#122

Navarro River Total Maximum Daily Loads for Temperature and Sediment

Public Review Draft (September 2000)

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CHAPTER 1: INTRODUCTION

The Navarro River Total Maximum Daily Loads (TMDLs) for Temperature and Sediment are established by the U.S. Environmental Protection Agency (EPA) as required by Section 303(d) of the Clean Water Act. In accordance with Section 303(d), the State of California periodically identifies "those waters within its boundaries for which the effluent limitations . . . are not stringent enough to implement any water quality standard applicable to such waters." In its latest Section 303(d) list, adopted through Resolution 98-45 on 23 April 1998, the North Coast Regional Water Quality Control Board (Regional Water Board) identified the Navarro River as impaired due to elevated stream temperatures and sedimentation, both of which degrade freshwater habitat for salmonids. Both coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Oncorhynchus mykiss*) are listed as threatened under the federal Endangered Species Act in the northern California coast, including the Navarro River and its tributaries. The primary purpose of the Navarro River TMDLs is to identify temperature and sediment loading allocations that, when implemented, are expected to result in the attainment of the applicable water quality standards for temperature and sediment for the Navarro River and its tributaries.

In accordance with a consent decree (*Pacific Coast Federation of Fishermen's Associations, et al. v. Marcus*, No. 95-4474 MHP, 11 March 1997), 31 December 2000 is the deadline for establishment of TMDLs for the Navarro River. Because the State of California will not complete adoption of TMDLs for the Navarro River by this deadline, EPA is establishing the Navarro River TMDLs, with assistance from Regional Water Board staff.

The Navarro River TMDLs are based on the Navarro River Watershed Technical Support Document for Sediment and Technical Support Document for Temperature (TSD), dated 28 July 2000 (Regional Water Board 2000). The TSD was prepared by Regional Water Board staff to assist EPA with the development of the Navarro River TMDLs. The Regional Water Board staff used data on the Navarro watershed from a variety of sources in the development of the TSD. Regional Water Board staff supplemented the available data with extensive photo analysis and field measurements for shade analysis. Many of the subjects addressed below are described in more detail in the TSD. The TSD has not been through the Regional Water Board's public participation and adoption process, in part because it does not contain the monitoring and implementation plans required by state law. EPA expects the Regional Water Board to adopt the TMDLs, once they have completed development of monitoring and implementation plans.

The Navarro River watershed is located in coastal southern Mendocino County, California, encompassing approximately 315 square miles (201,600 acres). The Navarro River flows through the coastal range, the Anderson Valley, and enters the Pacific Ocean about fifteen miles south of the town of Mendocino (Entrix 1998, as cited in Regional Water Board 2000). The population of the watershed is about 3,500 people, with most living in and around the towns of Boonville, Philo, and Navarro (Entrix 1998, as cited in Regional Water Board 2000). Three geologic formations comprise most of the Navarro River watershed: the Melange Unit of the Franciscan Assemblage, the Coastal Belt of the Franciscan Assemblage, and alluvial fill. Elevations in the basin range from sea level to about 3,000 feet. Precipitation averages about 40.4 inches per year at Philo, with about 63 percent occurring between December 15 and March 31 (Division of Water Rights 1998, as cited in Regional Board 2000).

Land-use in the watershed includes forestland (70%), rangeland (25%), and agriculture (5%) with a small percentage devoted to rural residential development (Entrix 1998, as cited in Regional Water Board 2000). Timber harvesting began in earnest in the watershed during the mid-1800s following the gold rush. A second logging boom occurred from the later 1930s to the early 1950s, when large tracts of redwood-dominated forest in the mainstem Navarro River subwatershed were reharvested (Adams 1971, as cited in Regional Water Board 2000). Douglas fir-dominated forest in the North Fork Navarro subwatershed was cut for the first time during this period (Adams 1971, as cited in Regional Water Board 2000). Sheep and cattle have been grazed in the watershed since the 1870s. Today, commercial timber harvesting, viticulture, orchards, grazing, and tourism are the principal economic enterprises.

More information on the geology, vegetation, hydrology, land use, and other aspects of the Navarro River watershed can be found in the TSD (Regional Water Board 2000).

This report documents the TMDLs for temperature and sediment for the Navarro River. Chapters 2 (Problem Statement), 5 (Implementation and Monitoring Plans), and 6 (Public Participation) present information applicable to both TMDLs. Chapter 3 pertains specifically to temperature while Chapter 4 pertains specifically to sediment.

CHAPTER 2: PROBLEM STATEMENT

This chapter provides a description of the existing in-stream and surrounding watershed conditions, and presents an analysis of how sediment and increased stream temperatures are affecting the beneficial uses of the Navarro River and its tributaries associated with the cold water salmonid fishery.

2.1 Water Quality Standards

The water quality standards applicable to the Navarro River are contained in the *Water Quality Control Plan for the North Coast Region* (Basin Plan) as amended in 1996 (Regional Water Board 1996, as cited in Regional Water Board 2000). The Basin Plan identifies beneficial uses for the Navarro River and the water quality objectives designed to protect those uses. The water quality objectives are intended to protect the most sensitive of the beneficial uses, in this case those associated with the Navarro River's salmonid fishery. The beneficial uses addressed in these TMDLs are: Commercial or Sport Fishing (COMM), Cold Freshwater Habitat (COLD), Estuarine Habitat (EST), Migration of Aquatic Organisms (MIGR), and Spawning, Reproduction, and/or Early Development (SPWN).

The Basin Plan (Regional Water Board 1996, as cited in Regional Water Board 2000) identifies both numeric and narrative water quality objectives for the Navarro River. The objectives pertinent to the Navarro River TMDLs are narrative objectives, and they are listed in Table 2-1.

Table 2-1. Summary of Water Quality Objectives Addressed in the Navarro River TMDLs

Parameter	Water Quality Objective
Settleable Material	Waters shall not contain substances in concentrations that result in depositions of material that causes nuisance or adversely affect beneficial uses.
Sediment	The suspended sediment load and suspended sediment discharge rate of surface water shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.
Temperature	The natural receiving water temperature of intrastate waters shall not be altered unless it can be demonstrated to the satisfaction of the Regional Water Board that such alteration in temperature does not adversely affect beneficial uses. At no time or place shall temperature of any COLD water be increased by more than 5 F above natural receiving water temperature.

In addition to water quality objectives, the Basin Plan (Regional Water Board 1996) includes two prohibitions specifically applicable to logging, construction, and other associated non-point source activities:

- the discharge of soil, silt, bark, sawdust, or other organic and earthen material from any logging, construction, or associated activity of whatever nature into any stream or watercourse in the basin in quantities deleterious to fish, wildlife, or other beneficial uses is prohibited; and

- the placing or disposal of soil, silt, bark, slash, sawdust, or other organic and earthen material from any logging, construction, or associated activity of whatever nature at locations where such material could pass into any stream or watercourse in the basin in quantities which could be deleterious to fish, wildlife, or other beneficial uses is prohibited.

2.2 Decline of Coho and Steelhead

The beneficial uses identified above for the salmonid fishery are currently impaired. Freshwater habitat conditions in the Navarro River and its tributaries have degraded and are not adequate to support the beneficial uses. The degradation in freshwater habitat conditions has contributed to a dramatic decline in the populations of coho and steelhead from historical levels.

The number of coho in California (including the Navarro River and its tributaries) has dropped sharply since the 1940s. In the 1940s the number of adults returning to spawn apparently ranged between 200,000 and 500,000 fish per year (Brown et al. 1994, as cited in Regional Water Board 2000). By the mid-1960s, the number statewide was estimated to have fallen to about 100,000 fish per year (Weitkamp et al. 1995, CDFG 1965, and California Advisory Committee on Salmon and Steelhead Trout 1988; all as cited in Regional Water Board 2000), followed by a further decline to about 30,000 fish in the mid-1980s (Wahle and Pearson 1987, as cited in Regional Water Board 2000). This is a decline from the 1940s to the 1960s of 50-80% and from the 1960s to 1980s of 70% for a total decline from the 1940s to the 1980s of 85-94%. From 1987 to 1991, an average of about 31,000 adult salmon returned to spawn, with hatchery populations making up 57% of the total (Weitkamp et al. 1995 and Brown et al. 1994; both as cited in Regional Water Board 2000). Without the influence of hatcheries, the total decline from the 1940s to the early 1990s would have been 93-97%.

In December 1996, the National Marine Fisheries Service listed the coho in the Central California Coast Evolutionarily Significant Unit (an area including the Navarro River and its tributaries) as a threatened species (i.e., they are likely to become endangered in the foreseeable future) under the federal Endangered Species Act.

The number of steelhead has also declined dramatically, and the National Marine Fisheries Service listed steelhead in the Northern California Evolutionary Significant Unit (including the Navarro River and its tributaries) as threatened in June 2000.

2.3 Salmonid Life Cycle and Habitat Requirements

Anadromous salmonids, including coho and steelhead, are born in freshwater streams where they spend one to several years feeding, growing, and hiding from predators. Once they are mature enough, they undergo a physiological change which allows them to swim out to the ocean where they spend the next one to several years. Subsequently, they return to the streams in which they were born and lay their eggs, beginning the life cycle again. Salmonids have different habitat requirements at different life stages. Table 2-2 describes the salmonid life cycle in more detail and outlines potential impacts to salmonids and their habitat. The TSD (Regional Water Board 2000) describes a variety of requirements for temperature, sediment, and other parameters, including cover, stream flow, space, dissolved oxygen, barriers, and productivity of streams and food sources. The Navarro River TMDLs address the impairments to freshwater salmonid habitat related to sediment and temperature. However, salmonid populations may not fully recover until other factors (e.g., ocean rearing conditions) are addressed.

2.3.1. Temperature Requirements

Ambient water temperature is one of the most important factors affecting the success of salmonids and other aquatic life. With coho and steelhead, temperature influences growth and feeding rates; metabolism; development of embryos and juveniles; timing of life history events, such as upstream

Table 2-2. Salmonid Life Cycle Stages and Potential Impacts to Salmonids and their Habitat

Life Cycle Stage	Potential Impacts to Salmonids and their Habitat	Potential Sources of Impact
Migration	- Stop or impede access of adult fish to spawning grounds - Stop or impede access of fry to adequate shelter and food - Stop or impede access of juveniles to the estuary and/or ocean - Physical harm	- Low flow conditions - Sediment deltas or bars - Log or debris jams - Water supply dams - Poorly engineered or maintained road-stream crossings - Over fishing - Predation
Spawning	- Absence of or reduction in appropriate substrate sizes - Substrate embedded or substantially embedded by fine sediment	- Mass wasting, including debris flows and stream bank failures - Gully erosion - Sheet and rill erosion - Drought - Loss or substantial loss of sediment storage capacity (e.g., removal or reduction in the availability of large woody debris)
Incubation	- Scouring or movement of redds - Suffocation or substantial entombment of redds	- Spring freshets - Elevated peak flows - Physical disturbance - Fine sediment delivery and/or remobilization
Emergence	- Substrate embedded or substantially embedded by fine sediment	- Fine sediment delivery and/or remobilization
Summer Rearing	- Elevated stream temperatures - Absence of or decline in the volume of rearing space (e.g., pools) - Absence of or decline in the amount of shelter - Absence of or decline in the amount of food - Disease	- Loss of or reduction in riparian vegetation, vegetation vigor, or complexity of community structure - Loss of or reduction in deep water habitat - Loss of or reduction in summer groundwater inflow - Loss of or reduction in summer intergravel flow - Delivery and/or remobilization of sediment to pools - Loss of or substantial reduction in instream structural elements (e.g., large woody debris) - Delivery and/or remobilization of fine sediment over aquatic macroinvertibrate habitat (e.g., gravels) - Increase in the types or ferocity of diseases (e.g., via release of hatchery-raised fish)

Winter Rearing	- Absence of or decline in off-channel habitat - Absence of or decline in in-stream shelter (e.g., large woody debris) - Elevated peak flows - Increased stream flow velocities	- Disconnection of stream channel from floodplain - Removal or reduction of large woody debris and other structural elements in the stream channel - Modification of up-slope hydrology (e.g., compacted soils, expanded surface drainage system, reduction in vegetation transpiration rate)
Ocean Rearing	- Physical harm - Absence of or decline in food supplies - Alteration of water temperatures	- Over fishing - Predation - Disease - Pollution - Climatic changes (e.g., greenhouse warming)

migration, spawning, freshwater rearing, and seaward migration; and food availability. Elevated temperatures can cause stress and lethality (Ligon et al. 1999, as cited in Regional Water Board 2000). Temperature is such an important requirement that coho and steelhead are known as "cold water fish."

Coho and steelhead can be affected by both acute (short-term) and chronic (long-term) exposure to elevated stream temperatures. Chronic exposure is often defined in terms of the highest value of the 7-day moving average of temperatures. This is known as the Maximum Weekly Average Temperature (MWAT). Fish can withstand short-term exposure to temperatures higher than those required day in and day out without significant adverse effects, but there are maximum temperatures above which adverse effects are encountered after only short exposures.

The following ranges of values are used for comparison to MWAT values to characterize the temperature quality of surface waters in the Navarro River and its tributaries (Table 2-3).

Table 2-3. Temperature Characterization Criteria

Descriptor	Temperature Values	
	Coho Salmon	Steelhead Trout
Good	<15 C (<59 F)	<17 C (<63 F)
Marginal	15 - 17 C (59 - 63 F)	17 - 19 C (63 - 66 F)
Poor/Unsuitable	>17 C (>63 F)	>19 C (>66 F)

In addition, to assess acute conditions, season hours above temperature thresholds of 18, 20, 22, 23, 24, and 25 C were evaluated.

2.3.2. Sediment Requirements

Coho and steelhead have a variety of requirements related to sediment. Sediments of the proper amount and size are needed for redd (salmon nest) construction, spawning, and embryo development. Excessive amounts of sediment can adversely affect salmonid habitat.

Too much sediment delivery to a stream can be a problem for coho and steelhead by filling pools. CDFG habitat data indicates that the better coho streams in Northern California (including the Navarro River watershed) have as much as 40% of their total habitat in primary pools (Flosi et al. 1998, as cited in Regional Water Board 2000). Pools in first and second order streams are considered primary pools when they are as long as the low-flow channel width, occupy at least half the width of the low-flow channel, and are two feet or more in depth. Primary pools in third order and larger channels are defined the same, except that maximum pool depth must be three feet or more.

Excessive fine sediment can smother redds, reducing egg and embryo survival. The redd construction process can reduce the amount of fine sediments and organic matter in the pockets where eggs are deposited (Meehan 1991, McNeil and Ahnell 1964, Ringler 1970, Everest et al. 1987; as cited in Regional Water Board 2000). However, if fine sediments are being transported in a stream either as bedload or in suspension, some of them are likely to be deposited in the redd. Tappel and Bjornn (1983, as cited in Regional Water Board 2000) found that embryo survival decreases as the amount of fine sediment increases.

The summer or winter carrying capacity of the stream for fish declines when fine sediments fill the interstitial spaces of the substrate used by fish for shelter. Newly emerged fry can occupy the voids of substrate made up of 2-5 cm diameter rocks, but larger fish need larger (>7.5 cm diameter) substrates in order to occupy the voids. In a laboratory stream experiment, Crouse et al. (1981, as cited in Regional Water Board 2000) found that growth of juvenile coho was related to the amount of fine sediments in the substrate. Density of juvenile steelhead and chinook salmon (*Oncorhynchus tshawytscha*) in summer and winter were found to be reduced by more than half when enough sand was added to fully embed the large cobble substrate (Bjornn et al. 1977, as cited in Regional Water Board 2000).

The addition of fine sediments to stream substrates as a result of watershed disturbances and erosion may reduce the abundance of invertebrates, a primary food source for juvenile salmonids, as well.

2.4. Temperature Problems in the Navarro River and its Tributaries

Summertime water temperatures in the streams of the Navarro River watershed have been altered upward during the past fifty years. Land use activities, water withdrawals, changes in flow, dam construction and associated water releases, and natural factors have all contributed to changing water temperatures in the Navarro River and its tributaries.

A variety of activities and events, both human-induced and natural, can affect stream temperatures (Coutant 1999, as cited in Regional Water Board 2000). During summer, direct solar radiation is the primary source of heat energy input to streams (Brown 1970, Brown 1980, Beschta et al. 1987, Beschta 1997, Coutant 1999, Oregon Department of Environmental Quality 1999, Sinokrot and Stefan 1993, Sullivan et al. 1990; all as cited in Regional Water Board 2000). Activities described in the TSD (Regional Water Board 2000) that can affect stream temperatures include those that decrease streamside (riparian) vegetation, reduce stream flow, or change channel morphology. The available studies that have focused on relations of particular land management activities, including forestry and livestock grazing, to stream temperatures have concluded that changes in riparian shade conditions influence stream temperatures, and have further found that shade is a key variable in explaining observed variations in stream temperatures.

Regional Water Board staff analyzed available data to determine the extent to which various factors are affecting stream temperatures in the Navarro and its tributaries. They reviewed data on temperature collected continuously at 66 locations in the watershed by the Mendocino County Water Agency or the

Louisiana-Pacific Corporation. Of the 66 locations, 29 are located on main stream channels and 37 are located on smaller tributaries. Locations tend to be concentrated in forested areas and along the main stream channels.

Regional Water Board staff made several general observations. Current stream temperatures tend to be lowest in small tributary streams. Temperatures tend to be highest in locations on the main streams of Anderson, Indian, and Rancheria Creeks, and on the Navarro. The active channels are wider than normal in many reaches with high stream temperatures. Riparian vegetation in some of these reaches is sparse.

Maximum weekly average temperatures (MWAT) values were calculated for all locations to determine the extent of current problems. The results are presented in Figure 2-1. Most locations monitored are considered poor/unsuitable for both coho and steelhead, using the criteria identified in Table 2-3. At many locations, stream temperatures are high enough to be lethal to salmonids on many days during the summer months. Data for the entire watershed were used to generate Figure 2-1. The TSD (Regional Water Board 2000) also describes current temperature conditions in each of the major subwatersheds.

The data were also evaluated to determine when the MWATs occurred. As described in Figure 2-2, the MWAT most frequently occurred between July 16 and July 31, with the average date being July 22.

Figure 2-1. Frequency Distribution of Site-Averaged MWAT Values Navarro Watershed, 1995-1999

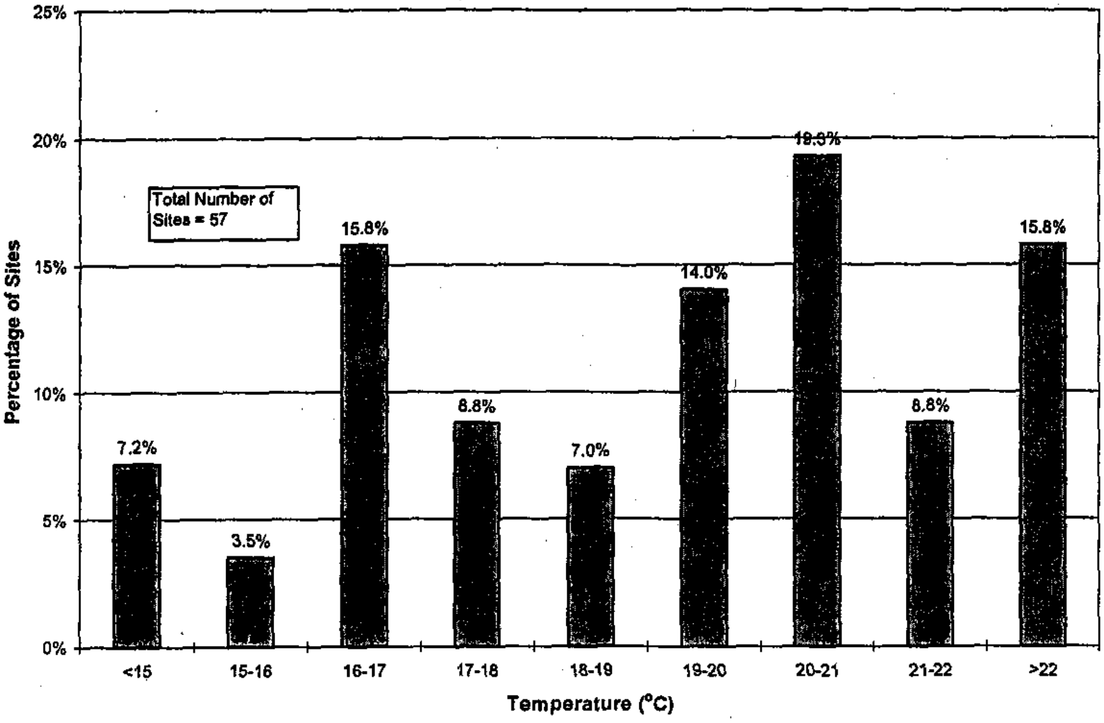
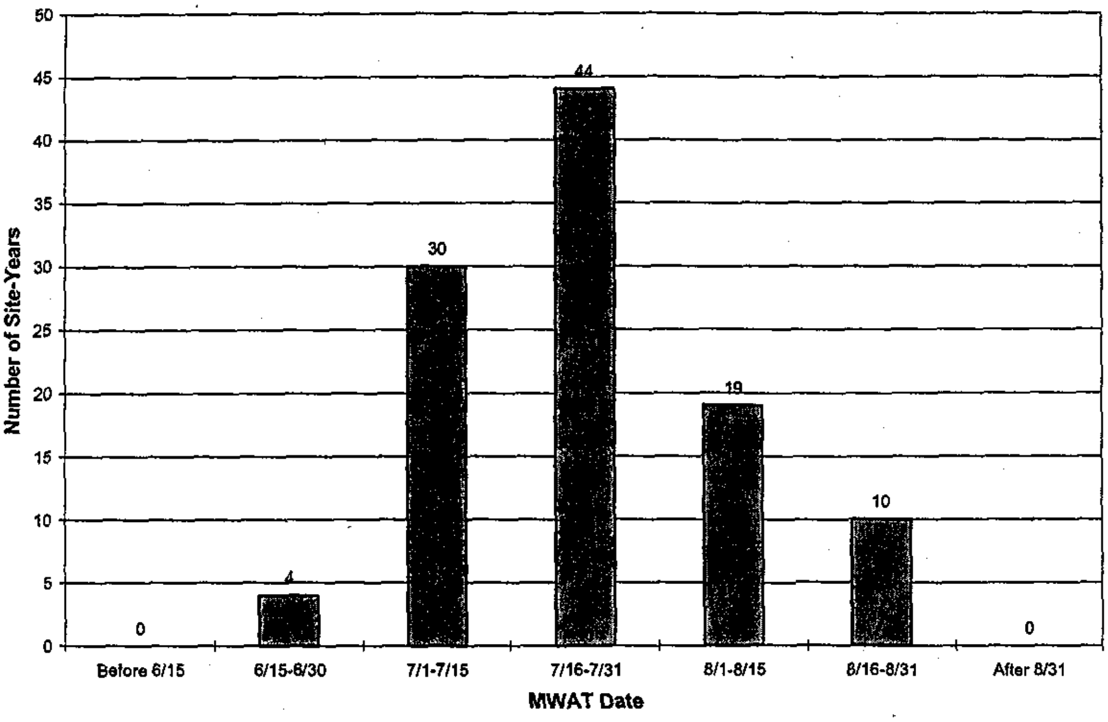


Figure 2-2. Frequency Distribution of MWAT Dates Navarro Watershed, 1995-1999



2.5. Sediment Problems in the Navarro River and its Tributaries

Sediment problems in the Navarro River and its tributaries are assessed by subwatershed (see Figure 2-3) below. Additional analysis is presented in the TSD (Regional Water Board 2000).

In the North Fork Navarro Basin, analysis of the in-stream data indicates salmonid habitat conditions, in general, have been degraded. The data suggests management activity has resulted in reduction of both the quantity and quality of pool habitat. In 1996, Entrix (1998, as cited in Regional Water Board 2000) found excessive deposition of fine sediments in pools and riffles in all reaches surveyed, as well as evidence of aggradation in the lower North Branch of the North Fork, and concluded that chronic fine sediment deposition and loss of large woody debris are adversely affecting stream reaches throughout the entire Navarro River watershed. Gravel samples evaluated by Mendocino Redwood Company (Surfleet 2000, as cited in Regional Water Board 2000) and Roger Foott Associates (1990, as cited in Regional Water Board 2000) indicate that gravel quality may also be a problem in the North Fork. The data indicates that on the whole, the suitability of gravels found in the North Fork is marginal for spawning.

The Mainstem Navarro River Basin is also adversely impacted by sediment. Data from CDFG surveys (CDFG 1998, as cited in Regional Water Board 2000) indicate that the quantity and quality of pool habitat in the tributary systems of the Mainstem Navarro River Basin are deficient. Entrix (1998, as cited in Regional Water Board 2000) reported that deposition of fine sediments in pools was widespread in Mill Creek, the largest tributary in the basin, and in general, accumulation of fine sediments was very high compared to most other stream reaches surveyed. They also reported evidence of accelerated bank erosion, which may explain the elevated fine sediment deposition, while CDFG (1998, as cited in Regional Water Board 2000) noted that several road crossings were adding sediment and suggested that the road system be treated to reduce sediment yield. Deposition of fine sediments has also affected the quality of spawning gravels in the Mainstem Navarro River Basin.

For the Rancheria Creek Basin, information in the recent past is slim. CDFG crews surveyed the entire length of Rancheria Creek and most major tributaries in 1962, and with the exception of the upper reaches of Camp Creek, every stream survey indicated intense degradation due to recent logging. CDFG data from 1996 for the lower reaches of Rancheria Creek indicates that these streams have at least partially recovered from the destruction of the 1960s.

In the Anderson Creek Basin, Entrix (1998, as cited in Regional Water Board 2000) surveyed two reaches of Con Creek, a tributary to Anderson Creek. They concluded that fine sediment deposition and accelerated bank erosion had occurred in both reaches. They analyzed aerial photos of unconfined reaches of Anderson Creek and concluded that evidence of present-day aggradation was strong, based on changes in active channel width, sediment storage in gravel bars, and cross-sections at bridges.

The Indian Creek Basin also demonstrates impacts from sediment. Entrix (1998, as cited in Regional Water Board 2000) surveyed a 1.5-mile stretch of the North Fork of Indian Creek in 1996. They concluded that coarse sediment deposition and persistent channel aggradation has occurred; that fine sediment deposition did not appear to be prevalent; and that there is moderate to strong evidence of wood loss. The stream survey also noted evidence of historical bank erosion problems that dated back fifteen to thirty years. Current bank erosion is moderate to low (25% to 30%) and most often occurs on outside bends.

Overall, these conditions indicate that excessive amounts of coarse and fine sediment are causing decreased habitat quality for salmonids.

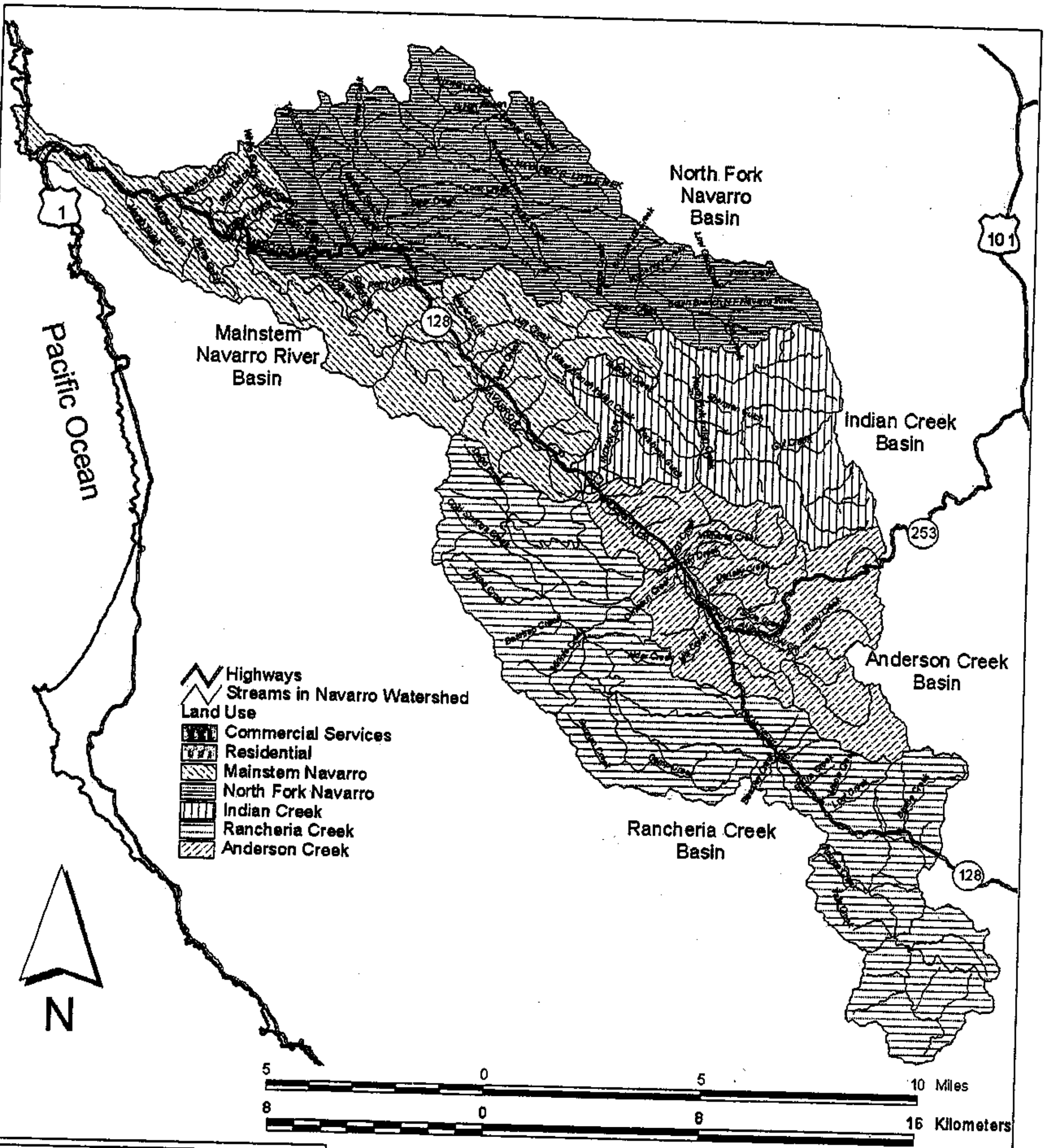


FIGURE 2-3
Navarro River Watershed TMDL Planning Areas and Sub-watersheds

Navarro River Watershed
August 2000

CHAPTER 3: TEMPERATURE

This chapter is divided into sections: (1) evaluation of the sources of heat and factors influencing water temperature in the Navarro River system; (2) identification of the stream temperature targets necessary to meet applicable water quality standards; (3) identification of the amount of riparian shade needed throughout the watershed; (4) identification of the specific shade conditions needed at a given location to meet the stream temperature targets; and (5) discussion of the margin of safety, critical conditions, and seasonal variation associated with the temperature TMDL.

3.1. Sources of Increased Stream Temperatures

There are no known point sources of heat to the Navarro or its tributaries, so this source analysis focuses exclusively on non-point sources, specifically solar radiation inputs. Regional Water Board staff used two approaches to assess which parameters affecting solar radiation inputs have the most effect on stream temperatures. First, a model based on equations describing the physical processes controlling stream temperature is applied to a reach of the Navarro. Second, regression analyses are used to look at management-related parameters for which data are available. Results indicate that air temperature, streamside shade, and wind speed are the most important variables affecting stream temperatures.

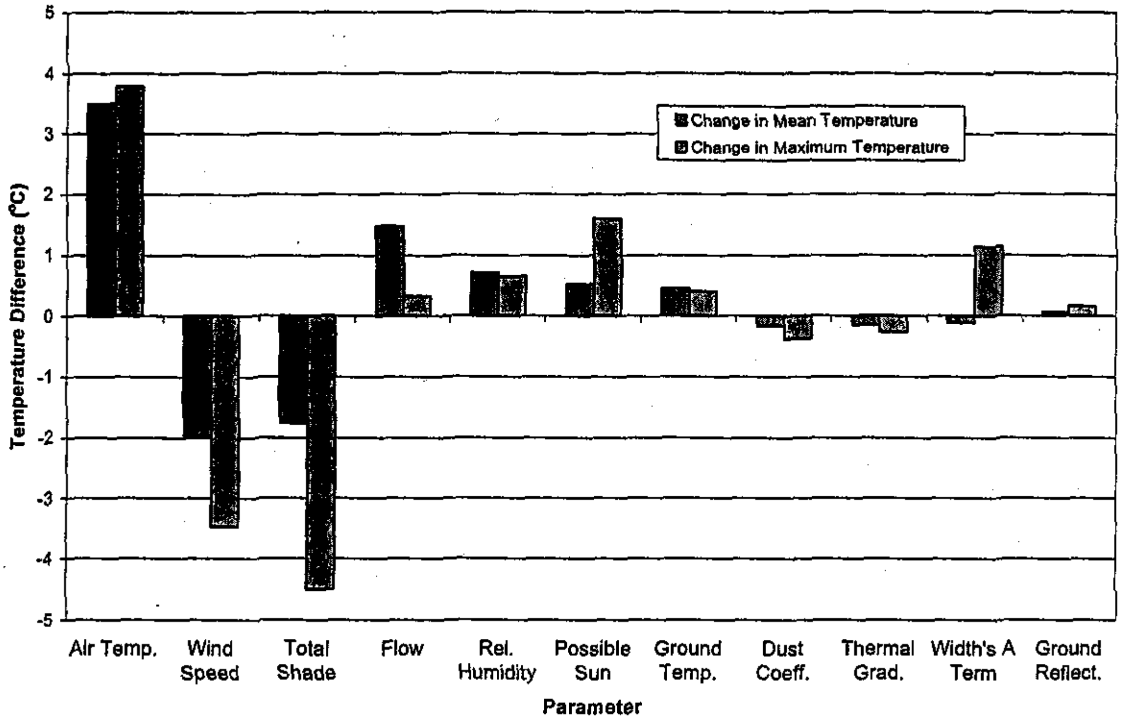
The first approach evaluates the relative importance of the various factors that affect stream temperatures in the Navarro watershed by modeling a portion of the Navarro River using was SSTEMP, a simplified version of SNTEMP (Stream Network Temperature Model) (Bartholow 1989, as cited in Regional Water Board 2000). Both SNTEMP and SSTEMP are public domain codes and are currently supported by the U.S. Geological Survey. Model inputs for the Navarro analysis are described in the TSD (Regional Water Board 2000).

Results of the sensitivity analysis are presented for both average and maximum temperatures. In these figures, parameters that directly relate to temperature are shown above the zero line, and parameters that are inversely related to temperature are shown below the line. For example, shade is inversely related to stream temperature (i.e., stream temperature decreases when shade increases), so the bars for shade extend downward from the zero line.

The results indicate that total shade, air temperature, and wind speed are the most important parameters influencing stream temperatures for the modeled reach of the Navarro. In Figure 3-1, the parameters are ranked by magnitude of effect on the predicted mean daily stream temperature, and the results indicate that mean temperature is most sensitive to air temperature, followed by wind speed and total shade. In Figure 3-2, the parameters are ranked by magnitude of effect on the estimated maximum daily stream temperature, and the results indicate that total shade is the most important parameter influencing maximum temperature, followed by air temperature and wind speed. Other parameters, including flow and channel width, appear to be of lesser importance as influences on both average and maximum stream temperature.

To investigate further the importance of the various factors affecting stream temperature, specific locations in the Navarro River and its tributaries were analyzed. Existing data on stream temperature and flow collected at fifteen stations were used in this regression analysis, supplemented by measurements of shade, channel geometry, and stream vegetation conditions taken by Regional Water Board staff (Regional Water Board 2000).

Figure 3-1. Sensitivity Analysis of SSTEMP on a Navarro River Reach Sorted by Effect of Parameter Variation on Mean Temperature



The data were used to look at the relationships of MWAT values to effective shade, stream width/depth ratios, and stream flow in 1995 and 1996. For both years, MWAT values show a good correlation with effective shade. There was little correlation with either width/depth ratio or stream flow.

The results of the sensitivity and regression analyses indicate that shade, air temperature, and wind speed are the most important factors affecting stream temperatures in the Navarro and its tributaries.

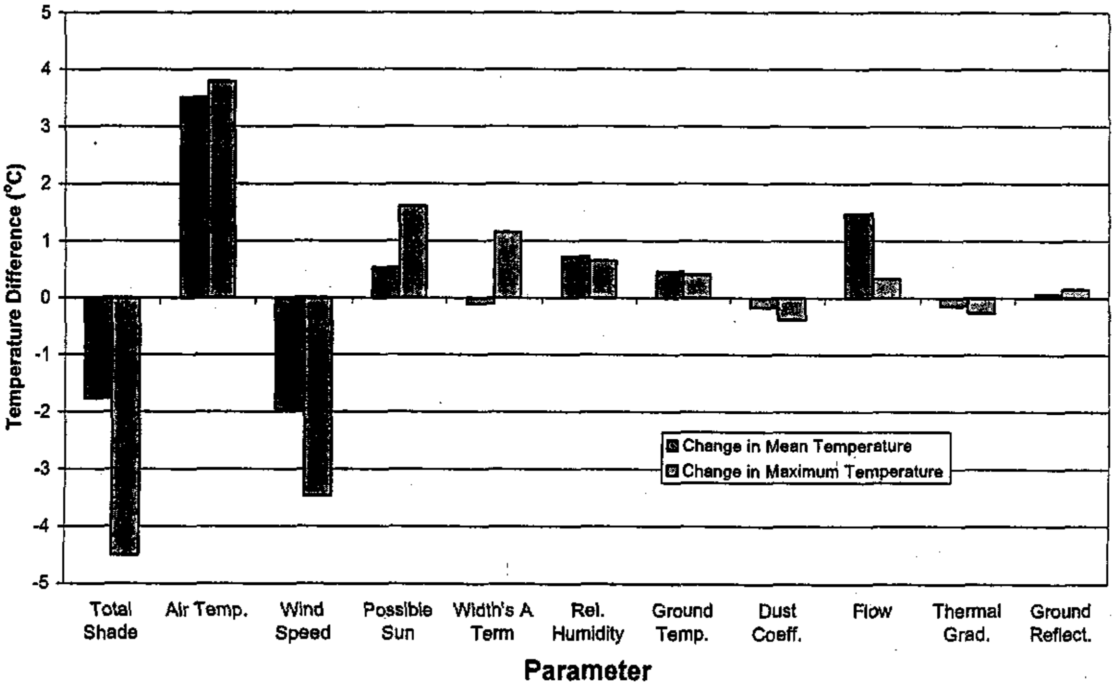
Although air temperature and wind speed are also important factors affecting stream temperature, this TMDL focuses on shade. All three factors are influenced by the extent of riparian vegetation (vegetated areas have lower summertime air temperatures and lower wind speeds [and also higher relative humidity] than open areas), but shade is the most directly related. Streamside vegetation is often the predominant source of shade along rivers. Also, shade can be related mathematically to solar radiation inputs, and it can be readily measured in the field.

To account, in part, for the effects of air temperature and wind speed, the TSD (Regional Water Board 2000) assessed potential future conditions assuming a riparian width of 30 m (about 100 feet). This width was selected based on reports in the scientific literature (Beschta et al. 1987, Steinblums et al. 1984, Ledwith 1996; all as cited in Regional Water Board 2000) that indicate 30 m is sufficient to achieve most of the moderating effects on stream temperature associated with air temperature and wind speed [other benefits of riparian areas, such as large woody debris recruitment, were not considered]. Thus, riparian width, as well as vegetation height, is an important consideration underlying this temperature TMDL.

3.2. Numeric Targets

In the context of TMDLs, targets are defined in order to interpret water quality standards. They provide

Figure 3-2. Sensitivity Analysis of SSTEMP on a Navarro River Reach Sorted by Effect of Parameter Variation on Maximum Temperature



indicators of watershed health, and represent habitat and related conditions necessary or adequate for the achievement of water quality standards. They can be used to compare existing conditions to target conditions, to provide an evaluation framework for analyzing monitoring data collected in the future (and making changes to the TMDL and implementation plan), and to assist in evaluating whether land management and restoration activities are effective in improving temperature conditions in the watershed.

The narrative water quality objective in the Basin Plan for temperature (see Table 2-1) states that: "natural receiving water temperature shall not be altered unless . . . such an alteration in temperature does not adversely affect beneficial uses." For the Navarro River temperature TMDL, this objective is further defined by estimating the "natural" water temperatures for the watershed. This is done by estimating the natural level of shade for streams in the watershed and calculating the resulting water temperatures using a GIS model. These water temperatures are the numeric targets for the Navarro River temperature TMDL.

The GIS model was used to determine the potential amount of shade that would be present if the vegetation near streams was fully mature. The GIS model, developed by Regional Water Board staff (Regional Water Board 2000), calculates the percent of possible solar radiation received at each location along the Navarro River and its tributaries, considering sun position, topography, stream location and orientation, the unvegetated channel width, the distribution of vegetation types in the watershed, and the potential height of mature vegetation (dependant on vegetation type). The results are expressed in terms of effective shade, which accounts for the fact that shade varies by time of day. Effective shade is the percent reduction of potential solar radiation delivered to the water surface. For example, if the combination of topography and vegetation at a specific location blocks 3/4 of the potential solar radiation from reaching the stream, the effective shade for that location would be 75%.

The potential effective shade results were then adjusted to account for the fact that, even under natural conditions, not all streamside vegetation is at 100% of its potential height. For example, fires and storms can lessen the amount and height of streamside vegetation. Potential shade conditions were, therefore, reduced by 10% to account for this natural variation.

Finally, the adjusted potential shade results were converted to maximum stream temperatures (MWATs) using an equation developed by Regional Water Board staff by plotting shade values versus measured MWATs (Regional Water Board 2000). The resulting MWAT values are displayed in Figure 3-3, along with the model estimates of current temperatures. The MWAT values for adjusted potential shade are the estimates of "natural" temperatures for the Navarro River and its tributaries. As such, they are the numeric targets for the Navarro River temperature TMDL. Achievement of these temperatures is expected to be adequate to allow salmonid populations to return to historic levels, if other limiting factors (e.g., sediment) are also addressed.

As shown in Figure 3-3, existing temperatures exceed potential (i.e., natural) temperatures in many locations. To illustrate the degree of existing temperature problems, the MWAT values for current and adjusted potential conditions are grouped by temperature class in Figure 3-4, using the temperature characterization criteria identified in Table 2-3.

3.3. Loading Capacity, TMDL, and Linkage Analysis

The total loading of a pollutant that a water body can assimilate while still meeting water quality standards is the loading capacity. While heat (radiant solar energy) is the pollutant of concern, this TMDL focuses on effective shade as a surrogate for heat, because effective shade is inversely and directly proportional to heat, and it is readily measured in the field or calculated using mathematical models. Therefore, the loading capacity of the Navarro River for temperature is defined in terms of the amount of effective shade possible along the Navarro River and its tributaries when riparian vegetation is in its adjusted potential condition.

The GIS model described in Section 3.2 was used to calculate effective shade values for the Navarro River and its tributaries for July 22, the date that, on average, is the hottest of the year in the watershed [July 22 is the mean of the dates of maximum temperature (MWAT) for individual locations in the watershed; see Figure 2-2]. Effective shade values were calculated for both current and adjusted potential vegetation conditions.

The results are described in Table 3-1, which identifies the length of streams in the watershed that would have specific amounts of effective shade, under current and under adjusted potential shade conditions. It also identifies the percentage of stream length in the watershed that has more than the specified amount of effective shade. For example, under current riparian vegetation conditions, 84 miles (134 km, or 15.6%) of the streams in the watershed have between 60% and 70% effective shade, and 5.3% of the streams in the watershed have more than 70% shade. However, under adjusted potential vegetation conditions, 125 miles (200 km; or 23.4%) of streams in the watershed would have between 60% and 70% effective shade, and 36.5% of the streams in the watershed would have more than 70% effective shade.

The results for adjusted potential vegetation are the amounts of effective shade needed to meet applicable water quality standards for temperature. When streams in the watershed have at least this much shade, it is expected that the temperature targets identified in Section 3.2 will be met. Thus, the values for adjusted potential conditions in Table 3-1 constitute the loading capacity, and therefore the TMDL, for temperature for the Navarro River and its tributaries.

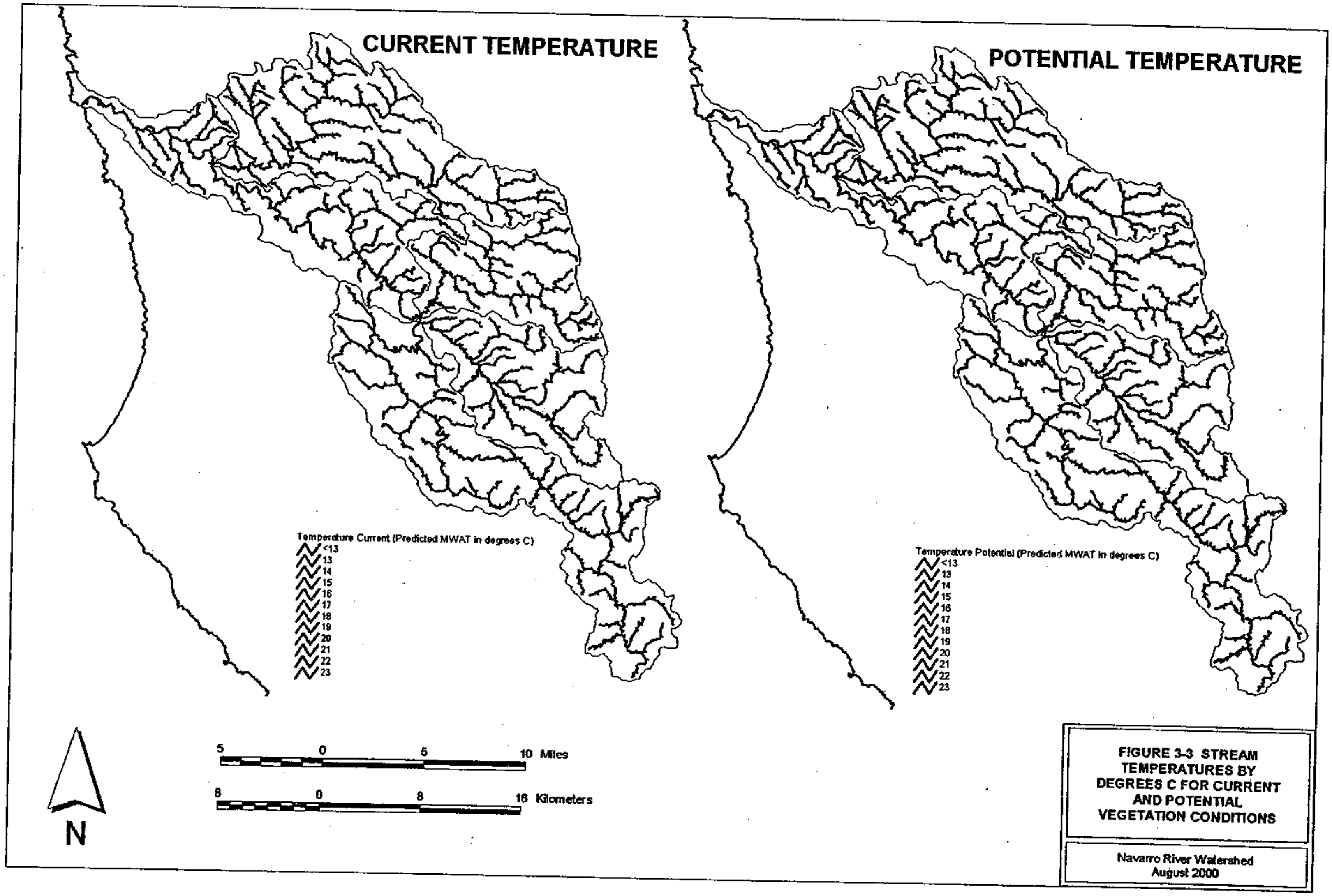


FIGURE 3-3 STREAM TEMPERATURES BY DEGREES C FOR CURRENT AND POTENTIAL VEGETATION CONDITIONS

Navarro River Watershed
August 2000

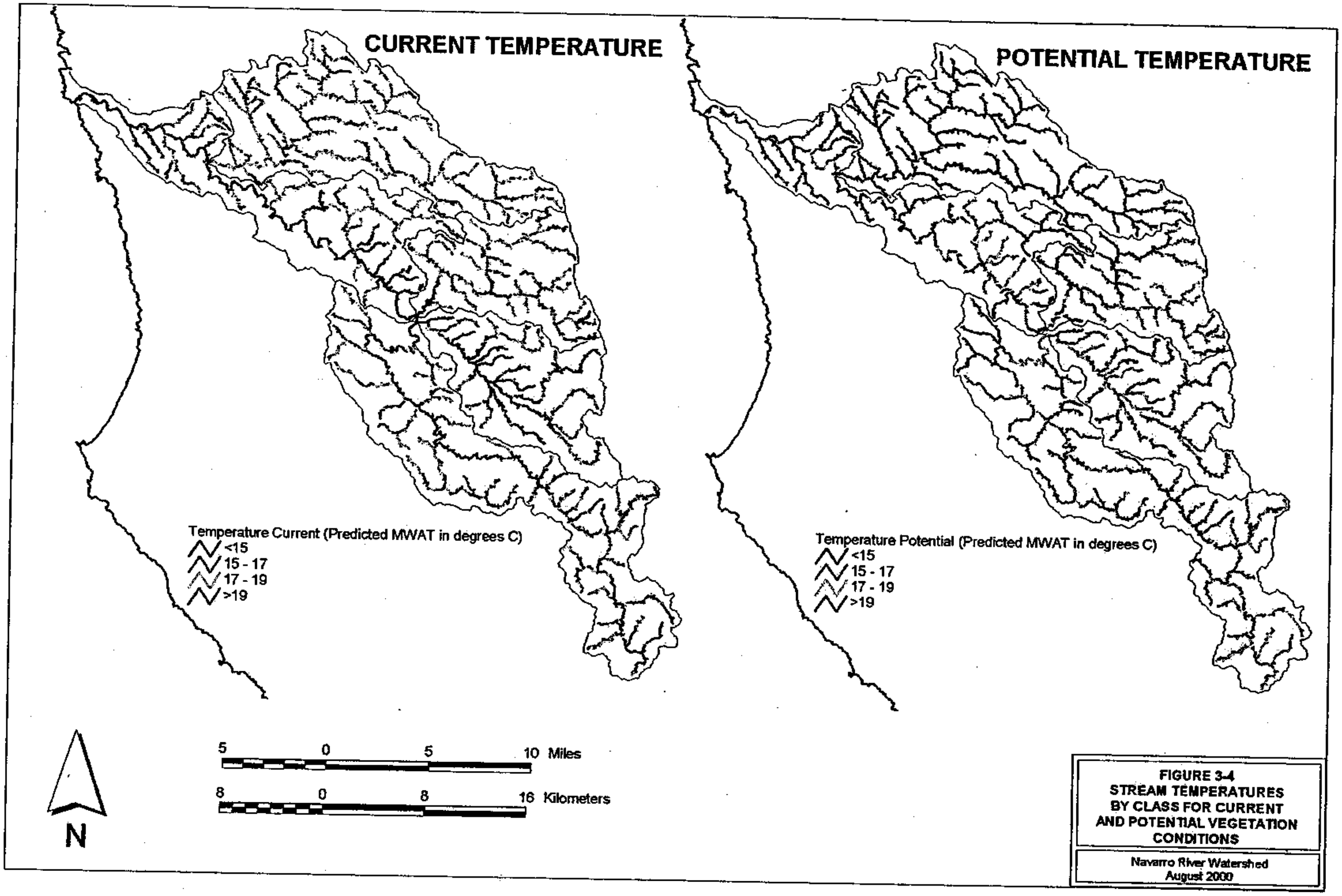


FIGURE 3-4
STREAM TEMPERATURES
BY CLASS FOR CURRENT
AND POTENTIAL VEGETATION
CONDITIONS

Navarro River Watershed
August 2000

Table 3-1. Total Length of Streams in the Watershed having Specified Amounts of Effective Shade (Loading Capacity and TMDL for Temperature)

Amount of Effective Shade (%)	Stream Length (miles [km])		% of Total		% Shadier (cumulative)	
	Current Vegetation Conditions	*Adjusted Potential Conditions*	Current Vegetation Conditions	*Adjusted Potential Conditions*	Current Vegetation Conditions	*Adjusted Potential Conditions*
0 - 10	0 [0]	*0 [0]*	0.0	*0.0*	100.0	*100.0*
10 - 20	0 [0]	*0 [0]*	0.0	*0.0*	100.0	*100.0*
20 - 30	58 [93]	*16 [25]*	10.9	*2.9*	89.1	*97.1*
30 - 40	89 [142]	*43 [69]*	16.5	*8.1*	72.6	*89.0*
40 - 50	132 [211]	*74 [119]*	24.6	*13.9*	48.0	*75.1*
50 - 60	145 [232]	*81 [130]*	27.0	*15.2*	20.9	*59.9*
60 - 70	84 [134]	*125 [200]*	15.6	*23.4*	5.3	*36.5*
70 - 80	25 [40]	*166 [265]*	4.6	*31.0*	0.7	*5.5*
80 - 90	3 [5]	*29 [47]*	0.6	*5.5*	0.0	*0.0*
90 - 100	0 [0]	*0 [0]*	0.0	*0.0*	0.0	*0.0*
Total*	**535 [856]**	*535 [856]*				

*Columns were summed before rounding, so totals listed may not equal the sum of the rounded column entries.

3.4. Load Allocations

In accordance with EPA regulations, the TMDL (i.e., loading capacity) for a water body is to be allocated among the various sources of the targeted pollutant, with a margin of safety. Allocations for point sources are known as wasteload allocations. Those for non-point sources are known as load allocations. As there are no known point sources of heat into the Navarro River and its tributaries, the wasteload allocation for point sources is set at zero. Thus, the TMDL for temperature for the Navarro River and its tributaries is divided among the non-point sources of heat in the watershed, with a margin of safety. In this case, with the non-point sources being sunlight at the various streamside locations in the watershed, and with effective shade being used as a surrogate for heat, the establishment of load allocations equates to the identification of the effective shade requirement for any specific streamside location.

The method used to calculate effective shade needs for the watershed as a whole is not appropriate for determining the requirements (i.e., load allocations) for specific stream reaches. As described in Section 3.3, the GIS model was used to calculate effective shade conditions under adjusted potential vegetation conditions for all streams in the watershed, with the aggregated values representing the loading capacity for the Navarro River and its tributaries. However, it is not feasible to use a GIS map to determine the amount of effective shade needed at a specific stream location. Therefore, the Regional Water Board developed a means of determining the necessary effective shade value for any given stream reach, based on conditions found in the field at that location.

The Regional Water Board developed effective shade curves in the TSD (Regional Water Board 2000), which correlate vegetation type, stream direction (e.g., north), and active (i.e., unvegetated) channel width with effective shade. The effective shade curves were developed using an Excel-based spreadsheet developed by the Oregon Department of Environmental Quality for TMDL applications. Effective shade curves are presented for various vegetation types: Redwood Forest (Figure 3-5), Douglas Fir and Mixed Hardwood-Conifer Forest (Figure 3-6), Klamath Mixed Conifer Forest and Ponderosa Pine Forest (Figure 3-7), and Oak Woodland (Figure 3-8). For example, take the case of a stream flowing west through a redwood forest with a channel 32 meters wide. Using Figure 3-5 (for redwood forest) and the line connecting the triangles (for a west flowing stream), the effective shade value corresponding to a channel width of 32 meters is about 85%.

The effective shade value corresponding to conditions for a particular stream reach is the load allocation for that location. The difference between current shade conditions and the load allocation constitutes the increase in effective shade needed to meet water quality standards at that location. If load allocations were actually calculated for all stream reaches in the watershed, using the effective shade curves, it is expected that the aggregated results would be equivalent to the values in Table 3-1 developed using the GIS model.

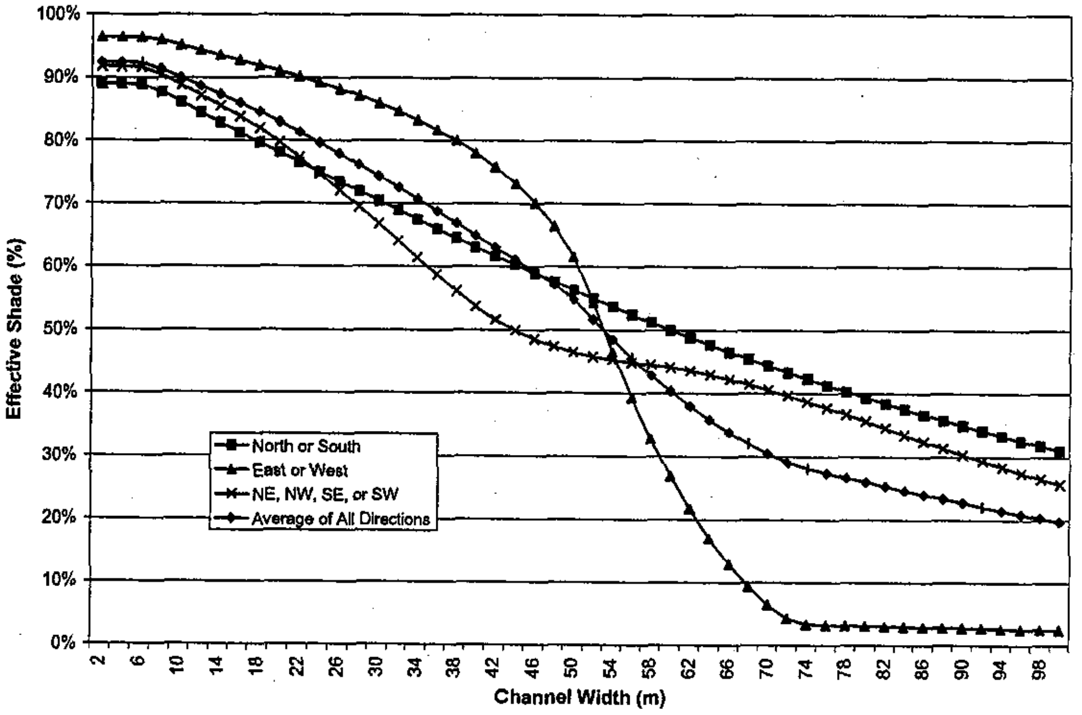


Figure 3-5. Effective Shade vs. Channel Width, Redwood Forest

Figure 3-6. Effective Shade vs. Channel Width, Douglas Fir Forest and Mixed Hardwood-Conifer Forest

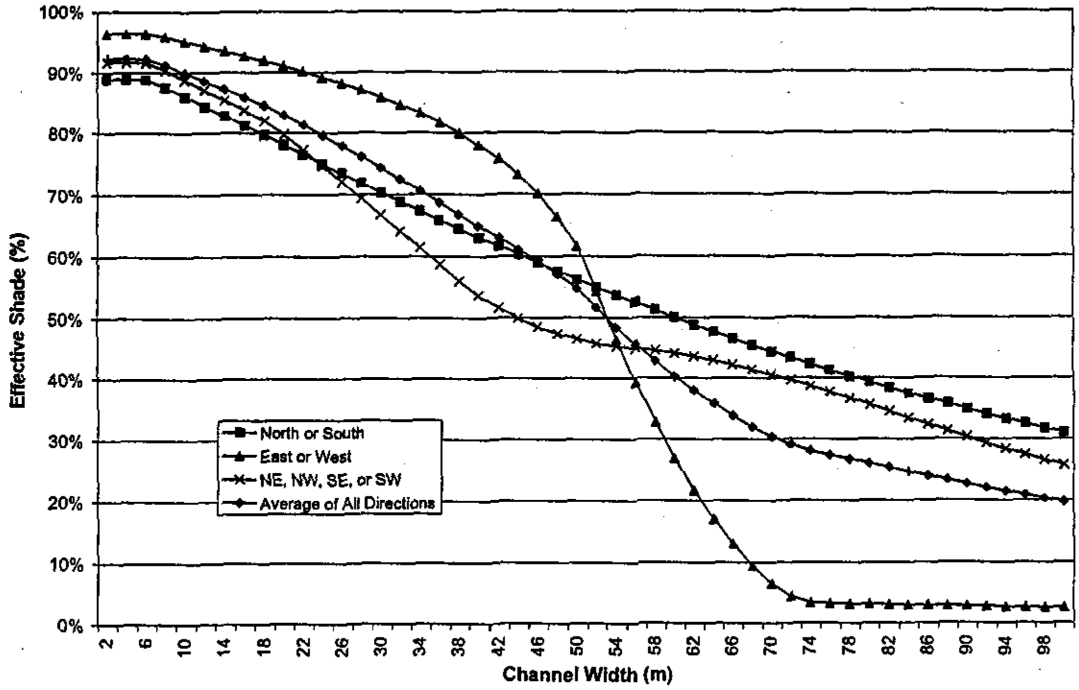


Figure 3-7. Effective Shade vs. Channel Width, Klamath Mixed Conifer Forest and Ponderosa Pine Forest

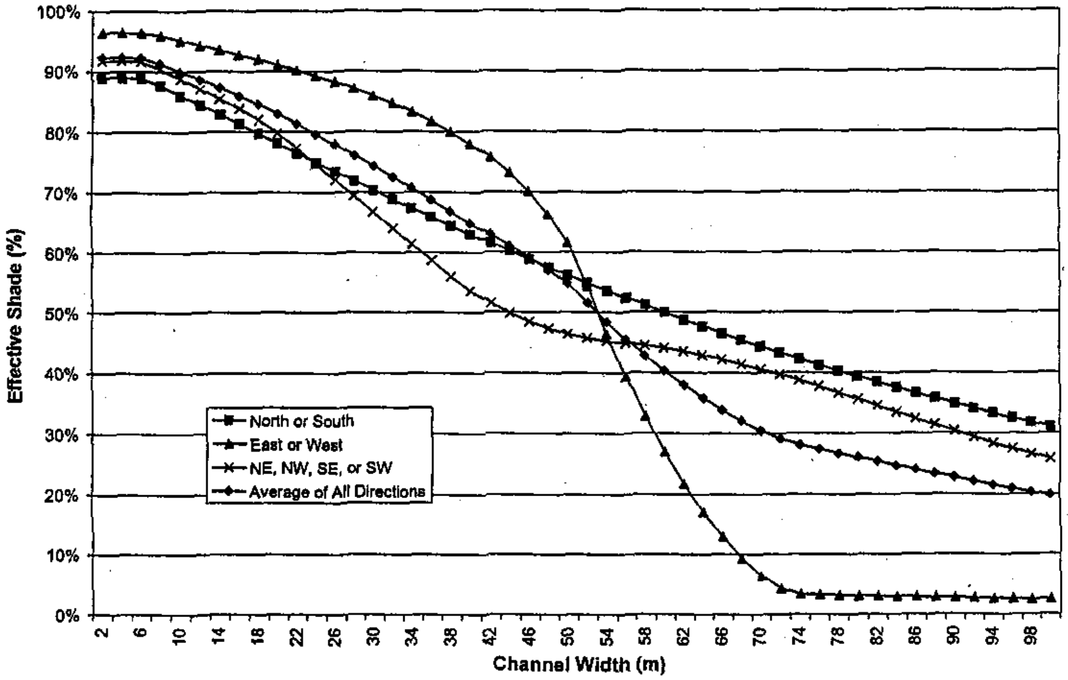
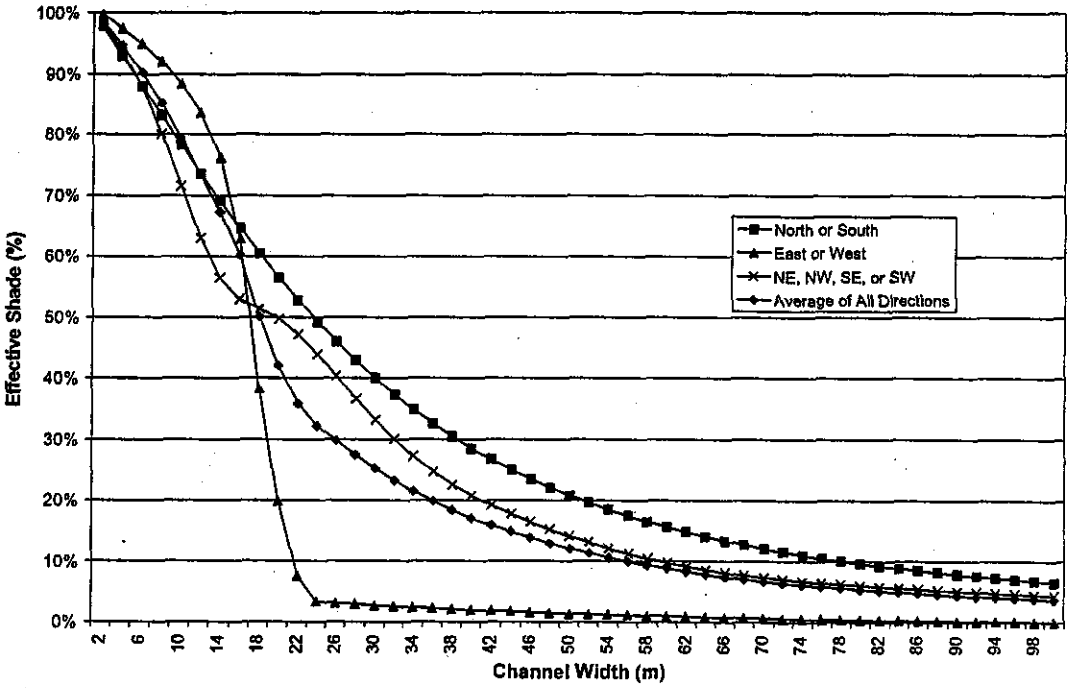


Figure 3-8. Effective Shade vs. Channel Width, Oak Woodland



3.5. Margin of Safety, Seasonal Variation, and Critical Conditions

Section 303(d) and associated regulations at 40 CFR 130.7 require that TMDLs include a margin of safety which takes into account any lack of knowledge concerning the relationship between the pollutant loads and the desired receiving water quality. The margin of safety can be implicitly incorporated into conservative assumptions used in calculating loading capacities, waste load allocations, and load allocations. For this TMDL, several conservative assumptions were made that account for uncertainties in the analysis and constitute the margin of safety.

- The effects of changes to streamside riparian areas toward mature trees will tend to create microclimates that will lead to improvements in stream temperatures. These effects were not accounted for in the temperature analysis.

- Changes in streamside vegetation toward larger, mature trees will increase the potential for contributions of large woody debris to the streams. Increases in large woody debris benefit stream temperatures and associated cool water habitat by increasing channel complexity, including the number and depth of pools, which can provide areas of cooler water for fish. These changes were not accounted for in the analysis.

- Potential shade estimates were adjusted (reduced) by 10% to allow for the effects of natural factors which reduce shade, such as fires and storms. The actual amount of reduction may be more, so the use of 10% results in conservative load allocations.

- The Navarro River TMDLs for temperature and sediment are based on separate analyses. Reduced sediment loads could be expected to lead to increased frequency and depth of pools and to reduced wetted channel width/depth ratios. These changes would tend to result in lower stream temperatures overall and in more lower-temperature pool habitat. Improvements in stream temperature that may result from reduced sedimentation were not considered in the analysis.

- While the potential shade conditions used to calculate the loading capacity assume that the occurrence of site potential vegetation extends to the bankfull channel width, the effective shade curves can be applied to either current channel widths or to projected bankfull widths. Application of the curves to current channel conditions, as was done in the analysis, does not account for channel narrowing that may occur as a result of reduced sediment loads.

The TMDL must also account for critical conditions and seasonal variations. In this case, the analysis is based on the most critical conditions (i.e., the period of highest stream temperatures). The shade conditions necessary during this season will be more than adequate during other seasons.

CHAPTER 4: SEDIMENT

This chapter identifies numeric targets for in-stream and surrounding watershed conditions that are needed to meet applicable water quality standards for sediment. It contains an evaluation of the sources of sediment, including the relative contribution of natural and human-caused sediment sources. It establishes the maximum amount of sediment that the system can tolerate and still attain water quality standards and allocates this amount among the various source categories. It concludes with a description of the margin of safety, critical conditions, and seasonal variation associated with the sediment TMDL.

4.1. Numeric Targets

The applicable water quality objectives for sediment for the Navarro River and its tributaries are listed in Table 2-1. The in-stream targets identified below are based on the Regional Water Board staff's interpretation of these objectives, specifically how increased sediment delivery causes nuisance and adversely affects beneficial uses (Regional Water Board 2000). These targets reflect in-stream sediment conditions that are required by cold water fishery species present in the Navarro and its tributaries. They are indicators of in-stream sediment supply and stream "health."

In addition, up-slope targets (i.e., targets applying to the hillslopes adjacent to streams) are identified as a means of evaluating the degree to which sediment production problems, and the associated risk of future delivery to streams (and, thus, overall watershed and future in-stream health), are addressed.

Of course, the ultimate numeric target is that of increasing returns of adult salmonids. However, since other processes beyond freshwater quality are significant, fish populations alone cannot be used as the gauge for determining decreasing impairment due to effects of sedimentation (i.e., desirable freshwater habitat conditions may be attained before salmonid populations recover).

Because of the inherent variability associated with stream channel conditions, it is appropriate to evaluate the attainment of the in-stream numeric targets based on a weight-of-evidence approach. No single parameter may be indicative of the health of the stream, but when considered together, the parameters are expected to provide a good indication of the condition of the stream.

The targets are divided into short-, mid-, and long-term categories, depending on how long it is expected to take for the target parameter to respond to changes.

4.1.1 Short-term Numeric Targets and Indicators

Short-term targets are for in-stream and up-slope parameters that respond relatively quickly (a few years). Short-term in-stream targets are expected to respond quickly to changes in sediment delivery to streams. (For instance, V* surveys are expected to respond to changes in the supply of fine sediments soon after those changes occur.) Similarly, changes in short-term targets for up-slope parameters are expected to result quickly in reductions of sediment production. (For example, decreases in the hydrologic connectivity between roads and streams are expected to decrease the delivery of road-related surface erosion soon after implementation.) Though the targets are called short-term targets (because they can be attained relatively quickly), they apply over the life of the TMDL.

V* 15%: Lower-order Streams

V* (pronounced "vee-star") is a measure of the fraction of a pool's volume that is filled by fine sediment and is representative of the in-channel supply of mobile bedload sediment (Lisle and Hilton 1992, as cited in Regional Water Board 2000). Lisle and Hilton (1999, as cited in Regional Water Board 2000) demonstrated the usefulness of the parameter by comparing annual sediment yields of select streams with their average V* values. The comparison indicated that V* was well correlated to annual sediment yield. They also demonstrated that V* values can quickly respond to changes in sediment supply. V* values in French Creek, a tributary to the Scott River, decreased to approximately one-third the initial value soon after an erosion control program focusing on roads was implemented. A study of more than sixty streams in the Franciscan geology of Northern California found that a mean V* value of 21% represented good stream conditions (Knopp 1993, as cited in Regional Water Board 2000). Knopp's study was conducted after a period of drought that many believe had affected the results. Lisle and Hilton (1999, as cited in Regional Water Board 2000) reported that V* values for Elder Creek, an undisturbed tributary of the South Fork Eel River in Coastal Belt Franciscan Geology, averaged only 9%. Therefore, the numeric target for V* in the Navarro and its tributaries is the average of 21% and 9%, which is 15%. The V* target applies to lower-order streams as a short-term indicator. It does not apply to higher-order streams on a short-term basis, because higher-order streams are not expected to be as responsive to changes in short-term sediment delivery, due to the high amounts of fine sediments currently stored as in-stream deposits.

Fine Sediment Volume of the Active Bed Matrix: Decreasing Trend

The fine sediment volume of the matrix material of the active bed is the volume of fine sediment in the subsurface of gravel bars. It is included as a method of tracking trends of in-stream fine sediment storage. The parameter is also intended to aid in interpretation of V* trends, and eventually as a means of describing changes in sediment supply. Volumes should be measured as described in Lisle and Hilton (1999, as cited in Regional Water Board 2000). No particular value is set as a target, only a decreasing trend in the volume stored.

Percent Fines 0.85 mm: 14%

The percent fines 0.85 is defined as the percentage of subsurface fine material in pool tail-outs 0.85 mm in diameter. This parameter is chosen as one of two surrogate measurements of spawning gravel suitability. The numeric target for this parameter is 14% based on the average of values reported for unmanaged streams in the studies by Peterson et al. (1992, as cited in Regional Water Board 2000) and Burns (1970, as cited in Regional Water Board 2000).

Percent Fines 6.4 mm: 30%

The percent fines 6.4 mm is defined as the percentage of subsurface fine material in pool tail-outs 6.4 mm in diameter. This parameter is chosen as the second of two surrogate measurements of spawning gravel suitability. The numeric target for this parameter is 30% based on Kondolf's (2000, as cited in Regional Water Board 2000) summary of information reported in various studies.

Hydrologic Connectivity of Roads: 10%

Hydrologic connectivity of roads, defined as the proportion of road length draining to a stream, is chosen as an indicator of sediment yield. Hydrologic connectivity is both an easily determined and easily correctable parameter that can result in immediate reductions in sediment yields associated with road surface erosion when treated. Hydrologic connectivity data from forty miles of roads in the Navarro watershed collected by Pacific Watershed Associates showed hydrologic connectivity was 56%. The target value of 10% is based on Regional Water Board staff's best professional judgment of what amount of reduction is possible (Regional Water Board 2000).

Diversion Potential: < 1%

Diversion potential is defined as the potential for a stream to be diverted out of its channel as a result of a plugged stream crossing. Like hydrologic connectivity, diversion potential is easily identifiable and correctable. This parameter is chosen as an indicator of risk of sediment delivery. The condition in itself is not a sediment contributor, but is a condition that greatly elevates the consequences of stream crossing failure. The numeric target is the elimination of diversion potential at all stream crossings except those that cannot be corrected without compromising safety, which are expected to comprise approximately 1% of all stream crossings.

Stream Crossings with High Risk of Failure: 1%

Risk of stream crossing failure is related to the size and configuration of the crossing. The National Marine Fisheries Service stream crossing guidelines (National Marine Fisheries Service 2000, as cited in Regional Water Board 2000) include a requirement that rural stream crossings have the hydraulic capacity to accommodate the 100-year flood flow. Flanagan et al. (1998, as cited in Regional Water Board 2000) have described other factors that increase risk of failure, such as culvert slope, width, and inlet basin configuration. The numeric target for stream crossings with high risk of failure is all stream crossings except those that cannot be corrected without compromising safety, which are expected to comprise approximately 1% of all stream crossings.

4.1.2. Mid-term Numeric Targets and Indicators

Mid-term targets are for parameters that are expected to improve as a result of restoration activities, but only after storm events of sufficient frequency and magnitude have occurred. This may take a decade or more.

V* 15%: Higher-order Streams

The fraction of a pool's volume filled with fine sediment, V*, should be monitored in higher-order streams to evaluate the effectiveness of restoration efforts. This parameter is considered a mid-term target due to the amount of fine sediment currently existing in the channels of the Navarro and its tributaries.

Residual Pool Depth: 2 feet for First and Second Order Channels, 3 feet for Higher-order Channels

Residual pool depth is defined as the maximum depth of a pool minus the maximum depth of its riffle crest (i.e., the depth of the pool at the point of zero flow). The numeric target for residual pool depth is an average of no less than two feet for first and second order channels and three feet for third and greater channels. CDFG data indicates that the better coho streams have as much as 40 percent of their total length in primary pools (Flosi et al. 1998, as cited in Regional Water Board 2000).

Stream Crossing Failures: Decreasing Trend

The objective of this parameter is to assess the degree to which stream crossing improvements are effective in reducing the delivery of sediments. Although high-risk stream crossings can be treated in a short time period, the effectiveness of those treatments will not be known until large storm events test their adequacy. Since large storm events are infrequent, it is unlikely that the effectiveness of stream crossing treatments can be assessed until at least a decade has passed.

Thalweg Variability: Increasing Trend

Thalweg variability is defined as the deviation of the thalweg (the deepest part of the channel) from the average channel slope. It is chosen as a surrogate measure of channel complexity. As the sediment load decreases and the frequency and depth of pools increases (thereby improving habitat for fish), the thalweg profile develops more dramatic variation around the mean profile slope. No specific numeric value is set as the target, only an increasing trend.

4.1.3. Long-term Numeric Targets and Indicators

Long-term targets and indicators are for parameters which are dependent on infrequent hydrologic events. Targets related to pools and landslides are identified which may not respond to changed land-management practices for decades. The proportion of pools may not change, regardless of reductions in sediment delivery, until a large flood occurs which reconfigures the entire stream channel. Likewise, a decrease in road-related landslides may not be apparent for decades, because landslides are often triggered only by major rainfall events.

Proportion of Stream Length in Pools: 40%

Habitat data from all sub-watersheds indicate that pool frequency may be a factor limiting the rearing capacity of streams in the Navarro watershed. Deep and frequent pools are necessary summer rearing habitat for salmonids, particularly coho. CDFG data indicates that the better coho streams have as much as 40 percent of their total length in primary pools (Flosi et al. 1998, as cited in Regional Water Board 2000).

Road-related Landslides: Decreasing Trend

Appropriate location, design, construction, and maintenance of roads are expected to result in a reduction in the rate of road-related landslides.

4.2. Source Analysis

The purpose of the sediment source analysis is to identify the various erosion processes in the Navarro watershed and to estimate the sediment yield from those sources in a way that allows them to be compared to each other. The approach taken focuses on rates of sediment yield that have occurred in the recent past (i.e., past twenty years).

The estimated rates are based on studies performed in the Navarro watershed, studies performed in nearby watersheds, interpretation of aerial photographs, and other published literature relating to sediment yield processes. A significant amount of information, including estimates of sediment yield from hillslope and streamside processes, came directly from the Navarro Watershed Restoration Plan (Entrix et al. 1998, as described in Regional Water Board 2000). Data describing current conditions of rural roads were provided to Regional Water Board staff by Danny Hagans of Pacific Watershed Associates. Information pertaining to sediment yield on industrial forestlands was taken from the Albion Watershed Analysis (Mendocino Redwood Company 1999, as cited in Regional Water Board 2000) and the Garcia Watershed Analysis (Louisiana-Pacific Corporation 1998, as cited in Regional Water Board 2000). Regional Water Board staff (Regional Water Board 2000) compared aerial photographs for the entire watershed taken in 1996 to photographs taken in 1984 to quantify sources of erosion (e.g., landslides and gullies) and their associated land uses, to provide information on roads, and to quantify the location and extent of lands under cultivation.

The results of the sediment source analysis are presented in Table 4-1. Human-caused sources account for about 40% of the total sediment yield of the Navarro watershed. Road-related sources dominate other anthropogenic sources, reflecting the dominant land uses in the watershed, specifically timber production and ranching, which use a vast network of roads. Vineyards, which occupy only about 2 percent of the watershed, have the potential to cause locally significant deleterious impacts.

Table 4-1. Results of Sediment Source Analysis

Sediment Source	**Estimated Average Yield (tons/mi^2/yr)**						
	Anderson	Indian	Main-stem	North Fork	Rancheria	Entire Watershed	
Shallow Landslides	180	210	150	160	200	**180**	**Natural: 1170**
Deep-Seated Landslides	0	0	250	0	130	**90**	
Gullies	550	270	60	30	380	**250**	
Bank Erosion	80	60	40	50	70	**60**	
Inner Gorge / Streamside Delivery	1180	400	510	280	670	**590**	
Road-Stream Crossing Failures	100	80	140	160	130	**130**	**Human-caused: 760** **(Roads: 620)**
Road-related Mass Wasting	90	80	140	150	110	**120**	
Road-related Gullying	90	90	150	150	110	**120**	
Road-related Surface Erosion	220	210	320	210	250	**250**	
Skid Trail Erosion	10	20	50	70	30	**40**	
Vineyard Erosion	120	0	110	5	5	**40**	
Management-related Mass Wasting	60	70	50	50	60	**60**	
Totals	**2680**	**1490**	**1970**	**1315**	**2145**	**1930**	

4.3. Linkage Analysis, Loading Capacity, and TMDL

The purpose of the linkage analysis is to estimate the extent of reductions in sediment sources needed to attain applicable water quality standards in the Navarro River and its tributaries. The loading capacity is the estimate of the total amount of sediment, from either natural or human-caused sources, that can be delivered to streams in the Navarro watershed without exceeding applicable water quality standards. In the case of the Navarro and its tributaries, the estimated loading capacity is based on an analysis of the amount of human-caused sediment delivery that can occur in addition to natural sediment delivery without causing adverse impacts to coho and steelhead.

This approach entailed estimating a sediment delivery rate for the watershed at a period when salmonids were abundant and comparing this to an estimated rate of natural sediment delivery. There are no sediment delivery data for the Navarro watershed at a time when salmonids were abundant. Therefore, data for a nearby watershed, the Noyo River watershed, was used in this analysis. Salmonids were abundant in the Noyo and its tributaries during the 1930s - 1950s period, so the corresponding sediment yield during this period must have been sufficiently low to allow salmonid habitat of suitable quality to persist. In the Noyo River Total Maximum Daily Load for Sediment, the total sediment yield during this period was estimated at 470 tons/mi^2/yr and the natural sediment yield was estimated at 370 tons/mi^2/yr (EPA 1999, as cited in Regional Water Board 2000). Thus, the anthropogenic load during this period was roughly 25% of the natural load (or, equivalently, 20% of the total load).

This 25% factor is applied to the Navarro, because of the proximity of the Noyo to the Navarro, as well as their similarities in vegetation, climate, geology, and land use history. Thus, the loading capacity of the Navarro and its tributaries for sediment is the estimated natural sediment delivery rate plus 25%. Multiplying 1170 tons/mi^2/yr by 1.25 equates to approximately 1463 tons/mi^2/yr. Therefore, 1463 tons/mi^2/yr is the TMDL for sediment for the Navarro River and its tributaries. Given the hydrologic variability typical of the Northern California Coast Ranges, EPA expects the TMDL to be evaluated as a ten-year rolling average.

4.4. Load Allocations

In accordance with EPA regulations, the loading capacity (i.e., TMDL) must be allocated to the various sources of sediment in the watershed. As there are no known point sources of sediment into the Navarro River and its tributaries, the wasteload allocation for point sources is set at zero. Thus, the TMDL for sediment for the Navarro River and its tributaries is divided among the categories of sediment identified in the source analysis, as load allocations, with a margin of safety.

The load allocations are calculated by applying the same percentage reduction from current sediment delivery rates to all human-caused sources. The total allowable human-caused sediment yield equals the loading capacity (1463 tons/mi^2/yr) minus the natural sediment yield (1170 tons/mi^2/yr), which equates to 293 tons/mi^2/yr. The source analysis indicates that the current human-caused sediment yield is 760 tons/mi^2/yr. It takes a reduction of a little more than 60% to get from 760 tons/mi^2/yr to 293 tons/mi^2/yr. Applying the necessary reduction to all anthropogenic sources yields the load allocations shown in Table 4-2.

The load allocations are expressed in terms of tons/mi^2/yr. They could be divided by 365 to derive daily loading rates (tons/mi^2/day), but EPA is expressing them as yearly averages, because sediment delivery to streams is naturally highly variable on a daily basis. In fact, EPA expects the load allocations to be evaluated on a ten-year rolling average basis, because of the variability in sediment delivery rates. In addition, the allocations are intended to apply on an average basis for the entire source category, even though the allocations are expressed in terms of square miles. In other words, EPA does not expect that each square mile within a particular source category will meet the load allocation; rather, EPA expects the average for the entire source category to meet the load allocation for that category.

4.5. Margin of Safety, Seasonal Variation, and Critical Conditions

Section 303(d) requires that TMDLs include a margin of safety to account for uncertainties concerning the relationship between pollutant loads and in-stream water quality. The margin of safety can be incorporated into conservative assumptions used to develop the TMDL, or added as separate quantitative component of the TMDL.

Table 4-2. Load Allocations

Sediment Source	**Current Load (tons/mi^2/yr)**	**Load Allocation (tons/mi^2/yr)**
Natural Sources		
Shallow Landslides	180	180
Deep-seated Landslides	90	90
Gullies	250	250
Bank Erosion	60	60
Inner Gorge / Stream-side Delivery	590	590
Subtotal	*1170*	*1170*
Anthropogenic Sources		
Road-Stream Crossing Failures	130	50
Road-related Mass Wasting	120	46
Road-related Gullying	120	46
Road-related Surface Erosion	250	96
Skid Trail Erosion	40	16*
Vineyard Erosion	40	16*
Management-related Mass Wasting	60	23
Subtotal	*760*	*293*
Totals	**1930**	**1463**

* These values were rounded up to ensure that the sum of the load allocations would equal 1463 tons/mi^2/yr.

The Navarro River sediment TMDL incorporates an implicit margin of safety based on conservative assumptions employed in the source analysis. The following examples illustrate the conservative assumptions which constitute the margin of safety.

- A conservative estimate of erosion rates for vineyards was used to address the uncertainty related to the lack of data on vineyard erosion processes.

- A conservative estimate of the rate of road gullying was used to address the uncertainty associated with the lack of data describing sediment delivery associated with road-related gullies.

- A conservative assumption that all unpaved rural roads are unsurfaced was used to address the uncertainty in the estimate of road surface erosion resulting from the lack of information on the proportion of unpaved rural roads that are rock surfaced.

- A conservative assumption that the entire contribution of bank erosion and inner gorge processes is natural was used to address the uncertainty associated with the relation of accelerated sediment yield, increased in-channel storage, and the resulting increased vulnerability of stream banks and inner gorge hillslopes. In fact, there is likely to be some decrease in bank erosion and inner gorge sediment delivery as restoration activities decrease up-slope erosion sources.

The TMDL must also account for critical conditions and seasonal variation. Sediment delivery to streams is an inherently seasonal phenomenon, with a disproportionate amount of erosion taking place in association with the winter rainy season. Sediment delivery is also variable on an annual basis, with considerably more sediment production occurring in years with large storms. To account for this normal inter-seasonal and inter-annual variability, the TMDL and load allocations are expressed as ten year rolling averages. Similarly, the approach used in this TMDL is to identify indicators that are reflective of the net effects over multiple years.

CHAPTER 5: IMPLEMENTATION AND MONITORING PLANS

The main responsibility for water quality management and monitoring resides with the States. EPA fully expects the State to develop and submit implementation plans to EPA (as part of revisions to the State water quality management plan) when it adopts and submits the TMDLs for temperature and sediment. The State implementation and monitoring plans for temperature and sediment should contain provisions for ensuring that the load allocations in the TMDLs will in fact be achieved. These provisions may be non-regulatory, regulatory, or incentive-based, consistent with applicable laws and programs, including the State's recently upgraded non-point source control program. In addition, the plans should include a public participation process and appropriate recognition of other relevant watershed management processes, such as local source water protection programs, state programs under Section 319 of the Clean Water Act, or State continuing planning activities under Section 303(e) of the Clean Water Act.

EPA encourages the State and landowners to work together to implement fully the implementation and monitoring plans. EPA intends to review the implementation and monitoring measures and to play an active role in assessing whether the measures will ensure that the load allocations are met.

CHAPTER 6: PUBLIC PARTICIPATION

EPA regulations require that TMDLs be subject to public review (40 CFR 130.7). EPA is providing public notice of the draft Navarro River temperature and sediment TMDLs by placing a notice in the Santa Rosa Press Democrat, Anderson Valley Advertiser, and Mendocino Beacon, newspapers of general circulation in the Navarro River watershed. EPA will prepare a written response to all written comments on the draft TMDLs received by EPA through the close of the comment period (16 October 2000).

EPA will hold an informal public meeting on Tuesday, 3 October 2000, to describe the draft TMDLs and answer clarifying questions regarding the draft TMDLs. The meeting will be held at the Apple Hall Dining Room at the Mendocino County Fairgrounds in Boonville, starting at 6:30 p.m.

The EPA draft TMDLs are based in large part on the TSD prepared by Regional Water Board staff (Regional Water Board 2000). Regional Water Board staff provided for public participation in the development of the TSD through several mechanisms as described in the TSD (Regional Water Board 2000).

Glossary

Aggradation	To fill and raise the elevation of the stream channel by deposition of sediment.
Anadromous	Refers to aquatic species which migrate up rivers from the sea to breed in fresh water.
Areas of instability	Locations on the landscape where land forms are present which have the ability to discharge sediment to a watercourse.
Beneficial Use	Uses, as designated in the Basin Plan, of waters of the state that may be protected against quality degradation including, but not limited to, domestic, municipal, agricultural and industrial supply; power generation; recreation; aesthetic enjoyment; navigation; and the preservation and enhancement of fish, wildlife and other aquatic resources or preserves.
Basin Plan	The *Water Quality Control Plan, North Coast Region-- Region 1.*
CDFG	The California Department of Fish and Game.
Debris torrents	Long stretches of bare, generally unstable stream channel banks scoured and eroded by the extremely rapid movement of water-laden debris, commonly caused by debris sliding or road stream crossing failure in the upper part of a drainage during a high intensity storm.
Deep seated landslide	Landslides involving deep regolith, weathered rock, and/or bedrock, as well as surficial soil. Deep seated landslides commonly include large (acres to hundreds of acres) slope features and are associated with geologic materials and structures.
Drainage structure	A structure or facility constructed to control road runoff, including (but not limited to) fords, inside ditches, water bars, outsloping, rolling dips, culverts or ditch drains.
Effective Shade	The percent reduction of potential solar radiation delivered to the water surface. It is the amount of shade, averaged to account for daily and seasonal cycles.
Embeddedness	The degree that larger particles (boulders, rubble or gravel) are surrounded or covered by fine sediment. It is usually measured in classes (<25%, 25-50%, 50-75%, and >75%) according to percentage of random large particles that are covered by fine sediment.
EPA	The United States Environmental Protection Agency.
Flooding	The overflowing of water onto land that is normally dry.
Fry	A young juvenile salmon after it has absorbed its egg sac and emerged from the redd.
GIS	Geographic Information System.
Inner gorge	A geomorphic feature formed by coalescing scars originating from mass wasting and erosional process caused by active stream erosion. The feature is identified as that area of stream bank situated immediately adjacent to the stream, having a slope generally over 65% and being situated below the first break in slope above the channel.
Inside ditch	The ditch on the inside of the road, usually at the foot of the cutbank.

Landslide	Any mass movement process characterized by downslope transport of soil and rock, under gravitational stress by sliding over a discrete failure surface-- or the resultant landform.
Large woody debris	A piece of woody material having a diameter greater than 30 cm (12 inches) and a length greater than 2 m (6 feet) located in a position where it may enter the watercourse channel.
Mass wasting	Downslope movement of soil mass under force of gravity-- often used synonymously with "landslide." Common types if mass soil movement include rock falls, soil creep, slumps, earthflows, debris avalanches, debris slides and debris torrents.
MWAT	Maximum Weekly Average Temperature.
Numeric targets	A numerical expression of the desired in-stream or hillslope environment. For each pollutant or stressor addressed in the problem statement, a numeric target is developed.
Redd	A gravel nest or depression in the stream substrate formed by a female salmonid in which eggs are laid, fertilized and incubated.
Regional Water Board	Regional Water Quality Control Board, North Coast Region.
Sediment	Fragmented material that originates from weathering of rocks and decomposed organic material that is transported by, suspended in, and eventually deposited by water or air.
Sediment delivery	Material (usually referring to sediment) which is delivered to a watercourse channel by wind, water or direct placement.
Sediment discharge	The mass or volume of sediment (usually mass) passing a watercourse transect in a unit of time.
Sediment erosion	The group of processes whereby sediment (earthen or rock material) is loosened, dissolved and removed from the landscape surface. It includes weathering, solubilization and transportation.
Sediment source	The physical location on the landscape where earthen material resides which has or may have the ability to discharge into a watercourse.
Sediment yield	The sediment yield consists of dissolved, suspended and bed loads of a watercourse channel through a given cross section in a given period of time.
Shallow seated landslide	A landslide produced by failure of the soil mantle on a steep slope (typically to a depth of one or two meters; sometimes includes some weathered bedrock). It includes debris slides, soil slips and failure of road cut-slopes and sidecast. The debris moves quickly (commonly breaking up and developing into a debris flow) leaving an elongated, concave scar.
Skid trail	Constructed trails or established paths used by tractors or other vehicles for skidding logs. Also known as tractor roads.
Steep slope	A hillslope, generally greater than 50% that leads without a significant break in slope to a watercourse. A significant break in slope is one that is wide enough to allow the deposition of sediment carried by runoff prior to reaching the downslope watercourse.
Stream	See watercourse.

Stream order	The designation (1,2,3, etc.) of the relative position of stream segments in the drainage basin network. For example, a first order stream is the smallest, unbranched, perennial tributary which terminates at the upper point. A second order stream is formed when two first order streams join. Etc.
Sub-basin	A subset or division of a watershed into smaller hydrologically meaningful watersheds. For example, the North Fork Navarro River watershed is a sub-basin of the larger Navarro River watershed.
Tail-out	The lower end of a pool where flow from the pool, in low flow conditions, discharges into the next habitat unit.
Thalweg	The deepest part of a stream channel at any given cross section.
Thalweg profile	Change in elevation of the thalweg as surveyed in an upstream-downstream direction against a fixed elevation.
TMDL	Total Maximum Daily Load.
TSD	Technical Support Document.
Unstable areas	Characterized by slide areas, gullies, eroding stream banks, or unstable soils. Slide areas include shallow and deep seated landslides, debris flows, debris slides, debris torrents, earthflows and inner gorges and hummocky ground. Unstable soils include unconsolidated, non-cohesive soils and colluvial debris.
V*	A numerical value which represents the proportion of fine sediment that occupies the scoured residual volume of a pool. Pronounced "V-star."
Watercourse	Any well-defined channel with a distinguishable bed and bank showing evidence of having contained flowing water indicated by deposit of rock, sand, gravel, or soil.
Waters of the state	Any ground or surface water, including saline water, within the boundaries of the state.
Watershed	Total land area draining to any point in a watercourse, as measured on a map, aerial photo or other horizontal plane. Also called a basin, drainage area, or catchment area.
Water quality criteria	Limits or level of water quality constituents or characteristics which are established for the reasonable protection of beneficial uses of water or the prevention of nuisance within a specific area.
Water quality objective	Water quality criteria as described in the Basin Plan.
Water quality standard	Consist of the beneficial uses of water and the water quality objectives as described in the Basin Plan.

California Regional Water Quality Control Board
North Coast Region

Navarro River Watershed

Technical Support Document
for the
Total Maximum Daily Load
for Sediment

and

Technical Support Document
for the
Total Maximum Daily Load
for Temperature

July 28, 2000

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CHAPTER 1
INTRODUCTION

The Navarro River Watershed Technical Support Document (TSD) for Sediment and for Temperature is intended to guide landowners, land managers, and resource protection agencies in the protection of water quality in the Navarro River watershed. The primary purpose of the Navarro River Watershed TSD for Sediment is to identify sediment loading allocations that, when implemented, are expected to result in the attainment of the applicable water quality standards for sediment, to protect beneficial uses. The key beneficial use of concern is the salmonid fishery, particularly the coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Oncorhynchus mykiss*) fishery. The primary purpose of the Navarro River Watershed TSD for Temperature is to identify temperature loading allocations that, when implemented, are expected to result in the attainment of the applicable water quality standards for temperature, including the protection of beneficial uses, in particular those relating to the salmonid fishery.

In 1996, the National Marine Fisheries Service (NMFS) listed coho salmon in the Northern California/Southern Oregon Coasts Evolutionarily Significant Unit (ESU) as a threatened species under the federal Endangered Species Act. This ESU includes all naturally spawned populations of coho salmon in coastal streams between Cape Blanco, Oregon, and Punta Gorda, California. On June 7, 2000, NMFS also listed steelhead trout in the Northern California Evolutionarily Significant Unit (ESU) as a threatened species. The Northern California ESU includes steelhead in California coastal river basins from Redwood Creek south to the Gualala River, inclusive. These listings are results of observed substantial declines in the salmonid populations over time.

1.1 Location of the Navarro River Watershed

The Navarro River watershed is a coastal watershed in southern Mendocino County, California. Encompassing approximately 315 square miles (201,600 acres), the Navarro River flows through the coastal range, the Anderson Valley, and out to the Pacific Ocean about fifteen miles south of the town of Mendocino (Entrix 1998). The watershed is the largest coastal basin in Mendocino County and can be subdivided into five major drainage basins: Mainstem Navarro River, North Fork Navarro River, Indian Creek, Anderson Creek, and Rancheria Creek. The hydrologic unit code for the Navarro River watershed is 113.50 (NCRWQCB 1996).

The population of the watershed is about 3,500 people, with most living in and around the towns of Boonville, Philo, and Navarro (Entrix 1998). State Highway 128 traverses much of the watershed, paralleling Rancheria Creek and the mainstem Navarro River for approximately twenty five miles. Elevations in the basin range to about 3,000 feet above sea level. Land-use in the watershed includes forestland (70%), rangeland (25%), and agriculture (5%) with a small percentage devoted to rural residential development (Entrix 1998). Timber production, livestock grazing, and other agricultural activities have been present in the Navarro River watershed since the mid-1800s. Today, commercial timber harvesting, viticulture, orchards, grazing, and tourism are the principal economic enterprises.

1.2 Application of Section 303(d) of the Clean Water Act to the Navarro River Watershed

The Navarro River watershed has been placed on a list of impaired water bodies as required by Section 303(d) of the Clean Water Act (CWA). The 303(d) list describes water bodies that do not fully support all beneficial uses or are not meeting water quality objectives. It also describes the pollutants for each water body that impair beneficial uses and water quality. Water quality objectives and beneficial uses are identified for all water bodies in the North Coast Region in the *Water Quality Control Plan for the North Coast Region* (the Basin Plan). As required by CWA Section 303(d), pollutant loading allocations must be prepared for waterbodies on the 303(d) list. The Navarro River watershed was listed due to water quality problems related to sedimentation and increased stream temperature. At the time of listing, sedimentation and increased stream temperature were judged to be associated, in part, with management-related activities. Sedimentation and increased stream temperature were determined to be impacting the cold water fishery and associated beneficial use of the Navarro River watershed, including the migration (MIGR), and spawning, reproduction, and early development (SPWN) of cold water fish such as coho salmon and steelhead trout. Cold freshwater (COLD), estuarine habitats (EST), and commercial and sport fishing (COMM) are also designated uses of the Navarro River watershed.

This analysis demonstrates that management-related activities have contributed to an increase in sediment delivery and stream temperature in the Navarro River watershed. It demonstrates that existing salmonid habitat is limited by various erosion-influenced factors and increased stream temperature. Some sedimentation factors include infrequent and shallow pools, few backwater pools and other overwintering habitat, embedded cobble, and elevated fines in potential spawning gravels. Reduced riparian shade and changes in channel morphology result in increased stream temperatures above that which supports salmonid life.

1.3 Technical Support Documents and the Components of a TMDL

A technical support document, or TSD, is a report developed by Regional Water Board staff which meets all federal requirements for a Total Maximum Daily Load (TMDL), but with no implementation or monitoring plan and no action on the part of the Regional or State Board. TSD's may also be known as "technical TMDLs," but TSD is used to emphasize that the documents have not been through the Regional or State Board's public participation and adoption process. The Navarro River watershed TSD for Sediment and Temperature will be transmitted directly to U.S. EPA upon completion by Regional Water Board staff. After minor revision, the U.S. EPA will publicly notice the document as a draft TMDL.

The required components of a Total Maximum Daily Load (TMDL) are described in 40 CFR §130.2 et. seq., Section 303(d) of the Clean Water Act, and in various guidance documents (e.g., U.S. EPA 1991). A TMDL is defined as the sum of the individual waste load allocations for point sources, load allocations for non-point sources, and natural background such that the capacity of the water body to assimilate pollutant loading (the loading capacity) is not exceeded (40 CFR §130.2). That is,

$$TMDL = \Sigma WLAs + \Sigma LAs + NB$$

where Σ = the sum, WLAs = waste load allocations, LAs = load allocations, and NB = natural background. A TMDL must consider seasonal variations and include a margin of safety to address uncertainty in the analysis.

This TSD includes:

- Problem Statement
- Source Analysis
- Linkage Analysis
- Numeric Targets
- Load Allocation / Allocation of Responsibility
- Margin of Safety and Seasonal Variation
- Implementation and Monitoring
- Public Participation

A **problem statement** provides a description of the existing in-stream and upslope watershed setting and the beneficial use impairments of concern. This section also includes an introduction to salmonid life cycles. It describes the problems associated with sedimentation and increased stream temperatures in the Navarro River watershed in terms of its impact on the various life cycle stages of salmonids and on the overall stability of the stream channel.

The **source analysis** provides an assessment of the relative contributions of sources to the use impairment (i.e. road, logging, bank erosion, gully erosion) and the extent of needed discharge reductions or controls. Per 40 CFR §130.2(i) and §130.7(c)(1), point, non-point, and background sources of pollutants of concern are described, including the magnitude and location of the sources. In short, the source analysis section provides a general assessment of the sources of sediment and temperature increases to the Navarro River watershed that are impacting water quality.

The **linkage analysis** describes the "... relationship between numeric target(s) and identified pollutant sources, and estimates total assimilative capacity (loading capacity) of the waterbody for the pollutant of concern" [40 CFR §130.7(d) and 40 CFR §130.2(i) and (f)]. The linkage analysis provides the basis for the amount of upslope and other controls necessary to attain water quality standards and protect the beneficial uses.

Numeric targets are based on and implement the water quality objectives adopted in the Basin Plan. Numeric targets provide indicators of watershed health and express the desired future condition for each stressor addressed in the TMDL. The numeric targets section presents the basis for which the proposed numeric targets are based. As additional data are developed for the Navarro River watershed, these targets can be refined to better reflect the site-specific conditions of the watershed. Further, the numeric targets must be understood as goals, not requirements. They provide a guidepost to landowners, resource managers and the public by which to determine how close the TMDL is to re-creating an instream environment suitable to support sustainable populations of salmonids. They are not intended to be attained immediately, nor are they directly enforceable.

The **load allocation/allocation of responsibility** results in the assignment of sediment load reduction, temperature load reduction, and/or restoration responsibility to land use activities in individual assessment areas necessary to attain water quality standards and protect beneficial uses. The sum of the load allocations equals the loading capacity. The allocation of responsibility section estimates source reductions to prevent human-caused releases that are likely to respond to mitigation or altered land management practices.

The discussion of the **margin of safety** summarizes the qualitative and quantitative means by which the final load allocations account for any uncertainty in the data or data analysis. The seasonal variation section summarizes the changes in the discharges of sediment, increases of temperature, and their associated effects on beneficial uses which may vary in different years and at different times of the year, and how the variation is addressed in this analysis.

A discussion of considerations for the future development of an implementation plan and monitoring plan is included. A discussion of the public participation opportunities which have been a part of the development of the TMDL is also included.

1.4 Data Sources

Data were provided from many sources. Some of the primary sources are listed below:

- Navarro Watershed Restoration Plan, June 1998. A joint project of the Mendocino County Water Agency, the Coastal Conservancy, and the Anderson Valley Land Trust. Prepared by Entrix, Inc., Pacific Watershed Associates, Circuit Rider Productions, Inc., the Navarro Watershed Community Advisory Group, and Daniel T. Sicular, Ph.D.
- Mendocino County Water Agency's temperature data.
- Louisiana-Pacific Corporation's temperature data.
- Garcia Watershed Analysis. Prepared for Louisiana-Pacific Corporation.
- Albion Watershed Analysis. Prepared for Mendocino Redwoods Company (MRC).
- Stream and Habitat Resource Survey 1994-1998. Prepared by the California Department of Fish and Game.
- Vegetation data from the Timberland Task Force.
- USGS Quad Sheets.
- Roger Foott and Associate's Geologic Report 1990
- Aerial photographs of the Navarro River watershed taken in 1996, 1984, and 1952.

1.5 Document Organization

This document consists of a Navarro River watershed TSD for sediment and a TSD for temperature. The two TSDs are presented together. Chapters 2, 3, and 4 present information applicable to the Navarro River watershed as a whole, Chapter 5 concentrates solely on temperature and Chapter 6 on sediment. The sections on implementation plans, monitoring plans, and public participation again take a watershed approach.

CHAPTER 2
GENERAL DESCRIPTION OF THE NAVARRO RIVER WATERSHED

The Navarro River watershed is a coastal watershed in southern Mendocino County, California, and is located approximately 120 miles north of San Francisco and thirty miles west of Ukiah (Figure 2-1), encompassing 315 square miles (201,600 acres). The Navarro River watershed flows in a northwesterly direction through the coastal range and the Anderson Valley to the Pacific Ocean. The mouth of the Navarro is about fifteen miles south of the town of Mendocino. Elevations in the Anderson Valley range from 200 feet above sea level in the northwest to 480 feet above sea level in the southeast (Entrix 1998). Elevations along the eastern ridge reach to about 3,000 feet above sea level (Division of Water Rights 1998). The watershed is the largest coastal basin in Mendocino County and can be subdivided into five major subwatersheds: Mainstem Navarro River, North Fork Navarro River, Indian Creek, Anderson Creek, and Rancheria Creek (Figure 2-2). The hydrologic unit code for the Navarro River watershed is 113.50 (NCRWQCB 1996).

State Highway 128 runs the length of the watershed and passes through the towns of Boonville, Philo, and Navarro. State Highway 253 connects with Highway 128 south of Boonville and runs to Ukiah through the Anderson Creek subwatershed. Other major roads in the watershed include Fish Rock Road, Mountain View Road, Philo-Greenwood Road, Peachland Road, Nash Mill Road, Flynn Creek Road, and Masonite Road.

2.1 Geology

The Navarro River watershed is composed of mostly three different geologic formations: the Melange Unit of the Franciscan Assemblage, the Coastal Belt of the Franciscan Assemblage, and alluvial fill (Figure 2-3).

The most extensive geologic formation found in the Navarro River watershed is the Coastal Belt Franciscan Formation (TKfs and TKfv). Most of this formation (TKfs), formed during the Tertiary to Cretaceous periods, is made up of well-consolidated clastic sedimentary rock, mainly sandstone and shale with minor amounts of limestone and conglomerate (Manson 1984). Mixed in with TKfs throughout the Navarro River watershed are small patches of TKfv, consisting of volcanic rock, greenstone, and metamorphosed tuffaceous sandstone (Manson 1984).

The second most extensive geologic formation is the Franciscan Melange (fm) which is located almost entirely in the Anderson Creek subwatershed and the upper reaches of the Rancheria Creek subwatershed. Of the Tertiary-Cretaceous period, the Melange consists of a pervasively sheared, clay-containing matrix which surrounds pebble-size to individually mappable blocks of graywacke, greenstone, chert, schist, serpentine, and serpentinized ultrabasic rocks (Manson 1984). The highly erodible, sheared shale matrix is generally unstable and prone to landsliding even on gentle slopes, generally by shallow debris slides along roads and creeks (Manson 1984).

Anderson Valley Alluvium (QTa) can be found throughout most of the Anderson Valley. The formation consists of compact but unconsolidated alluvial deposits ranging from cobble conglomerate to fine sand and silt (Manson 1984).

Thin arms of Q, Alluvium, are present along the streams and rivers of the Navarro River watershed. This formation of flat-lying alluvial deposits may be further divided up into the following:

- Qsc, Stream/River Channel Deposits (Holocene Period): sand and gravel in active stream channels; characteristically unvegetated (Manson 1984).
- Qac, River Terrace Deposits (Holocene-Pleistocene Period): dominantly sand and gravel with minor amounts of silt and clay deposited during higher flows of major streams and rivers (Manson 1984).

As seen in Figure 2-3, small patches of Marine Terrace Deposits, Qmts, are located in the lower portions of the Mainstem Navarro River subwatershed near the Pacific Coast. These deposits are undifferentiated and increase in age with an increase in elevation (Manson 1984). The Marine Terrace Deposits are generally made up of well-sorted quartz sand with minor amounts of gravel and dune sands (Manson 1984).

2.2 Vegetation

The Navarro River watershed is composed of a variety of vegetation types (Figures 2-4a and 2-4b), including:

- Redwood
- Douglas Fir / Redwood
- Klamath Mixed Conifer
- Mixed Hardwood Conifer: A mix of hardwoods (such as oak and madrone) with conifers (such as pine, fir, and redwood).
- Montane Hardwood: Montane hardwoods are usually found on relatively moist, upland slopes below large coniferous trees. This category includes oak woodlands.
- Closed Cone Pine
- White Fir
- Ponderosa Pine
- Shrubs
- Herbaceous: Plants lacking woody stems above the ground (i.e. grasses).
- New Vineyards: Vineyards planted between 1984 and 1996.Rancheria Creek

Rancheria Creek

Vegetation in the Rancheria Creek subwatershed is mainly composed of a mixed hardwood/conifer, montane hardwood, redwood, Douglas Fir-redwood mix, Klamath mixed

Insert
Figure 2-1

Navarro River Watershed
Location in Region 1

Insert
Figure 2-1

(Back)

Insert
Figure 2-2
Navarro River Watershed
TMDL Planning Areas
and Sub-watersheds

(Front)

Figure 2-2

(Back)

Insert
Figure 2-3
Generalized Geology
of the Navarro River Watershed

(Front)

Figure 2-3

(Back)

Insert
Figure 2-4a
Vegetation – Lower Navarro River Watershed

(Front)

Figure 2-4a

(Back)

Insert
Figure 2-4b
Vegetation – Upper Navarro River Watershed

(Front)

Figure 2-4b

(Back)

conifer, herbaceous, and shrub plant communities. Mixed hardwood conifer and montane hardwood are more abundant in the upper elevations of the subwatershed, while redwood, Douglas Fir, and Klamath mixed conifer are more plentiful in the lower reaches. Ponderosa pine stands, closed clone pine stands, and barren land also occur in the Rancheria Creek subwatershed.

Two sections of the Rancheria Creek subwatershed were studied by Entrix (1998) in regards to canopy closure: Bear Wallow Creek and Beasley Creek. Entrix (1998) found that canopy closure ranged from moderate (30-64% canopy closure) to high (>65% canopy closure) along Bear Wallow Creek. Beasley Creek had greater than 65% canopy closure that was composed of deciduous trees and hardwoods, with very few conifers (Entrix 1998).

Anderson Creek

Vegetation in the Anderson Creek subwatershed is similar to the upper reaches of Rancheria Creek, with an abundance of montane hardwood and a mixed hardwood-conifer. Herbaceous and shrub communities are present in distinct patches, and isolated groves of Douglas Fir, redwood, Klamath mixed conifer, and ponderosa pine forests can also be found. These groves are usually found on north facing slopes at higher elevations.

Stream surveys by Entrix (1998) of portions of the Anderson Creek subwatershed along Con Creek found that canopy closures is generally low (less than 30% canopy closure) with several isolated areas of moderate closure (30-64%). Most of this canopy was composed of young conifers, young to mature hardwoods, and young riparian deciduous trees (Entrix 1998).

Indian Creek

Vegetation in Indian Creek is roughly divided on a diagonal running from the southwest of the subwatershed to the northeast (Figures 2-4a and 2-4b). In the southeast half of the subwatershed, montane hardwood and mixed hardwood-conifer compose the majority of the vegetation. Douglas Fir, redwood, Klamath mixed conifer, ponderosa pine, and shrub vegetation types can also be found in this subwatershed.

Vegetation in the northwestern half of the Indian Creek subwatershed is mainly composed of mixed hardwood-conifer. Larger and more frequent patches occur of redwood, Douglas Fir, Klamath mixed conifer, and herbaceous and shrub vegetation types.

Surveyed portions of the North Fork Indian Creek had a low canopy closure of less than 30%, primarily because of the wide channel and the limited new growth on gravel bars (Entrix 1998).

Mainstem Navarro River & North Fork Navarro

Excluding Anderson Valley, the Mainstem Navarro River and North Fork Navarro subwatersheds have similar vegetation patterns. The overwhelming majority of the cover is mixed hardwood-conifer, Douglas Fir, and redwood. The highest concentration of Douglas Fir and redwood in the entire watershed can be found in the North Fork Navarro subwatershed.

Patches of montane hardwood, Klamath mixed conifer, closed cone pine, and shrub communities occur in both of these subwatersheds. Herbaceous grassland communities is also present along the coast.

Although a vegetated riparian zone is present along most of the length of the Mainstem Navarro River subwatershed, it is often set back from the active channel and provides little shade for the low flow channel (Entrix 1998). The canopy closure in the Mainstem Navarro River subwatershed varied from less than 30% along the mainstem to greater than 65% canopy closure on Marsh Gulch and Mill Creek (Entrix 1998). The North Fork subwatershed also varied greatly. Surveyed portions of the South Branch North Fork and the North Branch North Fork had less than 30% canopy closure. Meanwhile, Upper South Branch North Fork, Little North Fork, and John Smith Creek had moderate canopy closure of 30-64%.

2.3 Hydrology

Precipitation

According to the Division of Water Rights (1998), "Precipitation data from the Philo gage indicate there is an average of approximately 40.4 inches of precipitation per year, with about 63 percent of the precipitation occurring between December 15 and March 31."

Ground Water

The information in this section is from "Geology, Hydrology and Water quality of Alluviated Areas in Mendocino County and Recommended Standards of Water Well Construction and Sealing" by the Division of Water Resources (1956).

Ground water within Anderson Valley generally moves in a northwesterly direction following the topographic axis of the valley. Although there are no extensive or continuous aquifers in the Anderson Valley, ground water can be found in recent alluvium deposits, stream channel deposits, and terrace deposits. The Franciscan formation, which underlies much of the Navarro River watershed, and includes the coastal belt and melange units, is considered essentially nonwater-bearing. Only limited amounts of ground water can be found in the Franciscan formation's joints and fractures. This secondary permeability provides water for several minor springs and wells around the periphery of Anderson Valley, as well as supplying minor recharge to several surface streams).

The ground water found in alluvium, stream channel, and terrace deposits is ". . . limited because of the large proportion of silt and clay and the lenticularity of the more permeable zones. [However, these], . . . these deposition[s] still represent the most important source of ground water storage in Anderson Valley because of their widespread areal and vertical extent." The depth to water in alluvium and stream channel deposits generally ranges from zero to thirty feet while depth to water in terrace deposits ranges from ten to sixty feet.

Surface Water, Diversions & Flow

The United States Geological Survey (USGS) has maintained a stream flow gage on the Navarro River from 1951 to the present. USGS Station No. 1146800 is located in the Anderson Valley about nine miles upstream from the mouth of the Navarro at the Pacific Ocean. Gage records (Table 2-1) indicate the average daily flow has ranged from a low of 0.23 cubic feet per second (cfs) on July 13, 1977, to a high of 64,500 cfs on December 22, 1955. The annual minimum flow (based on average daily flow) ranges from the 0.23 cfs mention above in 1977 to 14.0 cfs in 1954 and 1958 (Jackson 1991). The average annual runoff is about 370,000 acre-feet per annum (afa) which has varied from a minimum of 18,035 afa in 1977 to a maximum of 949,794 afa in 1983 (Division of Water Rights 1998). These records are impaired flows, reflecting the reductions created by water rights on record with the State Water Resources Control Board, Division of Water Rights. Riparian or pre-1914 diversions, possible illegal diversions, and other natural losses within the watershed are unknown to the Division of Water Rights.

Table 2-1
Flow Measurements from USGS Gage No. 1146800

	Low		High	
	Amount	Year	Amount	Year
Average Daily Flow	0.23 cfs	1977	64,500 cfs	1955
Annual Minimum Flow	0.23 cfs	1977	14.00 cfs	1954 & 1958
Average Annual Runoff	18,035 afa	1977	949,794 afa	1983

The largest floods since rainfall data has been recorded occurred in 1955, 1964, and 1974, as seen in Table 2-2 (Entrix 1998). Residents of the area commented "... that floods in the late 1950s and early 1960s had significantly greater impacts in terms of channel widening, silt and debris deposition on floodplains, and landsliding than did recent large floods occurring in 1993 and 1995 that were of similar magnitude" (Adams 1971, as cited in Entrix 1998).

Table 2-2
Record of Large Floods Between 1951 & 1997

Date	Water Year (10/1 – 9/30)	Recurrence Interval (yrs)	Peak Discharge (cfs)
12/22/55	1955	47.1	64,500
02/24/58	1958	5.2	34,100
01/31/63	1963	4.7	33,100
12/22/64	1965	15.7	52,100
01/05/66	1966	4.7	33,100
01/24/70	1970	5.9	43,900
01/16/74	1974	23.5	61,000
01/26/83	1983	7.8	48,200
02/17/86	1986	9.4	49,000
01/21/93	1993	7.8	48,200
01/09/95	1995	11.8	51,500
12/31/96	1997		40,600

Flows in the minor tributaries during the summer months are usually not of sufficient magnitude to reach Anderson Valley because of percolation and evapotranspiration losses (DWR 1956). The surface water that is present in these tributaries in the summer is primarily derived from springs. Year-round surface water is usually found in the mainstem Navarro River and lower reaches of Anderson Creek, Rancheria Creek, Indian Creek, and the North Fork as they receive recharge from both ground water and surface runoff, as surface runoff moves from adjacent forested areas and as return flow from applied irrigated water (DWR 1956). Surface water diversions and groundwater extraction, from residential, commercial, and agricultural uses, can lower water tables and reduce baseflow contributions. Summer low-flow periods reduce the available pool habitat, increase stream temperatures, and my completely dry the channel. Streamflow monitoring performed by the Mendocino County Water Agency and the State Water Resources Control Board, Division of Water Rights indicate that segments of Anderson Creek can go dry for brief periods due to pumping (Entrix 1998).

The Division of Water Rights "... has records of existing and proposed diversions that total approximately 4,600 acre-feet per annum (afa), or less than 2 percent of the average annual runoff of 370,000 afa. Most of these diversions are for agricultural irrigation and occur during the summer. Consequently, the measured flow during the winter is very close to the natural, or unimpaired, flow condition" (Division of Water Rights 1998b).

Slope

The slope of the mainstem Navarro River is mostly flat, as seen in Figure 2-5. The mainstems of the North Fork, Anderson Creek, and Rancheria Creek also flow at low slopes which range from zero to three percent. Indian Creek subwatershed has several tributaries with steeper slopes that range from zero to fifty percent slope.

2.4 Land Use

Approximately 3,500 people line in the Navarro River watershed, mostly around the towns of Boonville, Philo, and Navarro. According to Entrix (1998), commercial timber harvesting, grazing, viticulture, orchards, and tourism are the current principle economic enterprises in the watershed with land use roughly separated out into forestland (70%), rangeland (25%), and agriculture (5%). A small percentage is devoted to rural residential development (Entrix 1998).

Timber harvesting began in earnest in the Navarro River watershed during the mid 1800s following the gold rush. A second logging boom occurred in the watershed from the late 1930s to the early 1950s, when large tracts of redwood-dominated forest in the Mainstem Navarro River subwatershed was re-harvested (Adams 1971, as cited in Entrix 1998). Douglas fir dominated forest in the North Fork Navarro subwatershed was cut for the first time during this period (Adams 1971, as cited in Entrix 1998). Sheep and cattle have been grazed in the Navarro River watershed since the 1870s.

Insert
Figure 2-5

Slope

(Front)

Insert

Figure 2-5
Slope

(Back)

The following is a summary of the major land uses within each subwatershed of the Navarro River watershed:

- Rancheria Creek - Sheep and cattle gazing, logging, open space and rural residential homes are the most common land uses. Highway 128 is also a major feature along the upper reaches of Rancheria Creek (Entrix 1998).

- Anderson Creek - This is the most populated and urbanized subwatershed within the Navarro River watershed. Sheep and cattle grazing, orchards, row crops, agriculture, and viticulture are also common (Entrix 1998).

- Indian Creek - Land use includes timber production, hunting clubs, ranching, open space, residential and commercial urban uses, and viticulture. Most time is produced in the upper reaches of the North Fork of Indian Creek, while the most developed areas and vineyards are found on and near the floodplain along the lower reaches of Indian Creek and the town of Philo (Entrix 1998).

- North Fork Navarro River – Land use is primarily timber harvest, with some rural residential and vacation homes (Entrix 1998).

- Mainstem Navarro River - The most common land uses are rural residential, vacation homes, roads, current and former logging and lumber mills, timber production, vineyards, orchards, and open space (Entrix 1998).

CHAPTER 3
REGULATORY FRAMEWORK

The following laws and regulations can be divided into two categories. Laws such as the Clean Water Act, the Porter-Cologne Water Quality Control Act, and the Endangered Species Act are included because they lay the groundwork for TSD and TMDL development and establish legal authority. Laws such as the Z'Berg-Nejedly Forest Practice Act, the California Environmental Quality Act, and the Non-Point Source Program Strategy and Implementation Plan are included for reference. These three laws regulate land use management and are therefore applicable to the Navarro River watershed.

3.1 Clean Water Act

The TMDL program is required by Section 303(d)(1)(A) of the Clean Water Act (CWA) that states "Each State shall identify those waters within its boundaries for which the effluent limitations . . . are not stringent enough to implement any water quality standard applicable to such waters." The same part of the CWA also requires that the State "establish a priority ranking for such waters, taking into account the severity of the pollution and the uses to be made of such waters." In accordance with Section 303(d)(1)(A), the North Coast Regional Water Quality Control Board adopted, through Resolution No. 98-45 on April 23, 1998, a priority list of waters within the North Coast Region in which water quality standards were not being met. The Navarro River was included on that list based on the finding that sedimentation and increased stream temperatures were, in part, responsible for the impairment of the cold water fishery. Section 303(d)(1)(C) of the Clean Water Act requires 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 . . ."

Pursuant to a consent decree entered in the United States District Court, Northern District of California (*Pacific Coast Federation of Fishermen's Associations, et al. v. Marcus,* No. 95-4474 MHP, March 11, 1997), the EPA committed to assuring that TMDLs would be established for eighteen rivers by December 31, 2007. Pursuant to the consent decree, the EPA developed a Supplemental TMDL Establishment Schedule which set December 31, 2000, as the deadline for the establishment of a TMDL for the Navarro River.

The Navarro River watershed technical support document (TSD) meets all federal requirements for a Total Maximum Daily Load (TMDL), but with no implementation or monitoring plan and no action on the part of the Regional or State Board. TSD's may also be known as "technical TMDLs," but TSD is used to emphasize that the documents have not been through the Regional or State Board's public participation and adoption process. The Navarro River watershed TSD for Sediment and Temperature will be transmitted directly to U.S. EPA upon completion by Regional Water Board staff. After minor revision, the U.S. EPA will publicly notice the document as a draft TMDL.

3.2 Porter-Cologne Water Quality Control Act & the Water Quality Control Plan, North Coast Region (Basin Plan)

Existing water quality requirements are described in the Basin Plan, which is the tool for comprehensive water quality planning as set forth in both California's Porter-Cologne Water Quality Control Act and the federal Clean Water Act. The North Coast Region includes all of the watersheds draining into the Pacific Ocean from the California-Oregon state line to the southern boundary of the watershed of the Estero de San Antonio and Stemple Creek in Marin and Sonoma Counties. It also includes the Lower Klamath Lake and Lost River Basins. The Basin Plan is comprehensive in scope and is regularly updated through Basin Plan Amendments to ensure that new information and issues are adequately addressed.

Among other things, the Basin Plan describes the existing and potential beneficial uses of the surface and ground waters in each of the watersheds throughout the North Coast Region. It also identifies both numeric and narrative water quality objectives, the attainment of which is intended to protect the identified beneficial uses. The Navarro River watershed Technical Support Document is one means of attaining water quality objectives and protecting beneficial uses.

The Basin Plan also includes implementation plans that describe the means by which specific water quality issues will be addressed by the Regional Water Board, including specific prohibitions, action plans, and policies. The implementation plans associated with TMDLs are established under the authority of the Porter-Cologne Water Quality Control Act through the Basin Plan process amendment process

3.2.1 Beneficial Uses

The Basin Plan identifies the following existing beneficial uses of water in the watershed:

- Municipal and Domestic Supply (MUN)
- Agricultural Supply (AGR)
- Industrial Service Supply (IND)
- Recreational Uses (REC-1 & REC-2)
- Commercial and Sport Fishing (COMM)
- Cold Freshwater Habitat (COLD)
- Migration of Aquatic Organisms (MIGR)
- Spawning, Reproduction, and/or Early Development (SPWN)
- Estuarine Habitat (EST)
- Wildlife Habitat (WILD)
- Groundwater Recharge (GWR)
- Navigation (NAV)

The beneficial uses identified above as COMM, COLD, MIGR, SPWN, and EST are all related to the Navarro River watershed's cold water fishery. Beneficial uses associated with the cold water fishery appear to be the most sensitive in the watershed. As such, protection of these beneficial uses is presumed to protect any of the other beneficial uses that might also be harmed by sedimentation and increased stream temperature.

The COMM beneficial use applies to water bodies in which commercial or sport fishing occurs or historically occurred for the collection of fish, shellfish, or other organisms, including, but not limited to, the collection of organisms intended either for human consumption or bait purposes. The COLD beneficial use applies to water bodies that support or historically supported cold water ecosystems, including, but not limited to, the preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates. The MIGR beneficial use applies to water bodies that support or historically supported the habitats necessary for migration or other temporary activities by aquatic organisms, such as anadromous fish. The SPWN beneficial use applies to water bodies that support or historically supported high quality aquatic habitats suitable for the reproduction and early development of fish. The EST beneficial use applies to water bodies that support or historically supported estuarine ecosystems, including, but not limited to, the preservation or enhancement of estuarine habitats, vegetation, fish, shellfish, or wildlife (e.g., estuarine mammals, waterfowl, shorebirds).

3.2.2 Water Quality Objectives

The Porter-Cologne Water Quality Control Act, Chapter 4, Section 13241 specifies that each Regional Water Quality Control Board (Regional Water Board) shall establish water quality objectives which, in the Regional Water Board's judgment, are necessary for the reasonable protection of the beneficial uses and for the prevention of nuisances. The water quality objectives are considered to be necessary to protect those present and probably future beneficial uses stated above and to protect existing high quality waters of the state. As new information becomes available, the Regional Water Board will review the appropriateness of the objectives and adoption into the Basin Plan.

The following is a summary of Water Quality Objectives for the Navarro River watershed according to the Basin Plan as amended in 1996.

TABLE 3-1
NARRATIVE WATER QUALITY OBJECTIVES

Objective	Description
Color	Waters shall be free of coloration that causes nuisance or adversely affects beneficial uses.
Tastes and Odors	Waters shall not contain taste or odor producing substances in concentrations that impart undesirable tastes or odors to fish flesh or other edible products of aquatic origin, or that cause nuisance or adversely affect beneficial uses.

Objective	Description
Floating Material	Waters shall not contain floating material, including solids, liquids, foams, and scum, in concentrations that cause nuisance or adversely affect beneficial uses.
Suspended Material	Waters shall not contain suspended material in concentrations that cause nuisance or adversely affect beneficial uses.
Settleable Material	Waters shall not contain substances in concentrations that result in deposition of material that causes nuisance or adversely affect beneficial uses.
Oil and Grease	Waters shall not contain oils, greases, waxes, or other materials in concentrations that result in a visible film or coating on the surface of the water or on objects in the water, that cause nuisance, or that otherwise adversely affect beneficial uses.
Biostimulatory Substance	Waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses.
Sediment	The suspended sediment load and suspended sediment discharge rate of surface water shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.
Temperature	The natural receiving water temperature of intrastate waters shall not be altered unless it can be demonstrated to the satisfaction of the Regional Water Board that such alteration in temperature does not adversely affect beneficial uses. At no time or place shall the temperature of any COLD water be increased by more than 5°F above natural receiving water temperature.
Toxicity	All waters shall be maintained free of toxic substances in concentrations that are toxic to, or that produce detrimental physiological responses in human, plant, animal, or aquatic life.
Pesticides	No individual pesticide or combination of pesticides shall be present in concentrations that adversely affect beneficial uses. There shall be no bioaccumulation of pesticide concentrations found in bottom sediments or aquatic life.
Chemical Constituents	Waters designated for use as agricultural supply (AGR) shall not contain concentrations of chemical constituents in amounts which adversely affect such beneficial uses.
Radioactivity	Radionuclides shall not be present in concentrations which are deleterious to human, plant, animal or aquatic life nor which result in the accumulation of radionuclides in the food web to an extent which presents a hazard to human, plant, animal, or indigenous aquatic life.

TABLE 3-2 NUMERIC WATER QUALITY OBJECTIVES	
Objective	Description
Turbidity	Turbidity shall not be increased more than 20 percent above naturally occurring background levels.
pH	The pH of waters shall always fall within the range of 6.5 to 8.5.
Dissolved Oxygen	At a minimum, waters shall contain 7.0 mg/L at all times. Ninety percent of the samples collected in any year must contain at least 7.5 mg/L. Fifty percent of the monthly means in any calendar year shall contain at least 10.0 mg/L.
Bacteria	The bacteriological quality of waters of the North Coast Region shall not be degraded beyond natural background levels. Based on a minimum of not less than five samples for any 30-day period, the median fecal coliform concentrations in waters designated for contact recreation (REC-1) shall not exceed 50/100 ml. Nor shall more than ten percent of total samples during any 30-day period exceed 400/100 ml.
Specific Conductance	Ninety percent of the samples collected in any year must not exceed 285 micromhos at 77°F. Fifty percent of the monthly means in any calendar year shall contain at least 250 micromhos at 77°F.
Total Dissolved Solids	Ninety percent of the samples collected in any year must not exceed 170 mg/L. Fifty percent of the monthly means in any calendar year shall contain at least 150 mg/L.

3.2.3 Prohibitions

In addition to water quality objectives, the Basin Plan includes two discharge prohibitions specifically applicable to logging, construction, and other associated non-point source activities. They state:

- The discharge of soil, silt, bark, slash, sawdust, or other organic and earthen material from any logging, construction, or associated activity of whatever nature into any stream or watercourse in the basin in quantities deleterious to fish, wildlife, or other beneficial uses is prohibited.

- The placing or disposal of soil, silt, bark, slash, sawdust, or other organic and earthen material from any logging, construction, or associated activity of whatever nature at locations where such material could pass into any stream or watercourse in the basin in quantities which could be deleterious to fish, wildlife, or other beneficial uses is prohibited.

3.3 Endangered Species Act

Originally passed in 1973, the Endangered Species Act (ESA) is a federal law that provides for the designation and protection of invertebrates, wildlife, fish, and plant species that are in danger of becoming extinct and conserves the ecosystems on which such species depend. The ESA makes it illegal for any individual to kill, collect, remove, harass, import, or export an endangered or threatened species without a permit from the Secretary of the Department of the Interior or the Department of Commerce. An endangered species is any species that is in danger of becoming extinct throughout all or a significant portion of its range, excluding recognized insect pests. A threatened species is one that is likely to become endangered in the foreseeable future.

For a species to receive the full protection accorded by the ESA, the species must be placed on the List of Endangered and Threatened Wildlife and Plants. As the resources are not available to immediately add all species that are in danger of extinction to that list, another list is maintained of candidate species. Candidate species are plants and animals native to the United States for which there is sufficient information on biological vulnerability and threats to justify proposing to add them to the threatened and endangered species list, but cannot do so immediately because other species have a higher priority for listing.

The Fish and Wildlife Service under the U.S. Department of the Interior performs most administrative and regulatory actions under the Endangered Species Act. The National Marine Fisheries Service (NMFS) in the U.S. Department of Commerce deals with actions affecting marine species, including salmonids.

The listing process generally begins with a petition to the Secretary of the Interior or the Secretary of Commerce. Consultation with affected states is required prior to listing, but the Secretary makes the final decision. Whenever possible, a designation of critical habitat accompanies the listing of an endangered or threatened species. Critical habitat is the specific areas within the geographical area occupied by the species, at the time it is listed in accordance with the provisions of 16 USC §1533, on which are found those physical or biological features essential to the conservation of the species and which may require special management considerations or protection. An area may also be designated as critical habitat if the Secretary feels it is essential for conservation of the species. Critical habitat shall not include the entire geographical area which can be occupied by the threatened or endangered species except in those circumstances determined by the Secretary. The Secretary must publish and periodically update the lists and develop and implement recovery plans for the conservation and survival of endangered and threatened species.

On May 6, 1997, the National Marine Fisheries Service (NMFS) listed coho salmon in the Northern California/Southern Oregon Coasts Evolutionarily Significant Unit (ESU) as a threatened species under the federal Endangered Species Act (50 CFR §227). This ESU includes all naturally spawned populations of coho salmon in coastal streams between Cape Blanco, Oregon, and Punta Gorda, California. On June 7, 2000, NMFS also listed steelhead trout in the Northern California Evolutionarily Significant Unit (ESU) as a threatened species (50 CFR

§223). The Northern California ESU includes steelhead in California coastal river basins from Redwood Creek south to the Gualala River, inclusive. These listings are results of observed substantial declines in the salmonid populations over time and show that the beneficial uses as described in the Basin Plan are not being protected.

The Endangered Species Act can be found in Chapter 16 of the United States Code, beginning at Section 1531.

3.4 Z'Berg-Nejedly Forest Practice Act & the California Forest Practice Rules

The Z'Berg-Nejedly Forest Practice Act of 1973 is a state law written to ". . . encourage prudent and responsible forest resource management calculated to serve the public's need for timber and other forest products, while giving consideration to the public's need for watershed protection, fisheries and wildlife, and recreational opportunities alike in this and future generations" (Pub. Res. Code §4511(c)). The California Forest Practice Rules is the regulation used to ". . . implement the provisions of the Z'Berg-Nejedly Forest Practice Act of 1973 in a manner consistent with other laws, including but not limited to, the Timberland Productivity Act of 1982, the California Environmental Quality Act (CEQA) of 1970, the Porter Cologne Water Quality Act, and the California Endangered Species Act" (14 CCR §896(a)). Specifically, the Forest Practice Rules

> . . . shall apply to the conduct of timber operations and shall include, but shall not be limited to, measures for fire prevention and control, for soil erosion control, for site preparation that involves disturbance of soil or burning of vegetation following timber harvesting activities conducted after January 1, 1988, for water quality and watershed control, for flood control, for stocking, for protection against timber operations which unnecessarily destroy young timber growth or timber productivity of the soil, for prevention and control of damage by forest insects, pests, and disease, for the protection of natural and scenic qualities in special treatment areas . . ., and for the preparation of timber harvesting plans (Pub. Res. Code §4551.5).

3.4.1 Timber Harvest Plans

One of the main mechanisms used by the California Department of Forestry (CDF) to implement the Forest Practice Rules is through Timber Harvesting Plan (THP) requirements. As the Forest Practice Act states, "No person shall conduct timber operations unless a timber harvesting plan prepared by a registered professional forester has been submitted for such operations . . ." (Pub. Res. Code §4581). "Timber harvesting plans shall be applicable to a specific piece of property or properties and shall be based upon such characteristics of the property as vegetation type, soil stability, topography, geology, climate, and stream characteristics" (Pub. Res. Code §4582.5). The THP process is the functional equivalent of an Environmental Impact Report, under the California Environmental Quality Act.

Both the Forest Practice Act and the California Forest Practice Rules set out technical requirements for a Timber Harvesting Plan. Once CDF receives a THP, copies are made available for public review and copies are sent to the appropriate Regional Water Quality Control Board and the Department of Fish and Game for comments and recommendations per section 4582.6(a) of the Forest Practice Act. These comments "... shall be considered based on the comments' substance, and specificity, and in relation to the commenting agencies' area(s) of expertise and statutory mandate, as well as the level of documentation, explanation or other support provided with the comments" (14 CCR §1037.3). In addition, "the board of supervisors or planning commission of any county ... may request a public hearing on any timber harvesting plan submitted for lands within the county ... " (Pub. Res. Code §4582.6(d)).

If it is determined that the THP is not in conformance with the rules, the plan shall be returned to the applicant. "In addition the Director shall state any changes and reasonable conditions that in the Director's professional judgment are needed to bring the plan into conformance with the applicable rules of the Board and offer to confer with the RPF [Registered Professional Forester] in order to reach agreement on the conditions necessary to bring the plan into conformance" (14 CCR §1037.6). However, "If the plan is in conformance with the rules of the Board, then the person submitting the plan shall be notified, and timber operation thereunder may commence" (14 CCR §1037.7).

A THP is effective for not more than three years, unless work on a THP has commenced but not completed. In that case, the THP may be extended by amendment for a one-year period in order to complete the work, up to a maximum of two one-year extensions (Pub. Res. Code §4590(a)(1), (2)). Stocking work may continue for more than this time period, "... but shall be completed within five years after the conclusion of other work" (Pub. Res. Code §2590(b)).

3.4.2 Sustained Yield Plans

Another mechanism used by CDF to implement the California Forest Practice Rules is through a Sustained Yield Plan, or SYP. "Consistent with the protection of soil, water, air, fish and wildlife resources, a SYP shall clearly demonstrate how the submitter will achieve maximum sustained production of high quality timber products while giving consideration to regional economic vitality and employment at planned harvest levels during the planning horizon" (14 CCR 1091.4.5(a)). Although there is no maximum size area that a SYP can apply to, a Sustained Yield Plan shall at least encompass a planning watershed (14 CCR §1091.6(a)). In addition, "The effective period of SYPs shall be no more than ten years" (14 CCR §1091.9).

While a Sustained Yield Plan focuses on sustained timber production, watershed impacts, and fish and wildlife, the SYP is not designed to replace a Timber Harvesting Plan. "However, to the extent that sustained timber production, watershed impacts and fish and wildlife issues are addressed in the approved SYP, these issues shall be considered to be addressed in the THP; that is the THP may rely upon the SYP" (14 CCR 1091.3).

The Z'Berg-Nejedly Forest Practice Act can be found in the California Public Resources Code, Division 4, Part 2, Chapter 8. The California Forest Practice Rules can be found in Title 14 of the California Code of Regulations, Chapter 4 and 4.5. For inquires regarding the Forest Practice Act or the California Forest Practice Rules, please contact the California Department of Forestry and Fire Protection. The Navarro River watershed is a part of the Coast Forest District, which runs from the Oregon border to Santa Cruz County.

3.5 California Environmental Quality Act

The California Environmental Quality Act, or CEQA, was enacted in 1970 in order to ensure that state and local agencies consider the environmental impact of their decisions when approving a public or private project. CEQA is the broadest of California's environmental laws as it applies to all discretionary activities proposed to be carried out or approved by a public agency. CEQA is a component of the regulatory framework that influences land use regulations within the Navarro River watershed, and is therefore included in the Navarro River TSD.

The CEQA process begins with the identification of a project. Projects are activities which will potentially have a physical impact on the environment, directly or ultimately, such as an activity involving a public agency's issuance of a lease, permit, license, certificate, or other entitlement for use by a public agency (14 CCR §15378). CEQA requires one of these public agencies to serve as the lead where a project requires approval from more than one public agency. The lead agency must then complete the environmental review process.

Once a lead agency has been established and project status is determined, the next step is to decide if a project is exempt from CEQA. Statutory exemptions from CEQA include, but are not limited to, ministerial projects or when a State of Emergency has been declared by the governor. Categorical exemptions include, but are not limited to, basic data collection, research, experimental management, and resource evaluation activities (14 CCR §15306). A third category, Certified Regulatory Programs, also fall as exempt from CEQA. Certified Regulatory Programs, however, must still contain elements of CEQA's environmental review process. The next step is to perform an Initial Study to identify the environmental impacts of the project. The initial study may use a checklist format but must disclose the factual data or evidence used to reach conclusions regarding the significance of potential impacts. The Initial Study leads to a determination of the need for one of the following documents:

- Negative Declaration – A Negative Declaration is a written statement briefly explaining why a proposed project will not have a significant environmental effect.

- Mitigated Negative Declaration – If the proposed project is revised after the Initial Study was performed, or if the project proponent agrees to revise the project to mitigate the potential significant impacts before public review, a Mitigated Negative Declaration is prepared (14 CCR §15070(b)(1)).

- Environmental Impact Report (EIR) – An EIR is a detailed informational document prepared by a lead agency that analyzes a project's significant effects and identifies mitigation measures and reasonable alternatives (14 CCR §15121, 15362). The development of an EIR is a very structured and time consuming process. For more information, please refer to Title 14 of the California Code of Regulations, beginning with Section 15080.

The California Environmental Quality Act can be found in the California Public Resources Code, Division 13, beginning at Section 21000. The Guidelines for Implementation of the California Environmental Quality Act can be found in Title 14 of the California Code of Regulations, Chapter 3, beginning with Section 15000.

3.6 Non-Point Source Program Strategy and Implementation Plan, 1998-2013

The Non-Point Source Program Strategy and Implementation Plan, 1998-2013 was submitted in January 2000 by the State Water Resources Control Board and California Coast Commission for review and approval by the U.S. Environmental Protection Agency and the National Oceanic and Atmospheric Administration. Approval is expect in July 2000.The following summary is taken from the January 2000 document submitted by the State Water Resources Control Board and the California Coastal Commission.

The purpose of the Non-Point Source Plan is to improve the State's ability to effectively manage non-point source pollution and conform to the requirements of the federal Clean Water Act and the federal Coastal Zone Act Reauthorization Amendments of 1990 (CZARA). Specifically, Section 319 of the Clean Water Act requires each state to develop a statewide non-point source plan containing specified components, including management measures to control non-point source pollution. Section 6217 of CZARA requires each coastal state to develop and implement management measures to control non-point source pollution in coastal areas.

The first Non-Point Source Plan was developed in 1988 in order to meet the requirements of Section 319 of the CWA. However, with the passage of CZARA in 1990, the state decided to propose a statewide plan that would meet both statutes. Approval of the current Non-Point Source Plan by the U.S. Environmental Protection Agency and the National Oceanic and Atmospheric Administration is expected in July 2000.

The current Non-Point Source Plan outlines a fifteen year strategy for gradually limiting non-point source pollution throughout California. Instead of imposing new obligations on landowners, industry and any other possible polluters, the Non-Point Source Plan outlines how federal, state, and local agencies will identify the most urgent needs for non-point source controls, and will utilize their authority under existing laws. This includes sixty one Management Measures (MMs) that are to be implemented by 2013. The MMs are divided into categories for agriculture, forestry, urban areas, marinas and recreational boating, hydromodification, and wetlands and riparian areas. Some examples of individual MMs are listed below:

- Under the Agriculture category, develop numeric nutrient criteria and standards for heavy metals in organic and inorganic fertilizers by 2003 (MM 1C).

- Under the Agriculture category, develop TMDLs that include rangeland load allocations for the Humboldt and Garcia River watersheds along the North Coast by 2003 (MM 1E).
- Under MM 1A, Erosion and Sediment Control, in the Agriculture category, promote interagency coordination to improve information transfer and to provide a singular agency prospective in the Russian, Gualala, Garcia, and Navarro Rivers.
- Under MM 1A, Erosion and Sediment Control, in the Agriculture category, promote hillside vineyard management practices to reduce erosion/sedimentation and improve riparian function and fish habitat in the Russian, Gualala, Garcia, and Navarro Rivers.
- Under the Forestry category, plan silvicultural activities to reduce potential delivery of pollutants to surface waters (MM 2A).
- Under the Forestry category, conduct road construction/reconstruction so as to reduce sediment generation and delivery (MM 2C).
- Under the Urban Area category, mitigate the impacts of urban runoff and associated pollutants that result from new development or redevelopment (MM 3.1).
- Under the Urban Area category, provide financial, technical, and educational assistance to help ensure that on-site disposal systems are located, designed, installed, operated, inspected, and maintained to prevent the discharge of pollutants onto surface water and into ground water (MM 3.4)
- Under the Urban Area category, implement educational programs to provide greater understanding of watersheds (MM 3.6A).
- Under the Marina and Recreational Boating category, site and design marinas to protect against adverse impacts on fish and shellfish, aquatic vegetation, and important locally, State, or federally designated habitat areas (MM 4.1C).
- Under the Hydromodification category, by the year 2002, develop a technical assistance manual that will assist local governments and small businesses with guidelines for designing projects to avoid wetlands and riparian areas (MM 5.1).

The Non-Point Source Plan relies on a so-called "three tier" approach toward implementation. Tier One is a voluntary approach which assumes that property owners and others will implement the Best Management Practice (BMPs) that have been selected to carry out particular Management Measures, without the use of a permit from a regulatory agency or incorporation of the BMPs into the Basin Plan. Tier Two is the regulatory based encouragement of management practices. For example, the North Coast Regional Water Quality Control Board can waive Waste Discharge Requirements, which is a permit, on the condition that management measures or best management practices be implemented. Tier Three is full oversight by a regulatory agency. In this case, a regional board would impose Waste Discharge Requirements or issue a Cease and Desist Order or a Cleanup and Abatement Order.

CHAPTER 4
PROBLEM STATEMENT

This chapter provides a description of the existing in-stream and upslope watershed setting and the beneficial use impairments of concern. In other words, the problem statement provides background information about the Navarro River watershed which is intended to assist readers in understanding the context for the TSD analysis. This chapter specifically focuses on the problems associated with sedimentation and increased stream temperatures in the Navarro River watershed in terms of its impact on the various life cycle stages of salmonids and on the overall stability of the stream channel. In summary, the beneficial uses associated with the cold water fishery are currently not being protected, as seen by the listing of Coho Salmon and Steelhead Trout as a threatened species under the Endangered Species Act. The Navarro River watershed was listed under Section 303(d) of the Clean Water Act as an impaired water body due to sedimentation and increased stream temperature. The following chapter describes how sediment and increased stream temperatures affect the beneficial uses associated with the cold water fishery.

This analysis is based on those data that have been submitted to Regional Water Board staff for consideration. Due to the absence of information in some areas of the watershed and with respect to certain habitat parameters, conservative assumptions have been made regarding the factors that are potentially limiting salmonid populations in the basin. The discussion in Sections 5.4 and 6.3 (Numeric Targets) is based on the problems identified in this analysis. Should additional data become available in the future, the TMDL and numeric targets can be modified.

4.1 Introduction to Salmonids

Salmonids are fish species in the family Salmonidae, including salmon, trout and char (Meehan 1991). There are both anadromous and nonanadromous salmonids. Nonanadromous fish are those that mature and spawn in freshwater, such as rainbow trout. Anadromous fish are those that mature in the ocean but spawn in freshwater. Those of interest in the Navarro River watershed include: coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Oncorhynchus mykiss*), the anadromous version of rainbow trout. Chinook salmon (*Oncorhynchus tshawytscha*) are not found in the Navarro River, although populations are established to both the north and south of the Navarro River watershed. The California Coastal Chinook Salmon Evolutionarily Significant Unit (ESU), as defined by NMFS and stated in 65 FR §32, includes Humboldt Bay, Redwood Creek, and the Mad, Eel, Mattole, and Russian Rivers.

The life cycle of salmonids can be broken into seven distinct life cycle stages, each with its own specific set of environmental requirements. The life cycle requirements are well understood for some life cycle stages and not as well understood for others. Much of what is known about some life cycle stages (e.g., spawning, incubation, and emergence) is gathered from laboratory tests. Other knowledge is gathered from field studies and observations.

The typical life cycle of anadromous salmonids includes the following stages, as described by Meehan et al. 1991:

- Adult females and males migrate to fresh water spawning grounds. The timing of migration depends on the species.
- The female builds several redds (gravel nest) and lays eggs in them over which the male ejects his milt, or sperm.
- The fertilized eggs (embryos) hatch from the eggs as alevins in 1-3 months. The alevins emerge with yolk sacs and reside in the interstices of the gravel until they are ready to feed on macroinvertebrates in the water column.
- The alevins emerge from the gravel as fry in 1-5 months, generally in the spring or summer.
- The juvenile fish remain in fresh water for a few days to 4 years, depending on the species and locality.
- The juvenile fish undergo "smoltification" then migrate to the ocean as smolts, generally in the spring or early summer. Smoltification is a process of physical change that allows a freshwater fish to survive in a saline environment.
- The smolt resides and grows in the ocean for 1-4 years before returning to its natal stream for spawning.

Steelhead trout do not invariably die after spawning, although Pacific salmon do.

<u>Coho salmon</u>

In September 1995, the National Marine Fisheries Service published a report entitled "Status Review of Coho Salmon from Washington, Oregon, and California" (Weitkamp et al. 1995). The following is taken from the NMFS report.

From central British Columbia south, the vast majority of coho salmon adults are 3-year-olds, having spent approximately 18 months in fresh water and 18 months in salt water (as cited in Weitkamp et al. 1995: Gilbert 1912, Pritchard 1940, Marr 1943, Briggs 1953, Shapovalov and Taft 1954, Foerster 1955, Milne 1957, Salo and Bayliff 1958, Loeffel and Wendler 1968, and Wright 1970). The primary exception to this pattern are "jacks," sexually mature males that return to freshwater to spawn after only five to seven months in the ocean. As cited in the NMFS report, Drucker (1972) suggested that there is a latitudinal cline in the proportion of jacks in a coho salmon population, with populations in California having more jacks and those in British Columbia having almost none. Although the production of jacks is a heritable trait in coho salmon (as cited in Weitkamp et al. 1995: Iwamoto et al. 1984), it is also strongly influenced by environmental factors (as cited in Weitkamp et al. 1995: Shapovalov and Taft 1954, and Silverstein and Hershberger 1992). The proportion of jacks in a given coho salmon population appears to be highly variable and may range from less than 6% to over 43% (as cited in Weitkamp et al. 1995: Shapovalov and Taft 1954, Fraser et al. 1983, and Cramer and Cramer 1994).

Most west coast coho salmon enter rivers in October in response to increased freshwater outflows to the ocean and spawn from November to December and occasionally into January. However, coho salmon on the Mendocino Coast, including the Navarro River watershed, generally enter freshwater much later, in late December or January, and spawn immediately afterwards, probably in response to later peak river flows of limited duration. Consequently, Mendocino Coastal fish spend little time between river entry and spawning, while northern stocks may spend one or two months in fresh water before spawning (as cited in Weitkamp et al. 1995: Flint and Zillges 1980, and Fraser et al. 1983).

According to Weldon Jones (1994, referenced in Weitkamp et al. 1995), smolt outmigration occurs in the Navarro River watershed from late February to June. In 1964 and 1968, Graves and Burns (1970, as cited in Weitkamp et al. 1995) measured mean smolt size in Caspar Creek as 92 mm length with a range of 83-95 mm. No other smolt size measurements for watersheds in the Mendocino Coast Hydrologic Unit are reported.

Coho salmon spawning escapement in California (including the Navarro River watershed) apparently ranged between 200,000 and 500,000 adults per year in the 1940s (Brown et al. 1994, as cited in Weitkamp et al. 1995. By the mid-1960s, statewide spawning escapement was estimated to have fallen to about 100,000 fish per year (as cited in Weitkamp et al. 1995: CDFG 1965, and California Advisory Committee on Salmon and Steelhead Trout 1988), followed by a further decline to about 30,000 fish in the mid-1980s (Wahle and Pearson 1987, as cited in Weitkamp et al. 1995). This is a decline from the 1940s to the 1960s of 50-80% and from the 1960s to 1980s of 70% for a total decline from the 1940s to the 1980s of 85-94%. From 1987 to 1991, spawning escapement averaged about 31,000, with hatchery populations making up 57% of this total (as cited in Weitkamp et al. 1995: Brown et al. 1994). Without the influence of hatcheries, the total decline from the 1940s to the early 1990s would have been from 93-97%.

Higgins et al. (1992, referenced in Weitkamp et al.1995) has evaluated coho salmon population trends and assesses their status as of special concern in the Navarro River watershed. In December 1996, the National Marine Fisheries Service (NMFS) listed the coho salmon in the Central California Coast Evolutionarily Significant Unit (ESU) as a threatened species, i.e., they are likely to become endangered in the foreseeable future. The Central California Coast ESU includes the coastal river basins from Santa Cruz in the south to the borders of the Eel River Watershed in the north.

Steelhead trout

In August 1996, the National Marine Fisheries Service published a report entitled "Status Review of West Coast Steelhead from Washington, Idaho, Oregon, and California" (Busby et al. 1996). The following is taken from the NMFS report.

Oncorhynchus mykiss is considered by many to have the greatest diversity of life history patterns of any Pacific salmonid species (as cited in Busby et al. 1996: Shapovalov and Taft 1954, Barnhart 1986), including varying degrees of anadromy, differences in reproductive biology, and plasticity of life history between generations.

Biologically, steelhead can be divided into two basic reproductive ecotypes, based on the state of sexual maturity at the time of river entry and duration of spawning migration (as cited in Busby et al. 1996: Burgner et al. 1992). The stream-maturing type (commonly known as summer steelhead in the Pacific Northwest and northern California) enters fresh water in a sexually immature condition and requires several months to mature and spawn. The ocean-maturing type (winter steelhead) enters fresh water with well-developed gonads and spawns shortly thereafter. It appears that the summer steelhead occur where habitat is not fully utilized by winter steelhead; summer steelhead usually spawn farther upstream than winter steelhead (as cited in Busby et al. 1996: Withler 1966, Roelofs 1983, Behnke 1992). Where the two types co-occur, they are often separated by a seasonal hydrologic barrier, such as a waterfall. Coastal streams, such as the Navarro River watershed, are dominated by winter steelhead.

In the 1960s, a total of 65,000 steelhead trout are estimated to have existed in the Mendocino Coast Hydrologic Unit (e.g., 9000 from the Ten Mile, 8000 from the Noyo, 12,000 from the Big, 16,000 from the Navarro, 4000 from the Garcia and 16,000 from the Gualala). No current estimates are given.

Based in part on this data, steelhead trout in the Northern California ESU were listed by NMFS in March 1998 as a candidate species and as a proposed threatened species on February 11, 2000. The Northern California ESU includes steelhead in coastal river basins from the Gualala River north to Redwood Creek, inclusive.

4.2 Salmonid Habitat Requirements in Freshwater Streams

The abundance of juvenile salmon, trout and char in streams is a function of many factors, including abundance of newly emerged fry, quantity and quality of suitable habitat, abundance and composition of food, and interactions with other fish, birds, and mammals. Changes in spawning abundance and variation in the success of incubation and emergence affect the number of young fish entering a stream. Density-independent environmental factors (e.g., amount of suitable habitat, quality of cover, productivity of the stream, and certain types of predation) set an upper limit on the abundance of juveniles, and the population is held to that level by interactions that function in a density-dependent fashion (competition and some types of predation). Temperature, productivity, suitable space, and water quality (turbidity, DO, etc.) are examples of variables that regulate the general distribution and abundance of fish within a stream or drainage. All of the general factors must be within suitable ranges for salmonids during the time they use a stream segment; otherwise there will be no fish present.

Table 4-1 identifies the seven life cycle stages common to each of the salmonid species of concern. It also identifies potential impacts to salmonids at each life cycle stage. Finally, it lists some of the potential sources of the impacts named. Note that salmonids can be impacted by both natural and anthropogenic factors

Table 4-1
Salmonid life cycle stages and potential impacts to them

Life Cycle Stage	Potential Impacts	Potential Sources of Impact
Migration	• Stop or impede access of adult fish to spawning grounds • Stop or impede access of fry to adequate shelter and food • Stop or impede access of juveniles to the estuary and/or ocean • Physical harm	• Low flow conditions • Sediment deltas or bars • Log or debris jams • Water supply dams • Poorly engineered or maintained road crossings (e.g., shotgun culverts) • Over-fishing • Predation
Spawning	• Absence of or reduction in appropriate substrate sizes • Substrate embedded or substantially embedded by fine sediment	• Mass wasting, including debris flows and stream bank failures • Gully erosion • Sheet and rill erosion • Drought • Loss or substantial loss of sediment storage capacity (e.g., removal or reduction in the availability of large woody debris)
Incubation	• Scouring or movement of redds • Suffocation or substantial entombment of redds	• Spring freshets • Elevated peak flows • Physical disturbance • Fine sediment delivery and/or remobilization
Emergence	• Substrate embedded or substantially embedded by fine sediment	• Fine sediment delivery and/or remobilization
Summer Rearing	• Elevated stream temperatures • Absence of or decline in the volume of rearing space (e.g., pools) • Absence of or decline in the amount of shelter • Absence of or decline in the amount of food • Disease	• Loss of or reduction in riparian vegetation, vegetation vigor, or complexity of community structure • Loss of or reduction in deep water habitat • Loss of or reduction in summer groundwater inflow • Loss of or reduction in summer intergravel flow • Delivery and/or remobilization of sediment to pools • Loss of or substantial reduction in instream structural elements (e.g., large woody debris) • Delivery and/or remobilization of fine sediment over aquatic macroinvertebrate habitat (e.g., gravels) • Increase in the types or ferocity of diseases (e.g., via release of hatchery-raised fish)
Winter Rearing	• Absence of or decline in off-channel habitat • Absence of or decline in instream shelter (e.g., large woody debris) • Elevated peak flows • Increased stream flow velocities	• Disconnection of stream channel from floodplain • Removal or reduction of large woody debris and other structural elements in the stream channel • Modification of upslope hydrology (e.g., compacted soils, expanded surface drainage system, reduction in vegetation transpiration rate)

Life Cycle Stage	Potential Impacts	Potential Sources of Impact
Ocean Rearing	• Physical harm • Absence of or decline in food supplies • Alteration of water temperatures	• Over fishing • Predation • Disease • Pollution • Climatic changes (e.g., greenhouse warming)

4.2.1 Temperature & Related Salmonid Requirements

Temperature is one of the most important factors affecting the success of salmonids and other aquatic life. Most aquatic organisms, including salmon and steelhead, are poikilotherms, meaning their temperature and metabolism are determined by the ambient temperature of water. Temperature therefore influences growth and feeding rates, metabolism, development of embryos and alevins, timing of life history events such as upstream migration, spawning, freshwater rearing, and seaward migration, and the availability of food. Temperature changes can also cause stress and lethality (Ligon et al. 1999).

Much of the information reported in the literature characterizes temperature requirements with terms such as "preferred" or "optimum" or "tolerable". Preferred temperatures are those that fish most frequently inhabit when allowed to freely select temperatures in a thermal gradient (McCullough 1999). An optimum range provides for feeding activity, normal physiological response, and normal behavior (without symptoms of thermal stress) (McCullough 1999). A tolerable temperature range refers to temperatures at which an organism can survive.

Chronic sublethal temperatures may cause stress that is more important to a population of fish than lethal temperatures. Ligon et al. (1999) discuss sublethal temperature effects that "effectively block migration, reduce growth rate, create disease problems, and inhibit smoltification" (Elliott 1981 as cited in Ligon et al. 1999) as "directly and indirectly linked with survival in natural populations of salmonids" (Ligon et al. 1999). In addition, the stressful impacts of water temperatures on salmonids are cumulative and positively correlated to the duration and severity of the exposure. Thus, the longer the salmonid is exposed to thermal stress, the less chance it has for long-term survival."

Most interpretations of water temperature effects on salmonids and, by extension, water temperature standards, have been based on laboratory studies. Many studies have also looked at the relationship of high temperatures to salmonid occurrence, abundance and distribution in the field.

Literature reviews were conducted to determine temperature requirements for the various life stages of steelhead trout (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus kisutch*). When possible, species specific requirements were summarized by four life stages: migrating adults, spawning, embryo incubation and fry emergence, and freshwater rearing. Results are summarized in Table 4-2. Some of the references reviewed covered salmonids as a general class of fish, while others were species specific.

Table 4-2: Summary of Temperature Tolerance Information

	COHO SALMON		STEELHEAD	
	Values - in °C (°F)	Reference	Values - in °C (°F)	Reference
Lower Lethal Temp.	1.7 (35) 0 (32)	Brett, 1952 Bell, 1986	0 (32)	Bell, 1986
Upper Lethal Temp.	25 (77) 23-25 (73.4-77) 24-25.8 (75.2-78.4)	Brett, 1952 Brungs and Jones, 1977 NMFS, 1997	27 (80.6) [d] 21 (69.8) [d] 23.9 (75) 24-26.7 (75.2-80)	Brungs and Jones, 1977 Brungs and Jones, 1977 Bell, 1986 McCullough, 1999
Preferred Temp.	12-14 (54-57)	Brett, 1952	13-19 (55.4-66.2) [d] 10-13 (50-55.4)	Brungs and Jones, 1977 Bell, 1986
Optimum	15 (59) 13.2 (55.8)	Brungs and Jones, 1977 NMFS, 1997	17-19 (62.6-66.2) [d] 7.2-14.4 (45-58)	Brungs and Jones, 1977 Bell, 1986
Upstream Migration	7.2-15.6 (45-60) 21.1 (70) migration delayed	Bell, 1986 Bell, 1986	21.1 (70) movement limited	Lantz, 1971 cited in ODEQ, 1995
Spawning	Prefer:4.4-9.4 (40-49) >50% Survival: 2-11 (35.6-51.8) >50% Survival: 1.4-12.1 (34.5-53.8) MWAT for spawning: 10 (50)	Bell, 1986 Murray and McPhail, 1988 Murray et al., 1990 Brungs and Jones, 1977	Prefer: 3.9-9.4 (39-49) MWAT for spawning: 9 (48) [d]	Bell, 1986 Brungs and Jones, 1977
Incubation	4.4-13.3 (40-56) >50% Survival: 2-11 (35.6-51.8) >50% Survival: 1.4-12.2 (34.5-54) >50% Survival: <13.3 (56) Max short-term temp: 13 (55)	Bell, 1986 Murray and McPhail, 1988 Murray et al., 1990 Spence, 1996 Brungs and Jones, 1977	Prefer: 10 (50) Max short-term temp.: 13 (55) [d]	Bell, 1986 Brungs and Jones, 1977
Rearing	12.2-13.9 (54-57) MWAT for growth[c]: 18 (64) [a] 17.7-18.3 (63.8-65) [b] 16.8-17.4 (62.2-63.2) [b] Max short-term temp, (50% survival) 23.7 (74.7)	Brett, 1952 Brungs and Jones, 1977 Brungs and Jones, 1977 NMFS, 1997 Brungs and Jones, 1977	MWAT for growth[c]: 19 (66) [d] Max short-term temp, (50% survival) 23.9 (75) [d]	Brungs and Jones, 1977 Brungs and Jones, 1977

a: cited in reference
b: calculated from upper lethal & optimum temperatures from references as noted above
c: MWAT for growth = OT + (UUILT-OT)/3
d: values are for rainbow trout

MWAT=Maximum Weekly Average Temperature
OT=Optimum Temperature
UUILT=Ultimate Upper Incipient Lethal Temperature

It is useful to have measures of chronic and acute temperature exposures for assessing stream temperature data. An EPA document, *Temperature Criteria for Freshwater Fish: Protocol and Procedures* (Brungs and Jones 1977) discusses development of criteria for assessing temperature tolerances of fish for several different life stages. Two measures of exposure are developed and applied: maximum weekly average temperature (MWAT) as a measure of chronic exposure and short-term maximum temperature as a measure of potentially lethal effects.

- **Maximum Weekly Average Temperatures** – The Maximum Weekly Average Temperature (MWAT) is the maximum value of the mathematical mean of multiple, equally spaced, daily temperatures over a 7-day consecutive period (Brungs and Jones 1977). In different words, this is the highest value of the 7-day moving average of temperature. Brungs and Jones develop MWATs for the growth phase of fish life, as growth appears to be the life stage most sensitive to modified temperatures and it integrates many physiological functions. They also develop MWATs for spawning. Brungs and Jones calculate MWAT for growth using the following equation:

  $$\text{MWAT for growth} = \text{OT} + (\text{UUILT} - \text{OT})/3$$

  This equation uses the physiological optimum temperature (OT) and the ultimate upper incipient lethal temperature (UUILT). The latter temperature is the "breaking point" between the highest temperature to which a fish can be acclimated and the lowest of the extreme upper temperatures that will kill the warm-acclimated fish.

  Brungs and Jones (1977) and EPA (1986) calculate a growth MWAT of 17.8°C (64°F) for juvenile coho salmon. This value will vary depending on the optimum and ultimate upper incipient lethal temperatures used in the calculation. An MWAT for steelhead is not reported, although there is an MWAT of 18.9°C (66°F) for rainbow trout.

- **Short-Term Maximum Temperatures** - Fish can withstand short-term exposure to temperatures higher than those required day in and day out without significant adverse effects. The short-term maximum temperature is intended as a measure for such conditions and is calculated using the following formula:

  $$\text{Temperature } (^{\circ}\text{C}) = \frac{(\log \text{time (minutes)} - a)}{b}$$

  For a daily maximum the equation would use 1440 minutes (24 hours). The constants "a" and "b" are intercept and slope, respectively, derived from each acclimation temperature for each species. The results of this calculation are the temperature at which there is 50% survival of the test population. A "safety factor" of 2 °C is subtracted to calculate the temperature at which 100% of a population is expected to survive.

  For juvenile coho salmon, when the acclimation temperature is 20 °C, $a = 20.4022$ and $b = -0.6713$, and the temperature at which there is 50% survival of a population is 23.7 °C (74.7 °F). With a 2°C adjustment, all fish in the test population would be expected to survive at a temperature of 21.7°C (71.1°C). Brungs and Jones (1977) do not calculate a short-term maximum temperature for steelhead, although there is a reported short-term maximum temperature value of 23.9°C (75 °F) for rainbow trout. Using the same 2°C adjustment yields a temperature of 21.9°C (71.4°F) for 100% survival.

The following paragraphs assess temperature requirements for various salmonid life stages.

Adult Migration

Salmon and trout respond to temperatures during their upstream migration (Bjornn and Reiser, 1991). Delays in migration have been observed for temperatures that were either too cold or too warm. Most salmonids have evolved with the temperature regime they historically used for migration and spawning, and deviations from the normal pattern can affect survival (Spence 1996).

Upstream migration of adult salmonids in the Navarro River occurs during a stream temperature transition period. Migration does not begin until the warmer summer period is waning, streamflows are increasing, and river temperatures are generally falling. Coho begin entering streams on the Mendocino Coast, including the Navarro River, in mid-October and may continue into February. Steelhead begin migrating in mid-November and continue through mid-March.

Bell (1986) notes migration temperatures ranging from 7.2-15.6°C (45-60°F) for coho. Several sources cite 21°C (70°F) as a temperature at which migration or movement is delayed or movement is limited for coho and steelhead (Table 4-2).

Spawning

Spawning occurs in the rainy season when flows have increased from winter rains and stream temperatures have decreased. Coho can begin spawning as soon as they reach natal spawning grounds, typically December through February. Steelhead spawning can begin in mid December and continue through mid May, with the peak in January through March. Spence et al. (1996) report that salmonid spawning has been observed at 1-20°C (33-57°F). Bell (1986) cites preferred spawning temperatures of 4.4-9.4°C (40-49°F) for coho and substantially similar values for steelhead (Table 4-2).

Incubation

It is critical that the embryos during incubation, and fry before emergence, have the proper environmental conditions, including temperature, as these life stages are essentially immobile. Water temperature during incubation affects the rate of embryo development, intragravel dissolved oxygen, and survival. In general, warmer water has been found to shorten the incubation period. Incubation temperatures can also affect the size of hatching alevins (Bjornn and Reiser 1991). Embryo incubation begins anytime after spawning has commenced. For coho, incubation peaks in December through March and can last through mid April. For steelhead, incubation peaks in January through March and can last until mid June. Bell (1986) cites a range of incubation temperatures for coho of 4.4-13.3°C (40-56°F). Others have found temperatures as low as 11°C (51.8°F) as lethal to coho during incubation (Table 4-2). There are not similar data for steelhead.

Freshwater Rearing

Temperature affects metabolism, behavior, and survival of both juvenile fish as well as other aquatic organisms that may be food sources. In streams of the Mendocino Coast, including the Navarro River, young coho and steelhead may rear in freshwater from one to four years before migrating to the ocean. Reported values of MWATs and short-term exposure maxima for juvenile rearing stages are presented in Table 4-2.

Freshwater Rearing – Coho Specific

Reported estimates of the MWAT for growth range from 16.8-18.3°C (62.2-65°F). Maximum short-term temperatures are reported by Brungs and Jones (1977) as 23.7°C (74.7°F). In an exhaustive study of both laboratory and field studies of temperature effects on salmonid and related species, McCullough (1999) concluded that upper short-term temperatures of approximately 22-24°C result in a limit to salmonid distribution, i.e., in total elimination of salmonids from a location. McCullough (1999) also notes that changes in competitive interactions between fish species can lead to a transition in dominance from salmonids to other species at temperatures 2-4°C lower than the range of total elimination.

Freshwater Rearing – Steelhead Specific

Brungs and Jones (1977) report a MWAT for growth of 19°C (66°F), and a short-term maximum temperature of 23.9°C (75°F). The conclusions in McCullough (1999) would also apply to steelhead, with respect to limitations on distributions in the field. There also is a report in the literature that addresses temperature as it relates to juvenile salmonid occurrence and behavior in the Navarro and similar streams. Nielsen et al. (1994) studied thermally stratified pools and their use by steelhead in three North Coast rivers including Rancheria Creek. In detailed observations of steelhead behavior in pools near thermally-stratified pools, they noted behavioral changes including decreased foraging and increased aggressive behavior as pool temperature reached approximately 22°C. As pool temperature increased above 22°C (71.6°F), fish left the observation pools and moved into stratified pools where temperatures were lower. These observations would seem to be generally consistent with the results reported in McCullough (1999).

4.2.2 Sediment & Related Salmonid Requirements

Substrate

The redd construction process reduces the amount of fine sediments and organic matter in the pockets where eggs are deposited (as cited in Meehan 1991: McNeil and Ahnell 1964; Ringler

1970; Everest et al. 1987). If fine sediments are being transported in a stream either as bedload or in suspension, some of them are likely to be deposited in the redd. Tappel and Bjornn (1983, as cited in Meehan 1991) relate percent embryo survival to percentage of fines <6.35 mm in diameter (Table 4-3). Chinook salmon survival decreases to 75% when the percentage of fines <6.35 mm reaches about 35%. It decreases to 50% when the percentage of fines <6.35 mm reaches about 40%. Steelhead trout survival decreases to 75% when the percentage of fines <6.35 mm reaches about 30%. It decreases to 50% when the percentage of fines <6.35 mm reaches about 40%. No relationship was reported for coho salmon.

Table 4-3
Relationship of Percent Fines to Embryo Survival

Species	% Fines < 6.35mm	% Embryo Survival
Chinook	35%	75%
	40%	50%
Steelhead	30%	75%
	40%	50%

Newly emerged fry can occupy the voids of substrate made up of 2-5 cm diameter rocks, but larger fish need cobble and boulder-size (>7.5 cm diameter) substrates in order to occupy the voids. The summer or winter carrying capacity of the stream for fish declines when fine sediments fill the interstitial spaces of the substrate. In a laboratory stream experiment, Crouse et al. (1981) found that production (tissue elaboration) of juvenile coho salmon was related to the amount of fine sediments in the substrate. Density of juvenile steelhead and chinook salmon in summer and winter were found to be reduced by more than half when enough sand was added to fully embed the large cobble substrate (Bjornn et al. 1977, as cited in Meehan 1991). The addition of fine sediments to stream substrates as a result of watershed disturbances and erosion may reduce the abundance of invertebrates, as well.

Turbidity

Migrating salmonids avoid waters with high silt loads, or cease migration when such loads are unavoidable (Cordone and Kelley 1961). Bell (1986) cited a study in which salmonids did not move in streams where the suspended sediment concentration exceeded 4,000 mg/L (as a result of a landslide). High turbidity in rivers may delay migration, but turbidity alone generally does not seem to affect the homing of salmonids very much.

Larger juvenile and adult salmon and trout appear to be little affected by ephemerally high concentrations of suspended sediments that occur during most storms and episodes of snowmelt (Cordone and Kelley 1961; as cited in Meehan 1991: Sorenson et al. 1977). Bisson and Bilby (1982) reported, however, that juvenile coho salmon avoided water with turbidities that exceeded 70 NTU (nephelometric turbidity units), which may occur in certain types of watersheds and with severe erosion. (Berg and Northcote 1985, as cited in Meehan 1991) reported that feeding and territorial behavior of juvenile coho salmon were disrupted by short-term exposures (2.5-4.5 days) to turbid water with up to 60 NTU. Turbidities in the 25-50 NTU range reduced growth and caused more newly emerged salmonids to emigrate from laboratory streams than did clear water (Sigler et al. 1984).

Percent Fines <0.85 mm

As the percentage of fines increases as a proportion of the total bulk core sample, the survival to emergence decreases. Fines that impact embryo development are generally defined as particles that pass through a 0.85-mm sieve. The 0.85mm cut off is an arbitrarily established value based on the available sieve sizes at the time of the initial studies in this area.

Identifying a specific percentage of fines that can comprise the bulk core sample and still ensure adequate embryo survival is not clearly established in the literature. For example, Cederholm et al. (1981) found that coho salmon survival in a Washington stream was 30% at about 10% fines <0.85 mm in trough mixes and at 15% fines in natural redds. Koski (1966, as cited in Meehan, 1991), on the other hand, found that coho survival was about 45% on an Oregon stream when fines <0.85 mm were measured at 20%. This differs yet again from Tappel and Bjornn's (1983 as cited in Meehan 1991) work in Idaho and Washington which found that survival at 10% fines smaller than 0.85 mm varied from 20% to 80% as the amount of fines 9.5 mm or less varied from 60% to 25%. For example, Tappel and Bjornn (1983 as cited in Meehan 1991) predicted that a 70% steelhead embryo survival rate required no more than 11% fines < 0.85 mm and 23% fines < 9.50 mm. McNeil and Ahnell (1964) in their early work in Alaska found no more than 12% fines <0.85 mm in moderately to highly productive pink salmon streams.

In a broad survey of literature reporting percent fines in unmanaged streams (streams without a history of land management activities), Peterson et al. (1992, as cited in Meehan 1991) found fines <0.85 mm ranging from 4% in the Queen Charlotte Islands to 28% on the Oregon Coast, with a median value for all the data of about 11%. Peterson et al. (1992, as cited in Meehan 1991) recommended the use of 11% fines < 0.85 mm as a target for Washington streams because the study sites in unmanaged streams in Washington congregated around that figure. None of the data summarized by Peterson et al. (1992, as cited in Meehan 1991) were from California.

Burns (1970) conducted three years of study in Northern California streams, including three streams he classified as unmanaged: Godwood and South Fork Yager creeks in Humboldt County and North Fork Caspar Creek in Mendocino County. He found a range of values for fines < 0.8 mm in each of these streams: 17-18% in Godwood Creek, 16-22% in South Fork Yager Creek, and 18-23% in Caspar Creek. Data collection for this study began a few years following big storms in 1964 that many conclude caused extensive hillside erosion and instream aggradation, the results of which we still observe today.

4.2.3 Other Salmonid Habitat Requirements

Cover

Some of the features that may provide cover and increase the carrying capacity of streams for fish are water depth, water turbulence, large-particle substrates, overhanging or undercut banks, overhanging riparian vegetation, woody debris (brush, logs), and aquatic vegetation. Coho salmon production declined when woody debris was removed from second-order streams in southeast Alaska (as cited in Meehan 1991: Dollof 1983). More large woody debris and juvenile coho salmon were found in streams surrounded by mature, mixed-conifer forest than in streams lined by red alder that had grown in a 20-year-old clear-cut (as cited in Meehan 1991: House and Boehne 1986). When wood debris was removed from a stream, the surface area, number and size of pools decreased, water velocity increased, and the biomass of Dolly Varden decreased (Elliott 1986 as cited in RAC 1999). Dolly Varden is a species of char with similar life cycle requirements to salmonids. In another stream, young steelhead were more abundant in clear-cut than in wooded areas in summer but moved to areas with pools and forest canopy in winter (as cited in Meehan 1991: Johnson et al. 1986). In addition, some anadromous fish—chinook salmon and steelhead trout, for example—enter freshwater streams and arrive at the spawning grounds weeks or even months before they spawn. Nearness of cover to spawning areas may be a factor in the selection of spawning sites by some species.

Streamflow

Bell (1986) reports the following minimum depths (m) and maximum velocities (m/s) for successful upstream migration: fall chinook salmon (0.24 m, 2.44 m/s); coho salmon (0.18 m, 2.44 m/s); and steelhead trout (0.18 m, 2.44 m/s). Streamflow also regulates the amount of spawning area available in any stream by regulating the area covered by water and the velocities and depths of water over the gravel beds.

Smoker (1955, as cited in Meehan 1991) found a correlation between the commercial catch of coho salmon and annual runoff, summer flow, and lowest monthly flow in twenty one western Washington drainages. In the last two decades, hatchery production of coho salmon smolts has increased markedly and made such comparisons more difficult. The implication of the available studies is that the abundance of adult coho salmon is a function of the number of smolts produced, which is in turn related to streamflow and the other factors that regulate the production of smolts.

Depth, velocity, and substrate requirements can be found for fall chinook salmon, coho salmon and steelhead trout in Table 4-4.

Given flow in a stream, velocity is probably the next most important factor in determining the amount of suitable space for rearing salmonids (as cited in Meehan 1991: Chapman 1966; deGraaf and Bain 1986). Newly emerged fry (20-35 mm long) of salmon, trout and char require velocities of less than 10 cm/s, based on studies of sites selected by the fish in streams (as cited in Meehan 1991: Chapman and Bjornn 1969; Everest and Chapman 1972; Griffith 1972; Hanson 1977; Smith and Li 1983; Konopacky 1984; Pratt 1984; Bugert 1985; Moyle and Baltz 1985; Sheppard and Johnson 1985). Larger fish (4-18 cm long) usually occupy sites with velocities up to about 40 cm/s.

Table 4-4
Streamflow Requirements

Species	*Depth (cm)*	*Velocity for Adult Salmonids (cm/s)*	*Substrate size (cm)*
Fall chinook salmon	≥24 (Thompson, 1972*)	30-91 (Thompson, 1972*)	1.3-10.2 (Bell 1986)
Coho salmon	≥18 (Thompson, 1972*)	30-91 (Thompson, 1972*)	1.3-10.2 (Bell 1986)
Steelhead	≥24 (Smith, 1973)	40-91 (Smith, 1973)	0.6-10.2 (Estimated)
	≥18 (Bell, 1986)		

* Thompson, 1972 was cited in Meehan, 1991.

Young trout and salmon have been seen in water barely deep enough to cover them and in water more than a meter deep. Densities (fish/m^2) of some salmonids are often higher in pools than in other habitat types; but, that may reflect the space available rather than a preference for deep water, especially for smaller fish (<15 cm long). Everest and Chapman (1972, as cited in Meehan 1991) found significant correlation between size of fish and total water depth at sites occupied by juvenile chinook salmon and steelhead. Most fish, regardless of size were near the bottom.

Streamflows and velocities are at their highest in coastal streams in northern California during winter months due to rainfall. As a result, overwintering salmonids must find shelter out of high winter stream velocities. For example, Mundie and Traber (1983, as cited in Meehan 1991) found higher densities of steelhead (0.66 smolts/m^2 and 9.94 g/m^2) and coho salmon (0.85 smolts/m^2 and 12.8 g/m^2) in side-channel pools than are commonly found in the main channels of Pacific coastal streams. Peterson (1982a, 1982b, as cited in Meehan 1991) reported coho salmon moving into side-channel pools for the winter. Salmonids will even hide in the interstitial spaces in stream substrates, particularly in winter when voids are accessible (as cited in Meehan 1991: Chapman and Bjornn 1969; Bjornn and Morrill 1972; Gibson 1978; Rimmer et al. 1984; Hillman et al. 1987). The discussion of large woody debris as cover under summer freshwater rearing, above, is relevant here, as well.

Space

During the spawning stage of the salmonid life cycle, the number of redds that can be built in a stream depends on the amount of suitable spawning habitat and the area required per spawning pair of fish (as cited in Meehan 1991: Reiser and Ramey 1984, 1987; IEC Beak 1984; Reiser 1986). Many salmonids prefer to spawn in the transitional area between pools and riffles because of the downwelling there (as cited in Meehan 1991: Hazzard 1932; Hobbs 1937; Smith 1941; Briggs 1953; Stuart 1953). According to Burner (1951, as cited in Meehan 1991), the average area of a fall chinook salmon redd is 5.1m^2 while that of a coho salmon is 2.8m^2. The average area of a steelhead trout redd ranges from 4.4-5.4m^2, depending on the study (as cited in

Meehan 1991: Orcutt et al. 1968, Hunter 1973, Reiser and White 1981). Burner (1951, as cited in Meehan 1991) recommends 20.1m^2 and 11.7m^2 of spawning habitat per spawning pair of fall chinook salmon and coho salmon, respectively.

As the salmonid population matures, fish densities in streams provide a measure of the spatial requirements of juvenile salmonids, but the wide variation in observed densities illustrates the diversity of habitat quantity and quality and other factors that regulate fish abundance. Based on (Allen 1969, as cited in Meehan 1991), the summer space requirements of juvenile salmonids during their first year in streams probably range from 0.25m^2 to 10m^2 of stream per fish, depending on such things as the species and age composition of fish present, stream productivity, and quality of the space. (Bjornn et al. 1977, as cited in Meehan 1991) demonstrated that by reducing pool volume by half and surface area of water deeper than 0.3m by two-thirds, fish numbers declined by two-thirds.

Dissolved Oxygen

The minimum DO recommended for spawning fish is 5.0 mg/L with at least 80% saturation. Salmonids may be able to survive when DO concentrations are relatively low (<5 mg/L), but growth, food conversion efficiency, and swimming performance will be adversely affected. High water temperature, which reduces oxygen solubility, can compound the stress on fish caused by marginal DO concentrations.

Silver et al. (1963, as cited in Meehan 1991) reported that newly hatched steelhead and chinook salmon alevins were smaller and weaker when they had been incubated as embryos at low and intermediate DO concentrations than when they were incubated at higher concentrations. In field studies, survival of steelhead embryos (as cited in Meehan 1991: Coble 1961) and coho salmon embryos (as cited in Meehan 1991: Phillips and Campbell 1961) were positively correlated with intragravel DO in redds. Phillips and Campbell (1961, as cited in Meehan 1991) concluded that intragravel DO must average 8 mg/L for embryos and alevins to survive well.

Barriers

In general, the success of a leap will depend on factors specific to the barrier (e.g., jump pool characteristics and stream velocity) and factors specific to the fish (e.g., species, size and condition). Both Jones (1959) and Stuart (1962, as cited in Meehan 1991) observed salmon jumping over obstacles 2-3m in height. Powers and Orsborn (1985, as cited in Meehan 1991) reported that the abilities of salmon and trout to pass over barriers depended on the swimming velocity of the fish, the horizontal and vertical distances to be jumped, and the angle to the top of the barrier. Reiser and Peacock (1985, as cited in Meehan 1991) computed maximum jumping heights of salmonids on the basis of darting speeds: chinook salmon (2.4m), coho salmon (2.2m), and steelhead trout (3.4m). These values represent upper limits of potential, not preferred or even readily achievable heights.

Productivity of Streams & Food Sources

Streams vary in productivity due largely to the nutrients and energy available. If the findings for sockeye salmon (as cited in Meehan 1991: Brett et al. 1969) are similar for other salmonids, a yearling salmonid in a stream with daily mean temperature of 10°C would need a daily food supply equivalent to 6-7% of its body weight to attain maximum growth. Production of aquatic invertebrates that juvenile salmonids eat depends on the amount of organic material available in streams. Nearly 75% of the organic matter deposited in first-order streams is associated with debris dams, versus 58% in second-order stream and 20% in third-order streams (Bilby and Likens 1980).

4.3 Factors Affecting Temperature Conditions in Streams

It is highly likely that summertime water temperatures in the streams of the Navarro River watershed have been altered upward during the past fifty years. Land use activities, water withdrawals, changes in flow, dam construction and associated water releases, point source discharges, and natural factors have contributed to the change. This section discusses findings of many researchers on the effects of management activities on stream temperatures.

During summer, direct solar radiation is the primary source of heat energy input to streams (Brown 1970; Brown 1980; Beschta et al. 1987; Beschta 1997; Coutant 1999; ODEQ 1999; Sinokrot and Stefan 1993; Sullivan et al. 1990). Water temperatures in streams follow seasonal and diurnal (daily) cycles (Sinokrot and Stefan 1993) in concert with changes in incoming solar radiation. As observed in temperature data collected in the Navarro (discussed in Section 4.3), the highest stream temperatures occur in the summer months when solar insolation is highest. In addition, in northern California during the summer, the highest rates of solar insolation coincide with periods of low streamflow.

Shade, stream channel characteristics and channel morphology influence the amount of heat gained and lost by a stream (Beschta et al. 1987). Wide active channels providing little or no shade to a stream allow a greater proportion of the sun's radiant energy to reach the stream. For a given discharge, streams with wide, shallow summer low-flow channels receive more energy than narrow, deep channels. Similarly, for a given exposed stream surface area and energy input, a high-discharge stream would be expected to change temperature less than a low-discharge stream. In other words, temperature changes would be expected to change directly with energy input and exposed surface area, and inversely with discharge and depth (Brown 1970; Beschta et al. 1987).

Temperature patterns of exposed streams are notably different from those of shaded streams. For shaded channels, heat fluxes (movement of heat from areas of higher to lower temperature) are small. As a consequence, diurnal temperature fluctuations are also small. As an example, Figure 4-1 presents 1995 water temperatures for Bear Wallow Creek, a tributary of Rancheria Creek. If a wetted stream channel is exposed, solar radiation received by the stream and other secondary heat fluxes can be significant, leading to large heat gains and losses, large diurnal fluctuations,

Figure 4-1. 1995 Water Temperatures in Bear Wallow Creek Near Faulkner Park (MCWA-22)

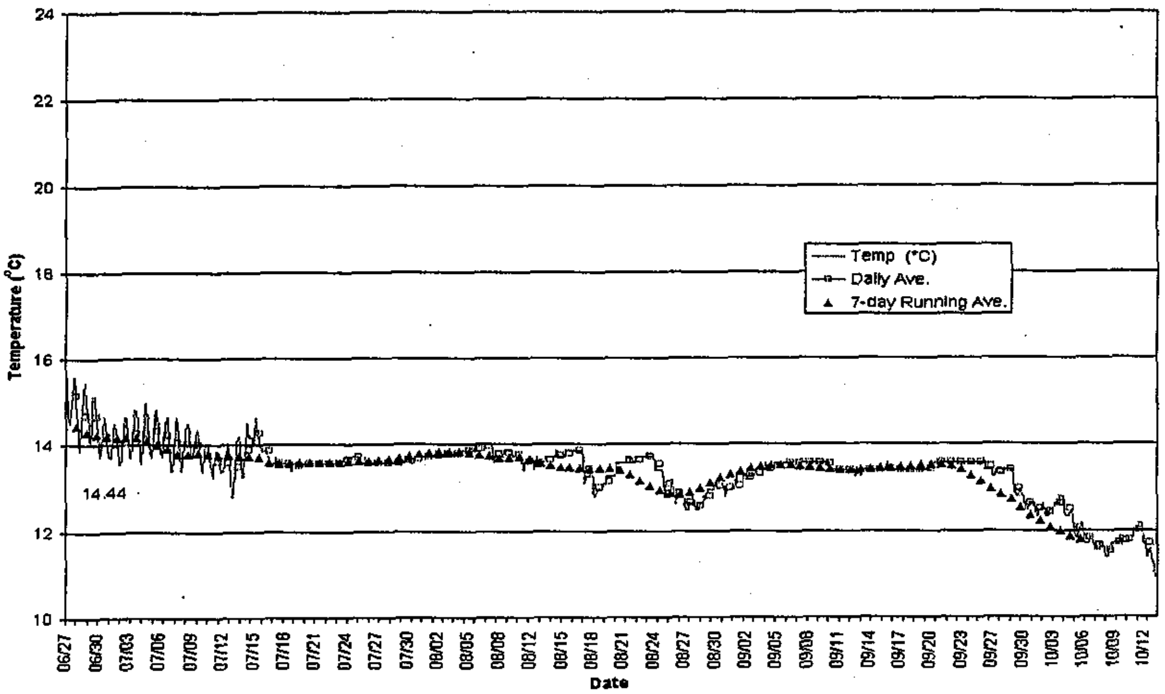
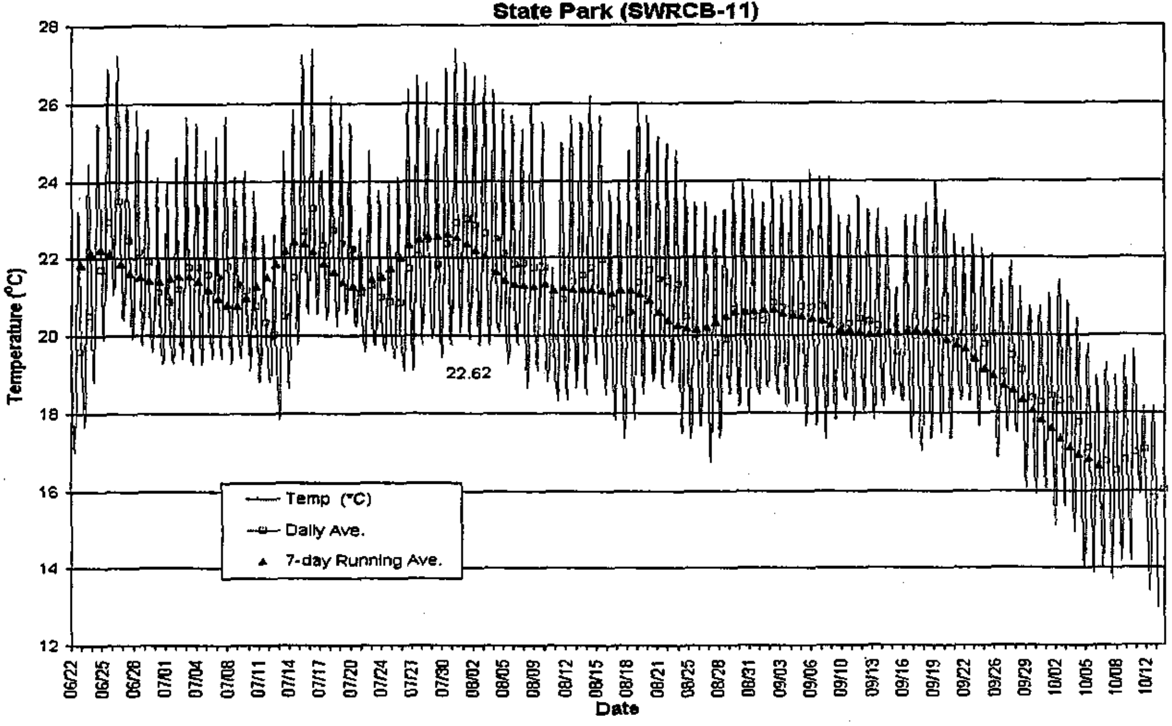


Figure 4-2. 1995 Water Temperatures in the Navarro River at Hendy Woods State Park (SWRCB-11)



and higher average temperatures. The Navarro River at Hendy Woods State Park is an extreme example of a stream exposed to near-maximum solar radiation inputs in the summer months (Figure 4-2). Stream temperatures show high average values and a large diurnal fluctuation.

A variety of activities and events, both human-induced and natural, can affect stream temperatures (Coutant 1999). Activities or events that result in changes in the height, density, or condition of streamside (riparian) vegetation can affect stream temperatures. Such activities or events could include fire, earth movement, logging, road-building, agricultural practices associated with vineyards, orchards and row crops, flood control work, grazing, homebuilding and urban development.

Activities that lead to reduced streamflow may also affect temperatures. Withdrawals and diversions of surface water and groundwater affect or can affect streamflows and may in turn affect temperatures by reducing the thermal mass available to absorb solar radiation.

Activities and events that lead to changes in channel morphology can also affect temperatures. These could include landslides, debris torrents and other mass wasting events, direct modification of channel form associated with road-building, flood control, gravel extraction, or channel realignment. It is also possible to have indirect effects on channel form. Activities or events that increase sediment load of a stream often lead to wider, shallower stream channels, decreased depth of pools, increased stream width:depth ratios, and increased heat gains and losses of streams. Landslides, for example, may actively contribute sediment to streams over periods of years and decades. These changes in turn make streams far more susceptible to deleterious changes in the stream's temperature regime.

Many studies have looked at the effects of logging on stream temperatures. Fewer studies have looked at the effects of other activities on stream temperature. Some studies that have looked at the interaction of management activities and stream temperature are summarized in the following paragraphs.

Beschta et al. (1987) summarize a number of studies of summer temperature changes associated with forest management activities in forested watersheds of the Pacific Northwest. Most of the studies looked at sites that had been clear-cut. Some sites were clear-cut and burned. For the studies cited, diurnal temperature ranges increased as much as 3.2°C (5.8°F) and summertime maxima increased from 2.8 to 10°C (5 to 18°F). They conclude that because solar radiation is the primary factor affecting summer stream temperatures, leaving buffer strips is an effective means of preventing temperature changes. They further conclude that leaving buffer strips with widths of 30m (100ft) or more generally provides a level of shading similar to that of an old-growth stand. Ledwith (1996) found changes in air temperature and realtive humidity up to the 150 meter buffer width used as the control in the study. He concluded that buffer widths greater than 150 meters may affect riparian microclimate.

Brown (1980) reports an extreme case of the increase in diurnal temperature range of 15°C (28°F) measured as part of the Alsea Watershed Study in Oregon's Coast Range. Hetrick et al. (1998), in a study of two coho streams in southeast Alaska, cleared streamside vegetation in portions of experimental reaches of similar character. They measured increases in daily average temperatures of as much as 2°C (4°F) and increases in daily maxima of as much as 4°C (7°F). Similar changes have been noted in eastern Washington (Coutant, 1999). Cafferata (1990), in a study conducted on North Fork Caspar Creek, observed maximum stream temperature increases of about 2.2°C (4°F) when comparing sites above and below recent clearcuts. He used Brown's equation (Brown 1970) to predict changes in stream temperature resulting from clearcuts. The equation requires input on flow, stream surface area, and the change in solar loading. Cafferata (1990) used a Solar Pathfinder to measure effective shade (and thus solar loading) above and below the clear-cut. He estimated a change in maximum stream temperature of 4.5°F (2.5°C), which compared favorably with an observed change of 4°F (2.2°C).

Impacts of livestock grazing on stream temperatures have also been studied. Li et al. (1994) studied cumulative effects of riparian disturbance by grazing on trout streams in the John Day Basin of eastern Oregon. They found that watersheds with greater riparian canopy had higher standing crops of rainbow trout (*Oncorhynchus mykiss*), lower daily maximum temperatures (range of 16-23°C compared to 26-31°C), and perennial flow. In another study of forested watersheds in eastern Oregon, Maloney et al. (1999) looked at differences in a variety of factors, including grazing strategy, to explain observed temperature conditions. In comparing ungrazed and intensively managed reaches, they found maximum hourly temperature differences of about 10°C (18°F) and mean weekly temperature differences of over 4°C (7°F).

In an extensive study conducted as part of Washington's 1988 Timber/Fish/Wildlife Agreement (TFW) Sullivan et al. (1990) reported data on a lengthy suite of geographic, climatic, stream channel, and shading parameters (Table 4-5). In all, ninety two sites reflecting coastal, montane, and interior areas of Washington were examined in the study. Among many interesting results, they found that 89% of sites classified on the basis of two site characteristics, shade and elevation, were correctly placed when compared to measured temperatures. The study included sites ranging in elevation from near sea level to about 1200m (3900 ft).

Table 4-5
Types of Variables Considered in Stream Heating Processes

General Variable	Specific Variable	Measure
Geography	Latitude, longitude, elevation	Solar azimuth, solar altitude, effective shade
Climate (including microclimate conditions)	Air temperature, relative humidity, wind velocity, cloud cover, ground temperature	Air temperature, relative humidity, wind velocity, possible sun, groundwater temperature
Stream Channel Characteristics	Stream depth, width, velocity, active channel width, aspect, substrate composition	Width:depth ratio, flow, effective shade
Riparian and Topographic Shading	Vegetation height, density, overhang, topographic shade	Effective shade

To summarize, the available studies that have focused on relations of particular land management activities to stream temperatures have reached similar general conclusions that changes in riparian shade conditions affect stream temperatures, and have further found that shade is a key variable in explaining observed variations in stream temperatures.

4.4 Summary of Temperature-Related Water Quality Impairments in the Navarro Watershed

The Navarro River watershed is listed under Section 303(d) of the Clean Water Act as impaired due to sedimentation and temperature. The following describes the existing in-stream watershed conditions and the beneficial use impairments of concern.

4.4.1 Solar Loadings and Temperature

Because 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 as more sunlight reaches streams and raises water temperatures. The pollutant (excessive solar heat energy) is a source of stream temperature increases and is targeted in this TMDL.

Available temperature data (discussed in Sections 4.4.3 through 4.4.8) indicate that at many locations in the Navarro River watershed, stream temperatures exceed salmonid growth and survival thresholds summarized in Table 4-2, indicating the potential for lethal and sub-lethal effects to salmonids in the watershed.

A 7-day running average of temperature data is used here as a primary statistical measure for interpretation of stream temperature conditions in the Navarro. The following ranges of values are used for comparison to 7-day moving average stream temperature values to characterize the temperature quality of surface waters in the Navarro River watershed:

Descriptor	Coho Salmon	Steelhead
Good	<15°C (<59°F)	<17°C (<63°F)
Marginal	15°-17°C (59°-63°)	17°-19°C (63°-66°F)
Poor/Unsuitable	>17°C (63°F)	>19°C (>66°F)

The Maximum Weekly Average Temperature (MWAT) is the maximum value of the 7-day moving average of temperatures during a season. The MWAT is used to characterize chronic conditions that could affect growth or survival of salmonids.

In addition, to assess acute conditions, season hours above temperature thresholds of 18, 20, 22, 23, 24, and 25°C are tabulated and discussed.

4.4.2 Temperature Data Sources

A variety of stream temperature data have been collected in the Navarro watershed:

- USGS has collected spot temperature data and some continuous temperature records at established stream gaging stations (Blodgett 1971). Observations in the Navarro watershed have been made since 1953 at the Navarro gaging station, on Rancheria Creek, and Soda Creek. Continuous data were collected in 1966, 1967, and 1968 at the Navarro gage.
- As part of stream survey work conducted mostly in the 1960s, California Department of Fish and Game (CDFG) collected spot measurements of stream temperatures.
- Since 1989, Louisiana-Pacific (LP, now Mendocino Redwoods Co.) has collected continuous temperature data during the summer of at least one year at fourteen stations.
- Starting in 1995, Mendocino County Water Agency (MCWA) has deployed thermal monitoring equipment at locations in the watershed. They have collected continuous temperature data during the summer months from 1995 to 1999 at over fifty locations.
- In cooperation with the University of California Cooperative Extension Service, landowners in the Navarro have been collecting continuous temperature data during the summer months in recent years at a number of locations in the watershed.

Continuous thermal monitoring records were used in this analysis, since they are the only records suitable for analysis of daily thermal fluctuations, trends over time, running averages, and extreme conditions. The thermal monitoring records collected by MCWA and LP were publicly available or made available to Regional Water Board staff, and formed the basis for this analysis. The Navarro Watershed Restoration Plan (1998) presented much of the MCWA temperature data collected in 1995, 1996, and 1997. This report summarizes those data and adds data collected by MCWA in 1998 and 1999 and by LP in 1989 through 1996. Plots of the temperature records used in this analysis are included as Appendix A. The plots show temperature fluctuations during each day of the summer season, daily averages, and 7-day running averages.

Figure 4-3 shows the locations where continuous thermal monitoring data have been collected in the Navarro watershed by MCWA and LP. Table 4-6 summarizes State Water Resources Control Board (SWRCB), MCWA and LP monitoring site information. This table includes sixteen stations initially established by the SWRCB at which MCWA has monitored temperature. The SWRCB in 1995 and MCWA in years since 1995 have also monitored flow at all or some of these stations (Table 4-6). Tables 4-7 and 4-8 summarize temperature information from data collected at SWRCB, MCWA, and LP locations. Figure 4-4 shows the distribution of MWAT values using the temperature categories presented in Section 4.4.1. Figure 4-5 shows the distribution of the dates when the MWAT has occurred for each year of data collected at each site in the watershed. For this figure, when a temperature record showed multiple distinct peaks that differed from one another by less than 0.3°C, each of the values was used.

Regional Water Board staff were provided with the original data at more than fifty MCWA and six LP sites (the latter identified by MCWA as LP-60 through LP-65). For other LP sites, summary results developed from monitoring data were available. As a result, the characterization of the data differs slightly for the two sources. For example, the LP data sets present daily averages and maxima, but do not present 7-day running average values. Thus, daily averages are compared to the

MWAT ranges presented above, and daily maxima are totaled for comparison to acute temperature thresholds. Because of these differences, results from the two data sources are discussed separately.

At many sites, temperature data were collected in more than one year. At some sites, data have been collected in as many as five years. Review of the data from these sites indicates that MWAT values show little variation from year to year. Sites 16 and 116 show the maximum range in MWAT values of 1.55 and 1.59°C, respectively. Hourly data are more variable, although general trends are still evident. Variations in MWAT values from year to year could be reflective of changes in meteorological conditions, flow conditions, pool depth, or other environmental factors. Changes could also be the result of changes in the placement of the instrument. Regardless, since the variations are relatively small among years, for sites with multiple years of data, the data from the site are considered together.

The MCWA temperature monitors generally were placed in the bottoms of pools, and thus tend to reflect conditions favorable to salmonids in the reaches monitored.

Insert
Figure 4-3
Locations of Monitoring Sites in the Navarro Watershed

(Front)

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Figure 4-3

(back)

Table 4-6
Summary Information on Navarro Watershed Monitoring Stations

gency	Site No.	Description	MWAT Range (°C)	Lat N	Long W	Elevation (ft)	Types of Data Collected
WRCB	1	Beebe Creek @ Hwy. 128		385451	1231519	840	Flows 1995
WRCB	2	Rancheria Creek @ Fish Rock Rd. & Hwy. 128, mm 36.56	20.21-20.28	385514	1231734	760	Flows, WQ, Hobo 1995-96, ref. mark, vol. monitoring
WRCB	3	Anderson Creek @ Hwy. 253, mm 0.53	23.32-23.42	390001	1232050	480	Flows, WQ, Hobo 1995-96, staff gage, ref. mark, vol. monitor
WRCB	4	Soda Creek @ Hwy. 253, mm 3.2	20.25-21.39	390103	1231910	1320	Flows, WQ, Hobo 1995, 1996, staff gage
WRCB	5	Robinson Creek @ Mountain View Rd. Bridge near Anderson Valley H.S.	19.49-19.97	390044	1232218	350	Flows, WQ, Nobo 1995-96, staff gage, vol. minitoring
WRCB	6	Con Creek @ Anderson Valley Way & Hwy. 128	19.30-20.77	390151	1232312	299	Flows, WQ, Hobo 1995, 1996, staff gage
WRCB	7	Anderson Creek @ Connie Best's property on Anderson Valley Way	20.81-22.11	390211	1232356	255	Flows, WQ, Hobo 1995-97 air temp hobo 1997, vol monitoring
WRCB	8	Rancheria Creek above confl. with Anderson Creek	23.20-23.28	390309	1232629	186	Stage rec. 1995-98, flows, WQ, Hobo 95-98, ref., vol. monitor
WRCB	9	Anderson Creek above confl. with Rancheria Creek	20.84-21.38	390312	1232621	180	Stage rec. 1995-98, flows, WQ, Hobo 95-98, ref., vol. monitor
WRCB	10	Indian Creek @ Hwy. 128, mm 23.48 near Philo	18.53-20.11	390340	1232607	179	Stage rec. 1995, flows, WQ, Hobo 1995-96
WRCB	11	Navarro River @ Hendy Woods State Park Day Use Area	22.10-22.62	390429	1232749	130	Flows, WQ, Hobos 1995-1999, staff gage, ref. gage 1995
WRCB	12	Navarro River on Husch Vineyards property	21.80-22.15	390600	1233006	100	Stage recorder 1995, 1996; flows, WQ staff gage, ref. on rock
WRCB	13	Mill Creek @ Hwy. 128, mm 17.88	17.40-17.58	390647	1233027	180	Flows, WQ, Hobo 1995, 1996, staff gage
JCD-SWRCB	14	North Fork Navarro River @ Hwy. 128 bridge, mm 12.72 (Priority1)	18.09-19.63	390937	1233358	80	Flows, WQ, staff gage
JCD-SWRCB	15	Flynn Creek @ Hwy. 128 bridge, mm.11.63 (Priority 9)	16.32-16.96	390939	1233456	60	Flows, WQ, Hobo 1995, 1996, staff gage
WRCB	16	North Fork Navarro @ Paul Dimmick State Park, Hwy. 128 mm 8.28	17.14-18.68	390925	1233809	30	Stage recorder 1995-1998, flows, WQ, Hobos 1995-1997, 1999
WRCB	17	Indian Creek above confl. with Navarro River @ Shenoa		390328	1232629	180	Stage recorder 1996-1998, flows, WQ
ICWA	18	Beartrap Creek below confl. w/ Rancheria Cr. D/S of Mountian View Rd Bridge		385958	1232650	400	WQ
ICWA	19	Rancheria Creek below confl. with Beartrap Creek		385959	1232650	400	WQ
ICWA	20	Rancheria Creek @ Foppiano Railroad Car Bridge	23.45-24.24	385141	1231426	968	Hobo 1995, 1996, staff gage
ICWA	21	Camp Creek above confl. with German Cr. on Larry Mailliard's property	18.88	385601	1232233		Hobo 1995, staff gage. This site was washed out in 01/1996
ICWA	22	Bear Wallow Creek @ Mountain View Rd., mm 22.33 near Faulkner Park	14.44	390024	1232436	100	Hobo 1995
ICWA	23	Rancheria Creek @ Mountain View Rd. Bridge, SW of Boonville	23.98-24.44	385939	1232602		Hobo 1995, 1996
ICWA	24	Con Creek on Connie Best's property	19.23	390241	1232100	960	Hobo 1995, 1996
ICWA	25	Anderson Creek @ Hwy. 128 in Boonville (above confl. w/ Robinson Cr.)	22.44-23.07	390051	1232218	330	Hobo 1995, 1996, vol. monitoring
ICWA	26	Anderson Creek on Steve Hall's property	23.41	390110	1232252	310	Hobo 1995, staff gage, vol monitoring
ICWA	27	Indian Creek above confl. with North Fork Indian Creek on Helen Libeu's property	22.69-23.50	390439	1232226		Hobos 1995, 1996
ICWA	28	North Fork Indian Creek above confl. with Indian Creek on Helen Libeu's property	20.62-21.11	390442	1232229		Hobo 1995, 1996
ICWA	29	Indian Creek @ redwood grove on Helen Libeu's property	22.10	390435	1232307		Hobo 1995
ICWA	30	Indian Creek above confl. with Parkinson Gulch on Karen Calvert's proptery	21.15-22.36	390514	1232435	435	Hobos 1995, 1996, 1997, 1998, 1999

ncy	Site No.	Description	MWAT Range (°C)	Lat N	Long W	Elevation (ft)	Types of Data Collected
WA	31	Parkinson Gulch above confl. with Indian Creek on Karen Calvert's property	16.64-17.18	390509	1232436	440	Hobos 1995-1998
WA	32	Indian Creek about 1/3 mile north of Hwy. 128	20.34-20.41	390353	1232600		Hobo 1995, 1996
WA	33	Navarro River below confl. with Anderson & Rancheria creeks at Shenoa		390317	1232624		Occasional WQ monitoring
WA	34	Anderson Creek below confl. with Robinson Cr. @ Anderson Valley H.S.		390051	1232222	345	This site was renamed SWRCB-17.
WA	35	Navarro R. 200' below confl. w/ Indian Cr. @ summer ford railcar bdge @ Shenoa		390330	1232632	180	Volunteer monitoring
WA	36	Navarro River @ Philo-Greenwood Ridge Road Bridge		390506	1232901		Staff gage 1995
WA	37	Lazy Creek @ Hwy. 123 mm 18.69	16.31-17.28	390619	1232946		Hobo 1995, 1996
WA	38	Lazy Creek above confl. with Navarro River on Husch Vineyards property	16.61	390602	1232958		Hobo 1995
WA	39	Mill Creek above confl. with Navarro River on Husch Vineyards property	17.64	390603	1233005		Hobo 1995
WA	40	Navarro River below confl. with Mill Creek on Husch Vineyards property		390603	1233011		Hobo 1995, 1996
WA	41	North Fork Navarro River @ Mendocino Redwoods (LP) Demo. Forest		390942	1233356		Hobo 1995, 1996
WA	42	Navarro River U/S of USGS gauging station, Hwy. 128 mm 5.1	20.92	391016	1233953	135	Hobo 1995, 1996
WA	43	Navarro River Estuary under Hwy. 1 Bridge	20.81-24.11	391150	1234446	10	Hobos 1995-1999
WA	44	Navarro River Estuary near mouth, RB	16.32	391146	1234522	39	Hobo 1995-1997
WA	45	Navarro River Estuary near mouth, in deep water		391140	1234529		Hobo 1995
WA	46	Navarro River on Dan Myer's property, "Cheesecake"		390533	1232924	115	Staff gage, vol. monitoring
WA	47	Bear Wallow Creek above confl. with Rancheria Creek	19.12	385942	1232603		Hobo 1996
WA	48	Rancheria Creek @ Redwood House, Hwy. 128 mm 35.87		385535	1231757		Staff Gage
WA	49	Bacon Creek above confl. with Camp Creek on Larry Mailliard's property	20.12	385604	1232207		Hobo 1996
WA	50	Indian Creek @ Sweetwater Ranch	21.13-20.65	390433	1232532	220	Hobo 1997, 1998, 1999, vol. monitoring
WA	51	Dago Creek about 100' to 750' above confl. with Rancheria Creek	16.42-18.18	390242	1232852	340	Hobo 1996, 1997, 1998, 1999, vol. monitoring
WA	52	Mill Creek about 200' D/S of Nash Mill Rd. bridge @ Ashton property	17.83	390735	1232824	360	Hobo 1997, vol. mointoring
WA	53	Indian Creek above confl. with Navarro River @ Shenoa		390328	1232629	180	Volunteer monitoring
WA	54	Navarro R. 230 yds U/S of confl. w/ Indian Cr. & Suspension Bridge @ Shenoa		390321	1232623	180	Volunteer monitoring
WA	55	Con Creek above confl. w/ Anderson Cr. @ Anderson Valley Elementary School		390147	1232321	280	Volunteer monitoring
WA	56	Indian Creek 50 yards U/S of Hwy. 128 bridge		390344	1232600	190	Volunteer monitoring
WA	57	Robinson Creek 150 ' U/S of Hwy. 128 bridge near Forest Fire Station		385904	1232057	485	Volunteer monitoring
WA	58	Flynn Creek 150 yards U/S of Hwy. 128 bridge		390947	1233455	60	Volunteer monitoring
WA	59	Camp Creek below confl. with Bacon Creek on Larry Mailliard's property	16.33	385600	1232211	880	Hobo 1997, vol. monitoring
	60	South Branch of upper North Fork Navarro River on LP property	20.32	390918	1232812		Hobo 1995

Agency	Site No.	Description	MWAT Range (°C)	Lat N	Long W	Elevation (ft)	Types of Data Collected
LP	61	South Branch of lower North Fork Navarro River on LP property	19.50	391015	1233327		Hobo 1995
LP	62	North Fork of upper Indian Creek on LP property	20.30	390648	1232233		Hobo 1995
LP	63	North Fork of lower Indian Creek on LP property	20.26	390602	1232246		Hobo 1995
LP	64	North Branch of upper North Fork Navarro River on LP property	18.54	391225	1233204		Hobo 1995
LP	65	North Branch of lower North Fork Navarro River on LP property	19.43	391019	1233334		Hobo 1995
MCWA	66	Anderson Creek behind Anderson Valley Elementary School		390144	1232328	340	Volunteer monitoring
MCWA	67	Rancheria Creek above confl. with Anderson Creek, D/S of SWRCB-8 @ Shenoa		390312	1232625	182	Volunteer monitoring
MCWA	68	Upper Flynn Creek below confl. with Tank 4 Gulch	13.40-14.33	391200	1233619	230	Hobo 1996, 1998, 1999
MCWA	69	Shingle Mill Creek above confl. with North Fork Navarro River	15.08	390936	1232531	560	Hobo 1997
MCWA	80	Navarro River @ Gowan's property		390452	1232822	160	Volunteer monitoring
MCWA	81	Cold Springs Creek above confl. with Rancheria Creek	17.77-18.06	390154	1232912	380	Hobo 1997, 1998, 1999
MCWA	82	John Smith Creek below Gulch 15, trib. to Little North Fork Navarro River	14.24-15.34	391323	1233151	385	Hobo 1997, 1998, 1999
MCWA	83	Mill Cr. @ Chris Bing's property, 200 yds d/s of Myers G. or 0.8 mi. from Hy. 128		390956	1233021	230	Volunteer monitoring
MCWA	104	North Fork Navarro R. @ Hwy. 128 & Flynn Cr. Rd., above confl. w/ Flynn Creek		390939	1233452	60	WQ 1998
MCWA	105	South Fork Dago Creek above confl. with Dago Cr.		390249	1232254	360	WQ, vol. monitoring
MCWA	106	Dago Creek below confl. with North Fork Dago Creek		390250	1232856	360	WQ, vol. monitoring
MCWA	107	Rancheria Creek below confl. with Dago Creek		390235	1232845	320	WQ, vol. monitoring
MCWA	115	Meyer Gulch, 150 yards U/S of Holmes Ranch Road, trib to Mill Cr.	16.04	390734	1233026	225	Hobo 1998
MCWA	116	Hungry Hollow Creek, tributary to Mill Creek, 100' U/S of Mill Creek	14.39-15.98	390738	1232655	540	Hobo 1998
MCWA	117	South Fork Dago Creek, about 40' U/S of confl. with Dago Creek	16.72-17.31	390246	1232856	350	Hobo 1998, 1999
MCWA	121	Dutch Henry Creek about 200' above Hollow Tree Rd.		391145	1233328	270	Hobo 1998: see site # 153 for hobo in 1999
MCWA	122	Mill Creek 50' D/S of Hungry Hollow Rd. crossing	16.54-16.58	390719	1232731	460	Hobo 1998
MCWA	140	Horse Creek above confl. with Rancheria Creek, below Mtn.View Rd. Bridge	20.31	390037	1232730	395	WQ, hobo 1999
MCWA	141	Rancheria Creek below confl. with Horse Creek, below Mountain View Rd Bridge		390038	1232731	390	WQ
MCWA	142	Unnamed Tributary to Rancheria Cr. on LB (w. side) of Rancheria, below Horse Cr.		390021	1232729	360	WQ
MCWA	143	Rancheria Cr. below confl. with Unnamed Tributary on LB (west side) of Rancheria		390105	1232751	360	WQ
MCWA	144	Rancheria Creek below confl. with Cold Springs Creek		390156	1232902	340	WQ
MCWA	145	Ham Canyon Creek below confl. with Rancheria Creek		390213	1232629	240	WQ
MCWA	149	Maple Creek @ Hwy. 128 mm 36.01, above confl. with Rancheria Creek		385534	1231759	760	WQ
MCWA	150	Shearing Creek @ Hwy. 128 mm 34.4, above confl. with Rancheria Creek		385633	1231922	680	WQ

ncy	Site No.	Description	MWAT Range (°C)	Lat N	Long W	Eleva-tion (ft)	Types of Data Collected
:WA	151	Ornbaun Creek @ Hwy. 128 mm 33.8, above confl. with Rancheria Creek		385652	1231959	670	WQ
:WA	152	Rancheria Creek above confl. with Ornbaun Creek		385650	1231959	672	WQ
:WA	153	Dutch Henry Creek above Hollow Tree Road, about 1000'	14.84	391149	1233334	280	Hobo 1999
:WA	157	West Branch Indian Creek 175' above confl. with Indian Creek	17.91	390526	1232515	390	Hobo 1999
D	162	Road Cut @ Hwy. 128 mm 11.54 (Priority 4)					
D	163	Coon Creek @ Hwy. 128 mm 10.18 (Priority 3)					
D	164	Lost Gulch @ Hwy. 128 mm 9.94 (Priority 2)					
D	165	Dead Horse Gulch @ Hwy. 128 mm 9.49 (Priority 8)					
D	166	Road Cut @ Hwy. 128 mm 8.95 (Priority 5)					
D	167	Buried Log Gulch @ Hwy. 128 mm 8.68 (Priority 7)					
D	168	North Fork Navarro R. @ Dimmick State Park Campground (Priority 6)					
:WA	169	Little Mill Cr., tributary to Mill Creek: access from Nashmill Road		390751	1232905	360	Hobo 1999
:WA	172	Navarro River @ USGS gauge cableway		391020	1234006	115	turbidity
:WA	179	Robinson Creek @ Anderson Valley H.S. (above confl. w/ Anderson Cr.)		390049	1232222	347	WQ

Table 4-7
Summary of Results of Thermal Monitoring Performed by Mendocino County Water Agency, 1995-1999

			MWAT		Min. Temp		Max. Temp		Temp Range for MWAT Week		Season Hours Above °C (in hours)				
Site No.	Year	Week of	°C	°F	°C	°F	°C	°F	°C	°F	20°C	22°C	23°C	24°C	25°C
2	1995	6/24/1995	20.21	68.38	17.19	62.94	24.09	75.36	6.90	12.42	126	39	21	1.5	0
2	1996	7/6/1996	20.28	68.50	17.67	63.81	23.07	73.53	5.40	9.72	312	73.5	12	0	0
3	1995	7/30/1995	23.42	74.16	18.31	64.96	29.23	84.61	10.92	19.66	1114.5	673.5	505.5	348	234
3	1996	7/25/1996	23.32	73.98	18.79	65.82	28.87	83.97	10.08	18.14	1347	877.5	678	486	328.5
4	1995	8/1/1995	20.25	68.45	18.15	64.67	21.90	71.42	3.75	6.75	41205	85.5	28.5	13.5	9
4	1996	7/25/1996	21.39	70.51	18.31	64.96	23.75	74.75	5.44	9.79	795	324	180	87	25.5
5	1995	7/30/1995	19.49	67.09	17.99	64.38	20.73	69.32	2.74	4.94	201	7.5	0	0	0
5	1996	7/26/1996	19.97	67.95	18.15	64.67	22.57	72.62	4.42	7.95	369	31.5	0	0	0
6	1995	6/23/1995	20.77	69.38	16.55	61.79	26.53	79.75	9.98	17.96	394.5	150	81	28.5	9
6	1996	6/30/1996	19.30	66.75	14.81	58.66	24.78	76.60	9.97	17.95	216	66	34.5	6	0
7	1995	7/30/1995	22.11	71.80	18.15	64.67	27.59	81.66	9.44	16.99	1110	567	400.5	268.5	154.5
7	1996	7/1/1996	21.30	70.34	16.07	60.93	27.95	82.31	11.88	21.38	667.5	466.5	352.5	222	112.5
7	1997	7/22/1997	20.81	69.46	17.99	64.38	25.13	77.24	7.14	12.86	666	346.5	181.5	60	6
7	1998	7/21/1998	21.20	70.16	18.15	64.67	25.66	78.18	7.51	13.51	888	363	220.5	102	37.5
7	1999	8/23/1999	20.98	69.77	18.79	65.82	24.12	75.42	5.33	9.59	822	115.5	25.5	1.5	0
8	1995	7/30/1995	23.20	73.76	19.47	67.05	27.24	81.03	7.77	13.99	1357.5	670.5	516	325.5	172.5
8	1996	7/25/1996	23.28	73.91	20.14	68.25	27.68	81.82	7.54	13.57	1558.5	756	562.5	337.5	181.5
9	1995	6/24/1995	21.38	70.49	18.46	65.23	26.46	79.63	8.00	14.40	586.5	148.5	90	30	7.5
9	1996	7/1/1996	20.84	69.52	17.47	63.45	24.51	76.12	7.04	12.67	583.5	109.5	54	7.5	0
10	1995	6/24/1995	20.11	68.19	17.19	62.94	24.27	75.68	7.08	12.74	471	78	19.5	4.5	0
10	1996	6/2/1996	18.53	65.35	15.76	60.36	21.57	70.82	5.81	10.46	57	0	0	0	0
11	1995	7/30/1995	22.62	72.72	19.44	66.99	27.41	81.34	7.97	14.35	1455	715.5	489	256.5	139.5
11	1996	7/25/1996	22.39	72.31	19.28	66.70	27.23	81.01	7.95	14.31	1342.5	756	510	334.5	156
11	1997	8/4/1997	22.57	72.62	18.96	66.13	27.06	80.71	8.10	14.58	1681.5	943.5	696	448.5	232.5
11	1998	8/10/1998	22.10	71.77	18.47	65.25	27.23	81.01	8.76	15.77	1146	595.5	403.5	238.5	105
12	1995	7/30/1995	22.15	71.86	18.79	65.82	26.01	78.82	7.22	13.00	1101	463.5	256.5	106.5	37.5
12	1996	7/6/1996	21.80	71.24	18.63	65.54	25.83	78.49	7.19	12.95	1243.5	456	202.5	70.5	12

			MWAT		Min. Temp		Max. Temp		Temp Range for MWAT Week		Season Hours Above °C (in hours)				
Site No.	Year	Week of	°C	°F	°C	°F	°C	°F	°C	°F	20°C	22°C	23°C	24°C	25°C
13	1995	7/16/1995	17.58	63.64	15.91	60.64	20.41	68.74	4.50	8.10	16.5	0	0	0	0
13	1996	7/25/1996	17.40	63.32	15.12	59.22	20.08	68.14	4.96	8.93	1.5	0	0	0	0
14	1995	7/14/1995	19.68	67.42	16.82	62.28	23.01	73.42	6.19	11.14	303	28.5	4.5	0	0
14	1996	7/6/1996	19.63	67.33	17.16	62.89	22.62	72.72	5.46	9.83	357	31.5	0	0	0
14	1999	7/11/1999	18.09	64.56	16.39	61.50	19.60	67.28	3.21	5.78	0	0	0	0	0
15	1995	7/15/1995	16.96	62.52	15.44	59.79	18.96	66.12	3.52	6.33	0	0	0	0	0
15	1996	7/26/1996	16.32	61.38	14.97	58.95	17.83	64.09	2.86	5.15	0	0	0	0	0
16	1995	7/15/1995	18.67	65.61	17.51	63.52	19.76	67.57	2.25	4.05	4.5	0	0	0	0
16	1996	7/2/1996	17.14	62.86	16.55	61.79	17.51	63.52	0.96	1.73	0	0	0	0	0
16	1997	7/2/1997	17.90	64.23	16.07	60.93	18.96	66.13	2.89	5.20	0	0	0	0	0
16	1998	7/15/1998	18.68	65.63	17.34	63.21	19.92	67.86	2.58	4.64	0	0	0	0	0
16	1999	7/11/1999	18.09	64.56	16.39	61.50	19.60	67.28	3.21	5.78	0	0	0	0	0
20	1995	8/3/1995	23.45	74.21	20.41	68.74	27.59	81.66	7.18	12.92	1516.5	904.5	604.5	370.5	198
20	1996	7/26/1996	24.24	75.64	21.90	71.42	26.71	80.08	4.81	8.66	1504.5	1041	771	511.5	256.5
21	1995	7/15/1995	18.88	65.98	16.87	62.37	21.90	71.42	5.03	9.05	25.5	0	0	0	0
22	1995	6/27/1995	14.44	57.99	13.57	56.43	15.76	60.37	2.19	3.94	0	0	0	0	0
23	1995	6/24/1995	23.98	75.16	18.96	66.12	30.34	86.62	11.39	20.50	1453.5	867	586.5	379.5	220.5
23	1996	7/8/1996	24.44	75.99	21.23	70.22	27.41	81.34	6.18	11.12	1654.5	1096.5	813	546	312
24	1996	7/25/1996	19.23	66.61	15.91	60.64	23.75	74.75	7.84	14.11	225	42	10.5	0	0
25	1995	6/23/1995	23.07	73.53	17.83	64.09	29.60	85.28	11.77	21.19	898.5	445.5	318	220.5	136.5
25	1996	7/1/1996	22.44	72.40	16.55	61.79	29.79	85.62	13.24	23.83	991.5	447	276	172.5	94.5
26	1995	7/30/1995	23.41	74.13	17.83	64.09	31.49	88.68	13.66	24.59	1227	817.5	645	504	385.5
27	1995	7/30/1995	22.69	72.84	18.15	64.67	27.77	81.99	9.62	17.32	1044	661.5	513	346.5	225
27	1996	7/25/1996	23.50	74.31	19.12	66.42	29.60	85.28	10.48	18.86	1320	832.5	648	459	321
28	1995	7/31/1995	20.62	69.12	17.67	63.81	24.78	76.60	7.11	12.80	667.5	258	127.5	55.5	0
28	1996	7/25/1996	21.11	70.01	17.67	63.81	25.31	77.56	7.64	13.75	792	342	180	60	9
29	1995	7/30/1995	22.10	71.79	17.99	64.38	26.71	80.08	8.72	15.70	901.5	468	202.5	202.5	109.5
30	1995	7/14/1995	21.63	70.94	16.87	62.37	26.18	79.12	9.31	16.76	643.5	309	94.5	94.5	22.5
30	1996	7/25/1996	22.36	72.25	18.63	65.54	26.53	79.75	7.89	14.21	960	501	205.5	205.5	94.5
30	1997	7/19/1997	21.31	70.36	17.51	63.52	26.53	79.75	9.02	16.24	979.5	477	148.5	148.5	54

			MWAT		Min. Temp		Max. Temp		Temp Range for MWAT Week		Season Hours Above °C (in hours)				
Site No.	Year	Week of	°C	°F	°C	°F	°C	°F	°C	°F	20°C	22°C	23°C	24°C	25°C
30	1998	8/1/1998	21.27	70.29	17.34	63.22	24.78	76.61	7.44	13.39	789	333	52.5	52.5	0
30	1999	7/9/1999	21.15	70.07	16.39	61.50	25.48	77.86	9.09	16.36	660	187.5	36	36	9
31	1995	7/15/1995	17.04	62.67	15.28	59.50	18.63	65.54	3.36	6.04	0	0	0	0	0
31	1996	7/25/1996	17.18	62.93	15.44	59.79	19.12	66.42	3.68	6.62	0	0	0	0	0
31	1997	8/5/1997	16.78	62.20	14.97	58.95	18.63	65.53	3.66	6.59	0	0	0	0	0
31	1998	8/10/1998	16.64	61.94	14.49	58.09	18.63	65.54	4.14	7.45	0	0	0	0	0
32	1995	6/24/1995	20.41	68.73	17.47	63.45	24.86	76.75	7.39	13.30	561	123	7.5	7.5	0
32	1996	7/6/1996	20.34	68.61	17.47	63.45	23.72	74.70	6.25	11.25	654	157.5	0	0	0
37	1995	7/15/1995	17.28	63.11	15.28	59.50	20.90	69.62	5.62	10.12	1.5	0	0	0	0
37	1996	7/1/1996	16.31	61.35	13.41	56.14	18.63	65.53	5.22	9.40	0	0	0	0	0
38	1995	7/16/1995	16.61	61.90	15.91	60.64	17.51	63.52	1.60	2.88	0	0	0	0	0
39	1995	7/29/1995	17.64	63.75	15.59	60.06	19.76	67.57	4.17	7.51	3	0	0	0	0
42	1996	7/1/1996	20.92	69.66	18.15	64.67	23.75	74.75	5.60	10.08	918	177	0	0	0
43	1995	9/30/1995	21.82	71.27	20.24	68.43	23.58	74.44	3.34	6.01	163.5	57	0	0	0
43	1996	10/8/1996	20.81	69.46	20.24	68.43	21.40	70.52	1.16	2.09	264	0	0	0	0
43	1997	9/7/1997	24.11	75.40	21.07	69.93	25.31	77.56	4.24	7.63	295.5	238.5	198	151.5	10.5
44	1996	9/19/1996	16.32	61.38	14.34	57.81	19.44	66.99	5.10	9.18	0	0	0	0	0
47	1996	7/25/1996	19.12	66.41	16.71	62.08	21.57	70.83	4.86	8.75	136.5	0	0	0	0
49	1996	7/25/1996	20.12	68.22	16.55	61.79	24.61	76.30	8.06	14.51	411	153	75	18	0
50	1997	8/4/1997	21.14	70.05	17.34	63.22	25.48	77.87	8.14	14.65	978	349.5	153	34.5	3
50	1998	8/10/1998	21.13	70.03	17.51	63.51	24.44	75.99	6.93	12.48	738	240	96	16.5	0
50	1999	7/9/1999	20.65	69.18	16.55	61.79	24.27	75.69	7.72	13.90	468	76.5	24	4.5	0
51	1996	8/23/1996	16.42	61.55	13.72	56.69	20.57	69.03	6.86	12.34	3	0	0	0	0
51	1997	8/7/1997	18.18	64.72	15.59	60.06	22.07	71.73	6.48	11.66	88.5	1.5	0	0	0
51	1998	8/10/1998	17.49	63.49	14.81	58.66	19.92	67.86	5.11	9.20	0	0	0	0	0
51	1999	8/23/1999	17.21	62.98	15.12	59.22	19.76	67.57	4.64	8.35	0	0	0	0	0
52	1997	8/5/1997	17.83	64.09	15.76	60.36	19.76	67.57	4.01	7.21	0	0	0	0	0
59*	1997	8/5/1997	16.33	61.40	15.59	60.06	16.87	62.37	1.28	2.30	0	0	0	0	0
60*	1995	7/14/1995	20.32	68.57	15.89	60.61	24.39	75.91	8.50	15.30	396	133.5	33	7.5	0
61*	1995	7/14/1995	19.50	67.10	16.23	61.21	23.06	73.51	6.83	12.29	153	13.5	1.5	0	0

			MWAT		Min. Temp		Max. Temp		Temp Range for MWAT Week		Season Hours Above °C (in hours)				
Site No.	Year	Week of	°C	°F	°C	°F	°C	°F	°C	°F	20°C	22°C	23°C	24°C	25°C
62*	1995	7/30/1995	20.30	68.55	17.51	63.51	24.44	75.99	6.93	12.48	285	109.5	46.5	9	0
63*	1995	7/30/1995	20.26	68.47	16.71	62.07	25.66	78.18	8.95	16.11	412.5	190.5	103.5	45	18
64*	1995	7/28/1995	18.54	65.37	15.73	60.31	22.02	71.64	6.29	11.32	79.5	4.5	0	0	0
65*	1995	7/31/1995	19.43	66.97	17.99	64.38	21.07	69.92	3.08	5.54	132	0	0	0	0
68	1997	8/28/1997	14.33	57.79	14.03	57.25	14.65	58.37	0.62	1.12	0	0	0	0	0
68	1998	8/3/1998	14.03	57.25	13.87	56.97	14.18	57.53	0.31	0.56	0	0	0	0	0
68	1999	8/24/1999	13.40	56.12	12.94	55.29	13.87	56.97	0.93	1.67	0	0	0	0	0
69	1997	8/7/1997	15.08	59.14	13.72	56.70	16.39	61.50	2.67	4.81	0	0	0	0	0
81	1997	8/7/1997	18.06	64.50	16.71	62.08	20.24	68.43	3.53	6.35	39	0	0	0	0
81	1998	8/10/1998	18.48	65.26	16.55	61.79	20.41	68.73	3.86	6.94	43.5	0	0	0	0
81	1999	7/11/1999	17.77	63.98	15.76	60.36	19.44	66.99	3.68	6.63	0	0	0	0	0
82	1997	7/3/1997	15.34	59.61	13.26	55.87	17.03	62.65	3.77	6.79	0	0	0	0	0
82	1998	8/3/1998	14.89	58.80	14.34	57.81	15.44	59.79	1.10	1.98	0	0	0	0	0
82	1999	8/7/1999	14.24	57.63	13.87	56.97	14.49	58.09	0.62	1.12	0	0	0	0	0
115	1998	7/21/1998	16.04	60.88	14.18	57.52	18.79	65.82	4.61	8.30	1.5	0	0	0	0
116	1998	8/10/1998	15.98	60.77	13.87	56.97	17.83	64.09	3.96	7.12	25.5	21	18	16.5	12
116	1999	8/24/1999	14.39	57.90	13.87	56.97	15.12	59.22	1.25	2.25	0	0	0	0	0
117	1998	8/10/1998	17.31	63.15	14.97	58.94	19.28	66.70	4.31	7.76	0	0	0	0	0
117	1999	8/23/1999	16.72	62.09	15.28	59.50	18.31	64.96	3.03	5.46	0	0	0	0	0
122	1998	8/10/1998	16.54	61.77	13.46	56.22	19.13	66.44	5.68	10.22	18	1.5	1.5	0	0
122	1999	8/23/1999	16.58	61.85	14.49	58.09	18.96	66.12	4.46	8.03	0	0	0	0	0
140	1999	7/10/1999	20.31	68.56	15.12	59.22	26.01	78.81	10.88	19.59	534	202.5	79.5	37.5	10.5
153	1999	8/24/1999	14.84	58.72	14.03	57.25	15.59	60.07	1.57	2.82	0	0	0	0	0
157	1999	8/23/1999	17.91	64.23	16.23	61.21	20.08	68.15	3.86	6.94	25.5	0	0	0	0

* Temperature data at Site 59-65 were collected by LP.

Table 4-8
Summary of Results of Thermal Monitoring Performed by Louisiana Pacific, 1989-1996

Stream Name	Sub.*	Site Identification			Year	Days Mean Daily Water Temperature >						Days Maximum Daily Water Temperature >						
		MCWA Site ID	Site ID (89-93)	Site ID (94-96)		16°C	17°C	18°C	20°C	22°C	20°C > 4 Days	18°C	20°C	22°C	23°C	24°C	23°C > 4 Days	Diurnal Range ≥10°C
Branch of North Navarro (Lower)	N	LP-65		81-1	1994	106	65	0	0	0	0	55	0	0	0	0	0	0
	N	LP-65		81-1	1995	81	79	48	0	0	0	77	28	0	0	0	0	0
Smith Creek (Upper)	N		81-17	81-2	1989	62	4	0	0	0	NC	57	0	0	NC	0	NC	ND
	N		81-17	81-2	1990	98	83	59	0	0	NC	81	50	2	NC	0	NC	ND
	N		81-17	81-2	1991	22	0	0	0	0	NC	17	0	0	NC	0	NC	ND
	N		81-17	81-2	1992	31	3	0	0	0	NC	29	0	0	NC	0	NC	ND
	N		81-17	81-2	1993	11	1	0	0	0	NC	5	0	0	NC	0	NC	ND
	N		81-17	81-2	1994	0	0	0	0	0	0	0	0	0	0	0	0	0
Smith Creek (Lower)	N		81-17A		1989	86	73	52	3	0	NC	93	71	11	NC	2	NC	ND
	N		81-17A		1991	49	18	3	0	0	NC	79	33	0	NC	0	NC	ND
Branch of North Navarro River er)	N	LP-64	81-19	81-3	1992	85	63	27	0	0	NC	86	37	0	NC	0	NC	ND
	N	LP-64	81-19	81-3	1993	82	39	11	0	0	NC	80	27	27	NC	2	NC	ND
	N	LP-64	81-19	81-3	1994	63	35	2	0	0	0	74	20	0	0	0	0	0
	N	LP-64	81-19	81-3	1995	50	22	16	0	0	0	46	25	3	0	0	0	0
h Gulch (Lower)	M		82-16	82-1	1989	4	0	0	0	0	NC	3	0	0	NC	0	NC	ND
	M		82-16	82-1	1991	0	0	0	0	0	NC	0	0	0	NC	0	NC	ND
	M		82-16	82-1	1992	0	0	0	0	0	NC	0	0	0	NC	0	NC	ND
	M		82-16	82-1	1993	0	0	0	0	0	NC	0	0	0	NC	0	NC	ND
	M		82-16	82-1	1994	0	0	0	0	0	0	0	0	0	0	0	0	0
h Gulch (Upper)	M		82-16A		1989	0	0	0	0	0	NC	0	0	0	NC	0	NC	ND
Creek	N		82-21	82-2	1993	6	0	0	0	0	NC	0	0	0	NC	0	NC	ND
	N		82-21	82-2	1994	0	0	0	0	0	0	0	0	0	0	0	0	0
rro River at Dimmick	M		82-14	82-3	1989	121	121	120	99	37	NC	121	117	93	NC	63	NC	ND
	M		82-14	82-3	1990	63	63	63	55	13	NC	63	62	55	NC	34	NC	ND
	M		82-14	82-3	1991	123	111	78	19	1	NC	110	82	51	NC	12	NC	ND
	M		82-14	82-3	1992	123	123	86	37	0	NC	123	78	50	NC	1	NC	ND

		Site Identification				Days Mean Daily Water Temperature >						Days Maximum Daily Water Temperature >						
tream Name	Sub.*	MCWA Site ID	Site ID (89-93)	Site ID (94-96)	Year	16°C	17°C	18°C	20°C	22°C	20°C > 4 Days	18°C	20°C	22°C	23°C	24°C	23°C > 4 Days	Diurnal Range >10°C
River at Dimmick	M		82-14	82-3	1993	76	65	61	14	2	NC	88	65	13	NC	2	NC	ND
nt.)	M		82-14	82-3	1994	92	77	65	5	0	0	79	64	39	1	0	0	0
ranch of North varro River	N	LP-61		85-1	1995	78	51	31	2	0	0	70	32	6	1	0	0	0
	N	LP-61		85-1	1996	89	59	32	0	0	0	79	33	1	0	0	0	0
ranch of North varro River	N	LP-60		85-2	1994	86	73	56	7	0	0	97	83	50	24	5	3	0
	N	LP-60		85-2	1995	79	57	41	12	0	2	80	39	19	4	1	0	0
	N	LP-60		85-2	1996	87	66	46	10	0	1	92	59	25	6	0	1	0
ork Indian Creek	I	LP-63	86-26	86-1	1993	96	87	73	7	0	NC	113	108	80	NC	31	NC	ND
	I	LP-63	86-26	86-1	1994	106	95	72	13	0	1	106	104	101	93	71	22	33
	I	LP-63	86-26	86-1	1995	84	82	47	10	0	1	84	82	55	42	27	8	0
	I	LP-63	86-26	86-1	1996	102	77	62	18	0	1	111	104	77	62	51	14	0
ork Indian Creek	I	LP-62		86-2	1994	106	96	78	33	0	7	106	89	72	58	38	13	0
	I	LP-62		86-2	1995	84	62	46	8	0	1	84	56	38	19	6	2	0
	I	LP-62		86-2	1996	96	74	58	17	0	1	98	79	44	17	2	3	0
River at Hendy	M		88-15	88-1	1990	120	119	118	94	53	NC	141	117	87	NC	61	NC	ND
	M		88-15	88-1	1991	111	111	99	69	12	NC	111	86	48	NC	7	NC	ND
	M		88-15	88-1	1992	122	122	109	69	12	NC	122	95	73	NC	26	NC	ND
	M		88-15	88-1	1993	112	104	94	60	3	NC	112	96	83	NC	49	NC	ND
	M		88-15	88-1	1994	103	103	104	63	0	13	106	91	45	4	3	0	0
River at Floodgate	M		82-14A		1989	122	122	122	89	31	NC	122	120	106	NC	77	NC	ND
	M		82-14A		1990	132	127	124	100	61	NC	129	124	107	NC	71	NC	ND
	M		82-14A		1991	122	116	105	68	6	NC	115	93	70	NC	35	NC	ND
	M		82-14A		1992	122	120	108	81	4	NC	122	101	81	NC	45	NC	ND

nd Abbreviations:
lo Data
lot Calculated

*** Subdrainage**
N: North Fork
M: Mainstem
I: Indian

Source: Mendocino Redwood Co. 1997, "Stream Temperatures for Watersheds in Louisiana Pacific's Coastal Mendocino Management Unit." (2 Volumes: Vol. 1 89-93; Vol. 2 94-96)

**Figure 4-4. Frequency Distribution of Site-Averaged M W AT Values
Navarro Watershed, 1995-1999**

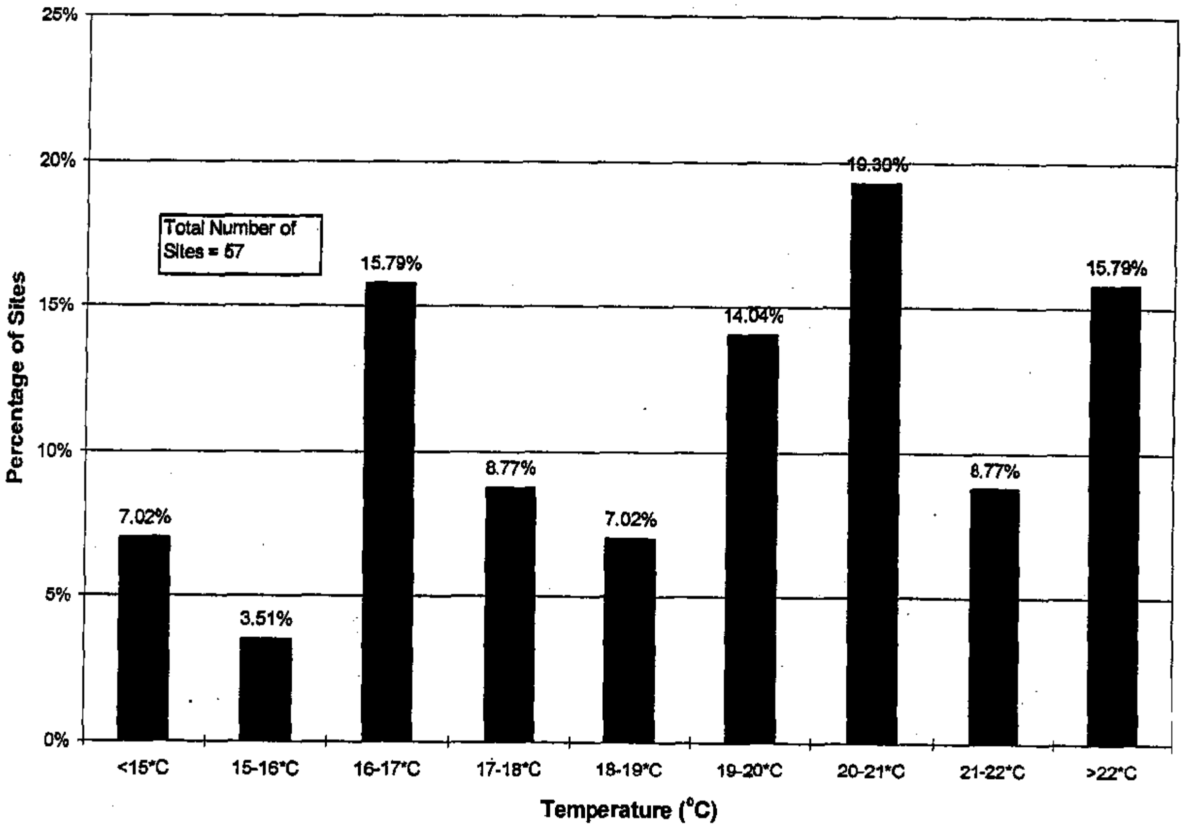
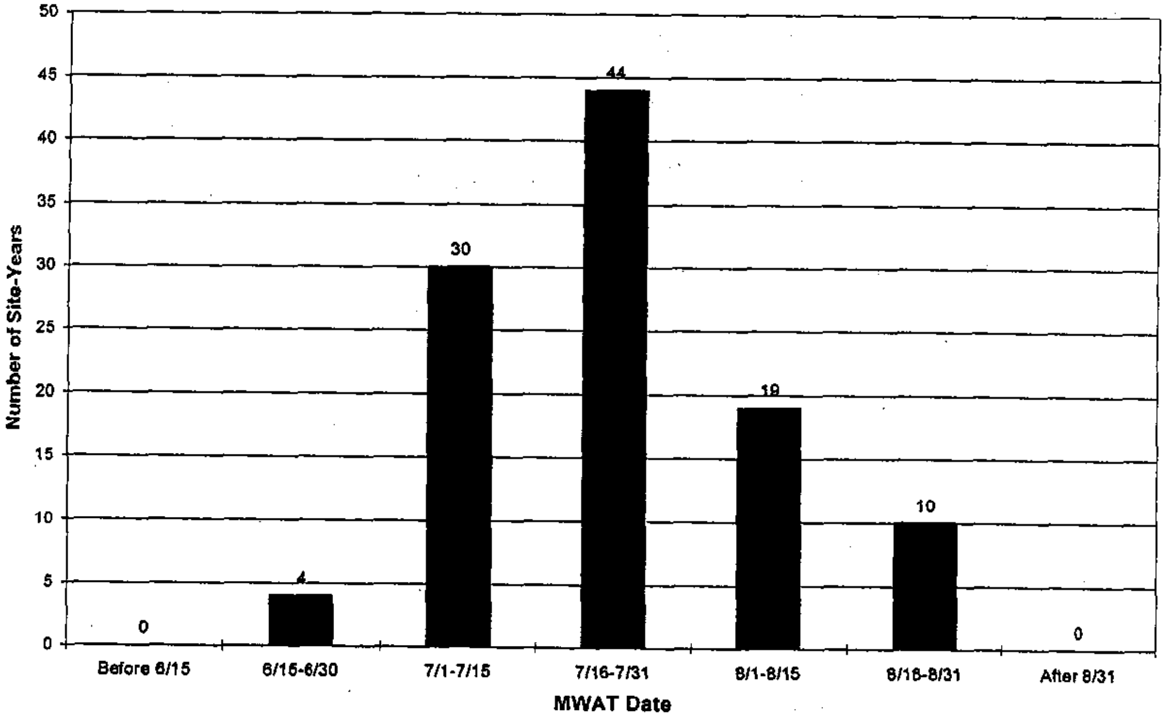


**Figure 4-5. Frequency Distribution of MWAT Dates
Navarro Watershed, 1995-1999**



4.4.3 Summary of Current Temperature Conditions

Continuous temperature monitoring records have been collected by MCWA or LP at sixty six locations in the watershed. The monitoring locations reflect a cross section of the thermal landscape of the watershed. Of the sixty six locations, twenty nine are located on main stream channels and thirty seven are located on smaller tributaries. Locations range in elevation from sea level to 1320 feet (402 m), and from the headwaters of Rancheria Creek to the Navarro River estuary. Locations tend to be concentrated in the forested areas of the watershed and along the main stream channels.

In general, stream temperatures tend to be lowest in small tributary streams. Temperatures tend to be highest in locations on the main streams of Anderson, Indian, and Rancheria Creeks, and on the Navarro. The channels in many of the reaches that show high stream temperatures are wide. Riparian vegetation in some of these reaches is sparse.

Most locations monitored are considered poor/unsuitable for both coho and steelhead, based on the temperature ranges presented in Section 4.4.1 (Figure 4-4). At many locations, stream temperatures are high enough to be lethal to salmonids on many days during the summer months.

The average date of the highest 7-day moving average temperature is July 22.

The following sections summarize temperature results in the five subdrainage assessment areas in the watershed.

4.4.4 Anderson Creek Assessment Area

MCWA Data

From 1995 through 1999, nineteen summer temperature records have been collected at nine sites. At all but one site, data were collected in 1995, 1996, or both years. At one station, SWRCB-7 located on Anderson Creek west of Boonville, temperature data have been collected each year from 1995 through 1999.

Most sites in this subdrainage are located in the alluvial Anderson Valley, an area of low elevation and relief. Five sites are located on Anderson Creek. Site SWRCB-3 is located at the Highway 253 crossing of Anderson Creek, near where the creek emerges onto the valley floor. SWRCB-4, at an elevation of 1320 feet, is the highest location at which temperatures have been recorded in the watershed by MCWA. This site and Site MCWA-24, at 960 feet in elevation, are located in areas of relatively high relief. As shown in Figure 2-3, cropland, grazing, and urban uses occupy a higher percentage of the land in this subdrainage than in other subdrainages. There is no industrial timberland in this subdrainage.

Temperatures measured at the 9 monitoring sites indicate conditions generally poor/unsuitable when compared to salmonid growth and survival metrics. Maximum Weekly Average Temperatures (MWAT) exceeded 17 and 19°C at all sites in all years for which data were collected. Temperature ranges during the MWAT week varied from a low of about 2°C at Site 5 to 10°C or more at Sites 3, 6, 7, 25, and 26. The week during which the MWAT occurs has ranged from June 23 to August 22.

Temperatures regularly exceeded 22°C at Site 24, regularly exceeded 24°C at four sites (3, 7, 25 and 26), and occasionally exceeded 24°C at three sites (4, 6 and 9).

4.4.5 Indian Creek Assessment Area

MCWA Data

From 1995 through 1999, twenty four summer temperature records have been collected at eleven sites. At Site MCWA-30, located on Indian Creek near Parkinson Gulch, temperature data have been collected each year from 1995 through 1999. Temperature data were collected at Site MCWA-31, Parkinson Gulch, from 1995 through 1998. Elevations of temperature monitoring sites range from 180 feet (55m) to 960 feet (290m).

Six of the eleven sites in this subdrainage are located on Indian Creek from near the confluence with North Fork Indian Creek to the confluence with Rancheria Creek near Philo. Review of aerial photos indicates the active channel in this section is wide with braided channels evident in some reaches. Land in this subdrainage is used for vineyards, range, industrial timber production, and rural residences.

Temperatures measured at the eleven monitoring sites indicate conditions generally poor/unsuitable when compared to salmonid growth metrics. MWATs equaled or exceeded 17°C at all sites except MCWA-31 and exceeded 19°C at all sites except MCWA-31 and MCWA-157. MWAT values and daily averages have exceeded 20°C at nine sites and have exceeded 22°C at three sites (27, 29 and 30). Temperature ranges during the MWAT week were as low as about 3°C at Site 31 to 10°C or more at Sites 3, 6, 7, 25, and 26. The week during which the MWAT occurs has ranged from June 25 to August 10.

Hourly temperatures have regularly exceeded 22°C at Sites 10, 32, 50, and 62, have regularly exceeded 24°C at five sites (27, 28, 29, 30, and 63), and have occasionally exceeded 24°C at three sites (32, 50, and 62).

LP Data

From 1989 through 1996, LP collected seven summer temperature records at two sites in the Indian Creek drainage. The longest records are at Site 86-1 (LP-63), Lower North Fork Indian Creek (four years).

Temperatures measured at the two sites indicate poor/unsuitable conditions when compared to salmonid growth and survival metrics. Mean Daily Water Temperatures (MDWTs) exceeded

17°C and 19°C at both of the sites. Daily Maximum Water Temperatures (DMWTs) have regularly exceeded 22°C at both monitored sites in this drainage.

4.4.6 Rancheria Creek Assessment Area

MCWA Data

From 1995 through 1999, twenty three summer temperature records have been collected at 13 sites in the Rancheria Creek drainage. The longest records are at Site MCWA-51, Dago Creek (four years) and MCWA-81, Cold Springs Creek (three years). Elevations of temperature monitoring sites range from 180 feet (55m) to 970 feet (295m).

Four of the thirteen sites in this subdrainage are located on Rancheria Creek. Most of the sites are located on smaller drainages tributary to Rancheria. Land in this subdrainage is used for industrial timber production, non-industrial timber production, grazing, and rural residences. Field and row crop acreage is limited to a few locations. Vineyard acreage is increasing, particularly in the upper parts of the drainage.

Temperatures measured at the thirteen monitoring sites indicate conditions ranging from poor/unsuitable to good when compared to salmonid growth and survival metrics. MWATs were greater than 17°C in at least one year at all sites except 22 and 59. MWAT values and daily averages have exceeded 19C° at seven sites and have exceeded 22°C at three sites (8, 20, and 23). Temperature ranges during the MWAT week were less than 2°C at Sites 22 and 59 to 10°C or more at Sites 23 and 140. The week during which the MWAT occurs has ranged from June 24 to August 23.

Hourly temperatures have regularly exceeded 22°C at three sites (2, 49, and 140) and regularly exceeded 24°C at three sites (8, 20, and 23).

4.4.7 North Fork Navarro River Assessment Area

MCWA Data

From 1995 through 1999, 22 summer temperature records have been collected at thirteen sites in the North Fork Navarro River drainage. The longest records are at Site SWRCB-16, North Fork Navarro at Dimmick State Park (five years), MCWA-68, Flynn Creek near Tank 4 Gulch (three years), and MCWA-82, John Smith Creek (three years). Elevations of temperature monitoring sites range from 30 feet (9m) to 560 feet (170m).

Of the thirteen sites in this drainage, two are located on the North Fork, two are located on the South Branch of the North Fork, two are located on the North Branch of the North Fork, and the remainder are located on smaller tributary drainages. Land in this subdrainage is used primarily for industrial timber production, with some non-industrial timber production and rural residences.

Temperatures measured at the thirteen monitoring sites indicate conditions ranging from poor/unsuitable to good when compared to salmonid growth and survival metrics. MWATs were less than or equal to 17°C at five sites)15, 68, 69 82, and 153) and greater than or equal to 19°C at Sites 14, 60, 64, and 65. Temperature ranges during the MWAT week were less than 4°C at seven sites and did not exceed 7°C at any site. The week during which the MWAT occurs has ranged from July 2 to August 30.

Hourly temperatures regularly exceeded 22°C at Sites 14 and 60.

LP Data

From 1989 through 1996, LP collected twenty one summer temperature records at seven sites in the North Fork Navarro River drainage. The longest records are at Site 81-2, Upper John Smith Creek (six years), and Site 81-3 (LP-64), North Branch Navarro River (four years).

Temperatures measured at the seven sites indicate conditions ranging from poor/unsuitable to good when compared to salmonid growth and survival metrics. MDWTs were less than or equal to 17°C consistently at Site 82-2 and for one year at Site 81-2. MDWTs were less than or equal to 19°C for two years at Site 81-2.

DMWTs have regularly exceeded 20°C at all sites except Site 81-2 and Site 82-2. DMWTs regularly exceeded 22°C at Sites 81-17A, 81-3 (1993) and 85-2, and occasionally exceeded 22°C at Sites 81-2 (1990), 81-3 (1995), and 85-1.

4.4.8 Mainstem Navarro River Assessment Area

MCWA Data

From 1995 through 1999, twenty four summer temperature records were collected at twelve sites in the Mainstem Navarro River assessment area. The longest records are at Site SWRCB-11, Navarro River at Hendy Woods (five years) and MCWA-43, Navarro River Estuary at the Highway 1 Bridge (four years). Elevations of temperature monitoring sites range from sea level to 540 feet (165m). The two stations located in the estuary (MCWA-43 and MCWA-44) show markedly different patterns from the other sites and are discussed separately.

Of the ten remaining sites, three are located on the Navarro River. The other sites are located in either the Lazy Creek (two sites) or Mill Creek (five sites) drainages. Land in this assessment area is used for industrial timber production, non-industrial timber production, field and row crops (including orchards and vineyards), grazing, and rural residences.

Temperatures measured at the ten monitoring sites indicate conditions ranging from poor/unsuitable to good when compared to salmonid growth and survival metrics. MWATs were less than or equal to 17°C at Sites 38, 115, 116, and 122, and between 17 and 19°C at Sites 13, 37, and 52. All seven of these sites are on tributaries of the Navarro. MWAT values and daily averages have exceeded 20°C at Site 42 and have exceeded 22°C at two sites (11 and 12).

Temperature ranges during the MWAT week were less than 2°C at Site 38 and less than 4°C at Site 37. At Sites 11 and 12, temperature ranges exceeded 8°C. The week during which the MWAT occurs has ranged from July 1 to August 26.

Hourly temperatures have regularly exceeded 22°C at Site 42 and have regularly exceeded 24°C at Sites 11 and 12.

Estuary Stations

Sites 43 and 44, located in the estuary, have shown MWAT values and daily averages exceeding 20°C, with MWAT dates occurring in September or October.

LP Data

From 1989 through 1996, twenty one summer temperature records have been collected at five sites in the Mainstem Navarro River drainage. The longest records are at Site 82-1, Lower Marsh Gulch (five years); Site 82-3, Navarro River at Dimmick Park (six years); Site 88-1, Navarro River at Hendy Woods (five years); and Site 82-14A, Navarro River at Floodgate Creek (four years).

Temperatures measured at the five sites indicate conditions ranging from poor/unsuitable to good when compared to salmonid growth and survival metrics. MDWTs were less than or equal to 17°C at Sites 82-1 and 82-16A.

DMWTs have regularly exceeded 18°C, 20°C, and 22°C at all sites except Site 82-1 and Site 82-16A. DMWTs occasionally exceeded 18°C during 1989 at Site 82-1

4.5 Summary of Sediment-Related Water Quality Impairments in the Navarro Watershed

The Navarro River watershed is listed under Section 303(d) of the Clean Water Act as impaired due to sedimentation and temperature. The following describes the existing in-stream and up-slope watershed conditions and the beneficial use impairments of concern.

Regional Water Board staff relied on data from a variety of sources, in addition to direct observations, to assess sediment impairments in the Navarro watershed. Stream Inventory Reports prepared by the California Department of Fish and Game (CDFG) and Fish Habitat and Channel Condition surveys conducted by Entrix comprise the bulk of in-stream data for the Navarro River watershed. Bulk gravel sample data was obtained from Mendocino Redwood Company (MRC) and Roger Foott Associates' "Phase II Geologic Study Navarro River Basin For Louisiana-Pacific" (1990).

4.5.1 North Fork Navarro River Assessment Area

The North Fork Navarro River assessment area is the most studied of all the assessment areas. The reason for the focus on this area is primarily due to the fact that this sub-basin has the majority of the natal streams of Coho in the Navarro River watershed. Also, the majority of lands in the North Fork Navarro assessment area are owned by Mendocino Redwood Company and before them Louisiana-Pacific (LP), which have collected data on their lands.

Stream Surveys conducted in the early 1960's by CDFG personnel indicate that some streams in the North Fork Navarro were significantly degraded at that time, while others were considered excellent salmonid spawning and nursery streams. A history of logging in the Navarro watershed prepared by A. A. Rich and Associates (1991), and timber harvest plan data from California Department of Forestry (CDF), show that most of the basin has been logged at least twice. Most areas were logged in a period between 1945 and 1973 and once again since 1974. Some areas, particularly the riparian areas of the lower reaches of John Smith Creek and the North and South Branches of the North Fork were logged once prior to 1945 and once again since 1974.

A Stream Survey of the North Branch of the North Fork in 1962 indicates that logging activities and roads had severely impacted the salmonid habitats in the reaches surveyed. Notes taken at the time of the survey include an estimate that "rubble (cobble) present is at least 50% covered by sand and silt" (CDFG 1962). Evidently these impacts had not begun to diminish the frequency of pools, since the surveyor estimated that pools comprised 50% of the habitat. Stream inventories of the same reaches conducted in 1994 found pools comprised only 20% of the habitat, suggesting that the stream reaches continued to degrade.

A similar comparison of Soda Creek indicates the stream was an excellent salmonid-rearing stream in 1962, but has degraded since. The survey (CDFG 1962) reported pools made up 70% of available habitat, 80% of the spawning areas were rated as excellent, and the watershed was mostly virgin timber. The surveyor attributed the stream conditions to the fact that the property owners had "kept the creek in excellent condition" (CDFG 1962). A Stream Inventory Report from 1995 indicates the habitat had changed. Pools consisted of only 13% of the available habitat, with only 17% of the pools had a depth of two feet or more (CDFG 1995). Gravel quality was also poor, with 63% of pool tail-outs having embeddedness values greater than 50% (CDFG 1995). Based on their survey, CDFG (1995) recommended that sediment sources in the basin be identified and treated, and suggested that roads were a possible cause of increased sedimentation.

In general, analysis of the in-stream data indicates salmonid habitat conditions in the North Fork of the Navarro have been degraded. This data suggests management activity has resulted in reduction of both the quantity and quality of pool habitats. For instance, only 9% of the available habitat in the North Fork Navarro qualify as primary pool habitat. CDFG habitat data indicates that the better Coho streams in Northern California have as much as 40% of their total habitat in primary pools (Flosi et al. 1998). Pools in first and second order streams are considered primary pools when they are as long as the low-flow channel width, occupy at least half the width of the low-flow channel, and are two feet or more in depth. Primary pools in third order and larger channels are defined the same, except that maximum pool depth must be three feet or more. A total of forty-seven miles of streams of the North Fork of the Navarro were surveyed by CDFG in 1994 and 1995.

Figures 4-6 and 4-7 show the distribution of pool depths measured by CDFG in the North Fork of the Navarro. In both figures, the x-axis represents the residual pool depth measured in two foot increments. The bar graphs represent the number of sampled pools. For example, Figure 4-6 shows that about 160 pools were found to be between 1.2 and 1.39 feet. The line graphs on both figures represent the cumulative percent of sampled pools with a certain depth. Again, as an example seen in Figure 4-6, 66.7% of the pools sampled had a pool depth of 1.99 feet or less.

In 1996, Entrix (1998) surveyed some of the same reaches as CDFG (John Smith Ck, Little North Fork, North and South Branches, seven miles total). Their data, although qualitative, supports the conclusions drawn from the CDFG data. They found deposition of fine sediments in pools and riffles in all reaches surveyed, as well as evidence of aggradation in the lower North Branch. They concluded that chronic fine sediment deposition and loss of large woody debris are adversely affecting stream reaches throughout the Navarro River watershed.

Gravel samples measured by Mendocino Redwood Company (Surfleet 2000) and Roger Foott Associates (1990) indicate that gravel quality may also be a problem in the North Fork of the Navarro. Tappel and Bjornn (1983, as cited in Meehan 1991) examined the effects of gravel distributions on salmonid survival-to-emergence and related percent survival to the percent of redd gravels finer than 9.5mm and 0.85mm. In 1989, Roger Foott and Associates (1990) sampled particle size distributions of salmonid redds found in streams throughout the Navarro River watershed. Application of Tappel and Bjornn's steelhead embryo survival index to this data predicts that five of the nine sampled redds had embryo survival rates less than 50%. Some of the sampled redds would likely have been Coho redds, which are expected to have lower emergence success from sedimented redds. Also, the Tappel/Bjornn index was computed with percent finer than 6.35 mm rather than 9.5 mm, which would be expected to over-predict survival rates.

Stream	Tappel/Bjornn Index
SBNF Nav River R-1	0.0
SBNF Nav River R-2T	0.0
SBNF Nav River R-2	0.4
SBNF R-4T	17.8
North Fork R-1T (#10)	21.4
SBNF Nav River R-1T	51.2
SBNF R-3 (#40)	68.5
North Fork R-1 (#10)	82.2
SBNF R-4	91.8

Figure 4-6
Residual Pool Depths of First and Second Order Streams of the North Fork Navarro

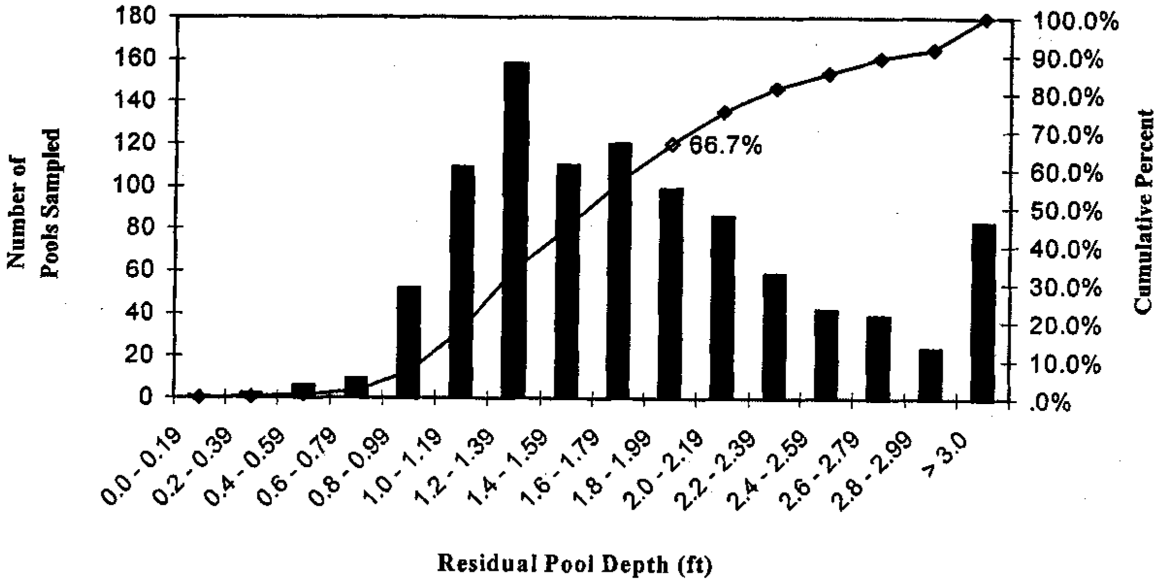
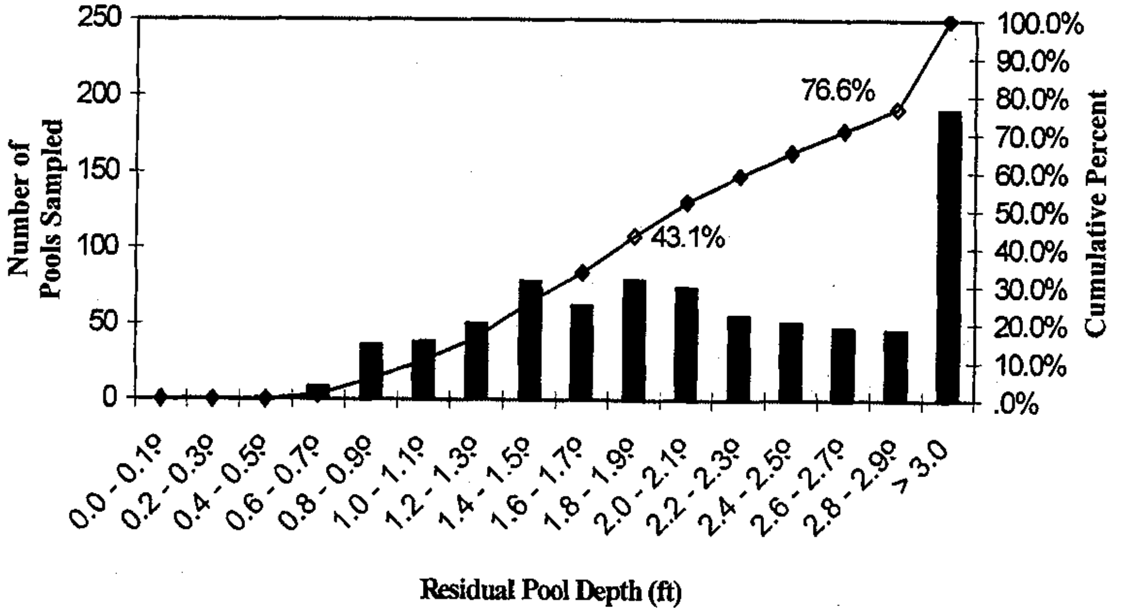


Figure 4-7
Residual Pool Depths of Third Order and Larger Streams of the North Fork Navarro



Mendocino Redwood Company sampled potential spawning gravels in the North Fork of the Navarro during the summer of 1999. These data show that in most cases the percent fines < 0.85mm appears to be in a suitable range for salmonid emergence (mean = 10%). However, the percent fines < 6.35mm averages 40% (after converting to percent-by-volume as in Shirazi et al. (1981). Kondolf (2000) reviewed the results of a number of studies and concluded that percent fines < 6.35mm should not exceed 30% for a survival rate of 50%. The data indicates that on the whole, the suitability of gravels found in the North Fork of the Navarro is marginal for spawning at best.

4.5.2 Mainstem Navarro Assessment Area

CDFG crews surveyed almost the entire length of Mill Creek, the largest tributary of the assessment area, in 1998. Other smaller streams in the assessment area were also surveyed, although the total length of those surveys was less than the Mill Creek survey. Entrix (1998) surveyed approximately five miles of stream reaches in the Mainstem Navarro Assessment Area (MNAA) in the summer of 1996.

Data from the CDFG surveys (CDFG 1998) indicate that the quantity and quality of pool habitats in the tributary streams of the MNAA are deficient. The distribution of habitat types for the Assessment Area is shown in Table 4-9. Floodgate Creek appears to provide the best pool habitat of the MNAA, with 38% of the length of the stream qualifying as primary pools, respectively. The condition of other streams in the MNAA is not as good. Only 50% of the length of pool habitats, 13% of the total habitat length, qualify as primary pools.

Table 4-9
Distribution of Habitat Types for the Mainstem Navarro Assessment Area

Stream	Total Length Surveyed (ft)	Cumulative **Riffle** Length per Habitat Type	Riffle %	Cumulative **Run** Length per Habitat Type	Run %	Cumulative **Pool** Length per Habitat Type	Pool %
Little Mill Creek	4854.1	561	12%	3719	77%	574.1	12%
Meyer Gulch	2851.0	591.0	21%	1468	51%	792	28%
Mill Creek	34032.4	6206.4	18%	20498	60%	7328	22%
Hungry Hollow	1798.0	189	11%	1385	77%	224	12%
Berry Creek	1796.0	459	26%	1014	56%	323	18%
Blackrock Creek	3354.0	782	23%	1714	51%	858	26%
Floodgate Creek	1841.0	217	12%	381	21%	1243	68%
Flume Gulch	7620.0	2577	34%	2211	29%	2832	37%
Marsh Gulch	2692.0	1088.0	40%	883	33%	721	27%
Murray Gulch	4285.0	1640	38%	1625	38%	1020	24%
Mustard Gulch	806.0	0	0%	486	60%	320	40%
MNAA	65929.5	14310.4	**22%**	35384	**54%**	16235.1	**25%**

Observations reported by Entrix (1998) provide an explanation for the low frequency and depths of pools in the MNAA. They reported that deposition of fines in pools was widespread in Mill Creek, and in general, accumulation of fine sediments was very high compared to most other stream reaches surveyed. Entrix (1998) noted evidence of accelerated bank erosion, which may explain the elevated fine sediment deposition, while CDFG (1998) noted that several road crossings were adding sediment and suggested that the road system be treated to reduce sediment yield.

Deposition of fine sediments has also affected the quality of spawning gravels in the MNAA. Analysis of particle size distribution samples of potential spawning gravels collected by MRC (Table 4-10) indicate that fine sediments (diameter < 9.5mm) are currently in excess of suitable conditions for successful incubation and emergence.

Table 4-10
Particle Size Distribution in the Mainstem Navarro River Assessment Area
(collected by Mendocino Redwood Company)

Location	Date	% < 6.3mm	% < 4.75mm	% < 2.36mm	% < 0.85mm
Main Stem	1989	**42%**	36%	23%	**15%**
Main Stem	1989	**51%**	46%	34%	**18%**
Main Stem	1989	**35%**	31%	19%	**9%**
Main Stem	1989	**50%**	46%	39%	**30%**
Main Stem	1989	**61%**	56%	43%	**29%**
Main Stem	1989	**50%**	42%	28%	**15%**
Flume Gulch	1989	**26%**	24%	15%	**10%**
Flume Gulch	1989	**34%**	30%	20%	**10%**
Flume Gulch	1989	**52%**	45%	32%	**15%**
Flume Gulch	1989	**44%**	38%	26%	**14%**
Main Stem	1999	**39%**	33%	21%	**12%**
Main Stem	1999	**47%**	42%	30%	**15%**
Main Stem	1999	**33%**	29%	18%	**7%**
Main Stem	1999	**45%**	41%	34%	**26%**
Main Stem	1999	**58%**	52%	38%	**25%**
Main Stem	1999	**47%**	40%	25%	**13%**
Flume Gulch	1999	**23%**	21%	13%	**8%**
Flume Gulch	1999	**31%**	27%	17%	**8%**
Flume Gulch	1999	**49%**	42%	29%	**13%**
Flume Gulch	1999	**40%**	34%	22%	**12%**
Mean		43%	38%	26%	15%
Standard Deviation		10%	9%	8%	7%

Changes in cross-sectional profiles of the river channel at the Highway One and Greenwood Road bridges (as cited in Entrix 1998) demonstrate the effect increased sediment yield has had. Comparison of the 1947 and 1999 cross sections at the Highway One bridge show that the elevation of the channel has increased three to five feet. Photographs of the mouth of the Navarro in 1890 and 1940 and historical accounts from 1860s (Adams 2000) suggest that the 1947 cross-section may reflect accelerated sediment yields prior to that time. Thus it is reasonable to conclude that the 1999 channel elevation is over three to five feet higher than the elevation that existed prior to Anglo-American resource exploitation.

The Greenwood Road Bridge cross-sections also illustrate the impacts of sedimentation. Comparison of the 1950 and 1999 cross-sections show that the maximum depth of the pool along the right bank of the channel has filled approximately five feet since 1950. The change in depth has been accompanied by an increase in width of approximately 20 feet. Entrix (1998) found that the width of unconfined stream channels increased substantially from 1952 to 1965 throughout the Navarro Watershed. Given the extent of logging activities observed in the 1952 aerial photos and the yarding methods employed at that time, it is reasonable to assume that the channel had been affected by increased sediment yields prior to 1950. Observations of the Greenwood Road pool by Regional Water Board staff indicated that the pool has filled with sand and pebbles, and is in a very unnatural state.

4.5.3 Rancheria Creek Assessment Area

The information collected in Rancheria Creek in the recent past is slim. CDFG crews surveyed the lower reaches of Rancheria Creek in the summer and fall of 1996 from the mouth of Indian Creek to the mouth of Minnie Creek, including Dago, Ham Canyon, and Horse Creeks. Entrix (1998) surveyed 2.5 miles of Beasley and Bear Wallow Creeks in 1996. Unfortunately, little recent quantitative information is available for the upper reaches of Rancheria Creek.

There is a considerable amount of information describing 1960s conditions in Rancheria Creek. CDFG crews surveyed the entire length of Rancheria Creek and most major tributaries in 1962. With the exception of the upper reaches of Camp Creek, every stream survey indicated intense degradation due to recent logging. Many of the surveys reported roads and landings in the stream channel. An excerpt from the 1962 Dago Creek Stream Survey reveals the extent of degradation at that time:

> The extensive logging damage in recent and past years has rendered this stream almost useless to anadromous fish life. The main Dago Creek from the road crossing upstream up to the landing/turn around, approximately 1.9 miles, is a continuous log jam, heavily silted-in area. Landings and clearings have been created at many places throughout the stream as well as all tributary confluences. The amount of material stacked up is fabulous. The main creek is no longer. It is just a wide path used by logging trucks and skid trails by tractors (CDFG 1962).

The CDFG data from 1996 indicates that these streams have at least partially recovered from the destruction of the 1960s. Table 4-11 shows the range of habitats found in the Rancheria Creek Assessment Area. The percentage of the stream lengths associated with pools is higher than other assessment areas. Pool depths are still shallow, with only 11% of pools in the tributary streams and 22% of Rancheria Creek pools qualifying as primary pools. The true percentage of primary pools over the entire length of Rancheria Creek is possibly lower than that reported for the lower reaches.

Table 4-11
Distribution of Habitat Types for the Rancheria Creek Assessment Area

Stream	Total Length Surveyed (ft)	Cumulative **Riffle** Length per Habitat Type (ft)	Riffle %	Cumulative **Run** Length per Habitat Type (ft)	Run %	Cumulative **Pool** Length per Habitat Type (ft)	Pool %
Dago Creek	5717	479	8%	3056	53%	2182	38%
Ham Canyon Ck	12933	1153	9%	8958	69%	2822	22%
Horse Creek	13745	1581	12%	8083	59%	4081	30%
Rancheria	58320	5185	9%	34156	59%	18979	33%
S. Fork Dago Ck	5367	528	10%	3316	33%	1523	28%
RCAA	96081.7	8926	**9%**	57569	**60%**	29587	**31%**

Particle size distributions of potential spawning gravels collected in 1989 suggest that fine sediments are slightly less abundant in Rancheria Creek than in the North Fork and Mainstem Navarro Assessment Areas. Table 4-12 summarizes the distribution of fine sediments found in potential spawning gravels of three tributaries of Rancheria Creek.

Table 4-12
Particle Size Distribution in the Rancheria Creek Assessment Area

Location	Date	**% < 6.3mm**	% < 4.75mm	% < 2.36mm	**% < 0.85 mm**
Dago Creek	1989	36%	33%	23%	13%
SF Dago Creek	1989	26%	23%	18%	10%
Bear Trap	1989	32%	28%	22%	13%

The only recent data that exists for the upper reaches of Rancheria Creek are cross-sectional profiles at county bridges. Unfortunately the record at these locations is short. Fish Rock Road Bridge has the longest record, which goes back to 1976 (as cited in Entrix 1998). The series of cross-sections indicate that the stream bed elevation has decreased since 1976, and has been relatively stable since 1996. The only other bridge with a record extending past ten years is the Hibbard Road Bridge, which extends to 1985. Comparison of the cross-sections at this site is inconclusive.

4.5.4 Anderson Creek Assessment Area

In 1996, Entrix (1998) surveyed two reaches of Con Creek, a tributary to Anderson Creek. The stream survey found that in both reaches, fine sediment deposits in pools were widespread and among the highest values observed in any reach surveyed. The average maximum depth of pools (not residual pool depth) was found to be 1.5 feet. Pools comprised 28% of the length of the reaches surveyed and were spaced about 6.4 channel widths apart. They estimated that prior to disturbance estimated pool spacing would typically have been two channel widths per pool or less. They concluded that fine sediment deposition had occurred in both reaches.

Entrix also found that accelerated bank erosion was occurring in both surveyed reaches. They estimated that more than forty percent of the banks were actively eroding. Much of this erosion was coming from terrace bank erosion and recent large landslides related to an abandoned logging road located on steep slopes adjacent to the surveyed reaches.

Entrix (1998) analyzed aerial photos of unconfined reaches of Anderson Creek and concluded that evidence of present-day aggradation was strong. They based their assessment on changes in active channel width, sediment storage in gravel bars, and bridge cross-sections.

4.5.5 Indian Creek Assessment Area

Entrix (1998) surveyed a 1.5-mile reach of the North Fork of Indian Creek in 1996. They found that bars predominately composed of gravel, cobble, and few fine sediments covered approximately 60% of the streambed along the reaches surveyed. In addition, old-growth redwood stumps were found in the active channel and appeared to be in the upright, growth position. The rootswells of these stumps were often found partially buried by coarse substrate and elevations of the rootswells "...indicated aggradation of at least a few meters" (Entrix 1998). They concluded that coarse sediment deposition and persistent channel aggradation has occurred. They also concluded that fine sediment deposition did not appear to be prevalent along the North Fork of Indian Creek.

Entrix (1998) found that fine sediment deposits were localized or patchy in pools along surveyed reaches of the North Fork of Indian Creek. In addition, the average maximum pool depth was found to be 2.3 feet with pools comprising 18% of the total length surveyed. Pool spacing was found to be approximately 3.7 channel widths per one pool, with large woody debris acting as the primary and/or secondary control on the formation of about half of all the pools in this reach. Prior to disturbance, Entrix (1998) expects most pools to be formed by large woody debris with pool spacing to be less than two channel widths per pool. From this information, Entrix (1998) concluded that there is moderate to strong evidence of wood loss in the surveyed reaches of North Fork Indian Creek. The stream survey also noted evidence of historical bank erosion problems that date back fifteen to thirty years. Current bank erosion is moderate to low (25% to 30%) and most often occurs on outside bends.

CHAPTER 5
TEMPERATURE

5.1 Introduction and Summary

This chapter presents the analysis that leads to the Technical Support Document and load allocations. The TSD analysis components include:

- Source analysis
- Loading capacity estimate
- Development of numeric targets
- Load allocations.

The starting point for the analysis is the equation that describes the Total Maximum Daily Load:

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

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

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

Because 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 as more sunlight reaches streams and raises water temperatures. The source of stream temperature increases is excessive solar heat energy delivered to streams and is the pollutant targeted in this TSD.

This TSD uses effective shade as a surrogate measure for solar heat energy. Effective shade is the shade from topography and vegetation that blocks solar radiation from reaching streams. The following equation relates effective shade and solar radiation inputs at a location:

$$\text{Actual Solar Radiation Input} = \text{Potential Solar Radiation Input} - \text{Effective Shade}$$

The narrative water quality objective for temperature (Section 3.2.2) states that the natural receiving water temperature of intrastate water shall not be altered. To meet this objective, solar radiation inputs and effective shade for this TSD will be those that result in no alteration of natural receiving water temperatures.

In this document, natural effective shade is estimated by first calculating potential effective shade based on fully mature trees growing along the bankfull channel of the streams. This potential vegetation is then reduced by 10% to account for natural effects such as fire, windthrow, and earth movements that would reduce the actual riparian area vegetation below the site potential. This modified condition is taken to represent natural vegetation, and is referred to in this document as adjusted potential vegetation. The target water temperatures are those that result from achieving the adjusted potential vegetation conditions in the watershed.

With the TMDL equation as the starting point, the analysis proceeds through the steps bulleted at the beginning of this section. The source analysis looks at the parameters that exert the most influence on stream temperature and focuses on those that are management-related. The analysis identifies air temperatures, wind speed, and shade as the most important parameters affecting stream temperatures, with flow, relative humidity, possible sun, and channel morphology as secondarily important.

Loading capacity is an estimate of the assimilative capacity of a waterbody for the pollutant of concern. For the Navarro temperature TMDL analysis, loading capacity refers to the adjusted potential effective shade conditions and associated solar loadings that result in no alteration of natural stream temperatures. The TMDL equation becomes:

TMDL = Loading Capacity = Adjusted Potential Effective Shade

The loading capacity estimate uses a Geographic Information System (GIS) model developed as part of this analysis (and described in Section 5.4) to describe potential shade conditions reflective of fully mature natural vegetation throughout the watershed. This potential condition is modified to account for natural events such as fire, landslides, and wind-throw that would reduce effective shade under natural conditions. This adjusted depiction of effective shade is referred to as adjusted potential effective shade and is used to set the target water temperature conditions for this TMDL.

The GIS model also was used to estimate current effective shade conditions. The difference between current and adjusted potential effective shade is that effective shade increase and reduced solar loading required to restore beneficial uses.

Effective shade curves are presented that show adjusted potential shade for different riparian vegetation types. The adjusted potential shade condition at all locations on the stream network in the watershed equals the load to be allocated. Meeting the shade conditions described in the effective shade curves will result in meeting adjusted potential effective shade conditions. This will result in reduced solar radiation loadings and achievement of target water temperatures.

The following sections present details on the steps described briefly above.

5.2 Sources of Increased Stream Temperatures

In looking at stream temperatures, the locations of most interest are closest to the streams, in the riparian corridors along stream courses. It is close to the streams that changed conditions can allow increased heat energy from sunlight to reach streams directly and raise temperatures.

There are no known point sources of heat to the Navarro or its tributaries. The source analysis will focus on natural and management-related (non-point) controls on solar radiation inputs to streams. This section looks at factors including streamside shading, riparian buffers, the dimensions (width and depth) of wetted stream channels in the critical summer low-flow periods, and summer low flows as possible controls related to management activities to account for observed stream temperatures.

The section starts with a discussion of the physical processes that affect stream temperatures. Next, two approaches are used to assess the most important parameters affecting stream temperatures in the watershed. First, a model based on equations describing the physical processes controlling stream temperatures is applied to a reach of the Navarro. Second, regression analyses are used to look at management-related parameters for which data are available. Results indicate that air temperature, wind speed, and streamside shade are the most important management-related variables affecting stream temperatures, with flow, relative humidity, and channel morphology as secondarily important.

5.2.1 Stream Heating Processes

Water temperature is a measure of the total heat energy contained in a volume of water. Stream temperature is the product of a complex set of interacting heat exchange processes. These processes include heat gain from direct solar (short-wave) radiation, long-wave radiation, evaporation, convection, conduction and advection (Brown 1980; Beschta et al. 1987; Sinokrot and Stefan 1993).

- Net direct solar radiation reaching a stream surface is the difference between measured incoming radiation and reflected radiation, reduced by the fraction of radiation that is blocked by topography and stream bank vegetation (Sinokrot and Stefan 1993). For a given location, incoming solar radiation is a function of position of the sun, which in turn is determined by latitude and day of the year. During the summer months, when solar radiation levels are highest and streamflows are low, shade from streamside forests and vegetation can be a significant control on direct solar radiation reaching streams (Beschta et al. 1987).

- Long-wave radiation can cool streams when emitted from the stream surface. 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 1999). During the course of a 24-hour period, heat leaving and heat entering a stream via long-wave radiation generally balance (Beschta 1997; ODEQ 1999).

- 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 would tend to lower temperatures. The rate of evaporation increases with increasing stream temperature. Air movement (wind) and low vapor pressures increase the rate of evaporation and accelerate stream cooling (ODEQ 1999).

- 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 describes the 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 stream if the bed is warmer than the stream (ODEQ 1999). 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 accounts for heat added to a stream by tributaries or groundwater. Advection may warm or cool a stream depending on whether a tributary or groundwater entering a 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, and is the change in the water bodies heat storage. This change in storage may be positive, leading to higher stream temperatures, or negative, leading to lower stream temperatures.

5.2.2 Screening Analysis of Stream Heating Mechanisms in the Navarro Watershed

This section presents two ways of identifying and assessing the important variables affecting stream temperatures in the Navarro watershed. The results indicate that of those factors that may be affected by management activities, shade is the single most important, and has a direct effect on the amount of solar radiation that reaches streams. Low flow channel and flow conditions were found to be less important than shade. Air temperature and wind speed are roughly as important as shade. These variables, along with relative humidity, interact with one another in microclimates associated with riparian corridors, and thus have an indirect effect on stream temperatures. For the Navarro, these variables may be important, though there are not any data to quantify their effects on stream temperatures.

Sensitivity Analysis Using SSTEMP

The various heat exchange processes have different magnitudes and interact in different ways depending on site-specific conditions. The effects of local conditions are expressed through the general factors noted in Table 4-4. These factors in turn are expressed through different values of variables in the mathematical equations that describe the heat exchange fluxes. To evaluate the relative significance of the variables that affect heat exchange rates for Navarro watershed streams, heat fluxes in a portion of the Navarro River were modeled. The model used, named SSTEMP, is intended for application to a segment or reach of a stream or river (Bartholow 1999). It is a simplified version of SNTEMP (Stream Network Temperature Model) (Bartholow

1989). SNTEMP can be used to model stream temperatures for an entire watershed. SSTEMP was used to perform a sensitivity analysis using ranges of values of parameters reflective of conditions in the Navarro watershed. Both SNTEMP and SSTEMP are public domain codes and are currently supported by the US Geological Survey (USGS).

Sensitivity analysis, as applied in this report, is a technique that can be used to understand the influences that various stream geometry, meteorological, and hydrological variables have on stream temperature. The primary uses for sensitivity analysis in this report are: 1) to rank parameters according to effect on predicted stream temperatures, and 2) to identify the most important management-related parameters. Sensitivity analysis for a model such as SSTEMP can be performed in many different ways. The approach used here involves varying the value of one parameter while holding others constant, and observing the effects on the predicted temperatures.

Model Inputs

Model input requirements are summarized in Table 5-1. Because the model requires input on both temperatures and flow for the date being modeled, the choice of reaches was limited to those where: 1) temperature and flow data were available at both ends of a reach and 2) it would be possible to collect data on shade conditions. While temperature data have been collected at over 60 locations in the watershed by either MCWA or LP, flow data have been collected only at Sites SWRCB-2 through SWRCB-16. Of these, only a few locations occur as pairs on a reach. The reach selected for application of the model is on the Navarro River from Hendy Woods (SWRCB-11) to near the Navarro's confluence with Mill Creek (SWRCB-12 and MCWA-40).

Table 5-1
SSTEMP Model Input Requirements

Hydrology	Meteorology
Segment Inflow (cfs)*	Air Temperature (°F)*
Inflow Temperature (°C)	Relative Humidity (%)*
Segment Outflow (cfs)*	Wind Speed (mph)*
Accretion Temperature (°F)*	Ground Temperature (°F)*
	Thermal Gradient (j/m2/s/c)*
Geometry	Possible Sun (%)*
Latitude (°)	Dust Coefficient *
Segment Length (mi.)	Ground Reflectivity (%)*
Upstream Elevation (ft)	
Downstream Elevation (ft)	Shade*
Width's A Term *	
Manning's n	Time of Year (mm/dd)

* Input parameter that was varied as part of the sensitivity analysis.

The input parameters used for the sensitivity analysis are marked with an asterisk in Table 5-1. The values of the parameters were varied individually over ranges considered reasonable for the reach, watershed, or time of year, as appropriate. The ranges used are presented in Table 5-2. Where watershed-specific information was not available for a parameter, the full range of values suggested in the SSTEMP documentation (Bartholow 1999) was used. Note that this approach does not account for synergistic effects among model variables. For example, varying total shade does not explicitly account for the changes in near stream air temperature, relative humidity, and wind speed that would likely be associated with changes in total shade.

Table 5-2
Summary of Ranges of Values Used in SSTEMP Sensitivity Analysis*

Parameter		Units	Reference	Low	High
Air Temperature (mean daily)		°F	69	60	80
Total Shade		%	32	5	70
Wind Speed		mph	5	0	15
Relative Humidity		%	70	60	80
Possible Sun		%	65	50	90
Inflow		cfs	18.65	3	40
Outflow		cfs	19.8	5.4	42.4
Width's A Term**		Dimensionless	7.634	2.65	10.61
Ground Temperature		°F	62	55	67
Thermal Gradient		joules/m^2/sec/°C	1.65	0.65	2.65
Dust Coefficient		dimensionless	5	3	15
Ground Reflectivity		%	10	5	30

* Reference run is calib000721.

** The range of the A Term is equivalent to a width:depth ratio range from 4.7 to 75.

The sensitivity analysis for flow relates outflow and inflow on the reach based on a comparison of flows measured at Sites 11 and 12 in 1995 and 1996. These flow measurements indicate that flow at Site 12 (downstream end of the reach) exceeds flow at Site 11 by an average of 2.4 cfs (range from 0.8 to 4.3 cfs) over flows at Site 12 ranging from 5.4 to 41.6 cfs. The difference between inflow and outflow on the reach represents the contribution of subsurface water inputs (e.g., groundwater seepage and intergravel flows) to streamflow on the reach.

Results

Results of the sensitivity analysis are presented in Figures 5-1 and 5-2. In Figure 5-1, the parameters are ranked by magnitude of effect on the predicted mean daily stream temperature, as measured at the downstream end of the modeled reach. In Figure 5-2, the parameters are ranked by magnitude of effect on the estimated maximum daily temperature. In these figures, parameters that directly relate to the temperature measure are shown above the zero line, and parameters that are inversely related to the temperature measure are shown below the zero line.

Figure 5-1. Sensitivity Analysis of SSTEMP on a Navarro River Reach Sorted by Effect of Parameter Variation on Mean Temperature

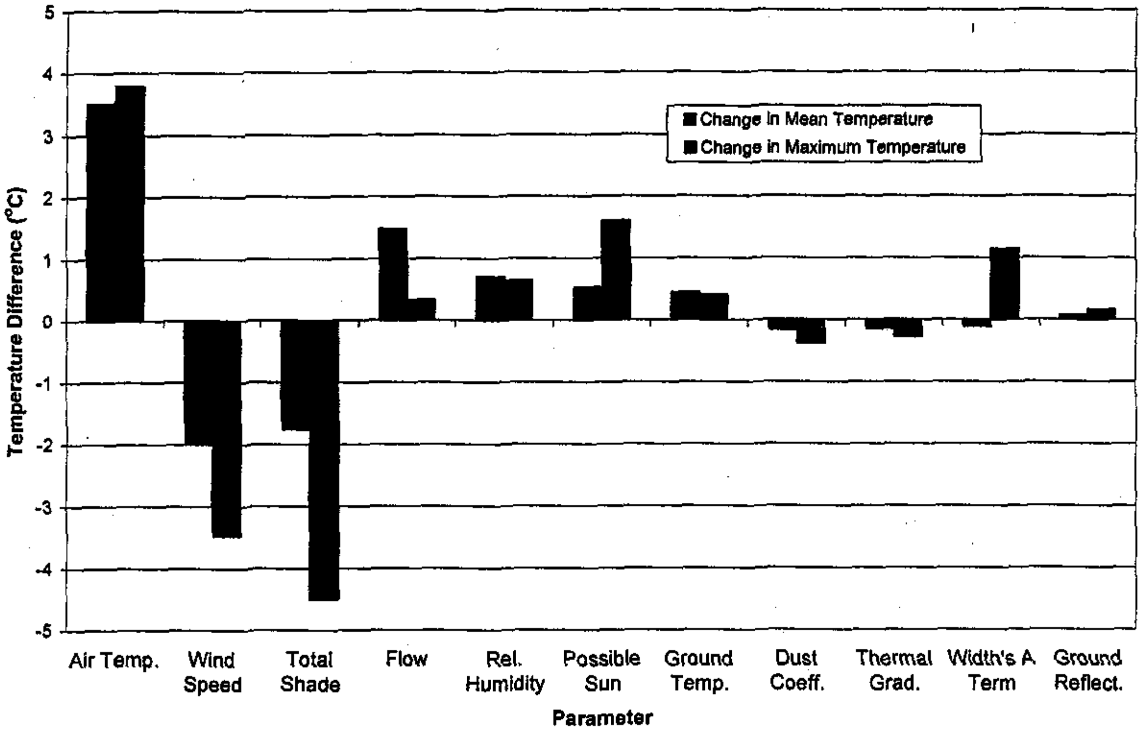
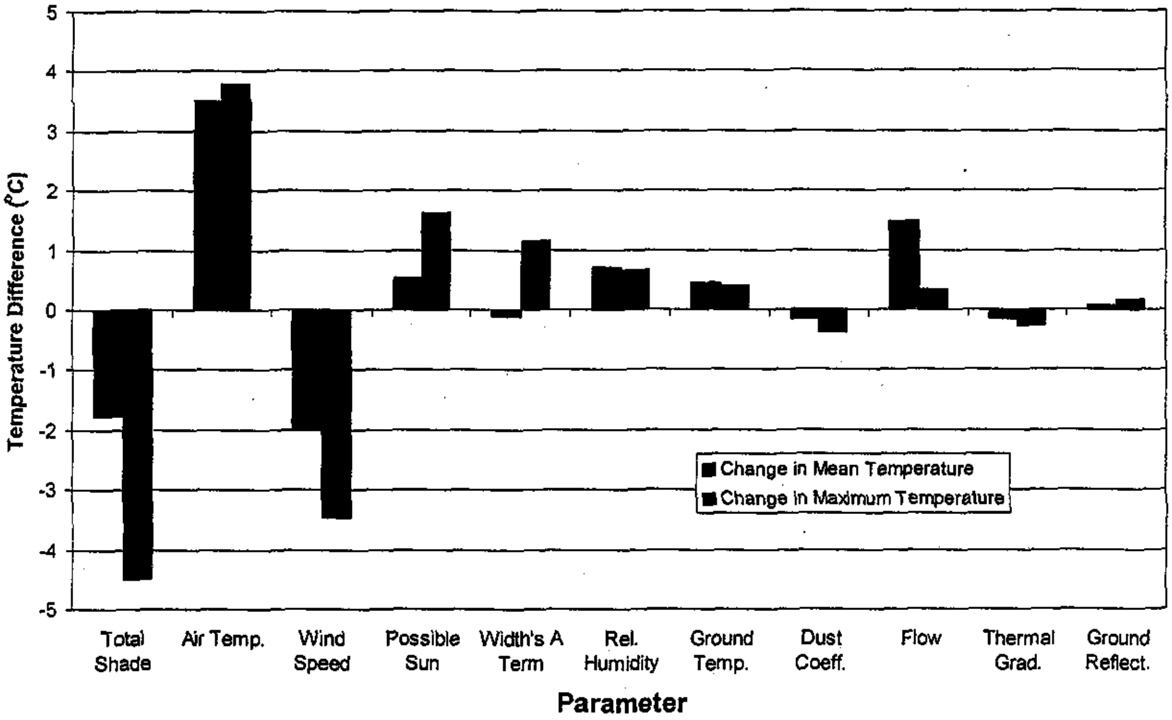


Figure 5-2. Sensitivity Analysis of SSTEMP on a Navarro River Reach Sorted by Effect of Parameter Variation on Maximum Temperature



The sensitivity analysis results indicate that predicted mean stream temperature is most sensitive to air temperature, and is also sensitive to wind speed, total shade, and flow. Predicted mean stream temperature is somewhat sensitive to relative humidity, possible sun (a measure of cloud cover) and ground temperature. Predicted mean stream temperature is insensitive to the other parameters tested, including dust coefficient, thermal gradient, ground reflectivity, and wetted channel width (as described by the parameter called "width's A term").

When the results are ranked by effect on the maximum stream temperature estimated by the model, total shade is the most important parameter, with air temperature and wind speed also important. Maximum temperature is somewhat sensitive to possible sun and wetted channel width, and is relatively insensitive to the remaining parameters including flow, relative humidity, ground temperature, thermal gradient, dust coefficient, and ground reflectivity.

The parameters to which mean or maximum temperatures are very sensitive or somewhat sensitive include total shade, air temperature, wind speed, relative humidity, possible sun, width's A term, flow, and ground temperature.

Total shade reflects topographic, vegetation, and channel conditions in and near streams. The presence, type, height, and density of vegetation near streams all affect the nature and character of streamside shade.

Channel width, or width's A term, a measure of channel geometry, can change in response to changes in sediment loads transported by a stream or river; increased sediment loads often lead to wider, shallower channels. The model results indicate that these factors affect estimated temperatures by increasing diurnal temperature fluctuations.

While air temperature, wind speed, and relative humidity would not be subject to management measures on a regional basis, values of these parameters may reflect microclimate conditions near streams. In particular, these parameters could indirectly reflect or be affected by changes in riparian vegetation conditions (Section 4.3). These parameters would be expected to vary together and balance one another to a certain extent. For example, a shaded streamside area would have lower air temperatures, lower wind speeds, and higher relative humidity than an open area. The net of these changes is lower temperatures in more buffered, shaded areas.

Results indicate that while changes in flow have little effect on maximum temperatures, they have a modest effect on predicted mean temperatures. The effect is produced as modeled inflows are reduced to levels where cooler subsurface water inputs become an increasingly important component of the outflow for the reach. This effect becomes less significant at higher inflow values and as the difference between surface water and subsurface water temperatures decreases.

Possible sun and ground temperature are both of lesser importance than other parameters and would not be expected to be influenced by management measures.

Conclusions

The sensitivity analysis results indicate that total shade, air temperature, and wind speed are the three most important parameters influencing stream temperatures for the modeled reach of the Navarro. Shade is of greatest interest for this TMDL because stream temperatures are sensitive to shade, shade is subject to change as a result of land management measures, shade can be directly related to solar radiation inputs that affect stream temperatures, and shade can be readily measured in the field. While stream temperatures may also be sensitive to air temperature and wind speed, and these parameters are subject to change as a result of management of streamside vegetation, there are few data on these parameters, they cannot be directly related to solar radiation inputs, and they are not as readily measured in the field. These variables are addressed by assuming, based on reports in the literature, that a width of 30m (about 100 feet) will achieve most of the key buffer functional characteristics, including reduced air temperatures, increased relative humidity and reduced wind speeds (Beschta et al. 1987, Steinblums et al. 1984, Ledwith 1996).

Other parameters subject to changes as a result of management, including channel width and flow, appear to be of lesser importance as sources of increased stream temperature.

Analysis of Conditions at Selected Navarro Watershed Stations

To investigate the screening results further, additional analysis was conducted using data collected at fifteen of the stations established by the SWRCB in 1995. Available data at these stations includes continuous temperature records and monthly streamflows through the summer. The flow measurement data sheets in turn include detailed measurements of wetted channel widths, depths, and velocities at the measured cross sections. There are not data of similar completeness available on the other parameters that SSTEMP identified as potentially important, e.g., air temperature, wind speed, and relative humidity.

To supplement these data, Regional Water Board staff measured shade conditions at the temperature monitoring stations and for reaches upstream of the stations. Shade was measured at locations spaced 100m apart for reaches up to 600m long. Shade at each transect was measured using a Solar Pathfinder to develop a chart of effective shade. The Solar Pathfinder is an instrument developed originally for use in the solar energy industry for siting solar collectors. With a single observation taken at any time of year it is possible to record those topographic, vegetation, and other features that block the sun during each month of the year at a given location.

Supplemental observations of channel geometry (wetted channel width, active channel width, location of the wetted channel within the active channel) and streamside vegetation conditions (dominant tree species, tree heights, distance from the wetted channel, overhang) were made at each transect

Solar Pathfinder measurements were attempted at thirteen of the fifteen stations. Data from two stations were not used in the analysis because it was not possible to position the instrument in the low-flow channel due to access or high streamflow limitations. At one site, the only transect measured was not considered representative of the upstream reach. For the remaining ten stations, effective shade values were calculated for June, July, and August and averaged for the reach. The Solar Pathfinder protocol and a summary of results are presented in Appendix B.

These data and previously collected data were used to look at relationships of Maximum Weekly Average Temperature (MWAT) values to effective shade, stream width:depth ratios, and streamflow. Monthly streamflow values were taken directly from data sheets summarizing field measurements. Width:depth ratios were calculated from cross-section widths and areas presented on the summary data sheets for each month. Linear interpolation between monthly values was used to estimate values corresponding to the MWAT date. Results for 1995 and 1996 showing the relationships of MWAT values to effective shade, stream width:depth ratios, and streamflow are presented in Figures 5-3, 5-4, 5-5, 5-6, and 5-7.

For both 1995 and 1996, MWAT values show a good correlation with reach-averaged effective shade (r^2 =0.762 and r^2=0.707 for 1995 and 1996, respectively, where r^2 is the proportion of variation explained by the model). These results appear to be consistent with observations made by Cafferata (1990) in a study conducted on the North Fork Caspar Creek. Width:depth ratio shows a weak positive correlation with MWAT for 1995 (r^2=0.120) and virtually no correlation for 1996 (r^2=0.003).

Estimated streamflow on MWAT dates shows little correlation with MWAT values (r^2=0.107). For example, both highest and lowest MWAT values occur at flows of less than two cfs. Similarly, flows spanning the full range of observed values (from 0.1 to 28 cfs) are associated with MWAT values in excess of 21°C.

To further investigate the relationship between flow and temperature extremes, flow was plotted against MWAT for three sites where both flow and temperature have been monitored for three or more years (Figure 5-8). The results do not show a consistent trend among the sites. At Site 11 (Navarro River at Hendy Woods State Park), MWAT values have varied little while flows have varied from 4 to 25 cfs. At Sites 7 and 16 (Anderson Creek below Conn Creek and North Fork Navarro at Paul Dimmick State Park), highest MWATs have occurred at intermediate flow values.

Figure 5-3. Maximum Weekly Average Temperature vs. Reach-Averaged Effective Shade, 1995

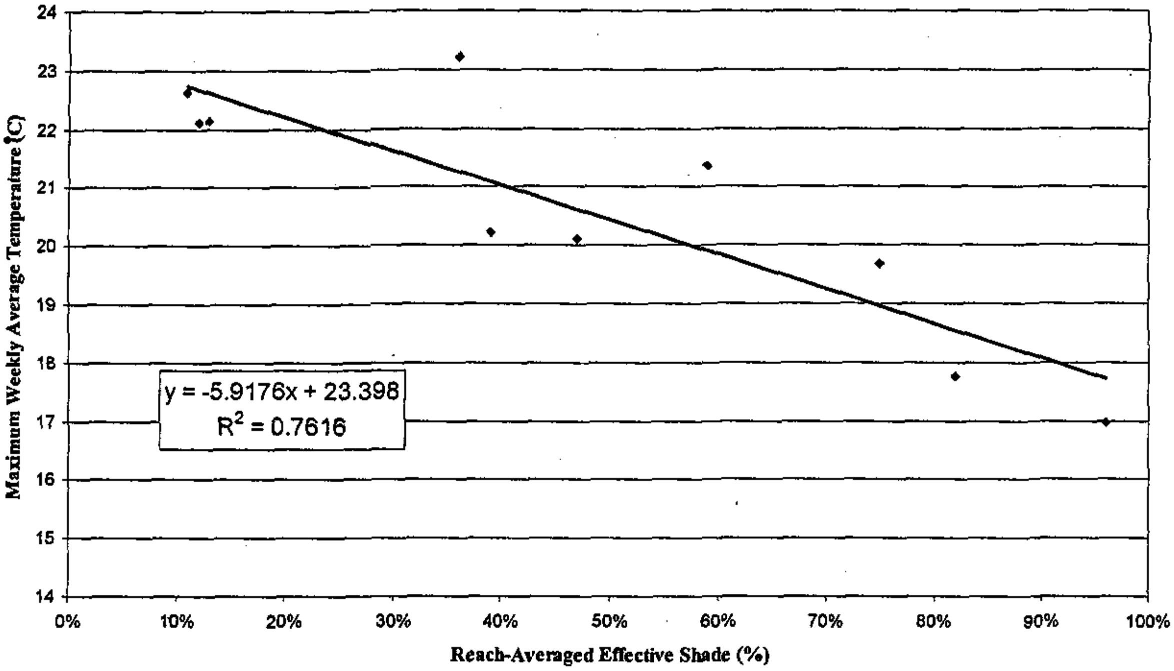


Figure 5-4. Maximum Weekly Average Temperature vs. Reach-Averaged Effective Shade, 1996

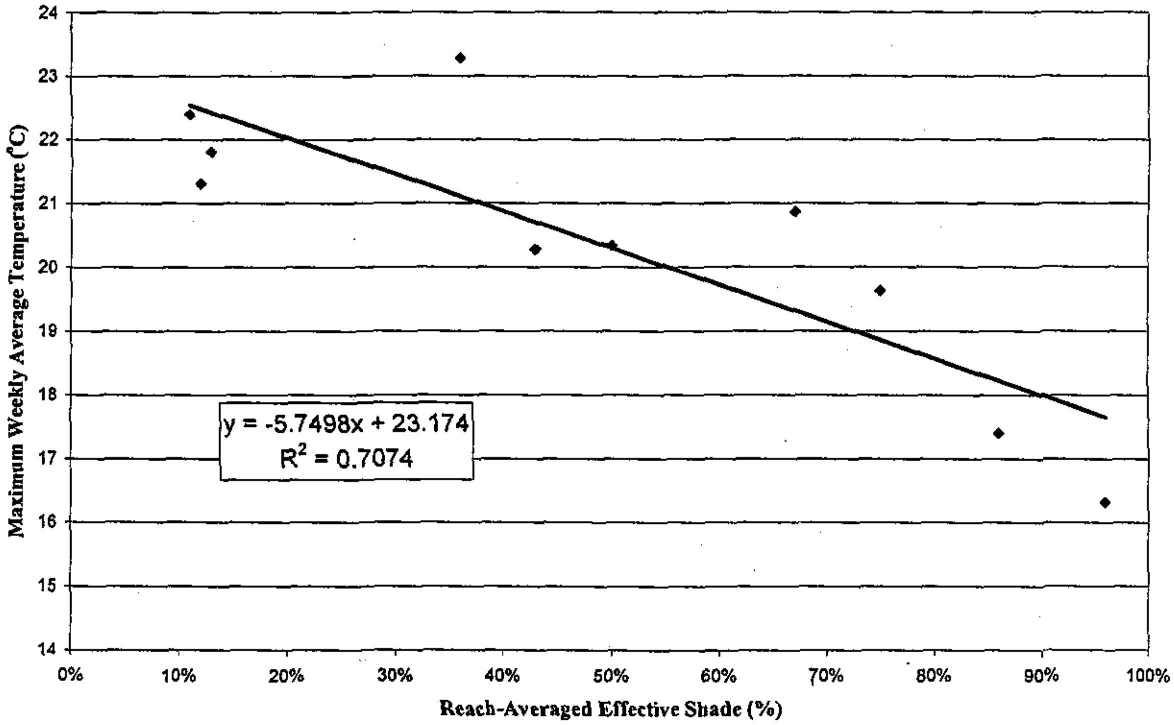


Figure 5-5. Maximum Weekly Average Temperature vs. Width:Depth Ratio Navarro River Watershed, 1995

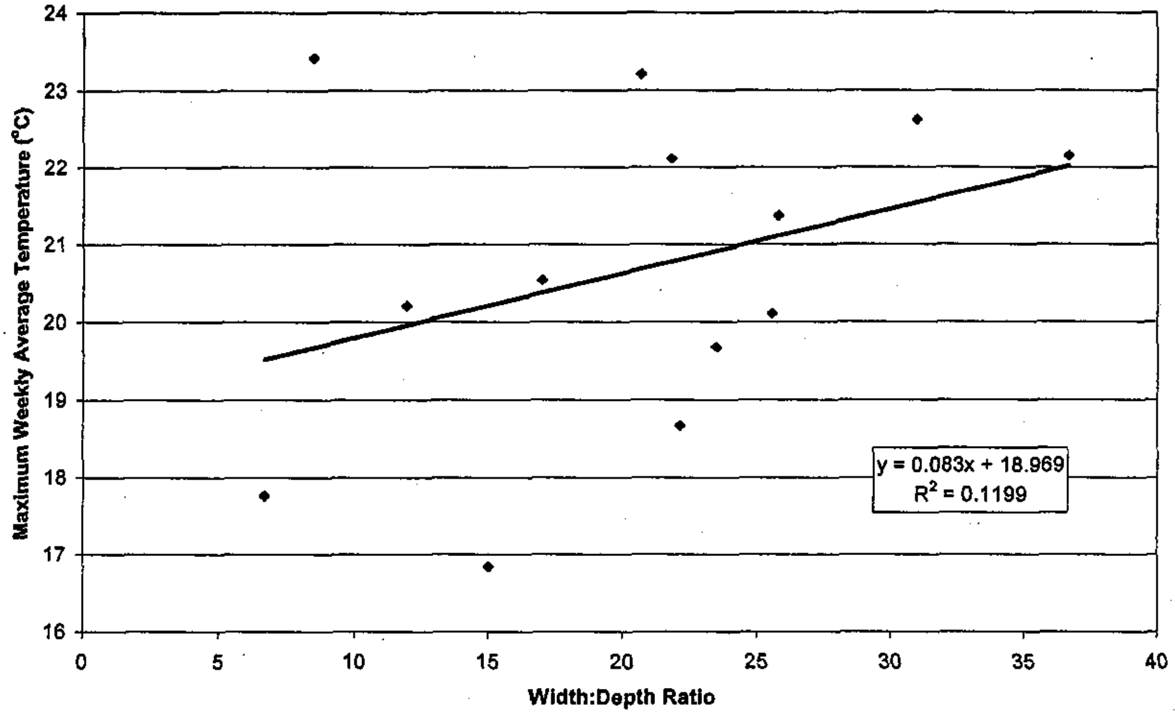


Figure 5-6. Maximum Weekly Average Temperature vs. Width:Depth Ratio Navarro River Watershed, 1996

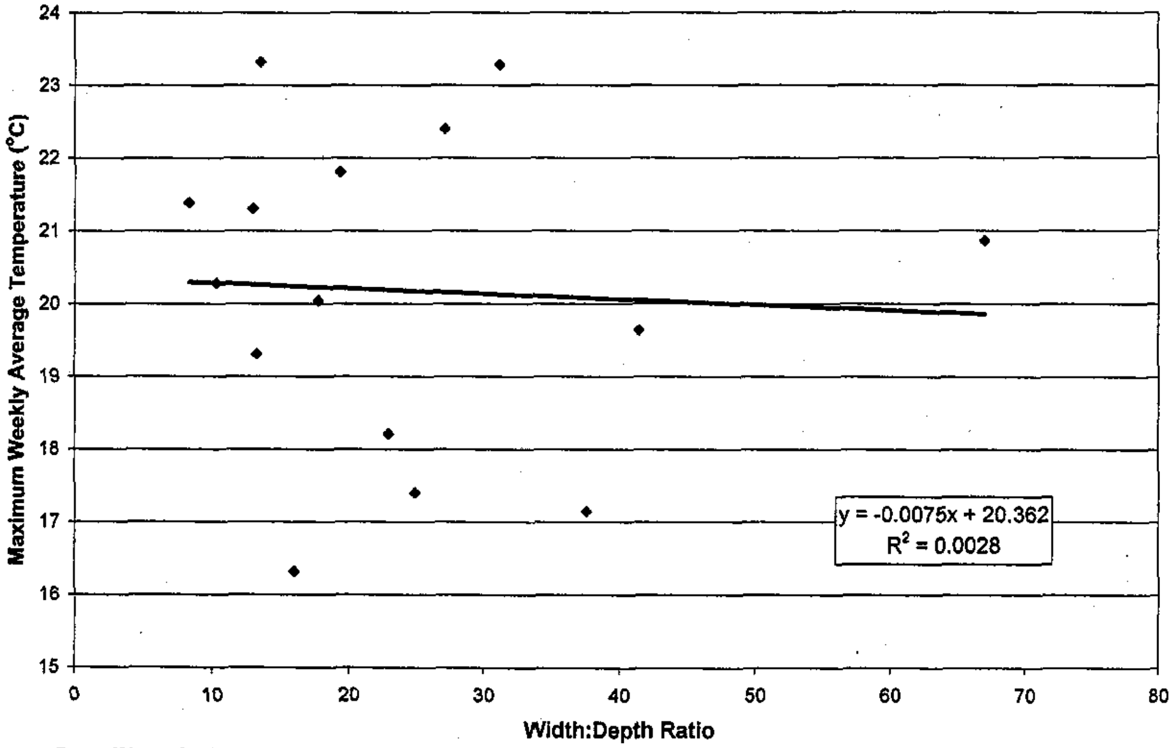


Figure 5-7. Maximum Weekly Average Temperatures vs. Streamflow, Navarro Watershed, 1995-96

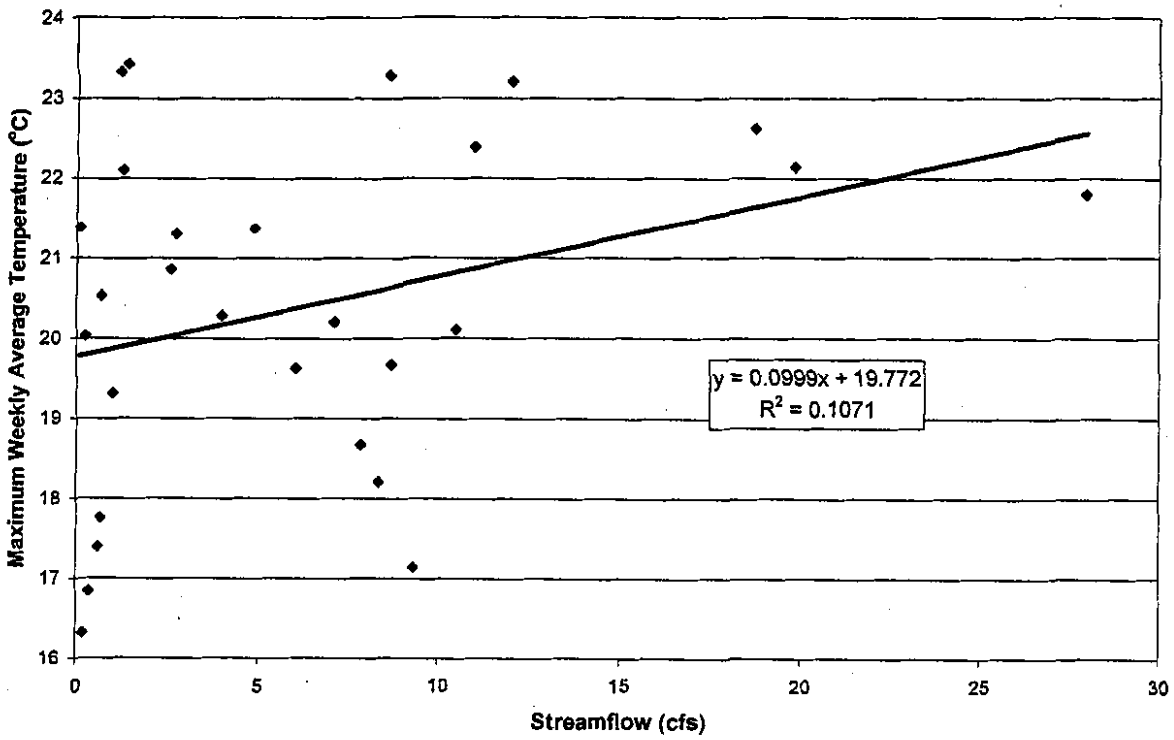
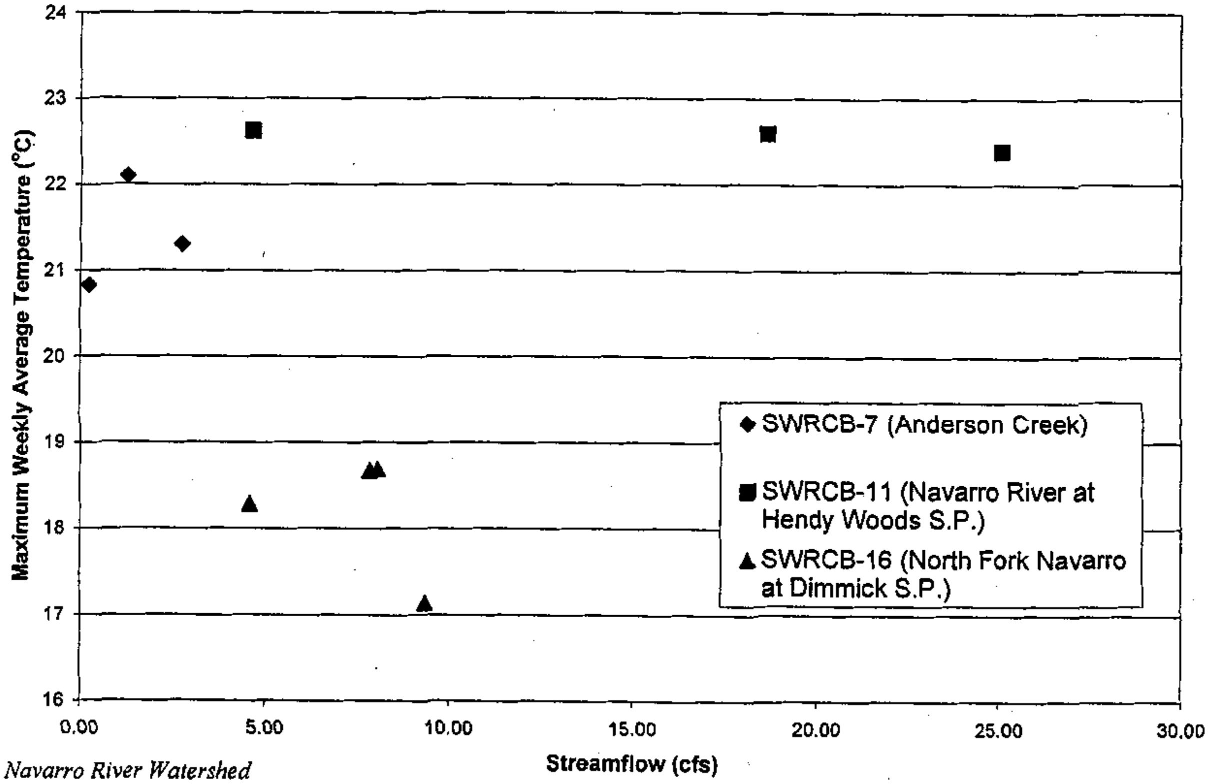


Figure 5-8. Maximum Weekly Average Temperature vs. Streamflow for Sites 7, 11 and 16, Navarro River Watershed



These results suggest that although wetted channel characteristics and flow would be expected to affect stream temperatures, the available watershed-specific data do not allow a conclusion to be drawn. The lack of a clear relationship could be the result of a number of factors:

- Flow measurements are typically collected at locations where the cross section dimensions are as regular as possible. Typically, these measurements are taken at riffles. In the Navarro, temperature probes routinely have been placed in pools. Thus, the poor correlation of MWAT to channel geometry could be a result of differences in measurement location.
- Pool depths may vary significantly from year to year. This in turn may affect temperatures at some stations. Data for the three sites plotted in Figure 5-8 include results for 1997, after large channel-shaping flows in the previous winter.
- Pumping at the times of flow measurement may have affected the measurements.
- Comparing temperature extremes to surface water flows may not reflect the complex relationships of surface water flow and temperature to subsurface water inputs and exchanges, including groundwater seepage and intergravel flows.
- Pool temperatures may be influenced by small volume inputs of relatively cool groundwater that are not reflected in the flow measurements. Deeper pools may be thermally stratified.
- Flow at a location may have an inverse relationship with temperature for certain ranges of flow, by causing mixing of cool and warm waters in pools. Nielsen et al. (1994) observed this for a reach of Rancheria Creek.
- Wetted channel characteristics may be less important than other variables affecting temperature.

The SSTEMP model looks at relationships among heat transfer mechanisms and at the effects of heat transfer on stream temperatures. In this model, flow functions as a mechanism for heat transfer through the modeled reach. The model does not look at the availability of aquatic habitat or the relationship of available aquatic habitat to flow.

5.3 Development of Pollutant Loading Capacities and Surrogate Measures

Under the TMDL framework, and in this Technical Support Document, identification of the "loading capacity" is a required step. The loading capacity represents the total loading of a pollutant that a water body can assimilate while still meeting water quality objectives and protecting beneficial uses. The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring a water body into compliance with standards. For this temperature TSD, the loading capacity is expressed as effective shade on the mean date of the MWAT for the watershed. Effective shade is a surrogate for solar radiant energy load. This is equivalent to a percentage reduction of the possible radiant energy load reaching the streams of the watershed on the MWAT date (July 22). See Section 4.4.2 for the mean MWAT calculation.

To use the loading capacity and to be able to compare it to current conditions, a surrogate measure of loading capacity is proposed. EPA regulations (40 CFR §130.2(i)) allow for the use of other appropriate measures (surrogate measures) to allocate loads for conditions "when the impairment is tied to a pollutant for which a numeric criterion is not possible..." (EPA 1998). There are no numeric criteria for radiant heat loads. However, it is possible to relate heat load to effective shade (that shade resulting from topography and vegetation that reduces the heat load reaching a stream) and to relate effective shade to temperature conditions. Effective shade can be readily measured in the field and also can be calculated using mathematical equations.

Effective shade is proposed as a surrogate measure for solar loading capacities for this TMDL. Effective shade is defined as the percent reduction of potential solar radiation delivered to the water surface. Effective shade translates directly and linearly to solar loading capacities (Section 5.1).

As described in the next section, a GIS model was used to develop the potential effective shade values that equate to the solar radiation loading capacity of the streams of the watershed.

5.4 Numeric Targets for Effective Shade and Temperature

Targets interpret water quality objectives, provide indicators of watershed health, and represent habitat and related conditions necessary or adequate for the success of salmonids. The narrative water quality objectives described in the Basin Plan (see Section 3.2) state that "natural receiving water temperature shall not be altered unless "...such an alteration in temperature does not adversely affect beneficial uses." Natural receiving water temperatures are considered here to be the reference condition that would not adversely affect beneficial uses associated with salmonid use of the watershed. This reference condition was developed using the following approach:

- A GIS model capable of representing solar radiation, topography, stream locations and orientation, and the effects of vegetation near streams on stream shading was developed by the Regional Board for this TMDL. The model calculates the percent of possible solar radiation received at each location in the watershed, and the effective shade offered by topography and vegetation to the stream network. By relating effective shade to temperature, estimated temperatures in the streams for different shade conditions can be portrayed.

- The model was used to describe stream shade considering: 1) only topography (no vegetation), 2) with vegetation reflecting late-seral stage (fully mature) tree growth, and 3) with current vegetation conditions.

- Model results were then modified to an adjusted potential shade condition for use in developing target stream temperatures.

As a key step in model development,, input on the vegetation type, height, and extent is required for both potential and current vegetation conditions. Vegetation information was developed from available GIS coverages, literature information on occurrence and characteristics of particular tree species, field observations in the watershed, and review of historic and recent aerial photos.

The Timberland Task Force (TTF) Klamath Province habitat database developed as part of the Klamath Region Vegetation Mapping Project was the primary source of distributed (watershed-scale) vegetation information. Particularly useful database fields included the vegetation classification by Wildlife Habitat Relationships (WHR) type, tree size classes (classified into dbh ranges), and estimates of percent conifer/percent hardwood for each polygon mapped in the coverage. A polygon is a closed shape defining an area of similar characteristics. To describe potential vegetation height conditions, the mature tree heights (Table 5-3) for hardwoods and conifers by vegetation class (WHR type) were combined with the polygon percent conifer and percent hardwood values to calculate polygon-specific potential vegetation heights. For current vegetation conditions, an additional step was performed. Each polygon in the GIS coverage has an associated dbh class. Using the conversions in Table 5-4, dbh information was converted to estimated current vegetation heights for each polygon.

Topography

Topography was developed using 10m Digital Elevation Model (DEM) input acquired from CDF and developed by the U.S. Geological Survey). The DEM results in development of the hydrographic network and aspect of streams in addition to the topography of the watershed.

Vegetation Height Estimates for Current and Potential Conditions

As a first step, a summary of tree species occurring in the Navarro watershed was compiled from published reports (Griffin and Critchfield 1972) and field observations, and is presented in Table 5-3. For each species, reported heights of mature trees were compiled from a variety of sources (Burns and Honkala1990; Fowells 1975; Hickman 1993; Munz 1968; Sudworth 1908; Whitney 1998). For each species, a typical mature tree height was selected from the compiled values. In addition, estimated tree heights associated with diameter at breast height (dbh) classes were developed (Burns and Honkala 1990; Fowells 1975) for later use in characterizing current vegetation height conditions, as seen in Figure 5-9. Next, key tree species associated with the Klamath Region Vegetation Mapping Project habitat database vegetation types were identified.

Examples of vegetation types are redwood forest, Douglas fir forest, and mixed hardwood-conifer forest. For each vegetation type, height values were developed for each dbh class for groupings of conifers and hardwoods. Results are presented in Table 5-4.

Vegetation Extent

Vegetation extent near streams was handled differently for potential and current conditions. First, no attempt was made to separate Class I from Class II streams. As indicated in EPA (1999), eliminating Class II streams from consideration in the vegetation and shade scenarios can result in significant underestimate of the potential suitable aquatic habitat in the watershed. For this analysis, all drainages shown on USGS 1:100,000 topographical coverages as blueline streams were included in the analysis. In addition, streams shown on USGS 1:24000 topographical coverages occurring within 300 meters of the 1:100,000 streams also were included in the analysis. The underlying stream network was developed from USGS topographic data, available as a 10m Digital Elevation Model (DEM) coverage. The coverage is generally

Table 5-3
Summary of Tree Species and Mature Height Estimates for Near-Stream Vegetation Characterization

Tree Name		Mature Heights									Selected Value	
		Sudworth		Whitney	Burns & Honkala		Munz		Jepson Manual			
Common	Latin	Typical (ft)	Extreme (ft)	(ft)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)
onifers												
rand fir	*Abies grandis*	150-200	250-275	100-200	140-200	43-61	40-295	12-90	<240	<73	190	58
ishop pine	*Pinus muricata*	30-60	75-80				50-80	15-25	<165	<51	65	20
onderosa pine	*Pinus ponderosa*	125-140	150-200		130	40	50-230	15-70	<225	<68	130	40
ouglas fir	*Pseudotsuga menziesii*	180-190	200	80-200	250	76	<230	<70	<220	<67	190	58
edwood	*Sequoia sempervirens*	190-280	300-350	200-325	300	91	165-330	50-100	<380	<115	280	85
ardwoods												
igleaf maple	*Acer macrophyllum*	60-80		30-70			15-100	5-30	15-100	5-30	70	21
alifornia buckeye	*Aesculus californica*	10-20	25-50	25			23-40	7-12	12-40	4-12	35	11
Vhite alder	*Alnus rhombifolia*	50-75		70			35-115	10-35	<115	<35	70	21
ed alder	*Alnus rubra*	60-90		40-100	100-130	30-40	50-80	15-25	<80	<25	80	24
acific madrone	*Arbutus menziesii*	60-80		20-80	110	34	16-130	5-40	<130	<40	110	34
regon ash	*Fraxinus latifolia*	60-75		80			35-80	10-25	<80	<25	75	23
anoak	*Lithocarpus densiflorus*	50-75	80-85	50-80	150	46	65-150	20-45	<100	<30	90	27
lue oak	*Quercus douglasii*	30-40	60-75				20-65	6-20	20-65	8-20	60	18
regon oak	*Quercus garryana*	50-60	75-90	30-70	70		25-65	8-20	25-65	8-20	65	20
alifornia black oak	*Quercus kelloggii*	50-75	80-85	30-80	82	25	35-80	10-25	<80	<25	80	24
alley oak	*Quercus lobata*	60-75	80-100				40-115	12-35	<115	<35	80	24
nterior live oak	*Quercus wislizenii*	25-50	60-75	30-70			35-70	10-22	30-70	10-22	70	21
oodding's black willow	*Salix gooddingii*	25-50	60-80				35-65	10-20	<100	<30	60	18
acific willow	*Salix lucida ssp.lasiandra*	25-30	40-50	20-50			20-50	6-15	<30	<10	40	12
alifornia bay	*Umbellularia californica*	30-40	60-80	40-80	100	30	100-150	30-45	<150	<45	110	34

eferences:

Burns, R. M., and B. H. Honkala, 1990. Silvics of North America. Agriculture Handbook 654. USDA.
Hickman, James C., ed. 1993. The Jepson Manual: higher plants of California. University of California Press.
Munz, P. and D. D. Keck, 1968. A California Flora, University of California Press, Berkeley.
Sudworth, G., 1908. Forest Trees of the Pacific Slope. Dover Publications, New York, 1967.
Whitney, S. 1998. Western Forests. Chanticleer Press, National Audubon Society Nature Guides.

Figure 5-9. Relation of Tree Height to Diameter at Breast Height

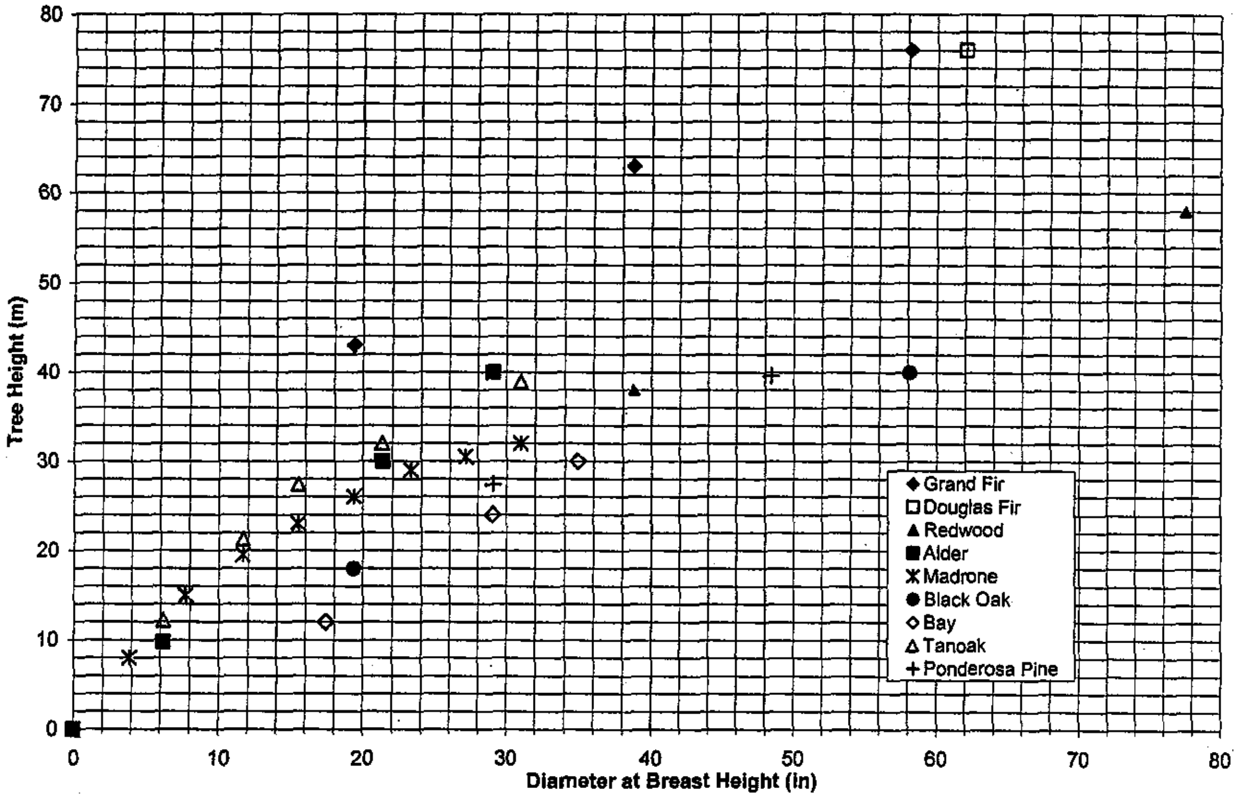


Table 5-4
Summary of Vegetation Class Tree Heights and DBH Conversions

DBH (in)	Tree Height (m)										
	CCP	DFR		KMC		MHC/MHW		PPN		RDW	
		Conifer	Hardwood	Conifer	Hardwood	Conifer	Hardwood	Conifer	Hardwood	Conifer	Hardwood
1-6		14	5	9	6	10	5	4	4	8	5
6-11		24	12	17	13	18	12	10	9	14	12
11-24		31	21	30	25	31	21	20	17	25	23
>24		42	31	40	34	42	31	27	27	36	34
>36		56	35	46	34	56	35	40	34	58	34
Reference	18	58	27	46	24	61	27	40	24	80	27

Vegetation Types:

CCP	Closed-Cone Pine	MHW	Mixed Hardwood
DFR	Douglas Fir	PPN	Ponderosa Pine
KMC	Klamath Mixed Conifer	RDW	Redwood
MHC	Mixed Hardwood Conifer	WFR	White Fir

Notes:
DFR values were used for WFR type.
For each polygon, conifer and hardwood height estimates were combined with TTF conifer and hardwood percentages to develop average heights.

close to the USGS blueline streams except in areas of low slope and some areas near drainage headwaters.

For potential conditions, the unvegetated channel was defined using bankfull width, centered on the centerline of the stream channel. Bankfull widths were assigned using a relationship for the Mendocino Coast developed with techniques and equations described in Leopold, Wolman and Miller (1964) and stream channel geometry information (hydraulic geometry exponents needed for the equations) for Mendocino Coast streams developed by Leopold (2000) and as part of this analysis (Figure 5-10). For current conditions, aerial photographic coverage for the watershed flown in 1996 was reviewed and compared to current USGS topographic coverage representing the occurrence of trees and forested areas in the watershed. These results were used to identify the current occurrence of trees near streams. This analysis was limited to areas within 300 meters of the blue line streams mapped on USGS 1:100,000 topographic coverage.

Sun Track for Mean MWAT Date

The GIS model uses sun position in calculating shading from topography and vegetation. Equations presented in Boes (1981) were used to calculate hourly solar azimuths and altitudes for July 22, the mean MWAT date for the watershed. These values were then used as input to the ArcInfo HILLSHADE module. A HILLSHADE simulation was run for each hour of the MWAT date. The results then were weighted to reflect variations in solar intensity during the day, using the solar radiation intensity distribution for July from the Solar Pathfinder sunpath diagram for a horizontal collector at 37-43°N latitude. These results were summed to develop watershed-scale portrayals of shade conditions.

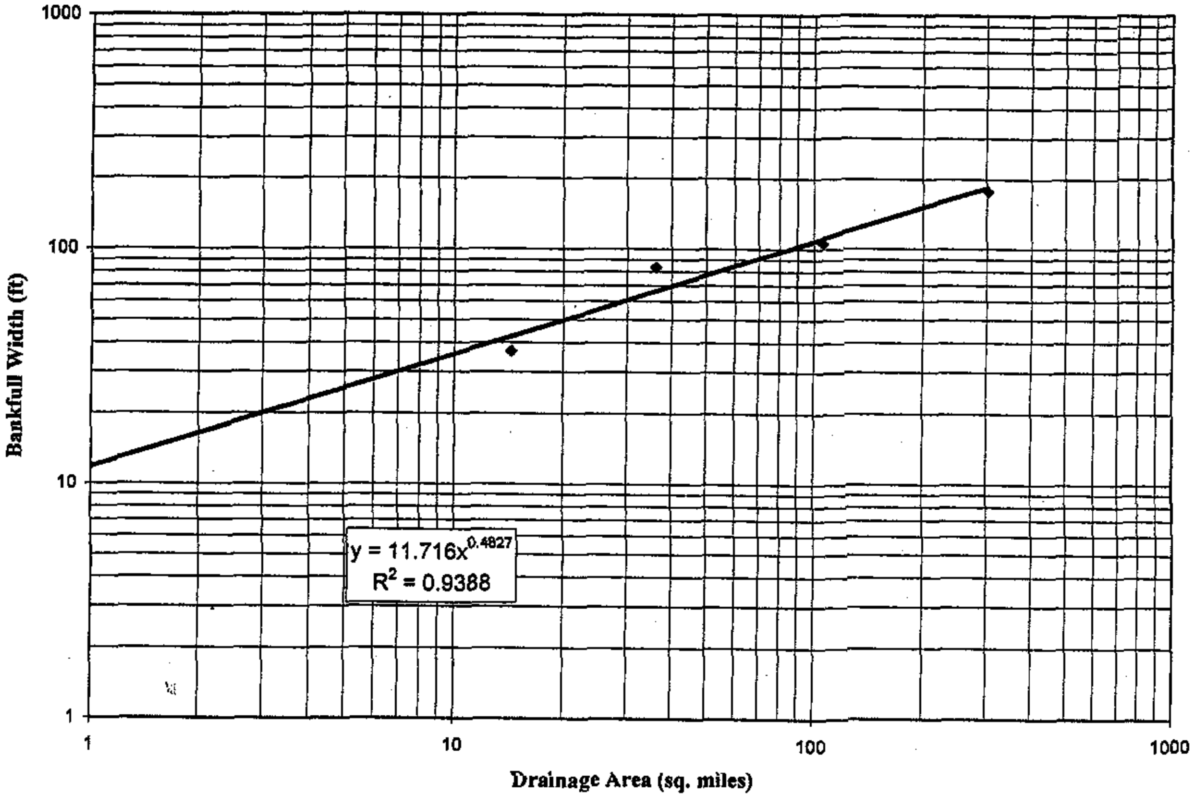
GIS Model

The GIS model consists of the combination as appropriate of coverages of current and potential vegetation heights and extent, topography, and sun track to estimate shading on the streams of the watershed for both current and an idealized potential shade condition. Potential shade conditions were reduced by 10% to represent an adjusted potential shade condition that was used in developing target stream temperatures.

Results

Results of the GIS effective shade calculations are presented in Figure 5-11. Figure 5-12 presents the difference between the potential and current shade conditions along the stream network, and the locations and magnitude (on a percentage basis) where current shade is less than potential shade. This figure is useful in highlighting locations where opportunities for improving shade conditions (and reducing solar loads) exist.

Figure 5-10. Bankfull Width vs. Drainage Area, Mendocino Coast Area



Insert
Figure 5-11
Effective Shade for Current and Potential Vegetation Conditions

(Front)

Figure 5-11

(Back)

Insert
Figure 5-12
Effective Shade between Current and Potential Vegetation Conditions

Insert

Figure 5-12

(Back)

Figure 5-13 shows the results for adjusted potential shade and current shade aggregated into cumulative frequency curves for the entire set of stream reaches included in the analysis. These curves are analogous to curves such as grain size distribution curves that show the percent of the grain size sample that is finer than a given grain diameter. In this case, the curves show the percent of the stream length in the watershed that is shadier than a given shade value.

Table 5-5 presents in tabular form the same information as Figure 5-13. Table 5-5 constitutes the loading capacity for the watershed and hence the TMDL for temperature for the watershed.

For both potential and current conditions, the shade results were converted to estimated MWAT values using the following relationship between modeled predicted reach-averaged effective shade and site-averaged MWAT values:

$$\text{MWAT} = -8.15 \times \text{Effective Shade}(\%) + 21.7$$

Figure 5-14 shows estimated temperatures on a degree Celsius scale that is broken down into salmonid specific temperature ranges. As described in Section 4.4.1, stream temperatures less than 15°C are characterized as good for both Coho and Steelhead. Temperatures between 15°C and 17°C are characterized as marginal for Coho and good for Steelhead. Temperatures between 17°C and 19°C are characterized as poor for Coho and marginal for Steelhead. Temperatures above 19°C are poor for both Coho and Steelhead.

The difference between current and potential temperature conditions is presented for the watershed in Figure 5-15.

Figure 5-16 presents cumulative frequency plots of temperature comparing current and potential MWAT values as they relate to current and adjusted potential vegetation conditions. These curves show the percent of the stream length of the watershed with temperatures less than the given MWAT value. Table 5-6 presents this same information in tabular form. Table 5-6 shows stream length classified by temperature for both adjusted potential and current vegetation conditions. Under adjusted potential conditions, when vegetation has reached its fully mature height, stream temperatures in the Navarro are predicted spann the range from poor/unsuitable to good for coho and steelhead in the watershed. Comparison of the stream lengths for potential and current conditions indicates a potential increase of 354 km (221 miles) of stream good or marginal as summer rearing habitat for coho and a potential increase of 183 km (114 miles) of stream good or marginal for steelhead. This difference is an indicator of the load reduction necessary to restore beneficial uses associated with the cold water fishery.

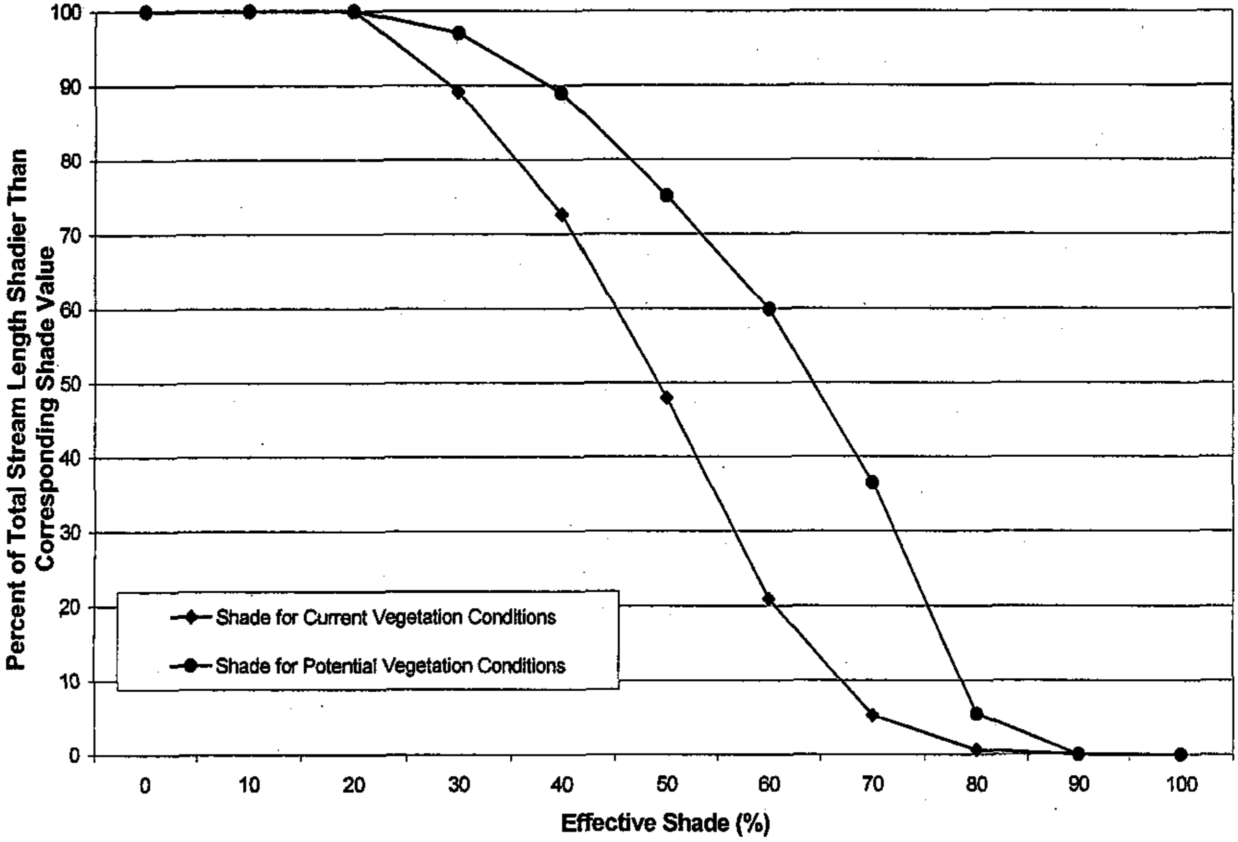


Figure 5-13. Shade Exceedance Curves for Current and Adjusted Potential Vegetation Conditions, All Stream Reaches

Table 5-5. Summary of Stream Lengths in Shade Classes for Current and Adjusted Potential Vegetation Conditions

Shade Class	Stream Length Current Vegetation Conditions						Stream Length Potential Vegetation Conditions					
	By Class			Cumulative			By Class			Cumulative		
(%)	(miles)	(km)	% of Total	(miles)	(km)	% Shadier	(miles)	(km)	% of Total	(miles)	(km)	% Shadier
0	0	0	0.0	0	0	100.0	0	0	0.0	0	0	100.0
10	0	0	0.0	0	0	100.0	0	0	0.0	0	0	100.0
20	58	93	10.9	0	0	100.0	16	25	2.9	0	0	100.0
30	89	142	16.5	58	93	89.1	43	69	8.1	16	25	97.1
40	132	211	24.6	147	235	72.6	74	119	13.9	59	94	89.0
50	145	232	27.0	279	446	48.0	81	130	15.2	133	213	75.1
60	84	134	15.6	423	677	20.9	125	200	23.4	214	343	59.9
70	25	40	4.6	507	811	5.3	166	265	31.0	340	544	36.5
80	3	5	0.6	532	851	0.7	29	47	5.5	506	809	5.5
90	0	0	0.0	535	856	0.0	0	0	0.0	535	856	0.0
100				535	856	0.0				535	856	0.0
Total	535	856					535	856				

Insert
Figure 5-14
Stream Temperatures for Current and Potential Vegetation Conditions

(Front)

Figure 5-14

(Back)

Insert
Figure 5-15

Difference in MWAT
based Stream Temperatures
Between Current and Potential
Vegetation Conditions

(Front)

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Figure 5-15

(Back)

Figure 5-16. MWAT-Based Temperature Exceedance Curves for Current and Potential Vegetation Conditions, All Stream Reaches

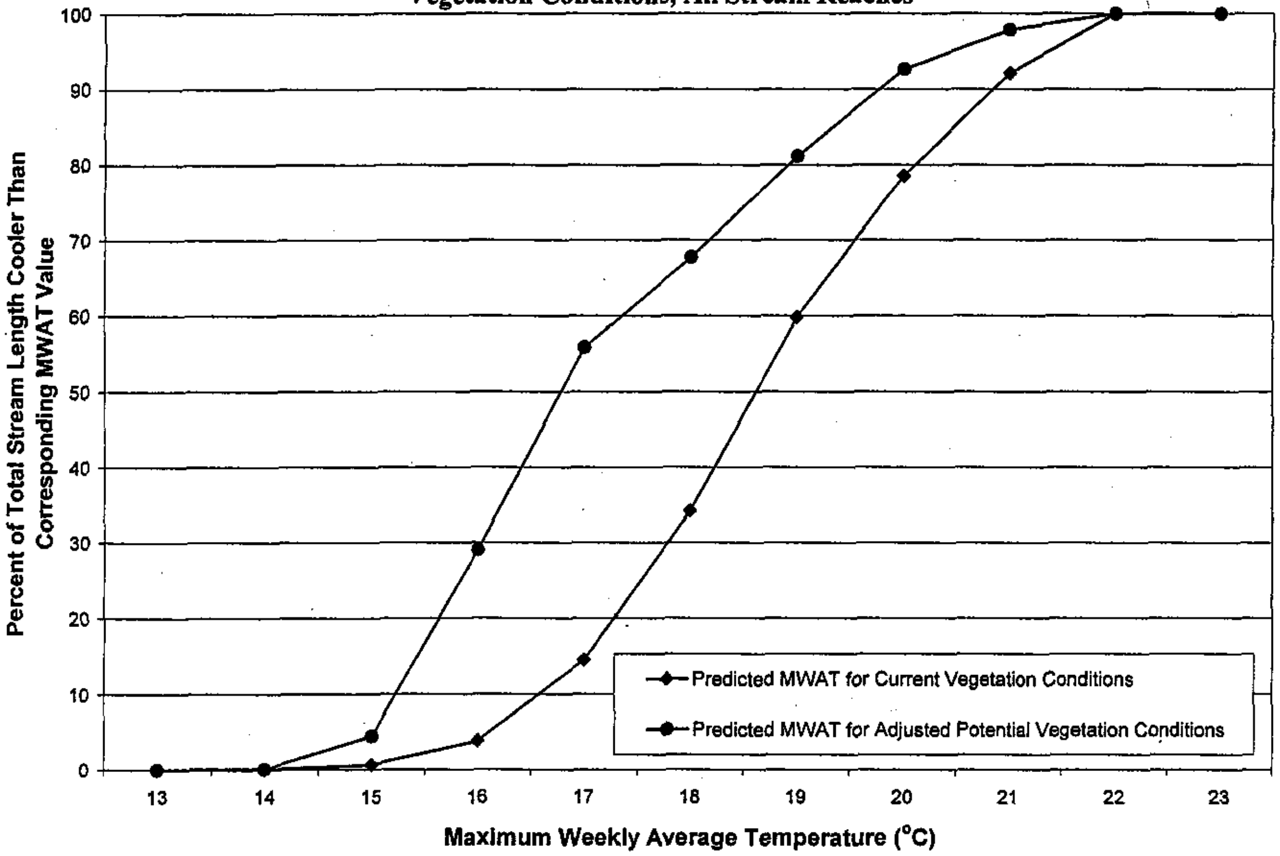


Table 5-6. Summary of Stream Lengths in MWAT Classes for Current and Adjusted Potential Vegetation Conditions

MWAT Class		Stream Length Current Vegetation Conditions						Stream Length Potential Vegetation Conditions					
		By Class			Cumulative			By Class			Cumulative		
°C	°F	(miles)	(km)	% of Total	(miles)	(km)	% Cooler	(miles)	(km)	% of Total	(miles)	(km)	% Cooler
12	53.6	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
13	55.4	0	0	0.0	0	0	0.0	0	1	0.1	0	0	0.0
14	57.2	3	5	0.6	0	0	0.0	23	38	4.4	0	1	0.1
15	59	17	27	3.2	4	6	0.7	131	210	24.6	24	38	4.5
16	60.8	57	92	10.7	20	33	3.8	144	230	26.8	155	249	29.0
17	62.6	106	169	19.7	78	124	14.5	63	101	11.8	299	478	55.9
18	64.4	137	219	25.6	183	293	34.2	72	115	13.4	362	580	67.7
19	66.2	100	160	18.7	320	512	59.8	62	99	11.5	434	695	81.1
20	68	73	116	13.6	420	673	78.5	28	45	5.2	496	793	92.7
21	69.8	42	67	7.9	493	789	92.1	11	18	2.1	524	838	97.9
22	71.6	0	0	0.0	535	856	100.0	0	0	0.0	535	856	100.0
23	73.4	0	0	0.0	535	856	100.0	0	0	0.0	535	856	100.0
24	75.2	0	0	0.0	535	856	100.0	0	0	0.0	535	856	100.0
Totals		535	856					535	856				

5.5 Effective Shade Curves

To apply these results to particular reaches of the watershed requires correlation of vegetation type, stream aspect, and active (unvegetated) channel width with effective shade. These relationships are functions of vegetation type, channel geometry, topography, and solar position.

Two models used to predict shade given channel characteristics as input were tested for use in estimating potential shade on a reach-by-reach basis. ODEQ (1999) has developed an Excel-based spreadsheet that allows calculation of effective shade as a function of vegetation height, stream aspect, active channel width, stream buffer width and buffer density. The spreadsheet is based on equations presented by Boyd (1996) and expanded for TMDL applications. USGS (Bartholow 1999) also has a shade model. The two models were tested using observations of channel characteristics at sites where Solar Pathfinder measurements were taken. Results are presented in Figure 5-17. The ODEQ spreadsheet, named SHADE, was selected for use in developing target shade curves for different vegetation types occurring along riparian corridors of the Navarro River and its tributary streams because it is better adapted for TMDL applications and has been approved as part of a temperature TMDL (ODEQ 2000).

Effective shade targets for the vegetation classes occurring in the watershed were set at 90% of the potential vegetation height for the class (Table 5-4). Effective shade curves are presented for redwood (RDW) forest (buffer height of 63m), Douglas Fir (DFR) and Mixed Hardwood-Conifer (MHC) forest (40m), Klamath Mixed Conifer (KMC) and Ponderosa Pine (PPN) forest (35m), and Oak Woodland (20m) (Figures 5-18, 5-19, 5-20, and 5-21). Buffer widths are assumed at 30m for all curves. Buffer densities are set at 80% or greater. Effective shade curves represent vegetation types occurring along riparian corridors in the watershed, as noted on the figures. The potential effective shade value corresponding to conditions at a particular is the load allocation for that location. The difference between current shade conditions at a location and the potential effective shade as indicated on the appropriate curve constitutes the targeted increase in effective shade. The sum of the load allocations for individual locations in the watershed is equivalent to the loading capacity for the watershed as a whole..

5.6 Margins of Safety & Seasonal Variation

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

- This report analyzes temperature and sediment separately. Some improvements in stream temperature that may result from reduced sedimentation are not calculated explicitly. Reduced sediment loads could be expected to lead to increased frequency and depth of pools and to reduced wetted channel width:depth ratios. These changes would tend to result in lower stream temperatures overall and in more lower temperature pool habitat. These changes are not accounted for in the analysis and provide a margin of safety.

- While the potential shade conditions used to calculate the loading capacity assume that the occurrence of site potential vegetation extends to the bankfull channel width, the effective shade curves can be applied to either current channel widths or to projected bankfull widths. Application of the curves to current channel conditions does not account for channel narrowing that may occur as a result of reduced sediment loads. These effects constitute a margin of safety.

- The effects of changes to streamside riparian areas towards mature trees will tend to create microclimates that will lead to improvements in stream temperatures. These effects were not accounted for in the temperature analysis and provide a margin of safety.

- Changes in streamside vegetation toward larger, mature trees will increase the potential for contributions of large woody debris to the streams. Increases in large woody debris benefit stream temperatures and associated cool water habitat by increasing channel complexity, including the number and depth of pools. These changes were not accounted for in the analysis and provide a margin of safety.

With respect to seasonal variations in stream temperatures, the analysis takes the most extreme heating conditions as measured by the 7-day running average of temperatures as constituting a limiting condition for salmonid survival with respect to temperature.

Figure 5-17. Predicted Effective Shade vs. Observed Effective Shade, July

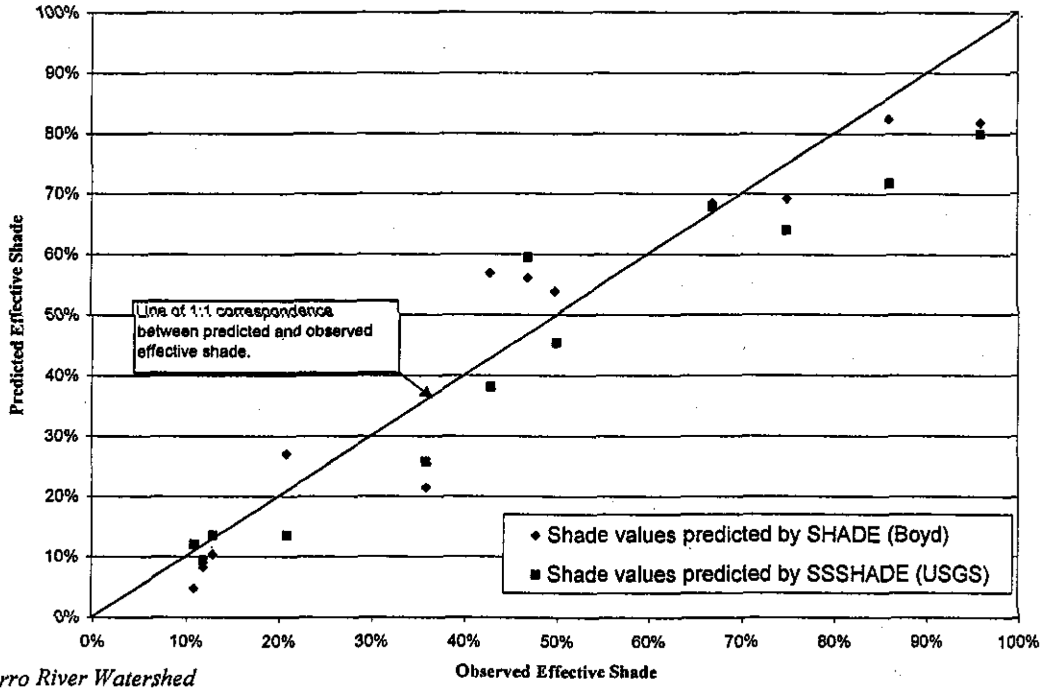


Figure 5-18. Effective Shade vs. Channel Width, Redwood Forest (RDW) Buffer Height=63m

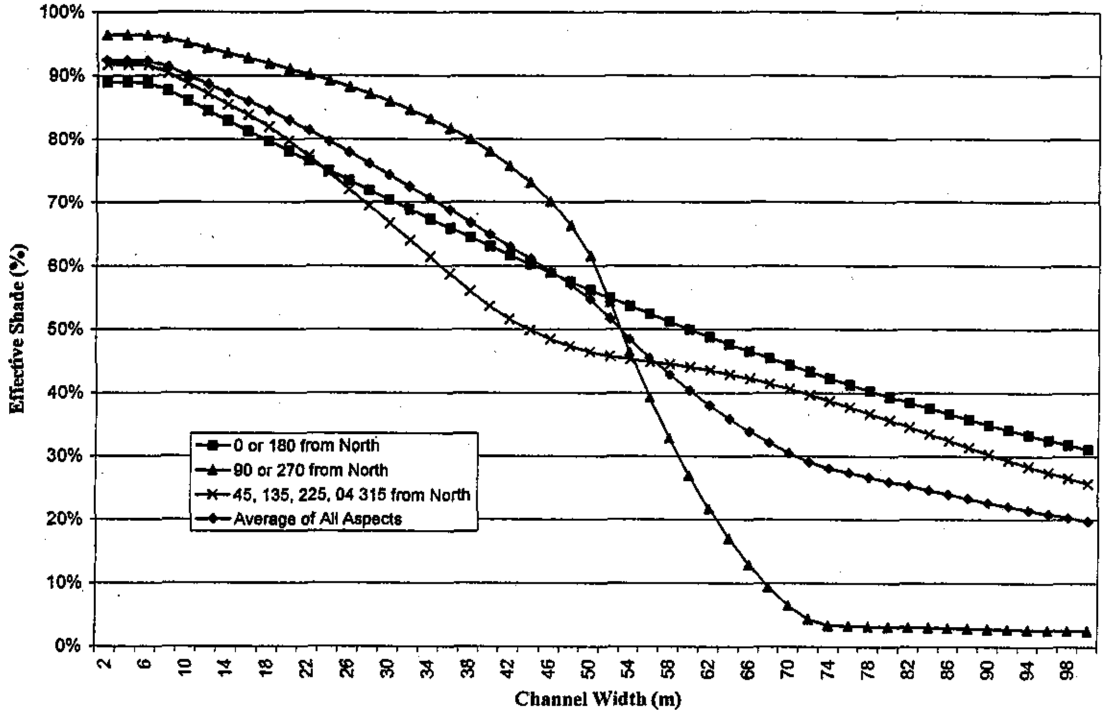


Figure 5-19. Effective Shade vs. Channel Width, Douglas Fir Forest (DFR) and Mixed Hardwood-Conifer Forest (MHC), Buffer Height=40m

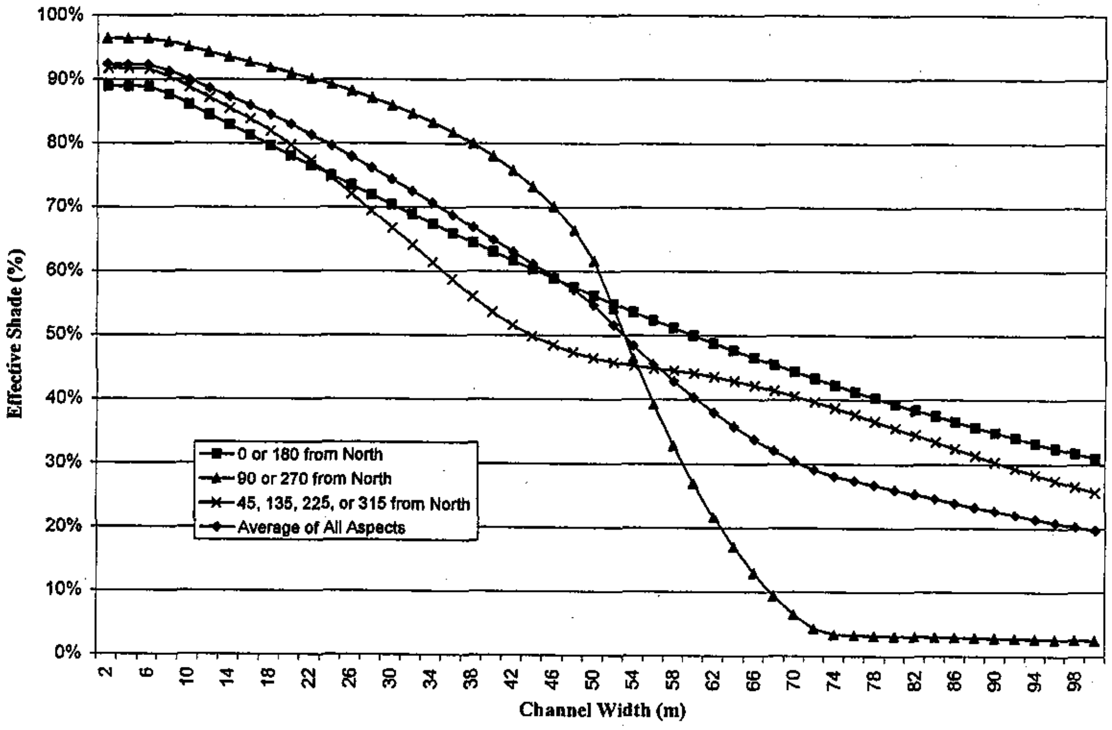


Figure 5-20. Effective Shade vs. Channel Width, Klamath Mixed Conifer Forest (KMC) and Ponderosa Pine Forest (PPN), Buffer Height=35m

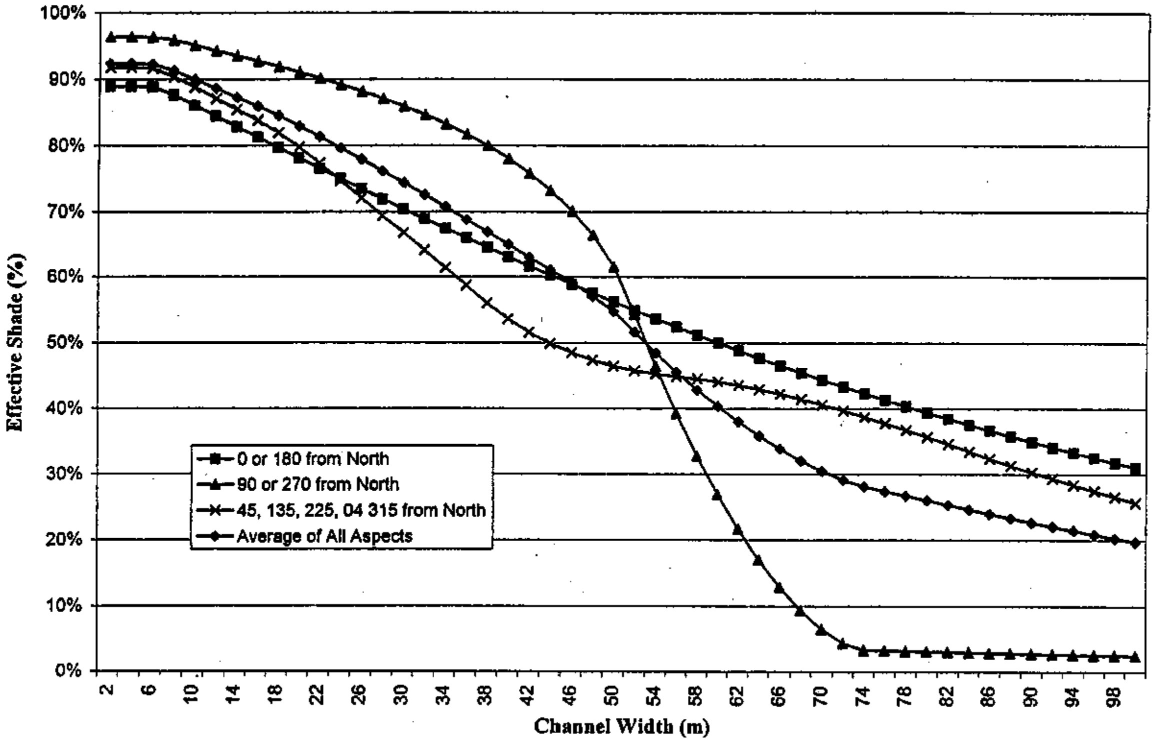
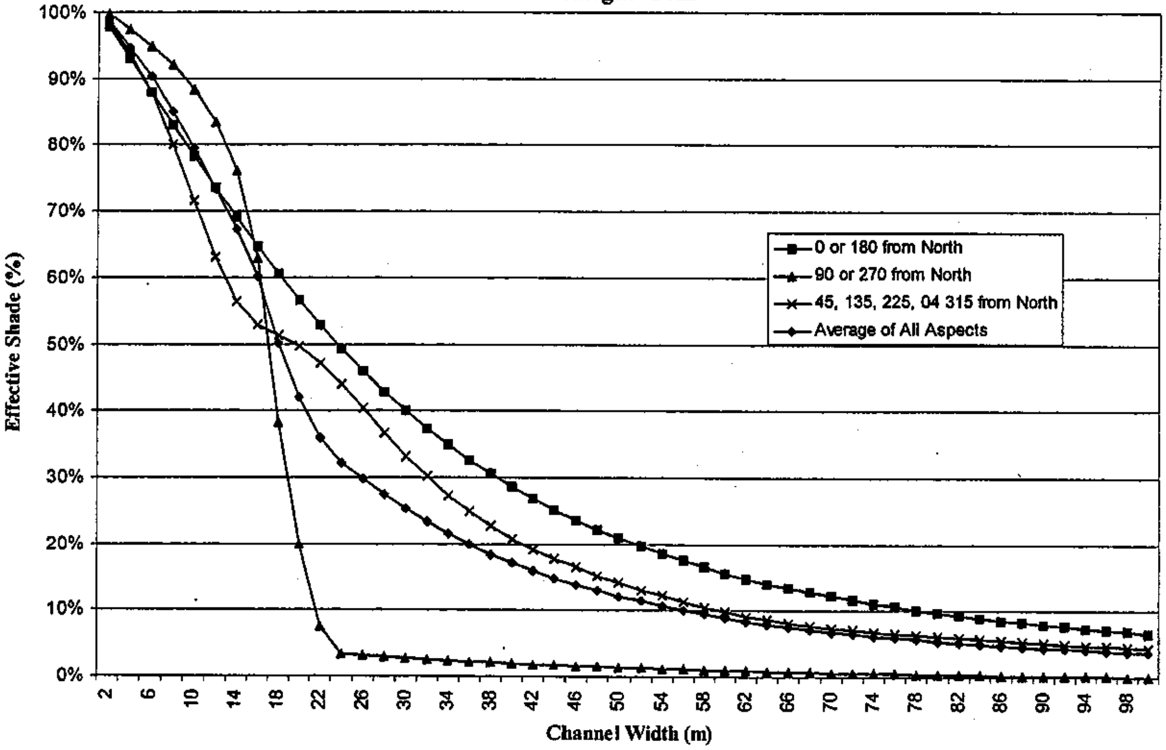


Figure 5-21. Effective Shade vs. Channel Width, Oak Woodland Buffer Height=20m



CHAPTER 6
SEDIMENT

6.1 Source Analysis

The purpose of the source analysis is to identify the various erosion processes in the watershed and to quantify the estimated sediment yield contribution of those processes in a way that allows them to be compared to one another.

The results of the Source Analysis show that human-caused sediment sources deliver approximately 40% of the total sediment yield of the Navarro River watershed. The dominant sources of human-caused sediment delivery (road-related sources) reflect the dominant land uses of the watershed. Both timber production and ranching make use of a vast network of roads, which deliver the majority of the human-caused sediment. Vineyards, which occupy approximately two percent of the watershed, contribute a small amount in relation to other processes across the watershed. Vineyards do have potential to deliver large volumes of sediment to streams, and thus have potential to cause locally significant deleterious impacts.

The approach taken to develop the source analysis for sediment yield focuses on rates of sediment yield that have occurred in the recent past (i.e. past 2twenty years). The estimated rates are based on studies performed in the Navarro River watershed, studies performed in nearby watersheds, interpretation of aerial photographs by Regional Water Board staff for this TSD, and other published literature relating to sediment yield processes. Sediment delivery calculations for processes estimated by Regional Water Board staff are included in Appendix C.

6.1.1 Methods

A significant amount of information used in the sediment source analysis came directly from the Navarro Watershed Restoration Plan (NWRP). Estimates of sediment yield rates from hillslope and streamside processes reported in the NWRP have been incorporated into the sediment source assessment. The rates reported in the NWRP were derived from field reconnaissance and measurements, as well as literature values taken from studies of similar watersheds.

Data describing current conditions of rural roads were obtained from Danny Hagans of Pacific Watershed Associates (PWA). The data is based on detailed surveys of forty miles of roads in the Mill and Dago Creek subwatersheds conducted during the summer of 1998. The data is assumed to reflect the typical conditions of rural non-industrial dirt roads in the Navarro River Watershed. The assumption is reasonable given that the majority of dirt roads in the watershed observed by Regional Water Board staff have been built with a similar design (i.e. cut-and-fill construction, insloped road surface, inboard ditch, outside berm, undersized stream crossing structures, and inadequate drainage of runoff). Also, since the roads PWA surveyed are in the Navarro River watershed, it is reasonable to assume that they have been subjected to the same climatic conditions as the remainder of the roads in the watershed.

Information pertaining to sediment yield on industrial forestlands was taken from the Albion Watershed Analysis (Mendocino Redwood Company 1999) and the Garcia Watershed Analysis

(Louisiana-Pacific 1998). Data describing rates of sediment yield from industrial timber roads, skid trails, and hillslope processes in the neighboring watersheds was used to estimate the sediment contribution from the same sources in the Navarro watershed. Data from the Garcia watershed was assumed to be an upper bound, and data from the Albion watershed a lower bound, based on the opinion of Chris Surfleet, Mendocino Redwood Company Watershed Hydrologist (Surfleet 2000). Surfleet communicated to the Regional Water Board staff his belief that the roads in the Navarro contribute more sediment than those in MRC's Albion ownership, but not as much as the roads in the company's Garcia ownership. His opinion was based on observations and experiences he gained while preparing the Garcia and Albion Watershed Analyses, and his comparison of MRC's Navarro, Garcia, and Albion roads.

Aerial Photo Analysis

Aerial photos taken in 1984 and 1996 were analyzed to quantify sources of erosion (shallow landslides, deep-seated landslides, new gullies, road surface area, etc.) and their associated land uses, to improve the road database, and to quantify the location and extent of lands under cultivation. The results of the exercise provided Regional Water Board staff with high quality estimates of the length of roads in the basin, the length of recently built roads, the frequency of use of those roads, and the magnitude of management-related mass wasting (not related to roads) in relation to natural mass wasting. This information was then multiplied by rates taken from other studies to generate estimates of sediment delivery scaled to the magnitude of processes in Navarro watershed.

Erosion features that existed on the 1996 photos but not on the 1984 photos were measured in order to gain information on the rate of erosional processes since 1984. The reasons for choosing the '84 to '96 time period were that it represented current land management trends, spanned a time period that included a variety of water years (normal, wet, and drought), and revealed the current extent of the road network. The areal extent of each erosional feature was measured and a depth assumed for each type of feature. Landslides were assumed to have a depth of 5.5 feet and road fill failures were assumed to have a depth of four feet, based on data from surveys conducted by Louisiana-Pacific in the Garcia River watershed.

For each erosion feature a determination was made as to whether or not the feature was related to a management activity. Features were determined to be management related if there was evidence of past ground-disturbing management activity. Examples of such cases include; road fill failures, gullies and shallow debris slides in vineyards, gullies originating from new roads, landslides in clear-cut timber harvest units, etc.

6.1.2 Rates of Road-Related Sediment Yield

Rates of road-related sediment yield were developed from a variety of data. A list of road-related erosion processes and their rates is shown in Table 6-1. Sediment delivery calculations for processes estimated by Regional Water Board staff are included in Appendix C.

Table 6-1
Road Related Mass Wasting & Corresponding Erosion Rates

TIMBER ROADS

Parameter	Value	Source
Road-Related Mass Wasting	47 tons/mi/yr	MRC 1999; L-P 1998
Road-Related Surface Erosion	48 tons/mi/yr	MRC 1999; L-P 1998
Skid Trail Surface Erosion	361 tons/mi^2/yr	MRC 1999; L-P 1998

SURFACE EROSION FROM EXISTING ROADS

Parameter	Value	Source
Primary Roads	140.6 tons/mi/yr (>45" precipitation) 72tons/mi/yr (<45" precipitation)	WFPB 1997; Hagans 2000
Secondary Roads	37.6 tons/mi/yr	WFPB 1997; Hagans 2000
Rarely Used Roads	5.3 tons/mi/yr (>45" precipitation) 4.3 tons/mi/yr (<45" precipitation	WFPB 1997; Hagans 2000

SURFACE EROSION FROM RECENTLY CONSTRUCTED ROADS

Parameter	Value	Source
Primary Roads	98.8 tons/mi/yr (>45" precipitation) 54.9 tons/mi/yr (<45" precipitation)	WFPB 1997; Hagans 2000
Secondary Roads	33 tons/mi/yr	WFPB 1997; Hagans 2000
Rarely Used Roads	12.4 tons/mi/yr (>45" precipitation) 11.75 tons/mi/yr (<45" precipitation	WFPB 1997; Hagans 2000

RURAL ROAD MASS WASTING

Parameter	Value	Source
Stream Crossing Erosion	11.1 tons/crossing/yr	Hagans 2000; Furniss et al. 1998
Cutbank and Fillslope Failures	19.7 tons/mi/yr	Hagans 2000
Gullies	21.2 tons/mi/yr	Hagans 2000

Rates of road-related sediment yield for roads on industrial timberlands were taken from the Albion Watershed Analysis (Mendocino Redwood Company 1999) and the Garcia Watershed Analysis (Louisiana-Pacific 1998). Both of these analyses made use of the Washington Forest Practice Board's watershed analysis methodology. Application of the Garcia and Albion data to the industrial timberlands of the Navarro assumes that road construction and logging practices, as well as the rates of activities, in the three watersheds have been similar over the past twenty years. This is a reasonable assumption given that the three areas were owned and managed by the same company over the time period. Indeed, it is likely that the same personnel were responsible for building and maintaining the roads, and that the rate of harvest was nearly the same.

Sediment yields attributable to erosion of skid trails was also estimated from data reported in the Garcia and Albion Watershed Analyses. The average rate of skid trail erosion per square mile of areas harvested by tractor yarding in the Garcia and Albion watersheds was applied to the area harvested by tractor yarding in the Navarro River watershed. The assumption is that tractor yarding practices employed on L-P's Garcia and Albion properties has resulted in nearly the same rate of sediment delivery as tractor yarding practices on timberlands in the Navarro watershed. This is a reasonable assumption given the Garcia, Albion, and Navarro watersheds have nearly identical geology, topography, and climates. The area tractor yarded in the Navarro watershed was estimated from randomly sampling a subset of timber harvest plan (THP) areas on aerial photos and extrapolating the percentage of the THP area tractor yarded to the rest of the timber harvest plans.

Rates of road-related surface erosion for non-industrial forest and rangeland roads were derived from combinations of locally collected data and a modified version of the Washington Forest Practices Board's (WFPB) watershed analysis methodology. Values of average road width and hydrologic connectivity provided by PWA were combined with aerial photo data to provide information required for road surface erosion estimates via the modified WFPB methodology.

A map of the road network was created based on interpretation of aerial photos. The study period used to characterize the road network was from 1984 to 1996. Roads were categorized as being built before or after 1984 and as either primary, secondary, or as recently abandoned / rarely used. Roads that existed in the past but were un-driveable in 1984 were not recorded. It was assumed that these roads have not contributed a significant quantity of sediment since 1984. This assumption was based on observations that on these roads many stream crossings had already failed, unstable fills had already caused debris slides, and the gullies originating from these roads appeared to have stabilized.

The categorization of roads by use level was a subjective process. In most cases, the level of use a road received was apparent; roads that lead to residences can be categorized as primary with a high level of confidence, as can roads that are rarely used. Categorization of secondary roads was more uncertain. Generally speaking, roads were categorized as secondary when they appeared to receive frequent use (i.e. no vegetation on road surface) but did not lead to primary structures, such as houses and farming facilities. When roads led to small cabins or barns, which are often only used seasonally, a subjective judgement was made whether the road was primary, secondary, or rarely used. In cases where staff felt uncertain, the higher use level was assumed.

In the WFPB methodology, roads are assumed to have the highest rate of erosion for the first two years after construction. Because information detailing the year that roads were constructed was not available, the rate of new road construction in the 12 year period between 1984 and 1996 was assumed to be constant during the time period. For the purpose of the analysis then, all new roads were treated as if they were constructed at the midpoint of the time period. All new road contribution then, is assumed to have occurred six years into the study period, with the corresponding sediment delivery only occurring over the next six years in the study period. The annual sediment yield for the new roads in Table 6-1 appears to indicate that new roads yield less surface erosion than older roads. This is due to the fact that those values report six years of sediment yield averaged over twelve years.

The estimated rate of road surface erosion for industrial timberland roads appears to be less than that for non-industrial roads. The fact that L-P and MRC estimates incorporate the length of their roads that are rock surfaced explains the decreased erosion rate estimate. Regional Water Board staff assumed that the percentage of industrial timberland roads that have been rock surfaced is nearly the same for the Garcia, Albion, and Navarro Watersheds. This is a reasonable assumption given that these lands have been managed similarly by the same company and are in very similar terrain.

Regional Water Board staff assumed that non-industrial forest and rangeland roads have not been rock surfaced. It is likely that portions of non-industrial forest roads are rocked. In the absence of information describing the percentage of those roads that are rocked, Regional Water Board staff conservatively assumed that none of the non-industrial forest and rangeland roads are rock surfaced. This assumption is incorporated into the margin of safety.

Stream crossing erosion yields were estimated by combining information from surveys of 109 stream crossings in the Navarro watershed (Hagans 2000) with detailed stream crossing erosion data collected after large flood events in Washington, Oregon, and Northern California (Furniss et al. 1998). Rates of stream crossing erosion associated with large storms were estimated by applying the rate of failure and distribution of fill volume erosion reported by Furniss et al. to the average volume of stream crossing fill in the Navarro River watershed.

The approach assumes that the rate of stream crossing failure (68%) reported by Furniss et al. (1998) is representative of the rate of failure resulting from large storm events in the Navarro watershed. Regional Water Board staff then used information describing the proportion of stream crossings failing by a given percentage reported by Furniss et al. (1998) coupled with the average fill volume of stream crossings in the Navarro River watershed, to estimate the amount of sediment eroded from stream crossings during large storm events. Regional Water Board staff conservatively used the upper bounds of fill volume erosion (see Appendix C). This may tend to overestimate the true rate of delivery, however the lack of accounting for stream diversion at failed crossings leads to an underestimate. Regional Water Board staff assumed that these two factors roughly cancel each other.

Large storms triggering stream-crossing failures were assumed to occur every ten years, twice since 1980. The assumption that storms triggering stream crossing failures occur once every ten years on average seems reasonable given the flood record. The analysis assumes that the processes that led to stream crossing failures on the road networks surveyed by Furniss et al. (plugging by woody debris and sediment, debris torrents, and hydraulic capacity exceedance) are the same processes at work in the Navarro River watershed. This is reasonable given the similar vegetation, climate, and geology.

Rates of road-related mass wasting on rural non-industrial forest and rangeland roads were estimated from the estimated landslide yield per mile of road reported by PWA. The landslide delivery PWA reports is not time specific. In order to estimate an annual delivery rate, the landslide yield was assumed to be delivered during large storm events. The estimated landslide delivery then was divided by ten years, the estimated rate of occurrence of storm events triggering landslides.

Road-related gully erosion was estimated by best professional judgement based on on-the-ground-observations, aerial photo observations, and the judgement and experience of Pacific Watershed Associates (Hagans 2000). The road-related gully contribution was estimated to be approximately equivalent to the road-stream crossing erosion contribution. The estimated volume of sediment delivered to streams due to failed stream crossings was divided by the total length of roads. The resulting average stream crossing delivery per mile of road was then applied to the length of roads in each subwatershed to estimate the contribution of road-related gullies. The resulting estimate is likely an overestimate of the true rate of delivery associated with road-related gullies. This conservative estimate is incorporated into the margin of safety.

6.1.3 Rates of Sediment Yield Attributed to Vineyards

Very little information describing rates of soil loss from vineyards was available for estimating soil loss from vineyards. The two documents that reported estimates of vineyard erosion simply stated that rills develop and soil loss becomes noticeable when erosion reaches 15 tons/acre/year (White 1986) and 8-15 tons/acre/year (Sotoyome Resource Conservation District 1999). Observations made by Regional Water Board staff indicated that conservation practices used by vineyards (cover cropping, buffer strips, terracing, etc.) are variable. Vineyards with active erosion occurring, as well as vineyards with no soil exposure, were observed. Rate of sediment yield from vineyards was estimated to be 5 tons/acre/year by assuming that the average rate of soil loss is 10 tons/acre/year and approximately 50% of eroded soils reach the stream network. Regional Water Board staff acknowledges the considerable uncertainty of the estimate, however in the absence of better information, estimates erring towards protection of the resource are required. The estimated rate of sediment yield associated with vineyards is assumed to slightly overestimate the true delivery rate, this conservative estimate is incorporated into the margin of safety.

6.1.4 Rates of Delivery Attributed to Shallow Debris Slides

Estimated rates of sediment delivery attributed to shallow debris slides were taken from values reported in the NWRP and modified based on aerial photo analysis. Entrix (1998) estimated the long-term rate of shallow debris slide delivery associated with natural processes by applying results of studies conducted in similar watersheds. Entrix (1998) did not estimate rates of shallow debris slides caused by management activities. To address rates of management-related shallow debris slides, Regional Water Board staff analyzed aerial photos and estimated the ratio of anthropogenic-to-natural shallow debris slides. The results indicate that sediment yield associated with management related shallow debris slides (not including road-related slides) is approximately 32% of the yield associated with shallow debris slides attributed to natural processes.

6.1.5 Stream Bank Erosion and Streamside Sediment Production

Rates of sediment yield from erosion of stream banks and near-stream shallow debris slides were also taken from the NWRP. Entrix (1998) estimated long-term rates of bank erosion for first and second order channels by applying rates of soil creep reported in studies of similar geologic terrain to the channel network. The analysis assumes that rates of bank erosion in these small sub-basins are currently in equilibrium with rates of soil production.

Entrix (1998) estimated rates of stream bank erosion in third order and larger channels from measurement surveys of approximately five miles of streams distributed throughout the Navarro watershed. These estimates were checked for applicability with qualitative bank erosion data collected during channel condition and sediment storage studies on sixteen miles of streams in the Navarro River watershed.

Observations of channel conditions and bank erosion in the Navarro watershed by Regional Water Board staff suggest rates of bank erosion and near-stream shallow debris slide processes in the Navarro have been elevated from historic natural rates. Aggradation and associated changes in channel form appear to have caused significant fluctuations in meander bend geometry. The combination of increased thalweg elevation and unstable meander geometry appears to have resulted in increased vulnerability of stream banks and toes of hillslopes. Although there is undoubtedly some increase in streamside sediment production due to anthropogenic activities, it is extremely difficult to quantitatively evaluate these effects. Therefore, the entire bank erosion and streamside sediment yield is assumed to be natural, and any decrease in bank erosion and streamside sediment yield resulting from reduced cumulative watershed impacts is considered part of the margin of safety.

6.1.6 Gully Erosion

Entrix (1998) used studies of gully erosion in similar watersheds to estimate the sediment yield of gullies in the Navarro River watershed. They used measurements of gully expansion from the Willow Creek watershed in Sonoma County and the Lacks Creek watershed in Humboldt County to estimate gully yields in the melange terrain of the Navarro watershed. Rates of gully erosion in the semi-coherent Coastal Belt geology were approximated from sediment yield studies of Lone Tree Creek in Marin County and Redwood Creek in Humboldt County. Regional Water Board staff compared aerial photos of Lacks Creek, Redwood Creek, and Lone Tree Creek to aerial photos of areas of the Navarro to verify the applicability of measured rates. Comparison of the photos supports the applicability of gully erosion estimates from the studied watersheds to the Navarro River watershed. These photos show that the size, extent, and density of gullies are similar in the reference watersheds when compared to the respective areas of the Navarro watershed.

6.1.7 Source Analysis Results

The results of the sediment source analysis are presented in Table 6-2. Management related sediment yield accounts for approximately 40% of the total sediment yield in the Navarro watershed, which corresponds to an increase equal to 65% of the natural load. The analysis shows that road-related erosion processes are the dominant anthropogenic source of increased sediment yield. The total yield associated with human activities is estimated to be 760 tons/mi^2/year. Regional Water Board staff believes that 760 tons/mi^2/yr may actually be an overestimate of the true yield. In cases of uncertainty conservative estimates are required. These conservative estimates have been incorporated into the margin of safety

Table 6-2
Results of Sediment Source Analysis

	Estimated Yield (tons/mi^2/yr)						
Sediment Source	Anderson	Indian	Mainstem	North Fork	Rancheria	Entire Watershed	
Shallow Landslides	180	210	150	160	200	**180**	**Natural: 1170**
Deep-Seated Landslides	0	0	250	0	130	**90**	
Gullies	550	270	60	30	380	**250**	
Bank Erosion	80	60	40	50	70	**60**	
Inner Gorge/Stream Side Delivery	1180	400	510	280	670	**590**	
Road-Stream Crossing Failures	100	80	140	160	130	**130**	**Human-Caused: 760** **(Roads: 620)**
Road-Related Mass Wasting	90	80	140	150	110	**120**	
Road-Related Gullying	90	90	150	150	110	**120**	
Road-Related Surface Erosion	220	210	320	210	250	**250**	
Skid Trail Erosion	10	20	50	70	30	**40**	
Vineyard Erosion	120	0	110	5	5	**40**	
Management Related Mass Wasting	60	70	50	50	60	**60**	
Totals	**2680**	**1490**	**1970**	**1315**	**2145**	**1930**	

The uncertainty of the sediment yield estimates highlights the need for higher quality data, as well as the need for revision of the TSD as new data becomes available. Multiple data collection and analysis efforts are currently underway in the Navarro River watershed. As these data become available in the next few years, the Navarro Sediment TMDL should be revised to reflect the new information.

Despite the uncertainties of sediment yield estimates, the source analysis and data presented in the summary of water quality impairments supports the following points:

1. Sediment yields in the Navarro River watershed have been dramatically increased by human activities, primarily the construction and existence of roads.

2. Salmonid habitats have been significantly degraded as a result of excess sediment loads, particularly fine sediments.

3. Most human-induced processes attributed to increased sediment yields are easily prevented and corrected.

6.1.8 Loading Capacity Estimate

The purpose of a Loading Capacity Estimate is to estimate the amount of a pollutant that can be discharged to a waterbody without violating water quality standards. The water quality standards that relate to sediment-related concerns in the Navarro watershed are found in the Water Quality Control Plan for the North Coast Region (commonly referred to as the "Basin Plan"). The water quality standards state:

> The suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.
>
> And
>
> Waters shall not contain substances in concentrations that result in deposition of material that causes nuisance or adversely affects beneficial uses.

The beneficial use most sensitive to sediment impacts in the Navarro watershed is the cold water fishery. Thus, the Loading Capacity Estimate attempts to quantify the amount of sediment, in addition to natural sources, that can be introduced to the waters of the Navarro watershed without adversely affecting the cold water fishery resource.

Many studies have documented adverse changes to salmonid habitats following substantial increases in sediment yield. However, these studies present qualitative rather than quantitative relationships. A mathematical relationship relating degradation of specific factors of salmonid habitat quality to increased sediment yields does not exist.

For the Navarro Loading Capacity Estimate, Regional Water Board staff has adopted the approach taken by USEPA for the South Fork Eel TMDL. This approach uses information from the Noyo watershed to relate the sediment yield regime to salmonid abundance. This method assumes that since salmonids were abundant during the 1930s-1950s period, the corresponding sediment yield during that period must have been sufficiently low to allow salmonid habitat of suitable quality to persist. During this era the estimated rate of sediment yield is 470 tons/mi^2/yr. Approximately 370 tons/mi^2/yr of this load is attributed to natural processes. Stated another way, the anthropogenic load during this time period is approximately 25% of the natural load. Given the proximity of the Noyo to the Navarro, as well as their similarities in vegetation, climate, geology, and land use history, Regional Water Board staff conclude that a reasonable loading capacity estimate for the Navarro watershed is an anthropogenic load that is 25% of the natural load. Thus, the total maximum daily load is 125% of the natural load, which translates to 1460 tons/mi^2/yr. Given the hydrologic variability typical of the Northern California Coast Ranges, it is appropriate that the total maximum daily load be calculated as a ten year rolling average.

The loading capacity estimate should be re-evaluated during future revisions of the Navarro Sediment TMDL. An approach that takes into account sediment storage and long term sediment transport capacity should be considered.

6.2 Load Allocation

The purpose of the load allocation is to identify the amount of reduction of individual sediment source categories required to meet the loading capacity. The loading capacity estimate is 125% of the natural load. This corresponds to a natural load of 1170 tons/mi^2/yr (as defined in the Source Analysis) and an anthropogenic load of 293 tons/mi^2/yr when applied to the estimated sediment load. The loading capacity is equivalent to a 60% reduction of the current estimated anthropogenic sediment yield. Applying this reduction to all anthropogenic sources yields the allocations shown in Table 6-3:

Table 6-3
Sediment Source Allocations

Sediment Source	Current Load (tons/mi^2/yr)	Load Allocation (tons/mi^2/yr)
Shallow Landslides	180	180
Deep-Seated Landslides	90	90
Gullies	250	250
Bank Erosion	60	60
Inner Gorge/Stream-Side Delivery	590	590
Road-Stream Crossing Failures	130	49
Road-Related Mass Wasting	120	46
Road-Related Gullying	120	46
Road-Related Surface Erosion	250	95
Skid Trail Erosion	40	15
Vineyard Erosion	40	15
Management Related Mass Wasting	60	23
Totals (rounded to nearest ten)	1930	1460

6.3 Margin of Safety, Seasonal Variation and Critical Conditions

Section 303(d) of the Clean Water Act requires that TMDLs include a margin of safety to account for major uncertainties concerning the relationship between pollutant loads and instream water quality. The margin of safety can be incorporated into conservative assumptions used to develop the TMDL, or added as a separate quantitative component of the TMDL. Section 303(d) also requires that TMDLs account for seasonal variation and critical conditions.

6.3.1 Margin of Safety

This TSD incorporates an implicit margin of safety based on conservative assumptions employed in the Source Analysis. In cases of uncertainty, estimates erring towards protection of the resource were made. The following examples illustrate the conservative assumptions that lead to the margin of safety:

- Vineyard-related sediment delivery estimates. Given the sparse literature describing vineyard erosion processes, conservative estimates were required. The approach estimated the rate of sediment delivery associated with vineyards based on the upper bounds of what is likely to be occurring. This approach provides a margin of safety.

- Rate of sediment delivery associated with road-related gullies. Given the lack of data describing sediment delivery associated with road-related gullies, the rate of road gullying was conservatively estimated. This approach provides a margin of safety.

- Rates of sediment delivery associated with road surface erosion. Because of the lack of data describing the proportions of unpaved rural roads that are rock surfaced, Regional Water Board staff conservatively assumed that all unpaved rural roads are unsurfaced. Additionally, conservative judgements were made when the use level of the roads was estimated. These conservative estimates provide a margin of safety.

Relation of management activities to inner gorge processes. Due to the uncertainty of the relation of accelerated sediment yield, increased in-channel storage, and the resulting increased vulnerability of stream banks and inner gorge hillslopes, the entire contribution of bank erosion and inner gorge processes are assumed to be natural. As upslope sediment yields decrease as a result of implementation, the portion of streamside erosion processes that are related to anthropogenic activities will also decrease. This decrease represents a margin of safety.

6.3.2 Seasonal Variation and Critical Conditions

Seasonal variations summarize the changes in the discharges of sediment and their associated effects on beneficial uses which may vary in different years and at different times of the year. Sediment delivery to streams is an inherently seasonal phenomenon. For this reason the TSD allocates sediment loads based on a ten-year rolling average. This TSD does not explicitly address critical conditions. Instream sediment conditions are a function of what has occurred upstream over a long period of time. The approach chosen then, is to use indicators which are reflective of the net long term effects.

6.4 Numeric Targets

The water quality standards that apply to sediment conditions and those activities that affect them are:

> The suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.
>
> <u>And</u>
>
> Waters shall not contain substances in concentrations that result in deposition of material that causes nuisance or adversely affects beneficial uses.

The instream numeric targets proposed below are based on Regional Water Board staff's interpretation of how increased sediment delivery causes nuisance and adversely affect beneficial uses. These targets reflect some of the instream sediment conditions that are required by cold water fishery species present in the Navarro watershed. The upslope targets are proposed as a means of evaluating the degree to which identified problems are addressed.

Two categories of numeric targets are proposed; targets based on indicators of in-stream sediment supply and stream "health", and targets based on indicators of sediment loading and risk of future delivery. These numeric targets are further categorized in terms of short, mid, and long-term processes and effects. Of course the ultimate numeric target is that of increasing returns of adult salmonids. However, since other processes beyond sedimentation are significant, fish populations alone cannot be used as a gauge for determining decreasing impairment due to effects of sedimentation (i.e. desirable habitat conditions may be attained long before salmonid populations recover).

Because of the inherent variability associated with stream channel conditions, it is appropriate to evaluate the attainment of the instream numeric targets based on a weight-of-evidence approach. Also, instream targets should be evaluated based on a five year rolling average to allow for short term changes due to large flood events.

6.4.1 Short-Term Numeric Targets and Indicators

The short-term targets are proposed as a means of quantifying changes in the up-slope sediment supply and corresponding in-stream conditions that manifest themselves on a time-scale of a few years. For instance, decreases in hydrologic connectivity are expected to decrease the delivery of road-related surface erosion soon after implementation. Likewise, V* surveys are expected to detect changes in the supply of fine sediments soon after those changes occur. Though the targets called short-term targets, they are meant to apply over the life of the TMDL.

V* ≤ 0.15: Lower-Order Streams

V* (pronounced "vee-star") is a measure of the fraction of a pool's volume that is filled by fine sediment and is representative of the in-channel supply of mobile bedload sediment (Lisle and Hilton 1992). Lisle and Hilton (1999) demonstrated the usefulness of the parameter by comparing annual sediment yields of select streams with their average V* values. The comparison indicated that V* was well correlated to annual sediment yield. They also demonstrated that V* values can quickly respond to changes in sediment supply. V* values in French Creek, a tributary to the Scott River, decreased to approximately one-third the initial value soon after an erosion control program focusing on roads was implemented. A study of over sixty streams in the Franciscan geology of Northern California found that a mean V* value of 0.21 (21 %) represented good stream conditions (Knopp 1993). Knopp's study was conducted after a period of drought that many believe had affected the results. Lisle and Hilton (1999) reported that V* values for Elder Creek, an undisturbed tributary of the South Fork Eel River in Coastal Belt Franciscan Geology, averaged only 0.09. Therefore, the numeric target for V* in the Navarro Watershed is the average of 0.21 and 0.09, 0.15.

In order to discern short-term changes in sediment supply, V* values from lower order streams should be analyzed. It is expected that V* values for higher order streams will not be as responsive to those changes due to high amounts of fine sediment volume currently stored as in-stream deposits.

Fine Sediment Volume Of The Active Bed Matrix: Decreasing Trend

The fine sediment volume of the matrix material of the active bed is included as a method of tracking trends of in-stream fine sediment storage. The parameter is also intended to aid in interpretation of V* trends, and eventually as a means of describing changes in sediment supply. Volumes should be measured as described in Lisle and Hilton (1999). No particular value is set as a target, only a decreasing trend in the volume stored.

Percent Fines ≤ 0.85 Mm: ≤ 14%

The percent fines ≤ 0.85 mm is defined as the percentage of subsurface fine material in pool tail-outs ≤ 0.85 mm in diameter. This parameter is chosen as one of two surrogate measurements of spawning gravel suitability. The numeric target for this parameter is 14% based on the average of values reported for unmanaged streams in the studies by Peterson et al. (1992) and Burns (1970).

Percent Fines ≤ 6.4 mm: ≤ 30%

The percent fines ≤ 6.4 mm is defined as the percentage of subsurface fine material in pool tail-outs ≤ 6.4 mm in diameter. This parameter is chosen as the second of two surrogate measurements of spawning gravel suitability. The numeric target for this parameter is 30% based on Kondolf's (2000) summary of information reported in various studies.

Hydrologic Connectivity of Roads: ≤ 10%

Hydrologic connectivity of roads, defined as the proportion of road length draining to a stream, is chosen as an indicator of sediment yield. Hydrologic connectivity is both an easily determined and easily correctable parameter that can result in immediate reductions in sediment yields associated with road surface erosion when treated. Hydrologic connectivity data from 40 miles of roads in the Navarro Watershed collected by Pacific Watershed Associates showed hydrologic connectivity was 56%. The target value of 10% is based on Regional Water Board staff's best professional judgement of what amount of reduction is possible.

Diversion Potential: < 1%

Diversion potential is defined as the potential for a stream to be diverted out of its channel as a result of a plugged stream crossing. Like hydrologic connectivity, diversion potential is easily identifiable and correctable. This parameter is chosen as an indicator of risk of sediment delivery. The condition in itself is not a sediment contributor, but is a condition that greatly elevates the consequences of stream crossing failure. The numeric target is the elimination of diversion potential at all stream crossings except those that cannot be corrected without compromising safety, which are expected to comprise approximately 1% of all stream crossings.

Stream Crossings with High Risk of Failure: ≤1%

Risk of stream crossing failure is related to the size and configuration of the crossing. The National Marine Fisheries Service stream crossing guidelines (NMFS 2000) include a requirement that rural stream crossings have the hydraulic capacity to accommodate the 100-year flood flow. The hydraulic capacity of stream crossings is defined as the discharge corresponding to water levels at the top of the crossing inlet (HW/D=1). Flanagan et al. (1998) has described other factors that increase risk of failure such as culvert slope, width, and inlet basin configuration. The numeric target for stream crossings with high risk of failure is all stream crossings except those that cannot be corrected without compromising safety, which are expected to comprise approximately 1% of all stream crossings.

6.4.2 Mid-Term Numeric Targets and Indicators

Mid-term targets are for parameters that are not expected to be responsive until a decade or more after up-slope restoration activities have taken place. These targets address processes that are dependent on the frequency and magnitude of storm events, however it is assumed that the processes will be responsive to those events once restoration activities have been completed.

V* ≤ 15% : Higher-Order Streams

The fraction of a pool's volume filled with fine sediment, V*, should be monitored in higher-order streams to evaluate the effectiveness of restoration efforts. This parameter is considered a mid-term target due to the amount of fine sediments currently existing in the channels of the Navarro River Watershed.

Residual Pool Depths: 2 feet for first and second order channels, 3 feet for higher order channels

Residual pool depth is defined as the maximum depth of a pool minus the maximum depth of its riffle crest (i.e. the depth of the pool at the point of zero flow). The numeric target for residual pool depth is an average of no less than two feet for first and second order channels and three feet for third order and greater channels. California Department of Fish and Game data indicates that the better Coho streams have as much as forty percent of their total length in primary pools (Flosi et al. 1998).

Stream Crossing Failures: Decreasing Trend

The objective of this parameter is to assess to what degree stream crossing improvements are effective in reducing the delivery of sediments. Although high-risk stream crossings can be treated in a short time period, the effectiveness of those treatments will not be known until large storm events test their adequacy. Since large storm events are infrequent, it is unlikely that the effectiveness of stream crossing treatments can be assessed until at least a decade has passed.

Thalweg Variability: Increasing Trend

Thalweg variability is defined as the deviation of the thalweg (deepest part of the channel) from the average channel slope. It is chosen as a surrogate measure of channel complexity. As the sediment load decreases and the frequency and depth of pools increases, the thalweg profile develops more dramatic variation around the mean profile slope. No specific numeric value is set as the target, only an increasing trend.

6.4.3 Long-Term Numeric Targets and Indicators

Long-term targets and indicators are for parameters that might not respond until decades after restoration activities have been accomplished. These parameters are dependent on infrequent hydrologic events that alter channel configurations and trigger mass wasting. As such, they are not expected to improve in the near future.

Proportion of Stream Length in Pools: 40%

Habitat data from all sub-watersheds indicate that pool frequency may be a factor limiting the rearing capacity of streams in the Navarro watershed. Deep and frequent pools are necessary summer rearing habitat for salmonids, particularly Coho. California Department of Fish and Game data indicates that the better Coho streams have as much as forty percent of their total length in primary pools (Flosi et al. 1998).

Road-Related Landslides: Decreasing Trend

Since road failures usually occur many years after roads are constructed and are often unpredictable, it is expected that the rate of road-related landslides is not likely to decrease until roads in problem areas are treated or re-located. Appropriate location, design, construction and maintenance of roads is expected to result in a reduction of the rate of road failures. However, the reduced rate of road failure is expected to lag improved practices by a decade or more.

CHAPTER 7
IMPLEMENTATION & MONITORING PLANS

The Navarro River Watershed TSD for Temperature and Sediment is a technical support document (TSD), and is lacking implementation and monitoring plans. A TSD is a report developed by Regional Water Board staff which meets all federal requirements for a Total Maximum Daily Load (TMDL), but with no implementation or monitoring plan and no action on the part of the Regional or State Board. TSD's may also be known as "technical TMDLs," but TSD is used to emphasize that the documents have not been through the Regional or State Board's public participation and adoption process. The Navarro River watershed TSD for Sediment and Temperature will be transmitted directly to U.S. EPA upon completion by Regional Water Board staff. After minor revision, the U.S. EPA will publicly notice the document as a draft TMDL.

While an implementation plan is not strictly a requirement of a TMDL, it is required per 40 CFR §130.6, to be included in the State Water Quality Management Plan for the North Coast Region (Basin Plan). Therefore, implementation and monitoring plans must be established by the State, either concurrently with the TSD or at a later date.

CHAPTER 8
PUBLIC PARTICIPATION

Federal regulations require that Total Maximum Daily Loads (TMDLs) be subject to public review (40 CFR §130.7). While the Navarro River Watershed Technical Support Document for Sediment and Temperature is not a TMDL, Regional Water Board staff provided for public participation through several mechanisms.

Meetings have been held with representatives of a number of stakeholder groups in the watershed, including the Anderson Valley Land Trust, the Anderson Valley Farm Center, Navarro Watershed Landowners' Group, Friends of the Navarro Watershed, and the Navarro Estuary Project. Regional Water Board staff made a presentation to a joint meeting of the Anderson Valley Farm Center and the Navarro Watershed Landowners' Group in November 1999. Staff reviewed the history and anticipated content of the temperature and sediment TSDs in preparation for the Navarro River. Regional Water Board staff made two more presentations in June 2000, one to the general public at the Boonville Fairgrounds, and the second to a joint meeting of the Anderson Valley Farm Center and the Navarro Watershed Landowners' Group. In both of these presentations, staff reviewed the preliminary results of the Navarro TSD, the supporting methodology, and the current status of the TSD. Staff have also made contact with local, state, and federal regulatory agency staff working in the watershed, and with public works staff managing public infrastructure (primarily roads) in the watershed.

A newsletter outlining the TMDL process and the background of the Section 303(d) listings for the Navarro was released in the winter of 99/00. A second newsletter was released in the spring of 2000 which advertised the public meetings mentioned above and summarized the status of the TSD. Recipients of both newsletters included members of the former Watershed Advisory Group in the watershed, and a number of other interested parties identified through a variety of sources and contacts.

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GLOSSARY

Abandoned road	The designation of a road following use and completion of abandonment activities. These roads are left in a condition where no sediment sources remain and no maintenance of the road is required. These roads may be reconstructed and used for future land management activities.
Abandonment	The practice of closing a road, landing, skid trail or other facility so that regular maintenance is no longer needed and future erosion is largely prevented.
Aggradation	To fill and raise the elevation of the stream channel by deposition of sediment.
Agricultural facility	Any building, corral, pen, pasture, field, trail, or other feature on the landscape which is attributable to or associated with agricultural operations
Alevin	An alevin is a salmonid during a distinct life-cycle stage which begins from one to three months after egg fertilization. At this time, alevins emerge from eggs with yolk sacs and reside in the interstices of the gravel until they are ready to feed on macroinvertebrates in the water column. Alevins typically emerge from the gravel in one to five months as fry.
Alluvium	Clay, silt, sand, gravel, or similar material deposited by running water.
Anadromous	Refers to aquatic species which migrate up rivers from the sea to breed in fresh water.
Areas of instability	Locations on the landscape where land forms are present which have the ability to discharge sediment to a watercourse.
Baseline data	Data derived from field based monitoring or inventories used to characterize existing conditions and used to establish a database for planning or future comparisons.
Beneficial Use	Uses of waters of the state that may be protected against quality degradation including, but not limited to, domestic, municipal, agricultural and industrial supply; power generation; recreation; aesthetic enjoyment; navigation; and the preservation and enhancement of fish, wildlife and other aquatic resources or preserves.
Channel roughness	A numerical value used to describe the relative roughness of a stream channel in relationship to the size of particles on the stream bed. Roughness effects the turbulence of the stream flow.

Char	Small-scaled trout of the genus Salvelinus.
Class I	Watercourses which contain domestic water supplies, including springs, on site and/or within 100 feet downstream of the operation area and/or have fish always or seasonally present onsite, including habitat to sustain fish migration and spawning. Class I streams include historically fish-bearing streams.
Class II	Watercourses which have fish always or seasonally present offsite within 1000 feet downstream; and/or contain aquatic habitat for non-fish aquatic species. Class II waters do not include Class III waters that are directly tributary to Class I waters.
Class III	Watercourses which do not have aquatic life present, but show evidence of being capable of sediment transport to Class I and II waters under normal high flow conditions during and after completion of land management activities.
Class IV	Man-made watercourses, which usually supply downstream established domestic, agricultural, hydroelectric supply or other beneficial uses.
Colluvium	Loose rock material and soil accumulated at the foot of a slope.
Controllable source	Any source of sediment with the potential to enter a water of the State which is caused by human activity and will respond to mitigation, restoration, or altered land management.
Debris torrents	Long stretches of bare, generally unstable stream channel banks scoured and eroded by the extremely rapid movement of water-ladened debris, commonly caused by debris sliding or road stream crossing failure in the upper part of a drainage during a high intensity storm.
Decommission	See obliteration.
Deep seated landslide	Landslides involving deep regolith, weathered rock, and/or bedrock, as well as surficial soil. Deep seated landslides commonly include large (acres to hundreds of acres) slope features and are associated with geologic materials and structures.
Ditch relief	A drainage structure which will move water from an inside road ditch to an outside area, beyond the outer edge of the road fill. Ditch relief structures can include culverts, rolling dips, and/or water bars. Ditches are adequately relieved when there is no downcutting of the inside ditch or gully erosion at the outlet of the relief structure.

Drainage structure	A structure or facility constructed to control road runoff. These structures include but are not limited to fords, inside ditches, water bars, outsloping, rolling dips, culverts, or ditch drains.
Flooding	The overflowing of water onto land that is normally dry.
Fry	A young juvenile salmon after it has absorbed its egg sac and emerged from the redd.
Headwater swale	The swale or dip in the natural topography that is upslope from a stream, at its headwater. There may or may not be evidence of overland or surface flow of water in the headwater swale.
Interstices	The space between particles (e.g. space between sand grains).
Inner gorge	A geomorphic feature formed by coalescing scars originating from mass wasting and erosional process caused by active stream erosion. The feature is identified as that area of stream bank situated immediately adjacent to the stream, having a slope generally over 65% and being situated below the first break in slope above the channel.
Inside ditch	The ditch on the inside of the road, usually at the foot of the cutbank.
Landslide	Any mass movement process characterized by downslope transport of soil and rock, under gravitational stress by sliding over a discrete failure surface, or the resultant landform.
Large woody debris	A piece of woody material having a diameter greater than 30 cm (12 inches) and a length greater than 2 m (6 feet) that is located in a position where it may enter the watercourse channel.
Mass wasting	Downslope movement of soil mass under the force of gravity - often used synonymously with "landslide." Common types of mass soil movement include rock falls, soil creep, slumps, earthflows, debris avalanches, debris slides and debris torrents.
Maximum Weekly Average Temperature (MWAT)	The maximum value of the mathematical mean of multiple, equally spaced, daily temperatures over a seven day consecutive period. In other words, this is the highest value of the seven day moving average of temperature. Brungs and Jones (1977) calculate MWAT for the growth phase of fish life using the following equation: $\text{MWAT for growth} = \text{OT} + (\text{UUILT} - \text{OT}) / 3$ where OT is the physiological optimum temperature and UUILT is the ultimate upper incipient lethal temperature.

Numeric targets	A numerical expression of the desired instream environment. A numeric target is developed based on the numeric or narrative State water quality standards which are needed to recovered the impaired beneficial use.
Obliterated road	The designation of a road following use and completion of decommission activities. These roads are left in a condition where hillslope drainage is returned to its natural drainage pattern and no slope stability hazards remain. These roads will not be reconstructed and used for future land management activities.
Obliteration	To remove those elements of a road, landing, skid trail, or other facilities that unnaturally reroute hillslope drainage or present slope stability hazards.
Permanent drainage structure	A road drainage structure designed and constructed to remain in place following active land management activities while allowing year round access on a road.
Permanent road	A road which is planned and constructed to be part of a permanent all-season transportation system. These roads have a surface which is suitable for hauling forest and ranch products throughout the entire winter period and have drainage structures, if any, at watercourse crossings which will accommodate the fifty-year flood flow, including debris. Permanent roads receive regular and storm period inspection and maintenance.
Primary Pools	In first and second order streams, a primary pool is defined to have a maximum depth of at least two feet, occupy at least half the width of the low-flow channel, and be as long as the low-flow channel width. In third and forth order streams, the criteria is the same, except maximum depth must be at least three feet. DFG habitat typing data indicate the better coastal coho streams may have as much as forty percent of their total habitat length in primary pools.
Redd	A gravel nest or depression in the stream substrate formed by a female salmonid in which eggs are laid, fertilized and incubated.
Riparian Management Zone (RMZ)	The strip of land along both sides of a watercourse where conservation measures are required for the protection of water quality and beneficial uses of water, fish and riparian habitat and for controlling erosion.
Rolling dip	A shallow, rounded dip in the road where the road grade reverses for a short distance and the surface runoff is directed in the dip or trough to the outside or inside of the road. Rolling dips are drainage facilities constructed to remain effective while allowing passage of motor vehicles at reduced road speed.

Seasonal road	A road which is planned and constructed as part of the permanent transportation system where most hauling and heavy use may be discontinued during the winter period and whose use is restricted to periods when the surface is dry. Most seasonal roads are not surfaced for winter use, but have a surface adequate for hauling of forest and ranch products in the non-winter period, and in the extended dry periods or hard frozen conditions occurring during the winter period. Seasonal roads have drainage structures at watercourse crossings which will accommodate the fifty-year flood flow and associated debris.
Sediment	Fragmented material that originates from weathering of rocks and decomposed organic material that is transported by, suspended in, and eventually deposited by water or air.
Sediment budget	An accounting of the sources, movement, storage and deposition of sediment produced by a variety of erosional processes, from its origin to its exit from a basin.
Sediment delivery	Process by which material (usually referring to sediment) is delivered to a watercourse channel by wind, water or direct placement. It is a function of the soils, slope, rainfall, soil disturbance, amount of water flowing across the site from upslope, and the filtering effect of soils and vegetation as sediment travels downslope.
Sediment discharge	The mass or volume of sediment (usually mass) passing a watercourse transect in a unit of time.
Sediment erosion	The group of processes whereby sediment (earthen or rock material) is loosened, dissolved and removed from the landscape surface. It includes weathering, solubilization and transportation.
Sediment source	The physical location on the landscape where earthen material resides which has or may have the ability to discharge into a watercourse.
Sediment yield	The sediment yield consists of dissolved, suspended, and bed loads of a watercouse channel through a given cross-section in a given period of time.
Sensitive areas	Any area, particularly in the riparian zone, which when altered by land management activities results in a loss or reduction in ecological functioning.

Shallow seated landslide	A landslide produced by the failure of the soil mantle (typically to a depth of one or two meters, sometimes includes some weathered bedrock), on a steep slope. It includes debris slides, soil slips and failure of road cut-slopes and sidecast. The debris moves quickly (commonly breaking up and developing into a debris flow) leaving an elongated, concave scar.
Sidecast	The excess earthen material pushed or dumped over the side of roads and landings.
Skid trail	Constructed trails or established paths used by tractors or other vehicles for skidding logs. Also known as tractor roads.
Smolt	A young salmon at the stage at which it migrates from fresh water to the sea.
Steep slope	A hillslope, generally greater than 50% that leads without a significant break in slope to a watercourse. A significant break in slope is one that is wide enough to allow the deposition of sediment carried by runoff prior to reaching the downslope watercourse.
Stocking	A measure of the degree to which space is occupied by well-distributed countable trees.
Stream	See watercourse.
Stream class	The classification of waters of the state, based on beneficial uses, as required by the Department of Forestry in Timber Harvest Plan development. See definitions for Class I, Class II, Class III, and Class IV for more specific definitions.
Stream order	The designation (1,2,3, etc.) of the relative position of stream segments in the drainage basin network. For example, a first order stream is the smallest, unbranched, perennial tributary which terminates at the upper point. A second order stream is formed when two first order streams join. Etc.
Subwatershed	A subset or division of a watershed into smaller hydrologically meaningful Watersheds. For example, the North Fork Navarro River is a subwatershed of the larger Navarro River watershed.
Swale	A channel-like linear depression or low spot on a hillslope which rarely carries runoff except during extreme rainfall events. Some swales may no longer carry surface flow under the present climatic conditions.

Temporary drainage structure	A road drainage structure designed and constructed to allow access during active land management activities. The temporary structure will be removed following active land management.
Thalweg	The deepest part of a stream channel at any given cross section.
Thalweg profile	Change in elevation of the thalweg as surveyed in an upstream-downstream direction against a fixed elevation.
Timber Harvest Plan	A plan, prepared by a registered professional forester and submitted to the California Department of Forestry for approval, which provides specific information regarding commercial timber operations to be undertaken by a landowner.
Unstable areas	Characterized by slide areas, gullies, eroding stream banks, or unstable soils. Slide areas include shallow and deep seated landslides, debris flows, debris slides, debris torrents, earthflows and inner gorges and hummocky ground. Unstable soils include unconsolidated, non-cohesive soils and colluvial debris.
V*	A numerical value which represents the proportion of fine sediment that occupies the scoured residual volume of a pool.
Watercourse	Any well-defined channel with a distinguishable bed and bank showing evidence of having contained flowing water indicated by deposit of rock, sand, gravel, or soil.
Watercourse & lake protection zone	As used in the Forest Practice Rules, the strip of land, along both sides of a watercourse or around the circumference of a lake or spring, where additional practices may be required for the protection of the quality and beneficial uses of water, fish and riparian wildlife habitat, other forest resources and for controlling sediment.
Waters of the state	Any surface water or groundwater, including saline water, within the boundaries of the state.
Watershed	Total land area draining to any point in a watercourse, as measured on a map, aerial photo or other horizontal plane. Also called a basin, drainage area, or catchment area.
Water quality objective	Limits or level of water quality constituents or characteristics which are established for the reasonable protection of beneficial uses of water or the prevention of nuisance within a specific area.

Water quality standard	Consist of the beneficial uses of water and the water quality objectives as described in the Water Quality Control Plan for the North Coast Region.
Yarding	The movement of forest products from the point of felling to a landing