin within a period of 3 years using the words "will" or "shall" in the proposed basin plan amendment language in Table 4 "Shasta River Dissolved Oxygen and Temperature TMDL Implementation Actions". Please change the existing language directed toward the State Board in the table from "may" to "will", as in "If after five years, . . . the Regional Water Board will recommend . . .".

This is the language used for actions assigned to the California Department of Fish and Game (CDFG), the California Department of Forestry, and the California Department of Transportation Activities (CalTrans). Directives to the State Board's Division of Water Rights should be as clear.

4. Flow as Component of TMDL

Coast Action Group comment:
The TMDL Action/Implementation does not lay out a clear path for how such a substantial increase in flow could be achieved.

California Trout comment:
California Trout supports the Water Board's recommendation to improve instream flows amounts to meet TMDL temperature criteria. Indeed, there is general consensus that more cold water is needed to meet the needs of over summering coho salmon and steelhead and is a key parameter for river restoration. We read, however, that the Action Plan does not actually prescribe the increase in flow but instead recommends that strategies be developed on where those cold water flows should come from.

Environmental Protection Information Center comment:
EPIC is very concerned that adequate flows be provided and maintained in the Shasta River to ensure survivability of salmonids. This is critical. A substantial increase in flow is imperative to ensure survivability of dependent salmonids. The issue of flows cannot be separated from many of the limiting factors and existing conditions on the Shasta River, including elevated temperature, lack of Dissolved Oxygen, nutrient loading, and pH, which increases ammonia toxicity. The Basin Plan's anti-degradation policy must be met. The TMDL Action Plan must also ensure enforceability of standards. Monitoring is key, and should not be delayed.

California Trout comment:
California Trout would like to emphasize that the success of the Shasta River TMDL Action Plan depends in large on the participation of land owners and water users. We recognize the need for increased flows and are encouraged that the Water Board is seeking solutions on this issue, but without proper involvement by the Water Board and an influx of resources meeting these goals may be impossible.

Save Our Scott and Shasta comment:
It is important that the Regional Board consider the legal context in which it is acting, and not take action to promote consequences beyond its expertise and intended function. It should not—and cannot legally—prescribe implementation of a different flow regime to be achieved by reduced diversions under the guise of "implementing" a TMDL.

5. Superior Court Appropriate Water Rights Forum

California Farm Bureau Federation comment:
The Board should also note that the Shasta River water rights are adjudicated by the Siskiyou County Superior Court, and as such neither the Regional Board nor the State Water Board has authority to convene a water rights proceeding under its own jurisdiction. The State Water Board's only option in the case of the Shasta River would be to file a petition to modify the existing decrees in the Superior Court for Siskiyou County. The Regional Board does not even have this option.

Save Our Scott and Shasta comment:
The Regional Board has neither the authority, nor sufficient information, to determine water rights. Nor have those with rights to divert the water been afforded due process concerning any modification of those rights. In its finding in paragraph 9 of Resolution R1-2006-0052, the Regional Board appropriately acknowledges that it has no jurisdiction over water rights. The Regional Board's responses to comments, at page 32, likewise acknowledge that determining water rights is not the Regional Board's function. The finding in paragraph 9 goes on, however, to justify the Regional Board's focus on water diversions on the grounds that "it entirely appropriate to address low flows in its Basin Plan for the Division of Water Rights' and State Water Board's consideration." But the Action Plan goes well beyond providing information concerning low flows for the State Board's consideration. In Table 4, the plan purports to require "water diverters" to make progress reports to the Regional Board "concerning measures taken to increase the dedicated cold water instream flow in the Shasta River by 45 cfs or alternative flow regime that achieves the same temperature reductions from May 15 to October 15." In addition, Table 4 would impose reporting and other requirements upon the operators of facilities used to exercise water rights, including Dwinnell Dam, Lake Shastina and minor impoundments. It appears that the Regional Board is attempting to impose conditions on water diverters, based on their diversion of water. That contradicts the Regional Board's disavowal of any attempt to claim jurisdiction over the exercise of water rights. The rights to use the water of the Shasta River are the subject of a court decree. The Superior Court, not the Regional Board or even the State Board, is the appropriate forum for any proceedings involving amendment or adjustment of such rights, assuming any such adjustment were appropriate.

6. Reduction of Water Rights

California Farm Bureau Federation comment:
Based upon the foregoing, CFBF opposes any action by the Regional Water Quality Control Board to try to adjust the water rights of farmers and ranchers in the Shasta River Watershed in order to meet temperature goals that are the subject of the Shasta River TMDL for Temperature and Dissolved Oxygen, and opposes the Board's consideration of such a fundamental policy shift in the context of in individual TMDL decision without adequate notice to the public of the nature of the action being considered. CFBF objects to the Regional Water Board addressing such a fundamental policy issue as reducing water rights through the TMDL process in the context of an individual TMDL.

Siskiyou Board of Supervisors comment:
The implication of the staff recommendation is that the RWB can overturn long-standing water rights law. Such actions, if taken by the RWB, we believe are unnecessary given the existing efforts, which you acknowledge, to improve and restore the Shasta River system for anadromous fish, for other species, and to retain open space for agricultural and other uses. Further, implementation of the staff recommendation could well result in land being withdrawn from agricultural pursuits, subdivided, with all the adverse consequences that may bring.

Save Our Scott and Shasta comment:
This language *(Resolution Finding 9)* is of concern to the extent it suggests that action taken by the Regional Board is designed to foster the reallocation of water away from existing beneficial uses by diverters in the watershed to other uses. There is, of course, a relationship between water quality and water quantity. For example, in general, the greater the quantity of water, the greater its assimilative capacity. But that relationship in itself does not justify action by the Regional Board that delves into water rights.

7. Lack of Flow Objective for Shasta River

California Farm Bureau Federation comment:
There is no actual flow objective established for the Shasta River, and hence there is no impairment for flow in the Shasta River. On that basis alone, the Board has no authority to impose a flow standard in the TMDL process (as implied by the desired increase in flow of 45 c.f.s.) or to try to change any water rights to achieve any such flow standards. Stated alternatively, the effort to impose a 45 c.f.s. flow increase in the TMDL process is an illegal effort to adopt a water quality standard or objective without compliance with the requirements of the Porter-Cologne Act, including but not limited to Water Code Sections 13241 and 13242.

8. Need for Minimum Flow Requirement

Pacific Coast Federation of Fisherman's Associations comment:
The need for a baseline minimum flow with most reaches of the Shasta River, and the importance to salmon production (and the jobs that production represents) of maintaining minimum flows even during low water years cannot be over-stated.

National Oceanic and Atmospheric Administration comment:
Both a minimum flow requirement and an enforcement mechanism are needed. Furthermore, the current level of water diversion and appropriation along the Shasta River provides no guarantee that water dedicated to increase instream flows will remain in the river.

National Oceanic and Atmospheric Administration comment:

In the same way that flow requirements are being established in the Shasta River down stream of Dwinnell Dam, flow requirements should also be established for the Shasta River up stream of Dwinnell Reservoir to Old Stage Road. In this reach, the Shasta River channel is degrading due to loss of riparian vegetation. The COLD beneficial use in this part of the watershed also needs to be protected. Furthermore, NMFS believes that maintenance of flows in both Parks Creek and the Little Shasta River should also be explored as these two tributaries to the Shasta River could support significant numbers of listed salmonids and would contribute to the full attainment of the beneficial uses in the Shasta River system.

National Oceanic and Atmospheric Administration comment:
NMFS, in conjunction with the CDFG, has developed instream flow guidelines that are utilized in the Coastal watersheds from the Mattole River to San Francisco. These guidelines establish bypass flow requirements and have been incorporated into water rights law via AB2121. They could be adapted for application within the Shasta watershed.

In the same manner that lack of flows are classified as pollution under the CWA (man-induced alteration of the chemical, physical, biological and radiological integrity of water), so the presence of a dam which impairs attainment of a beneficial use by blocking access to needed habitat may be classified as pollution (*i.e.*, physical alteration). The impairment of the beneficial uses for anadromous salmonids may be alleviated by accessing habitat in the watersheds above Dwinnell Dam if this habitat is still suitable for salmonids or can be restored.

9. <u>Guarantee for Dedication of Increased Flow</u>

Humboldt Board of Supervisors comment:
It is important water conservation practices result not in increased agricultural use but in increased water flows.

Coast Action Group comment:
The Regional Water Board and SWRCB should actively encourage the purchase of water rights for the purpose of maintaining adequate stream flows.

National Oceanic and Atmospheric Administration comment:
If instream flows are augmented; they merely enable lower priority water rights to be exercised. It is worth emphasizing that Shasta River flows are entirely allocated by adjudicated water right holders in most years. If, for example, an additional flow of 45 cfs is dedicated to the Shasta River from the Big Springs area, it would be diverted by lower priority water right holders. It should also be noted that the Shasta River is open to further diversions of water during the April 1 to October 1 period, via appropriative rights. While these water rights are junior to other existing rights, they do place even more demands on an already over-allocated water resource. Finally, riparian rights supersede both appropriative and adjudicated water rights.

National Oceanic and Atmospheric Administration comment:
It is possible that exercise of riparian water rights will increase in the Shasta Valley, as conversion of ranch lands to smaller homesteads continues. Such conversion often involves the exercise of riparian water rights. We agree with the Regional Board that if a water savings project can be initiated to improve instream conditions, it must contain a mechanism to guarantee that the dedicated water will stay in the stream to benefit the ecosystem.

National Oceanic and Atmospheric Administration comment:
To ensure enforcement of instream flow requirements, there needs to be clearly defined and non-contradictory water management authorities assigned to state agencies involved in water resource management. These authorities need to be established to define and protect instream flow dedications in the interim, while ongoing research, like the instream flow incremental methodology (IFIM), continues to scientifically identify minimum flows necessary to attain resource protection goals.

10. DWR and Watermaster Service

Sierra Club comment:
Where the problem is the result of diminished in-stream flows harming public trust water rights, the problem must be resolved with the involvement of the DWR and an examination and resolution of the inter-related water rights. We support the specific recommendations in the revised action plan, that the Department of Water Resources coordinate the activities of a water master service to achieve the temperature goals, that the regional board make periodic reviews and that the board recommend re-examination of the terms of adjudication should it become necessary.

11. Groundwater Issues

Coast Action Group comment:
This section of the TMDL contains good discussions of why groundwater accretions and spring inflows are important to water temperatures in the Shasta River. Groundwater accretions and spring inflows are not included in the TMDL's water quality model.

National Oceanic and Atmospheric Administration comment:
It is widely recognized that there will be difficulty in attaining the 45 cfs increase in Big Springs (obtained from historic flow data) surface flows because there is currently only about 22 cfs in the system following diversions. NMFS agrees with the Regional Board that the diminished Big Springs surface flow is probably affected by enhanced ground water pumping in the area which is unregulated. Ground water investigations need to be undertaken to determine the connectivity of surface and groundwater in the Pluto Caves/Big Springs area, as this area is the primary source of cold water to the Shasta River at this time.

We encourage the Regional Board to actively coordinate with the State Water Resources Control Board Division of Water Rights to conduct studies of ground water resources, particularly in this area. These studies will inform decision making processes and facilitate planning of how the impaired beneficial uses will be attained.

12. Adapt AB 2121 for Shasta River

National Oceanic and Atmospheric Administration comment:
NMFS, in conjunction with the CDFG, has developed instream flow guidelines that are utilized in the Coastal watersheds from Mattole River to San Francisco. These guidelines establish bypass flow requirements and have been incorporated into water rights law via AB2121. They could be adopted for application within the Shasta watershed.

13. Adjudication, Riparian and Groundwater Rights

Klamath Forest Alliance comment:
The longer the State of California delays implementing water pollution and water management laws and codes the more difficult the final reckoning will be; especially for the farmers and ranchers of the Shasta River Valley. If the Water Board does not do its job there will be action to open the Shasta River Adjudication to deal with those water pollution issues that are directly related to low flows and slow moving water.

Coast Action Group comment:
Revisit adjudication to stop riparian appropriation of water purchased for instream flows and fish. If after **two years**, the Regional Board Executive Officer finds that the above-measures have failed to be implemented or are otherwise ineffective, the Regional Board will recommend that the SWRCB consider seeking modifications to the decree, conducting proceedings under the public trust doctrine, and/or conducting proceedings under the waste and unreasonable use provisions of the California Constitution and the California Water Code.

National Oceanic and Atmospheric Administration (NMFS) comment:
NMFS would also like to recognize in the Regional Board's record that when the basin was adjudicated in 1932, riparian rights and groundwater pumping were not subject to the decree. No protection of instream beneficial uses was built into the decree. Similar to other proceedings, such as Mono Lake (*e.g.,* the Mono Lake hearings) and Friant Dam on the San Joaquin River (NRDC v. Rodgers), this basin may be subject to a reexamination of the impacts of water diversions on instream beneficial uses. Procuring sufficient flows to protect instream beneficial uses could avoid reopening the adjudication. The greatest likelihood of achieving an outcome that is acceptable to all will come from a process whereby all parties involved in the basin collaboratively work together to address the impacts. A willing seller system, as called for in the Shasta Watershed Restoration Plan, is a logical first start, but is far from a guaranteed process and does not seem likely to

succeed without an accounting of the impacts of riparian and groundwater users in this basin.

Response to Comment Categories 1-13:

Similar to the first, the second public comment period yielded numerous comments on the TMDL implementation plan section that addresses cold instream flow and the resolution provision describing state jurisdiction over water quality and quantity.[1] Many parties wrote in support of the resolution language and flow measure. Several parties objected to the proposed resolution provision and argue that water quantity is not a matter properly addressed in the TMDL process.

The resolution language was meant to be a simple description of jurisdiction over water resources in California. Unfortunately, as currently drafted, the language appears to be fueling the mistaken notion that the TMDL is promulgating flow objectives that will bind the State Water Board and the Division of Water Rights in a water rights proceeding. This may be due in part to a recent decision by the Third District Court of Appeal, issued in February, 2006. (*State Water Resources Control Board Cases* (2006) 136 Cal.App.4th.) That case involved a challenge to the manner in which the State Water Board had been implementing the Bay-Delta Water Quality Control Plan, a state policy for water quality control. The Bay-Delta Plan included instream flow objectives and implementing language that directed the State Water Board to conduct a water right proceeding to reallocate water rights in accordance with the flow objectives in the Plan. After a subsequent water right proceeding, the State Water Board adopted a water right decision that did not strictly implement several of these objectives.

The court held that the State Water Board could not implement alternate flow objectives in lieu of flow objectives actually provided for in Water Quality Plan. (*Id.* at 77-78 ("[W]hen a water quality control plan calls for a particular flow objective to be achieved by allocating responsibility to meet that objective in a water rights proceeding, and the plan does not provide for any alternate, experimental flow objective to be met on an interim basis, the decision in a water rights proceeding must fully implement the flow objectives provided for in the plan"].) The State Water Board must fully implement the water quality plan or duly amend it. Had the water quality plan allowed more flexibility in its objectives and its implementing language, the State Water Board's decision would likely have been upheld in its entirety. But the plan had clearly specified the water right decision "will allocate responsibility for meeting objectives." Thus, the exact language

[1] The resolution language provides: "Lack of water is a form of pollution, a term defined by the Clean Water Act as the "man-induced alteration of the chemical, physical, biological, and radiological integrity of water." Water quality includes water quantity and no artificial distinction can be made between them. California combines water rights and water quality functions of the state government into one agency for this very reason. Jurisdiction over the administration of water rights lies with the Division of Water Rights and the State Water Board, however, the Regional Water Board finds it entirely appropriate to address low flows in its Basin Plan for the Division of Water Rights' and State Water Board's consideration."

in the plan becomes extremely important. The Bay-Delta plan that included flow objectives and implementation directing a water right proceeding is perfectly valid.

Like the Bay-Delta plan, the Action Plan for the Shasta River Watershed Temperature and Dissolved Oxygen TMDLs (Shasta TMDL Action Plan) includes flow considerations as a means to achieve water quality objectives. Nevertheless, the Shasta TMDL Action Plan takes a very different approach. The Shasta TMDL Action Plan requests water diverters to participate in, and implement applicable flow-related measures that result in dedicated cold instream surface flow in the Shasta River and tributaries. This approach is consistent with other provisions in the plan that lend support to the on-going, proactive collaborative processes already taking place in the watershed. The Regional Water Board expects progress reports after two years and four years, and will reassess the success of these measures after five years. The flow measure is not a flow objective or a flow related objective. Moreover, the implementation plan contains no language directing the State Water Board to hold any water rights proceeding. The only consequence if parties do not implement the recommended flow measure is the Regional Water Board's ability to request that the State Board consider various water right actions.

To ensure that this point is patently clear, Regional Water Board staff proposes the following language to be inserted in Table 4 in the source section on flow:

This recommended flow measure does not alter or reallocate water rights in the Shasta River watershed, nor bind the State Water Board, Division of Water Rights in any water right decision.

As explained previously, there are several reasons to support the flow recommendation approach rather than promulgating flow objectives and directing a water right proceeding in the Shasta watershed at this time. First, applicable flow-related measures implemented via the CRMP or CDFG programs are collaborative based, and could therefore involve all diverters including riparian, and groundwater users. All water users contribute to low flow problems and therefore should participate in solutions, not just those subject to the decree. Second, the collaborative nature of the programs will allow flexibility for more efficient results without procedural burdens. Reopening an adjudication, or any public trust or waste and unreasonable use hearing before the State Water Board will be costly and time-consuming. Investing those resources in solutions now could yield better results. In addition, as the Chief of the Division of Water Rights has pointed out on several occasions, the Water Code does not contain a provision allowing the State Water Board to "reopen" an adjudication on its own motion. Third, more information is needed before determining flow objectives for the Shasta River that should take into consideration the greater Klamath River system. Finally, the collaborative approach allows parties to generate and implement the solution in a more creative way, assuming that parties take advantage of the opportunity.

Regional Water Board staff agrees with comments stating that the law requires the state to establish total maximum daily loads "for those *pollutants* that EPA identifies under section 1314(a)(2) suitable for such calculation." (33 U.S.C. § 1313(d)(C) (italics added).) The term "pollutant" means dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal and agricultural waste discharged to water. (33 U.S.C. § 1362(6).) The Shasta TMDL addresses temperature or heat, which is a pollutant under federal law. "Pollution," on the other hand, is the man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water. (33 U.S.C. §1362.) Section 303(d) if the Clean Water Act requires states to identify impaired waters where effluent limits not stringent enough to implement water quality standards, and rank priority in terms of severity of *pollution* and uses of the waters. (33 U.S.C. § 1313(d).)

This is consistent with the preamble of federal TMDL regulations that explain EPA's interpretation of the Clean Water Act cited by one commenter. EPA has previously supported TMDLs that include flow components (*see e.g.* Resolution R5-2005-0005 [Amending the Water Quality Control Plan for the Sacramento River and San Joaquin River basins for the Control Program for Factors Contributing to the Dissolved Oxygen Impairment in the Stockton Deep Water Ship Channel]) and has also expressed support for the current draft of the Shasta TMDL Implementation Plan. (EPA Region 9 comments on the February 7, 2006 Public Review Draft Shasta River Temperature and Dissolved Oxygen TMDLs ["The inclusion of the influence of flow on temperature is consistent with previous EPA temperature TMDLs in the North Coast"].) To any extent that the Shasta implementation plan might be inconsistent with EPA's preamble interpretation, the EPA preamble is meant to be guidance language for federal law and does not prevent the proper application of state law. Federal law is intended to act as a minimum requirement for water quality protection and does not prevent the state from implementing more stringent control. (*See* 33 U.S.C. § 1370 ["[N]othing in this chapter shall… preclude or deny the right of any State or political subdivision thereof or interstate agency to adopt or enforce…any requirement respecting control and abatement of pollution"]; *City of Arcadia v. State Water Resources Control Bd.* (2006) 135 Cal.App.4th 1392, 1432 [EPA lacks implementation authority over non point source pollution].)

It is entirely appropriate for the Regional Water Board to consider water quantity in its water quality planning, especially when traditional controls are not adequate to achieve water quality objectives. "Water Quality Control" means the regulation of any activity or factor which may affect the quality of the waters of the state…." (Wat. Code, § 13050, subd. (i).) The Regional Water Board must consider flows in determining the assimilative capacity of the water and seasonal variation in determining the loading capacity of pollutant. The Regional Water Board has discretion to further consider flows in developing the load reductions necessary to attain standards. The goal of establishing TMDLs is to assure that water quality standards are attained and maintained. (65 Federal Register 43588.) "The TMDL program is the primary program responsible for achieving clean water where traditional controls on point sources have proven inadequate. The program is thus charged with creating plans that consider all sources and causes of impairment, and allocating responsibility for corrective measures, regardless of the sources or cause, that will attain water quality standards." (Water Quality Control Policy for Addressing Impaired Waters: Regulatory Structure and Options (2004).) Moreover, California law requires a program of implementation for achieving objectives, which includes a description of actions necessary for achieving water quality objectives including recommendations for appropriate action by any entity, public or private; a time schedule for actions to be taken; and monitoring to determine compliance with objectives. (Wat. Code, § 13242.) The recommended flow measure is necessary to achieve water quality standards, and is consistent with state and federal law. The non-regulatory approach is also within the Regional Water Board's discretion, and an appropriate measure to address this issue in the Shasta River watershed at this time.

Several comments argued that it is inappropriate to include the specific flow number of 45 cfs for various reasons, many relating to whether the flow provision is a recommendation or a requirement. The "45 cfs or alternative flow regime that achieves temperature reductions" language was added to express the target by which the Regional Water Board will gage progress toward increasing cold flows into the Shasta River. It was added in response to some comments requesting more definition on how the Regional Water Board will assess the progress in this area in its five-year evaluation. It is not an instream flow requirement or objective. The language explicitly allows flexibility for other flow measures that will achieve temperature reductions. In addition, the glossary includes a definition for dedicated instream flow as follows: "water remaining in the stream in a manner that the diverter, either individually or as a group, can ensure will result in water quality benefits. Temperature, length and timing are factors to consider when determining the water quality benefits of an instream flow." This definition will also help guide the Regional Board staff in evaluating progress of flow measures.

Other parties requested a more detailed description of actions to provide substantial increases in flow and suggest that the flow provision be made an enforceable mandate. As previously discussed, the Shasta TMDL Action Plan strikes the right balance for flows in the Shasta River watershed at this time. To make flow provisions mandatory, the Regional Water Board would need to promulgate flow objectives and a Basin Plan amendment directing the State Water Board to conduct a water right proceeding in order to achieve the objectives. Instead, the current plan allows time for parties to actively engage in developing their own solutions in this area, with reporting requirements to the Regional Water Board in order to evaluate progress. Parties should work closely with the CDFG programs, the RCD, and other agencies with expertise including for example the California Department of Water Resources to develop specific ideas and actions for implementation of flow measures.

The Shasta RCD and other parties requested an extension of the five-year reevaluation period to ten years to better restore and protect water quality. The commenters seem to suggest that asking parties to voluntarily participate in flow measures will lead to further subdivision of agricultural land. This is not the intent of the Shasta TMDL Action Plan flow provisions. There is substantial evidence that farmers can figure out ways to introduce cold instream flow to the Shasta River without going out of business. There are numerous management strategies available to address water quality requirements associated with flow short of reopening the Shasta River adjudication. These include actions associated with water use efficiency, system operation, water transfers, municipal water reuse, groundwater storage/conjunctive use, agricultural land stewardship, and economic incentives (e.g., grants and loans). All of these strategies are currently being employed to solve water quality and related environmental challenges in California, and most are being employed in the Shasta River watershed. If after five years, there is evidence that progress is being made in this area, the Regional Board has discretion to allow another five years for these programs to succeed. For the same reason, Regional Board staff does not recommend changing the word "may" to "will" to allow discretion in whether making a recommendation to the State Water Board at the five-year evaluation period.

One comment suggested that the Regional Board adopt the AB2121 guidelines for the Shasta. The Division of Water Rights is in the process of preparing a State Water Board Policy for Maintaining Instream Flows in Northern California Coastal Streams. The proposed policy may affect water diversions in coastal streams in portions of Marin, Napa, Sonoma, Mendocino, and Humboldt Counties. The policy will focus on specific counties where the Division of Water Rights has a backlog of water right applications and will help in processing these applications. The Division of Water Rights has a one year deadline to promulgate this policy and it would be inappropriate at this time to add an entirely new area with a different and discrete set of issues. Moreover, as explained above, the Regional Board would allow time for collaborative-based solutions to increase flow to succeed before deciding to refer the matter to the State Water Board. It may be appropriate to add the Klamath Basin to the enforcement component of that plan in the future.

Section 2 - Implementation Issues

14. Regional Water Board Commitment to Implementation

California Trout comment:
What is needed now more than anything in the Shasta River is coordination among regulatory parties (i.e. Department of Fish and Game and the Water Board) and resources to achieve goals set out in these proceedings. These strategies need time and resources to work and we hope that the Water Board is committed to first coordinating with existing efforts and secondly working on an implementation plan that is achievable.

Response: The Regional Water Board will work with other agencies to implement the Shasta River TMDL. The Action Plan relies heavily on existing efforts in the Shasta River watershed.

California Trout comment:

The Water Board must follow up the Action Plan with a strong commitment to aid in implementation.

Response: The Regional Water Board will commit resources to Shasta TMDL implementation.

Tim McKay comment:
The NCRWQCB must take a larger responsibility for restoration of the watershed's fisheries by assuring that the Shasta TMDL contains enforceable actions that address the root causes of the river's temperature problems.

Response: See Appendix J of the staff report, comment category 9.

15. Implementation Milestones, Monitoring and Enforcement

Klamath RiverKeeper comment:
The best course is to bite the bullet and do what is right for the river and what is just for those downstream. That means increased flows, eliminating polluted agricultural discharges and putting in place a clear time-line for dealing with Dwinnell Dam and reservoir.

Response: The TMDL Action Plan addresses each of these issues except for migration blockage by Dwinnell Dam. The Regional Water Board will be coordinating with the California Department of Fish and Game to mitigate the impacts of the dam. Regional Water Board staff agree that appropriate agencies should explore ways to ameliorate the fish migration barrier at Dwinell Dam. CDFG is the primary state agency with authority to implement the Fish and Game Code and is the trustee agency for this resource. While the Regional Board has the duty to protect beneficial uses, which includes cold water fisheries, the Shasta TMDL focuses on temperature and low dissolved oxygen impacts and how those impacts affect the fisheries. Fish migration issues were not included within the scope of this planning effort. It may be appropriate to review this issue when reviewing the study results from Dwinnell Dam.

Pacific Coast Federation of Fisherman's Associations comment:
To implement the TMDL and comply with the Basin Plan Objectives, the Action Plan must adequately describe specific and measurable actions to achieve water quality standards, with reasonable assurance of success. Timelines with milestones and monitoring are needed to determine whether these actions are working over time.

Coast Action Group comment:
The Shasta TMDL Action Plan language is comprised of language that is insufficient in ability to meet Water Quality Standards due to the fact that a significant amount of language in the Action/Implementation Plan is unenforceable.

The issues of dealing the problem related to unenforceable language can be addressed in several ways (including use of Waste Discharge Reporting and/or Conditional Waivers).

Coast Action Group would like to remind the Board the actions necessary to Implement (the Action Plan) the TMDL must be adequately described, there must be reasonable assurance of success in meeting Water Quality Standards, and there must be timelines and monitoring to assure and test efficacy.

Response: See Appendix J of the staff report, comment category 9.

Coast Action Group comment:
The Shasta TMDL does not set a clear monitoring program, leaving it until a year after TMDL approval. It would seem wise to encourage continuation of specific ongoing monitoring efforts of relevant parameters before the more comprehensive plan is drafted.

Response: Comment noted. The Regional Water Board encourages the continuation of ongoing monitoring efforts. As noted in Chapter 9 of the staff report, the Regional Water Board will coordinate efforts with the Shasta Valley Resource Conservation District (SVRCD) and the Shasta River Coordinated Resources Management and Planning Committee (Shasta CRMP) in developing and carrying out the monitoring plan.

16. Tailwater Return Flows

Coast Action Group comment:
The most important mechanism by which tailwater returns affect DO is not included in the bullets on page 4-15. Tailwater returns are increasing nitrogen levels in the Shasta River, which can increase growth of aquatic plants. As shown in Chapter 7, respiration of aquatic plants, stimulated by high nutrient levels, is by far the largest contributor to dissolved oxygen demand in the Shasta River. While it is worthwhile to mention that tailwater returns do increase nitrogenous oxygen demand of the Shasta River, the most significant effect of tailwater on oxygen demand is to increase total nitrogen levels and stimulate aquatic plant growth.

We recognize that tail water returns are a substantial contributor to water quality problems. Tailwater returns contain nutrient pollutants. We support many of the recommendations in this section.

Response: The text in section 4.4.1 has been modified. See also the response provided in Appendix J of the Staff Report, section 2, individual commenter #3.

National Oceanic and Atmospheric Administration (NMFS) comment:
NMFS feels that addressing these tail water returns is a very high priority action and should be attempted within the first five years of the implementation plan. Large tail

water returns should be corrected first, leaving the remaining 5% - 10% of tail water (small return sites) to be corrected whenever potential benefits warrant the cost.

In addition to the potential actions mentioned in the TMDL action plan, NMFS would like to point out that solar powered aeration and/or circulation pump systems are becoming much more available and common. Their use should be explored in conjunction with the use of settling ponds in the system for addressing not only the tail water systems, but for urban and suburban runoff.

Response: Comment noted.

17. Lake Shastina

Coast Action Group comment:
This section does not mention two of Lake Shastina's most important effects on oxygen demand in the Shasta River:

> 1. Shastina reduces peak flows, allowing organic matter and fine sediments to accumulate in the channel, contributing to oxygen demand via macrophyte respiration, and
> 2. Shastina increases nitrogen concentrations, stimulating aquatic plant growth and hence contributing to oxygen demand via macrophyte respiration.

Enforceable language needs to be developed to deal with the nutrient loading problem and bioaccumulation of nuisance materials (related to nutrients) in Lake Shastina.

> "Initiate, complete, and submit to the Regional Water Board the results of an investigation characterizing, quantifying, and analyzing the sources of nitrogenous oxygen demanding substances contributing to low dissolved oxygen levels affecting the beneficial uses of water in Lake Shastina and to waters of the Shasta River downstream from Dwinnell Dam.
>
> Based on the results of the investigation, the Regional Water Board shall determine appropriate implementation actions necessary to reduce the nitrogenous oxygen demand that is lowering dissolved oxygen concentrations in Lake Shastina and affected areas downstream from Dwinnell Dam".

Initiate within two years, complete and submit to the Regional Water Board within five years, the results of an investigation characterizing, quantifying, and analyzing the sources of, and ways to reduce, nutrients and nitrogenous oxygen demanding substances contributing to low dissolved oxygen levels affecting the beneficial uses of water in Lake Shastina and to waters of the Shasta River downstream from Dwinnell Dam.

Based on the results of the investigation, the Regional Water Board shall determine appropriate implementation actions necessary to reduce the nutrients and nitrogenous oxygen demand that is lowering dissolved oxygen concentrations in Lake Shastina and affected areas downstream from Dwinnell Dam.

The Regional Water Board shall study the possibility of using pulse flows from Lake Shastina to clean out accumulated organic matter and macrophytes from the Shasta River.

Response: The Shasta TMDL Action Plan calls for 1) a study of water quality conditions and factors affecting water quality conditions and 2) a plan for addressing factors affecting water quality conditions both to be completed within 2 years of EPA approval of the TMDL. The plan shall begin implementation within 5 years. This is a more aggressive schedule than called for by the commenter.

National Oceanic and Atmospheric Administration (NMFS) comment:
The study required by the Regional Board of the Montague Water Conservation District should include potential use of a multi-level intake structure to access water that is not only oxygenated but also in an acceptable temperature range. A combination of temperature and aeration possibilities may need to be explored. Further studies are also needed to assess inputs from neighboring septic systems, and other upslope pollutant sources. Reservoir water quality improvements will foster efforts to provide fish passage through the Dwinnell complex in the future.

Response: Suggestions noted. The Action Plan requires a study of the pollution sources impacting water quality in Lake Shastina and will consider septic systems and other upslope pollutant sources that are significant.

18. Minor Impoundments

Coast Action comment:
Language regarding irrigation structures and stream flow impediments is sufficient.

Response: Comment noted.

19. Urban and Suburban Runoff

National Oceanic and Atmospheric Administration (NMFS) comment:
In regards to the urban and suburban areas, NMFS encourages the Regional Board to require that communities be developed in accordance with the stormwater treatment standards that are already in place in more urbanized areas such as Sonoma County and to which CalTrans is already subject.

Response: Comment noted. The Regional Water Board will work with municipalities to implement appropriate management measures for reducing pollutants in urban and suburban runoff.

20. Timber Harvest Activities

Coast Action Group comment:
Report of the Scientific Review Panel On California Forest Practice Rules and Salmonid Habitat, Prepared for The Resources Agency of California and the National Marine Fisheries Service, comprised of a selected panel of scientists, 1999, indicates that "the Forest Practice Rules" and their administration by the California Department of Forestry "do not protect the beneficial uses of water." ""Silviculture is the leading source of impairment to water quality in the North Coast of California. Related to these water quality problems, California has a number of species, in particular salmon, that are endangered threatened or otherwise seriously at risk, due in very significant part to forestry activities that impair their spawning, breeding and rearing habitat." (Findings for the California Coastal Non-point Program and CZARA Action Plan, USEPA/NOAA, 1999) A Scientific Basis for the Prediction of Cumulative Watershed Effects, UC, Berkeley, June 2001, and finally the Final Report on Sediment Impairment and Effects on the Beneficial Uses of Elk River and Stitz, Bear, and Jordan Creeks, Concur, 2002, also support the findings noted above. All of these noted scientific reviews indicate the Forest Practice Rules, including projects related to small landowners and Non-Industrial Timber Plans, are deficient in Cumulative Impacts Analysis and can not be counted on to protect the beneficial uses of water and meet Basin Plan water quality objectives. No study has shown that smaller timberland owners and/or Non-Industrial Timber Plans have lessened impacts related to pollutant inputs from timber harvest activity

These documents, noted above, not only indicate impairment from current and historic forest practices, they provide analysis and prescriptive measures to be taken to address attainment of WQS. These documents all point to, but do not address directly, the level a disturbance precedent to the deteriorated watersheds conditions present in the Shasta River. They do indicate that level of disturbance is a major factor and needs to be addressed if we are ever going to meet WQS. And, in fact, a TMDL is a vehicle designed to (in this case) make determinations regarding level of disturbance that is acceptable and related mandatory controls to meet WQS.

Recommendation**:** That the (above mentioned) readily available information be reviewed for development of comprehensive and enforceable language to be added to the Implementation/Action Plan of the Shasta River TMDL.

The suggested use of existing permitting and enforcement tools (e.g. THP Review process, WDRs (and Waivers of same)) are not sufficient to address shortfalls that have been noted as part of this process by many agency and independent scientific review panels (including the NCRWQCB itself).

Response: Regional Water Board staff concur that addition management measures beyond the minimum Forest Practice Rules are required to adequately protect the beneficial uses of waters of the state. However Regional Water Board staff believe that the general waste discharge requirements and waivers adopted by the Regional Water Board in 2004 for timber harvest activities and provisions for issuance of specific waste discharge requirements as needed provide additional and necessary regulatory oversight.

21. <u>Grazing</u>

Coast Action Group comment:
Grazing and other land use not in conformance with actions that will attain WQS must be limited by enforceable language. Grazing guidelines that will recover and maintain properly functioning riparian need to be developed. Grazing Practices must provide described criteria/actions to maintain properly functioning riparian corridor and inhibit soil loss from poor grazing practices. Reasonable timelines for implementation and effective monitoring must be in place.

Response: Per the Shasta TMDL Action Plan, landowners involved with grazing and other range management activities are required to submit an annual report, either individually or through the Shasta CRMP, of land management practices implemented to attain water quality standards. The Shasta Valley RCD and its CRMP as well as the California Department of Fish and Game will assist landowners in implementing appropriate management measures. If these actions are found by the Regional Water Board to be ineffective at attaining water quality standards, landowners will be required to submit and implement a range management plan on a site specific as-needed basis. The Regional Water Board will also address the removal of riparian vegetation through the development of the Stream and Wetland System Protection Policy. More information about TMDL actions to address impacts of range management can be found in the Shasta TMDL Action Plan.

Coast Action Group comment:
The discussion of urban and suburban runoff does not contain any language regarding planning or design, an oversight that should be corrected.

A Stormwater Runoff Plan needs to be developed and integrated in to Urban and County Planning. We recommended the addition of the following language:

> "New developments should be designed to minimize stormwater runoff and maximum infiltration by minimizing impervious surface area, minimizing hydrologic connection between impervious surfaces and watercourses, and constructing stormwater retention basins. Existing developments should be retrofitted to minimize stormwater runoff."

Response: The Regional Water Board will work with municipalities to develop appropriate management measures to reduce pollutants in urban and suburban runoff. The specifics of planning and design of these measures will be part of the planning process to be completed within two years of EPA adoption of the TMDL. The suggested language has been noted.

22. Yreka WWTF

National Oceanic and Atmospheric Administration (NMFS) comment:
For the Yreka wastewater treatment facility, we encourage maximum water reuse. A primary crop in this region is alfalfa, which is considered to be salt tolerant. The City of Yreka should conduct a pilot project to determine if its wastewater could irrigate alfalfa. If it does not show any problems, the City may find it less expensive to distribute the water to local growers than to upgrade treatment to a level where it no longer impacts receiving water quality.

Response: Comment noted. The Regional Water Board does not have the authority to dictate the manner of compliance with water quality objectives. This suggestion should be made to the city.

Section 3 - Other Issues

23. Dwinnell Dam and Fish Passage

National Oceanic and Atmospheric Administration (NMFS) comment:
NMFS suggests that the Regional Board and all other related agencies Federal and local, explore the possibility of fish passage above Dwinnell Dam. Based upon the description in the Introduction section of the TMDL action plan, significant flows are diverted from Parks Creek into the Shasta River for storage in Lake Shastina. Along with passage through the Dwinnell complex and restoration of flows in Parks Creek, passage of salmonids to the upper Shasta River watershed via Parks Creek should be explored. NMFS is interested to learn about the current diversion structure and if it could be redesigned and properly screened to serve as a fish passage structure. This could allow fish passage not only to the slopes of Mount Eddy on Parks Creek, but closer to the cold water resources of the Mount Shasta Wilderness area.

Response: The Regional Water Board will coordinate with the California Department of Fish and Game to mitigate the impacts of Dwinnell Dam on salmonid migration. For additional information please see response under Category15: Implementation Milestones, Monitoring and Enforcement.

National Oceanic and Atmospheric Administration (NMFS) comment:

NMFS also recognizes that subsurface leakage of Dwinnell Reservoir water to the Shasta River is likely causing low dissolved oxygen problems. Clearly, the water quality in the reservoir needs to be improved.

Response: The Action Plan requires a study of the pollutant sources contributing to water quality problems in Lake Shastina. This study will consider subsurface leakage and the impact on dissolved oxygen if it is found to be significant.

24. Lack of Attainment of Beneficial Uses

National Oceanic and Atmospheric Administration (NMFS) comment:
The Regional Board's Shasta flow temperature/dissolved oxygen model produces instream conditions suitable to sustain fisheries at the Salmon Heaven site in the Shasta Canyon, about five and one-half miles upstream from the mouth of the Shasta River. This approach does not take in account Shasta River water quality from that point down stream to the confluence of the Shasta and Klamath Rivers. The modeled criteria of: 1) 45 cfs from Big Springs; 2) riparian shade equal to 90% of site potential shade; and 3) tail water return causing a zero net increase in receiving water temperature, may not improve river conditions below Salmon Heaven. This leaves the beneficial uses unattained in this stretch of the river.

Response: The temperature TMDL addresses the three factors affecting Shasta River watershed stream temperature: shade, irrigation tailwater return flow, and surface water flow. Additional reductions in stream temperature downstream of Salmon Heaven can only be achieved through additional increase of dedicated cold water instream flow above the 45 cfs goal. Regional Water Board staff believe that when fully implemented, the temperature TMDL load allocations would result in compliance with the narrative temperature objective in the Shasta River.

25. Affirmative Duties and Public Trust

Environmental Protection Information Center (EPIC) comment:
EPIC believes the Regional Board needs to secure all of its statutory and public trust authority to provide necessary protection for the Shasta, which will ensure restoration of adequate flows and development of conditions which reduce pollutants so as to ensure survivability and enhancement of fish runs.

Response: Comment noted.

Tim McKay comment:
With these concerns in mind, we are specifically asking that the NCRWQCB should exercise "an affirmative duty" in the Shasta TMDL to make protection and restoration of fisheries a priority. Shasta Valley polluters must bear an equal burden in remediating and restoring the

basin fisheries. To date it appears that the small number of polluters in Siskiyou County are above the law.

Response: Comment noted. Implementation of the Shasta TMDL is a Regional Water Board priority, and resources have been committed.

26. Adopt Plan as Is

Brett Lutz comment:
Please take these comments as strong support for voting this Draft Resolution into implemented action.

Don Morrill comment:
Please adopt the Shasta TMDL and Action Plan as is with no changes.

Mark Pringle comment:
I am asking the Board to adopt the Shasta TMDL and Action Plan as is with no more amendments or deletions.

Robert Rasmussen comment:
Adoption of the Shasta TMDL and Action Plan AS IT IS NOW WRITTEN is essential to the survival of salmon runs that sustain the northern California fishery.

Response: Comments noted.

27. Miscellaneous Issues

Bruce Campbell comment:
Your board deserves legal action if you keep delaying the long-overdue action plan to seriously address water quality and quantity problems in both the Shasta and Scott River watersheds. Please act decisively to address this key problem with the Klamath River ecosystem, a problem which for the past few months is getting the national attention that it deserves.

Response: Comments noted.

Coast Action Group comment:
Section 303(d) and the regulations at 40 CFR 130.7 require that "TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numerical water quality standards with seasonal variations and a margin of safety which

takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality." The margin of safety can either be incorporated into conservative assumptions used to develop the TMDL or added as a separate component of the TMDL (EPA, 1991). Conservative assumptions have **not** been made in each case as a way of addressing the uncertainty and areas that are underestimated associated with the data.

There are a number of uncertainties associated with the supporting documentation, most notably in the source analysis. Given these uncertainties, additional conservative assumptions should be made regarding the amount of loading reductions that are needed to attain WQS. This approach is warranted and meets the statutory requirements that a margin of safety take into account any lack of knowledge concerning the relationship between the effluent limitations and water quality.

Response: Conservative assumptions were made. See sections 6.6 and 7.6 of the TMDL staff report.

Coast Action Group comment:
Due to the time schedule related to the Consent Decree, action must be taken in compliance with this schedule. It is recommended that either, the Regional Board (and SWRCB) adopt the currently proposed TMDL (noting deficiencies), with attached direction to staff to address specific issues needing correction. In addition, the SWRCB must take some action (not necessarily attached to the Basin Plan Amendment) to address flow maintenance issues.

Response: Comment noted.

Coast Action Group comment:
It is noted that, both, groundwater inflows, and stream shade (near stream micro-climate) are primary factors related to stream temperatures. Areas of sparse streamside vegetation are noted. However, the impacts of water use for irrigation on groundwater supply to the instream flows are not documented. It is known that there is a relationship, but the exact nature (ratio of use to instream flow) of the relationship remains to be determined. Impacts of sediment buildup on stream flow must be analyzed /assessed, with linkage to both temperature impairment and salmonid habitat conditions, to develop comprehensive pollutant loading analysis and implementation strategy.

The temperature analysis should consider the best science available for flow and riparian assessment. Studies by Bartholow, Essig, Poole, and Berman should be referenced in terms of impacts of microclimate and overstory on stream temperature. These studies indicate that air temperature and near stream microclimate to be major factor in determining instream water temperature. FEMAT suggests that the zone of riparian influence is two site potential trees - where buffering, in the form of cool air temperatures and high humidity over the stream, deteriorates rapidly under one site potential tree height protection.

The NCRWQCB based much of their scientific discussion of temperature values on Sullivan, K et al, 2000, An Analysis of the Effects of Temperature on Salmonids of the Pacific Northwest with Implications for Selecting Temperature Criteria, Sustainable Ecosystem Institute. There were many other citations including Spence et al (a major compendium of relevant science - see quotes below), Hines and Ambrose, etc..

Temperature studies from Mendocino (Hines and Ambrose, 2000 - which included work on Big and Ten Mile Rivers) and Humboldt (Welsh et. al) counties that examined salmonid habitat utilization and temperature relationships. There are some more current papers out on temperature effects on salmonids, not considered. One by Essig (1998) on the background effects of temperature on salmonids. Additional information on temperature affects on salmonids can be found in An Ecosystem Approach to Salmonid Conservation, B. Spence, G. Lomnickey, R. Hughes, R. Novitzki, for Management Technology (MANTECH), 1996.

Response: The salmonid biological requirements used in the Shasta TMDL analysis are based on USEPA Region 10 reports, as noted and cited in the staff report. The Regional Water Board performed a source analysis for impacts to water temperature and discussed, in the staff's best professional judgement, the main causes of the impairment. Loads were allocated based on the source analysis and modeling of the Shasta River temperature dynamics. The Action Plan was developed based on the technical analysis to address impacts to water temperature. While there are always more data that can be used to further the technical analysis, the Regional Water Board believes that the current assessment is sufficient to fulfill the TMDL mandate and develop an Action Plan that is effective at addressing the impairments. In the future, as more data is collected and analyzed, it may be incorporated into analysis and the TMDL may be refined. The commentor's suggestions have been noted.

28. Coho Salmon Issues

Pacific Coast Federation of Fisherman's Associations comment:
Coho spawning is well known in the Shasta (in fact, the Shasta represents some of the most historically important coho spawning areas), yet the TMDL Action Plan proposal does not specifically focus protection or restoration on reaches or tributaries that presently harbor ESA-listed coho or which are important for coho recovery.

Response: The Shasta TMDL Action Plan is focused on attaining water quality standards for temperature and dissolved oxygen throughout the Shasta River watershed including those reaches and tributaries that support coho salmon. The Shasta TMDL Action Plan is not focused on restoring coho in general; rather it is aimed specifically at restoring water temperatures and dissolved oxygen levels that meet the biological needs of all salmonid species. The Action Plan addresses salmonid species because their related beneficial uses are the most sensitive to temperature and dissolved oxygen impairment in the Shasta River watershed.

Tim McKay comment:
If the Shasta TMDL results in continued harm to listed Coho salmon shouldn't a consultation with the National Marine Fisheries Service [or NOAA Fisheries] be required?

Response: As part of the TMDL development process, staff of the Regional Board and the US EPA have regularly consulted with US Fish and Wildlife Service and National Marine Fisheries Service with respect to listed species.

29. Volunteerism

Shasta Valley Resource Conservation District comment:
The Shasta Valley RCD has been actively working with landowners in the Shasta Valley to improve and restore the Shasta River system for anadromous fish and other wildlife, and to retain open space for agriculture and other uses. You have acknowledged these efforts and we hope that the Water Board staff will consider the concerns we have expressed. Continued voluntary efforts by landowners in the Shasta Valley is the vital component to continuing the improvements in the Shasta River.

Response: Comment noted.

Coast Action Group comment:
Implementation relies heavily on voluntary measures. RB language stressing the ability to follow up with enforcement helps, yet there is no assurance of compliance and/or description of actions to take place.

The RB and SWRCB are required to take actions to attain WQS (water quality objectives and beneficial protection and restoration) The final TMDL Action/Implementation plan must assure movement towards attainment of WQS by adoption of the *Shasta TMDL Action/Implementation Plan* in to the *Basin Plan* (NCRWQCB, 2001). If there are multiple ways to meet the objectives, we support giving landowners the flexibility to decide how they want to meet those objectives. For example, <u>if</u> other regulatory and policy processes such as the *Shasta Incidental Take Permit* (SCROD, In Draft), *Coho Recovery Plan* (CDFG, 2004), and Timber Harvest Plans will result in the attainment of water quality objectives, then further regulation by the RB is not necessary.

Duplicative and overlapping regulation benefits no one. Unfortunately, these other processes often rely on voluntary measures that neither guarantee that water quality problems will be remedied nor that TMDL objectives will be achieved. When other policy approaches and voluntary landowner actions fail to achieve the TMDL objectives, then the RB must use its considerable regulatory and enforcement authority to take necessary actions to ensure results.

Reliance on voluntary actions to solve the flow problem is not sufficient remedy (nor does is meet CEQA, TMDL, and Water Code mandates).

While many of the ideas proposed in the *Coho Recovery Plan* are positive, they are also voluntary. It is important for the Regional Water Board to remember that it has a responsibility to protect public trust resources and ensure results. If voluntary measures work, that would be great, but they are often insufficient and further action is required.

The State Non-Point Source Policy mandates regulation of pollutants by use of Waste Discharge Permits, Conditional Waivers (related to the WDRs), and/or Prohibitions. The word voluntary is not in the lexicon of the State Non-Point Source Policy. Voluntary Implementation proposal should be considered, if and only if, such proposal meets the standards necessary under Section 12342 of the State Water Code, with adequate descriptive language for the proposed actions that includes performance standards and timelines, with performance monitoring to be accomplished. TMDLs should nexus with and be in conformance with State NPS Policy.

There are aspects of the implementation plan that are actions yet to be described, and requests for actions where the implementation of same are totally voluntary. This renders aspects of the Action/Implementation Plan unenforceable.

State water law says that an implementation plan (Water Quality Control Plan) must contain a description of the nature of specific actions that are needed to achieve the water quality objectives, a time schedule, and a plan for monitoring compliance (State Water Code Section 13242). As a Water Quality Control Plan, the Implementation/ Action Plan must be adopted into the Basin Plan.

Reliance on unenforceable language is inconsistent with Cal Water Code - unless voluntary actions submitted as planning documents to be approved by the Regional Board are found to be equal to or better than enforceable criteria capable of meeting Water Quality Standards. Such voluntary actions (meeting Cal Water Code) should be held open as options for attaining targets and to meet Water Quality Standards.

The Implementation /Action Plan lacks linkage and consideration with what is, or should be, the matrix of near-stream and in-stream desired conditions - or - linkage and explanation of how such voluntary actions will, or are capable, of attaining these near-stream and in-stream desired conditions or Water Quality Standards.

Response: See Comment Category 9 ‘Volunteerism and Timelines’ in Appendix J of the staff report. With regard to desired conditions, the Regional Water Board is in the process of developing the Stream and Wetland System Protection Policy that will address desired conditions in the riparian zone. In addition, a desired condition matrix is being developed for sediment condition indicators.

30. Anti Degradation Policy

Coast Action Group comment:
The Basin Plan has a non-degradation objective - that is currently being violated. Temperature sensitive habitat is being degraded. Flows are a controllable issue and inputs of additional pollutants (in this case elevated temperature) are not permissible.

Habitat is currently in a degraded condition. A flows target to lower instream temperature by 5 degrees is necessary to meet WQS. Additional stream shade is important. Stream shade alone can not reach the stated target. Affects from stream shade recruitment will not be seen for at least 40 years. Note: Maintenance of the instream flow target is supported in the Peer Review in the file by Dr. Coutant.

Response: The proposed Action Plan will not result in degradation to the Shasta River.

31. pH

Coast Action Group comment:
"Narrative and Numeric Water Quality Objectives applicable to the Shasta River basin TMDLs" should also include the *Basin Plan* water quality objectives for pH in the Shasta River. The Shasta River is not officially listed as pH impaired, summer pH values in mainstem Shasta River are extremely high (>9.5), and are unequivocally related to nutrients and DO. Analysis of pH data is a valuable tool to help understand the spatial and temporal dynamics of DO and nutrient impairment (Kier and Associates 2006).

Response: See response provided in Appendix J of the staff report, section 2, individual commenter #3.

Coast Action Group comment:
The pollutant pH should also be specifically mentioned in this sentence on page 2-24, "In this context for the Shasta River TMDL, Regional Board staff define nuisance aquatic growth as that which contributes to violation of numeric water quality objectives (particularly dissolved oxygen) or adversely affects beneficial uses."

Response: See response provided in Appendix J of the staff report, section 2, individual commenter #3.

32. Water Temperature

Coast Action Group comment:
The TMDL states "Weekly maximum temperatures exceed the spawning, incubation, and emergence threshold (i.e. MWMT of 13°C) at all Shasta River reaches from April

through June, and during the second half of September." Data shows temperatures are above 13°C until mid-October, not September. This should be corrected.

Response: This has been corrected in the staff report.

Coast Action Group comment:
On page 3-6, there is discussion of a reach at river mile 37.3 shown in Figure 3.2 where the riparian vegetation noticeably changes from sparsely vegetated to densely vegetated, coincident with a 4 degree drop in temperature. It seems unlikely that riparian vegetation would rapidly cool temperatures by 4 degrees C. As Dr. Coutant points out in the peer-review (Appendix I) another possibility is that hyporheic exchange cooled the water.

Response: See response provided in Appendix J of the staff report, section 2, individual commenter #3.

Coast Action Group comment:
Temperature analysis in this TMDL should have a good reference background of Targets for desired conditions.

Temperature analysis in this TMDL should have a good scientific reference to, both Targets, and affects of elevated temperatures on salmonids. **See** - *EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards, 2003, and other temperature science noted in the listing fact sheets.*

Most of the monitoring data and analysis presented indicating existing temperature regimes (in MWAT) far in excess of conditions suitable for salmonids in various life stages. A matrix of acceptable Targets should be developed for reaches of the watershed indication the acceptable MWAT range and percent of habit that should fall into that range. A Target of 16.7 C (absence line for coho) is a logical goal. It should be determined what percentage of the watershed should meet this target to address beneficial use issue.

Targets should also be developed for other factors that influence elevated temperature loading (i.e. Percent shaded area appropriate for forested areas, percent shaded area appropriate for non-forested areas, minimum or acceptable low flow targets for various reaches of the drainage, etc.). These Targets should be the basis for the development of enforceable implementation policy.

Response: The TMDL for the Shasta River watershed already contains the elements suggested by the commenter. The TMDL staff report includes a discussion of the effects of elevated temperatures on salmonids (2.3.1) and uses these temperature 'targets' as the basis for the water quality compliance scenario. The TMDL then assigns load allocations in the form of shade targets for the Shasta River watershed, reduced heat loading from irrigation return flows, and increased flows of cold water necessary to reach compliance.

Coast Action Group comment:
The Shasta TMDL does not address the October 1 deadline for shutting off stock water and increasing stream flows for fish passage. Snyder (1931) noted that fall Chinook salmon entered the Shasta River in September. Fish now delay their migration until after October 1 because of lack of sufficient flow and associated warm water temperatures. This delayed pattern of entry into the Shasta River is manifest in both wet and dry years. Fall chinook forced to sit for weeks in stressful Klamath River conditions likely have reduced fecundity. This intensive selection pressure likely selects for later run timing.

Response: See response provided in Appendix J of the staff report, section 2, individual commenter #3.

Coast Action Group comment:
The TMDL should consider the potential of hyporheic function. Connection of surface water to these sub-surface waters is recognized as having a potential cooling influence (Poole and Berman, 2001; U.S. EPA 2003). While magnitude and distribution of this effect in the Shasta River is unknown, it may be significant (and likely the cause of the cooling described in section 3.3.2 and shown in Figure 3.2). As Dr. Coutant mentioned in his review, the model could potentially simulate this effect: As noted by Dr. Coutant, failing to include this mechanism would lead to incorrect findings.

Response: See response provided in Appendix J of the staff report, section 2, individual commenter #3.

33. Nutrients

Coast Action Group comment:
The nutrient concentration required to cause impairment in a stream varies widely according to many factors, thus the more specific the analysis the better. Thus, we cannot see any justification for the TMDL to use the numbers presented Dodds et al. (1998) derived from across North America and New Zealand, rather than the USEPA (2002) criteria derived from data in Nutrient Ecoregion II (Western Forested Mountains) of the western United States. We recommend that both Dodds et al. (1998) and USEPA (2002) remain in the literature review presented in 2.5.1, but that when analyzing Shasta River nutrient data in section 2.5.2 (Shasta River Watershed Nutrient Conditions), the USEPA (2002) recommended criteria should be used instead.

Response: See response provided in Appendix J of the staff report, section 2, individual commenter #3.

Coast Action Group comment:
Consideration of total Phosphorus inputs has left out contributions from land use.

Response: Regional Water Board staff do not understand this comment. Section 7.2.1 does address the effect of phosphorus on algal productivity. Action Plan controls targeting nitrogenous oxygen demand reductions from Dwinnell Dam, Yreka Creek, and irrigation tailwater return flows, will also control phosphorus. See also response provided in Appendix J of the staff report, section 2, individual commenter #3.

Coast Action Group comment:
Consideration of N inputs and complex relationships are not considered in sufficient depth, except to understand that there is a problem. The real problem with nutrient sources, which the TMDL repeatedly overlooks, is the total amount of nitrogen (in all forms) contained in those nutrients sources and its stimulation of aquatic plant growth. This occurs throughout the Staff Report and the *Basin Plan* amendment language, and should be corrected.

Response: See response provided in Appendix J of the staff report, section 2, individual commenter #3.

Coast Action Group comment:
The TMDL should also recognize that the form of nitrogen is also important (as inorganic forms of nitrogen such as ammonia and nitrate are available to immediately stimulate plant growth). The statement "Total nitrogen values in springs are generally within the mesotrophic boundary" (p 2-30) is inconsistent with the rest of the nutrient discussion. The statement should be changed to "Total nitrogen values in springs are several times higher than the USEPA (2002) recommended ecoregional criteria."

Response: See response provided in Appendix J of the staff report, section 2, individual commenter #3.

Coast Action Group comment:
Little evidence is provided to support the statement that "Maximum total nitrogen levels in the mainstem Shasta River increase in a downstream direction." Table 2.8 provides total nitrogen data on the Shasta River near the headwaters, Shasta River above Dwinnell, and then lumps all mainstem sites below that as "Shasta River below Dwinnell Dam." To support that statement, the sites below Dwinnell Dam should be analyzed individually. Appendix B of the TMDL contains USGS and RWB data from 2002-2003 indicating that the patterns at sites below Dwinnell Dam are complex and that analysis of the data is confounded due to the use of a laboratory with inadequate detection limits for Kjeldahl nitrogen.

Response: See response provided in Appendix J of the staff report, section 2, individual commenter #3.

Coast Action Group comment:
Discussions of Dwinnell Reservoir in Section 2.5.2 note increased nutrients as compared to reaches of the Shasta River above, but do not mention the role of the nitrogen-fixing blue green algae *Anabaena flos-aquae* as one of the sources of nutrient pollution (though it is later in the document in Chapter 4). *Anabaena flos-aquae* is correctly noted in the text to be a producer of anatoxins.

Response: See response provided in Appendix J of the staff report, section 2, individual commenter #3.

Coast Action Group comment:
The TMDL is lacking in linkage and analysis (and modeling) regarding the relationship of flows and their effects on pollutant levels – or how increased flows might limit the effects of N, P, and pH conditions.

Response: Comment noted. The analysis does evaluate the linkage between flow on dissolved oxygen and temperature, the parameters for which the TMDL is developed. Regional Water Board staff agree that additional modeling analysis of the relationship between flows and nutrients and pH is of interest, but contend that this analysis is beyond the scope of this TMDL.

34. Dissolved Oxygen

Coast Action Group comment:
This section does not mention a third important way in which flow affects dissolved oxygen. We recommend that the following text be added to the last sentence in this section (after "…caused by photosynthesis and respiration.") on page 4-21:

> Flow can affect dissolved oxygen through its effects on water temperature. For instance, larger volumes of water have a higher thermal mass are more resistant to heating and cooling. So if a large volume of water is cool (i.e. from a spring-fed creek such as Big Springs) it can travel downstream and retain its low temperature. Low temperatures allow water to water hold more dissolved oxygen. Through this mechanism, flow can affect dissolved oxygen.

Response: See response provided in Appendix J of the staff report, section 2, individual commenter #3.

35. Model Results

National Oceanic and Atmospheric Administration (NMFS) comment:

The model results are based on one year of fish survey information from the Shasta River Canyon. Because of large annual variability, survey information over a longer time period is needed to better understand fish production in the entire Shasta Canyon area, and to calibrate the model.

Response: The Shasta River temperature and dissolved oxygen model was calibrated/validated for the summer months 2002. Beneficial use support was evaluated for the August 2002 model scenario results based on readily available information about fish in the watershed. Regional Water Board staff agree there is large annual variability in fish survey information, and encourage on-going evaluation of TMDL compliance with respect to beneficial use support as more information becomes available.

The Effects of Temperature on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function by Life Stage

Implications for Klamath Basin TMDLs

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North Coast Region

August 2005

Introduction and Purpose
Temperature is one of the most important environmental influences on salmonid biology. Most aquatic organisms, including salmon and steelhead, are poikilotherms, meaning their temperature and metabolism is determined by the ambient temperature of water. Temperature therefore influences growth and feeding rates, metabolism, development of embryos and alevins, timing of life history events such as upstream migration, spawning, freshwater rearing, and seaward migration, and the availability of food. Temperature changes can also cause stress and lethality (Ligon et al. 1999). Temperatures at sub-lethal levels can effectively block migration, lead to reduced growth, stress fish, affect reproduction, inhibit smoltification, create disease problems, and alter competitive dominance (Elliott 1981, USEPA 1999). Further, the stressful impacts of water temperatures on salmonids are cumulative and positively correlated to the duration and severity of exposure. The longer the salmonid is exposed to thermal stress, the less chance it has for long-term survival (Ligon et al. 1999).

A literature review was performed to evaluate temperature needs for the various life stages of steelhead trout (*Oncorhynchus mykiss*), coho salmon (*Oncorhynchus kisutch*), and Chinook salmon (*Oncorhynchus tschawytscha)*. The purpose of this review was to identify temperature thresholds that are protective of salmonids by life stage, as a basis for evaluating Klamath River basin stream temperatures.

This review included USEPA temperature guidance, Oregons' and Washingtons' temperature standards reviews, reports that compiled and summarized existing scientific information, and laboratory and field studies. When possible, species-specific needs were summarized by the following life stages: migrating adults, spawning and incubation/emergence, and freshwater rearing and growth. Additionally, the effects of temperature on disease and lethality are also discussed. Some of the references reviewed covered salmonids as a general class of fish, while others were species specific. Information for fall run coho salmon, spring/summer, fall, and winter steelhead, and spring and fall run Chinook salmon are compiled by life stage in Table 1 through Table 12.

Temperature Metrics
In considering the effect of temperature on salmonids, it is useful to have a measure of chronic (i.e. sub-lethal) and acute (i.e. lethal) temperature exposures. A common measure of chronic exposure is the maximum weekly average temperature (MWAT). The MWAT is the maximum seasonal or yearly value of the mathematical mean of multiple, equally spaced, daily temperatures over a running seven-day consecutive period (Brungs and Jones 1977, p.10). In other words, it is the highest single value of the seven-day moving average temperature. A common measure of acute effects is the instantaneous maximum. A third metric, the maximum weekly maximum temperature (MWMT), can be used as a measure of both chronic and acute effects. The MWMT (also known as the seven-day average of the daily maximum temperatures (7-DADM)) is the maximum seasonal or yearly-value of the daily maximum temperatures over a running seven-day consecutive period. The MWMT is useful because it describes the maximum temperatures in a stream, but is not overly influenced by the maximum temperature of a single day.

Much of the information reported in the literature characterizes temperature needs with terms such as "preferred" or "optimum". Preferred stream temperatures are those that fish most frequently inhabit when allowed to freely select temperatures in a thermal gradient (USEPA 1999). An optimum range provides suitable temperatures for feeding activity, normal physiological response, and normal behavior (without symptoms of thermal stress) (USEPA 1999). Optimal temperatures have also been described as those temperatures at which growth rates, expressed as weight gain per unit of time, are maximal for the life stage (Armour 1991).

Salmonid stocks do not tend to vary much in their life history thermal needs, regardless of their geographic location. The USEPA (2001) in their *Summary of Technical Literature Examining the Physiological Effects of Temperature on Salmonids* makes the case that there is not enough significant genetic variation among stocks or among species of salmonids to warrant geographically specific water temperature standards.

> Climate conditions vary substantially among regions of the State and the entire Pacific Northwest. …Such [varying climatic] conditions could potentially have led to evolutionary adaptations, resulting in development of subspecies differences in thermal tolerance. …[However,] the literature on genetic variation in thermal effects indicates occasionally significant but very small differences among stocks and increasing differences among subspecies, species, and families of fishes. Many differences that had been attributed in the literature to stock differences are now considered to be statistical problems in analysis, fish behavioral responses under test conditions, or allowing insufficient time for fish to shift from field conditions to test conditions (Mathur & Silver 1980, Konecki et al. 1993, both as cited in USEPA 2001).

Additionally:

> There are many possible explanations why salmonids have not made a significant adaptation to high temperature in streams of the Pacific Northwest. Temperature tolerance is probably controlled by multiple genes, and consequently would be a core characteristic of the species not easily modified through evolutionary change without a radical shift in associated physiological systems. Also, the majority of the life cycle of salmon and steelhead is spent in the ocean rearing phase, where the smolt, subadults, and adults seek waters with temperatures less than 59°F (15°C) (Welch et al, 1995, as cited in USEPA 2001).

As a result, literature on the temperature needs of coho and Chinook salmon and steelhead trout stemming from data collected in streams outside Northern California are cited in this document and are considered relevant to characterizing the thermal needs of salmonids which use Northern California rivers and streams.

Adult Migration and Holding

All of the adult migration and holding temperature needs referenced in this section can be found in Table 1 through Table 3. Salmon and trout respond to temperatures during their upstream migration (Bjornn and Reiser 1991). Delays in migration have been observed in response to temperatures that were either too cold or too warm. Most salmonids have evolved with the temperature regime they historically used for migration and spawning, and deviations from the normal pattern can affect survival (Spence et al. 1996).

The USEPA document *EPA Region 10 Guidance for Pacific Northwest State and Tribal Water Quality Standards* (2003) recommends that the seven-day average of the daily maximum temperatures (7-DADM) should not exceed 18°C in waters where both adult salmonid migration and "non-core" juvenile rearing occur during the period of summer maximum temperatures. The document does not define what constitutes the "summer" period. Non-core juvenile rearing is defined as moderate to low density salmon and trout rearing usually occurring in the mid or lower part of the basin, as opposed to areas of high density rearing which are termed "core" rearing areas. This criterion is derived from analysis and synthesis of past laboratory and field research. The USEPA believes that this temperature recommendation will protect against lethal conditions, prevent migration blockage, provide optimal or near optimal juvenile growth conditions, and prevent high disease risk by minimizing the exposure time to temperatures which can lead to elevated disease rates.

A 7-DADM temperature of 20°C is recommended by the USEPA (2003) for waterbodies that are used almost exclusively for migration during the period of summer maximum temperatures.

> "EPA believes that a 20°C criterion would protect migrating juveniles and adults from lethal temperatures and would prevent migration blockage conditions. However, EPA is concerned that rivers with significant hydrologic alterations (e.g., rivers with dams and reservoirs, water withdrawals, and /or significant river channelization) may experience a

loss of temperature diversity in the river, such that maximum temperatures occur for an extended period of time and there is little cold water refugia available for fish to escape maximum temperatures. In this case, even if the river meets a 20°C criterion for maximum temperatures, the duration of exposure to 20°C temperatures may cause adverse effects in the form of increased disease and decreased swimming performance in adults, and increased disease, impaired smoltification, reduced growth, and increased predation for late emigrating juveniles…."

Therefore, the USEPA recommends a narrative provision to protect and, if possible, restore the natural thermal regime accompany the 7-DADM 20°C criterion for rivers with significant hydrologic alterations.

In an exhaustive study of both laboratory and field studies of temperature effects on salmonids and related species, USEPA (1999, 2001) concluded that temperatures of approximately 22-24°C limit salmonid distribution, i.e., they totally eliminate salmonids from a location. USEPA (1999) also notes that changes in competitive interactions between fish species can lead to a transition in dominance from salmonids to other species at temperatures 2-4°C lower than the range of total elimination.

Steelhead Trout Migration

In a review of numerous studies, WDOE (2002) concluded that daily average temperatures of 21-24°C are associated with avoidance behavior and migration blockage in steelhead trout. WDOE suggests that the MWMT should not exceed 17-18°C, and daily maximum temperatures should not exceed 21-22°C to be fully protective of adult steelhead migration.

Table 1: Effects of Temperature in Considering Adult Steelhead and Migration

<table>
<tr><th>C</th><th colspan="3">Migration</th></tr>
<tr><td>24</td><td rowspan="4">21-24 Average daily temperature associated with avoidance and migration blockage (2)</td><td colspan="2" rowspan="3">22-24 Temperature range which eliminates salmonids from an area (3,4)</td></tr>
<tr><td>23</td></tr>
<tr><td>22</td></tr>
<tr><td>21</td><td>21-22 Daily maximum temperature should not exceed this to be fully protective (2)</td><td rowspan="4">18-22 Temperature range at which transition in dominance from salmonids to other species occurs (4)</td></tr>
<tr><td>20</td><td colspan="2">20 MWMT should not exceed this in waterbodies used almost exclusively for migration. Should be used in conjunction with a narrative provision about protecting/restoring the natural thermal regime for rivers with significant hydrologic alterations (1)</td></tr>
<tr><td>19</td><td colspan="2"></td></tr>
<tr><td>18</td><td rowspan="2">17-18 MWMT should not exceed this to be fully protective (2)</td><td>18 MWMT should not exceed this where migration and non-core rearing occur (1)</td></tr>
<tr><td>17</td><td colspan="2"></td></tr>
</table>

References

1 USEPA 2003 (reviewed many literature sources to make assessments of temperature needs)
2 WDOE 2002 (reviewed many literature sources to make assessments of temperature needs)
3 USEPA 2001 (reviewed many literature sources to make assessments of temperature needs)
4 USEPA 1999 (reviewed many literature sources to make assessments of temperature needs)

Chinook Salmon Migration and Holding

USEPA (2001) cited various literature sources that identified thermal blockages to Chinook salmon migration at temperatures ranging from 19-23.9°C, with the majority of references citing migration barriers at temperatures around 21°C.

Table 2: Effects of Temperature in Considering Adult Chinook and Migration and Holding

<table>
<tr><th>°C</th><th colspan="6">Migration</th></tr>
<tr><td>24</td><td colspan="2"></td><td colspan="2" rowspan="3">22-24 Temperature range which eliminates salmonids from an area (3,5)</td><td rowspan="6">19-23.9 Range of temperatures causing thermal blockage to migration (3)</td><td></td></tr>
<tr><td>23</td><td colspan="2">23 Klamath Basin fall Chinook begin migration upstream at temperatures as high as 23C if temperatures are rapidly falling (6)</td><td></td></tr>
<tr><td>22</td><td colspan="2">22 Klamath Basin fall Chinook will not migrate upstream when mean daily temperatures are 22C or greater (6)</td><td rowspan="4">18-22 Temperature range at which transition in dominance from salmonids to other species occurs (5)</td></tr>
<tr><td>21</td><td colspan="2">21-22 Daily maximum temperature should not exceed this range to be protective of migration (2)</td><td colspan="2">21 Most references cite as thermal block to migration (3)
21 Klamath Basin fall Chinook will not migrate upstream if temperatures are 21C or above and rising (6)</td></tr>
<tr><td>20</td><td colspan="4">20 MWMT should not exceed this in waterbodies used almost exclusively for migration. Should be used in conjunction with a narrative provision about protecting/restoring the natural thermal regime for rivers with significant hydrologic alterations (1)</td></tr>
<tr><td>19</td><td colspan="3"></td><td rowspan="10">10.6-19.6 Temperature range where adult fall Chinook migrate (4)</td></tr>
<tr><td>18</td><td colspan="3"></td><td colspan="2">18 MWMT should not exceed this where migration and non-core rearing occur (1)</td></tr>
<tr><td>17</td><td colspan="3" rowspan="2">16-17 MWMT should be below this where Chinook are holding (2)</td><td colspan="2"></td></tr>
<tr><td>16</td><td colspan="2"></td></tr>
<tr><td>15</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>14</td><td colspan="3" rowspan="8">7.2-14.5 Preferred temperatures for Chinook (4)</td><td colspan="2" rowspan="2">13-14 Average daily temperature should be below this where spring Chinook are holding (2)</td></tr>
<tr><td>13</td></tr>
<tr><td>12</td><td colspan="2" rowspan="7">3.3-13.3 Temperature range where adult spring Chinook migrate (4)</td></tr>
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<tr><td>6</td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>5</td><td></td><td colspan="2"></td><td></td><td colspan="2"></td></tr>
<tr><td>4</td><td></td><td colspan="2"></td><td></td><td colspan="2"></td></tr>
<tr><td>3</td><td></td><td colspan="2"></td><td></td><td colspan="2"></td></tr>
</table>

References

1 USEPA 2003 (reviewed many literature sources to make assessments of temperature needs)
2 WDOE 2002 (reviewed many literature sources to make assessments of temperature needs)
3 USEPA 2001 (reviewed many literature sources to make assessments of temperature needs)
4 Bell 1986 (reviewed many literature sources to make assessments of temperature needs)
5 USEPA 1999 (reviewed many literature sources to make assessments of temperature needs)
6 Strange (personal communication 2005)

A radio tracking study on spring Chinook revealed that when maximum temperatures of 21.1°C were reached, a thermal barrier to migration was established (Bumgarner et al. 1997, as cited by USEPA 1999). Bell (1986) reviewed various studies and notes spring Chinook migrate at water temperatures ranging from 3.3-13.3°C, while fall Chinook migrate at temperatures of 10.6-19.6°C. Preferred temperatures for Chinook range from 7.2-14.5°C (Bell 1986). Based on a technical literature review, WDOE (2002) concluded that daily maximum temperatures should not exceed 21-22°C during Chinook migration.

Utilizing radio telemetry to track the movements and monitor the internal body temperatures of adult fall Chinook salmon during their upriver spawning migration in the Klamath basin, Strange (personal communication 2005) found that fall Chinook will not migrate upstream when mean daily temperatures are ≥22°C. Strange (personal communication 2005) also noted that adult fall Chinook in the Klamath basin will not migrate upstream if temperatures are 21°C or above and rising, but will migrate at temperatures as high as 23°C if temperatures are rapidly falling.

Spring Chinook begin entering freshwater streams during a relatively cool-water season but must hold throughout the warm summer period, awaiting cooler spawning temperatures (ODEQ 1995). The cumulative effects of management practices such as elevated water temperatures, reduced cover from large woody debris, and reduced resting pool area due to pool filling increase the susceptibility of holding adult fish to mortality from thermal effects (ODEQ 1995). WDOE (2002) states that where spring Chinook are holding over for the summer prior to spawning the average daily water temperature should be below 13-14°C and the MWMT should be below 16-17°C.

Coho Salmon Migration

Migration for coho is delayed when water temperatures reach 21.1°C (Bell 1986). Bell (1986) also notes that the preferred water temperatures for coho range from 11.7-14.5°C. In California coho salmon typically migrate upstream when water temperatures range from 4-14°C (Briggs, 1953 and Shapovalov and Taft, 1954, as cited by Hassler, 1987). WDOE (2002) reviewed various studies and concluded that to be protective of adult coho migration, MWMTs should not exceed 16.5°C.

Reutter and Herdendorf (1974) conducted laboratory experiments and found that the preferred temperature, that is the temperature where fish will ultimately congregate given an infinite gradient of temperatures to choose from (Fry 1947, as cited by Reutter and Herdendorf 1974), for coho salmon was 11.4°C.

Table 3: Effects of Temperature in Considering Adult Coho and Migration

<table>
<tr><th>°C</th><th colspan="3">Migration</th></tr>
<tr><td>24</td><td colspan="2" rowspan="3">22-24 Temperature range which eliminates salmonids from an area (3,6)</td><td></td></tr>
<tr><td>23</td><td></td></tr>
<tr><td>22</td><td rowspan="5">18-22 Temperature range at which transition in dominance from salmonids to other species occurs (6)</td></tr>
<tr><td>21</td><td colspan="2">21.1 Migration is delayed when temperatures reach this value (4)</td></tr>
<tr><td>20</td><td colspan="2">20 MWMT should not exceed this in waterbodies used almost exclusively for migration. Should be used in conjunction with a narrative provision about protecting/restoring the natural thermal regime for rivers with significant hydrologic alterations (1)</td></tr>
<tr><td>19</td><td colspan="2"></td></tr>
<tr><td>18</td><td colspan="2">18 MWMT should not exceed this where migration and non-core rearing occur (1)</td></tr>
<tr><td>17</td><td colspan="3"></td></tr>
<tr><td>16</td><td colspan="3">16.5 MWMT should not exceed this value to be fully protective (2)</td></tr>
<tr><td>15</td><td colspan="3"></td></tr>
<tr><td>14</td><td rowspan="3">11.7-14.5 Preferred temperature range (4)</td><td colspan="2" rowspan="4">4-14 Temperature range at which migration typically occurs (5)</td></tr>
<tr><td>13</td></tr>
<tr><td>12</td></tr>
<tr><td>11</td><td>11.4 Preferred temperature (7)</td></tr>
</table>

References
1 USEPA 2003 (reviewed many literature sources to make assessments of temperature needs)
2 WDOE 2002 (reviewed many literature sources to make assessments of temperature needs)
3 USEPA 2001 (reviewed many literature sources to make assessments of temperature needs)
4 Bell 1986 (reviewed many literature sources to make assessments of temperature needs)
5 Briggs 1953, and Shapovalov and Taft (1954, as cited by Hassler 1987)
6 USEPA 1999 (reviewed many literature sources to make assessments of temperature needs)
7 Reutter and Herdendorf 1974 (laboratory study)

Spawning, Incubation, and Emergence

All of the spawning, incubation, and emergence temperature needs referenced in this section can be found in Table 4 through Table 7. Many sources have stated that temperature affects the time of migration in adults and thus the time of spawning, which influences the incubation temperature regime, which in turn influences survival rates, development rates, and growth of embryos and alevins (Murray and McPhail 1988). USEPA Region 10 (2003) recommends that the 7-DADM temperatures should not exceed 13°C for salmonid spawning, egg incubation, and fry emergence. Optimum temperatures for salmonid egg survival ranges from 6-10°C (USEPA 2001).

Steelhead Spawning, Incubation, and Emergence

In a discussion paper and literature summary evaluating temperature criteria for fish species including salmonids and trout, WDOE (2002) cites studies showing that steelhead were observed spawning in temperatures ranging from 3.9-21.1°C, and that the preferred temperatures for steelhead spawning range from 4.4-12.8°C. In a review of various studies, Bell (1986) concludes that steelhead spawning occurs at water temperatures ranging from 3.9-9.4°C.

Steelhead and rainbow trout eggs had the highest survival rates between 5-10°C according to Myrick and Cech (2001) and while they can tolerate temperatures as low as 2°C or as high as 15°C, mortality is increased at these temperatures. WDOE (2002) reviewed literature on the survival of steelhead and rainbow trout embryos and alevins at various temperatures and concluded that the average water temperature should not exceed 7-10°C throughout development, and the maximum daily average temperature should be below 11-12°C at the time of hatching.

Table 4: Effects of Temperature in Considering Steelhead Incubation and Emergence

<table>
<tr><th>°C</th><th colspan="3">Incubation and Emergence</th></tr>
<tr><td>15</td><td colspan="3">15 Steelhead and rainbow trout eggs can survive at temperatures as high as this but mortality is high compared to lower temperatures (3)</td></tr>
<tr><td>14</td><td colspan="3"></td></tr>
<tr><td>13</td><td colspan="3">13 MWMT should not exceed this value to be protective of spawning, egg incubation, and fry emergence (1)</td></tr>
<tr><td>12</td><td colspan="3" rowspan="2">11-12 Maximum daily average temperature should be below this range at the time of hatching (2)</td></tr>
<tr><td>11</td></tr>
<tr><td>10</td><td rowspan="6">5-10 Steelhead and rainbow trout eggs had the highest survival within this range (3)</td><td rowspan="5">6-10 Optimum temperature for salmonid eggs survival to hatching (4)</td><td rowspan="4">7-10 Average daily temperature should not exceed this range throughout embryo development (2)</td></tr>
<tr><td>9</td></tr>
<tr><td>8</td></tr>
<tr><td>7</td></tr>
<tr><td>6</td><td></td></tr>
<tr><td>5</td><td colspan="2"></td></tr>
<tr><td>4</td><td colspan="3"></td></tr>
<tr><td>3</td><td colspan="3"></td></tr>
<tr><td>2</td><td colspan="3">2 Steelhead and rainbow trout eggs can survive at temperatures as low as this but mortality is high compared to higher temperatures (3)</td></tr>
</table>

References

1 USEPA 2003 (reviewed many literature sources to make assessments of temperature needs)
2 WDOE 2002 (reviewed many literature sources to make assessments of temperature needs)
3 Myrick and Cech 2001 (reviewed many literature sources to make assessments of temperature needs)
4 USEPA 2001 (reviewed many literature sources to make assessments of temperature needs)

Chinook Spawning, Incubation, and Emergence

The Oregon Department of Environmental Quality (ODEQ 1995) reviewed numerous studies and recommended a temperature range of 5.6-12.8°C for spawning Chinook. A discussion paper and literature summary by WDOE (2002) found that the literature reviewed noted a wide range of temperatures associated with Chinook spawning (5.6-17.7°C), although the majority of these temperature observations cite daily maximum temperatures below 14.5°C. Reiser and Bjornn (1979, as cited by Armour et al. 1991) cites recommended spawning temperature ranges for spring, summer and fall Chinook salmon populations in the Pacific Northwest of 5.6-13.9°C. When ripe adult spring Chinook females experience temperatures above 13-15.5°C, pre-spawning adult mortality becomes pronounced (ODEQ 1995). Additionally, there is decreased survival of eggs to the eyed stage and alevin development is inhibited due to the exposure of the ripe female to warm temperatures, even if the stream temperatures during the egg and alevin development are appropriate (ODEQ 1995).

WDOE (2002) reviewed numerous references on the effects of various temperatures on Chinook incubation and development and used these studies to derive the temperatures that are protective of Chinook salmon from fertilization through fry development. References reviewed by WDOE (2002) include laboratory studies assessing Chinook embryo survival at various constant temperatures, studies attempting to mimic naturally fluctuating temperatures experienced by incubating eggs, studies which have made stepwise reductions in the incubation temperatures as incubation progressed to evaluate survival of eggs, and studies on the effects of transferring eggs to optimal constant incubation temperatures after they had been exposed to higher temperatures for various periods. As a result of this review, WDOE (2002) recommends that average daily temperatures remain below 11-12.8°C at the initiation of incubation, and that the seasonal average should not exceed 8-9°C in order to provide full protection from fertilization through initial fry development. The highest single day maximum temperature should not exceed 17.5-20°C to protect eggs and embryos from acute lethal conditions.

Table 5: Effects of Temperature in Considering Chinook Incubation and Emergence

<table>
<tr><th>°C</th><th colspan="6">Incubation and Emergence</th></tr>
<tr><td>20</td><td colspan="6" rowspan="4">17.5-20 The highest single day maximum temperature should not exceed this range to protect eggs and embryos from acute lethal conditions (2)</td></tr>
<tr><td>19</td></tr>
<tr><td>18</td></tr>
<tr><td>17</td></tr>
<tr><td>16</td><td colspan="5"></td><td rowspan="16">1.7-16.7 Eggs can survive these temps. but mortality is greatly increased at the extremes (3)</td></tr>
<tr><td>15</td><td colspan="5"></td></tr>
<tr><td>14</td><td rowspan="10">5-14.4 Recom-mended temp. range for incubation (4)</td><td rowspan="2">13.5-14.5 Daily maximum temperatures should not exceed this from fertilization through initial fry development (5)</td><td colspan="2">14 Moderate embryo survival (6)</td><td rowspan="13">2-14 Range of temps. for normal embryo develop-ment (6)</td></tr>
<tr><td>13</td><td colspan="2">13 MWMT should not exceed this value to be protective of spawning, egg incubation, and fry emergence (1)</td></tr>
<tr><td>12</td><td></td><td rowspan="9">4-12 Lowest levels of egg mortality at these temps. (3)</td><td rowspan="2">11-12.8 Average daily temperatures should be below this range at beginning of incubation (2)</td></tr>
<tr><td>11</td><td>11 High embryo survival (6)</td></tr>
<tr><td>10</td><td>9-10 Optimal temp. should be below this range (5)</td><td rowspan="5">6-10 Optimum temperature for salmonid eggs survival to hatching (5)</td></tr>
<tr><td>9</td><td>8-9 Seasonal ave. temps. should not exceed this range from fertilization through initial fry development (2)</td></tr>
<tr><td>8</td><td>8 High embryo survival (6)</td></tr>
<tr><td>7</td><td></td></tr>
<tr><td>6</td><td></td></tr>
<tr><td>5</td><td>5 High embryo survival (6)</td><td></td></tr>
<tr><td>4</td><td></td><td></td><td></td></tr>
<tr><td>3</td><td colspan="4"></td></tr>
<tr><td>2</td><td colspan="4">2 Poor embryo survival (6)</td></tr>
<tr><td>1</td><td colspan="5"></td></tr>
</table>

References
1 USEPA 2003 (reviewed many literature sources to make assessments of temperature needs)
2 WDOE 2002 (reviewed many literature sources to make assessments of temperature needs)
3 Myrick and Cech 2001 (reviewed many literature sources to make assessments of temperature needs)
4 Reiser and Bjornn (1979, as cited by Armour et al. 1991)
5 USEPA 2001 (reviewed many literature sources to make assessments of temperature needs)
6 Murray and McPhail 1988 (laboratory study)

USEPA (2001) reviewed multiple literature sources and concluded that optimal protection from fertilization through initial fry development requires that temperatures be maintained below 9-10°C, and that daily maximum temperatures should not exceed 13.5-14.5°C. Reiser and Bjornn (1979, as cited by Armour et al. 1991) list recommended temperature ranges of 5.0-14.4°C for spring, summer and fall Chinook salmon incubation in the Pacific Northwest. Myrick and Cech (2001) reviewed studies on the Sacramento-San Joaquin R. and concluded that the lowest levels of Chinook egg mortality occurred at temperatures between 4-12°C, and while eggs can survive at temperatures from 1.7-16.7°C, mortality is greatly increased at the temperature extremes.

Embryo survival was studied in a laboratory experiment conducted by Murray and McPhail (1988). They incubated five species of Pacific salmon, including Chinook, at five incubation temperatures (2, 5, 8, 11, 14°C). Chinook embryo survival was high at 5, 8, and 11°C, but survival was moderate at 14°C and poor at 2°C. As a result of their study, Murray and McPhail (1988) concluded that the range of temperatures for normal embryo development is > 2°C and <14°C.

Coho Spawning, Incubation, and Emergence

WDOE (2002) found that several studies and literature reviews state that spawning activity in coho may typically occur in the range of 4.4-13.3ºC. According to a review by Bell (1986), preferred spawning temperatures range from 4.5-9.4ºC. Brungs and Jones (1977) used existing data on the optimum and range of temperatures for coho spawning and embryo survival to create criteria using protocols from the National Academy of Sciences and National Academy of Engineering. The resultant criteria were that the MWAT should not exceed 10ºC and the daily maximum temperature should not exceed 13ºC to be protective of coho (Brungs and Jones 1977, p.16).

Table 6: Effects of Temperature in Considering Coho Incubation and Emergence

<table>
<tr><th>°C</th><th colspan="5">Incubation and Emergence</th></tr>
<tr><td>14</td><td colspan="5">14 Upper limit for normal embryo development (5)</td></tr>
<tr><td>13</td><td colspan="3">13 MWMT should not exceed this value to be protective of spawning, egg incubation, and fry emergence (1)</td><td>13 Daily maximum temperature should not exceed this value to be protective (6)</td><td rowspan="10">4.5-13.3 Preferred emergence temperature range (3)</td></tr>
<tr><td>12</td><td colspan="2"></td><td rowspan="4">9-12 MWMT should not exceed this range to be fully protective (4)</td><td></td></tr>
<tr><td>11</td><td colspan="2"></td><td></td></tr>
<tr><td>10</td><td rowspan="5">6-10 Optimum temperature for salmonid eggs survival to hatching (4)</td><td rowspan="3">8-10 Ave. daily temp. during incubation should be at or below this to be supportive (2)</td><td>10 MWAT should not exceed this to be protective (6)</td></tr>
<tr><td>9</td><td></td></tr>
<tr><td>8</td><td></td><td></td></tr>
<tr><td>7</td><td colspan="3"></td></tr>
<tr><td>6</td><td colspan="3"></td></tr>
<tr><td>5</td><td></td><td colspan="3"></td></tr>
<tr><td>4</td><td></td><td colspan="3"></td></tr>
</table>

References
1 USEPA 2003 (reviewed many literature sources to make assessments of temperature needs)
2 WDOE 2002 (reviewed many literature sources to make assessments of temperature needs)
3 Bell 1986 (reviewed many literature sources to make assessments of temperature needs)
4 USEPA 2001 (reviewed many literature sources to make assessments of temperature needs)
5 Murray and McPhail 1988 (laboratory study)
6 Brungs and Jones 1977 (used existing data on the optimum range of temperatures for spawning and embryo survival to create criteria using protocols from the National Academy of Engineering (1973)).

In a discussion paper and literature summary WDOE (2002) reviewed studies that assessed the survival of embryos and alevin at various temperatures. Based on the findings of these studies WDOE (2002) has determined that the average daily temperature during the incubation period should be at or below 8-10ºC to fully support this coho salmon life stage. According to a review of various literature sources by Bell (1986), the preferred emergence temperatures for coho range from 4.5-13.3ºC. USEPA (2001) concluded that to fully support pre-emergent stages of coho development MWMTs should not exceed 9-12°C.

Murray and McPhail (1988) incubated five species of Pacific salmon, including coho, at five temperatures (2, 5, 8, 11, 14°C) to determine embryo survival at various temperatures. Coho embryos suffered increased mortality above 11°C although survival was still high. They concluded that the upper limit for normal coho embryo development is 14°C (Murray and McPhail 1988).

Table 7: Effects of Temperature in Considering Steelhead, Chinook, and Coho Spawning

<table>
<tr><th>°C</th><th colspan="3">Steelhead</th><th colspan="3">Chinook</th><th colspan="2">Coho</th><th>All Salmonids</th></tr>
<tr><td>21</td><td rowspan="19">3.9-21.2 Steelhead observed spawning in this temp. range (2)</td><td colspan="2"></td><td colspan="3"></td><td colspan="2"></td><td></td></tr>
<tr><td>20</td><td colspan="2"></td><td colspan="3"></td><td colspan="2"></td><td></td></tr>
<tr><td>19</td><td colspan="2"></td><td colspan="3"></td><td colspan="2"></td><td></td></tr>
<tr><td>18</td><td colspan="2"></td><td colspan="3"></td><td colspan="2"></td><td></td></tr>
<tr><td>17</td><td colspan="2"></td><td></td><td></td><td rowspan="13">5.6-17.7 Range of temps. associated with spawning from references reviewed (2)</td><td colspan="2"></td><td></td></tr>
<tr><td>16</td><td colspan="2"></td><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>15</td><td colspan="2"></td><td rowspan="3">13-15.5 Temp. range at which pre-spawning mortality becomes pronounced in ripe spring Chinook (4)</td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>14</td><td colspan="2"></td><td>14.5 Majority of refs. cite daily max temps. associated with spawning below this level (2)</td><td colspan="2"></td><td></td></tr>
<tr><td>13</td><td></td><td></td><td rowspan="9">5.6-13.9 Recommended temperature range for spawning (5)</td><td>13 Daily maximum temp. not to exceed this value to be protective (6)</td><td rowspan="10">4.4-13.3 Typical temps. during which spawning occurs (2)</td><td>13 MWMT not exceed this value during spawning, egg incubation, and fry emergence (1)</td></tr>
<tr><td>12</td><td></td><td rowspan="9">4.4-12.8 Preferred temp. range for spawning (2)</td><td rowspan="8">5.6-12.8 Recom-mended temperature range for spawning (4)</td><td></td><td></td></tr>
<tr><td>11</td><td></td><td></td><td></td></tr>
<tr><td>10</td><td></td><td>10 MWAT not exceed this value to be protective (6)</td><td></td></tr>
<tr><td>9</td><td rowspan="7">3.9-9.4 Temp. range where spawning occurs (3)</td><td rowspan="6">4.5-9.4 Preferred spawning temperature range (3)</td><td></td></tr>
<tr><td>8</td><td></td></tr>
<tr><td>7</td><td></td></tr>
<tr><td>6</td><td></td></tr>
<tr><td>5</td><td></td></tr>
<tr><td>4</td><td colspan="3"></td><td></td></tr>
<tr><td>3</td><td></td><td colspan="3"></td><td colspan="2"></td><td></td></tr>
</table>

References

1 USEPA 2003 (reviewed many literature sources to make assessments of temperature needs)

2 WDOE 2002 (reviewed many literature sources to make assessments of temperature needs)

3 Bell 1986 (reviewed many literature sources to make assessments of temperature needs)

4 ODEQ 1995 (reviewed many literature sources to make assessments of temperature needs)

5 Reiser and Bjornn (1979, as cited by Armour et al. 1991)

6 Brungs and Jones 1977 (used existing data on the optimum range of temperatures for spawning and embryo survival to create criteria using protocols from the National Academy of Engineering (1973))

Freshwater Rearing and Growth

All of the freshwater rearing and growth temperature needs referenced in this section can be found in Table 8 through Table 10. Temperature affects metabolism, behavior, and survival of both juvenile fish as well as other aquatic organisms that may be food sources. In streams of the Northern California Coast, including the Klamath River, young Chinook, coho and steelhead may rear in freshwater from one to four years before migrating to the ocean.

In an exhaustive study of both laboratory and field studies of temperature effects on salmonids and related species, USEPA (1999) concluded that temperatures of approximately 22-24°C limit salmonid distribution, i.e., they totally eliminate salmonids from a location. USEPA (1999) also notes that changes in competitive interactions between fish species can lead to a transition in dominance from salmonids to other species at temperatures 2-4°C lower than the range of total elimination.

To protect salmon and trout during summer juvenile rearing the USEPA (2003) for Region 10 provided a single guidance metric designating 16°C as the 7-DADM temperature that should not be exceeded in areas designated as "core" rearing locations. Core rearing areas are defined as areas with moderate to high densities of summertime salmonid juvenile rearing generally found in the mid- to upper portions of river basins. This criterion will protect juvenile salmonids from lethal temperatures, provide optimal to upper optimal conditions for juvenile growth depending on the time of year, avoid temperatures where salmonids are at a competitive disadvantage with other fish species, protect against increased disease rates caused by elevated temperatures, and provide temperatures which salmonids prefer according to scientific studies.

Steelhead Freshwater Rearing and Growth

Nielsen et al. (1994) studied thermally stratified pools and their use by juvenile steelhead in three California North Coast rivers including the Middle Fork Eel River, Redwood Creek at Redwood National Park, and Rancheria Creek, located in the Navarro River watershed. In detailed observations of juvenile steelhead behavior in and near thermally stratified pools in Rancheria Creek, Nielsen et al. (1994) noted behavioral changes including decreased foraging and increased aggressive behavior as pool temperature reached approximately 22°C. As pool temperature increased above 22°C, juveniles left the observation pools and moved into stratified pools where temperatures were lower.

Wurtsbaugh and Davis (1977, as cited by USEPA 2001) found that steelhead trout growth could be enhanced by temperature increases up to 16.5°C. Using a risk assessment approach which took into account "realistic food estimates", Sullivan et al. (2000) report temperatures of 13-17.0°C (MWAT), 14.5-21°C (MWMT), and 15.5-21°C (annual maximum) will ensure no more than a 10% reduction from maximum growth for steelhead. Reduction from maximum growth will be ≤20% for temperatures ranging from 10-19.0°C (MWAT), 10-24°C (MWMT), and 10.5-26°C (annual maximum).

Table 8: Effects of Temperature in Considering Juvenile Steelhead Rearing and Growth

°C	Rearing and Growth					
26						21-26 Annual maximum temp. which will ensure no more than 20% reduction from max. growth (4)
25						
24	22-24 Temperature range which totally eliminates salmonids from area, limiting their distribution (6)				21-24 MWMT which will ensure no more than 20% reduction from max growth (4)	
23		>22 Juveniles left observation pools and moved to pools with lower temperatures (2)				
22		22 Decreased foraging, increased aggressive behavior (2)		18-22 Temperature range at which transition in dominance from salmonids to other species occurs (6)		
21					14.5-21 MWMT which will ensure no more than 10% reduction from maximum growth (4)	15.5-21 Annual maximum temperature which will ensure no more than 10% reduction from maximum growth (4)
20						
19		17-19 MWAT will ensure no more than 20% reduction from max. growth (4)	17.2-19 Growth may be maximized at temperatures as high as this under satiated feeding conditions, lab studies at constant temperature (5)			
18				15.5-18 Average daily temperatures at which maximum growth occurs under satiated feeding, lab studies at varying temps (5)		
17		13-17 MWAT range which will ensure no more than 10% reduction from maximum growth (4)				
16	16.5 Growth enhanced by temp. increases up to this temp. (3) 16.2 Mean temp. at which max. growth occurred during the summer, lab studies using natural feeding conditions and varying temps. (5)		16 MWMT should not exceed this value to be protective of core rearing locations (1)			
15	15.2 Mean temp. at which max. growth occurred during the fall, lab studies using natural feeding conditions and varying temps. (5)					10.5-15.5 Annual maximum temperature which will ensure no more than 20% reduction from maximum growth (4)
14					10-14.5 MWMT which will ensure no more than 20% reduction from maximum growth (4)	
13	13.3 Mean temp. at which max. growth occurred during the spring, lab studies using natural feeding conditions and varying temps. (5)	10-13 MWAT will ensure no more than 20% reduction from maximum growth (4)				
12						
11						
10						

References

1 USEPA 2003 (reviewed many literature sources to make assessments of temperature needs)

2 Nielsen et al. 1994. (field study)

3 Wurtsbaugh and Davis (1977, as cited by USEPA 2001)

4 Sullivan et al. 2000 (developed method for estimating effects of temperature and food consumption on gain/ loss of weight, using previously collected data)

5 WDOE 2002 (reviewed many literature sources to make assessments of temperature needs)

6 USEPA (1999)

A literature review was conducted by WDOE (2002) in which studies to determine the water temperature that would allow for maximum growth of steelhead trout were analyzed. These included laboratory studies conducted at constant and fluctuating temperatures. One of the studies was conducted using feeding rates comparable to those observed in natural creeks, although most of the laboratory studies were conducted under satiated feeding conditions. As a result of this review of laboratory studies conducted at constant temperatures, WDOE (2002) concludes that under satiated rations growth may be maximized at temperatures as high as 17.2-19°C. Results from laboratory studies using variable temperatures show maximum growth occurs at average daily temperatures between 15.5-18°C, and that under feeding rates similar to natural conditions at various times of the year maximum growth rates occurred at mean temperatures of 13.3°C (spring season), 15.2°C (fall season) and 16.2°C (summer season).

Chinook Freshwater Rearing and Growth

In a laboratory study, Brett (1952) demonstrated that juvenile Chinook salmon, acclimated to a temperature of 20°C, selectively aggregated in areas where the temperature was in the region of 12-13°C.

ODEQ (1995), reviewed numerous studies and concluded for juvenile spring Chinook salmon rearing, positive growth takes place at temperatures between 4.5-19°C, and that optimum rearing production is between 10.0-15.6°C. However, as the extremes of this temperature range are reached growth reaches zero. Above and below these thresholds growth becomes negative as feeding ceases and respiration rates increase and/or decrease rapidly.

After synthesizing data from several sources USEPA (2001), came up with the same recommended optimum temperature zone for all Chinook salmon as ODEQ (1995) of 10.0-15.6°C. While there is research suggesting that some Chinook stocks exhibit adequate rearing capabilities above 15.6°C, USEPA (2001) conclude that anything over this threshold significantly increases the risk of mortality from warm-water diseases.

In a laboratory study Marine and Cech (2004) studied the incremental effects of chronic exposure to three temperature regimes (13-16 °C, 17-20 °C, and 21-24 °C) on Chinook juveniles during rearing and smoltification. Their findings reflected that Chinook juveniles reared at the 17-20 ºC and 21-24 ºC temperature ranges experienced significantly decreased growth rates, impaired smoltification indices, and increased predation vulnerability compared with juveniles reared at 13-16 ºC.

In a field study Chinook grew faster in a stream where temperatures peaked at 16°C compared to a stream where temperatures peaked at 20°C (ODFW 1992, as cited by WDOE 2002). WDOE (2002) reviewed literature on Chinook growth including laboratory studies conducted at a constant temperature, laboratory studies conducted at fluctuating temperatures, and field studies to evaluate the water temperature that would be protective of Chinook and allow for maximum growth. Most of the laboratory studies were conducted under satiated feeding conditions, although one of the studies was conducted using feeding rates more comparable to those observed in natural creeks. As a result of this review of laboratory studies conducted at constant temperatures, WDOE (2002) concludes that maximum growth is expected to occur with exposure to constant temperatures from 15.6-19°C. However, increased growth at temperatures above 15.6°C was inconsistently greater, and under natural rations the temperatures at which maximum growth occurs may decline by as much as 4.2°C. Recommendations based on the review of two laboratory studies conducted at fluctuating temperatures are that "…average temperatures below 19°C are necessary to support maximum growth rates in Chinook salmon, and that the average temperature that produces maximum growth rates likely lies between 15-18°C (median 16.5°C)".

Table 9: Effects of Temperature in Considering Juvenile Chinook Rearing and Growth

°C	Rearing and Growth				
24	22-24 Temperature range which totally eliminates salmonids from area, limiting their distribution (7)			21-24 Decreased growth, impaired smoltification, increased predation compared to juveniles reared at 13-16 (6)	
23					
22					
21			18-22 Temperature range at which transition in dominance from salmonids to other species occurs (7)		
20				17-20 Decreased growth, impaired smoltification, increased predation compared to juveniles reared at 13-16 (6)	
19	19 Temperatures above this do not support maximum growth, lab studies at varying temperatures (3)	15.6-19 Maximum growth expected according to lab studies conducted at constant temperature and satiated rations. Under natural feeding conditions maximum growth may occur at temperatures as much as 4.2C lower (3)			4.5-19 Temperature range at which positive growth takes place (5)
18	15-18 Average temperature where maximum growth occurs, lab studies conducted at varying temperatures (3)				
17					
16			16 Chinook grew faster in a stream where temperatures peaked at 16 than when they peaked at 19C (3) 16 MWMT should not exceed this value to be protective of core rearing locations (2)	13-16 Increased growth, unimpaired smoltification, lower predation compared to juveniles reared at 21-24, or 17-20 (6)	
15	10-15.6 Temperature range for optimal growth. Anything over this threshold increases the risk of mortality from warm water disease (1)		10-15.6 Optimal temperature range for rearing (5)		
14					
13				12-13 Juvenile Chinook acclimated to 20 selectively aggregate to these water temperatures (4)	
12					
11					
10					
9					
8					
7					
6					
5					
4					

References

1 USEPA 2001 (reviewed many literature sources to make assessments of temperature needs)
2 USEPA 2003 (reviewed many literature sources to make assessments of temperature needs)
3 WDOE 2002 (reviewed many literature sources to make assessments of temperature needs)
4 Brett 1952 (laboratory study)
5 ODEQ 1995 (reviewed many literature sources to make assessments of temperature needs)
6 Marine and Cech 2004 (laboratory study)
7 USEPA (1999)

Coho Freshwater Rearing and Growth

In a study of juvenile coho presence and absence in the Mattole watershed, Welsh et al. (2001) used logistic regression to determine that an MWAT greater than 16.8°C or a MWMT greater than 18.1°C may preclude the presence of juvenile coho salmon in the stream. The criterion correctly determined the presence or absence of juvenile coho in 18 of 21 streams. Welsh et al. (2001) also reported that juvenile coho were found in all streams with an MWAT less than 14.5°C, or a MWMT less than 16.3°C.

Sullivan et al. (2000) reviewed sub-lethal and acute temperature thresholds from a wide range of studies, incorporating information from laboratory-based research, field observations, and risk assessment approaches. Using a risk assessment approach based on "realistic food estimates" Sullivan et al (2000) suggest that MWATs ranging from 12.5-14.5°C for coho will result in no more than a 10% reduction from maximum growth, and that a range for the MWAT of 9-18.5°C will reduce growth no more than 20% from maximum. Sullivan et al. (2000) also calculated temperature ranges for MWMT (13-16.5°C) and the annual maximum temperature (13-17.5°C) that will result in no more than a 10% reduction in maximum growth. They further calculated ranges for MWMT (9-22.5°C) and the annual maximum temperature (9.5-23°C) that will result in no more than a 20% growth loss.

In an attempt to determine the water temperature that will allow for maximum growth of coho salmon, WDOE (2002) reviewed literature on laboratory studies conducted at a constant temperature and fluctuating temperatures, and field studies. The two laboratory studies reviewed were conducted under satiated feeding conditions. Shelbourn (1980, as cited by WDOE 2002) found that maximum growth occurred at a constant temperature of 17°C, while Everson (1973, as cited by WDOE 2002) tested fish at different temperatures and determined that coho had the greatest growth at the temperature test regime from 12.1-20.8°C (median 16.5°C). While the various field studies reviewed did not provide an estimate of the temperature best for maximum growth they did allow for WDOE (2002) to conclude that weekly average temperatures of 14-15°C were more beneficial to growth than lower temperature regimes, and daily maximum temperatures of 21-26°C were detrimental to growth.

Brett (1952) acclimated five different species of salmon to various temperatures ranging from 5-24°C and found that coho salmon showed the greatest preference for temperatures between 12-14°C. It was also determined that coho showed a general avoidance of temperatures above 15°C even in fish who were acclimated to temperatures as high as 24°C.

Konecki et al. (1995a) raised two groups of juvenile coho salmon under identical regimes to test the hypothesis that the group from a stream with lower and less variable temperature would have a lower and less variable preferred temperature than the group from a stream with warmer and more variable temperatures. Results reflected that the two groups tended to differ in their preferred temperature range as predicted above, but the differences were slight. Konecki et al. (1995a) concluded that the temperature preference of juvenile coho salmon in their study was 10-12°C.

Table 10: Effects of Temperature in Considering Juvenile Coho Rearing and Growth

°C	Rearing and Growth				
26	21-26 Daily maximum temperatures in this range are detrimental to growth, according to field studies (3)				
25					
24			22-24 Temperature range which totally eliminates salmonids from an area, limiting their distribution (9)		
23					17.5-23 Annual maximum temperature will ensure no more than 20% reduction from maximum growth (2)
22			16.5-22.5 MWMT will ensure no more than 20% reduction from maximum growth (2)	18-22 Temperature range at which transition in dominance from salmonids to other species occurs (9)	
21					
20		12.1-20.8 Greatest growth occurs in this temperature range under satiated conditions, lab study (7)			
19					
18	18.1 MWMT above this may preclude the presence of juvenile coho in steams (5)				
17	14.5-18.5 MWAT will ensure no more than 20% reduction from maximum growth (2)			17 Maximum growth at this constant temperature, at satiated rations in a lab study (6)	13.5 17.5 Annual maximum temperature will ensure no more than 10% reduction from maximum growth (2)
16			13-16.5 MWMT will ensure no more than 10% reduction from maximum growth (2)	16.8 MWAT above this may preclude the presence of juvenile coho in streams (5) 16.3 Juveniles found in all streams with MWMT less than this value (5) 16 MWMT not exceed this value to be protective of core rearing locations (1)	
15				>15 Juveniles show avoidance, even those acclimated to 24C (4) 14-15 Weekly average temperatures in this range are more beneficial than lower temperatures (3)	
14	14.5 Juvenile coho found in all streams with MWAT less than this value (5) 12.5-14.5 MWAT will ensure no more than 10% reduction from maximum growth (2)			12-14 Preferred temperature range (4)	
13			9-13 MWMT will ensure no more than 20% reduction from maximum growth (2)		9.5-13.5 Annual maximum temperature will ensure no more than 20% reduction from max. growth (2)
12	9-12.5 MWAT will ensure no more than 20% reduction from maximum growth (2)			10-12 Preferred temperature range (8)	
11					
10					
9					

References

1 USEPA 2003 (reviewed many literature sources to make assessments of temperature needs)
2 Sullivan et al. 2000 (developed method for estimating effects of temperature and food consumption on gain/ loss of weight, using previously collected data)
3 WDOE 2002 (reviewed many literature sources to make assessments of temperature needs)
4 Brett 1952 (laboratory study)
5 Welsh et al. 2001 (study on coho presence and absence in the Mattole watershed, using logistic regression to determine temperature needs)
6 Shelbourn (1980, as cited by WDOE 2002) (laboratory study)
7 Everson (1973, as cited by WDOE 2002) (laboratory study)
8 Konecki et al. 1995a (laboratory study)
9 USEPA (1999)

Lethality

All of the lethal temperatures referenced in this section can be found in Table 11. WDOE (2002) reviewed literature on three types of studies (constant exposure temperature studies, fluctuating temperature lethality studies, and field studies) and used this information to calculate the MWMT that, if exceeded, may result in adult and juvenile salmonid mortality. The resultant MWMTs for these various types of studies are as follows: constant exposure studies 22.64°C, fluctuating lethality studies 23.05°C , and field studies 22.18°C.

Table 11: Effects of Temperature in Considering Lethality and Salmonids

°C	Steelhead	Chinook	Coho	All Salmonids
28			28 LT50[1] for age 0-fish acclimated to a 10-13C cycle (6)	
27				
26			26 LT50[1] for presmolts (age 2-fish) acclimated to a 10-13C cycle (6)	
25		25.1 Upper lethal temp. at which 50% of the population would die after infinite exposure, juvenile Chinook acclimated to temperatures from 5-24C (4)	25.6 Upper lethal threshold (3)	
		25 Upper lethal threshold (3)	25 Upper lethal temp. at which 50% of the population would die after infinite exposure, juvenile coho acclimated to temps. from 5-24C (4)	
		25 Chronic (exposure >7 days) upper lethal limit for juvenile Chinook (5).		
24		24-24.5 Survival becomes less than 100% for juvenile Chinook acclimated to temperatures from 5-24C (4)		
23	23.9 Upper lethal threshold for steelhead (3)			23.05 do not exceed this value to prevent adult and juvenile mortality, data from fluctuating temp. studies (1)
22				22.64 do not exceed this value to prevent adult and juvenile mortality, data from constant exposure studies (1)
				22.18 do not exceed this value to prevent adult and juvenile mortality, data from field studies (1)
21	21.1 Temperature lethal to adults (7)			
	21 Lethal threshold for steelhead acclimated to 19C (2)			

[1] Maximum temperature in the cycle at which 50% mortality occurred

References

1 WDOE 2002 (reviewed many literature sources to make assessments of temperature needs)
2 Coutant (1970, as cited by USEPA 1999)
3 Bell 1986 (reviewed many literature sources to make assessments of temperature needs)
4 Brett 1952 (laboratory study)
5 Myrick and Cech 2001 (reviewed many literature sources to make assessments of temperature needs)
6 Thomas et al. 1986 (laboratory study)
7 CDFG 2001 (reviewed literature sources to make assessments)

Steelhead Lethality

Coutant (1970, as cited by USEPA 1999) found that Columbia River steelhead, which were acclimated to a river temperature of 19°C, had a lethal threshold of 21°C. Bell (1986) reviewed various studies and states that the lethal threshold for steelhead is 23.9°C. According to the California Department of Fish and Game (2001, p.419), temperatures of 21.1°C have been reported as being lethal to adults.

Chinook Lethality

In a laboratory study Brett (1952) acclimated five different species of juvenile salmon to various temperatures ranging from 5-24°C. At temperatures of 24°C and below there was 100% survival of fish during the one-week duration of the experiment. Brett (1952) concluded that the lethal temperature (temperature where survival becomes less than 100%) was between 24.0 and 24.5°C, and the ultimate upper lethal temperature was 25.1°C (temperature at which 50% of the population is dead after infinite exposure). A review of numerous studies led Bell (1986) to conclude that the upper lethal temperature for Chinook is 25°C. Myrick and Cech (2001) reviewed literature on studies from the Central Valley and found data to suggest that the chronic (exposure >7 days) upper lethal limit for juvenile Chinook is approximately 25°C.

Coho Lethality

In a review of various literature sources, Bell (1986) found that the upper lethal temperature for coho is 25.6°C. Brett (1952) concluded that the ultimate upper lethal temperature of juvenile coho salmon was 25.0°C (temperature at which 50% of the population is dead after infinite exposure). Thomas et al. (1986) conducted a study to determine the mortality of coho subjected to fluctuating temperatures. It was determined that the LT50 (the temperature at which 50% of the population will die) for fish acclimated to a 10-13°C cycle was 26°C for presmolts (age-2 fish), and 28°C for age-0 fish.

Disease

All of the effects of temperatures on disease risk in salmonids referenced in this section can be found in Table 12. WDOE (2002) reviewed studies of disease outbreak in salmonids and estimates that an MWMT of 14.38°C will virtually prevent warm water disease effects. To avoid serious rates of infection and mortality the MWMT should not exceed 17.38°C, and that severe infections and catastrophic outbreaks become a serious concern when the MWMTs exceed 20.88°C.

In a summary of temperature considerations, USEPA (2003) states that disease risks for juvenile rearing and adult migration are minimized at temperatures from 12-13°C, elevated from 14-17°C, and high at temperatures from 18-20°C.

Acknowledging that there are many diseases that affect salmonids, the following discussion will focus on three which are common in the Klamath Basin: Ichthyophthiriasis (Ich), Ceratomyxosis, and Columnaris. *Ichthyophthirius multifiliis* is a protozoan parasite that causes the disease known as Ichthyophthiriasis (Ich). The disease ceratomyxosis is caused by a parasite, *Ceratomyxa shasta* (*C. shasta*). Columnaris disease is a bacterial infection caused by *Flavobacterium columnare* (synomyms*: Bacillus columnaris, Chondrococcus columnaris, Cytophaga columnaris, Flexibacter columnaris*).

Ichthyophthiriasis (Ich)

Nigrelli et al. (1976, as cited by Dickerson et al. 1995) proposed that there are physiological races of Ich, which are related to the temperature tolerance of the host fishes. Thus, there are races of Ich that infect cold-water (7.2-10.6°C) fishes such as salmon, and others that infect warm-water (12.8-16.1°C) tropical fishes. Bell (1986) discusses Ich and states that at water temperatures above 15.6°C, this disease often breaks out in salmon fingerlings, especially Chinook. CDWR (1988) states that serious outbreaks of Ich occur at temperatures from 18.3-21.2°C.

Numerous studies and reviews have been conducted on the optimal temperature for Ich. Piper et al. (1982, p.316.) wrote that optimal temperatures range from 21-23.9°C. CDWR (1988) stated the optimum temperature for Ich is in the range of 25 to 26.7°C, while Bell (1986) states optimum temperatures are noted from 21.2-26.7°C.

Temperature is an important factor in the persistence of Ich infections in salmonids. The growth period varies from 1 week at 20 °C to 20 days at 7 °C (Nigrelli et al. 1976, as cited by Dickerson et al. 1995). Piper et al. (1982, p.316) state that at optimal temperatures of 21-23.9°C, the life cycle may take as few as 3-4 days. The cycle requires 2 weeks at 15.5°C, and more than 5 weeks at 10°C (Piper et al. 1982, p.316). Durborow et al. (1998) note that to complete its lifecycle, Ich requires from less than 4 days at temperatures higher than 24°C, to more than 5 weeks at temperatures lower than 7°C. Although studies report varying lengths of time for Ich to complete its lifecycle at similar temperatures, it is clear that the speed at which Ich develops increases as temperatures increase.

Ceratomyxosis

In reviewing the literature on Ceratomyxosis it is clear that the intensity of the disease increases, and the incubation period decreases, as water temperatures increase (CDWR 1988, Letritz and Lewis, Udey et al. 1975). At water temperatures greater than 10°C steelhead will show evidence of Ceratomyxosis in approximately 38 days (Leitritz and Lewis 1976, p.154). In a study of juvenile coho salmon by Udey et al. (1975), time from exposure to death was more than 90% temperature dependent, and increased from 12.5 days at 23.3°C to 146 days at 9.4°C indicating the accelerating effect of higher temperatures on the progress of the disease. The time from exposure to death of juvenile rainbow trout was nearly 97% temperature dependent, increasing from 14 days at 23.3°C to 155 days at 6.7°C (Udey et al. 1975).

C. shasta appears to become infective at temperatures around 10-11°C (CDWR 1988). According to Leitritz and Lewis (1976, p.154), steelhead from the Klamath River are quite susceptible to *C. shasta* infections and suffer severe losses when exposed.

Udey et al. (1975) conducted a study to determine the relation of water temperature to Ceratomyxosis in juvenile rainbow trout and coho salmon. Rainbow trout from the Roaring River Hatchery, and coho from Fall Creek Salmon Hatchery (both in Oregon) were used in this experiment. Groups of 25 fish exposed to *C. shasta* were transferred to 12.2°C water, and then were tempered to one of eight experimental temperatures from 3.9 to 23.3°C (2.8°C increments).

In the juvenile coho salmon experiment Udey et al. (1975) found that percent mortality increased progressively from 2% at 9.4°C to 22% at 15.0°C and 84% at 20.5°C. No deaths occurred in coho salmon maintained at 3.9 and 6.7°C, indicating that ceratomyxosis in coho can be suppressed by water temperatures of 6.7°C or below (Udey et al. 1975).

Tests conducted by Udey et al. (1975) on rainbow trout juveniles indicate that once infection is initiated, juvenile rainbow trout have little or no ability to overcome *C. shasta* infections at water temperatures between 6.7 and 23.3°C. Fatal infections varied from 75-86% at temperatures ranging from 6.7 to 15.0°C (Udey et al. 1975). Mortality in trout held at 20.5 and 23.3°C were lower (72% and 52% respectively) due to losses from *Flexibacter columnaris,* which occurred well before the onset of deaths caused by *C. shasta,* in spite of efforts to control it with terramycin (Udey et al. 1975). The results from Udey et al. (1975) also reflected no deaths occurred in juvenile trout held at 3.9°C.

Table 12: Effects of Temperature in Considering Disease and Salmonids

°C	Ich		Ceratomyxosis		Columnaris	Disease (general)	
26		21-26.7 Optimum temp. range for Ich, compilation of temps. from three references (3,4,5)					
25							
24	>24 Lifecycle takes less than 4 days (5)						
23	21-23.9 Life cycle takes as few as 3-4 days (5)		23.3 Juvenile coho salmon and rainbow trout time from exposure to death is 12.5 and 14 days respectively (9)	6.7-23.3 Juvenile rainbow trout have little or no ability to overcome infection, and mortality varied from 75-86% (9)	23.3 Juvenile spring Chinook mortality was 92%, and time from exposure to death was 2.3 days (13)		
22					22.2 Mortality is 100% in juvenile sockeye exposed to *C. columnaris* (10)		
21					>21.1 Temperatures at this level are associated with a 28-74% infection rate in Chinook (11)		
20	18.3-21.2 Serious outbreaks of Ich occur (4)	20 Lifecycle takes 1 week (6)	20.5 Mortality is 84% in juvenile coho exposed to *C. shasta* (9).		20.5 Mortality in juvenile steelhead and coho from Columnaris was 100%, and 70% in juvenile spring Chinook (13)	>20.88 MWMTs over this value can result in severe infections and catastrophic outbreaks (1)	18-20 Temperature range which is associated with a high risk of disease in rearing juveniles and migrating adults (2)
					20.5 In juvenile steelhead and coho time from exposure to death was 1.6-1.7 days (13)		
					20 Average water temperature at which low virulence strains show signs of outbreak (3, 12)		
19							
18							
17					17.8 Mortality rates were 52, 92, and 99% for juvenile spring Chinook, steelhead and coho respectively (13)	17.38 MWMT should not be exceeded to avoid serious rates of infection and mortality (1)	14-17 Temperature range which is associated with an elevated risk of disease in rearing juveniles and migrating adults (2)
16					16.1 Mortality is 30% in juvenile sockeye exposed to *C. columnaris* (10)		
15	>15.6 Associated with outbreaks in salmonid fingerlings, especially Chinook (3)		15 Mortality is 22% in juvenile coho exposed to *C. shasta* (9).		15.6 Average water temperature at which low virulence strains show signs of outbreak (3)		
	15.5 Lifecycle of Ich takes 2 weeks (5)				15 Mortality was 31, 56, and 51% for juvenile spring Chinook, steelhead, and coho respectively (13)		
14						14.38 MWMT will virtually prevent all warm water disease (1)	

Table 12 (continued):Effects of Temperature in Considering Disease and Salmonids

°C	Ich	Ceratomyxosis		Columnaris	Disease (general)
13					12-13 Temperature range which minimizes the risk of disease in rearing juveniles and migrating adults (2)
12				12.8 After 7 days of infection mortality is 60-100% (majority of tests 100%) (12)	
				12.2 Mortality was 4-20% in juvenile spring Chinook, steelhead, and coho respectively. Time from exposure to death ranged from 7.6-12.2 days (13).	
11		10-11 *C. shasta* appears to be come infective (4)			
10	10 Lifecycle takes more than 5 weeks (5)	<10 Steelhead show evidence of *C. shasta* in ~38 days (8)	6.7-23.3 Juvenile rainbow trout have little or no ability to overcome infection, and mortality varied from 75-86% (9)		
9		9.4 Juvenile coho time from exposure to death is 146 days, mortality is 2% (9)			
8					
7	7 Lifecycle takes 20 days (6)				
	<7 Lifecycle takes more than 5 weeks (7)				
6			6.7 Juvenile rainbow trout time from exposure to death is 155 days (9)	3.9-9.4 No mortality in spring Chinook, steelhead, or coho from Columnaris (13)	
5			3.9-6.7 No mortality in Juvenile coho exposed to *C. shasta* (9)		
4					
3					

References

1 WDOE 2002 (reviewed many literature sources to make assessments of temperature needs)
2 USEPA 2003 (reviewed many literature sources to make assessments of temperature needs)
3 Bell 1986 (reviewed many literature sources to make assessments of temperature needs)
4 CDWR (1988)
5 Piper et al. (1982)
6 Nigrelli et al. (1976, as cited by Dickerson et al. 1995)
7 Durborow et al. (1998)
8 Leitritz and Lewis (1976)
9 Udey et al. (1975)
10 Ordal and Rucker (1944, as cited by Pacha et al. 1970)
11 USEPA 1999 (reviewed many literature sources to make assessments of temperature needs)
12 Pacha et al. (1970)
13 Holt et al. (1975)

Columnaris

The importance of temperature on infections of Columnaris has been demonstrated in numerous laboratory studies. Ordal and Rucker (1944, as cited by Pacha et al. 1970) exposed juvenile sockeye salmon to *C. columnaris* and studied the effect of temperature on the disease. In these studies, the overall mortality ranged from 30% in fish held at 16.1°C to 100% in those held at 22.2°C (Ordal and Rucker 1944, as cited by Pacha et al. 1970). USEPA (1999) cites studies that conducted surveys of Columnaris infection frequency on Chinook in the Snake River in July and early August of 1955-1957, which revealed 28-75% of fish infected when water temperature was >21.1°C.

Low virulence strains of Columnaris show signs of outbreak when average water temperatures are over 20°C (Bell 1986, Pacha et al. 1970). Bell (1986) states that outbreaks of high virulence strains occur when average water temperatures reach 15.6°C, and Pacha et al. (1970) found mortalities of 60-100% (majority of tests 100%) occur at temperatures of 12.8°C after 7 days of infection. With regard to strains of higher virulence, while these strains are capable of beginning infection and producing disease at water temperatures as low as 12.8°C, the disease process becomes progressively slower as the water temperature is lowered (Pacha et al. 1970).

Holt et al. (1975) performed a study on the relation of water temperature to Columnaris in juvenile steelhead trout and juvenile coho and spring Chinook salmon. Tests were performed on groups of 25-35 fish at eight temperatures ranging from 3.9°C to 23.3°C (2.8°C increments). At 20.5°C mortality was 100% in juvenile steelhead trout and coho salmon, 70% in juvenile spring Chinook salmon, and at temperatures 23.3°C juvenile spring Chinook mortality was 92% (Holt et al. 1975). Mortality rates were 52, 92, and 99% at 17.8°C for juvenile spring Chinook, steelhead trout, and coho salmon respectively, and mortality dropped to 31, 56, and 51% at 15.0°C (Holt et al. 1975). At 12.2°C mortality varied from 4 to 20% among juveniles of the three species, and at temperatures of 9.4°C and below, no deaths due to the experimental infection with *F. columnaris* occurred (Holt et al. 1975). Holt et al. (1975) state that these results indicate that under the conditions of these experiments Columnaris disease was completely suppressed by water temperatures of 9.4°C or below.

In general, data from laboratory studies indicates that as water temperatures increase, the time to death decreases (Pacha et al. 1970). With juvenile steelhead trout and juvenile coho and spring Chinook salmon as the temperature increased above 12.2°C, the disease process was progressively accelerated, resulting in a minimum time to death at 20.5 or 23.3°C and a maximum at 12.2°C (Holt et al. 1975). In these juvenile salmonids Holt et al. (1975) found the mean time to death decreased from 7.6-12.2 days at 12.2°C to 1.6-1.7 days at 20.5°C for juvenile coho and steelhead, and 2.3 days at 23.3°C for juvenile spring Chinook (Holt et al. 1975).

Selection of TMDL Temperature Thresholds

As a result of this literature review, Regional Water Board staff has selected chronic and acute temperature thresholds for evaluation of Klamath River basin stream temperatures. Chronic temperature thresholds (MWMTs) were selected from the USEPA document *EPA Region 10 Guidance For Pacific Northwest State and Tribal Temperature Water Quality Standards* (2003), and are presented in Table 13. The Region 10 guidance is the product of a three-year interagency effort, and has been reviewed by both independent science review panels and the public. Acute lethal temperature thresholds were selected based upon best professional judgment of the literature, and are presented in Table 14.

Table 13: Temperature Thresholds-from USEPA 2003

Life Stage	MWMT (°C)
Adult Migration	**20**
Adult Migration plus Non-Core[1] Juvenile Rearing	**18**
Core[2] Juvenile Rearing	**16**
Spawning, Egg Incubation, and Fry Emergence	**13**

[1] Non-Core is defined as moderate to low density salmon and trout rearing usually occurring in the mid or lower part of the basin (moderate and low not defined).
[2] Core is defines as areas of high density rearing (high is not specifically defined).

Table 14: Lethal Temperature Thresholds

Lethal Threshold (°C)			
Life Stage	**Steelhead**	**Chinook**	**Coho**
Adult Migration and Holding	**24**	**25**	**25**
Juvenile Growth and Rearing	**24**	**25**	**25**
Spawning, Egg Incubation, and Fry Emergence	**20**	**20**	**20**

In some cases it may be necessary to calculate MWATs for a given waterbody, and compare these to MWAT thresholds. USEPA (2003) states that for many rivers in the Pacific Northwest the MWMT is about 3°C higher than the MWAT (USEPA 2003, as cited by Dunham et al. 2001and Chapman 2002). Rather than list MWAT thresholds in this document using the 3°C difference suggested above, the Regional Water Board will consider stream temperatures within an individual watershed. Thus the Regional Water Board will calculate both MWMTs and MWATs for a given waterbody, and characterize the actual difference between these temperature metrics for the watershed using an approach similar to that used in Sullivan et al. (2000). Once this relationship is understood, MWAT thresholds for each life stage can be identified for a specific watershed, and compared to the watershed MWATs.

The freshwater temperature thresholds presented in this section are applicable during the season or time of year when the life stage of each species is present. Periodicity information is not discussed in this document and will be presented in the watershed-specific TMDLs. Where life history, timing, and/or species needs overlap, the lowest of each temperature metric applies.

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The Effects of Dissolved Oxygen on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function by Life Stage

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Introduction

Adequate concentrations of dissolved oxygen in fresh water streams are critical for the survival of salmonids. Fish have evolved very efficient physiological mechanisms for obtaining and using oxygen in the water to oxygenate the blood and meet their metabolic demands (WDOE 2002). However, reduced levels of dissolved oxygen can impact growth and development of different life stages of salmon, including eggs, alevins, and fry, as well as the swimming, feeding and reproductive ability of juveniles and adults. Such impacts can affect fitness and survival by altering embryo incubation periods, decreasing the size of fry, increasing the likelihood of predation, and decreasing feeding activity. Under extreme conditions, low dissolved oxygen concentrations can be lethal to salmonids.

Literature reviewed for this analysis included EPA guidance, other states' standards, reports that compiled and summarized existing scientific information, and numerous laboratory studies. When possible, species-specific requirements were summarized for the following life stages: migrating adults, incubation and emergence, and freshwater rearing and growth. The following information applies to salmonids in general, with specific references to coho, Chinook, steelhead, and other species of salmonids as appropriate.

Adult Migration

Reduced concentrations of dissolved oxygen can negatively affect the swimming performance of migrating salmonids (Bjornn and Reiser 1991). The upstream migration by adult salmonids is typically a stressful endeavor. Sustained swimming over long distances requires high expenditures of energy and therefore requires adequate levels of dissolved oxygen. Migrating adult Chinook salmon in the San Joaquin River exhibited an avoidance response when dissolved oxygen was below 4.2 mg/L, and most Chinook waited to migrate until dissolved oxygen levels were at 5 mg/L or higher (Hallock et al. 1970).

Incubation/Emergence

Low levels of dissolved oxygen can be directly lethal to salmonids, and can also have sublethal effects such as changing the rate of embryological development, the time to hatching, and size of emerging fry (Spence et al. 1996). The embryonic and larval stages of salmonid development are especially susceptible to low dissolved oxygen levels as their ability to extract oxygen is not fully developed and their relative immobility inhibits their ability to migrate to more favorable conditions. The dissolved oxygen requirements for successful incubation of embryos and emergence of fry is tied to intragravel dissolved oxygen levels. Intragravel dissolved oxygen is typically a function of many chemical, physical, and hydrological variables, including: the dissolved oxygen concentration of the overlying stream water, water temperature, substrate size and porosity, biochemical oxygen demand of the intragravel water, sediment oxygen demand, the gradient and velocity of the stream, channel configuration, and depth of water. As a result the dissolved oxygen concentration within the gravels can be depleted causing problems for salmonid embryos and larvae, even when overlying surface water oxygen levels are suitable (USEPA 1986).

Studies note that water column dissolved oxygen concentrations are typically estimated to be reduced by 1-3 mg/L as water is transmitted to redds containing developing eggs and larvae (WDOE 2002). USEPA (1986) concluded that dissolved oxygen levels within the gravels should be considered to be at least 3 mg/L lower than concentrations in the overlying water. ODEQ (1995) expect the loss of an average of 3 mg/L dissolved oxygen from surface water to the gravels.

Incubation mortality
Phillips and Campbell (1961, as cited by Bjornn and Reiser, 1991) concluded that intragravel dissolved oxygen must average 8 mg/L for embryos and alevins to survive well. After reviewing numerous studies Davis (1975) states that a dissolved oxygen concentration of 9.75 mg/L is fully protective of larvae and mature eggs, while at 8 mg/L the average member of the incubating population will exhibit symptoms of oxygen distress, and at 6.5 mg/L a large portion of the incubating eggs may be affected. Bjornn and Reiser (1991) reviewed numerous references and recommend that dissolved oxygen should drop no lower than 5 mg/L, and should be at or near saturation for successful incubation.

In a review of several laboratory studies, ODEQ (1995) concluded that at near optimum (10°C) constant temperatures acute mortality to salmonid embryos occurs at relatively low concentrations of dissolved oxygen, near or below 3 mg/L. Field studies reviewed by ODEQ (1995) demonstrate that embryo survival is low when the dissolved oxygen content in the gravels drops near or below 5 mg/L, and survival is greater at 8 mg/L.

Silver et al. (1963) performed a study with Chinook salmon and steelhead trout, rearing eggs at various constant dissolved oxygen concentrations and water velocities. They found that steelhead embryos held at 9.5°C and Chinook salmon embryos held at 11°C experienced complete mortality at dissolved oxygen concentrations of 1.6 mg/L. Survival of a large percentage of embryos reared at oxygen levels as low as 2.5 mg/L appeared to be possible by reduction of respiration rates and consequent reduction of growth and development rates.

In a field study Cobel (1961) found that the survival of steelhead embryos was correlated to intragravel dissolved oxygen in the redds, with higher survival at higher levels of dissolved oxygen. At 9.25 mg/L survival was 62%, but survival was only 16% at 2.6 mg/L. A laboratory study by Eddy (1971) found that Chinook salmon survival at 10.4 mg/L (13.5 °C) was approximately 67%, however at dissolved oxygen levels of 7.3 mg/L (13.5 °C) survival dropped to 49-57.6%. At temperatures more suitable for Chinook incubation (10.5 °C) Eddy (1971) found the percent survival remained high (over 90%) at dissolved oxygen levels from 11 mg/L to 3.5 mg/L; however, as dissolved oxygen levels decreased, the number of days to hatching increased and the mean dry weight of the fry decreased substantially. WDOE (2002) also points out that the studies above did not consider the act of emerging through the redds, and the metabolic requirements to emerge would be expected to be substantial. Therefore, it is likely that higher oxygen levels may be needed to fully protect hatching and emergence, than to just support hatching alone.

Incubation growth
Embryos can survive when dissolved oxygen is below saturation (and above a critical level), but development typically deviates from normal (Bjornn and Reiser, 1991). Embryos were found to be smaller than normal, and hatching either delayed or premature, when dissolved oxygen was below saturation throughout development (Doudoroff and Warren 1965, as cited by Bjornn and Reiser 1991).

Garside (1966) found the number of days it took for rainbow trout to go from fertilization to hatching increased as dissolved oxygen concentrations and water temperature decreased. In this study, rainbow trout were incubated at temperatures between 2.5 - 17.5°C and dissolved oxygen levels from 2.5 - 11.3 mg/L. At 10°C and 7.5°C the total time for incubation was delayed 6 and 9 days respectively at dissolved oxygen levels of 2.5 mg/L versus embryos incubated at approximately 10.5 mg/L.

Silver et al. (1963) found that hatching of steelhead trout held at 9.5°C was delayed 5 to 8 days at dissolved oxygen concentrations averaging 2.6 mg/L versus embryos reared at 11.2 mg/L. A smaller delay of hatching was observed at oxygen levels of 4.2 and 5.7 mg/L, although none was apparent at 7.9 mg/L. For Chinook salmon held at 11°C, Silver et al. observed that embryos reared at oxygen levels lower than 11 mg/L experienced a delay in hatching, with the most significant delay in those reared at dissolved oxygen levels of 2.5 mg/L (6 to 9 days). The size of both Chinook and steelhead embryos increased with increases in dissolved oxygen up to 11.2 mg/L. External examination of embryos revealed abnormal structural development in Chinook salmon tested at dissolved oxygen concentrations of 1.6 mg/L, and abnormalities in steelhead trout at concentrations of 1.6 and 2.6 mg/L. The survival of Chinook salmon after hatching was only depressed at the 2.5 mg/L level, the lowest level at which hatching occurred, with lower mortalities occurring at higher velocities. Post hatching survival of steelhead trout could not be determined due to numerous confounding factors.

Shumway et al. (1964) conducted a laboratory study to determine the influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. The experiments were conducted at a temperature of 10°C and oxygen levels generally ranging from 2.5 - 11.5 mg/L and flows from 3 to 750 cm/hour. It was concluded that the median time to hatching decreased and size of fry increased as dissolved oxygen levels increased. For example, steelhead trout embryos reared at 2.9 mg/L hatched in approximately 41 days and had a wet weight of 17 mg, while embryos reared at 11.9 mg/L hatched in 36 days and weighed 32.3 mg. The authors found that a reduction of either the oxygen concentration or the water velocity will reduce the size of fry and increase the incubation period, although the affect of various water velocities tested was less than the effect of the different dissolved oxygen concentrations tested.

WDOE (2002) reviewed various references and found that at favorable incubation temperatures a mean oxygen concentration of 10.5 mg/L will result in a 2% reduction in growth. At other oxygen concentrations, growth is reduced as follows: 8% reduction at oxygen levels of 9 mg/L, 10% reduction at 7 mg/L, and a 25% reduction at 6 mg/L.

Incubation avoidance/preference
Alevin showed a strong preference for oxygen concentrations of 8 - 10 mg/L and moved through the gravel medium to these concentrations, avoiding concentrations from 4 - 6 mg/L (WDOE 2002).

Emergence mortality
"The hatching time, size, and growth rate of developing embryos is proportional to the dissolved oxygen concentrations up to 8 mg/L or greater. The ability of fry to survive their natural environment may be related to the size of fry at hatch (ODEQ 1995)." McMahon (1983) recommends dissolved oxygen levels be ≥ 8 mg/L for high survival and emergence of fry. In a review of controlled field and lab studies on emergence, WDOE (2002) states that average intragravel oxygen concentrations of 6 - 6.5 mg/L and lower can cause stress and mortality in developing embryos and alevin. It is also noted that field studies on emergence consistently cite intragravel oxygen concentrations of 8 mg/L or greater as being associated with or necessary for superior health and survival, oxygen concentrations below 6 - 7 mg/L result in a 50% reduction in survival through emergence, and oxygen concentrations below 5 mg/L result in negligible survival. According to various laboratory studies, the threshold for complete mortality of emerging salmonids is noted to occur between 2 - 2.5 mg/L (WDOE, 2002).

After reviewing numerous literature sources, the USEPA (1986) concluded that the embryonic and larval stages of salmonid development will experience no impairment when water column dissolved oxygen concentrations are 11 mg/L. This translates into an intragravel dissolved oxygen concentration of 8 mg/L (USEPA assumes a 3 mg/L loss between the surface water and gravels). Table 1 from the USEPA (1986) lists the water column and intragravel dissolved oxygen concentrations associated with various health effects. These health affects range from no production impairment to acute mortality.

Table 1: Dissolved oxygen concentrations and their effects salmonid embryo and larval stages (USEPA, 1986).

Level of Effect	Water Column DO (mg/L)	Intragravel DO (mg/L)
No Production Impairment	11	8*
Slight Production Impairment	9	6*
Moderate Production Impairment	8	5*
Severe Production Impairment	7	4*
Limit to Avoid Acute Mortality	6	3*

* A 3 mg/L loss is assumed between the water column dissolved oxygen levels and those intragravel.

Freshwater Rearing and Growth

Swimming and activity

Salmonids are strong active swimmers requiring highly oxygenated waters (Spence 1996), and this is true during the rearing period when the fish are feeding, growing, and avoiding predation. Salmonids may be able to survive when dissolved oxygen concentrations are low (<5 mg/L), but growth, food conversion efficiency, and swimming performance will be adversely affected (Bjornn and Reiser 1991). Davis (1975) reviewed numerous studies and reported no impairment to rearing salmonids if dissolved oxygen concentrations averaged 9 mg/L, while at oxygen levels of 6.5 mg/L "the average member of the community will exhibit symptoms of oxygen distress", and at 4 mg/L a large portion of salmonids may be affected. Dahlberg et al. (1968) state that at temperatures near 20°C any considerable decrease in the oxygen concentration below 9 mg/L (the air saturation level) resulted in some reduction of the final swimming speed. They found that between dissolved oxygen concentrations of 7 to 2 mg/L the swimming speed of coho declined markedly with the decrease in dissolved oxygen concentration.

In a laboratory study, Davis et al. (1963) reported that the maximum sustainable swimming speeds of wild juvenile coho salmon were reduced when dissolved oxygen dropped below saturation at water temperatures of 10, 15, and 20°C. Air-saturation values for these dissolved oxygen concentrations were cited as 11.3, 10.2, and 9.2 mg/L respectively. They found that the maximum sustained swimming speeds (based on first and second swimming failures at all temperatures) were reduced by 3.2 - 6.4%, 5.9 - 10.1%, 9.9 - 13.9%, 16.7 - 21.2%, and 26.6 - 33.8% at dissolved oxygen concentrations of 7, 6, 5, 4, and 3 mg/L respectively. The authors also conducted tests on juvenile Chinook salmon and found that the percent reductions from maximum swimming speed at temperatures ranging from 11 to 15°C were greater than those for juvenile coho. At the dissolved oxygen concentrations listed above swimming speeds were decreased by 10%, 14%, 20%, 27%, and 38% respectively.

WDOE (2002) reviewed various data and concluded that swimming fitness of salmonids is maximized when the daily minimum dissolved oxygen levels are above 8 - 9 mg/L. Jones et al. (1971, as cited by USEPA 1986) found the swimming speed of rainbow trout was decreased 30% from maximum at dissolved oxygen concentrations of 5.1 mg/L and 14°C. At oxygen levels of

3.8 mg/L and a temperature of 22°C, they found a 43% reduction in the maximum swimming speed.

Growth

In a review of constant oxygen exposure studies WDOE (2002) concluded salmonid growth rates decreased less than 10% at dissolved oxygen concentrations of 8 mg/L or more, less than 20% at 7 mg/L, and generally less than 22% at 5 - 6 mg/L. Herrmann (1958) found that the mean percentage of weight gain in juvenile coho held at constant dissolved oxygen concentrations was 7.2% around 2 mg/L, 33.6% at 3 mg/L, 55.8% near 4 mg/L, and 67.9% at or near 5 mg/L. In a laboratory study Fischer (1963) found that the growth rates of juvenile coho exposed to constant oxygen concentrations ranging from 2.5 to 35.5 mg/L (fed to satiation, temperature at approximately 18 °C) dramatically decreased with decreases in the oxygen concentration below 9.5 mg/L (air saturation level). WDOE (2002) concludes that a monthly or weekly average concentration of 9 mg/L, and a monthly average of the daily minimum concentrations should be at or above 8 - 8.5 mg/L to have a negligible effect (5% or less) on growth and support healthy growth rates.

Food conversion efficiency is related to dissolved oxygen levels and the process becomes less efficient when oxygen concentrations are below 4 - 4.5 mg/L (ODEQ 1995). Bjornn and Reiser (1991) state that growth, food conversion efficiency, and swimming performance are adversely affected when dissolved oxygen concentrations are <5 mg/L. The USEPA (1986) reviewed growth data from a study conducted by Warren et al. (1973) where tests were conducted at various temperatures to determine the growth of coho and Chinook. USEPA cites that, with the exception of tests conducted at 22 °C, the results supported the idea that the effects of low dissolved oxygen become more severe at higher temperatures.

Brett and Blackburn (1981) performed a laboratory study to determine the growth rate and food conversion efficiency of young coho and sockeye salmon fed full rations. Tests were performed at dissolved oxygen concentrations ranging from 2 to 15 mg/L at a constant temperature of 15°C, the approximate optimum temperature for growth of Pacific Salmon. Both species showed a strong dependence of growth on the environmental oxygen concentrations when levels were below 5 mg/L. For coho, zero growth was observed at dissolved oxygen concentrations of 2.3 mg/L. The mean value for maximum coho growth occurred at 4 mg/L, and at dissolved oxygen concentrations above this level growth did not appear to be dependant on the dissolved oxygen. Sockeye displayed zero growth at oxygen levels of 2.6 mg/L, and reached the zone of independence (growth not dependant on dissolved oxygen levels) at 4.2 mg/L. Brett and Blackburn (1981) conclude that the critical inflection from oxygen dependence to independence occurs at 4 - 4.2 mg/L for coho and sockeye.

Herrmann et al. (1962) studied the influence of various oxygen concentrations on the growth of age 0 coho salmon held at 20 °C. Coho were held in containers at a constant mean dissolved oxygen level ranging from 2.1 - 9.9 mg/L and were fed full rations. The authors concluded that oxygen concentrations below 5 mg/L resulted in a sharp decrease in growth and food consumption. A reduction in the mean oxygen levels from 8.3 mg/L to 6 and 5 mg/L resulted in slight decreases in food consumption and growth. Weight gain in grams per gram of food consumed was slightly depressed at dissolved oxygen concentrations near 4 mg/L, and were markedly reduced at lower concentrations. At oxygen levels of 2.1 and 2.3 mg/L, many fish died and the surviving fish lost weight and consumed very little food.

USEPA (1986) calculated the median percent reduction in growth rate of Chinook and coho salmon fed full rations at various dissolved oxygen concentrations. They calculated no reduction in growth at dissolved oxygen concentrations of 8 and 9 mg/L, and a 1% reduction in growth at 7 mg/L for both species. At 6 mg/L Chinook and coho growth were reduced by 7% and 4% respectively. Dissolved oxygen levels of 4 mg/L result in a 29% reduction in growth for Chinook salmon and 21% reduction in growth for coho. At 3 mg/L there was a 47% decrease in Chinook growth and a 37% reduction in coho growth. USEPA (1986) states that due to the variability inherent in growth studies the reductions in growth rates seen above 6 mg/L are not usually statistically significant, while reductions in growth at dissolved oxygen levels below 4 mg/L are considered severe.

Avoidance and preference

Salmonids have been reported to actively avoid areas with low dissolved oxygen concentrations, which is likely a useful protective mechanism that enhances survival (Davis 1975). Field and laboratory studies have found that avoidance reactions in juvenile salmonids consistently occur at concentrations of 5 mg/L and lower, and there is some indication that avoidance is triggered at concentrations as high as 6 mg/L. Therefore these dissolved oxygen levels should be considered a potential barrier to the movement and habitat selection of salmonids (WDOE 2002).

Spoor (1990) performed a laboratory study on the distribution of fingerling brook trout in dissolved oxygen concentration gradients. Sixteen gradients between 1 and 8.9 mg/L were used for the study to determine what level of dissolved oxygen is preferred by the brook trout. It was found that in the absence of a gradient with dissolved oxygen concentrations at 6 mg/L or more throughout the system, the fish moved freely without showing preference or avoidance. Movement from low to higher oxygen concentrations were noted throughout the study. Fish moved away from water with dissolved oxygen concentrations from 1 - 1.9 mg/L within one hour, moved away from water with dissolved oxygen concentrations of 2 - 2.9 mg/L within 1 - 2 hours, and moved away more slowly from concentrations of 3 - 3.9 mg/L. From his study, Spoor (1996) concluded that brook trout will avoid oxygen concentrations below 4 mg/L, and preferred oxygen levels of 5 mg/L or higher.

Whitmore et al. (1960) performed studies with juvenile coho and Chinook salmon to determine their avoidance reaction to dissolved oxygen concentration of 1.5, 3 , 4.5, and 6 mg/L at variable river water temperatures. Juvenile Chinook salmon showed marked avoidance of oxygen concentrations near 1.5, 3, and 4.5 mg/L in the summer at mean temperatures ranging from 20.7 - 22.8°C, but no avoidance to levels near 6 mg/L at a mean temperature of 18.4°C. Chinook did not show as strong an avoidance to these oxygen levels in the fall when water temperatures were lower, ranging from 11.8 - 13.2°C. Chinook showed little avoidance of dissolved oxygen concentrations near 4.5 mg/L during the fall, and no avoidance to concentrations near 6 mg/L. In all cases avoidance became progressively larger with reductions in the oxygen concentration below 6 mg/L. Seasonal differences of avoidance are most likely due to differences in water temperature. At temperatures ranging from 18.4 - 19°C juvenile coho salmon showed some avoidance to all of the above oxygen concentrations, including 6 mg/L. Their behavior was more erratic than that of Chinook, and their avoidance of concentrations near 4.5 mg/L and lower was not as pronounced at corresponding temperatures. The juvenile coho often started upon entering water with low dissolved oxygen and then darted around until they found their way out of the experimental channel.

USEPA (1986) performed a literature review and cites the effects of various dissolved oxygen concentrations on salmonid life stages other than embryonic and larval (Table 2). These effects range from no impairment at 8 mg/L to acute mortality at dissolved oxygen levels below 3 mg/L.

Table 2: Dissolved oxygen concentrations and their effects on salmonid life stages other than embryonic and larval (USEPA, 1986).

Level of Effect	Water Column DO (mg/L)
No Production Impairment	8
Slight Production Impairment	6
Moderate Production Impairment	5
Severe Production Impairment	4
Limit to Avoid Acute Mortality	3

Lethality

Salmonid mortality begins to occur when dissolved oxygen concentrations are below 3 mg/L for periods longer than 3.5 days (US EPA 1986). A summary of various field study results by WDOE (2002) reports that significant mortality occurs in natural waters when dissolved oxygen concentrations fluctuate the range of 2.5 - 3 mg/L. Long-term (20 - 30 days) constant exposure to mean dissolved oxygen concentrations below 3 - 3.3 mg/L is likely to result in 50% mortality of juvenile salmonids (WDOE, 2002). According to a short-term (1 - 4 hours) exposure study by Burdick et al. (1954, as cited by WDOE, 2002), in warm water (20 - 21°C) salmonids may require daily minimum oxygen levels to remain above 2.6 mg/L to avoid significant (50%) mortality. From these and other types of studies, WDOE (2002) concluded that juvenile salmonid mortality can be avoided if daily minimum dissolved oxygen concentration remain above 3.9 mg/L, and the monthly or weekly average of minimum concentrations remains above 4.6 mg/L.

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California Regional Water Quality Control Board
North Coast Region

Shasta River Water Quality Conditions

2002 & 2003

May 2004

Draft for Public Review

Table of Contents

Introduction

Staff of the North Coast Regional Water Quality Control Board's (Regional Water Board) Total Maximum Daily Load (TMDL) Development Unit are scheduled to complete the technical analyses for the Shasta River dissolved oxygen and temperature TMDLs by December 2004. In support of these TMDL analyses, Regional Water Board staff and U.S. Geological Survey (USGS) completed water quality monitoring studies in the Shasta River watershed in 2002 and 2003. The studies conducted by USGS were completed under contract to the Regional Water Board. The objectives of the monitoring studies conducted in 2003 are outlined in the "Shasta River Dissolved Oxygen Monitoring Plan" (NCRWQCB, 2003a). Monitoring conducted by Regional Water Board staff was in accordance with the "Klamath River Basin TMDLs Quality Assurance Project Plan" (NCRWQCB, 2003b). Monitoring conducted by USGS was in accordance with the USGS "National Field Manual for Water-Quality Sampling" (Wilde and others, 1998) and the USGS "Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Site Selection, Field Operation, Calibration, Record Computation, and Reporting" (Wagner and others, 2000). Results of the Shasta River 2002 and 2003 water quality monitoring studies conducted by Regional Water Board staff and USGS are presented in this document.

Monitoring Studies and Results

A number of water quality monitoring studies were conducted in 2002 and 2003 in the Shasta River watershed. The results of the monitoring studies are presented according to the following monitoring categories:
1) Grab sample analysis of physical parameters, nutrients, constituents that exert an oxygen demand, and chlorophyll a;
2) Continuous measurement of temperature, dissolved oxygen, pH, and specific conductance;
3) Instantaneous field measurement of temperature, dissolved oxygen, pH, specific conductance, and flow; and
4) Sediment oxygen demand.

Monitoring locations and site names are shown in **Table 1** and **Figure 1**. The monitoring categories conducted at each site are also identified in Table 1.

Grab Samples

Grab samples were collected for laboratory analysis of ammonia (NH_3 as N), nitrate-nitrite (NO_2/NO_3 as N), total Kjeldahl nitrogen (TKN), ortho-phosphate (Ortho-P), total phosphorus (Phosphorus), total dissolved solids (TDS), total suspended solids (TSS), biochemical oxygen demand (BOD), total organic carbon (TOC), chlorophyll a (Chl–a), and pheophytin a (Pheo-a). Grab samples were not analyzed for each water quality parameter at every sample event, in accordance with the monitoring objectives.

In 2002 USGS collected grab samples once per month in July, August, and September at the following Shasta River locations: Edgewood Road, Montague-Grenada Road, and near the mouth at the USGS gage (see Table 1 and Figure 1 for site location descriptions). 2002 analytical results are presented (along with 2003 results) in **Table 2**.

In 2003 water quality grab samples were collected to support various Shasta River studies, as outlined below.

Parcel Tracking

Parcel tracking studies were conducted in June, August, and October 2003 by Regional Water Board staff and USGS to provide a more direct investigation of changes in water quality with distance downstream. The June parcel tracking study was conducted over a two-day period, June 17-18. In August parcel tracking studies were conducted on two consecutive days, August 19 and 20. The October study was conducted on the 22nd. During each parcel tracking study grab samples were collected at the following Shasta River locations: Riverside Drive, 1.9 miles downstream of Big Springs Creek, Highway A12, Freeman Road, Montague-Grenada Road, Highway 3, Yreka-Ager Road, and near the mouth at the USGS Gage. Analytical results of the parcel tracking studies are presented in **Tables 2 and 3** and **Figures 2 to 8**.

Background Nutrients

The objective of the background nutrient sampling was to quantify nutrient levels in upper tributary locations and springs within various geologic regions of the Shasta River watershed. The following springs were sampled at least once during the summer 2003: Big Spring Spring and Big Spring Lake, Hidden Valley Spring, Bassey Spring, Soda Spring, Jim Spring, and Evan Spring. The following tributaries were sampled close to their source at least three times during the summer 2003: Beaughton Creek, Parks Creek, No Name Fork Shasta River, the Little Shasta River (at Ball Mountain Road and Martin's Dairy Campground), and upper Shasta River (at Old Stage Road). Analytical results of the background nutrient sampling are presented in **Table 4**.

Wastewater Treatment Plant Bracketing

The objective of the wastewater treatment plant bracketing sampling was to evaluate whether the City of Weed, City of Montague, and City of Yreka wastewater treatment disposal systems affect the water quality of Boles Creek, Oregon Slough, and Yreka Creek, respectively. Grab samples were collected from Boles Creek upstream and downstream of the Weed wastewater treatment disposal ponds once in June, July, and October. Grab samples were collected from Oregon Slough upstream and downstream of the Montague wastewater treatment disposal ponds once in June, July, and October. Grab samples were collected from Yreka Creek upstream, at, and downstream of the Yreka wastewater treatment disposal system once in June and July. Analytical results of the wastewater treatment plant bracketing are presented in **Table 5**.

Irrigation Return Flows

The objective of the irrigation return flow (tailwater) monitoring was to characterize the water quality of representative irrigation return flows. Irrigation return flows were sampled at a total of 16 locations during the summer of 2003. Due to property owner concerns, the locations of the irrigation return flow samples are not identified in this report. Analytical results of the irrigation return flow sampling are presented in **Table 6**.

Lake Shastina Profile

The objective of the Lake Shastina profile sampling was to evaluate differences in concentrations of nutrients and algae (chlorophyll a and pheophytin a) with depth. On September 10 and 11, 2003, samples were collected at two locations of Lake Shastina: Station “B” is located near the center of the reservoir; Station “C” is located near the dam. There is no Station “A”. At each location samples were collect at three depths: at the surface, at mid-depth, and just off the bottom. Analytical results of the Lake Shastina sampling are presented in **Table 7**.

Bacteriological Sampling

The sample methodology for the Sediment Oxygen Demand study (discussed below) required prolonged contact with Shasta River water by Regional Water Board and USGS staff. To evaluate potential health risks to staff, bacteriological sampling was conducted at Montague-Grenada Road and Highway 3 on July 24, 2003. Analytical results of the bacteriological sampling are presented in **Table 8**.

Continuous Water Quality Monitors

Continuous water quality monitors are instruments capable of measuring temperature, dissolved oxygen, pH, and specific conductance at hourly or sub-hourly intervals for extended periods of time. Sondes are capable of measuring all four water quality parameters. Optic StowAways measure only water temperature.

Sondes

The objective of the sonde deployments was to characterize the spatial and temporal variation of temperature, dissolved oxygen, pH, and specific conductance in the Shasta River. In 2002 USGS measured temperature, dissolved oxygen, pH, and specific conductance with YSI 6920 sondes from June 25 through October at one-hour intervals at three Shasta River locations: Edgewood Road, Montague-Grenada Road, and near the mouth at the USGS gage.

In 2003 USGS measured temperature, dissolved oxygen, pH, and specific conductance at one-hour intervals with YSI 6920 sondes from May through September at four Shasta River locations: Edgewood Road, Montague-Grenada Road, Highway 3, and near the mouth at the USGS gage. Graphs of the USGS 2002 and 2003 sonde data are presented in **Figures 9 to 24**.

Appendix 1 presents USGS' methodology for correcting continuous dissolved oxygen data from USGS datasonde sensors, and discusses uncertainty associated with datasonde dissolved oxygen records.

In 2003 Regional Water Board staff measured temperature, dissolved oxygen, pH, and specific conductance at 15-minute intervals with YSI 6600 sondes for two to three-day periods at the following sites and months:

Location	June	July	August	September	October
Shasta River at Riverside Drive	X	X	X		X
Shasta River downstream of Big Springs Creek	X		X		
Shasta River at Highway A12	X	X	X	X	X
Shasta River at Freeman Road	X	X	X		
Shasta River at Montague-Grenada Road		X			X
Shasta River at Highway 3		X			X
Shasta River at Yreka Ager Road	X	X	X		X
Lake Shastina				X	
Little Shasta River near Mouth	X				
Big Springs Spring			X	X	
Big Springs Lake				X	
Hidden Valley Spring				X	
Bassey Spring				X	

Graphs of the Regional Water Board 2003 sonde data are presented in **Figures 25 to 31**. Graphs of diel (24-hour) dissolved oxygen fluctuations, as well as field measurements of dissolved oxygen, are presented in **Figures 32 to 38**. The 2003 sonde data from Little Shasta River near the mouth, Big Springs Spring, Big Springs Lake, Hidden Valley Spring, and Bassey Spring are presented in **Table 9**.

On September 10, 2003 temperature, dissolved oxygen, and pH were measured at one- and two-foot increments at two locations ("B" and "C") in Lake Shastina. Station "B" is located near the center of the reservoir. Station "C" is located near the dam. There is no Station "A". The results of these profile measurements are presented in **Figure 39**.

On September 10-11, 2003 sondes were deployed at Stations "B" and "C" in Lake Shastina at three depths: surface, mid-depth, and just off the bottom. Graphs of the Lake Shastina sonde deployments are presented in **Figures 40 to 43**.

Optic StowAways

In 2003 Regional Water Board staff measured water temperature at ½-hour intervals from June to October at the following 9 locations: Shasta River at Riverside Drive, Shasta River at Highway A12, Shasta River at Freeman Road, Shasta River at Yreka-Ager Road, Shasta River at Old Shasta River Road, Little Shasta River near mouth, Little Shasta River at Ball Mountain Road, Parks Creek near Stewart Springs Resort, and Boles Creek near Old Edgewood Drive. Graphs of the Regional Water Board 2003 Optic StowAway data are presented in **Figures 44 to 53**.

Field Measurements

Temperature, Dissolved Oxygen, pH, and Specific Conductance

Field measurement of temperature, dissolved oxygen, pH, and specific conductance was performed by Regional Water Board staff at grab sample and continuous water quality monitoring locations using YSI 600XL sondes. The field measurement of temperature, dissolved oxygen, pH, and specific conductance at the continuous water quality monitoring locations serve as a check to the continuous water quality monitor results. Field measurement results of temperature, dissolved oxygen, pH, and specific conductance are presented in **Tables 2 to 6** and field measurement results of dissolved oxygen are shown on **Figures 32 to 38**.

Winkler Dissolved Oxygen Titration

Field analysis of dissolved oxygen was conducted at the Regional Water Board continuous water quality monitoring locations using the Winkler Dissolved Oxygen test. The Winkler Dissolved Oxygen test is a modified Winkler dissolved oxygen titration, performed with a Hach digital titration kit. This field analysis was generally performed at least once at each Regional Water Board sonde deployment. The Winkler dissolved oxygen titration results serve as a check to the continuous water quality monitor results. The Winkler dissolved oxygen titration results are presented in **Figures 32 to 38**.

Flow

Flow was measured at the water quality monitoring locations during most sample events. Flow was measured using Marsh McBirney flow meters. Flow measurement results are presented in **Table 10**.

Sediment Oxygen Demand

USGS and Regional Water Board staff conducted a Sediment Oxygen Demand (SOD) study in the Shasta River from August 12-14, 2003. SOD is the rate of dissolved oxygen loss from a waterbody through its uptake and consumption by biotic and abiotic reactions in surficial sediments. SOD rates were measured and sediment characteristics classified in the Shasta River upstream and downstream of Montague-Grenada Road and at four locations near the Highway 3 bridge. Results of the SOD study are presented in **Table 11**. **Appendix 2** presents the methodolgy employed for measuring SOD rates in the Shasta River.

Acknowledgements

Staff of the Regional Water Board owe special thanks to the property owners who allowed access to private property necessary for conducting these water quality monitoring studies. We also thank the members of the Shasta River TMDL Technical Advisory Group for assistance in developing the 2003 monitoring plan. Finally, we wish to thank the California Department of Fish and Game for loaning six Optic StowAways used in these studies.

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List of Tables

Table 1. Shasta River Water Quality Monitoring Locations and Activities						
Site ID	**Site Location**	**River Mile**[1]	**Grab Sampling**	**Sonde Location**[2]	**Temperature Location**[3]	**SOD Location**[4]
Shanrmth	Shasta River near Mouth at USGS Gage	0.6	X	X		
Shaosrr	Shasta River at Old Shasta River Road	4.0			X	
Shaatyard	Shasta River at Yreka-Ager Road	10.4	X	X	X	
Shaathwy3	Shasta River at Highway 3	12.3	X	X		X
Shaatmgr	Shasta River at Montague-Grenada Road	14.7	X	X		X
Shaatfrln	Shasta River at Freeman Road	17.9	X	X	X	
Shaata12	Shasta River at Highway A12	21.9	X	X	X	
Shaatptrs	Shasta River 1.9 Miles Downstream of Big Springs Creek	27.9	X	X		
Shaathvr	Shasta River at Big Springs Road	33.7	X			
Shaatrvsd	Shasta River at Riverside Drive	35.7	X	X	X	
Lake Shastina (Dwinnell Reservoir) is located at river mile 36.4.						
All locations upstream of Shastina are determined using an assumed stream length along the floor of Shastina.						
LkshastB	Lake Shastina -- Station B		X	X		
LkshastC	Lake Shastina -- Station C		X	X		
Shaatedgrd	Shasta River at Edgewood Road	42.9	X	X		
Shaatosr	Shasta River at Old Stage Road	47.7	X			
Shannf	North N Fork Shasta River	47.5+0.1	X			
Lshanrmth	Little Shasta River Near Mouth	15.5+0.3	X	X	X	
Lshaatbmr	Little Shasta River at Ball Mountain Road	15.5+10.0	X			
Lshatmd	Little Shasta River at Martin's Dairy Campground	15.5+23.8	X			
Yreatagr	Yreka Creek at Anderson Grade Road	7.6+0.6	X			
Yreatact	Yreka Creek at Cutoff Trench	7.6+2.9	X			
Yreathwy3	Yreka Creek at Highway 3	7.6+3.4	X			
Yreatobrd	Yreka Creek at Oberlin Road	7.6+5.3	X			
Orslus	Oregon Slough Upstream of Montague Wastewater Treatment Ponds	11.2+1.6	X			
Orslds	Oregon Slough Downstream of Montague Wastewater Treatment Ponds	11.2+1.1	X			
Parus	Parks Creek Upper	30.4+17.0	X		X	
Beaatspr	Beaughton Creek Upper	43.7+5.8	X			
Bolds	Boles Creek Downstream of City of Weed Wastewater Treatment Ponds	44.8+1.8	X		X	
Bolus	Boles Creek Upstream of City of Weed Wastewater Treatment Ponds	44.8+2.3	X			
Bassp	Bassey Spring		X	X		
Sodsp	Soda Spring		X			
Evasp	Evans Spring		X			
Jimsp	Jim Spring		X			
Hvrsp	Hidden Valley Spring		X	X		
Bigsplk	Big Springs Lake		X	X		
Bigsp	Big Springs Spring		X	X		

[1] River Miles for tributary locations are identified as the Shasta River miles at the confluence + the miles upstream of the confluence

[2] Sonde Location = Continuous measurement of temperature, dissolved oxygen, pH, and specific conductance with sonde.

[3] Temperature Location = Continuous measurement of temperature with Optic StowAway.

[4] SOD Location = Sediment oxygen demand measurement location.

Table 2. Shasta River Water Quality Results from Field Measurement and Grab Sample Analysis, 2002 and 2003 -- By Location

			Field Parameter					Lab Analysis (mg/L)												
Location	Date	Time	Tw	pH	DO mg/l	DO sat (%)	Sp Cond	NH3 as N	NO3 as N	NO2 as N	NO2+NO3 as N	Ortho P	Phosphorus	TDS	TSS	TKN	BOD	Chl - a	Pheo-a	TOC
Shasta River @ Riverside Dr																				
	18-Jun-03	9:10	14.5	7.58	9.22	90.6	237	0.069		ND	ND	ND	ND	110	ND	0.53	ND	ND		2.9
	19-Aug-03	8:30	19.5	7.91	7.47	81.5	245	ND	ND	ND	ND	ND	0.078	170	30	ND	3.4	0.0210		3.8
	20-Aug-03	9:20	19.8	7.94	7.47	82.0	245	ND	ND	ND	ND	ND	0.086	190	ND	0.60	15.0	0.0210		3.8
	22-Oct-03	16:45	17.3	8.09	8.06	84.0	275	0.090			0.120	0.094	ND	170	ND	0.92	ND			2.7
Shasta River @ Big Springs Road																				
	18-Jun-03	17:30						ND			ND	0.110	0.170	200	ND	ND				4.0
Shasta River below Big Springs Creek (1.9 miles downstream)																				
	17-Jun-03	9:40	16.0	7.75	8.95	90.8	391	ND		ND	0.064	0.140	0.100	250	ND	ND	ND	ND		2.7
	19-Aug-03	10:30	16.1	7.73	8.81	89.5	395	0.081	0.190	ND	0.190	0.180	0.190	250	ND	ND	ND	0.0022		2.0
	20-Aug-03	10:00	15.3	7.65	8.09	80.5	418	ND	0.180	ND	0.180	0.130	0.160	310	ND	ND	ND	ND		1.8
Shasta River @ County Road A-12																				
	17-Jun-03	8:40	19.6	8.00	6.80	83.0	426	ND			ND	0.140	0.150			0.23		0.0017	4.6	3.7
	19-Aug-03	8:30	18.2	7.90	6.60	77.0	426	ND			ND	0.150	0.170			0.20		0.0010	3.7	4.1
	20-Aug-03	10:45	18.8	8.07	8.93	96.0	420	0.053	ND	ND	ND	0.140	0.170	270	ND	ND	ND	0.0018		2.2
	22-Oct-03	17:05	13.9	8.23	11.34	109.8	402	ND			0.230	0.170	0.170	260	ND	ND	ND			0.9
Shasta River @ Freeman Road																				
	17-Jun-03	12:45	21.0	7.99	9.35	105.2	464	ND		ND	ND	0.160	0.170	240	ND	0.61	ND	ND		3.8
	19-Aug-03	14:45	21.4	8.13	10.55	119.8	461	0.140	ND	ND	ND	0.140	0.170	280	ND	ND	ND	0.0011		2.9
	20-Aug-03	12:00	19.7	8.07	8.79	96.2	498	ND	ND	ND	ND	0.160	0.170	330	ND	ND	ND	0.0011		2.6
Shasta River @ Montague-Grenada Rd																				
	11-Jul-02	11:30	23.0	8.40	8.20	106.0	516	0.009			ND	0.160	0.190			0.33		0.0010	1.7	3.4
	15-Aug-02	9:25	19.0	7.90	7.20	86.0	503	ND			ND	0.150	0.160			0.22		0.0004	1.2	2.9
	18-Sep-02	16:15	19.0	8.30	11.00	130.0	522	ND			ND	0.160	0.160			0.18		0.0004	1.1	5.0
	9-Apr-03	18:20	15.0	8.30	9.60	105.0	454	ND			0.079	0.120	0.140			0.23	ND	0.0019	3.5	5.3
	17-Jun-03	11:50	21.0	8.30	8.70	109.0	479	ND			ND	0.140	0.170			0.33		0.0009	2.9	5.6
	19-Aug-03	11:20	21.0	8.20	8.90	110.0	490	ND			ND	0.170	0.190			0.30		0.0007	1.5	5.0
	20-Aug-03	13:30	21.9	8.22	9.94	113.6	551	ND	ND	ND	ND	0.260	0.310	340	ND	ND	ND	0.0016		5.0
	22-Oct-03	8:15	12.0	8.01	8.80	81.9	427	0.110			0.180	ND	0.160	260	ND	ND	ND			1.1
Shasta River @ Highway 3																				
	10-Apr-03	10:50	12.0	8.30	9.10	93.0	472	ND			0.072	0.120	0.140			0.21	ND	0.0034	4.0	4.8
	17-Jun-03	14:35	23.0	8.40	9.90	129.0	484	ND			ND	0.150	0.170			0.35		0.0007	2.1	4.5
	19-Aug-03	12:50	22.0	8.40	10.00	127.0	498	ND			ND	0.140	0.170			0.38		0.0009	1.6	5.7
	20-Aug-03	12:30	21.4	8.26	9.51	107.6	514	ND	ND	ND	ND	0.220	0.240	370	ND	0.86	ND	0.0016		5.0
	22-Oct-03	8:45	12.2	8.09	8.94	83.4	428	0.071			0.170	0.210	0.180	270	ND	ND	ND			1.1
Shasta River @ Yreka-Ager Rd																				
	17-Jun-03	17:00	24.6	8.16	9.28	111.3	503	0.097		ND	ND	0.150	0.130	280	ND	0.64		ND		1.3
	19-Aug-03	16:30	24.0	8.40	10.75	127.8	510	0.450	ND	ND	ND	0.140	0.170	310	ND	ND	3.5	0.0016		4.3
	20-Aug-03	13:30	22.9	8.35	10.33	120.4	517	ND	ND	ND	ND	0.170	0.190	370	ND	0.63	ND	0.0018		4.5
	22-Oct-03	7:45	12.6	8.05	8.77	82.6	436	0.095			0.150	0.190	0.660	270	ND	ND	ND			1.2
	22-Oct-03	14:00	13.5	8.44	11.98	115.1	433	0.140			0.140	0.200	0.130			ND				
	22-Oct-03	19:00	13.7	8.43	10.35	99.9	432	ND			0.140	0.170	0.140			ND				
Shasta River near Mouth @ USGS Gage																				
	10-Jul-02	16:45	30.0	8.60	7.10	98.0	590	0.030			0.016	0.290	0.350			0.52		0.0021	3.8	7.3
	14-Aug-02	13:40	25.0	8.40	9.40	124.0	642	0.010			ND	0.320	0.340			0.59		0.0016	2.5	7.9
	17-Sep-02	15:15	19.0	8.50	9.40	110.0	627	0.009			0.015	0.260	0.270			0.47		0.0017	3.4	10.6
	10-Apr-03	15:40	15.5	8.80	10.30	112.0	480	ND			0.051	0.100	0.120			0.22	ND	0.0028	3.5	4.5
	17-Jun-03	18:15	26.0	8.80	8.80	121.0	494	ND			ND	0.150	0.170			0.36		0.0004	1.1	5.1
	19-Aug-03	18:20	25.5	8.80	7.30	97.0	530	ND			ND	0.160	0.190			0.41		0.0009	2.7	6.7
	20-Aug-03	15:30						0.054	ND	ND	ND	0.160	0.180	350	ND	0.51	ND	0.0020		5.0
	22-Oct-03	18:15	14.4	8.62	9.84	96.3	438	ND			0.120	0.170	0.130	280	ND	ND	ND			1.3
				Reporting Limits (mg/L)				0.050	0.050	0.050	0.050	0.050	0.050	10	10	0.50		0.0005	0.0005	0.80

Notes: ND = Non-Detect (parameter is not present or present at concentrations below the laboratory reporting limit).
An empty cell = No sample for this parameter.

Table 3. Shasta River Water Quality Results from Field Measurement and Grab Sample Analysis, 2003 -- Parcel Tracking Study

			Field Parameter						Lab Analysis (mg/L)											
Date	Location	Time	Tw	pH	DO mg/l	DO Sat (%)	Sp Cond	NH3 as N	NO3 as N	NO2 as N	NO2+NO3 as N	Ortho P	Phosphorus	TDS	TSS	TKN	BOD	Chl - a	Pheo-a	TOC
17-Jun-03 / 18-Jun-03																				
	Riverside Drive	9:10	14.5	7.58	9.22	90.6	237	0.069		ND	ND	ND	ND	110	ND	0.53	ND	ND		2.9
	below Big Springs Crk	9:40	16.0	7.75	8.95	90.8	391	ND		ND	0.064	0.140	0.100	250	ND	ND	ND	ND		2.7
	County Road A-12	8:40	19.6	8.00	6.80	83.0	426	ND			ND	0.140	0.150			0.23		0.0017	4.6	3.7
	Freeman Road	12:45	21.0	7.99	9.35	105.2	464	ND		ND	ND	0.160	0.170	240	ND	0.61	ND	ND		3.8
	Montague-Grenada Rd	11:50	21.0	8.30	8.70	109.0	479	ND			ND	0.140	0.170			0.33		0.0009	2.9	5.6
	Highway 3	14:35	23.0	8.40	9.90	129.0	484	ND			ND	0.150	0.170			0.35		0.0007	2.1	4.5
	Yreka-Ager Road	17:00	24.6	8.16	9.28	111.3	503	0.097		ND	ND	0.150	0.130	280	ND	0.64		ND		1.3
	USGS Gage	18:15	26.0	8.80	8.80	121.0	494	ND			ND	0.150	0.170			0.36		0.0004	1.1	5.1
19-Aug-2003																				
	Riverside Drive	8:30	19.5	7.91	7.47	81.5	245	ND	ND	ND	ND	ND	0.078	170	30	ND	3.4	0.0210		3.8
	below Big Springs Crk	10:30	16.1	7.73	8.81	89.5	395	0.081	0.190	ND	0.190	0.180	0.190	250	ND	ND	ND	0.0022		2.0
	County Road A-12	8:30	18.2	7.90	6.60	77.0	426	ND			ND	0.150	0.170			0.20		0.0010	3.7	4.1
	Freeman Road	14:45	21.4	8.13	10.55	119.8	461	0.140	ND	ND	ND	0.140	0.170	280	ND	ND	ND	0.0011		2.9
	Montague-Grenada Rd	11:20	21.0	8.20	8.90	110.0	490	ND			ND	0.170	0.190			0.30		0.0007	1.5	5.0
	Highway 3	12:50	22.0	8.40	10.00	127.0	498	ND			ND	0.140	0.170			0.38		0.0009	1.6	5.7
	Yreka-Ager Road	16:30	24.0	8.40	10.75	127.8	510	0.450	ND	ND	ND	0.140	0.170	310	ND	ND	3.5	0.0016		4.3
	USGS Gage	18:20	25.5	8.80	7.30	97.0	530	ND			ND	0.160	0.190			0.41		0.0009	2.7	6.7
20-Aug-2003																				
	Riverside Drive	9:20	19.8	7.94	7.47	82.0	245	ND	ND	ND	ND	ND	0.086	190	ND	0.60	15.0	0.0210		3.8
	below Big Springs Crk	10:00	15.3	7.65	8.09	80.5	418	ND	0.180	ND	0.180	0.130	0.160	310	ND	ND	ND	ND		1.8
	County Road A-12	10:45	18.8	8.07	8.93	96.0	420	0.053	ND	ND	ND	0.140	0.170	270	ND	ND	ND	0.0018		2.2
	Freeman Road	12:00	19.7	8.07	8.79	96.2	498	ND	ND	ND	ND	0.160	0.170	330	ND	ND	ND	0.0011		2.6
	Montague-Grenada Rd	13:30	21.9	8.22	9.94	113.6	551	ND	ND	ND	ND	0.260	0.310	340	ND	ND	ND	0.0016		5.0
	Highway 3	12:30	21.4	8.26	9.51	107.6	514	ND	ND	ND	ND	0.220	0.240	370	ND	0.86	ND	0.0016		5.0
	Yreka-Ager Road	13:30	22.9	8.35	10.33	120.4	517	ND	ND	ND	ND	0.170	0.190	370	ND	0.63	ND	0.0018		4.5
	USGS Gage	15:30						0.054	ND	ND	ND	0.160	0.180	350	ND	0.51	ND	0.0020		5.0
22-Oct-2003																				
	Riverside Drive	16:45	17.3	8.09	8.06	84.0	275	0.090			0.120	0.094	ND	170	ND	0.92	ND			2.7
	County Road A-12	17:05	13.9	8.23	11.34	109.8	402	ND			0.230	0.170	0.170	260	ND	ND	ND			0.9
	Montague-Grenada Rd	8:15	12.0	8.01	8.80	81.9	427	0.110			0.180	ND	0.160	260	ND	ND	ND			1.1
	Highway 3	8:45	12.2	8.09	8.94	83.4	428	0.071			0.170	0.210	0.180	270	ND	ND	ND			1.1
	Yreka-Ager Road	19:00	13.7	8.43	10.35	99.9	432	ND			0.140	0.170	0.140			ND				
	USGS Gage	18:15	14.4	8.62	9.84	96.3	438	ND			0.120	0.170	0.130	280	ND	ND	ND			1.3
				Reporting Limits (mg/L)				0.050	0.050	0.050	0.050	0.050	0.050	10	10	0.50		0.0005	0.0005	0.80

Notes: ND = Non-Detect (parameter is not present or present at concentrations below the laboratory reporting limit).
An empty cell = No sample for this parameter.

Table 4. Shasta River Tributaries and Springs -- Water Quality Results from Field Measurement and Grab Sample Analysis, 2003.

				Field Parameters					Lab Analysis (mg/L)												
Watershed	Location	Date	Time	Tw	pH	DO mg/l	DO Sat (%)	Sp Cond	NH3 as N	NO3 as N	NO2 as N	NO2+NO3 as N	Ortho P	Phosphorus	TDS	TSS	TKN	BOD	Chl - a	Pheo-a	TOC
Little Shasta River Watershed (Springs)																					
	Bassey Spring	21-Aug-03	9:30	9.81	6.84	9.75	86.0	327	0.088	0.290	ND	0.290		ND			ND				
	Bassey Spring	17-Sep-03	10:00	9.19	7.13	10.08	87.7	303	0.071			0.240	0.066	0.460			ND				
	Soda Spring	17-Sep-03	10:15						0.340			ND	ND	0.350			6.50				
	Jim Spring	21-Aug-03	10:35	7.60	7.31	11.10	92.8	91	ND	0.260	ND	0.260		0.110			ND				
	Evan Spring	21-Aug-03	10:05	8.50	7.09	9.60	82.1	101	ND	0.210	ND	0.210		ND			ND				
Shasta River Watershed (Springs)																					
	Hidden Valley Spring	18-Jun-03	18:00						ND			0.220	0.120	0.088			ND				
	Hidden Valley Spring	23-Jul-03	10:50	13.01	7.26	4.42	41.8	290	ND			0.180	0.098	0.200			0.69				
	Hidden Valley Spring	16-Sep-03	16:30	12.5	7.5	2.8	26.4	268.0	ND			0.140	ND	0.070			ND				
	Big Springs Spring	16-Sep-03	17:30	11.3	7.0	9.6	87.7	381.0	ND			0.140	0.160	0.220			ND				
				Springs		Maximum value			0.340	0.290	ND	0.290	0.160	0.460			6.500				
						Minimum value			ND	0.210	ND	ND	ND	ND			ND				
Shasta River Watershed (Lake)																					
	Big Springs Lake	19-Aug-03	13:00	13.38	6.58	11.80	-	358	ND	0.170	ND	0.170	0.200	0.210	260	ND	ND	ND	ND		ND
	Big Springs Lake	16-Sep-03	17:45	12.8	6.9	12.2	115.0	353.0	ND			ND	0.150	0.330			ND				
Little Shasta River Watershed																					
	Little Shasta River at MDC	22-Jul-03	16:40	9.70	7.60	10.71	94.3	100	ND			0.063	ND	0.120			ND				
	Little Shasta River at BMR	19-Jun-03	16:00	16.30	8.16	9.15	93.3	94	ND			ND		ND			ND				
	Little Shasta River at BMR	21-Jul-03	11:05	17.40	8.16	9.01	94.1	108	ND			ND	ND	ND			ND				
	Little Shasta River at BMR	21-Aug-03	10:40	15.26	8.10	9.14	91.2	110	ND	ND	ND	ND		ND			ND				
	Little Shasta River at Mouth	17-Jun-03	14:30	27.07	8.27	10.96	138.4	845	ND		ND	ND	0.092	0.098	480	ND	0.95	ND			2.10
Upper Shasta River Watershed (Above Dwinnell Reservoir - SE)																					
	Beaughton Creek Upper	19-Jun-03	14:45	-	-	-	-	-	ND			0.089	0.160	0.150			ND				
	Beaughton Creek Upper	22-Jul-03	10:00	5.72	7.24	12.48	104.3	106	ND			0.083	0.190	0.400			ND				
	Beaughton Creek Upper	21-Oct-03	11:25	7.34	7.36	10.76	89.3	106	0.050			0.110	0.210	0.070			ND				
Upper Shasta River Watershed (Above Dwinnell Reservoir - SW)																					
	Shasta River at ER	11-Jul-02	13:30	28	8.9	7.5	108	238	0.009			0.012	0.070	0.100			0.32		0.0026	0.0042	4.40
	Shasta River at ER	15-Aug-02	11:30	22	8	9.9	127	219	<.015			<.013	0.050	0.070			0.23		0.0065	0.0047	3.90
	Shasta River at ER	19-Sep-02	8:15	11.5	7.7	10.4	106	201	<.015			<.013	0.060	0.080			0.16		0.0060	0.0086	4.10
	Shasta River at ER	09-Apr-03	13:25	13	8.7	11	116	199	<.015			0.018	0.030	0.040			0.08		0.0036	0.0022	3.10
	Shasta River at ER	22-Oct-03	15:45	16.28	8.99	11.12	113.3	179	ND			0.081	ND	0.084	130	ND	ND	ND			1.90
	Shasta River at OSR	19-Jun-03	15:50	-	-	-	-	-	ND			ND	ND	ND			ND				
	Shasta River at OSR	22-Jul-03	10:50	16.77	8.30	9.54	98.3	163	0.056			ND	ND	ND			ND				
	Shasta River at OSR	21-Aug-03	13:45	16.83	8.33	9.01	93.0	200	ND	ND	ND	ND		ND			ND				
	NNF Shasta River	19-Jun-03	16:00	-	-	-	-	-	ND			ND	ND	ND			ND				
	NNF Shasta River	22-Jul-03	11:10	19.95	8.10	8.40	92.4	202	ND			0.051	ND	ND			1.00				
	NNF Shasta River	21-Aug-03	13:30	17.15	8.09	8.75	90.9	186	ND	ND	ND	ND		ND			ND				
Parks Creek																					
	Parks Creek Upper	19-Jun-03	18:00	13.02	8.29	9.81	92.7	106	ND			ND		ND			ND				
	Parks Creek Upper	22-Jul-03	11:20	17.63	8.45	8.81	92.5	203	ND			0.061	ND	0.230			0.66				
	Parks Creek Upper	21-Aug-03	13:00	27.00	8.37	9.13	91.3	238	ND	0.098	ND	0.098		ND			ND				
	Parks Creek Upper	21-Oct-03	14:15	10.30	8.36	10.13	90.5	253	ND			0.110	ND	ND			ND				
					Reporting Limits (mg/L)				0.050	0.050	0.050	0.050	0.050	0.050	10	10	0.50		0.0005	0.0005	0.80

Location Notes:
- Little Shasta River at MDC = Little Shasta River at Martin's Dairy Campground
- Little Shasta River at BMR = Little Shasta River at Ball Mountain Road
- Shasta River at ER = Shasta River at Edgewood Road
- Shasta River at OSR = Shasta River at Old Stage Road
- NNF Shasta River = North N Fork Shasta River

Notes: ND = Non-Detect (parameter is not present or present at concentrations below the laboratory reporting limit).
An empty cell = No sample for this parameter.

Table 5. Wastewater Treatment Plant Bracketing -- Water Quality Results from Field Measurement and Grab Sample Analysis, 2003

Location	Time	Field Parameters					Lab Analysis (mg/L)												
		Tw	pH	DO mg/l	DO Sat (%)	Sp Cond	NH3 as N	NO3 as N	NO2 as N	NO2+NO3 as N	Ortho P	Phosphorus	TDS	TSS	TKN	BOD	Chl - a	Pheo-a	TOC
Weed Waste Water Treatment Facility - 6/18/2003																			
Above	16:20	13.56	8.32	9.70	93.3	167	ND			0.460	0.082	0.160	150	ND	ND				ND
Below	15:15	14.68	8.27	10.33	101.3	172	ND			0.360	0.100	0.076	150	ND	ND				ND
Weed Waste Water Treatment Facility - 7/22/2003																			
Above	13:35	15.45	8.04	9.79	98.1	174	ND			0.530	0.094	0.120	150	ND	ND	9.2			ND
Below	13:00	16.96	8.02	9.67	100.1	177	ND			0.530	0.110	0.100	180	ND	ND	ND			ND
Weed Waste Water Treatment Facility - 10/21/2003																			
Above	13:40	11.54	7.96	10.04	92.3	168	ND			0.560	0.120	0.098	140	12	ND	ND			ND
Below	12:50	11.87	7.98	10.20	94.5	173	ND			0.520	0.100	0.074	140	10	ND	ND			ND
Montague Waste Water Treament Facility - 6/18/2003																			
Above (1)	13:00	21.47	8.22	12.39	141.4	541	0.220			0.140	0.220	0.270	340	18	0.78				1.8
Below (1)	13:35	23.14	8.31	10.56	123.4	574	0.052			0.090	0.250	14.000	380	19	1.30				2.2
Below (2)	11:49	22.23	7.85	11.65	134.3	692	0.260			0.210	0.250	0.260	430	ND	0.90				0.9
Montague Waste Water Treament Facility - 7/21/2003																			
Above (2)	12:25	24.39	8.37	11.26	134.9	624	0.071			0.270	0.240	0.400	420	16	0.82	2.7			7.9
Below (1)	12:10	23.27	8.34	13.68	161.2	590	0.071			0.130	0.220	0.220	400	14	0.97	ND			8.0
Montague Waste Water Treament Facility - 10/22/2003																			
Above (2)	9:30	11.53	8.05	8.63	79.4	806	0.094			0.390	0.092	0.580	500	ND	ND	ND			3.0
Below (1)	9:50	11.53	8.19	12.20	93.8	805	0.097			0.340	0.260	0.051	500	ND	ND	ND			2.9
Yreka Waste Water Treatment Facility - 6/19/2003																			
Above (2)	11:20	16.07	8.01	10.91	110.9	502	ND			0.170		ND			ND				
Above (1)	8:20	14.06	7.83	8.33	81.3	497	ND			0.620	ND	ND	270	ND	ND				0.2
At	10:00	14.23	7.88	9.69	94.8	506	0.094			0.720	0.070	0.070	280	ND	ND				0.2
Below	10:30	14.68	8.26	10.98	108.4	509	ND			0.870	0.150	0.150	280	ND	0.56				0.3
Yreka Waste Water Treatment Facility - 7/21/2003																			
Above (2)	14:30	19.61	7.59	10.03	109.8	557			ND	0.098	ND	ND			ND				
Above (1)	13:10	18.50	7.71	10.22	109.1	520	ND			0.860	ND	0.057	330	ND	ND	ND			ND
At	15:10	19.25	7.80	9.43	102.7	535	0.200			1.000	0.150	0.130	340	ND	ND	ND			ND
Below	15:40	22.70	8.26	8.67	100.9	542	0.180			1.600	0.170	0.210	360	10	ND	ND			1.2
Reporting Limits (mg/L)							0.050	0.050	0.050	0.050	0.050	0.050	10	10	0.50		0.0005	0.0005	0.80

Location Notes:

Weed Wastewater Treatment Facility "Above" = Boles Creek approx. 200 meters downstream of bridge to the Weed Golf Club.
Weed Wastewater Treatment Facility "Below" = Boles Creek approx. 200 meters downstream "Above" location.
Montague Wastewater Treatment Facility "Above 1" = Oregon Slough at Ager Road.
Montague Wastewater Treatment Facility "Above 2" = Oregon Slough approximately 0.7 miles downstream of Ager Road.
Montague Wastewater Treatment Facility "Below 1" = Oregon Slough at Southern Pacific Railroad tressel.
Montague Wastewater Treatment Facility "Below 2" = Oregon Slough approximately 0.5 miles downstream of Southern Pacific Railroad tressel.
Yreka Wastewater Treatment Facility "Above 2" = Yreka Creek at Oberlin Road.
Yreka Wastewater Treatment Facility "Above 1" = Yreka Creek at Highway 3.
Yreka Wastewater Treatment Facility "At" = Yreka Creek at Cutoff Trench.
Yreka Wastewater Treatment Facility "Below" = Yreka Creek at Anderson Grade Road.

Notes: ND = Non-Detect (parameter is not present or present at concentrations below the laboratory reporting limit).
An empty cell = No sample for this parameter.

Table 6. Irrigation Return Flow (Tailwater) Water Quality Results from Field Measurement and Grab Sample Analysis, 2003

			Field Parameters					Lab Analysis (mg/L)												
Date	Sta ID	Time	Tw	pH	DO mg/l	DO Sat (%)	Sp Cond	NH3 as N	NO3 as N	NO2 as N	NO2+NO3 as N	Ortho P	Phosphorus	TDS	TSS	TKN	BOD	Chl - a	Pheo-a	TOC
19-Jun-2003																				
	Tail-Water 01	9:30						0.065			0.170	0.150	ND	470	11	0.80				5.2
	Tail-Water 02	11:00										ND		450	140					2.0
	Tail-Water 03	11:15						ND			0.083	ND	ND	400	ND	0.63				1.9
	Tail-Water 04	11:45						0.064			0.180	0.260	0.360	450	ND	1.30				2.4
	Tail-Water 05	12:00						ND			0.098	ND	ND	420	ND	ND				0.5
23-Jul-2003																				
	Tail-Water 06	9:00	21.7	8.05	6.68	76.0	740	0.074			0.061	ND	0.230	440	34	0.92	ND			2.6
	Tail-Water 07	9:40	19.6	8.13	9.57	104.7	761	0.051			0.520	0.068	0.074	470	ND	1.10	ND			2.6
17-Sept-2003 / 18-Sept-2003																				
	Tail-Water 08	8:45	8.6	7.84	9.42	81.0	450	0.061			ND	0.390	0.360	250	ND	0.57	ND			6.7
	Tail-Water 09	11:50						0.063			0.100	0.230	0.340	380	ND	2.30	4.3			20.0
	Tail-Water 10	13:15						0.110			0.077	0.290	0.094	350	ND	1.30	4.4			11.0
	Tail-Water 11	11:15	12.3	7.40	5.07	48.1	580	0.650			ND	0.790	0.880	450	24	3.90	7.0			20.0
	Tail-Water 12	12:00						ND			ND	0.230	0.280	340	ND	ND	ND			4.1
	Tail-Water 13	14:15						ND			ND	0.200	0.250	260	ND	0.81	2.0			5.5
26-Sept-2003 / 29-Sept-2003																				
	Tail-Water 14	16:15						0.094			ND	0.320	0.380	370	ND	2.10	2.4			18.0
	Tail-Water 15	11:15						0.058			ND	0.080	0.210	290	ND	ND	2.5			5.0
	Tail-Water 16	11:30						0.099			0.092	ND	0.420	730	ND	1.70	ND			21.0
					Maximum value			0.650			0.520	0.790	0.880	730	140	3.90	7.0			21.0
					Minimum value			ND			ND	ND	ND	250	ND	ND	ND			0.5
				Reporting Limits (mg/L)				0.050	0.050	0.050	0.050	0.050	0.050	10	10	0.50		0.0005	0.0005	0.80

Note:
Tailwater sample locations are not identified in this report, due to property owner concerns.

Notes: ND = Non-Detect (parameter is not present or present at concentrations below the laboratory reporting limit).
An empty cell = No sample for this parameter.

Table 7. Lake Shastina Water Quality Results from Field Measurement and Grab Sample Analysis, 2003

	Field Parameters								Lab Analysis												
	Depth (meters)	Date	Time	Tw	pH	DO mg/l	DO Sat (%)	Sp Cond	NH3 as N	NO3 as N	NO2 as N	NO2+NO3 as N	Ortho P	Phosphorus	TDS	TSS	TKN	BOD	Chl - a	Pheo-a	TOC
Lake Shastina Station "B"																					
	Surface	10-Sep-03	15:15	21.15	9.28	17.25	194.1	244	**0.093**			ND	ND	ND			**0.88**		**0.062**	**0.0095**	
	Surface	11-Sep-03	9:40	19.72	8.52	6.41	70.1	253	ND			ND	ND	ND			**0.67**				
	4 meters	10-Sep-03	16:00	19.79	8.56	5.89	64.6	254	ND			ND	ND	**0.072**			**0.84**		**0.038**	**0.0064**	
	4 meters	11-Sep-03	9:30	19.56	8.72	6.41	69.9	254	ND			ND	ND	ND			ND				
	8 meters	10-Sep-03	16:15	18.82	7.36	0.75	8.1	298	ND			ND	**0.08**	**0.16**			**0.54**				
	8 meters	11-Sep-03	9:15	18.95	7.49	0.31	3.3	281	ND			ND	ND	ND			ND				
Lake Shastina Station "C"																					
	Surface	10-Sep-03	17:05	26.22	9.43	21.35	250.0	244	ND			ND	ND	**0.59**			**1.2**		**0.081**	**0.0081**	
	Surface	11-Sep-03	10:10	19.84	8.61	7.23	79.3	252	ND			ND	**0.17**	ND			**1**				
	6 meters	10-Sep-03	16:55	19.49	8.29	3.13	34.1	257	ND			ND	ND	ND			ND		**0.012**	**0.0065**	
	6 meters	11-Sep-03	9:55	19.39	8.03	1.91	20.7	259	ND			ND	ND	ND			ND				
	13 meters	10-Sep-03	16:45	12.47	6.88	0.21	2.0	258	**1.6**			ND	ND	**0.18**			**2.5**				
	13 meters	11-Sep-03	9:50	12.43	6.88	0.13	1.2	259	**2.2**			ND	**0.37**	**0.059**			**2.4**				
					Reporting Limits (mg/L)				**0.050**	**0.050**	**0.050**	**0.050**	**0.050**	**0.050**	**10**	**10**	**0.50**		**0.0005**	**0.0005**	**0.80**

Location Notes:

There is no Station "A"

Station "B" is located near the center of the reservoir.

Station "C" is located near the dam.

Notes: ND = Non-Detect (parameter is not present or present at concentrations below the laboratory reporting limit).
An empty cell = No sample for this parameter.

Table 8. Shasta River Bacteriological Sample Results 2003

Site	Total Coliform (MPN/100 ml)	Fecal Coliform (MPN/100 ml)	E. coli (MPN/100 ml)	Enterococcus (MPN/100 ml)
Montague-Grenada Road	≥ 2,419.2	300	249.5	1091.0
Highway 3	≥ 2,419.2	500	285.1	165.2
CA DHS Threshold Level	10,000	400	235	61

Notes:
MPN = Most Probable Number
The California Department of Health Services (DHS) recommends posting fresh water beaches when single sample values exceed the levels identified in the fourth row of the table. California Department of Health Services. July 24, 2001. Draft Guidance for Fresh Water Beaches.
http://www.dhs.ca.gov/ps/ddwem/beaches/freshwater.htm
Total and fecal coliform, enterococcus, and e. coli are "indicator organisms" of microbiological contamination and are used by health authorities as surrogates for disease-causing organisms that are likely to be present in sewage, but are difficult to analyze for directly. Presence of these indicator organisms at both Shasta River sample locations at levels above the DHS thresholds indicates there may be disease-causing organisms present in the Shasta River.

Table 9. Shasta River Tributary and Springs -- Water Quality Results from Datasondes, 2003

	Temperature (Degrees C)			Specific Conductance (uS/cm)			Dissolved Oxygen (mg/L)			pH		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
Little Shasta River near Mouth												
06/16/03 - 06/20/03	15.72	27.92	20.80	707	843	775	4.03	11.37	6.98	7.96	8.46	8.18
10/20/03 - 10/23/03	11.08	16.23	13.45	914	947	937	6.56	19.30	9.82	8.16	8.57	8.34
Big Springs Lake at Spring												
08/18/03 - 08/22/03	11.26	11.27	11.26	386	399	393	9.69	12.03	10.66	6.31	6.45	6.37
09/16/2003 - 09/18/03	11.28	11.31	11.29	296	351	301	9.84	11.21	10.39	6.27	6.58	6.30
Big Springs Lake at Lake Outlet												
09/16/2003 - 09/18/03	10.49	12.86	11.65	338	356	344	8.16	13.09	10.63	6.43	6.65	6.57
Hidden Valley Spring												
09/16/2003 - 09/18/03	12.34	12.49	12.36	268	288	273	1.34	8.38	3.19	7.14	7.20	7.17
Bassey Spring												
09/16/2003 - 09/18/03	9.07	9.46	9.25	307	312	309	9.87	11.34	10.33	6.64	6.75	6.70

Table 10. Shasta River Flows (Cubic Feet Per Second) at Water Quality Monitoring Locations, 2002 and 2003

Shasta River Location	Date	Time	Flow
Near Mouth at USGS Gage	7/10/02	1645	20
	8/14/02	1340	16
	9/17/02	1515	19
	4/10/03	1540	209
	6/17/03	1815	103
	8/19/03	1820	62
Yreka-Ager Road	6/17/03	1630	74
	7/23/03	0830	62
	8/19/03	1630	61
Highway 3	4/10/03	1050	171
	6/17/03	1435	81
	8/19/03	1250	59
Montague-Grenada Road	7/11/02	1130	36
	8/15/02	0925	25
	9/18/02	1615	35
	4/09/03	1820	174
	6/17/03	1150	73
	8/19/03	1120	64
Freeman Road	6/17/03	1300	107
	7/23/03	1030	95
	8/19/03	1030	86
	8/20/03	1200	89
Highway A12	6/17/03	840	103
	8/19/03	0830	83
1.9 miles downstream of Big Springs Creek	6/17/03	0845	186
	8/19/03	1030	121
	8/20/03	1030	122
Riverside Drive	6/20/03	1130	3
	7/22/03	1400	10
	8/19/03	0830	9
Edgewood Road	7/11/02	1330	9
	8/15/02	1130	12
	9/19/02	0815	12
	4/09/03	1325	89

Table 11. Measured Sediment Oxygen Demand Rates and Sediment Characteristics at Shasta River Sites.

Sites[1]	Date	Replicate	Water Depth (meters)	Blank-Corrected SOD Rate at 20°C (SOD_{20}, $g/m^2/d$) [2]	Sediment Organic Content (%)	Sediment: Percent Finer than 63 microns (%)
Shasta River upstream of Montague- Grenada Road	Aug 12, 2003	1	0.9	2.0	2.3	5.7
		2	0.8	---	1.4	3.2
		3	0.7	1.0	1.7	3.3
Shasta River downstream of Montague- Grenada Road	Aug 12, 2003	1	0.7	1.6	4.8	5.0
		2	0.6	0.5	7.5	54.3
		3	0.5	1.0	4.1	2.4
Shasta River near Highway 3 – site A	Aug 13, 2003	1	0.9	1.5	2.6	2.1
		2	0.9	0.7	1.0	0.8
		3	0.8	0.1	1.5	1.6
Shasta River near Highway 3 – site B	Aug 13, 2003	1	0.9	1.3	1.4	3.3
		2	0.9	1.4	1.2	1.3
		3	0.8	1.7	1.5	2.9
Shasta River near Highway 3 – site C	Aug 14, 2003	1	0.7	2.1	0.9	0.7
		2	0.5	---	1.2	8.9
		3	0.4	2.3	0.8	2.3
Shasta River near Highway 3 – site D	Aug 14, 2003	1	0.6	1.8	6.5	29.9
		2	0.7	---	3.4	48.9
		3	0.7	2.3	6.3	44.4

Notes

1. Site Locations:
   Shasta River upstream of Montague- Grenada Road is located 100-200 meters upstream of the bridge.
   Shasta River downstream of Montague- Grenada Road is located approximately 400 meters downstream of bridge.
   Shasta River near Highway 3 – site A is located approximately 1 kilometer upstream of bridge; 200-300 meters upstream of pump house on right bank.
   Shasta River near Highway 3 – site B is located 50-100 meters upstream of site A, at bend in river.
   Shasta River near Highway 3 – site C is located 100-200 meters downstream of bridge.
   Shasta River near Highway 3 – site D is located 25-50 meters upstream of site C.

2. SOD_{20}, $g/m^2/d$ is sediment oxygen demand corrected for temperature of 20°C in grams per square meter per day.

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53. Continuous Temperature Data – Boles Creek- Collected by NCRWQCB: 06/01/03 - 10/31/03

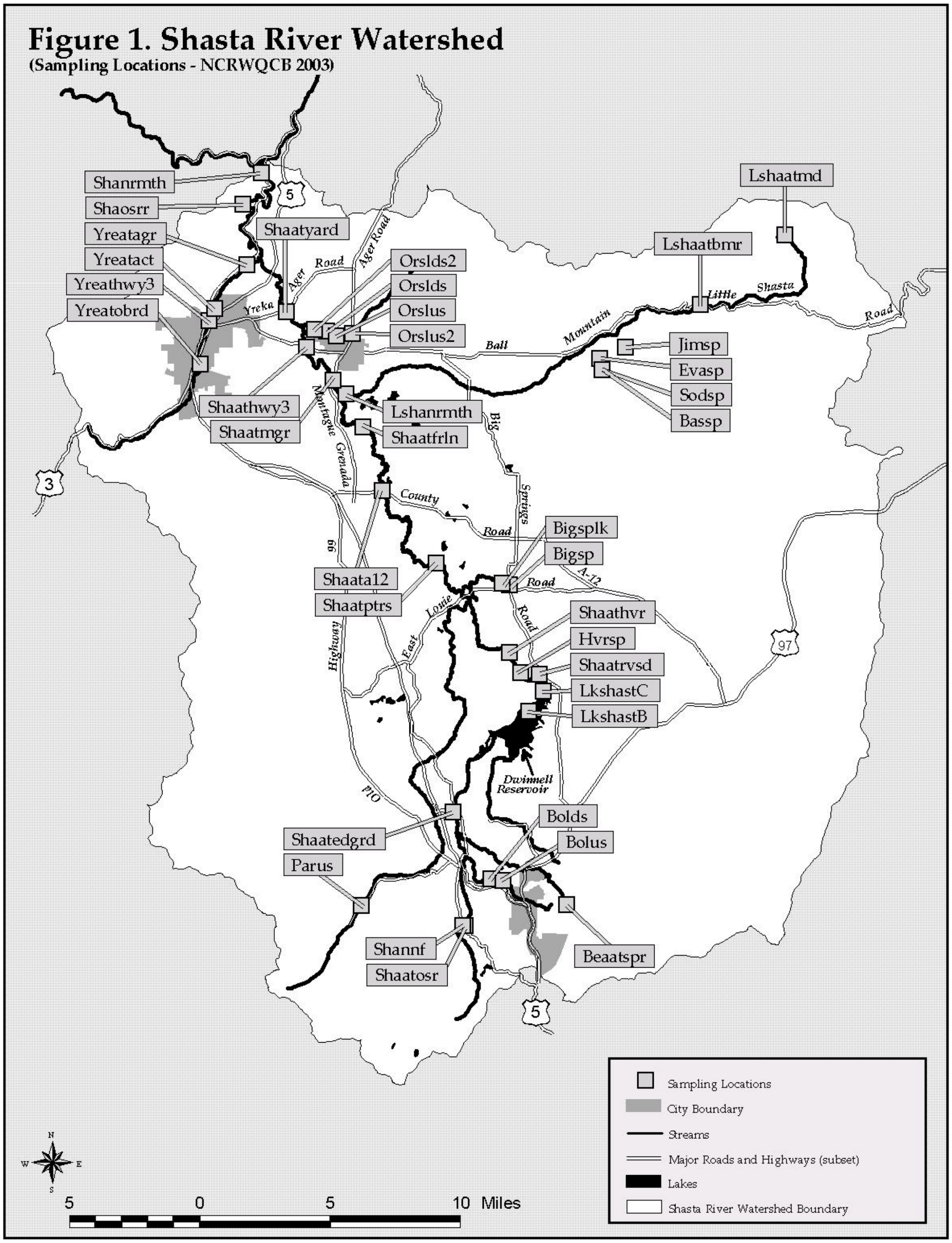
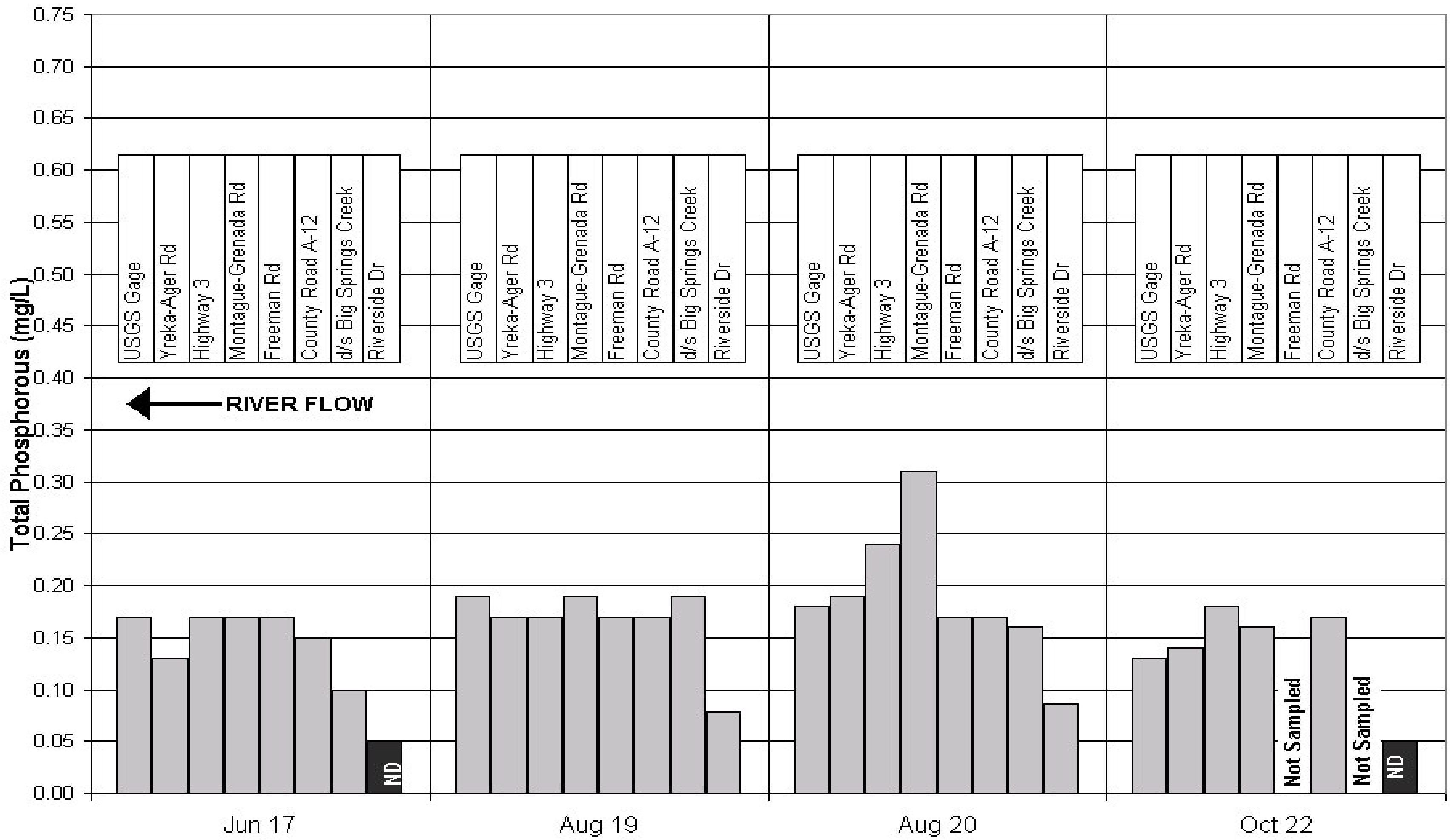
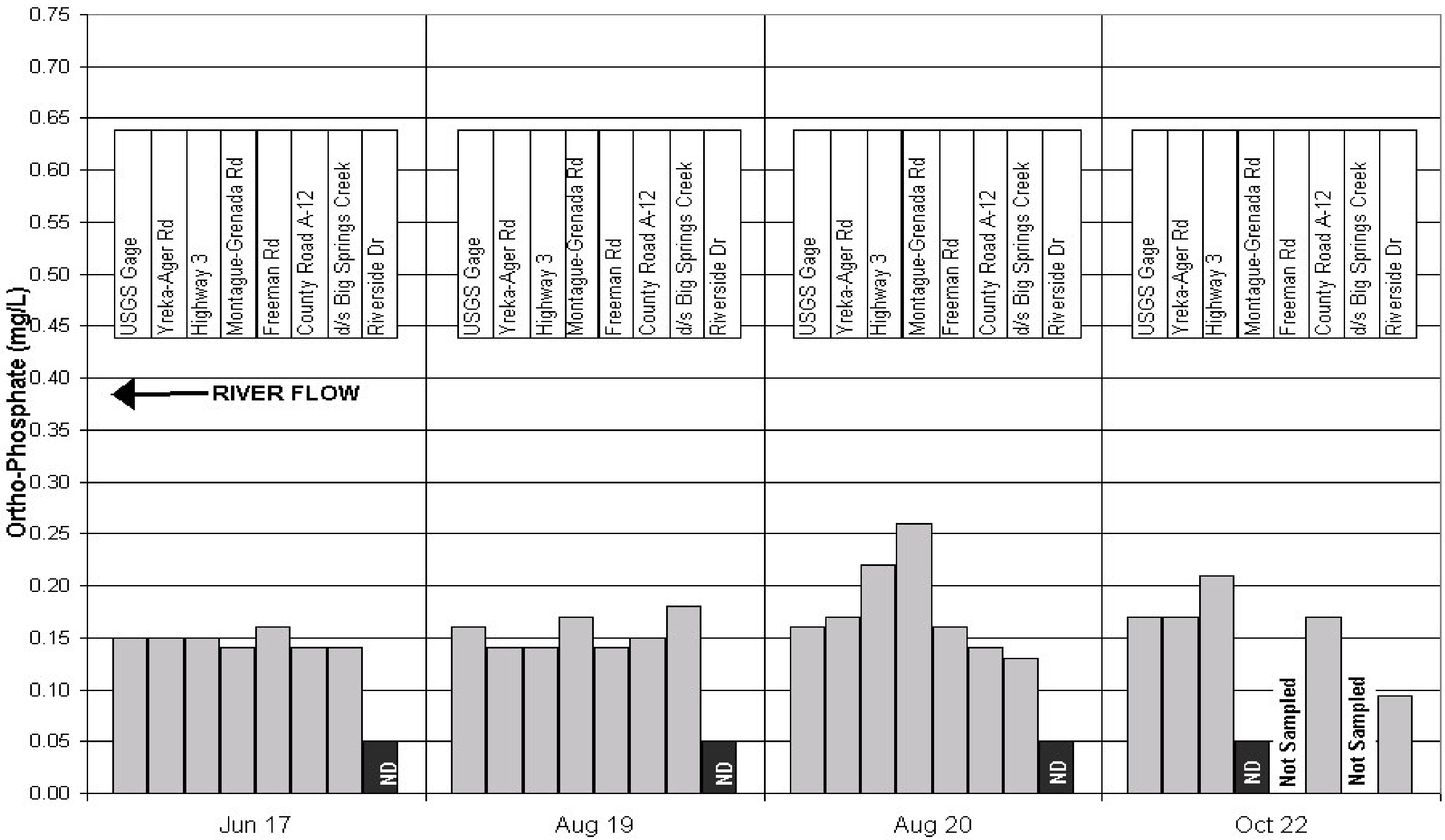


Figure 1. Shasta River Watershed
(Sampling Locations - NCRWQCB 2003)



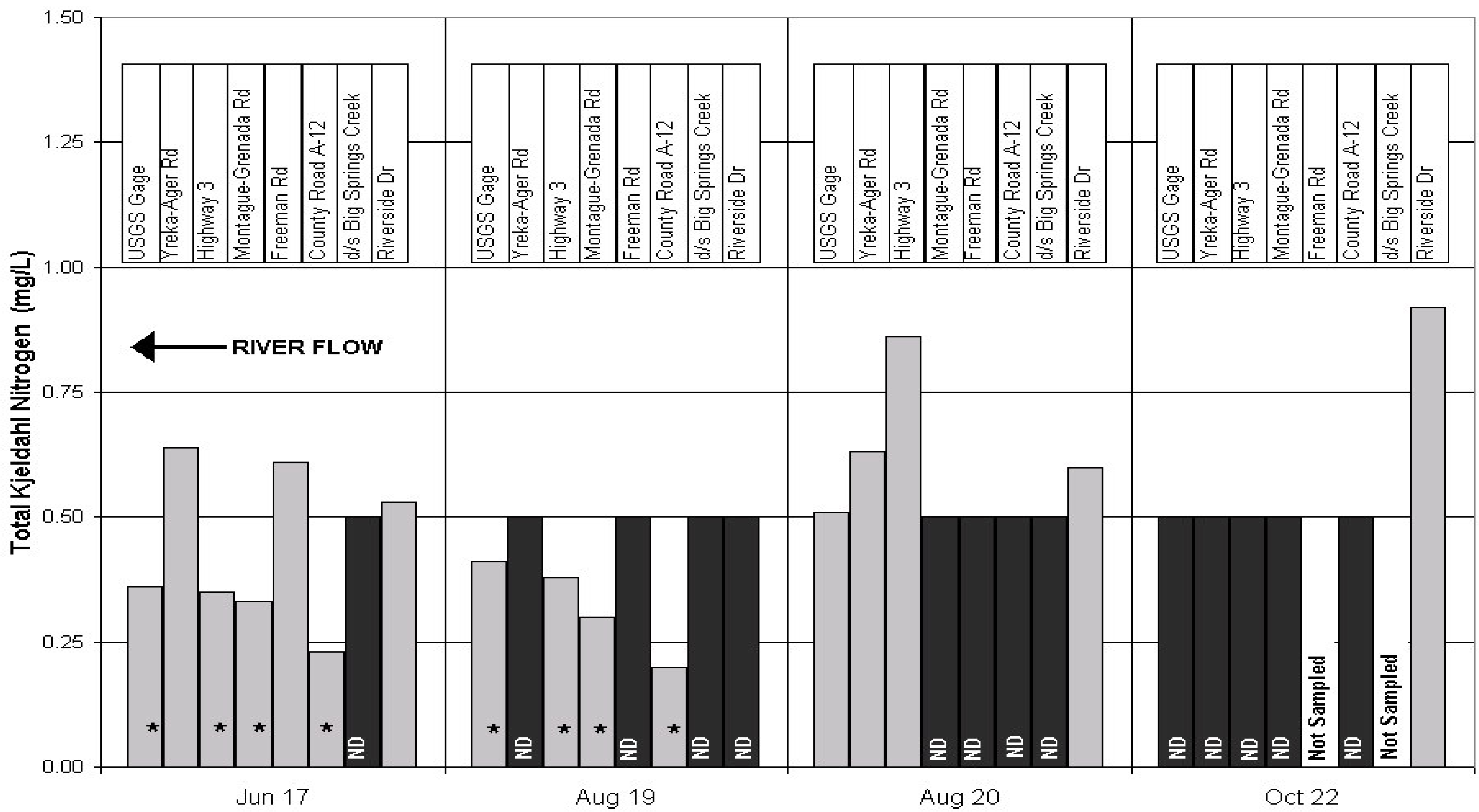
Notes: ND = Non-Detect (parameter is not present or present at concentrations below the laboratory reporting limit).

Figure 2. Total Phosphorus Grab Sample Data – Shasta River at Various Locations (Summer 2003) – Collected by NCRWQCB & USGS



Notes: ND = Non-Detect (parameter is not present or present at concentrations below the laboratory reporting limit).

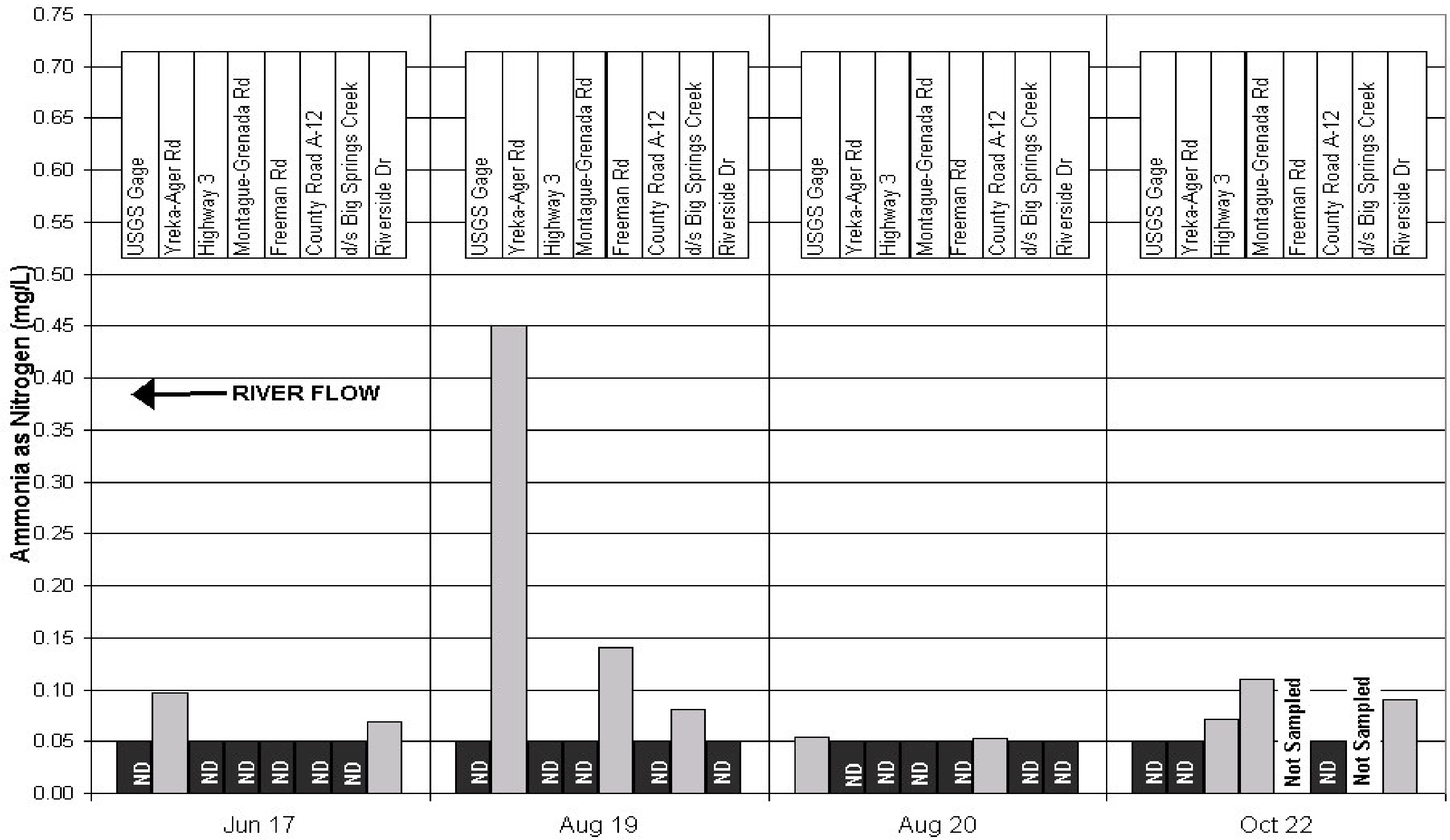
Figure 3. Ortho-Phosphate Grab Sample Data – Shasta River at Various Locations (Summer 2003) – Collected by NCRWQCB & USGS



Notes: ND = Non-Detect (parameter is not present or present at concentrations below the laboratory reporting limit).

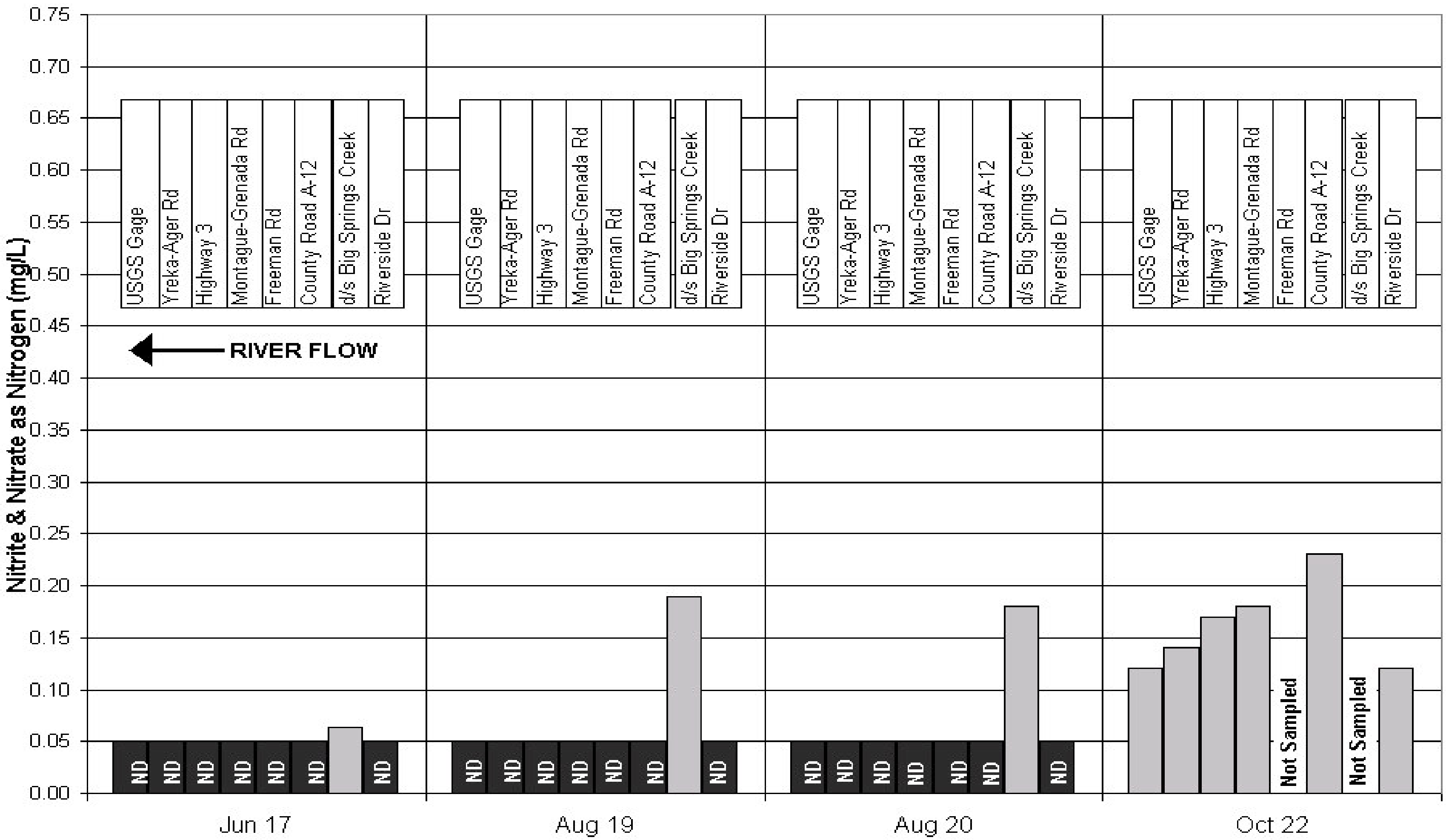
* = Sites sampled by USGS – Values reported using a laboratory analytical method with a lower reporting limit.

Figure 4. Total Kjeldahl Nitrogen Grab Sample Data – Shasta River at Various Locations (Summer 2003) – Collected by NCRWQCB & USGS



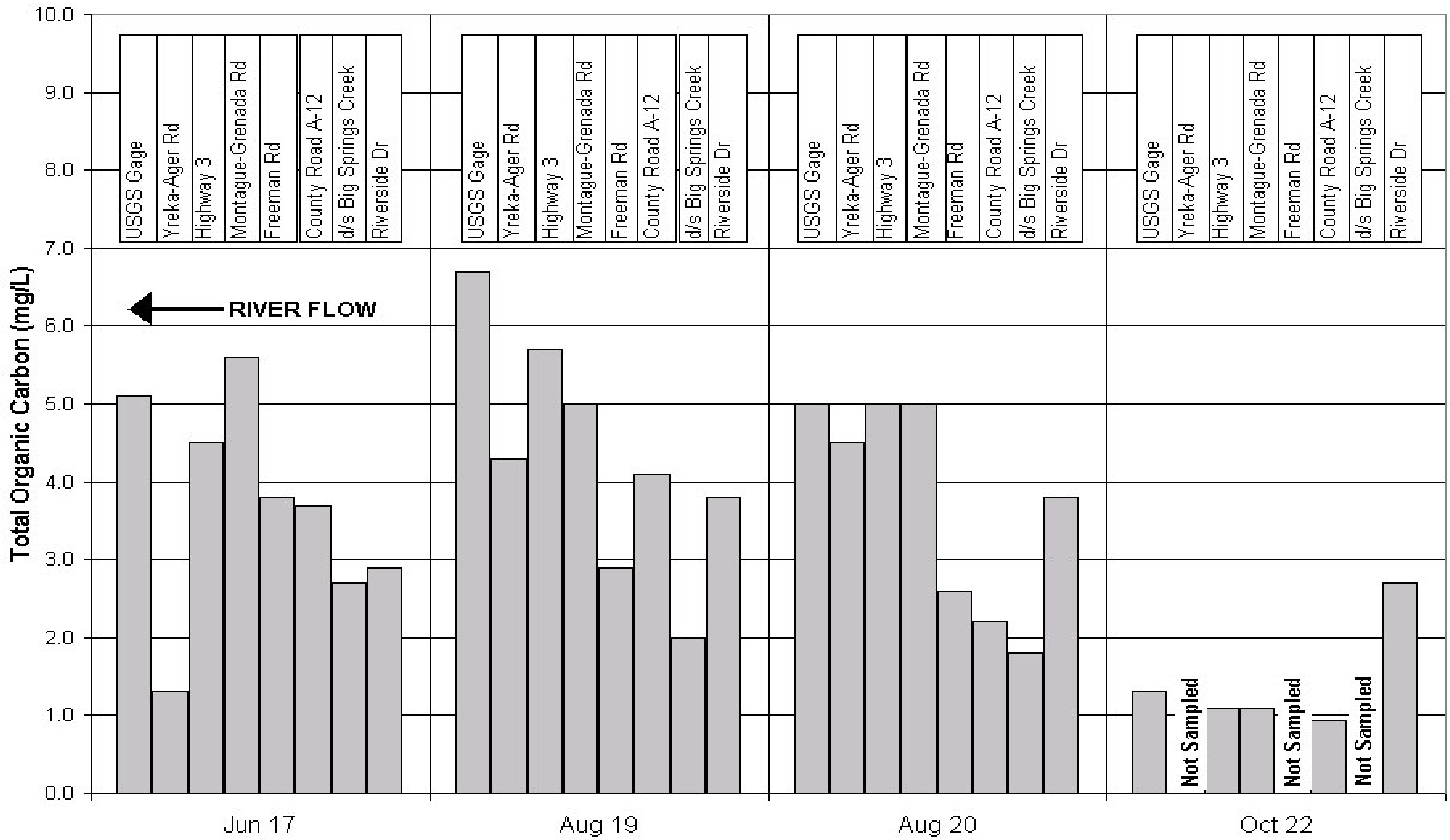
Notes: ND = Non-Detect (parameter is not present or present at concentrations below the laboratory reporting limit).

Figure 5. Ammonia Grab Sample Data – Shasta River at Various Locations (Summer 2003) – Collected by NCRWQCB & USGS



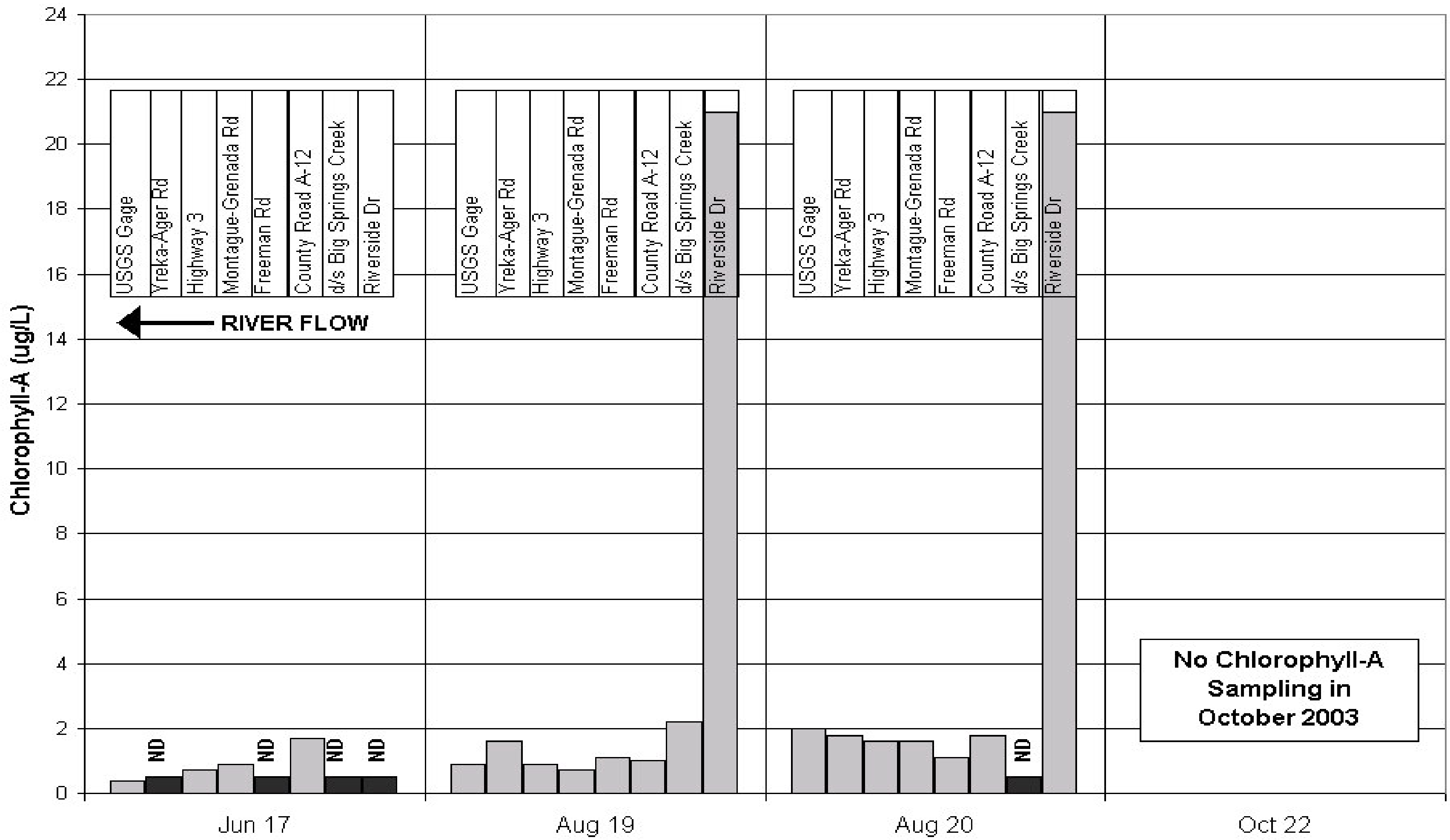
Notes: ND = Non-Detect (parameter is not present or present at concentrations below the laboratory reporting limit).

Figure 6. Nitrite + Nitrate Grab Sample Data – Shasta River at Various Locations (Summer 2003) – Collected by NCRWQCB & USGS



Notes: ND = Non-Detect (parameter is not present or present at concentrations below the laboratory reporting limit).

Figure 7. Total Organic Carbon Grab Sample Data – Shasta River at Various Locations (Summer 2003) – Collected by NCRWQCB & USGS



Notes: ND = Non-Detect (parameter is not present or present at concentrations below the laboratory reporting limit).

Figure 8. Chlorophyll-A Grab Sample Data – Shasta River at Various Locations (Summer 2003) – Collected by NCRWQCB & USGS.

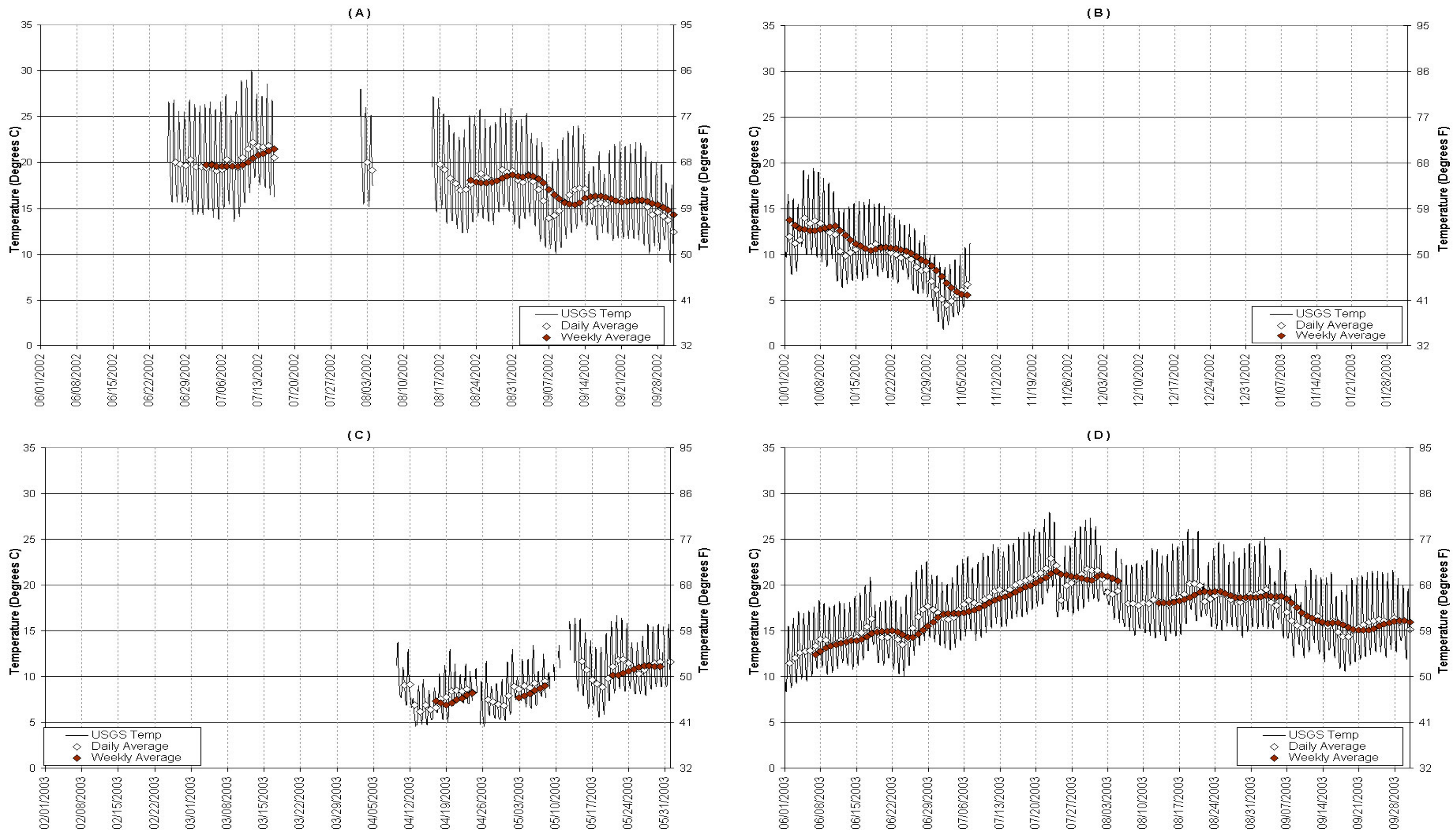


Figure 9. Continuous Temperature Data - Shasta River @ Edgewood Road - Collected by USGS: (A) 06/01/02 - 09/30/02, (B) 10/01/02 – 01/31/03, (C) 02/01/03 – 05/31/03, (D) 06/01/03 – 09/30/03.

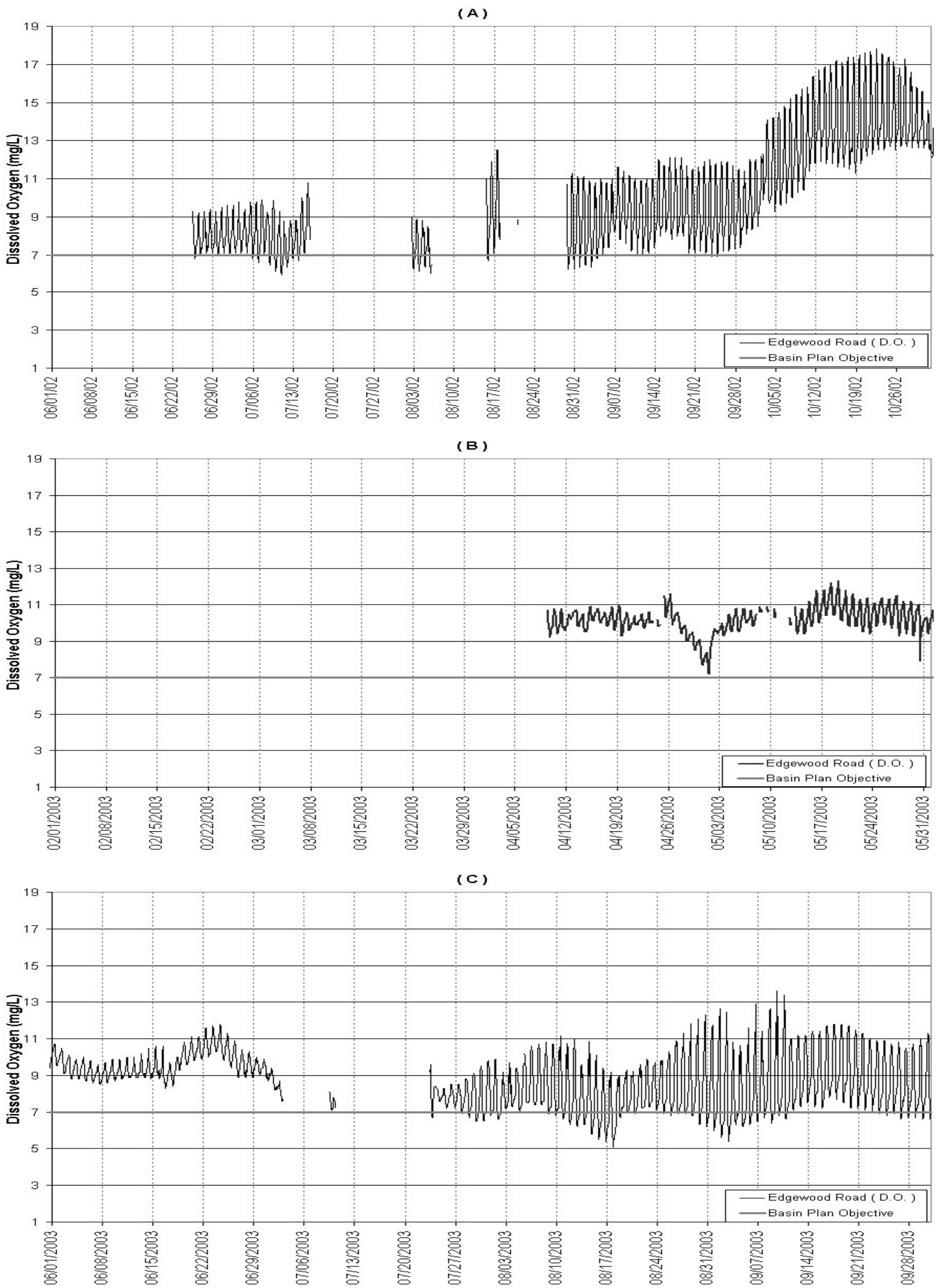


Figure 10. Continuous Dissolved Oxygen Data - Shasta River @ Edgewood Road - Collected by USGS: (A) 06/01/02 - 10/31/02, (B) 02/01/03 – 05/31/03, (C) 06/01/03 – 09/30/03.

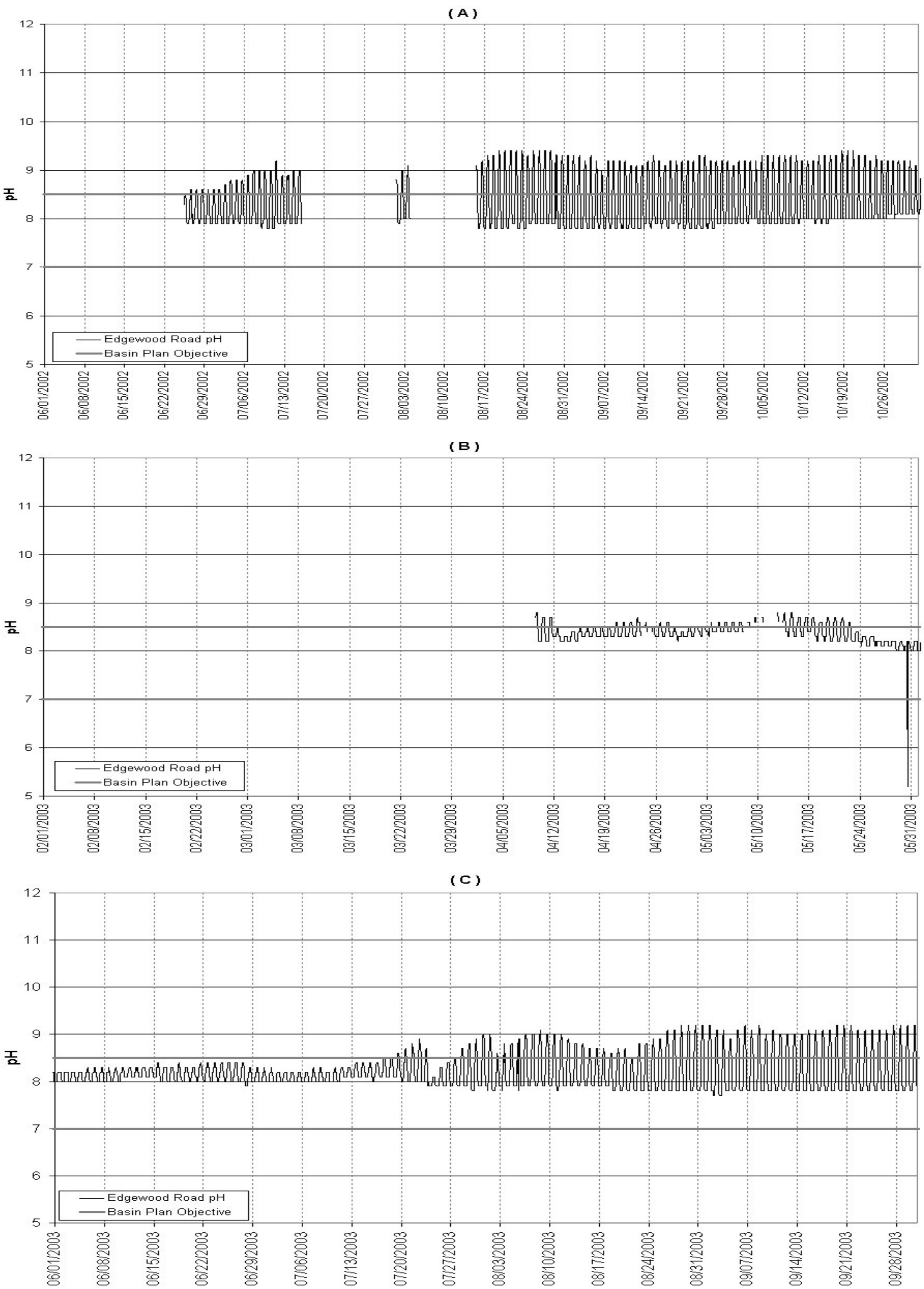


Figure 11. Continuous pH Data - Shasta River @ Edgewood Road - Collected by USGS: (A) 06/01/02 - 10/31/02, (B) 02/01/03 – 05/31/03, (C) 06/01/03 – 09/30/03.

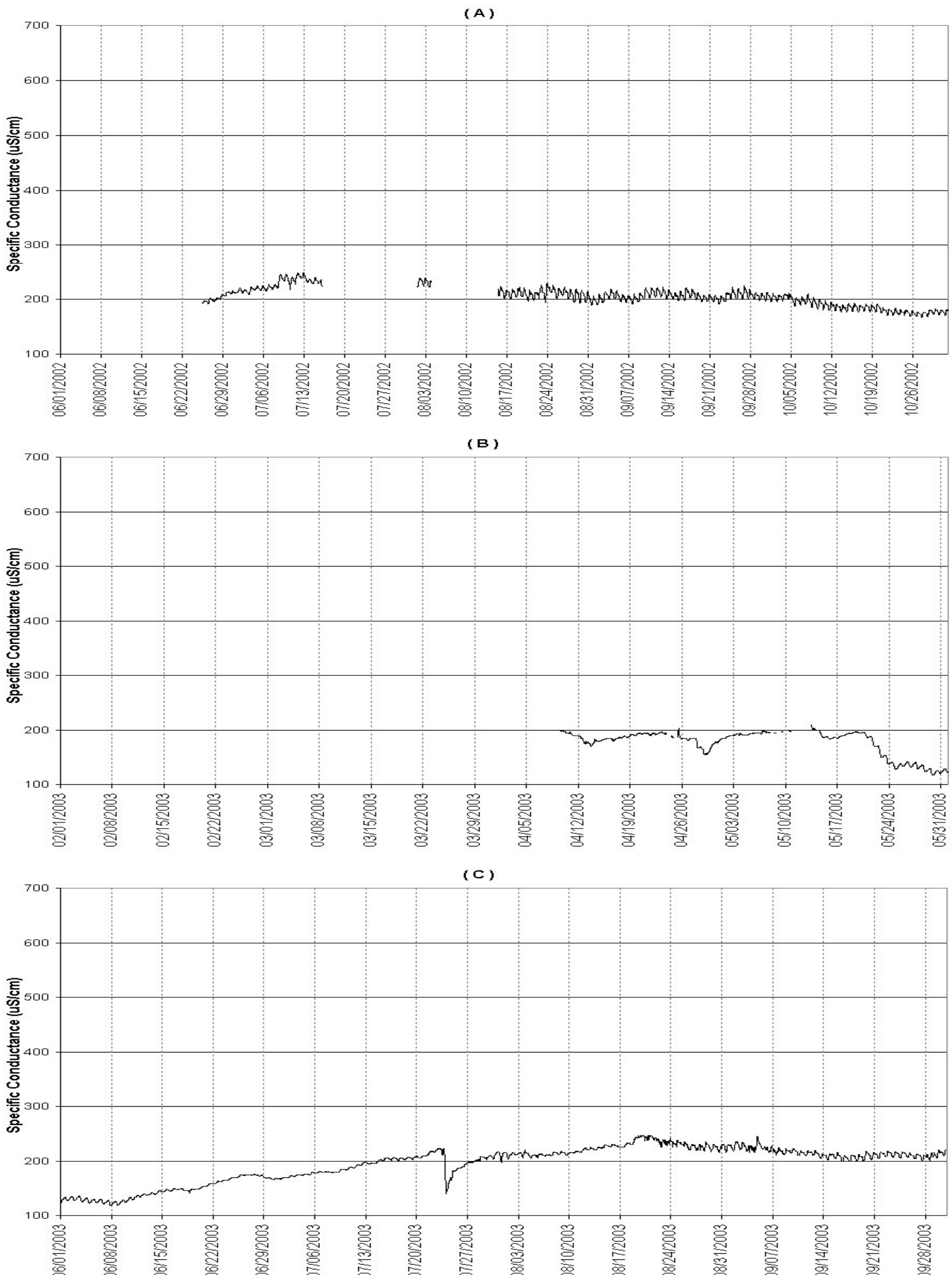


Figure 12. Continuous Specific Conductance Data - Shasta River @ Edgewood Road - Collected by USGS: (A) 06/01/02 - 10/31/02, (B) 02/01/03 – 05/31/03, (C) 06/01/03 – 09/30/03.

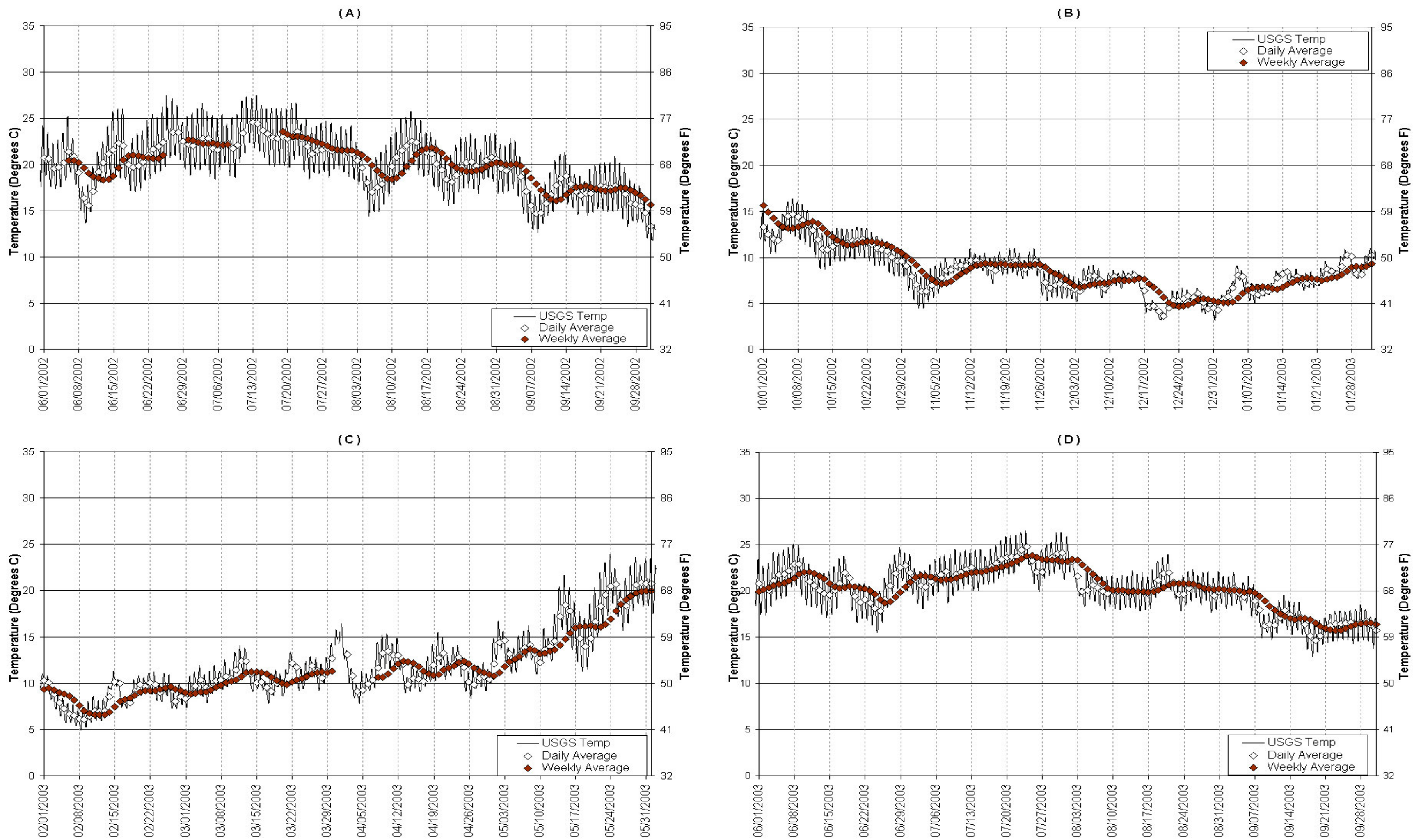


Figure 13. Continuous Temperature Data - Shasta River @ Montague-Grenada Road - Collected by USGS: (A) 06/01/02 - 09/30/02, (B) 10/01/02 – 01/31/03, (C) 02/01/03 – 05/31/03, (D) 06/01/03 – 09/30/03.

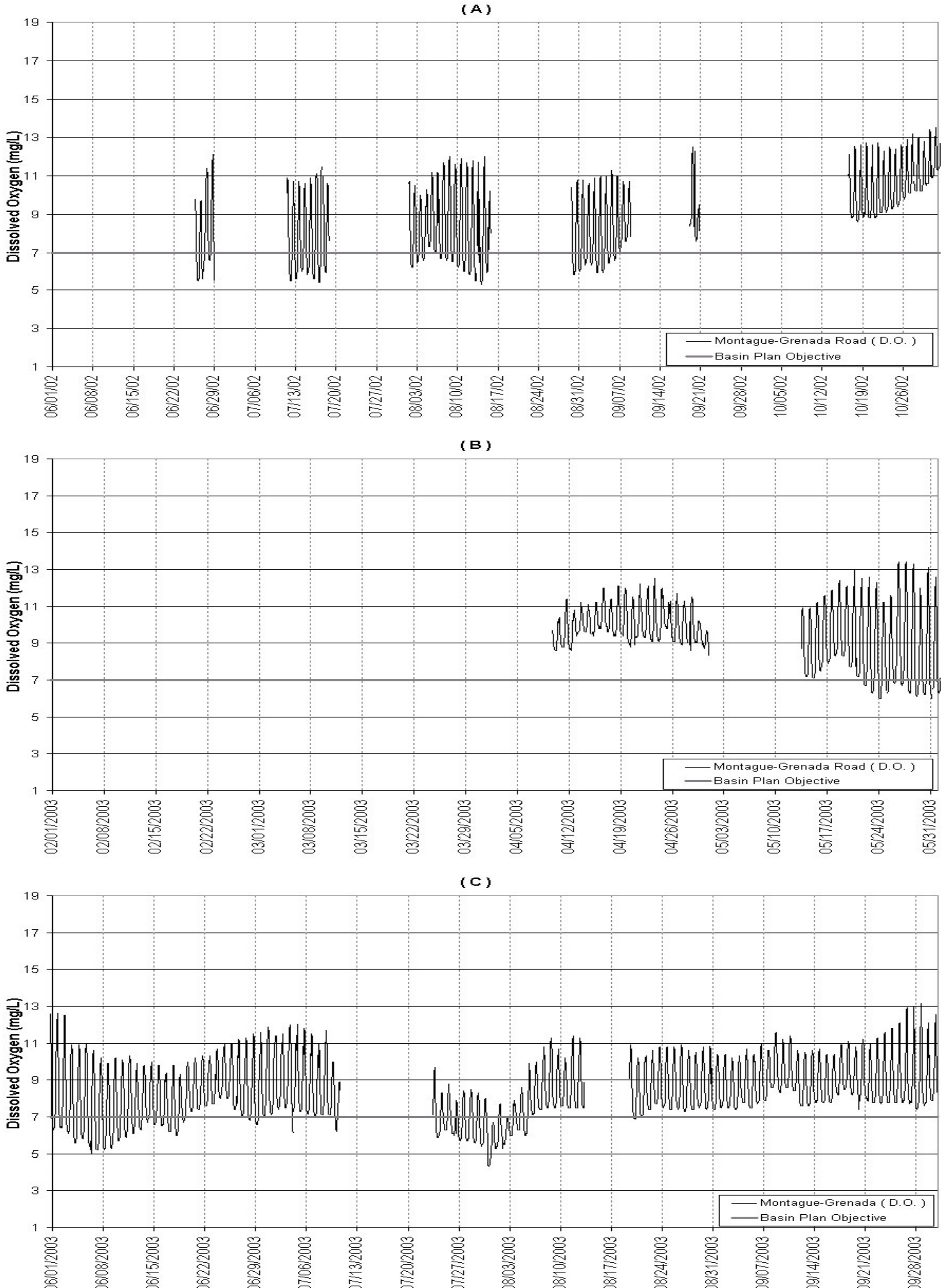


Figure 14. Continuous Dissolved Oxygen Data - Shasta River @ Montague-Grenada Road - Collected by USGS: (A) 06/01/02 - 10/31/02, (B) 02/01/03 – 05/31/03, (C) 06/01/03 – 09/30/03.

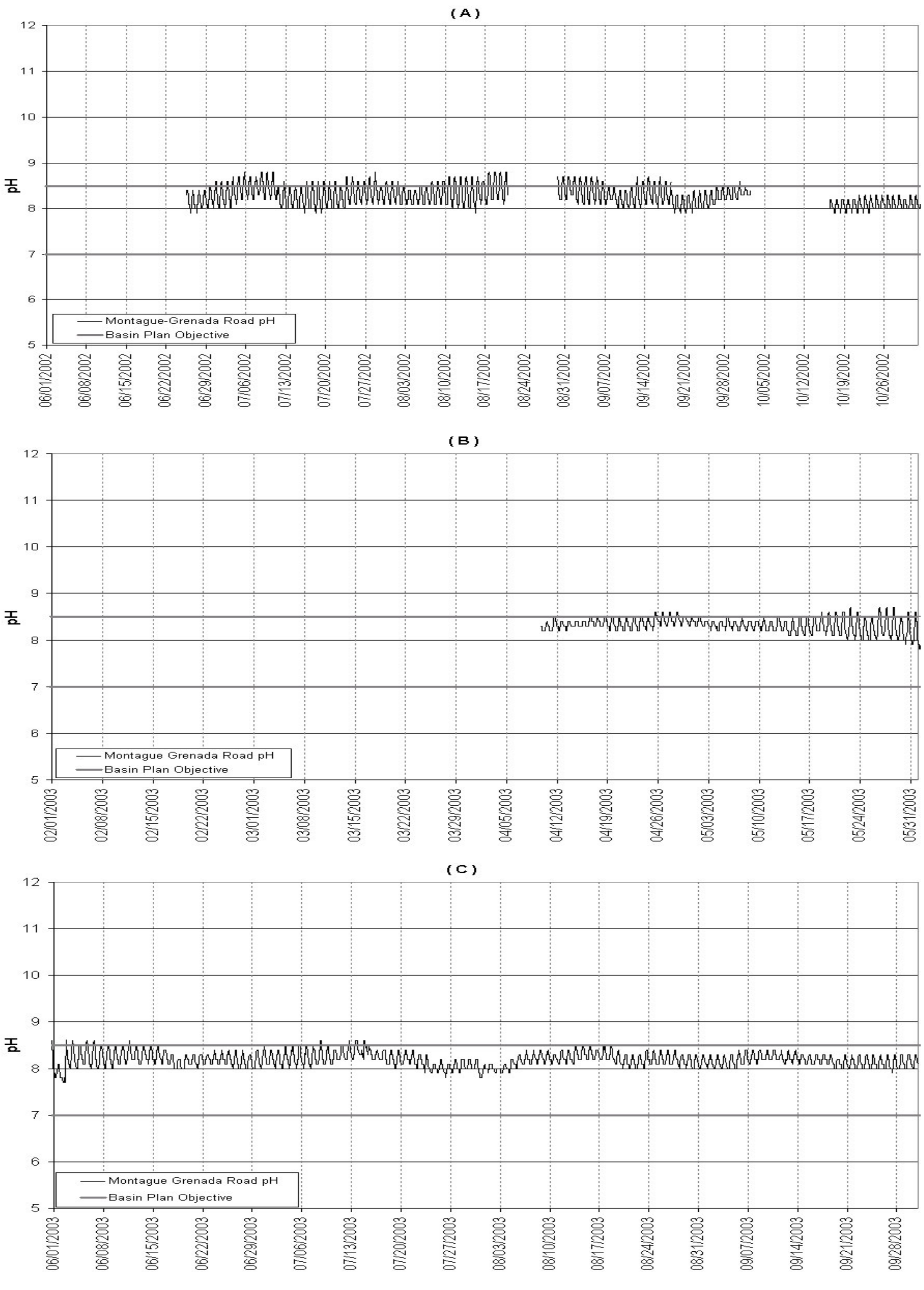


Figure 15. Continuous pH Data - Shasta River @ Montague-Grenada Road - Collected by USGS: (A) 06/01/02 - 10/31/02, (B) 02/01/03 – 05/31/03, (C) 06/01/03 – 09/30/03.

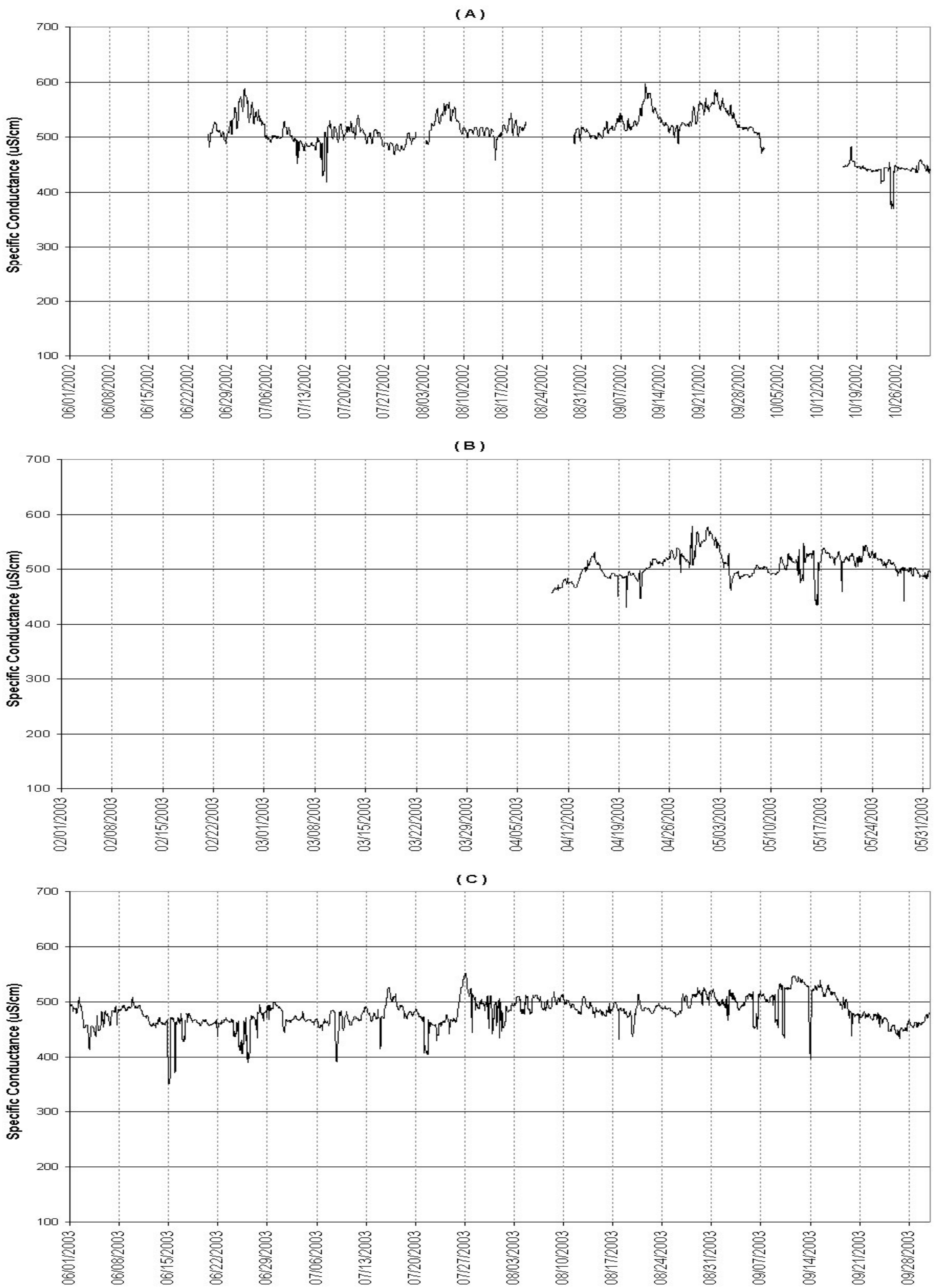


Figure 16. Continuous Conductance Data - Shasta River @ Montague-Grenada Road - Collected by USGS: (A) 06/01/02 - 10/31/02, (B) 02/01/03 – 05/31/03, (C) 06/01/03 – 09/30/03.

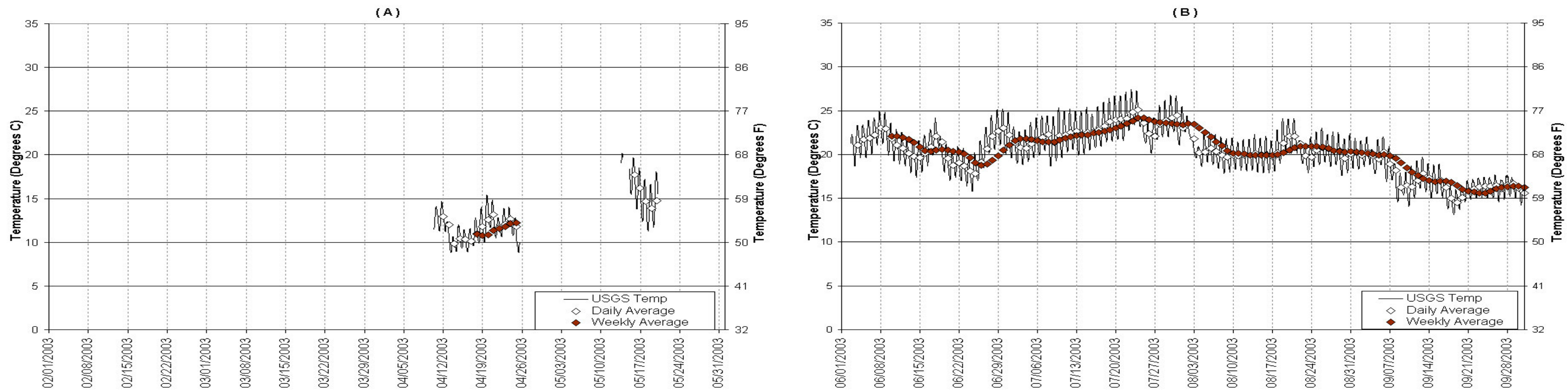


Figure 17. Continuous Temperature Data - Shasta River @ Highway 3 - Collected by USGS: (A) 02/01/03 – 05/31/03, (B) 06/01/03 – 09/30/03.

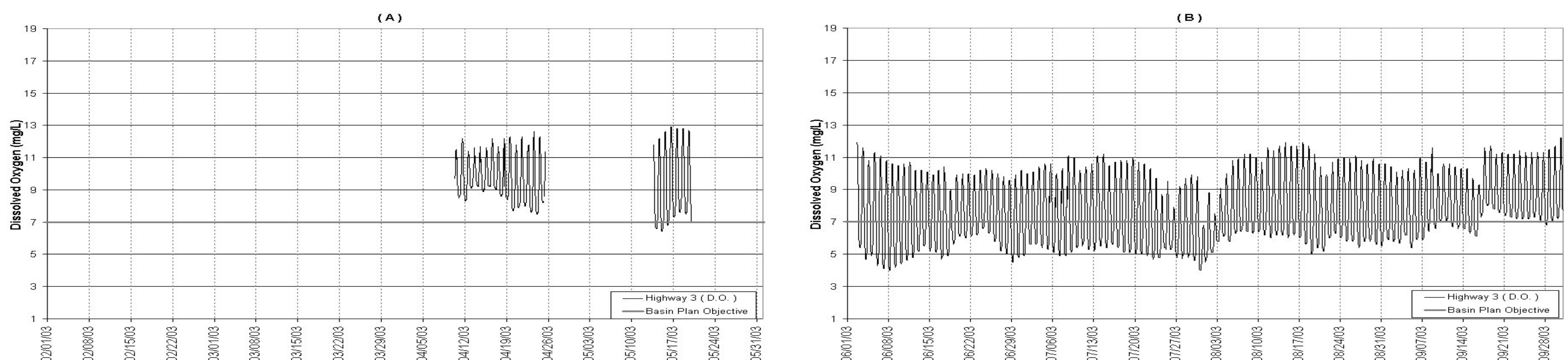


Figure 18. Continuous Dissolved Oxygen Data - Shasta River @ Highway 3 - Collected by USGS: (A) 02/01/03 – 05/31/03, (B) 06/01/03 – 09/30/03.

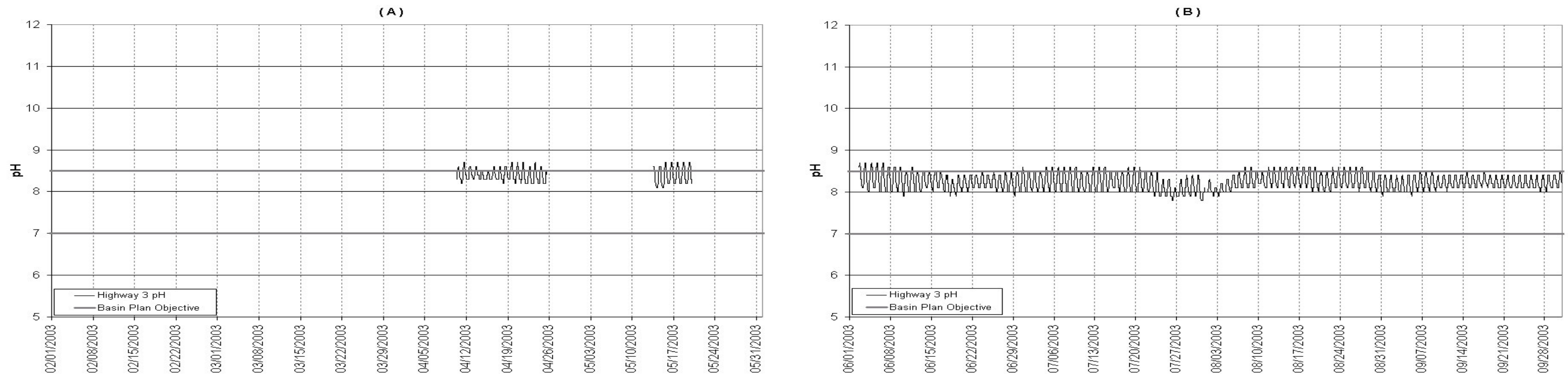


Figure 19. Continuous pH Data - Shasta River @ Highway 3 - Collected by USGS: (A) 02/01/03 – 05/31/03, (B) 06/01/03 – 09/30/03.

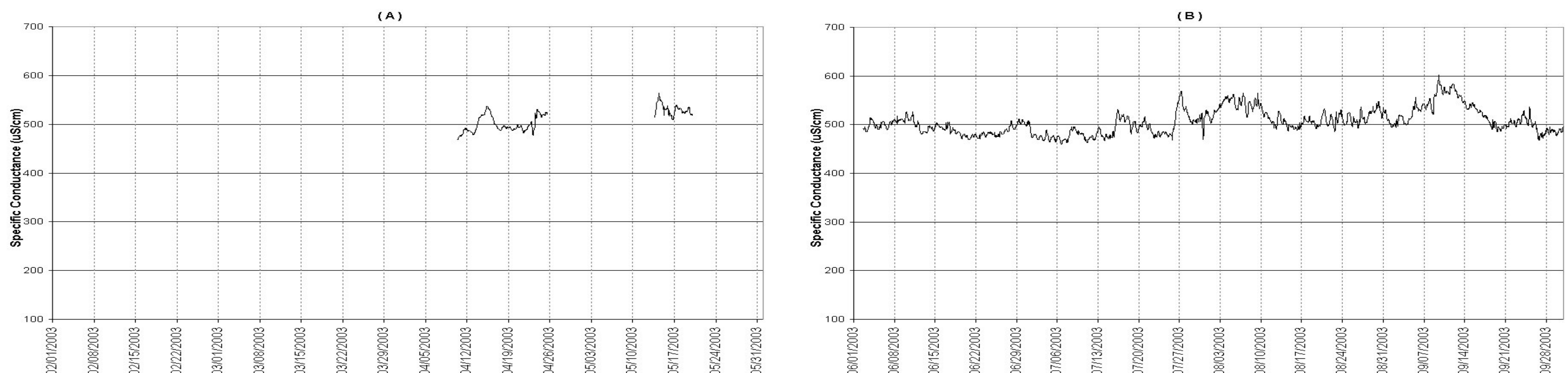


Figure 20. Continuous Conductance Data - Shasta River @ Highway 3 - Collected by USGS: (A) 02/01/03 – 05/31/03, (B) 06/01/03 – 09/30/03

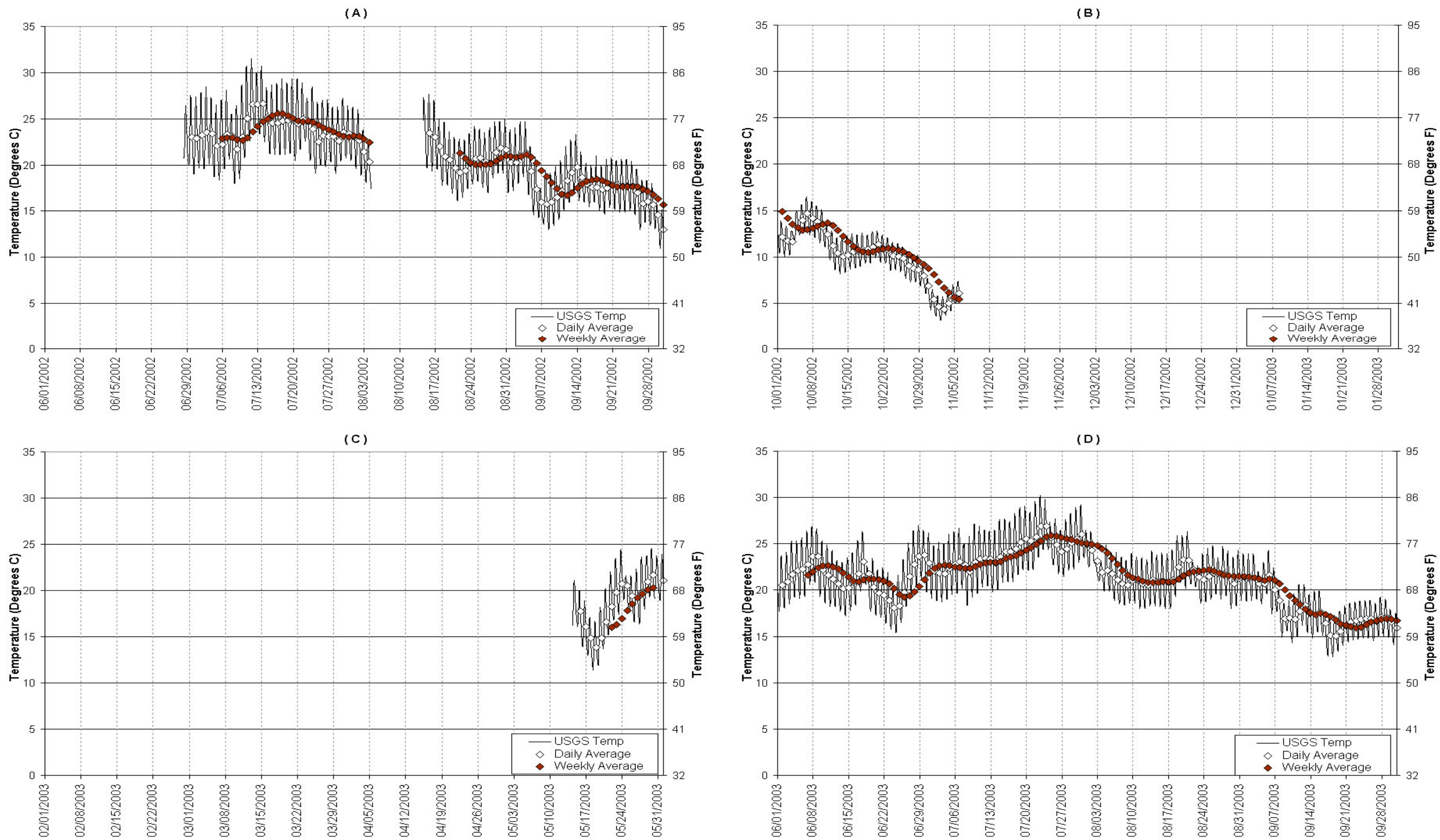


Figure 21. Continuous Temperature Data - Shasta River Near Mouth @ USGS Gage - Collected by USGS: (A) 06/01/02 - 09/30/02, (B) 10/01/02 – 01/31/03, (C) 02/01/03 – 05/31/03, (D) 06/01/03 – 09/30/03.

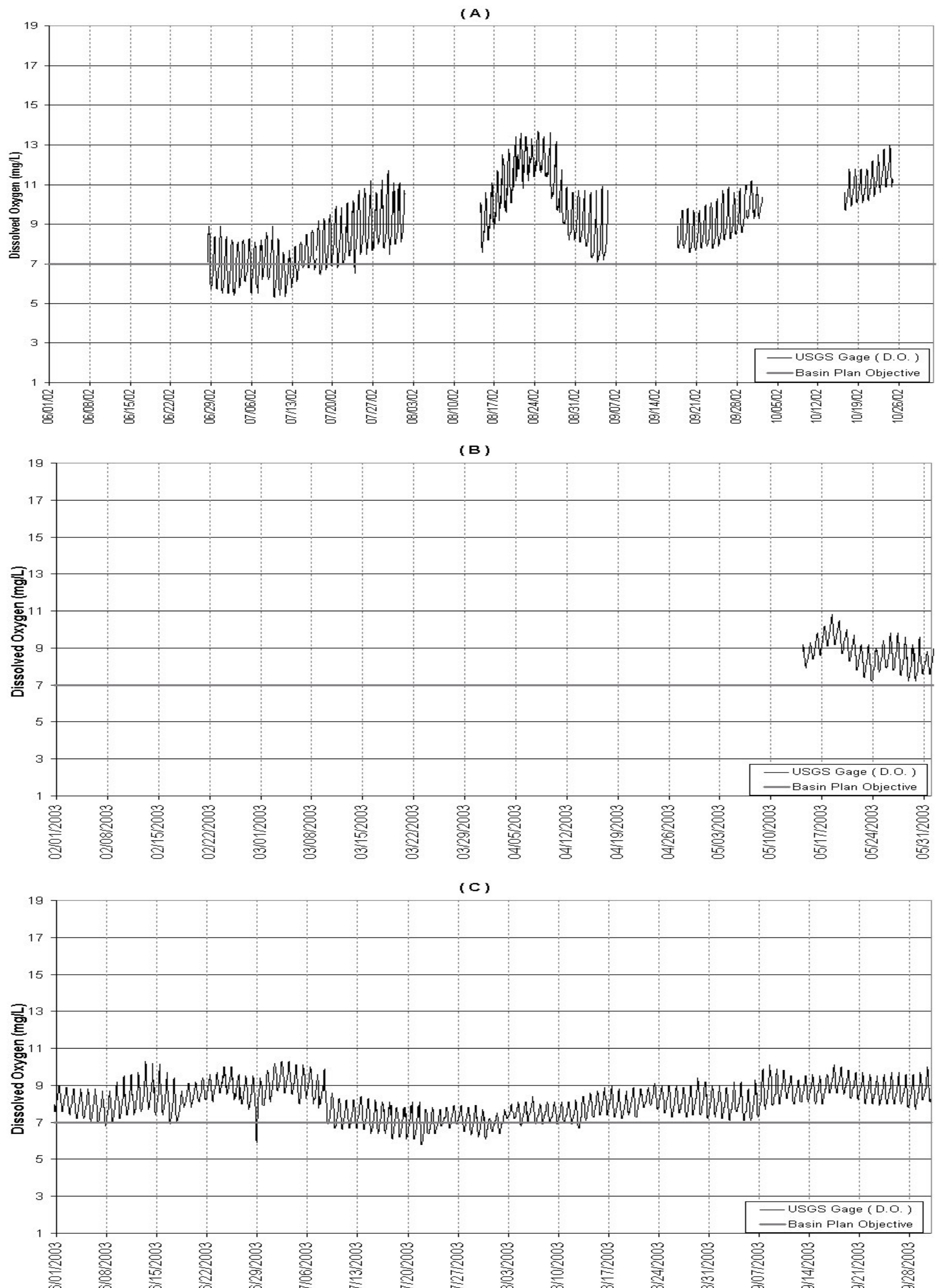


Figure 22. Continuous Dissolved Oxygen Data - Shasta River Near Mouth @ USGS Gage - Collected by USGS: (A) 06/01/02 - 10/31/02, (B) 02/01/03 – 05/31/03, (C) 06/01/03 – 09/30/03.

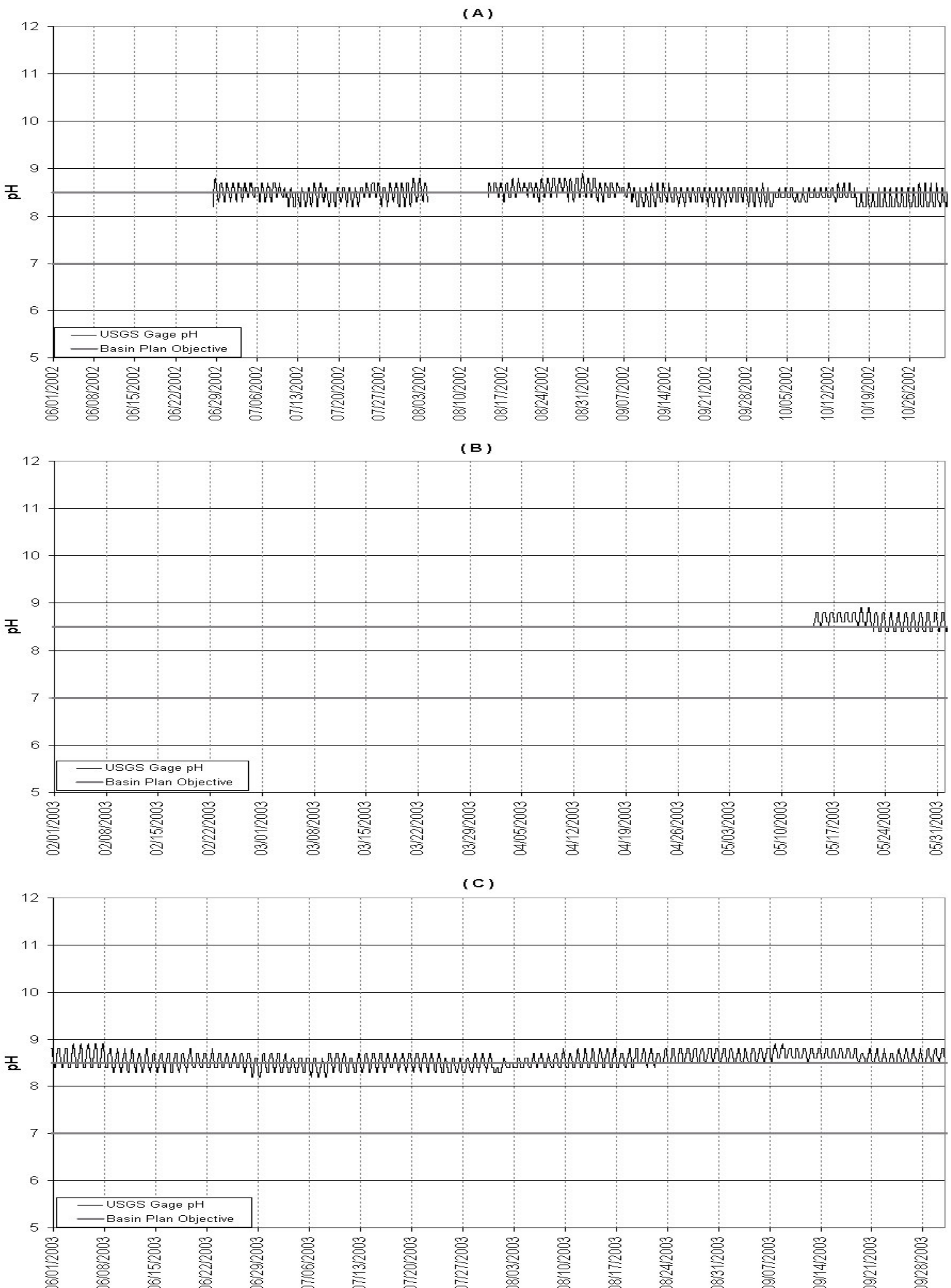


Figure 23. Continuous pH Data - Shasta River Near Mouth @ USGS Gage - Collected by USGS: (A) 06/01/02 - 10/31/02, (B) 02/01/03 – 05/31/03, (C) 06/01/03 – 09/30/03.

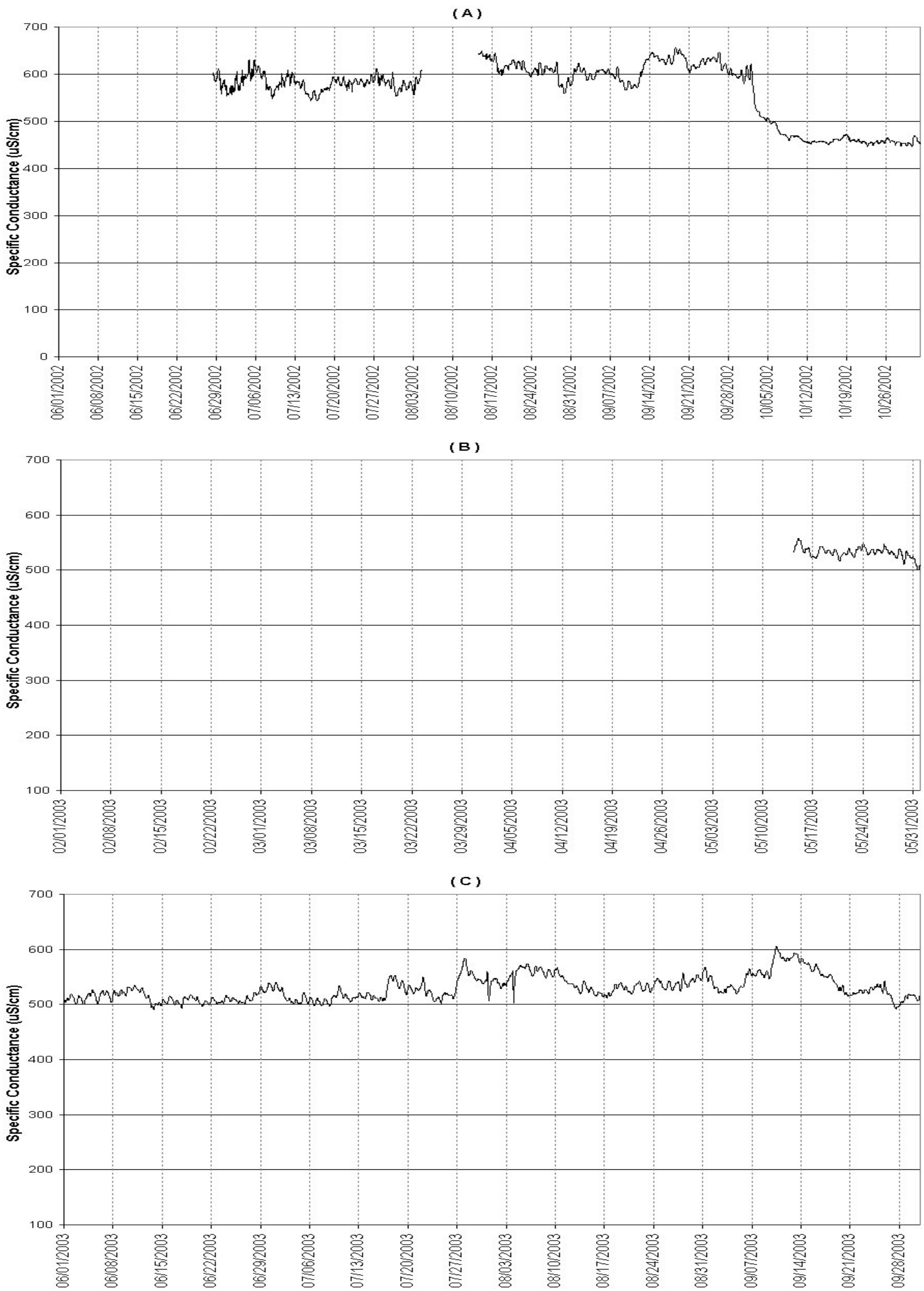


Figure 24. Continuous Conductance Data - Shasta River Near Mouth @ USGS Gage - Collected by USGS: (A) 06/01/02 - 10/31/02, (B) 02/01/03 – 05/31/03, (C) 06/01/03 – 09/30/03.

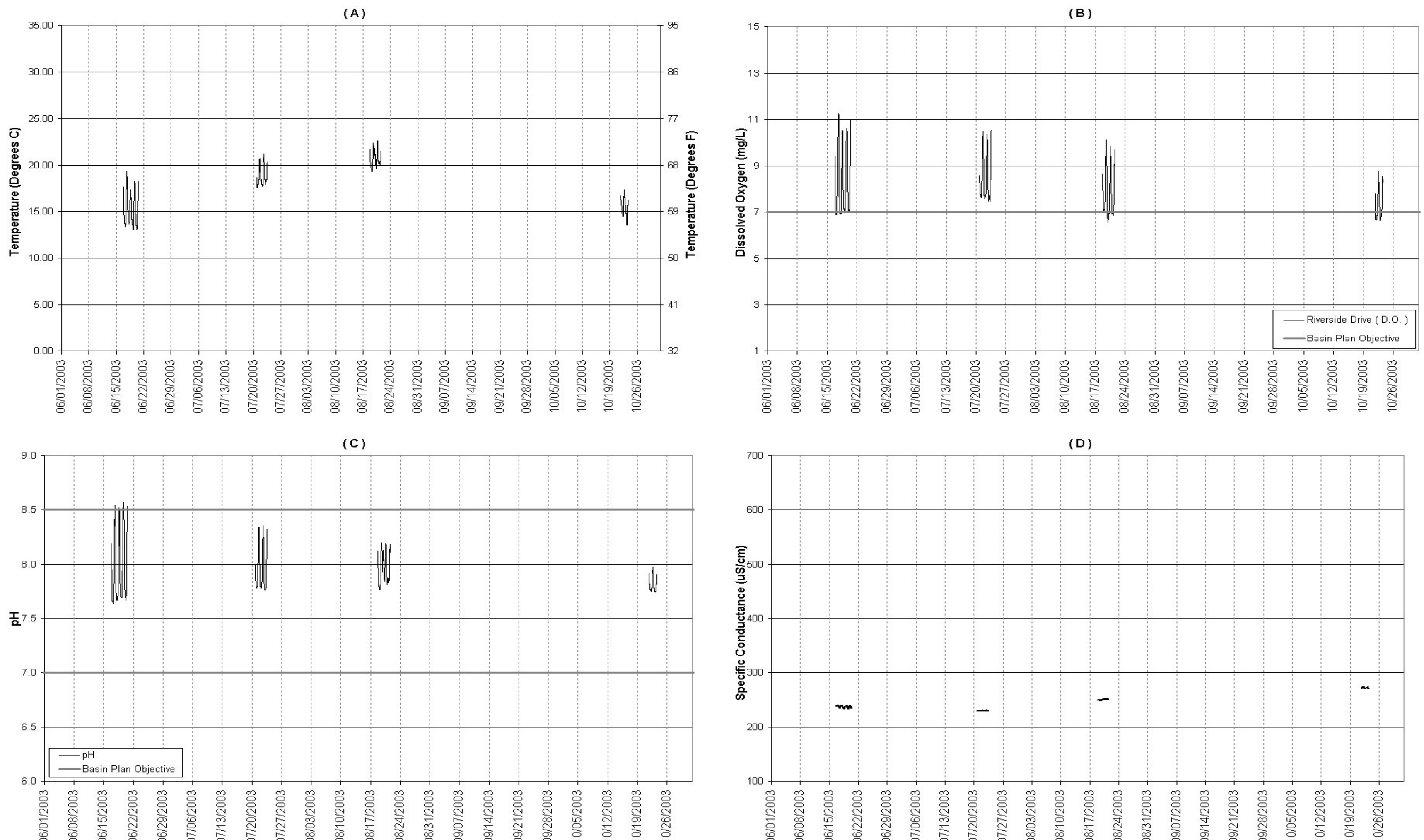


Figure 25. Continuous Sonde Data - Shasta River @ Riverside Drive - Collected by NCRWQCB: 06/01/03 – 10/31/03 (A) Temperature, (B) Dissolved Oxygen, (C) pH, (D) Specific Conductance.

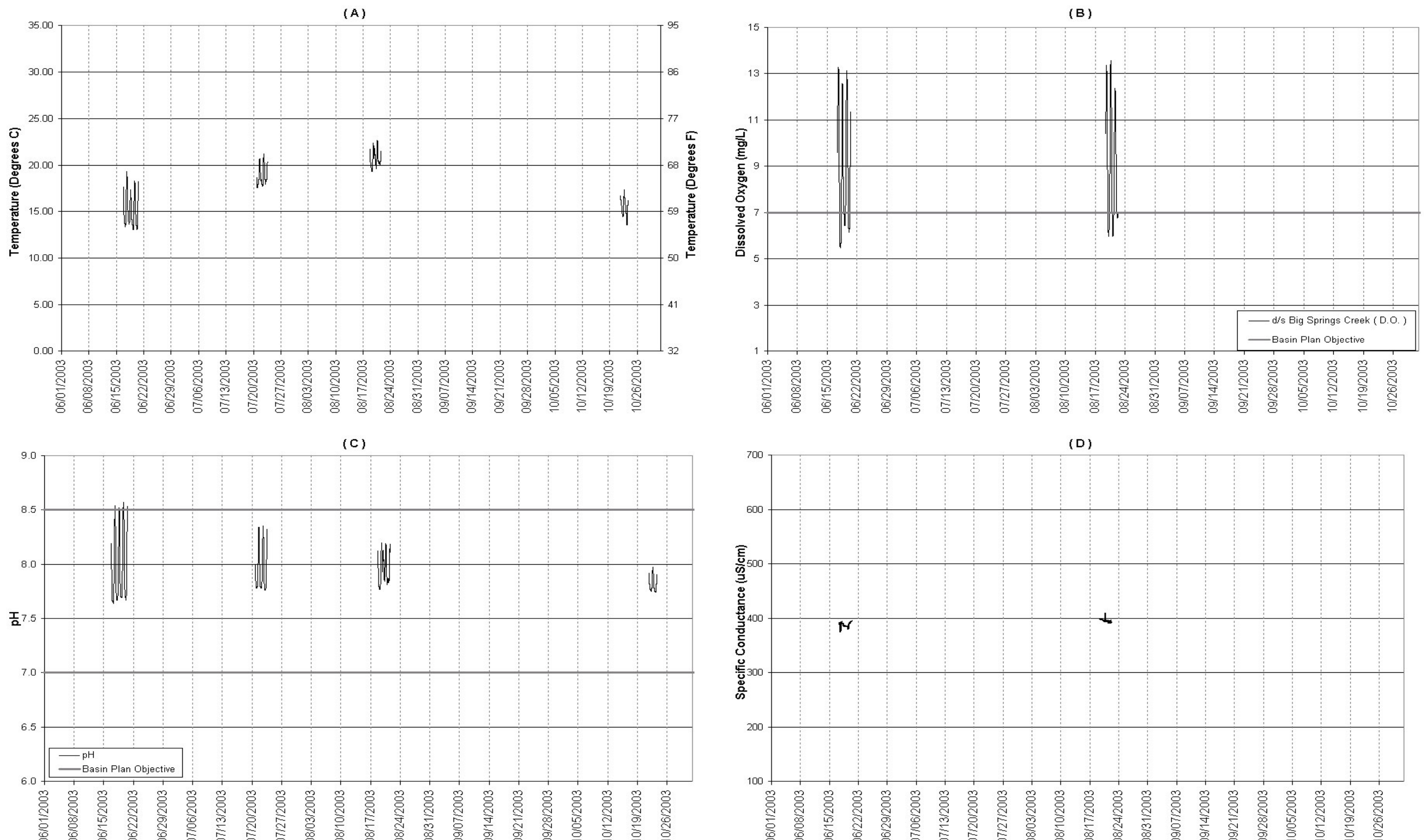


Figure 26. Continuous Sonde Data - Shasta River d/s Big Springs Creek - Collected by NCRWQCB: 06/01/03 – 10/31/03 (A) Temperature, (B) Dissolved Oxygen, (C) pH, (D) Specific Conductance.

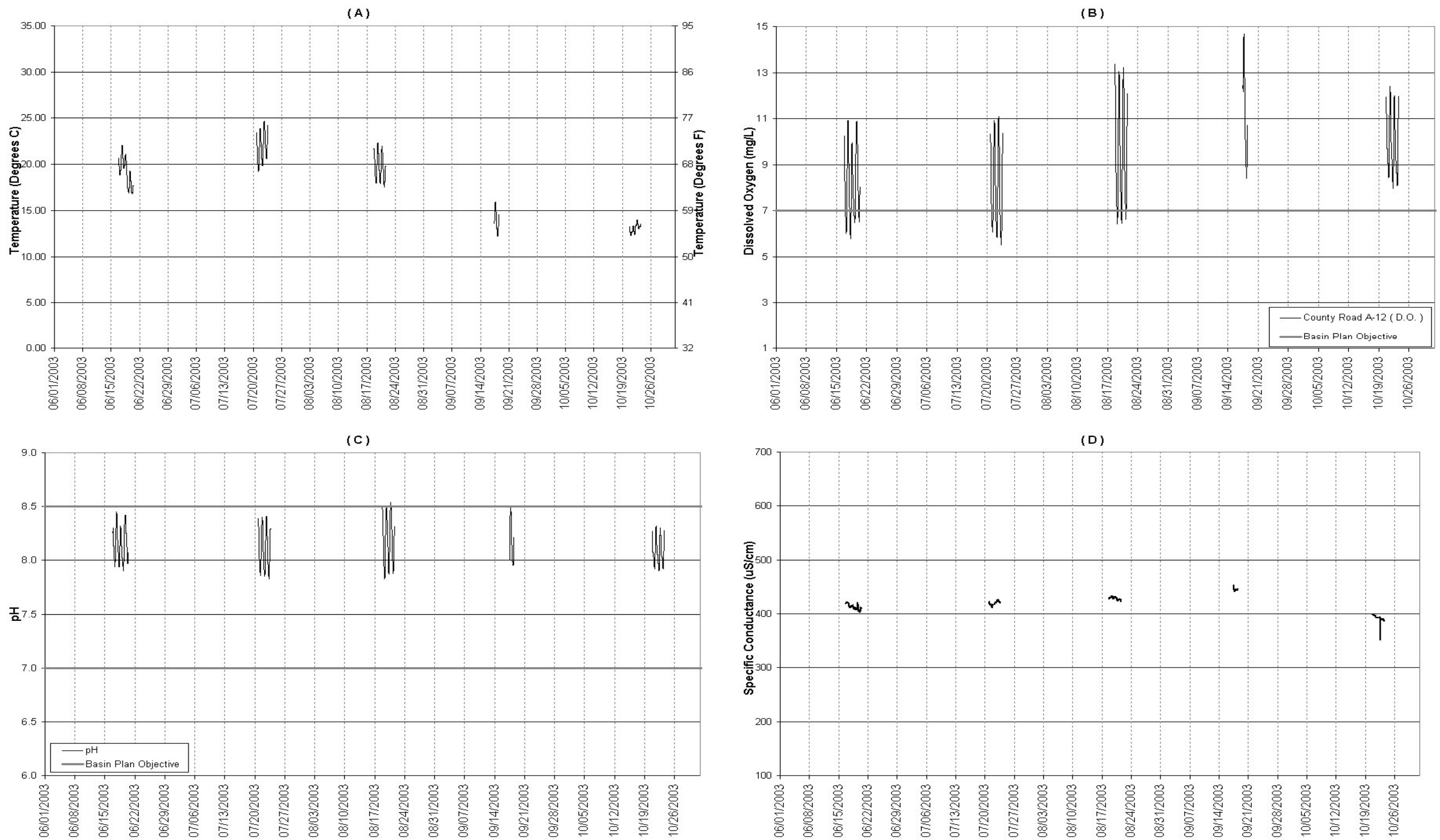


Figure 27. Continuous Sonde Data - Shasta River @ County Road A-12 - Collected by NCRWQCB: 06/01/03 – 10/31/03 (A) Temperature, (B) Dissolved Oxygen, (C) pH, (D) Specific Conductance.

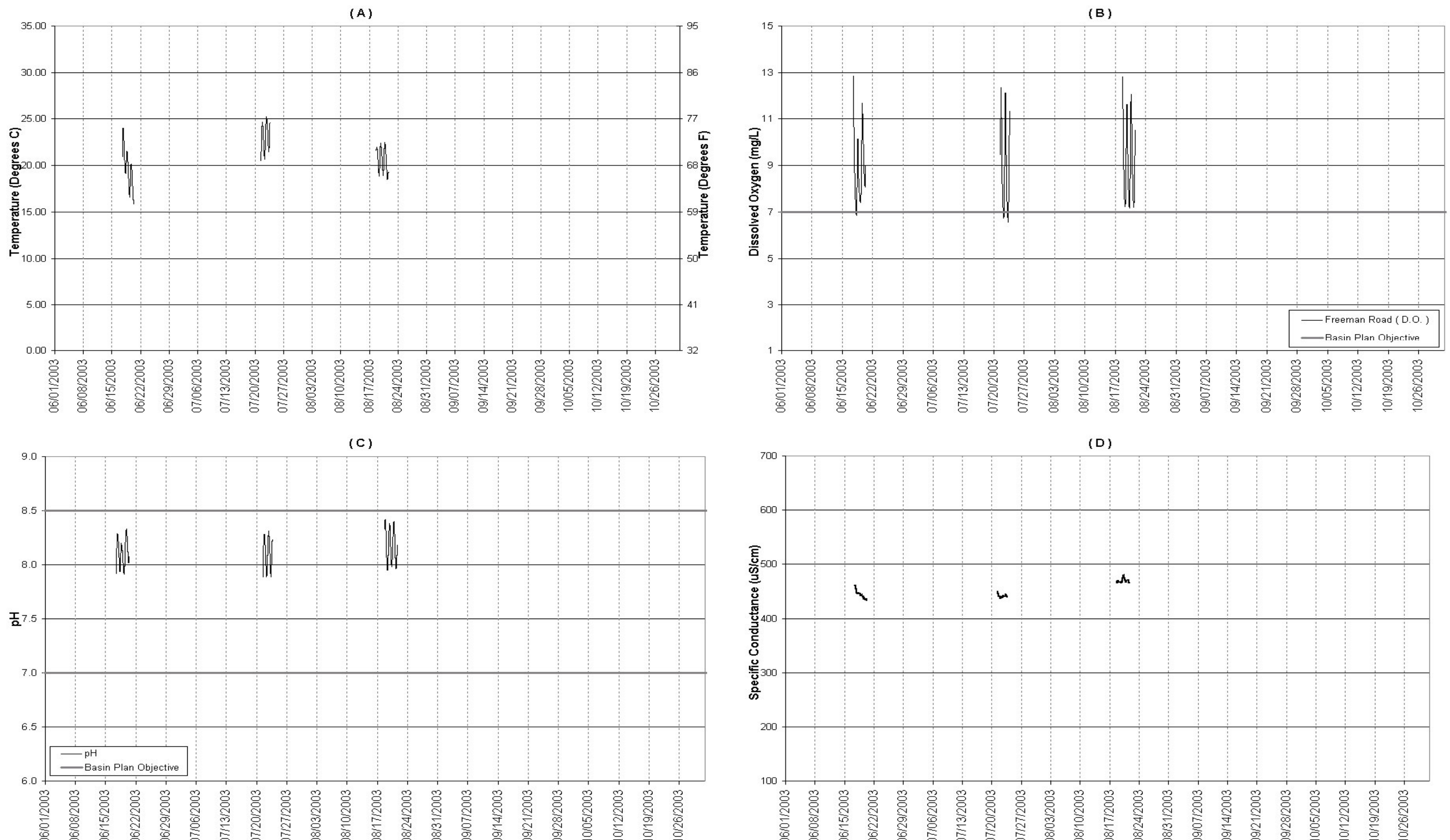


Figure 28. Continuous Sonde Data - Shasta River @ Freeman Road - Collected by NCRWQCB: 06/01/03 – 10/31/03 (A) Temperature, (B) Dissolved Oxygen, (C) pH, (D) Specific Conductance.

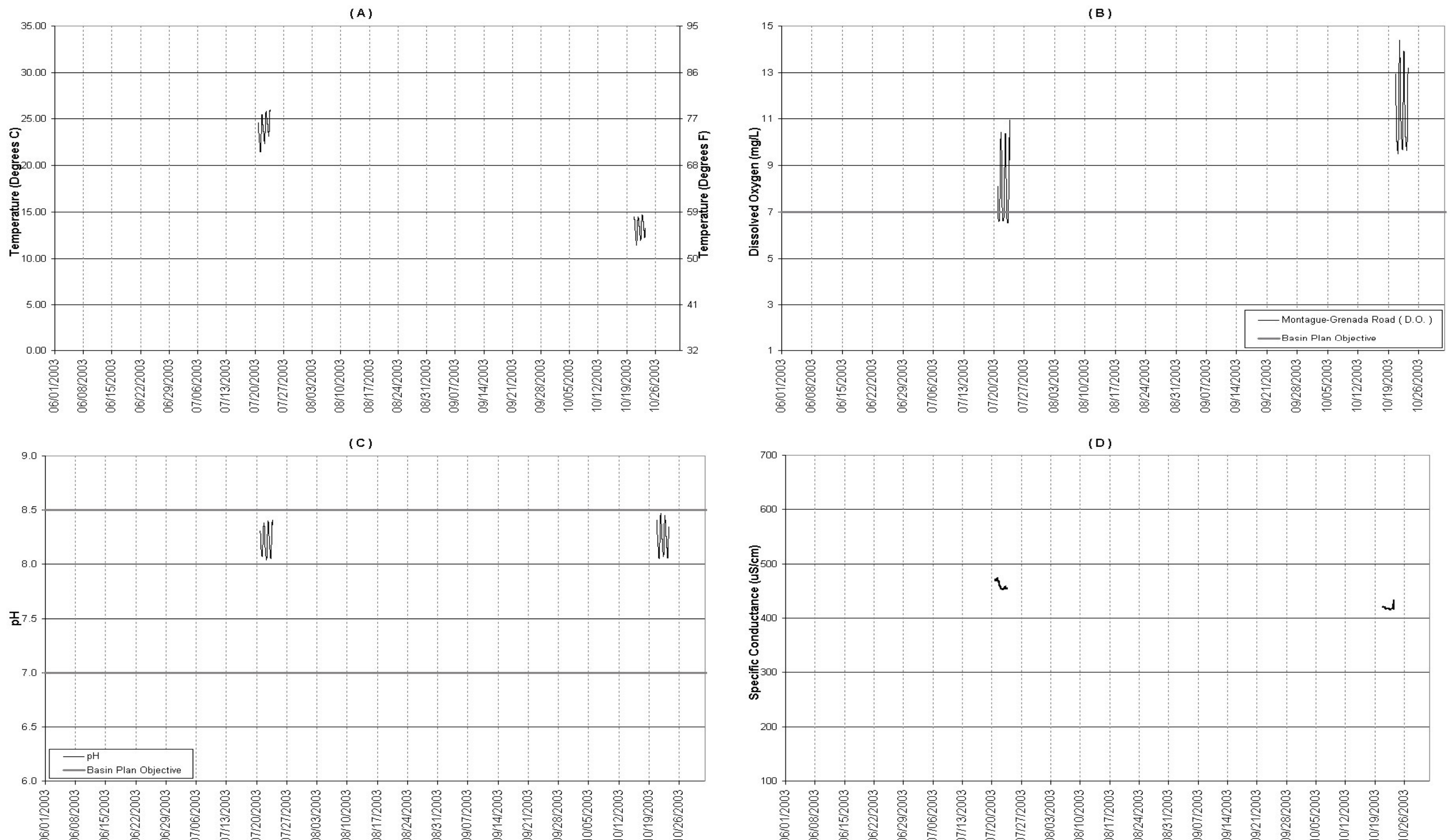


Figure 29. Continuous Sonde Data - Shasta River @ Montague-Grenada Road - Collected by NCRWQCB: 06/01/03 – 10/31/03 (A) Temperature, (B) Dissolved Oxygen, (C) pH, (D) Specific Conductance.

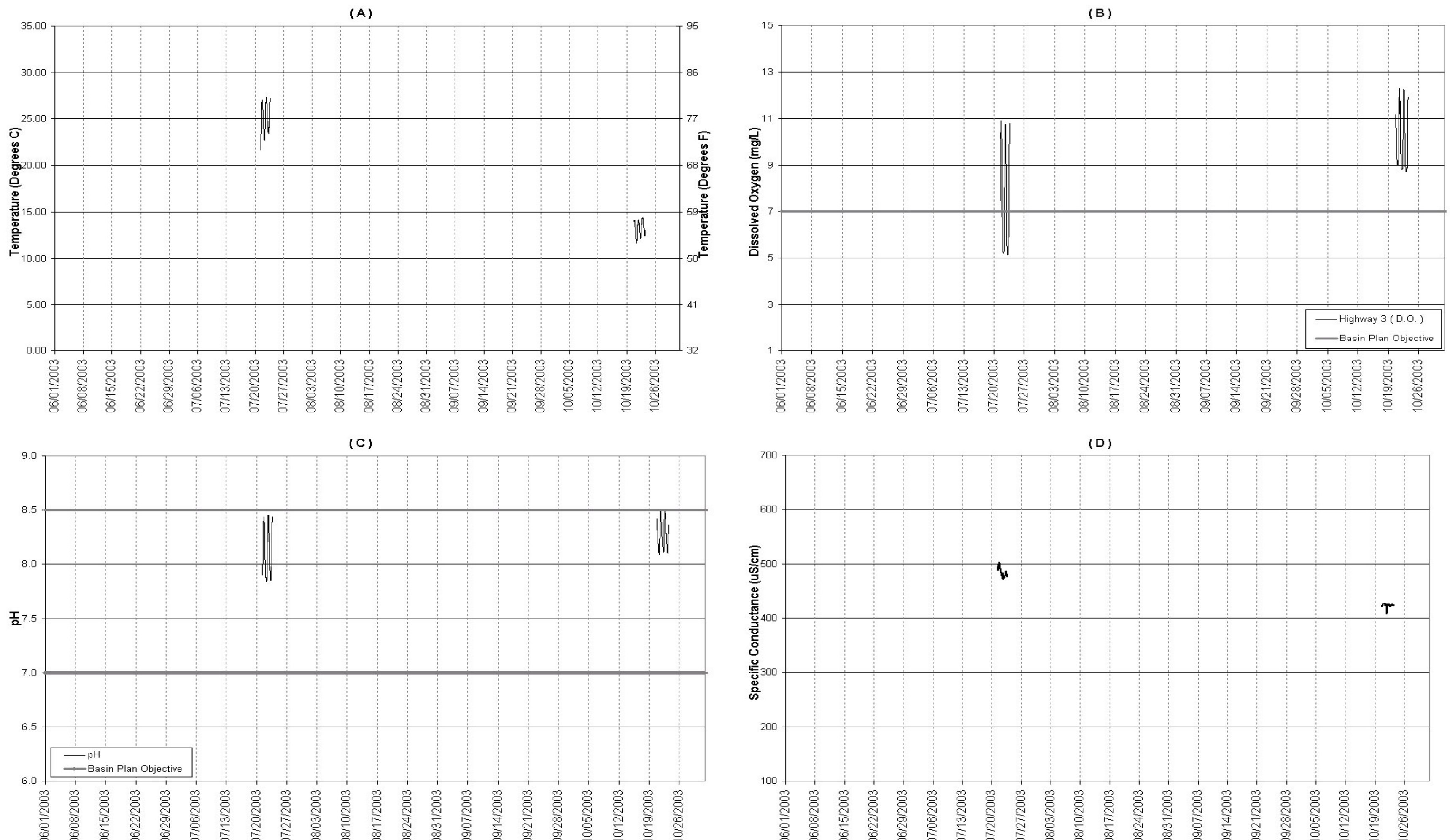


Figure 30. Continuous Sonde Data - Shasta River @ Highway 3 - Collected by NCRWQCB: 06/01/03 – 10/31/03 (A) Temperature, (B) Dissolved Oxygen, (C) pH, (D) Specific Conductance.

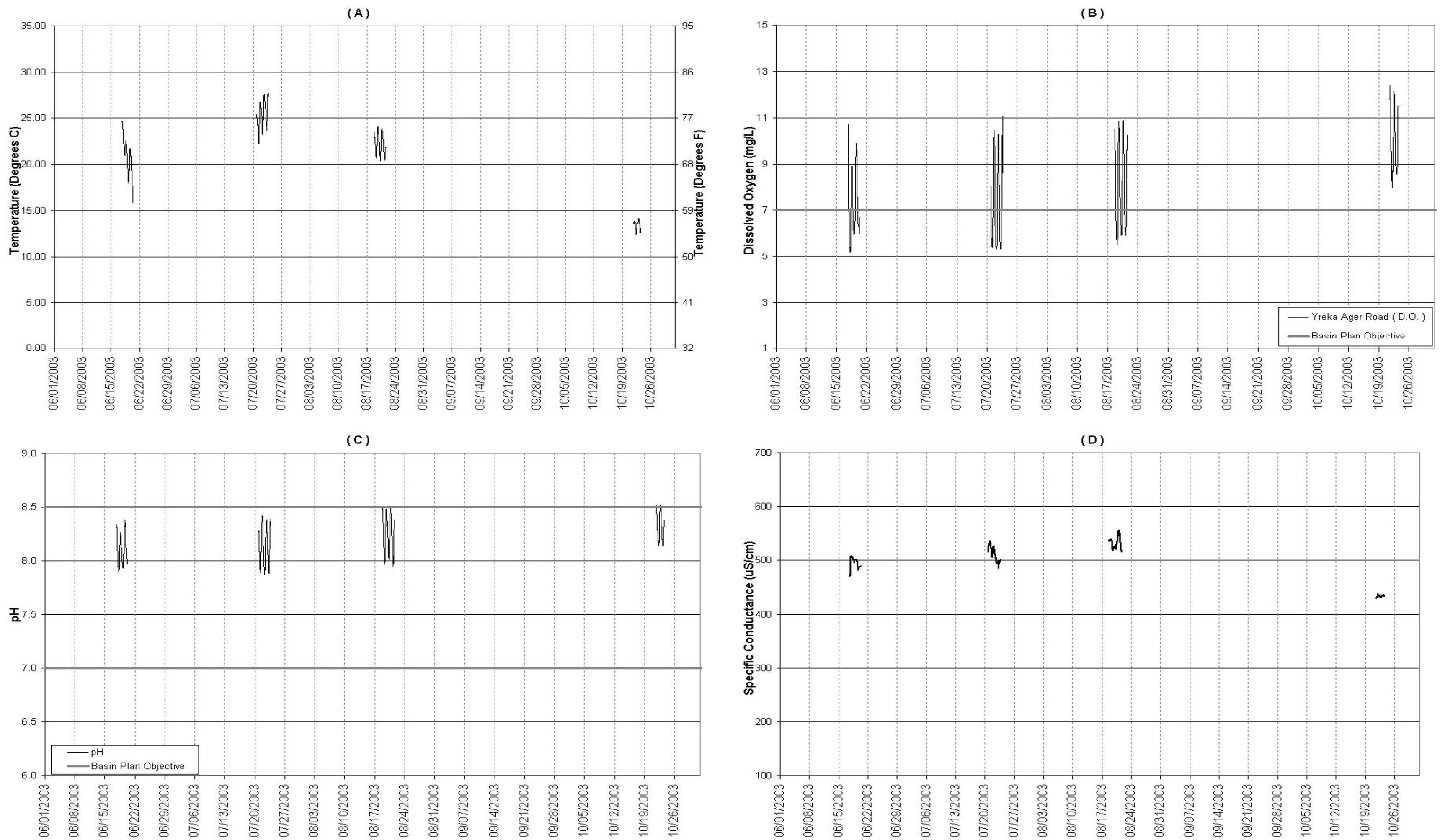


Figure 31. Continuous Sonde Data - Shasta River @ Yreka-Ager Road - Collected by NCRWQCB: 06/01/03 – 10/31/03 (A) Temperature, (B) Dissolved Oxygen, (C) pH, (D) Specific Conductance.

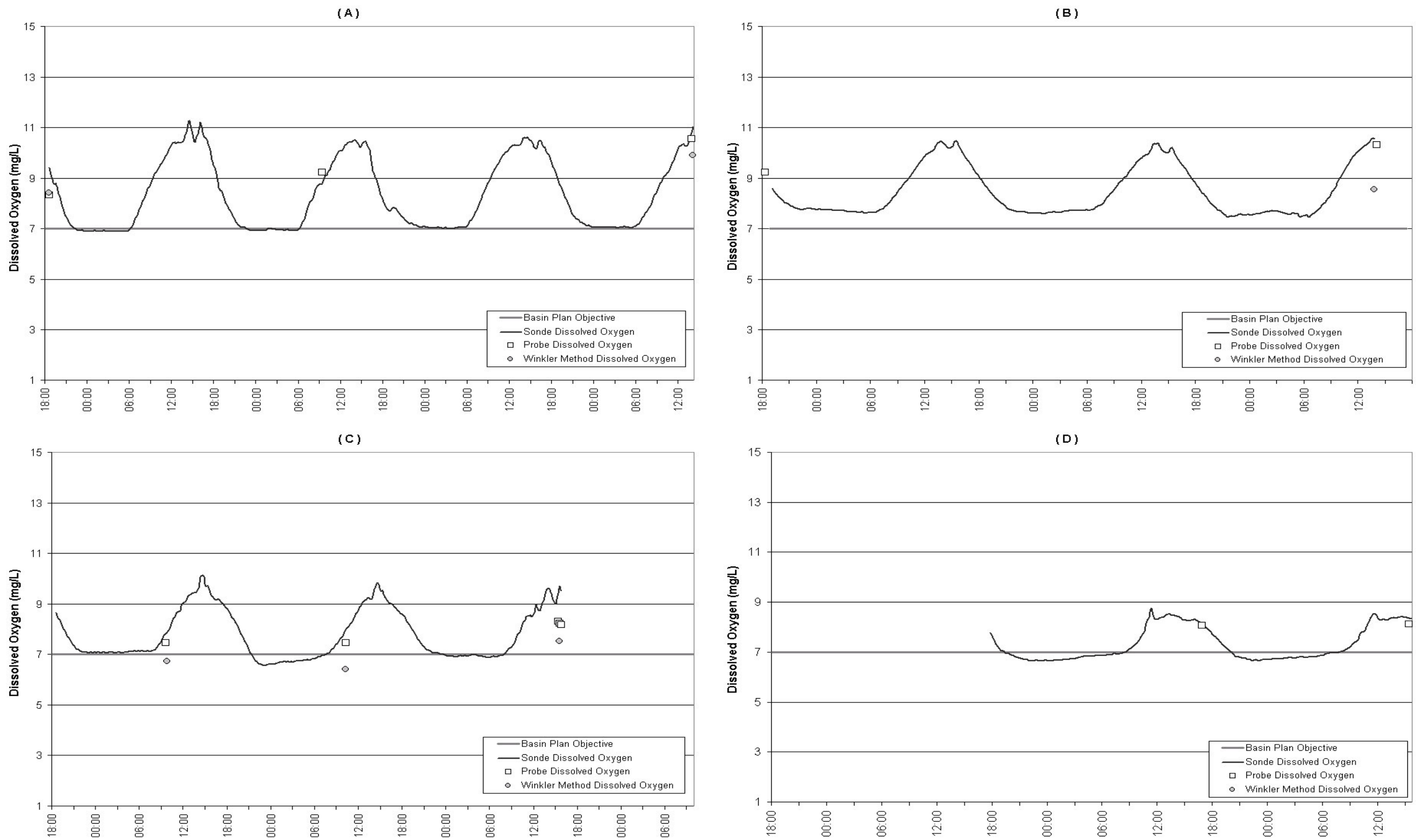


Figure 32. Continuous Dissolved Oxygen Data - Shasta River @ Riverside Drive - Collected by NCRWQCB: (A) 06/16/03 – 06/20/03, (B) 07/20/03 – 07/23/03, (C) 08/18/03 – 08/22/03, (D) 10/20/03 – 10/23/03.

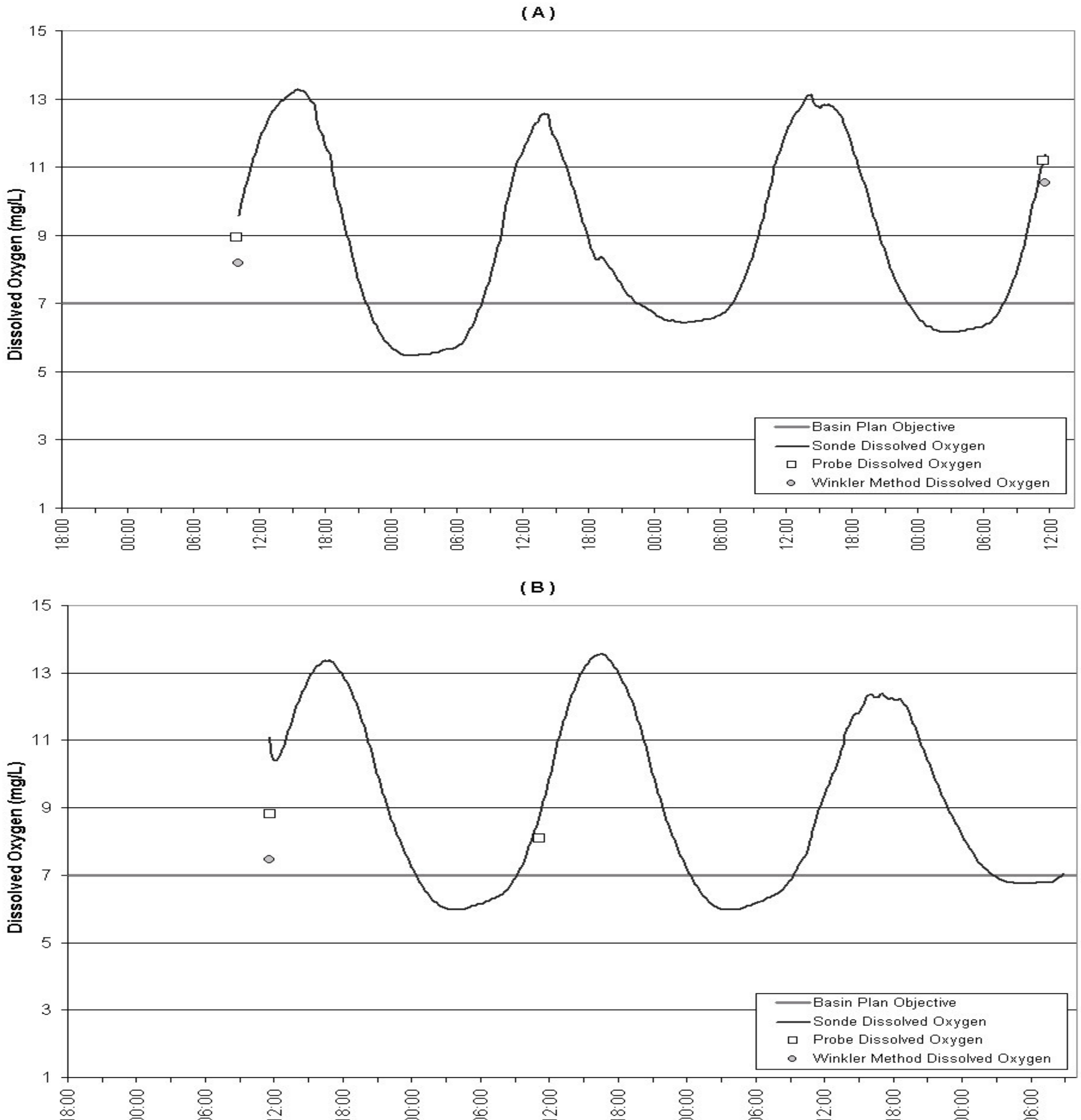


Figure 33. Continuous Dissolved Oxygen Data - Shasta River d/s Big Springs Creek - Collected by NCRWQCB: (A) 06/16/03 – 06/20/03, (B) 08/18/03 – 08/22/03.

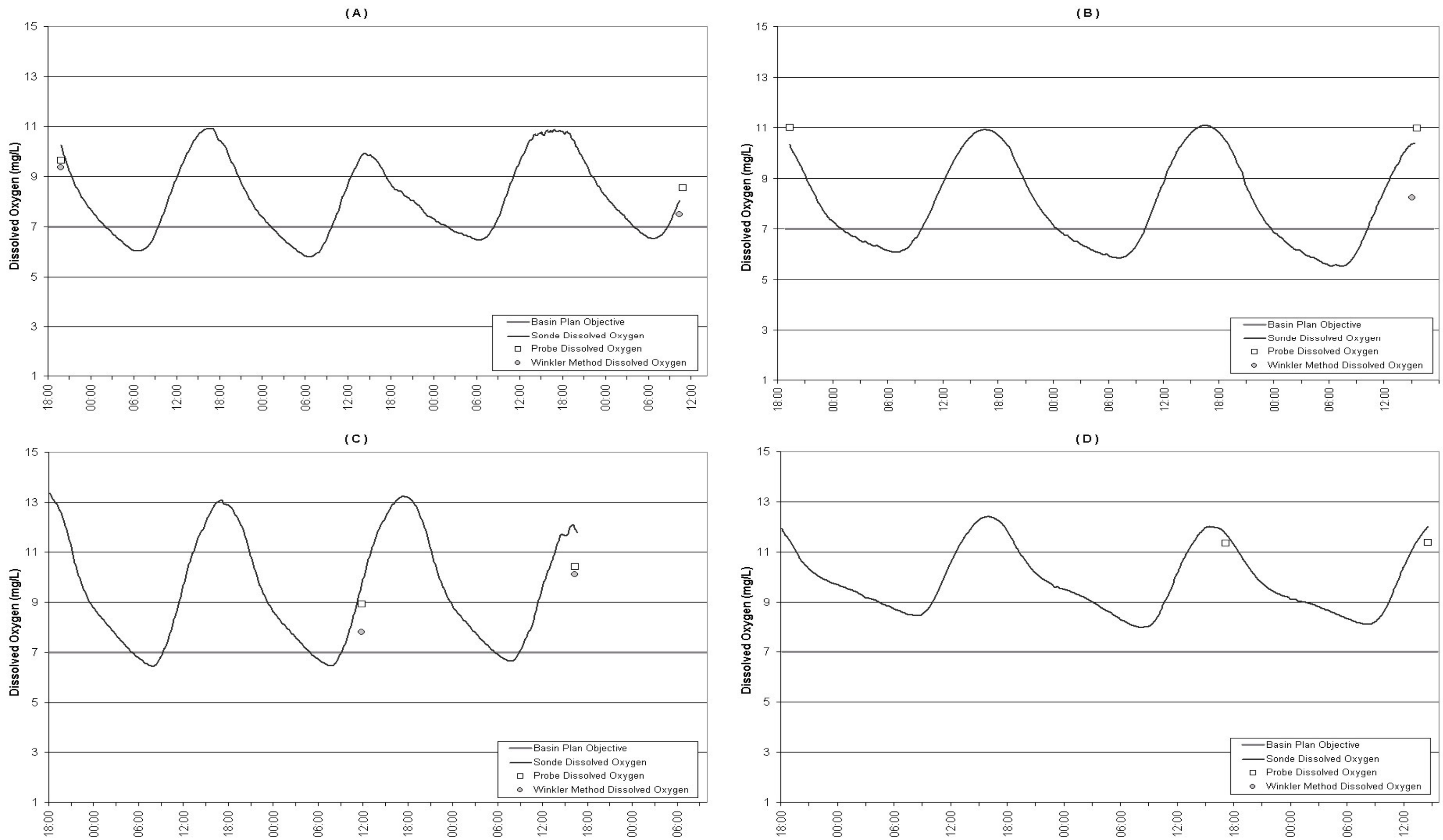


Figure 34. Continuous Dissolved Oxygen Data - Shasta River @ County Road A-12 - Collected by NCRWQCB: (A) 06/16/03 – 06/20/03, (B) 07/20/03 – 07/23/03, (C) 08/18/03 – 08/22/03, (D) 10/20/03 – 10/23/03.

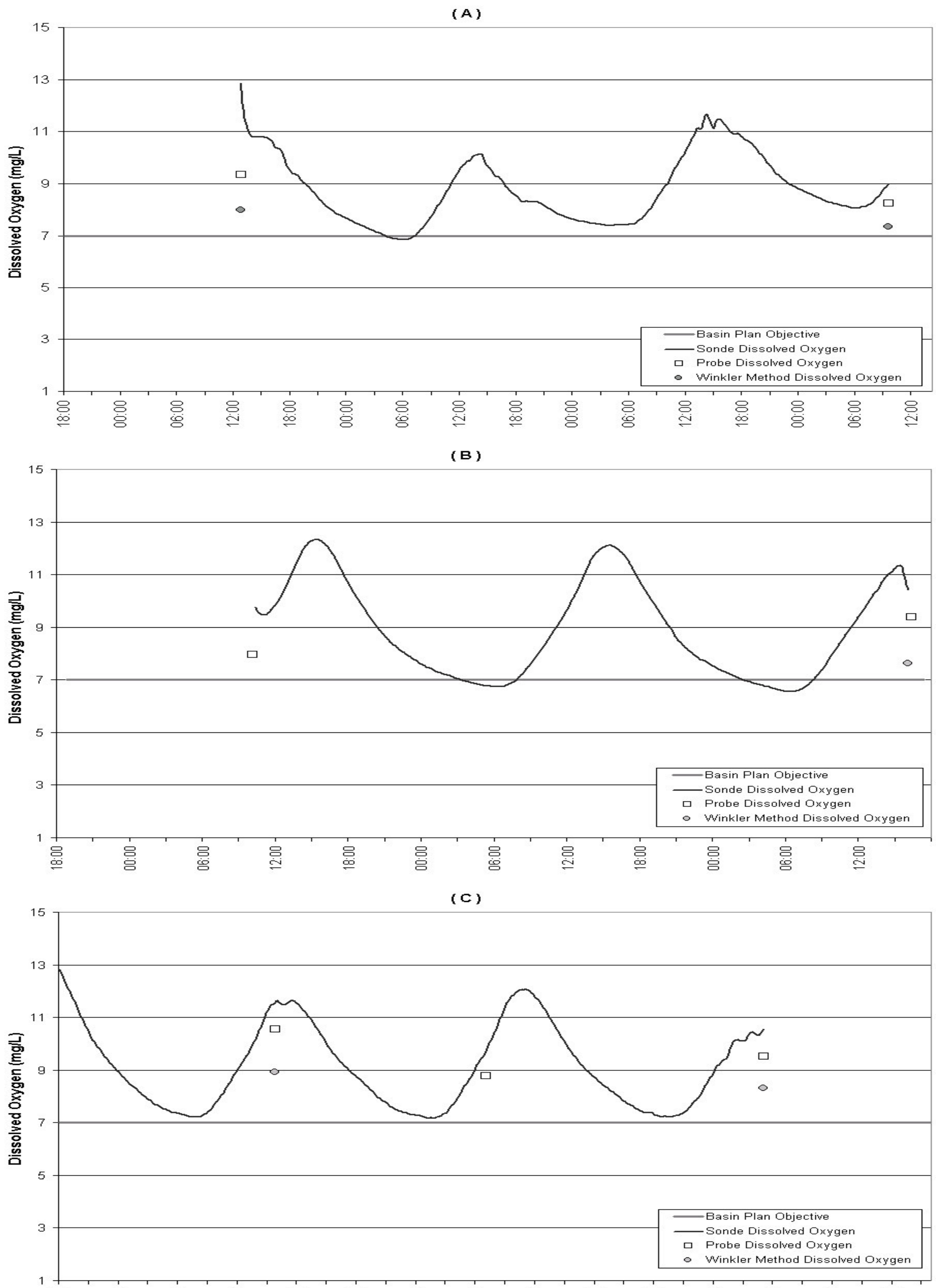


Figure 35. Continuous Dissolved Oxygen Data - Shasta River @ Freeman Road - Collected by NCRWQCB: (A) 06/16/03 – 06/20/03, (B) 07/20/03 – 07/23/03, (C) 08/18/03 – 08/22/03.

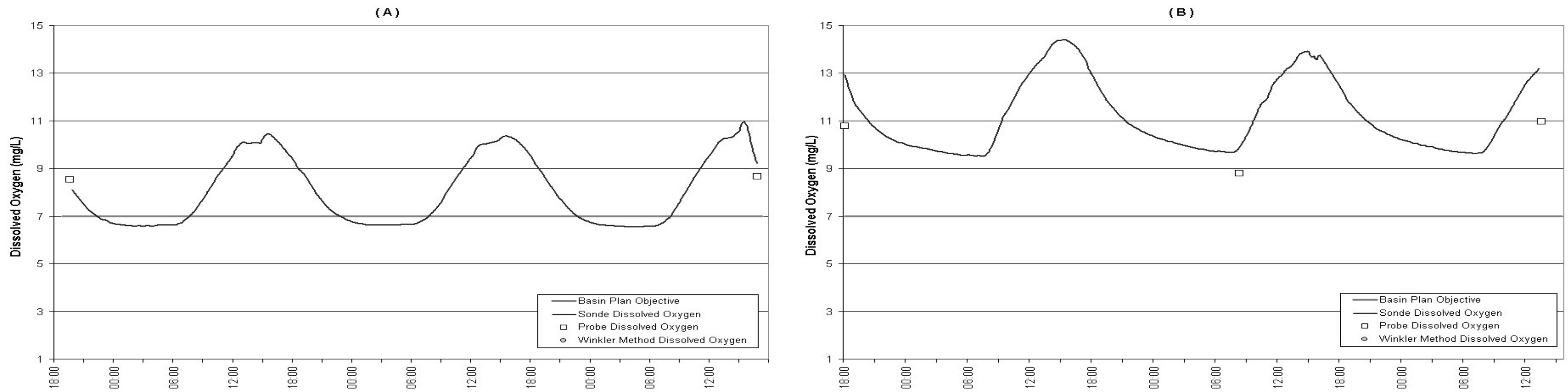


Figure 36. Continuous Dissolved Oxygen Data - Shasta River @ Montague-Grenada Road - Collected by NCRWQCB: (A) 07/20/03 – 07/23/03, (B) 10/20/03 – 10/23/03.

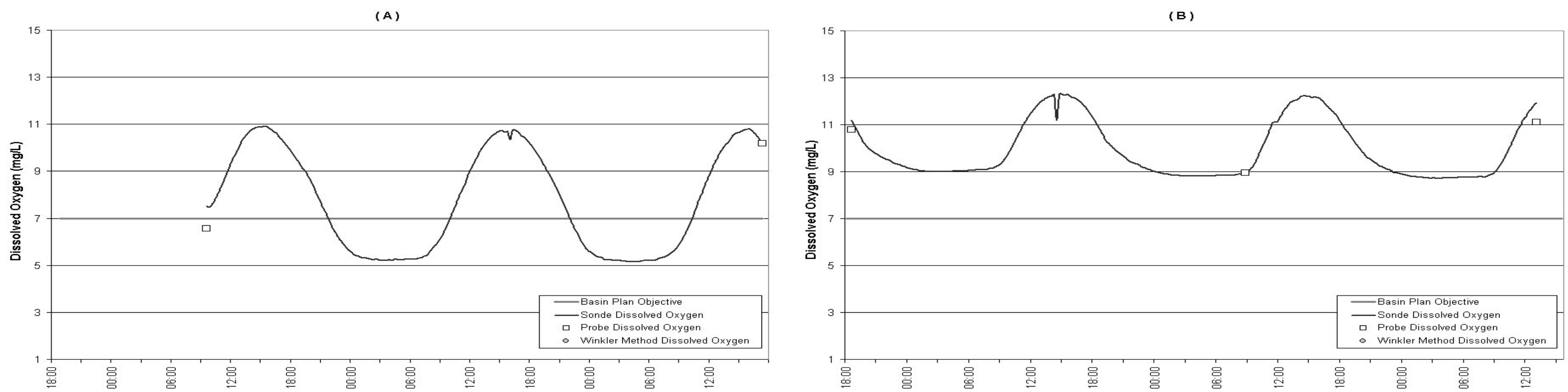


Figure 37. Continuous Dissolved Oxygen Data - Shasta River @ Highway 3 - Collected by NCRWQCB: (A) 07/20/03 – 07/23/03, (B) 10/20/03 – 10/23/03.

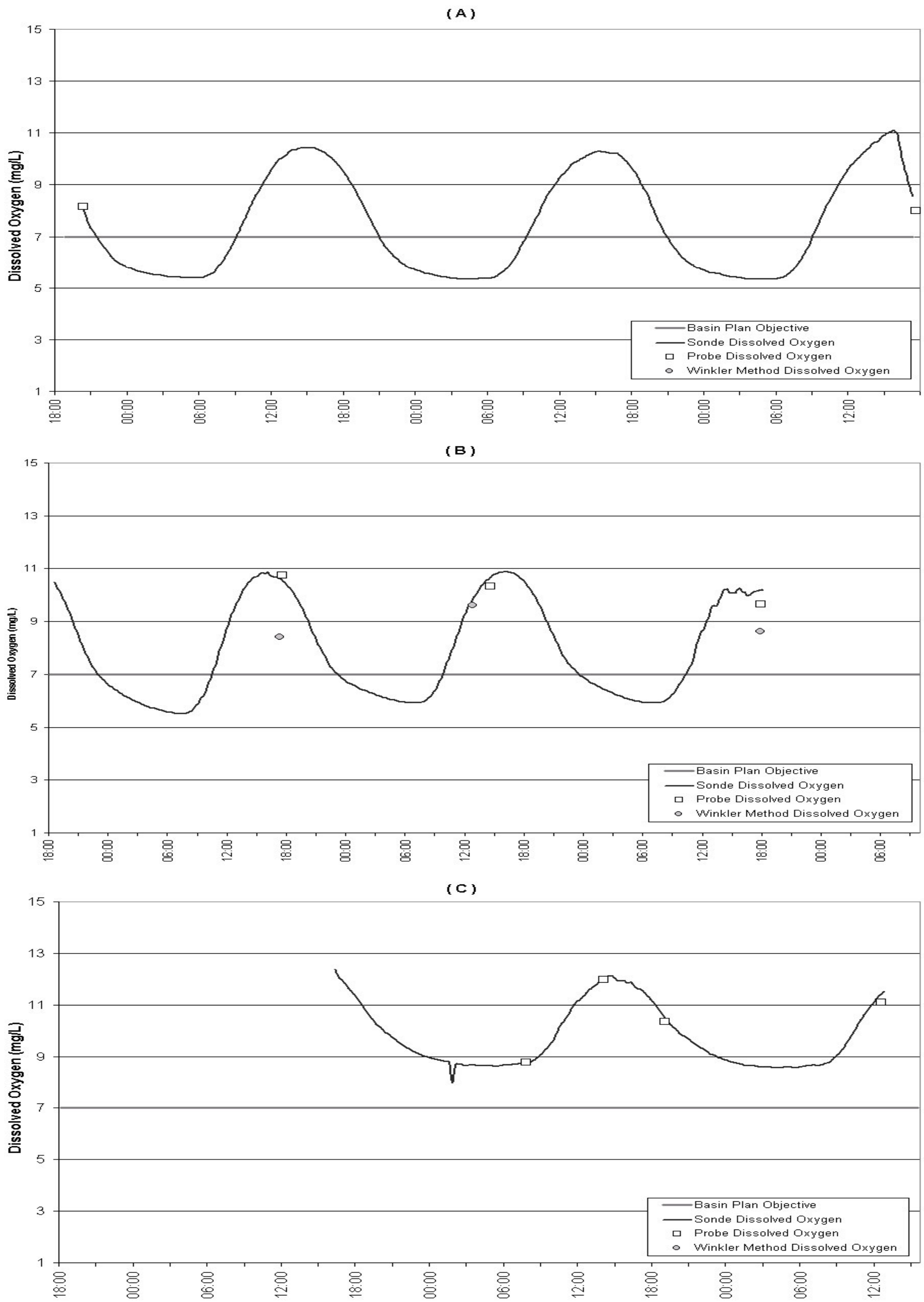


Figure 38. Continuous Dissolved Oxygen Data - Shasta River @ Yreka-Ager Road - Collected by NCRWQCB: (A) 07/20/03 – 07/23/03, (B) 08/18/03 – 08/22/03, (C) 10/20/03 – 10/23/03.

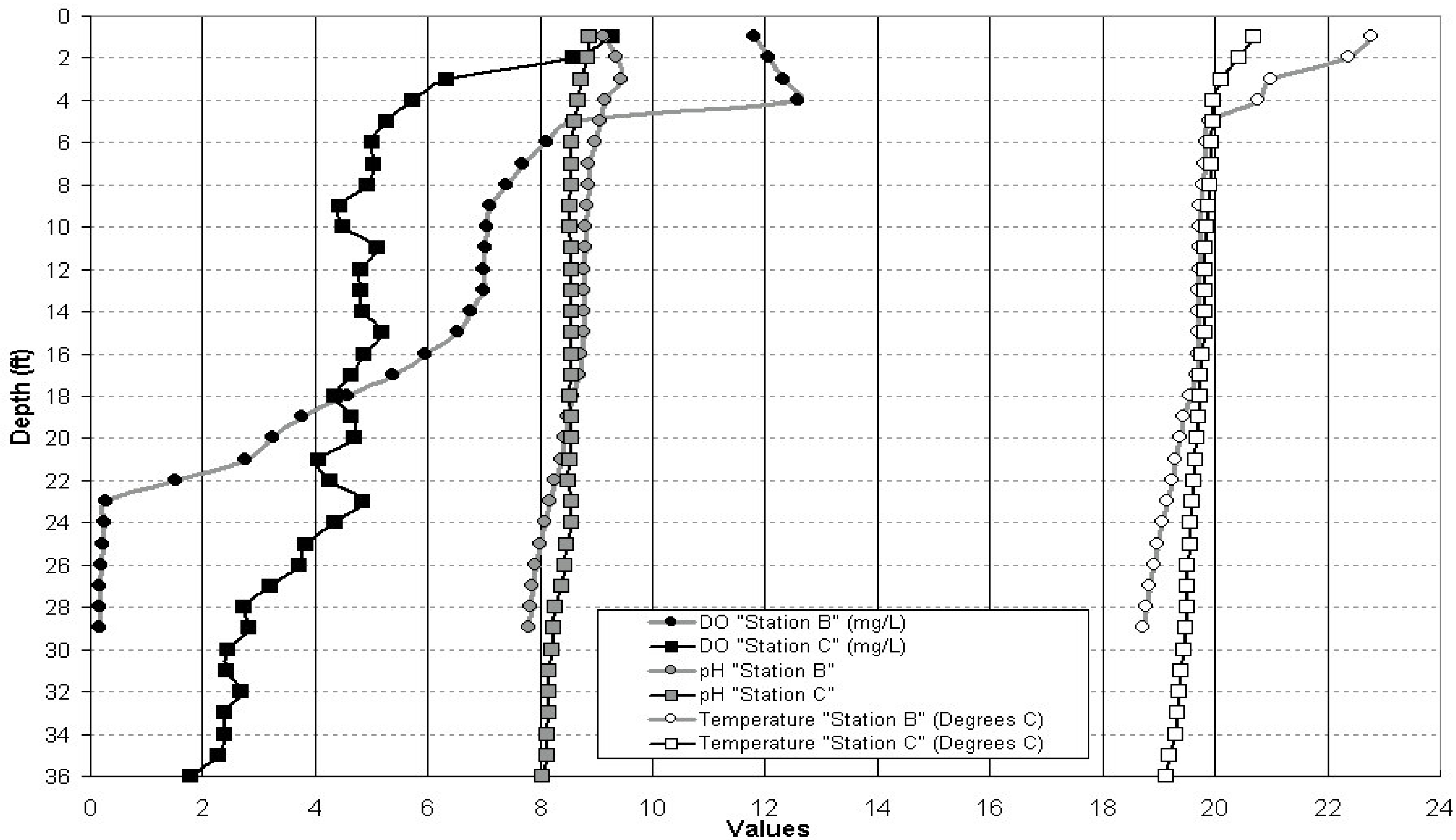


Figure 39. Temperature, Dissolved Oxygen, pH Profile Data – Lake Shastina - Collected by NCRWQCB: 09/10/03.

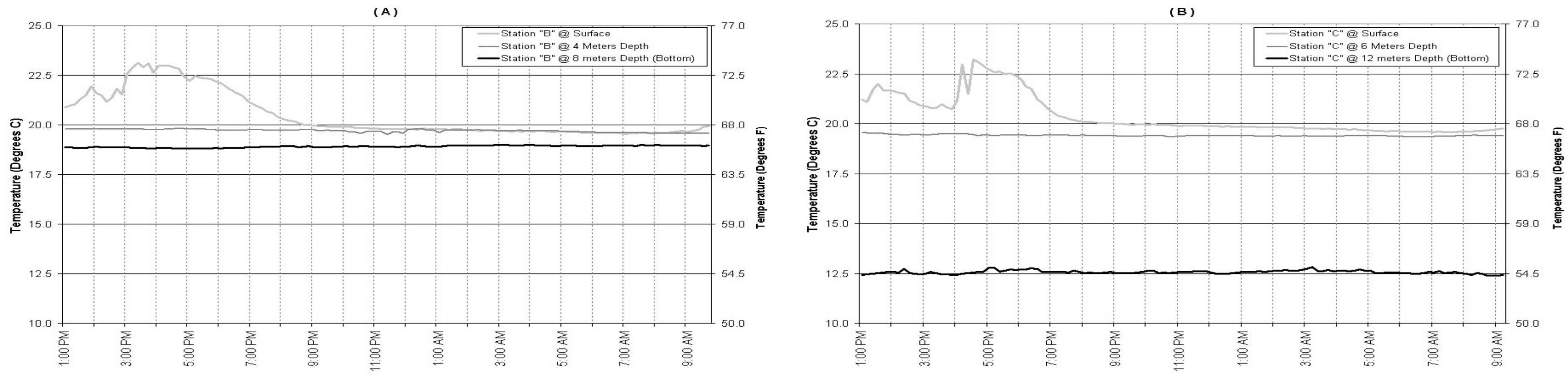


Figure 40. Continuous Temperature Data – Lake Shastina - Collected by NCRWQCB: A) Station "B" 09/10/03, (B) Station "C" 09/10/03.

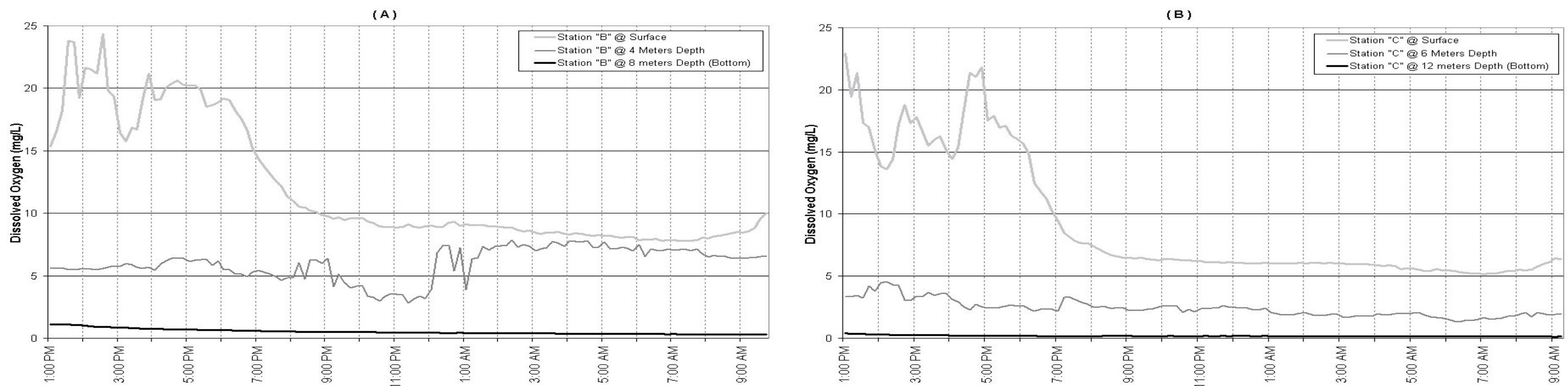


Figure 41. Continuous Dissolved Oxygen Data – Lake Shastina - Collected by NCRWQCB: : A) Station "B" 09/10/03, (B) Station "C" 09/10/03.

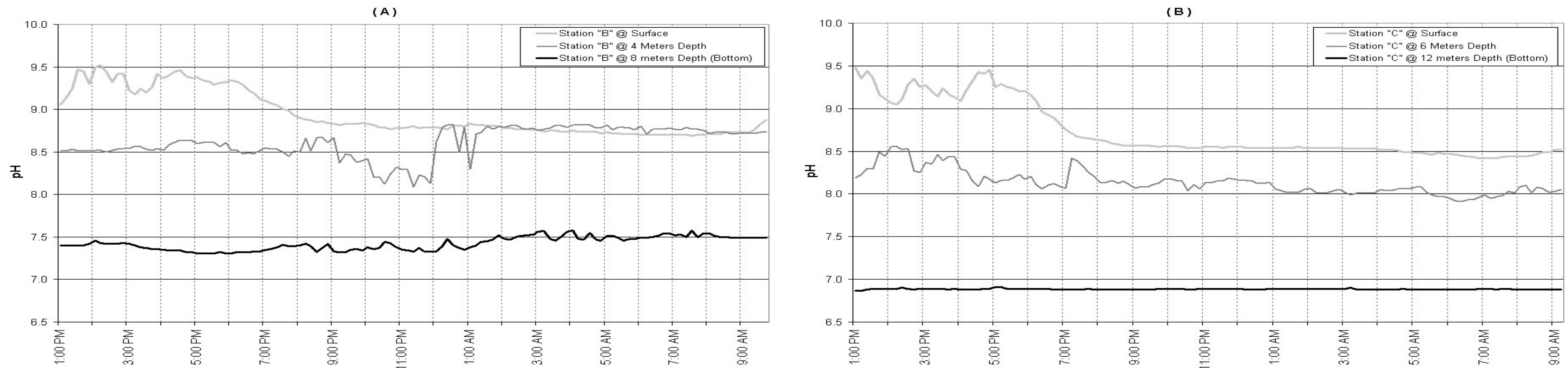


Figure 42. Continuous pH Data – Lake Shastina - Collected by NCRWQCB: A) Station "B" 09/10/03, (B) Station "C" 09/10/03.

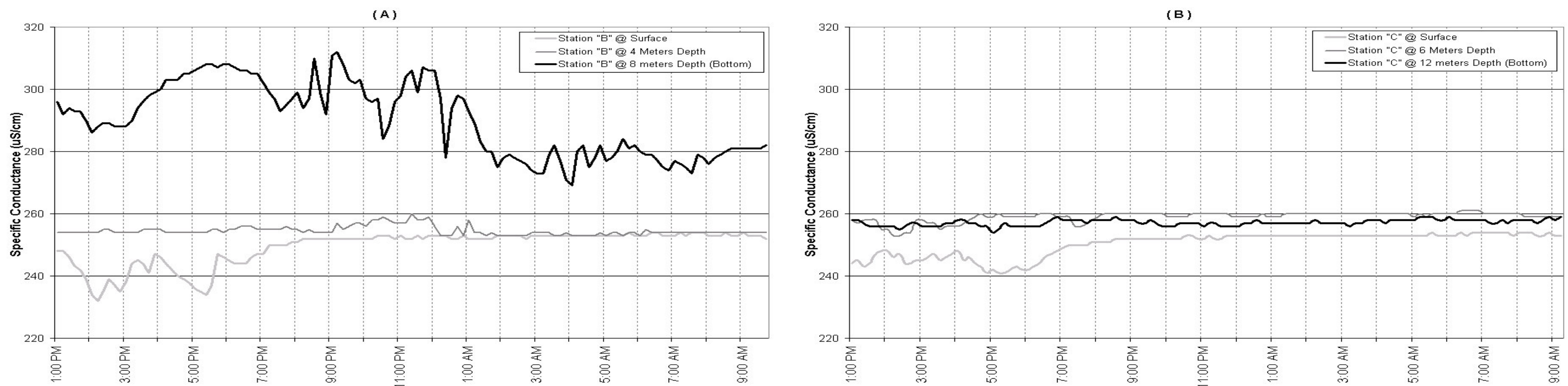


Figure 43. Continuous Specific Conductance Data – Lake Shastina - Collected by NCRWQCB: A) Station "B" 09/10/03, (B) Station "C" 09/10/03.

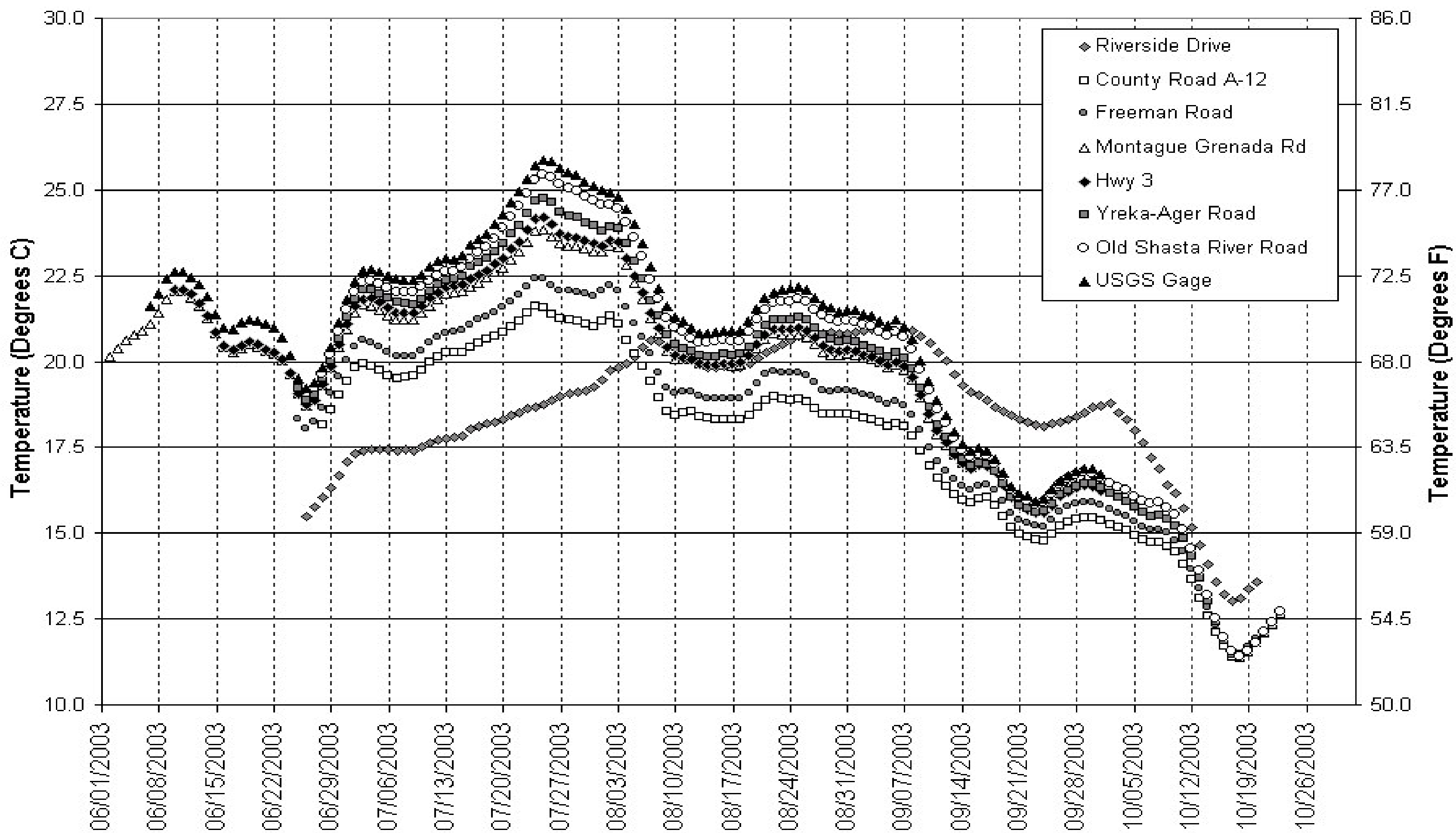


Figure 44. Weekly Average Temperature – Shasta River @ Various Locations - Collected by NCRWQCB & USGS: 06/01/03 – 10/31/03.

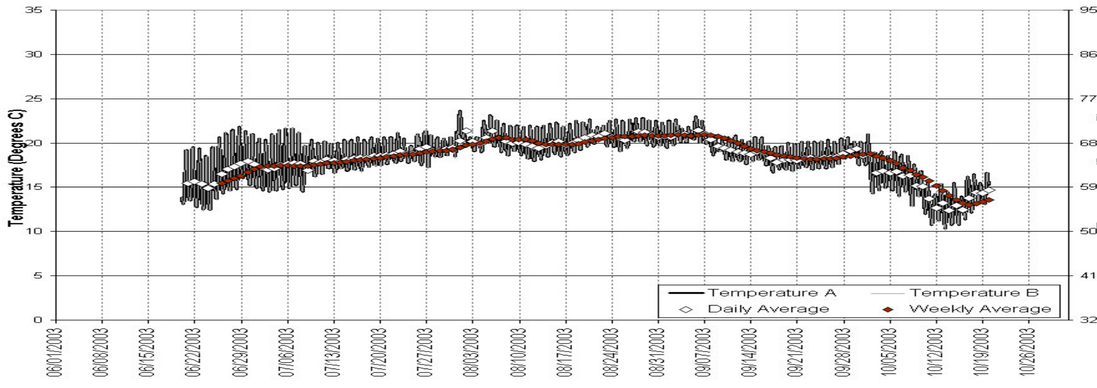


Figure 45. Continuous Temperature Data - Shasta River @ Riverside Drive - Collected by NCRWQCB: 06/01/03 - 10/31/03. **(For quality control purposes, two optic StowAway sensors (A and B) were deployed at this site).**

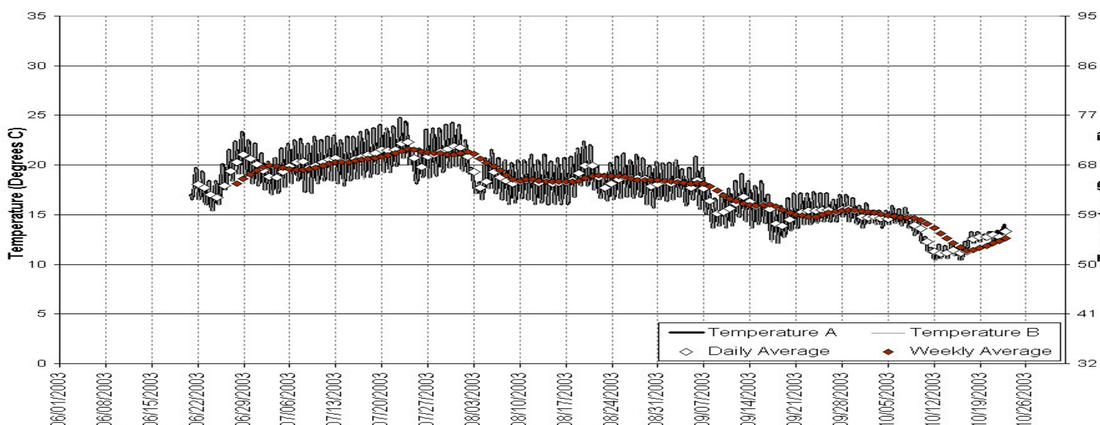


Figure 46. Continuous Temperature Data - Shasta River @ County Road A-12 - Collected by NCRWQCB: 06/01/03 - 10/31/03. **(For quality control purposes, two optic StowAway sensors (A and B) were deployed at this site).**

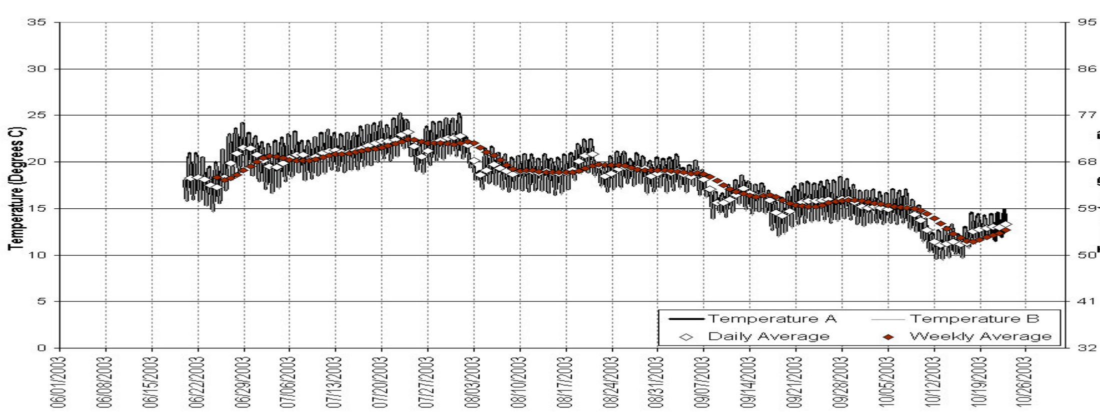


Figure 47. Continuous Temperature Data - Shasta River @ Freeman Road - Collected by NCRWQCB: 06/01/03 - 10/31/03. **(For quality control purposes, two optic StowAway sensors (A and B) were deployed at this site).**

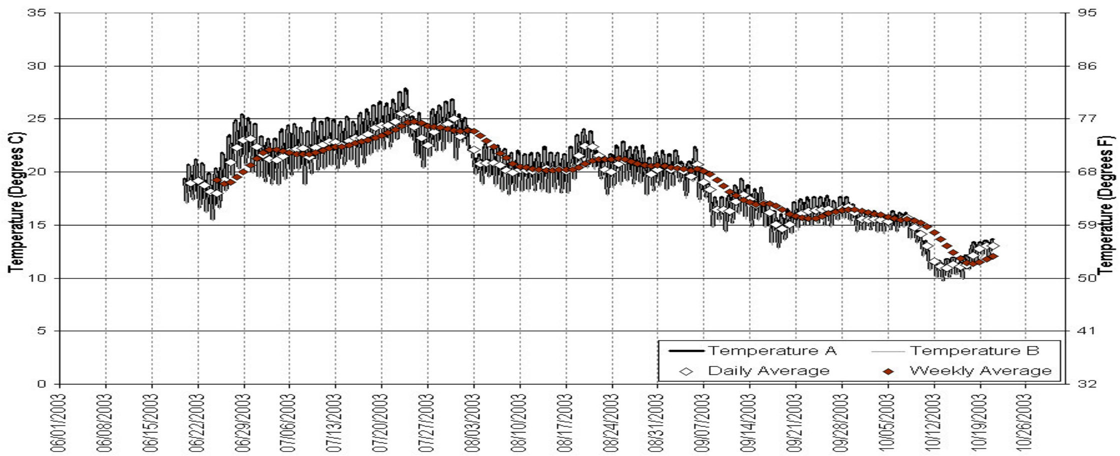


Figure 48. Continuous Temperature Data - Shasta River @ Yreka-Ager Road - Collected by NCRWQCB: 06/01/03 - 10/31/03. **(For quality control purposes, two optic StowAway sensors (A and B) were deployed at this site).**

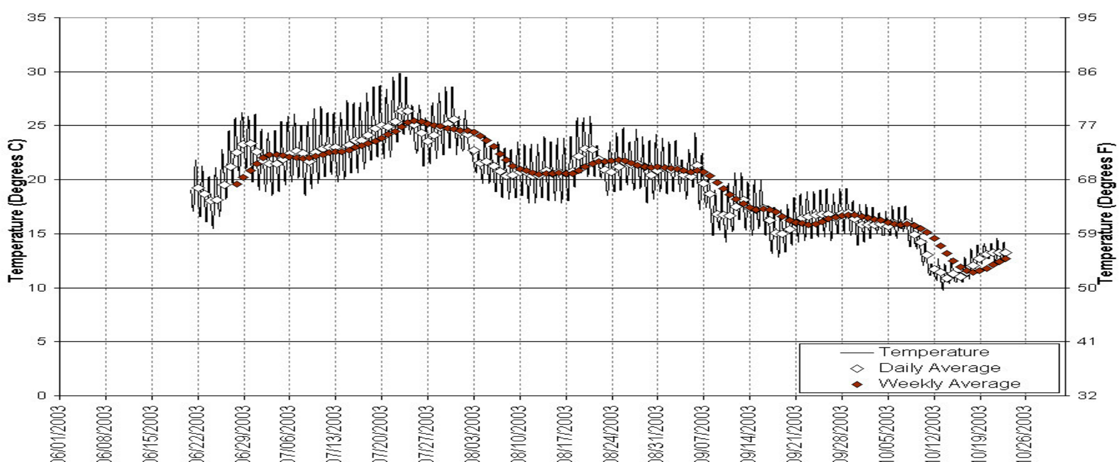


Figure 49. Continuous Temperature Data - Shasta River @ Old Shasta River Road - Collected by NCRWQCB: 06/01/03 - 10/31/03.

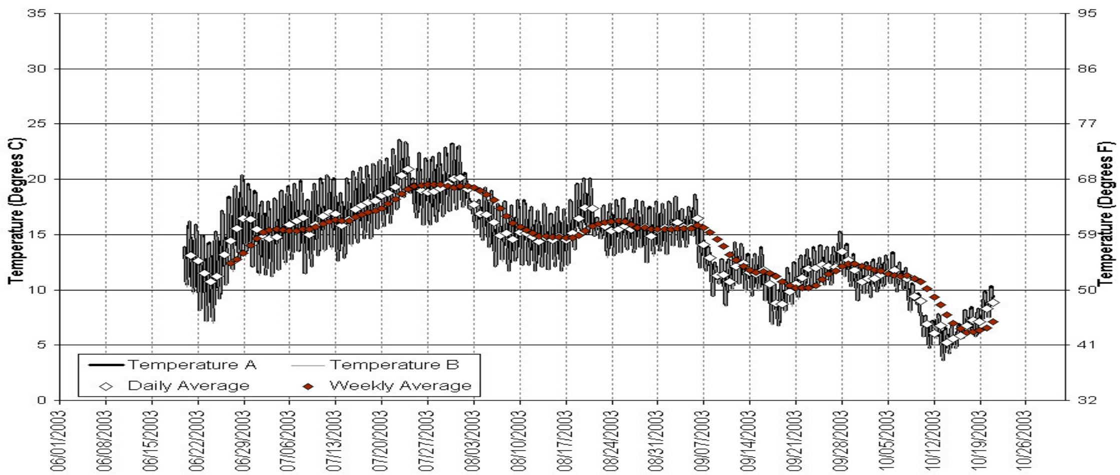


Figure 50. Continuous Temperature Data – Little Shasta River @ Ball Mountain Road - Collected by NCRWQCB: 06/01/03 - 10/31/03. **(For quality control purposes, two optic StowAway sensors (A and B) were deployed at this site).**

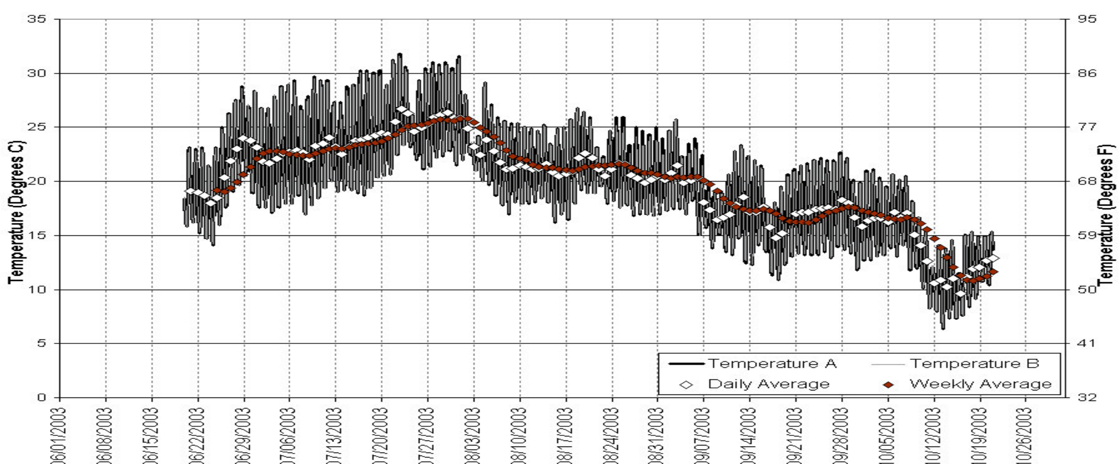


Figure 51. Continuous Temperature Data – Little Shasta River near Mouth - Collected by NCRWQCB: 06/01/03 - 10/31/03. **(For quality control purposes, two optic StowAway sensors (A and B) were deployed at this site).**

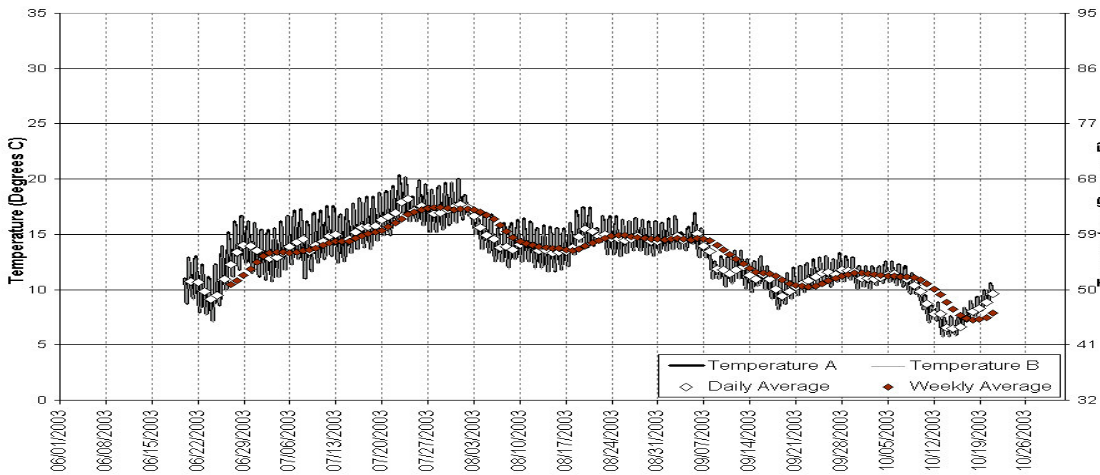


Figure 52. Continuous Temperature Data – Upper Parks Creek - Collected by NCRWQCB: 06/01/03 - 10/31/03. **(For quality control purposes, two optic StowAway sensors (A and B) were deployed at this site).**

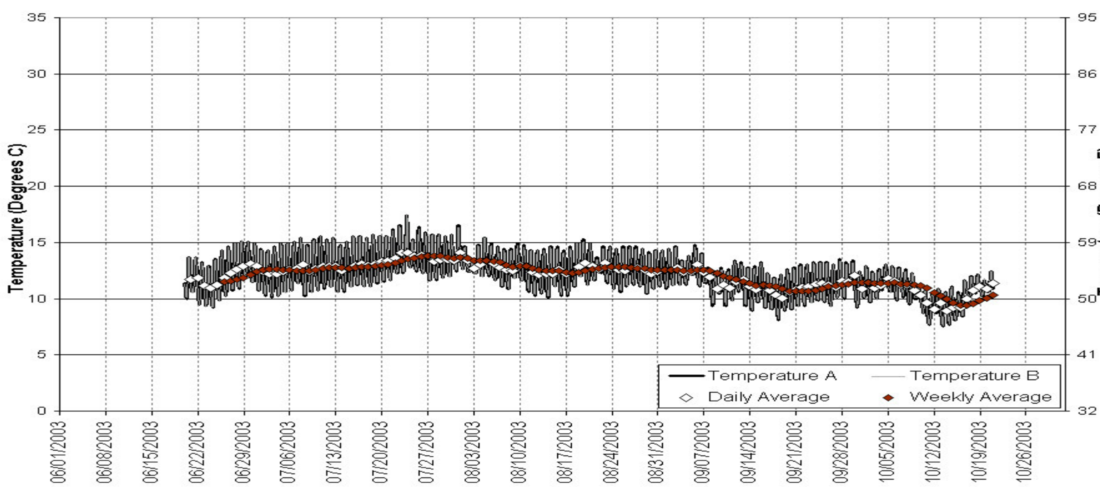


Figure 53. Continuous Temperature Data – Boles Creek - Collected by NCRWQCB: 06/01/03 - 10/31/03. **(For quality control purposes, two optic StowAway sensors (A and B) were deployed at this site).**

Appendix 1: Methodology for Correcting Continuous Dissolved Oxygen Data from USGS Datasonde Sensors and Associated Data Uncertainty

NOTE: This appendix is excerpted from a USGS report by Flint and co-workers (2004), which, as of May 5, 2004, is in draft and is subject to revision.

The continuous field measurement of dissolved oxygen is difficult and requires frequent site visits for probe maintenance and cleaning due to biofouling and recalibration for sensor drift. Data are thus corrected to maintain the best accuracy according to field calibrations. In order to illustrate reliability of USGS dissolved oxygen data collection and data accuracy, the following discussion describes the theory of dissolved oxygen measurements and inherent errors associated with the measurements. USGS protocols for probe deployment and maintenance, data processing, and reporting are briefly described with information excerpted from Wagner and others (2000). This publication and several other publications are available for more details on USGS protocols (Radke and others, 1998; Wilde and Radke, 1998). Additional discussion regarding supersaturated dissolved oxygen conditions comes from studies in Oregon lakes and rivers (Doyle and Caldwell, 1996; Kelly, 1997; Rounds and others, 1998; Wood and Rounds, 1998). Examples of data collected on the Shasta River for 2002 and 2003 are used to illustrate data uncertainty in the Lower Klamath River Basin.

Theory and Measurement of Dissolved Oxygen

The DO concentration in surface water is related primarily to atmospheric reaeration and photosynthetic activity of aquatic plants (*Radtke and others, 1998*). The range of observed DO in surface waters typically is from 2 to 10 milligrams per liter (mg/L) at 20 °C. The value for 100-percent saturation of DO decreases with increased temperature and salinity, and increases with increased atmospheric pressure. Occasions of excess oxygen (supersaturation) often are related to extreme photosynthetic production of oxygen by aquatic plants as a result of nutrient (nitrogen and phosphorus) enrichment, sunlight, and low-flow conditions. Occasions of saturated oxygen commonly are related to cascading flow conditions, both natural and artificial. DO may be depleted by inorganic oxidation reactions or by biological and chemical processes that consume dissolved, suspended, or precipitated organic matter (*Hem, 1989*).

The most commonly used technique for measuring DO concentrations with continuous water-quality sensors is the amperometric method, which measures DO with a temperature-compensated polarographic membrane-type sensor. While polarographic membrane-type sensors generally provide accurate results, they commonly are sensitive to temperature and water velocity and are prone to fouling. Because the permeability of the membrane and solubility of oxygen in water change as functions of temperature, barometric pressure, and salinity, it is critical that the DO sensors be calibrated. DO sensors are prone to inaccuracies from algal fouling, sedimentation, low velocity, and very high velocities. They also experience drift in the electronics, and can experience leakage of the membrane. A complete discussion of DO calibration, measurement, and limitations can be found in *Radtke and others (1998)*.

USGS Protocols for Collecting, Processing, and Reporting Continuous Dissolved Oxygen Data

Lower Klamath River Basin studies implemented YSI 6920 Data Sonde meters with dissolved oxygen sensors. Implementation of the meters during the 2002 and 2003 field seasons followed standard USGS protocols for the collection of continuous dissolved oxygen data, calibration of meters, and correction and reporting of data (Wilde and Radtke, 1998).

Collecting field measurements of dissolved oxygen

Maintenance frequency of DO sensors generally is governed by the fouling rate, and this rate varies by sensor type, hydrologic environment, and season. In addition to fouling problems, physical disruptions (such as pump failure, recording equipment malfunction, sedimentation, electrical disruption, debris, or vandalism) or battery failure also may require additional site visits.

During a site visit the sensor inspection is done to provide an ending point for the interval of water quality record since the last service visit, a beginning point for the next interval of water-quality record, and verification that the sensor is working properly. This is accomplished by recording the initial sensor readings, servicing the sensors, recording the cleaned sensor readings, performing a calibration check of sensors by using the 100% oxygen saturated standard, and if the readings of the DO sensor are outside the range of acceptable differences, +/- 0.3 mg/L, recalibrating the sensor. The difference between the initial sensor reading and the cleaned sensor reading is the sensor error as a result of fouling; the difference between the calibration-check reading and calibrated-sensor reading, if necessary, is a result of drift.

Data-processing procedures

Corrections to data should not be made unless the causes of errors can be validated or explained by information or observations in the field notes or by comparison to information from adjacent stations. The initial data evaluation checks the success of the transfer of raw field data (instrument readings) to the office data base and provides the opportunity for initial checks to evaluate and correct erroneous data. The application of corrections and shifts allows data to be adjusted to compensate for errors that occurred during the service interval as a result of environmental or instrumentation effects. The sequence for determining the type and degree of measurement error in the field for DO generally is for fouling, then drift. If the deviation between actual value and sensor reading exceed the criterion for water-quality data shifts, a correction is required. The correction is a linear interpolation over the time between sensor inspections. The allowable limit of +/- 0.3 mg/L is a minimal requirement.

Identification of electronic drift or loss of sensor sensitivity should be distinguished from fouling drift, if at all possible. The degree of fouling is determined from the difference between sensor measurements before and after the sensors are cleaned and is assumed to occur linearly with time between sensor checks. A calibration drift is an electronic drift in the equipment from the last time it was calibrated and is determined by the difference between readings of a cleaned sensor in standards or buffers and a calibrated sensor. If, after checking, the deviation from calibrations is within the calibration criteria of the sensor, then no sensor drift is present. Drift is assumed to occur at a constant rate across the service interval. If the sensor readings exceed the shift criteria of 0.3 mg/L, then the correction is a linear interpolation over the time between calibration checks.

Systematic adoption of a standardized final data evaluation process, including maximum allowable limits and publication criteria are used by USGS District offices, which have established quality-control limits for shifting data. These commonly are referred to as “maximum allowable limits.” If the recorded values differ from the field-measured values by more than the maximum allowable limits, the data are not published. For DO, the maximum allowable limit is 2.0 mg/L. This is considered a minimum standard for quality, and Districts are encouraged to establish stricter requirements. Even with the establishment of maximum allowable limits, professional judgment by the hydrographer still is needed in record processing.

Uncertainty in Dissolved Oxygen Data Collection and Processing

Although DO probes are designed to operate linearly, biofouling with time is most likely not a linear function. To the best of our knowledge, few studies have been conducted to measure rates of biofouling and/or instrument drift, and it is not clear exactly how a biofilm affects recorded DO levels, though it likely varies according to numerous factors, including photo-intensity, time of day, temperature, etc. Given these uncertainties, it is USGS’ practice to apply a time-prorated linear data correction to DO data records that exhibit biofouling and instrument drift and report the recorded levels of DO with a qualitative rating of the data. The USGS is one of the only agencies that correct DO data.

Dissolved oxygen data on the Shasta River, 2002-2003

Dissolved oxygen concentrations were measured at three locations in the Shasta River from June through November of 2002, and at four locations from April through September of 2003 (Table 1). To illustrate the methods of data processing, the following data and calculations are included: (1) data following the initial data evaluation, which checks the success of the transfer of raw field data (instrument readings) to the office database and provides the opportunity for initial checks to evaluate and correct erroneous data, (2) computed data following corrections and shifts, and (3) dissolved oxygen at saturation calculated from measured water temperature and atmospheric pressure (average values on the basis of measurements during site visits) (Figures 1 through 4). Occasional corrections for biofouling and drift are evident, more often as decreases in the computed data, although occasionally as increases. There are generally large diurnal fluctuations in the data in mid to late summer, especially at the upper 3 sites where the water is shallower and more slowly moving.

For purposes of example, the site at Edgewood (Figure 4) has site visits noted on the figure. At that site, the instrument was deployed in 2002 at the bottom of an approximately 50-m long riffle. In 2003 the monitor was relocated to above the riffle. Corrections were made following site visits for biofouling in 2002, and for biofouling and drift in 2003 according to Table 2. Calibrations were performed monthly in 2002, and at every site visit in 2003. Corresponding corrections and shifts to the data can be seen as linear prorated changes.

Although the measured DO values commonly exceed the solubility of DO, indicating supersaturated conditions, only three times did the entire diurnal cycle remain supersaturated through 24-hour periods: at Yreka in August (possibly a periphyton bloom/die off) and October of 2002, and at Edgewood in October 2002. The record at Edgewood in October of 2002 is of particular interest, as the diurnal fluctuations in DO exceeded saturated conditions on a 24-hour basis for nearly a month. Comparison of this occurrence with other sites where DO has been studied indicates that supersaturated conditions for extended periods of time do occur occasionally. Studies in Oregon on the Tualatin River and in Upper Klamath Lake (Rounds and others, 1999; Wood and Rounds, 1998; *http://oregon.usgs.gov/projs_dir/or207/klake_data_2002. html*), indicate it is not unusual at all for this to occur, particularly in a system with little turbulence, few waterfalls or riffles, and an abundance of algae. These conditions are prevalent in the Shasta River which has an abundance of rooted aquatic plants in addition to a substantial population of attached algae. As long as conditions are favorable for the continued growth of the algae and aquatic plants, they can easily produce sufficient dissolved oxygen via photosynthesis to offset any consumptive processes and any losses to the atmosphere. Studies show that supersaturation is an annual occurrence in many systems in Oregon. For example, the Tualatin River has a record of continuous DO data since 1991 (Doyle and Caldwell, 1996; *http://oregon.usgs.gov/cgi-bin/grapher/graph_setup.pl? site_id=14207200*). At that site, supersaturated conditions occurred annually for 24-hour periods extending from 1 to 6 weeks. In 1992, supersaturated conditions persisted for a month at a time for several periods, and as high as 250 percent saturation, even though that river has a TMDL meant to protect it from low dissolved oxygen conditions. Locations in Upper Klamath Lake exceed 100% saturation values for 24-hour periods for extended periods of time from May until October, 2002, probably for over 60% of the 5-month time period (*http://oregon.usgs.gov/projs_dir/or207/klake_data_2002.html*).

There are many uncertainties associated with DO data and with the Shasta River data in particular. At the beginning of the 2002 field season, field crews unfamiliar with the collection of continuous DO data were trained in the USGS procedures, following Wagner and others (2000). In 2002, YSI 6920 Multi-parameter Water Quality Loggers with probes for DO, pH, and specific conductance/water temperature were rented from the USGS Hydrologic Instrumentation Facility. Numerous battery failures and other problems occurred with the probes, in addition to the expected biofouling. Drift was not corrected for in 2002, and field calibrations were done, whenever it was noted as necessary, to replace the DO sensor (approximately monthly). In 2003, new instruments were obtained and more frequent field visits were made (Table 2). In addition to corrections for biofouling, drift corrections were made and DO sensors were replaced as needed following inspections and calibrations in 2003 (approximately every two weeks).

Uncertainties in DO data collected continuously in the field can be exemplified by the data collected in the Shasta River in 2002 and 2003. USGS field protocols were followed more rigorously in 2003 than in 2002, with more frequent site visits, field calibrations, and sensor replacements, thus providing more certainty in the data in between visits. In addition, both biofouling and drift corrections were made in 2003. Data occurring as a result of obvious probe failure, membrane leakage or battery failure were removed in the intial data review, but more frequent site visits and probe inspections in 2002 could have provided more confidence in data collected between site visits and field calibrations. In general, uncertainties governed by probe behavior due to biofouling and drift are consistently corrected for deviations from field calibrated values by greater than 0.3 mg/L and by no more than 2.0 mg/L, with the exception of 8/18/03 and 9/30/03 at Edgewood when they were corrected by -2.2 and -2.4 mg/L, respectively. Uncertainties in the linear prorated corrections between calibrations, therefore, introduce no more error than the correction factor for that time period as noted in Table 2. Very careful inspection of the entire dataset, including the dependent data collected coincidentally of water temperature, pH, and specific conductance, as well as discharge, although not necessarily at the identical location, as well as specific consideration of individual site characteristics, weather conditions, nutrients, and presence of algal and macrophyte populations, would assist in the interpretation of the adequacy and uncertainty of the DO data at these sites.

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Table 1. USGS 2002 - 2003 continuous monitoring stations on the Shasta River basin.

[ID, USGS station identification number; sq. mi., square miles; latitude and longitude in decimal degrees; R., River]

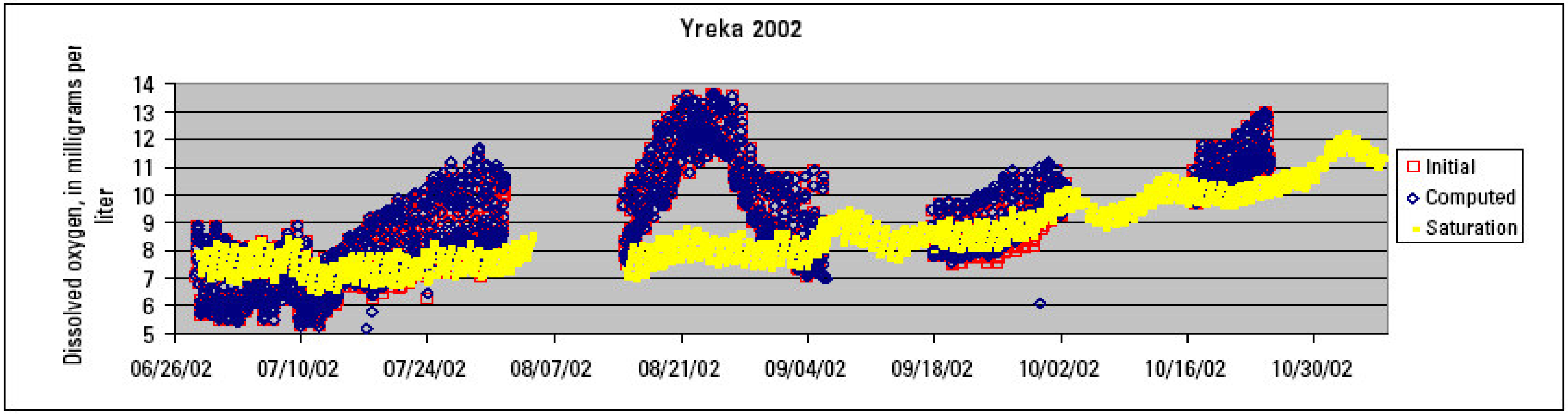
Abbreviation	Name[1]	ID	Latitude	Longitude	Drain-age area (sq. mi)	Location	Measurement Dates 2002	2003
YREKA	Shasta R. near Yreka	11517500	41.8229	-122.5956	793	Shasta R. just upstream of confluence with Klamath R.	6/29/02 - 11/6/02	5/14/03 - 9/30/03
HWY3	Shasta R at Hwy 3 near Montague	11510715	41.7268	-122.5584	676	Shasta R. at Hwy 3		4/10/03 - 9/30/03
MONTAGUE	Shasta R. near Montague	11517000	41.7092	-122.5369	673	1 mi below Little Shasta R.	6/26/02 - 11/6/02	4/11/03 - 9/30/03
EDGE	Shasta R. near Edgewood	11516750	41.4714	-122.4397	70	0.8 mi downstream from Beaughton Creek	6/26/02 - 11/6/02	4/11/03 - 9/30/03

Note: The station names are reported by the Regional Water Board as follows:

Shasta R. near Yreka = Shasta River Near Mouth at USGS Gage
Shasta R at Hwy 3 near Montague = Shasta River at Highway 3
Shasta R. near Montague = Shasta River at Montague-Grenada Road
Shasta R. near Edgewood = Shasta River at Edgewood Road

Table 2. Corrections and shifts made to dissolved oxygen data at Edgewood site on the Shasta River during 2002-2003.

Date of site visit	Correction due to biofouling	Correction due to drift	Total correction	Comment
6/25/2002				Sonde deployed
8/2/2002	0.0		0.0	7/16/02 - 8/1/02 battery failure, 8/2/02 faulty probe
8/15/2002	-0.9		-0.9	
8/29/2002	0.0		0.0	8/4/02 - 8/15/02 battery failure, 8/18/02 - 8/29/02 faulty probe
9/19/2002	0.4		0.4	
9/30/2002	-1.5		-1.5	
10/2/2002	0.0		0.0	
10/16/2002	0.0		0.0	
11/6/2002	0.7		0.7	Sonde removed for season
4/9/2003			0.0	Sonde deployed
5/13/2003			0.0	4/24/03 and 5/9/03 - 5/12/03 battery failure, new Sonde deployed
5/30/2003	0.0	-0.9	-0.9	
6/16/2003	0.0	0.5	0.5	
6/27/2003	0.0	0.0	0.0	
7/3/2003	0.0	2.0	2.0	
7/9/2003	0.0	0.0	0.0	hole found in membrane, drift correction applied to 6/27/03 - 7/3/03
7/23/2003	0.0	0.0	0.0	7/10/03 probe failure, 7/23/03 hole found in membrane, no data 7/9/03 - 7/22/03
8/5/2003	0.0	-0.5	-0.5	
8/18/2003	-2.0	-0.2	-2.2	
9/11/2003	0.0	-1.8	-1.8	
9/30/2003	-0.2	-2.2	-2.4	Sonde removed for season



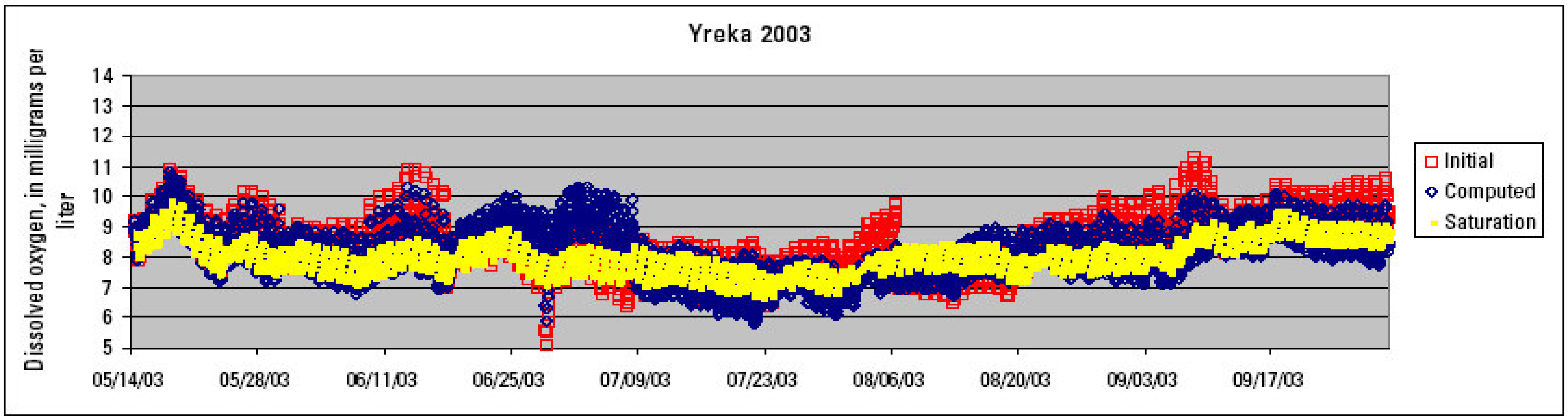


Figure 1. Measured continuous data of dissolved oxygen with initial edited record, computed record, and saturated values for 2002 and 2003 for the USGS site on the Shasta River at Yreka. The Regional Water Board refers to this station as "Shasta River Near Mouth at USGS Gage".

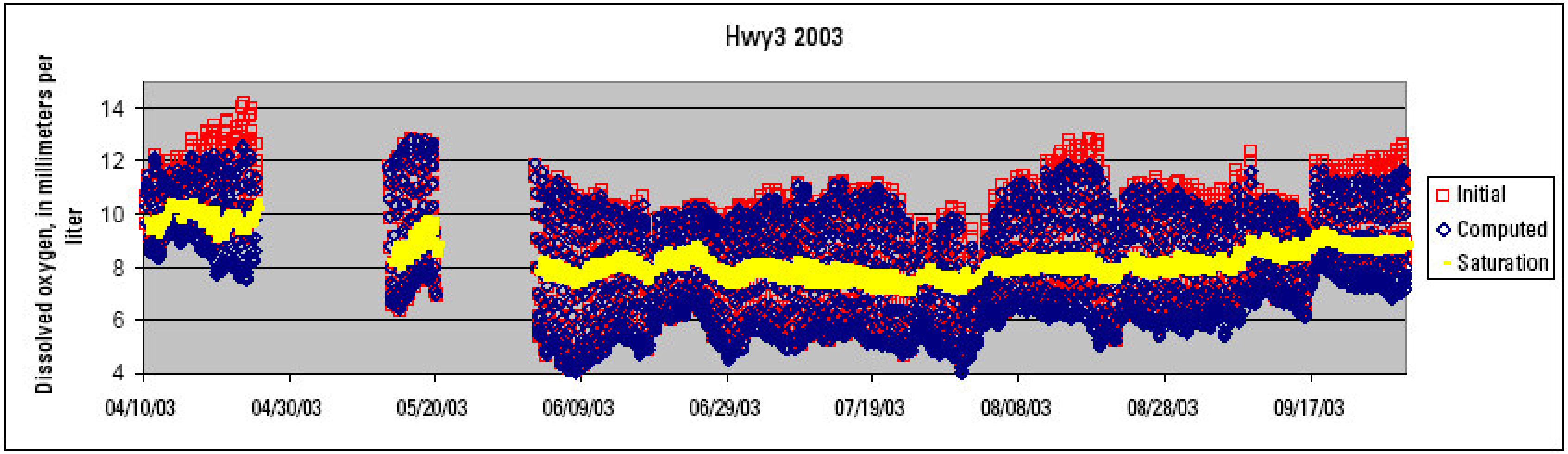


Figure 2. Measured continuous data of dissolved oxygen with initial edited record, computed record, and saturated values for 2003 for the USGS site on the Shasta River at Hwy 3. The Regional Water Board refers to this station as “Shasta River at Highway 3”.

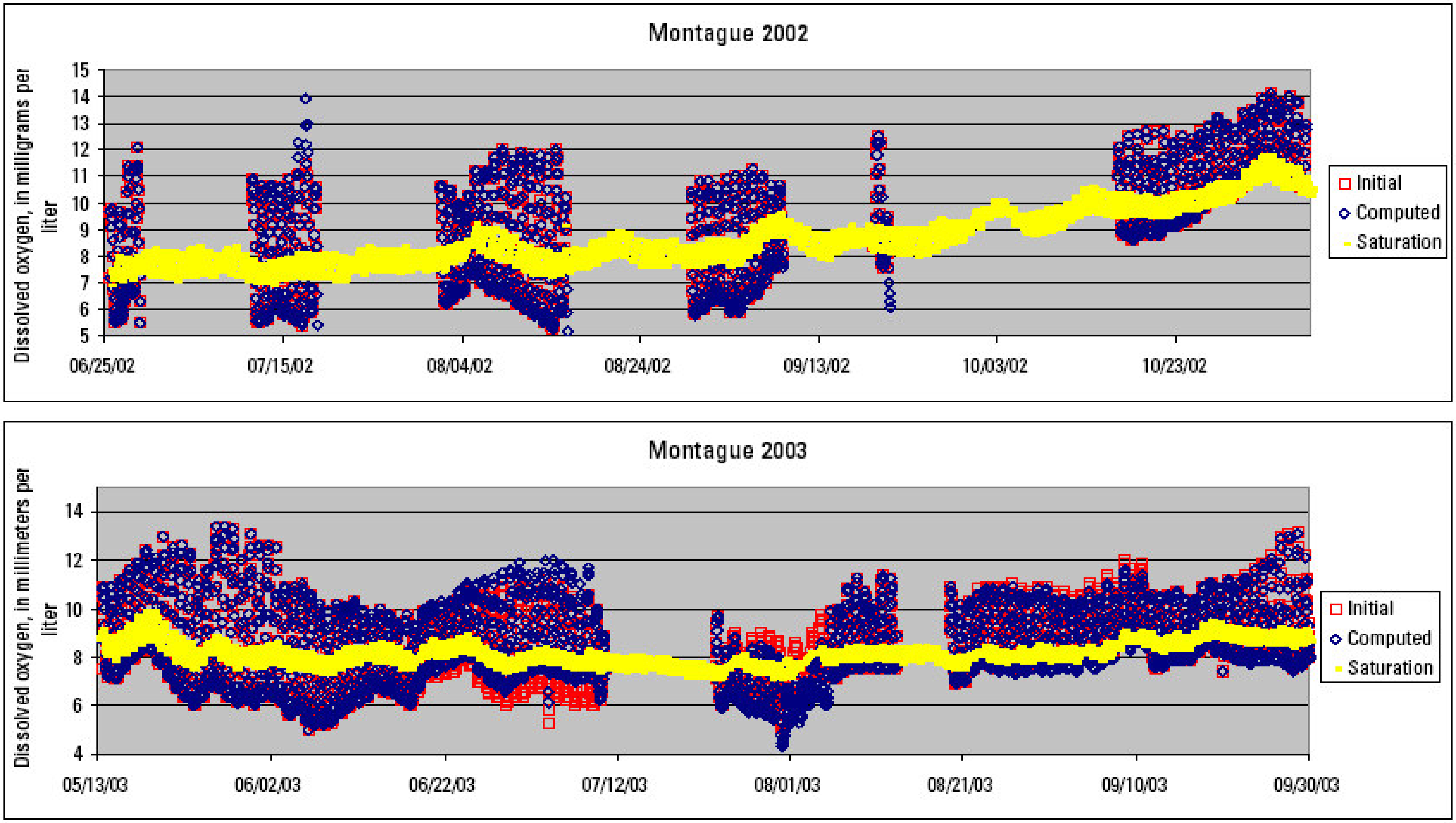
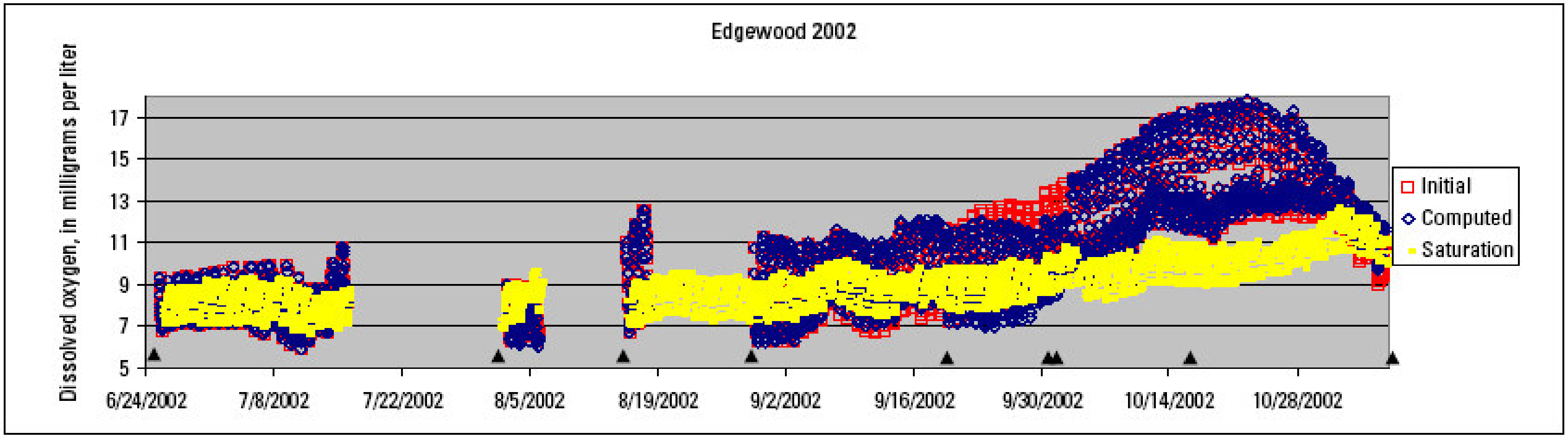


Figure 3. Measured continuous data of dissolved oxygen with initial edited record, computed record, and saturated values for 2002 and 2003 for the USGS site on the Shasta River at Montague. The Regional Water Board refers to this station as “Shasta River at Montague-Grenada Road”.



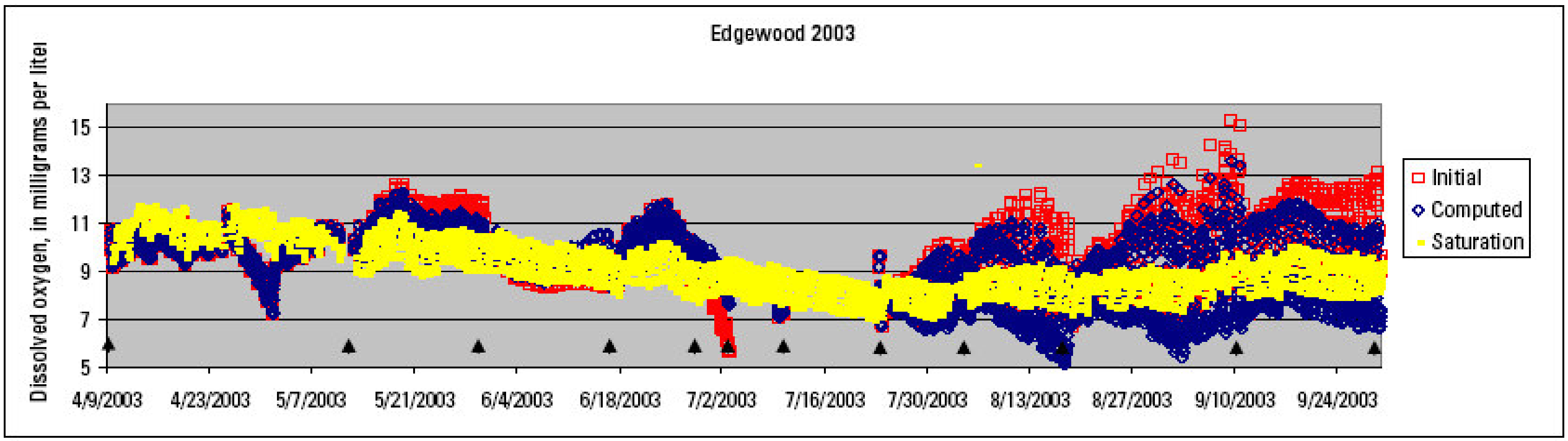


Figure 4. Measured continuous data of dissolved oxygen with initial edited record, computed record, and saturated values for 2002 and 2003 for the USGS site on the Shasta River at Edgewood. The Regional Water Board refers to this station as "Shasta River at Edgewood Road". Filled triangles identify dates of site inspections by USGS.

Appendix 2: Sediment Oxygen Demand Study on the Shasta River – Methodology

This section of the document is excerpted from a USGS report by Flint and co-workers (2004).

Background

Sediment oxygen demand (SOD) is the rate of dissolved oxygen loss from a waterbody through its uptake and consumption by biotic or abiotic reactions in surficial sediments. In most systems, such oxygen consumption is dominated by microbially mediated decomposition processes. In other words, organic materials in the waterbody's sediments rot and decompose; that process requires oxygen to proceed, and the oxygen is supplied from the overlying water. In streams with an abundance of sedimentary organic material, from soil erosion or an accumulation of plant and algal detritus, SOD can be an important part of the stream's dissolved oxygen budget. Observations of sediment accumulation and low dissolved oxygen levels indicate that some reaches of the Shasta River may have a significant SOD; as a result, this investigation was initiated to measure that rate.

The rate of SOD was measured at six sites in two reaches of the Shasta River (**Table 10**). These sites were chosen because they are located in a reach of the Shasta River that is known to have dissolved oxygen problems and to accumulate some amount of fine sediment and plant detritus. Other considerations for site selection included access, type of stream substrate, and the amount of macrophyte (aquatic plant) growth.

Procedure

Sediment oxygen demand rates were measured with *in-situ* chambers, as previously described by Murphy and Hicks (1986), Caldwell and Doyle (1995), Rounds and Doyle (1997), and Doyle and Rounds (2003). These chambers allow a known volume of water to be isolated above a known area of stream sediment. The dissolved oxygen concentration in that isolated water then is monitored over the course of at least two hours. Measurements typically are performed with three such chambers at each site to assess the variability of the site's SOD. In addition, a fourth chamber with a sealed bottom to exclude interaction with stream sediments is used to assess the level of oxygen loss due to biochemical oxygen demand (BOD) in the water column. The measured oxygen loss rate in each of the three SOD chambers, once corrected for the effects of BOD as measured in the fourth chamber, is a direct measurement of the site's SOD rate. Final SOD rates are corrected to 20° C (SOD_{20}) and reported as a loss rate in grams of oxygen per square meter per day ($g/m^2/d$). Details of the procedures were documented previously by Rounds and Doyle (1997). An estimate of the SOD rate at any temperature is then given by:

$$SOD_T = SOD_{20} \times 1.065^{(T-20)}$$

where SOD_T is the SOD rate at temperature T (°C).

To measure SOD rates with this type of *in-situ* chamber, (1) the stream must be deep enough to submerge the chamber (> 0.4 meters), (2) the sediments must be fine enough to allow the chamber's cutting edge to seat and seal to the stream bottom, and (3) the stream's dissolved oxygen concentration must be high enough (> 4 mg/L, approx.) to provide a measurable loss rate and a stable aerobic environment for the sediment's microbial community.

In the reaches where the SOD rate was measured, the Shasta River has a productive population of attached algae and an abundance of rooted aquatic plants (macrophytes). Both the algae and the macrophytes produce dissolved oxygen through photosynthesis. In order to measure only the effects of SOD (and BOD), it was important to exclude these oxygen producers from the SOD measuring chambers, either through prudent site selection or by physical removal of these plants prior to chamber deployment.

At the two sites near Montague-Grenada Road, macrophytes were less abundant, allowing suitable sites for chamber deployment to be found without removing any plant material. At all sites near Highway 3, however, macrophytes were abundant and had to be removed from the site of each chamber deployment prior to SOD measurement. The tops of the plants were removed by cutting them off near their base, taking care not to disturb the plants' roots or the site's sediments. In this manner, the plant's production of dissolved oxygen was eliminated without disturbing the sediments or any respiration processes in the plant's roots. Such measures may introduce additional uncertainty into the subsequent SOD measurement, but it was the only way to collect such a measurement in areas dominated by macrophytes.

At each SOD measuring site, samples also were collected to roughly characterize the organic content and particle size of the stream sediments. Samples were analyzed for percent organic content (loss on ignition: Fishman and Friedman, 1989) and for the size fraction finer than 63 microns (Guy, 1969) by the USGS Cascades Volcano Observatory sediment laboratory.

Results are presented in **Table 10**.

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Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. C1, p. 18-30.

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Water-Quality Data from 2002 to 2003 and Analysis of Data Gaps for Development of Total Maximum Daily Loads in the Lower Klamath River Basin, California

By Lorraine E. Flint, Alan L. Flint, Debra S. Curry, Stewart A. Rounds, and Micelis C. Doyle

In cooperation with the North Coast Regional Water Quality Control Board

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Contents

Figures

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Conversion Factors and Abbreviations

SI to Inch/Pound

Multiply	By	To obtain
gram (g)	0.0353	ounce, avoirdupois (oz)
grams per day (g/day)	0.0353	pound avoirdupois per day (lb per day)
kilogram (kg)	2.205	pound avoirdupois (lb)
kilogram per day (kg/day)	2.205	pound avoirdupois per day (lb per day)
kilometer	0.6214	mile
liter (L)	61.02	cubic inch (in^3)
meter (m)	3.281	foot (ft)
square kilometer (km^2)	0.3861	square mile (mi^2)

Inch/Pound to SI

Multiply	By	To obtain
cubic foot per second (ft^3/s)	4.800	cubic meter per second (m^3/s)
foot (ft)	0.3048	meter (m)
mile (mi)	1.6093	kilometer (km)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C= (°F-32)/1.8$$

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the National Geodetic Vertical Datum of 1929 (NGVD of 1929).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations

BOD	biochemical oxygen demand
CBOD	carbonaceous biochemical oxygen demand
CIMIS	California Irrigation Management Information System
DEM	digital elevation model
DO	dissolved oxygen
EDNA	elevation derivatives for National application
FERC	Federal Energy Regulatory Commission
$g/m^2/day$	gram per square meter per day
mm	millimeter
mm Hg	millimeter of Mercury
NCDC	National Climatic Data Center

NCRWQCB	North Coast Regional Water Quality Control Board
NREL	National Renewable Energy Laboratory
NTU	nephelomatric turbidity units
NWIS	National Water Information System
RAWS	Remote Automated Weather Stations
SOD	sediment oxygen demand
SOD_{20}	sediment oxygen demand values corrected to 20°C
TOC	total organic carbon
TMDL	total maximum daily load
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WQRRS	Water Quality for River-Reservoir System
WRCC	Western Regional Climate Center

Water-Quality Data from 2002 to 2003 and Analysis of Data Gaps for Development of Total Maximum Daily Loads in the Lower Klamath River Basin, California

By Lorraine E. Flint, Alan L. Flint, Debra S. Curry, Stewart A. Rounds, and Micelis C. Doyle

Abstract

The U.S. Geological Survey (USGS) collected water-quality data during 2002 and 2003 in the Lower Klamath River Basin, in northern California, to support studies of river conditions as they pertain to the viability of Chinook and Coho salmon and endangered suckers. To address the data needs of the North Coast Regional Water Quality Control Board for the development of Total Maximum Daily Loads (TMDLs), water temperature, dissolved oxygen, specific conductance, and pH were continuously monitored at sites on the Klamath, Trinity, Shasta, and Lost Rivers. Water-quality samples were collected and analyzed for selected nutrients, organic carbon, chlorophyll-*a*, pheophytin-*a*, and trace elements. Sediment oxygen demand was measured on the Shasta River. Results of analysis of the data collected were used to identify locations in the Lower Klamath River Basin and periods of time during 2002 and 2003 when river conditions were more likely to be detrimental to salmonid or sucker health because of occasional high water temperatures, low dissolved oxygen, and conditions that supported abundant populations of algae and aquatic plants. The results were also used to assess gaps in data by furthering the development of the conceptual model of water flow and quality in the Lower Klamath River Basin using available data and the current understanding of processes that affect water quality and by assessing needs for the develoment of mathematical models of the system. The most notable gap in information for the study area is in sufficient knowledge about the occurrence and productivity of algal communities. Other gaps in data include vertical water-quality profiles for the reservoirs in the study area, and in an adequate understanding of the chemical oxygen demands and the sediment oxygen demands in the rivers and of the influence of riparian shading on the rivers. Several mathematical models are discussed in this report for use in characterizing the river systems in the study area; also discussed are the specific data needed for the models, and the spatial and temporal data available as boundary conditions. The models will be useful for the future development of TMDLs for temperature, nutrients, and dissolved oxygen and for assessing the role of natural and anthropogenic sources of heat, oxygen-producing and -consuming substances, and nutrients in the Klamath, Shasta, and Lost Rivers.

Introduction

The study area is the Lower Klamath River Basin and for this study includes the Klamath River and the Lost River systems in northern California (*fig. 1*). The 2001 and 2002 droughts in the Klamath River Basin in Oregon and California, along with Federal legal requirements regarding water use, resulted in a scarcity of water available both for agricultural use and for maintenance of water levels necessary to sustain threatened and endangered fish populations in the Klamath Basin. Low streamflows and agricultural return flows with concurrent high water temperatures, excess nutrients, and decreased dissolved oxygen may have contributed to a large die-off in September 2002 of Chinook salmon, and some Coho salmon, a threatened anadromous fish.

Three rivers in the Lower Klamath River Basin (*fig. 1*) are listed on California's 303(d) List of Impaired Water Bodies (California Environmental Protection Agency, accessed April 2004):

- The Lost River, owing to high water temperatures and excess nutrients that may be impairing the beneficial uses of the water body.
- The Klamath River, owing to high water temperatures, low dissolved oxygen, and excess nutrients.
- The Shasta River, which flows into the Klamath River, owing to high water temperatures and low dissolved oxygen.

Placement of a water body on the 303(d) List triggers action for developing a pollution control plan, called Total Maximum Daily Load (TMDL), for that water body and the associated pollutant/stressor on the list. The TMDL serves as the means to attain and maintain water-quality standards for the impaired water body.

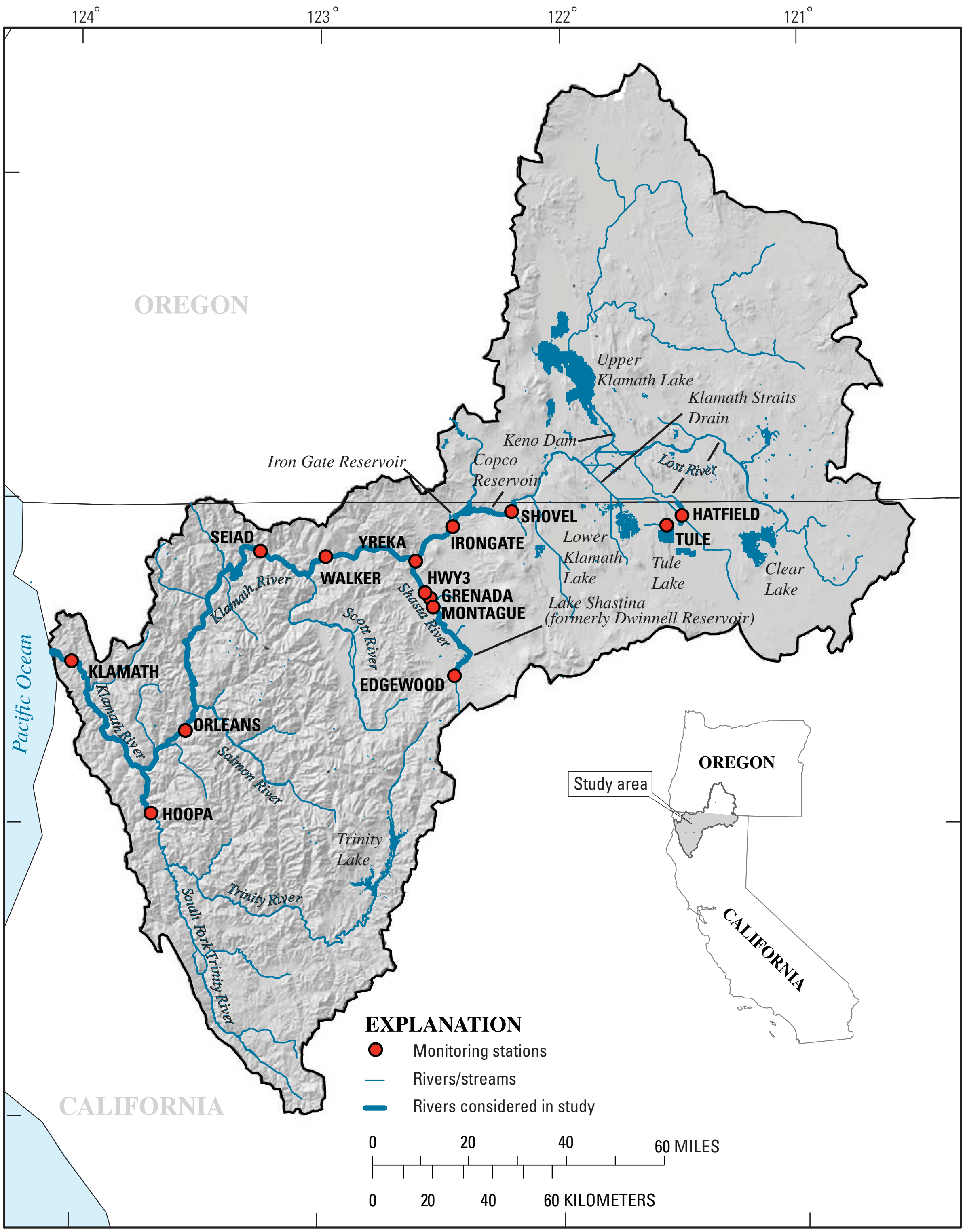

Figure 1. Location of Klamath River Basin, California, and water-quality monitoring sites.

The development of a TMDL is a long-term process. The U.S. Geological Survey (USGS), in cooperation with the North Coast Regional Water Quality Control Board (NCRWQCB), collected and analyzed water-quality and streamflow data to support that process for water bodies in the Lower Klamath River Basin.

Objective

The objective of this study is to collect and analyze water-quality data in order to provide hydrologic and water-quality information needed to develop TMDLs for the Klamath and the Lost Rivers. These data are being used for several purposes, including

- Characterizing the water quality of the Klamath and the Lost Rivers and identifying changes or trends in water quality over time—especially as related to land use and river modifications
- Providing specific data for water-quality models that will be used to develop TMDLs for water temperature, nutrients, and dissolved oxygen (DO)
- Identifying specific existing or emerging water-quality problems
- Developing analytical tools to support characterization of past or possible future conditions in these river systems
- Identifying data gaps and additional assessments and analyses needed to develop TMDLs

The purpose of this report is to summarize data collected during 2002 and 2003 and to identify gaps in information and additional water-quality investigations to support a more complete understanding of water-quality dynamics of the lower Klamath River. The report describes specific approaches for evaluating spatial and temporal variations in water quality and discusses data necessary in the development of a water-quality model of the Klamath River between Upper Klamath Lake and the Pacific Ocean, including that section of the Lost River from the California border to where the river flows into the Klamath River. Such a model can be used to assess

- Natural and anthropogenic sources and sinks of heat, DO, and nutrients
- Additional data needs (identification of data gaps) through model sensitivity analysis (such as the sensitivity of water temperature to shading), or needs for identifying, through additional monitoring or sampling, tributaries that affect water quality
- Gaps in the understanding of processes contributing to water quality through model sensitivity analysis (such as the role of attached algae in primary production of oxygen and carbon dioxide or the influence of sediment oxygen demand on DO)

This report presents the water-quality studies undertaken by the U.S. Geological Survey in the Lower Klamath River Basin, data collection methods and results for the Trinity, Klamath, Shasta, and Lost Rivers, the parcel-tracking study on the Klamath and Shasta Rivers, and the sediment oxygen demand study on the Shasta River. It also discusses and compares various models being considered for use in the basin, potential sources of data for those models, and existing gaps in the currently available data. Also included is a discussion of the methodology for correcting dissolved oxygen data from DataSonde sensors and the associated data uncertainty, using the data collected at sites on the Shasta River in 2002 and 2003 as an example (*appendix 2*).

Approach

Several approaches can be used to evaluate the quality and quantity of existing hydrologic and water-quality data and to identify additional data needs for better understanding of the river systems in the Lower Klamath River Basin. As a calibrated mathematical model is necessary for scenario development in the future preparation of TMDLs for the Klamath and Lost Rivers, it was decided to evaluate the data from a modeling perspective. This report provides an analysis of the data in the absence of a model, and in order to adequately evaluate the data and gaps in the data, includes a philosophical approach to modeling, and discusses the reasons why the integration of data collection and modeling would provide a better solution to determining data gaps and data adequacy. In the context of the available data, an analysis of potentially useful models for future development of TMDLs is included, along with possible sources for the additional data necessary to apply such models.

Sufficient data are currently available for rivers in the Lower Klamath River Basin to construct a conceptual and mathematical model that can be used to better evaluate where additional data are needed. The philosophical modeling approach used for this study provided a theoretical basis for evaluating the features, processes, and hydrological events in the river system that most influence the constituents being considered for the TMDLs. A numerical or process model developed using only the existing data could be used to develop TMDLs for this basin, but because of uncertainties associated with many of the parameters that are required as input, it is encouraged that the data gaps identified in this report be filled to provide a rigorous and defensible model. It is through the interactive process of data collection, data analysis, and model sensitivity analysis that a nexus can be achieved between a sufficiency of high-quality data and an adequate understanding of water-quality processes. Only then can sufficient data be acquired and an accurate and reliable model built to provide a foundation for preparing TMDLs.

Model Development

Models representing natural systems generally are composed of two parts: a conceptual model and a mathematical model (Hsieh and others, 2001). In general terms, a conceptual model is qualitative and is expressed by ideas, words, and figures. A mathematical model is quantitative and is expressed as mathematical equations. The two are closely related. In essence, the mathematical model results from translating the conceptual model into a well-posed mathematical problem that can be solved.

A key component to assessing data gaps is the integration of the available data and of information on the natural processes contributing to water quality into conceptual and mathematical models of a river system. When developed and supported by field data, models can be effective tools for understanding complex phenomena and for making informed predictions for a variety of future scenarios. However, model results are always subject to some degree of uncertainty owing to limitations in field data and incomplete knowledge of natural processes contributing to water quality.

To put the modeling development and implementation into a conceptual framework, the modeling process can be viewed as an iterative sequence of actions that includes (1) identifying a site-specific problem; (2) conceptualizing dominant features, processes, and hydrologic events; (3) implementing a quantitative description of each process; (4) collecting and assimilating field data, and using those data to calibrate the model and to evaluate its predictive capabilities; and (5) developing predictions for use in resolving the identified problem. This process is illustrated by the flow chart in *figure 2*. Once the problem has been established, the next goal (*fig. 2*) is to assess the available site-specific data. The following section describes the data collected by the USGS during 2002 and 2003 and provides preliminary analyses of that data.

Water Quality

Data collection was done at Klamath River and Lost River locations. There was continuous monitoring of dissolved oxygen, water temperature, specific conductivity, and pH for both 2002 and 2003. Monthly sampling for water-quality constituents was done in 2002 and parcel-tracking and sediment oxygen demand studies were conducted in 2003. Between June and November 2002, the USGS began using automated continuous monitors to determine water quality at 12 surface-water stations in the Lower Klamath River Basin: 6 stations on the Klamath River; 3 stations on the Shasta River, and 1 station on the Trinity River (the Shasta River and the Trinity River drain into the Klamath River); 1 station on the Lost River upstream of Tule Lake; and 1 station on the Lost River downstream from Tule Lake (*fig. 1*). The HATFIELD station represents water input from the upper Lost River system into Tule Lake, and the TULE station represents water that has moved through Tule Lake to be pumped westward into Lower Klamath Lake

In 2003, the stations on the Lost River (HATFIELD and TULE) and the Trinity River (HOOPA) were discontinued and an additional station was added on the Shasta River (HWY3). These 10 stations were monitored from April through November 2003. Monthly discrete/instantaneous samples for selected nutrient and trace element analyses were collected at the 10 monitoring stations in July, August, and September of 2002. In 2003, in order to get a better understanding of how water-quality processes changed between the various reaches of the Shasta River and Klamath River, a parcel-tracking (Lagrangian sampling) study was conducted during June and August at stations on the Klamath River, and during July and September at stations on the Shasta Rivers, where the same water-quality constituents were collected. A study also was conducted at six sites on the Shasta River to investigate sediment oxygen demand (SOD).

Data Collection and Analysis

Water-quality data have been collected by various agencies in the Klamath Basin for nearly 20 years. Because of the recent assignment of impairments on the Klamath, Shasta, and Lost Rivers, the USGS collected additional data in 2002 and 2003 for the purpose of supplying the NCRWQCB with information necessary for them to develop a TMDL and a Water Quality Management Plan for the Lower Klamath Basin.

Continuous Monitoring

Continuous water-quality monitoring instruments were installed at 12 locations in June and July 2002 (*fig. 1*; *table 1*). All the hourly data that had quality-control checks are shown in subsequent figures. The complete data set is archived in the U.S. Geological Survey (USGS) California District National Water Information System (NWIS) database. An additional site was installed in the Shasta River near Hwy 3 in April 2003 (HWY3); the HOOPA, TULE, and HATFIELD stations were discontinued after the 2002 season. Multi-parameter water-quality instruments from Yellow Springs Instruments, model 6920, were used to collect DO (mg/L), water temperature (^{o}C), specific conductance (µS/cm), and pH on an hourly basis. Standard USGS protocols were used for site selection, verification of the representativeness of a stream cross section, cleaning and calibration of probes, quality assurance procedures, and the shifting of data to account for measured biofouling and instrument drift. These protocols are documented by Wagner and others (2000); some are also documented in a USGS National Field Manual by Wilde and Radtke (1998). Instrument maintenance was done approximately biweekly. A detailed accounting of station maintenance and data analysis, along with an assessment of the uncertainty in the DO data for the Shasta River, is included in *appendix 2*.

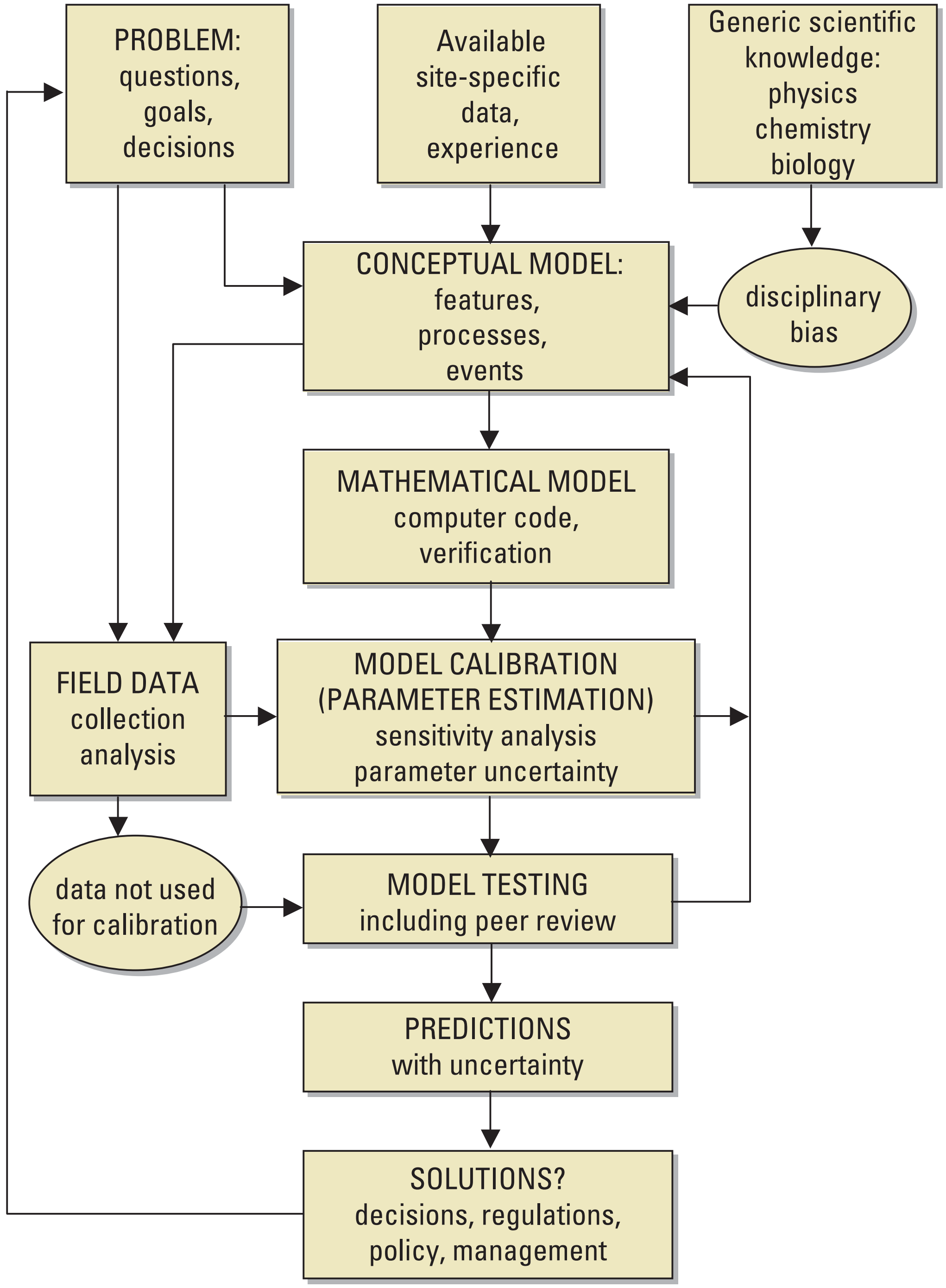

Figure 2. Flow chart illustrating the elements of the modeling process.

Table 1. Station location and measurement periods for continuous monitoring stations in the lower Klamath River Basin, California, 2002 and 2003.

[Stations are listed in order from the mouth of the Klamath River upstream. The Shasta River near Grenada site (GRENADA) that was used in the parcel tracking study is included to provide location information. ID, U.S. Geolological Survey station identification number; Latitude and longitude are referenced to the North American Datum of 1983, NAD83; ft, foot; mi, mile; mi^2, square miles; latitude and longitude in decimal degrees; R., River; — , no drainage area information available]

Abbreviated station name	Station name	Station ID	Latitude	Longitude	Drainage area (mi^2)	Location	Measurement periods	
							2002	2003
KLAMATH	Klamath R. near Klamath	11530500	41.5143	–124.0004	12,100	0.2 mi upstream from Turwar Creek	7/10/02 – 11/1/02	4/29/03 – 11/30/03
HOOPA	Trinity R. at Hoopa	11530000	41.0499	–123.6720	2,853	Hoopa Valley Indian Res. 0.1 mi upstream from Supply Creek	6/27/02 – 10/28/02	
ORLEANS	Klamath R. at Orleans	11523000	41.3034	–123.5345	8,475	Orleans, 25 ft upstream from highway bridge	6/27/02 – 11/5/02	4/29/03 – 11/30/03
SEIAD	Klamath R. near Seiad Valley	11520500	41.8537	–123.2323	6,940	0.4 m upstream from Bittenbender Creek	6/28/02 – 11/5/02	4/29/03 – 11/30/03
WALKER	Klamath R. at Walker Bridge near Klamath R.	11517818	41.8376	–122.8645	5,885	1 mi downstream from Grouse Creek	6/28/02 – 11/5/02	4/29/03 – 11/30/03
YREKA	Shasta R. near Yreka	11517500	41.8229	–122.5956	793	Shasta R. just upstream of confluence with Klamath R.	6/29/02 – 11/6/02	5/14/03 – 11/30/03
HWY3	Shasta R. at Hwy 3 near Montague	11511705	41.7268	–122.5584	676	Shasta R. at Hwy 3		4/10/03 – 11/30/03
MONTAGUE	Shasta R. near Montague	11517000	41.7090	–122.5381	673	1 mi below Little Shasta R.	6/26/02 – 11/6/02	4/11/03 – 11/30/03
GRENADA	Shasta R. near Grenada	11516880	Not defined			6 mi upstream from Montague, at Hwy A–2		
EGEWOOD	Shasta R. near Edgewood	11516750	41.4713	–122.4409	70	0.8 mi downstream from Beaughton Creek	6/26/02 – 11/6/02	4/11/03 – 11/30/03
IRONGATE	Klamath R. below Iron Gate Dam	11516530	41.9279	–122.4442	4,630	0.1 mi downstream from Bogus Creek, 0.6 mi downstream from Iron Gate Dam	6/26/02 – 11/6/02	5/15/03 – 11/30/03
SHOVEL	Klamath R. above Shovel Creek near Copco	11510990	41.9724	–122.2020	4,164	0.1 mi upstream from Shovel Creek	7/20/02 – 11/6/02	4/30/03 – 11/30/03
TULE	Tule Lake Canal at Sheepy Ridge Pumping Station near Hatfield	11488510	41.9247	–121.5661	—	0.8 mi downstream from Tule Lake Sump	7/19/02 – 10/1/02	
HATFIELD	Lost River near Hatfield	11488495	41.9539	–121.5033	—	0.9 mi upstream from Tule Lake Sump	7/18/02 – 9/19/02	

Additional water-quality data are available on various websites. Compiling and reviewing this additional data might be useful to the TMDL process. A compilation of all other non-USGS data is not available at this time, but this process should be established as soon as possible for development of the TMDL. The database should include quality-control information on all data, as well as on the sources of the data.

Klamath River Locations

Continuous monitoring stations were installed at seven locations between Iron Gate Dam and the mouth of the Klamath River. Fall-run Chinook salmon spawn in the main stem Klamath River in a 13-mile reach from Iron Gate Dam to the mouth of the Shasta River (Leidy and Leidy, 1984). The range of the spawning area for Coho salmon is not as well defined for the Klamath River Basin but they are much less prevalent. Chinook, Coho, and Steelhead currently are raised at the hatchery at the Iron Gate Dam (*fig.1*).

Temperature requirements vary with life stage: adult (migration and spawning), egg incubation and larvae, and juvenile rearing. Optimum temperatures for adult Chinook salmon are roughly 6 ° C to 14°C, and excessive temperatures may arrest fish migration, predispose adults to disease, accelerate or retard maturation, and generally provide stress to the fish. Temperatures exceeding 21°C arrest the migration of spawning adult Chinook salmon and cause mortality when the temperature is exceeded for extended periods. Thus, 21°C is considered the maximum temperature threshold. Chinook salmon become susceptible to lethal diseases when temperatures attain 16°C (Deas, 2000). The spawning Coho salmon have an acute response to water temperatures exceeding 25.8°C (Deas, 2000). The acute minimum threshold for DO for salmonid populations occurs at levels of 4.25 mg/L or less, with initial oxygen distress occurring at 6 mg/L (Davis, 1975) and chronic stress occurring at 7 mg/L (Campbell, 1995). The water-quality objectives for salmonids for the Karuk Tribe of California, who occupy much of the land bordering the lower one-third of the Klamath River, include acute minimum DO levels of 6 mg/L and minimum levels during salmonid egg incubation of 9 mg/L (Karuk Tribe of California, 2003). The NCRWQCB water-quality objectives define minimum levels of DO as 7.0 mg/L for tributaries to the Klamath River and 8.0 mg/L for the Klamath River mainstem (Deas, 2000).

Data collected from the 12 stations in 2002 and from the 10 stations in 2003 are illustrated in *appendix 1*. These stations are located from the mouth of the Klamath River upstream to the Lost River. Time gaps in the data for these stations generally were due to equipment failure or to extreme biofouling of the DO sensor. A more direct comparison of the data is shown in *figure 3* for water temperature and in *figure 4* for DO for 8 stations: 6 stations along the Klamath River, as well as the 1 station (HOOPA) on the Trinity River and 1 station (YREKA) on the Shasta River, both of which drain into the Klamath River.

Water Temperature

Water temperatures (*fig. 3A* and *B*) for the stations closest to the mouth of the Klamath River show less variation among stations and on a daily basis than temperatures farther upstream. The SHOVEL station (*fig. 1*), above the Copco Reservoir, generally had the coolest water temperatures, never rising above 25°C, and never above 22°C during August, possibly because of cool ground-water accretions in the Klamath River between this station and the Keno Dam below Lower Klamath Lake (Rykbost, 2001). Once the water travels through the Copco and the Iron Gate Reservoirs and is released from the Iron Gate Reservoir, the diurnal variation is greatly reduced. In 2002, the diurnal variation generally exceeded the daily maximum temperatures only at the SHOVEL station and only by about 1°C, except in the fall when heat stored in the reservoir water was still having an effect at IRONGATE. In 2003, the diurnal variation at SHOVEL was larger, with daily maximum temperatures often exceeding those at IRONGATE.

The water flowing into the Klamath River from the Shasta River, measured just upstream on the Shasta River at the YREKA station, had large diurnal fluctuations and the highest temperatures along the Klamath River system, reaching nearly 30°C in mid July (*fig. 3A*). Mid-August daily maximum temperatures reached 27°C. Temperatures at the YREKA station exceeded the 21°C maximum threshold for salmonid stress (Deas, 2000) on a daily basis for nearly the entire period between early July and mid September 2002. Farther downstream at the WALKER station, the downstream station of an in-between reach that only minor tributaries flow into, had measured water temperatures that were similar to those at the IRONGATE station; however, variations in daily temperatures at the WALKER station were greater. The water temperature at WALKER also exceeded the 21°C salmonid maximum stress threshold for all July and most of August. The water temperature at SEIAD, farther downstream, is very similar to that at WALKER. The temperature at ORLEANS was within the same range as that at SEIAD, had very little daily variation, and exceeded the 21°C threshold throughout July and August. The Trinity River delivers cooler water to the Klamath River, as indicated by a lower water temperature at KLAMATH during July. The temperature at KLAMATH exceeded the 21°C salmonid threshold for all of July and August 2002.

Water-temperature data for the stations along the Shasta River for 2002 and 2003 (*fig. 5A*) show that diurnal temperatures exceeded the 21°C salmonid threshold for the entire summer season (through September) of both 2002 and 2003. In 2002, the diel variation at the EDGEWOOD station, upstream of Lake Shastina, was larger than that at the other two stations (MONTAGUE and YREKA). In 2003, the three stations downstream from Lake Shastina (MONTAGUE, HWY3, and YREKA) had similar water temperatures throughout the summer season, with slightly higher temperatures at the YREKA station. The water temperatures at EDGEWOOD were lower than the temperatures at the other three stations for the entire 2003 measurement period, although the diurnal temperature also exceeded 21°C in mid July.

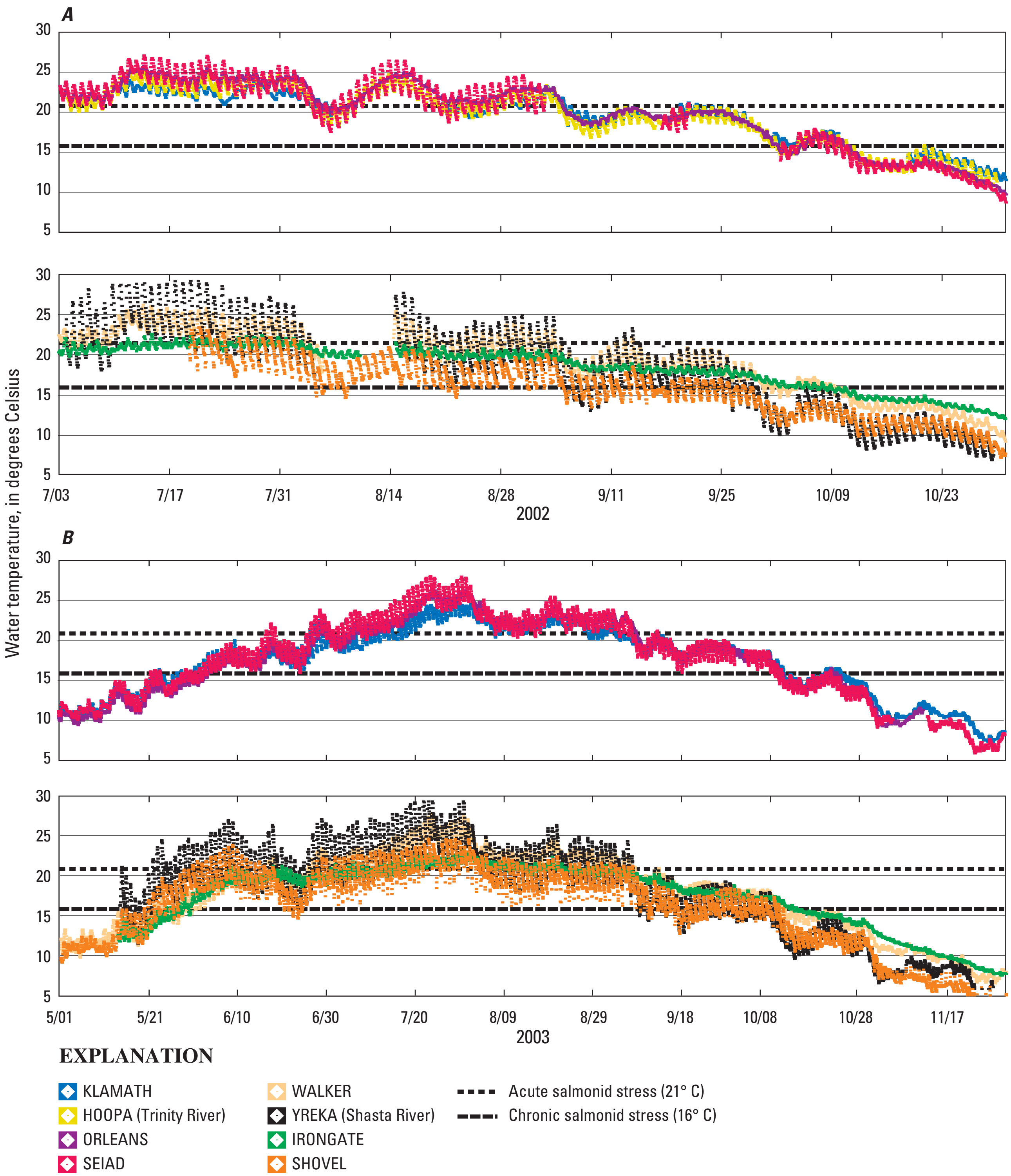

Figure 3. Water temperatures at continuous monitoring stations along the Klamath River in the Lower Klamath River Basin, California. ***A***, 2002. ***B***, 2003.

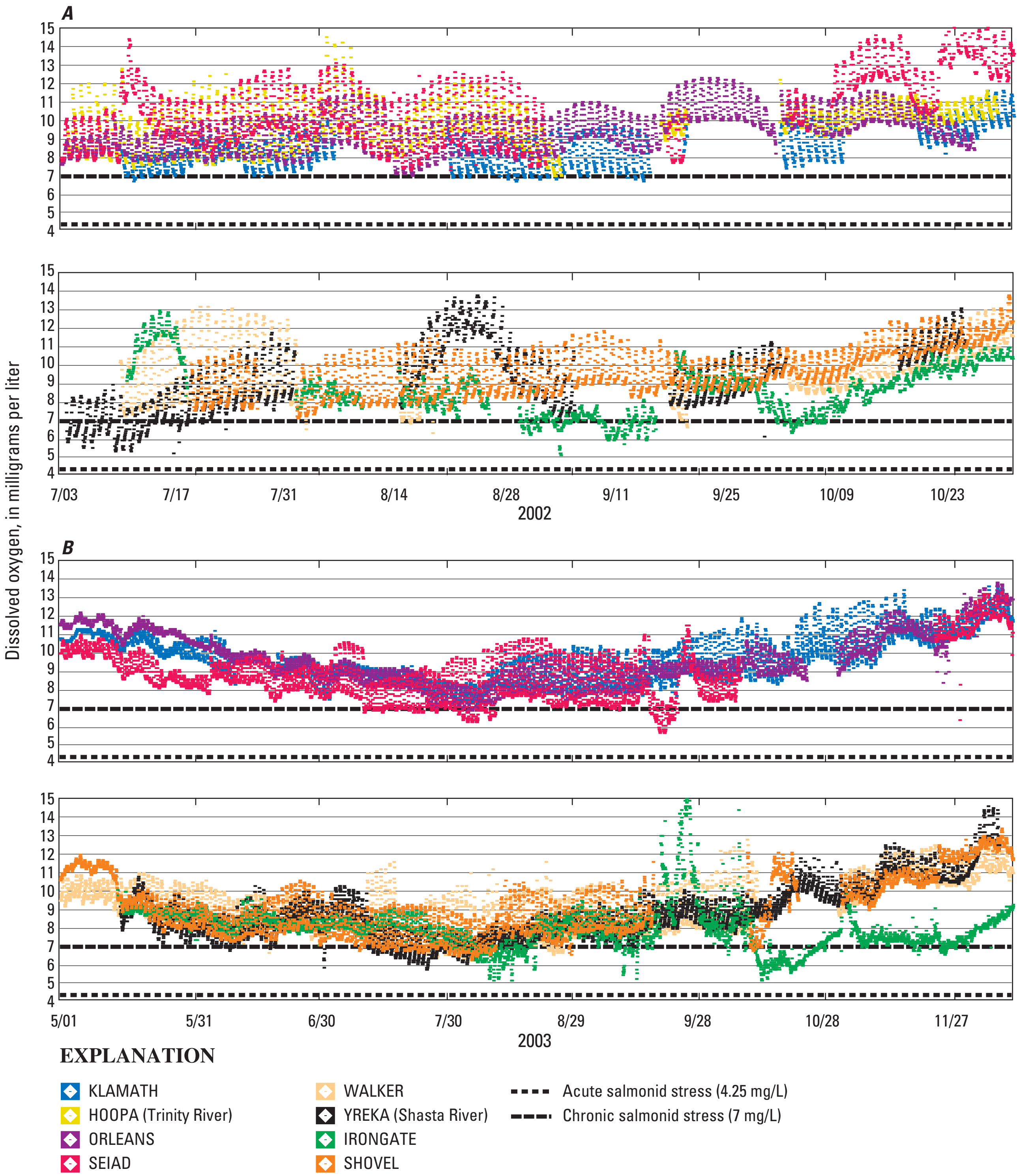

Figure 4. Dissolved oxygen at continuous monitoring stations along the Klamath River in the Lower Klamath River Basin, California. ***A.*** 2002. ***B.*** 2003.

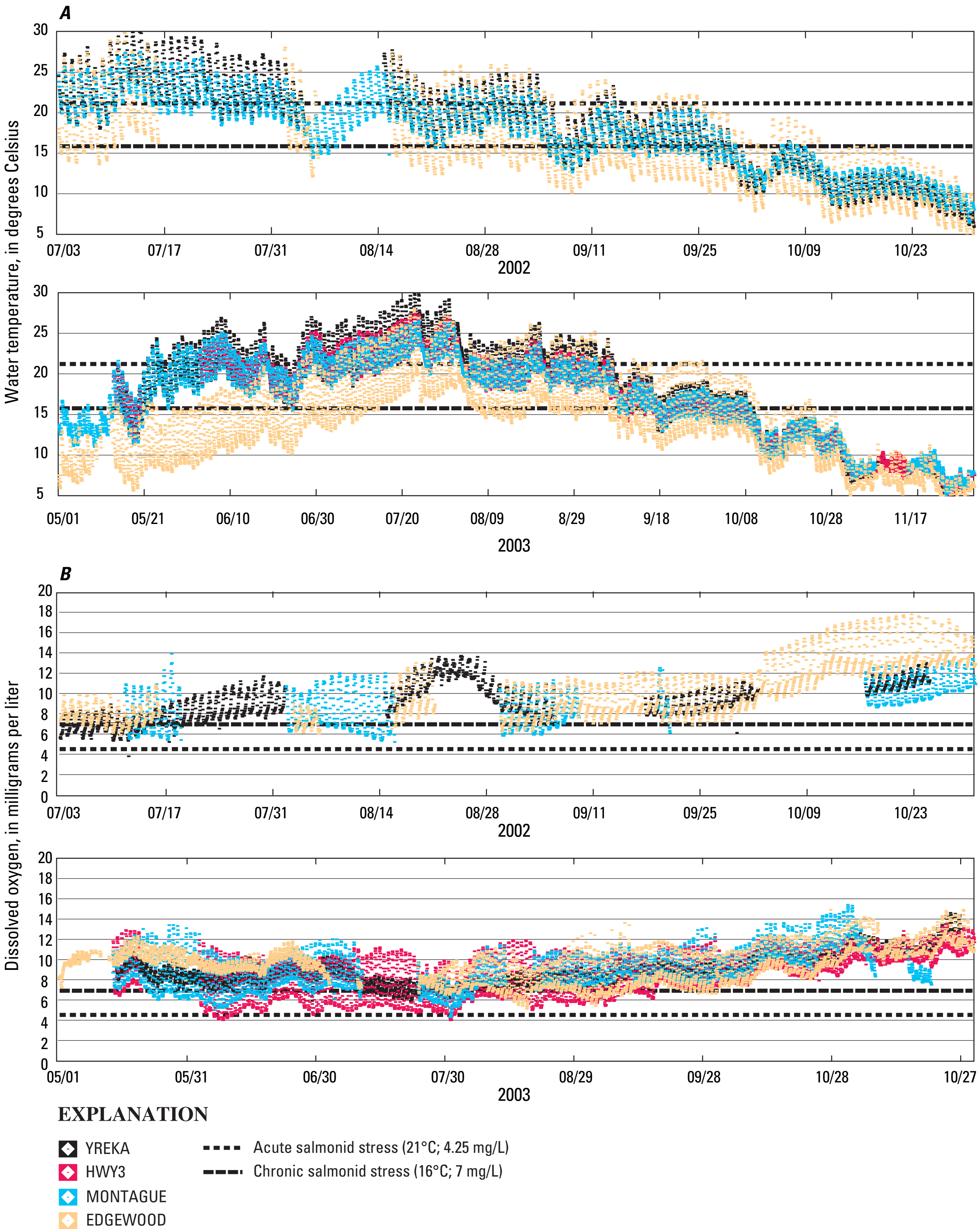

Figure 5. Measurements of (***A***) water temperature and (***B***) dissolved oxygen at continuous water-quality monitoring stations along the Shasta River in the Lower Klamath River Basin, California, 2002 and 2003.

Dissolved oxygen

Dissolved oxygen data for stations along the Shasta River for 2002 and 2003 (*fig. 5B*) show that during mid summer concentrations frequently dipped below the chronic level acceptable for salmonid health. The YREKA station had the smallest diurnal variation in DO, and the stations at MONTAGUE and EDGEWOOD had the largest. In addition, the large daily variations in DO and the frequent occurrence of supersaturated conditions are indicative of the presence of a strong influence of photosynthesis and respiration by algae and (or) aquatic plants at these sites.

Although the solubility of DO is such that DO and water temperature should be negatively correlated, relations between these two constituents at most of the stations on the Klamath River do not follow the dictates of solubility because of the influence other processes, such as algal photosynthesis, respiration, and decomposition. *Figure 6* illustrates the variation in the relation by showing DO data from three stations compared with water temperature and the calculated solubility (DO saturation calculated on the basis of barometric pressures in *table 2*). The region above and to the right of the line of solubility represents measurements when photosynthetic processes dominate the DO balance, and the region below and to the left of the line of solubility (saturation) represents measurements taken at periods of time when sediment oxygen demand (SOD) and biological oxygen demand (BOD) dominate the DO balance. The relation of DO to water temperature at the SHOVEL station was affected somewhat by photosynthetic processes between October and November. The SEIAD station was affected by algal photosynthesis and respiration between July and September and was not affected or only slightly affected between April and June. Data from the KLAMATH station, which had the smallest range in water temperature, showed the least effects owing to DO solubility.

The DO figures (*fig. 4A* and *B*) show the chronic (7 mg/L) and acute (4.25 mg/L) minimum thresholds for salmonids (Davis, 1975). Beginning upstream, the DO at the SHOVEL station, although extremely variable on a daily basis, never fell below the chronic threshold for salmonids in 2002. The relation between water temperature and DO at this location best represents a condition where flow is stable and relatively cool, and nutrient loads are low enough to not substantially influence the algal production that influences DO levels (*fig. 6*).

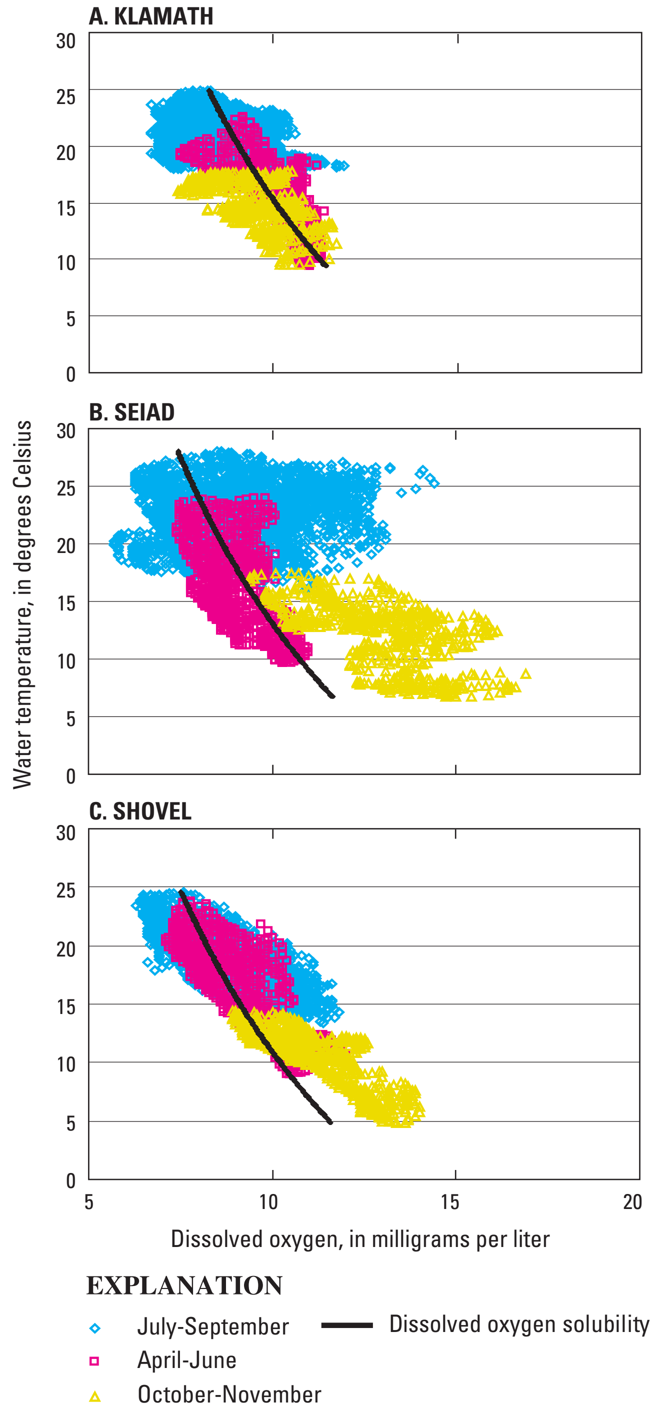

Figure 6. Relation between water temperature and dissolved oxygen (DO) for continuous water-quality monitoring stations at in the Lower Klamath River Basin, California, 2002 and 2003. ***A,*** KLAMATH; ***B,*** SEIAD; and ***C,*** SHOVEL.

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Abbreviated station name	Date	Time	Instantaneous discharge (ft^3/s) [00061]	Turbidity (NTU) [99872]	Barometric pressure (mm Hg) [00025]	Dissolved oxygen (mg/L) [00300]	Dissolved oxygen (percent saturation) [00301]	pH, (field standard units) [00400]	Specific conductance, unfiltered water (µS/cm) [00095]	Water temperature (°C) [00010]	Alkalinity, water disrict fet lab (mg/L as $CaCO_3$) [29801]
KLAMATH	7/15/02	1255	3020	2	760	8.2	94	8.4	170	22.0	75
	8/20/02	1400	2110	2.1	764	9.2	103	8.7	178	21.0	83
	9/24/02	1340	2030	E1.6	758	9.0	100	8.6	183	20.0	E82
HOOPA	7/9/02	1155	1010	1	750	8.1	94	8.6	149	22.0	68
	8/12/02	1350	707	1.6	745	9.2	112	7.7	142	24.0	68
	9/16/02	1130	631	0.7	750	9.8	106	7.5	145	18.5	E67
ORLEANS	7/9/02	1520	1820	0.8	747	8.9	105	8.3	180	22.5	77
	8/13/02	1055	1260	1.8	745	7.5	91	8.1	194	24.0	84
	9/16/02	1525	1290	1.1	747	10.4	116	8.4	193	19.5	E85
SEIAD	7/10/02	0840	1200	1.1	722	8.6	105	8.3	224	22.5	90
	8/13/02	1550	774	2.7	722	8.7	114	9.8	207	26.0	87
	9/17/02	0800	844	1.4	720	8.5	95	7.8	205	18.0	E88
WALKER	7/10/02	1315	1010	2.4	712	8.8	111	8.6	218	23.5	85
	8/14/02	1020	758	4.2	713	8.1	99	8.3	202	22.0	88
	9/17/02	1245	832	1.8	712	11.2	128	8.4	200	18.5	E85
YREKA	7/10/02	1645	21	2.6	735	7.1	98	8.6	590	30.0	280
	8/14/02	1340	17	3.8	702	9.4	124	8.4	642	25.0	310
	9/17/02	1515	24	1.1	703	9.4	110	8.5	627	19.0	E304
MONTAGUE	7/11/02	1130	38	2.3	692	8.2	106	8.4	516	23.0	234
	8/15/02	0925	25	2.9	693	7.2	86	7.9	503	19.0	233
	9/18/02	1615	33	2.9	696	11.0	130	8.3	522	19.0	E246

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

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Abbreviated station name	Date	Time	Instantaneous discharge (ft^3/s) [00061]	Turbidity (NTU) [99872]	Barometric pressure (mm Hg) [00025]	Dissolved oxygen (mg/L) [00300]	Dissolved oxygen (percent saturation) [00301]	pH, (field standard units) [00400]	Specific conductance, unfiltered water (µS/cm) [00095]	Water temperature (°C) [00010]	Alkalinity, water disrict fet lab (mg/L as $CaCO_3$) [29801]
EDGEWOOD	7/11/02	1330	9	1.6	682	7.5	108	8.9	238	28.0	120
	8/15/02	1130	12	2.8	680	9.9	127	8.0	219	22.0	111
	9/19/02	0815	12	1.6	685	10.4	106	7.7	201	11.5	E104
IRONGATE	7/11/02	0820	897	1.7	700	7.1	86	8.4	209	20.5	80
	8/14/02	1610	665	3.4	702	9.9	122	8.7	182	21.5	81
	9/18/02	0845	773	1.7	703	8.7	99	8.1	183	17.5	e77
SHOVEL	7/2/02	1225	414	3	688	9.0	111	9.0	149	20.5	67
	8/20/02	1125	428	1.9	690	9.9	111	8.4	176	16.0	80
	9/19/02	1315	706	2.7	693	10.0	110	8.3	226	15.5	e84
TULE	8/19/02	1445	151	11	654	9.2	120	9.8	570	20.5	137
	9/19/02	1630	219	6.5	655	11.3	145	9.5	530	20.0	E141
HATFIELD	7/18/02	1315	52	5.8	655	9.7	137	8.2	167	25.0	72
	8/19/02	1305	126	4.5	654	6.9	89	7.2	220	20.0	192
	9/19/02	1345	207	4.9	658	9.4	115	7.6	253	18.0	E114

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; kg/d, kilograms per day; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Abbreviated station Name	Date	Time	Nitrogen, ammonia, dissolved		Nitrogen, ammonia + organics, dissolved		Nitrogen, $NO_2 + NO_3$, dissolved		Total inorganic nitrogen (mg/L as N)	Nitrogen/orthophosphate (N/PO_4)	Orthophosphate, dissolved (mg/L as P) [00671]
			(mg/L as N) [00608]	(kg/d as N)	(mg/L as N) [00623]	(kg/d as N)	(mg/L as N) [00631])	(kg/d as N)			
KLAMATH	7/15/02	1255	<0.015	<110.8	0.11	813	E0.009	67.0	0.024	E1.2	E0.02
	8/20/02	1400	<0.015	<77.4	0.18	929	<0.013	<67.0	0.028	—	—
	9/24/02	1340	<0.015	<74.5	0.18	894	E0.009	45.0	0.024	0.8	0.03
HOOPA	7/9/02	1155	<0.015	<37.1	E0.05	124	0.011e	27.0	0.026	<1.3	<0.02
	8/12/02	1350	<0.015	<26.0	<0.1	<173	<0.013	<23.0	0.028	<1.4	<0.02
	9/16/02	1130	<0.015	<23.2	E0.05	77	<0.013	<20.0	0.028	<1.4	<0.02
ORLEANS	7/9/02	1520	<0.015	<66.8	0.21	935	<0.013	<58.0	0.028	0.7	0.04
	8/13/02	1055	<0.015	<46.2	0.29	894	<0.013	<40.0	0.028	0.7	0.04
	9/16/02	1525	<0.015	<47.3	0.33	1,042	<0.013	<41.0	0.028	0.4	0.07
SEIAD	7/10/02	0840	<0.015	<44.0	0.39	1,145	<0.013	<38.0	0.028	0.4	0.08
	8/13/02	1550	<0.015	<28.4	0.54	1,020	<0.013	<25.0	0.028	0.3	0.11
	9/17/02	0800	E0.01	20.7	0.51	1,050	0.069	140.0	0.079	0.7	0.12
WALKER	7/10/02	1315	<0.015	<37.1	0.48	1,186	<0.013	<32.0	0.028	0.3	0.1
	8/14/02	1020	0.017	31.5	0.59	1,090	0.115	213.0	0.132	1.1	0.12
	9/17/02	1245	E0.011	22.4	0.55	1,120	0.127	259.0	0.138	1.0	0.14
YREKA	7/10/02	1645	0.03	1.5	0.52	27	0.016	0.80	0.046	0.2	0.29
	8/14/02	1340	E0.01	0.4	0.59	25	<0.013	<0.50	0.023	0.1	0.32
	9/17/02	1515	E0.009	0.5	0.47	28	0.015	0.90	0.024	0.1	0.26
MONTAGUE	7/11/02	1130	E0.009	0.8	0.33	31	<0.013	<1.2	<0.022	0.1	0.16
	8/15/02	0925	<0.015	<0.9	0.22	14	<0.013	<0.80	<0.028	0.2	0.15
	9/18/02	1615	<0.015	<1.2	0.18	15	<0.013	<1.0	<0.028	0.2	0.16

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

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Abbreviated station Name	Date	Time	Nitrogen, ammonia, dissolved (mg/L as N) [00608]	Nitrogen, ammonia, dissolved (kg/d as N)	Nitrogen, ammonia + organics, dissolved (mg/L as N) [00623]	Nitrogen, ammonia + organics, dissolved (kg/d as N)	Nitrogen, $NO_2 + NO_3$, dissolved (mg/L as N) [00631])	Nitrogen, $NO_2 + NO_3$, dissolved (kg/d as N)	Total inorganic nitrogen (mg/L as N)	Nitrogen/orthophosphate (N/PO_4)	Orthophosphate, dissolved (mg/L as P) [00671]
EDGEWOOD	7/11/02	1330	E0.009	0.2	0.32	6.7	E0.012	0.30	E0.021	0.3	0.07
	8/15/02	1130	<0.015	<0.4	0.23	6.8	<0.013	<0.40	<0.028	0.6	0.05
	9/19/02	0815	<0.015	<0.4	0.16	4.7	<0.013	<0.40	<0.028	0.5	0.06
IRONGATE	7/11/02	0820	0.032	70.2	0.54	1,190	0.073	160.0	0.105	1.0	0.11
	8/14/02	1610	0.039	63.5	0.66	1,070	0.131	213.0	0.17	1.7	0.1
	9/18/02	0845	0.027	51.1	0.55	1,040	0.214	405.0	0.241	1.6	0.15
SHOVEL	7/2/02	1225	0.018	18.2	0.47	476	0.466	472.0	0.484	3.7	0.13
	8/20/02	1125	0.013	13.6	0.44	461	0.200	210.0	0.213	1.9	0.11
	9/19/02	1315	E0.009	15.5	0.76	1,310	0.211	365.0	0.22	1.8	0.12
TULE	8/19/02	1445	E0.013	4.8	1.8	670	<0.013	<4.8	0.026	0.9	0.03
	9/19/02	1630	0.02	10.7	1.9	1,020	<0.013	<7.0	0.033	1.7	0.02
HATFIELD	7/18/02	1315	0.036	4.6	0.95	120	0.277	35.2	0.313	1.3	0.24
	8/19/02	1305	0.078	24.0	0.98	302	0.385	119.0	0.463	1.9	0.24
	9/19/02	1345	0.069	35.0	0.95	481	0.294	149.0	0.363	1.4	0.26

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; kg/d, kilograms per day; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Site	Date	Time	Orthophosphate		Phosphorus total		Total organic carbon	Pheophytin-*a* phytoplankton		Chlor-*a* phytoplankton chromoflurom	
			(kg/d as P)	(mg/L as P) [00665]	(kg/d as P)	(mg/L as C) [00680]	(kg/d as C)	(µg/L) [62360]	(g/d)	(µg/L) [70953]	(g/d)
KLAMATH	7/15/02	1255	150	E0.03	220	1.7	13,000	0.9	7,000	2.9	21,000
	8/20/02	1400	—	E0.03	150	2.4	12,000	2.2	11,000	2.3	12,000
	9/24/02	1340	150	E0.05	250	4.3	21,000	2.8	14,000	2.8	14,000
HOOPA	7/9/02	1155	<50	<0.06	<150	0.8	2,000	0.3	700	0.2	500
	8/12/02	1350	<35	<0.06	<100	0.9	1,600	0.3	500	0.2	300
	9/16/02	1130	<31	<0.06	<90	1.2	1,900	0.8	1,000	0.4	600
ORLEANS	7/9/02	1520	E180	E0.05	220	2.7	12,000	0.7	3,000	0.7	3,000
	8/13/02	1055	120	0.06	190	4	12,000	3.1	9,600	2.3	7,100
	9/16/02	1525	220	0.1	320	4.1	13,000	2.6	8,200	1.9	6,000
SEIAD	7/10/02	0840	230	0.1	290	5.7	17,000	2.5	7,300	1.3	3,800
	8/13/02	1550	210	0.15	280	6.5	12,000	5.2	9,800	3.2	6,100
	9/17/02	0800	250	0.14	290	6.2	13,000	11.2	23,100	6	12,000
WALKER	7/10/02	1315	250	0.14	350	6.5	16,000	2.7	6,700	2.1	5,200
	8/14/02	1020	220	0.16	300	7.1	13,000	8.1	15,000	9.3	17,000
	9/17/02	1245	290	0.17	350	7	14,000	7.3	15,000	5.2	11,000
YREKA	7/10/02	1645	15	0.35	18	7.3	380	3.8	200	2.1	110
	8/14/02	1340	13	0.34	14	7.9	330	2.5	100	1.6	70
	9/17/02	1515	15	0.27	16	10.6	620	3.4	200	1.7	100
MONTAGUE	7/11/02	1130	15	0.19	18	3.4	300	1.7	200	1.0	100
	8/15/02	0925	9	0.16	9	2.9	200	1.2	100	0.4	0
	9/18/02	1615	13	0.16	13	5.0	400	1.1	100	0.4	0

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; kg/d, kilograms per day; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Site	Date	Time	Orthophosphate		Phosphorus total		Total organic carbon	Pheophytin-*a* phytoplankton		Chlor-*a* phytoplankton chromoflurom	
			(kg/d as P)	(mg/L as P) [00665]	(kg/d as P)	(mg/L as C) [00680]	(kg/d as C)	(µg/L) [62360]	(g/d)	(µg/L) [70953]	(g/d)
EDGEWOOD	7/11/02	1330	2	0.10	2	4.4	100	4.2	100	2.6	100
	8/15/02	1130	2	0.07	2	3.9	100	4.7	100	6.5	200
	9/19/02	0815	2	0.08	2	4.1	100	8.6	300	6.0	200
IRONGATE	7/11/02	0820	240	0.15	330	6.3	14,000	2	4,400	3.6	7,900
	8/14/02	1610	160	0.17	280	10.3	17,000	2.8	4,600	40.4	65,700
	9/18/02	0845	280	0.16	300	6.4	12,000	5	9,500	8.4	16,000
SHOVEL	7/2/02	1225	130	0.15	150	4.6	4,700	4.5	4,600	2.5	2,500
	8/20/02	1125	120	0.12	130	5.1	5,300	3.6	3,800	2.7	2,800
	9/19/02	1315	210	0.15	260	9.1	16,000	10.4	18,000	6.4	11,000
TULE	8/19/02	1445	11	0.24	89	29.8	11,000	8.3	3,100	37.2	13,700
	9/19/02	1630	11	0.24	130	28.5	15,000	25.9	13,900	45.5	24,400
HATFIELD	7/18/02	1315	31	0.32	41	11.4	1,500	31.6	4,020	22.8	2,900
	8/19/02	1305	74	0.29	89	11.2	3,500	9.3	2,900	5.0	2,000
	9/19/02	1345	130	0.31	160	11.2	5,700	17.3	8,760	27.0	14,000

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; kg/d, kilograms per day; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Site	Date	Time	Aluminum, dissolved (µg/L) [01106]	Antimony, dissolved (µg /L) [01095]	Arsenic, dissolved (µg /L) [01000]	Barium, dissolved (µg /L) [01005]	Beryllium, dissolved (µg /L) [01010]	Cadmium, dissolved (µg /L) [01025]	Chromium, dissolved (µg /L) [01030]	Cobalt, dissolved (µg /L) [01035]	Copper, dissolved (µg /L) [01040]
KLAMATH	7/15/02	1255	—	—	—	—	—	—	—	—	—
	8/20/02	1400	—	—	—	—	—	—	—	—	—
	9/24/02	1340	<1	<0.05	3	14.0	<0.06	<0.04	<0.8	0.08	0.7
HOOPA	7/9/02	1155	—	—	—	—	—	—	—	—	—
	8/12/02	1350	—	—	—	—	—	—	—	—	—
	9/16/02	1130	1	0.09	2	14.0	0.06	0.04	<0.8	0.04	0.5
ORLEANS	7/9/02	1520	—	—	—	—	—	—	—	—	—
	8/13/02	1055	—	—	—	—	—	—	—	—	—
	9/16/02	1525	1	E0.05	3	14.0	<0.06	<0.04	<0.8	0.1	0.8
SEIAD	7/10/02	0840	—	—	—	—	—	—	—	—	—
	8/13/02	1550	—	—	—	—	—	—	—	—	—
	9/17/02	0800	2	E0.04	4	10.0	<0.06	<0.04	2.4	0.13	1.2
WALKER	7/10/02	1315	—	—	—	—	—	—	—	—	—
	8/14/02	1020	—	—	—	—	—	—	—	—	—
	9/17/02	1245	2	E0.04	5	8.0	<0.06	<0.04	<0.8	0.13	0.6
YREKA	7/10/02	1645	—	—	—	—	—	—	—	—	—
	8/14/02	1340	—	—	—	—	—	—	—	—	—
	9/17/02	1515	1	0.09	6	42.0	<0.06	<0.04	<0.8	0.19	1.0
MONTAGUE	7/11/02	1130	—	—	—	—	—	—	—	—	—
	8/15/02	0925	—	—	—	—	—	—	—	—	—
	9/18/02	1615	<1	E0.04	7	29.0	<0.06	<0.04	<0.8	0.09	0.7

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; kg/d, kilograms per day; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Site	Date	Time	Aluminum, dissolved (µg/L) [01106]	Antimony, dissolved (µg /L) [01095]	Arsenic, dissolved (µg /L) [01000]	Barium, dissolved (µg /L) [01005]	Beryllium, dissolved (µg /L) [01010]	Cadmium, dissolved (µg /L) [01025]	Chromium, dissolved (µg /L) [01030]	Cobalt, dissolved (µg /L) [01035]	Copper, dissolved (µg /L) [01040]
EDGEWOOD	7/11/02	1330	—	—	—	—	—	—	—	—	—
	8/15/02	1130	—	—	—	—	—	—	—	—	—
	9/19/02	0815	1	0.07	2	7.0	<0.06	<0.04	<0.8	0.09	0.7
IRONGATE	7/11/02	0820	—	—	—	—	—	—	—	—	—
	8/14/02	1610	—	—	—	—	—	—	—	—	—
	9/18/02	0845	2	E0.03	5	7.0	<0.06	<0.04	<0.8	0.11	0.8
SHOVEL	7/2/02	1225	—	—	—	—	—	—	—	—	—
	8/20/02	1125	—	—	—	—	—	—	—	—	—
	9/19/02	1315	2	0.05	6	7.0	<0.06	E0.03	<0.8	0.15	0.8
TULE	8/19/02	1445	—	—	—	—	—	—	—	—	—
	9/19/02	1630	2	0.16	9	11.0	<0.06	E0.02	<0.8	0.2	1.7
HATFIELD	7/18/02	1315	—	0.04	1	0.3	0.2	0.3	11.4	31.6	22.8
	8/19/02	1305	—	0.08	1	0.4	0.2	0.3	11.2	9.3	5.0
	9/19/02	1345	3	0.07	1	0.3	0.3	0.3	11.2	17.3	27.0

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; kg/d, kilograms per day; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Site	Date	Time	Manganese, dissolved (µg /L) [01056]	Mercury, dissolved (µg /L) [71890]	Mercury, total recoverable (µg /L) [71900]	Molybdenum, dissolved (µg /L) [01060]	Nickel, dissolved (µg /L) [01065]	Selenium, dissolved (µg /L) [01145]	Silver, dissolved (µg /L) [01075]	Zinc, dissolved (µg /L) [01090]	Uranium, dissolved (µg /L) [22703]
KLAMATH	7/15/02	1255	—	—	—	—	—	—	—	—	—
	8/20/02	1400	—	—	—	—	—	—	—	—	—
	9/24/02	1340	3	E0.01	<0.01	0.6	2.43	E1	<1	1	0.07
HOOPA	7/9/02	1155	—	—	—	—	—	—	—	—	—
	8/12/02	1350	—	—	—	—	—	—	—	—	—
	9/16/02	1130	0.9	E0.01	E0.01	0.5	1.55	<2	<1	—	0.06
ORLEANS	7/9/02	1520	—	—	—	—	—	—	—	—	—
	8/13/02	1055	—	—	—	—	—	—	—	—	—
	9/16/02	1525	2.5	<0.01	<0.01	0.8	2.28	<2	<1	—	0.11
SEIAD	7/10/02	0840	—	—	—	—	—	—	—	—	—
	8/13/02	1550	—	—	—	—	—	—	—	—	—
	9/17/02	0800	7.2	0.01	0.02	1.0	1.36	<2	<1	—	0.12
WALKER	7/10/02	1315	—	—	—	—	—	—	—	—	—
	8/14/02	1020	—	—	—	—	—	—	—	—	—
	9/17/02	1245	6.1	E0.01	E0.01	1.0	1.00	<2	<1	—	0.13
YREKA	7/10/02	1645	—	—	—	—	—	—	—	—	—
	8/14/02	1340	—	—	—	—	—	—	—	—	—
	9/17/02	1515	9.7	0.04	0.05	1.0	5.05	<2	<1	—	0.72
MONTAGUE	7/11/02	1130	—	—	—	—	—	—	—	—	—
	8/15/02	0925	—	—	—	—	—	—	—	—	—
	9/18/02	1615	4.7	E0.01	<0.01	0.8	3.13	<2	<1	—	0.72

Table 2. Water-quality data collected in July, August, and September 2002 for 12 sites in the Lower Klamath River Basin, California—***Continued***.

[See table 1 for full station name and figure 1 for station location; E indicates value is estimated. Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS /cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; kg/d, kilograms per day; <, actual values are less than the values shown; —, no data; N/PO_4, ratio of total inorganic nitrogen to orthophosphate; mg/L, milligrams per liter; kg/d, kilograms per day; µg/L, micrograms per liter]

Site	Date	Time	Manganese, dissolved (µg /L) [01056]	Mercury, dissolved (µg /L) [71890]	Mercury, total recoverable (µg /L) [71900]	Molybdenum, dissolved (µg /L) [01060]	Nickel, dissolved (µg /L) [01065]	Selenium, dissolved (µg /L) [01145]	Silver, dissolved (µg /L) [01075]	Zinc, dissolved (µg /L) [01090]	Uranium, dissolved (µg /L) [22703]
EDGEWOOD	7/11/02	1330	—	—	—	—	—	—	—	—	—
	8/15/02	1130	—	—	—	—	—	—	—	—	—
	9/19/02	0815	3.7	<0.01	<0.01	0.5	9.28	<2	<1	—	0.07
IRONGATE	7/11/02	0820	—	—	—	—	—	—	—	—	—
	8/14/02	1610	—	—	—	—	—	—	—	—	—
	9/18/02	0845	7.3	E0.01	<0.01	1.0	0.80	<2	<1	—	0.10
SHOVEL	7/2/02	1225	—	—	—	—	—	—	—	—	—
	8/20/02	1125	—	—	—	—	—	—	—	—	—
	9/19/02	1315	4.9	E0.01	<0.01	1.7	0.92	<2	<1	—	0.17
TULE	8/19/02	1445	—	—	—	—	—	—	—	—	—
	9/19/02	1630	2.6	E0.01	E0.01	7.9	2.21	<2	<1	—	0.49
HATFIELD	7/18/02	1315	—	—	—	—	—	—	—	—	—
	8/19/02	1305	—	—	—	—	—	—	—	—	—
	9/19/02	1345	35.5	<0.01	E0.01	1.6	1.46	<2	<1	—	0.22

Streamflow is regulated in all but the smallest subbasins throughout the study area. The effects of regulation are most obvious at IRONGATE on the Klamath River and at HOOPA on the Trinity River (*fig. 7*). The greater short-term variability of flow at MONTAGUE and YREKA on the Shasta River represents a more natural regime. Estimation of natural flow, encompassing both seasonal and daily variations, is beyond the scope of this study but is under investigation by others (Perry and others, 2004). The stations downstream from the Iron Gate Reservoir on the Klamath River show changes in the release rates from the Iron Gate Dam that occurred as a reduction in discharge on July 11 and July 31, 2002, and July 10, 2003, and increased discharge on September 1 and September 27, 2002, and August 1, September 1, and September 21, 2003. *Figure 7* shows the effects of the dam release rates at seven streamflow-gaging stations on the Klamath, Trinity, and Shasta Rivers. Discharge was typically higher at all stations in 2003 than in 2002. Variations in the DO concentration at IRONGATE may be related to reservoir DO conditions that are accentuated by the change in discharge. DO fluctuations were smaller in 2003 than in 2002 for all stations throughout most of the measurement period, probably because of the increased discharge.

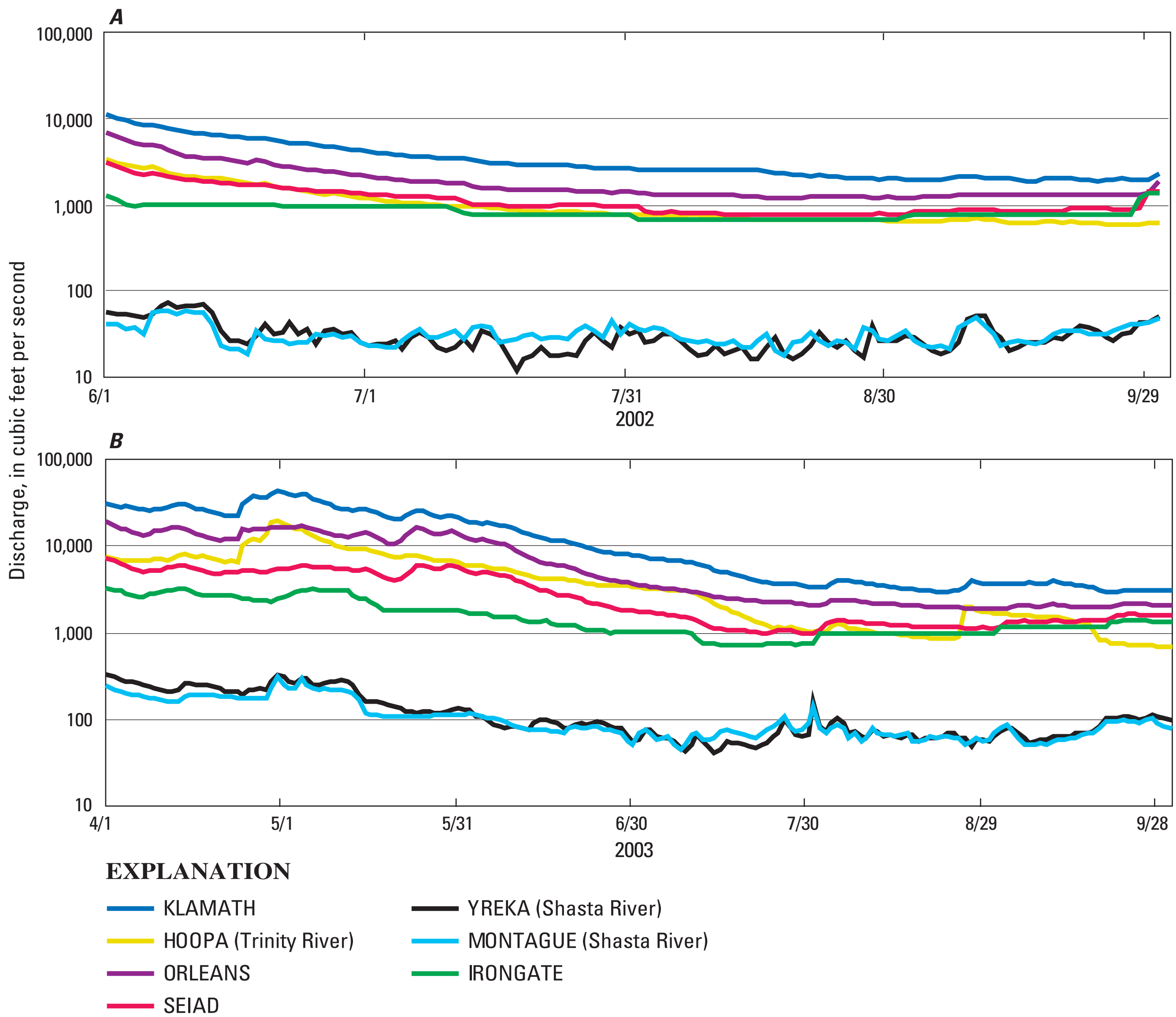

Figure 7. Discharge for seven USGS streamflow gaging stations on the Klamath, Trinity, and Shasta Rivers in the Lower Klamath River Basin, California, 2002 and 2003.

DO at the YREKA station on the Shasta River was low at times, below the chronic minimum of 7 mg/L for salmonids through more than half of July of both 2002 and 2003 (*fig. 4*, *tables 2* and *3*). Although the low DO water from the Shasta River flows into the Klamath River, the flows were too low to greatly affect the DO at the downstream WALKER station, which had DO values above the chronic threshold through July. Few data, however, were available for the WALKER station for August and September 2002. Values for the SEIAD station remain above the chronic minimum threshold for the entire 2002 season but decreased to below the chronic minimum in both July and September 2003. DO at the ORLEANS station never decreased below either minimum threshold. Some of the highs and lows in DO that occurred at the YREKA station were visible in the data from the SEIAD and the ORLEANS stations, yet the patterns do not extend all the way downstream to the KLAMATH station. These patterns may be due partly to climatic patterns that influence algal activity. DO at the HOOPA station was above the minimum thresholds. However, DO at the KLAMATH station was lower than at any other station downstream from the WALKER station for several periods between July and September of 2002, reaching or falling just below the chronic minimum threshold. DO concentration at the KLAMATH station was similar to that at the ORLEANS station in 2003, which was a higher discharge year.

Table 3. Water-quality data from Lagrangian parcel-tracking study in 2003 on the Shasta River and Klamath River in the Lower Klamath River Basin, California

[Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; mi^2, square miles; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; –, no drainage area information available; <, actual value less than the value shown; °C, degrees celsius; mg/L, milligrams per liter; —, no data; $CaCO_3$, calcium carbonate; acre-ft, acre-feet; e indicates value is estimated; N, nitrogen; P, phosphorus; µg/L, micrograms per liter]

Abbreviated station name.	Station ID	Date	Time	Instantaneous discharge (ft^3/s) [00061]	Drainage area (mi^2)	Turbidity (NTU) [99872]	Dissolved oxygen (mg/L) [00300]	Dissolved oxygen (percent saturation) [00301]	pH, field (standard units) [00400]	Specific conductivity, field (µS/cm)
Shasta River										
Grenada	11516880	6/17/03	0840	103		2.7	6.8	83	8.0	426
Montague	11517000	6/17/03	1150	73	673	5.3	8.7	109	8.3	479
Hwy3	11517015	6/17/03	1435	81	676	2.0	9.9	129	8.4	484
Yreka	11517500	6/17/03	1815	103	793	2.1	8.8	121	8.8	494
Grenada	11516880	8/19/03	0830	83	--	2.1	6.6	77	7.9	426
Montague	11517000	8/19/03	1120	64	673	3.6	8.9	110	8.2	490
Hwy3	11517015	8/19/03	1250	59	676	4.3	10.0	127	8.4	498
Yreka	11517500	8/19/03	1820	62	793	3.7	7.3	97	8.8	530
Klamath River										
Irongate	11516530	7/14/03	0810	747	4,630	1.9	8.6	105	8.2	198
Walker	11517818	7/14/03	1940	933	5,885	2.0	8.4	107	8.8	220
Seiad	11520500	7/15/03	0630	1,110	6,940	1.3	7.8	94	8.3	224
Orleans	11523000	7/16/03	0650	2,510	8,475	2.3	8.6	98	8.2	177
Klamath	11530500	7/17/03	0910	4,680	12,100	1.0	8.5	94	8.2	161
Irongate	11516530	9/15/03	0800	1,190	4,630	4.1	7.0	82	8.4	160
Walker	11517818	9/15/03	1930	1,410	5,885	3.2	8.8	102	8.5	186
Seiad	11520500	9/16/03	0650	1,370	6,940	3.6	8.7	95	8.1	200
Orleans	11523000	9/17/03	0720	1,990	8,475	4.4	9.4	100	8.3	189
Klamath	11530500	9/18/03	0920	3,110	12,100	2.3	9.4	97	8.1	168

Table 3. Water-quality data from Lagrangian parcel-tracking study in 2003 on the Shasta River and Klamath River in the Lower Klamath River Basin, California—***Continued.***

[Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; mi^2, square miles; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; –, no drainage area information available; <, actual value less than the value shown; °C, degrees celsius; mg/L, milligrams per liter; —, no data; $CaCO_3$, calcium carbonate; acre-ft, acre-feet; e indicates value is estimated; N, nitrogen; P, phosphorus; µg/L, micrograms per liter]

Abbreviated station name.	Station ID	Date	Time	Water temperature (°C) [00010]	Hardness, unfiltered (mg/L as $CaCO_3$)	Calcium, filtered (mg/L) [00915]	Magnesium, filtered (mg/L) [00935]	Potassium, filtered (mg/L) [00935]	Sodium, filtered (mg/L) [00930]	Sodium, percent in equiva-lents of major cations [00932]
Shasta River										
Grenada	11516880	6/17/03	0840	19.6	170	21.1	27.6	2.35	27.7	26
Montague	11517000	6/17/03	1150	21.0	180	24.0	30.3	2.78	31.7	27
Hwy3	11517015	6/17/03	1435	23.0	180	23.8	30.0	2.87	31.7	27
Yreka	11517500	6/17/03	1815	26.0	200	28.1	31.8	2.86	31.7	25
Grenada	11516880	8/19/03	0830	18.2	170	22.7	26.8	2.55	27.7	26
Montague	11517000	8/19/03	1120	21.0	190	27.5	29.8	3.10	32.1	26
Hwy3	11517015	8/19/03	1250	22.0	200	28.1	30.4	3.12	33.0	26
Yreka	11517500	8/19/03	1820	25.5	210	31.8	32.8	3.30	34.2	25
Klamath River										
Irongate	11516530	7/14/03	0810	21.5	65	13.4	7.73	3.03	16.3	34
Walker	11517818	7/14/03	1940	24.0		15.3	9.63	2.85	16.6	31
Seiad	11520500	7/15/03	0630	22.0	86	16.9	10.6	2.25	13.4	25
Orleans	11523000	7/16/03	0650	21.5	74	16.0	8.19	1.47	8.18	19
Klamath	11530500	7/17/03	0910	20.0	70	15.5	7.59	.91	5.25	14
Irongate	11516530	9/15/03	0800	19.5	55	11.5	6.43	2.54	13.2	33
Walker	11517818	9/15/03	1930	19.5		12.7	8.21	2.55	14.1	31
Seiad	11520500	9/16/03	0650	17.5	74	14.4	9.22	2.47	13.9	28
Orleans	11523000	9/17/03	0720	18.0	75	15.6	8.69	1.99	11.3	24
Klamath	11530500	9/18/03	0920	17.0	76	15.9	8.77	1.34	7.59	18

Table 3. Water-quality data from Lagrangian parcel-tracking study in 2003 on the Shasta River and Klamath River in the Lower Klamath River Basin, California—***Continued.***

[Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; mi^2, square miles; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; –, no drainage area information available; <, actual value less than the value shown; °C, degrees celsius; mg/L, milligrams per liter; —, no data; $CaCO_3$, calcium carbonate; acre-ft, acre-feet; e indicates value is estimated; N, nitrogen; P, phosphorus; µg/L, micrograms per liter]

Abbreviated station name.	Station ID	Date	Time	Alkalinity, water, filtered, field (mg/L as $CaCO_3$) [39086]	Bicarbonate, water, filtered, field (mg/L) [00453]	Carbonate, water, filtered, field (mg/L) [00452]	Chloride, water, filtered (mg/L) [00940]	Fluoride, water, filtered (mg/L) [00950]	Silica, water, filtered (mg/L) [00945]	Sulfate, water, filtered (mg/L) [00945]
Shasta River										
Grenada	11516880	6/17/03	0840	194	231	2	15.1	0.2	54.8	5.6
Montague	11517000	6/17/03	1150	263	314	3	18.3	.2	53.7	6.5
Hwy3	11517015	6/17/03	1435	227	268	4	18.4	.3	53.8	6.5
Yreka	11517500	6/17/03	1815	238	269	10	18.3	.3	49.0	7.6
Grenada	11516880	8/19/03	0830	188	227	<1	15.8	.3	57.7	5.8
Montague	11517000	8/19/03	1120	216	260	2	19.2	.3	57.3	6.2
Hwy3	11517015	8/19/03	1250	238	286	2	20.6	.3	57.3	6.4
Yreka	11517500	8/19/03	1820	240	280	6	21.6	.3	51.0	7.7
Klamath River										
Irongate	11516530	7/14/03	0810	100	122	<1	4.25	<0.2	28.1	13.3
Walker	11517818	7/14/03	1940	88	104	2	5.37	<.2	27.2	11.9
Seiad	11520500	7/15/03	0630	94	114	1	5.48	<.2	23.9	10.5
Orleans	11523000	7/16/03	0650	86	104	<1	3.78	<.2	19.8	7.0
Klamath	11530500	7/17/03	0910	72	87	<1	2.87	<.2	16.2	5.7
Irongate	11516530	9/15/03	0800	76	92	1	3.88	<.2	37.5	6.3
Walker	11517818	9/15/03	1930	78	94	1	5.21	<.2	36.1	6.4
Seiad	11520500	9/16/03	0650	76	92	1	5.65	<.2	34.4	6.5
Orleans	11523000	9/17/03	0720	90	109	<1	5.23	<.2	29.2	5.9
Klamath	11530500	9/18/03	0920	78	95	<1	3.87	<.2	21.4	5.4

Table 3. Water-quality data from Lagrangian parcel-tracking study in 2003 on the Shasta River and Klamath River in the Lower Klamath River Basin, California—***Continued.***

[Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft³/s, cubic feet per second; mi², square miles; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; –, no drainage area information available; <, actual value less than the value shown; °C, degrees celsius; mg/L, milligrams per liter; —, no data; $CaCO_3$, calcium carbonate; acre-ft, acre-feet; e indicates value is estimated; N, nitrogen; P, phosphorus; µg/L, micrograms per liter]

Abbreviated station name.	Station ID	Date	Time	Residue on evaporation, dried at 180 C, water, filtered (mg/L) [70300]	Ammonia plus organic nitrogen, water, filtered (mg/L as N) [00608]	Ammonia, water, filtered (mg/L as N)	Nitrite plus nitrate, water, filtered (mg/L as N) [00631]	Orthophosphate, water, filtered (mg/L as P) [00671]	Total phosphorus, water, unfiltered (mg/L) [00665]
Shasta River									
Grenada	11516880	6/17/03	0840	275	0.23	<0.015	<0.022	0.14	0.15
Montague	11517000	6/17/03	1150	289	.33	<.015	<.022	.14	.17
Hwy3	11517015	6/17/03	1435	300	.35	<.015	<.022	.15	.17
Yreka	11517500	6/17/03	1815	309	.36	<.015	<.022	.15	.17
Grenada	11516880	8/19/03	0830	270	.20	<.015	<.022	.15	.17
Montague	11517000	8/19/03	1120	302	.30	<.015	<.022	.17	.19
Hwy3	11517015	8/19/03	1250	317	.38	<.015	<.022	.14	.17
Yreka	11517500	8/19/03	1820	335	.41	<.015	<.022	.16	.19
Klamath River									
Irongate	11516530	7/14/03	0810	150	0.53	0.014	0.125	0.1	0.12
Walker	11517818	7/14/03	1940	139	.49	<.015	.013	.1	.11
Seiad	11520500	7/15/03	0630	140	.35	<.015	.038	.07	.08
Orleans	11523000	7/16/03	0650	120	.16	<.015	<.022	.03	.04
Klamath	11530500	7/17/03	0910	100	.10	<.015	<.022	.01	.02
Irongate	11516530	9/15/03	0800	130	.61	.009	.317	.12	.16
Walker	11517818	9/15/03	1930	147	.58	.010	.285	.12	.16
Seiad	11520500	9/16/03	0650	141	.55	.008	.257	.11	.16
Orleans	11523000	9/17/03	0720	136	.36	<.015	.018	.06	.11
Klamath	11530500	9/18/03	0920	122	.17	<.015	<.022	.03	.06

Table 3. Water-quality data from Lagrangian parcel-tracking study in 2003 on the Shasta River and Klamath River in the Lower Klamath River Basin, California—***Continued.***

[Parameter code, in brackets, is a 5-digit number from the U.S. Geological Survey computerized data system, National Water Information System (NWIS), used to uniquely identify a specific constituent or property. ft^3/s, cubic feet per second; mi^2, square miles; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; –, no drainage area information available; <, actual value less than the value shown; °C, degrees celsius; mg/L, milligrams per liter; —, no data; $CaCO_3$, calcium carbonate; acre-ft, acre-feet; e indicates value is estimated; N, nitrogen; P, phosphorus; µg/L, micrograms per liter]

Abbreviated station name.	Station ID	Date	Time	Total nitrogen, water, filtered (mg/L) [00602]	Organic carbon, water, unfiltered (mg/L) [00680]	Pheophytin-*a*, phytoplankton (µg/L) [62360]	Chlorophyll-*a*, phytoplankton, chromatographic-fluorometric method (µg/L) [70953]	Iron, water, filtered (µg/L) [01046]	Manganese, water, filtered (µg/L) [01056]
Shasta River									
Grenada	11516880	6/17/03	0840		3.7	4.6	1.7	9	3.4
Montague	11517000	6/17/03	1150		5.6	2.9	.9	12	9.2
Hwy3	11517015	6/17/03	1435		4.5	2.1	.7	10	12.4
Yreka	11517500	6/17/03	1815		5.1	1.1	.4	9	3.7
Grenada	11516880	8/19/03	0830		4.1	3.7	1.0	8	2.9
Montague	11517000	8/19/03	1120		5	1.5	.7	12	5.7
Hwy3	11517015	8/19/03	1250		5.7	1.6	.9	11	7.2
Yreka	11517500	8/19/03	1820		6.7	2.7	.9	7	6.6
Klamath River									
Irongate	11516530	7/14/03	0810	0.65	6.9	3.8	5.8	24	3.2
Walker	11517818	7/14/03	1940		6.2	1.6	.8	23	5.4
Seiad	11520500	7/15/03	0630	.39	4.8	2.6	1.2	20	4.5
Orleans	11523000	7/16/03	0650		2.3	1.5	.8	14	1.4
Klamath	11530500	7/17/03	0910		1.5	.6	.9	8	1.1
Irongate	11516530	9/15/03	0800	.93	8.5	3.8	6.8	21	2.4
Walker	11517818	9/15/03	1930		8.8	4.2	5.0	21	4.8
Seiad	11520500	9/16/03	0650	.80	7.6	5.5	5.0	24	4.2
Orleans	11523000	9/17/03	0720		8.1	5.7	9.7	19	1.8
Klamath	11530500	9/18/03	0920		3.2	2.5	6.2	11	1.3

Lost River Locations

Two species of suckers are endangered in the Lost River. These fish require less oxygen than salmonids, but DO concentrations of less than 2.4 mg/L are considered lethal to suckers (Rykbost, 2001). Water temperatures of greater than 31 to 33 °C are considered above the maximum threshold for suckers in the Klamath Basin (National Research Council, 2004). Water-quality constituents are being measured at the HATFIELD station, which is located on the Lost River where it drains into Tule Lake, and at the TULE station, which is located at the exit of the lake where water is pumped from Tule Lake into Lower Klamath Lake.

Water temperature and DO for the Lost River stations are shown in *figure 8*. Water temperatures were above 21°C for most of July and August, extending above 25°C on several days. Water temperatures at the Lost River stations were nearly always higher than those at the SHOVEL station (*fig. 3A*). Daily concentrations of DO were extremely variable at the HATFIELD station, but were relatively low at the TULE station. Although the record for the HATFIELD station has large gaps, variations in the weekly or bi-weekly concentrations were quite large, indicating the influences of a complex system at this site (*fig. 8*). The DO concentrations at the HATFIELD station were below the lethal limit for suckers on most days during the period of record; the DO concentrations at the TULE station also were problematic for fish health. These wide variations in DO concentrations at the Lost River sites reflect the complex interaction of nutrient and sunlight availability, algal productivity, and biologic and sediment oxygen demand in the Lost River and Tule Lake, where water has a much longer average residence time than in any of the Klamath River reaches. Trends in the DO data for the SHOVEL station (*fig. 4A*), the closest station to receive water flowing from Tule Lake, are similar to those for the stations on the Klamath River, indicating very different influences of flow and other factors on DO between the stations in the two river systems. Information on water-quality conditions in the stretch of river between the Upper Klamath Lake and the SHOVEL station would help clarify the relative importance of the processes affecting DO in the reach upstream of the SHOVEL station.

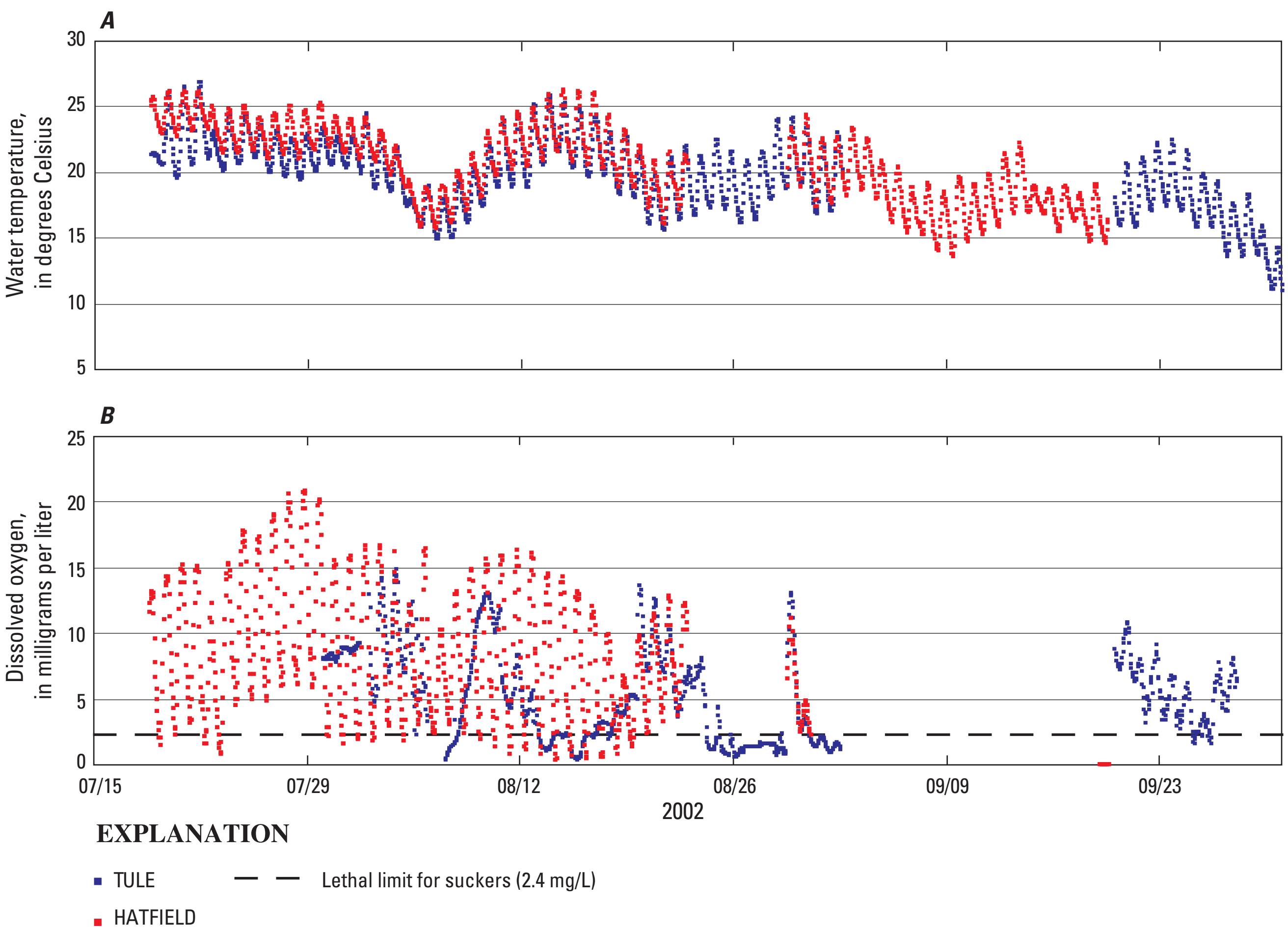

Figure 8. (***A***) Water temperature and (***B***) dissolved oxygen at continuous water-quality monitoring stations at TULE and HATFIELD on the Lost River in the Lower Klamath River Basin, California, 2002.

Monthly Water-Quality Sampling

Water-quality samples were collected at 12 stations each month from July through September 2002 using an equal-discharge increment depth-integrated method at five centroids across the stream cross section; all data that were collected and analyzed are given in *table 2* according to standard USGS procedures and quality-control protocols used at the USGS National Water Quality Laboratory. In 2003, the data-collection approach was changed to a parcel-tracking study to determine physical and chemical changes to a “parcel” of water as it moved downstream (the Lagrangian approach) from IRONGATE to the estuary at the mouth of the Klamath River at the KLAMATH station and from the GRENADA station to the YREKA station on the Shasta River.

The existing Water Quality Control Plan for the North Coast Region (North Coast Regional Water Quality Control Plan, accessed April 2002) includes no direct guidelines for nutrient concentrations, except that “waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses.” The range in allowable pH is 7.0 to 8.5 for the Klamath, Trinity, and Shasta Rivers and 7.0 to 9.0 for Tule Lake and the Lost River. The U.S. Environmental Protection Agency (USEPA) has a “desired goal,” rather than a criterion, of 0.1 mg/L for total phosphorus for the prevention of plant nuisances in streams (U.S. Environmental Protection Agency, 1986). Furthermore, the USEPA’s desired goal for total phosphorus should not exceed 0.05 mg/L in any stream at the point where it enters any lake or reservoir nor 0.025 mg/L within the lake or reservoir.

In 2001, the USEPA developed recommended nutrient criteria for rivers and streams of 13 aggregate ecoregions in the United States (U.S. Environmental Protection Agency, 2002). The USEPA’s recommended ecoregional nutrient criteria represent conditions of surface waters that have minimal impacts caused by human activities. The criteria are suggested baselines. California and the Regional Technical Advisory Group: National Nutrient Development, Region 9, are in the process of refining these ecoregional criteria. The USEPA’s recommended total phosphorus and total nitrogen criteria for ecoregion II, which includes the Klamath and Lost Rivers, are 0.01 and 0.12 mg/L, respectively (U.S. Environmental Protection Agency, 2002), as well as a recommended level of chlorophyll-*a* of no more than 1.08 µg/L. The interpretation of the measured nutrient data for the Lower Klamath River Basin is based on these recommendations, as well as on our experience and observations of conditions that likely may cause nuisance levels of algae or that may adversely affect beneficial uses of the water.

2002 Sampling Program

Klamath River Locations

Selected data from the monthly water-quality sampling that occurred in July, August, and September 2002, are shown in *figures 9*, *10*, and *11*. All the hourly data for which quality-assurance checks were completed are shown in the figures. The complete data set is archived in the California District NWIS database. *Figure 9* shows discharge, DO, turbidity, conductivity, alkalinity, water temperature, and pH. The data are presented in groups of three with each bar representing the data for each month for that station. Turbidity was somewhat elevated in August at the IRONGATE, YREKA, and WALKER stations, but diminished downstream. Conductance and alkalinity were very high at the YREKA station for all 3 months (consistent with the continuously monitored data for that station, see *appendix 1*), confirming the relative hardness of the water in the Shasta River compared with that in the rest of the Klamath River drainage, which may be related to the effects of irrigation and evaporation, as well as the geology of the Shasta River Basin. The hardness of the water provides a buffering capacity for specific conductivity in the Shasta River that doesn’t extend downstream in the Klamath River because of the small contribution of water from the Shasta River. The pH was high at all stations, but reached a peak in August at the SEIAD station at pH 9.8, which is above the recommended maximum of pH 8.5. There is no apparent relation between this high value of pH with any other constituents, and although it had the potential to influence ammonia toxicity, the filtered ammonia levels at this location were very low. These values are not inconsistent with the continuously collected data for these sites, many of which exceeded the 8.5 maximum on the Klamath River at many times throughout the 2002 season (*appendix 1*).

Concentrations of nitrogen constituents were low at all the stations measured, with the possible exception of the those at WALKER, IRONGATE, SHOVEL, and HATFIELD stations (*fig. 10*; *table 2*). The total nitrogen concentrations for the SHOVEL and HATFIELD stations could be considered a concern. Concentrations of orthophosphate were high enough to promote a nuisance level of algae at most sites, and concentrations at the SEIAD, WALKER, YREKA, MONTAGUE, IRONGATE, SHOVEL, and HATFIELD stations were high enough to be considered “excessive.” Levels of in-stream soluble phosphate greater than 0.025 mg/L contribute to a saturation of algal growth (Bothwell, 1989), levels at these sites approached or exceeded this concentration for the sampling dates in 2002. Concentrations of orthophosphate at the upstream stations, particularly concentrations at the HATFIELD station on the Lost River and at the YREKA station on the Shasta River, were large enough to be considered hypereutrophic, similar to concentrations in Upper Klamath Lake where hypereutrophic conditions occurred at these levels (Boyd and others, 2002), whereas concentrations at the KLAMATH, HOOPA, ORLEANS, and TULE stations

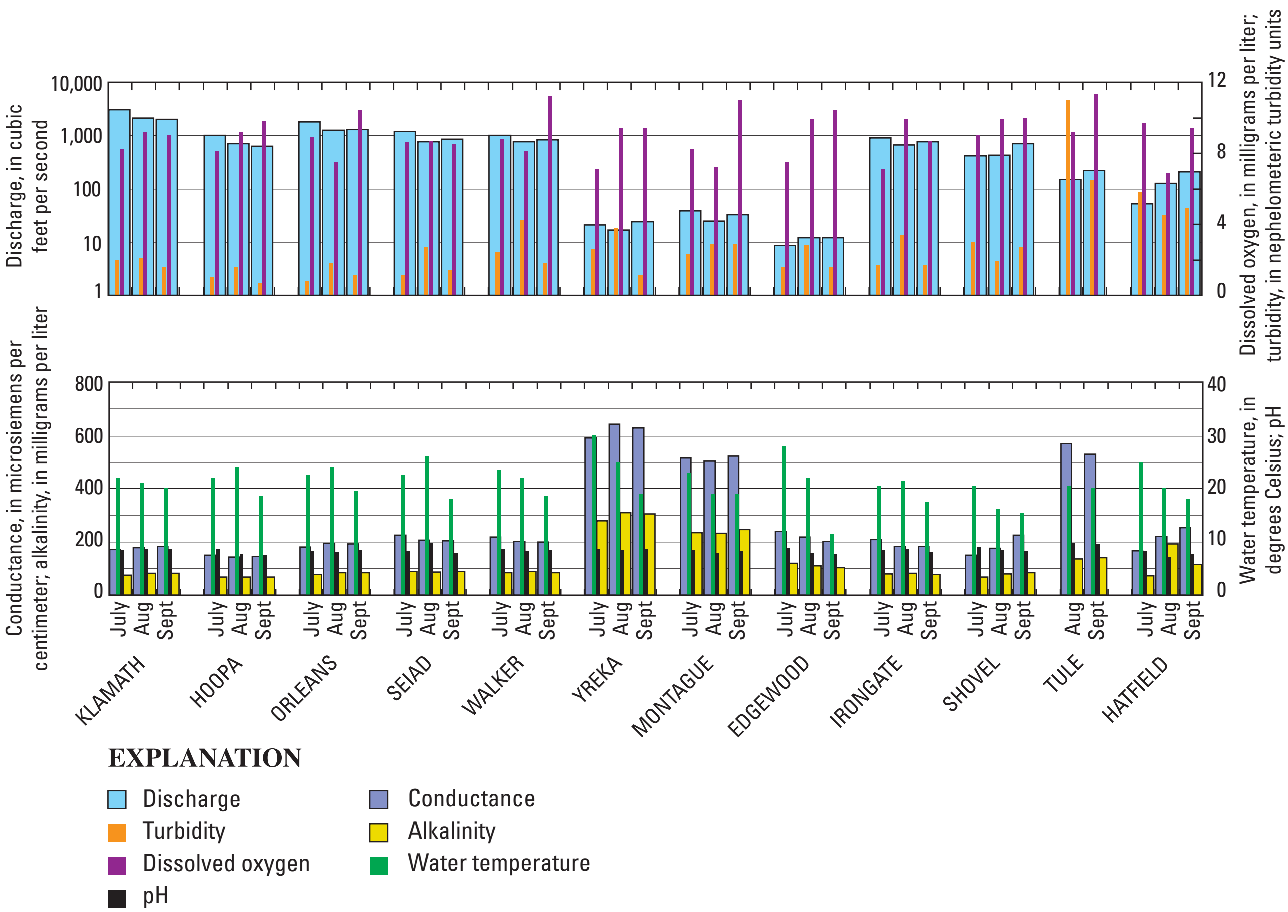

Figure 9. Monthly water-quality sampling data for July, August, and September 2002 for six sites on the Klamath River, one site on the Trinity River, three sites on the Shasta River, and two sites on the Lost River in the Lower Klamath River Basin, Califonia. ***A.*** Instantaneous discharge, dissolved oxygen (DO), and turbidity, and ***B.*** Specific conductance, alkalinity, water temperature, and pH.

probably were low enough to limit further algal growth. Concentrations of total phosphorus exceeded the recommended level of 0.01 mg/L for Ecoregion II, the Klamath River Basin, at all stations.

Loads were calculated using measured discharge (*table 2*) and concentrations for the nitrogen and phosphorus species, total organic carbon, chlorophyll-*a,* and pheophytin-*a,* and are presented in *figure 11* along with the nitrogen:phosphorus ratio. The mass ratio of total inorganic nitrogen to orthophosphorus in algae is about 7, much higher than the maximum 3.7 and median 1.0 measured in the 2002 monthly samples. Thus it is clear there is no P limitation on phytoplankton/algal growth. This is not necessarily true for blue-green algae such as *Aphanizomenon flos-aquae* which are fixed to atmospheric nitrogen and are predominant in the Iron Gate and Copco Reservoirs. Benthic algae such as *Cladophora spp*. reside throughout the mainstem Klamath River. Reducing phosphorus inputs would affect algal biomass only under conditions where sufficient reduction takes place to make phosphorus a growth-limiting constituent (Lee and Jones, 1991). The required reduction of phosphorus to restrict algal growth would be difficult given its high concentration in the natural environment of this basin. The concept of using limiting nutrients to manage eutrophication in the Klamath River Basin is questionable.

The Iron Gate Reservoir has more than twice the load of ammonia + organic nitrogen, although less nitrates and nitrites, as that at the SHOVEL station (*fig. 11*). This is also reflected at the WALKER station on the Shasta River, which contributes very little nutrient load. Indicators of phytoplankton biomass, chlorophyll-*a* and pheophytin-*a* in the Shasta and Trinity Rivers suggest that these constituents did not

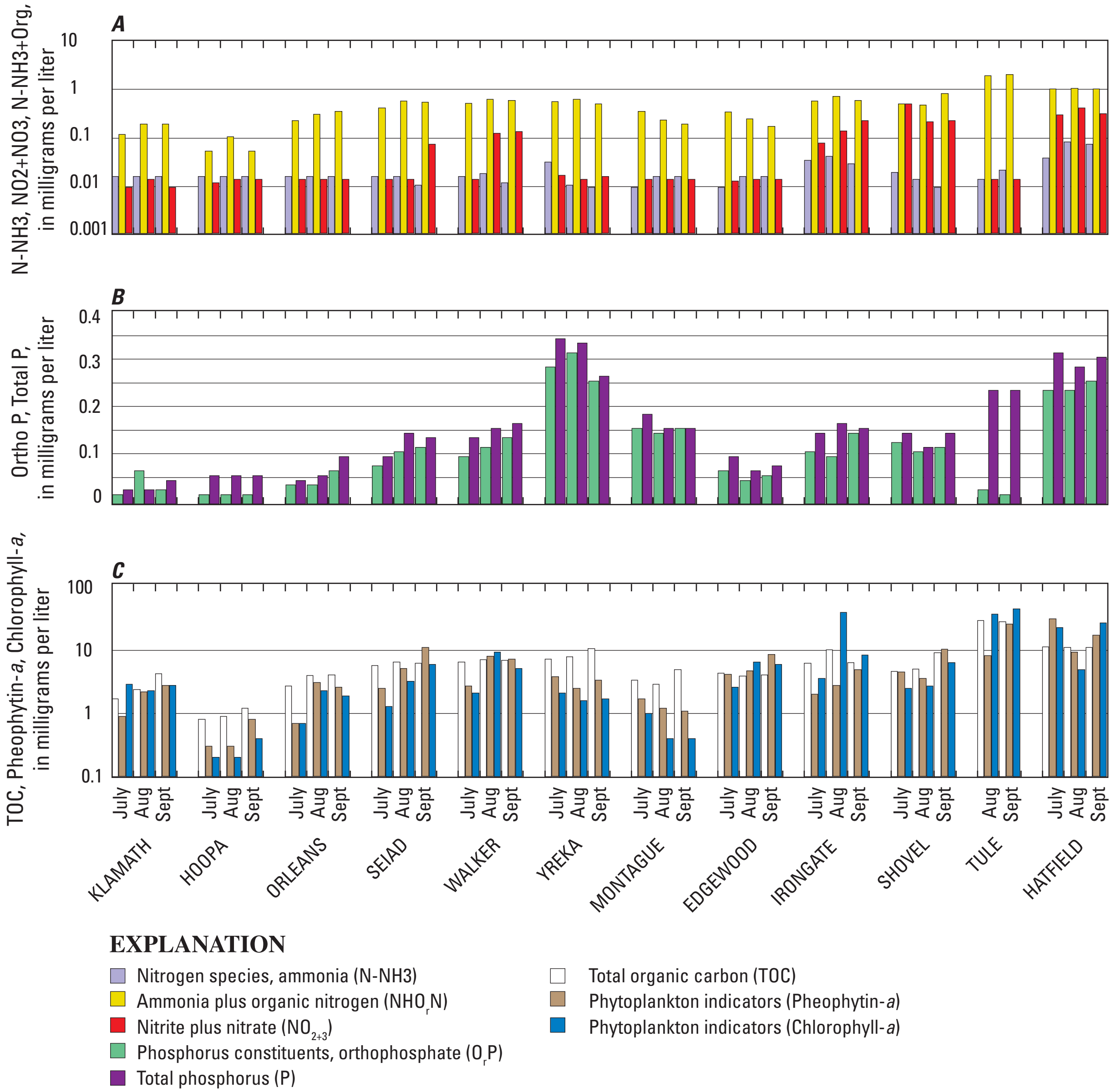

Figure 10. Monthly water-quality sampling data for July, August, and September 2002 for six sites on the Klamath River, one site on the Trinity River, three sites on the Shasta River, and two sites on the Lost River in the Lower Klamath River Basin, California. ***A.*** Nitrogen, ***B.*** Phosphorus constituents, and ***C.*** Total organic carbon (TOC), and phytoplankton indicators pheophytin-***a*** and chlorophyll-***a***, calculated as concentrations.

contribute appreciably to the loads in the Klamath River. Biomass loads of chlorophyll-*a* and pheophytin-*a* were somewhat higher at the SHOVEL station in September as was ammonia + organic nitrogen. There was a peak in chlorophyll-*a* (40.4 µg/L, 65,700 g/day; *table 2*) at the IRONGATE station in August and a relatively high value (9.3 µg/L, 17,000 g/day; *table 2*) at the WALKER station, but it is not clear if this would have been partially responsible for the elevated pH at the SEIAD station that month. There were somewhat high loads of phytoplankton indicators present at the KLAMATH station in July and September, with low values being transmitted from upstream. The high phytoplankton loads could have contributed to the low DO concentration in the water during this time. Further analysis and modeling would be needed to integrate all factors responsible for phytoplankton growth and DO into the interpretation of cause or source, and to evaluate other possible sources between the ORLEANS and the KLAMATH stations.

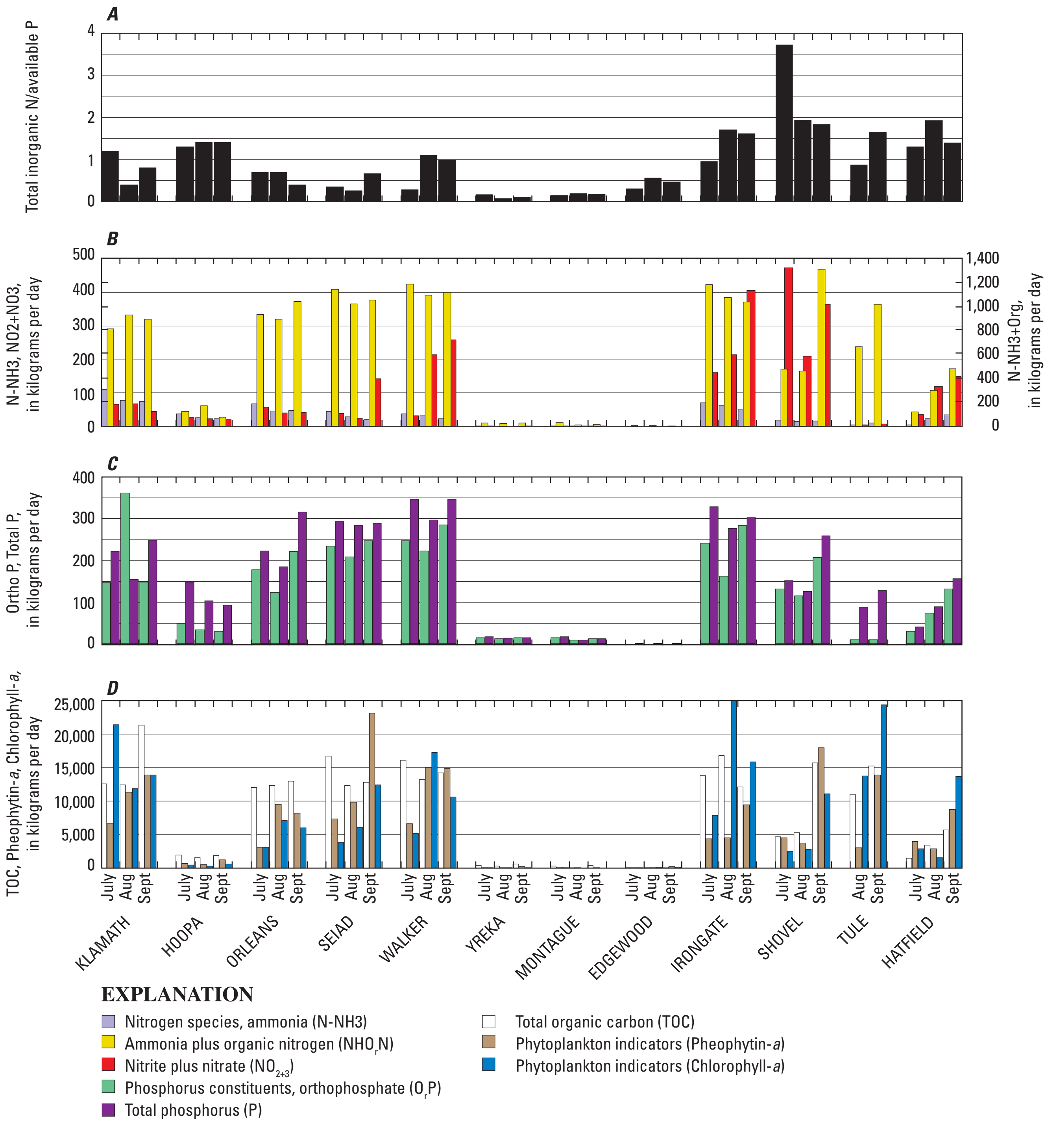

Figure 11. Monthly water-quality sampling data for July, August, and September of 2002 for six sites on the Klamath River, one site on the Trinity River, three sites on the Shasta River, and two sites on the Lost River in the Lower Klamath River Basin, California.
A. Nitrogen phosphorus ratio, ***B.*** Nitrogen and ***C.*** Phosphorus constituents, and ***D.*** Total organic carbon (TOC), and phytoplankton indicators pheophytin-***a*** and chlorophyll-***a***, calculated as loads.

Lost River Locations

Figures 9, *10*, and *11* and *table 2* show selected water-quality data for August and September for the TULE station and for July, August, and September for the HATFIELD station. The HATFIELD station represents water input from the upper Lost River system into Tule Lake, and the TULE station represents water that has moved through Tule Lake to be pumped westward into Lower Klamath Lake. Turbidity and conductivity were particularly high at the TULE station, as was pH, which exceeded 9.5 both months; this is verified in the continuous monitor data. A pH of 9.0 is the maximum pH standard for these sites; the measured pH of >9.5 is considered lethal to suckers, as is the measured DO concentration of < 2.4 mg/L (K. Rykbost, Oregon State University, written commun., 2001). Both of these conditions existed for a good portion of the summer at TULE. The HATFIELD station typically contributes water with low DO (*appendix 1*), which is not apparent from the monthly sampling data because of the large diurnal variations. Ammonia + organic nitrogen was greater than 1 mg/L at the TULE station and was just below that at the HATFIELD station, although the other nitrogen constituents were low (*table 2*). Phosphorus values were high at the HATFIELD station, and total organic carbon was quite elevated at the TULE station, nearly 30 mg/L, which was one-third higher than that at the HATFIELD station (*fig. 10*). Very large concentrations of the phytoplankton indicators were found at both sites, although total loads were higher at the TULE station than at the HATFIELD station. The evidence of algal communities is supported by the concentrations of orthophosphate (ortho P) and total phosphorus (P) at the TULE station, which indicates that an abundance of algae grow in Tule Lake, using up most of the available phosphorus in the process. On the other hand, the concentration of total P at the HATFIELD station indicates that streamflow at this station delivers a large amount of orthophosphate to Tule Lake (orthophosphate concentration was 80 percent of the total P). Data for the TULE station show that orthophosphate was only 10 percent of the total P, again indicating that the phosphorus has been incorporated into algal biomass in Tule Lake. *Table 2* also shows the trace elements and metals for all stations; concentrations of beryllium, cadmium, chromium, cobalt, copper, and manganese are notably high at the HATFIELD station.

2003: Parcel-Tracking Study on the Klamath and Shasta Rivers

In 2003, the NCRWQCB requested that the data collection approach be changed from the fixed interval (Eulerian) sampling used in 2002 to a parcel-tracking (Lagrangian) method in 2003. By using a parcel-tracking approach, a particular "parcel" of water can be followed downstream, and the changes in the physical, chemical, and hydrologic characteristics with location can be evaluated. This approach can provide information regarding the locations or reaches that have conditions contributing to the changes in measured constituents. Lagrangian sample sets can be more useful than Eulerian data for identifying in-stream processes and, thus, for constructing transport models (Battaglin and others, 2001).

The request for parcel-tracking sampling came from the NCRWQB in the spring of 2003. Because the data were needed in 2003, there was not ample time to perform a tracer study to estimate time of travel. Estimates of time of travel from the release at Iron Gate Dam to the mouth of the Klamath River were instead based on analyses of the changes in the stage height caused by a change in release flows in 2002 recorded at the IRONGATE station. Abrupt changes in discharge recorded at IRONGATE can be seen in the downstream discharge records. For example, the decrease in flow at IRONGATE on July 10, 2002, is seen at SEIAD 23 hours later, at ORLEANS 47 hours later and at KLAMATH 73 hours later. The monitoring site at WALKER has no flow gage, so the travel time was estimated as half the travel time between IRONGATE and SEIAD, as it is approximately half way between the two gage sites. Average times of travel were estimated using the decreases in flow on July 10 and July 31 and the increases on August 31 and September 27, 2002, the months that sampling would be done in 2003.

Similarly, time of travel on the Shasta River was estimated using the timing of the change in stage height due to operations at Dwinnell Dam, and the travel time to the HWY3 sampling site estimated as half the time from the MONTAGUE gage to the YREKA gage. Average times of travel were estimated using the decreases in flow on June 12 and August 16, and the increases on June 5 and August 26, 2002, the months that sampling would be done in 2003.

This method gives only rough estimates of travel times in the rivers. As flow increases, so does the velocity of the water, and therefore, travel times are reduced, but this was not accounted for in the estimates of travel times for this study. This was the case in the Klamath River where there was significantly more water in the system in 2003 than in 2002. For most of 2003, the release from Iron Gate Dam was 40 to 60 percent higher than in 2002. In July the 2003 release fell below that of 2002, but in August the release was increased to around 1,190 ft^3/s, so that the 2003 release was again around 50 percent greater than the 2002 release. For most of 2003, discharge at Klamath ranged from 180 to 220 percent of the discharge recorded in 2002. During the third week of July through the third week of August, the flow dropped to around 130 percent. During the third week of August, the Iron Gate Dam release was increased; releases from Lewiston Dam on the Trinity River also were increased for the specific purposes of helping maintain flow and lowering water temperatures for the fall run of salmon in the Klamath and Trinity Rivers, and for the Hoopa Valley Tribe's White Dear Skin Boat Dance. The increase in flow in the Trinity River resulted in an increase in discharge of about 180 percent of that in 2002 at the KLAMATH station on the Klamath River; the increase lasted through the middle of September when it then decreased to about 130 percent of that in 2002. This change in flow regime could not be anticipated, therefore, no compensation could be made for the shorter travel times than those estimated from the 2002 data.

A comparison of the monthly data collected in 2002 with the data collected during the 2003 parcel-tracking study in the Klamath and Shasta Rivers (*table 3*) indicates that most constituents were at comparable levels in 2002 and 2003 at all sites. Notable exceptions include flow, as discussed above, and nitrate + nitrite. Nitrate + nitrite concentrations in September 2003 were more than twice those measured in September 2002 for all five stations on the Klamath River.

Klamath River Parcel Tracking

Figure 12 shows selected data from the parcel-tracking sampling on the Klamath River. In July 2003, the concentrations of most of the constituents decreased as the water moved downstream. In general, it is hard to infer processes underlying changes in temperature and dissolved oxygen since they fluctuate diurnally. Owing to the travel time in the Klamath River, IRONGATE, SEIAD, and ORLEANS were sampled before 8:00 a.m., when one would expect the coolest water temperatures and lower dissolved oxygen, while KLAMATH was sampled after 9:00 a.m., when water temperature and photosynthesis were increasing. WALKER was sampled at 7:30 p.m., when even higher water temperatures and dissolved oxygen were expected. In addition, the Shasta River, which usually has warmer, more alkaline water, discharges just above the WALKER sampling site, which complicates the interpretation of the changes in the various constituents between IRONGATE and WALKER beyond that of the diurnal fluctuations. However, because there is no data from the Shasta River at the time of the Klamath River sampling, its relative contribution could not be determined.

Results of the parcel-tracking sampling does lend credence to the inference made in the prior discussion of the 2002 data that the discharge of the Shasta River has a noticeable effect on the water quality at WALKER, but that the effect does not extend downstream. Nitrate + nitrite, pheophytin-*a,* and chlorophyll-*a* concentrations decreased appreciably from the concentrations at IRONGATE, increased at SEIAD, and then decreased as the water moved downstream. The water temperature leaving IRONGATE was 21.5°C. The temperature rose to 24°C at WALKER, and then decreased steadily until it reached 20°C at KLAMATH. Also specific conductivity, carbonate, and pH also were higher at WALKER than at IRONGATE.

Specific conductivity, carbonate, bicarbonate, and alkalinity all remained high or increased at SEIAD (*fig. 12*) indicating that the Scott River may also contribute to the buffering capacity of the Klamath River. The temperature dropped 2°C between WALKER and SEIAD, indicative of the lower water temperature contributed by the Scott River and (or) cool ground-water accretion between those sampling points. The SEIAD site had the highest concentrations of pheophytin-*a* and chlorophyll-*a* below IRONGATE. This and the large fluctuations of DO (6.4–11.5 mg/L; *fig. 4B*) shown in the continuous record during this time indicate a good amount of algae at this site.

The water-quality comparison for September 2003 was quite different. Specific conductivity, carbonate, bicarbonate, and alkalinity concentrations were lower at IRONGATE, but they increased as the water moved downstream, until the confluence of the Trinity. Total organic carbon, ammonia + organic nitrogen, nitrate + nitrite, DO, pheophytin-*a,* and chlorophyll-*a* were higher in 2003 than in 2002, and remained higher, and in some cases, increased as the water moved downstream. The nutrients obviously supported an increased biomass downstream; chlorophyll-*a* increased from about 5 to 6 µg/L to 9.7 µg/L at ORLEANS. Pheophytin-*a* increased from 3.8 µg/L at IRONGATE to 5.7 µg/L at ORLEANS.

The addition of Trinity River water between ORLEANS and KLAMATH is apparent in many ways besides flow: total organic carbon, pheophytin-*a*, chlorophyll-*a*, orthophosphate, phosphorus, and ammonia + organic nitrogen were all notably less at KLAMATH than at ORLEANS. In addition, pH, temperature, and turbidity also decreased, which improved the habitat for salmonids.

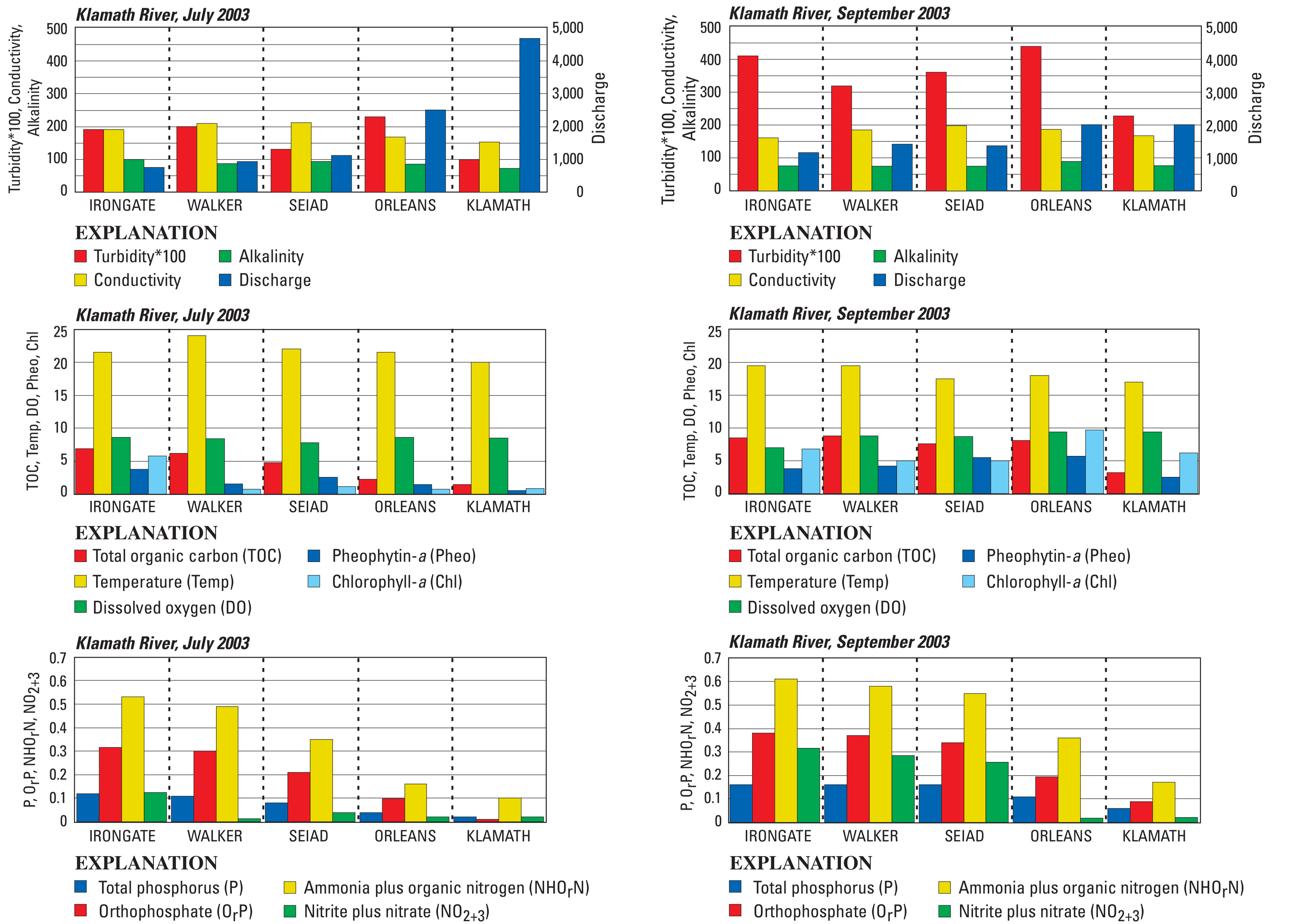

Figure 12. Data from parcel-tracking study on the Klamath River, California. ***A.*** July 2003, and ***B.*** September 2003 for various constituents. Turbidity is in nephalometric turbidity units, conductivity is in microsiemens per second, discharge is in cubic feet per second, water temperature (Temp) is in degrees Celsius, pheophytin-***a*** (Pheo) and chlorophyll-***a*** (Chl) are in micrograms per liter, alkalinity, total organic carbon (TOC), dissolved oxygen (DO), total phosphorus (P), orthophosphate (OrP), ammonia plus organic nitrogen (NHOrN), and nitrite plus nitrate (NO2+3) are in milligrams per liter.

Shasta River Parcel Tracking

Figure 13 shows selected data from the parcel-tracking sampling on the Shasta River. The timing of the sampling on the Shasta River caused more difficulty with respect to interpretation of temperature and dissolved oxygen data than it did for the Klamath River. GRENADA was sampled at 8:40 a.m., MONTAGUE at 11:50 a.m., HWY3 at 2:35 p.m., and YREKA at 6:15 p.m. for both sampling runs. The results of the June sampling discharge measurements show that the flows at GRENADA and YREKA were the same, but that flow between these two stations was considerably less. Alkalinity, turbidity, pH, conductance, total organic carbon, and ammonia + organic nitrogen increased significantly between GRENADA and MONTAGUE. Conductance, ammonia + organic nitrogen, and water temperature continued to increase as the water moved downstream, but the pheophytin-*a* and chlorophyll-*a* decreased. This pattern of changes in constituents, as well as the increase in concentration of nitrogen and carbon constituents, is consistent with the incidence of agricultural diversions and lower quality return flows. The considerably higher conductance, pH, and concentrations of nitrogen and carbon constituents were maintained in August, although the discharge at all sites was lower.

On the basis of this parcel-tracking study alone, it is difficult to draw specific conclusions about the changes in chemistry, water temperature, and biomass without additional information. Some general statements can be made, however. The water quality in the Shasta River is noticeably different from that of the Klamath River. The water quality of the Shasta River, however, does not account for all of the changes in the Klamath River between IRONGATE and WALKER; the concentration of DO in the water at IRONGATE in September 2003 was 7.0 mg/L, the concentration at WALKER was 8.8 mg/L, but the continuous monitoring indicates that the concentration in the Shasta River at about that time was around 9.0 mg/L. The increase in flow between IRONGATE and WALKER is only 15 percent, so it seems unlikely that a DO concentration of 9.0 mg/L could cause such an increase. Likewise, the decrease in temperature between WALKER and SEIAD probably cannot be explained by the small contribution of flow from the Scott River. The significant variability in DO at SEIAD also points to the need for further investigation in that area of the river. The decreases in nitrogen and phosphorus from WALKER to KLAMATH suggest a significant amount of uptake by a population of attached algae. In order to increase understanding of the changes in water quality in the Klamath River from Iron Gate Dam to the mouth, it would be necessary to conduct a much more rigorous study of parcel tracking that would include the effects of diurnal fluctuations and changes in flow between sampling sites. Such a study would include implementing dye or tracer tests to accurately determine the travel times between sites, and thus sampling the tributaries at the appropriate time to accurately represent travel time, and initiating the sampling at several times during the day to characterize the diurnal effects.

A comparison of the 2002 data collected during monthly sampling with data collected during the 2003 parcel-tracking study in the Klamath and Shasta Rivers (*table 3*) indicates that most of the constituents were at comparable levels for the 2 years for all sites. Notable exceptions include discharge and nitrate. Discharge at the IRONGATE station in July 2003 was 747 ft^3/s, which was lower than the 2002 discharge of 897 ft^3/s, but it was higher between the SEIAD and the ORLEANS stations (1,400 ft^3/s) and between the ORLEANS and the KLAMATH stations (2,170 ft^3/s) resulting in a discharge of 4,680 ft^3/s at the KLAMATH, which was 150 percent of that in July 2002. In September 2003, discharge at the IRONGATE station was 1,190 ft^3/s, much higher than 773 ft^3/s in 2002. In 2003, the reach between the WALKER and the SEIAD stations had reduced flows indicating a losing reach; nevertheless, discharge at the KLAMATH station was again 150 percent of that in 2002 (3,110 ft^3/s compared with 2,030 ft^3/s) because of the relatively large increases between the SEIAD, ORLEANS, and KLAMATH stations. Nitrate concentrations in September 2003 were more than twice those measured in September of 2002 for all five stations on the Klamath River.

Sediment Oxygen Demand Study on the Shasta River

Sediment oxygen demand (SOD) is the rate of DO loss from a water body through its uptake and consumption by biotic or abiotic reactions in surficial sediments. In most river systems, such oxygen consumption is dominated by microbially mediated decomposition processes. In other words, organic materials in the water body's sediments decompose; that process requires oxygen to proceed, and the oxygen is supplied from the overlying water. In streams with an abundance of sedimentary organic material from soil erosion or an accumulation of plant and algal detritus, SOD can be an important part of the stream's DO budget. Field observations of sediment accumulation and low DO levels measured by the authors indicate that some reaches of the Shasta River may have a significant SOD; as a result, an investigation was initiated to measure that rate.

The rate of SOD was measured at six sites in two reaches of the Shasta River (*table 4*). These sites were chosen because they are located in a reach of the Shasta River with measured low DO (*appendix 2*) and observed accumulation of fine sediment and plant detritus. Other considerations for site selection included access, type of stream substrate, and the amount of macrophyte (aquatic plant) growth.

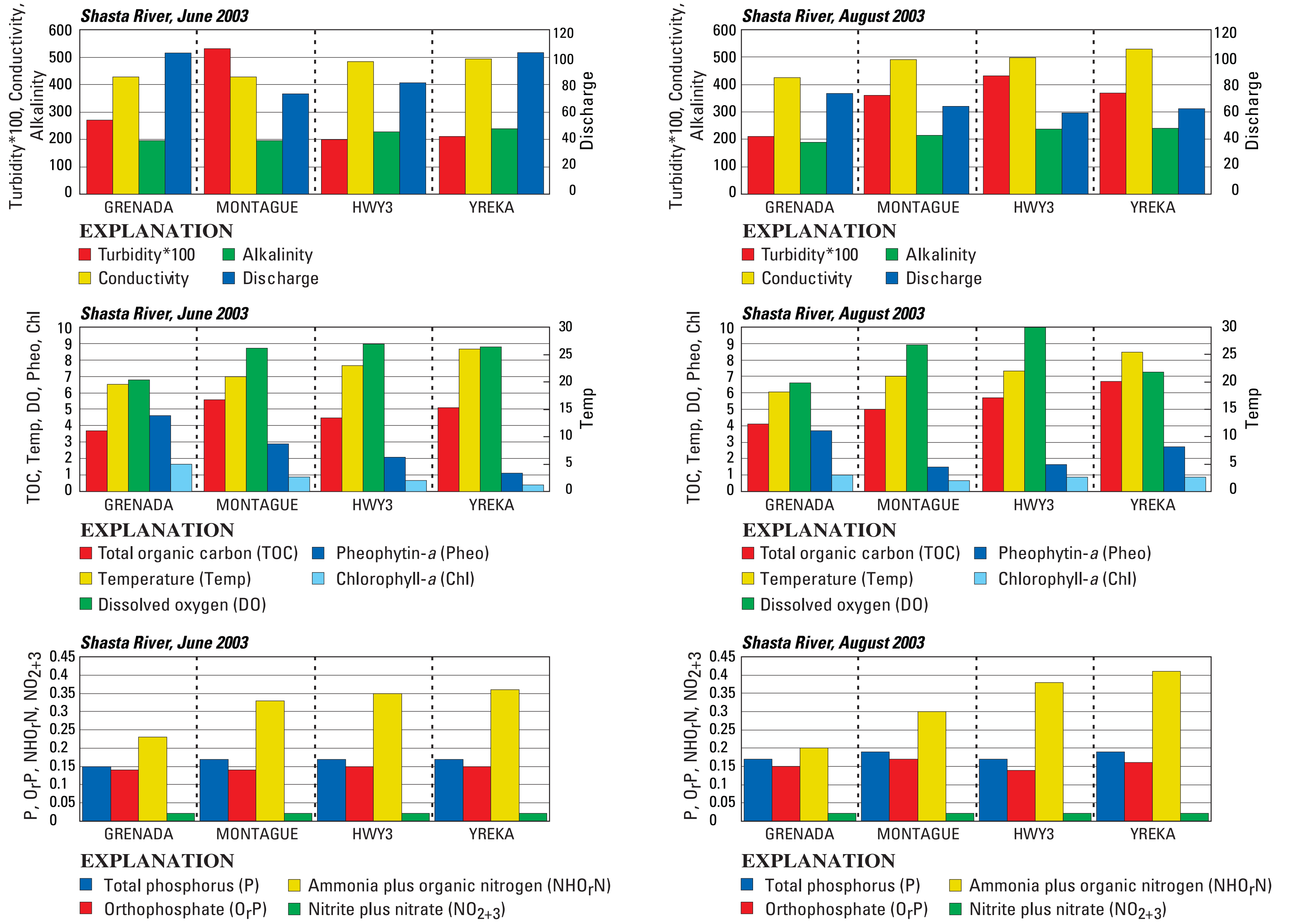

Figure 13. Data from parcel-tracking study on the Shasta River in lower Klamath River Basin, California. ***A***. June 2003, and ***B***. August 2003 for various constituents. Turbidity is in nephalometric turbidity units, conductivity is in microsiemens per second, discharge is in cubic feet per second, water temperature (Temp) is in degrees Celsius, pheophytin-***a*** (Pheo) and chlorophyll-***a*** (Chl) are in micrograms per liter, alkalinity, total organic carbon (TOC), dissolved oxygen (DO), total phosphorus (P), orthophosphate (OrP), ammonia plus organic nitrogen (NHOrN), and nitrite plus nitrate (NO2+3) are in milligrams per liter.

Table 4. Locations of sites used to measure sediment oxygen demand on the Shasta River in the Lower Klamath River Basin, California.

[Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Site Name	Latitude	Longitude	Location description
Shasta River upstream of Montague–Grenada Road	41.7081 N	–122.5378 W	100–200 meters upstream of bridge
Shasta River downstream of Montague–Grenada Road	41.7114 N	–122.5422 W	Approximately 400 meters downstream from bridge
Shasta River near Hwy 3—site A	41.7183 N	–122.5533 W	Approximately 1 kilometer upstream of bridge; 200–300 meters upstream of pump house on right bank
Shasta River near Hwy 3—site B	41.7158 N	–122.5517 W	50–100 meters upstream of site A, at bend in river
Shasta River near Hwy 3—site C	41.7272 N	–122.5569 W	100–200 meters downstream from bridge
Shasta River near Hwy 3—site D	41.7269 N	–122.5578 W	25–50 meters upstream of site C

Procedure

Sediment oxygen demand rates were measured with in-situ chambers, as previously described by Murphy and Hicks (1986), Caldwell and Doyle (1995), Rounds and Doyle (1997), and Doyle and Rounds (2003). These chambers allow a known volume of water to be isolated above a known area of stream sediment. The DO concentration in that isolated water then is monitored over the course of at least 2 hours. Measurements typically are performed with three such chambers at each site to assess the variability of the site's SOD. In addition, a fourth chamber with a sealed bottom to exclude interaction with stream sediments is used to assess the level of oxygen loss owing to biochemical oxygen demand (BOD) in the water column. The measured oxygen loss rate in each of the three SOD chambers, once corrected for the effects of BOD, is a direct measurement of the site's SOD rate. Final SOD rates are corrected to 20°C (SOD_{20}) and reported as a loss rate in grams of oxygen per square meter per day ($g/m^2/d$). Details of the procedures were documented previously by Rounds and Doyle (1997). An estimate of the SOD rate at any temperature is then given by

$$SOD_T = SOD_{20} \times 1.065^{(T\text{-}20)}$$

where SOD_T is the SOD rate at temperature T (°C).

To measure SOD rates with this type of in-situ chamber, (1) the stream must be deep enough (> 0.4 meters) to submerge the chamber, (2) the sediments must be fine enough to allow the chamber's cutting edge to seat and seal to the stream bottom, and (3) the stream's DO concentration must be high enough (> 4 mg/L, approximate) to provide a measurable loss rate and a stable aerobic environment for the sediment's microbial community.

Those reaches of the Shasta River where the SOD rate was measured had a productive population of attached algae and an abundance of rooted aquatic plants (macrophytes). Both the algae and the macrophytes produce DO through photosynthesis. In order to measure the effects of only SOD (and BOD), it was important to exclude these oxygen producers from the SOD measuring chambers, either by prudent site selection or by physical removal of these plants prior to chamber deployment.

At the two sites near the Montague-Grenada Road, macrophytes were less abundant which allowed suitable sites for chamber deployment without having to remove any plant material. At all sites near Highway 3, however, macrophytes were abundant and had to be removed from the site before each chamber was deployed. The tops of the plants were removed by cutting them off near their base, taking care not to disturb the plants' roots or the site's sediments. In this manner, the plant's production of DO was eliminated without disturbing the sediments or any respiration processes in the plant's roots. Such measures may introduce additional uncertainty into the SOD measurement, but it was the only way to collect such a measurement in areas dominated by macrophytes.

At each SOD measuring site, samples also were collected to roughly characterize the organic content and particle size of the stream sediments. Samples were analyzed for percent organic content (loss on ignition [Fishman and Friedman, 1989]) and for the size fraction finer than 63 microns (Guy, 1969) by the USGS Cascades Volcano Observatory sediment laboratory.

SOD Results

DO loss rates were measured in the SOD chambers. The loss rates were corrected for the effects of BOD ("blank corrected") and adjusted to a rate at 20°C. These rates, as well as the results from the sediment analyses, are shown in *table 5*. The measured SOD_{20} rates range from 0.1 to 2.3 $g/m^2/d$ with a median of 1.5 $g/m^2/d$. The organic-matter content and particle size analyses don't appear to correlate well with the measured SOD rate; the lack of such a correlation was also observed by Caldwell and Doyle (1995) for the lower Willamette River in Oregon and by Wood (2001) for the Upper Klamath and the Agency Lakes in Oregon. Knowing the amount of organic material present is useful, but that information does not provide insight into how fast that material might decompose. The SOD measurement is necessary to provide that rate.

Table 5. Measured sediment oxygen demand rates and sediment characteristics at sites on the Shasta River in the Lower Klamath River Basin, California.

[m, meters; SOD, sediment oxygen demand, blank-corrected; SOD_{20}, sediment oxygen demand corrected to a temperature of 20°C; $g/m^2/d$, grams per square meter per day; %, percent; —, no measurement]

Site	Date	Replicate	Water depth (m)	SOD rate at 20°C (SOD_{20}, $g/m^2/d$)	Sediment characteristics: Organic content (loss on ignition) (percent)	Sediment characteristics: Percent finer than 63 microns (percent)
Shasta River upstream of Montague–Grenada Road	8/12/03	1	0.9	2.0	2.3	5.7
		2	0.8	—	1.4	3.2
		3	0.7	1.0	1.7	3.3
Shasta River downstream from Montague–Grenada Road	8/12/03					
		1	0.7	1.6	4.8	5.0
		2	0.6	0.5	7.5	54.3
		3	0.5	1.0	4.1	2.4
Shasta River near Hwy 3—site A	8/13/03					
		1	0.9	1.5	2.6	2.1
		2	0.9	0.7	1.0	0.8
		3	0.8	0.1	1.5	1.6
Shasta River near Hwy 3—site B	8/13/03					
		1	0.9	1.3	1.4	3.3
		2	0.9	1.4	1.2	1.3
		3	0.8	1.7	1.5	2.9
Shasta River near Hwy 3—site C	8/14/03					
		1	0.4	2.1	0.9	0.7
		2	0.5	—	1.2	8.9
		3	0.4	2.3	0.8	2.3
Shasta River near Hwy 3—site D	8/14/03					
		1	0.6	1.8	6.5	29.9
		2	0.7	—	3.4	48.9
		3	0.7	2.3	6.3	44.4

A SOD rate of 1 to 2 $g/m^2/d$ is indicative of a system with organic material that is decomposing at a moderate rate. Similar rates have been measured in many other stream systems having a moderate amount of organic material in silty sediments that are not heavily affected by pollution (Murphy and Hicks, 1986; Rounds and Doyle, 1997). A moderate SOD rate indicates that the decomposing organic matter is neither extremely labile nor extremely refractory.

Some reaches of the Shasta River do not accumulate sediment; those reaches may have a gravelly or cobbly bottom and little to no SOD. For those reaches that do accumulate sediment, however, an SOD of 1.5 $g/m^2/d$ can represent a significant loss mechanism for DO. This is especially true for streams that are relatively shallow. The amount of DO that can be consumed by SOD over the course of a day is a function of stream depth and is calculated as the SOD rate in $g/m^2/d$ divided by the stream depth in meters. So, a stream having an SOD rate of 1.5 $g/m^2/d$ can reduce stream concentrations by 1.5 mg/L of DO to SOD over the course of 1 day if the SOD is acting on a water column that is 1 meter deep. The concentration reduction increases to 3.0 mg/L if the stream is only 0.5 meters deep. Many of the sites where SOD was measured in the Shasta River are relatively shallow (*table 5*) and SOD is therefore more likely to overwhelm other processes and to be a significant loss mechanism for DO in those reaches.

A complete assessment of the factors affecting DO in the Shasta River, though, needs to include more than just a measurement of SOD. Judging from the abundant levels of attached algae and rooted plants in the Shasta River, the effects of photosynthetic production and plant respiration also will contribute a lot to the DO budget. The effects of plant photosynthesis and respiration can be estimated using the SOD rate, estimates of BOD and the rate of oxygen exchange between the river and the atmosphere, and the analysis of continuous DO measurements from one or more locations. Such an analysis would be a logical next step in any assessment of DO in the Shasta River.

Relevance of Water-Quality Observations to 2002 Fish Kill on the Klamath River

Conclusions made by the California Department of Fish and Game in a preliminary analysis of the cause of the September 2002 fish kill near the mouth of the Klamath River (State of California, 2003) noted that the kill was the result of a combination of high densities of adult fish (due to low flows and possibly inadequate fish passage) and warm water-temperature conditions typical at that time of year. These conclusions were supported by an analysis of hydrologic conditions in the Klamath River Basin prior to the die-off (Lynch and Risley, 2003); the conclusions indicate that low streamflow and high water temperature contributed to the pathogenic infections that killed the fish. The September 2002 flow releases from the Iron Gate Dam were among the four lowest flows recorded since 1960, and the numbers of returning fall Chinook salmon were at average or above average levels. The September 2002 flows also were the lowest since the major storm events in 1997 and 1998 that may have caused aggraded channel conditions that threaten fish passage.

On the basis of an analysis of long-term water temperatures in the nearby Rogue River Basin and air temperatures within the Klamath River Basin, it was concluded that the water temperatures in September 2002 in the Lower Klamath River were probably above average (Lynch and Risley, 2003). Indeed, daily minimum water temperatures at ORLEANS, upstream of the fish die-off reach, remained above 18°C between September 1 and 24, 2002, which was a level at which disease rates in salmonids can be severe (Lynch and Risley, 2003). Measurements of DO were not analyzed in reports by either the State of California (2003) or Lynch and Risley (2003), but it is likely that the extended period of low DO measured in August and September of 2002 for this crrent study contributed to the fish kill by increasing the stress that could result in disease in salmonids. Given these results, it seems as though a combination of factors, including elevated temperature and phytoplankton indicators, contributed to the low DO values.

Model Code Selection and Analysis

The step following data collection and analysis in the iterative conceptual and numerical model development process is to use the available data to continue the development of the conceptual model of the Klamath River system (*fig. 2*). There have been many investigations over the years to evaluate water quality and fish habitat in this basin. These studies have contributed to the development of conceptual models of the system from various perspectives and levels of detail and scale. At least two different mathematical models (Deas, 2000; Campbell and others, 2001) have been used to simulate many of the interacting processes in the Klamath River. Results of these efforts and of future studies should be used to complete the conceptual model of processes and will require additional information and data and a variety of experts who can look at different parts of the river system (physics, chemistry, and biology).

The evaluation, testing, and implementation of a conceptual model using a mathematical model are the next steps in characterizing a natural river system. Several mathematical codes have been used to develop existing mathematical models of the rivers in the Klamath Basin, some of which were evaluated by the Oregon Department of Environmental Quality (Wells, 1995) for the Klamath River. Three model codes were analyzed for this current study of the Klamath River to aid in determining where there are gaps in data and where data are inadequate for developing TMDLs. The codes are from existing mathematical models of the Klamath River: the SIAM model suite (Bartholow and others, 2003), the WQRRS, RMA2, and RMA11 models (Deas, 2000), and the CE-QUAL-W2 (Cole and Wells, 2002). The model using SIAM and the model used by Deas (2000) were calibrated for the Klamath River. PacifiCorp, the firm responsible for operation of the Iron Gate Reservoir, is using the CE-QUAL-W2 model code for their analysis for Federal Energy Regulatory Commission (FERC) relicensing; this model code also was selected by the Oregon Department of Environmental Quality to model the Klamath River between the Link River and the Keno Dam (Scott Wells, Portland State University, written commun., 1995). Most recently, Deas completed work using two model codes: the CE-QUAL-W2 model for the Iron Gate Reservoir, and the RMA2 and RMA11 models for the Klamath River below the reservoir (Matt St. John, North Coast Regional Water Quality Control Board, written commun., 2003). It is important to match up the data needs of the model intended for use with the available data.

Model Description: SIAM

SIAM is a management interface to several underlying models. Campbell and others (2001) and Hanna and Campbell (2000) applied SIAM to MODSIM, a network water-quantity simulation program (John W. Labadie, MODSIM-DSS; accessed August 3, 2004) to simulate streamflow, and to HEC-5Q, a one-dimensional U.S. Army Corps of Engineers (Corps) program (Environmental Software and Services, accessed August 3, 2004) to simulate water quality. The work concentrated on temperature and DO as calibration variables.

MODSIM was used to simulate monthly mean streamflows through the river system. For dam operations and long-term simulations (many seasons), a monthly time step can meet most needs for the purposes of modeling water supply. However, simulating monthly flow data when the time frame for water-quality problems is hourly to weekly may not be the best practice. It is unclear whether this resulted in any major problems in model calibration or performance.

HEC-5Q is a one-dimensional water-quality model that utilizes the flow simulation capabilities of HEC-5. HEC-5 simulates multiple purpose, multiple reservoir systems in essentially any stream tributary configuration using a variable computational interval. It can simulate the longitudinal dimension in riverine reaches, or the vertical dimension in reservoirs where it is necessary to capture the effects of stratification on water quality. The model simulates one or the other dimension, not both. So, in a long reservoir where the retention time is long relative to the time scale of water-quality problems, HEC-5Q does not simulate any important longitudinal processes in the reservoir and will introduce some numerical dispersion in the longitudinal dimension. Water entering the head of the reservoir is immediately mixed into the appropriate model layer in the reservoir, and those layers extend from the head of the reservoir to the dam. So, if the time-varying nature of the inputs to the head of the reservoir is important, the simulations will smear signals in the reservoir and result in longitudinal numerical dispersion. Numerical dispersion also can be significant if the residence time is longer than the model time-step. HEC-5Q was run by Campbell and others (2001) using a daily time step, and outputs were stated to represent daily means. If the water-quality standards are written for daily maximum water temperatures or for daily minimum DO concentration, the model needs to be able to produce information on time scales of less than 1 day. In addition, if the reservoir residence times are less than 1 day, it is possible to induce significant numerical dispersion in the model results. HEC-5Q cannot simulate or use information regarding the amount of topographic or riparian shading of the stream channel. Shading was not considered, yet increased or restored riparian shading on stream-water temperature is often an important effect that must be evaluated by regulatory agencies when setting a TMDL for water temperature. If a mathematical model is used to help understand the dynamics and spatial variations in water temperature in the Klamath River, it will be necessary for the model to address the effects of shading. In general, the algorithms used to simulate heat exchange processes in the HEC-5Q model are sufficient for basic applications, but many of these processes are not simulated explicitly.

Dissolved oxygen can be simulated in HEC-5Q as a balance among inflows, outflows, reaeration (exchange with the atmosphere), biochemical oxygen demand (BOD decomposition of organic materials in the water column), sediment oxygen demand (SOD—decomposition of organic materials in the surficial sediments), photosynthesis (primary production by algae and (or) aquatic plants), respiration (by algae, plants, and bacteria), and ammonia nitrification (microbially facilitated conversion to nitrate). These typically are the most important components of the DO budget for most rivers and reservoirs. DO solubility is a strong function of water temperature; that effect appears in the implementation of reaeration algorithms in the model. Field verification of reaeration coefficients generally is advised if this appears to be a dominant process. The HEC-5Q model appears to include all the necessary processes for simulating DO. Use of the HEC-5Q model to improve understanding of the water quality of the Klamath River may not be the best overall choice though because of its limitation to one dimension in the reservoirs in this system, reservoirs that have the potential to influence the water quality in the streams.

Considering the difficulty of simulating a complex system with less than a full complement of simulated processes, USGS researchers (Hanna and Campbell, 2000; Campbell, 2001; Bartholow and others, 2003) were able to use SIAM to simulate daily mean water temperature over a several year period for the Seiad Valley with an average error of about 1.5 to 2°C and corresponding errors in predictions of lows in DO concentrations in flows below Iron Gate Dam of approximately ± 4 to 5 mg/L. Any failure in their efforts to simulate DO is indicative of a lack of data and a lack of quantification of those processes affecting DO.

Model Description: WQRRS; RMA2; RMA11

The Water Quality for River-Reservoir System (WQRRS), a Corps of Engineers computer package preceding HEC-5Q, simulates the water quality in a reservoir and the hydraulics of a river and the water quality of that river (Environmental Software and Services, accessed August 3, 2004). The WQRRS package consists of the programs Stream Hydraulics Package (SHP), WQRRSQ, and Reservoir Water Quality (WQRRSR) that interface with each other. The SHP and the Stream Water Quality (WQRRSQ) programs simulate flow and water-quality conditions for stream networks that can include branching channels and islands. The WQRRSR program is a one-dimensional model used to evaluate the vertical stratification of physical, chemical, and biological parameters in a reservoir. The SHP provides a range of optional methods for computing discharges, velocities, and depths as a function of time and location in a stream system. The hydraulic computations can be performed using either input stage-discharge relations, hydrologic routing, kinematic routing, steady-flow equations, or the full unsteady-flow St. Venant equations (finite-element method). The WQRRSR and the WQRRSQ programs provide capabilities for analyzing temperature and more than a dozen chemical, physical, biological, and organic constituents. WQRRS simulates the vertical distribution of thermal energy and chemical and biological materials in a reservoir through time. A reservoir is conceptualized as a vertical sequence of horizontal layers with thermal energy and materials uniformly distributed in each layer. The distribution of inflows among the horizontal layers is based on density differences. The model simulates the dynamics of more than a dozen water-quality variables, computing both in-pool and downstream release magnitudes.

RMA2 is a two-dimensional, depth-averaged, finite-element hydrodynamic numerical model (Boss, International; accessed August 3, 2004). Water-surface elevations and horizontal velocity components are computed for subcritical and turbulent flows. Both steady and transient (dynamic) problems can be analyzed.

RMA11 is a finite-element water-quality model for simulation of three-dimensional estuaries, bays, lakes, and rivers (Boss, International; accessed August 3, 2004). It can simulate one- and two-dimensional applications and is designed to accept input of velocities and depths either from text files or from output files produced by the two-dimensional hydrodynamic model RMA2 or by the three-dimensional stratified flow model RMA10.

Deas (2000) used the WQRRS model to simulate temperature, DO, pH, alkalinity, conductivity, pollutants, and nutrients in the Iron Gate Reservoir. He modeled the Klamath River from the Iron Gate Dam to the USGS gage at SEIAD using the RMA2 model to simulate the hydrodynamics of the river, and the RMA11 model to simulate water quality. The details of the modeling efforts are described in Deas (2000).

These three components of a river system, hydrodynamics, water quality, and reservoir dynamics, may also be simulated separately, as was done by Deas (2000) in his Klamath River application. This model assumes a one-dimensional system, which when applied to a reservoir is prone to numerical dispersion in the longitudinal direction, as is the HEC-5Q model. It takes into account the effects of mass transport owing to outflow, and it can model many different water-quality constituents.

Model Description: CE-QUAL-W2

CE-QUAL-W2 (W2) is a water-quality and hydrodynamic model in two dimensions (longitudinal-vertical) for rivers, estuaries, lakes, reservoirs, and river basin systems (Cole and Wells, 2002). W2 simulates basic eutrophication processes, such as temperature-nutrient-algae-DO-organic matter and sediment relations. This model is supported by the Corps of Engineers, Waterways Experiments Station, Vicksburg, Mississippi. The current model release (v3.1) enhancements were developed under research contracts between the Corps and researchers at Portland State University.

W2 simulates longitudinal-vertical hydrodynamics and water quality in stratified and non-stratified systems. It includes the simulation of nutrient and DO dynamics and biomass, and sedimentation of multiple algal groups, epiphyton/periphyton, in addition to carbonaceous biochemical oxygen demand (CBOD), nutrients, DO, pH, general water-quality constituents, internal dynamic pipe/culvert flow, hydraulic structures (weirs, spillways), and a dynamic shading algorithm based on topographic and vegetative cover. These more complex functions mean that W2 requires more computer power and is more difficult to use in optimization.

In contrast to the other models, W2 requires much more input data. Basic data needs for W2 include stream and reservoir geometric data, initial conditions, inflows, outflows, meteorological and water-quality data, as well as a substantial number of hydraulic and kinetic rates and parameters. A detailed list is available in the model's user manual (Cole and Wells, 2002).

Model Application and Data Gaps

To better understand DO in the Klamath River and its reservoirs, it is important to understand which parts of the DO budget are most important in each part of the basin. Certainly inputs, outputs, reaeration, and BOD must be included, and BOD appears to be large and important in the reaches just downstream from Upper Klamath Lake. The relative importance of algae and SOD, however, are not known specifically yet, but, on the basis of the data included in this report, are suspected to be significant. To adequately evaluate the effects of algae, an effort should be made to collect additional data to simulate these effects in a model. Note, however, that if the algae in the Klamath River downstream from IRONGATE are predominantly the attached varieties (periphyton)—growing in riverine reaches attached to the stream's rocky substrate rather than floating downstream with the water—then any simulation of those algae-related processes will be a difficult task. Few models address the effects of attached algae directly; among the models described here, only W2 has a simple set of algorithms that can be used to estimate the dynamics of periphyton. It is a much easier task to simulate the types of algae that float downstream with the water, as model calibration can rely on measurements of chlorophyll-*a* and other indicators present in the water. Coastal rivers almost always have a measurable community of attached algae in the summer. Decomposing algae (periphyton and phytoplankton combined) is likely a large component of any BOD other than that contributed from agricultural drain sources.

USGS researchers (Hanna and Campbell, 2000; Campbell, 2001; Campbell and others, 2001) indicate that water temperature in many streams is largely a result of climatic and streamflow conditions. Human-related factors that appear to be important are the presence of dams, the operation of those dams, and any disturbances to the stream's riparian vegetation. Those human-related factors are small (but measurable), however, compared to the effects of climate and streamflow.

In terms of DO, model simulations indicate that the large BOD loads from the Upper Klamath Lake and from the various agricultural return flows in Oregon are major influences on DO in the upper reaches of the Klamath River, extending to the Iron Gate Dam. Preliminary SOD data from stations on the Klamath River downstream from the Upper Klamath Lake support the conclusions from the model simulations, showing the rates to be significant, though potentially less important than those for BOD. Ammonia nitrification does not appear to have much influence in most of the Klamath River downstream from Keno, although some high concentrations have been recorded at Keno, which probably were due to high concentrations present just downstream from Upper Klamath Lake.

The effects of photosynthesis and respiration on DO in the reservoirs and the riverine reaches of the Klamath River, although evident qualitatively in the data presented in this report, have yet to be quantified numerically. Certainly, the nitrogen and phosphorus concentrations appear to be high enough to support a significant population of algae. Depending on the health of the *Aphanizomenon* population swept downstream from Upper Klamath Lake to the reservoirs, these algal-related processes could have impacts on the processes occurring in those reservoirs. A substantial population of attached algae also may thrive in parts of the river downstream from the IRONGATE station and needs to be investigated. Reaeration is always an important process; at times, it can be a significant part of the DO budget for both the reservoirs and the riverine reaches.

Some obvious gaps in data that need to be filled in order to better understand the relative importance of the various processes that affect DO in the reservoirs and in the riverine reaches include

- BOD data—It is imperative to measure BOD at various locations in the river system and at important inflow boundaries. If possible, the CBOD rate also should also be measured.
- Algae data—A better understanding is needed of the types and populations of algae (periphyton and phytoplankton) in the reservoirs and in the riverine reaches, unless another source of data is available, to determine if the *Aphanizomenon* in the reservoirs are thriving or slowly dying as they are swept downstream from Upper Klamath Lake. It also is necessary to determine if algal growth is limited by the nitrogen or phosphorus levels, to measure primary productivity, and to assess the adequacy of available nutrient data.
- SOD data—SOD can be a dominant process. The USGS Oregon District measured SOD rates in the Klamath River downstream from Upper Klamath Lake in March 2003. The data, which were provisional at the time of this study, are available at *http://oregon.usgs.gov/projs_dir/lake_ewauna_sod/rate_table.html* (accessed on February 6, 2004). The Upper Klamath Lake study supported the importance of the SOD process and is also shown to be important in the Shasta River study discussed in this report. The prevalence of the SOD process needs to be evaluated throughout the Klamath River system, but most importantly in reaches with lower levels of DO.

Additional data needs, beyond those mentioned above, include

- Meteorological data: air temperature, dew point temperature (or relative humidity), wind speed, wind direction, cloud cover, and solar radiation. These data are needed on an hourly basis from both coastal and inland areas if models require that these data to be used on time intervals of less than 1 day.
- Shading data for stream channels: Topographic-shading data are easily derived from digital elevation model (DEM) data. Riparian-shading data can be estimated or collected in the field. Some field data will be necessary to evaluate current shading conditions.
- Vertical reservoir profiles: The balance among processes in the Copco and Iron Gate Reservoirs is almost certainly different than that in the flowing reaches of the Klamath River, and understanding that balance is important to understanding the downstream effects of the reservoirs. Even for simple models, water temperature and DO profiles are necessary. PacifiCorp, the company operating the Iron Gate and Copco Dams for electricity generation, may have collected these profiles to support modeling they did to be relicensed by the Federal Energy Regulatory Commission (FERC). If profiles are not available, then at the minimum, monthly or twice-monthly water-temperature and DO profiles are needed; obtaining profiles throughout the year would result in a more complete understanding of the seasonal processes. Such profiles are useful for calibrating models of reservoirs that are stratified. For more complex models, vertical profiles of pH, conductivity, chlorophyll-*a*, total organic carbon, soluble reactive phosphorus, total phosphorus, nitrate + nitrite nitrogen, and ammonia nitrogen would be useful, particularly if CE-QUAL-W2 is used to model the reservoir/river system.

Potential Data Sources

Meteorological Data

The meteorological data necessary for any water-quality model are available from a variety of sources for many stations in the Klamath River Basin (*fig. 14*). For this current study, all relevant current and historical data (through 2001) were compiled from the National Climate Data Center (NCDC) for multiple locations and multiple datasets in and around the Klamath River Basin (station locations are shown in *fig. 14*; *appendix 3*, *tables A3-1*, *A3-2*, and *A3-3*). The NCDC data include precipitation, snowfall, maximum and minimum daily air temperature, wind speed, wind direction, dew point temperature, and total sky cover.

Hourly data for Tule Lake are available from the California Department of Water Resources and from the University of California, Davis (station locations are shown in *fig. 14*; *appendix 3*, *table A3-4*). These data, from the California Irrigation Management Information System (CIMIS; California Department of Water Resources, accessed February 6, 2004), include hourly measurements of potential evapotranspiration,

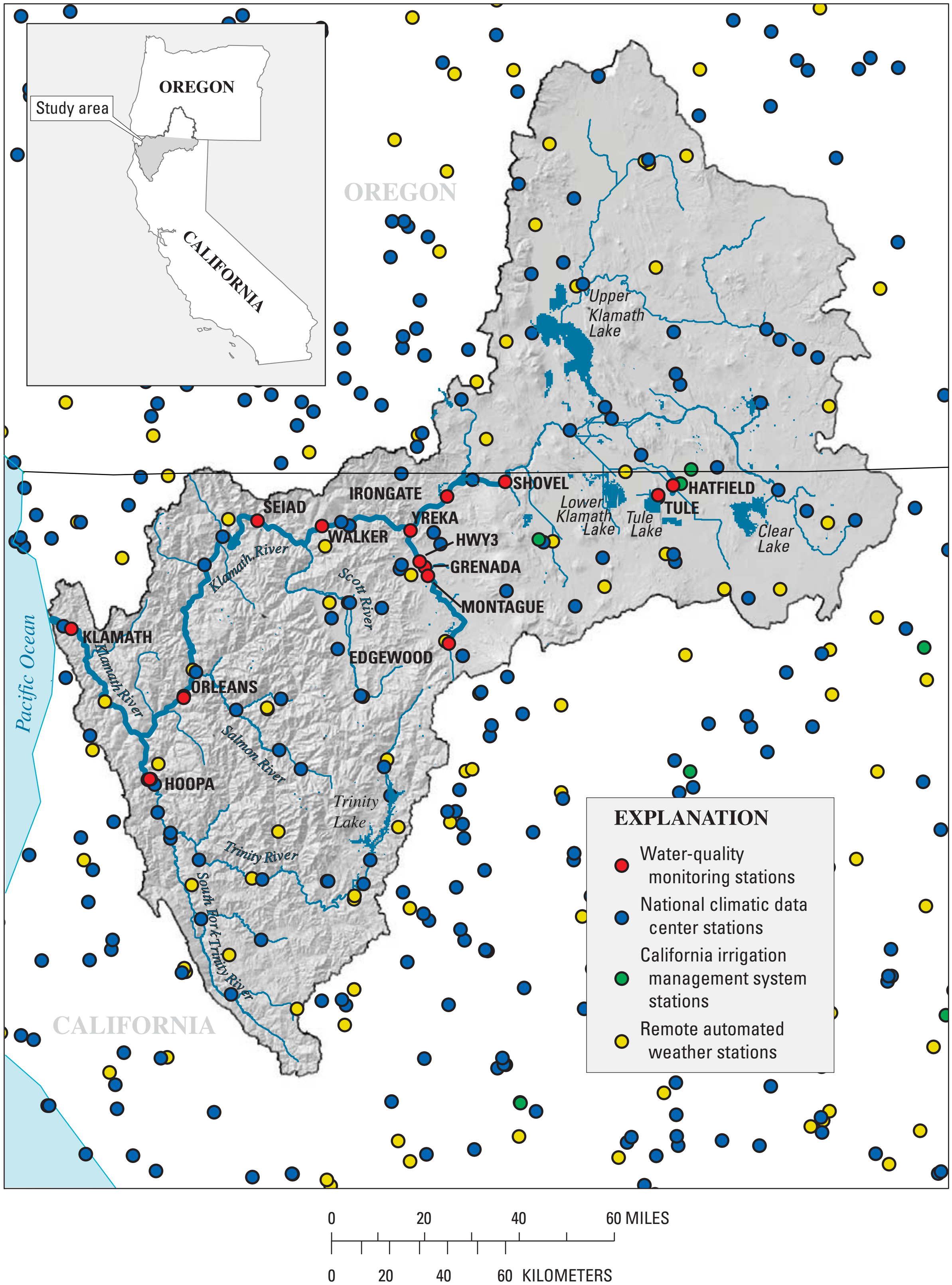

Figure 14. Meteorological stations in and around the Klamath River Basin in Oregon and California.

precipitation, solar radiation, vapor pressure, air temperature, wind speed, and wind direction, as well as daily measurements of potential evapotranspiration, solar radiation, minimum and maximum air temperature, and average vapor pressure.

Data were also compiled from the Solar and Meteorological Surface Observation Network, 1961–90 (National Renewable Energy Laboratory, U.S. Department of Energy) (station locations are shown on *fig. 14*; *appendix 3*, *table A3-5*). These data were used to develop a detailed solar radiation model, SOLRAD (Flint and Childs, 1987) that includes a calibrated equation to relate minimum and maximum air temperature to percent cloud cover (Bristow and Campbell, 1984) (there is much more air temperature data for the study area than there is cloud cover data, which makes the air temperature/cloud-cover relation useful for modeling the water temperatures in the basin). NREL data include hourly solar radiation, dew-point temperature, air temperature, and cloud cover, as well as monthly measurements of ozone, precipitable water, and Ångstrom's turbidity coefficient.

In addition, hourly data are available from a network of Remote Automated Weather Stations (RAWS) managed by the Western Regional Climate Center (WRCC) (station locations are shown on *fig. 14*; *appendix 3*, *table A3-6*). RAWS data include hourly measurements of air temperature, dew-point temperature (relative humidity), barometric pressure, precipitation, wind speed, and wind direction.

Another potential source of relevant meteorological data include Snotel weather stations managed by the WRCC. Data from all the sources described above should be evaluated before looking much further for additional sources.

Stream Shading

The most recent 30-m digital elevation models (DEM) for California and Oregon, which were used for calculations of topographic shading, are the Elevation Derivatives for National Applications (EDNA) data sets developed by the USGS. Some modeling packages include their own algorithms to calculate shading, but the USGS computer program, SKYVIEW, calculates topographic shading and blocking ridges around each pixel in the DEM. This program also can be used to calculate the shading effects of riparian vegetation. The resultant analysis is used in the program SOLRAD to calculate solar radiation loads for each pixel in the DEM at any time step required. The program SOLRAD incorporates the most significant atmospheric parameters for calculating solar radiation (ozone, precipitable water, and Ångstrom's Turbidity Coefficient). Minimum and maximum air temperatures are used in SOLRAD to estimate percent cloud cover when those data are not directly available for the site being modeled. SKYVIEW and SOLRAD model at point scales, river scales, or basin scales. When combined with air-temperature data, the model SOLRAD is converted to NETRAD to calculate the net radiation. This stand-alone analysis can be used to locate areas in the Klamath River Basin that would be most likely to cause increases in stream temperature owing to radiation loads.

Vertical Reservoir Profiles

Some profiles of temperature and DO already exist for the reservoirs in the study area, and have been used to calibrate existing reservoir models (Deas, 2000). PacifiCorp currently (2004) is in the process of collecting additional profiles, which may be available to others for TMDL model development.

Summary

The USGS investigated the water quality of the Lower Klamath River Basin in 2002 and 2003 in partnership with the California North Coast Regional Water Quality Control Board. In an attempt to identify and fill data gaps and to better understand water-quality processes in the river system of this basin, several investigations were undertaken. Water-quality constituents were measured using continuous monitors, and monthly water-quality samples were collected and analyzed. Sediment oxygen demand rates were measured. Lastly, existing models were assessed, gaps in data were identified, and directions for future research were suggested for the purpose of developing TMDLs for the rivers in the Lower Klamath River Basin.

The USGS deployed 12 continuous water-quality monitors in the Lower Klamath River Basin between June and November 2002 to collect hourly measurements of water temperature, DO, pH, and specific conductance. Six stations were on the Klamath River, one station on the Trinity River, three stations on the Shasta River, and two stations on the lower Lost River. Similar data were collected at 10 locations between April and September 2003; 3 of the 12 monitoring stations were discontinued (stations on the Trinity and Lost Rivers) and one station was added on the Shasta River. Data from these stations indicated that water temperatures were higher than that desired for the protection of Chinook salmon at most stations during mid summer. Low DO concentrations, were shown to be problematic in the lower Lost River. Low dissolved-oxygen concentrations that were likely to be stressful to Chinook salmon also were measured at stations in the Shasta and Klamath Rivers. Dissolved-oxygen concentrations varied greatly over the course of a day at most sites. Measured pH values exceeded water-quality standards at many of the stations; the highest recorded values were in the Lost River.

Monthly water-quality samples were collected at 12 sites in July, August, and September of 2002 and analyzed for selected nutrients, organic carbon, chlorophyll-*a*, and trace metals. Ammonia concentrations were low at all the sites, and nitrate + nitrate concentrations were low downstream from the WALKER station and moderate upstream. Phosphorus concentrations at most sites upstream of the ORLEANS station, however, were typically greater than 0.1 mg/L—large enough for the system to be classified as hypereutrophic with respect to phosphorus. Large populations of algae or aquatic plants could be supported in the Shasta River system and in the upper concentrations of phosphorus tended to decrease between the IRONGATE station and the KLAMATH station, the most downstream site, which may indicate the existence of a population of periphyton in that reach.

Two Lagrangian parcel-tracking studies were done on the Klamath (July, September) and Shasta (June, August) Rivers in 2003. Data from these studies were similar to that collected during the monthly sampling study in 2002, although the levels of nitrate in the Klamath River were markedly higher in the reach extending from the IRONGATE station to the SEIAD station than during any of the previous sampling periods. Similar trends of decreasing nitrogen and phosphorus concentrations were measured in the reach extending from the IRONGATE station to the most downstream KLAMATH station, again indicating potentially significant uptake by periphyton.

Sediment oxygen-demand rates were measured at six locations in two reaches on the Shasta River during the summer of 2003. The rates of SOD at these sites were moderate (median rate of 1.5 $g/m^2/d$); however, they were large enough for SOD to be a significant contributor in the loss of DO in the Shasta River, particularly for those shallow reaches that accumulate sediment and algal and plant detritus.

The process of determining and evaluating gaps in data using conceptual and mathematical models are discussed in this report. Several recent efforts to simulate water quality in the Klamath River also are discussed and evaluated. Learning from existing models is a good beginning to start understanding the most important influences on the water quality of a river system. Those models can be used to help identify gaps in both data and in the understanding of water-quality processes. Of the models evaluated, CE-QUAL-W2 may be best suited for further evaluations of the river systems in the Lower Klamath River Basin.

The appropriate and targeted use of modeling tools is one good method that can be used to lay the foundation for TMDL development, but additional data will likely be required before sufficiently robust and accurate predictive models can be constructed. Some data gaps are already known and are discussed in this report. Perhaps the largest data gap centers on algae both in the reservoirs and in the river downstream from the IRONGATE monitoring station. The gap in algae data includes unknowns regarding the types of algae present, the size, timing, and spatial distribution of algal communities, as well as their primary productivity and respiration rates. Additional data detailing the vertical water-quality profiles of DO and temperature for reservoirs in the Lower Klamath River Basin would be useful. More data are needed to define the BOD and SOD in the reservoirs and in the lower Klamath River. Information on the extent and importance of riparian shading is needed. These data gaps can be used to define additional studies needed to advance the understanding of water quality in the Klamath River, as well as to build tools that can be used to create a scientifically defensible framework for resource management and water-quality improvement.

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Appendix 1. Continuous dissolved oxygen, water temperature, ph, and specific conductance data measured at USGS sites in 2002 and 2003.

Continuously measured water-quality data are presented graphically for all USGS water-quality sites on the Klamath, Trinity, Shasta, and Lost Rivers in the Lower Klamath River Basin for the 2002 and 2003 field seasons. Data include dissolved oxygen, water temperature, pH, and specific conductance. All the hourly data that completed quality-assurance checks are shown in *figures A1-1a-h*. The complete data set is archived in the California District NWIS database.

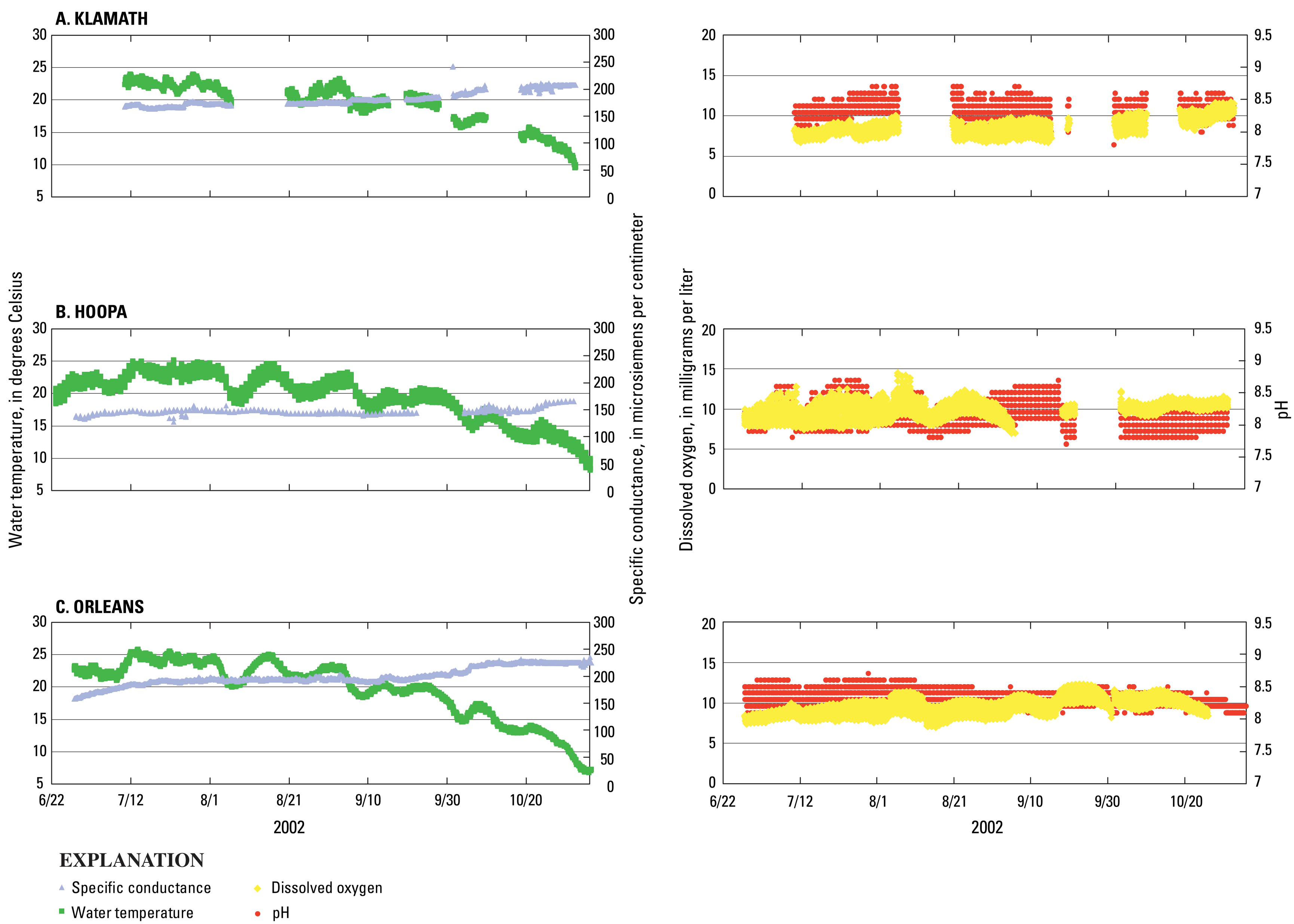


Figure A1-1. Measured continuous data of water temperature and specific conductance in left column, and dissolved oxygen and pH in right column for 2002 and 2003 for stations at (***A***) KLAMATH, (***B***) HOOPA, (***C***) ORLEANS, (***D***) SEIAD, (***E***) WALKER, (***F***) EDGEWOOD, (***G***) MONTAGUE, (***H***) HWY3, (***I***) YREKA, (***J***) IRONGATE, (***K***) SHOVEL, (***L***) TULE, and (***M***) HATFIELD.

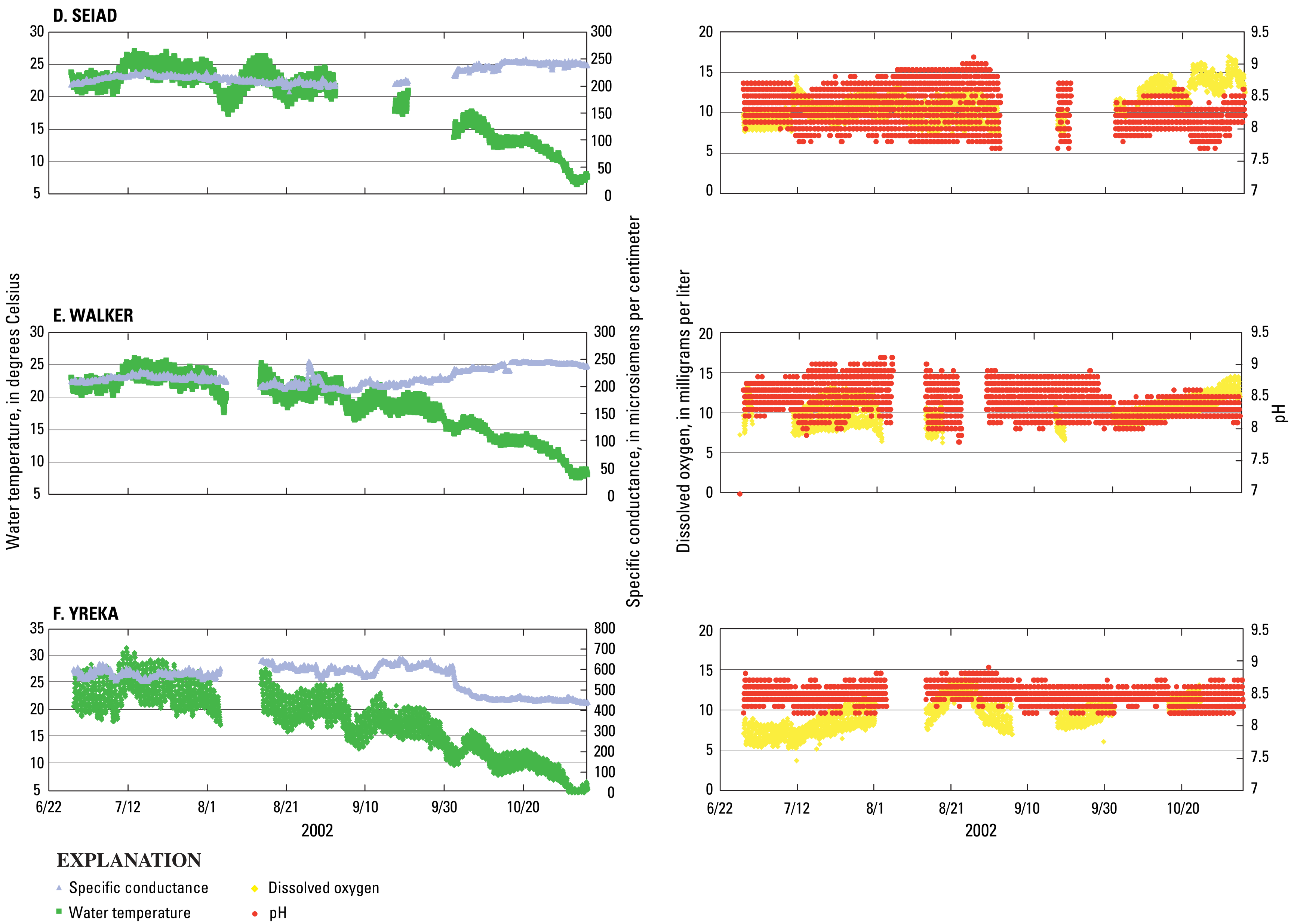
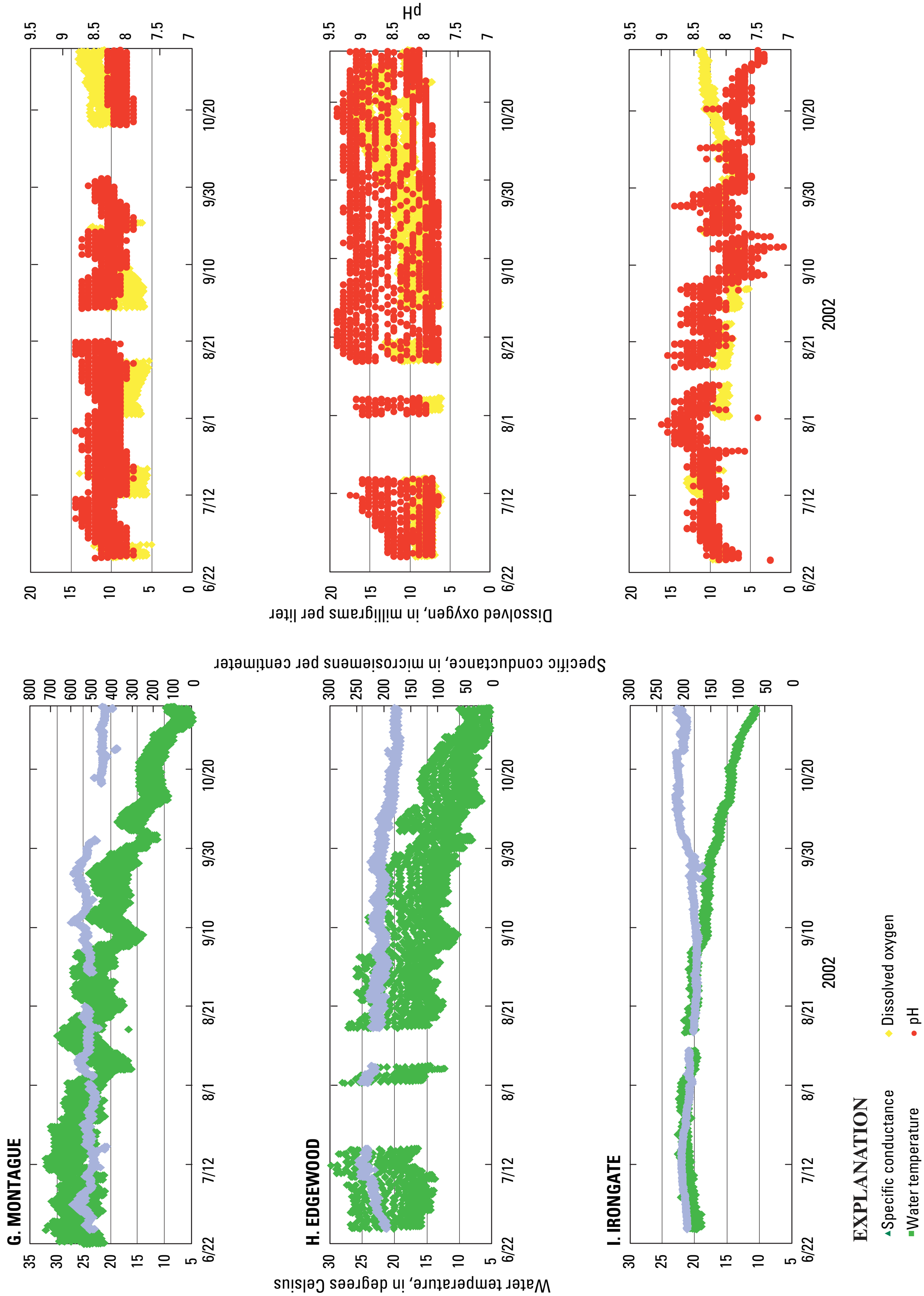


Figure A1-1.—***Continued.***



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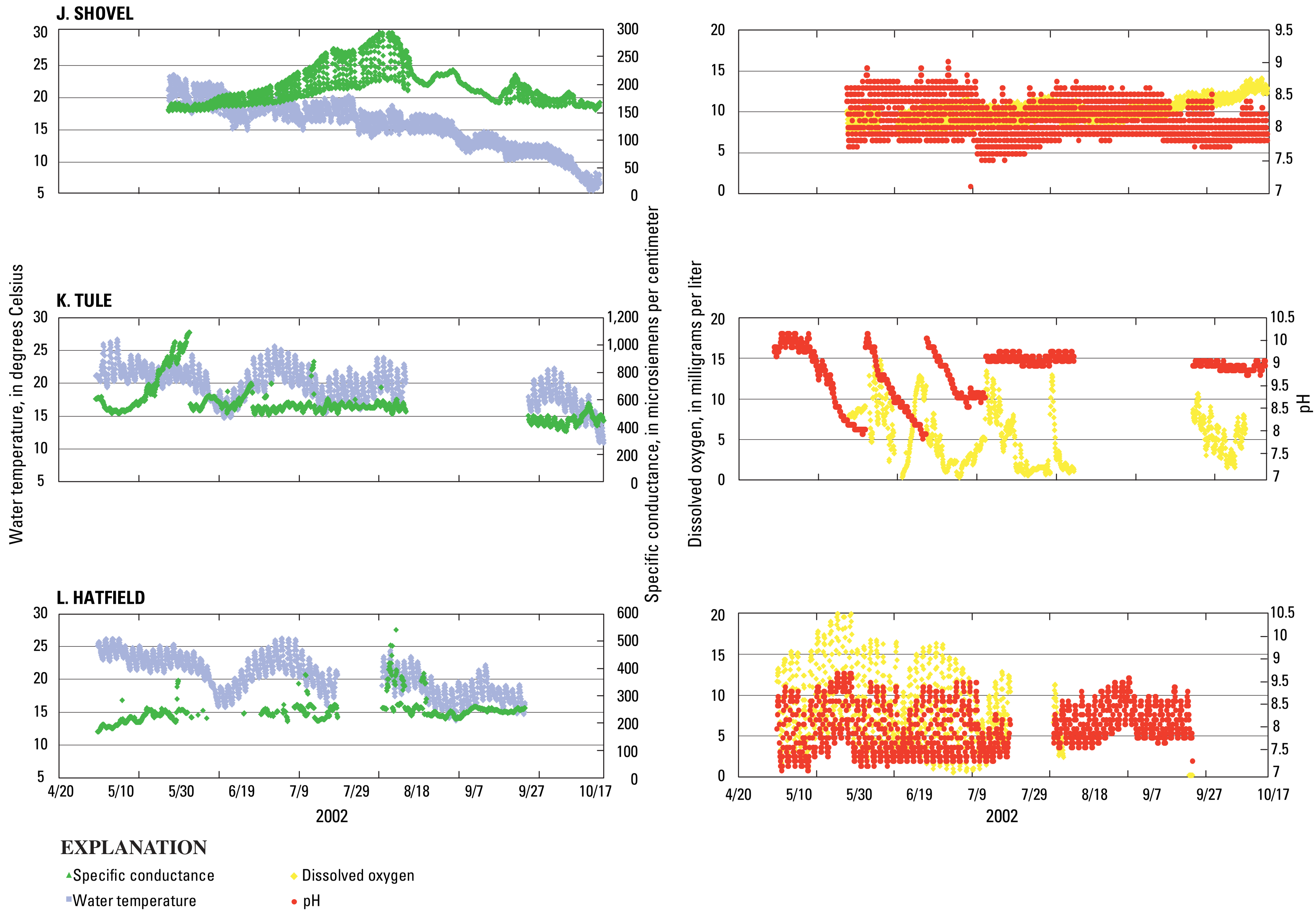

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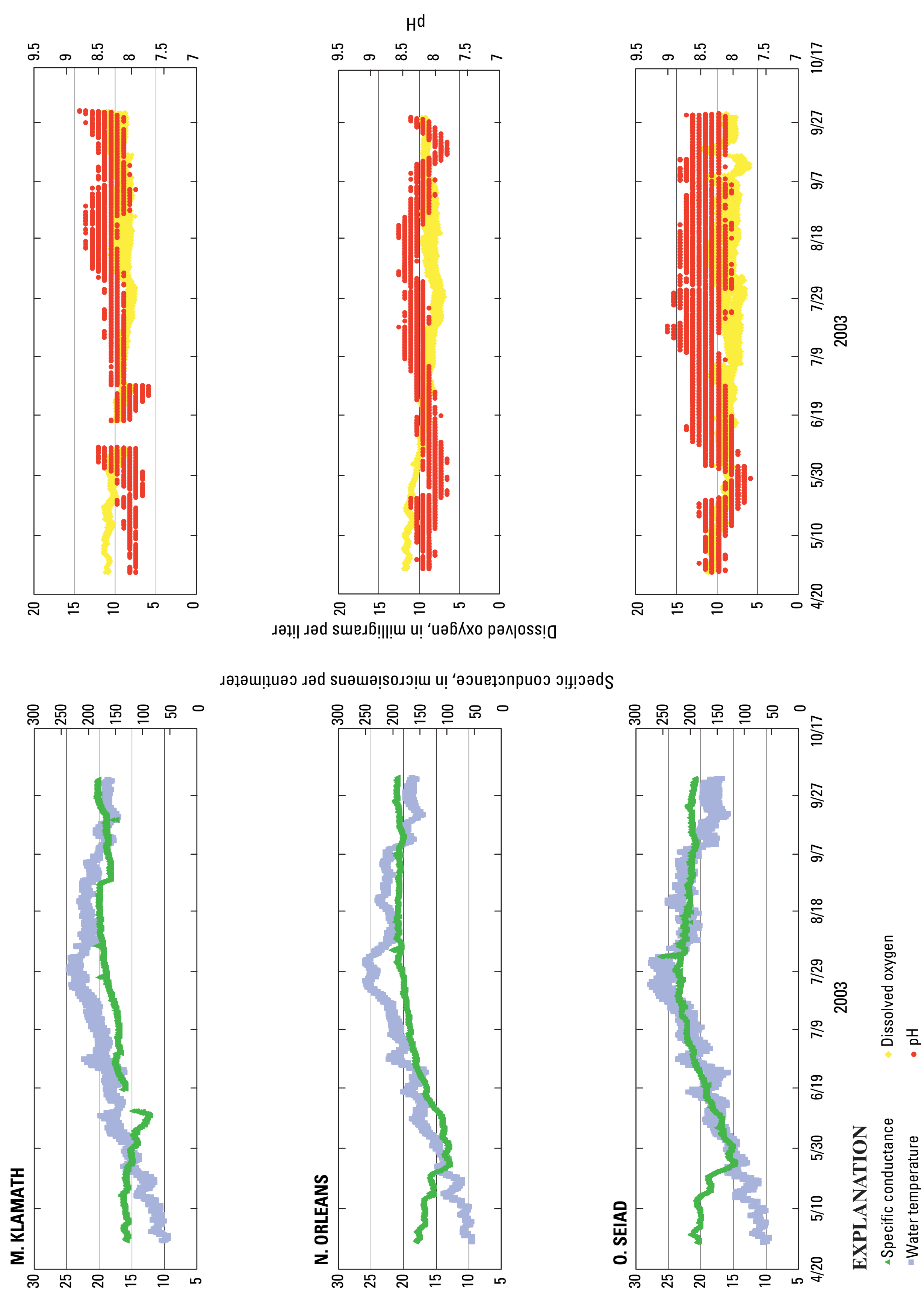

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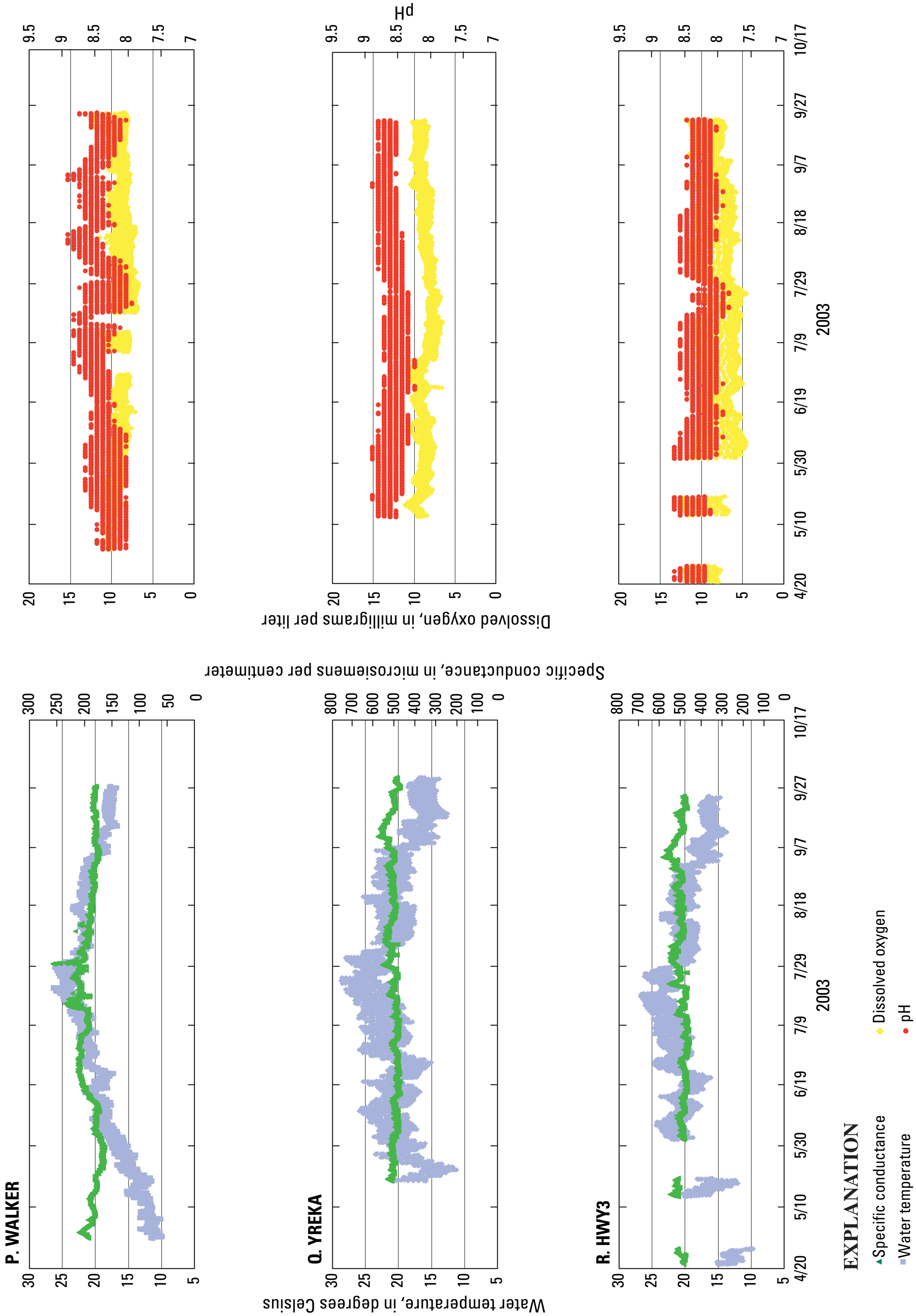

Figure A1-1.—*Continued.*

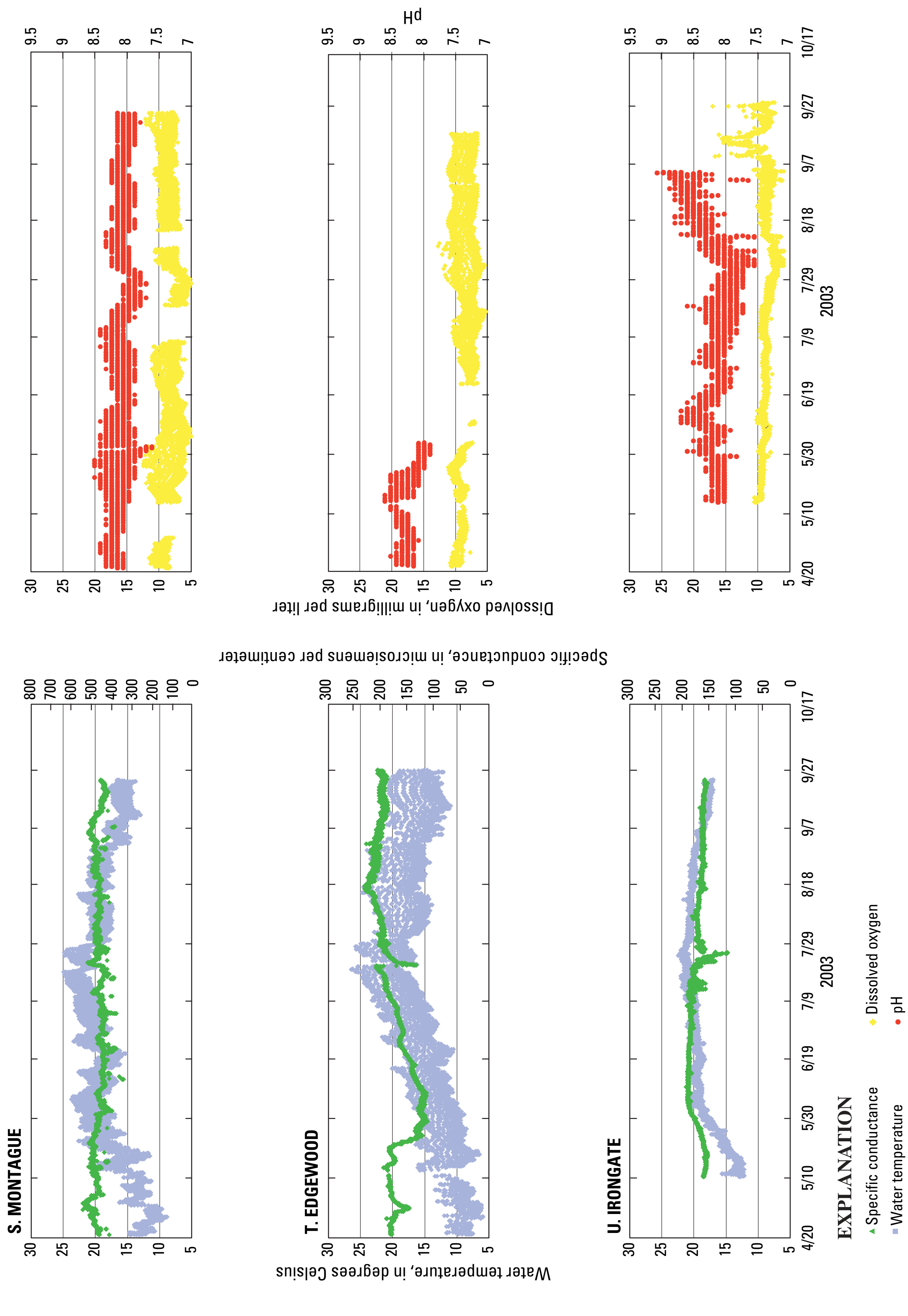

Figure A1-1.—*Continued.*

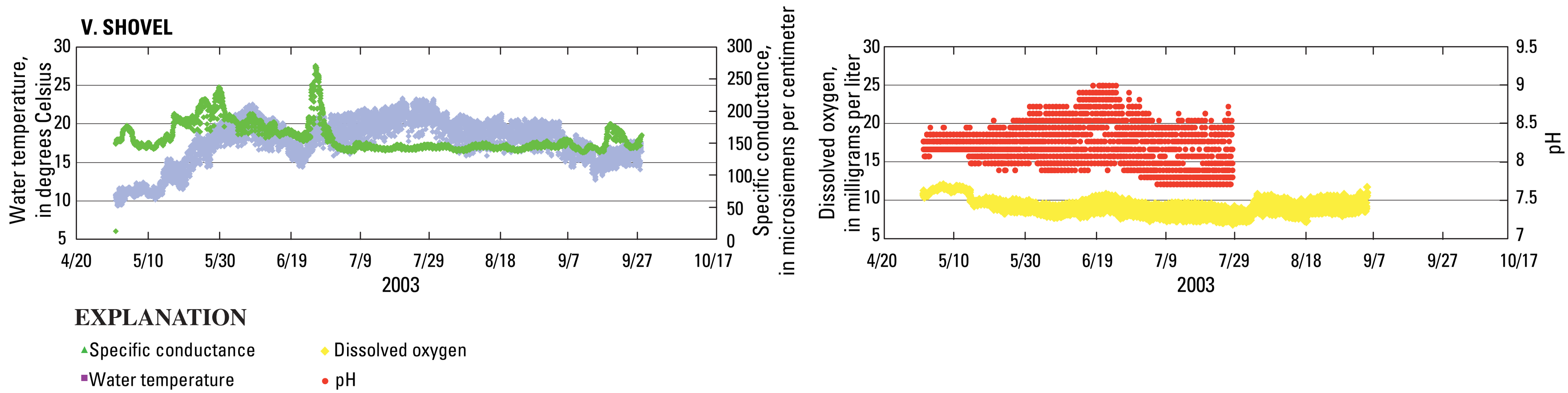

Figure A1-1.—***Continued***.

Appendix 2. Methodology for correcting continuous dissolved oxygen data from USGS datasonde sensors and associated data uncertainty.

Continuous field measurement of dissoved oxygen (DO) is difficult because it requires frequent site visits to maintain and clean the probes (to remove biofouling) and to recalibrate the probes (to correct the sensor drift). Data, therefore, must be corrected to maintain the best accuracy according to field calibrations. The theory for measuring DO and the inherent errors associated with the measurements are discussed in the following section to illustrate the reliability of the DO data collected by the USGS and the accuracy of that data. USGS protocols for deploying and maintaining the probes and for processing the data and reporting it are briefly described with information excerpted from Wagner and others (2000). For further details on USGS protocols, see Wagner and others (2000), as well as publications by Radtke and others (1998) and Wilde and Radtke (1998). For information regarding supersaturated DO conditions, refer to studies of Oregon lakes and rivers by Doyle and Caldwell (1996), Kelly (1997), Rounds and others (1999), and Wood and Rounds (1998). Examples of data collected on the Shasta River for 2002 and 2003 are used in this appendix to illustrate data uncertainty for the Lower Klamath River Basin.

Theory and Measurement of Dissolved Oxygen

The DO concentration in surface water is related primarily to atmospheric reaeration and photosynthetic activity of aquatic plants (Radtke and others, 1998). The range of observed DO in surface waters typically is from 2 to 10 milligrams per liter (mg/L) at 20°C. The value for 100-percent saturation of DO decreases with increased temperature and salinity, and increases with increased atmospheric pressure. Occasions of excess oxygen (supersaturation) are related to extreme photosynthetic production of oxygen by aquatic plants as a result of nutrient (nitrogen and phosphorus) enrichment, sunlight, and low-flow conditions. Occasions of saturated oxygen commonly are related to cascading flow conditions, both natural and artificial. DO may be depleted by inorganic oxidation reactions or by biological and chemical processes that consume dissolved, suspended, or precipitated organic matter (Hem, 1989).

The most commonly used technique for measuring DO concentrations with continuous water-quality sensors is the amperometric method, which measures DO with a temperature-compensated polarographic membrane-type sensor. Although polarographic membrane-type sensors generally provide accurate results, they commonly are sensitive to water temperature and water velocity and are prone to fouling. Because the permeability of the membrane and the solubility of oxygen in water change as functions of water temperature, barometric pressure, and salinity, it is critical that the DO sensors be calibrated. DO sensors are prone to inaccuracies from algal fouling, sedimentation, low velocity, and very high velocities. They also undergo drift in the electronics, and can be subjected to leakage of the membrane. For a complete discussion of DO sensor calibration, DO measurement, and instrument and data limitations, refer to Radtke and others (1998).

USGS Protocols for Collecting, Processing, and Reporting Continuous Dissolved Oxygen Data

YSI 6920 multiparameter datasondes were used to collect continuous DO measurements for this current study of the Lower Klamath River Basin. Standard USGS protocols were followed for the collection of continuous DO data, calibration of probes, and correction and reporting of data (Wilde and Radtke, 1998).

Collecting Field Measurements of Dissolved Oxygen

Maintenance frequency of DO sensors generally is governed by the fouling rate, and this rate varies by sensor type, hydrologic environment, and season. In addition to fouling problems, physical disruptions (such as pump failure, recording equipment malfunction, sedimentation, electrical disruption, debris, or vandalism), or battery failure may cause additional site visits.

During a site visit the sensor is inspected to provide the final quality control for the interval of water-quality record since the last service visit and the initial quality control for the next interval of water-quality record and to verify that the sensor is working properly. This is accomplished by recording the initial sensor readings, servicing the sensors, recording the cleaned-sensor readings, performing a calibration check of sensors at 100 percent oxygen saturation in air saturated with water vapor, and, if the readings of the DO sensor are outside the range of acceptable difference of ± 0.3 mg/L, recalibrating the sensor. The difference between the initial sensor reading and the cleaned sensor reading is the sensor error resulting from fouling during the preceding interval; the difference between the calibration-check reading and calibrated-sensor reading is a result of electronic drift. The tasks during a site visit are performed in sequence so as to properly distinguish errors in sensor measurement that are due to fouling from those that are due to electronic drift.

Data-Processing Procedures

The initial data evaluation serves as a check of the success of the transfer of raw data collected in the field (instrument readings) to the database at the office and provides the opportunity to evaluate obviously erroneous data, such as data recorded while the sensor was out of the water during a site visit. The data are then corrected, if necessary, for changes that occurred in the sensor during the service interval as a result of biofouling or electronic drift. Corrections to compensate for both of these types of measurement error are applied independently and are based on the quality-control information collected in the field during site visits, as described previously. In general, both types of corrections are applied when the measurement errors exceed ± 0.3 mg/L.

The degree of fouling is determined from the difference between sensor measurements before and after the sensors are cleaned in the field and is assumed to occur linearly with time between the sensor checks. A second calibrated instrument is brought into the field to measure any simultaneous changes in conditions so that an environmental change during servicing is not mistakenly attributed to fouling. A calibration drift is an electronic drift in the equipment from the last time it was calibrated and is determined by the difference between what the cleaned sensor reads in air saturated with water vapor and the 100 percent saturation concentration of oxygen in water at the ambient temperature and barometric pressure. If the deviation from calibration is within the manufacturer's calibration criteria for the sensor, then no sensor drift is indicated. Electronic drift is assumed to occur at a constant rate across the service interval. If the sensor readings exceed the shift criteria of 0.3 mg/L, then the correction is linearly interpolated over the time between calibration checks.

Systematic adoption of a standardized final data-evaluation process, including maximum allowable limits and publication criteria, are used by USGS District offices and have established quality-control limits to be used when shifting data. These commonly are referred to as "maximum allowable limits." If the sum of the absolute value of the fouling and calibration shifts is greater than the maximum allowable limit, the data are not published. For DO, the maximum allowable limit is 2.0 mg/L; this is considered a minimum standard for quality. USGS Districts are encouraged to establish stricter requirements. Even with the establishment of maximum allowable limits, professional judgment is required by a hydrographer when processing data.

Uncertainty in Dissolved Oxygen Data

Although DO probes are designed to operate linearly, biofouling with time may not be a linear function. To the best of our knowledge, few studies have been conducted to measure rates of biofouling and (or) instrument drift, and it is not clear exactly how a biofilm growing on the DO sensor affects DO levels, although it likely varies depending on numerous factors, including photo-intensity, time of day, temperature, etc. Given the uncertainties in the effect of biofouling on DO data, it is the practice of the USGS to apply a time-prorated linear data correction to DO data that show biofouling and instrument drift and to report the recorded levels of DO with a qualitative rating of the data. Various arguments can be made to support a nonlinear variation with time. Unfortunately, the only way to select among the many possible approaches to correcting DO data for biofouling is to make an additional measurement in the middle of the time interval. That measurement would require an additional site visit, but the incremental cost of the site visit would be small. The record would be processed as two intervals with linear corrections.

Dissolved Oxygen Data for the Shasta River, 2002–2003

Dissolved oxygen concentrations were measured continuously at three locations on the Shasta River between June and November 2002 and at four locations between April and September 2003 (*table A2-1*). To illustrate the methods used to process the data, the following data and calculations are shown (*fig. A2-1*): (1) field data from the initial data evaluation, which were used to check the success of the transfer of raw field data (instrument readings) to the office database and to provide an initial check for evaluating and correcting erroneous data; (2) computed data following corrections for biofouling and instrument drift; and (3) DO at saturation calculated from measured water temperature and atmospheric pressure (average values were based on measurements during site visits) (*fig. A2-1*). Generally, corrections for biofouling and drift are evident as decreases in the computed data, but occasionally it is evident as increases. There generally are large diurnal fluctuations in the data in mid to late summer, especially at the three upstream sites, EDGEWOOD, MONTAGUE, and HWY3 where the water is shallower and more slowly moving.

For purposes of example, the site at EDGEWOOD was chosen as providing the dataset with the most uncertainty, as this site has the slowest moving water and, therefore, generally has the most occurrences of extreme conditions of high or low DO, and the most biofouling. EDGEWOOD has site visits noted on *figure A2-1*. The probe deployed at that station in 2002 was at the bottom of an approximately 50-m long riffle. In 2003, the monitor was relocated to above the riffle. Corrections were made following site visits owing to biofouling in 2002, and to biofouling and drift in 2003, as noted in *table A2-1*. Calibrations and field checks with a hand-held meter were performed monthly in 2002, and at every site visit in 2003, with the exception of one visit in October when a hand-held meter was not used. Corresponding corrections and shifts to the data can be seen as linear prorated changes.

Although the measured DO values commonly exceed the solubility of DO, indicating supersaturated conditions, the entire diurnal cycle was supersaturated only three times during 24-hour periods: in August (possibly owing to periphyton bloom/die off) and in October 2002 at the YREKA station and in October 2002 at the EDGEWOOD station. The record for the EDGEWOOD station in October 2002 is of particular interest because the diurnal fluctuations in DO exceeded saturated conditions on a 24-hour basis for nearly a month. A comparison of this occurrence with occurrences at other sites where DO has been studied indicates that supersaturated conditions for extended periods of time do occur occasionally. Studies of the Tualatin River and of the Upper Klamath Lake in Oregon (Wood and Rounds, 1998; Rounds and others, 1999; U.S. Geological Survey, Upper Klamath Lake data, accessed March 26, 2004) indicate it is not unusual for this to occur, particularly in a system with little turbulence, few waterfalls or riffles, and an abundance of algae. These conditions are prevalent in the Shasta River which has an abundance of rooted aquatic plants in addition to a substantial population of attached algae. As long as conditions are favorable for the continued growth of the algae and aquatic plants, they can easily produce sufficient DO by photosynthesis to offset any consumptive processes and any losses to the atmosphere.

Studies show that supersaturation is an annual occurrence in many systems in Oregon. For example, the continuous DO record for a station on the Tualatin River (established in 1991) (Doyle and Caldwell, 1996; U.S. Geological Survey, Tualatin River data, accessed April 2004) shows that supersaturated conditions occurred annually at this station for 24-hour periods extending from 1 to 6 weeks. In 1992, supersaturated conditions persisted for a month at a time for several periods, and at saturations as high as 250 percent, even though that river has a TMDL meant to protect it from low DO conditions. Dissolved oxygen at shallow locations in the Upper Klamath Lake often exceeded 100 percent saturation values throughout the diel cycle for several days at a time between May and October of 2002 and 2003 (U.S. Geological Survey, Upper Klamath Lake data, accessed April 2004).

These comparisons give some credence to the data collected at the EDGEWOOD site; however, the site visit record, which was carefully scrutinized, indicates that although the meter was calibrated during the October visit, the only visit during the extended supersaturated period, there was no independent check of the meter for DO using a hand-held meter. This increases the uncertainty of this data for that period by not providing a means for defense; therefore, the computed data for EDGEWOOD for the period September 19, 2002, through November 6, 2002, have been removed from the dataset, although the original edited data remains. This is also true, but to a lesser degree, for the data from the YREKA site during August and September 2002, when there coincidentally was no independent check of the meter for DO during the field visit, and the subsequent visit indicated a failed sensor. As a result, the computed data for YREKA for the period of August 14, 2002, to September 17, 2002, have been removed from the dataset, while the original edited data remain.

There are many uncertainties associated with the DO data particularly the DO data for the Shasta River in particular. At the beginning of the 2002 field season, field crews unfamiliar with the collection of continuous DO data were trained in the USGS procedures decribed by Wagner and others (2000). In 2002, YSI 6920 multiparameter sondes having probes for measuring DO, pH, and specific conductance/water temperature were rented from the USGS Hydrologic Instrumentation Facility. There were numerous battery failures and other problems with the probes, in addition to the expected biofouling. Drift corrections were not made in 2002, but field calibrations were done and sensors were replaced as necessary (approximately monthly). In 2003, new instruments were obtained and more frequent field visits were made (*table A2-1*). In addition to corrections for biofouling, drift corrections were made and DO sensors were replaced as needed following inspections and calibrations in 2003 (approximately every 2 weeks).

Uncertainties in the DO data collected continuously in the field can be exemplified by the data collected in the Shasta River in 2002 and 2003. USGS field protocols were followed more rigorously in 2003 than in 2002, with more frequent site visits, field calibrations, and sensor replacements, thus providing more certainty in the data between visits. In addition, both biofouling and drift corrections were made in 2003. Data obtained during obvious probe failure, membrane leakage, or battery failure were removed in the initial data review, but more frequent site visits and probe inspections in 2002 could have provided more confidence in the data collected between site visits and in the field calibrations. In general, uncertainties governed by probe behavior due to biofouling and drift were consistently corrected for when deviations from the field calibrated values exceeded 0.3 mg/L but no more than 2.0 mg/L, except for the values collected at the EDGEWOOD station on August 18, 2003, and September 30, 2003, which were corrected by −2.2 and −2.4 mg/L, respectively. Careful inspection of other constituents, including coincident water temperature, pH, and specific conductance, as well as discharge, although not necessarily at the identical location, and specific consideration of individual site characteristics, weather conditions, nutrients, and the presence of algal and macrophyte populations would assist in the interpretation of the adequacy and uncertainty of the DO data at these sites.

Locations of active and inactive meteorological stations, type of data, and period of record are given in *table A3-1* Locations of active and inactive meterorological stations type of data, and period ofrecord are given in *table A3-1* through *A3-3* for the National Climatic Data Center (NCDC) stations, in *table A3-4* for the California Irrigation Management Information System (CIMIS) stations, and in *table A3-5* for the National Renewable Energy Laboratory (NREL) stations, and in *table A3-6* for the Remote Automated Weather Station (RAWS) sites.

Table A2-1. Corrections and shifts made to dissolved oxygen data, and comments on site visits to the EDGEWOOD station on the Shasta River in the Lower Klamath River Basin, California, 2002-2003.

[mg/L, milligrams per liter]

Date	Correction due to biofouling (mg/L)	Correction due to drift (mg/L)	Total correction	Comments
6/25/2002				Sonde deployed
7/11/2002	–8.6			Heavy algal growth on probe, fouling correction beyond allowable limit.
8/1/2002				7/16/02–8/1/02 battery failure
8/2/2002			0.0	
8/15/2002	–0.9		–0.9	8/4/02–8/15/02 battery failure
8/29/2002			0.0	8/18/02–8/29/02 faulty probe
9/19/2002	0.4		0.4	
10/2/2002	–0.4		–0.4	
10/16/2002			0.0	Cleaning visit only, no fouling correction needed
11/6/2002	0.7		0.7	Sonde removed for season
4/9/2003			0.0	Sonde deployed
4/25/2003			0.0	4/24/03–4/25/03 battery failure
5/13/2003			0.0	4/24/03 and 5/9/03–5/12/03 battery failure, new Sonde deployed
5/30/2003		–0.9	–0.9	
6/16/2003		0.5	0.5	
6/27/2003			0.0	no site visit
7/3/2003		2.0	2.0	no site visit
7/9/2003			0.0	hole found in membrane, replaced probe. Drift correction applied 6/27/03–7/3/03. 7/3/03–7/9/03 drift correction beyond allowable limit
7/23/2003			0.0	7/9/03 – 7/10/03 new probe questionable, 7/23/03 hole found in membrane, no data published 7/3/03–7/22/03
8/5/2003		–0.5	–0.5	
8/18/2003	–2.0	–0.2	–2.2	
9/11/2003		–1.8	–1.8	
10/1/2003	–0.2	–2.2	–2.4	
10/23/2003	–0.1	–1.4	–1.5	
11/14/2003		–0.9	–0.9	
12/1/2003	–0.1	–1.6	–1.7	Sonde removed for season

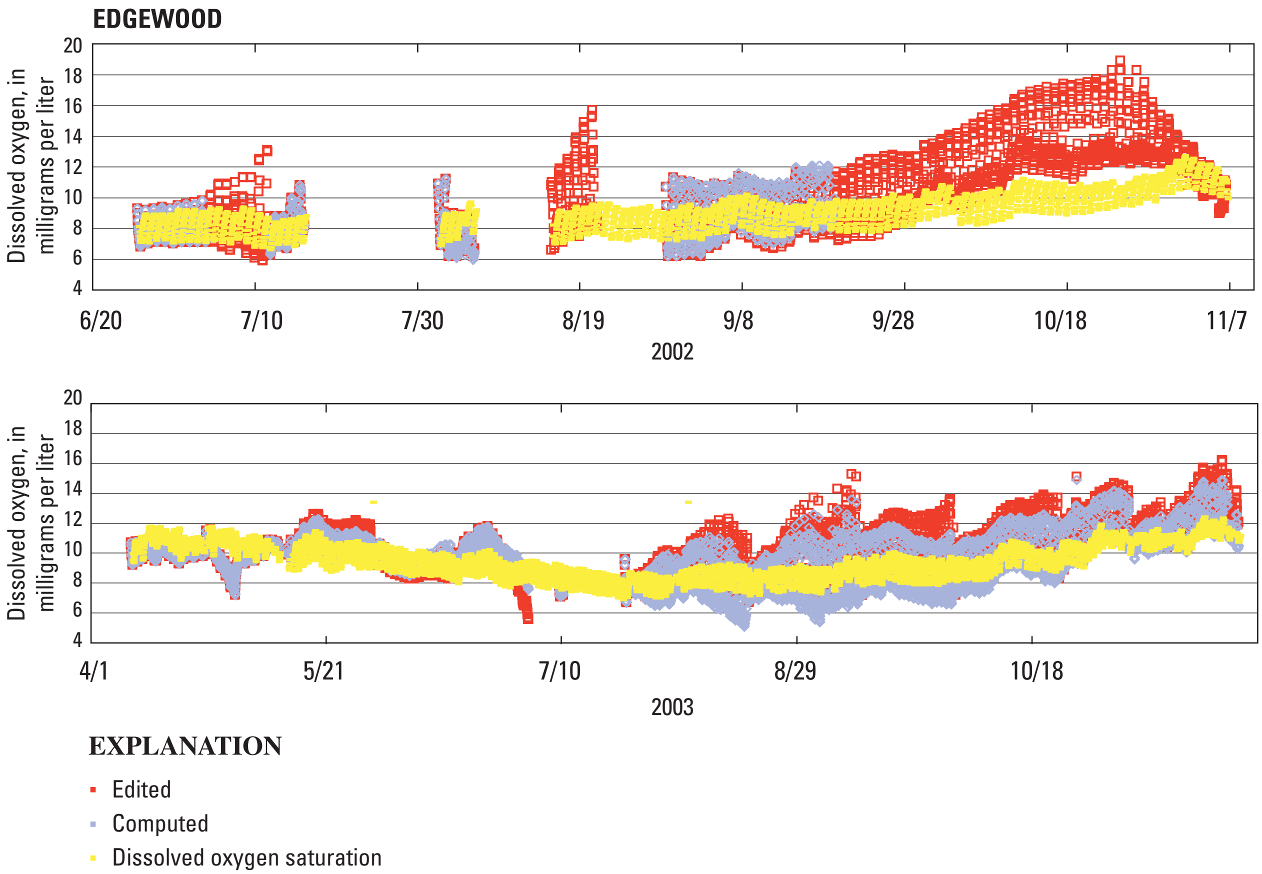

Figure A2-1. Measured continuous data of dissolved oxygen with initial edited record, computed record, and saturated values for 2002 and 2003 for USGS sites on the Shasta River, (***A***) EDGEWOOD, (***B***) MONTAGUE, (***C***) HWY3, and (***D***) YREKA.

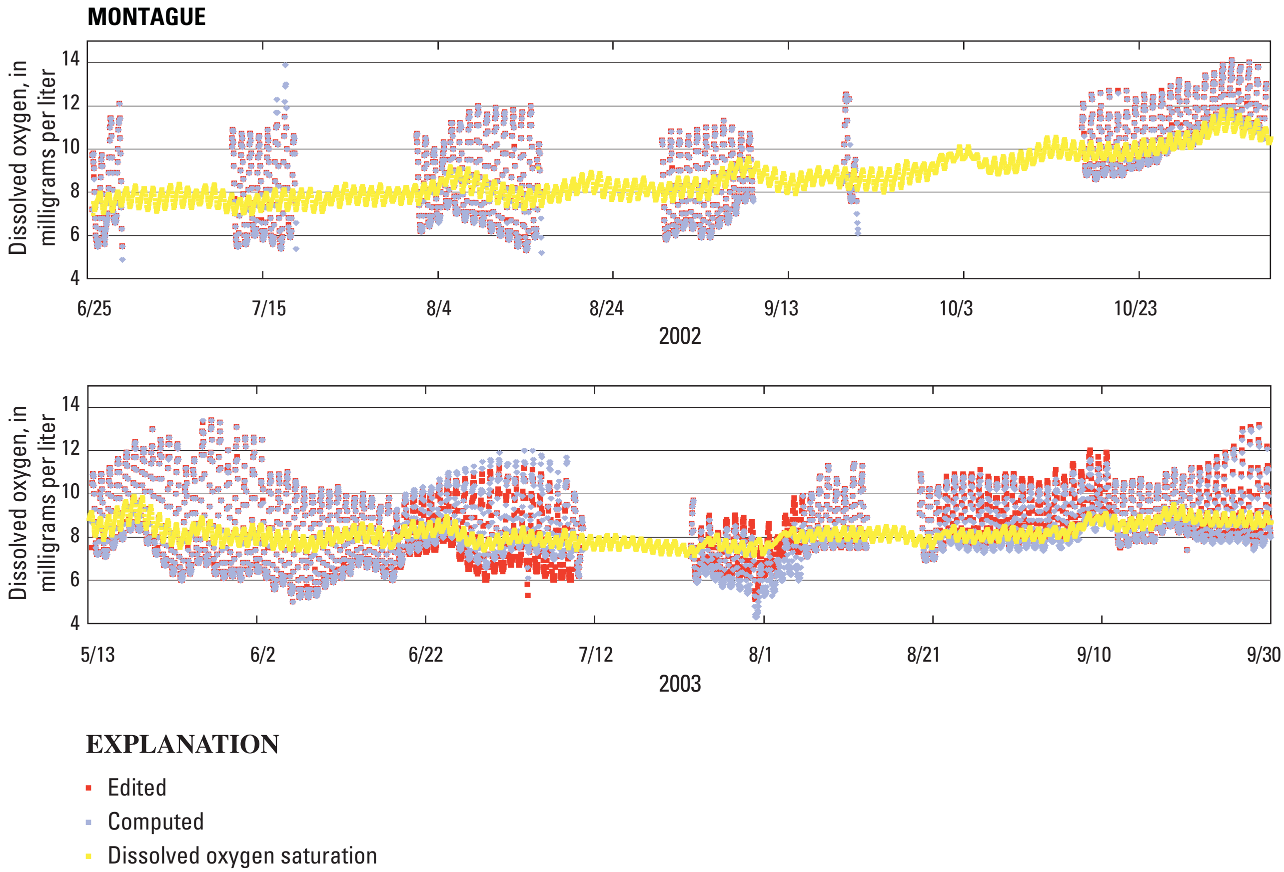

Figure A2-1.—***Continued.***

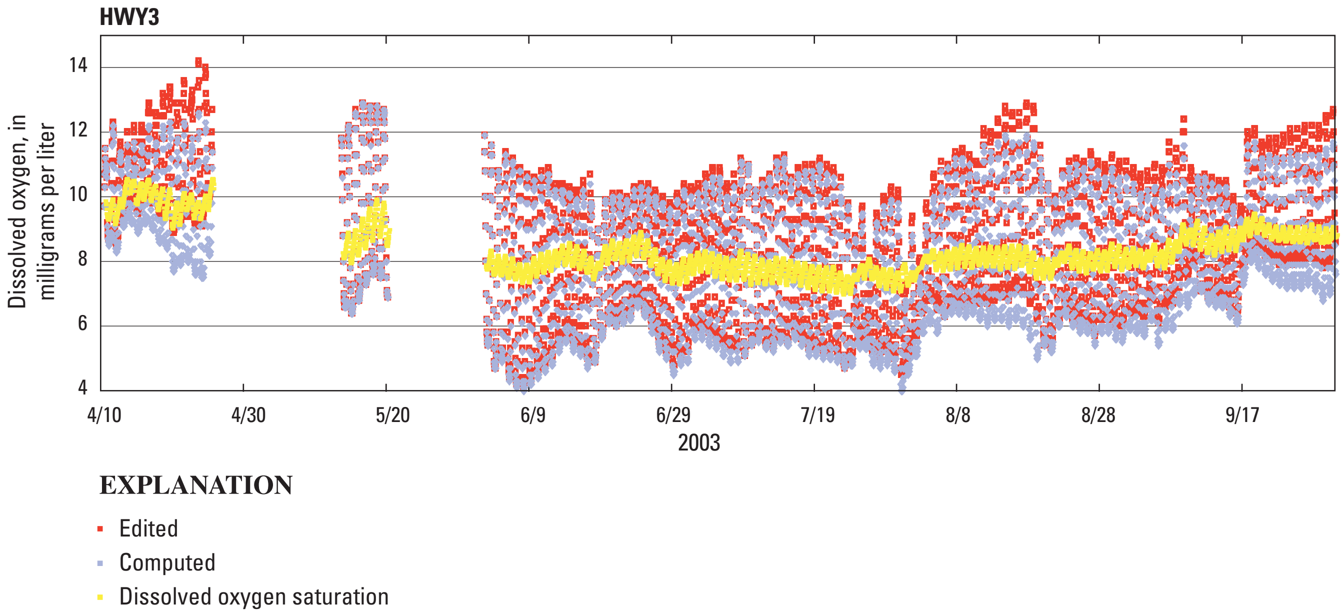

Figure A2-1.—*Continued*.

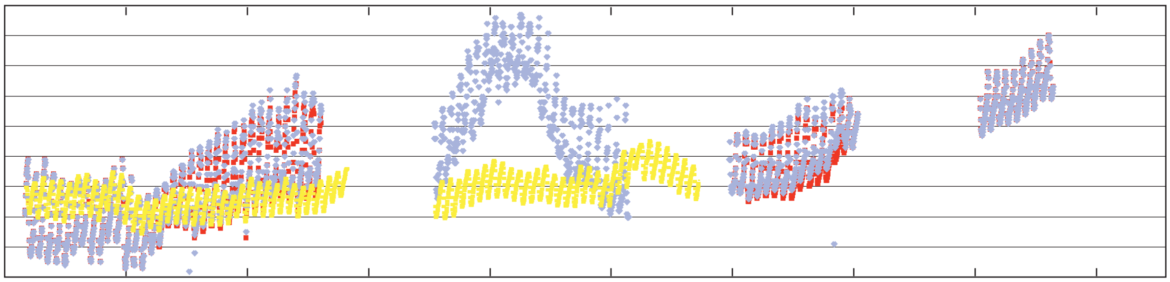

Figure A2-1.—***Continued***.

Table A3-1. Active National Climatic Data Center (NCDC) stations recording through 2003 in or around the Lower Klamath River Basin, California.

[Stations measure precipitation, snow, maximum and minimum air temperature. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Station Id.	Station name	Elevation (meters)	Latitude	Longitude	Begin date
California					
29	ADIN RS	4,195.0	41.19639	−120.94722	7/1/1948
161	ALTURAS	4,400.0	41.49306	−120.55278	5/11/1931
738	BIG BAR 4 E	1,250.0	40.74028	−123.20806	7/1/1948
1149	BUCKHORN	3,800.0	40.86694	−121.84639	7/1/1948
1159	BUCKS CREEK P H	1,850.0	39.91778	−121.35111	7/2/1959
1214	BURNEY	3,198.0	40.88000	−121.67278	7/1/1948
1316	CALLAHAN	3,185.0	41.31111	−122.80444	7/1/1948
1476	CANBY 3 SW	4,310.0	41.42194	−120.90167	7/1/1948
1497	CANYON DAM	4,560.0	40.17056	−121.08861	7/1/1948
1606	CECILVILLE	2,310.0	41.14167	−123.13917	11/1/1954
1614	CEDARVILLE	4,670.0	41.53361	−120.17361	7/1/1948
1700	CHESTER	4,530.0	40.30333	−121.24222	7/1/1948
1886	COFFEE CREEK R S	2,500.0	41.08944	−122.70861	1/1/1998
1907	COLEMAN FISHERIES STA	420.0	40.40000	−122.14333	7/1/1948
1990	COPCO NO 1 DAM	2,703.0	41.97972	−122.33778	5/1/1959
2081	COVELO	1,410.0	39.81583	−123.24444	7/1/1948
2147	CRESCENT CITY 3 NNW	40.0	41.79583	−124.21472	7/1/1948
2402	DE SABLA	2,710.0	39.87389	−121.61722	7/1/1948
2504	DOYLE	4,240.0	40.02417	−120.10444	7/2/1948
2506	DOYLE 4 SSE	4,390.0	39.97167	−120.08278	7/1/1956
2574	DUNSMUIR TREATMENT PLAN	2,170.0	41.18333	−122.27361	7/1/1978
2910	EUREKA WFO WOODLEY IS	20.0	40.81056	−124.16028	7/1/1948
2964	FALL RIVER MILLS CSD	3,310.0	41.01611	−121.44250	7/1/1948
3157	FORT BIDWELL	4,500.0	41.85944	−120.15139	7/1/1948
3182	FORT JONES RANGER STN	2,725.0	41.60000	−122.84778	7/1/1948
3357	GASQUET RS	384.0	41.84528	−123.96500	7/1/1948
3614	GREENVIEW	2,820.0	41.55194	−122.92361	7/1/1948
3761	HAPPY CAMP RANGER STN	1,120.0	41.80417	−123.37583	1/8/1931
3791	HARRISON GULCH R S	2,750.0	40.36361	−122.96500	7/1/1948
3824	HAT CREEK	3,015.0	40.93167	−121.54333	7/1/1948
3859	HAYFORK 2 W	2,300.0	40.55250	−123.21222	7/1/1948
4374	JESS VALLEY	5,400.0	41.26833	−120.29472	8/1/1948
4577	KLAMATH	25.0	41.52167	−124.03167	7/1/1948
4683	LAKEHEAD	1,260.0	40.91083	−122.38833	6/1/1998
4838	LAVA BEDS NAT MONUMENT	4,770.0	41.74000	−121.50667	10/7/1959
5311	MANZANITA LAKE	5,750.0	40.54194	−121.57639	1/1/1949
5449	MC CLOUD	3,280.0	41.25139	−122.13833	7/1/1948
5941	MOUNT HEBRON RNG STN	4,250.0	41.78361	−122.04472	7/1/1948
5983	MOUNT SHASTA	3,590.0	41.32056	−122.30806	7/1/1948
6328	OAK KNOLL W C	1,980.0	41.83917	−122.85028	7/1/1948
6498	ORICK PRAIRIE CREEK PAR	160.0	41.36194	−124.01917	7/1/1948
6508	ORLEANS	400.0	41.30889	−123.53222	7/1/1948
6946	PIT RIVER P H 5	1,458.0	40.98694	−121.97722	7/1/1948
7085	PORTOLA	4,850.0	39.80528	−120.47194	7/1/1948
7195	QUINCY	3,420.0	39.93667	−120.94750	7/1/1948
7292	RED BLUFF AP	353.0	40.15194	−122.25361	11/1/1933

Table A3-1. Active National Climatic Data Center (NCDC) stations recording through 2003 in or around the Lower Klamath River Basin, California—***Continued***.

[Stations measure precipitation, snow, maximum and minimum air temperature. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Station Id.	Station name	Elevation (meters)	Latitude	Longitude	Begin date
7293	RED BLUFF TREATMENT PLA	265.0	40.16222	–122.22028	5/1/2000
7298	REDDING CDF	502.0	40.51944	–122.29889	2/1/1998
7304	REDDING MUNICIPAL AP	497.0	40.51750	–122.29861	11/1/1986
7404	RICHARDSON GR ST PK	500.0	40.02556	–123.79194	11/9/1961
8045	SCOTIA	133.0	40.48333	–124.10389	1/9/1931
8135	SHASTA DAM	1,075.0	40.71417	–122.41611	7/1/1948
8163	SHELTER COVE AV	246.0	40.03306	–124.07278	9/1/1974
8490	STANDISH HICKEY ST PK	850.0	39.88028	–123.72639	5/1/1959
9026	TRINITY RIVER HATCHERY	1,860.0	40.72639	122.79472	8/1/1974
9053	TULELAKE	4,035.0	41.96000	–121.47444	1/1/1932
9351	VINTON	4,950.0	39.80556	–120.18583	3/1/1950
9390	VOLTA POWER HOUSE	2,220.0	40.45694	–121.86556	7/1/1948
9490	WEAVERVILLE	2,040.0	40.73500	–122.93917	7/1/1948
9621	WHISKEYTOWN RESERVOIR	1,295.0	40.61167	–122.52806	4/16/1960
9694	WILLOW CREEK 1 NW	461.0	40.94667	–123.63667	9/28/1968
9866	YREKA	2,625.0	41.70361	–122.64083	7/1/1948
Oregon					
36	ADEL	4,583.0	42.17611	–119.89611	3/7/1956
217	APPLEGATE	1,282.0	42.24500	–123.17472	1/1/1979
304	ASHLAND	1,746.0	42.21278	–122.71444	7/1/1948
856	BLY 4 SE	4,560.0	42.36833	–120.96528	2/1/2000
1055	BROOKINGS 2 SE	46.0	42.02833	–124.24528	1/1/1931
1149	BUNCOM 1 NNE	1,949.0	42.19306	–122.99889	8/1/1948
1448	CAVE JUNCTION 1 WNW	1,280.0	42.17694	–123.67528	3/9/1962
1574	CHILOQUIN 7 NW	4155.0	42.65111	–121.94806	8/1/1980
3356	GOLD BEACH RANGER STN	50.0	42.40361	–124.42417	7/1/1948
3509	GREEN SPRINGS POWER PLA	2,435.0	42.12583	–122.54500	9/21/1960
4060	HOWARD PRAIRIE DAM	4,567.0	42.22917	–122.38139	9/21/1960
4133	ILLAHE	348.0	42.62861	–124.05750	7/1/1948
4403	KENO	4,116.0	42.12972	–121.92972	7/1/1948
4511	KLAMATH FALLS AG STA	4,092.0	42.16444	–121.75472	9/1/1949
4634	LAKE CREEK 2 S	1,865.0	42.39028	–122.62583	1/22/1955
4670	LAKEVIEW 2 NNW	4,778.0	42.21389	–120.36361	1/1/1928
5055	LOST CREEK DAM	1,580.0	42.67222	–122.67500	6/1/1970
5174	MALIN 5 E	4,627.0	42.00778	–121.31861	11/1/1968
5424	MEDFORD EXPERIMENT STN	1,457.0	42.29611	–122.87000	9/1/1937
5429	MEDFORD WSO AP	1,300.0	42.38917	–122.87139	1/1/1928
6426	PAISLEY	4,360.0	42.69222	–120.54028	7/1/1948
7391	RUCH	1,550.0	42.22306	–123.04722	4/1/1963
7668	SELMA 4 E	1,460.0	42.27528	–123.52806	2/1/1998
7698	SEXTON SUMMIT	3,832.0	42.60028	–123.36417	7/1/1948
8812	VALLEY FALLS	4,325.0	42.48444	–120.28222	11/1/1948
9390	WILLIAMS 1 NW	1,450.0	42.22833	–123.28583	12/13/1900

Table A3-2. National Climatic Data Center (NCDC) surface airways stations in or around the Lower Klamath River Basin, California.

[When station data collection formats change, the station records are closed and new records begin. See figure 14 for locations of stations. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

State	Station name	Elevation (meters)	Latitude	Longitude	Period of record	
					Beginning date	Ending date
Stations with wind data						
California	MOUNT SHASTA	3,535	41.33250	−122.33278	4/1/1948	12/31/1963
California	MOUNT SHASTA	3,535	41.33250	−122.33278	1/1/1964	9/13/1985
California	RED BLUFF MUNICIPAL ARP	353	40.15194	−122.25361	1/1/1948	12/31/1963
California	RED BLUFF MUNICIPAL ARP	353	40.15194	−122.25361	1/1/1964	8/24/1986
California	RED BLUFF MUNICIPAL ARP	353	40.15194	−122.25361	3/1/1999	12/31/2003
Oregon	MEDFORD ROGUE VALLEY IN	1,300	42.38917	−122.87139	1/1/1948	12/31/1963
Oregon	MEDFORD ROGUE VALLEY IN	1,300	42.38917	−122.87139	1/1/1964	12/31/1997
Oregon	MEDFORD ROGUE VALLEY IN	1,300	42.38917	−122.87139	1/1/1998	12/31/2003
Oregon	SEXTON SUMMIT	3,832	42.60028	−123.36417	1/1/1948	12/31/1963
Oregon	SEXTON SUMMIT	3,832	42.60028	−123.36417	1/1/1964	12/31/1988
Oregon	SEXTON SUMMIT	3,832	42.60028	−123.36417	3/1/1999	12/31/2003
California	REDDING MUNICIPAL ARPT	497	40.51750	−122.29861	9/1/1986	6/30/1996
California	REDDING MUNICIPAL ARPT	497	40.51750	−122.29861	7/1/1996	12/31/2003
California	ARCATA EUREKA ARCATA AP	200	40.97806	−124.10861	12/1/1949	12/31/1963
California	ARCATA EUREKA ARCATA AP	200	40.97806	−124.10861	1/1/1964	1/31/2003
California	ARCATA EUREKA ARCATA AP	200	40.97806	−124.10861	2/1/2001	8/31/2003
Stations with cloudiness data						
California	ARCATA EUREKA ARCATA AP	200	40.97806	−124.10861	7/1/1996	2/1/2003
Oregon	MEDFORD ROGUE VALLEY IN	1,300	42.38917	−122.87139	3/1/1997	12/31/1997
Stations with dew point temperature data						
California	RED BLUFF MUNICIPAL ARP	353	40.15194	−122.25361	3/1/1999	12/31/2003
California	REDDING MUNICIPAL ARPT	497	40.51750	−122.29861	7/1/1996	12/31/2003
California	ARCATA EUREKA ARCATA AP	200	40.97806	−124.10861	7/1/1996	8/31/2003
Oregon	MEDFORD ROGUE VALLEY IN	1,300	42.38917	−122.87139	7/1/1996	12/31/2003
Oregon	SEXTON SUMMIT	3,832	42.60028	−123.36417	3/1/1999	12/31/2003
Stations with relative humidity data						
California	RED BLUFF MUNICIPAL ARP	353	40.15194	−122.25361	1/1/1948	12/31/2003
California	REDDING MUNICIPAL ARPT	497	40.51750	−122.29861	9/1/1986	12/31/2003
California	ARCATA EUREKA ARCATA AP	200	40.97806	−124.10861	12/1/1949	8/31/2003
California	MOUNT SHASTA	3,535	41.33250	−122.33278	4/1/1948	9/13/1985
Oregon	MEDFORD ROGUE VALLEY IN	1,300	42.38917	−122.87139	1/1/1948	12/31/2003
Oregon	SEXTON SUMMIT	3,832	42.60028	−123.36417	1/1/1948	12/31/2003

Table A3-3. Inactive National Climatic Data Center (NCDC) stations in or around the Lower Klamath River Basin, California.

[Stations measure precipitation, snow, and maximum and minimum air temperature. See figure 14 for locations of stations. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Station ID	Station name	Elevation (meters)	Latitude	Longitude	Period of record	
					Beginning date	Ending date
California						
88	ALDERPOINT	459	40.18333	−123.61667	8/1/1948	5/31/1980
615	BEEGUM	1,289	40.35000	−122.86667	7/1/1948	7/9/1958
721	BETTS RANCH	2,651	41.81667	−122.50000	7/2/1948	1/31/1950
731	BIEBER	4,125	41.12083	−121.13472	7/1/1948	9/30/1951
870	BLACKS MOUNTAIN RANCH	5,604	40.73333	−121.25000	7/1/1948	7/31/1960
903	BLUE LAKE REDWOOD CREEK	981	40.91667	−123.81667	2/1/1956	8/31/1965
1080	BRIDGEVILLE 4 NNW	2,100	40.51944	−123.82167	6/1/1954	1/31/2001
1082	BRIDGEVILLE HANSON RANCH	2,602	40.55000	−123.81667	7/1/1948	10/31/1952
1161	BUCKS LAKE	5,203	39.90000	−121.20000	7/1/1948	12/31/1970
1215	BURNT RANCH 1 S	2,150	40.80000	−123.46667	11/1/1959	6/30/1989
1233	BUTLER VALLEY RANCH	420	40.76667	−123.90000	5/20/1970	4/30/1975
1420	CAMP LASSEN	4,304	40.10000	−121.53333	11/1/1948	11/15/1949
1475	CANBY 11SW	4,505	41.36667	−121.05000	5/1/1959	4/30/1971
1522	CARIBOU PH	2,992	40.08333	−121.15000	6/1/1959	6/30/1977
1607	CECILVILLE 5 SE	3,002	41.08333	−123.05000	6/1/1950	10/31/1954
1731	CHINA FLAT	600	40.86667	−123.58333	7/1/1948	6/30/1955
1799	CLEAR CREEK	981	41.71667	−123.45000	9/2/1960	6/30/1977
1805	CLEAR LAKE DAM	4,573	41.93333	−121.06667	1/1/1950	9/30/1954
1890	COHASSET	2,523	39.91667	−121.73333	11/2/1960	8/31/1961
1891	COHASSET 1 NNE	3,192	39.93333	−121.71667	1/1/1962	6/30/1977
1953	COLYEAR SPRINGS	3,304	40.05000	−122.68333	9/1/1960	3/31/1962
2027	CORNING HOUGHTON RANCH	487	39.90000	−122.35000	7/1/1948	5/31/1984
2084	COVELO EEL RIVER RS	1,514	39.82611	−123.08500	7/1/1948	9/30/1951
2148	CRESCENT CITY 7 ENE	120	41.79417	−124.08500	12/4/1951	6/30/2001
2149	CRESCENT CITY CAA AIRPO	56	41.78333	−124.23333	4/1/1950	12/31/1954
2150	CRESCENT CITY MNTC STN	49	41.76667	−124.20000	7/1/1948	9/30/1951
2218	CUMMINGS	1,289	39.83333	−123.63333	9/1/1949	6/30/1981
2269	DANA 2 SE	3,323	41.10000	−121.51667	5/1/1959	5/31/1976
2296	DAVIS CREEK	4,754	41.73333	−120.36667	5/1/1959	11/30/1969
2306	DAY	3,650	41.21222	−121.37417	7/1/1948	9/30/1951
2379	DELTA	1,171	40.95000	−122.41667	11/1/1975	5/31/1978
2572	DUNSMUIR	2,421	41.21667	−122.26667	7/1/1948	6/30/1978
2595	EAGLE LAKE STONE RANCH	5,135	40.50000	−120.65000	5/1/1959	3/31/1961
2749	ELK VALLEY	1,705	41.98750	−123.71750	7/1/1948	4/18/1976
2899	ETNA	2,950	41.45556	−122.89833	7/1/1948	9/30/1951
3020	FERGUSON RANCH	801	40.35000	−122.45000	1/1/1952	7/31/1967
3025	FERNDALE 8 SSW	1,450	40.50000	−124.33333	11/23/1959	12/31/1971
3030	FERNDALE 2 NW	10	40.60000	−124.28333	3/17/1963	9/30/1973
3087	FLEMING FISH & GAME	4,003	40.36667	−120.31667	6/1/1959	6/30/1977
3130	FOREST GLEN	2,339	40.38333	−123.33333	7/1/1948	7/18/1985
3151	FORKS OF SALMON	1,240	41.26667	−123.31667	9/1/1960	5/31/1972
3173	FORT DICK	46	41.86667	−124.15000	11/1/1951	12/31/1988
3176	FORT JONES 6 ESE	3,323	41.58333	−122.71667	7/1/1948	9/30/1951
3204	FORWARD MILL	3,304	40.43333	−121.73333	1/1/1952	5/31/1958
3242	FRENCH GULCH	1,102	40.70000	−122.63333	1/1/1952	11/30/1982

Table A3–3. Inactive National Climatic Data Center (NCDC) stations in or around the Lower Klamath River Basin, California—***Continued***.

[Stations measure precipitation, snow, and maximum and minimum air temperature. See figure 14 for locations of stations. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Station ID	Station name	Elevation (meters)	Latitude	Longitude	Period of record	
					Beginning date	Ending date
3320	GARBERVILLE	340	40.10000	−123.80000	11/1/1948	3/31/1985
3405	GIBSON HIGHWAY MNT STN	1,650	41.01667	−122.40000	4/1/1965	6/30/1977
3510	GOOSE LAKE WEST	4,892	41.86667	−120.50000	5/1/1959	12/31/1962
3564	GRASS LAKE HWY MNTC ST	5,092	41.63333	−122.20000	9/1/1960	11/30/1967
3621	GREENVILLE R S	3,560	40.14056	−120.94278	7/1/1948	12/21/2001
3647	GRIZZLY CREEK STATE PAR	410	40.48611	−123.90917	12/1/1979	9/30/2001
3817	HATCHET MOUNTAIN MNTNC	4,373	40.85000	−121.76667	2/19/1957	6/30/1960
3821	HAT CREEK EXPERIMENT ST	3,353	40.80000	−121.50000	7/1/1948	9/30/1951
3987	HILTS SLASH DISPOSAL	2,904	42.00000	−122.63333	7/1/1948	12/31/1984
4074	HONEYDEW 1 SW	370	40.23750	−124.13222	11/1/1959	9/30/1972
4082	HOOPA	361	41.05000	−123.66667	7/1/1948	12/31/1983
4084	HOOPA 2 SE	322	41.03333	−123.65000	11/1/1954	10/31/1967
4089	HOOPA	333	41.04833	−123.67778	1/1/1984	5/31/1987
4166	HUNTER DISTR GRAVES RC	771	40.18333	−122.55000	9/1/1960	9/30/1970
4191	HYAMPOM	1,275	40.61639	−123.45667	7/1/1948	10/26/2001
4202	IDLEWILD HWY MNTNC STN	1,250	41.90000	−123.76667	5/1/1959	6/30/1977
4255	INDIAN WELL HQS	4,774	41.71667	−121.50000	8/1/1948	12/31/1949
4274	INSKIP INN	4,823	40.00000	−121.53333	8/17/1948	4/30/1954
4544	KILARC PH	2,651	40.68333	−121.86667	5/1/1959	6/30/1977
4586	KNEELAND 2	2,661	40.66667	−123.91667	7/2/1948	9/30/1951
4602	KORBEL	151	40.86667	−123.95000	11/1/1959	12/31/1974
4675	LAKE CITY	4,613	41.63333	−120.21667	7/1/1948	10/11/1960
4690	LAKE MOUNTAIN	3,163	40.01667	−123.40000	7/1/1948	9/30/1951
4709	LAKESHORE 2	1,079	40.86667	−122.38333	7/1/1948	7/31/1972
4988	LITTLE VALLEY	4,173	40.88333	−121.18333	10/1/1960	1/31/1974
5093	LOOKOUT 3 WSW	4,183	41.20000	−121.20000	5/1/1963	5/31/1977
5131	LOS MOLINOS	220	40.01667	−122.10000	7/1/1948	11/30/1948
5231	MADELINE	5,325	41.01667	−120.50000	6/1/1959	2/28/1975
5244	MAD RIVER RANGER STN	2,675	40.45000	−123.53333	7/1/1948	9/30/1988
5623	MILFORD LAUFMAN RS	4,860	40.14139	−120.35333	7/1/1948	9/30/1951
5679	MINERAL	4,875	40.34583	−121.60917	7/1/1948	11/30/2001
5713	MIRANDA SPENGLER RANCH	361	40.20000	−123.76667	7/1/1948	8/31/1966
5785	MONTAGUE 5 NE	2,635	41.78056	−122.47167	7/1/1948	7/17/1952
5809	MONTGOMERY CREEK	2,103	40.81667	−121.93333	7/1/1948	9/30/1951
5940	MOUNT HEBRON 11 ESE	4,383	41.73333	−121.80000	5/1/1952	12/31/1960
5980	MOUNT SHASTA SKI BOWL	7,844	41.36667	−122.20000	12/11/1958	8/31/1964
6173	NEW PINE CREEK 2 E	5,292	41.98333	−120.26667	10/1/1960	5/31/1961
6329	OAK KNOLL R S NO 2	1,700	41.85000	−122.88333	1/1/1972	1/31/1998
6455	ONO	978	40.48333	−122.61667	1/3/1952	3/31/1984
6499	ORICK 10 SE	2,480	41.18333	−123.91667	11/1/1959	5/31/1963
6726	PASKENTA RANGER STN	755	39.88556	−122.54333	7/3/1948	10/31/2001
6761	PAYNES CREEK	1,841	40.33333	−121.90000	1/1/1952	3/31/1984
6944	PIT RIVER P H 1	2,880	41.00000	−121.50000	9/1/1972	8/31/1996
6975	PLATINA	2,260	40.36667	−122.88333	3/24/1962	4/30/1974
7088	PORTOLA 2	4,833	39.80000	−120.48333	7/1/1948	9/30/1951
7106	POTTERS SAWMILL	4,213	41.23333	−121.21667	5/1/1961	11/30/1962

Table A3–3. Inactive National Climatic Data Center (NCDC) stations in or around the Lower Klamath River Basin, California—***Continued***.

[Stations measure precipitation, snow, and maximum and minimum air temperature. See figure 14 for locations of stations. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Station ID	Station name	Elevation (meters)	Latitude	Longitude	Period of record: Beginning date	Period of record: Ending date
7197	QUINCY USFS HELIPORT	3,652	39.98333	−120.95000	9/1/1979	3/31/1981
7290	RED BLUFF	287	40.18333	−122.23333	7/1/1948	12/31/1948
7294	RED BLUFF NO 2	310	40.16333	−122.22806	2/1/1998	6/30/1999
7296	REDDING FIRE STN 2	581	40.58333	−122.40000	1/11/1931	4/30/1979
7300	REDDING FIRE STN 4	470	40.55000	−122.38333	5/1/1979	4/30/1987
7580	ROUND MOUNTAIN	2,103	40.81667	−121.93333	1/1/1952	6/30/1970
7581	ROUND MOUNTAIN	2,100	40.79556	−121.93500	7/1/1970	8/31/2000
7698	SALYER RANGER STN	620	40.88333	−123.58333	7/1/1948	11/30/1968
8025	SAWYERS BAR RS	2,169	41.30111	−123.13306	7/1/1948	4/30/1988
8074	SECRET VALLEY	4,442	40.50000	−120.26667	9/1/1962	2/28/1977
8075	SECRET VALLEY M S	4,662	40.66667	−120.25000	5/1/1959	3/31/1981
8162	SHELTER COVE	110	40.03333	−124.06667	11/11/1959	4/30/1974
8175	SHINGLETOWN 2 E	3,556	40.50000	−121.85000	11/1/1958	3/31/1984
8292	SLOAT	4,124	39.86667	−120.73333	7/1/1957	5/31/1958
8311	SMITH RIVER 3 WNW	30	41.95000	−124.20000	10/1/1956	11/30/1958
8346	SOMESBAR 1 W	522	41.38333	−123.48333	11/1/1954	10/31/1967
8472	SQUAW CREEK GS	1,302	40.88333	−122.10000	7/1/1948	1/31/1949
8487	STANDISH 1 E	4,032	40.36667	−120.40000	5/1/1961	4/30/1973
8521	STEELE SWAMP	4,554	41.86667	−120.95000	7/1/1948	4/30/1950
8544	STIRLING CITY R S	3520	39.90417	−121.52806	7/1/1948	8/31/1966
8701	SUSANVILLE	4,173	40.41667	−120.65000	6/17/1952	6/30/1964
8702	SUSANVILLE 2 SW	4,184	40.41667	−120.66306	1/10/1931	12/29/2001
8705	SUSANVILLE STATE RNG	4,193	40.40000	−120.66667	6/1/1949	9/30/1951
8860	TENNANT	4,754	41.58333	−121.91667	5/1/1952	8/31/1957
8873	TERMO 1 E	5,300	40.86667	−120.43333	8/1/1948	3/31/1999
8875	TERMO BRIN MARR	5,364	40.91667	−120.26667	3/1/1960	6/30/1963
9023	TRINITY CENTER RANGER S	2,303	41.00000	−122.68333	7/1/1948	9/30/1951
9024	TRINITY DAM VISTA POINT	2,503	40.80000	−122.76667	7/1/1959	12/31/1973
9056	TULELAKE 5 WSW	4,032	41.91667	−121.56667	7/1/1948	10/31/1957
9057	TULELAKE INSPECTION STN	4,413	41.60000	−121.20000	5/1/1959	7/31/1959
9083	TURNTABLE CREEK	1,070	40.76667	−122.30000	7/1/1948	10/31/1969
9177	UPPER MATTOLE	255	40.25000	−124.18333	7/1/1948	4/30/1986
9386	VOLLMERS	1,342	40.95000	−122.45000	7/1/1948	10/31/1975
9498	WEED	3,514	41.43333	−122.38333	7/1/1948	2/28/1957
9499	WEED FIRE DEPT	3,589	41.43333	−122.38333	4/18/1957	7/31/1989
9526	WENDEL 10 SE	4,042	40.26667	−120.06667	5/1/1959	6/30/1977
9540	WEST BRANCH	3,222	39.93333	−121.53333	7/1/1948	9/30/1952
9599	WESTWOOD	5,072	40.30000	−121.00000	7/1/1948	4/12/1953
9600	WESTWOOD 3 WSW	4,993	40.30000	−121.05000	4/16/1953	6/30/1957
9612	WHEELER	49	39.88333	−123.91667	1/1/1950	10/31/1959
9620	WHISKEYTOWN	1,089	40.63333	−122.55000	7/1/1959	4/14/1960
9691	WILLOW CREEK RANCH	5,203	41.83333	−120.75000	7/1/1964	8/31/1966
9867	YREKA RANGER STN	2,631	41.71667	−122.63333	5/21/1957	5/21/1957

Table A3–3. Inactive National Climatic Data Center (NCDC) stations in or around the Lower Klamath River Basin, California—***Continued***.

[Stations measure precipitation, snow, and maximum and minimum air temperature. See figure 14 for locations of stations. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Station ID	Station name	Elevation (meters)	Latitude	Longitude	Period of record	
					Beginning date	Ending date
Nevada						
7261	SAND PASS	3,904	40.31667	−119.80000	1/1/1928	9/30/1971
8810	VYA	5,663	41.58333	−119.91667	9/1/1959	6/30/1980
Oregon						
853	BLY RANGER STN	4,390	42.40000	−121.04583	2/1/1950	9/30/1951
854	BLY 3 NW	4,378	42.43333	−121.10000	4/1/1988	9/30/1997
1207	BUTTE FALLS 1 SE	2,500	42.53778	−122.55250	2/1/1950	3/31/1986
1571	CHILOQUIN 1 E	4,193	42.58333	−121.86667	7/1/1948	12/31/1979
1826	COPPER	1,903	42.03333	−123.13333	8/1/1948	9/29/1951
2018	DAIRY 4 NNE YONNA	4,154	42.26667	−121.46667	3/1/1949	2/28/1953
2928	FISH LAKE	4,642	42.38333	−122.35000	1/2/1933	11/10/1956
3022	FORT KLAMATH 7 SW	4,163	42.61667	−122.08333	3/3/1953	8/31/1965
3232	GERBER DAM	4,850	42.20500	−121.13139	7/1/1948	10/26/1956
3445	GRANTS PASS	930	42.42444	−123.32361	1/2/1928	11/30/2001
4135	ILLAHE 2 N	488	42.65000	−124.05000	3/6/1963	5/27/1967
4216	JACKSONVILLE	1,640	42.30000	−122.98333	7/2/1948	11/30/1948
4420	KERBY	1,270	42.21667	−123.65000	2/1/1950	9/30/1951
4506	KLAMATH FALLS 2 SSW	4,098	42.20083	−121.78139	1/1/1928	5/31/2001
4633	LAKE CREEK 3 NE	2,400	42.45000	−122.56667	3/1/1978	11/30/1995
4635	LAKE CREEK 6 SE	1,752	42.36667	−122.53333	7/1/1948	3/31/1953
4636	LAKE CREEK 1 E	1,550	42.42583	−122.62306	1/1/1996	5/31/1998
5505	MERRILL 2 NW	4,081	42.05000	−121.63333	6/1/1949	3/31/1968
5656	MODOC ORCHARD	1,220	42.45000	−122.88333	7/1/1948	4/30/1966
6027	NEW PINE CREEK	4,882	42.00000	−120.30000	11/10/1961	6/30/1972
6717	PLUSH 1 N	4,514	42.41667	−119.90000	7/2/1948	8/31/1961
7285	ROCKY POINT 3 S	4,154	42.43333	−122.08333	10/19/1966	10/31/1975
7354	ROUND GROVE	4,888	42.34139	−120.88944	7/1/1948	12/22/1998
7670	SELMA 4 W	1,503	42.28333	−123.70000	11/12/1960	5/31/1961
7850	SISKIYOU SUMMIT	4,485	42.08333	−122.56667	7/1/1948	9/18/1948
8007	SPRAGUE RIVER 2 SE	4,483	42.43056	−121.48917	5/28/1953	2/28/2001
8071	STAR RANGER STN	1,581	42.15000	−123.06667	7/1/1948	7/31/1948
8338	TALENT	1,552	42.25000	−122.80000	7/1/1948	11/10/1960
8818	VALLEY FALLS 3 SSE	4,583	42.45000	−120.25000	4/8/1965	2/28/1983
9604	YONNA	4,183	42.30000	−121.48333	7/1/1948	1/31/1949

Table A3-4. California Irrigation Management Information System (CIMIS) reference evapotranspiration stations locations within or around the Lower Klamath River Basin, California.

[See figure 14 for locations of stations. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Station name	Station Id	County	Elevation (meters)	Latitude	Longitude
Gerber	8	Tehama	250	40.0450	−122.1640
McArthur	43	Shasta	3,310	41.0650	−121.4540
MacDoel	46	Siskiyou	4,254	41.7920	−122.0640
Tulelake	48	Siskiyou	4,042	42.0030	−121.4270
Buntingville	57	Lassen	4,005	40.2900	−120.4340
Alturas	90	Modoc	4,405	41.4330	−120.4790
Tulelake FS	91	Siskiyou	4,035	41.9590	−121.4710
Gerber Dryland	108	Tehama	245	40.0430	−122.1620

Table A3-5. National Renewable Energy Laboratory (NREL) weather stations in or around the Lower Klamath River Basin, California.

[Stations measure hourly solar radiation, dewpoint temperature, air temperature, and cloud cover, and monthly ozone, precipitable water, and atmospheric turbidity. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

Station	Latitude	Longitude	Period of record	
			Beginning date	Ending date
Arcata	40.9833	−124.1000	1/1/1960	12/31/1990
Medford	42.3667	−122.8667	1/1/1960	12/31/1990

Table A3-6. Remote Automated Weather Station (RAWS) locations in and around the Lower Klamath River Basin, California.

State	Station name	Latitude	Longitude
California	COOSKIE M	40.25694	–124.26611
California	GASQUET	41.84583	–123.97917
California	MAPLE CRE	40.79639	–123.93667
California	SCHOOL HO	41.13833	–123.90556
California	YUROK	41.28972	–123.85750
California	EEL RIVER	40.13833	–123.82361
California	SHIP MTN	41.73583	–123.79167
California	HOOPAH	41.04778	–123.67139
California	BIG HILL	41.09750	–123.63583
California	CRAZY PEA	41.99194	–123.60361
California	ALDER POI	40.18667	–123.59028
California	MAD RIVER	40.46333	–123.52389
California	SRF01 POR	40.45222	–123.51778
California	SOMES BAR	41.39000	–123.49583
California	UNDERWOOD	40.72194	–123.49528
California	SLATER BU	41.85861	–123.35250
California	FRIEND MT	40.50500	–123.34167
California	BIG BAR	40.74333	–123.25000
California	BLUE RIDG	41.27333	–123.19000
California	BLUE RIDG	41.26944	–123.18750
California	BACKBONE	40.88917	–123.14222
California	SAWYERS B	41.30028	–123.13222
California	EEL RIVER	39.82528	–123.08250
California	YOLLA BOL	40.33833	–123.06500
California	COLLINS B	41.77500	–122.95028
California	MENDOCINO	39.80750	–122.94500
California	WEAVERVIL	40.73500	–122.94333
California	QUARTZ HI	41.59972	–122.93278
California	PATTYMOCU	40.28833	–122.87167
California	KNF91 POR	41.60000	–122.85556
California	OAK KNOLL	41.83861	–122.84889
California	ARBUCKLE	40.39833	–122.83333
California	ARBUCKLE	40.39833	–122.83333
California	TRINITY C	40.67889	–122.83306
California	LOWDEN	40.68944	–122.83139
California	CALLAHAN	41.30750	–122.79583
California	SCORPION	41.11167	–122.69667
California	EAGLE PEA	39.92778	–122.65694
California	R501 PORT	40.90222	–122.65139
California	THOMES CR	39.86444	–122.60972
California	OAK BOTTO	40.65056	–122.60556
California	BRAZIE RA	41.68528	–122.59417
California	WEED AIRP	41.47889	–122.45389
California	SUGARLOAF	40.91667	–122.43833
California	SIMS	41.07500	–122.37333

Table A3-6. Remote Automated Weather Station (RAWS) locations in and around the Lower Klamath River Basin, California—***Continued***.

[Stations measure hourly air temperature, dewpoint temperature, barometric pressure, precipitation, wind speed, and wind direction. See figure 14 for locations of stations. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

State	Station name	Latitude	Longitude
California	SIMS TEST	41.08083	–122.34694
California	MT. SHAST	41.31556	–122.31556
California	REDDING	40.51583	–122.29056
California	CORNING	39.93889	–122.16972
California	JUANITA L	41.78611	–122.00556
California	OAK MOUNT	41.00639	–121.98333
California	ASH CREEK	41.27694	–121.97944
California	WHITMORE	40.62028	–121.90389
California	VAN BREMM	41.64306	–121.79389
California	COHASSET	39.87000	–121.76917
California	LASSEN LO	40.34417	–121.71361
California	LOWER KLA	41.99917	–121.70028
California	zz LOWER	41.99889	–121.70000
California	SOLDIER M	40.92583	–121.58556
California	CARPENTER	40.06861	–121.58250
California	MANZANITA	40.54000	–121.58028
California	INDIAN WE	41.74167	–121.53833
California	ROUND MOU	41.42722	–121.46389
California	SUMMIT	40.50167	–121.42250
California	LNF01 POR	40.69500	–121.35861
California	MDF04 POR	41.62778	–121.29833
California	TIMBER MO	41.62944	–121.29806
California	LADDER BU	40.80722	–121.29667
California	LNF02 POR	40.28333	–121.20000
California	LNF03 POR	40.28333	–121.20000
California	BLACKS MT	40.73139	–121.11833
California	CHESTER	40.28972	–121.08528
California	BOGARD R.	40.59806	–121.08306
California	MDF06 POR	41.62500	–121.06778
California	PNF21 POR	39.95556	–120.99222
California	PNF22 POR	39.97333	–120.94194
California	QUINCY RD	39.97333	–120.94194
California	CASHMAN	40.00167	–120.91500
California	WESTWOOD	40.30667	–120.90000
California	GORDON	40.75861	–120.89611
California	LNF05 POR	40.75861	–120.89611
California	CANBY	41.43417	–120.86778
California	RUSH CREE	41.29444	–120.86389
California	MDF03 POR	41.82778	–120.86389
California	GRASSHOPP	40.78278	–120.78167
California	ASH VALLE	41.05194	–120.68611
California	PNF14 POR	39.83333	–120.68056
California	DEVILS GA	41.53000	–120.67139
California	PIERCE	40.24611	–120.64222

Table A3-6. Remote Automated Weather Station (RAWS) locations in and around the Lower Klamath River Basin, California—***Continued***.

[Stations measure hourly air temperature, dewpoint temperature, barometric pressure, precipitation, wind speed, and wind direction. See figure 14 for locations of stations. Latitude and longitude in decimal degrees. Horizontal coordinate information is referenced to the North American Datum of 1983, NAD 83]

State	Station name	Latitude	Longitude
California	PNF11 POR	39.93417	−120.55111
California	HORSE LAK	40.63056	−120.50278
California	PNF12 POR	40.19306	−120.48778
California	JUNIPER C	41.33222	−120.47250
California	PNF13 POR	39.97611	−120.35611
California	LAUFMAN	40.14167	−120.35333
California	BLUE DOOR	41.05472	−120.33750
California	RAVENDALE	40.73083	−120.31639
California	BULL FLAT	40.48083	−120.11389
California	DOYLE	40.02222	−120.10556
Nevada	BARREL SP	41.91111	−119.93889
Oregon	RED MOUND	42.12333	−124.30056
Oregon	LAWSON	42.41667	−124.13333
Oregon	QUAIL PRA	42.21667	−124.03333
Oregon	BALD KNOB	42.70000	−124.03333
Oregon	AGNESS	42.33028	−124.02222
Oregon	ILLINOIS	42.11667	−123.66667
Oregon	ONION MOU	42.30000	−123.40000
Oregon	MERLIN SE	42.49472	−123.39722
Oregon	PROVOLT S	42.28972	−123.23028
Oregon	EVANS CRE	42.59778	−123.10333
Oregon	STAR	42.15000	−123.06667
Oregon	SQUAW PEA	42.06667	−123.01667
Oregon	BUCKHORN	42.11972	−122.56333
Oregon	ZIM	42.68889	−122.46833
Oregon	DEAD INDI	42.28333	−122.31667
Oregon	PARKER MO	42.10583	−122.27806
Oregon	SELDOM CR	42.40750	−122.19139
Oregon	CHILOQUIN	42.57694	−121.89361
Oregon	CALIMUS	42.63139	−121.55972
Oregon	GERBER RE	42.20556	−121.13889
Oregon	STRAWBERR	42.18944	−120.84639
Oregon	COFFEE PO	42.55000	−120.62000
Oregon	SUMMIT	42.19889	−120.24556

SHASTA RIVER FLOW AND TEMPERATURE MODELING PROJECT

Sponsored by the
Shasta Valley Resource Conservations District
with funding from the
California Department of Fish and Game

Watercourse Engineering, Inc.
1732 Jefferson St.
Napa, CA 94559
April, 2003

Watercourse Engineering Inc.

SHASTA RIVER FLOW AND TEMPERATURE MODELING PROJECT

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Prepared by
Michael Deas
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April, 2003

Watercourse Engineering Inc.

Executive Summary

The Shasta River basin, located in central Siskiyou County, is 800 square miles with a mean annual unimpaired runoff of approximately 162,300 acre-feet. The river originates in the Scott Mountains in the vicinity of Mt. Eddy and flows north and north-westward for roughly seventy miles before discharging into the Klamath River. Numerous accretions from tributaries, springs, and agricultural diversion and return flows contribute to a complex flow regime both seasonally and over the river length. The river is impounded by Dwinnell Dam at river mile 36.4.

Historically the Shasta River supported fall and spring-run chinook salmon, coho salmon and steelhead trout. According to annual spawning counts at the Shasta River weir, the 1931 run of over 80,000 chinook salmon had dropped to 553 fish in 1990 (DFG, 1991). The Department of Water Resources (DWR, 2001) has identified physical barriers (dams, weirs), flow alterations due to water management practices, and water quality issues such as temperature and contaminant concentration as potential problems associated with the ability of salmon to spawn in this basin. The DFG and the United States Fish and Wildlife Service have determined that flow and temperature are the critical water quality parameters for restoration of this system (DWR, 2001).

This modeling project, undertaken through the Great Northern Corporation with funding provided by the Klamath River Basin Fisheries Task Force and California Department of Fish and Game, is the second component of a two-part study to investigate the effects of management actions on these critical water quality parameters. The first part of this study included extensive efforts to collect the necessary field observations of flow, temperature, riparian vegetation, and other data to support analysis and modeling. Data collection was funded by the Klamath River Basin Fisheries Task Force, and administered by USFWS. Cost sharing between USFWS and DFG made this study possible.

The TVA hydrodynamic and water quality model ADYN and RQUAL were selected for the project. RQUAL was used to simulate temperature and was modified to accommodate spatially diverse riparian vegetation location, height and shade providing characteristics. As noted above, extensive field monitoring efforts were completed to support the modeling effort.

Critical components of the study include model implementation and testing: formulating input data, model parameters, and testing the sensitivity of model results to various input parameters and data values. The sensitivity analysis is a useful introduction to several model variables that are altered in the model application section of the report. Model calibration and validation was completed over week-long periods using multiple locations along the river.

Model application was completed to assess several alternative conditions, including the

thermal impacts of variable flow rates, pulse flow operations, tailwater return management, and various riparian vegetation shading conditions. Several hundred simulations were completed to define these scenarios completely. Results are presented in graphical and tabular form. The principal findings of the studies are identified below.

- Advection, the physical transport of thermal energy downstream is an important consideration in the Shasta River. The transport of water from upstream

- Additional volume of water generally translates to a reduction in the diurnal range in temperatures, i.e., lower daily maximum and higher daily minimum temperatures. Mean daily temperature may show some reduction over longer reaches of river due to increased flows, especially if upstream sources are cooler.

- Identifying the reach or reaches with the largest heat gain (e.g. °C per mile) provides insight into the locations where the greatest opportunity for decreasing mean daily temperature through increased flow exists.

- Pulse flows affect the water temperature through increase stream volume and reduction in transit time. The model effectively routed these transient flow conditions through the system. However, the thermal benefit is uncertain, primarily due to a lack of biological data relating changes in thermal regime to outmigrating salmonids

- Water temperature conditions should be monitored prior to and during the pulse flow to ensure water temperature conditions are conducive to the operation. For example if releases from Lake Shastina are inordinately warm, it may be more beneficial to not use that water in the pulse operation.

- Sequential pulse flow operations and simultaneous pulse flow operations showed modest differences in thermal regime. There are probably more pressing issues associated with the pulse flow than timing of diversions are shut down, such as meteorological conditions at the time of the pulse, the available flow, the time that all diversions are shut down in the simultaneous operation (morning better than evening), and ramping flows up and down in a manner that is beneficial to the objective of encouraging juvenile fish to move out.

- The amount, distribution, location, and temperature of return flow can impact the thermal regime of the river. The impacts for a single reach may be modest. The impacts of a system wide program were not analyzed.
- Riparian vegetation shading can potentially reduce minimum, mean, and particularly maximum daily, temperatures over the distance of a single reach (five to seven miles).
- Where water temperatures were closer to equilibrium conditions (e.g., away from

cool spring inflow influences) riparian vegetation had a more noticeable affect. This does not discount the importance of riparian vegetation in cool water areas.

- In general, the reduction in water temperature from a restored riparian vegetation condition does not persist more than several miles downstream (applicable to conditions where downstream reaches are not restored).
- Time of year and solar altitude play a role in ability of riparian vegetation to reduce incoming solar radiation, thus affecting the thermal regime of the river.
- Riparian restoration efforts are long-term management approaches to moderating and/or reducing river temperatures. Model simulations can assist decision makers in management approaches to address potential spatial distribution of restoration, how long it may take to reach maturity and provide temperature control benefits, and what thermal relief intermediate conditions may provide.
- Herbaceous riparian vegetation (e.g., bulrush) can provide sufficient shade to affect water temperature if present in sufficient quantity (density and distribution) along the river bank.
- Riparian vegetation on small river systems such as the Shasta River plays an important role in reducing mean daily temperatures (as well as maximum and minimum). Further studies should be completed to determine the trade-off between flow volume, riparian shading, and return flow management for various reaches of the Shasta River to identify a "most favorable" combination of management actions to meet desired objectives.

The developed models, as well as supporting data, have provided constructive insight into flow, temperature, and riparian vegetation shading inter-relationships. Not only have potential effects been identified, but the potential magnitude of temperature changes associated with various management strategies have been identified for locations specific to the Shasta River. The principal recommendation is to build upon the findings herein and apply the model to a broader set of alternatives – possibly combinations of certain management strategies identified herein. Additional recommendations were identified and are outlined below.

- Identify funding sources to support additional collection of field data to refine the geometric representation of the flow and temperature models. Seek to collect data system wide.
- Complete a pilot study, for a representative reach or area to identify the various modes at which water may enter the river (e.g., groundwater, diffuse surface flow, localized inflow), quantity of inflow, and temperature associated with each type of source. These data can then be entered into the flow and temperature model to assess potential impacts of managing these various sources.
- Conduct a field study to quantify the role of bed conduction in the heat budget.

Identify several locations based primarily on substrate to conduct the tests. Use the results to test/calibrate the bed conduction logic included in the model, and complete a battery of tests to determine the potential role of bed conduction in the Shasta River.

- Conduct a riparian vegetation survey that includes woody vegetation, as well as herbaceous. Identify plant species, as well as conditions that provide additional benefit or dis-benefit to shading potential (e.g., narrow or wide river width, high banks (local topographic shading) or low banks.). Use this data to update, as necessary, the riparian vegetation within the model

- Using solar radiation equipment similar to that used in Abbott and Deas (2003), carry out measurements adjacent to the Shasta River at several locations. Alternatively, use a digital elevation model to approximate shade reduction potential.

- Using a portable meteorological station and conduct field studies at the various locations within the Shasta Valley over several weeks. Use the NOAA station at the Montague Grenada Airport and the CDF station at Brazie Ranch as controls.

- Add and maintain a seasonal flow monitoring station at Anderson Grade, Highway A-12, and a location upstream of A-12 to collect daily flow information to support modeling and other management activities.

- Add and maintain additional temperature monitoring locations, principally in the accretion reaches upstream of A-12. Hourly data would be necessary to support modeling and other management activities.

- Complete a test using the model to quantify numerical dispersion, if any. Document the findings and append to the modeling report.

Acknowledgements

This project was sponsored by the Shasta Valley Resources Conservation District and funded through a grant from the California Department of Fish and Game. Great Northern Corporation managed the project funding. This project is one component of a two part study. The field work to support the flow and temperature modeling effort addressed herein was funded through a separate grant provided by the Klamath River Basin Fisheries Task Force and administered by the United States Fish and Wildlife Service. This cooperative effort was paramount to the success of the project and we wish to acknowledge those staff at both the California Department of Fish and Game and United States Fish and Wildlife Service who made such arrangements possible.

Our most sincere acknowledgements go to the landowners who provided access to the river for field surveys and data collection. We also would like to thank all those who attended and participated in public meetings and workshops. There are a few people whom we wish to specifically acknowledge for their support and participation.

Jim Cook	Great Northern Corporation
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Jim Whelan	California Department of Fish and Game
Mark Gilpin	California Department of Fish and Game
Dave Webb	CRMP Coordinator
Dan Drake	University of California Extension
Jerry Boles and staff	California Department of Water Resources

As well as many others, without whom this project would not have been feasible.

Preface

This document summarizes the flow and temperature modeling component of a two year study on the Shasta River that was funded through a grant from the California Department of Fish and Game. During this period field data was collected (funded separately through a Klamath Basin Fisheries Task Force grant), and a model was selected, modified to represent riparian shading, and applied. Because the results of any study have the potential to shape local water resources management practices, the authors have attempted to complete the work in a responsible and professional fashion with sufficient documentation to clearly present assumptions, decision, sources of information, and other pertinent information.

As such, this document has sections that are fairly technical. This information is placed early in the report because, although potentially wearisome reading for some, it forms the basis for all model applications. Outlined herein are the contents of the report with some guidance to the reader, if he or she pleases, to read selected portions of the report that are deemed of most interest.

Chapter 1 provides a brief background to the project objective, namely, to formulate a flow and temperature model and employ that tool to ascertain flow and temperature relationships to aid in the management of the Shasta River anadromous fishes. Included in this chapter is a brief discussion of thermal criteria for anadromous fish, a summary of basin characteristics, and the potential for riparian vegetation to reduce water temperature through direct reduction in incoming solar radiation (i.e., shade).

Chapter 2 presents the intricacies of the selected model, a discussion of the heat budget used to represent the exchange of thermal energy between the atmosphere and the water body, and a detailed description of the modifications completed to effectively represent riparian vegetation shading in the numerical model. This chapter, and the model user guide, can be used strictly as a reference for those readers seeking details of the model function, and can be skipped with little loss by those interested principally in model results.

Chapter 3 is a brief outline of the fieldwork performed to support the modeling effort. This work, funded by the Klamath Basin Fisheries Task Force, is presented in a separate report and the reader is referred to Abbott and Deas (2003) for a detailed description of the tasks and results.

Chapter 4 describes the process of model implementation and testing, essentially summarizing the data needs, model parameters, and sensitivity of model results to various input parameters and data. Review of this chapter will provide the reader with an appreciation of the steps and stages of modeling. The sensitivity analysis is a useful introduction to several model variables that are altered in the model application section of the report (Chapter 5). This chapter can also be treated as a reference section for those interested primarily in model results.

Chapter 5 includes of two main topics: model calibration and validation; and model application. Model calibration and validation results are useful in assessing model performance and uncertainty – two criteria that are valuable when interpreting simulation results. The model application section presents the findings of several studies completed with the model, including the thermal impacts of variable flow rates, pulse flow operations, tailwater return management, and various riparian vegetation shading conditions. Conclusions and findings of each study are presented within the body of this chapter. This portion of the report will be of most interest for those readers interested primarily in model results.

Chapter 6 includes recommendations that were borne out of this study, and Chapter 7 includes a list of references. Several appendices are included addressing model modification, model processors, and a summary of files used for the model application.

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List of Abbreviations

ADYN	Hydrodynamic component of RMS
BZR	Brazie Ranch Weather Station
CF	Vegetative Continuity Factor
CFS	Cubic Feet per Second
CRS	Shading subroutine in RMS
DFG	California Department of Fish and Game
DLG	Digital Line Graph
DWR	California Department of Water Resources
EBH	Effective Barrier height
EPA	Environmental Protection Agency
GID	Grenada Irrigation District Pumps
ICE	Information Center for the Environment
MAE	Mean Absolute Error
NHD	National Hydrography Dataset
PT	Pressure Transducer
RM	River Mile
RMS	River Modeling System
RQUAL	Water Quality component of RMS
SHSOL	Shade modeling parameter
SRP	Shasta Above Parks Creek
SWA	Shasta Water Users Association
Tr	Transmittance
TVA	Tennessee Valley Authority
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

1.0 Background

The California Department of Fish and Game (DFG) and the United States Fish and Wildlife Service (USFWS) have determined that flow and temperature are the critical water quality parameters for restoration of Shasta River salmon runs (DWR, 2001). This report describes results of flow and temperature modeling on the Shasta River, CA. This modeling project, undertaken through the Great Northern Corporation with funding provided by the Klamath River Basin Fisheries Task Force and DFG, is the second component of a two-part study to investigate the effects of management actions on these critical water quality parameters. The first part of this study included extensive efforts to collect the necessary field observations of flow, temperature, riparian vegetation, and other data to support analysis and modeling. Data collection was funded by the Klamath River Basin Fisheries Task Force, and administered by USFWS. Cost sharing between USFWS and DFG made this study possible.

1.1 Statement of Problem

The California Department of Fish and Game has determined that the Shasta River (Figure 1-1) is the most important spawning nursery area for chinook salmon in the Upper Klamath basin (DWR, 2001). Historically the Shasta supported fall and spring-run chinook salmon, coho salmon and steelhead trout. According to annual spawning counts at the Shasta River weir, the 1931 run of over 80,000 chinook salmon had dropped to 553 fish in 1990 (DFG, 1991). The Department of Water Resources (DWR) has identified physical barriers (dams, weirs), flow alterations due to water management practices, and water quality issues such as temperature and contaminant concentration as potential problems associated with the ability of salmon to spawn in this basin. The DFG and the United States Fish and Wildlife Service have determined that flow and temperature are the critical water quality parameters for restoration of this system (DWR, 2001).

Concern for fish habitat, water temperature and flow has prompted a number of studies in the Shasta River basin. The California Department of Fish and Game (DFG, 1995; DFG, 1996) and the United States Fish and Wildlife Service (USFWS, 1992) have carried out studies to assess the current fish habitat and associated needs. Flow and water temperature studies have been performed by the California Department of Water Resources (DWR, 1964; DWR, 1985). The Department of Civil and Environmental Engineering Modeling Group at the University of California, Davis (CEEMG) conducted a data inventory in 1997. In addition, Deas *et al.* (1996) conducted a woody riparian vegetation inventory. Preliminary modeling of flow and temperature was explored by the CEEMG (1998). These studies provide a basis for continuing work in the Shasta River basin.

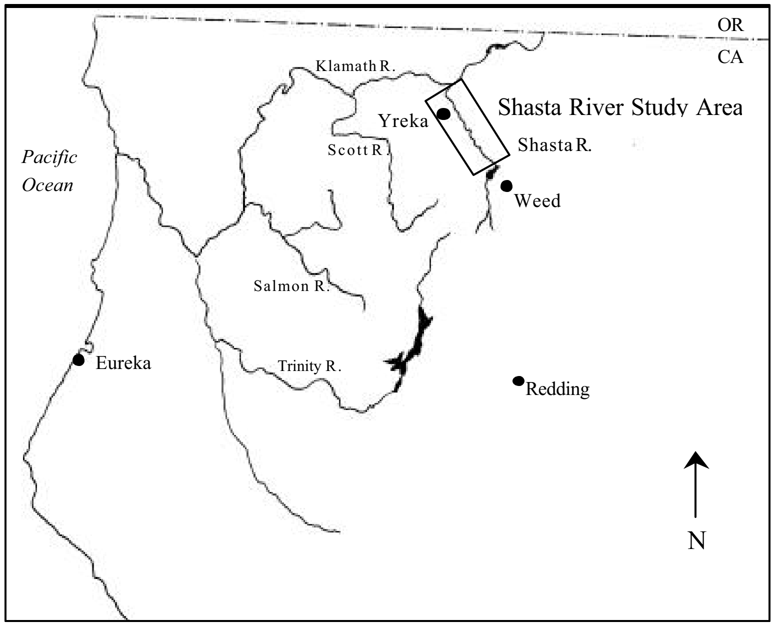


Figure 1-1 Location of the Shasta River

Water temperatures in sections of the 32-mile study reach of the Shasta River, which extends from four miles below Dwinnell Reservoir to the confluence with the Klamath River, are documented to occasionally exceed temperatures lethal to the three species of cold-water fish present in the basin (USFWS, 1992; Piper *et al*., 1983). The Shasta River basin is 800 square miles with a mean annual unimpaired runoff of approximately 162,300 acre-feet. The Shasta River receives numerous accretions from tributaries, springs, and agricultural return flows while losing water to several dams and irrigation diversions. For small streams, such as the Shasta River, riparian shading can play an important role in water temperature response through the direct reduction of incoming solar radiation. Thus, riparian restoration is a potentially useful tool to aid in control of stream temperature. The factors that make small streams sensitive to riparian shading include relatively shallow depths, low flows, and the ability of the tree canopy to shade significant portions of the stream. Riparian revegetation is not the only viable alternative to reduce stream temperatures. Flow also plays a vital role in the heating capacity of the system. Thus, two main options available to lower stream temperatures in the Shasta River are (a) to increase flow and (b) increase riparian vegetation. The focus of this study is to compare the effect of current riparian vegetation on stream temperature with the effect of riparian vegetation under various restoration scenarios.

1.2 Temperature and Anadromous Fisheries

Temperature is a critical parameter for fish survival because it controls the rates of many biological, physical, and chemical processes including active heart rate, metabolic rate, growth rate, swimming speed, feeding rate and efficiency of food conversion (Brett, 1971; Elliot, 1981). Temperatures adequate for fish survival vary with species and life stage. Temperature response for various life stages of chinook salmon, coho salmon, and steelhead trout are briefly outlined herein.

Chinook salmon eggs can survive temperatures between 1.7°C and 16.7°C, with highest survival rates between 4 and 12°C. Juvenile chinook salmon grow at temperatures from 8-24°C, under otherwise optimal conditions. Maximum growth rates occur between 13.2 and 20°C. Although chinook salmon exhibit high growth rates at temperatures approaching 19°C, lower temperatures are required to adapt to life in saltwater. Those salmon which smolt at temperatures above 16°C display reduced saltwater survival. Water temperature generally becomes lethal to Central Valley chinook salmon at chronic temperatures of approximately 25°C, although temperatures as high as 29°C can be tolerated for short periods of time. It is important to note that chinook begin to experience serious chronic effects at temperatures below their lethal limits. In addition, at higher temperatures salmon have increased risk of predations and are more sensitive to other water quality parameters and pathogens. (Myrick *et al.*, 2001)

Preferred temperatures for coho salmon eggs are between 4.4°C and 13.4°C. Juvenile coho salmon prefer temperatures between 11.8 and 14.6°C. However, coho can survive temperatures up to approximately 25°C (Hassler, 1987). Temperatures ranging from 7.2 to 16.7°C are required for coho out migration. The upper lethal limit for out migration of coho is also approximately 25°C (Birk, 1996).

Steelhead trout eggs can survive temperatures between 2 and 15°C, with highest survival rates between 7 and 10°C. Juvenile steelhead experience significant mortality at chronic temperatures of greater than 25°C, although temperatures as high as 29.6°C can be tolerated for short periods of time. Juvenile steelhead grow at temperatures from =6.9°C to at least 22.5°C, under otherwise optimal conditions. The highest growth rates reported for Central Valley steelhead occur at 19°C, however higher temperatures have not been tested. As with chinook salmon lower temperatures are required to become adapted to life in salt water. Steelhead smolt at temperatures between 6.5 and 11.3°C. (Myrick *et al.*, 2001)

In summary, chinook and coho salmon and steelhead trout survival rates exhibit a temperature dependence that varies with life stage. Eggs for these species show the highest survival rates at temperatures between approximately 4 and 13°C. Juveniles show maximum growth rates at warmer temperatures between 15 and 19°C for chinook and steelhead, and cooler water temperatures of about 11.8 to 14.6°C for coho. All three species require cooler temperatures for transition into salt water (10-17°C for chinook, 7-17°C for coho, and 6-10°C for steelhead). All three species experience increased mortality rates at chronic temperatures above 25°C. (Myrick *et al.* 2001; Hassler, 1987; Birk, 1996)

1.3 Functions of Riparian Vegetation

Riparian vegetation plays an important role in stream geomorphology and biology, and potentially water quality. Riparian vegetation acts as a cohesive agent to resist erosion from both precipitation and the stream itself. Biologically, vegetation provides habitat for various species, including insects that in turn provide food for juveniles. Trees are specifically vital to fish survival because they supply woody debris to the river that accumulate in log jams used as hiding places from predators in addition to providing a range of velocities acceptable to juveniles. A well-developed riparian zone can also assist in controlling water temperatures.

Riparian vegetation can affect stream temperature by altering the heat flux in several ways. Vegetation can affect the heat flux by reducing wind speed, altering the microclimate above the water surface (i.e. air temperature and relative humidity), and reflecting long-wave radiation (CEEMG, 2001). If the forest canopy covers a significant portion of the stream, perhaps its greatest effects are absorbing, filtering and reflecting solar radiation. Brown (1970) noted that incoming solar radiation may account for close to 95% of the heat input during midday in the summer. Under non-shaded conditions solar radiation has more of an influence on water temperature than air temperature, thus being the dominant source of heat input into the stream. In addition, Bartholow (1989) described two other (less effective) ways through which riparian vegetation affects stream temperature. First, vegetation reduces the amount of the water's back radiation at night, tending to moderate the minimum stream temperatures. Second, the vegetation produces its own long wave (thermal) radiation, which also tends to raise minimum temperatures at night.

For this study it is assumed that the largest impact riparian vegetation has on stream temperature of the Shasta River is through the filtering of incoming solar radiation. This research focuses on that primary role.

1.4 Summary of Vegetation Effects on Water Temperature

The aforementioned researchers and others have helped to provide a basis for understanding the effects of riparian vegetation on stream temperature through modification of existing temperature models to account for riparian vegetation. The USFWS adapted the model SNTEMP to include shading. Their modeling shows that streams are sensitive to shading when flows are low, the width-to-depth ratio is large, wind speed is low, and solar radiation is high. La Marche, *et al.* (1997) altered the stream temperature model STRTEMP to model vegetative effects on two reaches of the Dechutes River. They discovered that stream orientation and the width of a strip of buffer vegetation were key to maximizing shading effects. Chen, *et al.* (1997) modified a comprehensive hydrologic model, HSPF, to incorporate shading. In modeling of the Upper Grande Ronde watershed they determined that riparian vegetation was the only critical factor that could be managed to reduce stream temperature. Lowney (2001) adapted the finite-element water quality model RMA-10 to model several vegetative characteristics and their effects on the temperature of the Sacramento River. She found that, of all vegetative characteristics, shading had the largest effect on water temperature. She also concluded that riparian shading had a negligible effect on rivers the size of the Sacramento River. Based on the above findings, the Shasta River appears to present the ideal conditions for maximum use of vegetation to control river temperature. The Shasta River is a small system that experiences low summer flows with very high solar radiation fluxes.

1.5 Study Area

The Shasta River, located in central Siskiyou County, Northern California, originates in the Scott Mountains in the vicinity of Mt. Eddy and flows north and north-westward for roughly seventy miles before discharging into the Klamath River. The river is fed by glacial melting and precipitation runoff from Mount Shasta that is delivered to the river by groundwater flows and springs. The river is impounded by Dwinnell Dam at river mile 36.4. Due to minimal flows (J. Whelan, pers. comm.) and difficulty in gaining access to the upper river, the study area extends from approximately river mile 32 to the confluence with the Klamath River. Figure 1-2 depicts the Shasta River as derived from the National Hydrography Dataset. The upstream end of the study reach is referred to as Shasta River above Parks (SRP). The Shasta River flowing downstream from SRP is joined by several small tributaries including Parks Creek, Willow Creek, Little Shasta River, and Yreka Creek and a large tributary, Big Springs, that is spring fed. Many of the system's smaller tributaries are dry in the summer. During the irrigation season from April to October there are several agricultural diversions along the river. Although most diversions are associated with individual landowners, the larger diversions include the Grenada Irrigation District (GID) and the Shasta Water Users Association (SWA). Agricultural return flow varies along the system and enters the river in a variety of forms: as flow in defined channels, diffuse overland flow, and subsurface flow. The Shasta River is relatively steep at its headwaters with an average slope from Dwinnell Reservoir (RM 36.4) to SRP (RM 31.8) of 0.008, or about 40 feet per mile. Between SRP and where Interstate 5 crosses the river (RM 8.3) the average slope is approximately 0.002, or about 10 feet per mile. This allows the river to develop a complex set of meanders. For the last eight miles the river runs through a canyon with a steeper slope of 0.01, or about 50 feet per mile. Figure 1-3 illustrates the profile of the river with elevations taken from 1:24,000-scale United States Geological Survey (USGS) maps.

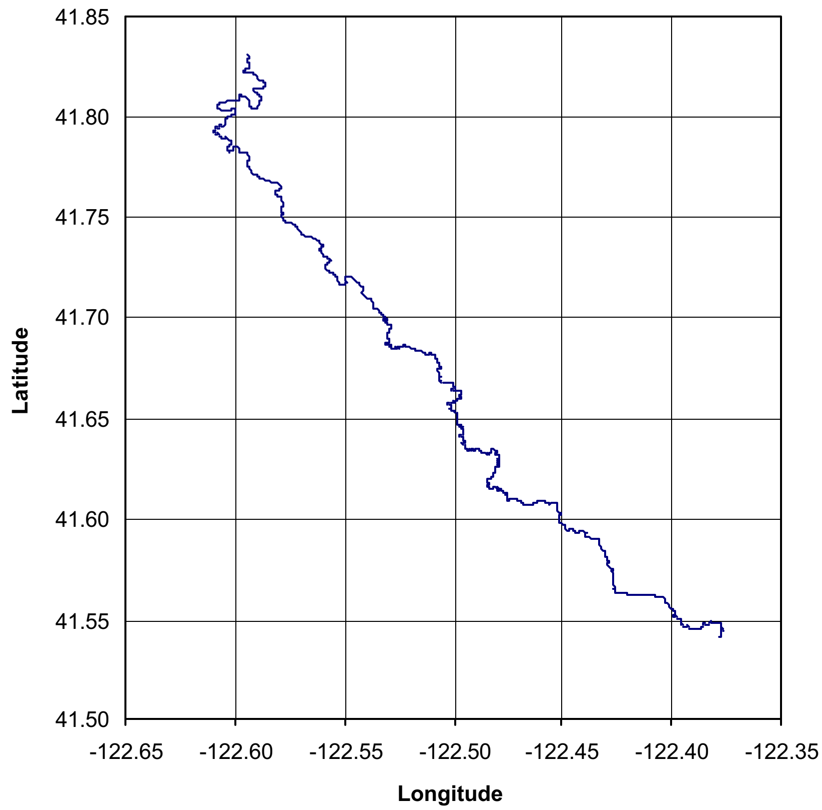


Figure 1-2 Shasta River as derived from the National Hydrography Dataset

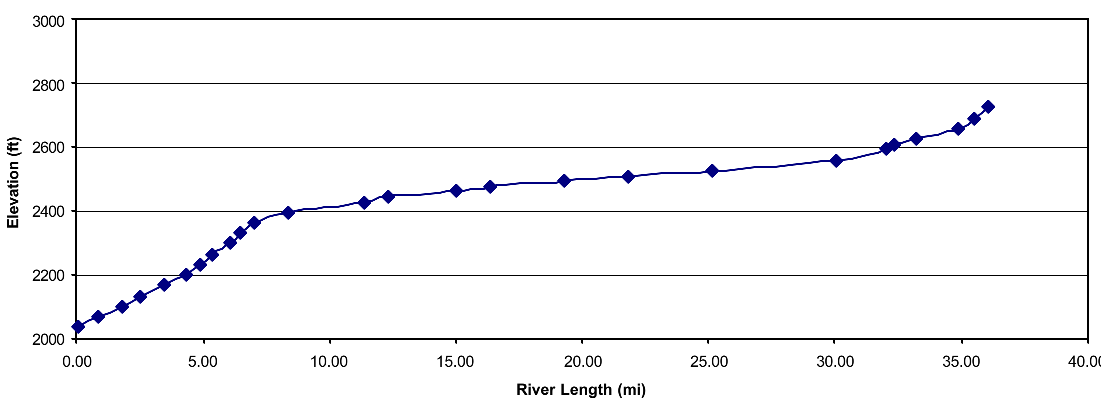


Figure 1-3 Shasta River longitudinal profile

2.0 Modeling Approach

To quantify the influence of riparian vegetation on Shasta River water temperatures, it was necessary to simulate flow, temperature, and riparian shade. This chapter addresses the choice of an appropriate model, the mathematical formulations in the model, the theoretical considerations in modeling temperature and a discussion of modifications made to the model for this particular application.

2.1 Model Choice

After a review of the models available in the public domain, the Tennessee Valley Authority's (TVA) River Modeling System (RMS), a one-dimensional hydrodynamic and water quality model, was chosen to model the Shasta River. This model was chosen because it is readily available, contains basic shading logic, allows for modeling at an hourly time step, and is supported by TVA. RMS has two components, the hydrodynamic model, ADYN, and the water quality model, RQUAL. These components may be used independently or in sequence. This section includes a discussion of the formulations of each model component. Information discussed below about model formulation was found in the RMS User's Manual (Hauser, 1995).

2.1.1 The Hydrodynamic Component: ADYN

ADYN solves the one-dimensional unsteady flow equations for conservation of mass and momentum using either a four-point implicit finite difference scheme with weighted spatial derivatives or a McCormack explicit scheme. The four-point implicit finite difference scheme was chosen for this application because the irregularity of the channel geometry rendered the explicit scheme inadequate. ADYN can model interactions with dynamic tributaries at channel junctions, multiple tributary systems with multiple internal boundary conditions along each system, and the effects of distributed or point lateral inflows. For this application the Shasta River will be modeled as one continuous reach with several distributed dynamic lateral inflows.

2.1.2 The Water Quality Component: RQUAL

RQUAL uses the geometry, velocities and depths from the hydrodynamic model in the calculation of water quality variables. RQUAL can be used to study several water quality parameters. However, this application employs only the temperature modeling capability. RQUAL offers three options of numerical schemes used to solve the one-dimensional transport equation: a four-point-implicit finite difference scheme with weighted spatial derivatives, a McCormack explicit scheme, or a Holly-Preissman scheme. Preliminary model testing found negligible difference in results between the four-point-implicit and Holly-Preissman schemes when applied to the Shasta River. The four-point implicit scheme was chosen for use in this application. In the coding of RQUAL, dispersion is neglected because the model was designed for application in highly river systems where transport is the dominant factor. Numerical dispersion serves to account for the lack of an explicit dispersion term (Hauser, pers. comm.).

The heat budget (outlined in Section 2.2) used in RQUAL includes logic for bed heat exchange and riparian shading. Bed conduction logic was not used in this modeling study. Existing shading logic was not entirely sufficient to represent the dynamics of the Shasta River, so modifications were made. These modifications are discussed in Section 2.3 of this report. In addition, a specific piece of shading logic that lowers dry bulb temperature in shade was not implemented.

It should be noted that RQUAL does not model shading by large-scale topographic features (e.g. hills, canyons, etc.). If this type of shading is considered to have a significant effect on water temperature, then modifications need to be made to the model to account for it. For the Shasta River the only potential for topographic shading of this type occurs between the Mouth and RM 7, where the Shasta enters a canyon below Anderson Grade. For this modeling effort the effect of topographic shading was not considered.

2.2 Heat Budget

Temperature models fall into two general classes: empirical models relating observations of stream temperature to stream properties (such as discharge, channel geometry, and streamside vegetation characteristics) and/or meteorological conditions, and models that represent the physical processes of heat exchange by means of the energy (or heat) budget. Although simple and generally convenient to use, empirical models are limited to assessing conditions within the range of data used to construct the relationship and do not provide detailed information about the effects of certain factors on stream temperature. These factors may include variations in discharge; changes in the location, size, and extent of vegetative cover; cumulative effects of upstream disturbances in riparian areas, and stream orientation effects on incoming solar radiation (La Marche, *et al.*, 1997). Brown (1969) noted that one of the most effective process-based techniques for predicting river temperatures and temperature changes is the heat budget approach. The water quality component of the TVA model (RQUAL) uses the heat budget approach that quantifies pertinent factors by formulations based on physical processes.

The heat budget approach quantifies the net exchange of heat at the air-water interface. TVA has extended the approach to also include heat exchange at the water-bed interface. This net change may be expressed as the sum of the major sources and sinks of thermal energy or the sum of the heat fluxes.

TVA Heat Budget Formulation

$$Q_n = \frac{Q_{ns} + Q_{na} + Q_{bed} - Q_b - Q_e - Q_c}{D}$$

where:

Q_n = the net heat flux (representing the rate of heat released from or added to storage in a particular volume) ($kcal/m^3s$)
Q_{ns} = net solar (short-wave) radiation flux adjusted for shade ($kcal/m^2s$)
Q_{na} = net atmospheric (long-wave) radiation flux ($kcal/m^2s$)
Q_{bed} = net flux of heat at the water- channel bed interface ($kcal/m^2s$)
Q_b = net flux of back (long-wave) radiation from water surface ($kcal/m^2s$)
Q_e = evaporative (latent or convective) heat flux ($kcal/m^2s$)
Q_c = conductive (sensible) heat flux ($kcal/m^2s$)
D = mean depth (m)

2.2.1 Net Solar (Short-wave) Radiation Flux

The net short-wave radiation flux (Q_{sn}) is that portion of the total short-wave solar radiation that reaches the water surface. This term represents that portion of the short-wave radiation that is not scattered, intercepted, or reflected by the atmosphere, clouds or vegetation on its way to the water surface. Hence, this term largely depends on the local altitude of the sun, cloud cover, vegetation cover, and an atmospheric turbidity factor. Some models calculate this value based on a theoretical value of solar radiation and the above-mentioned parameters. RMS represents incoming solar radiation (Q_s) as an input in the meteorology input file that is then adjusted in the model to account for the vegetation cover by shading factor (R_s).

$Q_{ns} = Q_s * R_s$.

where:
Q_s = incoming solar radiation (an input parameter for the model)
R_s. = shade factor, a fraction (0.0-1.0) of solar radiation that reaches the water surface

2.2.1.1 Computation of the Shade Factor (R_s)

The shade factor, R_s, depends on size and proximity of trees and banks, solar azimuth, river aspect, and the percent of solar radiation that penetrates the vegetation canopy (here referred to as vegetative transmittance, SHSOL).

There are three steps that must be taken before directly computing R_s:

1) Calculate the solar altitude (S_a)
2) Calculate the length of the shadow parallel to the azimuth of the sun (AZS)
3) Calculate the length of the shadow normal to the bank of the river

Solar altitude, S_a, is the angle between the sun and the observer's horizon (see Figure 2-1). S_a is a function of the latitude of the river, the declination of the sun, and the time of day (hour angle of the sun). S_a is calculated by the following equation (TVA 1972):

$$S_a = Sin^{-1}\left(Sin\phi Sin\delta + Cos\phi Cos\delta Cos\tau\right)$$

where:

S_a	= solar altitude (radians)
f	= latitude of the river (radians)
d	= declination of the sun (radians)
τ	= local hour angle of the sun (radians)

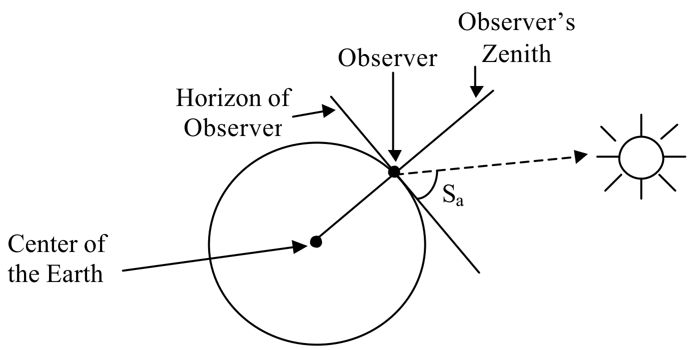


Figure 2-1 Diagram of the solar altitude

The declination of the sun is the angle between the earth's equator and the sun. It is dependent upon the time of year represented as Julian days. The declination is calculated by the following equation (TVA, 1972) where JD is the Julian day (1-365):

$$\delta = 23.45\left(\frac{2\pi}{360}\right)Cos\left(2\pi\,\frac{(172 - JD)}{365}\right)$$

The hour angle is the time of day, expressed in radians. The local hour angle, or the fraction of 2p that the earth has turned after local solar noon (CEEMG 2001), is calculated in RQUAL by the following equation. (Note: This formulation is appropriate for western longitudes.)

$$\tau = \left(180 + l - t_m - \left(360 \cdot \frac{hr}{24}\right)\right)\left(\frac{2\pi}{360}\right)$$

where:

l	= longitude of the river (degrees)
t_m	= local time zone meridian (degrees)

hr = hour of the day

Next the azimuth of the sun AZS (radians) must be determined to calculate the direction of the shadow cast by the vegetation. AZS is a function of declination, solar altitude, and the latitude of the river. This is done by the following equation which yields a value for AZ that varies from 0° to 180°. (Note: The azimuth of the sun is measured clockwise from north when the sun is east of the local meridian, and counter-clockwise from north when the sun is west of the local meridian.)

$$AZS = Cos^{-1}\left(\frac{Sin\delta - SinS_a Sin\phi}{CosS_a Cos\phi}\right)$$

where:

AZS = solar azimuth
S_a = solar altitude (radians)
f = latitude of the river (radians)
d = declination of the sun (radians)

The length of the shadow (X) cast by the effective barrier (e.g. vegetation) that is parallel to the azimuth of the sun (AZS) can be found by geometry as shown in Figure 2-2.

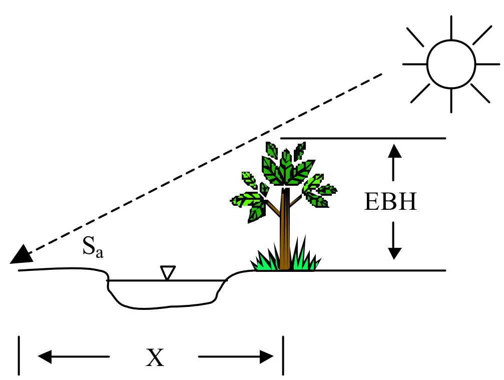


Figure 2-2 Diagram depicting the variables for calculating X, the length of the shadow parallel to the azimuth of the sun

$$X = \frac{EBH}{\tan(S_a)}$$

where:

EBH = effective barrier height (meters)
X = length of shadow parallel to the azimuth of the sun (meters)

Using geometry X_n, the length of the shadow normal to the stream aspect, can be calculated as shown in Figure 2-3.

$$X_n = X(\sin(AZS - AZ))$$

where:

X_n	= length of the shadow normal to the stream aspect
X	= length of the shadow cast by the effective barrier
AZS	= azimuth of the sun
AZ	= stream aspect

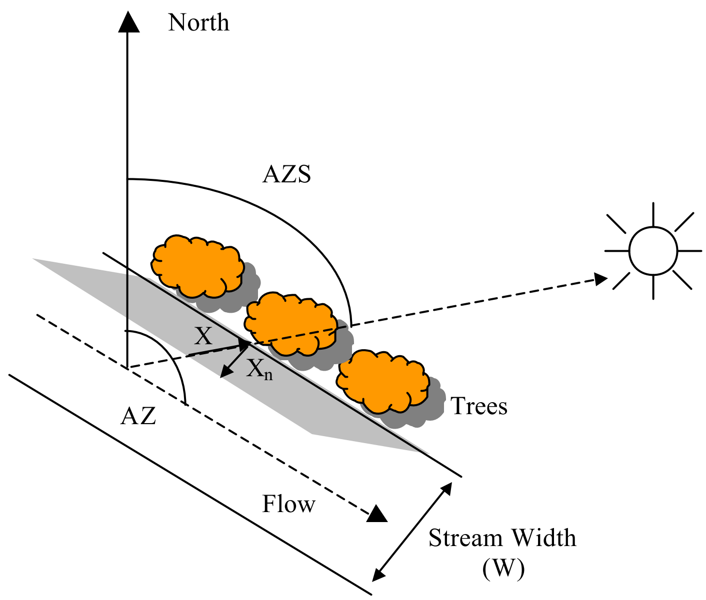


Figure 2-3 Diagram depicting the variables for calculating X_n

There are three possible shading conditions: shade free, partially shaded, and fully shaded. Once the length of the shadow normal to the stream bank is determined, R_s can be calculated by the following equations according to the appropriate scenario:

<u>No Shade</u>

($X_n = B$ or $\cos ß = 0.01$): $R_s = R_{sm}$

<u>Partial Shade</u>

($B < X_n = W+B$): $R_s = R_{sm} (W+B-X_n)/W + SHSOL(X_n-B)/W$

Full Shade

(W+B < X_n or S_a = 1.5 or hr < TFOG): R_s = SHSOL

where:

R_{sm} = the shade free absorption coefficient
X_n = shadow length normal to stream bank (m)
SHSOL = vegetative transmittance (0 = SHSOL = 1, 0 = no light gets through)
ß = angle between the sun and normal to the stream axis (radians)
S_a = solar altitude (radians)
TFOG = time of fog lift (hours)
B = bank width or vegetative setback (m)
W = channel width (m)

The shade free absorption coefficient (R_{sm}) is a factor that accounts for the reflectivity of the water surface given no shading by streamside vegetation. R_{sm} represents the fraction of solar radiation not reflected by the shade-free water surface. The formulation of this factor as found in RQUAL is taken from Anderson (1954):

$$R_{sm} = 1 - (a / (180*S_a/p)^b$$

where:

R_{sm} = shade free absorption coefficient
a, b = coefficients depending on cloud cover
S_a = solar altitude

and coefficients "a" and "b" are selected based on specific cloud cover conditions, C, as follows:

C	a	b
<0.05	1.18	0.77
0.05-0.5	2.20	0.97
0.5-0.95	0.95	0.75
>0.95	0.35	0.45

2.2.2 Net Atmospheric Radiation

The net atmospheric long-wave radiation flux (Q_{na}) originates from the atmosphere when clouds, dust, and other particles re-radiates short-wave radiation intercepted from the sun. This term depends on air temperature and cloud cover. The equation used to calculate Q_{na} is in a form derived from Swinbank (1963) with a value of 0.03 for the reflectivity of the water surface (R_L).

$$Q_{na} = 1.23 \times 10^{-16} \left(T_a + 273\right)^6 \left(1 + 0.17C^2\right)$$

where:
Q_{na} = net atmospheric radiation (kcal/m^2s)
C = cloud cover
T_a = dry bulb air temp (°C)

2.2.3 Net Back Radiation from the Water Surface

The net water surface long-wave radiation flux (Q_b) is heat radiated by the water surface. This term is mainly dependent on water temperature and is calculated using the Stefan-Boltzmann equation:

$$Q_b = \varepsilon\sigma (T + 273)^4$$

$$= 0.736 + 0.00117T$$

where:
Q_b = net back radiation (kcal/m^2s)
s = Stefan-Boltzmann constant
T = water temperature (°C)
e = emissivity. The commonly assumed value for objects on the earth's surface is e = 0.97

2.2.4 Net Evaporative Heat Flux

The evaporative (latent or convective) heat flux (Q_e) occurs at the stream surface. It is the transfer of heat through the state change of surface water to vapor, or water vapor to liquid water. Hence, the important factors in convection are the latent heat of vaporization, wind speed, the temperature gradient between air and water (usually expressed in the form of vapor pressures at the surface and in the atmosphere). In the RMS formulation if the saturation vapor pressure at the water surface is less than the pressure in the air, then the net evaporative heat loss is assumed to be zero. Hence, in RMS this term cannot be used to model condensation in addition to evaporation.

If $e_s > e_a$

$$Q_e = \rho L\left(a_1 + b_1 W\right)\left(e_s - e_a\right)$$

where:
? = density of water (kg/m^3)
L = latent heat of vaporization (kcal/kg) = 597-0.57 T
T = water temperature (°C)
a_1, = empirical wind coefficient (mb^{-1}m/s)
b_1 = empirical wind coefficient (mb^{-1})
W = wind speed (m/s)

e_a = saturation vapor pressure at air temp (mb)
e_s = saturation vapor pressure at water temp (mb)

Saturation vapor pressure at water temperature and air temperature are defined as:

$$e_a = 2.171 \times 10^8 \exp\left(\frac{-4157}{T_d 239.09}\right) \text{ and}$$

$$e_s = \alpha j + \beta j T$$

where:

T_d = dewpoint temperature (°C).

2.2.5 Net Conductive Heat Flux

The sensible or conductive heat flux, Q_c, is heat flux through molecular or turbulent transfer between the air and water surface. The amount of heat gained or lost through sensible heat flux depends on the gradient of temperature between the water and air. The RMS formulation of this equation is derived using Bowen's Ratio.

$$Q_c = \rho L(a_1 + b_1 W)(C_B \times 10^{-3} P)(T - T_a)$$

Q_c = net conductive heat transfer (kcal/m^{2}s)
C_B = Bowen's Ratio (0.61 °C^{-1})
and ?,L, T, a_1, b_1, W, T_a as defined above.

2.2.6 Net Bed Heat Flux

The bed heat flux or bed conduction, Q_{bed}, is the net transfer of heat from the channel bed to the water. This heat flux depends on the temperature gradient between the water and the bed. (Note: This term was turned off in the calculation of the heat budget for the Shasta River simulations. See Section 2.1.2.) The RMS formulation of this process is:

$$Q_{bed} = -(Q_{nsr} + Q_{bc})$$

where:
Q_{bed} = net bed heat flux (kcal/m^{2}s)
Q_{nsr} = net solar radiation available for warming the channel bed (kcal/m^{2}s)
Q_{bc} = heat conducted from water to bed due to temperature differential (kcal/m^{2}s)

And

$$Q_{nsr} = (1 - A_b)(1 - \beta)\exp(-\eta(D - 0.6))Q_{ns}$$

where:

Q_{nsr} = net solar radiation available for warming the channel bed (kcal/m^{2}s)
A_b = albedo of bed material
ß = fraction of solar radiation absorbed in surface 0.6m of water
? = extinction coefficient in water (1/m)
D = mean depth of water (m)
Q_{ns} = net short-wave solar radiation corrected for shading (kcal/m^{2}s)

$$Q_{bc} = \frac{10C_v K(T - T_{bed})/0.5L}{3600}$$

where:
Q_{bc} = heat conducted from water to bed due to temperature differential (kcal/m^{2}s)
C_v = heat storage capacity of bed material (cal/cm^3°C)
K = thermal diffusivity of bed material (cm^2/hr)
T = water temperature (°C)
T_{bed} = average temperature of the bed (°C)
L = effective bed thickness (cm).

2.3 Model Modifications

As originally formulations for calculating R_s, the shade factor in RQUAL, include the following limitations:

1) The user may enter only one value for vegetative transmittance (SHSOL) for an entire system.

2) The user may enter only one value for effective barrier (or, vegetation) height (EBH) per node.

These limitations were designed for a river system in which there is little variability of effective barrier height and continuity of vegetation. The Shasta River is fundamentally different from the rivers typically studied by the Tennessee Valley Authority (TVA), for which this model was designed. Whereas the rivers within the TVA study region run through thick forests, the Shasta River runs through reaches of sparse vegetation, where vegetation may only occur on one bank or the other. In addition, the purpose of the Shasta River modeling project is to assess the effect of riparian vegetation on stream temperature and to provide quantitative analysis of possible revegetation scenarios. In order to have the flexibility required to accurately represent the current streamside vegetation and to run various revegetation scenarios, the model required expansion of the current ability to represent the transmittance and effective barrier height. To accomplish this, the representation of SHSOL was expanded to allow for input of transmittance and EBH values for each bank. EBH was also expanded to allow for input of vegetation height on the right and left bank that could vary by location.

2.3.1 Altered Shading Logic

Several modifications were made to the model to implement the required changes:

1) Four solar output files were added to allow access to key variables in time series at each of four nodes. The key variables include EBH, SHSOL, SWS (incoming solar radiation), QNS (adjusted solar radiation), and T2 (water temperature).

2) Modifications were made to the main program and to subroutine CRS to allow the input of right and left bank parameters for EBH and SHSOL.

3) Shading logic was added in the subroutine CRS to process the new right and left bank parameters.

The solar output files currently are programmed to output information at specific nodes. This can be altered in the code by changing the node in the write statements to files 28-31 found in the main program beginning at line 940.

To make the code flexible, a flag (IRS) was added to the first line of the water quality coefficient input file that can turn on/off the new shading logic. If IRS = 1, the new shading logic is used. (See APPENDIX A for input file modifications.) The modifications made to the subroutine CRS in order to process the new right and left bank parameters are outlined below.

To determine which bank information to use, logic was include to determine which bank provides shade to the stream at sunrise. After the first bank is labeled the model switches bank information when the sun crosses the river. This is determined by comparing the aspect of the river and the azimuth of the sun. When the aspect of the river is equal to the azimuth of the sun then the sun is directly over the river and no shading occurs. To illustrate, if the stream was flowing north the aspect would be 0° (recall that stream aspect is measured clockwise from north ranging from 0°-360°), the right bank would be on the east side of the stream and the left bank would be on the west. At sunrise the east (right bank) will be shading the stream. When the sun's azimuth reaches 180° it is directly over the stream, and once the azimuth of the sun crosses the stream the west bank (or left bank) provides the shade, as shown in Figure 2-4.

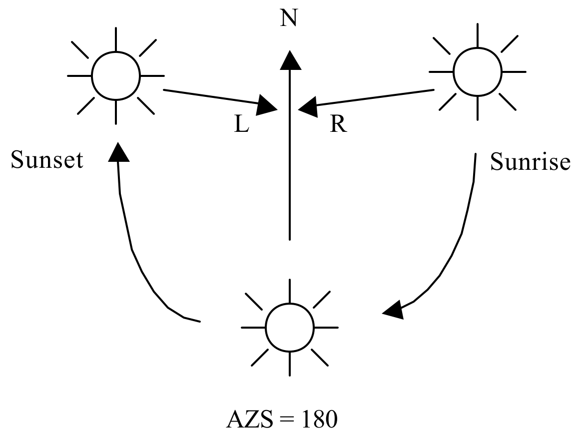


Figure 2-4 Diagram of sample stream, with aspect = 0.0

Figure 2-5 illustrates the situation if this same stream were flowing south instead of north. The aspect of the stream would be 180° and the first bank to provide shade would be the left bank.

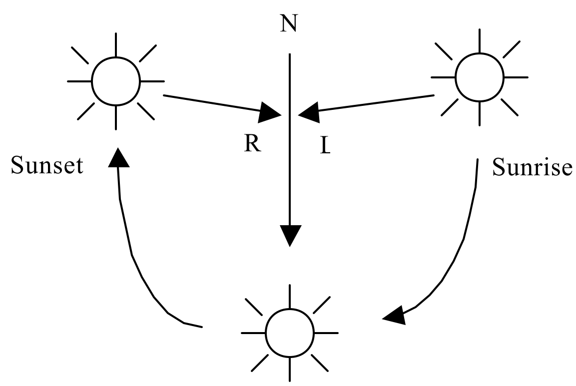


Figure 2-5 Diagram of sample stream, with aspect = 180.0

Determining which is the first bank to provide shade and then switching to use information from the opposite bank when the sun crosses the stream is accomplished by the logic described in Figure 2-6. Figure 2-6 is a flowchart of the two-bank shading logic added to RQUAL. The full listing of the modified program code can be found in Appendix B.

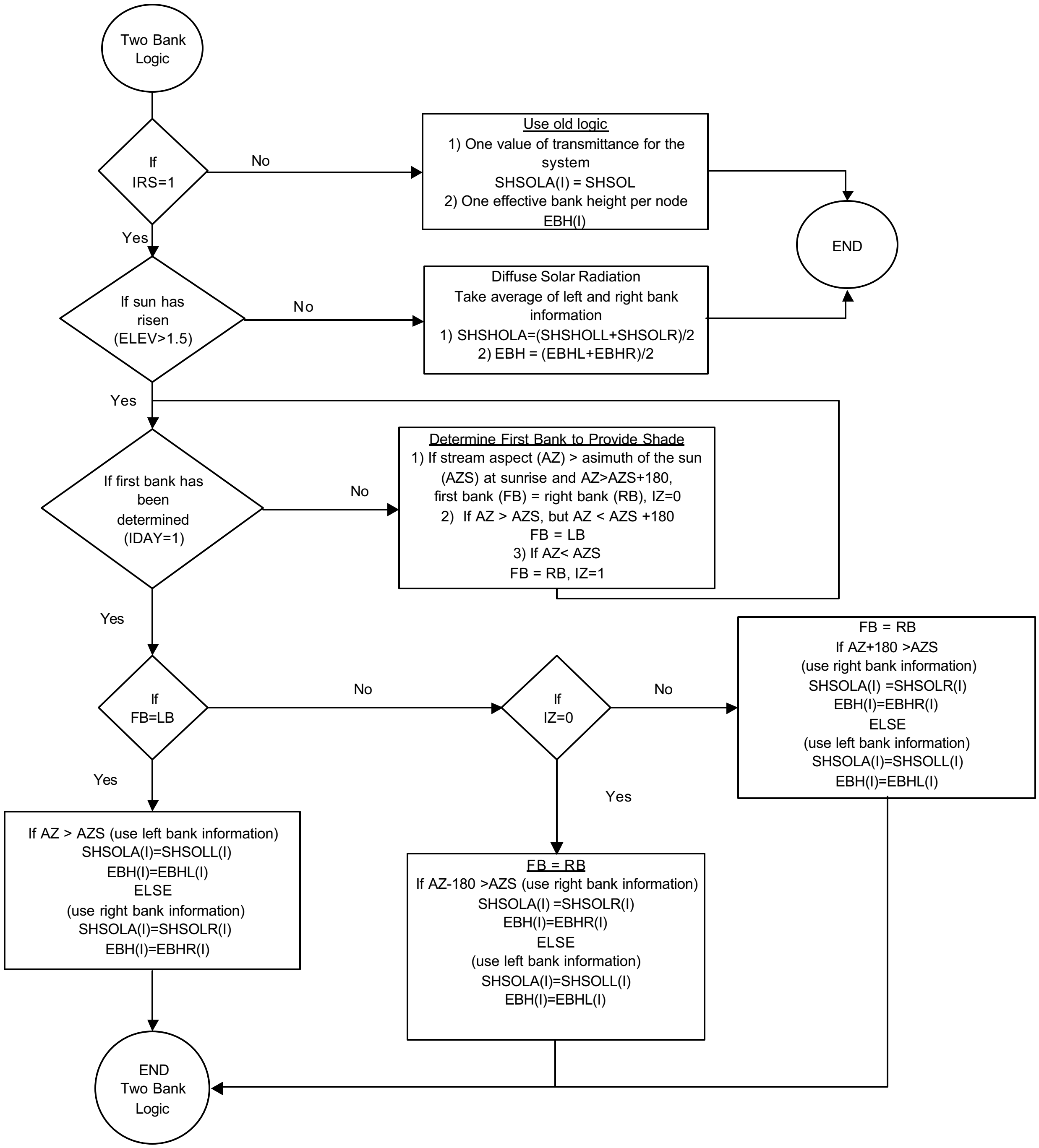


Figure 2-6 Flowchart of two-bank shading logic

Depicted in Figure 2-7 are the three scenarios to consider when assigning the first bank that provides shade to the river. Scenario One occurs when the stream aspect is less than the azimuth of the sun. Scenario Two occurs when the stream aspect is greater than the azimuth of the sun and less than the azimuth of the sun plus 180°. Scenario Three occurs when the stream aspect is greater than the azimuth of the sun and greater than the azimuth of the sun plus 180°.

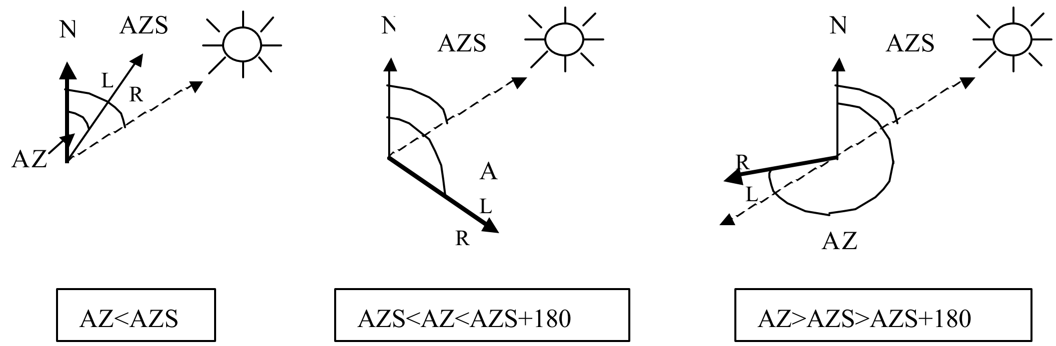


Figure 2-7 Diagram depicting three aspect scenarios of the two bank shading logic

In Scenario One the first bank to provide shade is the right bank. In Scenario Two, the first bank to provide shade is the left bank. In Scenario Three the first bank to provide shade is the right bank. After the first bank is assigned, the logic switches bank information as the sun's azimuth passes over the stream azimuth.

Before sunrise and after sunset the amount of solar radiation compared to peak daily values is negligible. Whatever solar radiation does exist at dawn and dusk is considered small. For modeling purposes SHSOL and EBH during these times is set to an average of right and left bank values. This is partially a relict of the original coding which requires a value for SHSOL and EBH during the nighttime hours. Since there is no appreciable solar radiation before sunrise or after sunset this logic does not affect simulated temperatures.

2.3.2 Testing of Modifications

The modified shading logic was tested using seven test cases. The test cases were run using a rectangular channel 2 feet deep and 100,000 feet long with flow of 100 cfs. Meteorological data from August 28, 2001 was used. Transmittance factors for all left bank nodes were set to 0.15 and all right bank nodes were set to 0.0. Effective barrier height (EBH) was set to 10 feet (3.048 m) for the left bank and 40 feet (12.192 m) for the right bank. Figure 2-8 depicts the stream aspects and compass direction for each test case, they were: 0(north), 45(northeast), 90(east), 135 (southeast), 180(south), 225 (southwest), 270 (west). Each test case was assigned a different stream aspect to test the ability of the model to use the appropriate bank information for each time step throughout a 24-hour period. It was expected that as the sun passed from one side of the stream to the other the value of SHSOL and EBH would change according to the values for the left and right bank. The model accurately assigned both variables for each time of day for each test case as shown in Table 2-1 and Table 2-2.

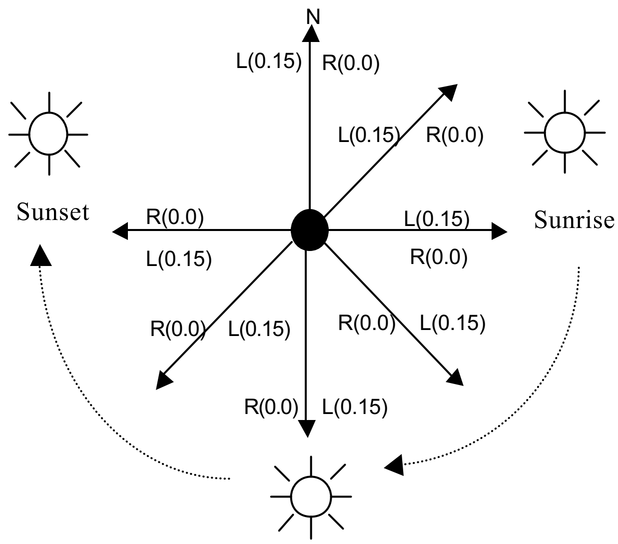


Figure 2-8 Diagram of stream aspects used in testing of two-bank shading logic

To illustrate, at 1pm (or hour 13) for the north flowing stream the transmittance switched from the right bank value of 0.0 to the left bank value of 0.15. In addition, the effective barrier height also changed from the right barrier height of 40 ft (12.192 m) to the left barrier height of 10 ft (3.048 m). Note that before sunrise and after sunset the value for SHSOL and EBH is an average of the values for right and left bank (explanation included in Section 2.3.1).

Table 2-1 Transmittance factors during the course of one day for seven test cases

SimHR	N	NE	E	SE	S	SW	W
1	0.075	0.075	0.075	0.075	0.075	0.075	0.075
2	0.075	0.075	0.075	0.075	0.075	0.075	0.075
3	0.075	0.075	0.075	0.075	0.075	0.075	0.075
4	0.075	0.075	0.075	0.075	0.075	0.075	0.075
5	0.075	0.075	0.075	0.075	0.075	0.075	0.075
6	0	0	0.15	0.15	0.15	0.15	0
7	0	0	0	0.15	0.15	0.15	0.15
8	0	0	0	0.15	0.15	0.15	0.15
9	0	0	0	0.15	0.15	0.15	0.15
10	0	0	0	0.15	0.15	0.15	0.15
11	0	0	0	0	0.15	0.15	0.15
12	0	0	0	0	0.15	0.15	0.15
13	0.15	0	0	0	0	0.15	0.15
14	0.15	0	0	0	0	0.15	0.15
15	0.15	0.15	0	0	0	0	0.15
16	0.15	0.15	0	0	0	0	0.15
17	0.15	0.15	0	0	0	0	0.15
18	0.15	0.15	0	0	0	0	0.15
19	0.075	0.075	0.075	0.075	0.075	0.075	0.075
20	0.075	0.075	0.075	0.075	0.075	0.075	0.075
21	0.075	0.075	0.075	0.075	0.075	0.075	0.075
22	0.075	0.075	0.075	0.075	0.075	0.075	0.075
23	0.075	0.075	0.075	0.075	0.075	0.075	0.075
24	0.075	0.075	0.075	0.075	0.075	0.075	0.075

Table 2-2 Effective barrier height during the course of one day for seven test cases

SimHR	N	NE	E	SE	S	SW	W
1	7.62	7.62	7.62	7.62	7.62	7.62	7.62
2	7.62	7.62	7.62	7.62	7.62	7.62	7.62
3	7.62	7.62	7.62	7.62	7.62	7.62	7.62
4	7.62	7.62	7.62	7.62	7.62	7.62	7.62
5	7.62	7.62	7.62	7.62	7.62	7.62	7.62
6	12.192	12.192	3.048	3.048	3.048	3.048	12.192
7	12.192	12.192	12.192	3.048	3.048	3.048	3.048
8	12.192	12.192	12.192	3.048	3.048	3.048	3.048
9	12.192	12.192	12.192	3.048	3.048	3.048	3.048
10	12.192	12.192	12.192	3.048	3.048	3.048	3.048
11	12.192	12.192	12.192	12.192	3.048	3.048	3.048
12	12.192	12.192	12.192	12.192	3.048	3.048	3.048
13	3.048	12.192	12.192	12.192	12.192	3.048	3.048
14	3.048	12.192	12.192	12.192	12.192	3.048	3.048
15	3.048	3.048	12.192	12.192	12.192	12.192	3.048
16	3.048	3.048	12.192	12.192	12.192	12.192	3.048
17	3.048	3.048	12.192	12.192	12.192	12.192	3.048
18	3.048	3.048	12.192	12.192	12.192	12.192	3.048
19	7.62	7.62	7.62	7.62	7.62	7.62	7.62
20	7.62	7.62	7.62	7.62	7.62	7.62	7.62
21	7.62	7.62	7.62	7.62	7.62	7.62	7.62
22	7.62	7.62	7.62	7.62	7.62	7.62	7.62
23	7.62	7.62	7.62	7.62	7.62	7.62	7.62
24	7.62	7.62	7.62	7.62	7.62	7.62	7.62

2.3.3 Limitations of the Shading Logic

There are limitations to the correct application of the shading logic in RQUAL. The two-bank shading logic should be applied to systems using an hourly or finer time step. Time steps greater than one hour could result in misapplication of bank information. There is a possibility that with large time steps the model would not be able to detect the first bank accurately. In addition, the formulation of the hour angle equation limits the use of this model to the western hemisphere.

3.0 Fieldwork

To support the flow and temperature model of the Shasta River, field programs to collect the necessary data were designed and implemented. This monitoring effort was funded through a separate grant from the Klamath Basin Fisheries Task Force and administered by the United States Fish and Wildlife Service.

Required data for modeling flow and temperature include geometric descriptions of locations and cross-sections, riparian vegetation data, flow data, water temperature data, and climatic data. Existing programs and information were reviewed to determine the availability of data and specific needs for monitoring. The individual programs are briefly outlined below. Complete details can be found in Abbott and Deas (2003, in press).

Geometry: Detailed stream cross-section geometry was largely unavailable. DFG habitat surveys were available, but provided only limited data. Additional fieldwork was carried out to further characterize the geometric stream channel representation of the river.

Riparian Vegetation: Riparian vegetation field monitoring included measurement of baseline (no shade) and reduced (shaded) incoming solar radiation conditions throughout the Shasta River twice during the 2001 field season and a survey of tree height throughout the basin. The focus of this element of the project was to quantify the effect of riparian shading on water temperature and water temperature control potential for anadromous fisheries restoration. Findings are relevant to re-vegetation projects, water temperature monitoring, water temperature modeling studies, and other restoration activities on the Shasta River as well as neighboring reaches of the main stem Klamath River and tributaries (e.g., Scott River).

Flow: A flow study was proposed to characterize the dynamic nature of the Shasta River during late spring through fall. Subtask elements included review of existing data, reevaluation of past monitoring efforts, selection of appropriate locations, development of a flow monitoring protocol, and remote gauging of flow at fifteen-minute intervals during low flow periods (seasonally). Flow monitoring sites were chosen by dividing the study reach into five approximately equal sections. The exact location of each monitoring site was governed by access (roads and land owner cooperation). Water temperature was monitored at all flow monitoring locations. These data proved invaluable in understand the flow and thermal variability of the Shasta River and were paramount to effective modeling of flow and temperature.

Temperature: Watercourse Engineering, Inc. assisted the DFG in implementing the 2001 and 2002 temperature monitoring programs. Subtask elements included review of existing data, reevaluation of past monitoring efforts, development of monitoring protocol, selection of appropriate locations, and remote gauging of temperature at hourly intervals during low flow periods (seasonally). Hourly temperature monitoring sites were chosen based on previous DFG monitoring sites and additional locations where more data was desirable as indicated by preliminary modeling. The exact location of each monitoring site was governed by access (roads and land owner cooperation).

Meteorological Data: Climatic data for the Shasta River basin was available from Brazie Ranch weather station. No additional field studies beyond the solar radiation measurements associated with quantifying riparian vegetation shading were carried out under this project.

4.0 Model Implementation and Sensitivity Testing

Model implementation is the process of gathering and formatting all necessary data for model application, selecting default model parameters and coefficients, and verifying model operation. In order to efficiently transfer the available geometric, flow, and water quality data into a format consistent with model requirements, computer programs (or, preprocessors) were constructed. One preprocessor was written for the hydrodynamic model, ADYN, and a separate preprocessor was written for the water quality model, RQUAL. A code listing for each preprocessor can be found in Appendix C.

After completion of input files, the Shasta River model was initially tested to insure it was functioning properly. Further testing provided insight into system response, the sensitivity and relationships between various modeling parameters. This section addresses sources for the modeling data and the results of model testing prior to model application.

4.1 Modeling Data

To implement the hydrodynamic and water quality models a significant amount of data was required to represent various characteristics of the system. Since temperature was the parameter of interest and highest temperatures often occur in July and August, two six-day modeling periods were selected, July 21-27 and August 17-23 of 2001. Geometric, meteorological, flow, temperature, and vegetation data were assembled for each modeling period. The following sections describe the data sources, and estimations or approximations used when data was unavailable.

4.1.1 Geometry

To characterize the geometry of the Shasta River three types of data were required: nodes with associated river aspects, bed elevations, and cross-sectional shape.

4.1.1.1 River Grid

Both the hydrodynamic and temperature models required the construction of a "grid" or "network" of nodes to represent the stream course. Bed elevation, cross section geometry, bed roughness, stream aspect, and riparian vegetation characteristics are assigned to each node. The Shasta River grid was formed with every third point of the NHD dataset (total of 1,310 points), including the first and last points, for a total of 438 nodes. Minimum node spacing was 110 feet, with maximum node spacing of 853 feet, with the higher resolution applied in the meandering reaches. In constructing the grid, NHD river mileage was preserved so that length of the entire river (not just the study section) was maintained at 36.38 miles. Because shading logic depends upon the orientation of each small river section, care was taken to preserve the north-south aspect of each node.

4.1.1.2 River Slope

The model calculated the river bed slope from the bed elevations input with the cross-sectional data. Bed elevations were estimated from USGS 1:24,000 topographical maps.

For those nodes located between the intersections of topographic contours and the river, bed elevations were linearly extrapolated between known values.

4.1.1.3 Cross Sections

Cross-sectional data were compiled from the 2001 field studies (Abbott and Deas, 2003). Cross-sections for the modeling were assembled for each of the 24 nodes corresponding to a measured cross-section and then linearly interpolated at the intermediate nodes. (NOTE: Measured data at River Mile 17.61 was not used due to an extremely wide measurement of 101 feet. This was not considered representative, i.e., it was inconsistent with upstream and downstream river reaches.) A modified trapezoidal cross-section was calculated assuming 1:1 side slopes, the maximum measured depth was assumed to occur in the middle of the section, the bottom width was approximated by the measured water surface on the day of field measurements. Bank heights were extended five feet to allow the modeling of larger flows. The maximum depth at each node was assigned the corresponding bed elevation from the 1:24,000 USGS maps. A sample cross-section is found in Figure 4-1.

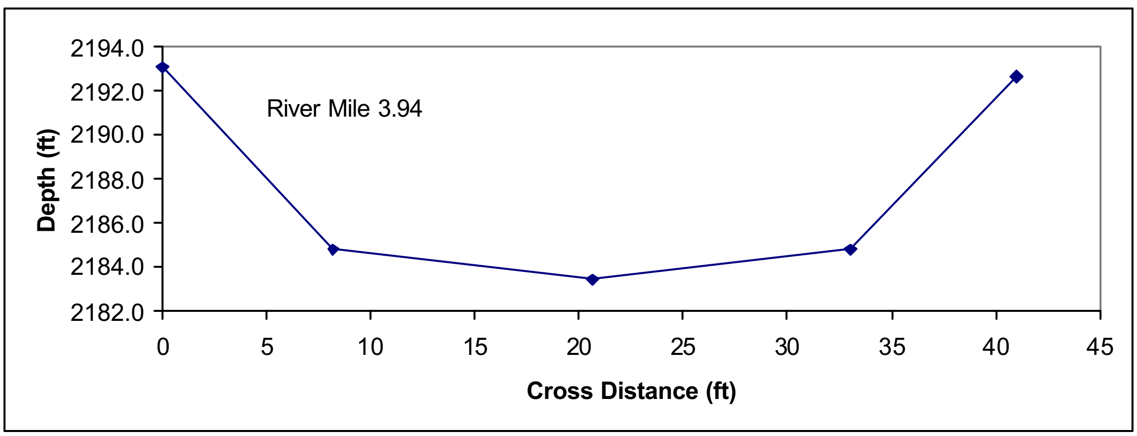


Figure 4-1 Sample cross section used for modeling river mile 3.94

4.1.2 Meteorological data

Meteorological data required to run the temperature model included cloud cover, barometric pressure (mb), dry bulb temperature (°C), wind speed (m/s), short wave solar radiation (Kcal/m^2/hr), and dew point temperature (°C). Cloud cover was assumed to be 0.0 (no cloud cover) for the simulation period, to simulate the warmest conditions and because cloud cover data was not available. Barometric pressure (P) was assumed constant (930 mb) and calculated according to the elevation (2430 ft) of the Shasta Valley (University of California Cooperative Extension, Leaflet 21372).

Hourly meteorological data was acquired from the USGS gauging site at Brazie Ranch (BZR) located to the west of the study area. The Brazie Ranch Handbar weather station is operated by California Department of Forestry. The data used from the BZR station were dry bulb air temperature (F), wind speed (mph), solar radiation (W/m^2), and relative humidity (%). The Brazie Ranch hourly data were corrected for daylight savings time by lagging the data one hour. (On the California Data Exchange Center website where the Brazie Ranch data is posted the solar radiation is listed with units of cal/cm. These units are incorrect and should be listed as W/m^2 (P. Gilbert, pers. comm.).

The dew point temperature was calculated using the relative humidity and dry bulb temperature from BZR by first converting the temperature to degrees Celsius.

$$T_c = \frac{5.0}{9.0}\left(T_f - 32.0\right)$$

Then the saturation vapor pressure (E_s) in mb was computed.

$$E_s = 6.11 \times 10.0^{\left(\frac{17.27 T_c}{237.3 T_c}\right)}$$

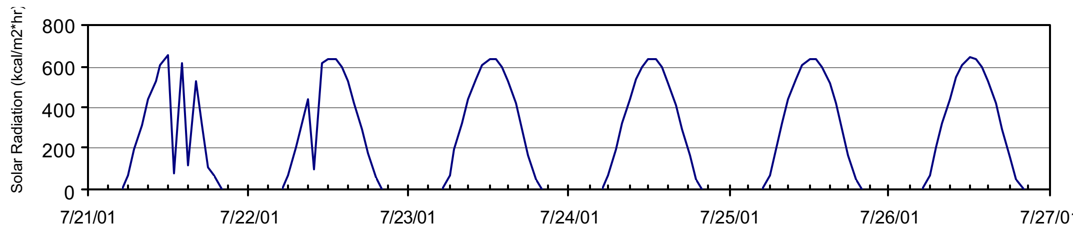
The vapor pressure (E) in mb is then computed by multiplying the relative humidity (RH, %) by the saturation vapor pressure.

$E = RH * E_s$

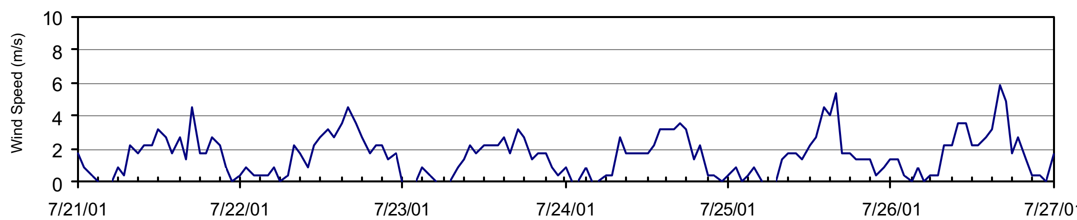
Finally dew point temperature (D) in ^{o}C is computed using the calculated vapor pressure (E).

$$D = \frac{\left(-430.22 + 237.7 + \ln\left[E\right]\right)}{\left(-\ln\left[E\right] + 19.08\right)}$$

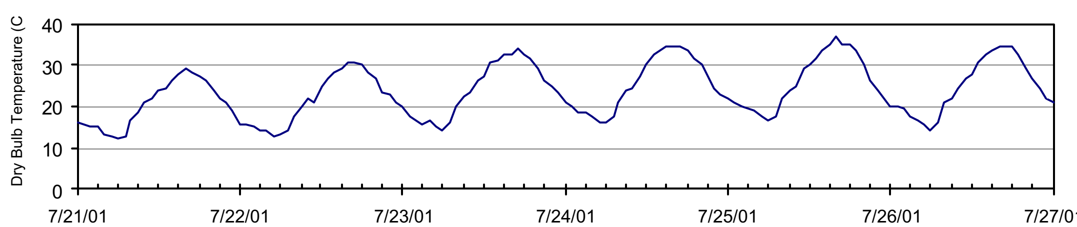
Meteorological data for modeling periods 1 and 2 can be found in Figure 4-2 and Figure 4-3 respectively.



(a)

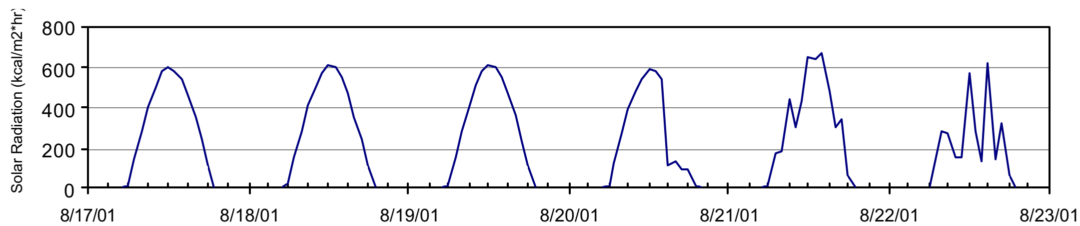


(b)

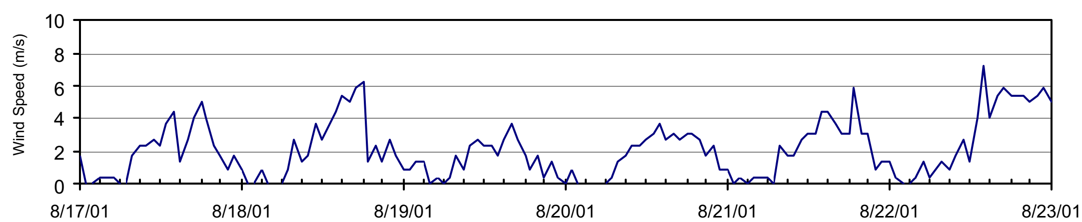


(c)

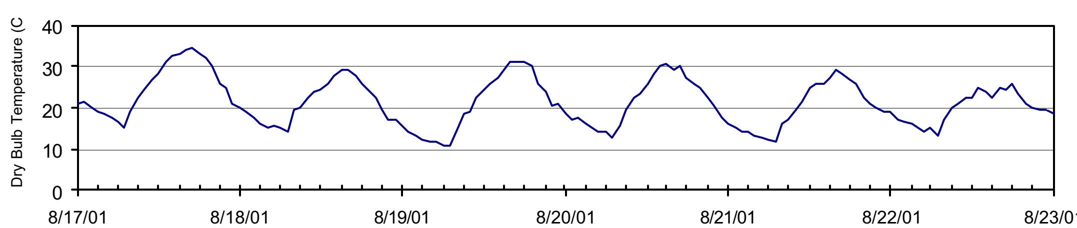
Figure 4-2 Meteorological data for July 21st to July 27th: (a) solar radiation (b) wind speed (c) dry bulb temperature



(a)



(b)



(c)

Figure 4-3 Meteorological data for Aug. 17th to Aug. 23rd: (a) solar radiation (b) wind speed (c) dry bulb temperature

4.1.3 Flow

Hourly measured flows were collected at six pressure-transducer sites in 2001 and in 2002 (Watercourse, 2001). These data were augmented with USGS gage data (RM 0.5). Hourly hydrograph at Shasta River above Parks was used as the upstream boundary condition for the hydrodynamic model. Diversions were estimated from irrigation district records, where available. Partial records were available from the Grenada Irrigation District and the Shasta Water Users Association. Parks Creek inflow was derived from the measured data. All of the above-mentioned data were used to determine the ungaged accretions (inflows) and depletions (outflows) in the system for each of the five study segments using a water balance approach.

4.1.3.1 Water Balance

The Shasta River has many ungaged diversions, spring flows, return flows and tributaries that may be described together as accretions and depletions. Because a particular reach can experience an accretion in one time period and a depletion during a subsequent time period, these ungaged flows are identified as “net accretion/depletion.” To determine accretions and depletions for each of the five study segments, a water balance approach was employed moving upstream to downstream.

Net accretions/depletions (net A/D) were assigned based on field survey, available records, and aerial photographs. The major accretion in Reach 5 was assigned to the location of Big Springs Creek. Based on flow records and aerial photographs of the channel this accretion is quite sizeable; however, the exact magnitude is unknown. Hence, this accretion was based on a water balance including Shasta River above Parks and Parks Creek measured inflows and measured flow at GID, taking into account the GID diversion. Diversions at the Grenada Irrigation District pumps were estimated from the irrigation records and include Huseman Ditch flows. Since the differences in flow between GID and A12 are small, and since little is known about this reach, net A/D for the GID-A12 reach was applied just above A12.

Between A12 and DWR, diversion by the Shasta Water Users Association was based on DWR water master records. There are accretions distributed along the reach, likely due to various return flows (e.g. Huseman Ditch, as well as others). Therefore, the net A/D was distributed uniformly throughout the entire reach. A water balance between A12 and DWR Weir, taking into account the SWA depletion, was used to determine the magnitude of net A/D of Reach 3.

Little information was available about A/D in Reach 2, so net A/D was assigned just above Anderson Grade. No accretion/depletion was calculated for Reach 1. The values of these net accretions/depletions are different for each modeling period, and vary by hour. Locations, methods of determination, and magnitudes of the accretions/depletions for each reach and modeling period are shown in Table 4-1 and Table 4-2.

Table 4-1 Location and method of determining flows

Reach	Location	River Mile	Method of determination
Upstream BC	Shasta above Parks	31.8	measured
5	Parks Creek	31.0	measured
	Net A/D: Big Springs Creek	29.9	calculated by water balance
	Diversion: GID	26.9	estimated from records
4	Net A/D: A12	21.9	calculated by water balance
3	Diversion: SWUA	16.8	estimated from records
	Net A/D: DWR	14.72–21.89*	calculated by water balance
2	Net A/D: Anderson Grade	7.9	calculated by water balance
1	N/A	N/A	N/A

* distributed throughout reach

Table 4-2 Average, minimum, and maximum values of lateral inflows (cfs)

Location	7-21 to 7-27-01			8-17 to 8-23-01		
	avg	min	max	avg	min	max
Parks Creek	5	4	8	2	2	3
Accretion: Big Springs Creek	66	61	72	59	55	63
Diversion: GID	-20	-20	-20	-10	-10	-10
Net A/D: A12	1	-4	7	-3	-7	2
Diversion: SWUA	-42	-42	-42	-42	-42	-42
Net A/D: DWR	9	1	15	11	4	54
Net A/D: Anderson Grade	-3	-16	7	0	-13	14

4.1.4 Water Temperature

Hourly water temperature data from 2001 field studies (Watercourse, 2001) were used to describe boundary conditions and for model calibration/validation. Inflow water temperatures for Shasta River above Parks and Parks Creek were taken from reported values. Water temperatures at Big Springs were assumed equal to water temperatures reported at GID. Water temperatures for all other accretions and depletions were assumed to be equal to the local temperature of the Shasta River.

4.1.5 Riparian Vegetation Representation

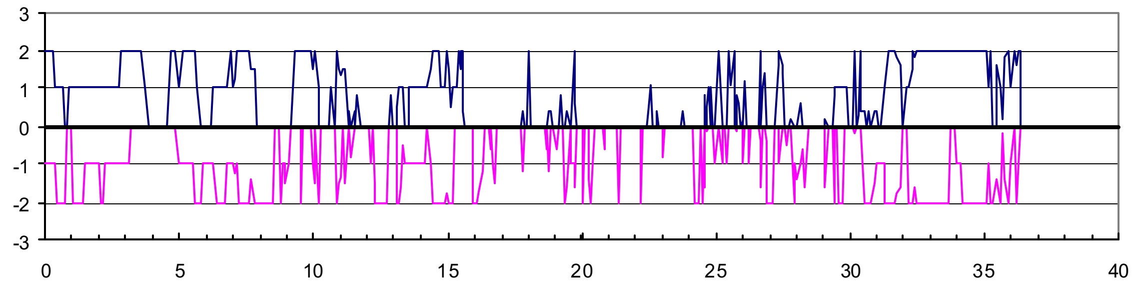
Data required to characterize riparian vegetation in the model include setback (bank width), effective barrier height, and net transmittance at each node (SHSOL). Due to the close proximity of the vegetation (where present) to the Shasta River, setback was assumed to be zero along the entire system. Because existing data do not describe riparian vegetation in detail, effective barrier (vegetation) height was estimated to be homogeneous throughout the basin and was modeled using results from the 2001 fieldwork. Tree height in the basin was estimated to be 22 feet, the average height of the majority of trees measured. Simulations tested the sensitivity of this parameter (see Section 4.2). Net transmittance is a function of the continuity, location, and density of vegetation at any particular node. These values were quantified during fieldwork completed in 1996 as cited in Shasta River Woody Riparian Vegetation (Deas, *et al.* 1996). In that study, every location was assigned a density classification, called a continuity factor (CF). Because the canopy along the Shasta River is not uniform, net transmittance at any node was estimated from weighted average of adjacent continuity factors.

Each continuity factor has an associated transmittance value. Where the CF=0 (i.e. no vegetation present) incoming solar radiation is not reduced and transmittance = 100%. Where CF=2, vegetation is continuous and transmittance is 10% (i.e. solar radiation is reduced by 90%). The transmittance value of 10% is an average value of "good" shading taken from the 2001 fieldwork (Abbott and Deas, 2003). Where CF=1, there are less than two trees per 100 feet. In these sparsely shaded areas, it was assumed that the average width-to-height ratio of a tree was 2/3, so that the width of a 22-foot high tree was 15 feet. Hence, the amount of shading over 100 feet of river classified CF=1 would be 15%, leading to an estimated transmittance of 85%. Where a node is adjacent to areas with different continuity factors, a weighted average was used to determine the net transmittance value (SHSOL) for the model. A summary of the transmittance values associated with each continuity factor is given in Table 4-3.

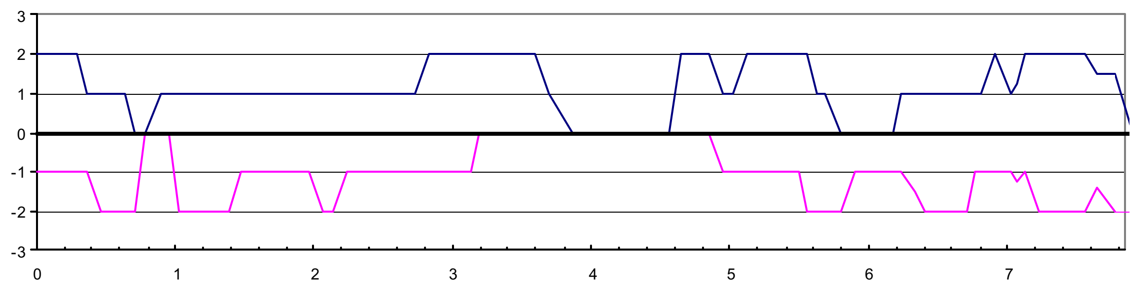
Table 4-3 Transmittance classification system

Description	Continuity Factor	Transmittance Value
No trees	0	100%
Less than 2 trees per 100 feet	1	85%
Greater than 2 trees per 100 feet	2	10%

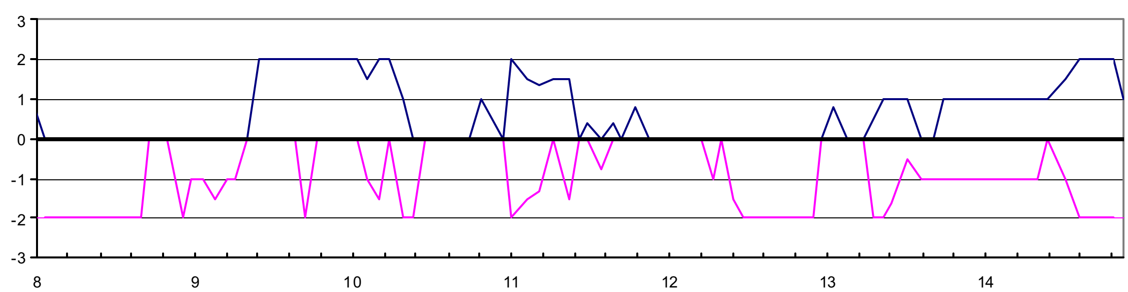
Continuity factors for right and left banks along the entire system are shown in Figure 4-4 (a). Values for the right bank are positive numbers (on the top), while left bank values are indicated by negative numbers (on the bottom). Continuity factors for each reach, ordered from the Mouth moving upstream are depicted in Figure 4-4 (b) through (f).



(a)

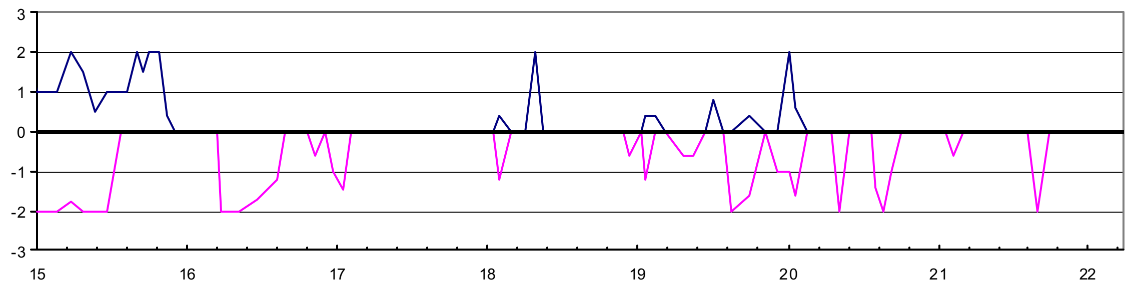


(b)

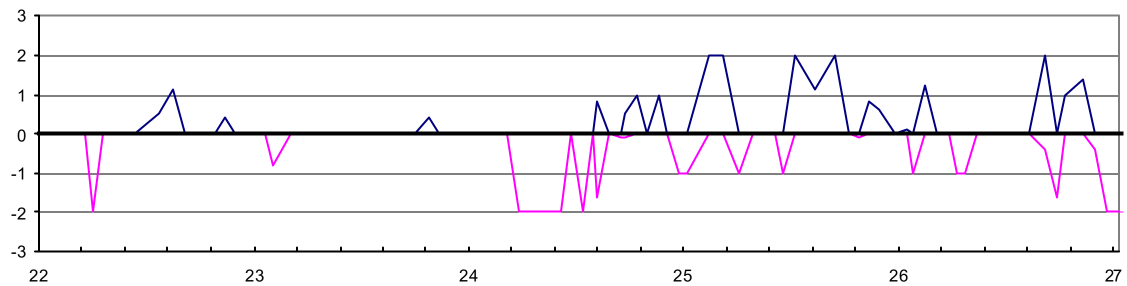


(c)

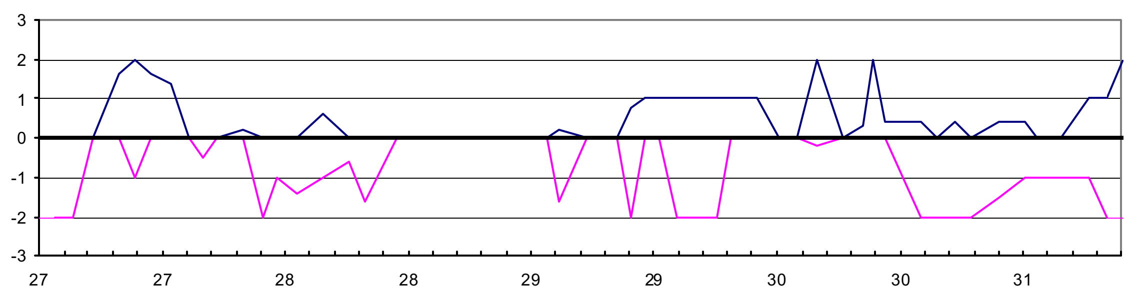
Figure 4-4 Vegetative continuity factors of the Shasta River (a) Mouth to Dwinnell Reservoir (b) Mouth to Anderson Grade (c) Anderson Grade to DWR Weir. Right bank values are positive and left bank values are negative.



(d)



(e)



(f)

Figure 4.4 cont. Vegetative continuity factors of the Shasta River (d) DWR Weir to Highway A12 (e) Highway A12 to GID (f) GID to Shasta Above Parks. Right bank values are positive and left bank values are negative.

4.1.6 Model Parameters

There are certain parameters in both the hydrodynamic and water quality components of the RMS components that were set before calibration and used throughout the modeling process. The four-point implicit scheme with an hourly time step was employed in each component. The section lists other parameters specific to each RMS component.

The flow model, ADYN, required selection of Manning's n, contraction/expansion coefficients, and numerical controls. Manning's n was set to 0.045 for each node. This value of Manning's n was chosen based on previous flow and temperature modeling of the Shasta River (CEEMG, 1998). The transition between each node was considered to be gradual so that the contraction coefficient = 0.1 and the expansion coefficient = 0.3. (Transition loss in the model is computed as the product of this coefficient and the difference in velocity head between the nodes (Hauser, 1995).) The flow model required tolerances for convergence of the Newton-Raphson iterations. The tolerance for flow = 0.005 cfs, tolerance for elevation = 0.005 feet. The weighting factor on spatial derivatives in ADYN was set to 0.55. Parameters specifications for ADYN are listed in Table 4-4.

Table 4-4 Parameters specified in flow model ADYN

Parameter	Specified value
Manning's n	0.045
Contraction coefficient	0.1
Expansion coefficient	0.3
Newton-Raphson convergence	
Flow:	0.005 cfs
Elevation:	0.005 feet
Weighting factor for spatial derivatives	0.55

The water quality component (RQUAL) required specification of river latitude/longitude, time of fog lift, wind coefficients, and numerical controls. River latitude was set to 41.875, longitude = 122.630. Since fog was not found to be a persistent condition on the Shasta River, time of fog lift was set to 6 am. The wind coefficients were initially set at: AA = 3.0E-09, BB = 1.4E-09. These coefficients were later used for calibration. The weighting factor on spatial derivatives in RQUAL was set to 0.5. Parameters specifications for ADYN are listed in Table 4-5.

Table 4-5 Parameters specified in water quality model RQUAL

Parameter		Specified value
River latitude		41.875
River longitude		122.630
Time of fog lift		6 am
Wind coefficients		
	AA:	3.0E-09
	BB:	1.4E-09
Weighting factor for spatial derivatives		0.5

4.2 Sensitivity Testing

Sensitivity testing involved making several trial simulations while varying certain parameters to ensure that the model was working properly and to assess the system response to each parameter.

4.2.1 ADYN: Flow Sensitivity Testing

Trial simulations made using the hydrodynamic model were used to check geometry file data and to compute system transit times at the following steady-state flows: 2 cfs, 5 cfs, 10 cfs, 50 cfs, 100 cfs, 150 cfs, and 200 cfs. Average velocities were captured at each node for each flow and averaged by study segment to compute travel times through each study segment. Table 4-6 contains the computed transit times. (Recall that reaches are numbered from downstream to upstream).

Table 4-6 Comparison of Shasta River transit times in hours for each study segment

Reach	Length (mi)	2 cfs	5 cfs	10 cfs	50 cfs	100 cfs	150 cfs	200 cfs
1	7.9	10.8	8.6	7.4	4.9	3.9	3.4	3.1
2	6.9	14.0	11.2	9.5	6.3	5.1	4.5	4.0
3	7.2	18.1	14.6	12.4	8.3	6.7	5.8	5.2
4	5.0	13.1	10.5	8.8	5.8	4.5	3.9	3.6
5	4.8	10.4	8.5	7.1	4.6	3.7	3.2	2.9
Total Time (hrs)		66.4	53.3	45.2	29.8	23.9	20.8	18.8
Total Time (days)		2.8	2.2	1.9	1.2	1.0	0.9	0.8

During the steady-state test runs, water surface elevation was determined and maximum water depth was calculated. Simulated maximum water depths at 10 cfs, 50 cfs, and 100 cfs are depicted in Figure 4-5. When flow was increased from 10 to 50 cfs, maximum water depth increased on average by about 1 foot. When the flow was increased from 50 to 100 cfs, maximum water depth increased on average 0.6 feet.

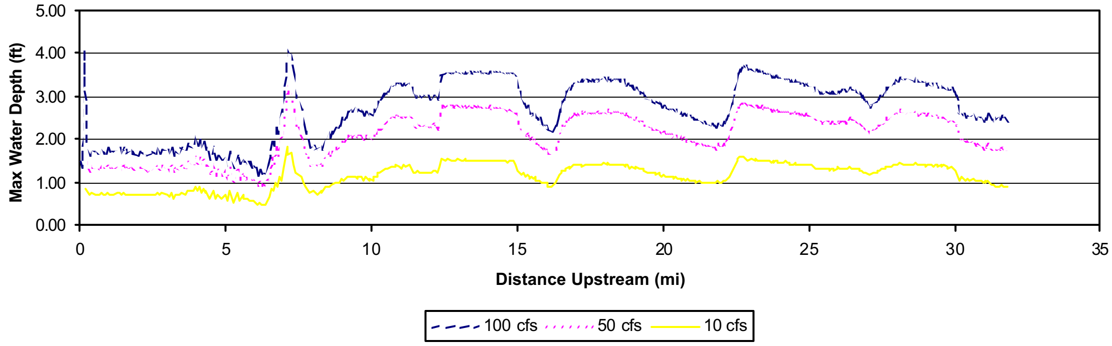


Figure 4-5 Steady-state test cases: maximum water depth

4.2.2 RQUAL: Temperature Sensitivity Testing

Using the water quality model and the Shasta River geometry file, simulations were made to test the sensitivity of the temperature response to three parameters: flow, tree height, and transmittance. Flow during these simulations was steady-state with no accretions or depletions, the upstream boundary had a constant temperature of 15°C, and meteorological data from August 28, 2001 was used.

4.2.2.1 Temperature Sensitivity to Flow

Sensitivity to flow was tested using 10 cfs, 50 cfs, and 100 cfs. The flow simulations contained no shading. Daily average temperature at each node over this range of flows is depicted in Figure 4-6.

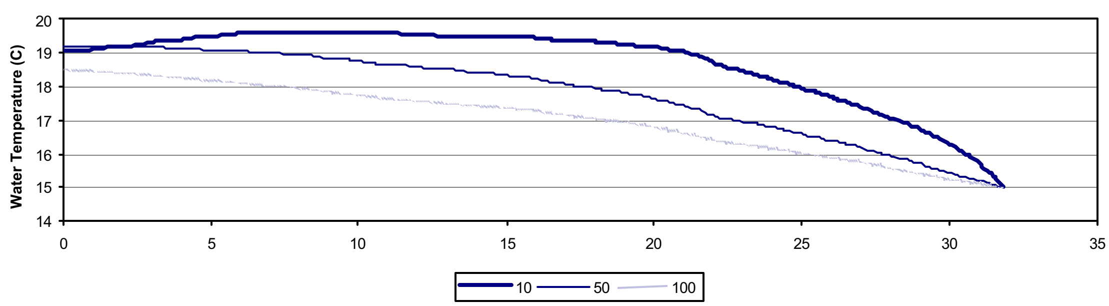


Figure 4-6 Longitudinal profile of average daily temperature by river mile for August 28, 2001 meteorological conditions for 10, 50, 100 cfs.

Notice that the flow-temperature relationship is not linear. The river warms approximately 0.7°C at the Mouth (RM 0.0) when the flow is reduced by 50% (100 cfs to 50 cfs). However, when the flow is reduced again by 80% (to 10 cfs), the river warms a maximum of 1.5°C in upper reaches and there is no net effect at the Mouth. The lack of a net effect at the Mouth is likely due to the water temperatures approaching an equilibrium with the meteorological conditions. Table 4.4 contains the average maximum and minimum daily temperatures for each of the three flow cases. This non-linear relationship illustrates that as flow increases, water temperature decreases at a slower rate. Whereas increasing flow from 10 to 50 cfs reduces the maximum daily temperature averaged over all reaches by 5°C, adding another 50 cfs only reduces the average maximum daily temperature by approximately 1.5°C.

Table 4-7 Average, maximum, and minimum temperatures for 10cfs, 50cfs, 100cfs test cases

Flow (cfs)	Average Minimum Daily Temperature (°C)	Average Maximum Daily Temperature (°C)	Avg Max – Avg Min (°C)
10	11.1	24.6	13.5
50	12.8	21.3	8.5
100	13.4	19.7	6.3

4.2.2.2 Temperature Sensitivity to Transmittance

To test the temperature response to transmittance, simulations were made over a range of flows (10 cfs, 50 cfs, 100 cfs) and transmittance factors (10%, 50%, 85%, 100%). For these simulations it was assumed that the river was fully shaded and that the trees were 22 feet in height. The effects of transmittance during flows of 50 cfs are presented in Figure 4-7. Recall that a transmittance factor of 10% translates to only 10% of the solar radiation being available for heating the river, whereas a transmittance factor of 100% represents no shading.

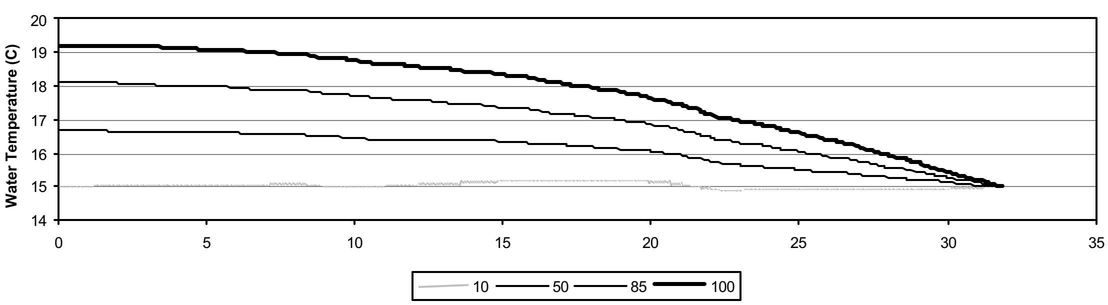


Figure 4-7 Longitudinal profile of average daily temperature for August 28, 2001 meteorological conditions for 50 cfs test case with varying transmittance (10%, 50%, 85%, 100%)

As seen in Figure 4-7, no shading produces an average daily temperature at the Mouth (RM 0.0) of 19.2°C. Reducing solar radiation by 15% translates to an average cooling of the system at the Mouth of about 1.5°C. If solar radiation is reduced to 50%, the average daily temperature is reduced by approximately 3.0°C. Finally, if solar radiation is reduced by 90%, average daily temperature is reduced by approximately 4.0°C. This last scenario implies that if the river were fully shaded and all shade has a transmittance factor of 10%, then there would be no net heating of the river through the study reach. The fieldwork supports an average transmittance factor of 10%, but recall that this simulated condition requires that the river be flowing through a "tunnel" of trees. Notice that this relationship is also non-linear (i.e. tripling the reduction in solar radiation resulted in a doubling of the reduction in average daily temperature at the Mouth).

4.2.2.3 Temperature Sensitivity to Tree Height

Sensitivity to tree height was tested using the 50 cfs test case and the average values of tree height found during the field season. Two tree heights were tested, the average tree height for Sandbar Willow (22 feet), and the average tree height for Arroyo Willow (38 feet). Temperature sensitivity to tree heights under two conditions (a) with a transmittance of 50% and (b) with a transmittance of 85% is illustrated in Figure 4-8. The average daily temperature at the Mouth in case (a) is reduced by 0.7°C when the tree height is increased to 38 feet. However, if the transmittance is increased to 85% then there is no noticeable difference in the average daily temperatures along the river due to tree height. It appears that the model is not as sensitive to variation in tree height as it is to flow and transmittance.

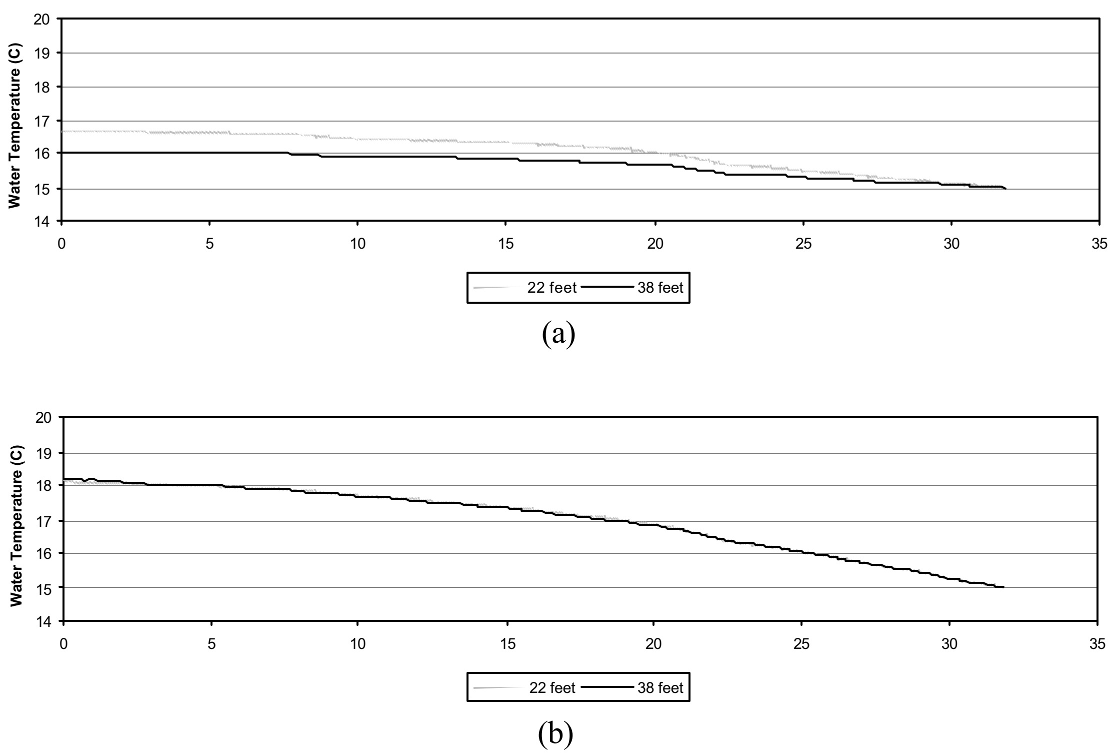
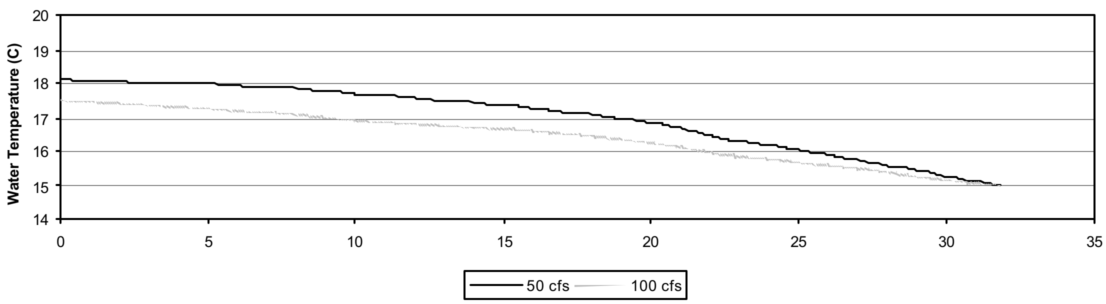


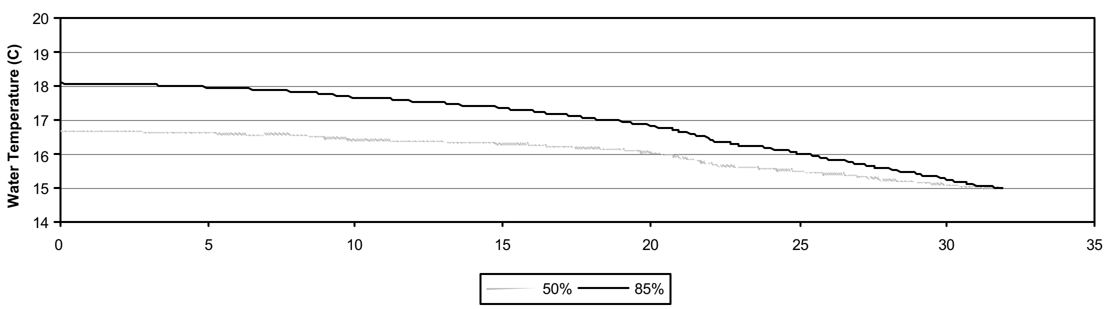
Figure 4-8 Longitudinal profile of average daily temperature for August 28, 2001 meteorological conditions for 50 cfs test case with varying tree height, (a) tr=50% (b) tr=85%

4.2.2.4 Temperature Sensitivity to Flow vs. Transmittance

The two main identified options available to lower temperature on the Shasta River are to (a) increase the flow and/or (b) increase the riparian vegetation. It is worthwhile, therefore, to compare the effects of increased flow and transmittance on water temperature. Since summer flows in the Shasta are closest to the 50 cfs test case and the majority of trees measured in the Shasta averaged 22 feet, these two parameters were used as the base case. In addition, there is currently modest riparian shading on the Shasta River; hence 85% transmittance will be used as in this base case. These simulations compare the impact of increasing flow 100%, and increasing the vegetation so that there is 50% transmittance along the entire river. Figure 4-9 (a) shows that an increase in flow reduces average daily water temperature by approximately 0.6°C at the Mouth, whereas Figure 4-9 (b) shows that an increase in vegetation reduces average daily water temperature by about 1.4°C at the Mouth. The simulated increase in vegetation has over twice the effect of the increase in flow.



(a)



(b)

Figure 4-9 Longitudinal profile of average daily temperature for August 28, 2001 meteorological conditions flow vs. transmittance sensitivity (a) flow increased from 50cfs to 100cfs (b) transmittance decreased from 85% to 50%

5.0 Model Application

Following model testing, calibration/validation and model application were completed. The model was calibrated using the field observations of flow and temperature and meteorological data from August 17th to August 23rd, 2001. Following this calibration the model was validated using the field observations and meteorological data from July 21st to July 27th, 2001. This section addresses the processes of calibration and validation, quantifying the errors of those processes, and using the model results to provide insight into various management scenarios.

5.1 Boundary and Initial Conditions

Model application required specification of boundary and initial conditions for both flow and temperature. The upstream boundary condition for flow was represented by the hourly hydrograph of Shasta River above Parks. The downstream boundary condition was calculated by the model using the Manning equation within the RQUAL model. Nine initial conditions were assigned along the system after each lateral inflow/outflow and at the Mouth using a flow and an elevation. There were seven lateral inflows/outflows as shown in Table 4.1. The upstream boundary condition for temperature was represented by the hourly temperatures measured at Shasta above Parks. The nine initial condition temperatures were specified according to the temperatures of the closest field location where observed data was available.

5.2 Flow Verification

This project included a hydrodynamic representation of the river to effectively model velocity, depth, and surface area; variables that were used in the temperature model to calculate the transport and fate of heat energy. The hydrodynamic representation was achieved by a system water balance as described in section 4.1.3. This section contains the results of the flow simulation for the calibration and validation periods. The figures contain graphs of simulated versus measured flow for all measured sites ordered upstream to downstream.

5.2.1 Calibration Period

Figure 5-1 to Figure 5-5 contain graphs of simulated versus measured flow for the calibration period, August 17th to August 23rd. All flow simulations were within 3 cfs of measured flows with two exceptions. The first exception was the short duration event observed in the DWR Weir hydrograph on August 18th. This event was apparently due to the Shasta River Water Users diversion being shut down for a period of time. It was difficult to simulate this peak because the accretion in this reach was assumed to be distributed over the entire reach. The second exception was at the Mouth. No correction was made for flow between Anderson Grade and the Mouth due to the limited information concerning accretions and depletions for this reach.

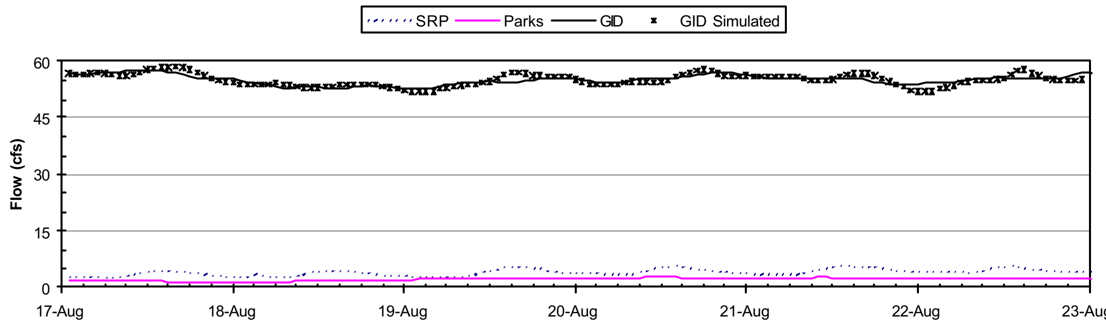


Figure 5-1 Measured vs. simulated flow for GID, Aug 17-Aug 23, 2001

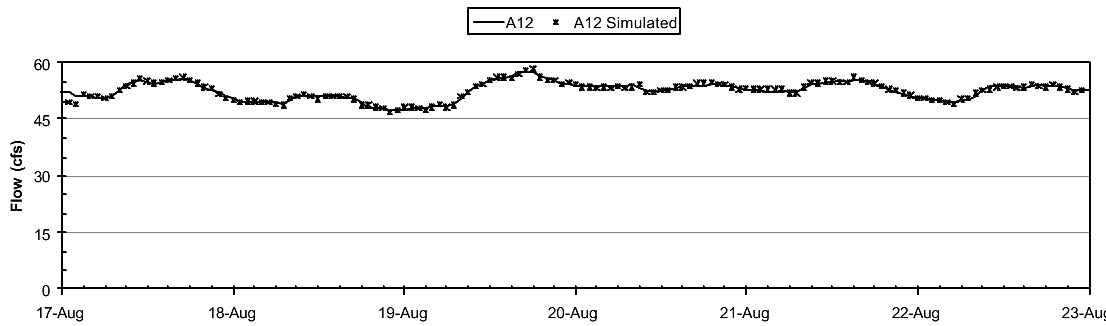


Figure 5-2 Measured vs. simulated flow for A12, Aug 17-Aug 23, 2001

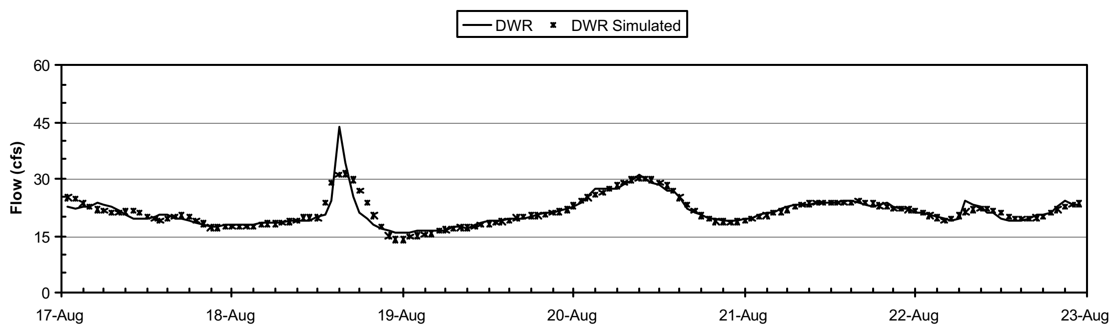


Figure 5-3 Measured vs. simulated flow for DWR Weir, Aug 17-Aug 23, 2001

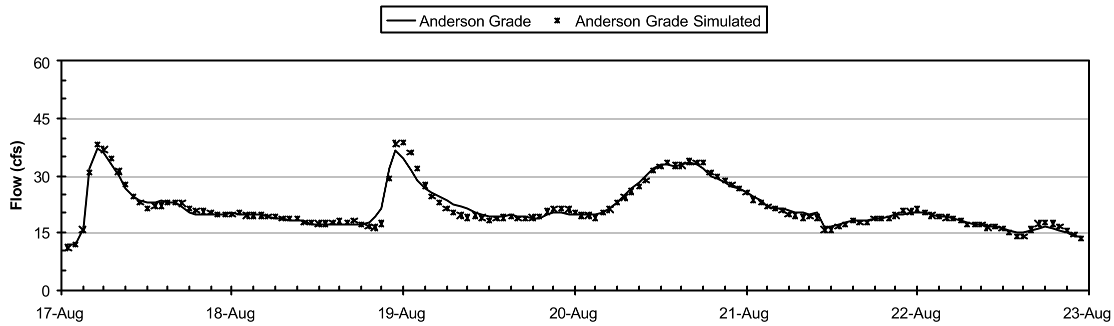


Figure 5-4 Measured vs. simulated flow for Anderson Grade, Aug 17-Aug 23, 2001

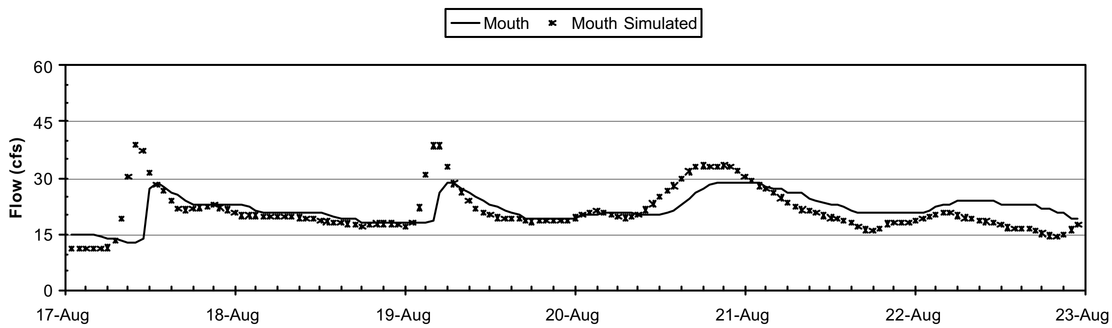


Figure 5-5 Measured vs. simulated flow for Mouth, Aug 17-Aug 23, 2001

5.2.2 Validation Period

Figure 5-6 to Figure 5-10 contain graphs of simulated versus measured flow for the validation period, July 21st to July 27th. All flows are within 3 cfs of the measured value with the exception of the flows at the Mouth. As with the calibration period, no correction was made for flows at the Mouth due to lack of data in that reach.

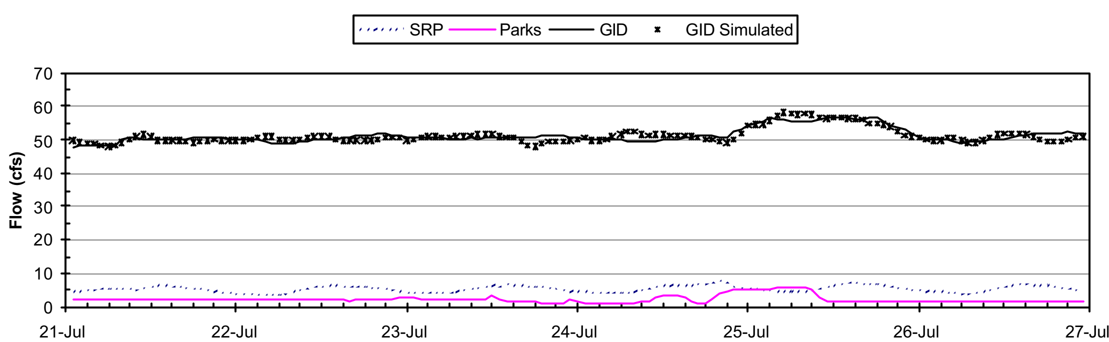


Figure 5-6 Measured vs. simulated flow for GID, July 21-July 27, 2001

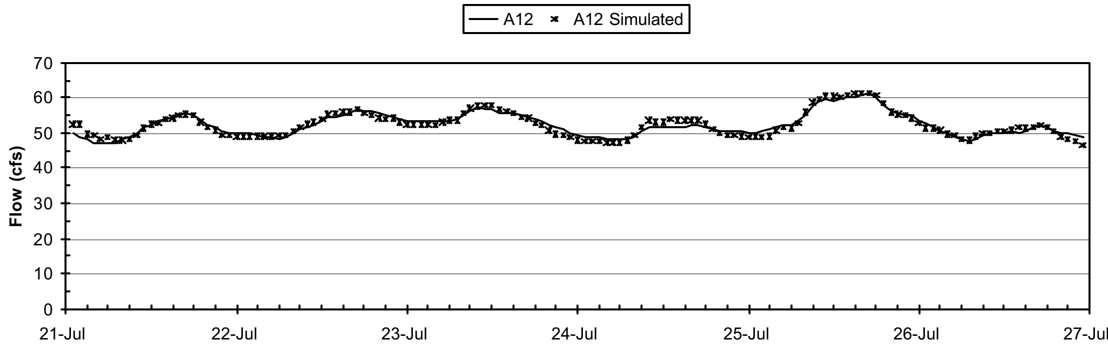


Figure 5-7 Measured vs. simulated flow for A12, July 21-July 27, 2001

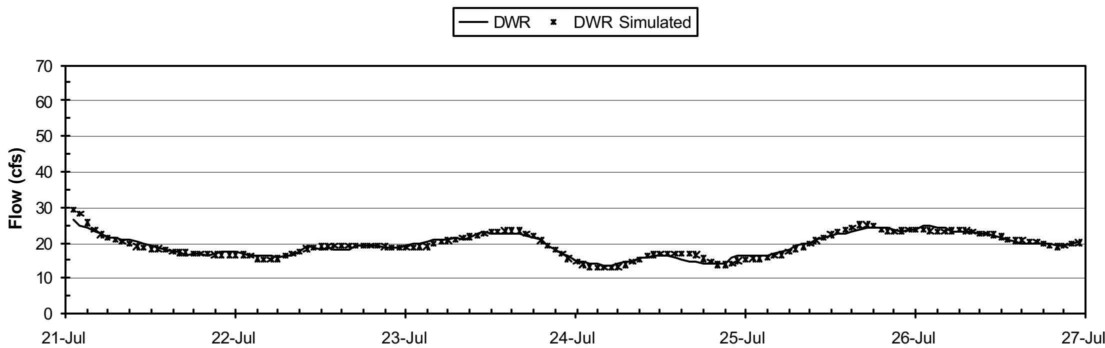


Figure 5-8 Measured vs. simulated flow for DWR Weir, July 21-July 27, 2001

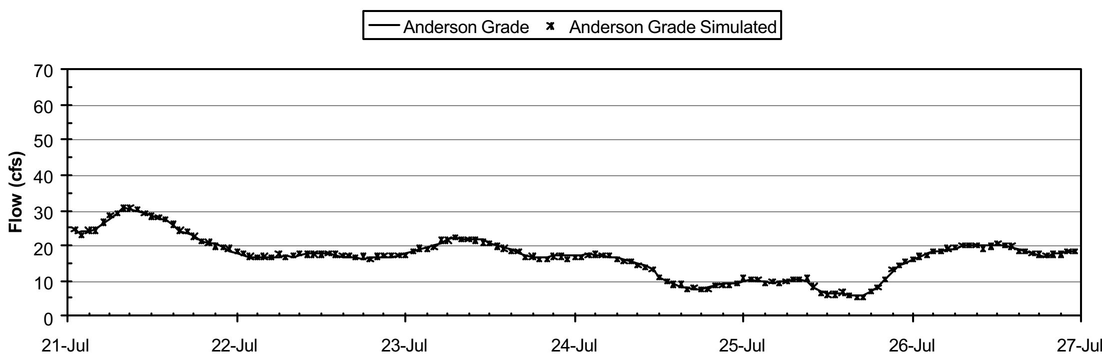


Figure 5-9 Measured vs. simulated flow for Anderson Grade, July 21-July 27, 2001

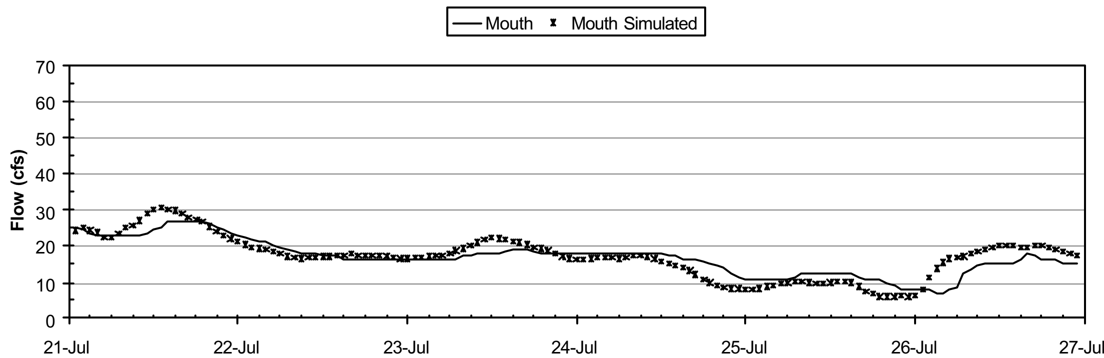


Figure 5-10 Measured vs. simulated flow for Mouth, July 21-July 27, 2001

5.3 Temperature Calibration

After verification of the flows was completed an initial temperature simulation was made with no temperatures assigned to the lateral inflows. It was evident from this first run that a diurnal temperature cycle needed to be applied to Parks Creek and the Big Springs accretion. The measured temperatures at Parks Creek were applied to the Parks Creek lateral inflow, and because measured temperatures were unavailable at Big Springs, the measured temperatures at GID were applied to the Big Springs accretion. Calibration continued by adjusting the evaporation coefficients AA and BB, refining the placement of accretions/depletions, and adjusting boundary condition temperatures. The final coefficients were AA = 0.1E-09 and BB = 1.4E-09. These are consistent with the range of default values given in the RMS User's Manual (Hauser, 1995). Simulated versus measured temperatures can be found in Figure 5-11 to Figure 5-16.

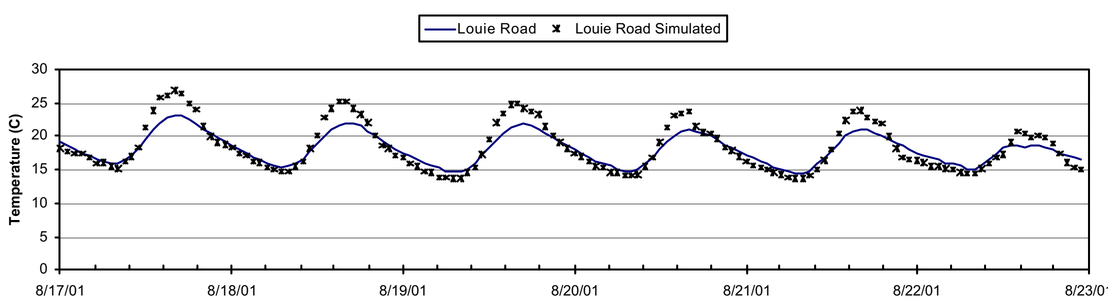


Figure 5-11 Measured vs. simulated temperature for Louie Rd., Aug 17-23, 2001

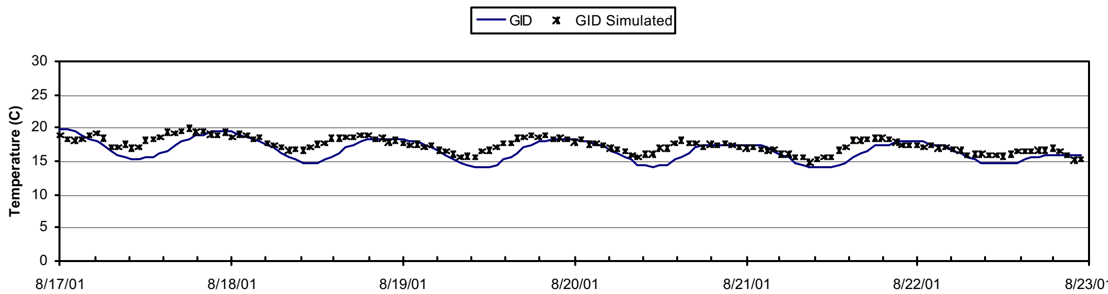


Figure 5-12 Measured vs. simulated temperature for GID, Aug 17-23, 2001

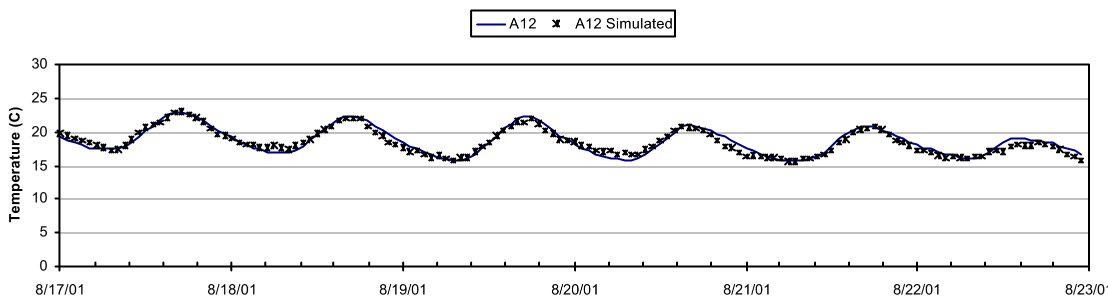


Figure 5-13 Measured vs. simulated temperature for A12, Aug 17-23, 2001

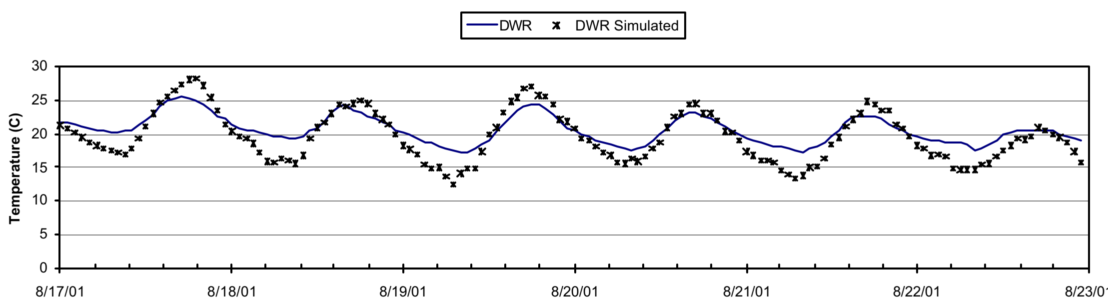


Figure 5-14 Measured vs. simulated temperature for DWR Weir, Aug 17-23, 2001

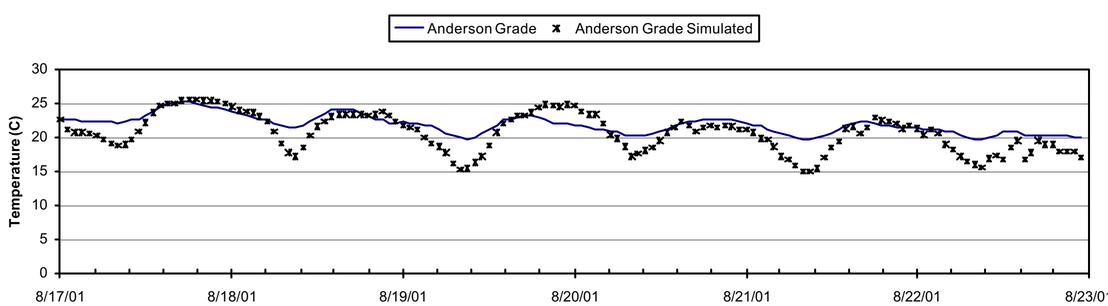


Figure 5-15 Measured vs. simulated temperature for Anderson Gr, Aug 17-23, 2001

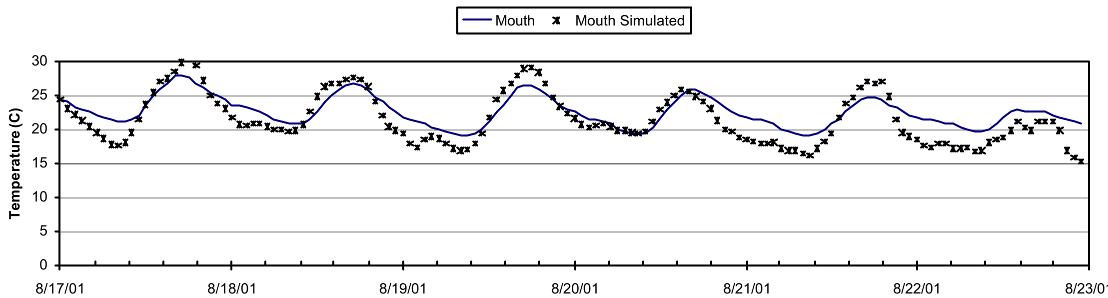


Figure 5-16 Measured vs. simulated temperature for Mouth, Aug 17-23, 2001

The water temperature regime of small rivers can be highly sensitive to meteorological conditions. The Shasta River, with highly variable flows, but generally small volumes, exhibits such behavior. This was evident during the final day of simulation, August 22nd, at Louie Road, DWR, Anderson Grade, and the Mouth. On this day at approximately 2:00 p.m. there was a disturbance in the solar radiation curve (Figure 4-3) that caused a drop in mid-day solar radiation of approximately 400 W/m^2. This was likely due to transient cloud cover. This disturbance was reflected in the temperature plots by a drop in simulated temperature at approximately the same time (see Figure 5-11 to Figure 5-16). This illustrated the model's sensitivity to meteorological conditions at low flows. However, when flows were larger, such as at GID or A12, the model was less sensitive to meteorological data.

Table 5-1 contains the error analysis of this temperature calibration. At GID (Figure 5-112) the mean absolute error (MAE) was 1.0°C. The simulated values consistently over-predict the measured values. This bias was possibly due to model sensitivity at low flows, uncertain placement and quantity of the reach A/D, assumed river geometry, and estimates on location and quality of riparian vegetation.

Table 5-1 Error analysis of the temperature calibration (°C)

Location	Average Bias	Maximum Bias	Minimum Bias	Mean Absolute Error
GID	-0.8	1.4	-3.0	1.0
A12	0.1	1.5	-1.1	0.5
DWR Weir	1.0	5.0	-3.4	1.7
Anderson Grade	1.2	4.8	-2.9	1.7
Mouth	1.1	5.5	-2.7	1.9

GID (Figure 5-12) had a MAE of about 1°C. The simulated temperature signal was out of phase with the measured signal by about 2 hours. This is most likely due to approximating Big Springs inflow temperatures with water temperatures from GID. A further confounding factor may be the accretion location and quantity. It is possible that more flow was coming into the system downstream or upstream of Big Springs, and that the Big Springs accretion was actually smaller. At A12 (Figure 5-13), the MAE was less than 0.5°C. This reach generally experienced high flows and relatively modest lateral inflows. The peaks were well positioned at DWR weir (Figure 5-14), however a there was a craggy temperature trace. Just above DWR Weir vegetation becomes more frequent. Several simulations with and without vegetation were completed to identify the source of the cragginess. It appears that the signal was due to the shading logic, or the riparian vegetation shading representation. The exact component, or interaction of components, was not identified.

The MAE at DWR Weir was approximately 1.7°C. This was likely due to placement and quantity of the a/d in this reach. To better understand this reach it would be necessary to have a gage upstream and downstream of the SWA diversion. The variation of the temperature signal at DWR was perpetuated downstream and affected the temperature trace at Anderson Grade (Figure 5-15). The simulated signal at Anderson Grade, however, did recreate the flat peaks that distinguished the measured signal. The low troughs may be partially due to the geometric approximation, an under estimation of the flow, unknown A/D location and temperature, and estimated riparian shading conditions. Further characterization of the flow conditions between DWR Weir and Anderson Grade, particularly below Yreka Creek, could lead to improved simulations in this reach. The signal at the Mouth (Figure 5-16) had the highest mean absolute error of 1.9°C. This was expected considering that a water balance was not computed between Anderson Grade and the Mouth (see Figure 5-5).

5.4 Temperature Validation

Validation is the process of applying the parameters set during calibration to an independent time period. Figure 5-17 through Figure 5-22 show the validated versus measured temperatures for each site. Similar trends appeared in the validation that were present in the calibration. Statistical analysis of validation can be found in Table 5-2.

Table 5-2 Error analysis of the temperature validation (°C)

Location	Average Bias	Maximum Bias	Minimum Bias	Mean Absolute Error
GID	-1.1	0.5	-3.3	1.1
A12	-0.2	1.9	-1.6	0.7
DWR Weir	-0.1	4.7	-5.0	1.9
Anderson Grade	-0.9	4.0	-6.5	1.9
Mouth	3.8	6.4	0.1	3.8

The phase of the temperature signal at GID (Figure 5-18) matched observed data well – about 1 hour out of phase with the measured data. This was an hour less than the calibration simulation. The MAE at GID was 1.1°C; 0.1°C more than in calibration. A12 (Figure 5-19) was the site with the lowest MAE. However, the MAE in validation was 0.7°C, 0.2°C greater than in August.

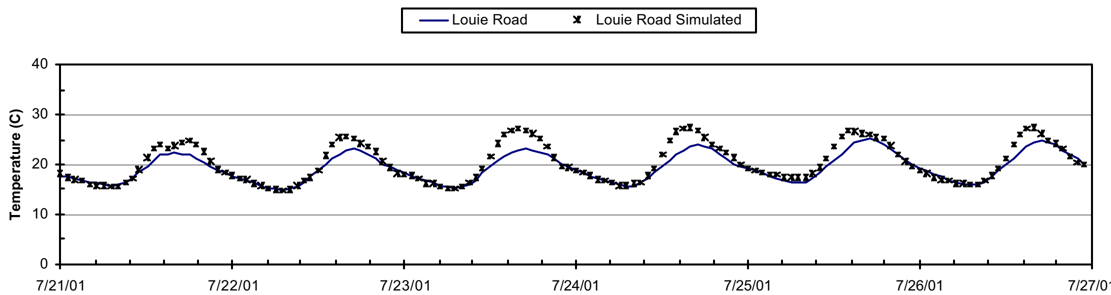


Figure 5-17 Measured vs. simulated temperature for Louie Road, July 21-27, 2001

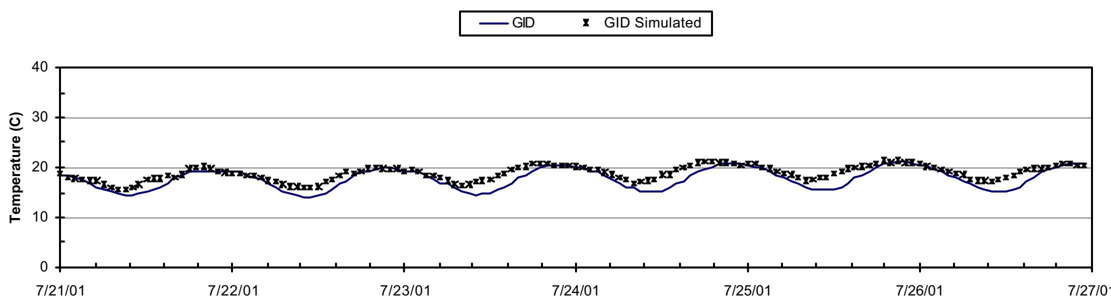


Figure 5-18 Measured vs. simulated temperature for GID, July 21-27, 2001

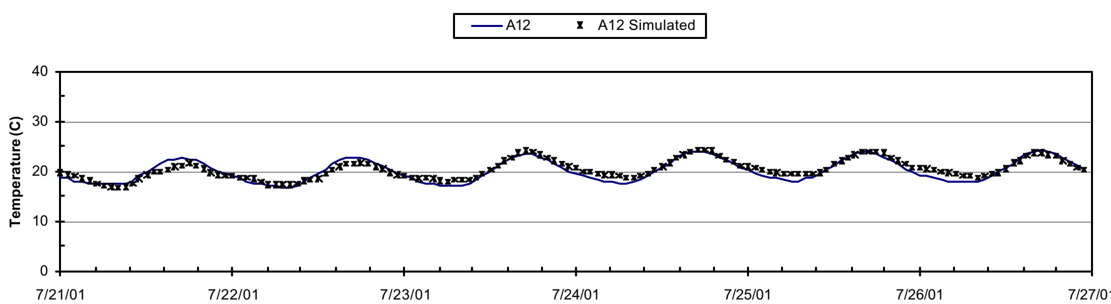


Figure 5-19 Measured vs. simulated temperature for A12, July 21-27, 2001

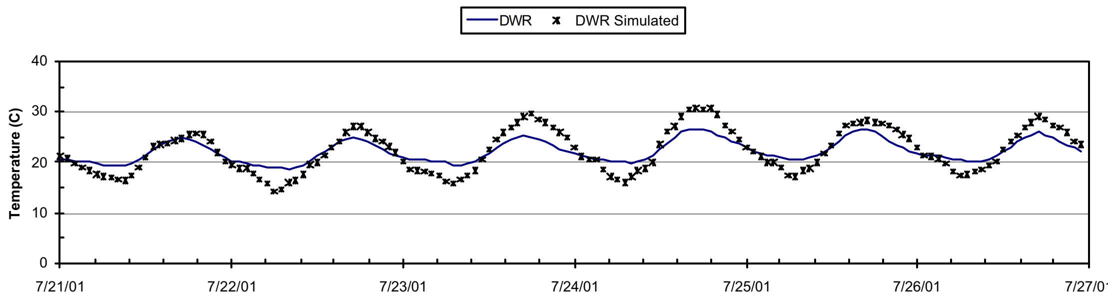


Figure 5-20 Measured vs. simulated temperature for DWR Weir, July 21-27, 2001

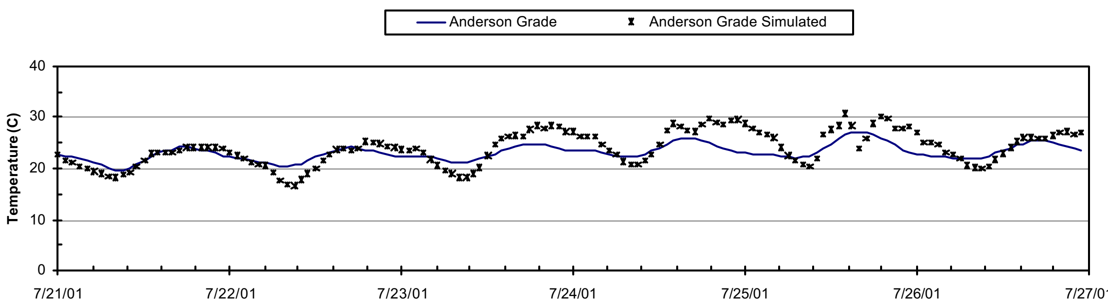


Figure 5-21 Measured vs. simulated temperature for Anderson Gr, July 21-27, 2001

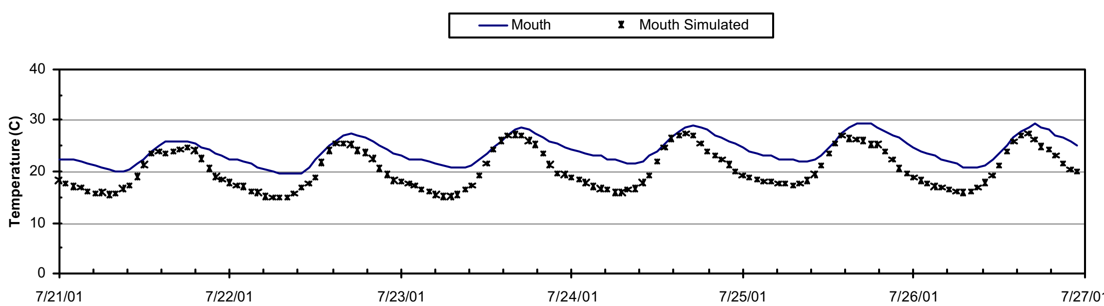


Figure 5-22 Measured vs. simulated temperature for Mouth, July 21-27, 2001

DWR Weir did not appear as craggy as in calibration and phase was well represented, but persisted in over-predicting the peaks and under-predicting the troughs with a MAE of 1.9°C, 0.2°C greater than calibration. Anderson Grade was particularly sensitive to the meteorological data on July 25th, and although the daytime lows were underpredicted, the moderated diurnal signal is evident in the simulated values. The MAE was the same as DWR Weir: 1.9°C. Again, the site at the Mouth experienced the largest deviation. However, whereas at upstream locations where the model deviations were predominately associated with amplitude, the simulated temperatures at the Mouth were systematically lower than observed data (Figure 5-22).

It was evident that the conditions that existed in calibration persisted in validation, illustrating that the model performed consistently.

5.5 Model Application

Several management scenarios were investigated with the calibrated and validated temperature model. Based on input from local stakeholders, four formal management schemes were identified to assess the potential impact on the river thermal regime.

1. Effects of modified flow regime
2. Impacts of pulse flows
3. Effects of tailwater management schemes
4. Variable riparian shading conditions

In addition, two other analyses were completed regarding variable riparian vegetation conditions along Shasta River reaches. These analyses follow riparian shading conditions study identified in item 4, listed above. Several of the studies presented in this report were completed over several months. Attempts have been made to keep performance metrics and results consistent; however, there is some variation in format.

5.5.1 Management Alternatives Study

Details and findings of the management alternatives investigated with the Shasta River Flow and Water Quality Model (SRWQM) are presented below. Basic assumptions on flow, water temperature and meteorological conditions are presented as well, followed by results for each alternative.

Scenarios associated with each alternative were based upon existing geometry, meteorology and water flows for June, August, and September 2001 and 2002. Because a complete set of inflow temperatures was not available for 2002, inflow temperatures from 2001 were employed for these studies. As a result, conditions do not necessarily represent particular historic periods as much as general conditions for spring, summer, and fall on the Shasta River. Where records of inflow temperatures were completely missing (e.g. tailwater inflows or accretion-depletions) water was assumed to enter the river at local river temperatures. As in calibration-validation, inflow temperatures for Big Springs area accretions, a significant source of water on the upper river, were assumed to be equal to those measured at Grenada Irrigation district (GID). Inflow at the headwaters of the model, Shasta River above Parks (SRP) was assumed to be 60 percent of the flow measured at Louie Road, with Parks Creek contributing 40 percent of the flow.

Boundary conditions for these investigations consisted of hourly-averaged meteorological and flow data repeated daily for seven days to minimize the effects of daily changes. Meteorological and flow were derived from reported data for the weeks of 6/14-20/2002, 8/6-12/2002, and 9/24-31/2002. Actual observed hourly water temperatures for the same weeks in year 2001 were used. Base-case simulations assumed existing shade conditions. All results, except for those from the Pulse flow study, were evaluated on the last day of simulation (Day 7). The same reaches identified earlier in this report were employed for these studies, namely: Shasta River above Parks (SRP) to Grenada Irrigation District

(GID), GID to Hwy A12 (A12), A12 to DWR Weir (DWR), DWR to Anderson Grade Road (AND), and AND to river's mouth (MOU).

5.5.2 Flow Regime Study

The relationship between flow and temperature is a well-established phenomenon in surface water systems. However, the particular impact of specific flow regimes on the water temperatures in the Shasta River is not straightforward. It has been proposed that increasing base flow in the Shasta River may potentially decrease the water temperature so as to affect the habitat for cold-water fish. The goal of this alternative was to determine the effect of altering the amount of flow in the Shasta River by adding base flow to the river at different locations at different times of the year and examining the impact on the thermal regime.

To assess the impact of flow regime on water temperature in the Shasta River additional water was added to the river base flow at rates of 10 and 20 cfs at the beginning of each study reach (SRP, GID, A12, DWR, and AND). For example, the one simulation included a 10 cfs inflow at GID. The next simulation required the removal of the 10 cfs inflow at GID and placing it at A-12, and so on for subsequent simulations. The inflow temperature for each reach was assumed equal to the river temperature at the inflow location. Thus, ten simulations were completed for each of three study period: June, August, and September. Results are compared to base-case simulations of river temperatures for each of the three study periods by examining (plotting) the deviation or temperature change compared to the baseline case. Base flow conditions are listed in Table 5-3.

Table 5-3 Average weekly base inflow boundary conditions for the flow regime alternative analysis periods

	Average Base Flow (cfs)		
Location	**June**	**August**	**September**
SRP	16.1	17.9	11.7
PKS	10.7	12.0	7.8
Big Springs	63.1	52.2	72.5
GID	-21.4	-25.0	-23.5
A12	-1.6	7.7	13.5
SWUA	-42.0	-42.0	-42.0
DWR	-2.6	-6.5	-11.1
AND	6.4	-0.3	1.2

June

June conditions suggest that the addition of 10 cfs had minimal impact on overall thermal regime, as represented by deviations in the daily maximum, mean, and minimum temperatures at the identified locations. Deviations from the base case were less than 1°C for all summary statistics (Figure 5-23). The addition of 20 cfs had a larger impact, especially on the middle and lower reaches where such inflows formed a larger proportion of the base flow. Minimum temperature dropped by up to 1.5°C, while maximum temperatures were reduced to a lesser extent in the reach between Hwy A-12 and the mouth (Figure 5-24). Certain results are counter-intuitive. For example, because the addition of water to the various reaches directly adds volume and reduces transit time, it is expected that the diurnal maximum and minimum temperature range may be reduced. However, under steady flow conditions the advective transport of thermal energy can produce aberrant temperature signals due to inflows of different quantities and temperatures. These conditions directly affect the maximum and minimum temperature values in the river at different locations. In June, where the river base line condition illustrates a decline in mean daily temperature from upstream to downstream, the addition of water at the local river temperature, results in an addition of water that is (over the daily cycle) warmer than downstream reaches. The result is a slight positive deviation for all runs from the baseline condition (for comparison, see discussion for August, below).

August

Simulation results from August suggest that as base flow drops, smaller volumes of water can have a larger impact during warm periods. The 10 cfs flow reduces maximum temperatures in the middle and lower reaches by 1°C-2°C and increased minimum temperatures by about 1°C (Figure 5-25). The 20 cfs flow reduces maximum temperatures in the middle and lower reaches by 2°C-3°C and increased minimum temperatures by about 2°C (Figure 5-26).

Mean daily temperatures show a maximum decrease of little over 0.5°C and 1.0°C for the 10 cfs and 20 cfs cases, respectively. The farther upstream the water is added, the more miles of river experience a decrease in water temperature. The largest impact occurs within the reach that illustrates the largest heat gain, which in this case is the A-12 to DWR reach. Water added at extreme downstream locations (e.g., DWR Weir, Anderson grade) do not provide the same level of benefit either in length of river affected or overall magnitude of mean daily temperature decrease. Because August conditions indicate the river is heating from upstream to downstream, the addition of water at the local river temperature, results in an addition of water that is (over the daily cycle) cooler than downstream reaches. This is the converse condition for June.

September

Simulation results from September suggest that additional water (added at local river temperature) has a modest impact if meteorological conditions produce cooler water temperatures, even when base flow is low. Meteorological conditions in September, namely solar energy considerations, are markedly different from June and August. The result is shorter days and lower solar altitude, and thus lower solar energy input to the river system. In August the simulated water temperatures ranged from roughly 17°C to

30°C, while in September the range is roughly 10°C to 20°C (Figure 5-27and Figure 5-28). Examination of the baseline condition shows the mean daily temperature from GID to the Mouth is almost constant at about 14°C to 15°C. These conditions are somewhat similar to June.

Summary

These three periods illustrate a wide range of conditions and suggest several important findings:

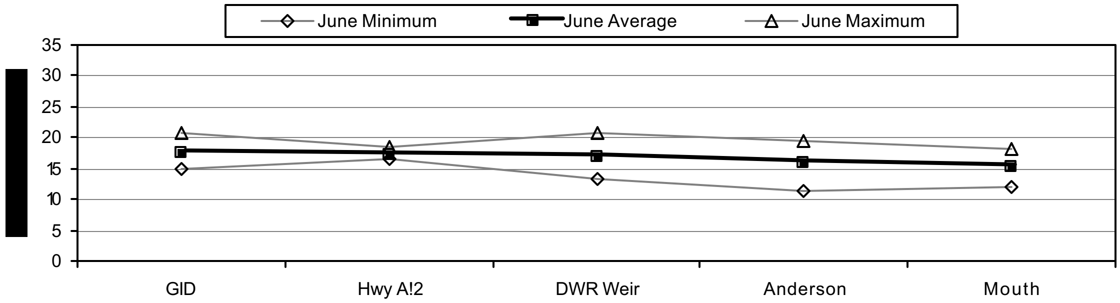
- Advection, the physical transport of thermal energy is an important consideration in the Shasta River. The transport of water from upstream locations to downstream locations affects downstream water temperature.

- When the river is generally warming in the downstream direction, additional volumes input at upstream locations reduce mean daily water temperatures over a both the length of river and in overall magnitude. The converse is true of the river is warmer in upstream reaches.

- Additional volume of water generally translates to a reduction in the diurnal range in temperatures, i.e., lower daily maximum and higher daily minimum temperatures.

- Identifying the reach or reaches with the largest heat gain (e.g. °C per mile) provides insight into the locations where the greatest opportunity for decreasing mean daily temperature through increased flow exists.

It is critical to recall that the three representative periods examined do not represent all possible conditions. Meteorology and hydrology of the Shasta River basin are highly variable annually, seasonally, and even over a few days. Short duration, severe meteorological conditions (heat waves) can occur from early-May through September.



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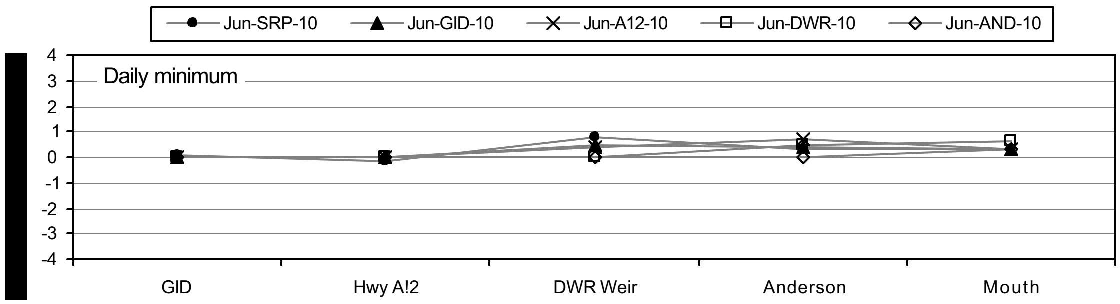

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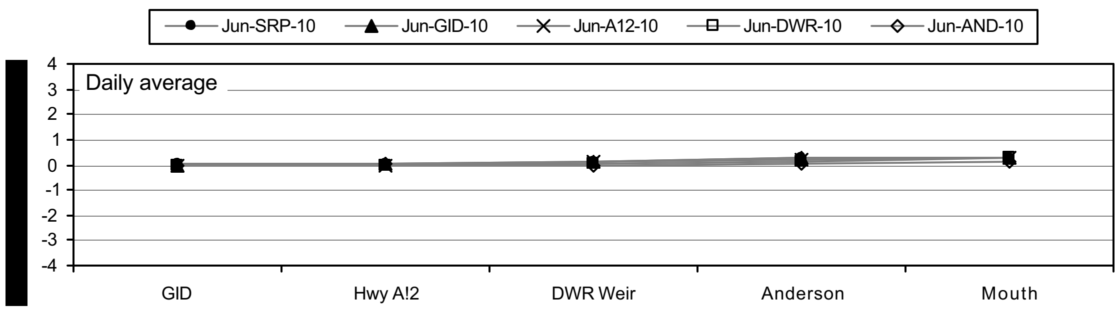

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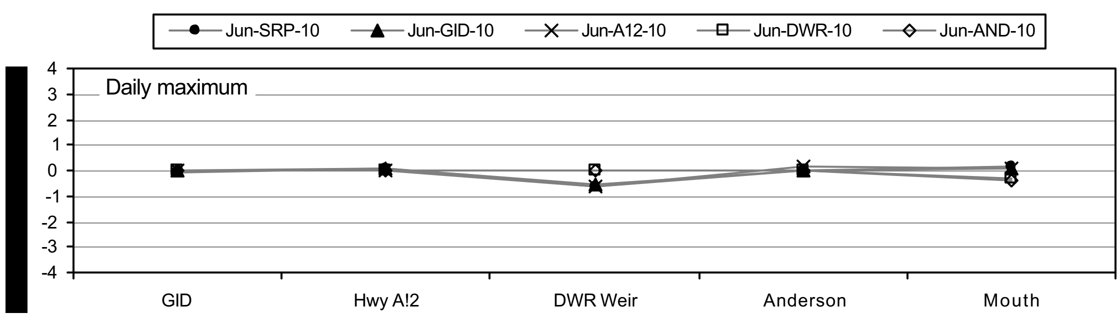

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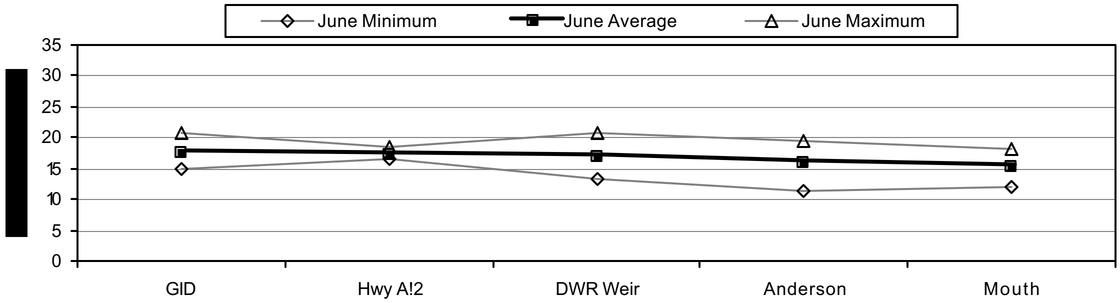
Figure 5-23 Flow Regime Study results for 10 cfs inflows in June. Deviations from (a) June base-case condition in (b) daily minima, (c) daily average, and (d) daily maxima of simulated water temperature at GID, Hwy 12, DWR Weir, Anderson Grade Road, and the mouth of the Shasta River.



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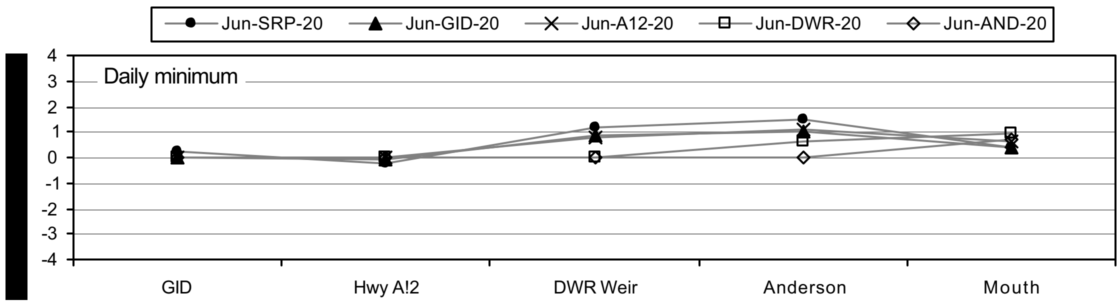

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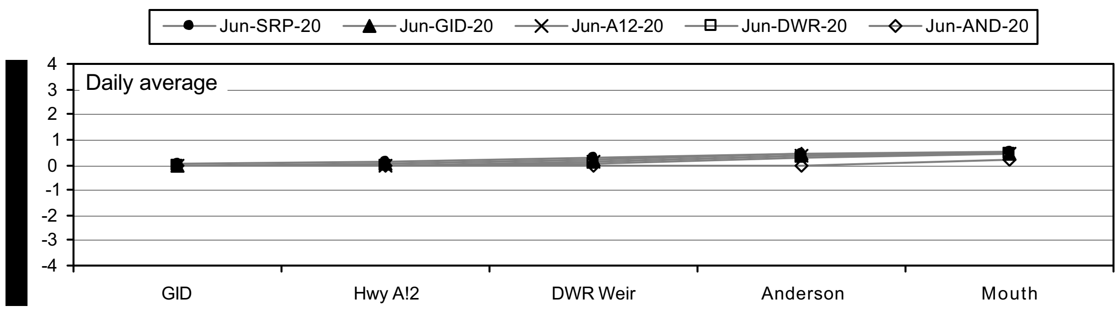

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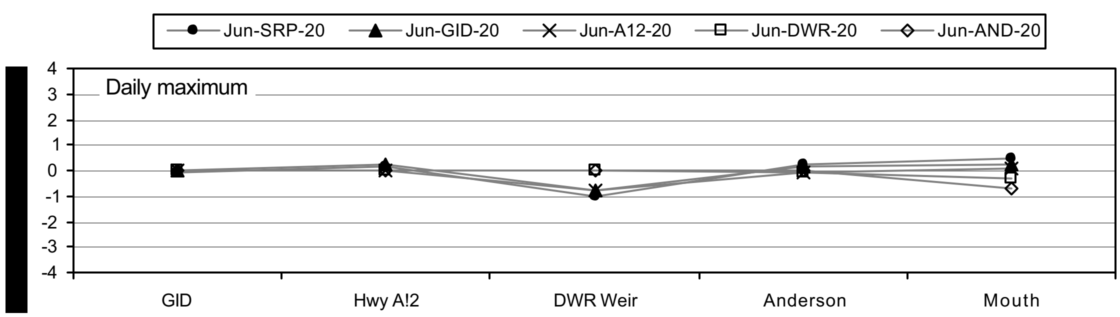

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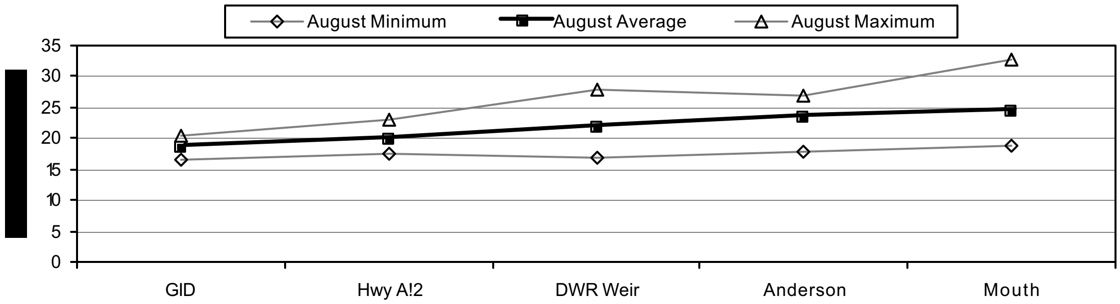
Figure 5-24 Flow Regime Study results for 20 cfs inflows in June. Deviations from (a) June base-case condition in (b) daily minima, (c) daily average, and (d) daily maxima of simulated water temperature at GID, Hwy 12, DWR Weir, Anderson Grade Road, and the mouth of the Shasta River.



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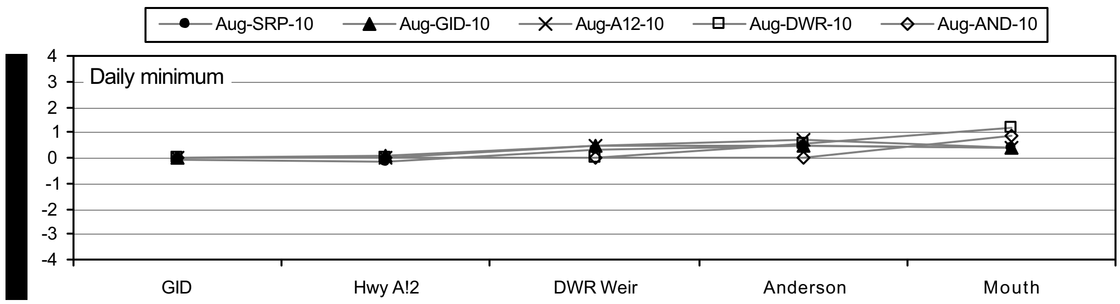

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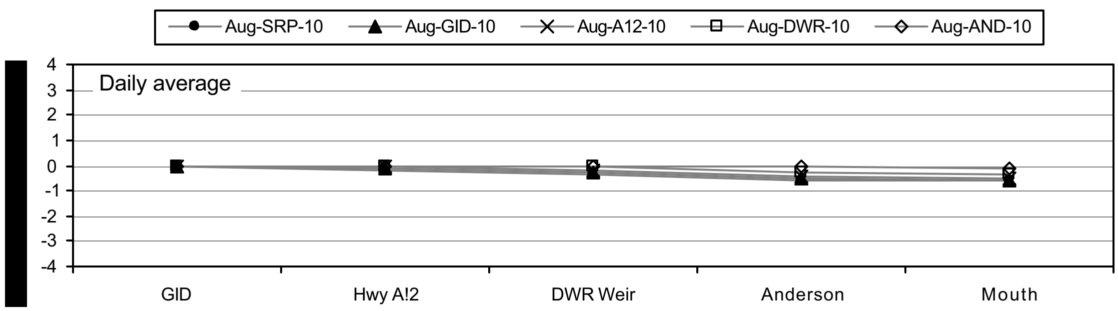

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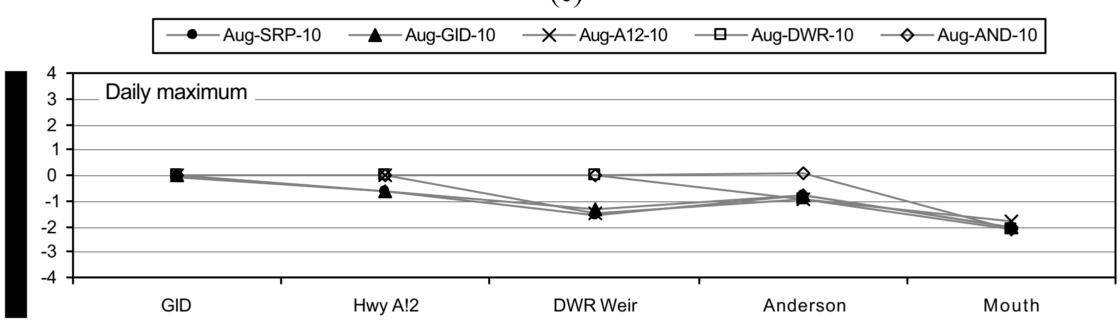

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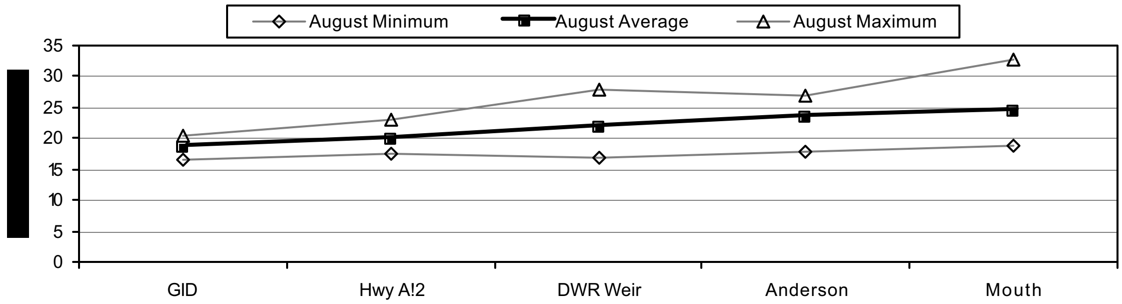
Figure 5-25 Flow Regime Study results for 10 cfs inflows in August. Deviations from (a) August base-case condition in (b) daily minima, (c) daily average, and (d) daily maxima of simulated water temperature at GID, Hwy 12, DWR Weir, Anderson Grade Road, and the mouth of the Shasta River.



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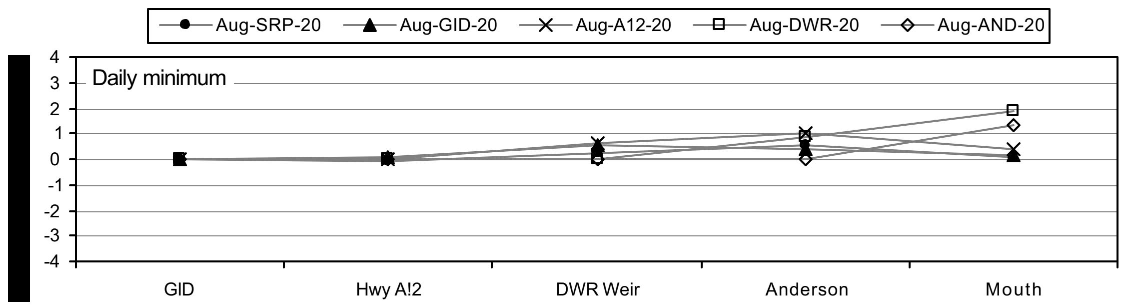

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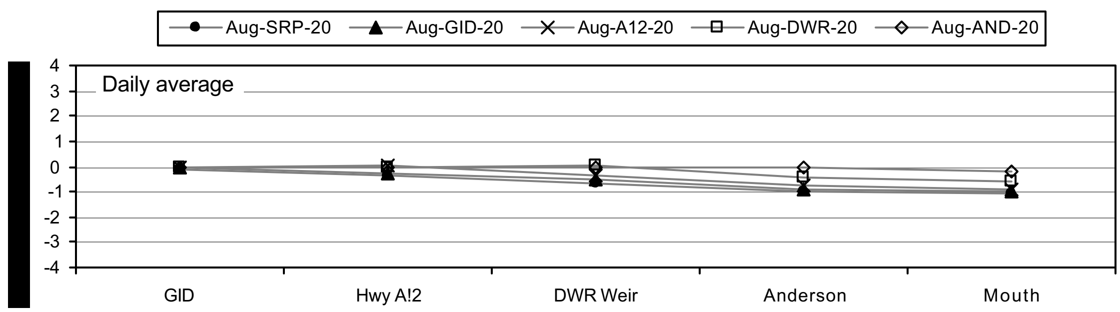

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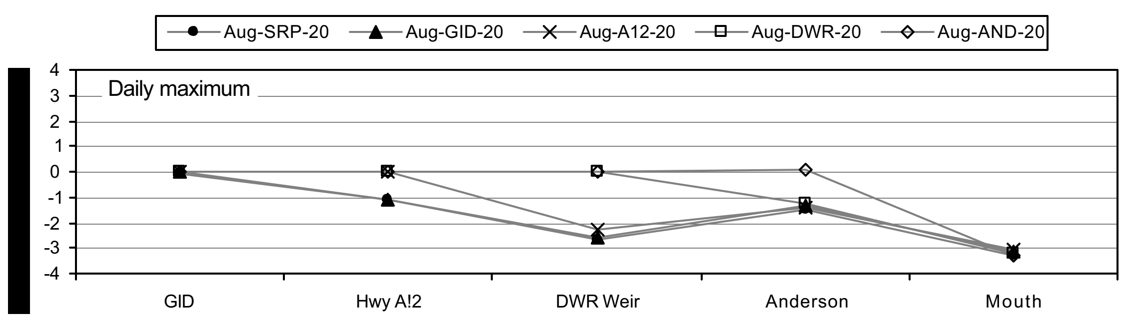

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Figure 5-26 Flow Regime Study results for 20 cfs inflows in August. Deviations from (a) August base-case condition in (b) daily minima, (c) daily average, and (d) daily maxima of simulated water temperature at GID, Hwy 12, DWR Weir, Anderson Grade Road, and the mouth of the Shasta River.

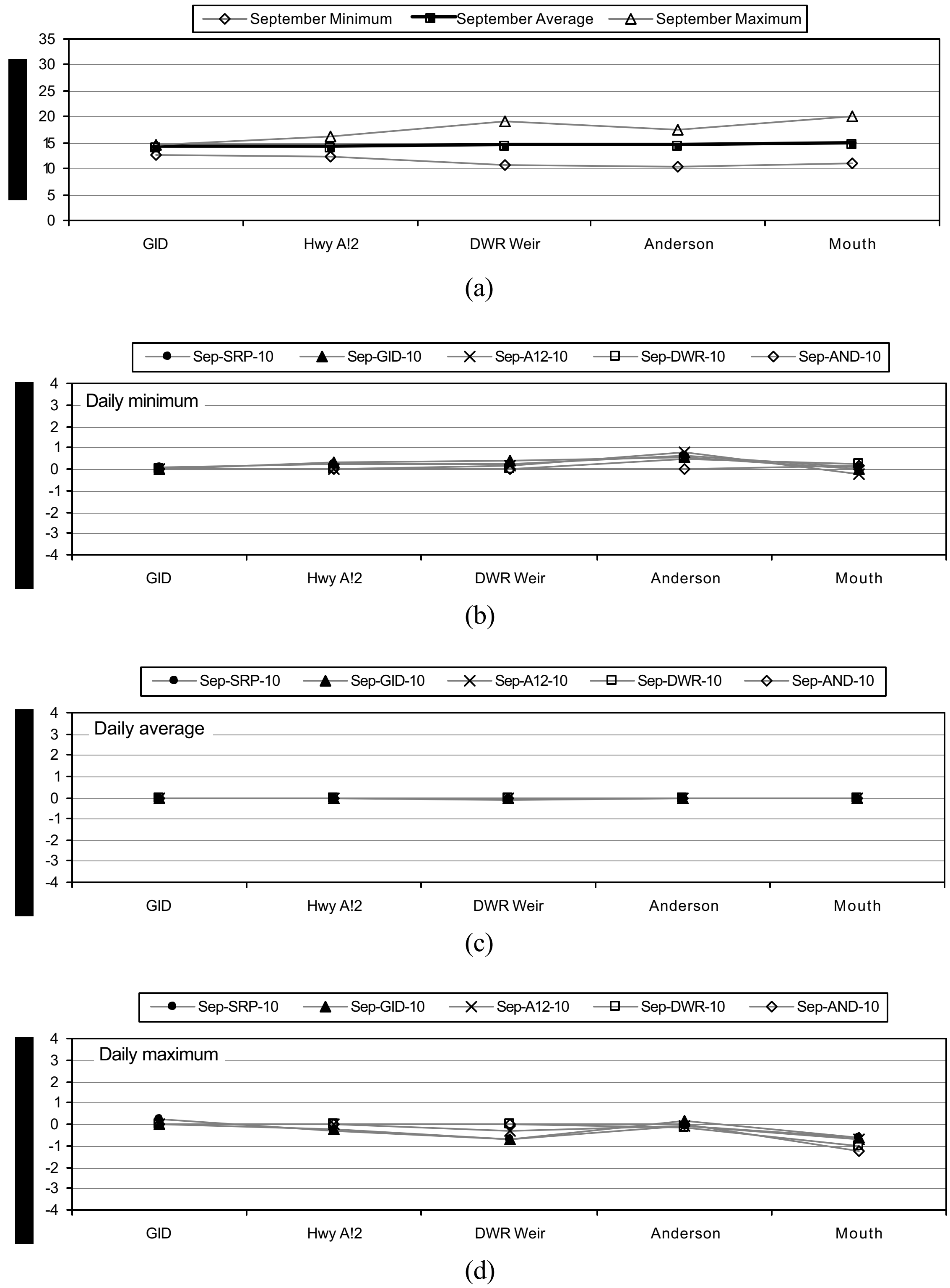
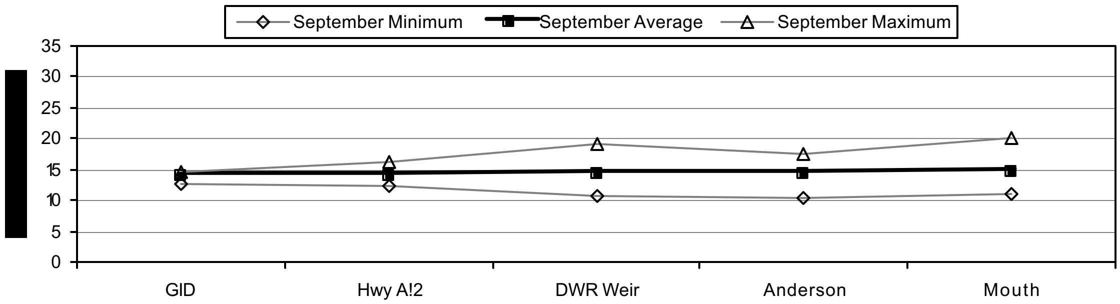


Figure 5-27 Flow Regime Study results for 10 cfs inflows in September. Deviations from (a) September base-case condition in (b) daily minima, (c) daily average, and (d) daily maxima of simulated water temperature at GID, Hwy 12, DW R Weir, Anderson Grade Road, and the mouth of the Shasta River.



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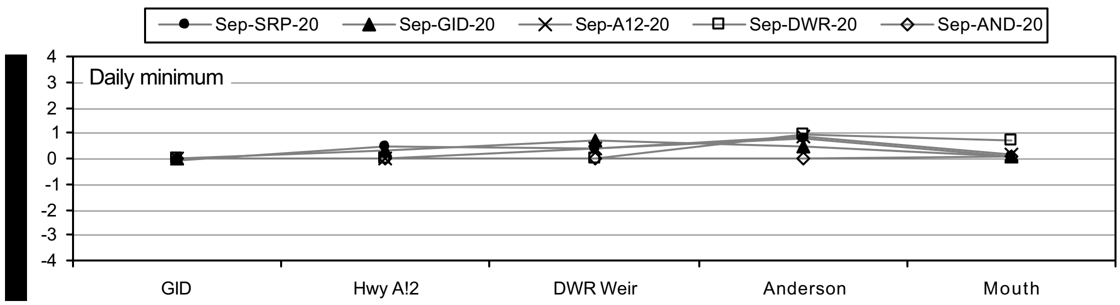

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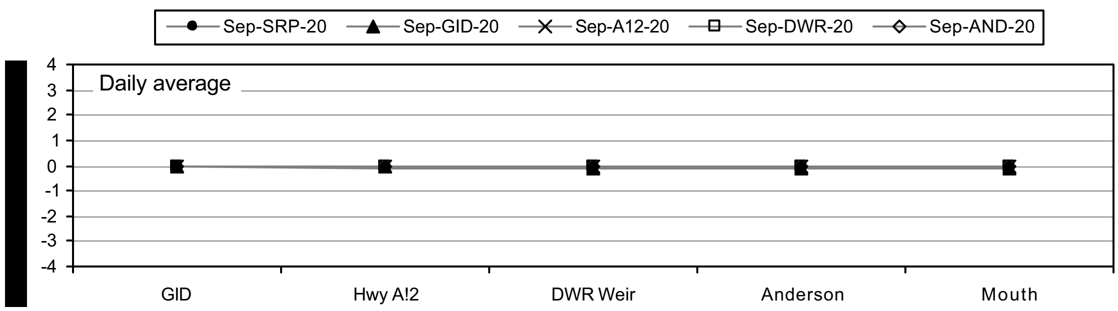

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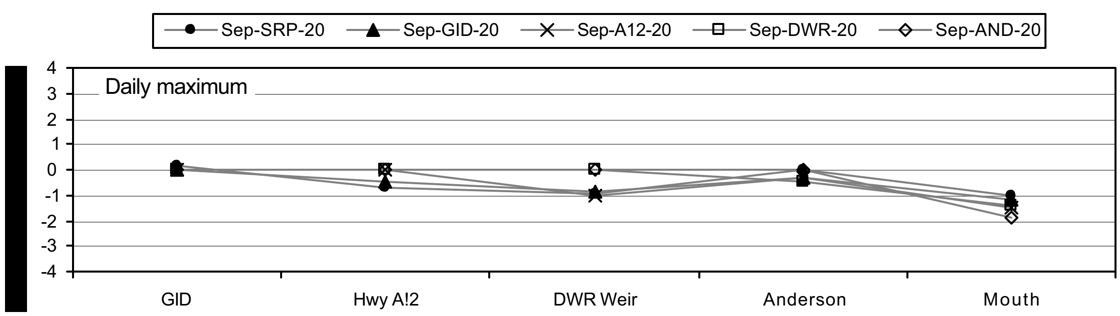

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Figure 5-28 Flow Regime Study results for 20 cfs inflows in September. Deviations from (a) September base-case condition in (b) daily minima, (c) daily average, and (d) daily maxima of simulated water temperature at GID, Hwy 12, DWR Weir, Anderson Grade Road, and the mouth of the Shasta River.

5.5.3 Pulse Flow

As noted in the flow regime study, above, there is a relationship between flow and temperature in surface water systems. The purpose of this scenario is to assess this relationship for a special pulse flow operation that is often carried out in the spring period (May/June) to assist outmigrating juvenile salmonids. Simulating this highly dynamic process is intended to assess flow and temperature during that pulse.

The dynamic flow regime from a week in early June was used to determined accretions and depletions in the system. The pulse flow was be simulated by adding water at the quantity and locations specified below in two scenarios. The first scenario represents a "sequential" pulse flow where flows were added (i.e., diversions terminated) in sequential order as the pulse travels down stream. The pulse flow was continued for 48 hours at any given location. For the sequential scenario the pulse was presumed to start at Dwinnell Dam at 3 a.m., and was estimated to arrive at Shasta above Parks (RM 31.8) five hours later. The model was used to route the pulse flow from Shasta above Parks to each identified site (see below). The second scenario represents a "simultaneous" operation where all users shut down at 7 p.m. on the first day and stay off line for 48 hours, then resume (no specific ramping of diversion rates will be applied).

- Montague Irrigation District - 10 cfs (to be applied at Shasta above Parks)[1]
- Grenada Irrigation District and Huseman Ditch – 50 cfs
- Novy Dam – 3 cfs (combined with Grenada Irrigation District and Huseman Ditch)
- Shasta Water Association, and other users – 50 cfs (applied at SWA)
- Highway 3 – 12 cfs
- Yreka-Ager Road – 3 cfs

The schedule for both the sequential and simultaneous pulse flows are provided in Table 5-4. The travel times, mean reach velocity, and arrival times of the pulse as derived from the hydrodynamic model are provided for the sequential and simultaneous pulse flows in Table 5-5 and Table 5-6. Not, travel time through the system is on the order of one day.

Table 5-4 Actual Inflow Schedule

Location	Flow (cfs)	Reach Travel time (hrs)	Inflows applied at hour: "Successive"	"Simultaneous"
SRP	10	5.0	8 (day 1 8:00)	19 (day 1 19:00)
GID	53	4.0	12 (day 1 12:00)	19 (day 1 19:00)
SWUA	50	9.0	21 (day 1 21:00)	19 (day 1 19:00)
HWY3	12	3.0	24 (day 2 0:00)	19 (day 1 19:00)
AGER	3	1.0	25 (day 2 1:00)	19 (day 1 19:00)
All diversions reinstated 48 hours after terminated				

Table 5-5 Sequential pulse flow data

Reach	Upstream Inflow Location	Location	Begin (RM)	End (RM)	Length (mi)	Mean Vel (ft/s)	Travel time (hr)	Pulse Arrival (hr)
-	Dwinnell	SRP	36.4	31.8	4.6	1.5	4.5	7.5
1	SRP	GID	31.8	26.9	4.9	1.6	4.4	11.9
2	GID	A12	26.9	21.9	5.0	1.8	4.1	16.0
3	A12	DWR	21.9	14.7	7.2	1.7	6.0	22.0
4	DWR	AND	14.7	7.9	6.8	2.2	4.5	26.5
5	AND	MOU	7.9	0.0	7.9	3.5	3.3	29.8

Dwinnell – release from the Montague Water Conservation District Canal
SRP – Shasta River above Parks
GID – Grenada Irrigation District
A12 – Highway A-12
DWR – DWR Water Master weir at Montague Grenada Road
AND – Anderson Grade
MOU – Mouth of the Shasta River
SWUA – Shasta Water Users Association

Table 5-6 Simultaneous pulse flow data

Reach	Upstream Inflow Location	Location	Begin (RM)	End (RM)	Length (mi)	Mean Velocity (ft/s)	Travel time (hr)	Pulse Arrival (hr)
-	Dwinnell	SRP	36.4	31.8	4.6	1.50	4.5	23.5
1	SRP	GID	31.8	26.9	4.9	1.64	4.4	23.4
2	GID	A12	26.9	21.9	5.0	1.69	4.4	23.4
-	SWUA	DWR	16.8	14.7	2.1	2.08	1.5	20.5
-	HWY3	AND	12.3	7.9	4.4	2.55	2.5	21.5
-	HWY3	MOU	12.3	0.0	12.3	3.15	5.7	24.7

Dwinnell – release from the Montague Water Conservation District Canal
SRP – Shasta River above Parks
GID – Grenada Irrigation District
A12 – Highway A-12
DWR – DWR Water Master weir at Montague Grenada Road
AND – Anderson Grade
MOU – Mouth of the Shasta River
SWUA – Shasta Water Users Association

Figure 5-29 illustrates longitudinal profiles of water temperature for pre-pulse flow conditions, as well as representative day one and day two conditions for the sequential and simultaneous pulse flows. Distance upstream represents miles from the Shasta River mouth. Prior to the pulse flow, all scenarios are coincident, which is to be expected. After one day, the impacts of pulse flow operations are evident between river miles 10 and 25. After two days the changes in thermal regime are between 1°C and 2°C throughout much of the middle and lower river reaches. The results indicate that the increased flow have reduced transit times and increased river volume.

The implications of these conditions are more clearly illustrated in time series of temperatures at SRP, GID, A12, DWR, AND, and MOU locations. Examining Figure 5-30 it is apparent that the peak daily temperature occurs earlier once the pulse flow has started (both sequential and simultaneous). Recall from Figure 5-23(a) that the river for the June period is warmer at upstream locations than downstream. Thus, not only does the peak occur earlier due to increased mean stream velocity, but in several cases the peak temperature is equal to or higher than the base condition. Reiterating the aforementioned point, this occurs because upstream conditions are warmer than downstream conditions. The conditions at DWR for baseline conditions suggest that this is one of the warmest locations on the river for the selected base line conditions with water temperatures peaking out at hour 40 at nearly 21°C. The larger volumes associated with the pulse flows result in a more moderated diurnal range at this location.

Generally there are only modest differences between the sequential and simultaneous pulse flow operations. Results at DWR and MOU suggest that the sequential scenario maintains lower minimum temperatures at certain times of the operation. After the pulse flow operations are terminated, conditions tend to return to baseline temperatures.

Summary

These two pulse flow operations suggest:

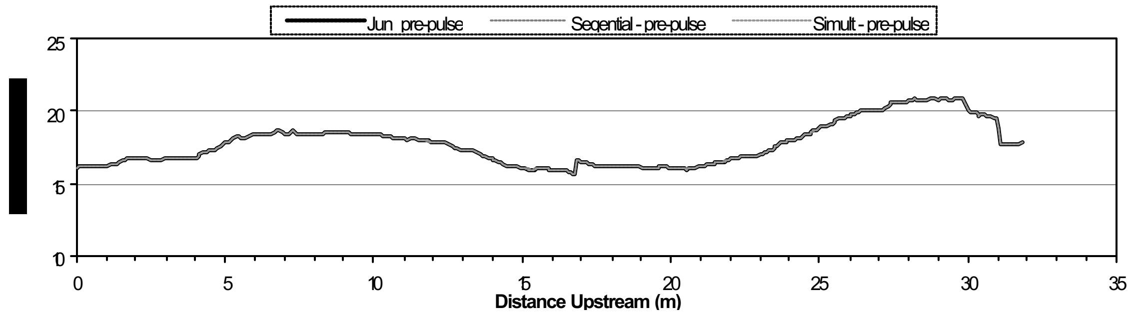
- As with the flow regime study, advection, the physical transport of thermal energy is an important consideration in the Shasta River in pulse flow operations. The transport of water from upstream locations to downstream locations affects downstream water temperature.

- Because the pulse flow traverses the river system in roughly one day, timing the commencement of the pulse flow operation should be examined in further detail. For example, it may yield more beneficial conditions for the simultaneously pulse flow operations if diversions were terminated at 7:00 a.m., when water temperatures are near minimum values than at 7:00 p.m. when water temperatures are still elevated above the mean daily values.

- Water temperature conditions should be monitored prior to and during the pulse flow. Temperature of release waters from Dwinnell (Montague Water Conservation District Canal) and in-river temperatures at intermediate locations should be determined prior to the pulse to ensure that desired water temperature conditions exist within the system. If upstream conditions are warmer than downstream, there is potential to heat the river (mean daily temperature). If upstream conditions are cooler, there is potential to cool the river with pulse flow operations.

- Further explore biological impacts on juvenile salmonids of shifting the peak daily temperature to earlier in the diurnal cycle, e.g., does shifting the diurnal signal promote, deter, or have no effect on outmigration.

- Additional conditions should be analyzed to examine the potential range of spring time, pulse flow conditions (flow, water temperature, and meteorological conditions). Variable meteorological conditions and magnitude and timing of pulse flows would lend additional insight into potential management actions.



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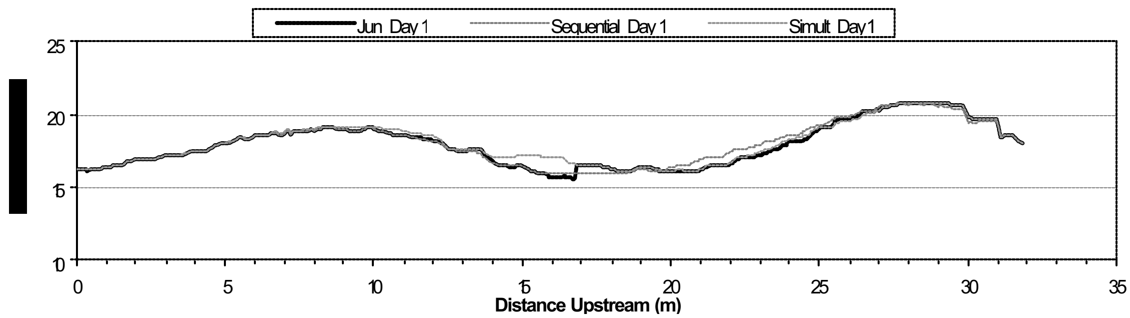

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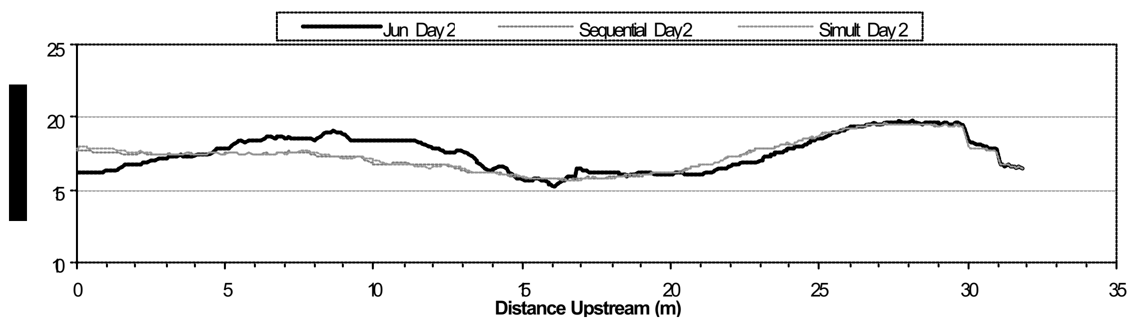
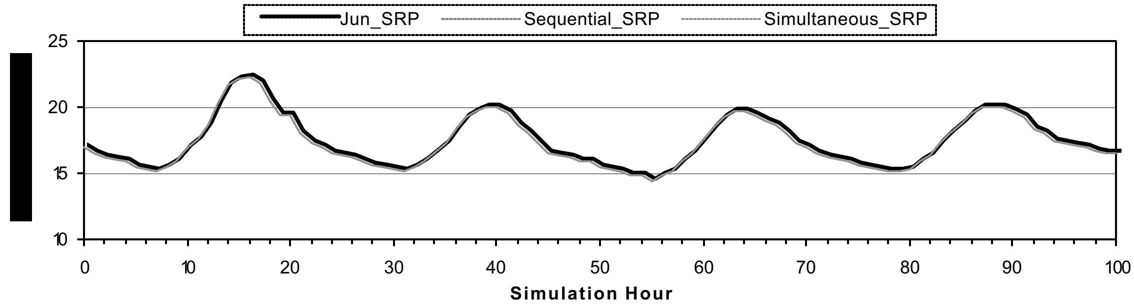
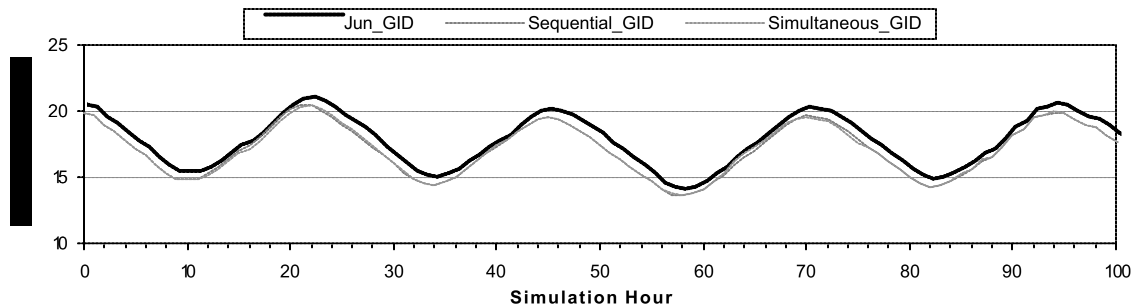


(c)

Figure 5-29 Longitudinal river temperature for June baseline, sequential, and simultaneous pulse flows: (a) pre-pulse, and representative (b) day 1 and (c) day 2 conditions.



(a)



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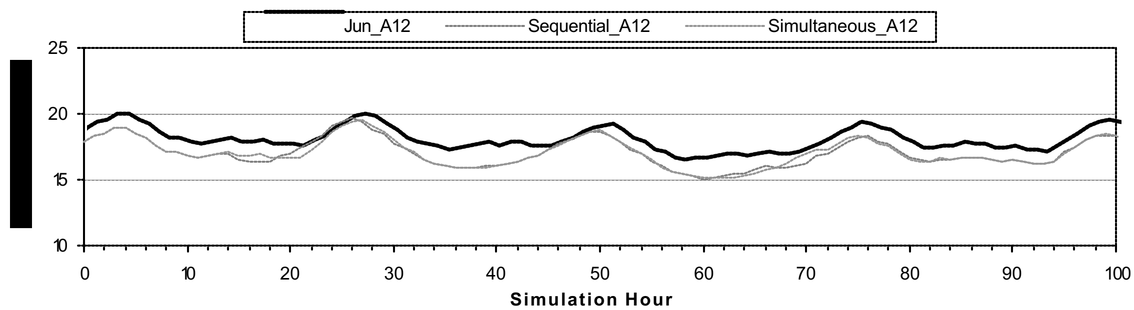
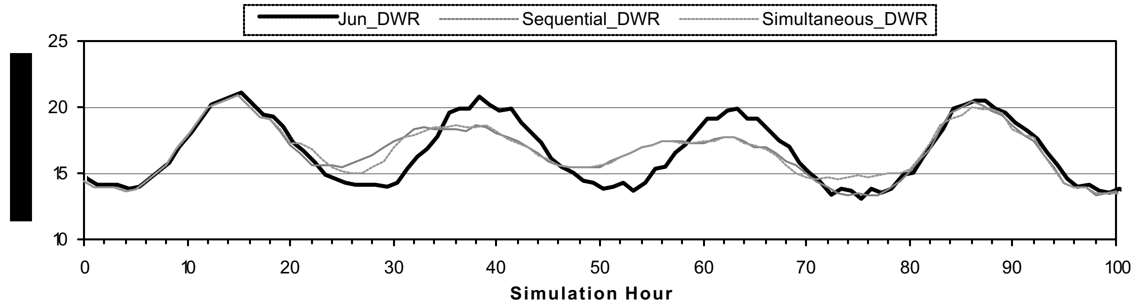


(c)

Figure 5-30 Time series from day 1 through 4 of the baseline, sequential, and simultaneous pulse flows for (a) SRP, (b) GID, (c) A12, (d) DWR, (e) AND, and (e) MOU locations. Continued on next page.



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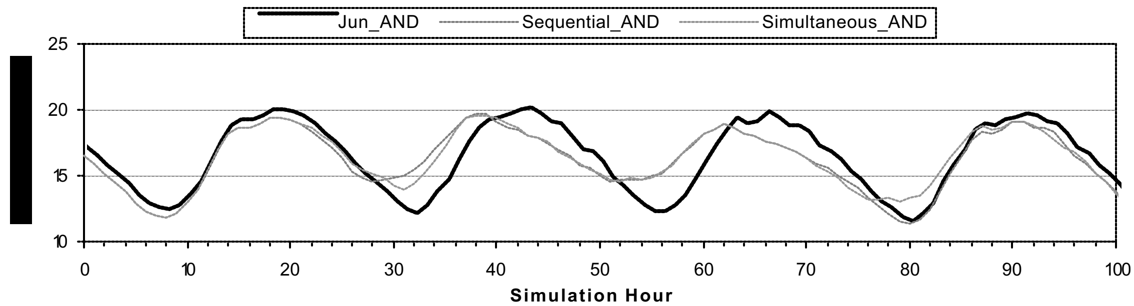

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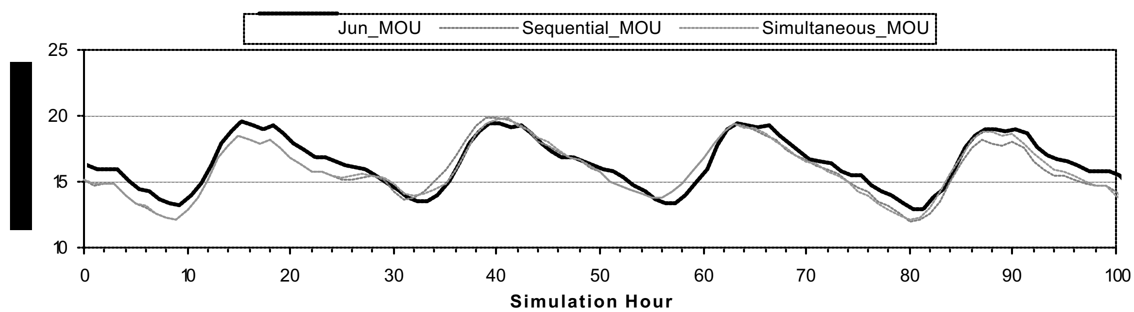


(f)

Figure 5-30, continued. Time series from day 1 through 4 of the baseline, sequential, and simultaneous pulse flows for (a) SRP, (b) GID, (c) A12, (d) DWR, (e) AND, and (e) MOU locations.

5.5.4 Tailwater return

The tailwater return study was designed to investigate the effects that distribution of tailwater returns might have on the temperature regime of the Shasta River. In this study, water was added to Reach 3 (DWR Weir to Anderson Grade Road) under a variety of different conditions. In the 32 simulations for this study, point source returns at the top of the reach are compared to returns of equal volume distributed over the entire reach. Comparisons between these two return flow distributions were made for two different tailwater inflows (5 and 10 cfs) at two times of year (June and September) with two upstream inflows (20 and 50 cfs at SRP) at two upstream inflow temperatures (15°C and 20°C at SRP). Returns flows were assumed to enter the river at local water temperature. All other inflows and diversions were eliminated from the model.

Results of this study are presented only from DWR to MOU locations and are shown in the following Figure 5-31 through Figure 5-38. Distribution of return flows resulted in lower downstream water temperatures than resulted from point inflow. Generally, the difference in mean daily temperatures was negligible. The difference in maximum and minimum water temperatures was small, always less than 1°C. For all simulations the mean difference between temperatures associated with point and distributed inflows of equal magnitude was 0.32°C (CV=0.90). The greatest differences occurred when headwater flow was 20 cfs and tailwater flow was 10 cfs, regardless of time-of-year or headwater temperature. Under these conditions, flows distributed over the reach produced an average drop in temperature of about 0.5°C at Anderson Grade Road and about 0.8°C at the river mouth. In this study, time-of-year made little difference (probably because meteorological conditions were similar in June and September). Not surprisingly, the scenario least affected by a change in inflow distribution was that in which high flows of 50 cfs were imposed on the upstream boundary at SRP.

Summary

The distributed return flow provided conditions of smaller in-river volume for the entire reach between DWR and AND, resulting in maximum and minimum river temperatures that were higher and lower, respectively, than the case where the discharge was a point source at the tope of the reach. These findings suggest:

- That distribution and location of return flow can impact the thermal regime of the river.
- The temperature of the return flow could potentially play an important role in the management of tailwater.

Further, carefully crafted studies that identify actual conditions along the Shasta River should be tested to explore the potential range of responses that could realistically be expected with tailwater control projects.

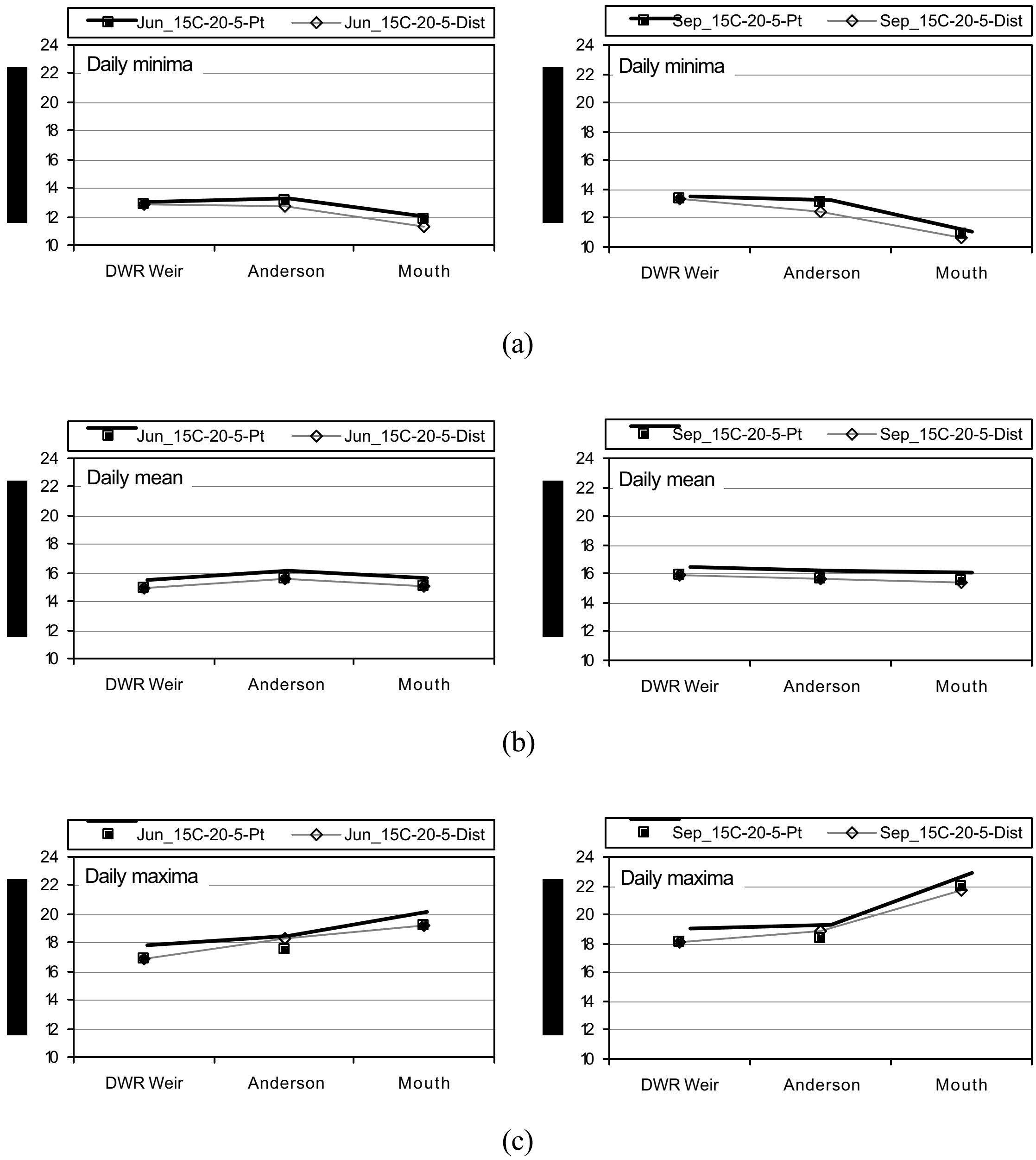
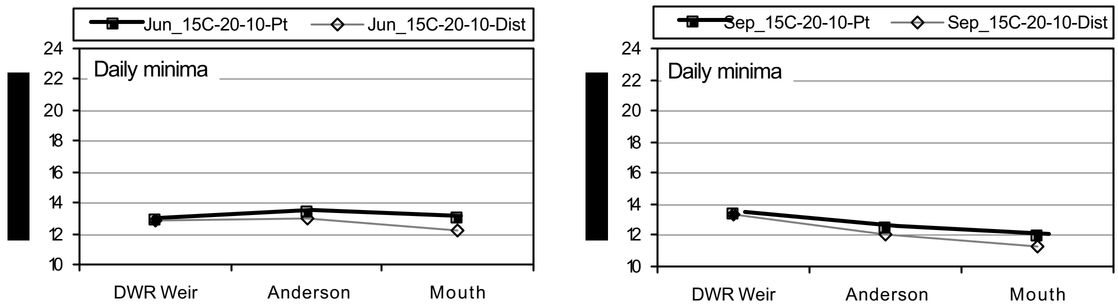


Figure 5-31 Tailwater Return Study 15°C-20-5 results for June and September. Upstream boundary condition of 15°C and 20 cfs at SRP, tailwater return flow of 5 cfs. Simulated (a) daily minimum, (b) daily average, and (c) daily maximum water temperature at DWR Weir, Anderson Grade Road, and the mouth of the Shasta River comparing point and distributed discharge of tailwater. Simulations designated by "month_upstream water temperature-upstream inflow-tailwater flow" (e.g. Sep_15C-20-5).



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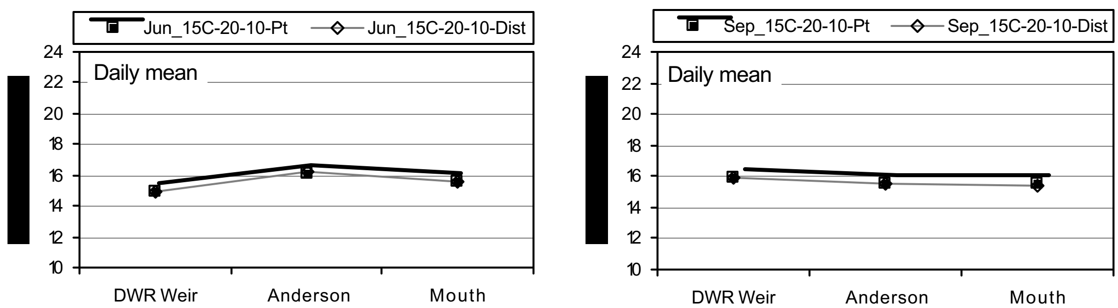

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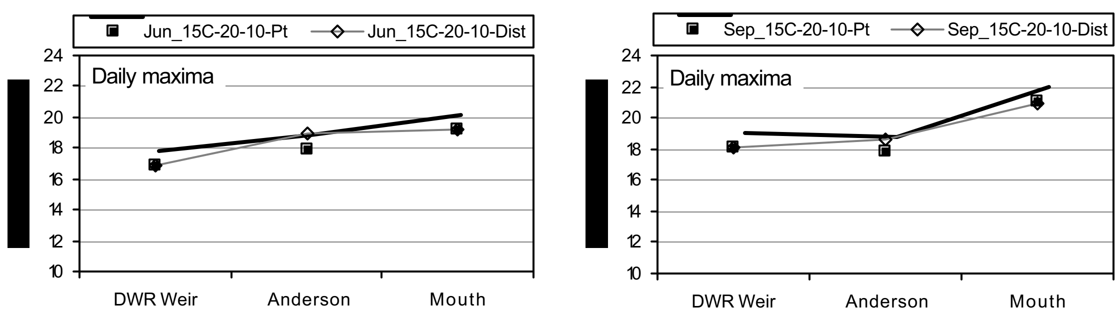
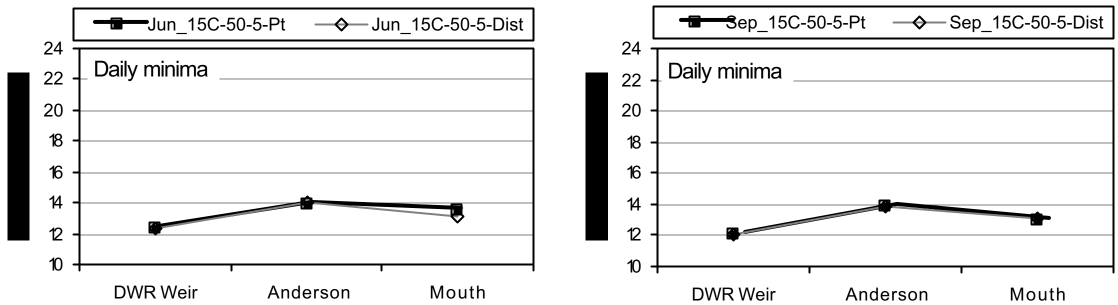
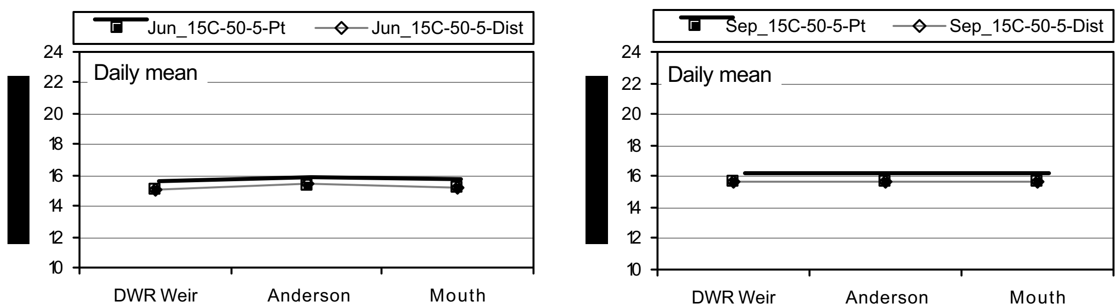


(c)

Figure 5-32 Tailwater Return Study 15°C-20-10 results for June and September. Upstream boundary condition of 15°C and 20 cfs at SRP, tailwater return flow of 10 cfs. Simulated (a) daily minimum, (b) daily average, and (c) daily maximum water temperature at DWR Weir, Anderson Grade Road, and the mouth of the Shasta River comparing point and distributed discharge of tailwater. Simulations designated by "month_upstream water temperature-upstream inflow-tailwater flow" (e.g. Sep_15C-20-10).



(a)



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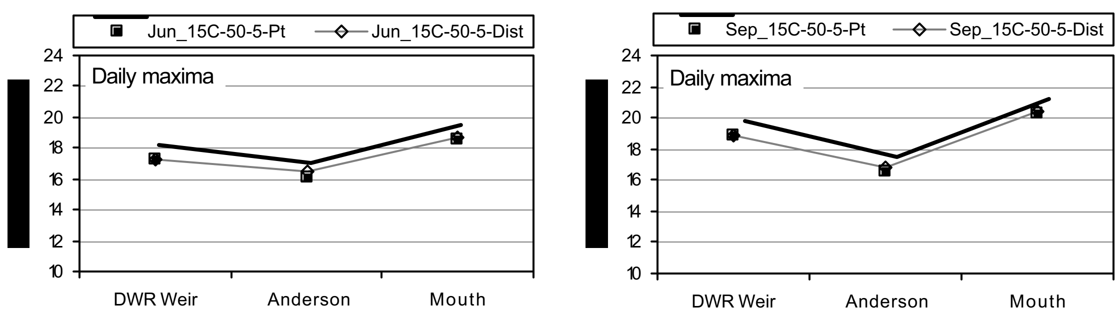
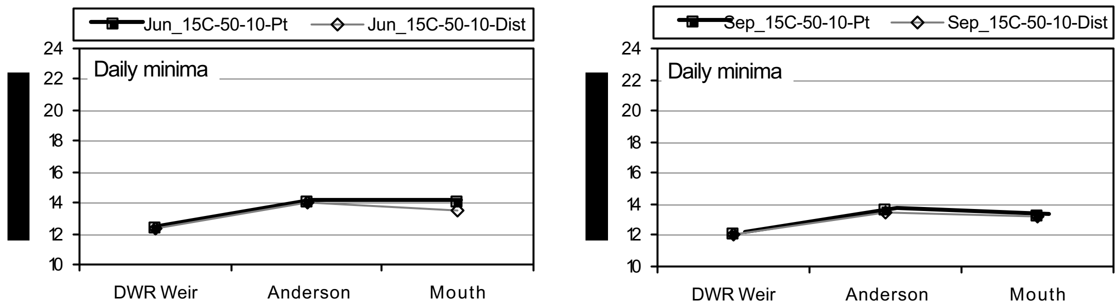
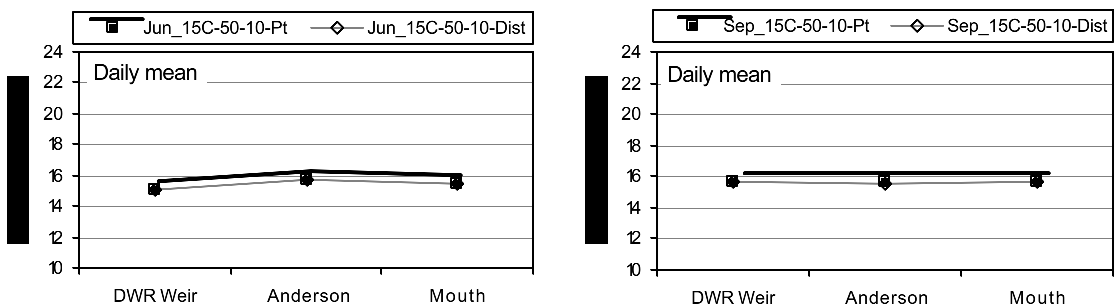


(c)

Figure 5-33 Tailwater Return Study 15°C-50-5 results for June and September. Upstream boundary condition of 15°C and 50 cfs at SRP, tailwater return flow of 5 cfs. Simulated (a) daily minimum, (b) daily average, and (c) daily maximum water temperature at DWR Weir, Anderson Grade Road, and the mouth of the Shasta River comparing point and distributed discharge of tailwater. Simulations designated by "month_upstream water temperature-upstream inflow-tailwater flow" (e.g. Sep_15C-50-5).



(a)



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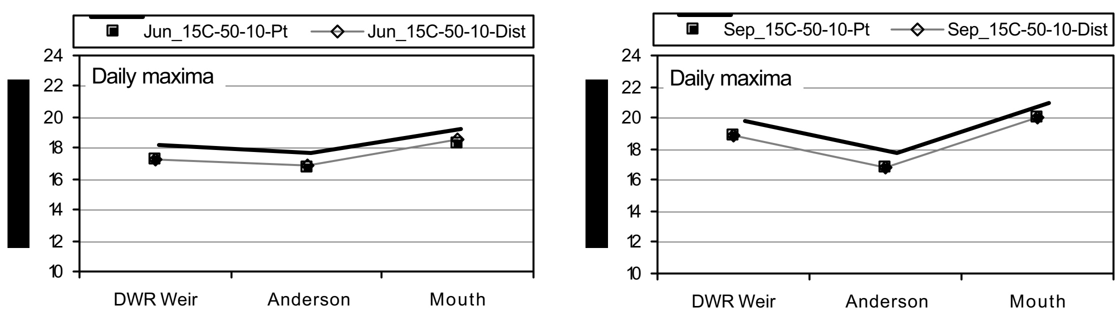
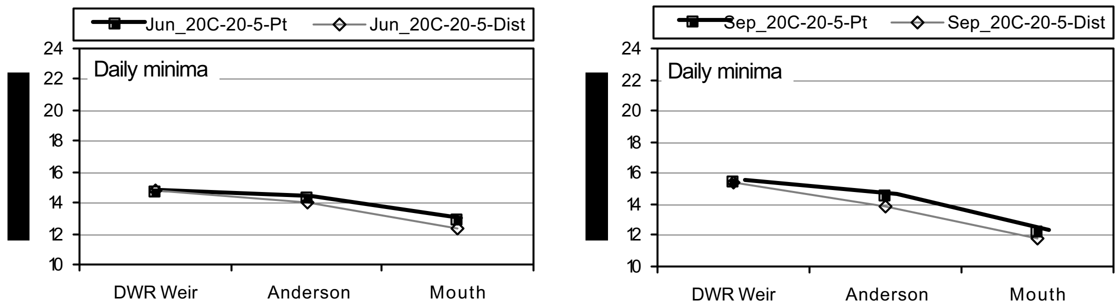
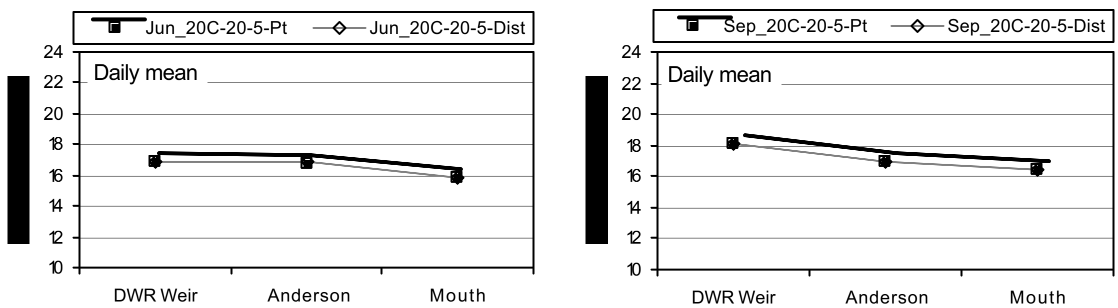


(c)

Figure 5-34 Tailwater Return Study 15°C-50-10 results for June and September. Upstream boundary condition of 15°C and 50 cfs at SRP, tailwater return flow of 10 cfs. Simulated (a) daily minimum, (b) daily average, and (c) daily maximum water temperature at DWR Weir, Anderson Grade Road, and the mouth of the Shasta River comparing point and distributed discharge of tailwater. Simulations designated by "month_upstream water temperature-upstream inflow-tailwater flow" (e.g. Sep_15C-50-10).



(a)



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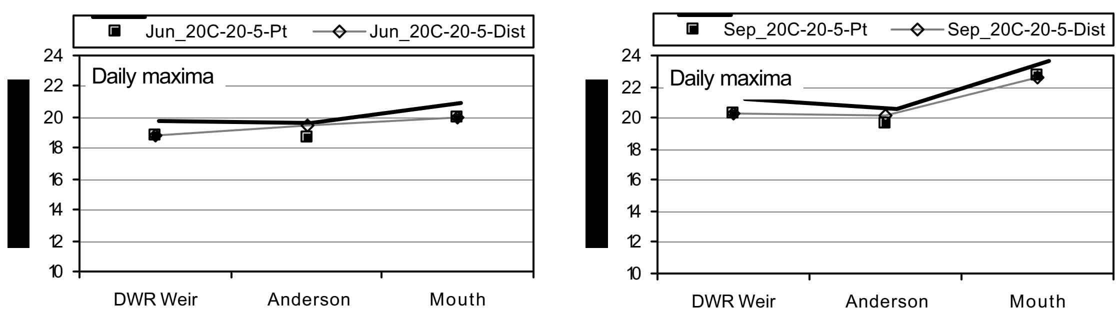


(c)

Figure 5-35 Tailwater Return Study 20°C-20-5 results for June and September. Upstream boundary condition of 20°C and 20 cfs at SRP, tailwater return flow of 5 cfs. Simulated (a) daily minimum, (b) daily average, and (c) daily maximum water temperature at DWR Weir, Anderson Grade Road, and the mouth of the Shasta River comparing point and distributed discharge of tailwater. Simulations designated by "month_upstream water temperature-upstream inflow-tailwater flow" (e.g. Sep_20C-20-5).

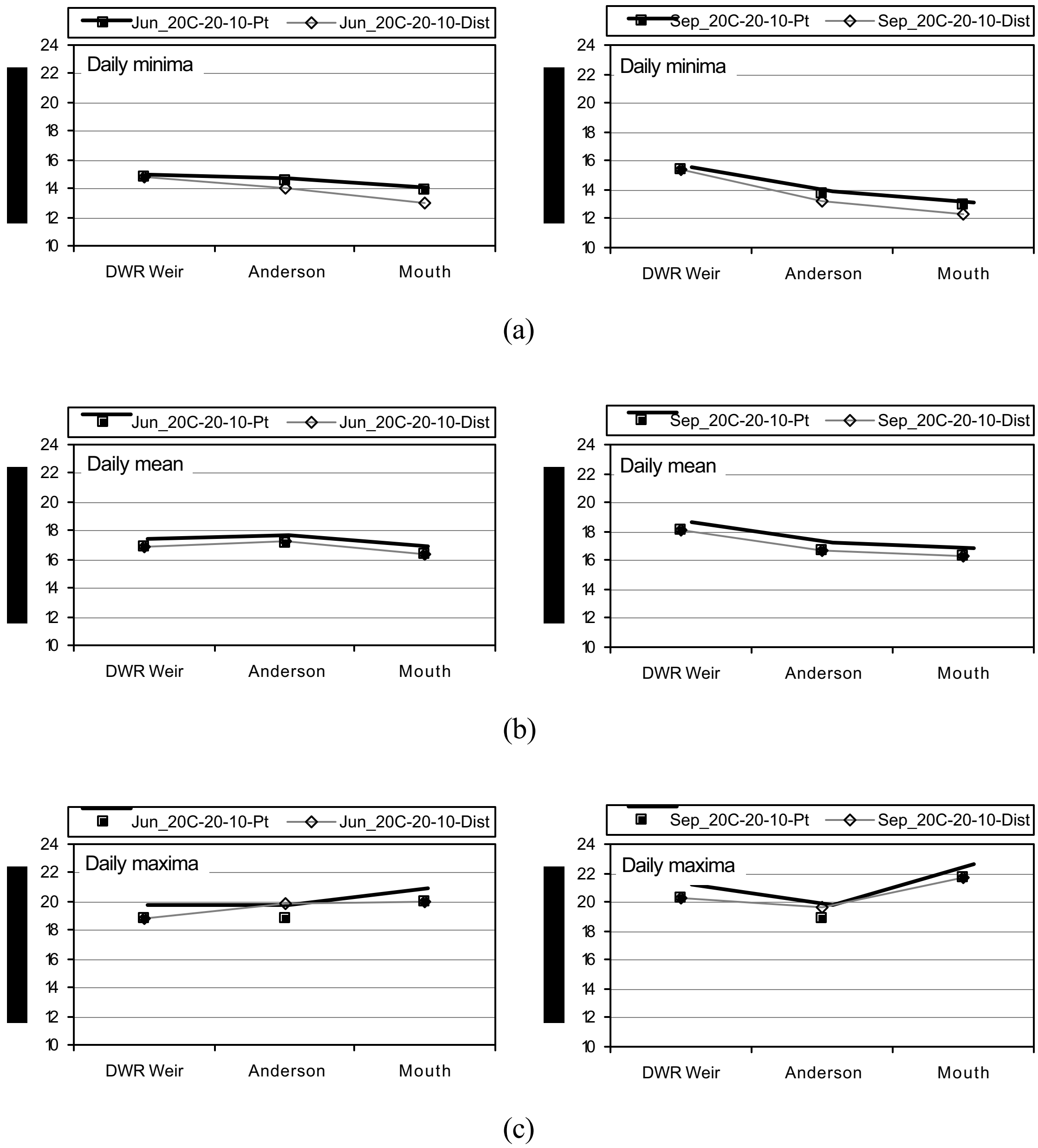


Figure 5-36 Tailwater Return Study 20°C-20-10 results for June and September. Upstream boundary condition of 20°C and 20 cfs at SRP, tailwater return flow of 5 cfs. Simulated (a) daily minimum, (b) daily average, and (c) daily maximum water temperature at DWR Weir, Anderson Grade Road, and the mouth of the Shasta River comparing point and distributed discharge of tailwater. Simulations designated by "month_upstream water temperature-upstream inflow-tailwater flow" (e.g. Sep_20C-20-10).

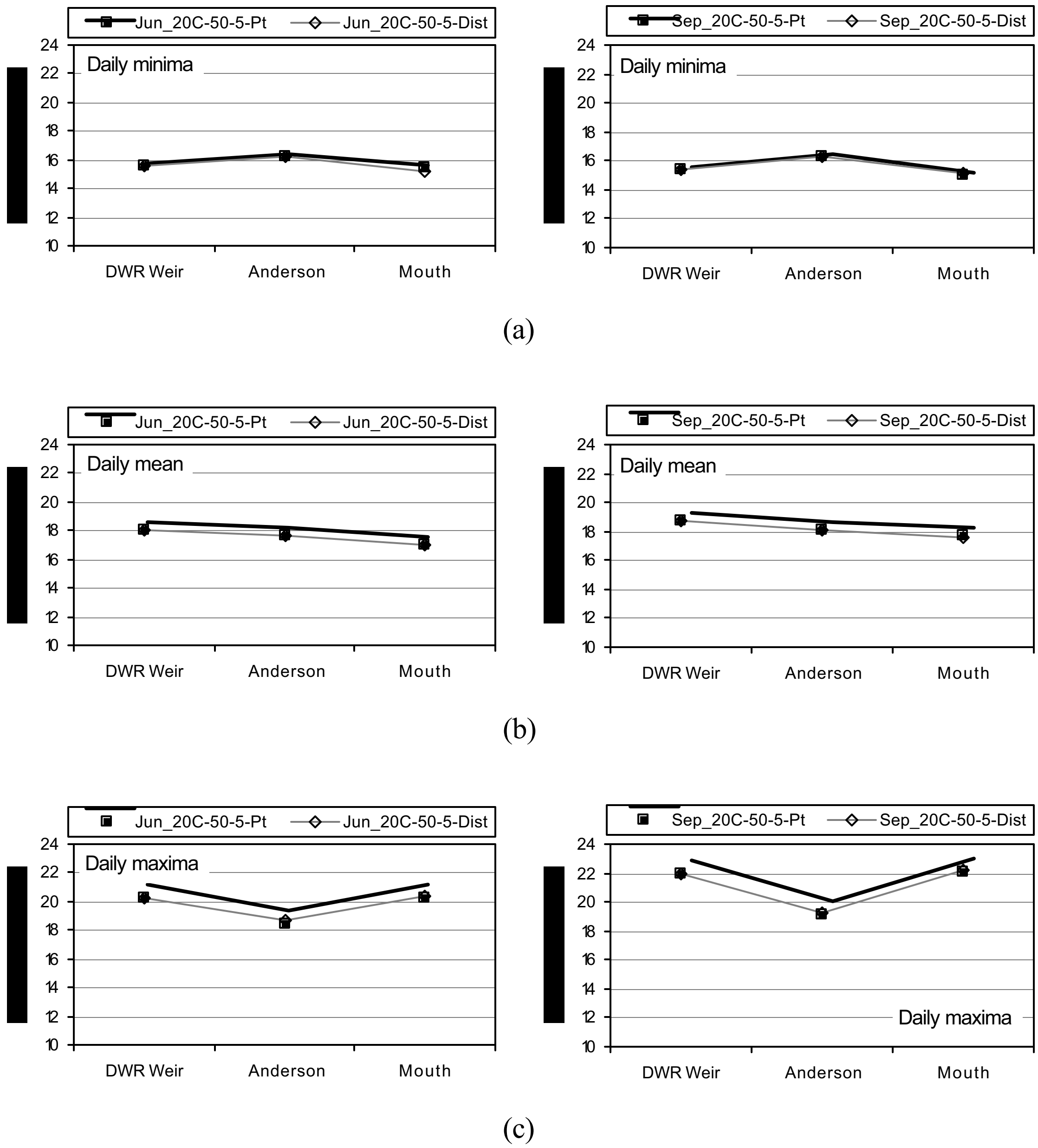
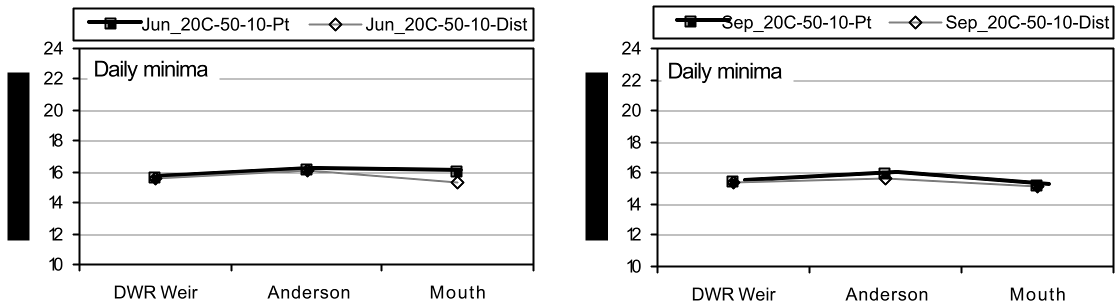


Figure 5-37 Tailwater Return Study 20°C-50-5 results for June and September. Upstream boundary condition of 20°C and 50 cfs at SRP, tailwater return flow of 5 cfs. Simulated (a) daily minimum, (b) daily average, and (c) daily maximum water temperature at DWR Weir, Anderson Grade Road, and the mouth of the Shasta River comparing point and distributed discharge of tailwater. Simulations designated by "month_upstream water temperature-upstream inflow-tailwater flow" (e.g. Sep_20C-50-5).



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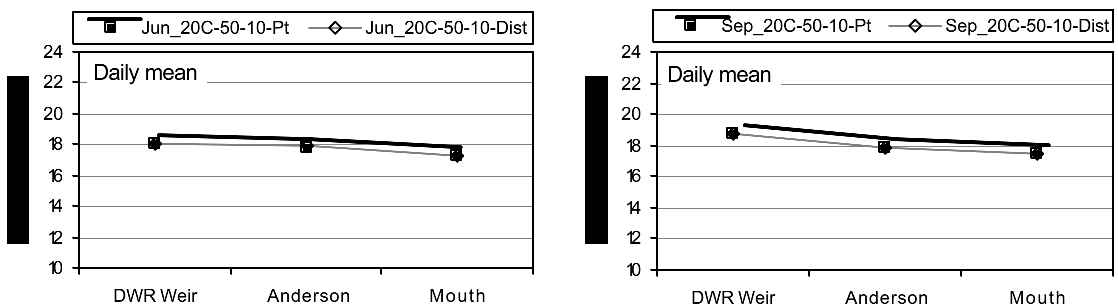

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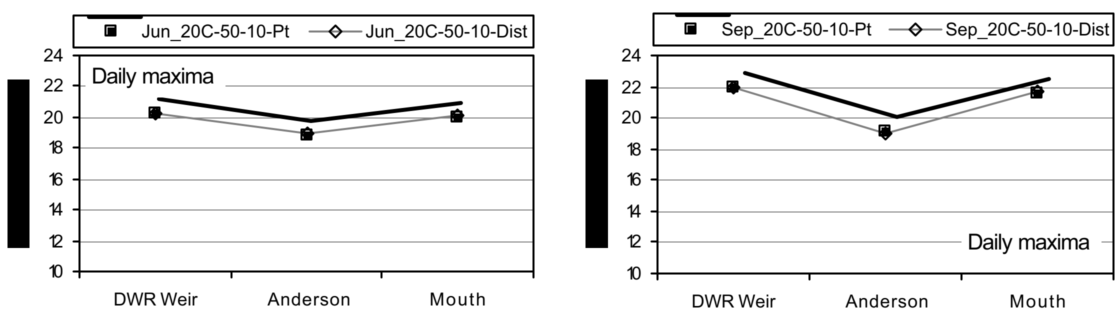


(c)

Figure 5-38 Tailwater Return Study 20°C-50-10 results for June and September. Upstream boundary condition of 20°C and 50 cfs at SRP, tailwater return flow of 5 cfs. Simulated (a) daily minimum, (b) daily average, and (c) daily maximum water temperature at DWR Weir, Anderson Grade Road, and the mouth of the Shasta River comparing point and distributed discharge of tailwater. Simulations designated by "month_upstream water temperature-upstream inflow-tailwater flow" (e.g. Sep_20C-50-10).

5.5.5 Shading Reach-by-Reach

The shading reach-by-reach alternative was designed to determine the effects of re-vegetation on the temperature regime of the Shasta River on a reach-by-reach basis during different times of the year. In this study, shade associated with existing riparian vegetation was applied to the entire river to determine the base-case condition for the time of year. Then, shading from mature trees was added to each reach of the river in turn. Only one reach was shaded with the re-vegetated growth at a time. Re-vegetated shade was represented by barrier heights of 22 feet on each bank of the river. Results are compared to base-case simulations of river temperatures for each of the three study periods.

Results of this study are shown in the following Figure 5-39 through Figure 5-41. As in the presentation of flow regime study results, results of each simulation are presented as deviations from the base-case. Base-case simulations were the same as those used in the flow regime study. Generally, shading always decreased all downstream temperatures. But the effects on mean daily temperatures were generally modest (mean= -0.29°C, CV=-0.75). As with added inflow, the effect of increased shading was most dramatic on maximum river temperatures. Maximum temperatures were reduced in downstream reaches as a result of shading in upstream reaches, but the effect was only significant in the first two reaches downstream from where additional riparian shading was provided. Reduction in maximum temperatures were most noticeable (i.e. >0.5°C) in August. Shading of Reach 5 (the most downstream reach) in August resulting in a lowering of water temperature at the mouth of 2.7°C. Shading also generally dropped minimum temperatures downstream, but this effect was only noticeable in August and September. Interestingly, the largest drop in minimum temperature (-1.2°C) occurred at the mouth when Reach 3 was shaded in August. This result is presumed to be associated with the analysis assumptions of steady flow boundary condition, temperature boundary conditions, stable meteorological conditions, and advective properties of the system.

June

The impact of shading individual reaches had little impact on maximum, mean, or minimum temperatures. This is probably due to the moderate water temperature conditions in the river during the selected week of study. As note in the flow regime alternative, mean daily river temperatures were fairly cool, between 15°C and 17°C and the river was cooling in the downstream direction. Additional shading under such circumstances would provide little additional benefit.

August

August conditions in the river were somewhat different than June. The river was significantly warmer and the system was typically gaining heat in the downstream directions. In upstream reaches where accretions from spring flow maintains cooler water temperatures (e.g., above A12), the addition of riparian vegetation provided only modest benefit locally and did not measurably improve conditions far downstream.

However, in downstream reaches where mean daily water temperatures rose from 20°C at A12 to 25°C at MOU (and were closer to equilibrium temperature), riparian shading had a larger impact, but again, somewhat local. Careful examination of the daily mean and maximum temperature change show that while riparian vegetation provided relief within and immediately downstream of the shaded reach, water temperatures quickly rose back to baseline levels over the distance of the next reach or two.

September

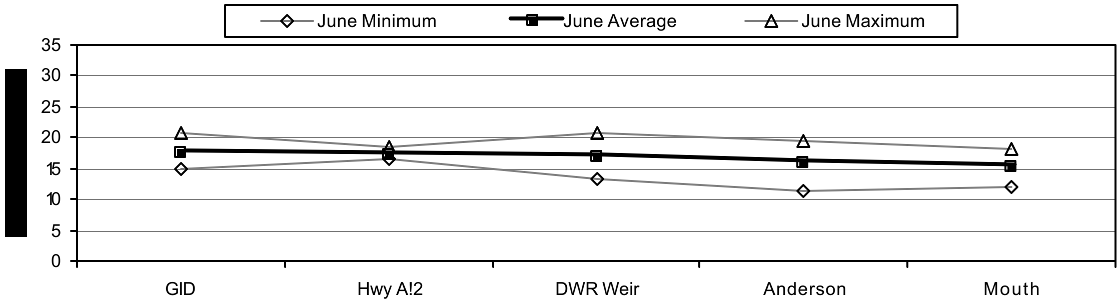
Although the thermal regime of the Shasta River in September was similar to June, the response of the river system to shading was more marked. Maximum, mean, and minimum water temperatures all illustrated reductions to shading. The main difference was probably due to the time of year and concomitant reduced solar altitude and shorter day length. The lower solar altitude would result in more efficient shading of the stream by riparian vegetation compared to the June period wherein the solar altitude and day length were nearly at the annual maximum. Further, in late September the shortening day length results in a lower equilibrium temperature for the river than that which occurred in June. Reaches experiencing water temperatures near equilibrium temperature benefited from riparian vegetation shading more than reaches where water temperatures were lower. This is most clearly seen in the figure presenting deviations from maximum daily water temperatures.

Summary

Reach by reach riparian vegetation restoration simulations illustrated insight into the thermal characteristics of the Shasta River and how conditions vary along its length, including:

- Riparian vegetation shading can potentially reduce mean, and particularly maximum daily, temperatures over the distance of a single reach (five to seven miles).
- Where water temperatures were closer to equilibrium conditions (e.g., away from cool spring inflow influences) riparian vegetation had a more noticeable affect. This does not discount the importance of riparian vegetation in cool water areas.
- In general, the reduction in water temperature from a restored condition does not persist more than a reach or two downstream.
- Time of year and solar altitude play a role in ability of riparian vegetation to reduce incoming solar radiation, thus affecting the thermal regime of the river.

One important factor in this analysis is the distribution of riparian vegetation in the base line condition. The reader is encouraged to review previous sections of this report, as well as to refer to the USFWS (Abbott and Deas, 2003) report to become familiar with longitudinal variation in vegetation. Certain reaches have appreciably more vegetation than others. The addition of shade providing vegetation to reaches where there is very little existing vegetation can produce a different thermal response than when additional vegetation is added to reaches that have more appreciable quantities.



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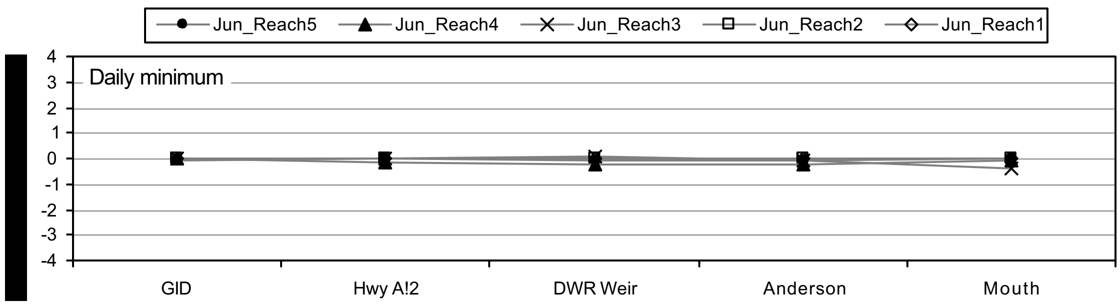

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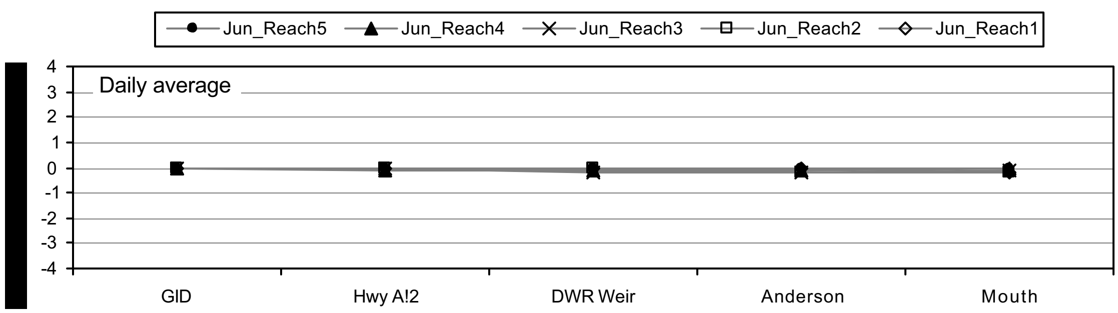

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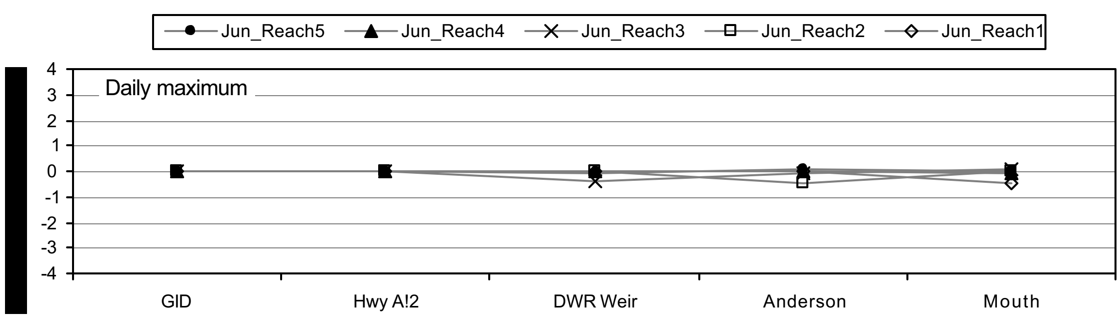
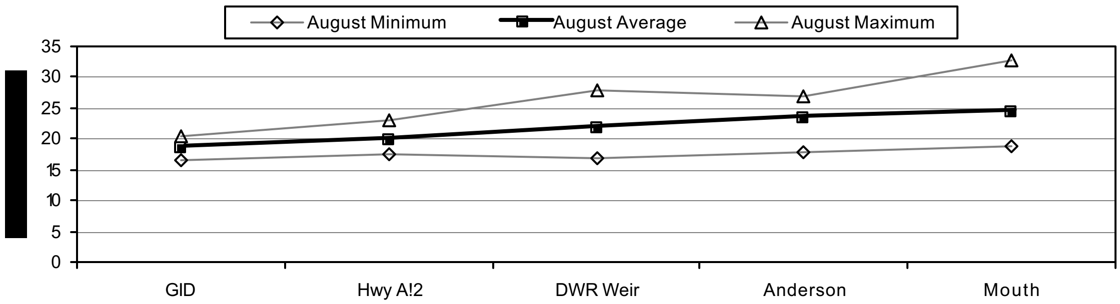


(d)

Figure 5-39 Shadinge Study results for June. Deviations from (a) June base-case condition in (b) daily minima, (c) daily average, and (d) daily maxima of simulated water temperature at GID, Hwy 12, DWR Weir, Anderson Grade Road, and the mouth of the Shasta River.



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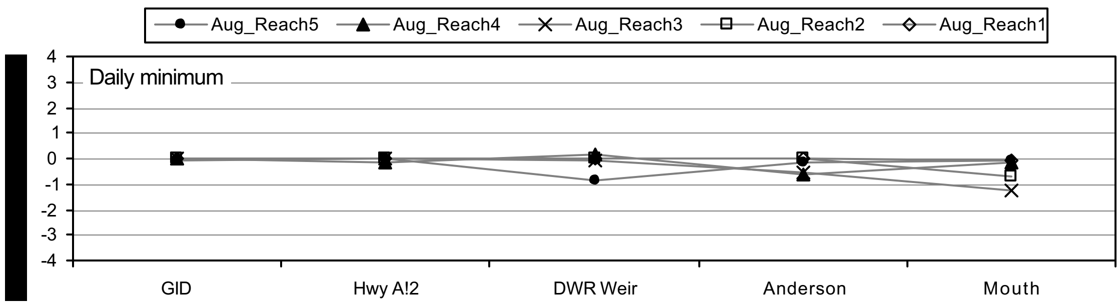

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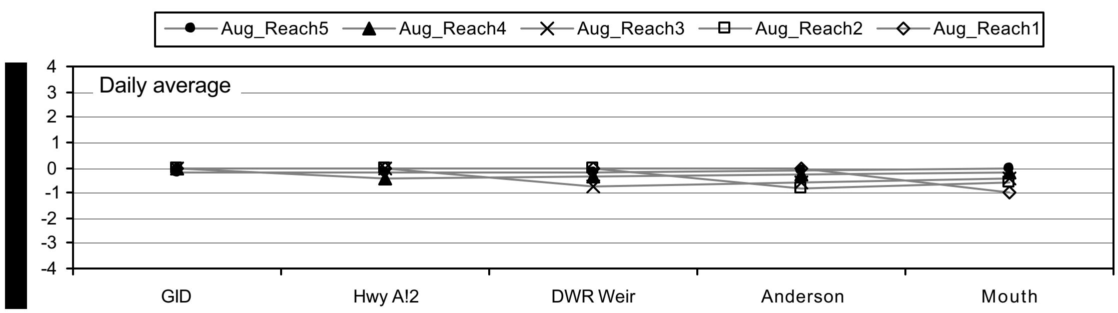

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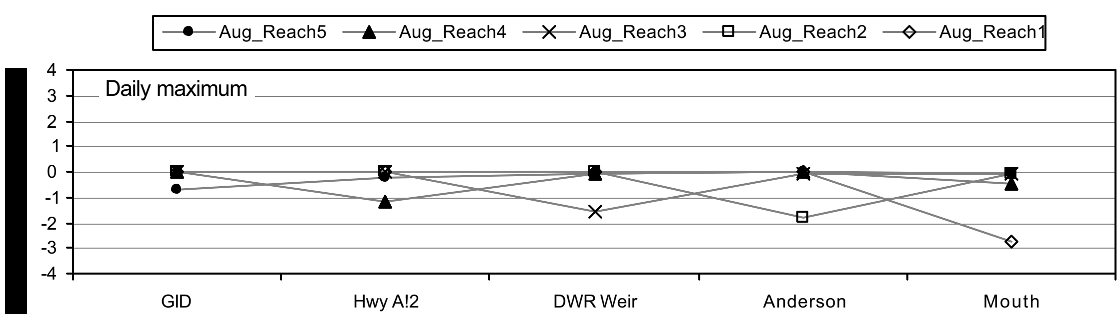
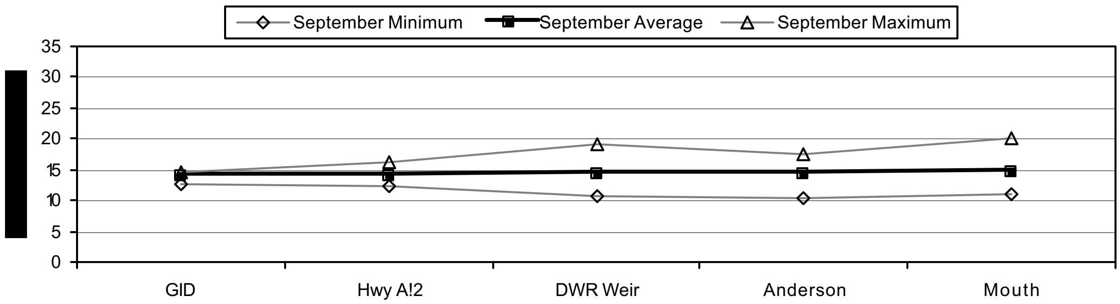


(d)

Figure 5-40 Shadinge Study results for August. Deviations from (a) August base-case condition in (b) daily minima, (c) daily average, and (d) daily maxima of simulated water temperature at GID, Hwy 12, DWR Weir, Anderson Grade Road, and the mouth of the Shasta River.



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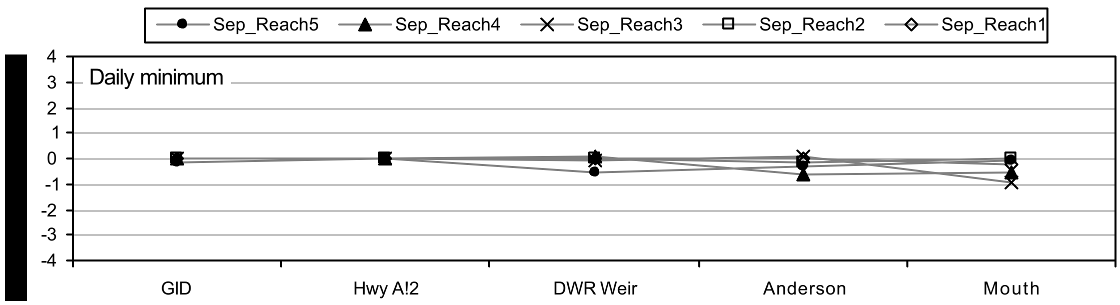

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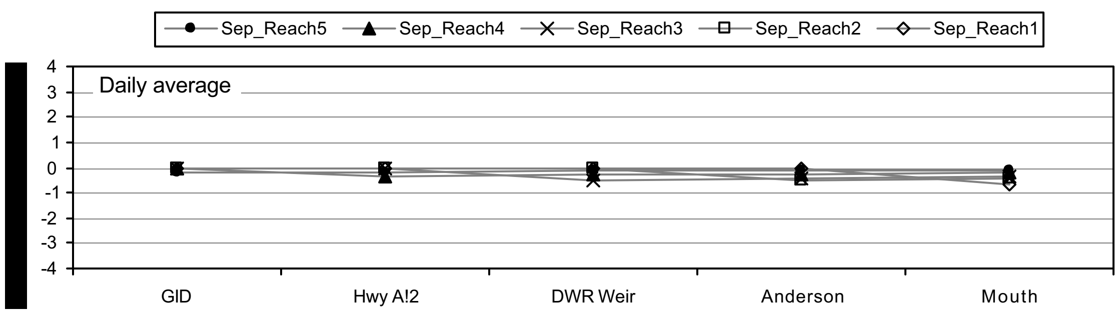

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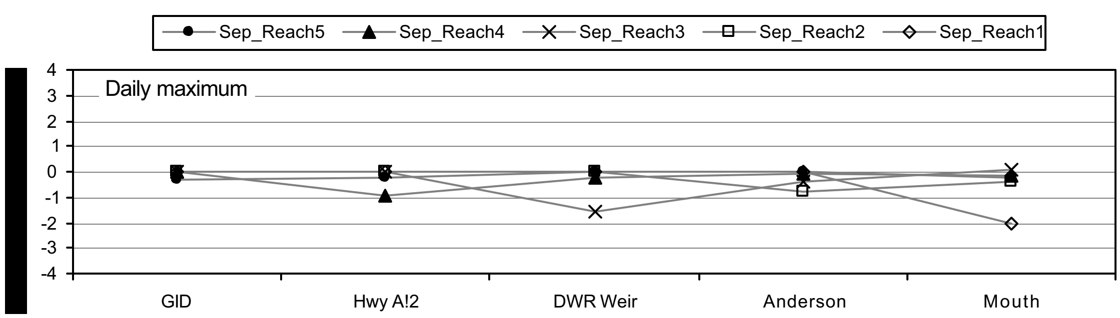

(d)

Figure 5-41 Shadinge Study results for September. Deviations from (a) September base-case condition in (b) daily minima, (c) daily average, and (d) daily maxima of simulated water temperature at GID, Hwy 12, DWR Weir, Anderson Grade Road, and the mouth of the Shasta River.

5.5.6 Additional Riparian Vegetation Management Analyses

Additional riparian vegetation management analyses had been completed during the life of the project. Although they were not formally part of the management alternatives developed above, the analysis did benefit from stakeholder involvement (both development and review). These studies augment the previously presented alternatives, providing additional information and insight into potential system response to riparian vegetation in the Shasta River basin.

5.5.6.1 Spatial and Temporal Riparian Vegetation Management Analysis

An initial modeling effort was completed early in the project to ascertain potential impacts of riparian vegetation on water temperatures in the Shasta River. Two concepts were addressed in these initial studies:

- The impact riparian vegetation shading conditions have on water temperature as riparian vegetation shading conditions change through time during potential restoration periods (temporal)

- The impact riparian vegetation shading conditions have on water temperature depending on location of riparian vegetation shading restoration efforts (spatial)

To determine the effect of various riparian vegetation scenarios on the Shasta River the data of the August 17th to August 23rd, 2001 period was used. Six day average maximum, mean, and minimum data were used to assess response. Each study will be discussed below.

Impact of Temporal Variation in Riparian Revegetation Restoration on Water Temperature

The concept of exploring temporal variation in riparian revegetation restoration efforts is borne out of the natural succession of vegetation types that would occur over a period of many years. With either active or passive measures, initially restoration would include colonization by wetland species such as sedges, grasses and rushes (e.g., bulrush). Ideally, these species would stabilize bank areas and after time give way to species such as willows, cottonwoods, and other woody riparian vegetation that could provide significant shading potential.

To provide insight on thermal conditions at the beginning, intermediate, and end point of a widespread riparian vegetation restoration effort, three simulations were completed to illustrate the current conditions, an intermediate point in time, and a final restored condition.

Current Condition

The current condition included riparian vegetation currently existing on the Shasta River.

Figure 5-42 is a plot of the longitudinal profile of river of 6-day average, minimum, and maximum simulated temperatures for the August 17th to 23rd simulation. From SRP to the Mouth there was an average temperature gain of approximately 4.4°C. The mean temperature at the Mouth was approximately 21.4°C, with a maximum temperature of about 30.0°C. The river is generally heating from upstream to downstream locations for this typical mid-summer flow and thermal regime. However, field observations and simulations of the Shasta River flow and water temperature suggest a complex relationship between flow and temperature along the system. The sharp decrease in temperature range at about RM 30 was likely due to the imposition of cool water accretions in the Big Springs Creek region. This increase in flow decreases transit time in downstream reaches and increases thermal mass – leading not only to maintenance of overall mean temperature, but a smaller diurnal range as well. The modest but abrupt increase in diurnal temperature range at approximately RM 17, was probably due to the decrease in flow and depths due to diversion.

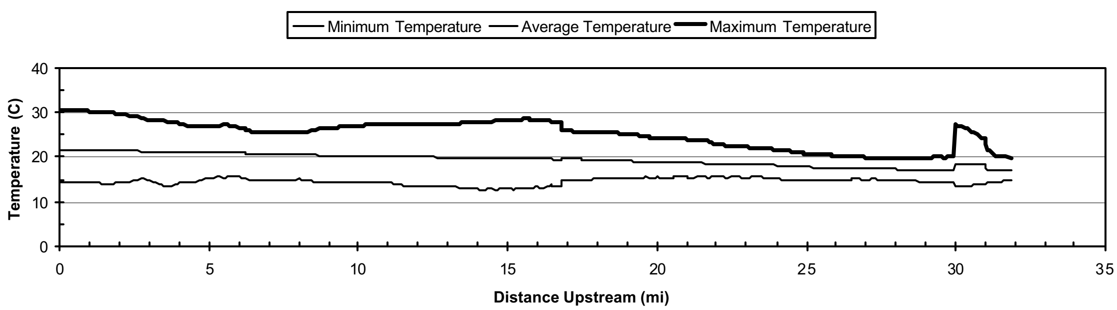

Figure 5-42 Simulated average, minimum, and maximum temperature at each node, Aug 17-Aug 23, 2001: current condition

Intermediate Restoration Potential

To represent an intermediate level of riparian vegetation restoration, it was assumed that bulrush would colonize areas currently devoid of woody riparian vegetation (existing vegetation was presumed to stay in place) over a period of several years. Based on field measurements (Abbott and Deas, 2003), bulrush could raise the maximum effective vegetation height to about 10 feet in the places where there is currently no vegetation. However, field measurements of both height and solar radiation identify that only 2/3 of the height of bulrush is effective at shading. Thus, an effective vegetation height of seven feet was applied. A vegetation transmittance value of 10 percent (vegetation reduces incoming solar radiation by 90 percent). Results of the simulation are shown in Figure 5-43.

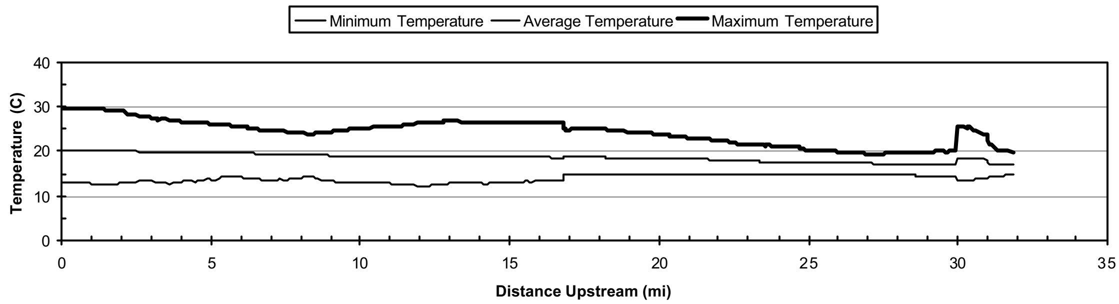

Figure 5-43 Simulated average, minimum, and maximum temperature at each node: Intermediate restoration potential

Results of this simulation suggest a total heat gain of about 3.2°C from SRP to the Mouth. The mean temperature at the Mouth is approximately 20.2°C, or about 1°C cooler than without bulrush providing shade. The maximum temperature at the Mouth is decreased from 30.2°C to 29.4°C, slightly less than a degree. It may not be feasible to attain complete colonization of all bank areas with bulrush; however even this very modest increase in shade – 7 foot high vegetation – produces a noticeable reduction water temperature. This finding suggests that herbaceous riparian vegetation should not be overlooked as a potential measure to reduce incoming solar radiation.

Mature Woody Riparian Vegetation

If riparian vegetation restoration were to occur throughout the study area it would likely be 10 to 20 years or more years before the trees were grown to full height and foliage. A simulation was completed wherein all areas currently devoid of vegetation were colonized by 22 foot high trees and a transmittance of 10 percent. Results of this simulation, shown in Figure 5-44, suggest that the overall mean daily temperature increase from SRP to the Mouth would be less than 1°C. The mean temperature at the Mouth is just over 17.0°C, with the maximum daily temperature at about 24.2°C. This simulation utilizes an extreme level of restoration that probably never have occurred naturally on the system, i.e., an optimal condition from SRP to the mouth that is probably not feasible (This point was addressed specifically in the incremental riparian vegetation shading shading analysis, below). Nonetheless, it does illustrate the potential of riparian vegetation to moderate and maintain water temperatures at lower levels than under current conditions.

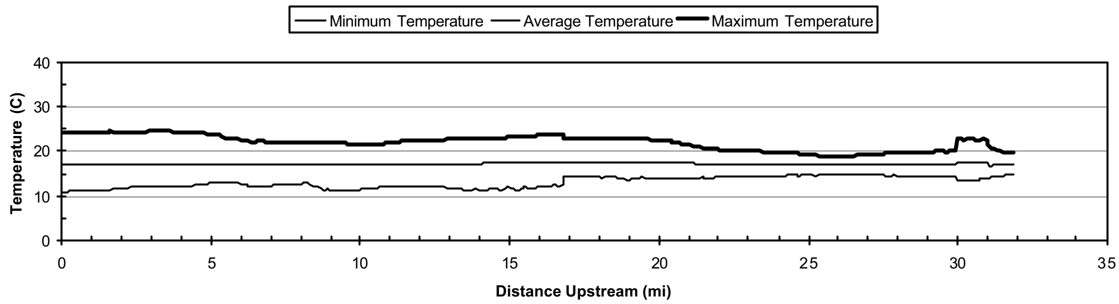

Figure 5-44 Simulated average, minimum, and maximum temperature at each node: fully shaded scenario (fully restored)

Impact of Spatial Variation in Riparian Revegetation Restoration on Water Temperature

It is likely that riparian vegetation restoration efforts would proceed in phases. To assess general response of river temperatures to different spatial patterns of riparian shading, two simulations were completed by essentially partitioning the restoration to roughly half of the river:

1) Upper River Restoration: full riparian vegetation restoration between RM 34 (SRP) and RM 17, with existing conditions from RM 17 to RM 0 (Mouth)

2) Lower River Restoration: existing conditions from RM 34 to RM 17, with full riparian vegetation restoration between RM 17 and RM 0

Tree height for full riparian vegetation restoration was assumed to be 22 feet with a transmittance of 10 percent. Figure 5-45 illustrates the longitudinal profile of river temperatures (maximum, average, and minimum) for the upper river restoration condition. Between RM 34 and RM 17 the reduction in solar radiation due to riparian vegetation shading resulted in retention of cool water down to RM 17, as well as moderated the diurnal range. Below RM 17 the river begins to increase in mean daily temperature. The diurnal range increases, but this is probably a combination of not only reduced riparian vegetation (back to the base case level), but also the result of the SWA diversion around RM 16.8 and the associated reduction in base flow. Compared with the base condition, the average temperature at the Mouth decreased from 21.4°C to 20.8°C, approximately 0.6°C, while the maximum temperature at the Mouth dropped from 31.2°C to 30.2°C, roughly 1.0°C.

Figure 5-46 illustrates the longitudinal profile of river temperatures for the lower river restoration condition. Between RM 17 and RM 0 the reduction in solar radiation due to riparian vegetation shading resulted in retention of cool water down to the Mouth, as well as moderated the diurnal range. Compared with the base condition, the average temperature at the Mouth decreased from 21.4°C to 19.7°C, approximately 1.5°C, while the maximum temperature at the Mouth dropped from 30.2°C to 28.3°C, roughly 2°C.

In sum, the upper river shading condition provided relief primarily to the upper river and immediate downstream reaches, but had only modest impact at the mouth. The lower river shading condition provided no reduction in temperatures above RM 17, but contributed more directly to reduction in average daily and maximum water temperatures at the mouth. Note, unlike volume changes addressed above in the flow regime studies, riparian shading served to potentially moderate diurnal range as well as reduce minimum daily temperatures. Additional flow volume generally reduced diurnal range through a reduction in daily maximum and increase in daily minimum, but had only modest affects on mean temperature.

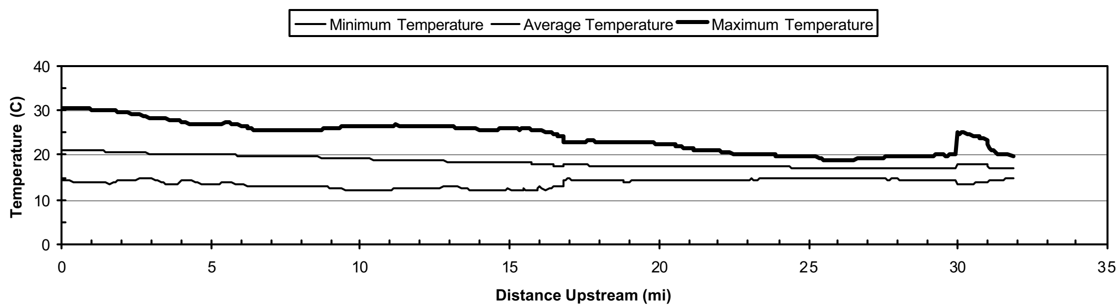

Figure 5-45 Simulated average, minimum, and maximum temperature: full riparian vegetation restoration between RM 34 and RM 17, with existing conditions from RM 17 to RM 0

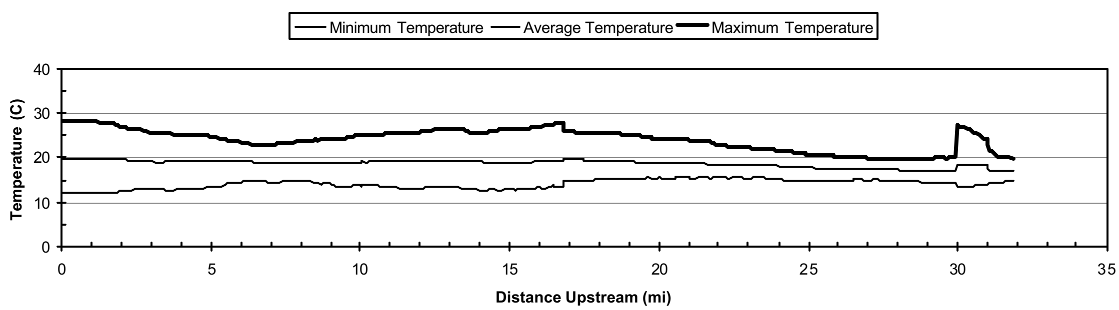

Figure 5-46 Simulated average, minimum, and maximum temperature at each node: downstream of SWA (RM 16.8) shaded

Summary

Riparian vegetation restoration does not produce short term results in terms of reduction in incoming solar radiation because it takes years for such efforts to return benefits. However, this analysis wherein existing conditions, intermediate and complete riparian restoration conditions were studies suggests that benefits may begin to manifest themselves well before mature woody riparian conditions are achieved. Table 5-7 presents mean and maximum temperatures and temperature gain from the upstream boundary (SRP) and at ten mile increments to the Mouth for all model simulations.

Table 5-7. Comparison of revegetation scenarios (all temperatures based on 6-day average, all values in °C)

Scenario	Location											
	Mouth			RM 10			RM 20			SRP		
	Mean	Max	Gain[a]	Mean	Max	Gain[a]	Mean	Max	Gain[a]	Mean	Max	Gain[a]
Base	21.4	31.2	4.4	20.2	27.3	3.2	18.9	24.6	1.9	17.0	19.9	0.0
Bulrush	20.2	29.4	3.2	19.0	25.4	2.0	18.4	23.6	1.4	17.0	19.9	0.0
Full Shade	17.1	24.2	0.1	17.1	22.4	0.1	17.1	22.2	0.1	17.0	19.9	0.0
Upper River	20.8	30.2	3.8	19.1	26.4	2.1	17.1	22.2	0.1	17.0	19.9	0.0
Lower River	19.7	28.3	2.7	19.0	25.1	2.0	18.9	24.6	1.9	17.0	19.9	0.0

[a] Gain is over the entire river reach from SRP to Mouth

Several points were illustrated through the spatial and temporal riparian vegetation management simulations, including:

- Riparian restoration efforts are long-term management approaches to moderating and/or reducing river temperatures. Model simulations can assist decision makers in management approaches to address potential spatial distribution of restoration, how long it may take to reach maturity and provide temperature control benefits, and what thermal relief intermediate conditions may provide.
- Herbaceous riparian vegetation (e.g., bulrush) can provide sufficient shade to affect water temperature if present in sufficient quantity (density and distribution) along the river bank.
- The lower river riparian restoration conditions showed a larger impact locally than the upper river riparian restoration conditions – probably because lower river reaches were closer to equilibrium temperature than cooler (spring influenced), upper river reaches.
- Riparian vegetation on small river systems such as the Shasta River plays an important role in reducing mean daily temperatures (as well as maximum and minimum). Further studies should be completed to determine the trade-off between flow volume and riparian shading to identify a “most favorable” combination of management actions to meet desired objectives.

5.5.6.2 Incremental Riparian Vegetation Shading Analysis

Introduction

During the project period a suite of model runs was completed to quantify the possible effects of incremental shading (i.e. reduction of incoming solar radiation due to woody riparian vegetation) on the thermal regime of the Shasta River. This section outlines the assumptions and results of this modeling analysis for increasing riparian shading in 0.5 mile increments along the river for a range of inflow quantities and water temperatures. These results were intended to provide insight into how much riparian vegetation may be necessary, in miles along the bank, to have an affect on stream temperatures.

Approach

To determine possible effects of incremental shading on the thermal regime of the Shasta River the following model assumptions were adopted:

1. Existing geometric representation of the Shasta River was used. (Specifically, the five-mile section used in this modeling exercise initiated at the upstream boundary (RM 31.8, Shasta above Parks) and extended five miles downstream to RM 26.8, just below the Grenada Irrigation District Pumps. This section was chosen as an illustration, however, the modeling exercise can be replicated anywhere in the system.)

2. The model parameters determined during the 2001 calibration of the Shasta River model were used.

3. For ease of interpretation steady-state flow regimes were chosen for this modeling exercise. This is used as an illustration and can be replicated with various flow regimes. The two steady-state flow regimes that were chosen for this modeling exercise were: 20 cfs, 50 cfs. These were chosen based on the range of potential flows during the summer of 2001. Running the model for two flow scenarios provided greater insight into system response in connection with the relationship between flow and temperature.

4. Two constant upstream inflow temperatures were applied to each flow regime: 15°C, 20°C. During the summer of 2001 typical inflow temperatures (based on observed temperatures at the model boundary at RM 31.8, Shasta above Parks Creek) ranged from 15°C to 23°C. Running the model with two upstream inflow temperatures provided greater insight into system thermal response.

5. Conservative vegetation parameters were chosen to simulate a modest level of revegetation. These values were determined based on input from local constituency representatives including CRMP staff, U.C. Extension, and California Department of Fish and Game.

a. Tree height was chosen to be 22 feet (the average height of a Sandbar Willow based on summer 2001 fieldwork, the smallest measured species, refer to Abbott and Deas (2003) for the details of this field work).

b. Transmittance was assumed to be approximately 50%. This value is calculated based on following assumptions:

   i. Vegetation consisted of 3 trees per 100 feet, where the width of a single tree canopy was approximately 2/3 of the total tree height. (These assumptions yielded approximately 50 feet of potential shade producing vegetation per 100 feet of river.)

   ii. Vegetation was equally distributed on the left and right bank (i.e., 3 trees per 100 feet of river on each bank).

   iii. From measured field data the vegetative transmittance of solar radiation was assigned a valued of 10% for shaded areas (i.e., 90% of the solar radiation was blocked by the vegetation).

   iv. Using a weighted average the overall transmittance of a reach with continuous vegetation was calculated.

6. Twenty-four hours of meteorological data from August 28, 2001 was used.

7. The effects of vegetative shading were simulated in 0.5-mile increments up to a total reach length of 5 miles.

Model Simulations and Results

Four model simulations were conducted: two at a flow regime of 20 cfs, and two at 50 cfs. The first simulation of each flow regime was assigned upstream inflow temperature of 15°C, whereas the second simulation of each flow regime was assigned an upstream inflow temperature of 20°C. Table 5-8 contains a list of the model simulations, associated conditions, and corresponding data tables in this document. For each simulation vegetative shading, as outlined above, was applied to the system in increments of 0.5 miles starting at the upstream boundary (RM 31.8) and continuing downstream for 5 miles. For each simulation the average daily water temperatures and the maximum daily water temperatures were determined from simulated hourly data. Each simulation is represented by four tables:

- Average Daily Water Temperatures
- Maximum Daily Water Temperatures
- Reduction in Average Daily Water Temperatures
- Reduction in Maximum Daily Water Temperatures.

A more detailed description of these tables will be presented after the discussion of the summary presented in Table 5-9.

Table 5-8 Summary of model simulation flows, upstream inflow temperatures, and associated data tables

Simulation	Flow (cfs)	Upstream Inflow Temperature (C)	Data Tables for Each Simulation
1	20	15	Table 5-10 to Table 5-13
2	20	20	Table 5-14 to Table 5-17
3	50	15	Table 5-18 to Table 5-21
4	50	20	Table 5-22 to Table 5-25

A summary of key findings of the model simulations has been tabulated (Table 5-9) from results presented in

to Table 5-25. This summary table contains the daily-average total heating (°C), as well as the daily average rates of heating (degrees Celsius per mile) for each simulation with (a) no shading and (b) with shading over the 5-mile river reach. When discussing the data found in Table 5-9 comparative analysis is used, hence the analysis focuses on relative differences, not absolute values.

Table 5-9 Total heating (°C) over 5 miles of the daily-average simulated water temperatures for the with shade and without shade cases and rates of heating for the daily-average simulated water temperatures (°C/mi) for the with shade and without shade cases

Simulation	Daily avg. total heating over 5 mi °C, (max T_w)						Daily Avg. Heating per mi (°C/mi)		
	W/O Shade			With Shade			W/O Shade	With Shade	?
	T_{RM5}	T_{RM0}	?	T_{RM5}	T_{RM0}	?			
1	17.6 (24.)	15.0 (15.0)	2.6 (9.0)	16.2 (20.9)	15.0 (15.0)	1.2 (4.9)	0.5	0.2	0.3
2	21.3 (27.0)	20.0 (20.0)	1.3 (7.0)	20.2 (24.1)	20.0 (20.)	0.2 (4.1)	0.3	0.0	0.3
3	16.5 (20.5)	15.0 (15.0)	1.5 (5.5)	15.8 (19.0)	15.0 (15.)	0.8 (4.0)	0.3	0.2	0.1
4	20.6 (24.8)	20.0 (20.0)	0.6 (4.8)	20.0 (23.4)	20.0 (20.0)	0.0 (3.4)	0.1	0.0	0.1

T_{RM5} = Water temperature five miles downstream from the upstream boundary
T_{RM0} = Water temperature at the upstream boundary
? = The change or difference between the two water temperatures or rates

Simulation 1: flow = 20 cfs, upstream inflow temperature = 15°C

For Simulation 1, as shown in Table 5-9, without shade the average daily temperature five miles downstream heated approximately 2.6°C, whereas with shade that same point heated 1.2 °C. The rate of heating over five miles of river without shade is approximately 0.5°C per mile. When shade was applied over the 5-mile reach, the rate of heating decreases to approximately 0.2°C per mile.

Simulation 2: flow = 20 cfs, upstream inflow temperature = 20°C

For Simulation 2, as shown in Table 5-9, without shade the average daily temperature five miles downstream heated approximately 1.3°C, whereas with shade that same point heated 0.2 °C. The rate of heating over five miles of river without shade was approximately 0.3°C per mile. When shade was applied over the 5-mile reach, the rate of heating decreased to less than a tenth of a degree Celsius per mile.

At the higher upstream inflow temperature the river did not heat as quickly as Simulation 1 due to the inflow temperature being closer to the equilibrium temperature* of the stream. (Rates of heating decrease as inflow temperatures approach equilibrium temperatures.) The difference in daily average heating rate with and without shading was similar for both upstream inflow temperatures: a reduction of 0.3°C/mile for Simulation 1, and 0.3°C/mile for Simulation 2.

Simulation 3: flow = 50 cfs, upstream inflow temperature = 15°C

The daily average heating rates for Simulations 3 & 4 are less than Simulations 1 & 2. This is due to the increased thermal mass and shorter transit time. (The transit time through the modeled section of river at 20 cfs is roughly 7 hours, while the transit time at 50 cfs is roughly 5 hours.) For Simulation 3, as shown in Table 5-9, without shade the average daily temperature five miles downstream heated approximately 1.5°C, whereas with shade that same point heated 0.8 °C. The rate of heating over five miles of river without shade was approximately 0.3°C per mile. When shade was applied to the 5-mile reach the rate of heating decreased to approximately 0.2°C per mile.

Simulation 4: flow = 50 cfs, upstream inflow temperature = 20°C

As shown in Table 5-9, Simulation 4, as with Simulation 2, did not heat as quickly as the simulations with lower inflow temperatures due to the close proximity to the equilibrium temperature of the river. Without shade the average daily temperature five miles downstream heated approximately 0.6°C, whereas with shade that same point did not

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* Equilibrium Temperature: water temperature at which the rate of heat leaving the fluid is exactly equal to the rate of heat entering the fluid. For these simulations equilibrium temperature is between about 22°C-24°C.

experience any net heating. The rate of heating over five miles of river without shade was approximately 0.1°C per mile. When shade was applied to the 5-mile reach there was no net heating of the river at the point.

As with Simulations 1 & 2, the rate reduction caused by shading was similar for both upstream inflow temperatures: a reduction of 0.1°C/mile for Simulation 3, and 0.1°C/mile for Simulation 4.

Findings

1. Under the "without shade" scenario the lower flow rate simulations (20 cfs) experienced higher heating rates than the higher flow rate simulations (50 cfs) due to decreased thermal mass and longer transit time through the reach.
2. Under the "with shade" scenario the lower flow rate simulations (20 cfs) experienced heating rates equal to that of the higher flow rate simulations (50 cfs) due to decreased incoming solar radiation.
3. For the assumptions stated in this study, simulations with upstream inflow temperatures far from equilibrium temperature (e.g. 15°C) experienced higher daily average rates of heating than those simulations with upstream inflow temperatures close to equilibrium temperature (e.g. 20°C).
4. For the assumptions stated in this study, under the "without shade" scenario flow has a pronounced effect on the average daily rates of heating. However, under the "with shade" scenario the effect of flow is not appreciable. Suggesting that the upstream inflow temperatures play a larger role in determining the average daily rates of heating when incoming solar radiation is appreciably reduced, i.e., shading in place.

Whereas the above findings provide valuable insight into the relationships between flow, solar radiation as altered by vegetative shading, and water temperature in the Shasta River this is only a brief illustration of how the Shasta River Flow and Water Temperature model can be used. The same exercise can be conducted on different reaches of the system, with different steady-state or dynamic flow regimes and various shading scenarios.

Data Tables and Interpretation

This section contains four data tables for each of the four simulations. The first two tables for each simulation represent the daily average and daily maximum water temperatures throughout the 5-mile reach. Moving from top to bottom the table rows present water temperature at 0.5-mile increments in the downstream direction for various longitudinal shading in increments of 0.5 mi, 1.0 mi, 1.5 mi, etc. (columns). Although these tables provide the necessary information to assess the impacts of vegetative shading it is easier to identify effects by comparing each simulation with the "no shade" scenario. The second two tables of each simulation present this information in a similar format for daily average and daily maximum temperatures, respectively. The diagonal entries (shown in bold) illustrate the extent of temperature reduction at 0.5-mile increments downstream. All temperatures are reported in °C. A brief discussion is presented for each set of tables.

Simulation 1: Flow = 20 cfs, Upstream Inflow Temperature = 15°C

Figure 5-12 suggests that under the assumed shading conditions, riparian vegetation would contribute on the order of about 0.3°C reduction in water temperatures per mile when compared with a "no shade" scenario for a steady state flow of 20 cfs and an upstream inflow temperature of about 15°C. Figure 5-13 indicates that maximum daily water temperatures were also reduced under the assumed shading conditions for a total reduction over 5 miles of about 3.1°C.

Simulation 2: Flow = 20 cfs, Upstream Inflow Temperature = 20°C

Table 5-16 illustrates that for an upstream inflow temperature of 20°C at a flow of 20 cfs for every mile of shading the water temperature was reduced by approximately 0.3°C, for a total reduction of 1.1°C at 5 miles of shading. As expected shading does not have as large an impact on warmer water temperatures because the temperature is closer to equilibrium temperature, thereby producing a slower rate of heating. Table 5-17 illustrates that the maximum daily water temperatures were also reduced under the assumed conditions for a total reduction over 5 miles of about 2.9°C.

Simulation 3: Flow = 50 cfs, Upstream Inflow Temperature = 15°C

Shading had less of an impact for the larger flow regime of 50 cfs. Table 5-20 illustrates that for an upstream inflow temperature of 15°C at a flow of 50 cfs for every mile of shading the water temperature was reduced by approximately 0.1°C for a total reduction of 0.7°C with 5 miles of shading. Table 5-21 indicates that the maximum daily water temperatures were also reduced under the conditions for a total reduction over 5 miles of about 1.5°C.

Simulation 4: Flow = 50 cfs, Upstream Inflow Temperature = 20°C

Similar to Simulation 3, for every mile of shading the water temperature was reduced by 0.1°C for a total reduction over 5 miles of 0.6 °C (see Table 5-24). As in Simulation 3, the maximum daily water temperatures were also reduced under the assumed conditions for a total reduction over 5 miles of about 1.5°C (see Table 5-25).

Table 5-10 Average daily simulated water temperatures for 20 cfs steady-state flow with a constant upstream boundary condition of 15°C with shade applied in 0.5 mile increments, Aug. 28, 2001 meteorological conditions

		Distance vegetative shading extends downstream										
		No Shade	0.5mi	1mi	1.5mi	2mi	2.5mi	3mi	3.5mi	4mi	4.5mi	5mi
Distance Downstream (mi)	0.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
	0.5	15.3	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
	1.0	15.6	15.4	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
	1.5	15.8	15.7	15.5	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4
	2.0	16.1	16.0	15.8	15.7	15.5	15.5	15.5	15.5	15.5	15.5	15.5
	2.5	16.4	16.2	16.1	15.9	15.7	15.6	15.6	15.6	15.6	15.6	15.6
	3.0	16.6	16.5	16.4	16.2	16.1	15.9	15.7	15.7	15.7	15.7	15.7
	3.5	16.9	16.7	16.6	16.5	16.3	16.2	16.0	15.8	15.8	15.8	15.8
	4.0	17.1	17.0	16.8	16.7	16.6	16.4	16.2	16.1	15.9	15.9	15.9
	4.5	17.3	17.2	17.1	17.0	16.8	16.7	16.5	16.4	16.2	16.1	16.1
	5.0	17.6	17.5	17.4	17.3	17.1	17.0	16.8	16.7	16.6	16.4	16.2

Table 5-11 Maximum daily simulated water temperatures for 20 cfs steady-state flow with a constant upstream boundary condition of 15°C with shade applied in 0.5 mile increments, Aug. 28, 2001 meteorological conditions

		Distance vegetative shading extends downstream										
		No Shade	0.5mi	1mi	1.5mi	2mi	2.5mi	3mi	3.5mi	4mi	4.5mi	5mi
Distance Downstream (mi)	0.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
	0.5	16.1	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9
	1.0	17.3	17.1	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8
	1.5	18.2	17.9	17.7	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4
	2.0	19.3	19.1	18.8	18.6	18.1	18.1	18.1	18.1	18.1	18.1	18.1
	2.5	20.2	20.0	19.8	19.6	19.1	18.7	18.7	18.7	18.7	18.7	18.7
	3.0	21.2	21.0	20.8	20.6	20.1	19.7	19.0	19.0	19.0	19.0	19.0
	3.5	22.0	21.7	21.6	21.4	21.0	20.6	19.9	19.4	19.4	19.4	19.4
	4.0	22.7	22.4	22.2	22.0	21.6	21.3	20.8	20.4	19.9	19.9	19.9
	4.5	23.4	23.1	22.9	22.6	22.3	22.0	21.8	21.4	20.9	20.5	20.5
	5.0	24.0	23.7	23.5	23.3	23.0	22.7	22.5	22.4	21.9	21.4	20.9

Table 5-12 Reduction in average daily simulated water temperatures for 20 cfs steady-state flow with a constant upstream boundary condition of 15°C with shade applied in 0.5 mile increments, Aug. 28, 2001 meteorological conditions

		Distance vegetative shading extends downstream										
		No Shade	**0.5mi**	**1mi**	**1.5mi**	**2mi**	**2.5mi**	**3mi**	**3.5mi**	**4mi**	**4.5mi**	**5mi**
Distance Downstream (mi)	**0.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.5		**0.2**	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	1.0			**0.3**	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	1.5				**0.5**	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	2.0					**0.6**	0.6	0.6	0.6	0.6	0.6	0.6
	2.5						**0.8**	0.8	0.8	0.8	0.8	0.8
	3.0							**0.9**	0.9	0.9	0.9	0.9
	3.5								**1.0**	1.0	1.0	1.0
	4.0									**1.2**	1.2	1.2
	4.5										**1.3**	1.3
	5.0											**1.4**

Table 5-13 Reduction in maximum daily simulated water temperatures for 20 cfs steady-state flow with a steady upstream boundary condition of 15°C with shade applied in 0.5 mile increments, Aug. 28, 2001 meteorological conditions

		Distance vegetative shading extends downstream										
		No Shade	0.5mi	1mi	1.5mi	2mi	2.5mi	3mi	3.5mi	4mi	4.5mi	5mi
Distance Downstream (mi)	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.5		**0.2**	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	1.0			**0.5**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	1.5				**0.7**	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	2.0					**1.2**	1.2	1.2	1.2	1.2	1.2	1.2
	2.5						**1.6**	1.6	1.6	1.6	1.6	1.6
	3.0							**2.2**	2.2	2.2	2.2	2.2
	3.5								**2.6**	2.6	2.6	2.6
	4.0									**2.9**	2.9	2.9
	4.5										**2.9**	2.9
	5.0											**3.1**

Table 5-14 Average daily simulated water temperatures for 20 cfs steady-state flow with a constant upstream boundary condition of 20°C with shade applied in 0.5 mile increments, Aug. 28, 2001 meteorological conditions

		Distance vegetative shading extends downstream										
		No Shade	0.5mi	1mi	1.5mi	2mi	2.5mi	3mi	3.5mi	4mi	4.5mi	5mi
Distance Downstream (mi)	**0.0**	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	0.5	20.2	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	1.0	20.3	20.2	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1
	1.5	20.5	20.3	20.2	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1
	2.0	20.6	20.5	20.4	20.3	20.1	20.1	20.1	20.1	20.1	20.1	20.1
	2.5	20.7	20.6	20.5	20.4	20.2	20.1	20.1	20.1	20.1	20.1	20.1
	3.0	20.9	20.8	20.6	20.6	20.4	20.3	20.1	20.1	20.1	20.1	20.1
	3.5	21.0	20.9	20.8	20.7	20.5	20.4	20.3	20.2	20.2	20.2	20.2
	4.0	21.1	21.0	20.9	20.8	20.7	20.5	20.4	20.3	20.1	20.1	20.1
	4.5	21.2	21.1	21.0	20.9	20.8	20.7	20.6	20.5	20.3	20.2	20.2
	5.0	21.3	21.2	21.1	21.1	20.9	20.8	20.7	20.6	20.5	20.3	20.2

Table 5-15 Maximum daily simulated water temperatures for 20 cfs steady-state flow with a constant upstream boundary condition of 20°C with shade applied in 0.5 mile increments, Aug. 28, 2001 meteorological conditions

		Distance vegetative shading extends downstream										
		No Shade	**0.5mi**	**1mi**	**1.5mi**	**2mi**	**2.5mi**	**3mi**	**3.5mi**	**4mi**	**4.5mi**	**5mi**
Distance Downstream (mi)	**0.0**	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	0.5	20.9	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7
	1.0	21.9	21.7	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4
	1.5	22.6	22.4	22.2	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9
	2.0	23.5	23.3	23.1	22.9	22.4	22.4	22.4	22.4	22.4	22.4	22.4
	2.5	24.3	24.0	23.9	23.7	23.2	22.8	22.8	22.8	22.8	22.8	22.8
	3.0	25.0	24.8	24.6	24.4	23.9	23.5	22.9	22.9	22.9	22.9	22.9
	3.5	25.6	25.4	25.2	25.0	24.6	24.2	23.6	23.2	23.2	23.2	23.2
	4.0	26.2	25.9	25.7	25.5	25.1	24.8	24.3	24.0	23.5	23.5	23.5
	4.5	26.6	26.4	26.2	26.0	25.7	25.3	25.1	24.8	24.3	24.0	24.0
	5.0	27.0	26.8	26.6	26.5	26.2	25.9	25.7	25.5	25.1	24.6	24.1

Table 5-16 Reduction in average daily simulated water temperatures for 20 cfs steady-state flow with a constant upstream boundary condition of 20°C with shade applied in 0.5 mile increments, Aug. 28, 2001 meteorological conditions

		Distance vegetative shading extends downstream										
		No Shade	**0.5mi**	**1mi**	**1.5mi**	**2mi**	**2.5mi**	**3mi**	**3.5mi**	**4mi**	**4.5mi**	**5mi**
Distance Downstream (mi)	**0.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.5		**0.1**	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	1.0			**0.3**	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	1.5				**0.4**	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	2.0					**0.5**	0.5	0.5	0.5	0.5	0.5	0.5
	2.5						**0.6**	0.6	0.6	0.6	0.6	0.6
	3.0							**0.7**	0.7	0.7	0.7	0.7
	3.5								**0.8**	0.8	0.8	0.8
	4.0									**0.9**	0.9	0.9
	4.5										**1.0**	1.0
	5.0											**1.1**

Table 5-17 Reduction in maximum daily simulated water temperatures for 20 cfs steady-state flow with a steady upstream boundary condition of 20°C with shade applied in 0.5 mile increments, Aug. 28, 2001 meteorological conditions

		Distance vegetative shading extends downstream										
		No Shade	**0.5mi**	**1mi**	**1.5mi**	**2mi**	**2.5mi**	**3mi**	**3.5mi**	**4mi**	**4.5mi**	**5mi**
Distance Downstream (mi)	**0.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.5		**0.2**	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	1.0			**0.5**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	1.5				**0.7**	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	2.0					**1.2**	1.2	1.2	1.2	1.2	1.2	1.2
	2.5						**1.6**	1.6	1.6	1.6	1.6	1.6
	3.0							**2.1**	2.1	2.1	2.1	2.1
	3.5								**2.5**	2.5	2.5	2.5
	4.0									**2.7**	2.7	2.7
	4.5										**2.7**	2.7
	5.0											**2.9**

Table 5-18 Average daily simulated water temperatures for 50 cfs steady-state flow with a constant upstream boundary condition of 15°C with shade applied in 0.5 mile increments, Aug. 28, 2001 meteorological conditions

		Distance vegetative shading extends downstream										
		No Shade	0.5mi	1mi	1.5mi	2mi	2.5mi	3mi	3.5mi	4mi	4.5mi	5mi
Distance Downstream (mi)	0.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
	0.5	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
	1.0	15.3	15.2	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
	1.5	15.4	15.3	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2
	2.0	15.5	15.5	15.4	15.3	15.2	15.2	15.2	15.2	15.2	15.2	15.2
	2.5	15.7	15.6	15.5	15.5	15.4	15.3	15.3	15.3	15.3	15.3	15.3
	3.0	15.9	15.8	15.7	15.7	15.6	15.5	15.4	15.4	15.4	15.4	15.4
	3.5	16.0	15.9	15.9	15.8	15.7	15.7	15.6	15.5	15.5	15.5	15.5
	4.0	16.2	16.1	16.0	16.0	15.9	15.8	15.7	15.7	15.6	15.6	15.6
	4.5	16.3	16.3	16.2	16.2	16.1	16.0	15.9	15.8	15.8	15.7	15.7
	5.0	16.5	16.4	16.4	16.3	16.3	16.2	16.1	16.0	15.9	15.9	15.8

Table 5-19 Maximum daily simulated water temperatures for 50 cfs steady-state flow with a constant upstream boundary condition of 15°C with shade applied in 0.5 mile increments, Aug. 28, 2001 meteorological conditions

		Distance vegetative shading extends downstream										
		No Shade	0.5mi	1mi	1.5mi	2mi	2.5mi	3mi	3.5mi	4mi	4.5mi	5mi
Distance Downstream (mi)	0.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
	0.5	15.5	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4
	1.0	16.0	15.9	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8
	1.5	16.4	16.3	16.2	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1
	2.0	17.0	16.9	16.8	16.7	16.5	16.5	16.5	16.5	16.5	16.5	16.5
	2.5	17.6	17.5	17.4	17.3	17.1	16.9	16.9	16.9	16.9	16.9	16.9
	3.0	18.3	18.2	18.1	18.1	17.9	17.7	17.4	17.4	17.4	17.4	17.4
	3.5	18.8	18.7	18.6	18.5	18.3	18.2	18.0	17.8	17.8	17.8	17.8
	4.0	19.3	19.2	19.2	19.1	18.9	18.8	18.6	18.4	18.2	18.2	18.2
	4.5	19.9	19.8	19.7	19.7	19.5	19.4	19.2	19.0	18.8	18.6	18.6
	5.0	20.5	20.4	20.3	20.2	20.1	19.9	19.8	19.7	19.5	19.3	19.0

Table 5-20 Reduction in average daily simulated water temperatures for 50 cfs steady-state flow with a constant upstream boundary condition of 15°C with shade applied in 0.5 mile increments, Aug. 28, 2001 meteorological conditions

		Distance vegetative shading extends downstream										
		No Shade	**0.5mi**	**1mi**	**1.5mi**	**2mi**	**2.5mi**	**3mi**	**3.5mi**	**4mi**	**4.5mi**	**5mi**
Distance Downstream (mi)	**0.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.5		**0.1**	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	1.0			**0.1**	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	1.5				**0.2**	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	2.0					**0.3**	0.3	0.3	0.3	0.3	0.3	0.3
	2.5						**0.4**	0.4	0.4	0.4	0.4	0.4
	3.0							**0.4**	0.4	0.4	0.4	0.4
	3.5								**0.5**	0.5	0.5	0.5
	4.0									**0.6**	0.6	0.6
	4.5										**0.7**	0.7
	5.0											**0.7**

Table 5-21 Reduction in maximum daily simulated water temperatures for 50 cfs steady-state flow with a steady upstream boundary condition of 15°C with shade applied in 0.5 mile increments, Aug. 28, 2001 meteorological conditions

		Distance vegetative shading extends downstream										
		No Shade	0.5mi	1mi	1.5mi	2mi	2.5mi	3mi	3.5mi	4mi	4.5mi	5mi
Distance Downstream (mi)	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.5		**0.1**	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	1.0			**0.2**	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	1.5				**0.3**	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	2.0					**0.4**	0.4	0.4	0.4	0.4	0.4	0.4
	2.5						**0.6**	0.6	0.6	0.6	0.6	0.6
	3.0							**0.9**	0.9	0.9	0.9	0.9
	3.5								**1.0**	1.0	1.0	1.0
	4.0									**1.2**	1.2	1.2
	4.5										**1.4**	1.4
	5.0											**1.5**

Table 5-22 Average daily simulated water temperatures for 50 cfs steady-state flow with a constant upstream boundary condition of 20°C with shade applied in 0.5 mile increments, Aug. 28, 2001 meteorological conditions

		Distance vegetative shading extends downstream										
		No Shade	0.5mi	1mi	1.5mi	2mi	2.5mi	3mi	3.5mi	4mi	4.5mi	5mi
Distance Downstream (mi)	0.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	0.5	20.1	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	1.0	20.1	20.1	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	1.5	20.2	20.1	20.1	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	2.0	20.2	20.2	20.1	20.1	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	2.5	20.3	20.3	20.2	20.1	20.1	20.0	20.0	20.0	20.0	20.0	20.0
	3.0	20.4	20.3	20.3	20.2	20.2	20.1	20.0	20.0	20.0	20.0	20.0
	3.5	20.4	20.4	20.3	20.3	20.2	20.2	20.1	20.0	20.0	20.0	20.0
	4.0	20.5	20.5	20.4	20.4	20.3	20.2	20.2	20.1	20.0	20.0	20.0
	4.5	20.6	20.5	20.5	20.4	20.4	20.3	20.2	20.2	20.1	20.0	20.0
	5.0	20.6	20.6	20.5	20.5	20.4	20.4	20.3	20.3	20.2	20.1	20.0

Table 5-23 Maximum daily simulated water temperatures for 50 cfs steady-state flow with a constant upstream boundary condition of 20°C with shade applied in 0.5 mile increments, Aug. 28, 2001 meteorological conditions

		Distance vegetative shading extends downstream										
		No Shade	**0.5mi**	**1mi**	**1.5mi**	**2mi**	**2.5mi**	**3mi**	**3.5mi**	**4mi**	**4.5mi**	**5mi**
Distance Downstream (mi)	**0.0**	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	0.5	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9
	1.0	21.1	21.0	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9
	1.5	21.4	21.3	21.1	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
	2.0	21.8	21.7	21.7	21.6	21.4	21.4	21.4	21.4	21.4	21.4	21.4
	2.5	22.3	22.3	22.2	22.1	21.8	21.7	21.7	21.7	21.7	21.7	21.7
	3.0	22.9	22.8	22.7	22.6	22.3	22.2	22.0	22.0	22.0	22.0	22.0
	3.5	23.3	23.2	23.1	23.0	22.8	22.7	22.6	22.5	22.5	22.5	22.5
	4.0	23.8	23.7	23.6	23.5	23.3	23.2	23.1	22.9	22.7	22.7	22.7
	4.5	24.2	24.1	24.0	23.9	23.8	23.6	23.5	23.4	23.2	23.0	23.0
	5.0	24.8	24.7	24.6	24.5	24.4	24.2	24.2	24.0	23.8	23.6	23.4

Table 5-24 Reduction in average daily simulated water temperatures for 50 cfs steady-state flow with a constant upstream boundary condition of 20°C with shade applied in 0.5 mile increments, Aug. 28, 2001 meteorological conditions

		Distance vegetative shading extends downstream										
		No Shade	0.5mi	1mi	1.5mi	2mi	2.5mi	3mi	3.5mi	4mi	4.5mi	5mi
Distance Downstream (mi)	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.5		**0.1**	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	1.0			**0.1**	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	1.5				**0.2**	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	2.0					**0.2**	0.2	0.2	0.2	0.2	0.2	0.2
	2.5						**0.3**	0.3	0.3	0.3	0.3	0.3
	3.0							**0.4**	0.4	0.4	0.4	0.4
	3.5								**0.4**	0.4	0.4	0.4
	4.0									**0.5**	0.5	0.5
	4.5										**0.5**	0.5
	5.0											**0.6**

Table 5-25 Reduction in maximum daily simulated water temperatures for 50 cfs steady-state flow with a steady upstream boundary condition of 20°C with shade applied in 0.5 mile increments, Aug. 28, 2001 meteorological conditions

		Distance vegetative shading extends downstream										
		No Shade	0.5mi	1mi	1.5mi	2mi	2.5mi	3mi	3.5mi	4mi	4.5mi	5mi
Distance Downstream (mi)	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.5		**0.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1.0			**0.2**	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	1.5				**0.4**	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	2.0					**0.4**	0.4	0.4	0.4	0.4	0.4	0.4
	2.5						**0.7**	0.7	0.7	0.7	0.7	0.7
	3.0							**0.9**	0.9	0.9	0.9	0.9
	3.5								**0.8**	0.8	0.8	0.8
	4.0									**1.1**	1.1	1.1
	4.5										**1.2**	1.2
	5.0											**1.5**

6.0 Findings and Recommendations

6.1 Findings

Through the implementation and application of a set of flow and temperature models several relationships between flow, variable flow patterns, tail water return distribution and riparian vegetation shading conditions. The principal findings are identified below.

- Advection, the physical transport of thermal energy downstream is an important consideration in the Shasta River. The transport of water from upstream

- Additional volume of water generally translates to a reduction in the diurnal range in temperatures, i.e., lower daily maximum and higher daily minimum temperatures. Mean daily temperature may show some reduction over longer reaches of river due to increased flows, especially if upstream sources are cooler.

- Identifying the reach or reaches with the largest heat gain (e.g. °C per mile) provides insight into the locations where the greatest opportunity for decreasing mean daily temperature through increased flow exists.

- Pulse flows affect the water temperature through increase stream volume and reduction in transit time. The model effectively routed these transient flow conditions through the system. However, the thermal benefit is uncertain, primarily due to a lack of biological data relating changes in thermal regime to outmigrating salmonids

- Water temperature conditions should be monitored prior to and during the pulse flow to ensure water temperature conditions are conducive to the operation. For example if releases from Dwinnell Dam (Lake Shastina) are inordinately warm, it may be more beneficial to not use that water in the pulse operation.

- Sequential pulse flow operations and simultaneous pulse flow operations showed modest differences in thermal regime. There are probably more pressing issues associated with the pulse flow than timing of diversions are shut down, such as meteorological conditions at the time of the pulse, the available flow, the time that all diversions are shut down in the simultaneous operation (morning better than evening), and ramping flows up and down in a manner that is beneficial to the objective of encouraging juvenile fish to move out.

- The amount, distribution, location, and temperature of return flow can impact the thermal regime of the river. The impacts for a single reach may be modest. The impacts of a system wide program were not analyzed.
- Riparian vegetation shading can potentially reduce minimum, mean, and particularly maximum daily, temperatures over the distance of a single reach (five to seven miles).
- Where water temperatures were closer to equilibrium conditions (e.g., away from

cool spring inflow influences) riparian vegetation had a more noticeable affect. This does not discount the importance of riparian vegetation in cool water areas.

- In general, the reduction in water temperature from a restored riparian vegetation condition does not persist more than several miles downstream (applicable to conditions where downstream reaches are not restored).
- Time of year and solar altitude play a role in ability of riparian vegetation to reduce incoming solar radiation, thus affecting the thermal regime of the river.
- Riparian restoration efforts are long-term management approaches to moderating and/or reducing river temperatures. Model simulations can assist decision makers in management approaches to address potential spatial distribution of restoration, how long it may take to reach maturity and provide temperature control benefits, and what thermal relief intermediate conditions may provide.
- Herbaceous riparian vegetation (e.g., bulrush) can provide sufficient shade to affect water temperature if present in sufficient quantity (density and distribution) along the river bank.
- Riparian vegetation on small river systems such as the Shasta River plays an important role in reducing mean daily temperatures (as well as maximum and minimum). Further studies should be completed to determine the trade-off between flow volume, riparian shading, and return flow management for various reaches of the Shasta River to identify a "most favorable" combination of management actions to meet desired objectives.

6.2 Recommendations

The developed models, as well as supporting data, have provided constructive insight into flow, temperature, and riparian vegetation shading inter-relationships. Not only have potential effects been identified, but the potential magnitude of temperature changes associated with various management strategies have been identified for locations specific to the Shasta River. The principal recommendation is to build upon the findings herein and apply the model to a broader set of alternatives – possibly combinations of certain management strategies identified herein.

Although further application of the models is the principal recommendation, additional recommendations were identified. As with most investigative studies, an appreciable amount of information and knowledge was gained during the project. This information and knowledge provided a new perspective on many aspects of the Shasta River system, and specific items were recognized as beyond the scope of the current work but worthy of further consideration. These items form the recommendations outlined below.

- River geometric data, principally cross section data, could be improved for the Shasta River flow and temperature model. Although field measurements were made to secure the information, a more comprehensive effort would provide more detailed representation in certain reaches.
  Recommendation: identify funding sources to support additional collection of

field data to refine the geometric representation of the flow and temperature models. Seek to collect data system wide.

- Accretions and depletions were estimated on a reach-by-reach basis using flow data from seasonal gages placed at the top and bottom of each reach. This proved to be useful, but certain reaches include several outflows (e.g., diversions) and/or inflows (e.g., return flows, springs, tributaries). System inflows are distributed non-uniformly along the river. Further, they experience variable flow rates magnitude and timing) and enter at various temperatures. Currently, the details of such inflows and outflows are not well characterized, but potentially play a critical role in the long-term management of the Shasta River.
  Recommendation: Complete a pilot study, for a representative reach or area to identify the various modes at which water may enter the river (e.g., groundwater, diffuse surface flow, localized inflow), quantity of inflow, and temperature associated with each type of source. These data can then be entered into the flow and temperature model to assess potential impacts of managing these various sources.

- Bed conduction in small, shallow rivers may play a role in the thermal regime of the system.
  Recommendation: Conduct a field study to quantify the role of bed conduction in the heat budget. Identify several locations based primarily on substrate to conduct the tests. Use the results to test/calibrate the bed conduction logic included in the model, and complete a battery of tests to determine the potential role of bed conduction in the Shasta River.

- Woody riparian vegetation was characterized in 1997 for a significant portion of the system using aerial photographs combined with site visits. Herbaceous riparian vegetation was not identified.
  Recommendation: Conduct a riparian vegetation survey that includes woody vegetation, as well as herbaceous. Identify plant species, as well as conditions that provide additional benefit or dis-benefit to shading potential (e.g., narrow or wide river width, high banks (local topographic shading) or low banks.). Use this data to update, as necessary, the riparian vegetation within the model

- Topographic shading may be a factor for the canyon reach of the Shasta River.
  Recommendation: Using solar radiation equipment similar to that used in Abbott and Deas (2003), carry out measurements adjacent to the Shasta River at several locations. Alternatively, use a digital elevation model to approximate shade reduction potential.

- The Shasta River in the study area changes in elevation of about 800 feet in the study area and flows through riparian corridors, open fields, and steep bedrock canyons. Meteorological conditions may vary throughout the reach.
  Recommendation: Using a portable meteorological station and conduct field studies at the various locations within the Shasta Valley over several weeks. Use

the NOAA station at the Montague Grenada Airport and the CDF station at Brazie Ranch as controls.

- There are two gages currently on the system: the DWR station at Montague Grenada Road, and the USGS station near the mouth. Two stations are insufficient to characterize the complexity of the Shasta River system. There are certain reaches of the system where flow data is underrepresented. Either flow data are unavailable or long-term records necessary to capture the natural variability of the system are unavailable. To effectively and efficiently manage water resources in the basin additional flow data is necessary.
  Recommendation: Add and maintain a seasonal flow monitoring station at Anderson Grade, Highway A-12, and a location upstream of A-12 to collect daily flow information to support modeling and other management activities.

- The current temperature monitoring program carried out by California Department of Fish and Game effectively covers a large portion of the Shasta River basin downstream of Dwinnell Dam. There are certain reaches of the system where temperature data is underrepresented. Either temperature data are unavailable or long-term records necessary to capture the natural variability of the system are unavailable. To effectively and efficiently manage water resources in the basin additional temperature data is necessary.
  Recommendation: Add and maintain additional temperature monitoring locations, principally in the accretion reaches upstream of A-12. Hourly data would be necessary to support modeling and other management activities.

- In the coding of TVA's RQUAL (water temperature model), dispersion is neglected. The numerical approximations used in solving the governing equations of transport probably introduce some level of numerical dispersion into the solution. (Numerical dispersion is a function of the mathematical approximation used in the solution of the governing equations, and has no relation to dispersive properties of the actual, physical system.)
  Recommendation: Complete a test using the model to quantify numerical dispersion, if any. Document the findings and append to the modeling report.

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Appendix A: Modified Input Files

One input file was modified and one input file was added to allow for the new shading logic. This appendix contains the modifications and the format for the new file.

A.1 Water Quality Coefficients (name.ric)

The first line (record) of the water quality coefficient input file was modified.

Original Input File (record number 1)

PRT,IPLT,THET,TSI,I02R,PLT,ROUTE,TDC,PDCX
(F8.0,I5,2F8.0,I5,F8.0,4X,A1,2F8.0)

Modified Input File (record number 1)

PRT,IPLT,THET,TSI,I02R,PLT,ROUTE,TDC,PDCX,IRS
(F8.0,I5,2F8.0,I5,F8.0,4X,A1,2F8.0,I5)

If IRS=0, RQUAL will run as originally constituted. If IRS=1, a shade data (shade.ris) input file is required. In addition, EBH and SHSOL should be left out of the .ric file.

A.2 Shade Data (shade.ris)

The shade data input file (shade.ris) must be named 'shade.ris' and be located in the same directory as RQUAL. The format of 'shade.ris' is (8X,4F8.0) where the first column may be used as an identifier with the node or river mile. The following four columns contain left effective barrier height, right effective barrier height, left bank transmittance factor, and right bank transmittance factor respectively.

Sample Input File (shade.ris)

```
Head        10.0   40.00    0.15      0.0  EBHL,EBHR,SHSOLL,SHSOLR
    2       10.0   40.00    0.15      0.0
    3       10.0   40.00    0.15      0.0
    4       10.0   40.00    0.15      0.0
    5       10.0   40.00    0.15      0.0
Mouth       10.0   40.00    0.15      0.0
```

Appendix B: Modified Program Code

Modifications were made in the main program, the subroutine CRS, in the commonblock RA which exists in the MAIN program and in subroutines CRS, BEDFLX, BEDFL2, INTEGR, TEMPDK, BODDK, NODDK, OXYDK, MROUTE, H-P, and in the commonblock CR which exists in the main program and in subroutine CRS. The original program code is in normal print, the modifications made for this application are in bold print. The dashed lines indicate that parts of the code have been deleted that were not of interest in these changes.

```
$debug
      PROGRAM RQUAL
C Modified version agpa 09/10/01
-----------------------------------------------------------------------------
      REAL N1,N2,NOD1,NOD2,NDK1,NDK2,NP1,NP2,NINIT,NK20,NODR,K1,K2
      CHARACTER*1 ROUTE
C
c agpa 9/17/01 modified EBH to accommodate both banks
c COMMON/CR/ EBH(500),AZ(500),BW(500),PHI,ALON,TZM,TFOG
c      COMMON/CR/ EBH(500),AZ(500),BW(500),PHI,ALON,TZM,TFOG,EBHL(500),
c     XEBHR(500),IEBH

c agpa 9/18/01 take out IEBH, no longer needed
c only one control variable will be used to turn on new shading logic
c if IRS=1 then the user inputs EBHL,EBHR and SHSOLL,SHSOLR
       COMMON/CR/ EBH(500),AZ(500),BW(500),PHI,ALON,TZM,TFOG,EBHL(500),
     XEBHR(500)

      COMMON/HYD/DX(499),Q1(500),Q2(500),H1(500),H2(500),
     X           A1(500),A2(500),E1(500),E2(500),W1(500),W2(500),
     X           K1(500),K2(500),DT,THET,TSI,
     X           QL1(499),QL2(499),QLAT1(44),QLAT2(44)
      COMMON/HYDNC/NC(500),ICONST,WFAC,WLEN,pdc,pdcx
c agpa 9/13/01 added IRS COMMON/RA/EXCO,HMAC,AA,BB,NXSEC,THR,THB,BK20,THS,SK20(500),
c     XTHN,NK20,THPR,IK2EQ,BS20,BETW,XL,XL2,DIF,CV,BEDALB,SHSOL,SHDBT

      COMMON/RA/EXCO,HMAC,AA,BB,NXSEC,THR,THB,BK20,THS,SK20(500),
     XTHN,NK20,THPR,IK2EQ,BS20,BETW,XL,XL2,DIF,CV,BEDALB,SHSOL,SHDBT,
     XIRS,SHSOLL(500),SHSOLR(500),SHSOLA(500),IDAY,JOLD
      COMMON/PHOT/PMAX(500),RESP(500),O2KM
C
      COMMON/PROCES/PHOTO(500),RESPR(500),REAR(500),NODR(500),BODR(500),
     XSODR(500),RETYP(500),TQS(500),TRS(500),TQA(500),TQB(500),TQE(500)
      COMMON/PROCS2/TBC(500),TBC2(500),TQC(500),IPROC
      COMMON/WQ/O1(500),O2(500),T1(500),T2(500),B1(500),B2(500),
     XOM(500),QM(500),N1(500),N2(500)
      COMMON/UWEIR/NEVQ,EVQ(20,2)
      COMMON/BDFX/TBED(500),TBED2(500)
      COMMON/LAT/NL,NLW,NLS(44,2),LSEC(11),INDS(11)
C
      COMMON/JUK/ RMI(500),CHB(500),RML(11),RMIND(11),
     X          RS1(500),RS2(500),ALPHX(500),IC(500),ICCH(500),
     X          TDK1(500),TDK2(500),TP1(500),TP2(500),
     X          BDK1(500),BDK2(500),BP1(500),BP2(500)
      COMMON/JUK1/RDBT1(500),RDBT2(500)
      COMMON/JUK2/ ODK1(500),ODK2(500),OP1(500),OP2(500),
     X           NDK1(500),NDK2(500),NP1(500),NP2(500)
      COMMON/JUK3/ WLT1(11),WLT2(11),WLO1(11),WLO2(11),
     X          WLB1(11),WLB2(11),WT1(499),WT2(499),
     X          WB1(499),WB2(499),WO1(499),WO2(499),
```

```
     X          WLN1(11),WLN2(11),WN1(499),WN2(499)
      COMMON/JUK4/ WTL2(11),WBL2(11),WOL2(11),WNL2(11)
C agpa 09/10/01 QNSO(I) added to output solar radiation in main program
c       DIMENSION JFIRST(4),NX(4),MCJ(3),NQLH(4),IDTSAVE(4)
        DIMENSION JFIRST(4),NX(4),MCJ(3),NQLH(4),IDTSAVE(4),QNSO(500)
      DATA IDTSAVE/4*0/,ipr/0/
--------------------------------------------------------------------------

C agpa 09/10/01 Added an output files for solar radiation and shade factor
C Four outfiles, one for each of four nodes. Output is a time series
C  OPEN SOLAR RADIATION OUTPUT FILE Solar.out
        OPEN(28,FILE='Solar1.out ',STATUS='unknown')
        WRITE(28,'(/A)')' ***********************************************'
      WRITE(28,'(A)') ' *  Solar Radiation Output for RQUAL            *'
      WRITE(28,'(A)') ' * SIM Hr = simulation hour,RMI = River Mile   *'
        WRITE(28,'(A)') ' * SHSOL = shade reduction factor,             *'
        WRITE(28,'(A)') ' * EBH = effective bank height,                *'
        WRITE(28,'(A)') ' * RS = shade reduction, QNS = reduced solar   *'
        WRITE(28,'(A)') ' * SWS = incoming solar (kcal/m2-s)            *'
      WRITE(28,'(A)') ' ***********************************************'
        WRITE(28,799)'SimHR','RMI','SHSOL','EBH','RS','QNS','SWS','Temp'
        WRITE(28,799) 'hr','mi','','m','','kcal/m2-s','kcal/m2-s','C'
        OPEN(29,FILE='Solar3.out ',STATUS='unknown')
        WRITE(29,'(/A)')' ***********************************************'
      WRITE(29,'(A)') ' *  Solar Radiation Output for RQUAL            *'
        WRITE(29,'(A)') ' * SIM Hr = simulation hour,RMI = River Mile   *'
        WRITE(29,'(A)') ' * SHSOL = shade reduction factor,             *'
        WRITE(29,'(A)') ' * EBH = effective bank height,                *'
        WRITE(29,'(A)') ' * RS = shade reduction, QNS = reduced solar   *'
        WRITE(29,'(A)') ' * SWS = incoming solar (kcal/m2-s)            *'
        WRITE(29,'(A)') ' ***********************************************'
        WRITE(29,799)'SimHR','RMI','SHSOL','EBH','RS','QNS','SWS','Temp'
        WRITE(29,799) 'hr','mi','','m','','kcal/m2-s','kcal/m2-s','C'
        OPEN(30,FILE='Solar5.out ',STATUS='unknown')
        WRITE(30,'(/A)')' ***********************************************'
      WRITE(30,'(A)') ' *  Solar Radiation Output for RQUAL            *'
      WRITE(30,'(A)') ' * SIM Hr = simulation hour,RMI = River Mile   *'
        WRITE(30,'(A)') ' * SHSOL = shade reduction factor,             *'
        WRITE(30,'(A)') ' * EBH = effective bank height,                *'
        WRITE(30,'(A)') ' * RS = shade reduction, QNS = reduced solar   *'
        WRITE(30,'(A)') ' * SWS = incoming solar (kcal/m2-s)            *'
      WRITE(30,'(A)') ' ***********************************************'
        WRITE(30,799)'SimHR','RMI','SHSOL','EBH','RS','QNS','SWS','Temp'
        WRITE(30,799) 'hr','mi','','m','','kcal/m2-s','kcal/m2-s','C'
        OPEN(31,FILE='Solar11.out ',STATUS='unknown')
        WRITE(31,'(/A)')' ***********************************************'
      WRITE(31,'(A)') ' *  Solar Radiation Output for RQUAL            *'
      WRITE(31,'(A)') ' * SIM Hr = simulation hour,RMI = River Mile   *'
        WRITE(31,'(A)') ' * SHSOL = shade reduction factor,             *'
        WRITE(31,'(A)') ' * EBH = effective bank height,                *'
        WRITE(31,'(A)') ' * RS = shade reduction, QNS = reduced solar   *'
        WRITE(31,'(A)') ' * SWS = incoming solar (kcal/m2-s)            *'
      WRITE(31,'(A)') ' ***********************************************'
        WRITE(31,799)'SimHR','RMI','SHSOL','EBH','RS','QNS','SWS','Temp'
        WRITE(31,799) 'hr','mi','','m','','kcal/m2-s','kcal/m2-s','C'
  799   FORMAT(8A10)
-------------------------------------------------------------------------------

c agpa 9/13/01 added new variable IRS to added SHSOL on both banks
c       READ(5,1011)PRT,IPLT,THET,TSI,IPROC,PLT,ROUTE,pdc,pdcx
c       WRITE(60,'(A)') ' PRT,IPLT,THET,TSI,IPROC,PLT,ROUTE='
c       WRITE(60,2013)PRT,IPLT,THET,TSI,IPROC,PLT,ROUTE

c agpa 9/17/01 added new variable IEBH as flag to turn on ability to enter l/r bank ebh
c agpa 9/18/01 went back to one control variable (IRS)
        READ(5,1011)PRT,IPLT,THET,TSI,IPROC,PLT,ROUTE,pdc,pdcx,IRS
      WRITE(60,'(A)') ' PRT,IPLT,THET,TSI,IPROC,PLT,ROUTE,IRS='
      WRITE(60,2013)PRT,IPLT,THET,TSI,IPROC,PLT,ROUTE,IRS
```

```
c agpa 9/18/01 took out IEBH, and reverted back to one control variable for new logic
(IRS)
c      READ(5,1011)PRT,IPLT,THET,TSI,IPROC,PLT,ROUTE,pdc,pdcx,IRS,IEBH
c      WRITE(60,'(A)') ' PRT,IPLT,THET,TSI,IPROC,PLT,ROUTE,IRS,IEBH='
c      WRITE(60,2013)PRT,IPLT,THET,TSI,IPROC,PLT,ROUTE,IRS,IEBH

      IF(PLT.EQ.0.0)PLT=PRT
C
      IF(PRT.GE.DTHR)GO TO 3
      WRITE(60,'(A)') ' PRT,DTHR='
      WRITE(60,3232)PRT,DTHR
 3232 FORMAT(/' ERROR...PRT<DT  PRT=',F6.3,' DT=',F6.3)
      GO TO 9999
    3 CONTINUE
      IF(PLT.GE.DTHR)GO TO 4
      WRITE(60,'(A)') ' PRT,DTHR='
      WRITE(60,3332)PLT,DTHR
 3332 FORMAT(/' ERROR...PLT<DT  PLT=',F6.3,' DT=',F6.3)
      GO TO 9999
    4 CONTINUE
C
C
      IF(THET.EQ.0.0)THET=0.5
      IF(TSI.EQ.0.0)TSI=1.0
c agpa 9/13/01 2013 FORMAT(F8.4,I5,2F8.2,I5,F8.2,4X,A1)
c agpa 9/13/01 1011 FORMAT(F8.0,I5,2F8.0,I5,F8.0,4X,A1,2f8.0)
 2013 FORMAT(F8.4,I5,2F8.2,I5,F8.2,4X,A1,I5)
 1011 FORMAT(F8.0,I5,2F8.0,I5,F8.0,4X,A1,2f8.0,I5)
c apga 9/18/01 2013 FORMAT(F8.4,I5,2F8.2,I5,F8.2,4X,A1,2I5)
c agpa 9/18/01 1011 FORMAT(F8.0,I5,2F8.0,I5,F8.0,4X,A1,2f8.0,2I5)

      READ(5,1001)(ALPHX(J),J=1,NXSEC)
      WRITE(60,7211)NXSEC,(ALPHX(J),J=1,5)
 7211 FORMAT(I5,5F8.2)
C
C  READ SHADING FACTOR DATA
C     PHI=LATITUDE,DECIMAL DEG
C     ALON=LONGITUDE, DECIMAL DEG
C     TZM=TIME ZONE MERIDIAN, DEG (TZM CHANGES EVERY 15 DEGREES
C          WEST OF 0 DEGREES AT GREENWICH.  WE ARE IN TIME ZONE
C           MERIDIAN AREA 75 , WHICH APPLIES TO AREA BETWEEN
C           LONGITUDES 75 AND 90)
      READ(5,1001) PHI,ALON,TZM,TFOG
      IF(TFOG.EQ.0.0) TFOG=10.
C
C  COMPUTE TIME ZONE MERIDIAN FROM LONGITUDE (I.E., IGNORE INPUT TZM)
      MTZ=IFIX(ALON)/15
       TZM=15.*FLOAT(MTZ)
      WRITE(60,'(A)') ' PHI,ALON,TZM,TFOG='
      WRITE(60,2011) PHI,ALON,TZM,TFOG
      READ(5,1001) (AZ(I),I=1,NXSEC)
      WRITE(60,2011) (AZ(I),I=1,NXSEC)
      READ(5,1001) (BW(I),I=1,NXSEC)
      WRITE(60,2011) (BW(I),I=1,NXSEC)
c      READ(5,1001) (EBH(I),I=1,NXSEC)
c      WRITE(60,2011) (EBH(I),I=1,NXSEC)

c agpa 9/17/01 flag turns on logic to read in EBH for l/r banks
c       IF (IEBH.eq.0) THEN
c         READ(5,1001) (EBH(I),I=1,NXSEC)
c         WRITE(60,2011) (EBH(I),I=1,NXSEC)
c       ELSE IF (IEBH.eq.1) THEN
c          READ(5,1001) (EBHL(I),I=1,NXSEC)
c         WRITE(60,2011) (EBHL(I),I=1,NXSEC)
c          READ(5,1001) (EBHR(I),I=1,NXSEC)
c         WRITE(60,2011) (EBHR(I),I=1,NXSEC)
c       ENDIF

C agpa 9/13/01 READ SHSOL FOR LEFT AND RIGHT BANK IF IRS=1, ELSE CONTINUE
```

```
c      IF (IRS .EQ. 1) THEN
c       READ(5,1001) (SHSOLL(I),I=1,NXSEC)
c      WRITE(60,'(A)') 'SHSOLL = '
c       WRITE(60,2011) (SHSOLL(I),I=1,NXSEC)
c       READ(5,1001) (SHSOLR(I),I=1,NXSEC)
c       WRITE(60,'(A)') 'SHSOLR = '
c      WRITE(60,2011) (SHSOLR(I),I=1,NXSEC)
c       ENDIF

c agpa 9/18/01 new input format for two bank shading input
c flag, IRS now opens a separate input file Unit=4
      IF (IRS.eq.0) THEN
          READ(5,1001) (EBH(I),I=1,NXSEC)
        WRITE(60,2011) (EBH(I),I=1,NXSEC)
       ELSE IF (IRS.eq.1) THEN
          OPEN(4,FILE='shade.ris',STATUS='OLD')
          WRITE (60,'(5A8)') 'RMI','EBHL','EBHR','SHSOLL','SHSOLR'
          WRITE (60,'(5A8)') '','ft','ft','',''
          DO J=1,NXSEC
            READ(4,'(8X,9F8.0)') EBHL(J),EBHR(J),SHSOLL(J),SHSOLR(J)
            WRITE(60,'(5F8.2)') RMI(J),EBHL(J),EBHR(J),SHSOLL(J),SHSOLR(J)
          ENDDO
       ENDIF


C
C  CHANGE BW,EBH UNITS FROM FT TO METERS
c      DO 12 J=1,NXSEC
c       BW(J)=0.3048*BW(J)
c        EBH(J)=0.3048*EBH(J)
c agpa 9/18/01 if IRS = 1 need to convert l/r bank
       DO 12 J=1,NXSEC
          IF (IRS.eq.1) THEN
          BW(J)=0.3048*BW(J)
          EBHL(J)=0.3048*EBHL(J)
            EBHR(J)=0.3048*EBHR(J)
          ELSE IF (IRS.eq.0) THEN
            BW(J)=0.3048*BW(J)
          EBH(J)=0.3048*EBH(J)
          ENDIF
   12 CONTINUE
C
 1012 FORMAT(/(5F12.0))
C
C  READ WIND COEFFICIENTS AND THERMAL PROPERTIES OF CHANNEL BED
C   EVAP=(AA+BB*WIND)*(ES-EA)
C     WHERE AA=M/(S MB)
C           BB=1/MB
C           ES,EA = MB
C   XL = THICKNESS OF UPPER BED (CM)
C   XL2 = THICKNESS OF LOWER BED (CM)
C   DIF = THERMAL DIFFUSIVITY OF BED (SQ CM/HR)
C   CV = HEAT STORAGE CAPACITY OF BED (CAL/ CU CM  DEG C)

c agpa 9/13/01 commented out to add l/r bank shade logic
c      READ(5,1001)AA,BB,XL,XL2,DIF,CV,BETW,BEDALB,SHSOL,SHDBT
C  SET DEFAULTS
c      WRITE(60,'(A)') ' AA,BB,XL,XL2,DIF,CV,BETW,BEDALB,SHSOL,SHDBT='
c      WRITE(60,2011) AA,BB,XL,XL2,DIF,CV,BETW,BEDALB,SHSOL,SHDBT
c      IF(SHSOL.EQ.0.0) SHSOL=0.2
c      IF(SHDBT.GT.1.0) SHDBT=1.0

c agpa 9/13/01 added to include IRS=1 for l/r bank shading
       IF (IRS.EQ.0) THEN
          READ(5,1001)AA,BB,XL,XL2,DIF,CV,BETW,BEDALB,SHSOL,SHDBT
C  SET DEFAULTS
        WRITE(60,'(A)') ' AA,BB,XL,XL2,DIF,CV,BETW,BEDALB,SHSOL,SHDBT='
        WRITE(60,2011) AA,BB,XL,XL2,DIF,CV,BETW,BEDALB,SHSOL,SHDBT
c agpa 9/18/01 turn off default for shsol       IF(SHSOL.EQ.0.0) SHSOL=0.2
```

```
         IF(SHDBT.GT.1.0) SHDBT=1.0
        ELSE IF (IRS.EQ.1) THEN
          READ(5,1001)AA,BB,XL,XL2,DIF,CV,BETW,BEDALB,SHDBT
         WRITE(60,'(A)') ' AA,BB,XL,XL2,DIF,CV,BETW,BEDALB,SHDBT='
         WRITE(60,2011) AA,BB,XL,XL2,DIF,CV,BETW,BEDALB,SHDBT
        ENDIF
-------------------------------------------------------------------------------
C
C  COMPUTE INITIAL SHADING FACTORS
c agpa 9/14/01 set flags for new shading logic
c IDAY=0 sets the flag for first time through the new shading logic
C JOLD = julian date of previous time step, initialized at 999
      IDAY=0
       JOLD=999
      CALL CRS(HOURJ,W1,RS1,RDBT1,CLD1)
C
C  INITIALIZE HEAT SOURCE, SINK TERMS
C     WRITE(60,3335)
C3335 FORMAT('  CALLING TEMPDK')
c agpa 9/10/01 added QNSO to pass solar radiation term back to main
c  114 CALL TEMPDK(A1,W1,CLD1,DBT1,DPT1,APR1,WND1,SWS1,RS1,RDBT1,
c     XT1,TDK1,TP1)
  114 CALL TEMPDK(A1,W1,CLD1,DBT1,DPT1,APR1,WND1,SWS1,RS1,RDBT1,
     XT1,TDK1,TP1,QNSO)
C     CALL BEDC(IDT,T1)
      CALL BEDFL2(T1,A1,W1,DTHR)
-------------------------------------------------------------------------------
C  BIG TIME LOOP FOR EACH DT
C
      SIMHR=0.0
    5 IDT=IDT+1
      HOURJ=HOURJ+DT/3600.
C     SIMHR=HOURJ-BHOURJ
      SIMHR=SIMHR+DT/3600.
C      WRITE(*,2789) SIMHR
C 2789 FORMAT('    BEGINNING SIMULATION HOUR',F8.3)
------------------------------------------------------------------------------
C  COMPUTE SHADING FACTORS
      CALL CRS(HOURJ,W2,RS2,RDBT2,CL2)
C      WRITE(8,3001)IDT,(RS2(J),J=1,NXSEC)
C3001 FORMAT(I5/(10F8.2))
C
C  SUM HEAT SOURCES,SINKS AND LINEARIZE SOURCE TERM
C     WRITE(60,3335)

c agpa 9/10/01 added QNSO to pass SWS adjusted for shading back to main program
c      CALL TEMPDK(A2,W2,CL2,DB2,DP2,AP2,WI2,SW2,RS2,
c       2RDBT2,T1,TDK2,TP2)
      CALL TEMPDK(A2,W2,CL2,DB2,DP2,AP2,WI2,SW2,RS2,
       2RDBT2,T1,TDK2,TP2,QNSO)

c agpa 09/10/01 added output to output file solar.out
C  Output solar time series at 4 nodes
C  OUTPUT TO SOLAR1.OUT-SOLAR4.out SHSOL,EBH,RS,SWS

c       WRITE(28,899)SIMHR,RMI(1),SHSOL,EBH(1),RS2(1),QNSO(1),SW2/3600.
c       WRITE(29,899)SIMHR,RMI(3),SHSOL,EBH(3),RS2(3),QNSO(3),SW2/3600.
c       WRITE(30,899)SIMHR,RMI(5),SHSOL,EBH(5),RS2(5),QNSO(5),SW2/3600.
c       WRITE(31,899)SIMHR,RMI(7),SHSOL,EBH(7),RS2(7),QNSO(7),SW2/3600.
c  899  FORMAT (7F8.3)

C  COMPUTE TEMPERATURES FOR NEW DT (INTEGRATE)
C     WRITE(60,3339)
C3339 FORMAT('  CALLING TEMP')
      ICONST=1
      IF(ROUTE.eq.'I') CALL INTEGR(TDK1,TP1,WT1,TDK2,TP2,WT2,T1,T2)
      IF(ROUTE.eq.'E')
     >  CALL MROUTE(TDK1,TP1,WT1,TDK2,TP2,WT2,T1,T2,IDTSAVE(ICONST))
      IF(ROUTE.eq.'H')
```

```
     >  CALL HPINTG(TDK1,TP1,WT1,TDK2,TP2,WT2,T1,T2)

c agpa 09/11/01 added temperature to solar output file
      WRITE(28,899)SIMHR,RMI(1),SHSOLA(1),EBH(1),RS2(1),QNSO(1),
      2SW2/3600.,T2(1)
      WRITE(29,899)SIMHR,RMI(3),SHSOLA(3),EBH(3),RS2(3),QNSO(3),
      2SW2/3600.,T2(3)
      WRITE(30,899)SIMHR,RMI(5),SHSOLA(5),EBH(5),RS2(5),QNSO(5),
      2SW2/3600.,T2(5)
      WRITE(31,899)SIMHR,RMI(11),SHSOLA(11),EBH(11),RS2(11),QNSO(11),
      2SW2/3600.,T2(11)
  899 FORMAT (8F10.3)
  ------------------------------------------------------------------------------

C**********************************************************************
C
      SUBROUTINE CRS(HOURJ,W,RS,RDBT,CLD)
C
C**********************************************************************
C  SUBROUTINE FOR COMPUTING ABSORPTION COEFFICIENTS ON A RIVER
C  VARIABLE DEFINITIONS
C  RS(I)=ABSORPTION COEFFICIENT FOR NODE I
C  RDBT(I)=DRYBULB TEMPERATURE REDUCTION FRACTION FOR NODE I
C  SHSOL=FRACTION OF SOLAR ABSORBED BY WATER IN THE SHADE (FORMERLY 0.2)
C  SHDBT=FRACTION OF DBT-DPT BY WHICH DBT IS REDUCED IN THE SHADE
C  EBH(I)=TREE HEIGHT ON EFFECTIVE BARRIER HEIGHT FOR EACH SUBREACH,M
C  AZ(I)=AZIMUTH OF RIVER SUBREACH,DEGREES
C  AZS=AZIMUTH OF SUN,DEGREES
C  BW(I)=BANK WIDTH,DISTANCE FROM TREES TO WATERS EDGE, METERS
C  THE= ANGLE BETWEEN SUN AND STREAM AXIS, DEGREES
C  BET= ANGLE BETWEEN SUN AND NORMAL TO THE STREAM AXIS, DEGREES
C  ELEV=ELEVATION OF THE SUN, DEGREES
C  XN= NORMAL DISTANCE FROM TREES TO EDGE OF SHADOW, METERS
C  X=  DISTANCE FROM TREES TO SHADOW ALONG A BEAM OF LIGHT, METERS
C  DEL= DECLINATION OF THE SUN, DEGREES
C  HA=  HOUR ANGLE FROM ZENITH TO SUN, DEGREES
C  DHA= CHANGE IN HOUR ANGLE PER TIME STEP, DEGREES
C  HAD= HOUR ANGLE AT MIDNIGHT, DEGREES
C  PHI= LATITUDE OF RIVER, DEGREES
C  ALON= LONGITUDE OF RIVER, DEGREES
C  TZM= TIME ZONE MERIDIAN
C  JDAT= JULIAN DATE FOR WHICH SHADING COMPUTATIONS ARE MADE
C  DR=  DEGREE TO RADIAN CONVERSION
C
C agpa 09/13/01 four parameters added to add shading from either/both banks
C  SHSOLL(I)=transmittance factor for left bank
C  SHSOLR(I)=transmittance factor for right bank
C  SHSOLA(I)=transmittance factor used at any given timestep
C  SHSOL= transmittance factor input if there is just one number for a whole system
c  IDAY = flag indicating the first time through new shading logic each day
c          iday=0 first time through, iday=1 not first time through
c  JOLD = julian date of previous time step, initialized as 999 in main program
c  FB = first bank to be shaded that day, RB=right, LB=left
c  IZ = flag, 1=Az<AZS, 0=AZ>AZS at first timestep after ELEV>1.5
c  IRS = flag to turn on logic for both banks (irs=1)

      REAL NK20
      DIMENSION A(4),B(4),RS(500),RDBT(500),W(500)
c agpa 9/17/01 modified ebh to accomodate both banks
c      COMMON/CR/ EBH(500),AZ(500),BW(500),PHI,ALON,TZM,TFOG
c       COMMON/CR/ EBH(500),AZ(500),BW(500),PHI,ALON,TZM,TFOG,EBHL(500),
c     XEBHR(500),IEBH
c agpa 9/18/01 IEBH removed
      COMMON/CR/ EBH(500),AZ(500),BW(500),PHI,ALON,TZM,TFOG,EBHL(500),
     XEBHR(500)
c agpa 9/13/01 added IRS  COMMON/RA/EXCO,HMAC,AA,BB,NXSEC,THR,THB,BK20,THS,SK20(500),
C     XTHN,NK20,THPR,IK2EQ,BS20,BETW,XL,XL2,DIF,CV,BEDALB,SHSOL,SHDBT

      COMMON/RA/EXCO,HMAC,AA,BB,NXSEC,THR,THB,BK20,THS,SK20(500),
```

```
     XTHN,NK20,THPR,IK2EQ,BS20,BETW,XL,XL2,DIF,CV,BEDALB,SHSOL,SHDBT,
     XIRS,SHSOLL(500),SHSOLR(500),SHSOLA(500),IDAY,JOLD
c agpa 9/14/01 new local variables for both bank shading logic
      INTEGER::IZ
       CHARACTER::FB*2

      DATA A/1.18,2.20,0.95,0.35/
      DATA B/0.77,0.97,0.75,0.45/
      DR=3.14159/180.0
      HOURD=AMOD(HOURJ,24.)
      DHA=DR*(HOURD*360./24.)
      PHI=PHI*DR
      JDAT=IFIX(HOURJ)/24+1
      DEL=DR*23.45*COS(6.2832*(172.0-FLOAT(JDAT))/365.0)
      HAD=(180.0+ALON-TZM)*DR
      SDSP=SIN(DEL)*SIN(PHI)
      CDCP=COS(DEL)*COS(PHI)
      HA=HAD-DHA
      S=SDSP+CDCP*COS(HA)
      ELEV=ASIN(S)/DR
      AZS=0.0
      IF(CLD.LT.0.05)N=1
      IF(CLD.GE.0.05.AND.CLD.LT.0.5)N=2
      IF(CLD.GE.0.5.AND.CLD.LT.0.95)N=3
      IF(CLD.GE.0.95)N=4
      IF(ELEV.GT.1.5)RSM=1.0-A(N)*(1.0/ELEV**B(N))
      IF(ELEV.GT.1.5)AZS=ACOS((SIN(DEL)-SIN(ELEV*DR)*SIN(PHI))/(COS
     X(ELEV*DR)*COS(PHI)))
      IF(HA.LT.0.0)AZS=360.0*DR-AZS
C     WRITE(60,3001) HA,S,ELEV,RSM,AZS,DEL,HAD,SDSP,CDCP
C3001 FORMAT(5H STEP,9E12.4)
C
      DO 12 I=1,NXSEC

C agpa 9/14/01 setup SHSOLA array with either SHSOL, or l/r bank information
      IF (IRS.eq.0) THEN
         SHSOLA(I)=SHSOL
       ELSE IF (IRS.eq.1) THEN
        IF (JDAT.ne.JOLD) IDAY=0
         IF (ELEV.gt.1.5) THEN
          !Set first bank
           IF (IDAY.eq.0) THEN
            IF (AZ(I).gt.AZS/DR) THEN
              IF (AZ(I).gt.(AZS/DR+180.0)) THEN
                FB='RB'
                     IZ=0
              ELSE
                     FB='LB'
              ENDIF
            ELSE
              FB='RB'
              IZ=1
            ENDIF
             IDAY=1
          ENDIF
          !Fill SHSOLA(I) array with appropriate bank transmittance factor
c agpa 9/18/01 added EBHL/EBHR to the new shading logic
          IF (IDAY.eq.1) THEN
            IF (FB.eq.'LB') THEN
              IF (AZ(I).gt.AZS/DR) THEN
                SHSOLA(I)=SHSOLL(I)
                  EBH(I)=EBHL(I)
              ELSE
                SHSOLA(I)=SHSOLR(I)
                  EBH(I)=EBHR(I)
              ENDIF
            ELSE IF (FB.eq.'RB') THEN
              IF (IZ.eq.0) THEN
                IF (AZ(I)-180.0.gt.AZS/DR) THEN
```

```
                 SHSOLA(I)=SHSOLR(I)
                   EBH(I)=EBHR(I)
               ELSE
                 SHSOLA(I)=SHSOLL(I)
                   EBH(I)=EBHL(I)
               ENDIF
             ELSE IF (IZ.eq.1) THEN
               IF (AZ(I)+180.0.gt.AZS/DR) THEN
                 SHSOLA(I)=SHSOLR(I)
                   EBH(I)=EBHR(I)
               ELSE
                 SHSOLA(I)=SHSOLL(I)
                   EBH(I)=EBHL(I)
               ENDIF
             ENDIF
           ENDIF
         ENDIF
       ELSE
       !River is fully shaded before sunrise, i.e. transmittance = 0.0
c agpa 9/17/01 make shsola() before sunrise the average of shsoll/shsolr
c to represent shading influence on diffusive solar radiation
c        SHSOLA(I)=0.2
         SHSOLA(I)=(SHSOLL(I)+SHSOLR(I))/2.
c agpa 9/18/01 make EBH(I) before sunrise the average of ebhl/ebhr
         EBH(I)=(EBHL(I)+EBHR(I))/2.
         ENDIF
      ENDIF

      WI=W(I)*0.3048
      IF(ELEV.GT.1.5) GO TO 1
C     RS(I)=0.2
C  MAKE FRAC OF SOLAR ABSORBED IN SHADED AREA AN INPUT VARIABLE
c     RS(I)=SHSOL
c agpa 9/14/01 make frac of solar absorbed/transmittance an array
      RS(I)=SHSOLA(I)
C  FRAC OF DBT-DPT TO REDUCE DBT BY IN SHADED AREA (INPUT VARIABLE)
      RDBT(I)=SHDBT
      GO TO 10
    1 THE=ABS(AZS-AZ(I)*DR)
      IF(THE.GT.(180.*DR)) THE=THE-180.*DR
      BET=ABS(THE-90.0*DR)
      X=EBH(I)/TAN(ELEV*DR)
      IF(COS(BET).GT.0.01) GO TO 2
      RS(I)=RSM
      RDBT(I)=0.0
      GO TO 10
    2 XN=X*COS(BET)
      IF(XN.GE.BW(I)) GO TO 3
      RS(I)=RSM
      RDBT(I)=0.0
      GO TO 10
    3 IF(XN.LE.(BW(I)+WI)) GO TO 4
C     RS(I)=0.2
c agpa 9/14/01 RS(I)=SHSOL
      RS(I)=SHSOLA(I)
      RDBT(I)=SHDBT
      GO TO 10
C   4 RS(I)=RSM*(WI+BW(I)-XN)/WI+0.2*(XN-BW(I))/
c agpa 9/14/01    4 RS(I)=RSM*(WI+BW(I)-XN)/WI+SHSOL*(XN-BW(I))/WI
    4 RS(I)=RSM*(WI+BW(I)-XN)/WI+SHSOLA(I)*(XN-BW(I))/WI
      RDBT(I)=0.0*(WI+BW(I)-XN)/WI+SHDBT*(XN-BW(I))/WI
C     WRITE(60,3002)I,THE,BET,X,XN,W(I),RS(I)
C3002 FORMAT(5H GRID,I5,9E13.2)
C  10 IF(HOURD.LT.TFOG) RS(I)=0.2
c agpa 9/14/01   10 IF(HOURD.LT.TFOG) RS(I)=SHSOL
c NOTE: If ELEV<=1.5 then SHSOLA(I) is an average of left and right bank,
c        IF ELEV>1.5 then SHSOLA(I) is assigned as left or right bank
   10 IF(HOURD.LT.TFOG) RS(I)=SHSOLA(I)
        IF(HOURD.LT.TFOG) RDBT(I)=SHDBT
```

```
      IF(I.EQ.35)WRITE(60,3001)HOURD,HA,ELEV,RSM,AZS,THE,BET,X,XN,RS(I)
 3001 FORMAT(10F8.3)
   12 CONTINUE
      PHI=PHI/DR
C     WRITE(60,5050)JDAT,TZM,PHI,ALON
C5050 FORMAT(1H0,39X,'ABSORPTION COEFFICIENTS FOR SOLAR RADIATION',38X,
C    X       //,53X,'JULIAN DAY ',I3,2X,',TIME ZONE  ',1F4.1,' DEGREES',29X,/,
C    X       53X,'LATITUDE=',1F5.1,' LONGITUDE= ',F5.1,' DEGREES',27X,//,
C    X       ' GRID    EBH     BW  AZIMUTH ****************************',
C    X       '****HOUR**********************************************',/,
C    X       8X,'METER  METER  DEGREE',4X,'5',5X,'6',5X,'7',5X,'8',5X,'9',4X,
C    X       '10',4X,'11',4X,'12',4X,'13',4X,'14',4X,'15',4X,'16',4X,'16',4X,'17
C    X       ,4X,'18',4X,'19',3X)
C     DO 11 I=1,NXSEC
C       WRITE(60,3000)I,EBH(I),BW(I),AZ(I),RS(I)
C3000 FORMAT(' ',I4,F9.1,F7.1,F8.1,1X,15F6.3)
   11 CONTINUE
c agpa 9/14/01 save previous time step julian date for next pass
      JOLD=JDAT

      RETURN
C     DEBUG UNIT(98),SUBTRACE
END
```

Appendix C: Preprocessor Code Listings

Two preprocessors were written to expeditiously transfer the needed data from EXCEL spreadsheets to the necessary model input formats.

C.1 Preprocessor for ADYN

```
! 10/30/01
!
! Program RMSPP: A preprocessor for the ADYN input file (.aii) for RMS by TVA.
!
!       By Alida Abbott
!
! This program reads a text files created in EXCEL and saved as .prn. and merges
! the data input by the user to form a complete ADYN input file. NOTE: This file
! is designed for the Shasta River Project and modifications may need to be made
! to apply it to other uses of RMS.
!
! This preprocessor is for 1 reach and no dynamic junctions.
! This preprocessor does not prepare for node interoplation by ADYN.
!
!
!    ~File Numbers~                          ~Hardwired Values~
! 1 Geometry Text File                            ICG = 1
I 2 Flow Text File                                XUNIT = 0
! 3 Lateral Inflow Text File                      NJUNC = 0
! 5 ADYN input file (.aii)                        DGEO = 50
!                                                 iMASS = 1
!                                                 PHIDEG = 0.0
!                                                 IQUAL = 1
!                                                 FNMX = 0.0
!                                                 IVRCH, IVEL = 0
!                                                 RFC = 0.0
!                                           DDIST1, DDIST2 = 0
!                                                 PLT=DT=QUALDT
!                                             IUSBC,IDSBC = 1
!                                                 NC(J) = 0
!                                                 QTTOL = 0.02
!                                                 QTOL = 0.005
!                                                 HTOL = 0.005
! Boundary Conditions:
```

```
! The upstream boundary is set to be a discharge hydrograph (CFS)
! The downstream boundary is set for the model to calculate using manning eq.
!The geometry text file has the following format:
!   Line 1: Title

!   Line 2: Identifiers
!   Line 3: nxsec, iseco, ixsec
!   Line 4: identifiers
!   Line 5: NX RMI d1 d2 d3 d4 d5 elev1 elev 2 elev3 elev4 elev5(r) NMN N Con Ex !
!   Line 5 format: I2,6F6.2,5F8.2,I2,3F6.3
!   Line 5 definitions:
!    NXSEC = number of uninterpolated cross-sections
!    ISECO = order of cross-sections (0=up/down, 1=down/up)
!    IXSEC = number of interpolated cross-sections
!       NX = number of coordinates in the cross-section
!       RMI = river mile
!      d1-5 = distance of the coordinates from the left bank
!   elev1-5 = corresponding elevations for each distance
!       NMN = number of mannings n's per cross-section
!         N = manning's n
!       CON = coefficient of contraction
!        EX =      coefficient of expansion
!  NOTE: You may only have one manning n per cross-section.
!        There is no limit NX, d, elev.
!
!   For the last cross-section put a negative number for Con and Ex.
!
!The lateral inflow text file has the following format:

!  Line 1: hi, nord, ifmt, isopt (just need to be separated by spaces)
!  Line 2: identifiers
!  Lines 3 and 4 are repeated for each lateral iflow (nqlh times)
!  Line 3: rmlat1, rmlat2 (seperated by spaces)
!  Line 4: date and time (14X), discharge in cfs (F10.2) repeated nord times
!-----------------------------------------------------------------------------------------------

        program RMS_PP
        implicit none

   character (80) geoname,ubcname,outname,yesno*1,title1,identifiers,
  2 name,latname,isolv*1
        integer no ,i , nns, iog, iroute, idmpqh, iplt,nxsec,iseco,ixsec,
        2 date, nord,ifmt,isopt,nqlh,j
   real rmi , frn, kce1, kce2, rmiog1,rmiog2,rmiog3,dt, prt,hi,
        2 rmlat1,rmlat2,rmic,qic,elic,theta
```

```
    real, dimension (5) :: x, elev
        real, dimension (5000) :: w, qlat

! Get file names of input files and open files

        !Ask user for file name
100     WRITE (*,*) "Enter geometry input file name:"
        READ(*,*) geoname
        WRITE(*,*) "Enter upstream boundary input file name:"
        READ(*,*) ubcname

        !Try to open files
        name = geoname
    OPEN (1, file=geoname, status='OLD', ERR=110)
        name = ubcname
    OPEN (2, file=ubcname, status='OLD',ERR=110)
        GOTO 120

        !Error handler
110     WRITE (*,*) "Error, could not open file:", name
        WRITE (*,*) "Try again? (y/n)"
        READ (*,*) yesno
        IF (yesno == "y".or. yesno == "Y") THEN
                GOTO 100
        ELSE
                WRITE (*,*) "RMS PreProcessor aborting."
        ENDIF

        !Got the files, ok to proceed
120     Continue

!Get output file name and open file
        WRITE (*,*) "Enter output file name"
        READ (*,*)    outname
        WRITE (*,*) "Output file name:", outname
        OPEN (5, file=outname, STATUS='unknown')

!Read input file title
        READ(1,"(A80)") title1
        WRITE(5,'(A)') title1
        READ(1,*) identifiers

!Get information from user and write line 1 for .aii
    WRITE (*,*) "Output geometry to DYNOUT?(0=no, 2=yes)"
        READ (*,*) iog
```

```
        WRITE (*,*) "Use ADYN to route (1) or just build geometry (0)?"
        READ (*,*) iroute
        WRITE (*,*) "Dump Q,H? (0=no dump, 1=dump)"
        READ (*,*) idmpqh
        WRITE (*,*) "Build plot file? (0=no, 1=yes)"
        READ (*,*) iplt
        WRITE(5,'(16I5)') 1,iog,0,iroute,1,idmpqh,iplt,1

!Get information from geo file and write line 2 for .aii
        READ(1,*) nxsec,iseco,ixsec
        WRITE (5,'(16I5)') nxsec,iseco,ixsec,0
        READ(1,*) identifiers

!Get information from user and write line 3 for .aii
    WRITE (*,*)"Enter 3 milleages for which geom table is desired:"
        READ (*,*) rmiog1, rmiog2, rmiog3
        WRITE (5,'(10F8.2)') 50.0,0.0, rmiog1,rmiog2,rmiog3,0.0,0.0

!Read information from Geo file write lines 4-10 for each cross-section
        DO
                READ(1,"(I2,6F6.2,5F8.2,I2,3F6.3)")  no, rmi ,
        1        (x(I),I=1,no), (elev(I),I=1,no), nns, frn, kce1,kce2
           WRITE (5,"(I5,F8.2)") no, rmi
                WRITE (5,"(10F8.2)") (elev(I), I=1,no)
                WRITE (5,"(10F8.2)") (x(I), I=1,no)
                WRITE (5,"(I5)") nns
                WRITE (5,"(10F8.3)") frn
                IF (kce1 .lt. 0 .and. kce2 .lt. 0) THEN
                 !End of Cross-sections do not write kce1 and kce2
            GOTO 130
           ELSE
                 WRITE (5,"(10F8.2)") kce1,kce2
           ENDIF
        ENDDO

 130  CONTINUE

!Get boundary conditions and write line 12 of .aii
        WRITE (*,*) "Enter beginning date of simulation (YYMMDD)."
        WRITE (*,*) "The clock will start on hour 24 of that day."
        READ (*,*) date
        WRITE (*,*) "Enter time step and print interval (hours):"
        READ (*,*) dt, prt
    WRITE (5,'(I6,5F8.2,A40)') date,24.00,dt,prt,dt,dt,
        2"begd/begt/dt/prt/plt/qdt"
```

```
!Get upstream boundary conditions from input file and print.
!Assumed upstream boundary is a discharge hydrograph, model calculates downstream
!Write lines 13-16 of .aii
    WRITE(5,"(2I5,A40)") 1,1,"Main Channel Boundary Conditions"
        READ(2,*) hi,nord,ifmt,isopt
        WRITE(5,'(F8.2)') hi
        WRITE(5,'(3I5)') nord,ifmt,isopt
        READ(2,'(A)') identifiers
    DO i=1,nord
         READ(2,"(12X,F10.0)") w(i)
        ENDDO
        WRITE(5,'(8F10.0)') (w(i),i=1,nord)

!Get downstream boundary conditions. (For IDSBC = 1 meaning the model calculates,
! no downstream conditions are needed. If this is changed the logic may be added here.)
!IDSBC = 1, records 17-21 omitted.


!Get internal boundary conditions for special nodes. This code is setup with NC(J) = 0,
! meaning there are no internal boundary conditions. If this is changed, logic can be
added here.
!NC(J) = 0, records 22-26 omitted

!Get lateral inflows.
!Write record 27 (.aii)
        WRITE(*,*) "Enter the number of lateral inflows:"
        READ(*,*) nqlh
        WRITE(5,'(I5)') nqlh
    IF (nqlh .gt.0) THEN
200      WRITE(*,*) "Enter the lateral inflow input file name:"
         READ(*,*) latname
         OPEN (3, file=latname, status='OLD', ERR=210)
         GOTO 220

        !Error handler
210       WRITE (*,*) "Error, could not open file:", latname
          WRITE (*,*) "Try again? (y/n)"
          READ (*,*) yesno
          IF (yesno == "y".or. yesno == "Y") THEN
                GOTO 200
          ELSE
                WRITE (*,*) "RMS PreProcessor aborting."
          ENDIF
```

```
          !Got the file, ok to proceed
220       Continue
          READ (3,*) hi,nord,ifmt,isopt
          READ (3,*) identifiers
!Write records 27-29 (.aii)
          WRITE(5,'(F8.2)') hi
          WRITE(5,'(3I5)') nord,ifmt,isopt
!Read lateral inflow hydrographs from lateral inflow text file
!Write records 30-31 (.aii)
      DO i=1,nqlh
           READ(3,*) rmlat1,rmlat2
                DO j=1,nord
                  READ (3,"(14X,F10.0)") qlat(j)
           ENDDO
          WRITE (5,'(2F8.2)') rmlat1,rmlat2
          WRITE (5,'(8F10.0)') (qlat(j),j=1,nord)
          ENDDO
        ELSE
          CONTINUE
        ENDIF

!Get initial conditions: assumed initial conditions entered only at downstream end
!Write records 32-34 (.aii)
        WRITE(*,*) "Enter initial condition at end node (RM,Q,Elev):"
        READ(*,*) rmic,qic,elic
        WRITE(5,'(I5)') 0
        WRITE(5,'(3F8.2)') rmic,qic,elic
        WRITE(5,'(F8.0)') -100.

!Get numerical solution control information
!Write record 35 (.aii)
     WRITE(*,*) "What type of numerical scheme? (I/E)"
        READ(*,*) isolv
        WRITE(*,*) "What value of theta for spacial derivatives? (0-1)"
        READ(*,*) theta
        WRITE(5,'(F8.3,4X,A1,3F8.3)') 0.02,isolv,theta,0.005,0.005
        WRITE (*,*) "RMSPP done."

     END
```

C.2 Preprocessor for RQUAL

```
! 12/17/01
!
! Program RMSPP2: A preprocessor for the RQUAL Water Quality Coefficients input
! file (.ric) for RMS by TVA for simulation of water temperature only in conjuction
```

```
! with two bank shading parameters.
!
!       By Alida Abbott
!
! This program reads text files created in EXCEL and saved as .prn and merges
! them data input by the user to form a complete WQC input file.
!
! The function of this program is to format the river aspect at each node and fill
! in zeros for the water quality parameters other than temperature.
!
! INPUT FILE:  The river aspect file should be in two columns, the first 15 spaces
! can be used as an identifer with river mile and node number, the second column should
! contain the river aspect.
!
! The only user inputs are the river aspects, and the initial conditions
! the following values are hardwired into this program:
!
!       PRT         Print interval in hours for output          1 hour
!       IPLT        Plot output flag (0= no plot, 1=plot)       1
!       THET        Spatial derivative weighting factor         0.5
!       TSI         model testing coeff. (dummy variable)       1.0
!       I02R        flag to caputre T and DO process rate       1.0
!       PLT         Plot file interval in hours                 1.0
!       ROUTE       Numerical scheme (I, E, H)                  I
!       PDC         Limits for H-P scheme                       0.0
!       PDCS        "                 "                         0.0
!       IRS         Flag to use new shading logic         1
!       alphx(i)    not used in current model                   0.0
!       PHI         latitude of river                           41.875
!       ALON        longitude of river                          122.63
!       TZM         no longer an input, model calculations      blank
!       TFOG        time of fog lift                            6:00 am
!       BW(i)       bank width                                  0.0
!       AA          windspeed coefficient                       3.0E-09
!       BB          "                           "               1.4E-09
!       XL,XL2      channel bed thickness (upper,lower)         10 cm, 50 cm
!       DIF         thermal diffusivity of bed (=0 turns of bed logic) 0
!       CV          bed heat storage capacity                           0.68
!       BETW        fraction of solar rad. absorbed in
!                   surface 0.6 m of water                      0.4
!       BEDALB      albedo of bed material                      0.25
!       SHDBT       fraction drybulb/dewpoint depression                1.0
!                   by which drybulb is coller over shaded water
!       THR         temp correction coef. for reaeration                99.0
!       THB         temp correction ceof. for BOD decay                 99.0
```

```
!       BK20        BOD deoxygenation rate                          0.0
!       THN         temp correction ceof for NOD decay              99.0
!       NK20        NOD deoxygenation rate                          0.0
!       THS         temp correction coef. for SOD                   99.0
!       EXCO        light extinction coeff                          0.0
!       HMAC                average weed height                          0.0
!       THPR        temp correction coeff for photo/resp            99.0
!       IK2EQ       reaeration equation choice                      0.0
!       BS20        BOD settling rate                               0.0
!       WFAC        factor to reduce weir aeration                  0.0
!       SFAC(i)     factor to multiply all SK20 to test sensitivty  0.0
!       PFAC(i)     factor to multiply all PMAX to test sensitivty       0.0
!       RFAC(i)     factor to multiply all RESP to test sensitivty  0.0
!---------------------------------------------------------------------------------------------------

        program RMS_PP2
        implicit none

        character (80) aname,yesno*1,title1,outname
        integer numnodes,i,no
        real rmic,tinit,binit,ninit
        real, dimension (500) :: alphx, aspect,bw,sfac,pfac,rfac

! Get file names of input files and open files

        !Ask user for file name
100     WRITE (*,*) "Enter aspect input file name:"
        READ(*,*) aname

        !Try to open file
    OPEN (1, file=aname, status='OLD', ERR=110)
        GOTO 120

        !Error handler
110     WRITE (*,*) "Error, could not open file:", aname
        WRITE (*,*) "Try again? (y/n)"
        READ (*,*) yesno
        IF (yesno == "y".or. yesno == "Y") THEN
                GOTO 100
        ELSE
                WRITE (*,*) "RMS PreProcessor2 aborting."
        ENDIF

        !Got the files, ok to proceed
120     Continue
```

```
!Get output file name and open file
        WRITE (*,*) "Enter output file name"
        READ (*,*)    outname
        WRITE (*,*) "Output file name:", outname
        OPEN (5, file=outname, STATUS='unknown')

!Read input file title
        READ(1,"(A80)") title1


!Write record 1 for .ric (PRT,IPLT,THET,TSI,I02R,PLT,ROUTE,PDC,PDCS,IRS)
        WRITE(5,'(F8.1,I5,2F8.1,I5,F8.1,4X,A1,2F8.1,I5)') 1.0,1,0.5,1.0,1,
    21.0,'I',0.0,0.0,1

!Write record 2 for .ric
        WRITE (*,*) "Enter the number of nodes:"
        READ (*,*) numnodes
        DO I=1,numnodes
         alphx(i)=0.0
        ENDDO
        WRITE (5,"(10F8.2)") (alphx(I), I=1,numnodes)

!Write record 3 for .ric PHI,ALON,TZM,TFOG (phi=lat of river, alon=lon of river)
        WRITE (5,'(2F8.3,8X,F8.2)') 41.875,122.63,6.0

!Read information from aspect file write record 4 for .ric
        DO i=1,numnodes
         READ(1,"(15X,F8.2)")  aspect(i)
        ENDDO
        WRITE (5,"(10F8.2)") (aspect(I), I=1,numnodes)


!Write record 5 of .ric (Bank Width is considered 0.0 for the Shasta River)
        DO i=1,numnodes
         BW(i)=0.0
        ENDDO
        WRITE (5,"(10F8.2)") (bw(I), I=1,numnodes)

!Skip EBH (record 6) due to new shading logic input file.

!Write record 7 to .ric Leave out SHSOL due to new shading logic input file
!AA,BB,XL,XL2,DIF,CV,BETW,BEDALB,SHDBT  where AA,BB are windspeed
coefficients
!This line turns off the bed conduction term by setting DIV = 0.0
```

```
        WRITE(5,'(2A8,8F8.2)')'3.0E-09','1.4E-09',10.,50.,0.,0.68,0.4,1.0,
        21.0

!Write record 8 (.ric)
!THR,THB,BK20,THN,NK20,THS,EXCO,DMAC,THPR,IK2EQ
!These are the rate coefficients for water quality parameters, they must be
!entered even when only modeling temperature
        WRITE (5,'(9F8.2,I5)') 99.0,99.0,0.0,99.0,0.0,99.0,0.0,0.0,99.0,0

!Write record 9 (.ric)
!BS20,WFAC
        WRITE(5,'(3F8.0)') 0.0, 0.0


!Write record 10 (.ric) SFAC = 0.0
        DO i=1,numnodes
         SFAC(i)=0.0
        ENDDO
        WRITE (5,"(F8.1)") 0.0
    WRITE (5,"(10F8.2)") 0.0,(sfac(I), I=1,numnodes)

!Write record 11 (.ric) PFAC = 0.0
        DO i=1,numnodes
         PFAC(i)=0.0
        ENDDO
        WRITE (5,"(F8.1)") 0.0
    WRITE (5,"(10F8.2)") 0.0,(pfac(I), I=1,numnodes)

!Write record 12 (.ric) RFAC = 0.0
        DO i=1,numnodes
         RFAC(i)=0.0
        ENDDO
        WRITE (5,"(F8.1)") 0.0
    WRITE (5,"(10F8.2)") 0.0,(rfac(I), I=1,numnodes)

!Write record 13 (.ric) The initial conditions. Need to be entered at at least two nodes
!RMIC= river mile of IC, TINIT=ini temp, BINIT= ini BOD, NINIT = ini NOD
        WRITE (*,*) "Enter number of initial conditions (at least two):"
        READ (*,*) no
        DO i=1, no
         WRITE(*,*) "Enter river mile of initial condition:"
         READ (*,*) rmic
         WRITE(*,*) "Enter initial temperature in degrees c:"
         READ (*,*) tinit
         WRITE(*,*) "Enter initial BOD concentration in mg/l:"
```

```
    READ (*,*) binit
    WRITE(*,*) "Enter initial NOD concentration in mg/l:"
    READ (*,*) ninit
    WRITE (5,'(10F8.2)') rmic,tinit,binit,ninit
   ENDDO
   WRITE(5,'(F8.1)') -100.0

   WRITE (*,*) "RMSPP2 done."

END
```

Appendix D: File Listing for Management Alternatives

In simulating management alternatives, four specific management schemes were investigated: flow regime changes, pulse flows, shading reach-by-reach, and tailwater flows. In all, over 60 simulations were made for the investigation of alternative management schemes that included flow regime changes (30), pulse flows (2), shading reach-by-reach (15), and tailwater flows (16). Additionally, three (3) base-case simulations were made for comparisons. The following tables list all input files used in simulations of management alternatives.

D.1 Base Cases

Base Case

#	Period	add Q (cfs)	at	ADYN input (.aii)	Meterology	Inflow Tw	Coeffs & ICs	Shade
1	Jun	--	--	Jun.aii	1DayJun.rim	Jun.rib	Shasta.ric	ExitingShade.ris
2	Aug	--	--	Aug.aii	1DayAug.rim	Aug.rib	Shasta.ric	ExitingShade.ris
3	Sep	--	--	Sep.aii	1DaySep.rim	Sep.rib	Shasta.ric	ExitingShade.ris

D.2 Flow Regime

Title Flow Regime
Abbreviation Flow
Objective Determine effects of altering flow regime in Shasta River by adding water from management of diversions.

Scenario 1: 10 cfs of flow added at top of each reach

#	Period	add Q (cfs)	at	ADYN input (.aii)	Meterology	Inflow Tw	Coeffs & ICs	Shade
4	Jun	10	SRP	Jun-SRP-10.aii	1DayJun.rim	Jun.rib	Shasta.ric	ExitingShade.ris
5	Jun	10	GID	Jun-GID-10.aii	1DayJun.rim	Jun.rib	Shasta.ric	ExitingShade.ris
6	Jun	10	A12	Jun-A12-10.aii	1DayJun.rim	Jun.rib	Shasta.ric	ExitingShade.ris
7	Jun	10	DWR	Jun-DWR-10.aii	1DayJun.rim	Jun.rib	Shasta.ric	ExitingShade.ris
8	Jun	10	AND	Jun-AND-10.aii	1DayJun.rim	Jun.rib	Shasta.ric	ExitingShade.ris
9	Aug	10	SRP	Aug-SRP-10.aii	1DayAug.rim	Aug.rib	Shasta.ric	ExitingShade.ris
10	Aug	10	GID	Aug-GID-10.aii	1DayAug.rim	Aug.rib	Shasta.ric	ExitingShade.ris
11	Aug	10	A12	Aug-A12-10.aii	1DayAug.rim	Aug.rib	Shasta.ric	ExitingShade.ris
12	Aug	10	DWR	Aug-DWR-10.aii	1DayAug.rim	Aug.rib	Shasta.ric	ExitingShade.ris
13	Aug	10	AND	Aug-AND-10.aii	1DayAug.rim	Aug.rib	Shasta.ric	ExitingShade.ris
14	Sep	10	SRP	Sep-SRP-10.aii	1DaySep.rim	Sep.rib	Shasta.ric	ExitingShade.ris
15	Sep	10	GID	Sep-GID-10.aii	1DaySep.rim	Sep.rib	Shasta.ric	ExitingShade.ris

D.2 Flow Regime, continued

Title Flow Regime, cont.
Abbreviation Flow
Objective Determine effects of altering flow regime in Shasta River by adding water from management of diversions.

Scenario 2; 20 cfs of flow added at top of each reach

#	Period	add Q (cfs)	at	ADYN input (.aii)	Meterology	Inflow Tw	Coeffs & ICs	Shade
19	Jun	20	SRP	Jun-SRP-20.aii	1DayJun.rim	Jun.rib	Shasta.ric	ExitingShade.ris
20	Jun	20	GID	Jun-GID-20.aii	1DayJun.rim	Jun.rib	Shasta.ric	ExitingShade.ris
21	Jun	20	A12	Jun-A12-20.aii	1DayJun.rim	Jun.rib	Shasta.ric	ExitingShade.ris
22	Jun	20	DWR	Jun-DWR-20.aii	1DayJun.rim	Jun.rib	Shasta.ric	ExitingShade.ris
23	Jun	20	AND	Jun-AND-20.aii	1DayJun.rim	Jun.rib	Shasta.ric	ExitingShade.ris
24	Aug	20	SRP	Aug-SRP-20.aii	1DayAug.rim	Aug.rib	Shasta.ric	ExitingShade.ris
25	Aug	20	GID	Aug-GID-20.aii	1DayAug.rim	Aug.rib	Shasta.ric	ExitingShade.ris
26	Aug	20	A12	Aug-A12-20.aii	1DayAug.rim	Aug.rib	Shasta.ric	ExitingShade.ris
27	Aug	20	DWR	Aug-DWR-20.aii	1DayAug.rim	Aug.rib	Shasta.ric	ExitingShade.ris
28	Aug	20	AND	Aug-AND-20.aii	1DayAug.rim	Aug.rib	Shasta.ric	ExitingShade.ris
29	Sep	20	SRP	Sep-SRP-20.aii	1DaySep.rim	Sep.rib	Shasta.ric	ExitingShade.ris
30	Sep	20	GID	Sep-GID-20.aii	1DaySep.rim	Sep.rib	Shasta.ric	ExitingShade.ris

D.3 Pulse Flows

Title	Pulse Flow
Abbreviation	Pulse
Objective	Determine the effect of a pulse flow on the temperature regime of the Shasts River

Base case

#	Condition	Flow	ADYN input	Meterology	Inflow Tw	Coeffs & ICs	Shade
1	Jun	All	All_Jun.aii	1DayJun.rim	Jun.rib	Shasta.ric	ExitingShade.ris

Scenario 1: Sequentially applied pulse flows

#	Condition	Flow	ADYN input	Meterology	Inflow Tw	Coeffs & ICs	Shade
2	Sequential	All	All_Pulsed.aii	1DayJun.rim	Pulse.rib	Shasta.ric	ExitingShade.ris

Scenario 2: Simultaneously applied pulse flows

#	Condition	Flow	ADYN input	Meterology	Inflow Tw	Coeffs & ICs	Shade
3	Simultaneous	All	All_Together.aii	1DayJun.rim	Pulse.rib	Shasta.ric	ExitingShade.ris

D.4 Shade Study

Title Shading Reach-by-Reach
Abbreviation Shade
Objective Determine the effect of revegetation on the temperature regime of the Shasts River

Base Cases

#	Period	ADYN input	Meterology	Inflow Tw	Coeffs & ICs	Shade
1	Jun	Jun.aii	1DayJun.rim	Jun.rib	Shasta.ric	ExitingShade.ris
2	Aug	Aug.aii	1DayAug.rim	Aug.rib	Shasta.ric	ExitingShade.ris
3	Sep	Sep.aii	1DaySep.rim	Sep.rib	Shasta.ric	ExitingShade.ris

Scenario 1: Shade Reach 1

#	Period	ADYN input	Meterology	Inflow Tw	Coeffs & ICs	Shade
4	Jun	Jun.aii	1DayJun.rim	Jun.rib	Shasta.ric	Reach1.ris
5	Aug	Aug.aii	1DayAug.rim	Aug.rib	Shasta.ric	Reach1.ris
6	Sep	Sep.aii	1DaySep.rim	Sep.rib	Shasta.ric	Reach1.ris

Scenario 2: Shade Reach 2

#	Period	ADYN input	Meterology	Inflow Tw	Coeffs & ICs	Shade
7	Jun	Jun.aii	1DayJun.rim	Jun.rib	Shasta.ric	Reach2.ris
8	Aug	Aug.aii	1DayAug.rim	Aug.rib	Shasta.ric	Reach2.ris
9	Sep	Sep.aii	1DaySep.rim	Sep.rib	Shasta.ric	Reach2.ris

Scenario 3: Shade Reach 3

#	Period	ADYN input	Meterology	Inflow Tw	Coeffs & ICs	Shade
10	Jun	Jun.aii	1DayJun.rim	Jun.rib	Shasta.ric	Reach3.ris
11	Aug	Aug.aii	1DayAug.rim	Aug.rib	Shasta.ric	Reach3.ris
12	Sep	Sep.aii	1DaySep.rim	Sep.rib	Shasta.ric	Reach3.ris

D.4 Shade Study, continued

Title Shading Reach-by-Reach, cont.

Abbreviation Shade

Objective Determine the effect of revegetation on the temperature regime of the Shasts River

Scenario 4: Shade Reach 4

#	Period	ADYN input	Meterology	Inflow Tw	Coeffs & ICs	Shade
13	Jun	Jun.aii	1DayJun.rim	Jun.rib	Shasta.ric	Reach4.ris
14	Aug	Aug.aii	1DayAug.rim	Aug.rib	Shasta.ric	Reach4.ris
15	Sep	Sep.aii	1DaySep.rim	Sep.rib	Shasta.ric	Reach4.ris

Scenario 5: Shade Reach 5

#	Period	ADYN input	Meterology	Inflow Tw	Coeffs & ICs	Shade
16	Jun	Jun.aii	1DayJun.rim	Jun.rib	Shasta.ric	Reach5.ris
17	Aug	Aug.aii	1DayAug.rim	Aug.rib	Shasta.ric	Reach5.ris
18	Sep	Sep.aii	1DaySep.rim	Sep.rib	Shasta.ric	Reach5.ris

D.5 Tailwater Study

Title Tailwater study

Abbreviation Tail

Objective Determine the effects of varying temperture and location of tailwater lateral flows on the temperature regime of the Shasts River

Scenario1: Pt inflow

#	Upstrm Q	Tailwtr Q	Pt/Dist	Upstrm Tw	Period	ADYN input (.aii)	Meterology	Inflow Tw	Coeffs & ICs	Shade
1	20	5	Pt	15	Jun	Q20-5-Pt.aii	1DayJun.rim	JunTail-15.rib	Shasta.ric	ExitingShade.ris
2	20	5	Pt	20	Jun	Q20-5-Pt.aii	1DayJun.rim	JunTail-20.rib	Shasta.ric	ExitingShade.ris
3	20	5	Pt	15	Sep	Q20-5-Pt.aii	1DaySep.rim	SepTail-15.rib	Shasta.ric	ExitingShade.ris
4	20	5	Pt	20	Sep	Q20-5-Pt.aii	1DaySep.rim	SepTail-20.rib	Shasta.ric	ExitingShade.ris
5	20	10	Pt	15	Jun	Q20-10-Pt.aii	1DayJun.rim	JunTail-15.rib	Shasta.ric	ExitingShade.ris
6	20	10	Pt	20	Jun	Q20-10-Pt.aii	1DayJun.rim	JunTail-20.rib	Shasta.ric	ExitingShade.ris
7	20	10	Pt	15	Sep	Q20-10-Pt.aii	1DaySep.rim	SepTail-15.rib	Shasta.ric	ExitingShade.ris
8	20	10	Pt	20	Sep	Q20-10-Pt.aii	1DaySep.rim	SepTail-20.rib	Shasta.ric	ExitingShade.ris
9	50	5	Pt	15	Jun	Q50-5-Pt.aii	1DayJun.rim	JunTail-15.rib	Shasta.ric	ExitingShade.ris
10	50	5	Pt	20	Jun	Q50-5-Pt.aii	1DayJun.rim	JunTail-20.rib	Shasta.ric	ExitingShade.ris
11	50	5	Pt	15	Sep	Q50-5-Pt.aii	1DaySep.rim	SepTail-15.rib	Shasta.ric	ExitingShade.ris
12	50	5	Pt	20	Sep	Q50-5-Pt.aii	1DaySep.rim	SepTail-20.rib	Shasta.ric	ExitingShade.ris
13	50	10	Pt	15	Jun	Q50-10-Pt.aii	1DayJun.rim	JunTail-15.rib	Shasta.ric	ExitingShade.ris
14	50	10	Pt	20	Jun	Q50-10-Pt.aii	1DayJun.rim	JunTail-20.rib	Shasta.ric	ExitingShade.ris
15	50	10	Pt	15	Sep	Q50-10-Pt.aii	1DaySep.rim	SepTail-15.rib	Shasta.ric	ExitingShade.ris
16	50	10	Pt	20	Sep	Q50-10-Pt.aii	1DaySep.rim	SepTail-20.rib	Shasta.ric	ExitingShade.ris

D.5 Tailwater Study, continued

Title Tailwater study, cont.
Abbreviation Tail
Objective Determine the effects of varying temperture and location of tailwater lateral flows on the temperature regime of the Shasts River

Scenario2: Distributed inflow

#	Upstrm Q	Tailwtr Q	Pt/Dist	Upstrm Tw	Period	ADYN input (.aii)	Meterology	Inflow Tw	Coeffs & ICs	Shade
17	20	5	Dist	15	Jun	Q20-5-Dist.aii	1DayJun.rim	JunTail-15.rib	Shasta.ric	ExitingShade.ris
18	20	5	Dist	20	Jun	Q20-5-Dist.aii	1DayJun.rim	JunTail-20.rib	Shasta.ric	ExitingShade.ris
19	20	5	Dist	15	Sep	Q20-5-Dist.aii	1DaySep.rim	SepTail-15.rib	Shasta.ric	ExitingShade.ris
20	20	5	Dist	20	Sep	Q20-5-Dist.aii	1DaySep.rim	SepTail-20.rib	Shasta.ric	ExitingShade.ris
21	20	10	Dist	15	Jun	Q20-10-Dist.aii	1DayJun.rim	JunTail-15.rib	Shasta.ric	ExitingShade.ris
22	20	10	Dist	20	Jun	Q20-10-Dist.aii	1DayJun.rim	JunTail-20.rib	Shasta.ric	ExitingShade.ris
23	20	10	Dist	15	Sep	Q20-10-Dist.aii	1DaySep.rim	SepTail-15.rib	Shasta.ric	ExitingShade.ris
24	20	10	Dist	20	Sep	Q20-10-Dist.aii	1DaySep.rim	SepTail-20.rib	Shasta.ric	ExitingShade.ris
25	50	5	Dist	15	Jun	Q50-5-Dist.aii	1DayJun.rim	JunTail-15.rib	Shasta.ric	ExitingShade.ris
26	50	5	Dist	20	Jun	Q50-5-Dist.aii	1DayJun.rim	JunTail-20.rib	Shasta.ric	ExitingShade.ris
27	50	5	Dist	15	Sep	Q50-5-Dist.aii	1DaySep.rim	SepTail-15.rib	Shasta.ric	ExitingShade.ris
28	50	5	Dist	20	Sep	Q50-5-Dist.aii	1DaySep.rim	SepTail-20.rib	Shasta.ric	ExitingShade.ris
29	50	10	Dist	15	Jun	Q50-10-Dist.aii	1DayJun.rim	JunTail-15.rib	Shasta.ric	ExitingShade.ris
30	50	10	Dist	20	Jun	Q50-10-Dist.aii	1DayJun.rim	JunTail-20.rib	Shasta.ric	ExitingShade.ris
31	50	10	Dist	15	Sep	Q50-10-Dist.aii	1DaySep.rim	SepTail-15.rib	Shasta.ric	ExitingShade.ris
32	50	10	Dist	20	Sep	Q50-10-Dist.aii	1DaySep.rim	SepTail-20.rib	Shasta.ric	ExitingShade.ris