California Regional Water Quality Control Board
North Coast Region

Upper Lost River and Clear Lake Reservoir Watershed

Total Maximum Daily Load Analysis
Water Temperature and Nutrients

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(The picture on front page shows Weed Valley Reservoir in June 2003.)

Upper Lost River and Clear Lake Reservoir Watershed TMDL Analysis

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EXECUTIVE SUMMARY

The Upper Lost River/Clear Lake Reservoir area is listed as impaired for nutrients and temperature in accordance with Section 303(d) of the federal Clean Water Act (CWA). The listings apparently were conferred from the Klamath River listings and not based on data or information specific to the Upper Lost River and Clear Lake Reservoir watershed. The appropriateness of the nutrients and temperature listings in the Upper Lost River is explored in this analysis. If the listings had been confirmed a TMDL would have been developed, however, the listings were not confirmed and de-listing for the watershed (including Clear Lake Reservoir, the streams draining to Clear Lake Reservoir and the Upper Lost River between the Clear Lake Reservoir dam and the Oregon border) is recommended.

The reasons for the recommendation to de-list the watershed include:

- There is no evidence that the biostimulatory narrative objective is exceeded;
- The system appears to be nitrogen limited and nitrogen levels are far below levels expected to cause biostimulation in this system;
- Although, phosphorus levels are elevated in comparison to U.S. EPA suggested levels, these suggested levels are not relevant because there is no evidence of excessive algal growth in the reservoir (perhaps due to turbidity levels that control light availability) and the system appears to be nitrogen limited;
- Dissolved oxygen levels are above the existing numeric water quality objectives;
- The nitrogen levels are below the concentration of concern for human health;
- There is no evidence of impacts from nutrients, dissolved oxygen, or other nutrient-related effects on the sensitive species of concern;
- The beneficial uses appear to be unaffected by water temperature;
- The natural range of water temperatures and nutrient concentrations above Clear Lake Reservoir do not appear to be affected by anthropogenic activities; and,
- The temperatures below Clear Lake Reservoir are affected by anthropogenic activities (i.e., the dam and water flow fluctuations) but these activities are not addressed by a TMDL.

The Upper Lost River/Clear Lake Reservoir watershed drains the north-central portion of the Modoc Plateau to the Clear Lake Reservoir, which feeds the Lost River. The Lost River flows northwesterly to Oregon, and it traverses about 100 miles in Oregon before returning to California and ending in a closed drainage basin at Tule Lake Sump (See Map 1). Water diversions for the U.S. Bureau of Reclamation (U.S. BOR) Klamath Project have connected the Klamath River with the Lost River through various canals. Generally, the Upper Lost River watershed can be characterized as high desert. Its climate is cool and dry, with most precipitation occurring as rain and snow from November to May. The geology and soils of the Upper Lost River watershed are strongly influenced by volcanic and erosional activity. The soils in the Upper Lost River/Clear Lake Reservoir watershed are derived from the weathered basalt flood flows with minor amounts of volcanic airfall deposits. These soils tend to be shallow, not well-developed, and are moderately to highly erosive. Vegetation is linked to soil type and is sparse except along Willow Creek, a tributary to Clear Lake Reservoir. There are no point source waste discharges within the watershed. The land use operations that may impact the watershed are livestock grazing and minor amounts of timber harvest. Although grazing has previously adversely impacted the aquatic habitat, the U.S. Fish & Wildlife Service (U.S. FWS) believes that current grazing practices have improved and will protect endangered species. The small amount of commercial forestry in the Clear Lake Reservoir watershed led the U.S.FWS to conclude that forestry does not present a threat to the endangered species.

The majority of the land in the study area is controlled by three federal agencies, although there are a few small, private in-holdings. The U.S. Bureau of Reclamation operates the Klamath Project including water deliveries from Clear Lake Reservoir. The U.S.FWS regulates the area immediately around Clear Lake Reservoir as a National Wildlife Refuge. The U.S. Forest Service (USFS) controls most of the watershed as the Modoc National Forest.

Three species listed under the federal Endangered Species Act are found in the study area – Lost River and shortnose suckers are classified as endangered species and bald eagles are listed as threatened species. The most sensitive beneficial uses most likely relate to the protection of the endangered sucker species. These fish can tolerate poor water quality such as low dissolved oxygen, high water temperature, and elevated pH levels, but the fish may not thrive at long-term, continual poor conditions resulting from habitat fragmentation, hydrologic regime alterations, and water diversion. Clear Lake Reservoir appears to possess a healthy population of Lost River and shortnose suckers compared to other populations in the Klamath and Lost River Basin. The water quality and habitat conditions in the reservoir and its tributaries are better than elsewhere in the Klamath River and Lost River basins. Although the North Coast Regional Water Quality Control Board Water Quality Control Plan (Basin Plan) lists a cold water fishery beneficial use for the study area, the current or historical presence of cold water fish could not be confirmed.

The data collection effort associated with this analysis consisted of three components – collection and review of existing data, water quality grab samples (and associated instantaneous field measurements), and the short-term use of continuous monitoring devices. Neither visual observations nor water quality sampling indicated impairment due to excess nutrients, although the turbidity levels in the reservoir and in the Upper Lost River probably suppress primary production. The high level of turbidity noted in the Upper Lost River is of concern, but was not the subject of this analysis. Computer simulation modeling suggests that decreasing solar radiation by increasing shade over the streams that drain into Clear Lake Reservoir could decrease water temperatures. The potential for increasing the shade due to riparian vegetation, however, is unlikely in all of these streams except for Willow Creek because of the inability of the soils to support increased vegetative growth. The Upper Lost River is more sensitive to the water temperature of the water released from Clear Lake Reservoir than to solar radiation. Even at current shade levels, the water temperature in the watershed supports the most sensitive beneficial use – the endangered sucker species.

There are some limitations to the data used in this analysis. None of the data gaps impede drawing conclusions about the water quality in the watershed, but addressing the limitations would add weight to the conclusions. The primary data limitations are discussed in the document.

The State of Oregon will conduct a water quality analysis of the Lost River segment in Oregon. If their analysis shows adverse impacts due to conditions upstream in California, the Regional Water Board may wish to conduct additional investigations. In particular, the presence of the reservoir and dam at the head of the Lost River may impact water temperatures downstream, and sediment introduced to the Lost River from Clear Lake Reservoir may lead to larger cumulative nutrient loads downstream.

The relative health of Clear Lake Reservoir's shortnose and Lost River sucker population is notable. Given the significance of the Clear Lake Reservoir watershed to preserving the Lost River and shortnose sucker populations, it is necessary to preserve the aquatic habitat from any harmful effects related to land use activities. Willow Creek and its tributaries (primarily Boles Creek) are the only spawning sites for the sucker populations; it is especially important to protect valuable properly functioning riparian conditions in this stream.

Regional Water Board staff has seen no information showing that the range of water temperature or nutrient concentrations in the streams draining into Clear Lake Reservoir are outside of the natural range[1] for that environment due to anthropogenic causes. Unlike the streams draining to Clear Lake Reservoir, alterations in the natural hydrologic regime in the Upper Lost River and the Clear Lake Reservoir have impacted the natural temperature and nutrient regimes in the mainstem Lost River. The alteration in hydrologic regime between Clear Lake Reservoir and Malone Reservoir at the Oregon border has resulted in a change in natural water temperatures due to high, turbid flows in the summer and very low flows in the winter. Creation of a reservoir in what naturally was an extensive wetland with emergent vegetation may have resulted in a change to the nutrient concentrations to the reservoir and to the river. The shallow reservoir with no emergent vegetation may no longer function as a sink for nutrients and sediment thus permitting these constituents to travel downstream. The operation of the dam and the lack of fish passage at either Clear Lake Reservoir or Malone Reservoir may have altered the habitat sufficiently that any suckers or redband trout that may have been present in the Upper Lost River could have been displaced. Although additional research would assist in answering these questions, addressing hydrologic regime changes and habitat fragmentation is beyond the scope of this analysis because these changes are not considered "pollutants" for the purposes of a TMDL analysis. It is not beyond the scope of the Regional Water Board's authority under the Clean Water Act, however, to establish minimum instream flow requirements in order to support beneficial uses.

The data and analysis in this investigation support removing the Upper Lost River/Clear Lake Reservoir area from the 303(d) list for temperature and nutrients. It is recommended that this document serve to support de-listing of the Upper Lost River and Clear Lake Reservoir area from the CWA §303(d) Listing of Impaired Waterbodies for nutrients and temperature in the regularly scheduled listing/de-listing process.

The water quality analysis for the Upper Lost River and Clear Lake Reservoir waterbodies indicates that physical impairments such as habitat fragmentation, flow alterations, and changes to the natural hydrologic regime are adversely affecting beneficial uses. A more complete analysis of the links between these alterations and water quality in these waterbodies should be conducted; using a more robust water quality data set than those collected by staff during the reconnaissance study presented in this document. Additional water quality investigations may be needed if the watershed is listed as impaired for other parameters in California (such as turbidity)

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1 In this context, "natural" means that the conditions of the watershed that affect water temperature and nutrient concentrations are not altered by past or present anthropogenic activities.

or if TMDL investigations by the State of Oregon indicate that impairments in the Lost River in Oregon are related to conditions upstream in California.

Although the Basin Plan lists a cold water beneficial use for this watershed, the presence of redband trout or other cold water species could not be confirmed in the Upper Lost River/Clear Lake Reservoir area. In order to definitively confirm or deny the presence of cold water species in the watershed, the Regional Water Board should support a biological survey in the area. Meanwhile, the possibility of the presence of a cold water species should not be used to mandate more stringent water quality requirements where the natural environment does not support those conditions. The potential for redband trout to exist in the Upper Lost River if the dams were removed and natural flow regimes were restored should be explored in an evaluation of the beneficial uses in this watershed.

1.0 INTRODUCTION

1.1 303(d) Listings, TMDL Requirements & Legal Authority

Section 303(d) of the federal Clean Water Act (CWA) requires that all states periodically develop a list of waterbodies whose water quality impairs beneficial uses. This section also requires that states establish a Total Maximum Daily Load (TMDL) for impaired waterbodies. TMDLs are written plans that analyze the water quality impairments and provide a mechanism for the waterbodies to attain and maintain water quality objectives.

A TMDL analysis quantifies the natural and anthropogenic sources of pollutants that impair listed waterbodies – in this case high nutrient concentrations and high water temperature. The following elements must be addressed in the TMDL:

- Applicable Area - A description of the geographic area and overview of the water quality impairments
- Target Identification - Specification of the applicable water quality standard
- Source Assessment – A complete analytical effort that encompasses background, nonpoint and point sources of pollution, as well as pollutant transport and dynamics
- Loading Capacity – The total allowable pollutant load that will ensure water quality standard compliance
- Waste Load Allocations and Load Allocations – The division of the loading capacity between sources as they are identified in the Source Assessment
- Margin of Safety – An explicit or implicit assurance of conservative approach
- Seasonal Variation – A description of the temporal variability of pollutant loading and water quality dynamics in the context of water quality compliance
- Water Quality Management Plan – To be included with the TMDL as part of the TMDL process.

The listing of the Upper Lost River/Clear Lake Reservoir watershed as impaired because of biostimulatory substances (nutrients) and high water temperature was made in 1996. In accordance with a consent decree,[2] 2005 is the deadline for adoption or de-listing of the TMDLs for the Upper Lost River/Clear Lake Reservoir area by the State of California.

Investigation into the basis of the listing revealed that these listings were conferred from the Klamath River Basin listings and not based on data or information specific to the Upper Lost River and Clear Lake Reservoir watershed. The appropriateness of the listings in the Upper Lost River will be explored in this analysis. If the waterbodies are not found to be impaired by the parameters for which they were listed the development of TMDLs is not warranted and de-listing would be appropriate.

1.2 Watershed Characteristics

1.2.1 Area and Location

The Upper Lost River/Clear Lake Reservoir basin is a geographically isolated 908 square mile watershed located in the northeastern corner of California in the northwestern quarter of Modoc County. Modoc County borders Klamath and Lake Counties to the north in Oregon (See Map 1). The county has a land area of 3,944 square miles (U.S. Bureau of Census 2002). The dam at Clear Lake Reservoir is about 39 miles southeast of Klamath Falls, Oregon. The Lost River, which

[2] Pacific Coast Federation of Fishermen's Associations, et al. v. Marcus, No. 95-4474 MHP, 11 March 1997.

originates from Clear Lake Reservoir and its tributaries on the Modoc Plateau, crosses the California-Oregon border, which comprises the northernmost boundary of the watershed in California. The towns of Newell and Tulelake lie just outside the watershed to the west along Highway 139. The town of Alturas lies outside the watershed to the south along Highway 299, and Goose Lake lies just outside the watershed to the east. The area is shown in Maps 1 and 2.

1.2.2 Population

The population of Modoc County in 2002 was 9,289 (U.S. Bureau of Census 2002). This is a population density of 2.4 persons per square mile (U.S. Bureau of Census 2002). It is the third least populated county in California, with Alpine and Sierra Counties each having lower populations. There are no metropolitan areas in the county, and there are no towns within the Upper Lost River/Clear Lake Reservoir watershed. The median family income for Modoc County is $35,987, with 16.4% of the families below the poverty level ($16,000 per year) (U.S. Bureau of Census 2002). The 3,635 classified workers within the county are divided into the following categories: private wage and salary workers, 49.7%; government workers, 33.4%; self employed workers in own unincorporated business 15.7%; and unpaid family workers, 1.2% (U.S. Bureau of Census 2002).

1.2.3 Climate

The Upper Lost River/Clear Lake Reservoir watershed is more than 100 miles inland from the Pacific Ocean, and much of the topography within that distance consists of rugged mountain ranges (USDA Forest Service 1993, USDA Soil Conservation Service 1980). The majority of precipitation originates from winter Pacific cyclonic storms with a short, erratic summer monsoon season that can be locally significant (Smith and Davidson 2003). The mountains to the west create a significant rain shadow effect and lower precipitation in the watershed compared to other parts of northern California. The climatic pattern of the area is classified as "Mediterranean Montane" (Bailey 1995), which is a higher elevation variant of the Mediterranean climate. Elevations on the Modoc Plateau-Lost River watershed range from about 4,000 to 6,000 feet (USDA Forest Service 1993).

Generally, the climate on the Modoc Plateau is cool and dry, with most precipitation occurring as rain and snow from November to May. A separate dry season exists from about mid-May to October where precipitation is close to zero. Precipitation varies from 12 to 40 inches, with average annual temperatures from 38^{o} F to 48^{o} F (Smith and Davidson 2003). Much of the winter precipitation on the Modoc Plateau falls as snowfall with a yearly average snowfall of 36.6 inches (USDA Soil Conservation Service 1980). Snow cover can last for long periods of time, but at lower elevations with higher temperatures snow generally does not stay on the ground long. "Prolonged droughts have frequently affected the Clear Lake watershed. The most extended occurred in the 1922-1937 period, when only one year of above-average inflow occurred in 15 years. In the drought of 1987-1992, inflow was above average in only one of six years."[3] In October 1992, as a result of drought and irrigation deliveries, the east lobe of Clear Lake Reservoir was dry except for a small pool near the dam (U.S. FWS 2001).

The mean minimum of the coldest month (January) varies from 12^{o} F in the Hat Mountain area to 21^{o} F south of Newell (Smith and Davidson 2003). The mean maximum of the warmest month

[3] U.S. FWS 2001.

(July) varies from 67.3^{o} F south of the Warner Mountains to 84^{o} F south of Newell (Smith and Davidson 2003). Average humidity is generally low to very low for most of the year, and evapotranspiration is high in the summertime. Tables showing the annual climate summary from the nearest large towns (Klamath Falls, Oregon to the northwest and Alturas, California to the southeast) and from the Devil's Garden district (bordering the watershed of interest) in the Modoc National Forest are below.

Average Monthly Climate Data for Klamath Falls, Oregon

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature (°C)												
mean	-1.2	1.5	4.3	7.7	11.9	15.8	20.3	19.5	15.6	9.8	3.3	-0.3
maximum	3.7	6.9	10.6	15.0	19.8	24.2	29.5	28.9	24.7	17.7	8.8	4.2
minimum	-6.0	-3.9	-1.9	0.3	4.1	7.6	11.0	10.0	6.5	2.0	-2.1	-4.9
Air Temperature (°F)												
mean	29.8	34.7	39.8	45.8	53.5	60.5	68.5	67.1	60.1	49.7	38.0	31.4
maximum	38.6	44.5	51.0	59.0	67.6	75.5	85.1	84.1	76.5	63.9	47.9	39.6
minimum	21.1	24.9	28.5	32.6	39.4	45.7	51.9	50.1	43.8	35.6	28.2	23.1
Precipitation (mm.)												
mean	51.31	34.04	33.78	21.34	26.67	20.32	7.62	11.68	13.72	26.42	44.96	57.15
Precipitation (in.)												
mean	2.02	1.34	1.33	0.84	1.05	0.80	0.30	0.46	0.54	1.04	1.77	2.25

From: Western Regional Climate Center, Reno, Nevada. Based on data from 1928 to 2000.
temperature data accessed 12/13/02: http://www.wrcc.dri.edu/cgi-bin/cliGCStT.pl?orklam
precipitation data accessed 12/13/02: http://www.wrcc.dri.edu/cgi-bin/cliGCStP.pl?orklam

Average Monthly Climate Data for Alturas, California

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature (°C)												
mean	-1.6	0.7	3.5	6.8	10.8	14.9	18.8	17.9	14.0	8.6	2.9	-0.7
maximum	-8.5	-6.4	-4.0	-1.9	1.6	4.9	6.7	5.3	1.9	-2.1	-5.2	-7.8
minimum	5.3	7.7	11.0	15.5	20.1	25.0	30.8	30.4	26.2	19.4	11.0	6.4
Air Temperature (°F)												
mean	29.1	33.2	38.3	44.3	51.5	58.9	65.8	64.2	57.3	47.5	37.3	30.8
maximum	16.6	20.5	24.7	28.6	34.9	40.8	44.1	41.5	35.5	28.2	22.7	18.0
minimum	41.6	45.8	51.9	59.9	68.2	77.0	87.5	86.8	79.1	66.9	51.9	43.6
Precipitation (mm.)												
mean	39.37	36.07	35.31	26.67	33.78	24.89	7.37	8.89	12.19	24.13	36.58	38.35
Precipitation (in.)												
mean	1.55	1.42	1.39	1.05	1.33	0.98	0.29	0.35	0.48	0.95	1.44	1.51

From: Western Regional Climate Center, Reno, Nevada. Based on data from 1931 to 2001.
temperature data accessed 12/13/02: http://www.wrcc.dri.edu/cgi-bin/cliGCStT.pl?caaltu
precipitation data accessed 12/13/02: http://www.wrcc.dri.edu/cgi-bin/cliRECtM.pl?caaltu

Average Monthly Climate Data for Devil's Garden, California												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Air Temperature (°C)												
mean	-1.3	2.0	2.6	7.1	11.2	17.8	23.5	20.5	16.5	8.3	5.0	-0.9
maximum	4.0	8.0	8.4	13.4	18.1	25.2	31.7	28.0	24.9	17.3	11.6	2.7
minimum	-6.4	-3.0	-3.4	1.1	3.4	9.0	13.7	10.2	7.7	0.9	-1.0	-4.9
Air Temperature (°F)												
mean	29.7	35.6	36.7	44.8	52.2	64.0	74.3	68.9	61.7	46.9	41.0	30.4
maximum	39.2	46.4	47.1	56.1	64.6	77.4	89.1	82.4	76.8	63.1	52.9	36.9
minimum	20.5	26.6	25.9	34.0	38.1	48.2	56.7	50.4	45.9	33.6	30.2	23.2
Precipitation (mm.)												
total	21.08	43.94	17.27	27.69	7.62	0.25	1.02	1.52	2.03	0.51	13.21	39.12
Precipitation (in.)												
total	0.83	1.73	0.68	1.09	0.30	0.01	0.04	0.06	0.08	0.02	0.52	1.54
From: Western Regional Climate Center, Reno, Nevada. Based on data from Dec 2001-Nov 2002. Data accessed 12/16/02: http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?caCDGR												

1.2.4 Hydrology

The Upper Lost River/Clear Lake Reservoir watershed drains the north-central portion of the Modoc Plateau to the Clear Lake Reservoir area, which feeds the Lost River. The Lost River flows northwesterly through Walter Flat into Malone Reservoir just across the Oregon border to the north, and it traverses about 100 miles in Oregon before naturally ending in a closed drainage at Tule Lake (Braunworth et al. 2002). Water diversions for the U.S. Bureau of Reclamation (U.S. BOR) Klamath Project have connected Klamath River water with the Lost River through various canals such as the Klamath Straits drain (U.S. BOR 2000). The Modoc Plateau extends westward to the Medicine Lake Highlands Volcanic area; it gradually transitions eastward into the gentle west slope of the Warner Mountains; and it is bordered by the Alturas Basin and the Adin (Big Valley) Mountains to the south.

There are five tributaries that flow into the Lost River and Clear Lake Reservoir from the Modoc Plateau in California (see Map 2). These are mostly intermittent streams that create a moderate drainage density for the area (Smith and Davidson 2003). Willow Creek is the tributary that provides the majority of the inflow into Clear Lake Reservoir (Shively et al. 1999). Willow Creek flows southwesterly into Clear Lake Reservoir. It originates from Weed Valley Marsh, near the Oregon border in the eastern Modoc Plateau. Several minor tributaries within Oregon also feed Weed Valley Marsh. Boles Creek is an intermittent creek that flows north into Willow Creek before entering Clear Lake Reservoir. Fletcher Creek intermittently feeds Boles Creek from the eastern portion of the Plateau via Boles Meadow. Mowitz Creek is another intermittent creek that drains the southern part of the Plateau and flows north into the eastern lobe of Clear Lake Reservoir south of the Willow Creek confluence. One smaller tributary, Rock Creek, flows south into the Lost River between Clear Lake Reservoir dam and Walter Flat.

Clear Lake Reservoir now occupies the site of a natural lake/marsh system (U.S. FWS 2001). Construction of a dam raised the lake level to the existing level. "The Lost River historically originated from the junction of the marsh at Clear Lake and adjacent Willow Creek" (Buettner and Scoppettone 1991). Prior to dam construction, the Lost River flowed during the wet winter months and had low to no flows from June to October (U.S. FWS 2001). Clear Lake Reservoir is divided into two lobes – an east lobe and a west lobe separated by a peninsula known as "The U." The dam is at the north end of the east lobe. The most significant tributary, Willow Creek enters the east lobe just south of the dam. Clear Lake Reservoir, the largest water storage facility in the watershed, is located near the western border of the watershed. It is used to store the seasonal runoff to meet irrigation needs for Langell Valley Irrigation District and Horsefly Irrigation District, from about April 15 until October 1 and is shut off the remainder of the year (U.S. FWS 2001). "Flows in the upper reach of the Lost River, from Clear Lake dam to the confluence with Rock Creek, are cut off from October to April during the nonirrigation season, with the only flows coming from accretion primarily by small springs and Rock Creek. During this time, fish are confined to any remaining pools and are thus likely subject to high predation, a lack of food, and poor water quality."[4]

Clear Lake Reservoir was designed to reduce high flows into the reclaimed wetlands in the Tule Lake area by limiting runoff and increasing evaporation rates (U.S. BOR 2000). Creating a large surface area with shallow depths accomplishes this goal, thus the reservoir is not an efficient water storage facility (U.S. FWS 2001). The original dam was an earth and rockfill dam constructed in 1910 with a total usable storage capacity of 527,000 acre-feet and maximum surface area of 25,760 acres (U.S. BOR 2000). The average annual inflow is 117,000 acre-feet; the normal irrigation release is 120 cfs; the maximum irrigation release is 170 cfs; and the firm annual yield is 11,000 acre-feet (U.S. BOR 2000). The original earthen dam was re-constructed as a concrete dam in 2002. The height of the new dam was the same as the height of the original dam, but the new dam has a higher operating capacity because the original dam was not filled to capacity because of safety concerns (U.S. FWS 2001). Neither the original dam or the new dam at Clear Lake Reservoir provided for passage for upstream fish migration. The new dam, unlike the old dam, has screens to prevent fish from being entrained in outflow. Other smaller reservoirs are scattered throughout the watershed primarily for livestock operations. "Above Clear Lake in Willow, Boles, and Fletcher Creeks there are at least 43 small earthen dams on U.S. Forest Service and private lands that potentially restrict upstream access to sucker habitat. The dams most likely to restrict sucker passage include Boles Meadow, Fletcher Creek, Avanzino, Weed Valley, and Fourmile Valley. They restrict access to a total of about 20 miles of stream habitat."[5]

1.2.5 Geology

The geology of the Upper Lost River watershed is strongly influenced by faulting and by volcanic and erosional activity (Smith and Davidson 2003, USDA Forest Service 1993, USDA Soil Conservation Service 1980). Volcanic activity has been continuous and massive for the last 60 million years, because the region is inland from active subducting plates near the boundary of the Pacific Ocean plate and the North American plate. Huge quantities of lava, mainly basaltic in nature, and associated pyroclastic materials flowed, or were deposited, over the landscape in almost continuous interbedded masses (USDA Forest Service 1993).

The Modoc Plateau is capped by basalt flood flows (Warner Basalts) of late Miocene to late Pleistocene age (25k to 20 Mya) (USDA Forest Service 1993, USDA Soil Conservation Service 1980). The Pliocene and Pleistocene basalts (Garden Basalt Veneer, 25k to 5 Mya) are relatively recent and slightly weathered (USDA Forest Service 1993, USDA Soil Conservation Service 1980). These flat basalt floodplains resemble the thicker Columbia Plateau basalts, but cannot be chronologically correlated (USDA Forest Service 1993). The basalt capping of the Plateau is

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4 U.S. FWS 2001
5 U.S. BOR 2001

estimated to be 400 to 1,000 feet thick with the southern margin of the Plateau being as thin as 15 feet (USDA Forest Service 1993). Underlying the basalt capping are a thick sequence of pyroclastic and andesitic rocks of the Cedarville series of the Warner Mountains (USDA Forest Service 1993) and ancient lakebed tuffs of the Alturas Formation (Smith and Davidson 2003). Sporadically recent basaltic cinder cones and low shield volcanoes occur on the Plateau, usually along the frequent northwest southeast trending faults (USDA Forest Service 1993). More recent lava flows have occurred on the west side of the Plateau adjacent to the Medicine Lake Highlands.

The Modoc Plateau extends westward to the Medicine Lake Highlands Volcanic area, which is a broad shield volcano composed of Tertiary (3 to 50 Mya) andesitic lava flows, a caldera where the original volcano collapsed, and resulting secondary volcanoes, lava flows and ash deposits (Smith and Davidson 2003). The Plateau gradually transitions eastward into the gentle west slope of the Warner Mountains and the rocks of the Cedarville Formation, estimated at 3,500 feet thick and 30 million years old (USDA Forest Service 1993). The Alturas Basin and the Adin (Big Valley) Mountains to the south border the Plateau. The Adin Mountains are composed of a sequence of non-marine deposits overlain with Miocene (11-25 Mya) andesitic/basalt flows and ash deposits, which have been subjected to syncline and anticline folding and block faulting that trends north-northwest (Smith and Davidson 2003, USDA Forest Service 1993).

1.2.6 Geomorphology

Volcanic processes, with lesser components of tectonic, fluvial, glacial, lacustrine, and mass wasting processes have dominated the geomorphic processes on the Modoc Plateau and the Upper Lost River/Clear Lake Reservoir watershed. The areas of gentle slopes include plains formed by extensive basalt outflows: the alluvial plains with nearly level intermittent lake basins, sloping alluvial fans, and high alluvial terraces. Steeper areas include the dissected mountain ranges and the fault or erosion formed escarpments. Many escarpment faces drop from the Modoc Plateau to the Alturas area, a difference in elevation of about 600 feet, to reveal the Alturas Formation lake deposits and underlying Warm Springs tuff rock (USDA Forest Service 1993, USDA Soil Conservation Service 1980).

The Upper Lost River/Clear Lake Reservoir watershed is bordered by various volcanic mountains (cinder cones) and fault or erosion formed escarpments that occur across the Modoc Plateau. To the west, the watershed is bordered by the Clear Lake Hills, adjacent to Clear Lake Reservoir, Double Head Mountain, and the slopes of the Medicine Lake Highlands. To the south, the watershed is bordered by Timber Mountain, just south-southwest of Clear Lake Reservoir, Spaulding Butte, Rail Mountain, Jack’s Butte, and Timbered Mountain (southeast of Clear Lake Reservoir), which separates the watershed from the Big Sage Reservoir drainage. To the east, the gentle slopes of the Warner Mountains border the watershed, including Dry Creek Rim next to Goose Lake and along the California-Oregon border and Crowder Mountain just west of the southern portion of Goose Lake.

1.2.7 Soils

The soils in the Upper Lost River/Clear Lake Reservoir watershed are derived from the weathered basalt flood flows with minor amounts of volcanic airfall deposits such as ash, pumice, and volcanic tuff (Smith and Davidson 2003). The soil temperature regimes, which affect soil chemical and biological processes, are predominately mesic (average annual soil temperature at 50 cm depth of 8-15^{o}C, or 46.4-59^{o}F) with minor amounts of frigid soils (average annual soil temperature at 50 cm depth of 8^{o}C, or 46.4^{o}F) located in the northeast quadrant of the watershed (Smith and Davidson 2003). Vegetation and biological activity are directly linked to soil temperature and soil type because of variations of available nutrients, heat energy, and moisture.

The Miocene flows (Warner Basalts, 5 to 20 Mya) found in the northeast portion of the watershed, which includes the Willow Creek area, have weathered into the deep, organic enriched soils that support the Ponderosa pine forest. The younger Pliocene and Pleistocene basalts (Garden Basalt Veneer, 25k to 5 Mya) found across the remainder of the watershed, tend to have shallower, less developed soils, which support western juniper, mountain big sagebrush, and Idaho fescue type vegetation.

The soil orders, or major soil classifications, that are commonly found in the watershed are Mollisols, Aridisols, Andisols, Vertisols, and Entisols (Smith and Davidson 2003).
The majority of soils in the watershed are Mollisols (80%) which have a thick organic enriched surface horizon that has developed in association with basalt deposits (Smith and Davidson 2003). These soils have a high nutrient content, with good forest productivity unless limited by high rock content, compaction and low water holding capacity, dry climate, cold, or a silica duripan. Aridisols, which are desert soils, occupy most of the area around Clear Lake Reservoir and some small, scattered sites across the watershed (Smith and Davidson 2003). Aridisols are dry most of the year, and develop where evapotranspiration greatly exceeds precipitation most of the year. These soils often have accumulated salts, elevated pH, shallow depths often overlying a claypan or silica duripan (silica cemented layer), slow permeability, low fertility, sparse vegetation, and moderate erosion potential (Smith and Davidson 2003, USDA Forest Service 1993). A small area of Andisols occurs just south of Clear Lake Reservoir in the Mowitz Creek drainage (Smith and Davidson 2003). These soils, derived from volcanic airfall deposits such as ash, pumice, and volcanic tuff, have low bulk density, high water holding capacity, sandy textures, high phosphate retention, high cation exchange capacity, and high particle surface areas that facilitate nutrient cycling and vegetative productivity (Smith and Davidson 2003). Vertisols are dark clay soils that have formed in the scattered basin areas across the watershed that are often classified as wetlands (Smith and Davidson 2003). These soils have high pH, poor drainage, poor saturated soil strength, swell and shrink by season to physically churn the soil and restrict vegetation to sagebrush, grasses and annual forbs. Entisols are weakly developed soils that commonly occur along the creeks in the watershed (Smith and Davidson 2003). These soil are sandy, well drained, with low water holding capacity that tend to be alluvially deposited, often with organic matter accumulations from inhabiting riparian vegetation.

The soils adjacent to the watercourses will have the most immediate affect upon water quality via nutrient cycling and potential erosion, which is attributed to soil chemical and physical properties and the inhabiting vegetation. Clear Lake Reservoir and Mowitz Creek are dominated by Puls, Roval and Dishner soils (USDA Forest Service 1993). The Puls soils are shallow, well-drained Aridisols derived from volcanic ash or basalt, and overlie a silica duripan; the Dishner soils are shallow, well-drained Aridisols, derived from basalts with slow permeability; and the Roval soils are shallow, well-drained Mollisols, derived from basalts with a silica duripan.

Entisols and Mollisols dominate Willow Creek, Boles Creek, and Fletcher Creek (USDA Forest Service 1993). The Entisols on side-slopes of the incised drainages are weakly developed with little clay or organic matter accumulation. On the lower side-slopes of the alluvial drainages, which are subject to spring flooding, clay content, organic matter and rooting depth increase. Mollisols, rich in organic matter, are common on the concave areas of alluvial drainage, which flood more routinely and support emergent riparian vegetation.

1.2.8 Vegetation

Vegetation throughout the area is highly variable and dependent on climatic and soil conditions (USDA Forest Service 1993). The temperate climate, with moist winters and dry, warm summers, creates a significant soil moisture deficit in the summer months when potential evapotranspiration far exceeds actual evapotranspiration (Smith and Davidson 2003). This climatic pattern dictates vegetation distribution and types that are adapted to summer soil water deficits.

In the southwestern quarter of the Modoc Plateau, the Mowitz Buttes land type association (Smith and Davidson 2003), ranges from 4,200 to 5,400 feet in elevation, and is dominated by Ponderosa pine with bitterbrush and balsamroot understory on clayey soils with enriched organic surface horizons. Limited occurrences of Ponderosa pine-incense cedar with bitterbrush and balsamroot understory are also found within this area on similar soils. On shallow, rocky soils western juniper and sage dominate plant communities. Small wetlands and lakes with associated wetland plants such as sedges, rushes, willows and aspen, are scattered across the area. The northeastern quarter of the Modoc Plateau (Willow Creek drainage) is the Crowder Flat land type association (Smith and Davidson 2003), with elevations from 4,700 to 6,000 feet. The dominant plant community is Ponderosa pine with serviceberry understory, which is located on deep, clay-enriched soils high in organic matter that are productive timberlands. The rest of the Modoc Plateau comprises the Devil's Garden land type association which is dominated by western juniper, mountain big sagebrush, and Idaho fescue (Smith and Davidson, 2003). Elevation ranges from 4,100 to 5,700 feet on shallow, rocky soils derived from volcanic materials. Numerous small wetlands and lakes are found across the area with associated wetland plants such as sedges, rushes, grasses, willows and aspen, and the silver sagebrush/Nevada bluegrass plant association is found in the alkaline clay basins (Smith and Davidson, 2003).

Many of the tributaries in the Upper Lost River watershed have down-cut through the recent basalt flows to create nearly vertical walls along the watercourses. In more level terrain these tributaries have deposited alluvium adjacent to the nearly vertical walls for emergent riparian vegetation to establish. However, most of the tributaries have few if any riparian trees due to the shallow soils on recent basalt flows. The only significant riparian forest observed in the watershed was along middle and upper reaches of Willow Creek, where older basalt flows had weathered to produce deeper soils to support the Ponderosa Pine and Willow forest.

1.3 History

The first non-Native settlers in Modoc County were probably trappers in the 1820's (USDA Soil Conservation Service 1980). Wagon trains went through the area in the 1840's and especially during the 1849 Gold Rush, but there were few permanent settlements until 1867. Few settlers remained until after the Indian Wars of 1873 (USDA Soil Conservation Service 1980). Modoc

County was established in 1874 with Dorris Bridge as the county seat, which was later named Alturas (Spanish for "a valley on top of the mountain") (USDA Soil Conservation Service 1980). The Swamp Act of 1850, the 1862 Homestead Act and the Desert Land Act in 1877 were used to acquire low-cost acreage (USDA Soil Conservation Service 1980).

Commerce increased when the export of cash crops became possible with railroad construction in 1881 (USDA Soil Conservation Service 1980). The railroad was extended to Likely in 1908 and through Goose Valley to Lakeview, Oregon by 1912. The railroad was widened in 1928-29 and extended to Klamath Falls, Oregon, which soon made Alturas a central shipping point. Now, U.S. Highway 395 serves as the major north to south route, and State Highway 299 serves as the major east to west route.

The Oregon and California legislatures passed legislation on January 20 and February 3, 1905, respectively, ceding certain lands in Lower Klamath Lake and Tule Lake to the United States for use by the Klamath Project development under provisions of the Reclamation Act of 1902 (U.S. BOR 2000). Project construction was authorized by the Secretary of the Interior on May 15, 1905 in accordance with the Reclamation Act[6] (U.S. BOR 2000). The project drained and reclaimed lake bed lands of the Lower Klamath and Tule Lakes, stored water of the Klamath and Lost Rivers, diverted irrigation supplies, and controlled flooding of reclaimed lands (U.S. BOR 2000). According to the provisions of the Reclamation Act, the Project costs were to be repaid by the beneficiaries of the reclaimed Project lands. Clear Lake Reservoir and dam, the largest facility in the Upper Lost River watershed, was completed in 1910 to provide flood protection and irrigation benefits to Lost River dependent lands. In 1911 Clear Lake Wildlife Refuge was established which included Clear Lake Reservoir and 26,000 surrounding acres. The Klamath Project presently includes 240,000 of irrigable lands plus national wildlife refuge lands.

In spite of the population growth and agriculture development elsewhere in the area, the Upper Lost River/Clear Lake Reservoir area remained geographically isolated, controlled by federal agencies with few private land holdings.

1.4 Land Use

1.4.1 Federal Agency Presence

There is little privately owned land in the watershed. Three federal agencies are present in the watershed:

- U.S. Bureau of Reclamation, which operates the Klamath Project and water deliveries from Clear Lake Reservoir dam;
- U.S. Fish and Wildlife Service, which operates the Clear Lake National Wildlife Refuge;
- U.S. Department of Agriculture/Forest Service, which operates the Modoc National Forest comprising the majority of land in the watershed.

6 43 U.S.C. S 372 *et seq.*, Act of June 17, 1902, 32 Stat. 388.

1.4.2 Timber Harvest

There is little timber harvest in the watershed, in large part because the soils in most of the watershed do not support large growth of timber. A more detailed discussion of timber harvest impacts on the watershed is found in Section 6.0 of this document.

1.4.3 Agriculture and Grazing

There are no significant agricultural operations in the watershed, however livestock grazing is the primary land use and is scattered across the area (Powell and Blackwell 2001). The Clear Lake National Wildlife Refuge was established with the dual purposes of maintaining waterfowl habitat and optimizing agriculture use. The U.S. FWS (1995) states that “In the case of Clear Lake, the only agricultural use that has been shown to be economically feasible is livestock grazing.” A more detailed discussion of grazing and its impacts on the watershed is found in Section 6.0 of this document.

1.4.4 Wildlife Refuges

Clear Lake National Wildlife Refuge, established in 1911, occupies 46,460 acres, with approximately 20,000 acres of open water surrounded by upland habitat of bunchgrass, sagebrush, and western juniper (U.S. FWS 2003). The refuge provides habitat for the Lost River and shortnose suckers, pronghorn antelope, mule deer, sage grouse, the American white pelican, the double-crested cormorant, and other colonial nesting birds. Except for limited waterfowl hunting and pronghorn antelope hunting during the regular California State seasons, the refuge is closed to the public in order to protect fragile habitats and reduce wildlife disturbances.

The U.S. FWS (1995) describes the refuge:

> Its 33,440 acres consist of 23,770 acres of open water (reservoir) at full pool and 9,670 acres of perennial grasses, forbs, low sage, and scattered juniper. Several islands created by the reservoir support breeding colonies of California and ring-billed gulls, Caspian terns, great blue herons, great and snowy egrets, double-crested cormorants, and the largest breeding colony of white pelicans (up to 2,000 nests) in California. One of the last remaining sage grouse leks in the vicinity is located on the refuge.

Management of the refuge is complex. The Kuchel Act of 1964[7] requires the U.S. FWS to preserve waterfowl habitat values and to give “full consideration for optimum agriculture uses that are consistent with that goal.”[8]

1.5 Water Diversions, Manipulations & the Klamath Project

Clear Lake Reservoir, operated by the U.S. BOR, is the primary source of water for the agricultural operations in the eastern half of the Klamath Basin (U.S. FWS 2003). The primary water diversions in the Upper Lost River watershed are from Clear Lake Reservoir to Langell Valley Irrigation District and Horsefly Irrigation District (both in Oregon), which total approximately 36,000 acre-feet per year (Braunworth et al. 2002). Releases from Clear Lake Reservoir from 1991 to 2000 averaged 46,000 acre-feet per calendar year, and the range was from 8,000 acre-feet in 1992 and 1994 (during a severe drought) to 118,000 acre-feet in 2000 (Braunworth et al. 2002). The additional releases were for downstream uses and to lower the lake levels in order to facilitate Clear Lake Reservoir dam reconstruction. The Lost River Diversion

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[7] Public Law 88-567, 78 Statute 850, September 2, 1964
[8] U.S. FWS 1995

Dam, on Lost River about four miles downstream of Olene, Oregon, diverts excess water to the Klamath River through the Lost River Diversion Channel. It also restrains downstream flow in the Lost River to control or restrict flooding of the reclaimed portions of Tule Lake and to regulate the flow into the restricted sumps of the Tulelake National Wildlife Refuge.

There is no groundwater augmentation in this part of the Klamath Project, the Upper Lost River/Clear Lake Reservoir watershed. This is due to lower intensity land use, primarily livestock grazing and no significant agricultural operations. Downstream of the Upper Lost River there is heavy agriculture use, diversions for agriculture use, input from Upper Klamath Lake, and augmentation of the river with groundwater.

The largest use of water from the watershed is for irrigation projects operated by the Langell Valley and Horsefly Irrigation Districts. Throughout the watershed, numerous smaller reservoirs and ponds have been created for watering livestock.

1.6 Endangered Species Act

Lost River and shortnose suckers were classified as endangered species under the federal Endangered Species Act (ESA) in 1988. The U.S. FWS (1988) blamed the decline of both species primarily on habitat alterations, including lack of spawning habitat, “damming of rivers, instream flow diversion, draining of marshes and other forms of water manipulation.” A complete discussion of these species is in Section 4.0 of this document. Bald eagles are listed as ESA threatened species and are found in the study area.

1.7 Point and Nonpoint Sources

There are no point source waste discharges within the watershed. The land use operations that may impact the Upper Lost River watershed as nonpoint sources of water pollution are livestock operations (grazing) and timber harvest. These activities are discussed in Section 6.0 of this document.

2.0 WATER QUALITY OBJECTIVES

The North Coast Regional Water Quality Control Board established water quality objectives that are necessary for the protection of beneficial uses in the Upper Lost River/Clear Lake Reservoir watershed. The standards are found in the Basin Plan (CRWQCB 1994). The objectives applicable to the Upper Lost River/Clear Lake Reservoir for this analysis are temperature and nutrients (biostimulatory substances). The Basin Plan temperature objectives applicable to the Lost River are more suited to waste discharges, not nonpoint land use activities that may impact water temperature. The Basin Plan standard applicable to nutrients is a narrative objective. The water quality for dissolved oxygen also is of interest in this analysis, although the Upper Lost River/Clear Lake Reservoir basin is not listed as impaired for dissolved oxygen.

<table>
<tr><th colspan="2">Applicable California Water Quality Objectives</th></tr>
<tr><th>Parameter</th><th>NCRWQCB Water Quality Objective</th></tr>
<tr><td>Nutrients

From CRWQCB 1994, Chapter 3, Biostimulatory Substances</td><td>Waters shall not contain biostimulatory substances in concentrations that promote aquatic growth to the extent that a nuisance is caused or beneficial use is adversely affected.</td></tr>
<tr><td>Temperature

From CRWQCB 1994, Appendix 3 “Water Quality Control Plan for the Control of Temperature in the Coastal and Interstate Waters and Enclosed Bays and Estuaries of California (Thermal Plan).”</td><td><u>Lost River</u>
1. Cold Interstate Waters:
A. Elevated temperature waste discharges into cold interstate waters are prohibited.
2. Warm Interstate Waters:
A. Thermal waste discharges having a maximum temperature greater than 5°F above natural receiving water temperature are prohibited.
B. Elevated temperature wastes shall not cause the temperature of warm interstate waters to increase by more than 5°F above natural temperature at any time or place.
D. Lost River – Elevated temperature wastes discharged to the Lost River shall not cause the temperature of the receiving water to increase by more than 2°F when the receiving water temperature is less than 62°F, and 0°F when the receiving water temperature exceeds 62°F.</td></tr>
<tr><td>Dissolved Oxygen

From CRWQCB 1994, Chapter 3, Table 1, Specific Water Quality Objectives for North Coast Region</td><td><u>Clear Lake, Upper & Lower Lost River, Tule Lake, Lower Klamath Lake</u>
≥ 5.0 mg/l, minimum
8.0 mg/l, 50% lower limit (this means that 50% or more of the monthly mean values must be equal to or greater than 8.0 mg/l).

<u>Other Streams in Upper Lost River HA</u>
≥ 7.0 mg/l, minimum
8.0 mg/l, 50% lower limit (this means that 50% or more of the monthly mean values must be equal to or greater than 8.0 mg/l).</td></tr>
</table>

There are no point source waste discharges to the Clear Lake Reservoir or the Upper Lost River, so the temperature water quality objectives cited above are not applicable. The temperature standard used for this analysis, then, is the support of beneficial uses. The narrative objective for nutrients and the numeric objective for dissolved oxygen is applicable to the Clear Lake Reservoir/Upper Lost River basin.

The Upper Lost River is an interstate waterbody, crossing from California into Oregon approximately eleven miles downstream of the Clear Lake Reservoir dam. State of Oregon water quality standards, therefore, are of interest to this analysis. The applicable Oregon water quality objectives are water temperature, pH, dissolved oxygen, chlorophyll-a, turbidity, and ammonia. These standards are shown below.

In Oregon, the Lost River is classified as a cool water ecosystem for the purpose of establishing water quality standards for dissolved oxygen and temperature (OAR 340-41-0180, Figure 180A). Anecdotal information suggests that adult redband rainbow trout are occasionally found in the Lost River in Oregon where cool water springs exist. The system is not believed to be capable of supporting salmonid reproduction due to natural limiting conditions. Oregon considers the redband trout and the endangered suckers as the most sensitive fish species.

Applicable Oregon Water Quality Objectives	
Parameter	**Oregon Water Quality Objective**
Water Temperature OAR 340-041-0028	(9) Cool Water Species. Waters that support cool water species may not be warmed by more than 0.3 degrees Celsius (0.5 degrees Fahrenheit) above the ambient condition unless a greater increase would not reasonably be expected to adversely affect fish or other aquatic life. Cool waters of the State are described on subbasin tables set out in OAR 340-041-0101 to 340-041-0340: Tables 140B, 180B, 201B, and 250B.
pH OAR 340-041-0185	pH values shall not fall outside the following ranges: (A) Fresh waters except Cascade lakes: pH values shall not fall outside the range of 6.5 – 8.5
Dissolved Oxygen OAR 340-41-0016	For waterbodies identified by the Department as providing cool-water aquatic life, the dissolved oxygen shall not be less than 6.5 mg/l as an absolute minimum. At the discretion of the Department, when the Department determines that adequate information exists, the dissolved oxygen may not fall below 6.5 mg/l as a 30-day mean minimum, 5.0 mg/l as a seven-day minimum mean, and may not fall below 4.0 mg/l as an absolute minimum (Table 21).

Chlorophyll-a (Nuisance Plankton Growth) OAR 340-041-0019	The following values and implementation program shall be applied to lakes, reservoirs, estuaries and streams, except for ponds and reservoirs less than ten acres in surface area, marshes and saline lakes: (1) (a)(A) Nuisance Phytoplankton Growth: Natural lakes that thermally stratify: 0.01 mg/l. (1) (a)(B) Nuisance Phytoplankton Growth: Natural lakes that do not thermally stratify, reservoirs, rivers and estuaries: 0.015 mg/l.
Turbidity OAR 340-041-0036	No more than 10% cumulative increase in natural stream turbidities may be allowed, as measured relative to a control point immediately upstream of the turbidity causing activity.
Ammonia OAR Table 33B, 340-041-0033	Ammonia criteria for freshwater may depend on pH, temperature, and the presence of salmonids or other fish with ammonia-sensitive early life stages. Values for freshwater criteria (of total ammonia nitrogen in mg N/L) can be calculated using the formulae specified in *1999Update of Ambient Water Quality Criteria for Ammonia* (EPA-822-R-99-014; http://www.epa.gov/ost/standards/ammonia/99update.pdf)

3.0 BENEFICIAL USES

A single water body can have multiple beneficial uses, but a TMDL monitoring program is typically designed to determine if anthropogenic activities are affecting the most sensitive designated use. The Basin Plan (CRWQCB 1994) lists the following beneficial uses for the Clear Lake Reservoir/Upper Lost River area:

Existing Beneficial Uses

- Agricultural Supply
- Freshwater Replenishment
- Groundwater Recharge
- Water Contact Recreation
- Non-Contact Water Recreation
- Commercial & Sport Fishing
- Warm Freshwater Habitat
- Cold Freshwater Habitat
- Wildlife Habitat
- Rare, Threatened or Endangered Species
- Migration of Aquatic Organisms
- Spawning, Reproduction and/or Early Development

Potential Beneficial Uses

- Municipal & Domestic Supply
- Industrial Service Supply
- Industrial Process Supply
- Navigation
- Hydropower Generation
- Shellfish Harvesting
- Aquaculture

The beneficial uses that support the endangered sucker species (i.e., warm freshwater habitat, rare, threatened or endangered species, migration of aquatic organisms, and spawning, reproduction and early development) are the beneficial uses that are most sensitive to water quality in the basin and are chosen as protective surrogates for the other, less sensitive beneficial uses.

4.0 LOST RIVER FISHERIES – LOST RIVER & SHORTNOSE SUCKERS

Lost River sucker *Deltistes luxatus*

(photo by Rollie White, U.S. FWS, at http://endangered.fws.gov/i/e2k.html)

Shortnose sucker *Chasmistes brevirostris*

(photo by Rollie White, U.S. FWS, at http://endangered.fws.gov/i/e2j.html)

4.1 ESA Status of Sucker Species

Lost River and shortnose suckers (abbreviated LRS and SNS, respectively) are classified as endangered species under the federal Endangered Species Act (ESA).[9] The species were proposed for listing on August 26, 1987 and were listed as endangered in 1988.[10] The U.S. Fish and Wildlife (U.S. FWS) demonstrated that both species were endangered due to:

- Present or threatened destruction, modification, or curtailment of habitat or range;
- Overharvesting;
- Disease or predation;
- Inadequacy of the existing regulatory mechanisms to protect the species; and,
- Other factors affecting the continued existence of the species.

Specifically, the decline of both species was blamed primarily on habitat alterations, including lack of spawning habitat, “damming of rivers, instream flow diversion, draining of marshes and

9 16 USC 1532 *et seq.*
10 52 FR 32145, August 26, 1987 and 53 FR 27130, July 18, 1988

other forms of water manipulation."[11] The U. S. FWS (1988) held dams especially responsible in the decline of the Lost River and shortnose sucker populations in the upper Klamath River basin.

> Dams have been particularly destructive in that they have blocked spawning runs of the fish and facilitated hybridization with other types of suckers in the dam's tailwaters. Although the construction of large reservoirs may provide suitable feeding and resting habitat for these lacustrine species, the reservoirs often lack long stretches of large inflowing rivers that are necessary for successful spawning. Such is the case in Clear Lake Reservoir, where small intermittent creeks are the only habitat that remains for spawning attempts.

A recovery plan for the suckers was adopted in 1993 (U.S. FWS 1993). Critical habitat for both species was proposed in 1994 but never adopted by U.S. FWS (1994). As recently as 2002, U.S. FWS denied a petition to de-list both species, citing continuing threats of habitat loss, degradation of water quality, periodic fish die-offs and entrainment of fish into water diversion devices.[12]

4.2 Abundance and Distribution

Early records indicate that the Lost River and shortnose sucker were once abundant in the Lost River and upper Klamath River basins. The fish were a major seasonal food source for native Americans and early settlers. During the annual spring spawning migrations, it is estimated that the Klamath and Modoc Tribes harvested and dried 50 tons of suckers annually at just one site on the Lost River. Settlers canned or salted suckers and processed the fish into oil. There were several commercial sucker canneries on the Lost River. (Powell and Blackwell 2001, U.S. FWS 2001). In Oregon, there was a game fishery for suckers on the Lost River that was terminated in 1987. The role of the now-closed fishery on the current abundance and distribution of suckers is unclear.

Historically, Lost River suckers in California were found in Tule Lake, Lost River, Klamath River, streams tributary to Tule Lake, Lower Klamath Lake, and Sheepy Lake (CDFG 1987a). Shortnose suckers in California were found in Lost River, Lower Klamath Lake, Clear Lake Reservoir, Tule Lake, Sheepy Lake, and Copco Reservoir. The populations of both species in Sheepy Lake and Lower Klamath Lake were lost when the lakes were drained for farming in 1924 (Coots 1965). Both lakes were later re-flooded, but the sucker populations did not recover.

The California Department of Fish and Game (CDFG 1987b) questioned whether SNS are native to the Lost River system, "There is some disagreement in the literature as to whether the SNS is native to the Lost River system (including Tule Lake and Clear Lake Reservoir) or gained entrance via the extensive canal system created by the Bureau of Reclamation." The U.S. FWS (1993), however, believes that shortnose suckers are native to the Lost River.

> It is likely that shortnose suckers also are native to the Lost River system (Scoppottone pers. comm.) and were documented in the Clear Lake watershed in 1955 (Coots 1965). Williams *et al.* (1985) hypothesized that the fish gained access to the Lost River, and subsequently the other areas, by way of irrigation canals associated with the Bureau of Reclamation's Klamath Project. However, their presence in Clear Lake is evidence that they may be native to the Lost River system. Clear Lake Dam was constructed in 1910 and created an impassible barrier for fish migrating upstream in the Lost River. Construction of the Lost River Diversion Channel that connects the Klamath and Lost River systems did not begin until 1911. The Klamath River and

[11] 52 FR 32145
[12] 67 FR 34422, May 14, 2002

Lost River were connected via a natural slough under high water conditions that may have allowed access under natural conditions prior to construction of irrigation canals.

The current distribution of Lost River and shortnose suckers is a fraction of their former distribution. Currently, the Lost River sucker is found in Clear Lake Reservoir, the Lost River, and Boles and Willow Creeks (tributaries to Clear Lake Reservoir) (CDFG 2000 and Moyle 2002). CDFG (2000) stated that "Populations of Lost River suckers in Copco Lake, Iron Gate Reservoir, and other areas of the Klamath River Basin Project in California are small and habitat conditions are poor, resulting in limited reproductive success in these waters." Shortnose suckers have a similar distribution, except that the shortnose sucker is more widely distributed within the Lost River system. A small population of shortnose suckers also is found in Tule Lake (U.S. FWS 1993, CDFG 2000, Moyle 2002).

By 1987, there had been no recruitment to the population of Lost River suckers for the previous 19 years and of shortnose suckers for the previous 18 years. CDFG (1987a, 1987b, 2000) attributed the severe population decline to:

- Habitat modifications caused by dams;
- Water diversions;
- Predation by introduced fish;
- Hybridization with other sucker species; and,
- A lack of spawning success related to
    - A lack of spawning habitat,
    - Spawning habitat blockage,
    - Entrainment of larvae in unscreened water diversions and
    - Decreases in water quality.

The U.S. FWS (1988) came to the same conclusions as CDFG, relating the decline of the Lost River and shortnose suckers, largely, to habitat changes, particularly dams and water diversions. Dams and habitat fragmentation not only reduce access to necessary habitat areas, but they also fragment the population and restrict genetic mixing within populations. The extraordinarily severe alteration in the natural river system of the Lost River resulted in habitat in which there is not sufficient water, and in degraded water quality. "Loss of habitat caused by numerous water diversions, degradation of water quality, increased sedimentation and other man caused changes have caused depletion of the species, and increased the probability of hybridization with other catostomids."[13]

The 11-mile stretch of the Upper Lost River between Clear Lake Reservoir and the Oregon border contains few suckers[14] because of the severe alteration in flow patterns, high gradient and lack of pool habitat (U.S. FWS 2001). The U.S. BOR (1999) conducted electrofishing in the Upper Lost River in July 1999 and no suckers were found.[15] Some suckers have been entrained in releases from Clear Lake Reservoir and, in 1999 and 2000, were captured and returned to the

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13 CDFG 1987

14 Although very few suckers have been found in the Lost River between Clear Lake dam and the Oregon border, the suckers that are found are primarily shortnose suckers (U.S. FWS 2001).

15 The U.S. BOR found brown bullhead, largemouth bass, Sacramento perch, blue chub, pumpkinseed sunfish, green sunfish, and fathead minnows.

reservoir by U.S. BOR after the stretch was dewatered following the irrigation season (Peck 2000 and 2001). Peck (2001) remarked that "sampling within the Lost River between Clear Lake Dam and Malone Reservoir indicates that there are only small, fragmented populations of suckers residing in this area." In Malone Reservoir, at the Oregon border, the U.S. BOR (1992) found two female shortnose suckers during fish population monitoring in July 1992 (no water was being released from Clear Lake Reservoir during the day of the sampling because of severe drought).

Releases from the Clear Lake Reservoir dam govern flow in this 11-mile stretch of the Upper Lost River between Clear Lake Reservoir and the Oregon. The releases are timed for agricultural irrigation on Oregon farms. Water normally is released from Clear Lake Reservoir between April 15 and September 30 of each year, with high flows during the summer and almost no flow in the winter – the opposite of the natural hydrograph. The winter flow in this reach comes primarily from springs and Rock Creek. The low flow confines any suckers in this reach of the Upper Lost River to shallow pools, which leads to predation, lack of food and poor water quality (U.S. FWS 2001).

The sucker populations in the Clear Lake Reservoir watershed are healthier and more robust than the populations elsewhere in the Klamath River, Lost River and Tule Lake system. The shortnose sucker population in Clear Lake Reservoir, in particular, shows consistent recruitment and diverse age structure (U.S. FWS 1993). The shortnose sucker population in Clear Lake Reservoir is unique because of its isolation from shortnose suckers elsewhere in the Klamath Basin, "A large, viable population of shortnose suckers exists in Clear Lake and its tributaries in Modoc County. The Clear Lake population is reproductively isolated and is different from shortnose suckers elsewhere in the Klamath Basin."[16]

4.3 Lost River and Shortnose Suckers Natural History

4.31. Taxonomy & Description

The U.S. Forest Service (USDA Forest Service 1996), Powell and Blackwell (2001), U.S. FWS (2001), and Moyle (2002) describe the basic biology and ecology of the Lost River and shortnose suckers. The Lost River sucker (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*) are known as lake suckers because they are adapted for life in shallow lakes – unlike other sucker species that are riverine. The Lost River sucker is an obligate lacustrine fish (meaning that they live in lakes), although they spawn in streams. The shortnose sucker is slightly more flexible regarding habitat and is a facultative lacustrine/riverine species (meaning that they can live in lakes or rivers), however, like Lost River suckers they spawn in streams. Shortnose suckers may be present at all lifestages in riverine habitats, although the extent of the stream-resident strategy in the Lost River and Klamath basins is not known but thought to be small.[17]

[16] CDFG 2000

[17] In 1992, when spawning migrations to Willow Creek were blocked by low flows, juvenile suckers were, nonetheless, found moving downstream to Clear Lake Reservoir. "…indicating that adult suckers had held over from previous years and successfully spawned in the system above the lake. We do not know how many years these fish may hold over in deep water refugia, or if indeed these fish have developed a resident status within the watershed." (USDA Forest Service 1996).

Lost River and shortnose suckers are long-lived – from 30 to 40+ years (U.S. FWS 2001). Sexual maturity for Lost River suckers occurs between six to 14 years. Shortnose suckers mature between five to eight years of age (U.S. FWS 1993, CDFG 2000, Moyle 2002). Suckers in Clear Lake Reservoir may mature earlier and grow slower than other populations, perhaps due to the low productivity of the water in the reservoir (U.S FWS 2001). Both species can reproduce many times although they do not spawn every year. Females produce large numbers of eggs. Braunworth et al. (2002) describe this life strategy as an evolutionary advantage in a harsh environment because it reduces the impact of extreme conditions on reproductive success: "…an individual's progeny production is spread over many years, increasing the likelihood of spawning when environmental conditions are favorable for progeny survival." However, the strategy can be flawed if there is high adult mortality such as fish kills in other parts of the species' range: "This life history strategy relies upon low adult mortality and longevity to persist through extended periods of poor recruitment. Recurrent events, such as fish kills, that increase adult mortality disrupt this life history strategy and may jeopardize long-term population viability."[18]

Adult Lost River and shortnose suckers have a high degree of morphologic variation. In general, though, Lost River suckers have a long, narrow head with a subterminal mouth, a long, rounded snout, dark coloring on the back and sides, and a white to yellow coloring on the belly. Shortnose suckers tend to be heavy-bodied with a nearly cylindrical shape, a large head, blunt snout and terminal mouth. The shortnose sucker shows a dark color above and a cream or white color below. The Lost River sucker is one of the largest sucker species, and adults may get up to one meter in length and 4.5 kg in weight (females are slightly larger than males). Adult shortnose suckers are smaller, usually less than 50 cm long.

4.3.2 Habitat Preferences

The optimal sucker habitat of the Lost River and shortnose suckers may be exemplified by the ecological conditions that existed before the extensive hydrologic changes imposed in the early 1900s:[19]

> Their optimum habitat is defined by conditions that existed in the large lakes prior to their degradation. The lakes were shallow (<12 m) but fairly clear (Secchi depths typically > 1 m), cool (summer temperatures 16-24ºC), and moderately alkaline (pH 7.2-9.2) (9, 11). The water was well mixed by summer winds, and so was oxygenated from top to bottom (6-10 mg/liter). These conditions allowed the growth of large beds of submerged aquatic plants and extensive marshes along the edges (9), providing plenty of invertebrate food for adults and dense coverage for larvae and juveniles. Today Clear Lake (a natural lake converted to a reservoir by a dam) comes closest to meeting these conditions, although it is highly turbid and does not support large beds of aquatic plants. Suckers are found throughout the reservoir, mainly at depths of less than 1.5 m (10, 11).

In Clear Lake Reservoir, adult Lost River suckers live in the deeper depths of the lakes in the winter and are more widespread in the lake in the summer (Moyle 2002). Powell and Blackwell (2001) cited a personal communication from Mark Buettner, U.S. BOR biologist:

> Suckers apparently avoid clear water except when showing ill effects of poor water quality (M. Buettner, USBR, pers. com.). These observations suggest that suckers are strongly associated with cover, primarily depth and turbidity.

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[18] Perkins et al. 2000
[19] Moyle 2002

Sucker species are oriented toward cover – depth, turbidity, and, in the case of juveniles and larvae, emergent vegetation; however, the use of Clear Lake Reservoir habitat is not well understood:[20]

> Habitat use by suckers in the reservoir is poorly understood; however, Buettner and Scoppettone (1991) noted that suckers were most plentiful in the northeast section of the lake and were sparse elsewhere. Mammoth Springs on the southeast side of Clear Lake has been identified as a possible sucker spawning site but this is unconfirmed (Koch and Contreras 1973).

Shallow lakes, such as Clear Lake Reservoir, may present a problem to the sucker population in winter due to reduced dissolved oxygen under the ice cover. Crowding the reservoir's fish into a smaller volume of water in the deeper sections of the reservoir under ice may result in localized oxygen depletion. In the biological opinion regarding the proposed operating conditions of the Klamath Project, the U.S. FWS (2001) found that the proposed operation of Clear Lake Reservoir will pose a threat to the endangered suckers in Clear Lake Reservoir due to low dissolved oxygen under ice cover as a result of low lake levels. They concluded that the proposed operations plan would:

> Reduce water volume/surface ratios during winter ice-cover conditions that influence dissolved oxygen concentrations and un-ionized ammonia will contribute to potentially lethal water quality conditions that are likely to reduce adult and juvenile sucker survival.

The dam at Clear Lake Reservoir was replaced in 2002. The old dam had not been filled to capacity because of safety concerns related to the structure of the dam. Although the height of the new dam was not changed from the height of the old, the U.S. BOR will be able to increase the storage volume because the safety of the dam would be more assured. The increased storage in the reservoir impounded by the new dam could be significant compared to the storage impoundment of the old dam. It is not clear, however, if the increased storage volume would translate into significantly deeper lake levels thus reducing the possibility of low winter dissolved oxygen in the lake.

4.3.3 Habitat Utilization in the Clear Lake Reservoir Watershed

The use of habitat in the Clear Lake Reservoir watershed by Lost River and shortnose suckers is shown in the table below. Adult suckers live in the deeper areas of the reservoir in the winter and are more widespread in the reservoir in the summer. Spawning occurs primarily in Willow Creek and its tributaries. Larval suckers migrate from their natal streams to the reservoir shortly after hatching. Larval and juvenile suckers congregate in the shallow nearshore areas of the reservoir and become more bottom-oriented as adults.

The 11-mile stretch of the Upper Lost River between the Clear Lake Reservoir dam and the Oregon border to the north does not currently support a population of Lost River or shortnose suckers. Any Lost River or shortnose suckers in the Lost River between Clear Lake Reservoir and Malone Reservoir (at the Oregon border) are assumed to have become entrained in the water from the Clear Lake Reservoir dam, as there are no fish passage facilities at either reservoir for upstream migration. There does not appear to be a sustainable population of these species in that stretch of river since the Clear Lake Reservoir dam blocks access of downstream fish to the spawning tributaries and to the preferred lake habitat. The Upper Lost River between Clear Lake Reservoir and Malone Reservoir is almost dewatered in the winter and the remaining pools do not provide sufficient habitat for the suckers:[21]

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20 U.S. FWS 2001
21 U.S. FWS 2001

> The Clear Lake Dam blocks all upstream sucker movement from the Lost River into Clear Lake. Following the irrigation season, flow to the Lost River is cut off, leaving only a small amount of leakage. Fish, including endangered suckers, seek refuge in shallow pools that remain. During salvage operations near the dam in September 1999 and 2000, a few LRS and SNS were collected. Large numbers of aquatic insects, snails, and unionid mussels were found freshly dead. DO in the pools was low owing to relatively high concentrations of aquatic organisms that moved into the pools and from those dying around the pool perimeters. The survival of suckers and other fish in these pool (sic) through the winter is questionable owing to oxygen depletion and increased predation. The dewatered reach of the upper Lost River below Clear Lake Dam may be as much as 8 miles long.

Life Stage Periodicity of Shortnose and Lost River Suckers in the Clear Lake Reservoir Watershed

Species & Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LRS(A)	lake	lake stream	stream	stream lake	lake							
LRS(L)			stream	stream lake	stream lake	stream lake	lake					
LRS(J)						lake						
SNS(A)*	lake	lake stream	stream	stream lake	lake							
SNS(L)			stream	stream lake	stream lake	stream lake	lake					
SNS(J)						lake						

SNS = Shortnose Sucker; LRS = Lost River Sucker; A = Adult; J = Juvenile; L = Larvae
lake = Clear Lake Reservoir; stream = spawning streams that are tributary to Clear Lake Reservoir
* Some adult shortnose suckers may be resident in streams.

<u>4.3.4 Spawning and Egg Incubation</u>

Lost River and shortnose suckers live in lakes and migrate to streams tributary to lakes for spawning, although in some years low water flows from the spawning streams can impede access to spawning habitat.[22] Some suckers may use lakeshore areas with spring inflows for spawning areas (CDFG 1987a, 1987b, Buettner 1997, Perkins and Scoppettone 1996, Moyle 2002). It is not known if spawners show natal-fidelity, returning to the same stream from which they were spawned (Braunworth et al. 2002). The Lost River suckers and shortnose suckers in Clear Lake Reservoir use Willow Creek and its tributaries[23] for spawning. Sucker larvae were found as far upstream as the point at which North Fork Willow Creek crosses the California/Oregon border, and in the headwaters of Fletcher Creek (about 8 miles upstream of Avanzino Reservoir) (U.S. FWS 2001).

Spawning migrants leave Clear Lake Reservoir between February and April. Perkins and Scoppettone (1996) observed that Lost River sucker spawning lasted for up to seven weeks. The

22 An example of low flow impeding spawning access is provided by USDA Forest Service (1996): "During 1992, streamflows into Clear Lake were so low as to preclude upstream spawning runs by lake resident fish. Willow Creek flows into Clear Lake over a large gravel bar, through a braided channel. Incoming flows simply were braided throughout this channel and not sufficient to support fish access into Willow Creek."

23 Willow Creek, Boles Creek, North Fork Willow Creek, East Fork Willow Creek, Wildhorse Creek and Fourmile Creek.

timing of the spawning migration may be related to water temperatures or to flow. Adults that spawn begin migrating to the spawning streams when water temperatures reach 10°C (CDFG 1987a). Perkins and Scoppottone (1996) used radio-telemetry to track Lost River and shortnose suckers during spawning runs in 1993 through 1995. They noted that the water temperature was 4-8°C when the Lost River sucker migrations began and 12°C when the Lost River sucker spawning migrations ended. They reported that shortnose suckers began spawning when temperatures reached 7-10°C and continued to spawn when water temperatures were above 20°C. Water temperature, however, may not be the primary trigger. Rising flows, which may trigger spawning, are often associated with a rise in water temperature (Moyle 2002). Moyle (2002) cites accounts showing that Lost River sucker spawning migrations have been observed while Clear Lake Reservoir was still iced and in-flowing temperatures were in the 4-7ºC range. Moyle (2002) observes that shortnose suckers also respond to increased flow as a signal for spawning migration and that temperatures during these spawning runs have ranged from 5.5 to 19°C. Timing the spawning migration with high spring-time flows may ensure that there is sufficient water to provide passage for the large adult suckers.

Larger males generally reach spawning areas one to two weeks before smaller males and females. Lost River suckers require deep water for spawning, due to the large size of spawning adults. The preferred spawning habitat for both sucker species (CDFG 1987a, U.S. FWS 2001) includes:

- Water depth of sufficient depth for the large size of adult suckers
- Clear water with moderately fast flows
- Gravel, rubble or large rock substrate
- Stream riffles with 50-100% gravel

The specific spawning habitat preferences of Lost River suckers are riffles with 66-88% of the gravel at least 1.25 cm in diameter, stream depth of 21-128 cm and stream velocity of 1-84 cm/s (U.S. FWS 2001, Moyle 2002). Shortnose suckers are similar and select spawning areas that provide large gravel to cobble, depths of 11-130 cm, and flows that are slightly higher than that preferred by Lost River suckers (18-125 cm/s) (U.S. FWS 2001, Moyle 2002).

Perkins and Scoppottone (1996) radio-tagged spawning suckers in Clear Lake Reservoir and observed that Lost River suckers migrated 3.7 to 5.5 km upstream and stayed in the streams for up to 16.4 days. Shortnose suckers tagged by Perkins and Scoppottone were found 4.4 to 46.7 km upstream and stayed in the streams for up to 43.9 days. They concluded that shortnose suckers have more habitat available for spawning because they migrate further upstream to spawn. Their observations about the Lost River and shortnose sucker spawning sites studied showed similar characteristics as discussed above. They noted that one spawning site in Willow Creek was located at a natural spring inflow.

Female suckers will spawn with several males. Eggs and sperm are released simultaneously by a female and one or more males. When gravel is present, fertilized eggs settle in gravel interstices where eggs incubate. When gravel is not present, eggs may settle in streambed crevices or may be swept downstream (U.S. FWS 1993). Suckers are highly fecund – female suckers can produce from 70,000 to more than 200,000 eggs in a spawning season. The large number of eggs does not translate to high recruitment to the population because larval and juvenile mortality is extremely high (Braunworth et al. 2002).

Adult suckers remain in the spawning grounds for two to three weeks (Moyle 2002). After spawning, the adults return to the lake (Buettner 1997).

4.3.5 Rearing

The length of time needed for embryo development is dependent on water temperature and may require several weeks. Perkins and Scoppottone (1996) cite a personal communication from Larry Dunsmoor, biologist for the Klamath Tribes, stating that Lost River suckers incubated at 14.4°C and require an average of 136 thermal units[24] to hatch, whereas shortnose suckers incubated at 15.3°C require 89 thermal units to hatch. After hatch, the larvae move downstream to the lake. Perkins and Scoppottone (1996) noted that Lost River sucker larval out-migration began between the end of March and mid-April and lasted for up to 50 days. Lost River suckers require an average of 278.4 thermal units to swim-up[25] while shortnose suckers require an average of 249.8 thermal units to swim-up (Dunsmoor, cited by Perkins and Scoppottone 1996). Moyle (2002) says that the larvae move mostly at night over a six-week period from late-March through early June (Moyle 2002).

Once in Clear Lake Reservoir the larvae inhabit shallow, nearshore areas, although larval sucker ecology in the reservoir is not well studied. In most sucker populations, larval suckers rely on nearshore, emergent vegetation for cover, but such vegetation is scarce in Clear Lake Reservoir. Instead, it is believed that the high turbidity and the shallow lake edges of Clear Lake Reservoir provide cover for larvae (Powell and Blackwell 2001, U.S. FWS 2001). The larval stage lasts about 40 to 50 days (Braunworth et al. 2002).

In lakes, larvae and juvenile suckers congregate in emergent vegetation along the nearshore lake edges in areas of high water quality (Powell and Blackwell 2001, Moyle 2002). Reducing connectivity between lakes and nearshore wetlands reduces the larval and juvenile rearing habitat. As the juveniles grow, they become oriented to the bottom. Moyle (2002) believes that the juveniles are subject to greater predation if cover provided by marshes and nearshore vegetation is lost. Growth rates of juveniles have been correlated with water temperature; shortnose suckers have slower growth rates than Lost River suckers (U.S. FWS 2001).

4.3.6 Food

Lost River adult and juvenile suckers are bottom feeders, feeding on invertebrates, detritus and some zooplankton. The unique morphology of the Lost River suckers, with an inferior mouth on the bottom of the head, especially suits them for bottom grazing (Buettner 1997, Moyle 2002). Sigler and Sigler (1987) describe this feeding as vacuuming food particles along with great quantities of substrate from the bottom of a lake.

Shortnose suckers feed in the water column on zooplankton in lakes (Buettner 1997, Moyle 2002). The feeding habits of shortnose suckers that reside in riverine habitats are not known, but the U.S. FWS (2001) states that: "… it seems unlikely that zooplankton is sufficiently abundant in riverine situations to support SNS."

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24 Perkins and Scoppottone define a thermal unit as water temperature times the number of days.

25 Swim-up is the term given to fry that have finished absorbing their yolk sac and are ready to start feeding.

4.4 Water Quality Requirements

Lost River and shortnose suckers can tolerate extreme water quality conditions. Research suggests that the suckers can tolerate low dissolved oxygen, elevated pH, and high water temperature. The ability to tolerate poor water quality for extended periods of time, during sensitive life stages, and in combination of more than one adverse water quality stressor, however, is uncertain. Some of what is known about sucker tolerance of poor water quality is based on observational reports associating water quality parameters at a particular site with the presence or absence of fish. Much of what is known is based on laboratory tests relating water quality parameter to endpoints such as mortality, or physiological or behavioral changes. Commonly these studies measure a response based on acute time periods (i.e., short-term periods, such as 24- or 96-hours) or chronic (i.e., longer-term periods, such as 14 to 30 days) exposures. There are limitations in applying the results of these tests to conditions that exist in the natural environment. The U.S. FWS (2001) advises that results from laboratory water quality studies should be applied cautiously to the natural environment:

> Such experiments may under- or over-estimate mortality that might occur in situ, and they tell us almost nothing about sublethal effects. We would, however, emphasize that laboratory-measured LC-50 values are perhaps best viewed as red flags that should alert us to potential problems. Such studies, even done under the most exacting conditions cannot, nor are they meant to, mimic real-life conditions where there are complex spatial and temporal variations in water quality parameters as well as even more complex behavioral, predator/ prey, parasitic and pathogenic, and competitive interactions. In situ studies like that of Martin (1997) done over short time periods where multiple parameters are measured simultaneously, are perhaps the best available way to examine the relationship between water quality and mortality; however, such experiments still fail to capture the long-term effects or the myriad ecological factors involved. We posit that laboratory and in situ studies provide ample reason to be concerned about the threat water quality poses to LRS and SNS and on the ecosystem on which they depend.

Castleberry and Cech (1990, 1993) studied temperature and oxygen requirements of adult shortnose suckers. They measured the critical thermal maxima and critical dissolved oxygen minima for shortnose suckers. Similarly, Falter and Cech (1991) measured the maximum pH tolerance of shortnose suckers.[26] The tolerance limits for temperature, dissolved oxygen, and pH are shown in the table below.

[26] The critical thermal maximum is defined as the high water temperature at which the fish permanently lose equilibrium. The critical dissolved oxygen minimum is the low dissolved oxygen concentration temperature at which the fish permanently lose equilibrium. The maximum pH tolerance is defined as the pH at which the fish showed sustained loss of equilibrium. The critical values are determined by gradually increasing or decreasing a parameter after acclimation to a specific value.

Critical Parameters for Shortnose Suckers		
Parameter	**Mean**	**Range**
Critical Thermal Maxima (ºC)	32.7 ± 0.1	32.1 – 33.3
Critical Oxygen Minima (mm Hg)*	11.8 + 1.0	7.5 – 16.7
Critical Oxygen Minima (mg/l, estimated from torr*)	0.63	0.40-0.89
Critical pH Maxima	9.55 ± 0.43	

NOTE: The critical thermal maximum is the high water temperature at which the fish permanently lose equilibrium. The critical dissolved oxygen minimum is the low dissolved oxygen concentration temperature at which the fish permanently lose equilibrium. The maximum pH tolerance is the pH at which the fish showed sustained loss of equilibrium.

* It is more common to express the water oxygen level in terms of mg O_2/l rather than the partial pressure of O_2 on the water surface. For the purposes of this discussion, the critical oxygen maxima of 11.8 mmHg was calculated to be 0.63 mg O_2/l and the range 0.40-0.89 mg O_2/l, assuming that the water temperature is 25°C and the pressure is one atmosphere.

From: Castleberry and Cech (1990, 1993) and Falter and Cech (1991)

Critical thermal maxima may overstate the upper tolerance limit by two to six degrees Celsius (Castleberry and Cech 1993). Bellerud and Saiki (1995) agree that critical maxima are useful for comparing relative tolerance of different lifestages or species but they say that critical maxima may overestimate the lethal level because "most organisms do not immediately lose equilibrium or die when exposed to environmental conditions that can eventually cause death." The critical parameter tolerances indicate that shortnose suckers may be adapted to tolerate high water temperatures, but Castleberry and Cech (1993) argue that the sucker population, nonetheless, may suffer from high temperatures because of the different susceptibilities of different life stages:

> This does not mean that high temperatures are not affecting the viability of fish populations in the Upper Klamath basin. Earlier life history (egg to juvenile) stages of fish may be more vulnerable to high temperatures, and the ability to reproduce may be more sensitive to environmental stress than any other aspect of a fishes' life history.

Bellerud and Saiki (1995) reported on lethal levels of water temperature, ammonia, pH, and dissolved oxygen to juvenile and larval Lost River and shortnose suckers in acute 96-hour LC_{50} tests.[27] They were attempting to establish whether ambient levels of these parameters in Upper Klamath Lake could result in sucker mortality. There was some mortality due to the shock of being transferred from the acclimation conditions to test conditions at near lethal levels. "Except for tests with ammonia, mortalities in the most stressful treatments occurred shortly after a given test was initiated. If fish survived the first hour of testing, they usually were still alive when the test was terminated. Tests with ammonia were exceptional because mortalities occurred continuously during the 96-hr testing period." The authors suggest that additional research is needed to evaluate whether the excess mortality due to handling and nutrition caused the 96-hour LC_{50}s to underestimate the actual tolerance limits.

The test results are shown in the table below. In pH tests, juvenile suckers were more sensitive than larval suckers, with juvenile SNS being the most sensitive. The "tolerance of larval and

[27] The median lethal concentration is reported as the LC_{50}, the concentration that resulted in the death of 50% of the test population.

juvenile Lost River and shortnose suckers to high pH and high un-ionized ammonia concentrations did not exhibit consistent patterns.” The results for ammonia are ambiguous because the 95% confidence intervals of SNS larvae replicate tests #1 and #2 do not overlap. Although not statistically significant, the authors concluded that the larvae of both sucker species were slightly more tolerant than juveniles to high water temperature, but the juveniles were more tolerant than larvae to low DO. The results for dissolved oxygen and SNS larvae are ambiguous because the 95% confidence intervals of two replicate tests do not overlap.

Mean Lethal Concentrations for pH, Ammonia, Temperature, and Dissolved Oxygen to Lost River and Shortnose Suckers

Water Quality Variable*	Species & Life Stage	96-Hour Mean Lethal Concentration (LC_{50})	95% Confidence Interval
pH	LRS larva	10.45	10.43-10.48
	LRS juvenile	9.92	9.87-9.96
	SNS larva test#1	10.33	10.01-10.66
	SNS larva test #2	10.46	10.12-10.83
	SNS juvenile	9.85	9.76-9.95
NH3 mg/l	LRS larva	not conducted because of limited number of specimens	
	LRS juvenile	0.750	0.599-0.944
	SNS larva test#1	0.750	0.730-0.770
	SNS larva test#2	1.40	1.24-1.68
	SNS juvenile	0.956	0.32-2.46
Temp °C	LRS larva	not conducted because of limited number of specimens	
	LRS juvenile	31.2	30.8-31.5
	SNS larva test#1	31.9	31.9-32.0
	SNS larva test#2	31.9	29.0-33.5
	SNS juvenile	31.2	30.8-31.6
DO mg/l or % saturation	LRS larva	2.1	2.0-2.2
	equal to:	25.8% sat.	24.9-26.8%
	LRS juvenile	1.4	1.0-2.0
	equal to:	19.1% sat.	13.9-26.2%
	SNS larva test #1	2.3	2.2-2.4
	equal to:	30.3% sat.	28.9-31.6%
	SNS larva test #2	1.7	1.6-1.8
	equal to:	22.3% sat.	21.0-23.6%
	SNS juvenile	1.2	0.7-1.7
	equal to:	14.7% sat.	7.6-22.5%

From Bellerud and Saiki (1995)

*   Except when the parameter being tested was varied, the experimental design called for water quality parameters to be maintained at: water temperature 20°C; pH 8.0; dissolved oxygen 100% saturation; and un-ionized ammonia <0.05 mg/l.

In 1999, Saiki et al. conducted similar tests on lethal levels of water quality parameters to juvenile and larval Lost River and shortnose suckers in acute tests. LC_{50}s were reported for 24-, 48-, 72-, and 96-hour test intervals. The mean lethal level of pH to the juvenile and larval suckers varied from 10.30 (at 96-hours in the LRS juvenile) to 10.69 (at 24-hours in the SNS juvenile). The short-term effects of high pH was described as follows:

> When exposed to the highest pH treatments, larvae and juveniles of both species experienced convulsions, erratic swimming, and excessive production of a mucus-like material. Some dead and

dying fish also exhibited hemorrhaging from the gill area and eyes, and several had eyes that were seemingly ruptured.

The LC_{50} of un-ionized ammonia varied from 0.48 mg/l (at 48-hours in SNS juveniles and 96-hours in LRS larvae) to 1.29 mg/l (at 24-hours in SNS larvae). Dying fish in the un-ionized ammonia tests bled from the gills at the higher concentrations, and some juveniles showed hyperactivity. Mean lethal water temperature ranged from 30.35°C (at 48-, 72- and 96-hours in SNS juvenile) to 31.93°C (at 24-hours in LRS larvae), however, the authors detected no statistical difference in the response of the species or life stages to high water temperature. The mean lethal concentrations for dissolved oxygen ranged from 1.14 mg/l (at 24-hours in SNS juveniles) to 2.10 mg/l (at 48-, 72-, and 96-hours in LRS larvae). There was little difference between the sensitivities of juvenile vs. larval suckers except that larvae of both species were more sensitive to low dissolved oxygen than the juveniles. The following table summarizes the results for both species of juvenile and larval suckers at 24-, 48-, 72-, and 96-hours.

Median Lethal Concentrations for pH, Ammonia, Temperature, and Dissolved Oxygen to Lost River and Shortnose Suckers					
Water Quality Variable*	**Species & Life Stage**	**Mean Lethal Concentration (LC_{50}) with the 95% Confidence Interval Shown in Parentheses**			
		24-Hours	**48-Hours**	**72-Hours**	**96-Hours**
pH	LRS larva	10.42 (10.38-10.47)	10.39 (10.32-10.46)	10.36 (10.27-10.46)	10.35 (10.26-10.45)
	LRS juvenile	10.66 (10.59-10.74)	10.62 (10.54-10.71)	10.39 (10.12-10.67)	10.30 (9.94-10.67)
	SNS larva	10.38 (10.31-10.46)	10.38 (10.31-10.46)	10.38 (10.31-10.46)	10.38 (10.31-10.46)
	SNS juvenile	10.69 (10.61-10.77)	10.66 (10.61-10.72)	10.58 (10.56-10.61)	10.39 (10.22-10.56)
NH3 mg/l	LRS larva	0.56 (0.52-0.61)	0.51 (0.47-0.55)	0.49 (0.45-0.54)	0.48 (0.44-0.52)
	LRS juvenile	1.02 (1.01-1.04)	0.92 (0.82-1.04)	0.89 (0.77-1.04)	0.78 (0.70-0.86)
	SNS larva	1.29 (0.83-2.00)	1.24 (0.82-1.88)	1.19 (0.79-1.78)	1.06 (0.73-1.53)
	SNS juvenile	0.51 (0.30-0.87)	0.48 (0.28-0.82)	0.54 (0.35-0.82)	0.53 (0.34-0.82)
Temp °C	LRS larva	31.93 (31.82-32.04)	31.85 (31.69-32.01)	31.77 (31.58-31.96)	31.69 (31.47-31.91)
	LRS juvenile	30.76 (30.04-31.50)	30.76 (30.04-31.50)	30.65 (30.04-31.27)	30.51 (29.99-31.04)
	SNS larva	31.85 (31.75-31.96)	31.85 (31.75-31.96)	31.85 (31.75-31.96)	31.82 (31.75-31.90)
	SNS juvenile	31.07 (29.44-32.80)	30.35 (29.44-31.28)	30.35 (29.44-31.28)	30.35 (29.44-31.28)
DO mg/l	LRS larva	2.01 (1.90-2.13)	2.10 (2.07-2.13)	2.10 (2.07-2.13)	2.10 (2.07-2.13)
	LRS juvenile	1.58 (1.35-1.86)	1.58 (1.35-1.86)	1.62 (1.41-1.86)	1.62 (1.41-1.86)
	SNS larva	1.92 (1.89-1.96)	2.04 (1.90-2.18)	2.09 (1.90-2.29)	2.09 (1.90-2.29)
	SNS juvenile	1.14 (0.84-1.55)	1.34 (1.15-1.55)	1.34 (1.15-1.55)	1.34 (1.15-1.55)

From Saiki et al. (1999)
* Except when the parameter being tested was varied, the experimental design called for water quality parameters to be maintained at: water temperature 20°C; pH 8.0; dissolved oxygen 7.6 mg/l; and un-ionized ammonia <0.01 mg/l.

Saiki et al. (1999) reported on individual water quality parameters and did not test the effect of multiple parameters acting in combination. Also, the Saiki et al. (1999) tests relied on acute rather than chronic exposures. The authors caution that their study design did not allow for a gradual acclimation to the test conditions, which may have allowed an increased tolerance of poor conditions.

Meyer et al. (2000) evaluated the effects of chronic exposure (14- or 30-days) to low dissolved oxygen, high pH, and elevated un-ionized ammonia concentrations on larval and late-juvenile

Lost River suckers.[28] In addition to survival, the researchers evaluated three sublethal toxicity endpoints: decreased growth, loss of body ions, and swimming performance. Their 14-day and 30-day results are shown in the table below, and were consistent with the 96-hour lethal concentrations reported by Saiki et al. (1999). The mortality thresholds reported were:

- Dissolved oxygen 1.44-1.54 mg/l;
- pH greater than 10.0; and,
- Un-ionized ammonia 0.69 mg/l.

Chronic Toxicity of Low Dissolved Oxygen, High pH & Elevated Ammonia Concentrations to Lost River Suckers

Parameter	Lifestage/Comments	Test Duration	Mean % Survival at Specified Concentration
DO	late juvenile provided with access to water surface	14 days	33.3% survival at mean DO concentration of 1.54 mg/l
	late juvenile not provided with access to water surface	14 days	41.7% survival at mean DO concentration of 1.44 mg/l
pH	larvae	30 days	91.8% survival at pH mean of 9.98
NH_3	larvae	30 days	1.4% survival at mean NH3-N concentration of 0.69 mg/l
	larvae	30 days	0% survival at mean NH3-N concentration of 1.16 mg/l
From Meyer et al. (2000) and Meyer & Hansen (2002)			

Meyer et al. (2000) were surprised to observe none of the three anticipated sublethal effects at concentrations that were not lethal:

> Contrary to the common expectation for fish chronically exposed to toxicants, Lost River suckers generally did not display sublethal responses to low DO concentrations, elevated pH, or elevated ammonia concentrations, based on the three traditional chronic-toxicity endpoints we used.

The only sublethal effect noted was a 14% decrease in whole-body sodium content. The authors imply that this is not an adverse effect and provide examples of whole-body sodium content losses in various fish species to place the 14% loss in context – the examples ranged from a 49% loss at death to 71% loss at death. Additional sublethal effects may have been observed if smaller concentration increments or larger sample sizes had been used. Two sublethal effects other than the three traditional endpoints mentioned above were noted:

- Shorter times to exhaustion at critical swimming speed when exposed to pH levels of 10.0, and
- Changes in gill structure, indicating tissue damage that did not noticeably impair fish function, were seen at sublethal ammonia concentrations.

[28] Meyer and Hansen (2002) reported on the same data for a peer-reviewed journal.

Meyer et al. (1999) reported on the toxicity of low dissolved oxygen to juvenile Lost River suckers and arrived at similar dissolved oxygen concentrations:

> Juvenile suckers exposed continuously to low dissolved oxygen concentrations exhibited significantly lower survival and growth at 1.5 ppm DO than did controls exposed to 6.3 ppm DO, whereas survival and growth of suckers exposed to 2.0 ppm DO did not differ significantly from controls.

The U.S. FWS (1993) sucker recovery plan summarizes the known water quality requirements of Lost River and shortnose suckers. The plan describes the pH and dissolved oxygen concentrations in Upper Klamath Lake and relates those levels to the known presence or absence of juvenile suckers. During sampling in 1988, dissolved oxygen in Upper Klamath Lake ranged from 1.3 to 20.0 mg/l but juvenile suckers were found only at sites where dissolved oxygen concentrations ranged from 4.5 to 12.9 mg/l. Juvenile suckers were rarely found at Upper Klamath Lake sites with pH values of 9.0 or higher (U.S. FWS 1993). These observations indicate that, though suckers can withstand poor water quality, they prefer to congregate in areas of high water quality.

Interactions of water quality parameters may lead to suckers being more susceptible to the effects of poor water quality. Some water quality parameters have been shown to have synergistic, additive or, even, antagonistic effects on fish. Long-term exposure to stressful levels of one parameter may make fish more susceptible to the harmful effects of another. Some examples:

- Thurston et al. (1981) discussed the increased toxicity of ammonia to rainbow trout fingerlings at low dissolved oxygen levels. LC_{50}s of aqueous ammonia were tested in rainbow trout at dissolved oxygen levels ranging from 2.6-8.6 mg/l. The researchers found a positive correlation between dissolved oxygen and un-ionized ammonia over the entire range tested. Ammonia toxicity increased as dissolved oxygen decreased. Martin and Saiki (1999) found that a similar relationship appears to exist for suckers.
- Cech et al. (1990) reported that at increased temperatures, rainbow trout were significantly less able to withstand the adverse effects of hypoxia.
- Falter and Cech (1993) note that increasing pH increases ammonia toxicity to fish.
- Martin and Saiki (1999) and Saiki et al. (1999) discussed work indicating that supersaturated dissolved oxygen conditions allow suckers to withstand high pH levels.[29]
- Perkins et al. (2000), in an analysis of a fish kill in Upper Klamath Lake, concluded that hypoxia was the probable cause of the kill, but also mentioned “The susceptibility of fish to hypoxia was probably enhanced by chronic exposure to stressful levels of pH, ammonia, and DO during summer months prior to and during initiation of the kills.”

Martin and Saiki (1999) performed regression analyses on the mortalities of juvenile Lost River suckers relative to water quality parameters. They reported that dissolved oxygen concentration <u>alone</u> had the largest impact on juvenile mortality. Martin and Saiki (1999) found that the mortality of caged juvenile Lost River suckers “exhibited little or no relationship with maximum temperature, maximum pH, and maximum un-ionized ammonia concentration…” The highest mortality of the caged Lost River suckers occurred when dissolved oxygen concentrations dropped to 1.05 mg/l or less. The relative importance of water quality parameters, singly and in

[29] Martin and Saiki (1990) explained that high pH levels reduce the ability of fish to transpire oxygen and that supersaturated oxygen levels can offset this effect.

combination, using stepwise logistic regression was rated. In order of the greatest impact to least impact on mortality the ranking is:

1. Minimum dissolved oxygen;
2. The combination of low dissolved oxygen and high pH;
3. The combination of low dissolved oxygen, high pH, and high un-ionized ammonia;
4. The combination of low dissolved oxygen and high un-ionized ammonia;
5. Maximum pH;
6. The combination of high pH and high un-ionized ammonia;
7. The combination of low dissolved oxygen, high pH, high un-ionized ammonia, and high water temperature;
8. Maximum water temperature;
9. The combination of high un-ionized ammonia and high water temperature; and,
10. Maximum un-ionized ammonia.

Martin and Saiki's work (1999) shows the importance of the interactions of water quality parameters to Lost River suckers.

The following table summarizes the temperature, dissolved oxygen, pH and ammonia tolerances of Lost River and shortnose suckers.

Water Quality Tolerances of Lost River and Shortnose Suckers					
Species/ Lifestage	**Parameter and Monitored Endpoint**				**Reference**
	Temperature	**Dissolved Oxygen**	**pH**	**N as Un-Ionized Ammonia**	
SNS(A)			9.55±0.43 critical maxima – loss of equilibrium		Falter and Cech 1991
SNS(A)	32.1-33.3°C critical maxima loss of equilibrium	0.40 –0.89 mg/l * critical minima – loss of equilibrium			Castleberry and Cech 1993
SNS(J)	31.2°C mean lethal	1.2 mg/l or 14.7% sat. mean lethal	9.85 mean lethal	0.95 mg/l mean lethal	Bellerud and Saiki 1995
SNS(J)	30.35°C mean lethal	1.34 mg/l mean lethal	10.39 mean lethal	0.48 mg/l mean lethal	Saiki et al. 1999
LRS(J)	31.2°C mean lethal	1.4 mg/l or 19.1% sat. mean lethal	9.92 mean lethal	0.75 mg/l mean lethal	Bellerud and Saiki 1995
LRS(J)	30.51°C mean lethal	1.62 mg/l mean lethal	10.30 mean lethal	0.78 mg/l mean lethal	Saiki et al. 1999
LRS(J)		1.05 mg/l highest mortality			Martin & Saiki 1999
LRS(J)		1.5 ppm mortality			Meyer et al. 1999
LRS(J)		1.44 mg/l mortality			Meyer et al. 2000 Meyer & Hansen 2002
SNS(L)	31.9°C mean lethal	2.3 mg/l or 30.3% sat. mean lethal	10.33 mean lethal	0.75 mg/l mean lethal	Bellerud and Saiki 1995
SNS(L)	31.9°C mean lethal	1.7 mg/l or 22.3% sat. mean lethal	10.46 mean lethal	1.40 mg/l mean lethal	Bellerud and Saiki 1995
SNS(L)	31.82°C mean lethal	2.09 mg/l mean lethal	10.38 mean lethal	1.06 mg/l mean lethal	Saiki et al. 1999
LRS(L)		2.1 mg/l or 25.8% sat. mean lethal	10.45 mean lethal		Bellerud and Saiki 1995
LRS(L)	31.69°C mean lethal	2.10 mg/l mean lethal	10.35 mean lethal	0.48 mg/l mean lethal	Saiki et al. 1999
LRS(L)			>10.0 mortality	0.69 mg/l mortality	Meyer et al. 2000 Meyer & Hansen 2002

SNS = Shortnose Sucker; LRS = Lost River Sucker; A = Adult; J = Juvenile; L = Larvae

* These data are reported by the authors as mmHg partial pressure. For the purposes of this discussion, the critical oxygen maxima range was calculated to be 0.40-0.89 mg O_2/l, assuming that the water temperature is 25°C and the pressure is one atmosphere.

Lost River and shortnose suckers can survive adverse water quality conditions, but their evolutionary adaptation may not allow them to thrive at long-term, continual poor conditions. Moyle (2002) stated:

> To a certain extent they can withstand adverse conditions; they can tolerate temperatures up to 31-33°C, oxygen levels near 1-2 mg/liter, and pH levels of around 10 (2,7,8,16), but it is clear they prefer more moderate conditions. Presumably a tolerance for adverse conditions allowed them to survive through natural periods of drought, when lake levels were low. However, it has not allowed them to adjust to the extreme conditions that exist more or less continuously at present.

4.5 Summary of the Requirements of Lost River and Shortnose Suckers

4.5.1 Factors Affecting Persistence & Abundance

The factors affecting the persistence and abundance of Lost River and shortnose suckers are among the litany cited by the U.S. FWS (1987, 1988 and 1993):

- Habitat fragmentation;
- Dams, draining of marshes, instream flow diversion and other forms of water manipulation;
- Loss of access to spawning habitat; and,
- Decreases in water quality associated with timber harvest, removal of riparian vegetation, livestock grazing, and agriculture practices.

It is clear that the watershed and stream alterations in the Clear Lake Reservoir/Upper Lost River basin have affected sucker habitat quantity and quality.

4.5.2 Water Quality Requirements

Suckers can tolerate low dissolved oxygen, high water temperature and elevated pH levels, but fish may not thrive at long-term, continual poor conditions and that different lifestages may be more sensitive. Long-term exposure to non-lethal, but stressful, levels of one water quality parameter may make fish more susceptible to the harmful effects of another. As additional research becomes available, the impact of the water quality in the Upper Lost River/Clear Lake Reservoir area should be re-evaluated.

In summary, the following water quality levels have been reported for the sensitive life stages of Lost River and shortnose suckers:

- DO > 2.3 mg/l (based on LC_{50} in SNS larvae);
- pH < 9.5 (based on critical maxima in SNS adult);
- Water temperature < 30.3ºC (based on LC_{50} in SNS juvenile);
- Un-ionized ammonia < 0.48 mg/l (based on LC_{50} in LRS larvae and SNS juvenile).

When comparing these levels to numeric water quality objectives, identifying target conditions, or comparing to watershed conditions, it is important to consider that these levels are based on mortality thresholds, and, in the case of the LC_{50}s, these levels resulted in the death of 50% of the test population. Target conditions should be set based on chronic criteria that protect all life stages and not on acute survival criteria. As discussed above, while suckers can withstand extremely poor water quality conditions, such conditions do not fully support the population or the biosystem upon which the suckers depend.

Caution should be exercised when using the values cited above to derive thresholds for several reasons. There have been few repeated tests using the same species under the same conditions so test-to-test variability is uncertain. Toxic response to some parameters did not show consistent patterns between tests. Different researchers used different age test species and test animals with nutritional deficiencies (see discussion in Bellerud and Saiki 1995). Additionally, most of the tests were based on varying a single water quality parameter in water that is otherwise optimal. In the Upper Lost River/Clear Lake Reservoir environment, suckers can be exposed to more than one stressor at a time, which may result in reduced ability to withstand physiological insults of all types.

5.0 LOST RIVER FISHERIES – REDBAND TROUT

Redband Trout *Oncorhynchus mykiss spp.*

(photo from California Department of Fish and Game at www.dfg.ca.gov/fishing/html/ WildTrout/trout/redband.htm)

NOTE: As discussed in detail below, it is unclear if there is a population of redband trout in the Clear Lake Reservoir drainage. Most of the information presented in this document about the life history, habitat preferences, and water quality requirements is taken from known populations of redband trout or rainbow trout in other basins. Redband trout may be resident in the Lost River in Oregon, but it is uncertain if they are present in the Upper Lost River between Clear Lake Reservoir and Malone dam because of the severe alteration in natural flow patterns in that reach.

5.1 ESA Status of Redband Trout

Redband trout in California are not protected under the federal Endangered Species Act. The U.S. FWS was petitioned to list Great Basin redband trout as threatened or endangered in 1997.[30] The Great Basin, for the purposes of the petition, was described as encompassing six endoheric (closed with no outlet to the ocean), high-desert basins of southeastern Oregon, northeast California, and northwestern Nevada – Catlow Basin, Harney Basin, Chewaucan Basin, Warner Basin, Goose Lake Basin, and Fort Rock Basin. The U.S. FWS completed a status review of the populations cited in the petition in February 2000 (see U.S. FWS 2000) and declined to protect the redband trout under the federal Endangered Species Act in March 2000 (see 65 FR 14932). Although they acknowledged threats to the species and a reduction in population from historic levels, the U.S. FWS (see 65 FR 14932, March 20, 2000) cited the species' persistence in spite of habitat degradation, particularly the rebound of the population after the severe drought in the early 1990s, and the apparent success of cooperative recovery efforts:

> Because redband trout populations in all basins have rebounded, the effects of any potential threats to the Great Basin redband trout and the likelihood of extinction of the species is substantially reduced.

[30] See Oregon Natural Desert Association et al. 1997 and 63 FR 63657, November 16, 1998.

5.2 Abundance and Distribution

Redband trout are native to several basins in the high desert areas of southern Oregon and northern California, including the Upper Klamath Lake and Goose Lake basins (Behnke 1992). Non-anadromous redband trout have declined substantially from their historic population numbers and range (ONDA et al. 1997). The Oregon Natural Desert Association ESA petition states that redband trout in the northwest are extinct in greater than 70% of their historic range and that there are "strong populations" in only 10% of their historic range (ONDA et al. 1997). In the status review prepared in response to the ONDA petition, the U.S. FWS (2000) acknowledged that information about the distribution and abundance of redband trout in the Great Basin is lacking.

It is unclear if redband trout are present in the Clear Lake Reservoir watershed. Thurow et al. (1997) describe the distribution of redband trout as "…the most widely distributed native salmonid…" of the Pacific Northwest, but caution that, "Despite their broad distribution, we know less about the current distribution of redband trout than that of any of the salmonids." That seems to be borne out when attempting to determine if redband trout are present in the Clear Lake Reservoir drainage. One personal communication suggested that the redband trout might be present, but most of the evidence resides in the *absence* of the watershed in distribution and abundance reports. Marty Yamigiwa, fisheries biologist for the Modoc National Forest, said that there have been anecdotal reports of redband trout in the Clear Lake Reservoir drainage (in Little Willow Creek and in Fletcher Creek) but he knows of no surveys or population estimates. Yamigiwa stated that most of the redband trout on the Modoc Plateau are in the Goose Lake/Pit River drainage, not in the Clear Lake Reservoir drainage. (Yamigiwa, pers. comm. 2002). No other references to redband trout in the Clear Lake Reservoir drainage could be found among the reports that describe redband trout in the region:

- Koch and Contreras (1973) sampled the Upper Lost River, Clear Lake Reservoir, Willow Creek in two locations, and Boles Creek in two locations using seining, electrofishing, gill nets and dip nets. They found suckers, dace, chubs, perch, and bullheads but no redband trout.
- In 1989 and 1990 Buettner and Scoppottone (1991) extensively sampled the Upper Lost River and Clear Lake Reservoir watershed, including sites on Willow Creek, Boles Creek and Fletcher Creek for suckers using trap nets, gill nets, and electrofishing. Although focusing on suckers, they reported finding tui and blue chub, Sacramento perch, black and brown bullheads, green sunfish, largemouth bass, bluegill, and marbled sculpin, but no redband trout.
- Behnke (1992) provides an extensive description of the distribution of redband trout but does not mention the Clear Lake Reservoir drainage.
- The Great Basin ESA petition (ONDA et al. 1997) did not identify a Clear Lake Reservoir redband trout population, although it discussed redband trout populations in desert basins adjacent to the Clear Lake Reservoir drainage.
- Thurow et al. (1997) do not describe a Clear Lake Reservoir drainage redband trout population, and stated that redband trout are largely absent from potential habitat in the southern Oregon area (the text does not discuss potential habitat of extreme northeastern California, although the maps of potential habitat and redband trout distribution include this area).

- In 1999 Dambacher et al. (2001) performed variable probability sampling to determine the distribution and abundance of Great Basin redband trout in the desert basins of southeast Oregon/northeast California – although the Goose Lake population was studied, no mention was made of redband trout in the adjacent Clear Lake Reservoir drainage.
- Peck (2000 and 2001) reported on operations in which fish entrained in dewatered irrigation conveyances in the Klamath Project (Clear Lake Reservoir to Tule Lake Sump) were salvaged. No redband trout were reported in the Upper Lost River between Clear Lake Reservoir dam and Malone Reservoir.
- In a comprehensive list of freshwater, anadromous, and euryhaline fish in California three populations of redband trout were mentioned – none were located in the Clear Lake drainage or in the Upper Lost River (Moyle et al. 2000).
- Moyle (2002) provides an extensive description of the distribution of redband trout in California (including the Goose Lake population) but did not identify a redband trout population in the Clear Lake Reservoir drainage.

Redband trout are present in the Lost River system in Oregon, including the Lost River and Langell Valley canals originating from Gerber Reservoir (ODFW 1995, Peck 2000 and 2001). The significant hydrologic alterations in the Upper Lost River, between Clear Lake Reservoir and Malone Reservoir at the Oregon border makes it unlikely that redband trout reside in that reach of the Lost River even if they were present historically. In fish population monitoring in Malone Reservoir in 1992 and the Upper Lost River in 1999 the U.S. BOR (1992 and 1999) found white crappie, Sacramento perch, brown bullhead, shortnose suckers, pumpkinseed sunfish, green sunfish, largemouth bass, and fathead minnows but no trout.

Although the presence of redband trout in the Clear Lake Reservoir/Upper Lost River watershed cannot be confirmed, Appendix B contains a discussion of the natural history and habitat requirements of redband trout. That information is included in this report because a cold water fishery is identified as a beneficial use in the watershed.[31] Although the basis for the listing could not be ascertained, it is thought that the similarity of the watershed to nearby watersheds in which redband trout are found was the basis for the listing.

[31] See Section 2 of the Water Quality Control Plan for the North Coast Region for a listing and description of the beneficial uses identified for this watershed.

6.0 IMPACT OF LAND USE ACTIVITIES

In addition to significant in-stream alterations that affect Lost River and shortnose sucker populations, land use management activities also may impact these threatened populations. Grazing and forestry activities are the most common land use activities in the Upper Lost River/Clear Lake Reservoir watershed.

6.1 Grazing

Grazing can have a large impact on fish habitat and is discussed in more detail in Spence et al. (1996) and U.S. FWS (1993, 1996, 2001, 2002a, 2002b) among others. Poorly managed grazing can reduce channel complexity and adversely impact stream morphology leading to the loss of specific habitat features, such as spawning gravels, undercut banks, connectivity with wetlands and stream sinuosity. Overgrazing can degrade stream channels so that they are wider and shallower than those in a natural state. This can lead to loss of deep pools and formation of ice throughout the water column reducing the ability of fish to over-winter in streams. Geomorphic changes in the streams can be caused by poorly managed grazing and can lead to a destabilization of stream structure and widening stream channels. Overgrazing can lead to degradation of riparian areas by removing riparian vegetation. In areas adjacent to lakeshores, refugial vegetation required by larvae and juvenile fish can be removed exposing the larvae and juveniles to predation. Reducing or removing streamside vegetation can increase stream temperatures by increasing the exposure of the stream to solar radiation. Grazing can influence the composition of vegetation through removal of native vegetation, introduction of non-native vegetation, and changing the soil characteristics so that native vegetation cannot re-establish. Overgrazing can increase the delivery of sediment and nutrients to streams. Outside of the riparian area, grazing can have a profound effect on soils by increasing soil compaction and soil erosion. The soils in the Upper Lost River/Clear Lake Reservoir watershed are largely volcanic. Eliminating vegetative cover from these soils will increase the susceptibility to erosion. The eroded soils contribute sediment, phosphorus, and salts to surface waters. Phosphorus in the streams contributes to downstream eutrophication processes.

In addition to physically degrading streams and fish habitat, grazing can further degraded water quality by the direct input of animal waste to the stream or adjacent to the stream. The animal waste contributes to the nutrient load (i.e. carbon, nitrogen, and salts) of the stream, which can further contribute to downstream eutrophication processes.

Grazing in the study area is largely regulated by the federal agencies – the Modoc National Forest regulates grazing in most of the area through its permit process, and the U.S. Fish and Wildlife Service regulates the area immediately around the reservoir.

Using the Byrne Ranch as an example, the Klamath Water Users Association outlined the changes in grazing practices from the early 1900s until today.[32] The information in this paragraph is taken from the Klamath Water Users Association.[33] The Byrne Ranch was established around Clear Lake Reservoir in the early 1900s. The ranch operations cover about 100,000 acres of both private and public land. Until 1950, cattle were herded over a 50-mile area

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32 Letter from Mr. Dan Keppen, Executive Director, Klamath Water Users Association, to Mr. Bill Hobson, Regional Water Board, dated September 29, 2004.

33 The Regional Water Board did not obtain, review, or independently verify this information.

during an 11-month grazing season. After 1950, the area was fenced and cattle were rotated through the pastures. In the 1980s, the Ranch increased the number of pastures and working a five-year rotation cycle, mimicking the earlier herding regime. Starting at this time, the Ranch also increased off-stream watering opportunities for the cattle. The Klamath Water Users Association also states that the Byrne Ranch has participated in riparian and water quality monitoring related to grazing impacts. The Byrne Ranch manages lands through which Willow Creek and Boles Creek flow, and the Klamath Water Users Association states that the Ranch operations are protective of these waterbodies that are important to the endangered sucker population.

In a review of past grazing management practices, the U.S. BOR (2002) concluded that grazing in the Clear Lake Reservoir area has previously destabilized streams "resulting in erosion, siltation, reduced quality of gravel and cobble spawning areas, increased water temperatures, wider and shallower stream channels, and lowered water tables." Based on monitoring that indicated high water temperatures in Willow Creek, changes to grazing practices were recommended (Jones and Sato 1988). A restoration project was conducted to evaluate the effects of riparian grazing exclusion on Mowitz Creek. Before exclusion, the Mowitz Creek riparian area was found to have degraded streambanks, increased water temperature, and increased turbidity due to grazing (Jones undated). This reference cited a water temperature increase of 10°F in Mowitz Creek between the lower end of the Mowitz Spring enclosure to the road crossing about 9,700 feet downstream. Jones (undated) attributed the temperature increase to excessive grazing and streambank trampling. After one year of grazing exclusion, water temperature monitoring showed some recovery that was thought to be due to the recovery and shading effect of instream sedges (Jones 1988). A forest hydrologist's evaluation of the condition of the Willow Creek grazing allotments confirmed the adverse effects of grazing on the riparian areas in the Doublehead Ranger District (Prud'homme undated). This evaluation cited streambank downcutting, increased width to depth ratios, increase in sediment delivery to streams, and a lack of riparian vegetation as the basis for recommending grazing management practices that would protect riparian areas.[34]

Changes in the U.S. Forest Service grazing management requirements during the 1990s provided protection for riparian habitat functions and riparian recovery (U.S. FS 1996, U.S. FWS 1996). Currently, grazing in the Modoc National Forest is allowed with 10-year renewable leases.[35] The leases can be transferred or held based on the quality of the property or the sale of livestock. Each lease has a series of contract-like conditions (operating instructions) and an allotment management plan to minimize the damaging effects of grazing. Most leases are for the summer season, with a few for the spring and one (for sheep) allows winter grazing. The grazing allotments are specific for the number of animals (including cow-calf pairs), the period of time animals are allowed to graze, and the specific grazing rotation for each grazed pasture. The allotment management plans have numeric utilization and management objectives for the protection of riparian areas, including maximum allowed herbaceous and woody forage

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[34] See also CRWQCB 1992 for a description of the adverse effects of grazing in the Clear Lake Reservoir drainage.

[35] See the USDA Forest Service Biological Assessment (USDA Forest Service 1996) and the U.S. Fish and Wildlife Service corresponding Biological Opinion (U.S. FWS 1996) for a detailed description of the grazing management system in the Modoc National Forest.

utilization, minimal streambank alteration, and a requirement for monitoring actual forage utilization during the grazing period. Allotments are inspected to assess vegetation and streambank impacts. Reaching any one of the management objective limits (e.g., combined 40% woody forage utilization by livestock and wildlife) is cause to move livestock from the allotment or pasture in question. Some allotments, such as that near the Willow Creek monitoring station (WCGSB), are rested for a long period of time (in the case of Willow Creek for 10 years) and then put on a rest-use rotation schedule. The Forest Service cites examples of riparian recovery in the Clear Lake Reservoir drainage when grazing is excluded or controlled (USDA Forest Service 1996), including an increase in riparian vegetation, deepening of the stream channel, and decrease in stream temperatures on Lower Willow Creek.

The U.S. FWS (1996) reviewed the improved Forest Service grazing program under an ESA §7 consultation and issued a Biological Opinion that found that the program, including consideration of cumulative effects, was sufficiently protective to not jeopardize the listed sucker species. The Grazing Program Biological Opinion provides specific management conditions that will "minimize adverse impacts of livestock grazing to instream, riparian, and upland conditions in watersheds that support Lost River, shortnose, and Modoc suckers." The Opinion stated that "most of the range allotments being assessed [*in this Biological Opinion*] already have improved range management systems designed to protect and recover the listed aquatic species."

The U.S. FWS (2001) Biological Opinion on the effects of the Klamath Project Operations also commented that grazing in the basin could be compatible with preservation of sucker populations. "Grazing, as currently practiced in the Clear Lake watershed, is not considered by the Service to be a significant threat to suckers."

Given the irreplaceable value of Willow Creek for Lost River and shortnose sucker spawning, its riparian area especially should be protected from harmful grazing. Grazing activities have the potential to destabilize banks and reduce or eliminate vegetative cover for erosion control and shading. The Ponderosa Pine riparian forest along the south side of Willow Creek offers the greatest shading potential now and in the future. Willow trees in the Willow Creek riparian area should be allowed to reach a mature size, which also provide more protection for spawning sites.

The U.S. FWS regulates the area around Clear Lake Reservoir in the National Wildlife Refuge. This area is not grazed *except* for the peninsula between the east and west lobes of the lake known as "The U." The north, south, and east shorelines of the reservoir, along with Willow Creek and several springs, are fenced to exclude grazing. The west shoreline of the reservoir is unfenced, due to intermingled private land, but this area is grazed in conjunction with the Modoc National Forest and private land pasture. The U.S. FWS allows late seasonal use of up to 600 AUMs,[36] between August and November, along "The U" peninsula and associated shoreline. A U.S. FWS Environmental Assessment (U.S. FWS 1995) explains that the livestock grazing is a "vegetative management tool to maintain refuge upland habitat conditions in the desired state." The explanation for using grazing as a tool to provide waterfowl habitat on the shoreline area of a wildlife refuge with moderate to highly erosive soils is that: "Late season grazing does not

[36] AUM stands for Animal Unit Month. An animal unit month is the amount of forage needed to sustain one animal for one month, with a beef cow weighing more than 700 pounds being equal to 1.0 animal unit. Sheep or lambs, by contrast, are counted as 0.1 animal unit.

significantly effect the condition and plant composition of the uplands as grasses have cured and seeded previous to livestock use and dry vegetative parts are not attractive to them."[37] The grazing on the shoreline extends to areas exposed when the water level recedes. This is to keep the vegetation in early seral development to "provide low aspect foraging habitat for western Canada geese and shorebirds."[38] U.S. FWS (1995) also explains that "Grazing will have no effect on colonial nesting water birds including white pelicans, double-crested cormorants, and Caspian terns which nest on islands in the lake that are not accessible to livestock." The impact of shoreline grazing on the turbidity levels in Clear Lake Reservoir and the Upper Lost River is not discussed in the 1995 Environmental Assessment.

6.2 Forestry

Poor forestry practices can cause or exacerbate water quality problems, including problems similar to those caused by overgrazing. Eliminating vegetative cover from the shallow volcanic soils in this watershed can change the timing and peak of runoff, and can increase erosion. Eroded soils contribute sediment, which carries phosphorus-rich soil particles and organic matter to surface waters. Phosphorus in the streams contributes to eutrophication processes downstream in the Lost River and Tule Lake (U.S. FWS 1993). Additionally, in general, forestry activities can cause an increase in stream temperature, alter hydrologic pathways, and reduce channel complexity (U.S. FWS 2001).

The small amount of commercial forestry in the Clear Lake Reservoir watershed led the U.S. FWS (2001) to conclude that forestry does not present a threat to the sucker population in the area:

> Forestry practices may also contribute to water quality declines in the upper Lost River Basin. However, because commercial forest comprises such a small area and will be infrequently harvested, the Service does not consider forestry in the Clear Lake watershed to be a significant threat to LRS and SNS.

Given the irreplaceable value of Willow Creek for Lost River and shortnose sucker spawning, its riparian area should be protected from harmful logging activities.

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[37] U.S. FWS 1995
[38] U.S. FWS 1995

Willow Creek from the Great Society Bridge, June 2002.

7.0 DATA COLLECTION, ANALYSIS and LIMITATIONS

The data collection effort associated with this analysis consisted of three components –collection and review of existing data, collection of water quality grab samples (and associated instantaneous field measurements), and the short-term use of continuous monitoring devices.

7.1 Existing Water Quality Data

There is a paucity of water quality data from the Upper Lost River/Clear Lake Reservoir watershed. Much of the extant data was collected incidentally as part of Endangered Species Act investigations on the status of the Lost River and shortnose suckers (see, for example, the discussion of turbidity results later in this Section).

California Department of Water Resources (CDWR unpublished data) collected limited data from Clear Lake Reservoir from May 1989 to May 1994, for nine sampling episodes.[39] Some of the sampling occurred during the severe drought of the early 1990s. CDWR stated that the sampling station for these episodes was located near the dam. The sampling parameters were Secchi depth, water temperature, dissolved oxygen, pH, alkalinity, turbidity, total dissolved solids, dissolved minerals, metals, and nitrogen and phosphorus species. Some of the data, including dissolved oxygen, pH, and water temperature, were collected at several depths. Supporting information, including methodology, the exact sampling location, and QC, is not available. The nine reported total nitrogen concentrations (calculated by adding total ammonia, organic nitrogen, nitrate and nitrite) ranged from 0.43 mg/l to 1.71 mg/l, with a median of 0.93 mg/l and a 95% upper confidence level concentration of 1.29 mg/l. The nine total phosphorus concentrations reported ranged from 0.05 mg/l to 1.20 mg/l, with a median of 0.24 mg/l and a 95% upper confidence level concentration of 0.59 mg/l. The nine reported dissolved orthophosphate concentrations ranged from 0.03 mg/l to 0.12 mg/l, with a median of 0.084 mg/l and a 95% upper confidence level concentration of 0.92 mg/l. These data represent the only information that Regional Water Board staff could locate on nutrient concentrations in the Clear Lake Reservoir. The CDWR data cannot be compared directly to the data obtained in 2001-2003 from the Upper Lost River and the streams leading to Clear Lake Reservoir, because the samples were not taken at the same location (river and streams data compared to lake data). There is no information about whether the nutrient species caused water quality impairments; the total phosphorus levels exceeded the levels suggested by U.S. EPA (1986) to control eutrophication in lakes. The turbidity of the lake may have prevented primary production. The reported turbidity ranged from 20 to 89 NTU. Secchi depth generally was low; out of nine measurements eight were less than 0.6 meters and one was 1.2 meters.

7.2 Collection of Additional Data

Based on the scarcity of existing data, additional data were collected for this analysis.

7.2.1 Purpose of the Sampling

The specific questions that the additional sampling was designed to address included:

- What are the current levels of nutrients and water temperature?
- How do these parameters vary temporally and spatially?
- Are beneficial uses impaired due to nutrients and water temperature?

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39 Sampling took place in May and August of 1989, April and August of 1990, May and September of 1991, May and September of 1993, and May of 1994.

- How does the timing and spacing of the most sensitive beneficial use[40] overlap with water quality impairment?
- Are beneficial uses impaired by other water quality parameters?

The sampling program used field observations, grab samples for laboratory analysis, instantaneous measurements in the field, season-long continuous water and air temperature monitoring, and short-term continuous monitoring for pH and dissolved oxygen.

7.2.2 Monitoring Stations

The monitoring locations for the Upper Lost River/Clear Lake Reservoir area are shown in Map 2 and are listed below with their station designations:

1. Lost River below Clear Lake Reservoir dam – LRCLDM
2. Lost River at Walter Flat – WFLAT
3. Mowitz Creek just downstream of the 136 bridge – MOWCRK
4. Boles Creek just upstream of the 136 ford – BCFORD
5. No. Fork Willow Creek below the Great Society Bridge – WCGSB
6. Fletcher Creek just upstream of the 73 ford – FCFORD

Two stations are on the Upper Lost River mainstem – one is downstream of the dam and the other at Walter Flat. Station LRCLDM is at a point about 1,000 meters downstream of Clear Lake Reservoir dam. Station WFLAT is at a point about 10 meters downstream of the Walter Flat Bridge, about eight miles downstream of the dam. These stations were chosen because they provided the only identified points with vehicle access between the dam and the Oregon border to the north. The Lost River station below the dam provided the most upstream data for the Lost River before the impact of land use and the input of tributaries. The Walter Flat station provides data reflecting the river before intensive land use and with the input from Rock Creek, the only significant tributary between the reservoir and Walter Flat. There was no station that showed the quality of water in the three miles between Walter Flat and the Oregon border. In addition to the two stations on the Upper Lost River, there were four monitoring locations in streams that lead to Clear Lake Reservoir – the source of the Lost River. One station was on North Fork Willow Creek, the main tributary to Clear Lake Reservoir and the primary spawning stream for the endangered Lost River and shortnose suckers (see discussion in Section 4.0 of this document). Two other sites, on Boles and Fletcher Creeks, drain into Willow Creek. The fourth site, on Mowitz Creek, drains directly into Clear Lake Reservoir but does not contribute much water to the reservoir. This site was added late in the investigation because of the opportunity to add to a sparse dataset.

All of the sites, except the station below the dam, were accessible only during late spring to early fall because wet weather made the roads impassable. Sampling locations were limited to areas that could be reached by truck. Logistical issues precluded sampling in Clear Lake Reservoir.

[40] The most sensitive beneficial use is the ESA-listed sucker species. See Section 3.0.

7.2.3 Water Quality Parameters

The water quality parameters that were sampled included:

Water Quality Parameters for Additional Data Collection Effort	
Instantaneous Field Measurements	Water temperature Air temperature Dissolved oxygen Specific conductance Turbidity pH Flow
Continuous Measurements	Water temperature Dissolved oxygen Specific conductance pH Air temperature Relative Humidity
Laboratory Analyses	Metals Mercury Nutrients Ammonia Total Kjeldahl Nitrogen Alkalinity Hardness Total Organic Carbon Chlorophyll-a Total Suspended Solids Total Dissolved Solids
Aerial Survey	Thermal infrared imaging (water temperature at the surface)

These parameters were chosen for the reasons discussed below.

Water, air temperature, and relative humidity measurements are important because the Lost River is listed on the State 303(d) impaired waterbodies list for temperature. Water temperature was collected by continuous monitors at hourly increments and was used for identification of critical thermal maximums and persistence of maximums. Understanding the timing and persistence of high water temperatures is needed to understand the potential impact to aquatic life. Water temperature affects the entire aquatic biologic community. Water temperature directly affects the metabolic requirements of aquatic life. Water temperature also affects the amount of oxygen that can be dissolved in water. Higher water temperatures result in less dissolved oxygen available at saturation at the same time that increased energy demands are placed on fish. Air temperature and relative humidity were collected because of their direct influence on water temperature.

Dissolved oxygen, specific conductance, and pH were measured in order to describe the physical characteristics of the water. Subdaily continuous monitors at two stations, WCGSB and WFLAT, provided measurements of dissolved oxygen and pH for short periods of time. Levels of pH are influenced by rates of photosynthesis. In Upper Klamath Lake, for example, high algal growth leads to photosynthetically induced high pH levels. Fish can be directly adversely affected by high pH, which controls the speciation of nutrients especially the toxicity potential of ammonia.

Measurement of nutrient species was planned because the Lost River is listed on the State 303(d) list for nutrients and this information is needed for system description. Ammonia, total Kjeldahl nitrogen (TKN), nitrate and nitrite were analytically determined. Total nitrogen was calculated from TKN, nitrate and nitrite. Total phosphorus and ortho-phosphate were analytically determined. A brief discussion of the various nutrient species of interest is presented here. For a more complete discussion, see Horne and Goldman (1994), U.S. EPA (2000c), and other references.

Total Nitrogen includes all forms of nitrogen, both organic and inorganic. Nitrogen is essential for plant growth. Blue-green algae[41] and some bacteria can utilize atmospheric nitrogen, which often makes nitrogen less limiting for algal growth than other required nutrients such as phosphorus. The impact of nitrogen on waterbodies varies depending on the forms and relative amounts of nitrogen present. For this analysis, total nitrogen in a water sample was calculated by adding the analytically derived concentrations of total Kjeldahl nitrogen, nitrite and nitrate.

Nitrite (NO_2^-) is an intermediate unstable form of nitrogen. In waterbodies exposed to oxygen, nitrites are rapidly oxidized to nitrates (Horne and Goldman 1994). This form of nitrogen can be used directly by plants. Nitrite is toxic to aquatic life at relatively low concentrations (e.g., see the discussion of nitrite toxicity to rainbow trout in Appendix B of this report).

Nitrate (NO_3^-) is the most oxidized and stable form of nitrogen in a water body. Nitrate is the principle form of inorganic nitrogen found in natural waters (Horne and Goldman 1994). Nitrate is the primary form of nitrogen used by plants as a nutrient, and can stimulate excess growth. At high levels it is toxic to human infants.

Total Organic Nitrogen is a measure of that portion of nitrogen that is organically bound, and is roughly equal to the combined concentrations of TKN and ammonia. Organic nitrogen includes all organic compounds such as proteins, polypeptides, amino acids, and urea. Dissolved organic nitrogen can often constitute over 50% of the total soluble nitrogen in fresh water. Organic nitrogen is not immediately available for biological activity. Therefore, it does not contribute to furthering plant proliferation until decomposition to the inorganic forms of nitrogen occurs.

Total Ammonia (NH_3 & NH_4^+) is the most reduced inorganic form of nitrogen in water and includes both the dissolved un-ionized ammonia molecule (NH_3) and the ammonium ion (NH_4^+). The ammonium ion is rapidly taken up by aquatic plants (Horne and Goldman 1994), which can result in prolific algal growths. Several factors influence the adverse effect of ammonia on aquatic life. Some of the factors affect the chemical equilibrium between the two forms and some factors affect the actual toxic effect of ammonia.

Largely pH and temperature govern the equilibrium between un-ionized ammonia and the ammonium ion. Emerson et al. (1975) offer a method to calculate the percentage of total

41 *Aphanizomenon flos aqua* is a blue-green algae (cyanobacteria) common in the Klamath River system that is capable of fixing atmospheric nitrogen.

ammonia in the ionized and un-ionized states for water with temperatures ranging from 0 to 30°C and pH from 6.0 to 10.0. As water temperature and pH increase, the percent of total ammonia present as un-ionized ammonia increases. For example at pH 6.0 and water temperature 5°C the fraction of total ammonia that is in the un-ionized form is 0.0125%, whereas at a pH of 10.0 and a temperature of 25°C, the percent of un-ionized ammonia rises to 85.1%.

Ammonia, particularly the un-ionized form, is toxic to aquatic life. One of the factors that exacerbates the toxicity of un-ionized ammonia to aquatic life is dissolved oxygen. Un-ionized ammonia is more toxic to fish as dissolved oxygen decreases (see, for example, Downing and Merkens 1955, Alabaster et al. 1979, Thurston et al. 1981). Total ammonia concentrations, expressed as milligrams of nitrogen per liter (mg N/L) varies with temperature and pH (U.S. EPA 1999). As temperature and pH increase, ammonia concentration decreases, however ammonia toxicity concentrations (or LC50) also decrease for aquatic biota. A more complete discussion of the effects and chemistry of ammonia in natural waters can be found in the U.S. EPA ammonia criteria document (U.S. EPA 1999).

Total Kjeldahl Nitrogen is a measure of both the ammonia and organic forms of nitrogen.

Total Phosphorus includes both inorganic and organic forms of phosphorus, which can be present as dissolved or particulate matter. It is an essential plant nutrient and is often the most limiting nutrient to plant growth in fresh water, although that does not appear to hold true for the Lost River. Phosphorus is one of the major contributing factors to eutrophication in fresh water systems. Unlike nitrogen, phosphorus does not exist in gaseous form. Phosphorus can be in soluble form or sorbed to fine particles. The U.S. EPA (1986) recommends that total phosphorus concentrations not exceed 0.025 mg/l to prevent eutrophication in lakes, 0.05 mg/l in streams leading to lakes to prevent eutrophication, and 0.10 mg/l in streams not entering lakes to prevent eutrophication.

Ortho-Phosphate (PO_4^{-3}) is an inorganic oxidized form of soluble phosphorus. This form of phosphorus is the most readily available for uptake during photosynthesis. Phytoplankton can readily use soluble phosphate (Horne and Goldman 1994).

Minerals and trace metals were analyzed in some samples in order to describe the water quality of the river. In the Lost River, these measurements could help to evaluate the effects of downstream augmentation of the surface water with groundwater for irrigation purposes. Some of the groundwater sources being used for augmentation have high temperature, indicating possible geothermal influence, which may contribute trace metals and minerals to the river. Some metals, such as iron, have a direct influence on the algal growth. Horne and Goldman (1994) report that “Iron availability may limit the growth of algae in lakes and streams, especially when nitrogen fixation is important.”

Chlorophyll-a was chosen as an analyte in order to evaluate nutrient enrichment and dissolved oxygen in the system. This is a measure of the phytoplankton or periphyton biomass in a body of water. It is directly related to the productivity and trophic state of the body of water. The Lost and Klamath Rivers are listed on the Oregon 303(d) list for chlorophyll-a.

Turbidity was measured to evaluate the effects of land use on water quality. As discussed in Section 1.0 of this document, the soils in the watershed are poorly developed and moderate to highly erosive. Land use can accelerate erosion. Eroded soils may contribute phosphorus to the system as soil organic matter phosphorus and inorganic soil/rock phosphorus. Turbidity may suppress the potential effects of nutrient enrichment by limiting the light penetration of the water column.

Sampling Frequency & Timing
The sampling period was from May to September to include the time period when water and air temperatures are highest. The frequency was monthly.

Remote Probes
Optic Stowaway data loggers were used for season-long continuous water temperature monitoring at each station and air temperature monitoring at three sites. The Stowaways recorded water temperature every 15 minutes.

On the Lost River, multiparameter data loggers were used for short-period continuous monitoring of dissolved oxygen, pH, specific conductivity, water temperature, and pH.

7.3 Data Analysis[42]

7.3.1 Water Temperature

The analysis and modeling of water temperature in the Upper Lost River/Clear Lake Reservoir watershed is found in Appendix A of this document. A brief summary of the conclusions of that analysis is presented here.

Water temperature in the Upper Lost River/Clear Lake Reservoir watershed was investigated using:

- Remote continuous water and air temperature monitors (Optic stowaway dataloggers) that took readings every 15 minutes from May through September 2002;
- Remote sensors that measured air temperature (Optic stowaway dataloggers) and relative humidity (HOBO instruments) every 15 minutes for three days in June 2003;
- Solar pathfinder measurements to calculate solar radiation that reached stream surfaces;
- A thermal infrared aerial survey in July 2001; and,
- Computer simulation modeling using the SSTEMP model.

The sensitivity analysis using SSTEMP showed that daily average water temperature at the sampling stations in the streams that drain to Clear Lake Reservoir is most sensitive to influence by air temperature, solar radiation, and relative humidity. In the two Upper Lost River stations downstream of Clear Lake Reservoir, water temperature is most sensitive to inflow temperature, that is, the temperature of the water released from the Clear Lake Reservoir.

42 The statistical analyses of the chemical constituents in this section were prepared using the NCSS statistical package (Hintze 2001).

The warmest stream temperatures during the data collection period were found during the week of July 15, 2002. The maximum weekly average temperatures (MWAT) at the sampling stations for that week were:

- WFLAT, 27.40°C
- LRCLDM, 26.64°C
- WCGSB, 27.63°C
- FCFORD, 22.75°C.

The monitoring instrument at the Boles Creek station was out of the water during that period due to seasonal dewatering and the sampling at Mowitz Creek did not begin until the following month.

The SSTEMP modeling shows that a reduction in solar radiation reaching the streams that drain to Clear Lake Reservoir could lead to reduction in water temperatures. For example, the model suggests that a doubling of the shade over Willow Creek could lead to a drop in water temperatures from the hottest daily average water temperature seen, 24.2°C, to 23.1°C. A quadrupling of the shade at the site could lead to a further reduction to 21.28°C. The potential reductions at Boles and Mowitz Creeks are not as significant. The model does not consider, however, whether such an increase in shade is possible. The riparian area of Willow Creek is the most developed, in large part because the soils in that area are deeper, clay-enriched, and more productive than the soils over the rest of the study area (see the discussion of soils and vegetative type in Section 1.0 of this document). Even with a higher potential to establish riparian shading in the Willow Creek, it is not clear if a doubling or quadrupling of the shade is possible. A doubling or quadrupling of the shade at the other sampling stations is highly unlikely given the poorly developed soils and the associated vegetation types (again, see the discussion in Section 1.0 of this document). The primary shade over these streams is topographic, not vegetative.

7.3.2 Nitrogen

Nitrogen concentration was measured from monthly grab samples at the six sampling stations, for a total of 57 samples. The analytical laboratory measured ammonia, nitrate, nitrite and TKN. Total nitrogen was calculated from the sum of TKN, nitrate, and nitrite. The total nitrogen levels showed some variability ranging from below the analytical reporting limit of 0.05 mg/l to 1.85 mg/l. Of the 57 samples, 17 were below the analytical reporting limit. Since nitrogen was present in the system these were assumed to be half of the reporting limit for statistical analyses.[43] [44] The highest concentration of total nitrogen, 1.85 mg/l, consisted entirely of TKN (ammonia and organic nitrogen). It was from a sample taken in August 2002 at Boles Creek during a time when the creek had no surface flow. The median of all of the total nitrogen results was 0.69 mg/l, and the 95% upper confidence level was 0.77 mg/l.

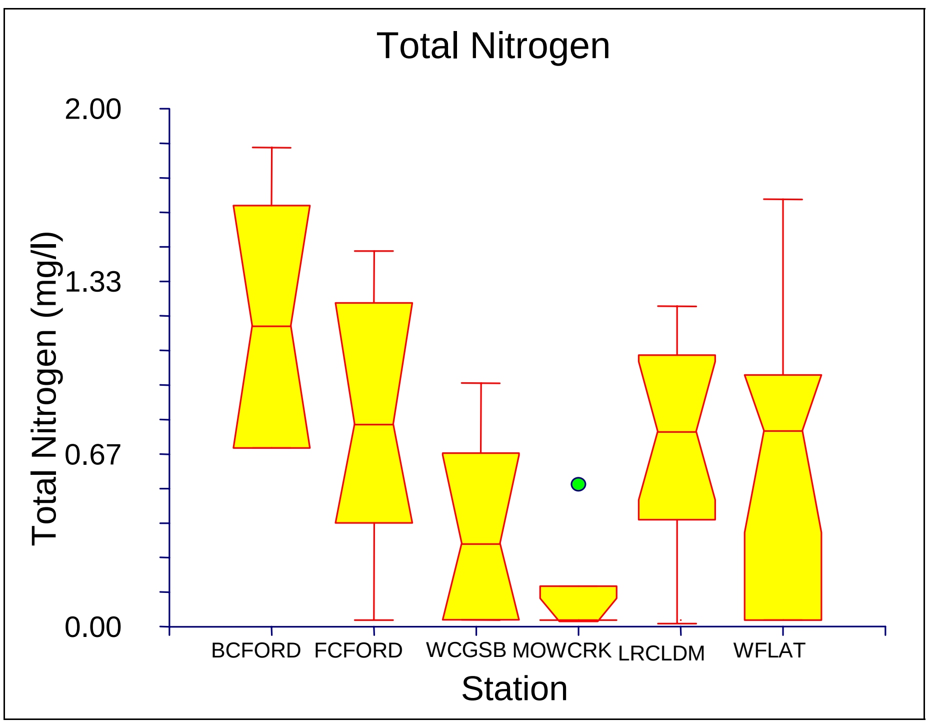
[43] Reporting limits are: TKN 0.50 mg/l, NO_2 and NO_3 0.050 mg/l.

[44] In the water quality samples, the results below the analytical reporting 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.

The two stations on the Upper Lost River (WFLAT and LRCLDM) were analyzed separately from the four upstream stations on streams that drain to Clear Lake Reservoir (MOWCRK, BCFORD, WCGSB, and FCFORD). The 28 data points for the two Upper Lost River stations showed total nitrogen concentrations ranging from below the laboratory reporting limit to 1.65 mg/l, with a median of 0.76 (including 8 nondetects assumed to be half of the reporting limit for statistical analysis purposes).

The 29 points from the four stations on streams leading to Clear Lake Reservoir showed total nitrogen concentrations ranging from below the laboratory reporting limit to 1.85 mg/l, with a median of 0.57 (including 10 nondetects assumed to be half of the reporting limit for statistical analysis purposes).

The total nitrogen concentrations were similar between the two Upper Lost River stations and the four stations upstream of Clear Lake Reservoir. The total nitrogen concentrations are well below the 10 mg/l NO_3-N set by the U.S. EPA (1986) to protect human health consuming domestic water supplies. A box plot chart comparing the total nitrogen values for all six stations is shown below.



Ammonia concentrations are low or below the laboratory reporting level at the six sampling stations. Analysis of all six stations grouped together shows that of 57 samples, 37 were below the analytical reporting limit. If the nondetects are included at a concentration equal to half of the reporting limit, the median concentration of ammonia is 0.025 mg/l (the default level for the nondetect samples), and the range is from below the reporting limit to 0.23 mg/l NH_4-N.

Separating the four upstream stations from the two Upper Lost River stations does not show a significant difference in ammonia concentrations. If the nondetects are included at a concentration equal to half of the laboratory reporting limit, both upstream stations and downstream stations have a median ammonia concentration of 0.025 NH_4-N. There is a large proportion of samples with ammonia concentrations below the laboratory reporting limit (29 total samples with 17 nondetects in the upstream stations and 20 nondetects out of 28 total samples in the downstream sites), so analysis of these data is difficult.

Calculations of the percentage of ammonia present as the toxic un-ionized ammonia were not necessary because the concentration of total ammonia at all of the stations is well below the level needed to protect the sensitive life stages of the sucker population.

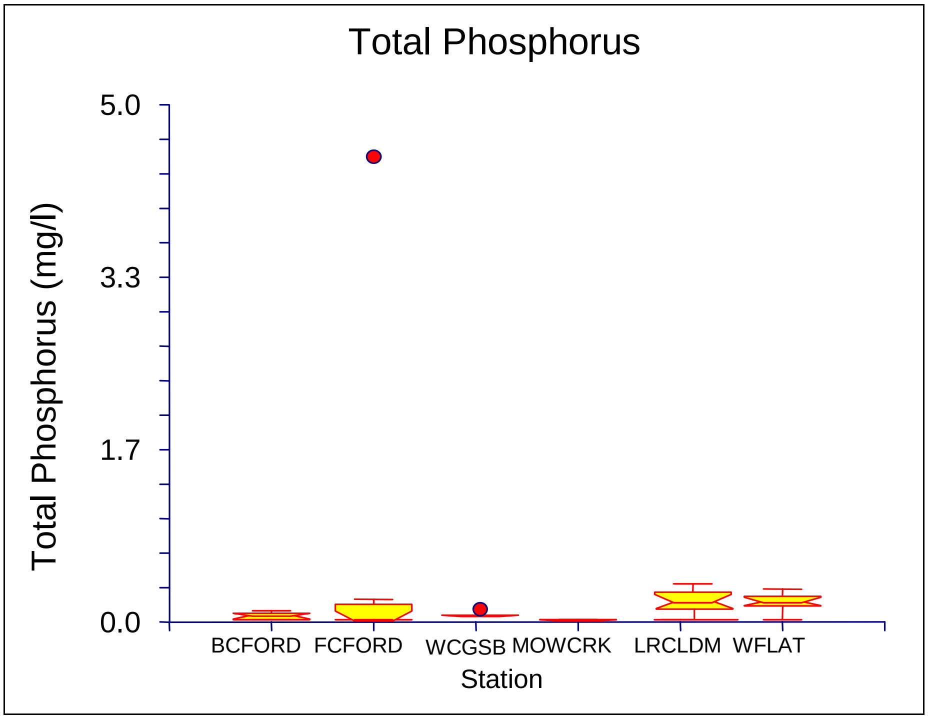
7.3.3 Phosphorus

Total phosphorus was measured from monthly grab samples at the six sampling stations, for a total of 57 samples. The total phosphorus levels showed variability ranging from below the analytical reporting level to 4.5 mg/l. Of the 57 samples, 26 were below the analytical reporting limit; since phosphorus was present in the system these concentrations were assumed to be half of the reporting limit for statistical analyses. The high measurement, 4.5 mg/l, was from a sample taken in May 2002 at Fletcher Creek. The median of all of the total phosphorus results was 0.068 mg/l, and the 95% upper confidence limit is 0.35 mg/l, a level influenced by the abnormally high concentration at Fletcher Creek in May 2002.

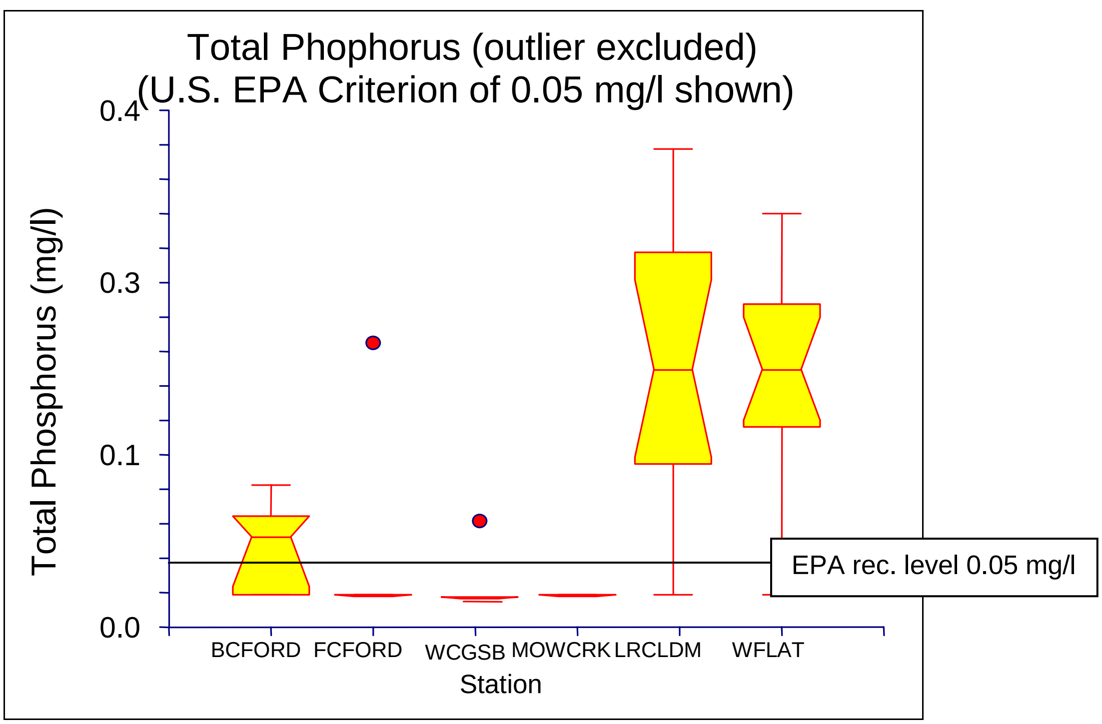
The two stations on the Upper Lost River (WFLAT and LRCLDM) were analyzed separately from the four upstream stations on streams that drain to Clear Lake Reservoir (MOWCRK, BCFORD, WCGSB, and FCFORD). The 28 data points for the two Upper Lost River stations showed total phosphorus concentrations ranging from below the laboratory reporting limit to 0.37 mg/l, with a median of 0.20 mg/l, and a 95% upper confidence level of 0.23 mg/l (including four nondetects assumed to be half of the reporting limit).

The 29 points from the four stations on streams leading to Clear Lake Reservoir showed total phosphorus concentrations ranging from below the laboratory reporting limit to 4.5 mg/l, with a median of 0.025 mg/l (this is half of the laboratory reporting limit), and a 95% upper confidence level of 0.51 mg/l. Although most of the data points in this dataset are nondetects (22 nondetects out of 29 data points), for the complete dataset analysis, they were assumed to be half of the reporting limit.

Total phosphorus levels were higher in the two downstream stations than in the stream stations upstream of Clear Lake Reservoir. A box plot chart comparing the total phosphorus values for all six stations is shown below.



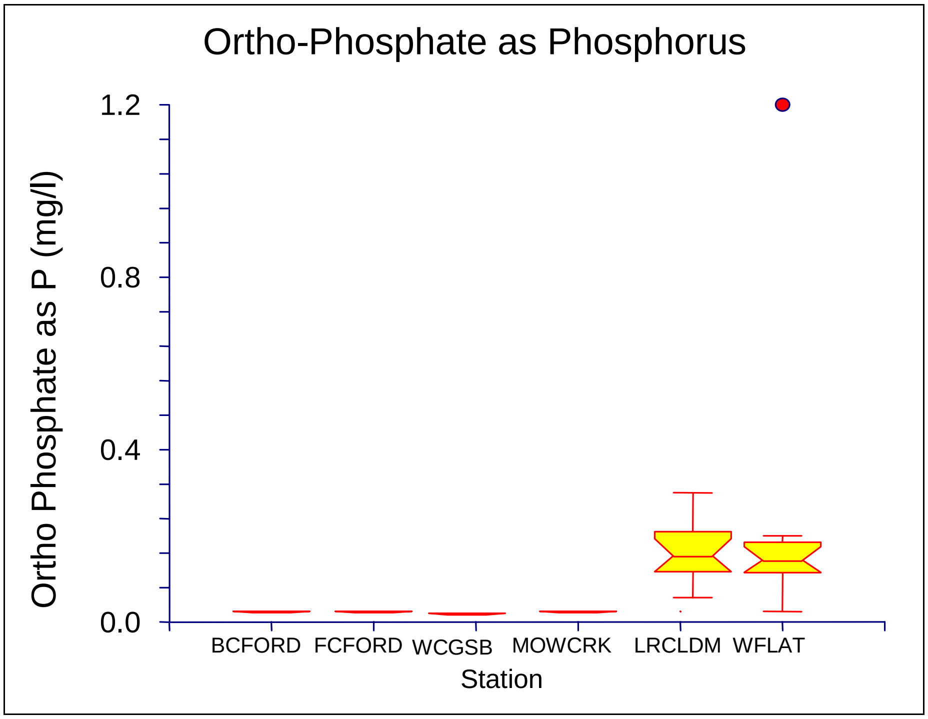
Simply for illustration purposes, the high value of 4.5 mg/l at Fletcher Creek in May 2002 was removed in the following box plot graph.

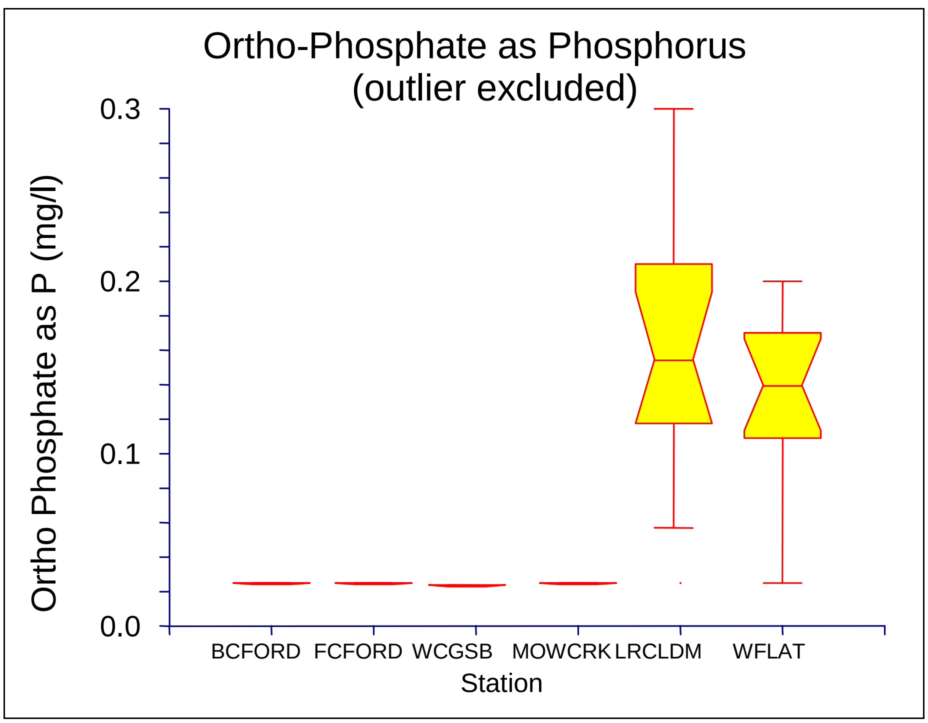


Median total phosphorus concentrations in the two Upper Lost River stations were above the 0.05 mg/l level suggested by the U.S. EPA to control eutrophication in streams that enter lakes (U.S. EPA 1986). Soil particles from discharged water from Clear Lake Reservoir may transport soil-organic-matter phosphorus and inorganic-soil/rock phosphorus to the Upper Lost River. The levels do not appear to present a eutrophication problem in the Upper Lost River or in Clear Lake Reservoir, probably because the high turbidity reduces sunlight penetration, as discussed elsewhere in this document. The U.S. BOR (2000) indicated that there has been extensive siltation of Clear Lake Reservoir. Loose bottom sediments may provide a reservoir of soils with residual organic and mineral phosphorus compounds to downstream locations.

Ortho-phosphate concentrations in all of the samples at Willow Creek, Mowitz Creek, Boles Creek, and Fletcher Creek were below the analytical reporting limit. In the Upper Lost River, at Walter Flat and below the dam, the o-P results ranged from below the analytical reporting limit of 0.05 mg/l to 1.2 mg/l at Walter Flat in October 2002. The high reading at Walter Flat was taken at a time when there were no releases from the Clear Lake Reservoir dam and the only water in the river at that point was from groundwater accretions and surface water inputs from much small surface water sources, such as Rock Creek. This data point, then, is not a true outlier, but represents natural variability in the system. It highlights the need for data collection that can be used to describe the whole system over all seasons. Out of 56 measurements for o-P, 30 were below the analytical reporting limit. Since o-P is present in the system, these values were assumed to be half of the reporting limit for statistical analyses. The median for these measurements was 0.025 mg/l; the median was equal to half of the reporting limit. The laboratory results showed that high turbidity in the Upper Lost River interfered to some degree with o-P results.[45] Box plots showing the o-P results are shown below. The first graph shows the data including the high value of 1.2 mg/l at Walter Flat. The second graph shows the data without the high value, simply for graphic purposes.

[45] There were five instances where the laboratory results showed that the concentration of o-P was greater than the concentration of total phosphorus. In one case, the o-P concentration was reported as 0.057 mg/l, whereas the total phosphorus concentration was reported as 0.050 mg/l. In this case, the values are probably the same value (within 20%) and the entire phosphorus concentration may be o-P. In the other four cases, the +/- 20% QA limits do not overlap. The laboratory analytical procedure resulted in less precise measurements in these cases because the samples were so turbid that total phosphorus samples were acidified and filtered. Ortho-phosphate cannot be filtered or acidified, and so is subject to matrix interferences that can be controlled for total phosphorus samples.



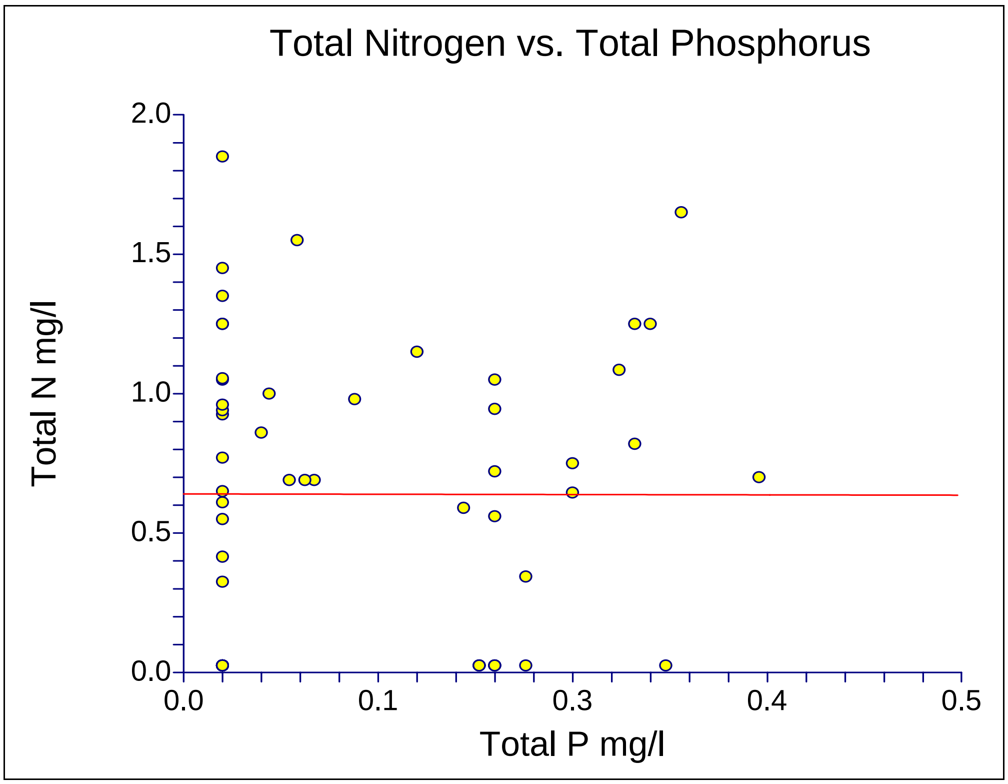


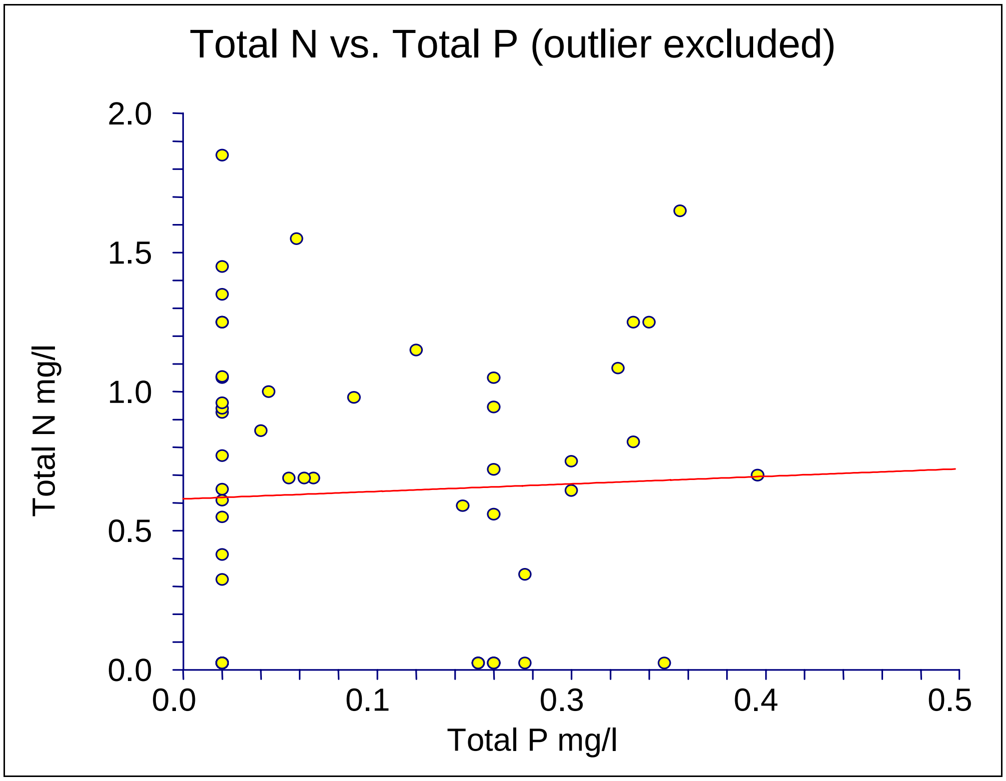
7.3.4 Nitrogen/Phosphorus Ratio

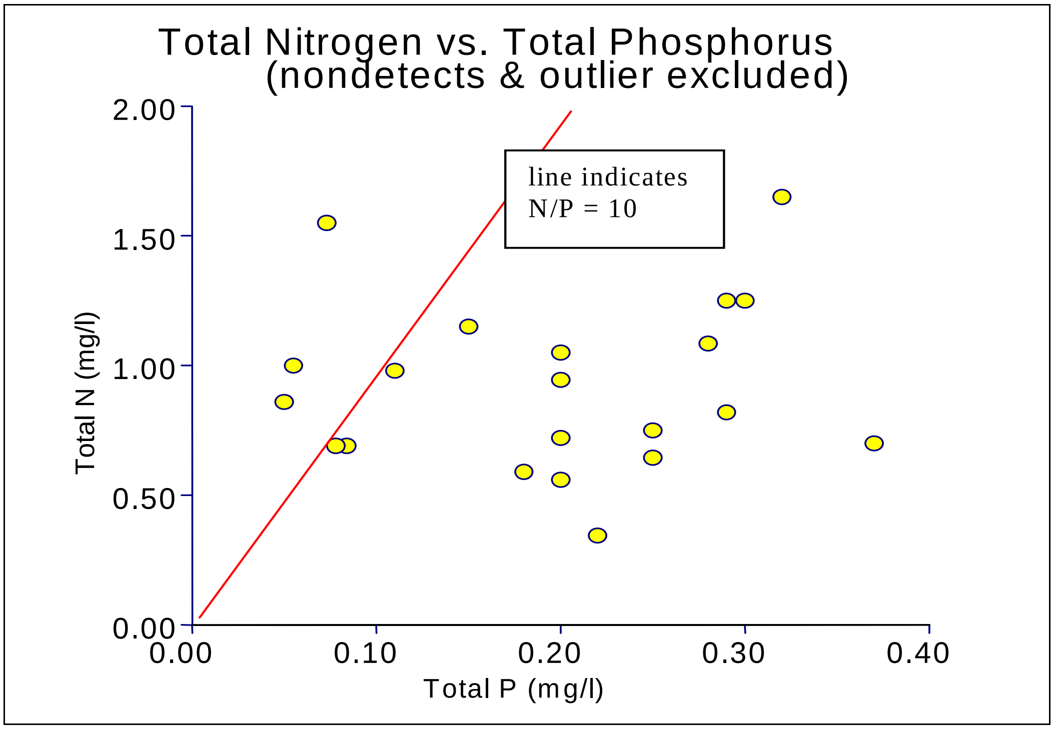
The ratio of nitrogen to phosphorus can be useful for an initial assessment of the relationship between nutrients and biomass. A nitrogen/phosphorus ratio of less than 10 indicates a system that is limiting in nitrogen, while a ratio of greater than 10 indicates a phosphorus limited system, although "The concept of the limiting nutrient is not as clear in streams as in lakes." (Horne and Goldman 1994). In many surface waters in California, phosphorus tends to be the limiting nutrient controlling plant growth, however, in the Klamath Basin the reverse is true as reported by Campbell (1999) among others.

In the 57 observations in this dataset, the ratio between total nitrogen and total phosphorus ranged from 0 to 74. The value of R-Squared, the proportion of variation in total nitrogen that can be accounted for by variation in total phosphorus, is 0.0001; the correlation between total nitrogen and total phosphorus is -0.0097. There is no correlation between the values. These values are slightly different if the nitrogen nondetect values were reported as zero rather than half of the reporting limit. The relationship between total nitrogen and total phosphorus is shown in the graphs below. The first linear regression plot shows the data with the abnormally high phosphorus value. The second linear regression plot shows the relationship without that value; there is a slightly stronger relationship between the two parameters. In the second analysis, without the high value, the value of R-Squared is 0.0020 and the correlation between total phosphorus and total nitrogen is 0.0444.

If the data sets with nondetects and the outlier are removed, there are 21 data points available for analysis of the nitrogen/phosphorus ratio. The N/P ratio for these points is shown in the third graph. A line showing an N/P of 10 is drawn for reference. Of the 21 data points, 18 have an N/P ratio of less than ten. This indicates a system that is nitrogen limited.




Total N vs. Total P (outlier excluded)
2.0
1.5
1.0
0.5
0.0
Total N mg/l
0.0
0.1
0.3
0.4
0.5
Total P mg/l


Total Nitrogen vs. Total Phosphorus
(nondetects & outlier excluded)
2.00
1.50
1.00
0.50
0.00
Total N (mg/l)
line indicates
N/P = 10
0.00
0.10
0.20
0.30
0.40
Total P (mg/l)

7.3.5 Chlorophyll-a

Chlorophyll-a in the water column was measured from monthly grab samples at the six sampling stations, for a total of 57 samples. The water samples were filtered in the field, rinsed with magnesium carbonate, and preserved on dry ice because full-volume samples could not be delivered to analytical laboratory within the recommended holding period. The chlorophyll-a concentrations showed variability ranging from below the analytical reporting limit (0.00050 mg/l) to 0.016 mg/l. Of the 57 samples, 38 were below the analytical reporting limit; for statistical analyses, these concentrations were assumed to be half of the reporting limit. The high measurement, 0.016 mg/l, was from a sample taken in October 2002 at Mowitz Creek. The median of all of the chlorophyll-a results was 0.00025 mg/l (the default value for samples below the reporting limit), and the 95% upper confidence limit is 0.00174 mg/l.

The two stations on the Upper Lost River (WFLAT and LRCLDM) were analyzed separately from the four upstream stations on streams that lead to Clear Lake Reservoir (MOWCRK, BCFORD, WCGSB, and FCFORD). The 28 data points for the two Upper Lost River stations showed chlorophyll-a concentrations ranging from below the analytical reporting limit to 0.0032 mg/l, with a median of 0.00025 mg/l (the default value for samples below the reporting limit), and an 95% upper confidence limit of 0.00174 mg/l (including 21 nondetects assumed to be half of the reporting limit).

The 29 points from the four stations on streams leading to Clear Lake Reservoir showed chlorophyll-a concentrations ranging from below the laboratory reporting limit to 0.016 mg/l, with a median of 0.00025 mg/l (this is half of the laboratory reporting limit), and a 95% upper confidence level of 0.00279 mg/l. Although most of the data points in this dataset are nondetects (17 nondetects out of 29 data points), for the statistical analysis, they were assumed to be half of the reporting limit.

Using the 57 observations in the complete dataset, the relationship between total phosphorus and chlorophyll-a was weak. The estimated change in chlorophyll-a (the response variable) per change in total phosphorus (the causal variable) is -0.0003 with a standard error of 0.0006. The value of R-Squared, the proportion of the variation in chlorophyll-a that can be accounted for by variation in total phosphorus, is 0.0051. The correlation between chlorophyll-a and total phosphorus is -0.0714, indicating a weak relationship.

7.3.6 Dissolved Oxygen

The Upper Lost River/Clear Lake Reservoir area is not listed as impaired for dissolved oxygen. This parameter, however, can be impacted by excessive biomass growth related to high nutrient concentrations. Diurnal cycles of algal respiration can lead to water that is photosynthetically supersaturated with dissolved oxygen in late afternoons and depressed in very early mornings by overnight respiration. The most sensitive beneficial use that could be impacted by low dissolved oxygen concentrations is the ESA-listed sucker species (see Section 4.0 of this document).

The amount of dissolved oxygen in water at 100% saturation is partly dependent on the altitude; the sampling stations in this analysis ranged in altitude from 4,163 to 4,921 feet above sea level.

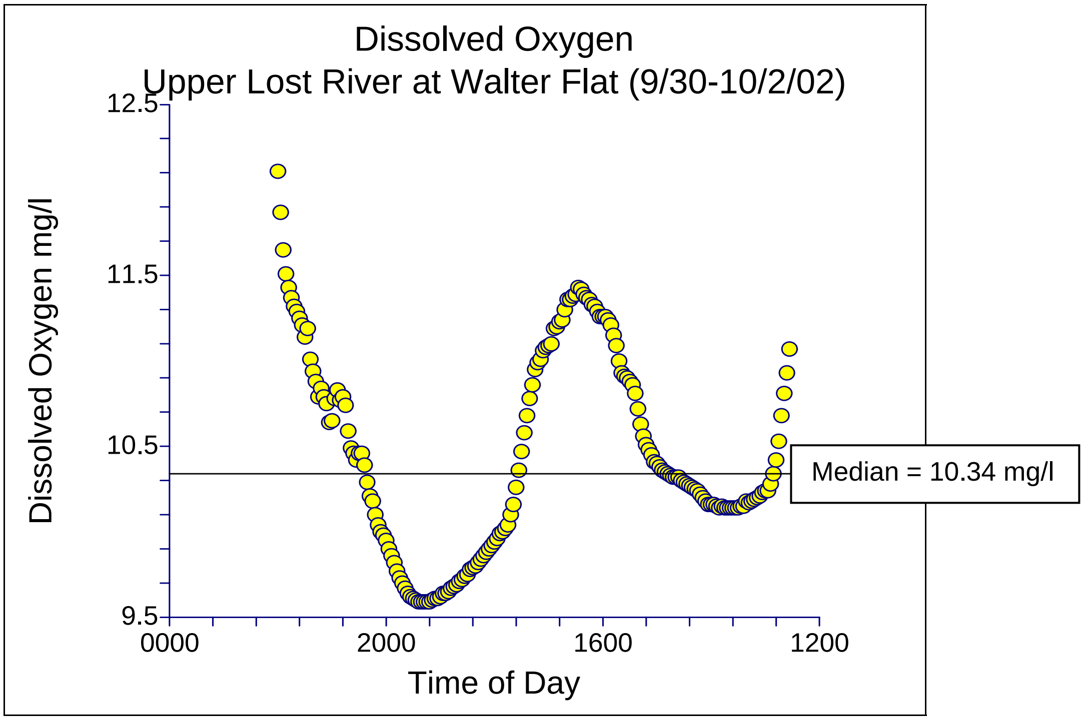
The water at this altitude can hold less dissolved oxygen, at 100% saturation, than water at lower elevations. Dissolved oxygen data at the six sampling stations consisted of instantaneous measurements at the time that grab samples were obtained and of two brief periods of continuous measurement.

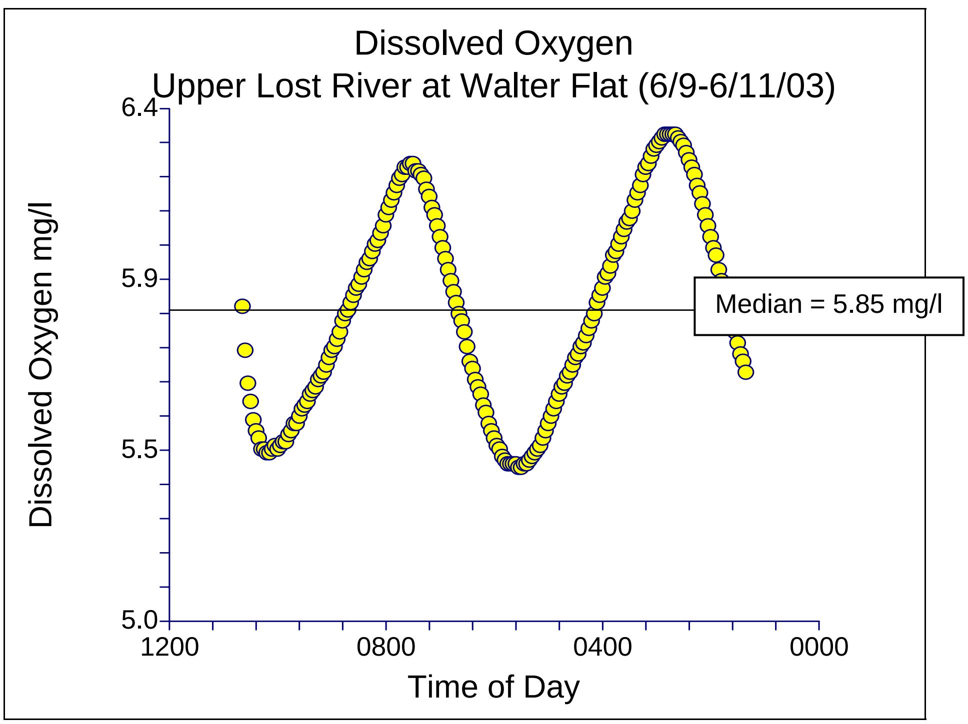
The Basin Plan (CRWQCB 1994) objectives for dissolved oxygen in the Upper Lost River/Clear Lake Reservoir area are 5.0 mg/l as a minimum and 8.0 as a 50% lower limit.[46] There were 57 instantaneous measurements of dissolved oxygen ranging from 6.1 mg/l to 13.02 mg/l. The mean value of these measurements is 8.83 mg/l, with a median of 8.53 mg/l, and a lower 95% confidence level of 8.44 mg/l. The high value of 13.02 mg/l was obtained at the Boles Creek station in October 2002 at a time when there was no surface flow; this value was taken at 14:30 and may represent a photosynthetically supersaturated condition. Field notes state that heavy algal growth was noted in the pool upstream of the dewatered area where samples were taken. The lowest values were still above the minimum required by the Basin Plan. The lowest value, 6.1 mg/l was obtained at 17:30 in June 2003 at Walter Flat. The next lowest value, 6.55 mg/l was obtained at 08:30 in August 2001 at the station just downstream of Clear Lake Reservoir dam.

Continuous dissolved oxygen measurements using a YSI Datasonde 6600 that measured dissolved oxygen, pH, specific conductivity, and water temperature at 15-minute increments were made in the Upper Lost River at Walter Flat from September 30 to October 2, 2002.[47] The data show a diurnal variation with a low of 9.59 mg/l and a high of 12.11 mg/l. The mean is 10.47 mg/l, the median is 10.34 mg/l, and the 95% lower confidence level is 10.38 mg/l. A Datasonde also was deployed at this station from June 9 through June 11, 2003. Again, a diurnal cycle is seen. The data from this sampling episode show warmer temperatures and lower dissolved oxygen concentrations, ranging from a low of 5.42 mg/l to a high of 6.32 mg/l. The mean of the measurements is 5.87 mg/l, the median is 5.85 mg/l, and the lower 95% confidence interval is 5.82 mg/l. The graphs below show the data from these sampling episodes.

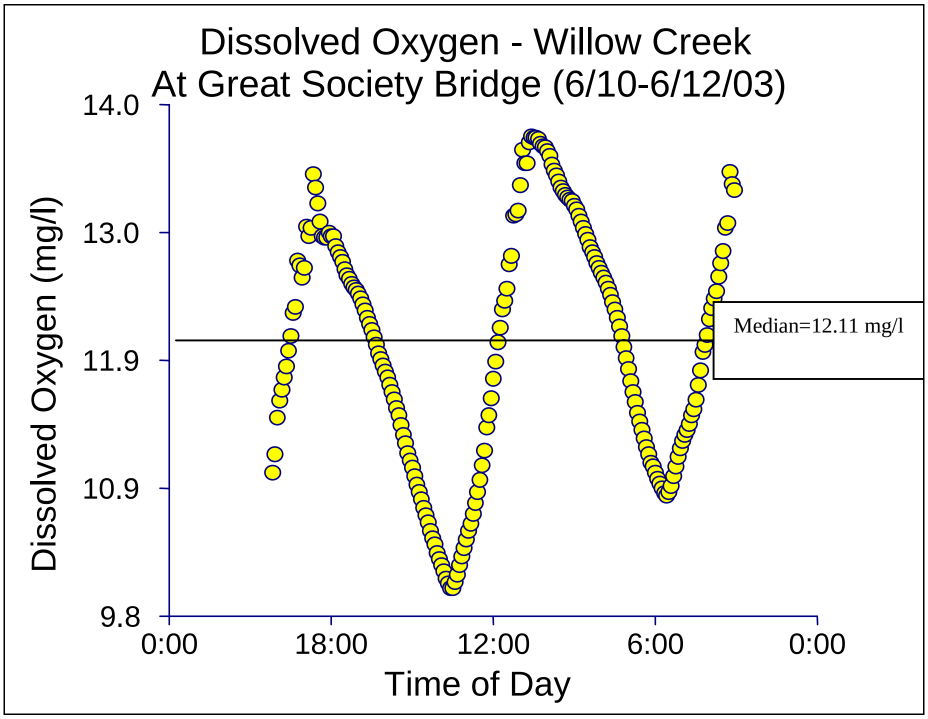
[46] The 50% lower limit means that 50% or more of the monthly mean values must be greater than or equal to the specified concentration, in this case, 50% of the monthly mean values must be greater than 8.0 mg/l.

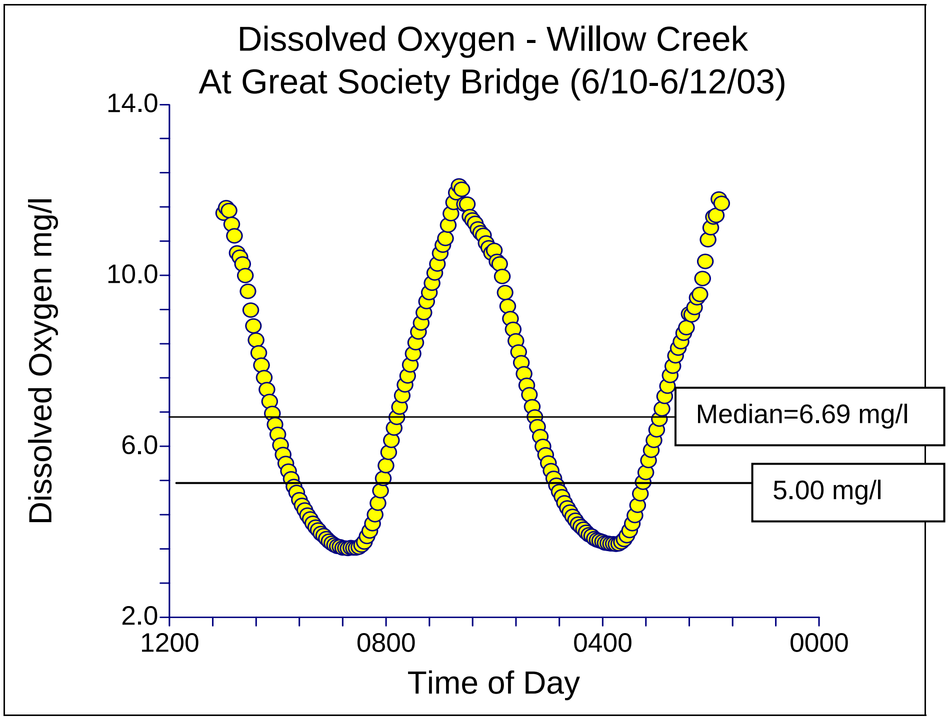
[47] Releases from Clear Lake Reservoir dam were halted for the season on October 1. The data after that time represents residual Clear Lake Reservoir water in the system along with groundwater accretions and surface water input from minor tributaries (principally Rock Creek).





Similarly, continuous dissolved oxygen measurements using a YSI Datasonde 6600 that measured dissolved oxygen, pH, specific conductivity, and water temperature at 15-minute increments were made in the Willow Creek sampling station from September 30 to October 2, 2002. The data show variation with a low of 10.03 mg/l and a high of 13.74 mg/l. The mean is 12.03 mg/l, the median is 12.11 mg/l, and the 95% lower confidence level is 11.89 mg/l. A Datasonde also was deployed at this station from June 10 through June 12, 2003. Again, a diurnal cycle is seen. The data from this sampling episode show warmer temperatures and lower dissolved oxygen concentrations, ranging from a low of 3.61 mg/l to a high of 12.1 mg/l. The mean of the measurements is 7.09 mg/l, the median is 6.69 mg/l, and the lower 95% confidence interval is 6.69 mg/l. Unfortunately, comparison of instantaneous dissolved oxygen measurements using a YSI 600 taken in Willow Creek at the same time the YSI 6600 Datasonde performed a reading on June 10 and June 12 shows significantly different readings. Field Winkler tests for dissolved oxygen also were performed and were significantly different from both instrument readings. This indicates a QA/QC problem that has not been resolved. The graphs below show the data from the continuous sampling episodes.





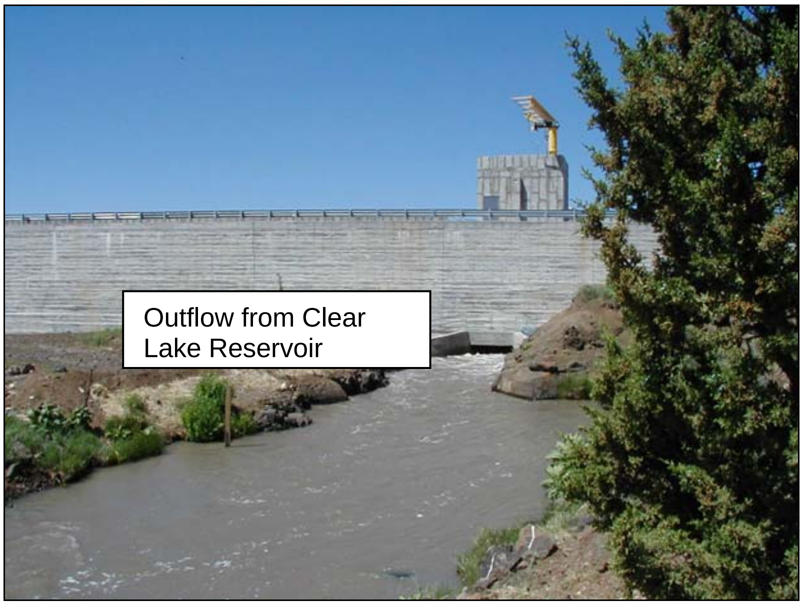
7.3.7 Turbidity

The water samples taken from two stations in the Upper Lost River downstream of Clear Lake Reservoir show high levels of turbidity. Results of the 28 samples ranged from 2.2 to 123 NTU, with a median value of 53.5 NTU. The two lowest values, 2.2 and 35 NTU, were taken at Walter Flat when there were no releases from Clear Lake Reservoir. The median of the 28 samples is 53.5 NTU. The turbidity levels in streams that feed Clear Lake Reservoir, by comparison, are far lower, ranging from 1.1 to 26.5 NTU. The median value for streams draining to Clear Lake Reservoir is 4.2 NTU. The highest value was from a sample obtained in a pool at Boles Creek after the creek was seasonally dewatered and may be related to algae growth. The relationship between total phosphorus and turbidity as demonstrated by the data collected in this analysis is not strong. The value of R-Squared, the proportion of the variation in total phosphorus that can be accounted for by variation in turbidity, is 0.0277. The correlation between total phosphorus and turbidity is -0.1663.

The Upper Lost River and Clear Lake Reservoir area is not listed as impaired for turbidity on the California CWA §303(d) list. Turbidity impairments are not the subject of this TMDL investigation, so the high turbidity levels were not explored. However, given the high levels of turbidity found in the Upper Lost River below Clear Lake Reservoir some discussion about turbidity is offered.

The purpose of the fall 2001 sampling was to gather data to develop the following year's sampling plan. There were no data gathered earlier that year so that the fall 2001 measurements could not be compared to conditions earlier that season. During the summer of 2002, a new dam at Clear Lake Reservoir was being constructed just downstream of the old, earthen dam. The new dam was to be the same height as the old dam, however, the new dam would allow the reservoir to hold more water with a larger surface area because concerns about the stability of the old dam kept the reservoir from being filled to capacity. Almost all of the data collected at the two Upper Lost River stations (WFLAT and LRCLDM) in 2002 may have been influenced by dam construction activities that disturbed sediment in the reservoir and adjacent shorelines. Dam construction was complete late in 2002. The two samples obtained in 2003 were obtained primarily to determine what effect, if any, the dam construction activities had on water quality in the Upper Lost River. In June 2003, several months after dam construction was completed, samples showed even higher levels of turbidity in the Upper Lost River.

The high turbidity in the Upper Lost River seems to be originating in Clear Lake Reservoir. The picture below shows releases from the reservoir on June 11, 2003.



Prior to the new dam construction during water quality sampling events from 1989 to 1994, the California Department of Water Resources (CDWR, unpublished data) obtained turbidity measurements from Clear Lake Reservoir. The turbidity ranged from 20 to 89 NTU in the lake. Perkins and Scoppettone (1996) reported other turbidity levels as part of a sucker radio-telemetry study conducted in March and April of 1995. The four samples taken from the west lobe of the reservoir showed turbidity from 86.8 to 90.1 NTU. Perkins and Scoppettone (1996) also reported on turbidity in Willow Creek (31.2 to 38.0 NTU), Boles Creek (27.1 to 27.7 NTU), and Fletcher Creek (7.4 to 15.6 NTU). While these levels are slightly higher than found in the Regional Water Board 2002 and 2003 sampling, they are much lower than reported in Clear Lake Reservoir during the same sampling events. The turbidity levels reported by Perkins and Scoppettone (1996) were taken in the spring when run-off events may produce higher turbidity levels than those measured in the summer of 2002 and 2003. Shively et al. (1999) reported on water quality in the Lost River in 1999. Their most upstream site was at Malone Reservoir, and they reported that this site had consistently high turbidity measurements, “presumably influenced by Clear Lake Reservoir.” From the graphs provided in Shively et al. (1999), the mean of the Malone Reservoir turbidity measurements was just over 60 NTU, with a high of 108 NTU (interestingly, the high turbidity measurement was obtained in mid-October, presumably after releases from Clear Lake Reservoir were halted for the season).

The turbidity levels at WFLAT and LRCLDM in 2002 (May through September) ranged up to 84 NTU while water was being released from the dam. When no releases from the dam occurred, turbidity ranged from 2 to 70 NTU. In mid-June of 2003, turbidity ranged from 105 to 120 NTU at WFLAT and LRCLDM.

In comparison, the major tributaries feeding Clear Lake Reservoir dam have much lower turbidity readings than those taken in the Upper Lost River below the dam. Turbidity in those tributaries in 2002 at MOWCRK, WCGSB, and FCFORD ranged from 1 to 9 NTU, while turbidity at BCFORD, which seasonally dewatered during the sampling period, ranged from 6 to 26 NTU.

The high turbidity levels originating from Clear Lake Reservoir may be due to a combination of factors. These factors include shallow reservoir waters, moderately erosive adjacent soils, potential loss of cover from grazing, loss of emergent riparian vegetation surrounding the reservoir by grazing and by the artificially varying water level, and the altered natural flow of water in the Lost River. The clay content and surface organic matter of the soils may keep the particles in a colloidal suspension that does not settle easily.

The shallow reservoir waters do not stratify significantly, and regular afternoon winds may keep the sediment suspended in the waters. The Puls-Roval Dishner Families complex of soils dominates the area around Clear Lake Reservoir (USDA Forest Service 1993). This complex of soils is readily manageable but poses a moderate erosion hazard due to slow permeability, shallow soil profile (10-20 inches), low water holding capacity with 15% to 35% coarse fragments (stony or cobbly clay loams or sandy clay loams) (USDA Forest Service 1993). Loss of cover by grazing along the shoreline may accelerate erosion in the moderate to highly erosive soils around Clear Lake Reservoir and contribute to the sediment load.

The loss of, or failure to reestablish, emergent and riparian vegetation may contribute further to sediment in the system. The rushes, sedges, and other emergent riparian vegetation trap sediments in the water as well as provide nutrient uptake, cooling, and fisheries habitat. Prior to the Klamath Project, the area now occupied by Clear Lake Reservoir was a natural lake and marsh/meadow complex that emptied into the Lost River and with very low flows from June through October (U.S. BOR 2000). The natural lake was estimated to be about one quarter of the size of the present Clear Lake Reservoir (Braunworth et al. 2002). The current fluctuating water levels in the reservoir due to high summer flows for irrigation in the Lost River below Clear Lake Reservoir and low flows in the winter have inhibited re-establishment of emergent riparian vegetation and near shore upland vegetation. This condition has led to sparsely vegetated shoreline along the reservoir, which is prone to wind and water erosion. Historically, it appears that the natural vegetation along with natural low flows in the summer might have diminished the turbidity levels far below what they are today. The shallow reservoir, erosive soils with high clay content (clay loam with 28% to 40% clay), and changes in the surrounding vegetation and water regimes may have contributed to today's turbidity levels.

There may be other anthropogenic sources of turbidity to the Upper Lost River system in addition to those mentioned above. Because of the re-constructed dam, the reservoir may now flood terrestrial areas that were not previously flooded, introducing a new source of sediment to the reservoir and the Upper Lost River. There also may be remnants of the old earthen dam suspended in the reservoir waters that are released to the Upper Lost River.

The high turbidity persists at least as far downstream as the WFLAT sampling station. The Regional Water Board does not have data downstream of WFLAT for comparison. We do not know if the high turbidity levels are temporary, and whether they may decline as sediment from the spring runoff (or from the remnants of the old dam or from newly flooded areas) settles. The only full season of data collected by the Regional Water Board, in the summer of 2002, do not show a seasonal decline, but dam construction activities may have provided an additional source of sediment or a mechanism for re-suspending sediment throughout that season. The increase in turbidity between 2001 and 2003 is interesting and the levels are sufficiently high that the impact of turbidity on beneficial uses should be investigated further. At a future date, downstream Oregon water quality investigations might prompt a revisit of the Upper Lost River turbidity levels, especially if downstream beneficial uses in Oregon are impaired by high turbidity. Further studies in the turbidity levels and riparian re-vegetation around Clear Lake Reservoir may be needed.

7.3.8 Other Parameters

In addition to the water quality parameters already discussed, water samples were analyzed for minerals and trace metals. The metals were analyzed as total (unfiltered) not dissolved metals. The concentrations of dissolved metals may be significantly less. Dissolved metals are more readily bioavailable. The information on trace metal concentrations in the water samples was collected to use as a comparison of upstream trace metals concentrations before the influence of groundwater that is pumped into the Lost River downstream of the study area.

Barium was present in all samples at levels that ranged from 0.010 mg/l (the analytical reporting limit) to 0.077 mg/l. Vanadium was present above the reporting limit in 33 of 57 samples ranging from 0.010 mg/l to 0.036 mg/l. There were nine reports of chromium above the reporting limit, ranging from 0.010 mg/l to 0.016 mg/l. Cobalt was reported in two samples at levels of 0.0076 mg/l and 0.010 mg/l. Cadmium was reported in two samples at levels of 0.027 mg/l and 0.015 mg/l.

The analytical results of unfiltered metals may be related to soil particles suspended in the water. The presence of these metals in the soils can be explained by isomorphic substitution (replacement of one element for another). Basalt flows comprise the majority of rocks found in the Upper Lost River watershed. Basalt is an igneous rock composed of plagioclase feldspar minerals (high in calcium and sodium), pyroxene minerals (high in iron and magnesium), olivine (high in magnesium), and other accessory minerals containing manganese, potassium, and phosphorus. The trace metals found in the water samples can be linked to their presence in the basalt minerals. Barium substitutes for calcium or sodium in the plagioclase. Cadmium, chromium, and vanadium substitute for iron in the pyroxenes.

Iron concentrations were analyzed to understand the dynamics of nutrient use by phytoplankton. Iron was present in all samples, ranging from 0.11 to 9.30 mg/l (the median concentration equals 1.95 mg/l).

7.4 Data Conclusions

The total nitrogen concentrations found in this analysis are well below the 10 mg/l NO_3-N set by the U.S. EPA (1986) to protect human health from domestic water supplies. Calculations of the percentage of ammonia present as the toxic un-ionized ammonia were not necessary because the concentration of total ammonia at all of the stations is well below the level needed to protect the sensitive stages of the sucker population. Median total phosphorus concentrations in the two Upper Lost River stations were above the 0.05 mg/l level suggested by the U.S. EPA to control eutrophication in streams that enter lakes (U.S. EPA 1986). Neither visual observations nor water column chlorophyll-a measurements indicated impairment due to excess phosphorus. Turbidity in the reservoir and in the Upper Lost River probably influences water quality to reduce the impact of phosphorus. The high turbidity in Clear Lake Reservoir keeps sunlight from penetrating the water column, limiting primary production. In the streams leading to Clear Lake Reservoir, some algal growth was noted late in the season, especially at Mowitz Creek and at Boles Creek after the surface water flow ceased, but the growth was not deemed to be excessive. Although, there was no fixed ratio between total nitrogen and total phosphorus in the 57 observations in the dataset (the ratio ranged from 0 to 74), when non-detects and the one phosphorus outlier were removed from the data it is clear that the system is nitrogen rather than phosphorus limited.

These data do not indicate over-enrichment of the water bodies. Phosphorus is present in the water systems. Nitrogen is present, but more limiting. Blue-green algae, widely present in the Lower Lost River and mainstem Klamath River system, can fix atmospheric nitrogen to ammonia and depend on the presence of phosphorus in the water for growth. Dissolved oxygen measurements do not indicate that over-enrichment by biostimulatory substances is affecting the endangered sucker species. Assuming the continuous readings at Willow Creek in June 2003 are accurate (in spite of the unresolved QA issues mentioned earlier), and assuming suckers were present in the stream at the time of the readings, the levels are well within the tolerance limits of the suckers.[48] The lack of chlorophyll-a in the water in the samples obtained for this analysis indicates that either the level of nutrients is too low to support excess algal growth or that some other factor is suppressing the algal growth. In either case, the beneficial uses of the Upper Lost River/Clear Lake Reservoir system are not impaired by nutrient concentrations. The high turbidity in the Clear Lake Reservoir and the Upper Lost River stations might suppress growth of blue-green algae by limiting light penetration. Attached algal growth was noted at the four stations in streams draining to Clear Lake Reservoir (especially the station at Mowitz Creek), but the water was clear and the growth was not deemed excessive. No objective measurement of this growth was conducted. No attached or water-column algal growth was noted in the two stations in the Upper Lost River downstream of Clear Lake Reservoir. A more complete analysis would include evaluation of the attached and water-column biomass.

Computer simulation modeling suggests that decreasing solar radiation by increasing shade over the streams that drain into Clear Lake Reservoir could decrease water temperatures in those streams. The potential for increasing the shade from riparian vegetation is unlikely in all of these streams except for Willow Creek because of the inability of the soils to support increased

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48 Although the dissolved oxygen levels may support the sensitive beneficial uses, additional work is needed to show if the waterbody meets Basin Plan water quality standards.

vegetative growth.[49] The Upper Lost River is most impacted by the water temperature of the water released from Clear Lake Reservoir, not by solar radiation inputs. Even at current shade levels, the water temperature in the watershed supports the most sensitive beneficial use – the ESA-listed sucker species.

The MWAT values calculated for the warmest week of the sampling period (22.75°C to 27.40°C) indicates values above the criterion for redband trout (22°C) suggested by Gamperl and Rodnick (2003).[50] As discussed in detail in Section 5.0 and Appendix B, however, it is unlikely that redband trout are found in the Upper Lost River/Clear Lake Reservoir drainage.

7.5 Data Limitations

There are some limitations to the data used in this analysis. None of the data gaps impede drawing conclusions about the water quality in the watershed, but addressing the limitations can add weight to the conclusions. The primary limitations are listed here and discussed below.

- The dataset is not robust. It is limited to monthly grab samples and instantaneous measurements for one season, continuous temperature monitoring for one season, and two short continuous multiparameter deployments.
- The sampling periods do not correspond to the time periods that the suckers are in the streams.
- There were limited spots at which the streams could be accessed; these might not correspond to the points that provide representative data.
- A new Clear Lake Reservoir dam was being constructed during the time that samples were obtained.
- A strong QA/QC protocol was not adopted until after much of the data were collected.
- There are gaps in the data.

The dataset is not robust. It represents only one full season – late spring to early fall – of one year. Climatic variability or natural oscillations in sucker fecundity, mortality, food availability, or stress may change the impact of conditions that were relied upon in this analysis. To some extent this limitation can be addressed by relying on supporting conclusions or data from other sources. The USFWS (1996) Biological Opinion, for example, states that water temperatures in the Clear Lake Reservoir area support suckers: "Water temperatures generally remain below 72°F, within the tolerance range of the suckers, but peak at above 75°F for one to four days during the summer."

The sampling stations represent points at which the streams could be accessed. They may not provide data that is representative of the entire stream or even of a reach. Typically, several sampling stations are chosen that can represent water quality parameters in a waterbody because spatial gradients might exist for the parameters. Diurnal cycles may influence parameters such as

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[49] Much of the area has poor soils that cannot support dense riparian growth. The soils tend to be shallow on recent basalt flows. The only significant riparian trees are found in the upper and middle reaches of Willow Creek where the basalt flows are older and have weathered to produce deeper soils. See the discussion of vegetation in Section 1 of this document. Emergent sedges and reeds in the streams leading to Clear Lake Reservoir may provide some shading. This possibility suggests that such growth should be protected from grazing activities.

[50] See this discussion in Appendix B.

nutrients, dissolved oxygen, temperature, and pH. The remoteness of the sampling locations made collection of diurnal data difficult.

The sampling period and locations – sampling during the summer months in streams – do not represent the time when suckers are present in the streams. Shortnose and Lost River suckers are lacustrine species that spawn in the streams in the late winter and early spring and return to the lake after spawning. Juveniles migrate from their natal streams to the lake shortly after hatching. Suckers are not in the streams at the time of sampling. The sampling period was set based on the inaccessibility of the area except from late spring to early fall. Drawing conclusions about the impact of water temperature and nutrients on suckers based on sampling during summer, however, is justified because those months represent the conditions worse than the fish encounter during their time in the streams. This is clearly true of water temperature, which is higher in the summer than in the winter and spring. Nutrient levels may be higher in the winter and spring because of high flows and surface runoff, but the deleterious impact of the nutrients, particularly low dissolved oxygen caused by nutrient-inspired biomass growth, would not be a problem until summer. Low temperatures, affecting both algal growth and the amount of oxygen that can be dissolved in water and a short photoperiod would ameliorate the effects of possibly higher nutrient concentrations in the winter and early spring. If conditions during the months that were sampled support the beneficial use, there is an implicit added margin of safety to this analysis.

During the summer of 2002, a new dam at Clear Lake Reservoir was being constructed just downstream of the old, earthen dam. Water quality downstream of the dam could have been affected by the construction activities in addition to possible impacts caused by flooding new lakeshore areas. The new dam was to be the same height as the old dam, however, the new dam would allow the reservoir to hold more water with a larger surface area because concerns about the stability of the old dam kept the reservoir from being filled to capacity. Almost all of the data collected at the two Upper Lost River stations (just below the dam and at Walter Flat) in 2002 may have been influenced by dam construction activities that disturbed sediment in the reservoir and adjacent shorelines. Dam construction was complete late in 2002. The two samples obtained in 2003 were obtained primarily to determine what effect, if any, the dam construction activities had on water quality in the Upper Lost River. Unfortunately, these samples were not sufficient to fully describe the impact of the new dam construction on water quality. In June 2003, several months after dam construction was completed, samples continued to show high levels of turbidity at the two stations on the Upper Lost River. The impact of dam construction activities may have extended beyond the impact on turbidity; without a more complete sampling program, other possible effects cannot be measured.

If a rigorous QA/QC plan had been developed and implemented sooner in the analysis, the issue of the total phosphorus/ortho-phosphate results would have been noted in time for a re-analysis. The dissolved oxygen discrepancies between the instantaneous measurements, continuous measurements, and field Winkler tests at the Willow Creek station have not been resolved.

The study design, short study period, and inaccessibility of the watershed contributed to gaps in the data. A longer period for the analysis could have provided time for the sampling plan to be adjusted if conditions warranted. In particular, the data gaps of concern include analysis for water-column chlorophyll-a without a corresponding analysis of biomass. The relationship between nutrients, dissolved oxygen and biomass must be better understood for a complete analysis of limiting factors in the watershed. Additionally, an analysis of soils in the watershed and the impact of soils on the levels of nutrients (notably phosphorus) in the water would be helpful.

8.0 CONCLUSIONS

The application of the habitat requirements of aquatic species to the development of a TMDL suggests the three questions asked by Spence et al. (1996) relative to water temperature:

> Do temperatures exceed the maximum tolerable level for the particular species? Are temperatures within the preferred temperature range during each specific life stage? And do temperatures depart significantly from the natural range of variability for the particular body of water? This latter question is critically important because of local adaptation of individual salmonid stocks to the specific thermal regimes in their spawning and rearing streams.

These same questions are pertinent to nutrients in addition to water temperature. Regional Water Board staff has seen no information showing that the natural range of water temperature or nutrient concentrations in the streams draining into Clear Lake Reservoir is outside of the natural range for that environment due to anthropogenic causes.

Clear Lake Reservoir appears to possess a healthy population of Lost River and shortnose suckers compared to other populations. The water quality and habitat conditions in the reservoir and its tributaries are better than elsewhere in the Klamath River and Lost River basins. "Clear Lake is a comparatively pristine environment and probably has the greatest potential for maintaining viable populations of this species and the shortnose sucker. Water quality conditions in Clear Lake are generally good, and the surrounding watershed is relatively undeveloped compared with conditions elsewhere."[51] The relative health of the Clear Lake Reservoir Lost River and shortnose sucker population provides a cushion for years when recruitment is low. "Because of the relatively consistent recruitment, and diverse age structure of the endangered sucker populations in Clear Lake, longer gaps in recruitment can occur at Clear Lake than at Upper Klamath Lake without harm to present populations."[52]

Moyle (2002) summarized the current status of the suckers and discusses the importance of Clear Lake Reservoir in maintaining a relatively healthy population of suckers:

> Lost River suckers and their principal habitats have been subjected to just about every environmental insult possible, with no end in sight. The suckers are gone from Lower Klamath and Sheepy Lakes, uncommon in Upper Klamath and Tule Lake, and common only in Clear Lake Reservoir. That a few thousand fish manage to hang on in various lakes is a tribute to their longevity, fecundity, and persistence in spawning.

Moyle (2002) believes that the recent rebuilding of the dam at Clear Lake Reservoir and the resulting increase in size of the reservoir is a positive development for the sucker population:

> On the other hand, by increasing the size of Clear Lake Reservoir, this dam may have increased the amount of habitat for fish during most years, and it may be the long-term best hope for the species. Ironically, the large, shallow lake was created as a means for evaporating large quantities of water in order to reduce the amount of water flowing to the Tule Lake region. However, in the drought years of 1991 and 1992 Clear Lake Reservoir was drawn down so low (maximum depth 1.2 m) by the Bureau of Reclamation to supply water to farmers that many fish were lost downstream (17). Concern over the survival of the remaining fish in the face of winter freezing was so great that some were captured and sent to Dexter National Fish Hatchery in New Mexico as potential brood stock.

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[51] CDFG 2000

[52] U.S. FWS 1992

Given the value of Willow Creek for Lost River and shortnose sucker spawning, its riparian area should be protected from harmful land management activities. The soils along this drainage are more developed and can support more complex riparian vegetation, including willows and Ponderosa pines, than other streams in this study area (Smith and Davidson 2003). Willow trees in the Willow Creek riparian area should be allowed to reach a mature size, providing protection for spawning sites. Restoration of full functionality to other streams in the watershed should be considered to provide additional sucker spawning areas, although the amount of riparian vegetation that can be expected along other streams in the drainage is low, emergent vegetation could provide value to aquatic habitat.

Unlike the streams draining to Clear Lake Reservoir, alterations in hydrologic regime in the Upper Lost River and the Clear Lake Reservoir have impacted the natural temperature and nutrient regimes in the mainstem Lost River. The alteration in hydrologic regime between Clear Lake Reservoir and Malone Reservoir at the Oregon border has resulted in a change in natural water temperatures due to high, turbid flows in the summer and very low flows in the winter. Creation of a reservoir in what naturally was an extensive wetland with emergent vegetation may have resulted in a change to the nutrient concentrations to the reservoir and to the river due to flooding of terrestrial areas and reduction of emergent and riparian vegetation. The shallow depth of the reservoir also may impact nutrient concentrations by the large areal extent of terrestrial flooding and the lack of stratification that may keep sediment suspended in the water column. The soils around Clear Lake Reservoir are shallow and moderately to highly erosive, especially if riparian and emergent vegetation cannot be maintained. The operation of the dam and the lack of fish passage at either Clear Lake or Malone Reservoir may have altered the habitat sufficiently that any suckers or redband trout that may have been present in the Upper Lost River were displaced. Although additional research would assist in answering these questions, addressing hydrologic regime changes and habitat fragmentation is beyond the scope of this analysis because these changes are not considered "pollutants"[53] for the purposes of TMDLs.

It is not beyond the scope of the Regional Water Board's authority under the Clean Water Act, however, to establish minimum instream flow requirements in order to support beneficial uses. The Supreme Court said that a strict distinction between water quality and water quantity is an artificial distinction:[54]

> Petitioners also assert more generally that the Clean Water Act is only concerned with water "quality," and does not allow the regulation of water "quantity." This is an artificial distinction. In many cases, water quantity is closely related to water quality; a sufficient lowering of the water quantity in a body of water could destroy all of its designated uses, be it for drinking water, recreation, navigation or, as here, as a fishery. In any event, there is recognition in the Clean Water Act itself that reduced stream flow, *i.e.*, diminishment of water quantity, can constitute water pollution. First, the Act's definition of pollution as "the man made or man induced alteration of the chemical, physical, biological, and radiological integrity of water" encompasses the effects of reduced water quantity. 33 U.S.C. § 1362(19). This broad conception of pollution – one which expressly evinces Congress' concern with the physical and biological integrity of water – refutes petitioners' assertion that the Act draws a sharp distinction between the regulation of water

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53 Section 303(d)(1)(C) states that "each State shall establish for the waters identified in paragraph (1)(A) of this subsection, and in accordance with the priority ranking, the total maximum daily load, for those pollutants which the Administrator identifies under section 304(a)(2) as suitable for such calculation.

54 US Supreme Ct Decision No. 92-1911, May 31, 1994, PUD No 1 of Jefferson County and City of Tacoma v. Washington Department of Ecology, 511 U.S. 700, 114 S. Ct. 1900, 128 L. Ed 2d 716, 1994.

> "quantity" and water "quality." Moreover, §304 of the Act expressly recognizes that water "pollution" may result from "changes in the movement, flow, or circulation of any navigable waters . . . including changes caused by the construction of dams." 33 U.S.C. § 1314(f). This concern with the flowage effects of dams and other diversions is also embodied in the EPA regulations, which expressly require existing dams to be operated to attain designated uses. 40 CFR § 131.10(g)(4).

The Regional Water Board may wish to consider its authority, apart from this TMDL analysis, in the quantity vs. quality issue more explicitly in the Klamath River Basin.

9.0 RECOMMENDATIONS

9.1 De-listing

The data and analysis support removing the Upper Lost River/Clear Lake Reservoir area from the 303(d) list for temperature and nutrients.

9.2 De-listing Mechanism

It is recommended that this document serve as the basis to support the removal of the Upper Lost River and Clear Lake Reservoir area from the CWA §303(d) Listing of Impaired Waterbodies in the regularly scheduled listing/de-listing cycle.

9.3 Additional Analysis

The water quality analysis for the Upper Lost River and Clear Lake Reservoir waterbodies indicates that habitat fragmentation, flow alterations, and changes to the natural hydrologic regime are adversely affecting beneficial uses. A more complete analysis of the links between these alterations and water quality in these waterbodies should be conducted, using more robust water quality data.

Additional water quality investigations may be needed to strengthen this assessment, if the watershed is listed as impaired for other parameters in California (such as turbidity), or if TMDL investigations by the State of Oregon indicate that impairments in the Lost River in Oregon are related to conditions upstream in California. Dissolved oxygen data, data about attached biomass, information about diurnal fluctuations and seasonal variation, turbidity data, and water quality data from Clear Lake Reservoir may be useful.

9.4 Water Quantity vs. Water Quality

The North Coast Regional Water Quality Control Board should consider a detailed review of its authority concerning the impact of habitat fragmentation and water quantity on water quality and beneficial uses with the goal of restoring watershed functions so that proper conditions to support beneficial uses are attained.

9.5 Protection of Willow Creek

The ESA-listed sucker species in the Upper Lost River/Clear Lake Reservoir area spawn almost entirely in one tributary to the reservoir, North Fork Willow Creek. The riparian habitat in this tributary should be protected from potential adverse effects of grazing, forestry activities, or water diversions. This recommendation is supported by the National Research Council (2003), which recommends "Rigorous protection of tributary spawning areas on Clear Lake and Gerber Reservoir where populations [*of endangered suckers*] are apparently stable."

9.6 Reduce Sediment Entering the Upper Lost River

Sediment entering the Upper Lost River may be controlled if sediment entering the Clear Lake Reservoir is controlled. The impact of changing lake elevation and grazing along the shoreline and near-shoreline areas around the reservoir on suppressing riparian and emergent should be evaluated.

9.7 Evaluate the “Cold Water” Beneficial Use Designation

The presence of redband trout or other cold water species could not be confirmed in the Upper Lost River/Clear Lake Reservoir area. In order to definitively confirm or deny the presence of cold water species in the watershed, the Regional Water Board should support a biological survey in the area. Meanwhile, the possibility of the presence of a cold water species should not be used to mandate more stringent water quality requirements where the natural environment does not support those conditions. The potential for redband trout to exist in the Upper Lost River if the dams were removed and natural flow regimes were restored should be explored in any future evaluation of the beneficial uses in this watershed.

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Appendix A
Upper Lost River and Clear Lake Reservoir Watershed Stream Temperature Analysis

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Appendix A
Upper Lost River and Clear Lake Reservoir Watershed Stream Temperature Analysis

Carey Wilder, North Coast Regional Water Quality Control Board

A.1 Sources of Increased Stream Temperatures

The water bodies in the Upper Lost River watershed are included on the 303(d) list as impaired for temperature. Because there are no known point sources of heat input to the streams of the Upper Lost River watershed, temperature loads from point sources are not considered further in this document.

Temperature is a measure of the heat energy per unit volume of a material. Elevated stream temperatures equate to increases in heat energy derived from solar radiation and other sources. However, the main source of increased energy entering a stream is from sunlight. As more sunlight reaches a stream it raises the water temperatures.

The narrative water quality objective for temperature (Section 2.0) states that the natural receiving water temperature of interstate water shall not be altered. To meet this objective, solar radiation inputs and effective shade will be analyzed to determine if there are alterations of natural receiving water temperatures from anthropogenic activities.

A.2 Summary

In evaluating the influence of human activities on stream temperatures, the areas adjacent to streams, that is the riparian corridors, are most critical. It is near the streams that a change of conditions can allow increased sunlight to reach streams directly and raise temperatures.

The source analysis focuses on natural and management-related (non-point) controls on solar radiation inputs to streams. There are no known point sources of heat to the Upper Lost River or its tributaries. This section looks at factors affecting stream temperatures during the summer when peak temperatures occur. Those factors include streamside shading, stream flow, the width and depth of wetted stream channels, and microclimate influences as possible controls related to management activities to account for observed stream temperatures. The summer peak temperatures represent worst case conditions because solar radiation inputs are the greatest and increases in solar radiation have the greatest effect on stream temperatures.

SSTEMP, a public domain model currently supported by the United States Geological Survey, is used to evaluate the effects of stream heating mechanisms in streams (Bartholow 2002), and was utilized in this analysis for the Upper Lost River.

The results of the SSTEMP modeling analysis show that changes in channel geometry and riparian conditions can increase or decrease stream temperatures. Specifically, increases in solar radiation inputs to streams result in elevated stream temperatures. Microclimate alteration due to reduction of riparian vegetation is not readily predictable, although the phenomenon has been well documented (Jones et al. 1990).

A.3 Temperature Sources: 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 include heat gain from direct solar (short–wave) radiation, both gain and loss of heat through long-wave radiation, convection, conduction, and advection, and heat loss from evaporation (Brown 1980; Beschta et al. 1987; Sinokrot and Stefan 1993; Theurer et al. 1984). These processes are described below:

- 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 the 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, shade from streamside forests and vegetation can be a significant control on direct solar radiation reaching streams (Beschta et al. 1987).

- Long-wave radiation emitted from the water surface can cool streams. Heat exchange via long-wave radiation at a stream surface is a function of the difference between air temperature and water surface temperature (Sinokrot and Stefan 1993; ODEQ 2000). 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 (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.

A.4 Analytical Methods and Results

The approach taken to develop the Upper Lost River Temperature analysis involved the use of a computer simulation model along with a thermal infrared and color videography (TIR/Visible band) aerial survey to investigate stream heating processes. The SSTEMP model was used to evaluate the relative importance of the various factors that affect stream temperatures. The SSTEMP model is intended for application to a segment or reach of a stream or river (Bartholow 2002). The TIR/Visible band survey was used during calibration of the SSTEMP model.

Limited data is available on the spatial and temporal distribution of stream and air temperature in the Upper Lost River watershed. Values for some parameters, including the wetted widths of streams, active channel widths, and flow rates necessary for stream temperature modeling are scarce. Given the lack of data in some areas, these parameters were estimated based on relationships developed from existing data. The following sections describe the data requirements of the model, how the data was developed, and the results of the modeling exercise.

A.4.1 Stream Temperature Simulation

The dynamics of stream heating processes are complex and non-linear. The degree to which a change in one factor will affect stream temperature depends on the values of other factors. Regional Water Board staff used the SSTEMP model to evaluate the importance and interaction of the relevant factors acting on stream temperatures in the Upper Lost River watershed. Stream temperature modeling is a well developed area of investigation and has been used extensively throughout the world to understand stream heating processes (Bartholow, 2002). The model was used to identify which factors affect stream temperatures the most and to evaluate the potential change in stream temperatures that could be expected under alternate riparian conditions, i.e. increased shade. The parameters required by the SSTEMP model are listed in Table A.1.

The five segments modeled in this study were chosen where historical data exists as well as the ability for NCWRCB staff to access each sample location.

Table A.1 SSTEMP model input requirements	
Hydrology Segment Inflow* Inflow Temperature* Segment Outflow* Accretion (Groundwater) Temperature* Geometry Latitude (°) Segment Length Upstream Elevation Downstream Elevation Width's A Term (a measure of width-to-depth ratio)* Manning's n * Dam at Head of Segment	Meteorology Air Temperature* Relative Humidity* Wind Speed* Ground Temperature* Thermal Gradient (j/m^2/s/C)* Possible Sun (%)* Solar Radiation* Shade Total Shade(%)* Time of Year Month/Day
* Input parameter that was varied as part of the sensitivity analysis.	

Model Inputs: The parameters required for the model were determined before the start of the study. This allowed for collection of adequate data to run the model successfully. The time of year chosen for this study was the summer peak temperatures, which represent the worst case conditions because solar radiation inputs are the greatest and increases in solar radiation have the greatest effect on stream temperatures.

Topography: Model input parameters such as length, upstream and downstream elevation, and latitude for each segment were obtained with the aid of United States Geological Survey maps at the scale of 1:24,000.

Vegetation Extent: During the SSTEMP model development, input on the vegetation extent is required for both potential and current vegetation conditions. The extent of vegetation and the shade provided to the stream was surveyed through solar pathfinder surveys done for each segment. Solar Pathfinder measurements were taken by NCRWQB staff at 50 meter intervals on both ends of each segment for approximately 300 meters. These measurements provide total percent shade reaching the stream.

Meteorological Data: The Western Regional Climate Center maintains one weather station within the watershed. It is located in Devils Garden, California (41° 31’ 19”N, 120° 40’ 05”W) with an elevation of 5022 feet above sea level. This weather station is located in Modoc County at the Devils Garden airport, which is approximately 8 miles west/northwest of the city of Alturas. The study area monitoring station elevations range from 4163 to 4921 feet above sea level, and are approximately 10 miles northwest of the weather station. This weather station provided the following parameters: average annual air temperature (ground & groundwater temperature) as well as, mean daily values for wind speed, solar radiation and relative humidity.

The remaining two meteorological parameters, possible sun and thermal gradient, used the SSTEMP models suggested values. All input data for each simulation scenario can be referred to at the end of this temperature analysis.

Hydrological Data: The hydrological data required for input into the SSTEMP model included: water temperature, flow measurements and stream widths. The literature value suggested by SSTEMP for Manning's n of 0.035 was used in all modeled segments.

Stream Flow Estimation: Stream flow was measured at the upstream end of each segment using the protocols contained in the Klamath River basin QAPP. Flow equipment included a top-setting wading rod, Marsh-McBirney electrical flow device, field book, measuring tape and two stakes. Stream flows were measured monthly from May through October 2002. Measurements were taken on the North Fork Willow Creek at the Great Society Bridge, Mowitz Creek and Boles Creek at the Road 136 crossing, the Lost River just below Clear Lake Reservoir and at Walter Flat. Due to the lack of time, data, or access, flow upstream was assumed to be equal to that of the flow downstream for all of the segments.

Stream Width Estimates: The SSTEMP requires an estimate of mean width as a function of discharge: $W = A*Q^b$. The width's A term is derived by calculating the wetted width-discharge relationship. The width's B term is then determined by plotting the stream width of the segment on the Y-axis and stream discharge on the X-axis. This relationship approximates a straight line, the slope of which is the B term.

Ground and Groundwater Temperature: Ground and groundwater temperatures were assumed to be equal to the mean annual air temperature. Mean annual air temperature was part of the meteorological data obtained from the Devils Garden weather station for the year of 2002.

Inflow Temperatures: Inflow temperatures were continuously measured at one hour intervals for each segment for the period represented in figure A.1. These data were used for model calibration, and determination of any beneficial use impairment related to stream temperatures.

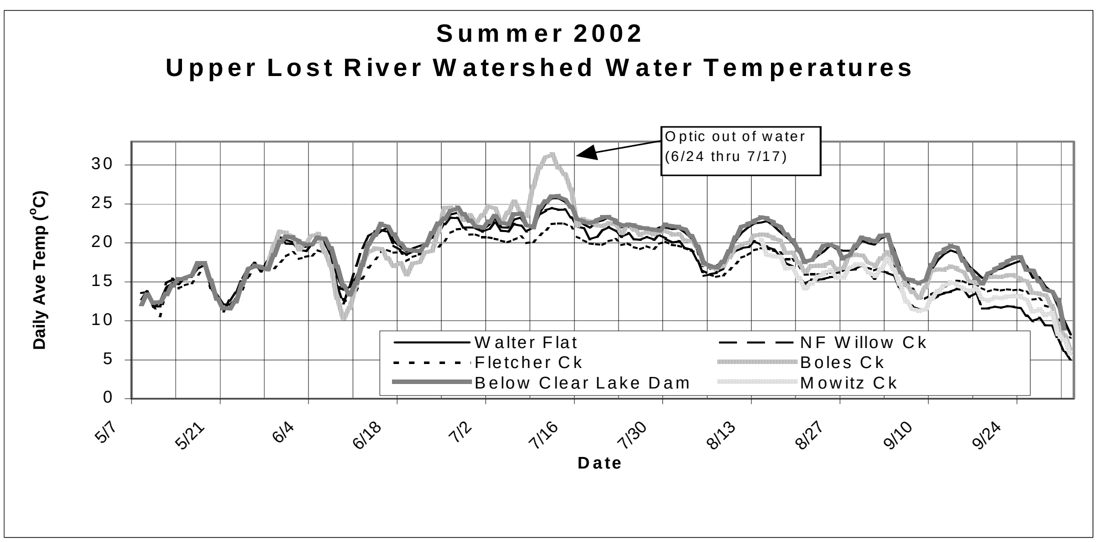


Figure A.1 – Water Temperatures Measured Continuously for Each Segment

Sensitivity Analysis: Sensitivity analysis is a technique that can be used to understand the influences that various stream geometry, meteorological, and hydrological conditions have on stream temperature (Bartholow 2002). The primary uses for sensitivity analysis in this report are to rank parameters and their interactions according to effects on predicted stream temperatures.

The sensitivity analysis approach used in this analysis is based on varying the value of one parameter while holding others constant. The approach uses the SSTEMP model to estimate the magnitude of effects that meteorological and stream conditions have on stream temperatures by using reasonable values of these parameters under different scenarios (Table A.2). This approach investigates the effect an individual parameter has on stream temperatures in segments located in the tributaries of the watershed and segments lower in the mainstem channel of the watershed. The Upper Lost River from just below Clear Lake Reservoir to Walter Flat was chosen to represent mainstem habitats while the North Fork Willow Creek from Weed Valley to the Great Society Bridge was chosen to represent low order streams for the tributaries of the Upper Lost River watershed. The North Fork Willow Creek is the primary spawning stream for the aquatic species present, as well as providing the majority of flow to Clear Lake Reservoir and therefore was chosen to represent the tributaries of the watershed. Note, the riparian corridor of North Fork Willow Creek supports areas of dense conifers and willows, a characteristic not seen in the other tributaries, therefore the shade values are considerably higher for this segment, and cannot be directly applied to the other tributary segments.

Table A.2 Summary of parameters and initial values used for SSTEMP sensitivity analysis

Parameter	Units	Reference Value (Daily Average)		
		Willow Creek	Clear Lake Reservoir to Walter Flat	Dependence
Air Temperature	°C (°F)	30.4 (86.7)	29.44 (85.0)	+
Total Shade	%	12.6	3.42	-
Relative Humidity	%	20	20	+
Accretion Temperature	°C (°F)	9.7 (49.5)	9.7 (49.5)	+
Width's A Term	Dimensionless	2.34	2.17	+
Width's B Term	Dimensionless	0.0088	0.0357	+
Segment Outflow	cms (cfs)	0.0110 (0.39)	3.596 (127)	-
Possible Sun	%	90	90	+
Ground Temperature	°C (°F)	9.7 (49.5)	9.7 (49.5)	+
Manning's n	Dimensionless	0.035	0.035	+
Wind Speed	m/s	3.3	3.3	-
Thermal Gradient	Joules/m^2/sec/°C	1.65	1.65	-
Dust Coefficient	Dimensionless	5	5	-
Ground Reflectivity	%	10	15	-
Segment Inflow	cms (cfs)	0.0110 (0.39)	3.596 (127)	+
Inflow Temperature	°C (°F)	24.18 (75.5)	25.3 (77.5)	+

Note: Sensitivity analysis performed using SSTEMP sensitivity analysis function. Parameters were varied +/- 10% from the Initial Value.

Note: Dependence column indicates temperature was directly dependent (+) or inversely dependent (-) on the parameter.

The input parameters used for the sensitivity analysis of individual parameters are marked with an asterisk in Table A.1. The values of the parameters were varied individually +/- 10% from the initial conditions. The initial conditions and ranges of variation are presented in Table A.2.

Sensitivity Analysis Results: Results of the sensitivity analysis are presented in Figures A.2 and A.3. The results indicate that the sensitivity of daily mean stream temperature to changes in factors influencing stream temperatures depends on the size of the stream being analyzed.

Of the factors that determine stream temperatures, shade and flow can be directly affected by management activities. Air temperature, relative humidity, wind speed, ground temperature, width-to-depth ratio, Manning's n, and ground reflectivity can be indirectly affected by management activities. Shade, air temperature, wind speed and relative humidity interact with one another in riparian corridors to create microclimates, and thus have a direct effect on stream temperatures. While these conditions are demonstrated to be important, data collected in the Upper Lost River watershed are not sufficient to quantify such effects.

Mainstem Upper Lost River: In the mainstem segment extending from just below Clear Lake Reservoir to Walter Flat, mean stream temperature was most sensitive to the segment inflow temperature (i.e., Clear Lake Reservoir releases). Mean stream temperature is sensitive to segment inflow and outflow, which in this case are equal to each other, as well as somewhat sensitive to air temperature and solar radiation. Mean stream temperature is insensitive to the other parameters tested, including relative humidity, groundwater temperature, total shade, wind speed, thermal gradient, accretion temperature, Manning's n, ground temperature, ground reflectivity, and possible sun. Sensitivities of maximum daily stream temperatures to changes in parameters in the mainstem segment are similar to the sensitivities of daily mean stream temperatures described above.

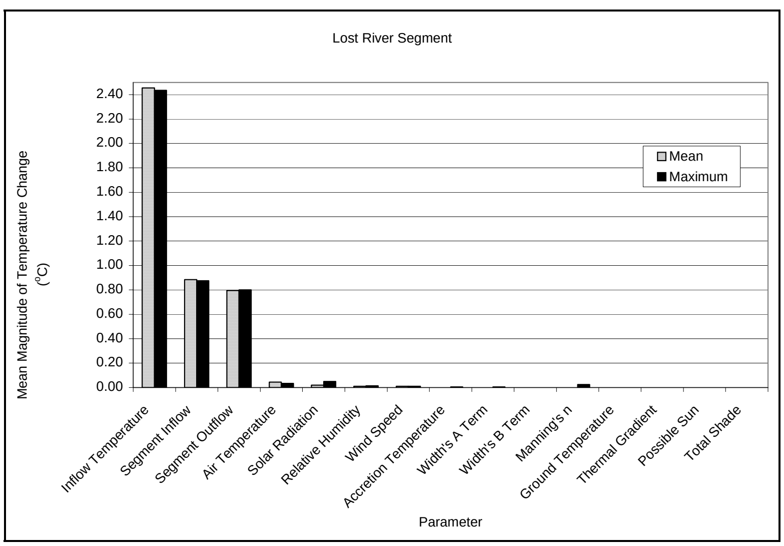


Figure A.2 – Sensitivity Analysis of SSTEMP to +/- 10% Variation of Each Parameter, Upper Lost River Mainstem from just Below Clear Lake Reservoir to Walter Flat Segment Simulation, Sorted by the Effect on Mean Temperature

Tributaries Upper Lost River: In smaller streams, mean stream temperature is most sensitive to air temperature, and it is also sensitive to solar radiation, relative humidity, and wind speed. Mean stream temperature is somewhat sensitive to the segment inflow and outflow. Mean stream temperature is not sensitive to the other parameters tested, including possible sun, total shade, thermal gradient, ground temperature, inflow temperature, accretion temperature and Manning's n. When the results are ranked by effect on the maximum stream temperature estimated by the model, air temperature is the most important parameter; solar radiation and wind speed are also important. Maximum temperature is somewhat sensitive to relative humidity and total shade, and it is relatively insensitive to the remaining parameters including possible sun (a measure of cloud cover), wetted channel width (width's A & B terms), ground temperature, thermal gradient, dust coefficient, and ground reflectivity.

Given the results of the sensitivity analysis, a logical question to ask is, "Why are smaller streams more sensitive to changes in effective shade than larger streams?" The answer lies in the stream geometry. The ability of vegetation or topography to provide shade to a stream channel is a function of the wetted width and orientation of the channel. As streams become wider, taller trees are required to shade the channel. In smaller streams like Willow Creek, vegetation is able to consistently provide more shade than it can provide in larger, wider channels. In larger streams, if the wetted channel runs along the bank in an area of tall trees, there is likely to be substantial shade provided by those trees. However, given the fact that low-flow wetted channels shift or braid within the confines of their active channel, it is unlikely that substantial shade will be provided throughout a lengthy segment.

The parameters to which mean or maximum temperatures are very sensitive or somewhat sensitive include air temperature, wind speed, relative humidity, solar radiation, possible sun, total shade, and flow (Figures A.2 and A.3).

Total shade reflects circumstances of topography, vegetation, channel orientation, sun angle, and channel conditions in and near streams. The presence, type, height, and density of vegetation near streams all affect the nature and quantity of streamside shade. Consequently, the shade parameter was increased to model alternate riparian conditions by doubling (x2) the current shade and then doubling it again (x4).

While air temperature, wind speed, relative humidity, and ground temperature would not be subject to management measures on a regional basis, values of these parameters may reflect local conditions near streams. In particular, these parameters can indirectly reflect or be affected by changes in riparian vegetation conditions. These parameters would vary together and balance one another to a certain extent. For example, a shaded streamside area generally has lower air temperatures, lower wind speeds and higher relative humidity than an open area. The net of these changes is lower water temperatures in more shaded areas. Possible sun is of lesser importance in the Upper Lost River than other parameters and in any case is not influenced by management measures.

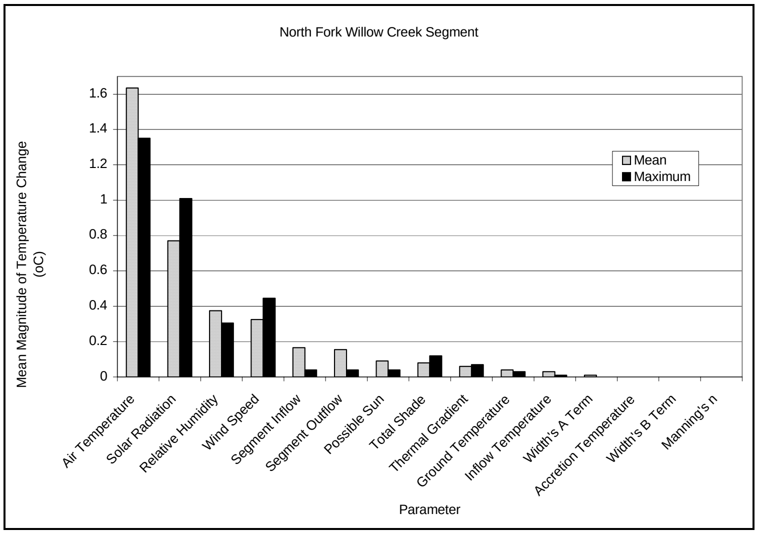


Figure A.3 – Sensitivity Analysis of SSTEMP to +/- 10% Variation of Each Parameter, Willow Creek from Weed Valley to the Great Society Bridge Segment Simulation, Sorted by the Effect on Mean Temperature

__Reach Level Simulation of Stream Temperatures__: The impact of changes in effective shade on stream temperatures was evaluated for five segments of streams in the Upper Lost River watershed using the SSTEMP model. The segments are listed in Table A.3. Stream temperature monitoring sites that could be simulated as a single segment were chosen for evaluation. Stream temperatures were simulated for current shade conditions, as well as alternate riparian conditions. The resulting shade conditions are referred to as adjusted alternate effective shade.

Table A.3 Modeled and Actual Daily Average Stream Temperatures of Modeled Segments

Segment	Current Effective Shade (%)	Adjusted (x Alternate Effective Shade (%)	Adjusted (x4) Alternate Effective Shade (%)	Measured Temperature **(^{o}C)** (^{o}F)	Simulated Current Temperature **(^{o}C)** (^{o}F)	Simulated Alternate (x2) Temperature **(^{o}C)** (^{o}F)	Simulated Alternate (x4) Temperature **(^{o}C)** (^{o}F)
Lost River, Clear Lake Reservoir to Walter Flat	3.4	6.8	13.6	**25.3** 77.5	**25.5** 77.9	**25.5** 77.9	**25.5** 77.9
Lost River, Walter Flat to CA/OR Border	9.0	18	36	**25.1** 77.2	**24.7** 76.4	**24.7** 76.4	**24.6** 76.3
North Fork Willow Creek	12.6	25.2	50.4	**24.2** 75.6	**23.9** 74.7	**23.1** 73.5	**21.3** 70.3
Boles Creek	0.25	0.50	1.0	**16.4** 61.4	**15.6** 60.1	**15.6** 60.1	**15.6** 60.0
Mowitz Creek	0.25	0.50	1.0	**14.2** 57.5	**14.5** 58.1	**14.5** 58.1	**14.5** 58.1

Temperatures predicted by the model for current conditions are within 0.4^{o}C of the measured temperatures in four of the five segments modeled (both mainstem segments: just below Clear Lake Reservoir to Walter Flat, and Walter Flat to the CA/OR boarder; as well as North Fork

Willow Creek and Mowitz Creek). The difference between predicted and measured temperatures for Boles Creek was 0.8^{o}C.

The results of the stream temperature simulations demonstrate the impact that changes in shade conditions have on stream temperatures. The simulations show that an increase in effective shade from current to alternate shade conditions result in a decrease in stream temperatures where the two shade conditions are significantly different. In the mainstem the potential for effective shade is not great, and shade does not appear to be a limiting factor. In smaller streams however, shade is shown to have a minimal effect on governing stream temperature conditions. The overall change in water temperature when maximum riparian shade was modeled, resulted in a 2.62^{o}C decrease in water temperatures in the North Fork Willow Creek. This decrease was the highest seen in this analysis. All other segments where only slightly influenced by the alternate shade conditions modeled.

A.4.2 Thermal Infrared Aerial Survey Results

On July 16, 2001, Watershed Sciences, LLC, conducted a survey of the Lost River through thermal infrared and color videography (TIR/Visible band). This survey extended from Clear Lake Reservoir downstream to Tule Lake, a distance of approximately 75 miles. However, this discussion focuses on the 11 miles of the Lost River beginning at the California/Oregon border and ending at the Clear Lake Reservoir, river miles 64 through 75. Table A.4 contains each tributary and associated river mile, the corresponding water temperature for the tributary, the water temperature of the mainstem Upper Lost River, and the difference between the two. The median surface water temperatures for each sampled image of the Lost River were plotted versus the corresponding river mile (Figure A.5). According to data provided by Watershed Sciences, LLC the outlet of Clear Lake Reservoir, river mile 75, water temperatures were approximately 22.0^{o}C, which was the same as the temperature of the lake surface. Below the reservoir, temperatures increased slightly in the downstream direction reaching 22.8^{o}C at river mile 66.7. Between river miles 66.7 and 64.5, stream temperatures dropped to approximately 20.4. This temperature drop generally corresponds to an area labeled as Walter Flat on topographic maps. The East Fork Lost River (21.1^{o}C at river mile 65.4) also enters the main stem through this segment.

Table A.4 Tributary and Side Channel Temperatures for the Upper Lost River

Tributary	km	mile	Tributary	Lost R.	Difference
Clear Lake Reservoir	120.8	75.0	21.5	22.1	-0.6
Unnamed (Right Bank)	117.5	73.0	22.4	22.4	0.0
Unnamed (Right Bank)	117.1	72.8	23.8	22.8	1.0
Rock Creek (Right Bank)	115.0	71.5	21.9	22.4	-0.5
East Fork (Right Bank)	105.2	65.4	21.1	21.5	-0.4

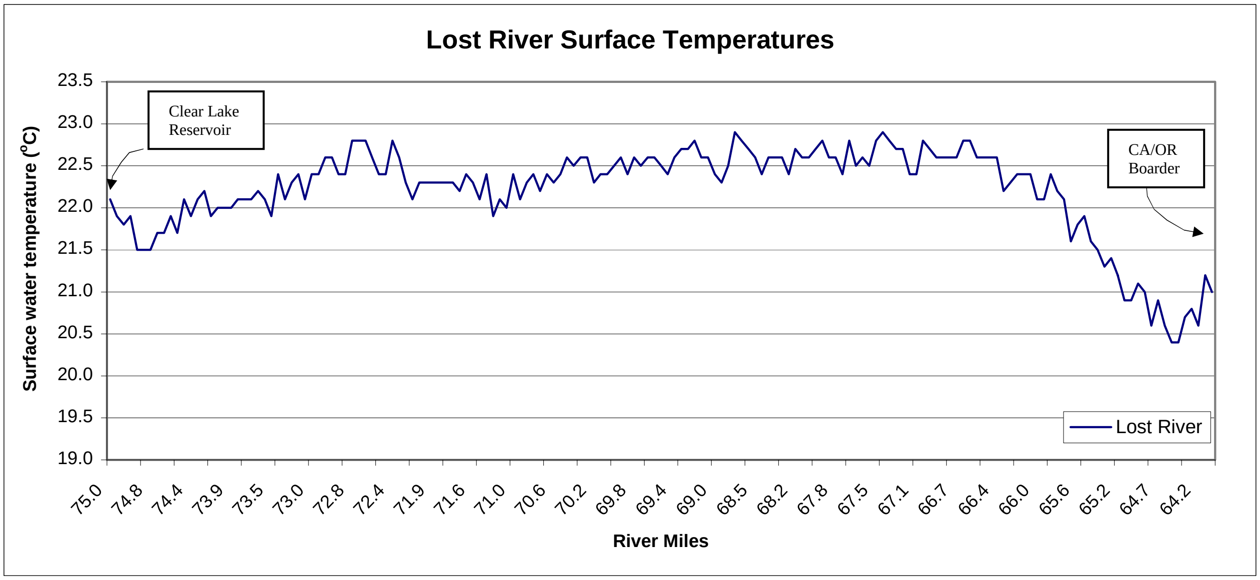
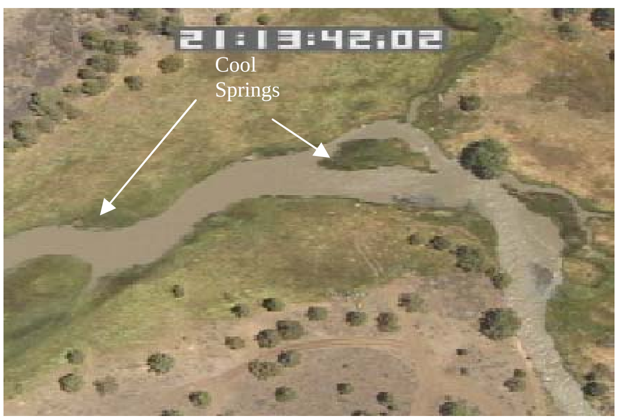


Figure A.5 – TIR/Visible band data representing instantaneous surface water temperatures versus river mile for the Lost River, from Clear Lake Reservoir to the CA/OR border.



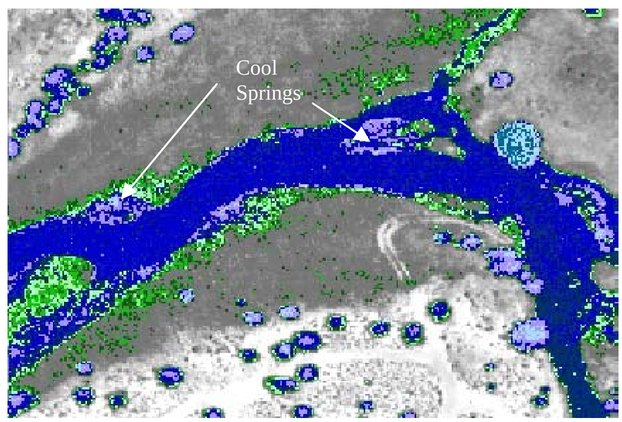
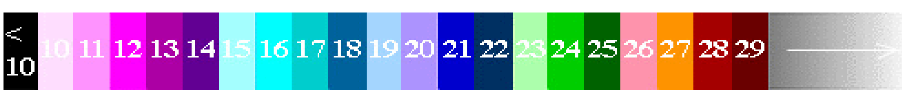


Figure A.6 – TIR/Visible band image showing cool springs feeding into the Lost River just below Clear Lake Reservoir.



Thermal imagery temperature scale bar (^{o}C)

During construction of the new Clear Lake Reservoir dam, flow was shut off to the mainstem of the Lost River for some of the summer months in 2002. Regional Water Board staff observed significant flow in the Lost River below the reservoir during this construction shut off. This suggests that much of the flow observed is contributed by springs and/or subsurface hydrologic processes. As shown in Figure A.5, the TIR/Visible band survey support the field observations, indicating the presence of cooler seeps and springs in and along the Lost River.

A.5 Conclusions

The sensitivity analysis results indicate that air temperature, solar radiation, and relative humidity are the three most important parameters influencing stream temperatures in streams above Clear Lake Reservoir. In the mainstem segments of the Upper Lost River, inflow temperature and the magnitude of releases from Clear Lake Reservoir are the most important factors controlling stream temperature.

The stream temperature modeling analysis demonstrates that changes in solar radiation inputs alone can lead to changes in stream temperatures of small streams. Furthermore, the modeling analysis demonstrates that an increase in stream shade from current conditions to those represented in this study that could be expected for the alternate vegetation conditions could lead to slightly improved stream temperatures.

In summary, this analysis demonstrates that stream shade is an influential factor affecting stream temperatures. However, stream temperatures in many places in the Upper Lost River watershed appear to be within a range suitable for the aquatic species that reside in the watershed.

From a management standpoint, the analysis leads to these conclusions:

1. Continued data collection and monitoring is recommended
2. Water diversion compilation was not part of this study and may be of major importance
3. Reduction of stream flow may affect water temperatures

Input Data for Each Simulation Scenario

Values for the following parameters were used in all the scenarios:

Accretion Temp/Ground Temp = 9.71°C
Possible Sun = 90%
Manning's N = 0.035
Relative Humidity = 20%
Thermal Gradient = 1.65 J/m^2/s/C
Wind Speed = 3.3 m/s
Solar Radiation = 716.32 Langleys/d

Scenario	Time of Year	Inflow (cms)	Inflow Temp (°C)	Outflow (cms)	Segment Length (km)	Width's A Term	Width's B Term	U/S Elevation (m)	D/S Elevation (m)	Air Temp (°C)	Total Shade (%)	Latitude (radians)
Clear Lake Dam to Walter Flat, **Current**	7/11/02	3.956	25.3	3.956	14.16	2.1709	0.0357	1374	1269	29.44	3.42	0.732
Clear Lake Dam to Walter Flat, **Potential**	7/11/02	3.956	25.3	3.956	14.16	2.1709	0.0357	1374	1269	29.44	6.84	0.732
Walter Flat to Oregon Border, **Current**	7/11/02	3.956	25.09	3.956	3.54	2.4962	0.2981	1269	1267	27.25	9.04	0.733
Walter Flat to Oregon Border, **Potential**	7/11/02	3.956	25.09	3.956	3.54	2.4962	0.2981	1269	1267	27.25	18.08	0.733
NF Willow Creek, **Current**	7/11/02	0.011	24.18	0.011	7.40	2.3362	0.0088	1549	1461	30.4	12.6	0.732
NF Willow Creek, **Potential**	7/11/02	0.011	24.18	0.011	7.40	2.3362	0.0088	1549	1461	30.4	25.2	0.732
Boles Creek, **Current**	8/21/02	0.027	16.35	0.027	7.47	2.3362	0.0088	4648	1389	11.93	0.25	0.730
Boles Creek, **Potential**	8/21/02	0.027	16.35	0.027	7.47	2.3362	0.0088	4648	1389	11.93	0.25	0.430
Mowitz Creek, **Current**	8/21/02	0.027	14.19	0.027	1.66	2.3362	0.0088	4524	1367	11.93	0.25	0.730
Mowitz Creek, **Potential**	8/21/02	0.027	14.19	0.027	1.66	2.3362	0.0088	4524	1367	11.93	0.25	0.730

A.5 Appendix A References

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Appendix B
Natural History and Habitat Requirements of Redband Trout

CONTENTS

Appendix B
Redband Trout in the Lost River Watershed and Surrounding Area

As discussed in Section 5 of this report, the presence of redband trout in the Clear Lake Reservoir/Upper Lost River watershed cannot be confirmed. The following information regarding the natural history, taxonomy, and habitat requirements because cold water fishery is identified as a beneficial use for the watershed.[55] Although the basis for the listing could not be ascertained, it is thought that the similarity of the watershed to nearby watersheds in which redband trout are found was the basis for the listing.

B.1 Redband Trout Natural History

Moyle et al. (1995) describe Goose Lake redband trout as a fish species of special concern in California. Goose Lake is a large, shallow lake straddling the Oregon-California border about 30 miles to the east of Clear Lake Reservoir. Goose Lake is fed mostly by drainage from the Oregon side of the watershed (Cramer 1999). Historically, at higher lake levels, Goose Lake has drained into the Pit River drainage (part of the Sacramento River Basin).[56] Goose Lake is not part of the Clear Lake Reservoir/Upper Lost River watershed, but the redband trout of the Goose Lake drainage are described here because it is adjacent to the Clear Lake Reservoir watershed and because the ambient environmental conditions are similar. If redband trout are present in the Clear Lake Reservoir watershed, they may have habitat requirements and life history similar to the Goose Lake redband trout.

B.1.1 Taxonomy & Description

There is disagreement among fisheries experts over the taxonomy of redband trout. Redband trout are classified as *Oncorhynchus mykiss* with various subspecies designations that are not agreed upon by taxonomists. Behnke (1992), recognized as a taxonomic authority on western trout, does not believe that redband trout native to the desert basins of south Oregon can be consistently distinguished from other redband trout populations. He states that, “their classification is a matter of personal preference and professional judgement.” Behnke (1992) believes that the morphologic variation within the redband trout group, despite showing distinct morphologic tendencies, is partially responsible for the lack of firm taxonomic definition. The Oregon Department of Fish and Wildlife (ODFW 1995) describes the confusion over the status of the species: “The species *Oncorhynchus mykiss* is one of the most complicated groups in Oregon. The species probably consists of multiple subspecies, none of which have been formally recognized.” CDFG (2002) recognizes three subspecies of redband trout (McCloud, Goose Lake, and Warner Valley – all classified by CDFG as *Oncorhynchus mykiss subspecies*) but states that the taxonomic status of the redband trout “…is not fully recognized by the taxonomic community.”

Redband trout are generally considered to be a native, inland, nonanadromous form of *Oncorhynchus mykiss* that developed in closed basins that are completely isolated by natural geographic features. Redband trout are similar in appearance to rainbow trout

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[55] See Chapter 2 of the Water Quality Control Plan for the North Coast Region for a listing and description of the beneficial uses identified for this watershed.

[56] Any connection between Goose Lake and the Pit River goes in only one direction since the spillway at Goose Lake is an impassable barrier to upstream migration (ODFW 1995).

with a "typical" trout shape. Adult size varies depending on the environment and food availability. Typically, redband trout range from six to eight inches long. In Goose Lake and Upper Klamath Lake, with the plentiful forage available, adult redband trout can get to 36 inches. The overall body color depends on the habitat, but often is greenish or bluish. The Great Basin redband trout have a rosy red to brick red stripe along the lateral line. The stream-strategy adults are spotted above and below the lateral line, have white-tipped fins, and parr marks along the lateral line are retained in adults. Great Basin lake-strategy redband trout show significantly less red color, fainter parr marks, and fewer spots than the stream-strategy form. (Behnke 2002).

B.1.2 Life History

The life history of redband trout populations varies with the specific habitat and environmental conditions. Redband trout in the Goose Lake drainage have two life history strategies: a lake-strategy and a headwaters stream-strategy (Moyle et al. 1995). This flexibility may be needed for the population to survive in a desert environment, since the Great Basin lakes are only semi-permanent and occasionally have dried to the point where they cannot be used by trout (Behnke 2002). The lake-strategy fish live in lakes, such as Goose Lake, and spawn in streams. The stream-strategy fish are resident in the streams. The lake-strategy redband trout grow larger than the stream-strategy redband trout, presumably because of more abundant food sources in the lake (including small forage fishes such as the tui chub). These two strategies may represent the same population because Goose Lake has completely dried up on several occasions (as recently as 1992) but has been re-colonized by the redband trout from streams in the drainage (Moyle et al. 1995, Moyle 2002, Behnke 2002). It is not clear if the life history pattern, i.e., whether a redband trout will exhibit a lake-strategy or stream-strategy, is genetically determined or opportunistic.

Great Basin redband trout mature mostly at age three and four with a small percentage maturing at age two, five and six (U.S. FWS 2000). Redband trout spawn in their natal streams and the trout that reside in lakes or larger streams return to the larger streams or lake after spawning. Young redband trout may spend one or two years in the streams before migrating to a lake if they are lake-strategy redband trout. The life history and biology of Goose Lake redband trout has not been studied (Moyle et al. 1995).

B.1.3 Habitat Preferences

The habitat requirements of redband trout are similar to that of other trout – riparian areas with cover, overhanging vegetation, undercut banks, large woody debris, stream complexity, loose non-embedded gravel, and well-oxygenated water (ONDA et al. 1997, U.S. FWS 2000). Moyle et al. (1995) describe the biology and specific habitat requirements of the Goose Lake redband trout as poorly known, but "presumably similar to other populations of redband trout that occupy small, high-elevation streams." They describe the same uncertainty about the biology and habitat needs of McCloud River redband trout. Dambacher et al. (2001) evaluated habitat parameters with population abundance in the Great Basin desert watersheds and concluded that redband trout are "generalists in their use of stream habitat" making it difficult to predict fish presence based on habitat parameters, at least at larger spatial scales.

B.1.4 Spawning and Egg Incubation

Sexual maturity in Goose Lake redband trout occurs after three to five years, with males maturing before females. An adult may spawn several times during its life, though not always in subsequent years (Cramer et al. 1999). Redband trout in the Great Basin area of Oregon spawn in the spring, generally between April and July, with the timing being dependent on water temperature, stream flow, and precipitation. (ONDA et al. 1997, U.S. FWS 2000). The timing of the spawning migration with higher spring flows may ensure that there is sufficient water depth for adult passage. The Klamath Basin redband trout population has been reported to spawn year-round near inflowing springs with relatively constant water temperatures (U.S. FWS 2000). Goose Lake redband trout and McCloud redband trout, like rainbow trout, spawn in the early spring. In 1988, Goose Lake redband trout spawning migrations were observed in late March (Moyle et al. 1995). Moyle et al. (1995) believe that the Goose Lake redband trout are similar to other high desert trout and that they spawn in their third spring and live four to five years. In the Goose Lake drainage, redband trout spawn in Willow Creek, a tributary that drains to Goose Lake from the east (Moyle et al. 1995).[57] Redband trout eggs hatch in four to seven weeks, depending on the temperature. Yolk absorption may require an additional three to seven days. After spawning, the lake-strategy adults (and the lake-strategy young after hatching) move back to the lake (Moyle et al. 1995, U.S. FWS 2000).

Goose Lake redband trout prefer stream riffles with clean gravel, suitable riparian cover, cool temperatures, a depth of at least six inches, and a velocity of 1.3 to 2.6 cfs for spawning habitat (Moyle et al. 1995, Cramer et al. 1999). McCloud redband trout have similar requirements, preferring riffles or runs with gravel substrate for spawning (USDA Forest Service 1998). Redband trout prefer non-embedded spawning gravels that are less than 2.5 cm in size. At least 75 percent of the total riffle area should be free of siltation (U.S. FWS 2000).

B.1.5 Rearing

Like other trout, juveniles and young-of-the-year occupy shallow stream edges under cover and interstitial substrate spaces (U.S. FWS 2000). Young Goose Lake redband trout can spend one to three years in streams before migrating to Goose Lake (Moyle et al. 1995, ONDA et al. 1997). Growth depends on genetics and environmental conditions (ONDA et al. 1997).

B.1.6 Food

"Redband trout eat a variety of foods. The most common foods eaten by redband trout are snails, leeches, aquatic insects, zooplankton, terrestrial insects, and fish."[58] Great Basin redband trout have been reported to feed on streamside and benthic macroinvertebrates (ONDA et al. 1997). Goose Lake redband trout have been reported to feed occasionally on Goose Lake tui chub (Moyle et al 1995).

Redband trout may interact with other species to obtain food. Juvenile rainbow trout, for example, follow Sacramento suckers to feed on the invertebrates disturbed by the bottom browsing of the larger sucker (Moyle 2002). Most trout are opportunistic feeders that will

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[57] There are at least three Willow Creeks on the upper Modoc Plateau. Two drain to Clear Lake Reservoir and one drains to Goose Lake.

[58] Cramer et al. 1999

consume whatever food is available in the water column and on the bottom, including terrestrial insects, aquatic insects, insect larvae, amphipods, snails and, sometimes, small fish. Generally, rainbow trout are not piscivorous, but lake-dwelling rainbows will feed on other fish more often than stream-dwelling trout (Behnke 1992).

B.2 Water Quality Requirements

Redband trout evolved in a high desert environment that is characterized by high summer water temperature, large diel temperature fluctuations, intermittent flows, and high alkalinity, so they have evolved traits that allow them to survive under conditions that would not support other trout species (Behnke 1992, Moyle et al. 1995). Goose Lake redband trout are tolerant of elevated temperatures, high alkalinity and high turbidity that would kill other trout species (Moyle et al. 1995). There is limited information on the physiology of redband trout; most of the information available is related to water temperature requirements.

B.2.1 Temperature

High water temperature decreases the solubility of dissolved oxygen in water at the same time it causes an increase in metabolic demands on salmonids. High desert redband trout survive in environments where summer stream temperatures can exceed 29°C and flows become intermittent, therefore they have developed behavioral strategies and physiological tolerances to cope with conditions that exert increased energy demands at the same time that less oxygen is available. “Thus, without physiological/biochemical adjustments to enhance oxygen delivery and maintain metabolic power in the face of elevated water temperatures, the ability of salmonids to perform and/or survive may be significantly compromised.”[59]

Although redband trout can withstand water temperatures of 27-29°C for short periods of time, and diel fluctuations of 16-20°C, Bowers et al. (1979) and the U.S. FWS (2000) believe that their optimal temperatures are below 21°C. Interestingly, the adaptive tolerance to higher temperatures does not appear to be accompanied by an increase in the upper incipient lethal temperature or the critical thermal maximum, which are similar to other salmonids (Bowers et al. 1979, U.S. FWS 2000, Rodnick et al. in press). The preferred temperature range for redband trout is lower than the range that can be tolerated. Redband trout from two distinct populations with different ambient environmental temperatures and different sizes selected the same preferred temperature in a laboratory gradient – just below 13°C (Gamperl and Rodnick 2003). As discussed below, however, redband trout have optimal growth rates at temperatures that are higher than other salmonids (see Behnke 1992).

Carline and Machung (2001) believe that, although both acclimation and genetics play a strong role in the CTM of trout, the role of genetics is stronger. They compared the CTM of hatchery and wild species of brook, brown and rainbow trout and found that the wild strains of all three species had significantly higher CTMs than did the hatchery-reared trout. Carline and Machung (2001) tentatively concluded genetic differences between wild trout and hatchery trout were responsible for the significant differences. Wild trout evolved under natural conditions that seasonally provided higher than optimal

[59] Gamperl and Rodnick 2003

temperatures, whereas hatchery stocks were selected, not for temperature tolerance, but for “traits such as disease resistance, growth and feed conversion.” This research suggests that redband trout *may* be evolutionarily selected for genetics that support tolerance (though not preference) of higher than optimal water temperatures.

At temperatures between 22 and 25°C most trout species reduce feeding and other species gain a competitive advantage (Behnke 1992). Studies on trout have shown that the optimal feeding temperature (the temperature at which metabolism, growth, and assimilation of food is optimized) is around 13 to 16°C. Lee and Rinne (1980) studied the critical thermal maxima of five adult trout species adapted to higher water temperatures in the southwestern United States (rainbow trout, brown trout, brook trout, Gila trout, and Arizona trout). They found that the critical thermal maxima were similar for all species tested, even though the rainbow, brown and brook trout were introduced and the Gila and Arizona trout were native to areas with natural higher water temperatures. Lee and Rinne (1980) also found that the two species of trout native to warmer environments could survive in waters up to 27°C, a value supported by field observations.

Although redband trout have critical thermal maxima and upper incipient lethal temperatures that are similar to other trout, not all physiological responses to temperature regimes are similar. Behnke (1992), for example, showed that redband trout had optimum growth rates at temperatures higher than the values reported for rainbow and brook trout. Behnke (1992) exposed young Catlow Valley redband trout to water temperatures of 13, 16 and 19°C. The growth curves (temperature units per centimeter of growth) of redband trout were unlike those of rainbow and brook trout, “indicating that optimum growth efficiency for this subspecies lies at some higher temperature (which was not tested).”

Three distinct populations of redband trout in southeastern Oregon were found to have the same critical thermal maximum of 29.4±0.1°C (Rodnick et al. in press). Rodnick et al. (in press) state that this is similar to the requirements of other trout species that have been acclimated to high water temperature. They determined that salmonids have similar CTMs regardless of habitat, but that redband trout have a unique tolerance for higher water temperatures.

> When determining the thermal/habitat requirements of a species for the development of protective standards and temperature criteria for self-sustaining fisheries, a comprehensive understanding of the thermal constraints and requirements for metabolism, feeding, food assimilation, growth, development and reproduction is essential. Although we still lack specific data on the thermal sensitivity of reproduction and development, there is now sufficient data to conclude that redband trout show a significant degree of ‘warmwater tolerance’ as compared to rainbow trout. In this study, we clearly show that thermal stress is not experienced until temperatures of at least 22-24ºC (2-4ºC greater than for rainbow trout, Heath and Hughes, 1973), and that MO2max and metabolic power at 24ºC are much higher than those previously measured for wild or hatchery-reared salmonids.

These results suggest that critical thermal maxima may not be the most appropriate index for understanding the thermal requirements of fish since the CTM is a measure of acute exposure and does not consider long-term exposure, acclimation or the requirements of different lifestages. Rodnick et al. (in press) suggest that the traditional indices used to define thermal tolerance of trout may not be useful when describing fish living in high temperature environments.

The U.S. FWS (2000) makes the distinction between lethal temperatures and temperatures to which redband trout have adapted. "Sustained summer water temperatures above 21°C (70°F) are thought to be harmful. Although water temperatures of 27°C (80.6°F) for short periods of time, and diurnal fluctuations of 16-20°C (30-35°F) have been recorded, such extremes are not desirable for redband trout (Bowers et al. 1979)." The temperature values described by the U.S. FWS are low when compared to the anecdotal information provided by Behnke (1981), "I have caught the desert redband trout by angling in water of 28.3°C. They fought well and had considerable metabolic reserve or scope for activity at this temperature."

Rodnick et al. (in press) demonstrated that different lifestages of redband trout have different responses to thermal stress. They found that larger/older redband trout have an increased sensitivity to thermal stress. Juvenile redband trout were less sensitive to higher temperatures as measured by routine oxygen consumption (RMO2). At first, RMO2 increased at a constant rate as water temperature was increased. The relationship changed for larger redband trout when temperatures reached 22ºC and RMO2 began to increase at a faster rate. For smaller redband trout, the increased rate of RMO2 did not occur until temperatures reached 24ºC. The authors conclude that, "These data suggest that large redband trout are more thermally-sensitive, and incur higher metabolic costs than small redband trout during acute exposure to high water temperatures." This conclusion was consistent with other research.

Gamperl and Rodnick (2003) evaluated sub-lethal stress caused by high temperatures in redband trout. They concluded, "redband trout begin to experience sub-lethal stress at 24ºC.The authors suggested that the physiologic cost of the increased oxygen consumption required by higher temperatures is ecologically significant. "Clearly, the added energetic cost of RMO2 at temperatures above 24ºC could reflect a loss of homeostatic capability and be of ecological significance for large rainbow trout."

It is not clear if redband trout have evolved physiologically to prefer higher water temperatures or if they occupy a niche that requires them to operate near their physiological limits (see Gamperl et al. 2002). Rodnick et al. (in press) believe that the latter is the case:

> Thus our results support Myrick and Cech's (2000) hypothesis that salmonids (with the exception of those restricted to high latitudes) have similar thermal tolerances irrespective of origin, and that the upper thermal tolerance of wild salmonids is phylogenetically conserved and resistant to evolutionary change (Beitinger *et al.* 2000).
>
> Based on field observations of redband trout in desert basins of western North America (Behnke 1992, Zoellick 1999), a question was raised as to whether these animals can tolerate higher maximum temperatures than other salmonids. Given that the CTM for redbands in southeastern Oregon differs very little from rainbow trout and most other salmonids, one might conclude that the redband trout is not 'uniquely' tolerant of warm water temperatures. **However, this study and others strongly promote the idea that the redband trout does have an enhanced capacity to function, and probably flourish, at warmer temperatures than most salmonids.**

(Emphasis added).

Oregon's Independent Multidisciplinary Science Team (OIMST 2000) discussed the issue of how apparently health fish populations can exist in streams with temperatures higher than studies would indicate as healthy. They agreed that gaps in the state of knowledge of stream ecosystems and fish physiology would not allow them to answer the question definitively, however, they speculated that several factors may account for the observed phenomenon:

- Fish might have physiological adaptations to survive at higher temperatures.
- Stream habitats might contain cooler refugial areas that allow a healthy population to survive.
- Ecological interactions might vary under different thermal regimes. This could result, for example, in changes to the fish response to disease or other stressors.
- Substantial differences between laboratory conditions and the natural environment might account for some of the differences.

The OIMST (2000) also questioned whether the mere occurrence of the fish in the apparently hostile environment constituted a health population. Delayed effects (such as decreased fecundity or decreased gamete variability) may be a non-measured response to higher than optimal stream temperatures.

B.2.2 Other Water Quality Requirements

As discussed earlier, interactions of water quality parameters may lead to fish being more susceptible to the effects of poor water quality. Some water quality parameters have been shown to have synergistic, additive or antagonistic effects on fish. Long-term exposure to stressful levels of one parameter may make fish more susceptible to the harmful effects of another.

Much of the discussion about water quality impacts below is generated from trout species other than redband trout. This is largely because of the paucity of data derived directly from redband trout. Information from other trout species is valuable and is presented in a cursory fashion, nonetheless, to elucidate possible relationships between the health of redband trout and the water quality in their environment. The discussion, however, is not exhaustive since its direct application is limited by the focus on species other than redband trout.

B.2.3 pH

Trout of the southeast Oregon deserts have evolved in conditions of high alkalinity. Trout in these areas prefer a pH of between 6.5 and 9.0, although some species can tolerate a pH of 10.0 to 10.5 (Bowers et al. 1979). The specific preferences of redband trout were not reported.

B.2.4 Nutrients

There have been many reports on the toxicity of ammonia to trout species. Solbe and Shurben (1989) evaluated the toxicity of ammonia to sensitive, early lifestages of rainbow trout. In tests that lasted 73 days, they found that un-ionized ammonia was more toxic earlier in the development that later. Exposure that began within 24 hours of fertilization showed severe mortality (>70%) at levels as low 0.027 mg/l, whereas exposure that began after the eggs eyed-up (about 24 days) was less severe (40% mortality of the eggs, yolk-sac fry, and fry). This test shows the importance of determining the most sensitive lifestage for toxicity evaluation.

Russo et al. (1974) evaluated the acute toxicity of nitrites to rainbow trout. The study showed a range of LC_{50}s: 0.96 mg/l (NO_2-N) in 2.3 g fish at 24 hours to 0.20 mg/l (NO_2-N) in 235 g fish at 96 hours. They reported that sac-fry were more tolerant than the more developed lifestages – the LC_{50} was 1.05 mg/l at 51 hours. The method of toxicity was oxidation of hemoglobin to methemoglobin, so the fish essentially suffered from anoxia.

B.2.5 Combined Factors – Dissolved Oxygen and Ammonia

The toxicity of ammonia to rainbow trout fingerlings was increased at low dissolved oxygen levels (Thurston et al. 1981). LC_{50}s of aqueous ammonia were tested in rainbow trout at dissolved oxygen levels ranging from 2.6-8.6 mg/l. The researchers found a positive correlation between dissolved oxygen and un-ionized ammonia over the entire range tested. Ammonia toxicity increased as dissolved oxygen decreased.

B.2.6 Combined Factors – Dissolved Oxygen and Temperature

Cech et al. (1990) evaluated the influence of temperature and hypoxia combined with varying temperatures on the distribution of seven fish species in California. None of the fish tested were redband trout, but one of the test species was rainbow trout. All the fish tested showed higher metabolic rates at higher water temperatures. In contrast, responses to low dissolved oxygen levels combined with varying temperatures were more species specific, showing a decreased tolerance of low dissolved oxygen with increasing temperatures: "Rainbow trout showed no response to hypoxia at 10°, showed a significant depression after an abrupt increase to 15°, and died at 20°." If redband trout have a similar response, the combination of low dissolved oxygen and high temperature may be synergistically stressful.

The relationship between increasing the adverse effects of hypoxia by increasing water temperature is also shown in embryonic development rates of rainbow trout. Higher water temperatures cause a non-linear acceleration of embryonic development in rainbow trout when oxygen levels approached saturation. Lower dissolved oxygen levels slows embryonic development in rainbow trout. Combining the higher water temperatures with progressively lower dissolved oxygen concentrations slowed the rate of embryonic development even more than a reduction of dissolved oxygen alone (Garside 1966). In other words, "for a specified level of hypoxia, there is a progressive increase in the relative effect with increasing temperature."[60] Presumably this effect is related to the higher metabolic need for oxygen at higher temperatures. Garside (1966) suggests that some species may compensate for a reduction in ambient oxygen by delaying the rate of development, but still achieve normal development.

Vinson and Levesque (1994) reported on the response of redband trout to hypoxia in a natural environment between August and December. Redband trout were observed in a natural, intermittent stream in Idaho. During the period of field observations, instantaneous measurements of dissolved oxygen and temperature were obtained. Dissolved oxygen concentration declined from 4.0 to less than 2.0 mg/l and temperature declined from 17 to 2°C. At the start of the study, 48 redband trout were observed; only

[60] Garside 1966

one could be found at the end of the study. Complicating the assessment of survival is the authors' note that "Additional survival would probably have occurred if not for repeated electrofishing." The one survivor tolerated, not only repeated electrofishing but also, at least 114 days in water with dissolved oxygen concentrations less than 4 mg/l; four redband trout survived 43 days of dissolved oxygen concentration less than 2.5 mg/l. The authors listed the negative effects of low dissolved oxygen on rainbow trout that became apparent at 5.0 to 6.0 mg/l, including elevated breathing amplitude, reduced heart rate, reduced swimming speed, and reduced capacity for anaerobic metabolism. The authors looked for explanations for the survival of redband trout at dissolved oxygen concentrations lower than those tolerated by rainbow trout. They investigated the pools for possible seeps with higher dissolved oxygen that might have offered refugia but none were found. Other explanations for survival at very low oxygen levels included a long acclimation period, declining water temperatures (thereby reducing metabolic demands), low water velocity (thereby reducing energy expenditures), and behavioral responses including respiration at the air-water interface (known as aquatic surface respiration[61]). In general, redband trout appear to tolerate lower dissolved oxygen concentrations than rainbow trout. In this study, there was no consistent relationship between size of redband trout and survival in low dissolved oxygen conditions. In one pool, the larger redband trout showed greater tolerance for low dissolved oxygen than did the smaller redband trout. In another pool of similar size only the smaller redband trout survived.

B.3 Summary of the Requirements of Redband Trout

There is a lack of information regarding the water quality requirements of redband trout. Some information about water temperature requirements is available, although redband-specific data for all life stages are not available. Redband trout can tolerate higher temperatures than other salmonids, although their upper incipient lethal limit and critical thermal maximum are the same as other salmonids. Even though redband trout can tolerate high water temperatures and large diel temperature fluctuations, they seem to prefer more moderate temperatures. Gamperl and Rodnick (2003) suggest that temperatures for <u>short-term exposure</u> not exceed 24ºC in order to protect sensitive redband trout life stages from sub-lethal thermal stress, and to account for the depression of thermal tolerance by other water quality characteristics such as high alkalinity, low oxygen saturation, high pH, and large diurnal temperature fluctuations. Even while recommending a short-term exposure limit of 24ºC, they acknowledge that intact natural systems in which redband trout have thrived may exceed this limit, therefore, the authors suggest that a temperature criterion based on an <u>average weekly maximum temperature</u> of 22ºC.

Gamperl and Rodnick (2003) note that salmonids take advantage of thermal refugia when water temperatures rise, but caution that thermal refugia in high desert habitat "may be too small and infrequent to sustain high densities" of redband trout that may be seeking such refuge in periods of thermal stress. Rodnick et al. (in press) show that redband trout can survive extreme diel water temperature fluctuations and relatively low dissolved

[61] Rutledge and Beitinger (1989) investigated the effects of dissolved oxygen concentrations on CTMs in three fishes that were native to warm, intermittent streams. Their work showed that CTMs were decreased when high temperatures were combined with hypoxia, although the CTMs did not change significantly by exposure to hyperoxic water. The CTMs, however, increased significantly in three fish exposed to hypoxic conditions if the fish were allowed access to the surface aquatic surface respiration.

oxygen. They note, however, the importance of cooler thermal conditions at regular intervals. “Further, the fact that stream temperatures do not remain at high values for extended periods and cooler conditions occur at predictable intervals may be critical for the health of trout.”

Aquatic surface respiration, observed in redband trout by Vinson and Levesque (1994) may be a strategy used to persist in habitat with dissolved oxygen concentrations lower than those required by other trout. This behavior provides easier access to higher dissolved oxygen levels found at the water surface. This is common behavior among in fish living in hypoxia-prone water, but had not been previously been reported for salmonids.

Information about the distribution, abundance, and habitat requirements of redband trout in the Upper Lost River/Clear Lake Reservoir area is lacking. Although it is unlikely that redband trout exist in the Clear Lake Reservoir drainage or in the Upper Lost River, there are similarities to the habitat and physical environment of the Great Basin, particularly the Goose Lake drainage. Factors that limit the production of fish in the Great Basin may serve to limit the production of similar fish in the Clear Lake Reservoir drainage. Moyle et al. (1995) describe habitat modification of the streams and the lake as the biggest threat facing the Goose Lake population of redband trout. Specifically, lack of access to spawning streams, channelization of streams in the lower reaches, heavy grazing, and siltation from roads are cited as threats. Sigler and Sigler (1987) also describe habitat degradation in the Great Basin as adversely affecting the fish of the Great Basin:

> The most direct and obvious decimating factor is destruction of habitat (including spawning areas) through modification. This may include pumping of water to such an extent that water levels are decreased in particular habitats or pumping of underground aquifers to such an extent that the continuous flow to these small habitats is interrupted or eliminated.

Thurow et al. (1997) found a strong correlation of strong salmonid populations in the Columbia River basin, Klamath River basin, and Great Basin with roadless areas, and of reduced populations with habitat degradation. The redband trout, though, remained more broadly distributed in the areas studied of other native salmonids and its disappearance from large areas of its historic range indicates a likelihood of strong habitat disruption, including dams, reservoirs, and diversions (Thurow et al. 1997). While the redband trout have evolved to withstand harsh, variable conditions they may be threatened when these conditions are coupled with habitat modification and degradation (Moyle et al. 1995, Thurow et al. 1997). Thurow et al. (1997) compared the requirements of redband trout to other salmonid species and concluded that redband trout are hardier than the other salmonids, but that redband trout have been subjected to extreme habitat disruption that adversely affects their populations:

> Their broad distribution suggests redband evolved over a wider range of environmental conditions than the other seven salmonid taxa examined, and may have less specific requirements. For example, redband trout exhibit tolerances to temperatures over 25ºC (Kunkel 1976), and their apparent persistence in heavily disturbed basins suggests some populations are less strongly influenced by habitat disruption than other salmonids. The loss of a redband trout population, then, may be an indication of substantial habitat disruption.

Gamperl and Rodnick (2003) concluded that the ability to survive in an environment hostile to other salmonid species places redband trout at risk when faced with habitat degradation:

> The listing of this group as a "species at risk" is related, in large part, to concerns about the influence of habitat degradation and irrigation on increasing summer stream temperatures, and suggests that "natural" thermal conditions in streams already force redband trout to operate near their physiological limits, and that their ability to perform functions such as swimming or to withstand further environmental perturbations is severely restricted.

The ability of redband trout to continue to survive may be compromised if "the habitat does not provide adequate forage to fuel metabolism and promote energy balance"[62] required under harsh conditions.

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[62] Gamperl and Rodnick 2003

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