U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION 9

REDWOOD CREEK SEDIMENT TOTAL MAXIMUM DAILY LOAD

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Section 1. Introduction

What Is A TMDL?

Section 303(d)(1)(A) of the Clean Water Act (CWA) requires that "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 CWA also requires states to establish a priority ranking for waters on the 303(d) list of impaired waters and establish Total Maximum Daily Loads (TMDLs) for such waters. As part of California's 1996 and 1998 303(d) list submittals, the North Coast Regional Water Quality Control Board (RWQCB) identified Redwood Creek as water quality limited due to clean sediment loading and designated the watershed as a high priority for TMDL development. The RWQCB began work on the sediment TMDL in 1997, and EPA and the RWQCB worked together to complete the sediment TMDL in 1998.

The elements of a TMDL are described in 40 CFR 130.2 and 130.7 and Section 303(d) of the CWA, as well as in EPA guidance documents (e.g., EPA, 1991). A TMDL is defined as "the sum of the individual waste load allocations for point sources and load allocations for nonpoint sources and natural background" (40 CFR 130.2) such that the capacity of the waterbody to assimilate pollutant loadings (the Loading Capacity) is not exceeded. A TMDL is also required to be developed with seasonal variations and include a margin of safety to address uncertainty in the analysis. In addition, pursuant to the regulations at 40 CFR 130.6, states must develop water quality management plans which incorporate approved TMDLs and implementation measures necessary to implement the TMDLs.

Upon establishment of TMDLs by EPA or the State, the State is required to incorporate the TMDLs along with appropriate implementation measures into the State Water Quality Management Plan (40 CFR 130.6(c)(1), 130.7). The Regional Board Basin Plan, and applicable state-wide plans, serve as the State Water Quality Management Plan governing the Redwood Creek watershed. If the State subsequently adopts and submits for EPA approval TMDLs which are different from the TMDLs established by EPA, EPA will review the State-submitted TMDLs to determine if they meet all TMDL requirements. If EPA approves the State TMDLs, EPA expects the State-established TMDLs would be applicable for the Redwood Creek watershed.

Why Is EPA Establishing These TMDLs?

The Environmental Protection Agency (EPA) has oversight authority for the 303(d) program and is required to review and either approve or disapprove the TMDLs submitted by states. If the EPA disapproves a TMDL submitted by a state, the EPA is required to establish a TMDL for that waterbody.

On October 31, 1997, EPA entered into a consent decree (decree), Pacific Coast Federation of Fishermen's Association, et. al. v. Marcus, (N.D. Cal. No. 95-4474 MHP), which established a timetable for development of TMDLs for several watersheds in northwest California, including Redwood Creek. The decree required development of two TMDLs by December 31, 1998. Pursuant to the decree, EPA developed a Supplemental TMDL Establishment Schedule which set December 31, 1998 as the deadline for the establishment of a sediment TMDL for Redwood Creek.

The RWQCB has drafted a TMDL for clean sediment for Redwood Creek, but has not taken final action to adopt it. Before the TMDL can be submitted to EPA for approval, the RWQCB and State Water Resources Control Board must adopt the TMDL, and the State Office of Administrative Law must concur on the TMDL. Because the State has not completed and submitted the Redwood Creek TMDL, EPA is now establishing the Redwood Creek TMDL for sediment, along with a sediment TMDL for South Fork Trinity River, in order to meet the requirements of the decree.

TMDL Organization and Comparison With State TMDLs

This TMDL report is organized in the following sections which provide the analytical basis for the TMDLs:

- Problem Statement
- Numeric Targets
- Source Analysis
- Loading Capacity Linkage Analysis
- TMDLs and Allocations
- Margin of Safety
- Seasonal Variations
- Critical Conditions
- Public Participation

In addition, the report discusses TMDL implementation and follow-up monitoring needs.

The TMDL proposed in this document very similar to the TMDL public noticed by the RWQCB on November 10, 1998. The organization of the EPA report follows the format used in EPA Region 9-established TMDLs. The RWQCB's draft TMDL format is designed to meet the needs of the Basin Planning administrative procedures and to focus more on specific implementation provisions. Therefore the formats of the State and EPA TMDL documents are somewhat different.

This final TMDL is based on a draft TMDL proposed by EPA on October 19, 1998. Changes were made in the final TMDL to address comments received from the public through written comments and oral testimony at a public hearing held November 19, 1998. The final TMDL incorporates changes in the following areas:

- clarification of instream numeric targets
- addition of hillslope numeric targets
- minor clarifications of the source analysis, linkage analysis, TMDL, and allocations
- restructuring of the margin of safety discussion, and
- additional detail in the implementation and monitoring recommendations.

Section 2. TMDL Summary

The Redwood Creek TMDL is being established at levels sufficient to result in attainment of applicable water quality standards for clean sediment, including designated beneficial uses and narrative water quality objectives. The TMDL is virtually identical to the draft sediment TMDL developed by the RWQCB in July, 1998 and is very similar to the TMDL public noticed by the RWQCB in November, 1998.

Redwood Creek watershed is a forested watershed located north of Eureka in northwestern California. The purpose of the Redwood Creek TMDL is to identify total allowable loads and loading allocations that, when implemented, are expected to result in attainment of applicable water quality standards for sediment.

Redwood Creek watershed was listed on California's Clean Water Act (CWA) Section 303(d) list beginning in 1992 as water quality limited due to sedimentation. The level of sedimentation in Redwood Creek watershed was judged to exceed the existing narrative water quality objectives (WQO) necessary to protect beneficial uses of the basin, particularly the cold water fishery. Accelerated erosion from land use practices and other causes is impacting the migration, spawning, reproduction, and early development of cold water anadromous fish such as coho salmon, chinook salmon, and steelhead trout.

The TMDL includes a problem assessment, which includes an assessment of existing instream and hillslope conditions; instream numeric targets, which interpret and are consistent with the narrative water quality standards and also represent the instream conditions for cold water fish where sediment is not a limiting factor, an assessment of significant sediment sources that have in the past or are presently impacting the stream system; an estimate of the loading capacity of the system for sediment discharges (and associated reductions) necessary to attain the numeric targets; allocations of loads among different sediment source categories; and several other sections designed to address considerations set forth in Section 303(d) of the Clean Water Act and U.S. EPA's guidance and implementing regulations at 40 CFR 130.7.

The TMDL is based on existing, readily available information concerning Redwood Creek watershed conditions and land management plans and other watersheds in the Pacific Northwest, along with TMDLs previously developed by the State and U.S. EPA. Detailed explanations of the basis for the calculations are provided in the report, and further background information can be found in the *Redwood Creek Watershed Analysis* (Redwood National and State Parks, hereinafter referred to as RNP, 1997).

Problem Statement

Anadromous fish populations in Redwood Creek have diminished substantially over the past 40 years (RNP, 1997). Reliable data about historical fish populations in Redwood Creek are lacking. In 1965, the California Department of Fish and Game roughly estimated spawning escapement of 5000 chinook, 2000 coho, and 10,000 winter steelhead. Although channel deepening and pool development may have begun to increase in all but the lower few miles of Redwood Creek, the mainstem generally lacks an adequate pool-riffle structure and cover. Coarse sediment deposited in the mainstem allows a large proportion of summer base flows to infiltrate and flow subsurface, thereby limiting the surface water available to fish and increasing surface water temperatures. Large deltas in some tributaries block tributary mouths and prevent migration of fish. A lack of suitable rearing habitat in the mainstem and tributaries has forced juvenile fish to the estuary, where they are subject to the impacts of sudden, extreme changes in salinity resulting from breaching of the sand bar by ocean waves and currents. Spawning habitat is improving slowly as gravels are cleaned of fine sediment. Key changes in the mainstem of Redwood Creek include (1) increases in the volume of stored sediment, (2) decreases in pool numbers and depth, (3) increases in stream width and decreases in stream depth, (4) reduced recruitment of large woody debris, (5) deposition of high levels of fine sediments on the stream bottom, and (6) reduced volumes of large woody debris.

Redwood Creek is particularly prone to storm-induced erosional events, and would probably experience extensive erosion under natural conditions. However, land management activities have accelerated this natural process, overwhelming the stream channel's ability to efficiently move the delivered sediment. Land management patterns and practices have contributed to increased erosion beyond natural rates through mass wasting (landsliding) and fluvial erosion (gullying and stream bank erosion). The resultant erosion caused sediment to enter the stream, filling deep pools and depositing silt in spawning gravels. Past studies indicate that streamside landsliding and fluvial hillslope erosion may be the most important processes delivering sediment to Redwood Creek. A large proportion of observed erosion is associated with an extensive road network (7.3 mi/mi^2) on private lands, improperly designed and maintained roads and skid trails, and timber harvesting.

Numeric Targets

Numeric targets were derived from the literature, available monitoring data for the watershed, recommendations of agencies commenting on the TMDL, and best professional judgment. The numeric targets are intended to be consistent with the narrative water quality standards in the Basin Plan and focus on the elimination of sediment as a limiting factor for salmonids. As such, they are an expression of desired future conditions. The TMDL contains numeric targets for instream channel indicators and for hillslope indicators which are associated with stable watersheds capable of supporting healthy salmonid habitat. The numeric targets are included in Table 1a and 1b, pp. 5-6.

Source Analysis

Ten categories of sediment delivery were identified for the Redwood Creek watershed (Table 2), eight of which are to some extent controllable: 1) erosion associated with roads, skid trails and landings; 2) gully erosion; 3) bare ground erosion associated with human activities; 4) stream bank erosion associated with human activities; 5) tributary landslides (road related); 6) tributary landslides (harvest related); 7) mainstem landslides (while many are natural, the delivery of sediment may be controllable to varying degrees); and 8) debris torrents. Controllable discharges or depositions are those discharges or depositions resulting from human activities that can influence water quality that can be reasonably controlled. The rates of delivery were estimated for those sources as well as sources deemed non-controllable using sediment source information from Redwood National Park. It was estimated that on average, about 4750 tons per square mile per year are produced from the Redwood Creek watershed, about 60 % of which is controllable (see Table 2, p. 7).

Table 1a. Instream Numeric Targets for the Redwood Creek Watershed.

Parameter	Numeric Targets (Desired Conditions)
Percent fines <0.85 mm in riffle crests of fish-bearing streams[2]	<14%
Percent fines <6.5 mm in riffle crests of fish-bearing streams	<30%
Percent of Stream Length in Riffles[3]	< 25-30% of stream reaches in riffles (reach gradient < 2%)
Pool depth in mainstem Redwood Creek reaches with pool-riffle morphology	the mean depth of pools at low flow exceeds 2 m
Depths of pools in 3rd and 4th order tributaries with pool-riffle morphology[4]	the mean depth of pools at low flow exceeds 1-1.5 m
Median particle size diameter (d_{50}) from riffle crest surfaces	≥ 37 mm (minimum for a reach) ≥69 mm (mean for a reach)
Percent fines < 2 mm at riffle crest surfaces in fish-bearing streams	<10-20%
Large Woody Debris in any watercourse capable of transporting sediment to a higher order watercourse	Improving trend towards increased large woody debris

[1] Targets should be evaluated as ten year rolling annual averages to avoid premature assessment of trends based on inadequate information. This approach addresses the variations in sediment loading and instream indicators which are characteristic of Redwood Creek and which may not indicate management related effects.

[2] Fish-Bearing Streams: Fish present seasonally or year-round, or having fish habitat capable of supporting fish. Fish habitat is the aquatic environment and the immediately surrounding terrestrial environment that, combined, afford the necessary biological and physical support systems required by fish species during various life history stages. Generally, these streams have gradients less than 3%.

[3] Riffle- low gradient: shallow stream channel areas with swiftly flowing turbulent water with some partially exposed substrate. Gradient< 4 %, substrate is usually cobble dominated. The gradient is the general slope, or rate of change in vertical elevation per unit of horizontal distance, of the water surface of a flowing stream; or the rate of change of any characteristic per unit of length.

[4] Stream order is the designation of the relative position of stream segments in the drainage basin network. For example, a first order stream is the smallest, unbranched, tributary which terminates at the upper point. A second order stream is formed when two first order streams join.

Table 1b: Hillslope Numeric Targets for the Redwood Creek Watershed.

Parameter	Numeric Targets (Desired Conditions)
Road stream crossings with diversion potential	No crossings have diversion potential (i.e., all crossings are reconfigured permanently to assure that no diversion will occur).
Road culvert/crossing sizing	All culverts and crossings are sized to pass the 50 year flood and associated sediment and debris. In addition, crossings and culverts in the snow zone (generally, upstream of Highway 299, are sized large enough to accommodate flows and associated sediment and debris caused by precipitation and snow melt runoff.
Landing and road fill stability	All landings and road fills (e.g., sidecasts) on slopes >50% and which could potentially deliver sediment to a water course are pulled back and stabilized.
Road surfacing and drainage	All roads have surfacing and drainage facilities or structures which are appropriate to their patterns and intensity of use.
Road inspection, maintenance, and decommissioning	All roads are inspected and maintained annually or decommissioned. Decommissioned roads (roads which are closed, abandoned, or obliterated) are hydrologically maintenance free.[1]
Road location in inner gorge or unstable headwall areas	Roads are not located in steep inner gorge or unstable headwall areas except where alternative road locations are unavailable.[2]
Use of clearcut and/or tractor yarding timber harvest methods	Clearcut and/or tractor yarding harvest methods are not used in steep inner gorge, unstable, or streamside areas unless a detailed geological assessment is performed which shows there is no potential for increased sediment delivery to water courses as a result of using these methods.[3]

1 Hydrologically maintenance free means that:
- drainage in the road area mimics natural hydrology,
- all drainage is dispersed to the slope through use, as appropriate, of outsloping or cross-road drains,
- all culverts and associated fill material is removed from crossing areas,
- all potentially unstable road fill and landing sidecasts are pulled back, and
- excavated spoils are placed in locations where they will not enter a water course.

2 This target is intended to address roads located adjacent to water courses with inner gorge topography or which cross steep, unstable headwall areas, and is not intended to apply to road crossings of inner gorge areas. Steep inner gorge areas generally exceed 65% in slope and are located adjacent to class 1 and 2 water courses. Characteristics of steep unstable headwall areas generally include the following:
- slopes greater than 50%,
- erosive or incompetent soil types or underlying geology,
- concave slope shape,
- convergent groundwater present, and/or
- evidence of past movement is present.

3 Characteristics of steep inner gorge, unstable, or streamside areas generally include the following:
- slopes greater than 50%,
- located within 300 feet of a Class 1, 2, or 3 watercourse,
- erosive or incompetent soil types or underlying geology,
- concave slope shape,
- convergent groundwater present, and/or
- evidence of past movement is present.

Table 2. Summary of Source Loading Estimates, Loading Capacity, and TMDL Allocations for the Redwood Creek watershed.

Source Mechanism	Historic Sediment Load[1] (t/sq.mi./yr)	Percent Controllable[2]	Controllable Load[3] (t/sq.mi./yr)	Remaining Load (Allocation)[4] (t/sq.mi./yr)
Roads, Landings and Skid Trails erosion	690	85%	586	104
Gully Erosion (~90% road related)	1020	85%	870	150
Bare Ground Erosion	400	85%	340	60
Stream Bank Erosion	590	35%	210	380
Tributary Landslides: Naturally Occurring	210	0%	0	210
Tributary Landslides: Road Related	360	80%	290	70
Tributary Landslides: Harvest Related	390	50%	190	200
Mainstem Landslides (Human Induced and Naturally Occurring) [5]	810	40%	320	490
Debris Torrents	100	50%	50	50
Other Mass Movements (Naturally Occurring): - earthflows - block slides	180	0%	0	180
Totals	4750	60%[6]	2850	1900

[1] The estimated historic sediment load for each source.

[2] The percent of that historic load that is estimated as controllable. Controllable discharges are those discharges resulting from human activities that can influence the quality of the waters of the State and that can be reasonably controlled.

[3] The load that is estimated as controllable (the percent controllable multiplied by the historic load).

[4] The difference between the historic load estimate and the controllable load estimate. This is the estimated load at which salmonids in the Redwood Creek watershed would no longer be limited by sediment.

[5] Study of 586 mainstem landslides revealed that approximately 50 % of the slides had one or more associated roads (Kelsey, et. al., 1981) The volume of each slide may be variable but may represent an average 50 percent of the total load. of mainstem landslides.

[6] Calculated Controllable Load (2850t/sq.mi./yr.) is 60% of Estimated Historic load (4750t/sq.mi./yr.). Reducing 4750t/sq.mi./yr. by sixty percent leaves a remainder of 1900t/sq.mi./yr.

Loading Capacity, Total Maximum Daily Loads, and Load Allocations

After considering the quantitative comparison of estimated loading rates and controllable portions of various types of loading, and the qualitative comparison of instream indicators with existing conditions, EPA estimates that a 60% reduction in total sediment loading from historical loading rates is needed in the Redwood Creek watershed as a whole to meet the instream targets. The estimated total allowable sediment load (the TMDL) is estimated to be approximately 1900 tons per square mile per year. This number was derived from estimated average annual sediment loads for the period 1954 -1997 for three reference watersheds within the Redwood Creek basin.

There are no point sources of discharge to Redwood Creek; therefore, there are no wasteload allocations established through this TMDL. The Redwood Creek load allocations: 1) were developed for erosion processes; 2) are associated with land use activities where feasible; and 3) are based on the source analysis of the various erosional processes. The load allocations were developed as long term annual average loads per square mile at the watershed scale and appear in Table 2, p. 7.

Margin of Safety, Seasonal Variations, and Critical Conditions

In every one of the components used to develop the TMDL, assumptions were made where sufficient data were lacking. Conservative assumptions were made in each case as a way of addressing uncertainty associated with the data; this constitutes an implicit margin of safety.

In Redwood Creek, there is inherent annual and seasonal variation in the delivery of sediment to stream systems and in the impacts sediment has on aquatic species during different life stages. However, sediment impacts often occur for periods long after the sediment loading to the stream, and in locations far removed from the loading site. For this TMDL, it was technically infeasible to vary the TMDL to account for temporal and spatial variations in sediment loadings and impacts. Instead, the TMDL is designed to account for long term erosion patterns and instream impacts associated with sediment in Redwood Creek by using longer time frames for implementation and evaluation. Furthermore, allocations are designed to apply to the sources of sediment, themselves, not the movement of sediment across the landscape or delivery of sediment directly to the stream channel. The TMDL and associated allocations are set at levels which reduce sediment loading to the point that creek habitat structure is able to recover and support the beneficial uses of concern.

Implementation and Monitoring Recommendations

Although they are not required components of federally-established TMDLs, this TMDL document includes implementation and monitoring recommendations to assist the State and watershed stakeholders in implementing the TMDL and conducting followup monitoring and review in the future. EPA strongly supports the RWQCB's draft TMDL implementation plan contained in the November 10, 1998 draft Water Quality Attainment Strategy for Redwood Creek. EPA also supports the State's commitment to work with landowners, agencies, and other stakeholders to develop a specific monitoring plan. In this document, EPA is recommending several specific provisions which would strengthen the implementation and monitoring provisions proposed by the State.

Section 3. Supporting Documentation

A Note On Methods Used To Establish the TMDL

Redwood Creek has been extensively studied by many researchers for over 30 years. As a result, substantial information and data concerning erosion causes, trends, and impacts has been developed for the basin, particularly by scientists associated with Redwood National and State Parks (RNP). The Redwood Creek TMDL is based on this existing body of analysis, as supplemented by the expert judgment offered by several researchers at RNP and by additional analysis conducted by EPA.

EPA recognizes that erosion processes which are responsible for sediment inputs to the system are highly dynamic and variable from year to year and in different locations in the basin. The main driving factor influencing variation in erosion and sediment inputs from year to year is variability in precipitation and, particularly, periodic high magnitude storms. Ideally, the TMDL and associated allocations could be expressed in dynamic terms as a function of the driving forces which determine the extent of erosion events (e.g., runoff intensity, topography, geology) and their impacts on receiving waters (e.g., proximity to water courses, stream morphology, and habitat distribution). However, it was infeasible to develop a dynamic predictive model of future erosion amounts, timing, and locations and the impacts of sediment delivery on the waterbody reaches most important for aquatic habitat based on existing information and scientific knowledge.

This TMDL analysis was based primarily on historical data concerning sediment loading, stream flows, and stream responses to erosional impacts, along with information on instream and hillslope conditions which in other locations were associated with well-functioning watersheds and aquatic ecosystems. It is difficult to predict future erosion and associated impacts based on past erosion patterns and on aquatic habitat conditions studied elsewhere. However, this TMDL does account for the important issues of temporal and spatial variability in erosion and stream responses in several ways:

<u>Temporal Considerations</u>

Indicators were selected for use in instream numeric target development and follow-up monitoring which are believed to integrate cumulative effects over annual timeframes (e.g. annual low flow measurements of stream bottom composition) instead of indicators which measure instantaneous conditions (e.g. turbidity).

Numeric targets (goals for instream indicators), the total allowable load, and specific load allocations are expressed in terms of 10 year rolling averages in recognition that trends are not discernible within shorter time frames and to allow for natural variation due to seasonal and annual differences.

The source analysis is based on sediment loading estimates developed for a time period of more than 40 years which encompasses a wide range of climatic and land use conditions. This period included several major storms which caused catastrophic sediment inputs as well as significant periods of drought during which precipitation, runoff, and associated sedimentation were far below normal. This timeframe also includes periods of widespread, intensive timber harvesting prior to the implementation of modern logging practices along with periods in which logging stopped in the lower basin (after the National Park was created) and intensive logging continued in the middle and upper basin using modern logging practices required by State timber harvest rules. Future erosion patterns may be different from historic patterns largely due to the removal of one third of the basin from timber harvest management and the institution of more protective forest practice rules. However, available information indicates that future erosion potential in the basin, chiefly associated with roads built before the advent of modern forest practice rules, remains very high (RNP, 1997). The degree to which modern timber harvest practices will protect Redwood Creek from excessive sedimentation has not been established or adequately tested. Therefore, it is reasonable to set a TMDL and associated allocations which will guide future land management decisions based on the extensive historical loading analysis.

Spatial Considerations

The TMDL was derived based primarily on analysis of conditions in different tributaries to Redwood Creek which are representative of different geologies and associated vulnerabilities to erosion. An effort was made to account for the differences in erosion potential associated with different geological conditions present in the watershed because geology was believed to be a key driving force influencing variability in erosion potential throughout the basin.

For some indicators, separate numeric targets are identified for different parts of the basin to account for differences in geomorphic conditions and habitat issues in different parts of the watershed. That is, separate numeric targets for fish rearing habitat were developed for tributaries versus the mainstem of Redwood Creek. In addition, hillslope targets are provided which recognize and address the higher erosion potential associated with roads and timber harvesting in steep, unstable terrain near water courses.

Section 3.1. Problem Statement

This section is based primarily on information contained in the draft Redwood Creek Watershed Analysis (RNP, 1997) and other publications by RNP researchers.

Watershed Overview

Redwood Creek watershed is a 285 square mile forested watershed in Humboldt County, California.. Redwood Creek flows into the Pacific Ocean near Orick. The drainage area upstream of the U.S. Geological Survey stream gauging station at Orick is 278 square miles (Figure 1). The Redwood Creek watershed consists mostly of mountainous, forested terrain from sea level to about 5,300 feet elevation. Primary land uses are tourism and fishing on park lands and timber and livestock production on lands upstream of Redwood National Park. The watershed is narrow and elongated, about 65 miles in length, from 4 to 7 miles wide. The lower basin includes the Park area and the middle and upper basin are located upstream from the Park.

The cold water fishery is identified by the Regional Water Board as a beneficial use of the Redwood Creek watershed. The creek historically supported large numbers of coho salmon, chinook salmon, steelhead trout, and other fish species. Reliable data about historical fish populations in Redwood Creek are lacking. In 1965, the California Department of Fish and Game roughly estimated spawning escapement of 5000 chinook, 2000 coho, and 10,000 winter steelhead. Coho salmon, a species native to the Redwood Creek, is listed by the National Marine Fisheries Service as a threatened species. In addition, steelhead and chinook salmon populations have declined significantly in the watershed. By 1994, five fish species found in Redwood Creek were classified as a species of concern, threatened or endangered by U.S. Fish and Wildlife Service and/or the California Department of Fish and Game: tidewater goby, coast cutthroat trout, coho salmon, spring run chinook salmon, and summer steelhead trout (RNP, 1997). Sedimentation due to natural geologic instability, past and present land use practices, and other factors has contributed to the reduction and loss of habitat necessary to support cold water fish including salmonids.

Climate and Hydrology

The climate of the Redwood Creek watershed is Mediterranean, with mild, wet winters (November to March), and warm, dry summers. Mean annual precipitation is roughly 80 inches, mostly rain, with snow frequently at altitudes above 1,600 feet. The snow zone of Redwood Creek watershed is roughly located upstream of Highway 299, which crosses the watershed approximately at the boundary between the middle and upper basin. Snow melt can increase streamflow peaks during rain-on-snow events, as occurred in 1964.

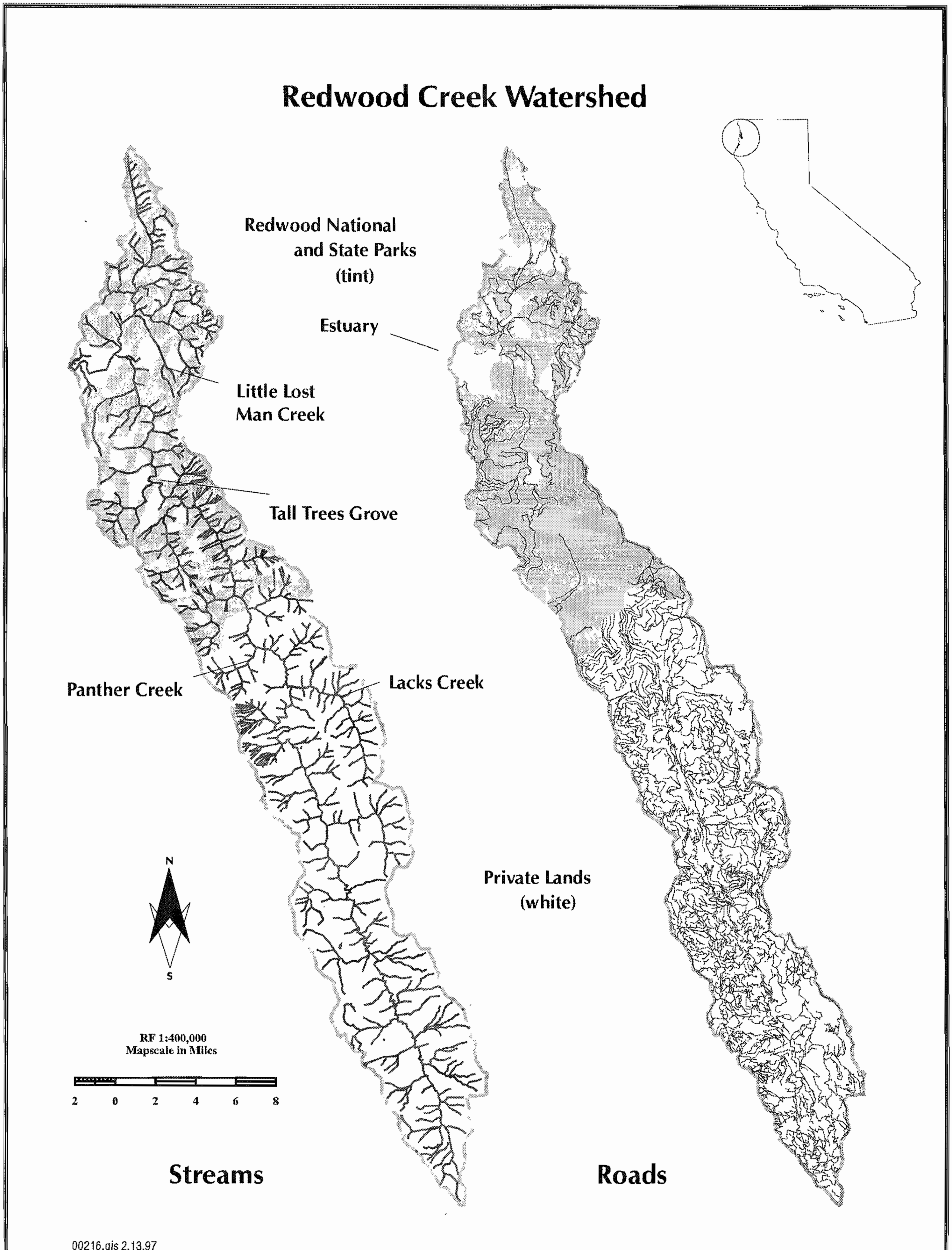
Streamflow in Redwood Creek is highly variable from year to year as a result of annual rainfall variations. Streamflow also varies seasonally, owing to the highly seasonal distribution of rainfall. Winter flood flows can be as much as four orders of magnitude higher than summer low flows.

Floods are critical events for the resources of Redwood Creek because they erode hillslopes, reshape channels, and transport large proportions of fluvial sediment loads. Recent large floods occurred in 1953, 1955, 1964, 1972 (two floods), and 1975. The 1964 storm was a regionally significant event that caused major damage to towns, highways, and other structures, as well as significant hillslope erosion and channel changes.

No large floods occurred after 1975, until the recent 11-year return period flood in January of 1997. During January 1997, the relatively small 11-year return period flood initiated debris torrents of mud, boulders, and whole trees directly into Redwood Creek adjacent to Tall Trees Grove; the effects of a major storm would probably be much more severe. Within the time period from 1975 to 2015, there is an 80% chance of a 25-year flood. It has been 23 years since the last 25-year flood in Redwood Creek, in 1975. It has been 34 years since the last 50-year flood, and erosion potential in this basin from such a storm is estimated at more than 5 million cubic yards. Of this, 90% is from the private roads upstream from the park. Within the time period from 1964 to 2014, there is a 64% chance of a 50-year flood.

Geology

Geologic structure in the Redwood Creek watershed is governed by several parallel north-northwest trending faults. For much of its length, the channel of Redwood Creek closely follows the Grogan Fault.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Redwood Creek watershed is characterized by relative steep, unstable hillslopes, very steep inner gorge slopes along much of the mainstem and some tributaries, and narrow valley bottoms. Most of the Redwood Creek watershed has experienced uplift over the past several hundred thousand years. The basin is underlain by the Franciscan complex of unmetamorphosed sandstones, mudstones, schists, and scattered blocks of other rock types. In general, slopes west of the Creek (which generally follows the Grogan fault) are underlain by schist, and slopes east of the Creek are underlain by sandstones and mudstones.

A very high percentage of the land area of Redwood Creek basin is underlain by rock types which are relatively weak and susceptible to erosion and mass soil movements (e.g., schists and mudstones). Remaining areas of the watershed which are underlain by more competent rock types (e.g. interbedded sandstone/mudstones) are somewhat more resistant to erosion, but form steep slopes which are susceptible to rapid, shallow landsliding processes.

Plants and Animals

The natural vegetation of the Redwood Creek watershed consists mostly of coniferous forest, but also includes areas of oak woodland and grassland prairie. The distribution of plant communities depends primarily on water availability and fire regime.

Old-growth forest currently covers 24,315 acres in the watershed, equivalent to 14% of its total area. Near the coast, the most common forest tree is the Sitka spruce. Most of the lower-basin forest, however, is dominated by coast redwoods. Farther inland, where summer temperatures are higher and fog is less frequent, Douglas fir is more common than redwood. Several hardwood species grow in association with both redwood and Douglas fir, including big-leaf maple, red alder, tanbark oak, madrone, and bay. Prairies and oak woodlands occur on south- and west-facing ridgetops and hillslopes on the east side of Redwood Creek.

Approximately 250 species of wildlife (amphibians, reptiles, mammals, and birds) are known to occupy habitats found in the Redwood Creek watershed. Thirty three species of wildlife are identified as species of special concern (threatened, endangered or sensitive to human activities, see RNP, 1997 for details).

The Redwood Creek watershed provides aquatic habitat for a variety of fish species. Anadromous and resident salmonids identified in Redwood Creek include steelhead and rainbow trout, coastal cutthroat trout, coho salmon, and chinook salmon. Other fish identified or reported include the tidewater goby, Humboldt sucker, threespine stickleback, coast range sculpin, Pacific lamprey, and eulachon. Five species of fish have been listed as species of special concern, endangered species, or sensitive species by federal and state agencies.

Land Use and Sedimentation Issues

Relations between floods, sediment, and land use have been central to the debate over resource protection in the Redwood Creek watershed. Damage to forest resources, fish, and other resources coincided with both intensive land use and a series of large storms that were accompanied by widespread flooding and erosion. Erosion rates in northwestern California are naturally high, and land use has significantly increased erosion above natural levels associated with storms. The question has obvious practical importance because erosion related to land use potentially can be prevented. In the Redwood Creek Watershed, the large number of improperly designed and maintained roads, landings and skid trails causes: 1) increased surface erosion and fine sediment production and delivery and 2) an increased potential for stream diversions (stream channel capture), rill and gully erosion, and road related landslides with corresponding increases in sediment production and delivery (See roads map, figure 3). Timber harvest operations on unstable slopes and removal of riparian vegetation have also contributed to increased erosion and sediment production.

Water Quality Objectives

Water quality objectives (the term used by the State of California to refer to water quality standards) adopted for the Redwood Creek basin are contained in the RWQCB Basin Plan. The beneficial uses of water for Redwood Creek are described in the Basin Plan as either existing or potential. The water quality objectives are designed to protect the most sensitive beneficial uses.

The beneficial uses addressed in the Redwood Creek TMDL include: cold freshwater habitat (COLD); migration of aquatic organisms (MIGR); estuarine habitat (EST); uses of water for community, military, or individual systems including, but not limited to drinking water supply (MUN); uses of water that support habitats necessary, at least in part, for the survival and successful maintenance of plant or animal species established under state or federal law as rare, threatened or endangered (RARE); and spawning, reproduction, and/or early development (SPAWN). The water quality objectives addressed include settleable material ("Water shall not contain substances that result in deposition of material that causes nuisance or adversely affect beneficial uses") and 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."). Discharges of sediment are also addressed by a discharge prohibition.

Beneficial Use Issues

Salmonids are born in fresh water streams where they spend one to several years of their lives feeding, growing, and hiding from predators. Once they are large enough, fresh water salmonids undergo a physiological change which allows them to swim out to the ocean where they then spend the next one to several years. Salmonids return to the streams in which they were born to lay eggs and begin the life cycle again. They require gravels free from excessive fine sediment to lay their eggs and for the eggs to develop into free-swimming fish. They also require deep pools for the young fish to feed and grow while protected from predators.

Redwood Creek is largely free of the effects of non-native aquatic species or hatchery stocks which might impact the native fishery. Although numbers of native salmonid species present in Redwood Creek have declined substantially (by perhaps 90% by the mid-1970s), remnant populations of coho, fall and summer chinook, winter and summer steelhead, and cutthroat trout are still present. Coho salmon were listed under the federal Endangered Species Act as a threatened species on May 6, 1997 by the National Marine Fisheries Service. Redwood Creek is located within the Evolutionarily Significant Unit (ESU) known as the Southern Oregon/Northern California Coast where coho salmon were listed.

Redwood Creek's ability to support fish populations is determined by habitat availability and quality. Habitat availability is limited by streamflow, stream gradients, and physical barriers such as boulders and log jams. Habitat quality is limited by channel bottom composition, pool structure, water temperature, dissolved oxygen, food supply, and predation (RNP, 1997). However, the TMDL only addresses habitat quality impacts associated with excessive sediment discharges. The key habitat problems in Redwood Creek associated with sedimentation appear to be pool quality, gravel quality (for spawning and food production), and changes in channel structure which contribute to temperature elevation.

Residents in the upper Redwood Creek basin commonly have instream domestic water intakes. These water supplies can be adversely impacted by high sediment loads, but that beneficial use is not currently impaired. Excessive sediment may result in turbidity, adverse tastes, and nuisance condition due to clogging of filters. It is anticipated that implementation of the TMDL will also help protect drinking water.

Summary of Existing Conditions

The Draft Redwood Creek Watershed Analysis (RNP, 1997) provides a summary analysis of existing stream conditions. In general, stream channels in the Redwood Creek basin are wider, shallower, and more homogeneous than is desirable or were historically present.

1. Stream Channel Conditions and Fish Habitat Impacts

Stream channel structure along the mainstem of Redwood Creek and its tributary watersheds has changed substantially over the last 40 years. Key changes in the mainstem of Redwood Creek include (1) increases in the volume of stored sediment, (2) decreases in pool numbers and depth, (3) increases in stream width and decreases in stream depth, (4) reduced recruitment of large woody debris, (5) deposition of high levels of fine sediments on the stream bottom, and (6) reduced volumes of large woody debris.

Stored Sediment

More sediment has been supplied to the low gradient reaches of the mainstem than it can effectively transport. Low gradient reaches of the mainstem Redwood Creek have acted as long term repositories of eroded sediment which originated in upstream areas. Although the creek is apparently beginning to downcut through aggraded sediments in its lower basin reaches, this stored sediment has the potential to affect channel structure and habitat values for centuries. In contrast, the higher gradient mainstem reaches in the upper watershed have removed about half the sediment deposited by the 1964 flood within 20 years (RNP, 1997).

Pool Distribution and Depth

Most mainstem pools were filled by sediments born primarily by the 1964 flood, and to a lesser extent by other high magnitude events between 1954 and 1975. Pool frequency and mean depth appeared to increase since 1975 as the creek began to move out previously deposited sediment loads, and pool recovery is more apparent in the upper basin. However, many pools were again filled by sediments following the moderate 1997 storm season. Reduced pool frequency and depth impairs rearing habitat by reducing availability of cool water refuges and increasing predation.

Channel Width and Depth

Many reaches of Redwood Creek became substantially wider and shallower in response to excessive sediment inputs and destructive flood flows which occurred between the mid 1950s and mid 1970s. Stream width increased and depth decreased in response to streambank erosion and channel aggradation. Although many reaches of Redwood Creek have begun to downcut through aggraded sediments (especially in the middle and upper basins), stream widths have not decreased substantially. Fish habitat impacts associated with increased width and decreased depth include increases in water temperature, decreased cover to hide from prey, and increased difficulty in moving up and down the stream in search of food and cool water refugia. In addition, aggraded sediment deposits have formed "deltas" at the mouths of many tributaries which impede fish passage upstream into tributaries. Finally, as the creek has widened and riparian timber has been harvested, canopy coverage of the stream has been reduced substantially, contributing to water temperature increases.

Fine Sediments

Although limited data are available concerning stream substrate composition in Redwood Creek, it appears that there is a slight trend toward coarsening of bed material since the 1970s. However, levels of fine sediment (which can be harmful to fish spawning success) appear to be higher than desirable for successful fish spawning in many reaches of Redwood Creek, principally in the lower basin.

Large Woody Debris

Large woody debris (LWD) in North Coast streams provides multiple functions which are key to the maintenance of healthy stream habitat and the moderation of sedimentation impacts on those streams. Presence of adequate LWD is a key factor in pool formation, sediment storage, and nutrient loading in many streams. Due to extensive harvesting of riparian forests along Redwood Creek and its tributaries along with extensive streambank erosion, recruitment of LWD is well below historic levels needed to support healthy fish habitat and to moderate sediment transport.

To summarize, fish populations in Redwood Creek are much reduced in comparison to historic accounts. Habitat conditions are probably still quite degraded relative to pristine conditions, but are showing signs of improvement. Although channel deepening and pool development have been observed in all but the lower few miles of the Creek, the mainstem generally lacks an adequate pool-riffle structure and cover. Coarse sediment deposited in the mainstem allows a large proportion of summer base flows to infiltrate and flow subsurface, thereby limiting the surface water available to fish and increasing surface water temperatures. Large deltas in some tributaries block some tributary mouths and prevent migration of fish. The lack of suitable rearing habitat in the mainstem and tributaries has forced juvenile fish to the estuary, where they are subject to the impacts of uncontrolled breaching of the sand bar. Spawning habitat is improving slowly as gravels are cleaned of fine sediment. Canopy closure along the upper reaches of Redwood Creek is increasing, but is still far less than it was early this century. Tributary water temperatures are generally suitable for salmonids, but are suboptimal for fish along much of the mainstem. Recruitment of large woody debris and nutrients are probably well below historic levels. This condition is likely to persist into the future as deciduous willows and alders take the place of evergreen conifers along much of the mainstem and tributaries, and as large conifers along watercourses in the upper basin are harvested (NPS, 1997). Willows and alders generally yield less durable LWD than conifers.

2. Hillslope Conditions

Timber harvesting is the most widespread land use in Redwood Creek basin. Over 85% of the basin upstream of the park has been logged, including about 30% which was logged between 1978-1992. About three-quarters of this recently logged area was logged using intensive silvicultural methods which remove all or almost all trees from the harvest area. Substantial areas of the park were intensively logged prior to their inclusion in the park. Harvested areas remain at greater risk of increased erosion (principally through landsliding) for at least a year or two following harvest, and possibly for longer periods of time. It is expected that timber harvesting of second growth timber in the upper basin will continue in the future, so erosion potential associated with these harvests will need to be addressed through the TMDL.

Most of the likely future erosion potential in the basin caused by human activity is associated with logging roads and skid trails, although roads constructed for other purposes also pose significant erosion potential. Roughly 1400 miles of forest roads and over 5000 miles of skid trails have been build within the basin, of which about 445 miles of roads and 3000 miles of skid trails were included within the national park boundaries. About half the roads and a very high percentage of skid trails upstream of the park are not properly maintained or have been abandoned. The Redwood Creek Watershed Analysis contains a detailed analysis of the status and condition of existing roads, and concludes that remaining erosion potential associated with poorly designed and maintained roads remains the largest future erosion source in the basin which can be controlled. Although there has been some recovery in the Redwood Creek and tributary channels, it is expected that a very high percentage of improperly constructed or maintained roads will fail during the next high magnitude storm. Unless corrected through road upgrading, maintenance, and/or decommissioning, such road failures are expected to cause substantial direct erosion (through crossing failures, stream diversions, etc.) and indirect erosion events (e.g. gully formation and mass wasting events).

Other continuing land uses in the basin pose less substantial erosion potential although potential impacts could be significant in local settings. Intensive timber harvesting, particularly using clearcutting and tractor logging in sensitive streamside areas may pose significant erosion potential in the future. State and county roads pose significant erosion potential in some locations. Ranching operations and residential property management may also have the potential to cause significant erosion, particularly in locations where livestock access contributes to bank erosion.

General Problem Statement

The Redwood Creek watershed has experienced a reduction in the quality and quantity of instream habitat which is capable of supporting the cold water fishery, particularly that of coho salmon, chinook salmon, and steelhead. Controllable factors contributing to this habitat loss include the acceleration of sediment production and delivery due to land management activities, including existing roads, and the loss of instream channel structure necessary to maintain the system's capacity to efficiently store, sort, and transport delivered sediment.

Three factors are important in describing the issue of sedimentation: sediment production, delivery, and transport. Water quality concerns arise when sediment is delivered to the stream in amounts or to locations that overwhelm the stream's capacity to transport it. Such is the case in the

Redwood Creek watershed. Habitat niches are filled by sediment and the stream channel is aggraded, in some places. It is important to note, though, that the aggradation of the upper mainstem and most tributaries appears to be reversing-- an indication that the process of recovery has begun. Adequate pool riffle structure and stream cover are still absent in the lower mainstem. Excessive sedimentation has also contributed to habitat degradation in the estuary.

For gravel-bed streams, such as the Redwood Creek, the presence of channel structure plays a crucial role in the efficient storage, sorting, and transport of sediment through the river system. Channel structure takes the form of large woody debris, boulders, armoured stream banks, and other structural elements. For streams in the Pacific Northwest, including northern California, large woody debris has been identified as a particularly important structural element. Thus, sediment delivery and instream channel structure, particularly large woody debris, are integral companions in the problems (and solutions) related to sedimentation and the reduction in the quality and quantity of instream habitat.

Instream Problem Statements

1. Fine Sediment in Spawning Gravels

Spawning gravels of the Redwood Creek watershed are impacted and likely to suffer additional impacts by the delivery of fine sediment to the stream which fills the interstices of the framework particles: 1) cementing them in place and reducing their viability as spawning substrate, 2) reducing the oxygen available to fish embryos, 3) reducing intragravel water velocities and the delivery of nutrients to and waste material from the interior of the redd (salmon nest), 4) and impairing the ability of young salmon to emerge as free-swimming fish. This statement relates to the SPAWN beneficial use and the potential for settleable material to affect spawning redds.

2. Channel Aggradation

Spawning gravels of the Redwood Creek watershed are impacted by the delivery of fine and coarse sediment to the stream which causes aggradation, the burial of large woody debris and other structural elements, a loss of the stream's ability to effectively sort gravel, and a potential reduction in the dominant particle sizes. This statement relates to the SPAWN and COLD beneficial uses and the potential for sediment and settleable material to adversely affect spawning substrate.

3. Lack of suitable pools for Rearing Habitat

Pools of the Redwood Creek watershed potentially suitable as rearing habitat are impacted by the delivery of fine and coarse sediment to the stream which: 1) reduces the volume of available rearing habitat by filling in pools and burying pool-forming structural elements such as large woody debris, 2) reduces pool depth and therefore the cool water refuge associated with temperature stratification, 3) reduces the availability of fish cover as a result of decreased depths and the burial of large woody debris and other structural elements, and 4) causes loss of surface flow as pools are filled in resulting in less available habitat and protection from predators. This statement relates to the SPAWN and COLD beneficial uses and the potential for sediment and settleable material to impact rearing habitat.

4. Stream Channel Instability

Increased sediment delivery to the Redwood Creek watershed impacts stream channel stability by causing: 1) aggradation, stream channel widening, greater flood potential, and greater stream bank erosion, and 2) the burial of channel structural elements such as large woody debris with a reduction in sediment transport efficiency. This statement relates to the COLD and EST beneficial uses and the potential for sediment to impact stream channel stability and habitat niches.

5. Physical Barriers to Migration

The migration of anadromous fish in the Redwood Creek watershed from the ocean, within the basin, and back to the ocean is impacted by the presence of migration barriers including shallow or dewatered stream segments due to aggradation (rising stream bed elevation). This statement relates to the MIGR beneficial use and the potential for sediment in the form of aggradation or road fill to prevent the migration of salmonids. (Natural barriers, such as bedrock falls, are not addressed here since they are not pollutants for which TMDLs are needed. In addition, the TMDL does not address anthropogenic barriers associated with culverts because EPA does not consider culverts a pollutant for which TMDL preparation is needed (EPA, 1997a)).

Hillslope Problem Statements

1. Improperly Designed or Maintained Roads

The large number of improperly designed and maintained roads, landings and skid trails in the Redwood Creek watershed causes: 1) increased surface erosion and fine sediment production and delivery and 2) an increased potential for stream diversions (stream channel capture), rill and gully erosion, and road related landslides with corresponding increases in sediment production and delivery. This statement relates to the COLD beneficial use and the potential for sediment and settleable matter to impact stream channel stability and habitat niches.

2. Sediment from Unstable Areas

Timber harvest operations on unstable slopes (e.g., inner gorges, headwall swales, active or potentially active landslides, or steep slopes) in the Redwood Creek watershed cause increased landsliding and the production and delivery of fine and coarse sediment. In addition, agricultural operations in streamside areas increase streambank erosion in localized settings. This statement relates to the COLD beneficial use and the potential for sediment and settleable matter to impact stream channel stability and habitat niches.

3. Removal of Riparian Trees and Loss of Large Woody Debris

The removal of vegetation (particularly large conifers) from the riparian zone of the Redwood Creek watershed causes: 1) a loss of stream bank stability and increased stream bank erosion, 2) a loss of sediment filtering capacity and increases in sediment delivery, and 3) a reduction in the potential for large woody debris recruitment to the stream and in the stream's sediment transport efficiency. This statement relates to the COLD beneficial use and the potential for sediment and settleable matter to impact stream channel stability and habitat niches.

Section 3.2. Numeric Targets

Section 303(d)(1)(C) of the Clean Water Act states that TMDLs "shall be established at a level necessary to implement the applicable water quality standards...." The numeric targets developed for the Redwood Creek TMDL are intended to interpret the narrative water quality standards adopted in the Basin Plan (1994). EPA notes that the Regional Board has indicated that it does not intend to bring enforcement action based on instream numeric target exceedences.

Instream numeric targets, as included in the TMDL, represent adequate stream habitat conditions for salmonid reproductive success. Instream targets provide a vital set of measures of whether, in the long run, beneficial uses impacted by sedimentation are recovering.

Hillslope numeric targets represent desired conditions for land management which are associated with properly functioning erosional processes and erosion rates which are not excessively accelerated by human influences. If these hillslope target conditions are attained, erosion rates and sediment delivery to streams should decline to levels which allow Redwood Creek stream habitat to recover from the effects of excessive sedimentation which occured in the past. EPA expects that recovery from these effects may take many years. Hillslope targets provide an immediately useful set of measures of whether land uses known to contribute much of the human-caused share of sediment loading to Redwood Creek are being modified in ways which will minimize future erosion potential and sediment delivery.

The numeric targets are based on scientific literature, available monitoring data for the basin and best professional judgment. When implemented, the TMDL should fully meet these targets and, as a result, the WQS. Table 3 depicts the instream numeric targets, and table 4 depicts the hillslope numeric targets..

Numeric targets interpret existing narrative water quality objectives in order to:

- describe physical conditions of Redwood Creek and the hillslopes around the Creek which are associated with attainment of the narrative objectives and beneficial uses,
- assist in estimating Redwood Creek's capacity to receive future sediment inputs and still support beneficial uses,
- compare existing and target conditions for sediment related indicators,
- provide an evaluation framework for analysing monitoring data collected in the future and making changes in the TMDL and/or Implementation Plan in response, and
- assist in evaluating whether land management and restoration actions are effective in adequately reducing erosion and subsequent sediment loading to the Creek.

<u>Instream Numeric Targets</u>

The indicators for which EPA is establishing instream numeric targets include percent fines <0.85 mm, percent fines <6.5 mm, median surface particle size (d_{50}), percent of surface fines <2 mm, percentage of mainstem creek length in riffles, residual large woody debris, and mean residual pool depth. Fine sediment targets are intended to apply in fish bearing reaches of generally low gradient (<3% slope). Separate pool depth targets are established for the mainstem and for tributaries to

Redwood Creek to reflect the differences in stream sizes and related differences in desirable pool characteristics. In addition, the stream riffle target is being set only for the lower gradient part of Redwood Creek to reflect the fact that pool riffle structure may be substantially different in higher gradient streams. Scientific literature suggests that these indicators are the most easily linked to fish habitat conditions which support salmonids and can assist in evaluating long term impacts of hillslope erosion and erosion reduction efforts (Knopp, 1993, Chapman, 1988, Peterson, et.al. 1992, NMFS, 1997). The targets are monitoring and evaluation goals intended to represent the desired condition where sediment is not a limiting factor for salmonid production.

Table 3. **Instream Numeric Targets for the Redwood Creek Watershed.**

Parameter	Numeric Targets (Desired Conditions)
Percent fines <0.85 mm in riffle crests of fish-bearing streams[2]	<14%
Percent fines <6.5 mm in riffle crests of fish-bearing streams	<30%
Percent of Stream Length in Riffles[3]	< 25-30% of stream reaches in riffles (reach gradient < 2%)
Pool depth in mainstem Redwood Creek reaches with pool-riffle morphology	the mean depth of pools at low flow exceeds 2 m
Depths of pools in 3rd and 4th order tributaries with pool-riffle morphology[4]	the mean depth of pools at low flow exceeds 1-1.5 m
Median particle size diameter (d_{50}) from riffle crest surfaces	$\geq$ 37 mm (minimum for a reach) $\geq$69 mm (mean for a reach)
Percent fines < 2 mm at riffle crest surfaces in fish-bearing streams	<10-20%
Large Woody Debris in any watercourse capable of transporting sediment to a higher order watercourse	Improving trend towards increased large woody debris

[1] Targets should be evaluated as ten year rolling annual averages to avoid premature assessment of trends based on inadequate information. This approach addresses the variations in sediment loading and instream indicators which are characteristic of Redwood Creek and which may not indicate management related effects.

[2] Fish-Bearing Streams: Fish present seasonally or year-round, or having fish habitat capable of supporting fish. Fish habitat is the aquatic environment and the immediately surrounding terrestrial environment that, combined, afford the necessary biological and physical support systems required by fish species during various life history stages.

[3] Riffle- low gradient: shallow stream channel areas with swiftly flowing turbulent water with some partially exposed substrate. Gradient< 4 %, substrate is usually cobble dominated. The gradient is the general slope, or rate of change in vertical elevation per unit of horizontal distance, of the water surface of a flowing stream; or the rate of change of any characteristic per unit of length.

[4] Stream order is the designation of the relative position of stream segments in the drainage basin network. For example, a first order stream is the smallest, unbranched, tributary which terminates at the upper point. A second order stream is formed when two first order streams join.

Some of the selected indicators and target values are sensitive to variations in conditions in different areas of the watershed which are influenced by differences in geology and stream morphology. However, the indicators and associated numeric targets are relatively insensitive to probable annual variations in future sediment loading and impacts over time. It would be desirable to use more dynamic indicators which set erosion reduction and habitat improvement goals as a function of the factors which determine year-to-year variations in sediment loading and stream responses. Ideally, the TMDL would include indicators which directly account for variations in precipitation and resultant runoff and flows. Use of this type of indicator would enable analysts to distinguish changes in erosion and instream effects associated with land management actions from changes attributable to differences in runoff intensity. This approach could make it easier to evaluate the effectiveness of the TMDL based on limited data. Because such indicators could not be identified for this TMDL, most of the numeric targets are expressed as ten year rolling averages. This approach helps ensure that conclusions concerning watershed responses to erosion control actions are not drawn prematurely. The drawback of this approach is that we must wait several years before we will be able to complete this critical evaluation of TMDL effectiveness.

1. <u>Percent Fines <0.85 mm</u>

Once the eggs are laid and fertilized, the spawners cover the redds with material from upstream, including clean gravels and cobbles. The interstitial spaces between the particles allow for water to flow into the interior cavity where dissolved oxygen, needed by the growing embryos, is replenished. Similarly, the interstitial spaces allow water to flow out of the interior cavity carrying away metabolic wastes. However, fine particles either delivered to the stream or mobilized by storm flow can intrude into those interstitial spaces, blocking the flow of oxygen into the redd and the metabolic wastes out of it. The reduced permeability into and out of the redd results in a reduction in the rate of embryo survival.

a. Numeric Target

<u>The numeric target for fines <.85mm for Redwood Creek is less than or equal to 14%.</u> The target should be monitored at stream riffles in reaches around existing monumented cross sections to be selected during the design of the monitoring plan. EPA intends that this target indicator should be measured through the use of bulk sampling of the surface and subsurface substrate layers (preferrably measuring dry weights). The target is selected as the midpoint between the percentages of fines reported in unmanaged streams in the Peterson (1992) and Burns (1970) studies. The target takes into account that the 11% fines <0.85 mm which was observed in unmanaged streams in the Pacific Northwest (Peterson et al., 1992) is probably lower than would be expected in California. On the other hand, the 17% fines <0.85 mm which was seen in unmanaged California streams beginning in 1967 (Burns, 1970) is probably too high given the huge sediment loads which were discharged to streams as a result of the 1964 storms. In addition, Tappel and Bjorn (1983) predicted that 14% fines <0.85 mm in combination with about 30% fines <9.5mm would provide an average of 50% survival to emergence for steelhead and an average of 70% survival to emergence for chinook salmon. These appear to be acceptable rates of survival to emergence. The literature sources reviewed in setting the target generally support the 14% target level as reasonably protective. EPA recognizes that there will be spatial and temporal variability around the target level for instream indicators.

b. Existing Conditions

Fine sediment size fractions are difficult to measure accurately. The percentage of fine sediment in the channel bottom is often measured through various bulk sampling methods which gather both surface and subsurface sediments from the stream bottom. No bulk sampling data has been published for Redwood Creek; however, the fraction of fine sediments <2 mm commonly exceeds 20% (personal communication with Mary Ann Madej, USGS, June 1998). Levels of very fine sediments are believed to be relatively higher in lower Redwood Creek than in the middle and upper basin (personal communication with Mary Ann Madej, USGS, June 1998). This is a reasonable expectation because (1) particles tend to break down as they move downstream, increasing the percentage of fines present, (2) lower Redwood Creek has a low gradient which would be more suited for deposition of fine sediments, and (3) lower Redwood Creek is still experiencing sediment aggradation associated with catastrophic historic floods and sediment loads.

c. Comparison of Numeric Target and Existing Conditions

A comparison of the numeric target and existing information helps provide information on the extent of the problem as well as the sediment reduction needed to meet water quality standards. However, it was infeasible to conduct a quantitative comparison of the numeric target and existing conditions because inadequate reliable data were available. If the rough assessment that levels of fines often exceeds 20% is true, portions of Redwood Creek probably exceed the numeric target.

2. <u>Percent fines <6.5 mm</u>

After 4 to 6 weeks or life, the embryos are ready to emerge from the gravel as fry (young swimming fish.) The presence of fine sediment in the gravel interstices can impede fry emergence. However, the size of fine particles likely to fill the interstices of redds sufficient to block passage of fry are larger than those likely to suffocate embryos. That is, particles ranging from 0.85 mm to 9.5 mm are capable of blocking fry emergence, depending on the sizes and angularity of the framework particles, while still allowing sufficient water flow through the gravels to support embryo development. Besides a correlation between percent fines and the rate of survival to emergence, there is also a correlation between percent fines and the length of incubation; i.e., the amount of time it takes for the fry to emerge from the egg. Percent fines is also inversely related to the size of emerging fry (Chapman, 1988). Each of these factors impact the ultimate survivability of the embryos and fry.

a. Numeric Target

<u>The numeric target for fines <6.5 mm is less than or equal to 30% for Redwood Creek</u>. The lower basin target should be monitored at stream riffles in reaches around existing monumented cross sections to be identified during the design of the monitoring program. EPA intends that this target indicator should be measured through the use of bulk sampling of the surface and subsurface substrate layers (preferrably measuring dry weights). The numeric target was selected based on a review of literature which evaluated the relationship between fines <6.5mm and survival to emergence rates for salmonids. Research results concerning the relationship between salmonid survival to emergence and levels of fines <6.5mm are relatively consistent. Tappel and Bjorn (1983) predicted that 30% fines <9.5mm in combination with 14% fines < 0.85mm would provide

an average of 50% survival to emergence for steelhead. The same study predicted that 32% fines <9.5mm in combination with 14% fines < 0.85mm would provide an average of 70% survival to emergence for chinook salmon. Both steelhead and chinook are expected to have greater emergence success than coho salmon when redds are sedimented. Kondolf (unpublished data), evaluating data from other studies, concluded that if one chooses a 50% survival to emergence rate, the data indicate that fines defined either as <3.35 or <6.5 mm should not comprise more than 30% of substrate composition. Finally, Chapman (1988) reported data from several other studies concerning fine sediment levels in unlogged Oregon watersheds which varied from 27-55%. The 30% target rate appears consistent with the research findings concerning acceptable survival to emergence rates and the levels of fines found in unlogged watersheds. EPA recognizes that there will be spatial and temporal variability around the target level for instream indicators.

b. Comparison of Numeric Target and Existing Conditions

Although no specific bulk sampling data have been published for Redwood Creek, the fraction of fine sediments <8 mm commonly exceeds 50% (personal communication with Mary Ann Madej, USGS, June, 1998).

Because data are so limited for fine sediment levels in Redwood Creek, it was not feasible to make quantitative comparisons between existing and target conditions. If the rough assessment of the amount of sediments < 8mm mentioned above is correct, levels of fine sediment in some reaches of Redwood Creek probably exceed the numeric target.

3. <u>Pool-Riffle Structure, and Percent Riffles</u>

Juvenile coho require pools for both summer and overwintering rearing. In the summer, pools provide cool, quiet habitat where coho feed and hide from predators. During the winter, off-channel pools provide habitat in which coho and steelhead both can get out of flood flows to avoid being swept downriver and out to sea. Steelhead prefer riffles for rearing during their first summer, but make more regular summer uses of pool habitat as they grow in size. Pool volumes are reduced either when a stream's hydrologic power is reduced (e.g., by increased sediment loading) or by the reduction of pool-forming elements. The number of pool-forming elements can be reduced by modification of the channel morphology (e.g., burial), physical removal (e.g., log-jam removal), reduction in supply (e.g., logging of near stream trees), or a combination of all three causes.

Various pool measures have been used (e.g., pool, frequency, spacing, or area) but are of limited value since the definition of the beginning and end of a pool is quite subjective. It is generally easier to identify riffle locations. Although some riffles are vital to north coast streams, excessive riffle habitat indicates that deep water habitat is deficient. Therefore, because riffles are easier to measure and provide an indirect indicator of pool abundance, this TMDL includes a target for the percentage of creek length in riffles (personal communication with Mary Ann Madej, June, 1998).

a. Numeric Target

<u>The target for percent riffles is no more than 25-30% riffles for creek reaches less than 2% in gradient.</u> This target is based on judgment of a Redwood Park researcher who is very familiar with

the pool/riffle structure of Redwood Creek and of north coast rivers with different habitat qualities (personal communication with Mary Ann Madej, June, 1998). The 25-30% level is believed to be consistent with the riffle patterns found in well-functioning north coast streams. This target only applies in the lower gradient sections of the creek because percent riffles may exceed the target level in steeper streams which support excellent habitat. In the long run, it may prove more effective to measure pool quality and distribution based on statistical analysis of longitudinal profile data collected at monumented reaches of Redwood Creek. This monitoring method has promise in providing a more discriminating indicator of channel roughness and variability, which can be adjusted (normalized) to account for and allow comparisons between streams of different sizes.

b. Existing Conditions and Comparison With Numeric Targets

In the 1970s and early 1980s, riffles comprised from 50 to 70% of observed reaches in study areas (personal communication with Mary Ann Madej, June, 1998). By the mid 1990s, riffles comprised 20 to 40% of observed reaches in study areas. Some reaches of Redwood Creek are still characterized by excessive riffle and insufficient pool structure.

4. Pool Depth

Salmonids rely on deep, cool pools during the rearing stage for protection from predators and as refuges from high temperature water. Pool depth is partly a function of stream disturbance (and associated channel changes) and partly a function of stream size. Pools in larger streams tend to be deeper, on average, than pools in smaller streams (assuming other factors are equal). Flosi and Reynolds (1994) concluded from the Department of Fish and Game's habitat typing data that better California coastal coho streams (stream order 3 or 4) have pools with depths of at least 3 feet.

a. Numeric Target

The numeric target for low flow pool depth is >2 meters on average for the mainstem of Redwood Creek, and 1-1.5 meter for third and fourth order tributaries to Redwood Creek. This target is based principally on the results reported by Flosi and Reynolds (1994) and applies only in reaches which have pool-riffle morphology. The targets for the mainstem of Redwood Creek are higher than the results reported by Flosi and Reynolds because Redwood Creek is a larger, higher order stream than the stream type referred to in this study. Several commenters have reported the existence of many pools greater than 10 feet deep prior to the onset of excessive sediment loading to the stream more than 30 years ago. In addition, there is some evidence that chinook salmon prefer deeper pools than coho. The targets are also consistent with the "species habitat needs matrix" developed by an interagency group in connection with resource management discussions with Pacific Lumber Company (NMFS, 1997).

b. Existing Conditions and Comparison with Numeric Target

Limited information is available concerning pool depths in Redwood Creek. The Redwood Creek Watershed Analysis (RNP, 1997) indicated that mean pool depths at three locations in Redwood Creek mainstem in 1986 were about 1.4-1.8 meters. Following the 1997 storm (11-year recurrence interval), pool recovery trends observed in previous monitoring were reversed (written comments of Redwood National Park, November 18, 1998) These results are too limited to draw a meaningful comparison with the numeric target levels for the mainstem and for tributaries.

5. Median Surface Particle Size Diameter (d_{50})

The d_{50} is the median value of the size distribution in a sample of surface pebble counts. It is a measure of the central tendency of the whole sample, and thus is one of several indicators of how "fine" or "coarse" the sample is overall. As discussed in the discussion for the percent fines targets, both amount and size of fine and coarse sediments can impact salmonid lifestages. Various measures of central tendency have been used by researchers (Young, et al. (1991) lists several). The d_{50} indicator is selected for Redwood Creek because it is easy to calculate based on results from pebble counts. In a study that evaluated the relationship between hillslope disturbance and various instream indicators, Knopp (1993) found that clear trend of decreasing particle sizes in the riffles was evident with increasing hillslope disturbance. Moreover, Knopp found that a statistically significant difference in average and minimum d_{50} values when comparing reaches in undisturbed and less disturbed watersheds with reaches in moderately and highly disturbed watersheds. Therefore, the d_{50} levels identified in undisturbed and less disturbed locations are good candidates for numeric targets for Redwood Creek. Knopp also found that the moderately disturbed reaches were not statistically different from the highly disturbed reaches. This indicates that d_{50} results may take upwards of 40 years before mitigation of current disturbance is positively reflected.

a. Numeric Targets

The targets for d_{50} are means greater than or equal to 69 mm and a minimum of greater than or equal to 37 mm. The d_{50} indicator has two targets associated with it. The higher number $\geq$69 mm represents the optimum target, while the lower number $\geq$37 mm represents the minimum number that should be found. By setting two numbers, EPA recognizes that there may be annual variability in this target. These values are based on Knopp's findings (1993) concerning d_{50} levels in north coast watersheds which were relatively undisturbed. Because Knopp found the d_{50} to be a discriminating indicator (that is, an indicator capable of distinguishing between watersheds which were more or less disturbed as a result of prior management), the indicator and associated target levels identified in Knopp's study are appropriate.

b. Existing Conditions

Table 4 is a summary of surface d_{50} data collected by USGS and Redwood National Park in 1979 and again in 1994 at 8 monitoring sites along the mainstem of Redwood Creek. It should be noted that these data were collected using a surface pebble count method. This method may not produce reliable results regarding percentages of very fine sediments due to operator variability. In addition, monitoring was conducted at a relatively small number of sites on only 2 occasions. For these reasons, firm conclusions concerning actual past or present conditions for fine sediment in Redwood Creek should not be drawn based on this limited data set. However, the limited data are reported to provide some basis for comparing historical and target conditions.

Table 4: Summary of Existing Data for Median Particle Size (d_{50})

Cross Section	d_{50} (1979)	d_{50} (1994)
2	16	16
5	8	12
16	15	27
17	9	12
20	11	16
32	19	41
34	12	27
40	41	not available
MEAN	16	22

Source: Unpublished USGS and NPS data reported in RNP, 1995.

c. Comparison of Numeric Targets and Existing Conditions

Quantitative comparisons of historical and target conditions are infeasible due to the limitations in the available data. While definitive comparisons cannot be drawn, it appears that d_{50} levels in the watershed may not meet the numeric target, and that mean particle sizes are higher in the middle/upper watershed than in the lower watershed. The numeric target for the mean particle size diameter is set for the watershed as a whole. However, particles tend to become finer as they are transported downstream due to stream power and friction. The targets set for the mean particle size diameter for the lower portion of the watershed may be higher than needed for recovery of spawning habitat. As more information becomes available during instream monitoring, the numeric targets for the lower part of the watershed may be adjusted during subsequent TMDL revisions.

6. Percent Surface Fines < 2 mm

As discussed above, salmonid egg growth and emergence of young fry are adversely affected when excessive levels of fine sediments are present on the stream bottom. In addition to the two measures of fine sediment used above, which are based on data for both surface and subsurface particle sizes collected through bulk sampling methods, a numeric target is included based on fine sediment on the surface of stream riffles which can be measured through the same pebble count method used to calculate the d_{50} particle size target established above. The target is being established for fines at the 2 mm size because this is approximately the smallest size particle which can be reliably identified through pebble count analysis. This indicator is being used because most past and expected future monitoring of substrate composition in Redwood Creek basin relies upon the pebble count method. In addition to providing a measure of fine sediment levels which may be associated with impacts to salmonid egg growth and emergence of fry, the level of fines on the stream surface is also a useful measure of the degree to which the stream is experiencing sediment loading in excess of sediment transport capacity.

a. Numeric Target

The numeric target for surface fines <2mm for Redwood Creek is less than or equal to 10-20%. The target should be monitored through pebble counts in riffle crests located at monumented cross sections in fish bearing streams, to be selected during the design of the monitoring plan. The target is selected based on a review of several literature sources, including Chapman and McLeod (1987) and Young, et.al. (1991). The target is set as a range to reflect (1) the relatively sparse research results regarding the levels of surface fines associated with good and poor quality salmonid habitats and (2) to reflect the significant variability which would be expected from year to year and in different locations within the watershed. EPA expects the target range to be exceeded in some years and is setting the target as a 10 year rolling average to account for expected interannual variability.

b. Existing Conditions

Fine sediment size fractions are difficult to measure accurately. The percentage of fine sediment in the channel bottom is often measured through various bulk sampling methods which gather both surface and subsurface sediments from the stream bottom. No bulk sampling data has been published for Redwood Creek; however, the fraction of fine sediments <2 mm commonly exceeds 20% (personal communication with Mary Ann Madej, NPS, June 1998). Surface particle size distributions can also be measured through the pebble count method. Table 5 is a summary of unpublished fine sediment monitoring data collected by USGS and Redwood National Park in 1979 and again in 1994 at 8 monitoring sites along the mainstem of lower and middle Redwood Creek. Table 5 on the following page reports data for the <2 mm size. It should be noted that the results are not reliable estimates for the stream as a whole or for the recent past. In addition, monitoring was conducted at a relatively small number of sites on only 2 occasions. For these reasons, firm conclusions concerning actual past or present conditions for fine sediment in Redwood Creek should not be drawn based on this limited data set. These data are presented here to provide a general sense of substrate surface particle sizes observed in 1979 and 1994. Because fines are often winnowed from the surface by stream flow, the fraction of fine sediment is expected to be higher when subsurface fines are also measured, as is done through bulk sampling methods (Lisle and Madej, 1992).

c. Comparison of Numeric Target and Existing Conditions

A comparison of the numeric target and existing information helps provide information on the extent of the problem as well as the sediment reduction needed to meet water quality standards. However, it was infeasible to conduct a quantitative comparison of the numeric target and existing conditions because inadequate reliable data were available.

Table 5: Summary of Existing Data for Fine Sediment Sizes on the Channel Bottom Surface

Cross Section	%fines<2mm (1979)	%fines<2mm (1994)
2	20	15
5	14	12
16	3	6
17	9	22
20	4	28
32	3	13
34	14	19
40	9	not available
MEAN	10	16

Source: RNP and USGS data reported in RNP (1995).

7. Large Woody Debris

The removal of vegetation (particularly large conifers) from the riparian zone of the Redwood Creek watershed causes: 1) a loss of stream bank stability and increased stream bank erosion, 2) adverse effects on stream channel morphology, including pool formation, and channel geometry, 3) a loss of sediment filtering capacity and increases in sediment delivery, and 4) a reduction in the potential for large woody debris recruitment to the stream and in the stream's sediment transport efficiency. This statement relates to the COLD beneficial use and the potential for sediment and settleable matter to impact stream channel stability and habitat niches.

a. Numeric Target

The numeric target for large woody debris is increasing trends in large woody debris. Insufficient data and information were available to support the delineation of a specific numeric target. To assist in reviewing whether large woody debris conditions are approaching satisfactory levels, table 5 lists suggested large woody debris frequency and size for streams of different widths based on research conducted by Bilby and Ward (1989) concerning woody debris levels in forested watersheds dominated by old growth douglas fir. The suggested woody debris levels are most appropriately used for comparative purposes in parts of Redwood Creek basin in which douglas fir is the predominant conifer type (generally, in the areas of the watershed upstream of the National Park). These suggested values are not being established as numeric targets for the TMDL because their applicability to Redwood Creek is not well understood at this time.

Table 5: Relationship between channel width and mean for debris diameter, length and volume and the number of pieces of debris in old-growth Douglas-fir streams.

Channel Width (ft)	Debris/100 ft	Geometric mean debris diameter (inches)	Geometric mean debris length (ft)	Mean debris piece volume (cubic feet)
15	16	14	18	13
20	12	16	20	26
25	9	17	22	38
30	7	18	25	51
40	5	21	29	75
50	4	23	33	100
55	4	25	35	113
60	3	26	37	125
65	3	27	40	137

Source: Adapted from Bilby and Ward (1989).

b. Existing Conditions and Comparison with Numeric Target

Limited information is available concerning large woody debris within the riparian management zone in Redwood Creek. In a study by Pitlick (1982), 16 tributaries in Redwood Creek Basin were evaluated for percentage of sediment stored by large woody debris. Values ranged from a low of 13 percent to a high of 94 percent. On average, greater than 40 percent of the sediment volume was stored by large woody debris.

Hillslope Numeric Targets

As described above, numeric targets are designed to interpret narrative State water quality standards in effect for Redwood Creek and identify the desired condition for the watershed with respect to sedimentation. The suite of instream numeric targets included in the TMDL are intended to identify key characteristics of the instream environment which, if attained, are expected to be adequate to ensure recovery of aquatic habitat health. To account for temporal variability in conditions, the instream targets are expressed as ten year rolling averages (i.e., they are not expected to yield reliable diagnostic results in periods of less than ten years). The drawback of this approach is that it does not provide indicators which are capable of guiding shorter term evaluation of whether the watershed is moving toward recovery of conditions which will support all beneficial uses of concern which were affected by excessive sediment delivery.

Hillslope numeric targets are included in the TMDL to describe desired conditions with respect to several land management uses which are ongoing in the watershed and which are expected to continue to pose significant erosion potential in the future. Hillslope targets are being established to identify appropriate road design, location, inspection, and maintenance patterns along with appropriate silvicultural practices in sensitive areas. If attained, these hillslope targets are expected to result in the reduction of erosion potential and future sediment delivery to streams to levels which will allow recovery of instream habitat from sediment impacts over the coming decades. Therefore, hillslope targets supplement instream targets by providing measureable goals which are not subject to the variability associated with water year type. They have the advantatge to the individual landowner that they can be converted directly into implementation plans and management practices which can be evaluated more frequently than the 10 year rolling average.

While inadequate information was available for this TMDL to support development of hillslope targets to address all potentially significant sediment sources (e.g. livestock impacts on streambanks), EPA believes the hillslope targets collectively describe the attributes of a well-functioning watershed which supports both healthy aquatic habitat and ongoing road use and logging. EPA also believes these hillslope targets are consistent with the proposed implementation provisions in the State's TMDL and implementation plan draft dated November 10, 1998. As additional information is collected in the future regarding the effectiveness of erosion prevention and control methods and associated stream habitat recovery trends, it may be appropriate to review and revise these hillslope targets accordingly.

Table 6 on the following page summarizes the hillslope targets, which are discussed in detail below.

8. Road stream crossings with diversion potential

A key source of continuing erosion potential in Redwood Creek watershed is the existence of many road crossings with diversion potential (i.e., the tendency to divert stream flow out of the channel and along and across the road surface) (RNP, 1997, Hagans and Weaver, 1987). Diversion of flow is associated with major road surface erosion and creation of debris flows and other mass wasting events. The potential for diversion is eliminated in well-designed crossings through the use of rolling dips or other measures which ensure that if the crossing fails, the flow remains in the channel.

a. Numeric Target

The numeric target is that no crossings have diversion potential (i.e., all crossings are reconfigured permanently to assure that no diversion will occur). This target is selected based on recommendations from Redwood National Park and USGS scientists (see comments from RNP and M. Madej, USGS) and EPA's review of literature sources concerning the potential for eliminating road-related erosion potential (Weaver and Hagans, 1994 and 1996; Spence et.al. 1996).

b. Existing Conditions and Comparison with Numeric Target

Although specific data concerning diversion potential of roads in Redwood Creek were not available to EPA for this TMDL, Redwood National Park researchers have estimated that about 55% of the approximately 1400 miles of roads in the basin are not maintained and are therefore more likely to fail during a storm than maintained roads. There are several thousand crossings associated with these roads. Therefore, it is likely that hundreds if not thousands of crossings continue to have diversion potential.

Table 6: Hillslope Numeric Targets for the Redwood Creek Watershed.

Parameter	Numeric Targets (Desired Conditions)
Road stream crossings with diversion potential	No crossings have diversion potential (i.e., all crossings are reconfigured permanently to assure that no diversion will occur).
Road culvert/crossing sizing	All culverts and crossings are sized to pass the 50 year flood and associated sediment and debris. In addition, crossings and culverts in the snow zone (generally, upstream of Highway 299, are sized large enough to accommodate flows and associated sediment and debris caused by precipitation and snow melt runoff.
Landing and road fill stability	All landings and road fills (e.g., sidecasts) on slopes >50% and which could potentially deliver sediment to a water course are pulled back and stabilized.
Road surfacing and drainage	All roads have surfacing and drainage facilities or structures which are appropriate to their patterns and intensity of use.
Road inspection, maintenance, and decommissioning	All roads are inspected and maintained annually or decommissioned. Decommissioned roads (roads which are closed, abandoned, or obliterated) are hydrologically maintenance free.[1]
Road location in inner gorge or unstable headwall areas	Roads are not located in steep inner gorge or unstable headwall areas except where alternative road locations are unavailable.[2]
Use of clearcut and/or tractor yarding timber harvest methods	Clearcut and/or tractor yarding harvest methods are not used in steep inner gorge, unstable, or streamside areas unless a detailed geological assessment is performed which shows there is no potential for increased sediment delivery to water courses as a result of using these methods.[3]

1 Hydrologically maintenance free means that:
- drainage in the road area mimics natural hydrology,
- all drainage is dispersed to the slope through use, as appropriate, of outsloping or cross-road drains,
- all culverts and associated fill material is removed from crossing areas,
- all potentially unstable road fill and landing sidecasts are pulled back, and
- excavated spoils are placed in locations where they will not enter a water course.

2 This target is intended to address roads located adjacent to water courses with inner gorge topography or which cross steep, unstable headwall areas, and is not intended to apply to road crossings of inner gorge areas. Steep inner gorge areas generally exceed 65% in slope and are located adjacent to class 1 and 2 water courses. Characteristics of steep unstable headwall areas generally include the following:
- slopes greater than 50%,
- erosive or incompetent soil types or underlying geology,
- concave slope shape,
- convergent groundwater present, and/or
- evidence of past movement is present.

3 Characteristics of steep inner gorge, unstable, or streamside areas generally include a the following:
- slopes greater than 50%,
- located within 300 feet of a Class 1, 2, or 3 watercourse,
- erosive or incompetent soil types or underlying geology,
- concave slope shape,
- convergent groundwater present, and/or
- evidence of past movement is present.

9. Road culvert/crossing sizing

A second important source of continuing erosion potential in Redwood Creek watershed is the existence of many road crossings with inadequately sized culverts or drainage structures. When culverts or crossings are blocked with debris during runoff events, the crossing may be fail, triggering debris flows which can scour downstream channels and deliver massive amounts of fill and scoured material to stream channels (RNP, 1997, RNP, 1998c, Hagans and Weaver, 1987). The potential for crossing failure is minimized when culverts or drainage structures are sized to handle the flow and associated debris and sediment load associated with infrequent but potentially destructive storms.

a. Numeric Target

The numeric target is that all culverts and crossings are sized to pass the 50 year flood and associated sediment and debris. In addition, crossings and culverts in the snow zone (generally, upstream of Highway 299, are sized large enough to accommodate flows and associated sediment and debris caused by precipitation and snow melt runoff.. This target is selected based on recommendations from Redwood National Park and USGS scientists (see comments from RNP and M. Madej, USGS) and EPA's review of literature sources concerning the potential for eliminating road-related erosion potential (Weaver and Hagans, 1994 and 1996; Spence et.al. 1996).

b. Existing Conditions and Comparison with Numeric Target

It has been estimated that on the basis of road maintenance status, hillslope gradient, geology, and soil types, stream crossing failures are likely to occur on about one third of the 1110 road miles upstream of the park during a large storm (RNP, 1998c). About 55% of the approximately 1400 miles of roads in the basin are not maintained and are therefore more likely to fail during a storm than maintained roads.

10. Landing and road fill stability

A third source of continuing erosion potential in Redwood Creek watershed is the existence of landings and roads which contain perched, unstable fill on steep slopes. Unstable fill is vulnerable to failure in response to major storm runoff and stream diversions from channels, which may cause large-scale debris torrents and sediment delivery to streams. (RNP, 1997, RNP, 1998c). The potential for failure of landing and road fills crossing failure is minimized when landings and road fills are properly located (e.g., not on excessively steep, unstable slopes) when in use and properly pulled back (i.e., excavated) following use.

a. Numeric Target

The numeric target is that all landings and road fills (e.g., sidecasts) on slopes >50% which could potentially deliver sediment to a water course are pulled back and stabilized. This target is selected based on recommendations from Redwood National Park and USGS scientists (see comments from RNP and M. Madej, USGS) and EPA's review of literature sources concerning the potential for eliminating road-related erosion potential (Weaver and Hagans, 1994, 1996; Spence et.al. 1996).

b. Existing Conditions and Comparison with Numeric Target

Specific estimates of the number of unstable landings and fills are unavailable. As described above, about 55% of the approximately 1400 miles of roads in the basin are not maintained and are therefore more likely to fail during a storm than maintained roads. About 80% of the roads in the basin were constructed before 1978, when lower road construction standards were generally in effect (RNP, 1998c). This suggests that several hundred to several thousand unstable landings and fills may exist in the basin. The percentage of these unstable fills and landings with potential to contribute sediment to watercourses is unknown, but is expected to be significant. Of the 50 miles of roads constructed on steep inner gorge slopes in the middle and upper basin upstream from the park, over 43 miles had been effectively abandoned by 1992 (RNP, 1998c).

11. Road surfacing and drainage

A very high percentage of roads in Redwood Creek are dirt surfaced roads with minimal or inadequate road surface drainage structures. Large quantities of sediments erode from road surfaces in response to storms, which can contribute to fluvial erosion and mass wasting on sites below roads (RNP, 1997, RNP, 1998c). The potential for excessive road surface erosion is minimized when roads are properly surfaced and have appropriate drainage structures. For example, roads which are used during wet weather periods should be rocked or paved, depending upon intensity of use. All roads should have appropriate drainage structures which disperse drainage across slopes and do not contribute to hillslope fluvial erosion or mass wasting.

a. Numeric Target

The numeric target is that all roads have surfacing and drainage facilities or structures which are appropriate to their patterns and intensity of use. This target is selected based on recommendations from Redwood National Park and USGS scientists (see comments from RNP and M. Madej, USGS) and EPA's review of literature sources concerning the potential for eliminating road-related erosion potential (Weaver and Hagans, 1994 and 1996; Spence et.al. 1996).

b. Existing Conditions and Comparison with Numeric Target

About 80% of the roads in the basin were constructed before 1978, when lower road construction standards were generally in effect (RNP, 1998c). These roads are less likely than recently constructed roads to have appropriate surfacing and drainage facilities. It is likely that road surfacing and drainage facilities have been upgraded on some roads at the time recent timber harvesting activities required the use of older roads in some parts of the basin. However, Redwood National Park researchers estimate that about 55% of the roads in the basin are not maintained (RNP, 1998c). These roads are therefore more likely to have degraded road surfaces or failing drainage structures. This suggests that several hundred miles of roads in the basin may have inadequate road surfacing and drainage facilities.

12. Road inspection, maintenance, and decommissioning

A very high percentage of roads in Redwood Creek are dirt surfaced roads with minimal or inadequate road surface drainage structures. Large quantities of sediments erode from road surfaces in response to storms, which can contribute to fluvial erosion and mass wasting on sites below roads (RNP, 1997, RNP, 1998c). The potential for excessive road surface erosion is minimized when roads are properly surfaced and have appropriate drainage structures. For example, roads which are used during wet weather periods should be rocked or paved, depending upon intensity of use. All roads should have appropriate drainage structures which disperse drainage across slopes and do not contribute to hillslope fluvial erosion or mass wasting.

a. Numeric Target

The numeric target is that all roads are inspected and maintained annually or decommissioned. Decommissioned roads (roads which are closed, abandoned, or obliterated) are hydrologically maintenance free. This target is selected based on recommendations from Redwood National Park and USGS scientists (see comments from RNP and M. Madej, USGS) and EPA's review of literature sources concerning the potential for eliminating road-related erosion potential (Weaver and Hagans, 1994 and 1996). EPA intends that annual road inspections need not involve intensive analysis of road conditions, and that this target would be attained if all roads are driven annually and inspected visually. The visual inspection may identify road-related problems which cause an increase in erosion potential, including, but not limited to culvert plugging, cracking or gullying of road fills and landings, and failures of drainage structures. These problems should be promptly corrected before the potential erosion and sediment delivery can occur. This road inspection and maintenance target would complement the initial, more intensive road inventory proposed in the State's draft TMDL implementation plan dated November 10, 1998.

Roads which cannot be inspected and maintained annually should be decommissioned in a manner which assures that erosion potential is prevented and the roads are hydrologically maintenance free. Hydrologically maintenance free means that:

- drainage in the road area mimics natural hydrology,
- all drainage is dispersed to the slope through use, as appropriate, of outsloping or cross-road drains,
- all culverts and associated fill material are removed from crossing areas,
- all potentially unstable road fill and landing sidecasts are pulled back, and
- excavated spoils are placed in locations where they will not enter a water course.

b. Existing Conditions and Comparison with Numeric Target

No information about road inspection activity in Redwood Creek was available for this TMDL; however, Redwood National Park researchers estimate that about 55% of the roads in the basin are not maintained on a regular basis (RNP, 1998c). Redwood National Park has decommissioned many roads since the park was established, and several private landowners have decommissioned roads which are no longer used. Under the park's proposed future management alternative, 155 miles of roads within the park would be decommissioned and over 900 miles of roads upstream from the park on private land would be decommissioned or upgraded (RNP, 1998a). Attainment of this target is likely to require increases in annual road inspection and maintenance activity on private lands, while decommissioning activity may be consistent with the park management plan preferred alternative.

13. Road location in inner gorge or unstable headwall areas

Roads in inner gorge areas are particularly prone to failures which can introduce substantial quantities of sediment into water courses. Roads in unstable headwall areas are also prone to failure, which may cause debris torrents which can transport large volumes of sediments to some watercourses (RNP, 1997, RNP, 1998c). It is difficult to engineer roads in these areas in a manner which assures that erosion potential is minimal; therefore, it is most appropriate that roads be eliminated in these areas. However, EPA recognizes that in some areas of the basin, there may be no alternative means of access if such roads are eliminated. In these situations, it may be appropriate for the roads to remain in place if a geological and engineering review is conducted which ensures that no erosion potential exists associated with the roads. In general, new roads should not be built in steep inner gorge or unstable headwall areas.

a. Numeric Target

The numeric target is that roads are not located in steep inner gorge or unstable headwall areas except where alternative road locations are unavailable. This target is intended to address roads located adjacent to water courses with steep inner gorge topography or which cross steep, unstable headwall areas, and is not intended to apply to road crossings of inner gorge areas. Steep inner gorge areas generally exceed 65% in slope and are located adjacent to class 1 and 2 water courses. Characteristics of steep unstable headwall areas generally include a combination of the following:

- slopes greater than 50%,
- erosive or incompetent soil types or underlying geology,
- concave slope shape,
- convergent groundwater present, and/or
- evidence of past movement is present.

This target is selected based on recommendations from Redwood National Park and USGS scientists (see comments from RNP and M. Madej, USGS) and EPA's review of literature sources concerning the potential for eliminating road-related erosion potential (Weaver and Hagans, 1994 and 1996).

b. Existing Conditions and Comparison with Numeric Target

Approximately 50 miles of roads in Redwood Creek basin above the park are located in steep inner gorge areas (RNP, 1998c), and an unknown but probably significant number of roads cross unstable headwall areas in the basin. About 85% of these inner gorge roads had been effectively abandoned by 1992, and 64% were no longer drivable. Therefore, it appears likely that most of these inner gorge roads above the park could be decommissioned without impairing access. Most if not all inner gorge roads in the park have been decommissioned. The number of roads crossing unstable headwall areas in the park is unknown, but EPA understands that such roads have been targeted for decommissioning work in the past.

14. Use of clearcut and/or tractor yarding timber harvest methods

Timber harvesting is expected to remain the primary land use on private lands upstream of the park. Most future harvesting is expected to occur in areas of second growth forests. Reentry and harvesting of second growth forests may cause excessive sediment loading unless more protective harvesting and yarding methods are used. Steep inner gorge, unstable, and streamside areas are most vulnerable to the effects of these more intensive harvesting and yarding methods because sediment from landslides and bare ground erosion is more likely to reach watercourses and cause adverse impacts to fish habitat.

Studies in the lower Eel River basin suggest that landslides in recently harvested second growth areas underlain by Franciscan geology (similar to that found in Redwood Creek) are larger and more common than those in areas of unharvested second growth (PWA, 1998). In Redwood Creek basin, Pitlick (1982) found that slides in harvested inner gorge areas were no more common but were much larger than those in uncut inner gorge slopes. Clearcut logging and tractor yarding were by far the most common methods used in Redwood Creek basin before the 1980s. Clearcut logging and tractor logging are significantly more disruptive of natural watershed processes including soil erosion than are other logging and yarding methods which do not cause as much ground surface disturbance (Spence, et.al, 1996). Although alternative silvicultural methods are increasingly in use in Redwood Creek, use of clearcut logging and tractor yarding methods is expected to continue in the future. In order to minimize the erosion potential associated with use of these methods, the TMDL includes a numeric target which focuses on the most vulnerable geologically unstable areas and streamside zones. The target articulates a future desired condition that clearcutting and tractor methods are not used in inner gorge, unstable or streamside areas except in cases where a thorough geological investigation shows that use of these methods will result in no increase in sediment loading to streams compared to pre-logging conditions. Attainment of this target is expected to reduce logging related erosion in unstable or streamside areas to acceptable levels.

a. Numeric target

The numeric target is that clearcut and/or tractor yarding harvest methods are not used in steep inner gorge, unstable, or streamside areas unless a detailed geological assessment is performed which shows there is no potential for increased sediment delivery to water courses as a result of using these methods. This target is selected based on recommendations from Redwood National Park and USGS scientists (see comments from RNP and M. Madej, USGS) and EPA's review of literature sources concerning the potential for minimizing logging-related erosion potential in inner gorge, unstable, and streamside areas (Spence, et.al., 1996, Reid, 1996 and 1998). Characteristics of steep inner gorge, unstable, or streamside areas generally include a combination of the following:

- slopes greater than 50%,
- located within 300 feet of a Class 1, 2, or 3 watercourse,
- erosive or incompetent soil types or underlying geology,
- concave slope shape,
- convergent groundwater present, and/or
- evidence of past movement is present.

b. Comparison of Existing Conditions and Numeric Targets

Past harvesting practices in Redwood Creek basin consisted almost entirely of large scale clearcuts using tractor yarding (RNP, 1998c). Between 1978-1995, about 30% of the area logged was clearcut (RNP, 1998c). During this period, tractor yarding was still the preferred method for removing logs. The extent to which streamside forest areas were harvested and the methods used for such harvesting in recent years is unknown, although California Forest Practice Rules specify watershed and lake protection zones which must be adhered to in preparation of timber harvest plans. Additionally, current Forest Practice Rules require plan review by a certified geologist under some conditions. Attainment of this target could require modification of harvest and yarding methods in a significant portion of the middle and upper basin which are managed primarily for timber harvesting.

Conclusion

The numeric targets are intended to interpret and apply the narrative water quality objectives. They were developed to support a goal of salmonid recovery which is a conservative approach. A variety of instream indicators were selected because no single indicator provides a truly effective, discriminating measure of the relationship between sediment loading and instream sediment impacts. The instream numeric targets are expressed as ten year rolling average values to account for interannual variability.

It should be noted that very useful monitoring information is being collected through the park's ongoing monitoring of monumented cross sections and associated thalweg (low flow channel) profiles. Although it was infeasible to derive specific indicators and numeric target values for these monitoring methods for this TMDL, researchers are currently developing indicators which could serve this purpose in the future. Cross section and thalweg measures should prove effective in the future as indicators of channel stability and change over time. Other new measures are also being developed (e.g., substrate permeability and turbidity measures) which could prove more effective than some of the indicators used in this TMDL. In future TMDL revisions, it may be appropriate to consider inclusion of indicators based on these and other new monitoring approaches as they become available in the future.

Hillslope indicators were also included in order to articulate desired conditions with respect to key land uses which are associated with future erosion potential. The best information available to EPA suggests that attainment of these targets would be an indicator that a managed watershed is capable of returning to an acceptable erosion regime and supporting recovery and maintenance of healthy instream habitat conditions.

As additional information concerning these indicators becomes available through ongoing monitoring efforts by the State, Redwood National Park, landowners, and other stakeholders, these indicators and targets will be revisited and revised if necessary to provide the most discriminating set of indicators possible.

It is recognized that no indicators were selected to address the issues of old growth redwood risks in the park or impairment of estuarine habitat near the mouth of Redwood Creek. EPA expects that if sediment reductions result in attainment of the numeric targets established in this TMDL, future risks to remaining streamside groves of old growth redwoods and sediment-related estuary impairments will be substantially reduced. However, some of the problems in the estuary apparently are associated with levee structures which the TMDL is not designed to address.

Section 3.3 Source Analysis

The purpose of the Source Analysis is to demonstrate that all pollutant sources have been considered, and significant sources estimated, in order to help determine the degree of loading reductions needed to meet numeric targets and allocation of loading allowances among sources. 40 CFR 130.2 defines a TMDL as the sum of individual wasteload allocations, load allocations and natural background. The TMDL must not exceed the loading capacity of the receiving water for the pollutant of concern (in this case, sediment). In order to estimate the loading capacity of Redwood Creek and develop individual load allocations, existing and potential sources must first be characterized. This section provides three types of information:

- an estimate of average annual sediment loads per square mile for the entire Redwood Creek watershed,
- estimates of average annual sediment loads per square mile for three "reference" tributary watersheds within the Redwood Creek basin, and
- estimates of historical sediment loading rates from all the significant sources of sediment in the Redwood Creek basin, organized by erosional process categories.

For Redwood Creek, two general types of sediment source information are available from geomorphic research and monitoring programs of the National Park Service and the U.S. Geological Survey. These are: 1) measurements of erosional processes within the watershed, and 2) records of sediment transport in Redwood Creek and some tributaries. The first type of information was used primarily to estimate the relative contributions of different source categories to overall sediment loading, and as the basis for allocating sediment source reductions and resulting TMDL load allocations. The second type of information was used to estimate overall sediment loading rates for the Redwood Creek basin and localized loading rates for three tributaries. The overall loading rate information provides the baseline against which TMDL-related sediment reductions are calculated. The localized tributary loading rate information assists in estimating the future loading capacity of Redwood Creek basin and the overall sediment discharge reductions needed to protect beneficial uses.

Long Term Estimates of Total Sediment Loading

An estimate of long term annual average sediment loading per square mile was determined for the Redwood Creek gauging station at Orick, near the downstream end of the basin. Data reported in the Redwood Creek Watershed Analysis, supplemented by data furnished by Redwood National Park researchers, were analysed to develop long term annual average sediment output rates for the period 1954-1997. This is the amount of sediment which actually moves out of the basin past the Orick gauging station.

During the 1954-1997 period, there was a substantial increase in instream storage of sediment delivered to Redwood Creek and its tributaries. Most of this increase in instream storage was the result of a few major discharge and flood events of which the 1964 flood was most important (RNP, 1997). The sediment budget calculated for the Redwood Creek Watershed Analysis estimates that there was a net increase in the volume of sediments added to instream storage which was on the order of 23% of the total sediment output from the basin (RNP, 1997). Most of the stored sediments are either in the mainstem of Redwood Creek or at the bottoms of tributary streams. It has been estimated that stored sediments may take several decades to be remobilised, move downstream, and eventually discharge from the basin. This huge increase in stored sediment in Redwood Creek caused major adverse impacts to the stream channel and to aquatic habitat as a result. The Watershed Analysis discusses these impacts in detail. The long term restoration of aquatic habitat in Redwood Creek depends, to a significant degree, on the ability of the system to erode and move out these excessive deposits of stored sediment.

For the loading estimates developed for this section, sediment storage was not included as a specific factor in the analysis for several reasons. It was infeasible to calculate a reliable estimate of changes in instream stored sediment for this period. Second, additions to stored sediment have caused significant damage to aquatic habitat in Redwood Creek. If instream storage were added to the loading estimate as a sediment sink, the overall estimate of sediment loading from 1954-1997 would be increased substantially. By including instream storage in the analysis, it could create the impression that continuing increases in instream storage in the future are acceptable. This is not the case; to the contrary, decreases in instream stored sediment are needed. Third, the estimates of sediment reductions needed in the basin were made through comparisons with "reference" watershed sediment loading rates for three tributary watersheds in Redwood Creek basin. The Watershed Analysis indicates that 60-80% of flood-related instream sediment deposits are flushed out of tributary watersheds within 10 years, in contrast to the mainstem. In order to more fairly compare loading rates for the tributary "reference" watersheds and the loading rates for the entire Redwood Creek basin, it is appropriate to exclude instream storage from the loading estimates for the Redwood Creek mainstem.

This analysis treats instream channel storage of sediment as a potentially long term, but still temporary sink for sediment which is associated with substantial adverse impacts to beneficial uses and which is generally not amenable to control after it has occurred. It is not expected that following the sediment loading reductions called for in the TMDL, there will be significant increases to instream storage except in response to very infrequent, high magnitude events. For these reasons, the simplifying assumption was made that in the long term, sediment inputs equal sediment outputs in properly functioning streams. In other words, the total sediment loading estimate does not separately account for instream storage as a sink or a source of sediment outputs at Orick.

Table 7 provides summaries of annual sediment loading per square mile at Orick based on estimates in the Watershed Analysis for the periods 1954-1980 and 1974-1992 along with loading estimates calculated for this report for the period 1981-1997 based on sediment loading data provided by Redwood National Park. Table 7 also provides an estimate of annual loading per square mile at Orick for the period 1954-1997 which is used as the baseline for calculating the TMDL and associated allocations. As discussed in Appendix C of the Watershed Analysis, the 1954-80 estimate is based on actual data collected by U.S. Geological Survey since 1971 along with an estimate of probable sediment yields from 1954-1971 by Knott (USGS, 1981, cited in RNP, 1997). The 1974-1992 estimate is based on USGS and NPS data collected at Orick and is reported in RNP, 1997. The 1981-1997 estimate is based on USGS and NPS data provided in RNP, 1997.

For the 1981-1997 estimate, where bedload data were not reported, it was assumed that bedload equals 25% of total sediment transport in the Redwood Creek system. This assumption is based on comparison of suspended and bedload sediment loading rates from 1974-1992 and is consistent with the Watershed Analysis, which reports that bedload accounts for roughly 20-25% of total sediment load, and with findings of other researchers (e.g. Lisle and Madej, 1992, which reports that bedload constitutes 10-30% of total load).

The 1954-1997 loading estimate was calculated as follows:

$$\frac{[(\text{54-80 av. loading rate}) * (\text{\# of years 54-80}) + (\text{81-97 av. loading rate}) * (\text{\# of years 81-97})]}{(\text{number of years 1954-1997})}$$

which is:

$$\frac{[(5995*27) + (2769*17)]}{44} = 4749 \text{ tons/square mile/year}$$

Table 6: Summaries of Annual Average Sediment Loading Per Square Mile at Orick

Time Period	Annual Average Load (tons/mi²/year)	Source
1954-1980	5995	Redwood Creek Watershed Analysis, Appendix C
1974-1992	3120	Watershed Analysis
1981-1997	2769	calculated from Watershed Analysis and RNP data
1954-1997	4749	calculated from Watershed Analysis and RNP data

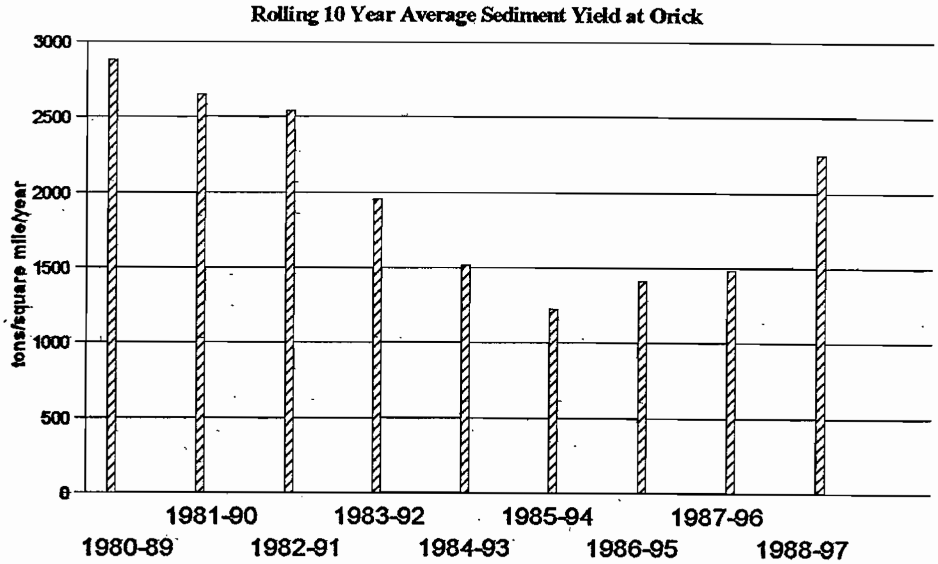
Because the TMDL is presented in terms of average annual sediment loading per square mile to be measured as ten year rolling averages, table 7 provides a summary of 10 year rolling average sediment yields at Orick, which can be compared with the TMDL of 1900 tons/square mile/year.

Table 7: Ten Year Rolling Average Sediment Yields at Orick

Time Period (Water years)	Average Sediment Yield (tons/square mile)
1980-89	**2880**
1981-90	**2649**
1982-91	**2539**
1983-92	**1955**
1984-93	**1517**
1985-94	**1225**
1986-95	**1412**
1987-96	**1481**
1988-97	**2251**

Figure 2 provides these 10 year rolling average data in graph form.

Figure 2:



Estimates of Annual Loading for "Reference" Tributaries

Annual average sediment loads per square mile were calculated for three tributaries of Redwood Creek which are believed to be in relatively good condition in terms of erosion potential and which, as a result, may serve as "reference streams" for purposes of comparing localized erosion rates with erosion rates of the basin as a whole. They have received relatively little disturbance through timber harvesting, road building, and other land management activities in recent decades when compared to most of Redwood Creek watershed, and are reasonably representative of the major geological formations present in the basin. This type of comparison assists in evaluating TMDL goals or desired conditions with respect to sediment loading rates and in estimating the basin's loading capacity for sediment inputs.

The first two tributary basins may be characterized as moderately vulnerable to erosion due to land management impacts:

<u>Panther Creek</u> is located on the west side of the valley and has experienced moderate logging during the past decade. Most of Panther Creek basin was also harvested several decades ago, although increased logging has resumed in the last 2 years (personal communication with Greg Bundros, RNP, June, 1998). Panther Creek was selected partly because it is underlain by Redwood Creek schist, the most common rock type west of Redwood Creek.

<u>Lacks Creek</u> is a larger tributary on the east side of the valley which has experienced relatively little timber harvesting during the past decade and now hosts extensive mature second growth forest (personal communication with Greg Bundros, RNP, June 1998). Lacks Creek is underlain by a combination of rock types -- principally the Coherent Unit of Lacks Creek (mostly less erosive sandstones) and the Incoherent Unit of Coyote Creek (more erosive silt and mudstones)-- and is believed to be generally representative of the geology of the east side of the valley.

Little Lost Man Creek is tributary to Prairie Creek, the largest tributary to Redwood Creek, and has experienced no significant logging or land management disturbance (personal communication with Randy Klein, RNP, June 1998). It is underlain by a third major rock type which characterizes the Prairie Creek subwatershed. Little Lost Man Creek (and Prairie Creek as a whole) are not representative of the rest of Redwood Creek basin because they are less steep, are underlain by a generally less erosive rock type, and are much less intensively managed.

Note that although these three tributary watersheds are appropriate for examination as historical reference watersheds, they are not assumed to be appropriate as future reference streams for comparative analysis. It is quite possible that Panther Creek and Lacks Creek will be subject to intensive future management which may result in unacceptably large increases in loading rates. Additional work would be needed to evaluate whether they are appropriate reference streams for the purpose of comparing future erosion rates with erosion rates for the entire Redwood Creek watershed.

Sediment transport data were collected at gauging stations near the mouths of the three tributaries discussed above: Panther Creek, Lacks Creek, and Little Lost Man Creek. Table 8 presents estimates for annual average loading rates per square mile for each of these locations. Because bedload data were not generally available after 1992, the estimates were based on the assumption that bedload equals 25% of total sediment loads (see above discussion for rationale).

In order to facilitate comparisons between loading rates for these locations and for the Redwood Creek watershed as a whole (as calculated for Orick from 1954-1997), Table 8 also presents adjusted loading rate estimates for each of these locations. The annual average loading rates were adjusted to account for different time periods covered by the data record in each location. The adjustments are based on the assumption that percentage differences in the average annual loading rates for the entire watershed between the 1954-1980 period and the 1981-1997 period also were experienced in the tributary watersheds. It is recognized that this assumption is not well validated; however, it is reasonable to assume that loading rates in the "reference" tributaries and for the watershed as a whole would vary in proportion to each other over time.

For Panther Creek, and Lacks Creek, data were generally available for 1981-1997 (although data for 1989-91 were missing). For Little Lost Man Creek, data were only available for 1993-1997.

For Redwood Creek at Orick, the annual loading rate for 1954-1997 was 172% of the loading rate at that location from 1981-1997. The adjusted estimated loading rates for Redwood Creek at Okane, Panther Creek, and Lacks Creek are equal to 172% of the estimated 1981-97 loading rates to account for the higher loading rates assumed to have occurred before 1981.

For Little Lost Man Creek, data were only available for 1993-1997. For Redwood Creek at Orick, the annual loading rate for 1954-1997 was 127% of the loading rate at the same location from 1993-1997. The adjusted estimated loading rate for Little Lost Man Creek is equal to 127% of the estimated 1993-97 loading rates to account for the higher loading rates assumed to have occurred before 1993.

Table 8: Estimated Average Annual Sediment Loading For Upper Basin and Tributaries

Location (area)	Unadjusted Average Annual Load (tons/mi^2/year) *	Adjusted Average Annual Load (1954-97) (tons/mi^2/year) [1]
Panther Creek (6.07 mi^2)	1119 (1980-97)	1930
Lacks Creek (16.9 mi^2)	1467 (1981-97)	2520
Little Lost Man Creek	238 (1993-97)	300

*Source: Redwood National Park and USGS Unpublished Data (RNP, 1998b)
[1] results were rounded to the nearest ten

Specific Source Estimates

Sediment loading associated with specific sediment source categories was estimated based primarily on analysis of the sediment budget in the Redwood Creek Watershed Analysis (RNP, 1997, Appendix C). A sediment budget quantifies sediment sources (inputs), by each erosional process, as well as changes in the amount of channel stored sediment, and sediment outputs as measured at gauging stations over a designated time frame (Reid and Dunne, 1996). The Redwood Creek sediment budget provides rough estimates of total erosion from all the significant source categories (erosional processes) for the period 1954-1980 along with estimates of instream sediment storage and sediment outputs at Orick. The results are not believed to be highly accurate (RNP, 1997). The individual source estimates for this TMDL were calculated by multiplying the percentage of total load associated with each individual source category by the total sediment load estimated above for the period 1954-1997.

This approach assumes that future loading rates from different source categories will be proportional to historical loading rates for these categories. This assumption is reasonable given that the main erosion processes of interest (and their causes) have not changed substantially in the watershed. There continue to be a large number of poorly designed and maintained roads and skid trails in the basin, and intensive timber harvesting activities continue. What has changed is spatial distribution of these land management activities. Road construction and logging have decreased in the lower watershed and increased in the upper watershed (RNP, 1997).

Quantifying sediment sources involves determining the volume of sediment delivered to stream channels by the variety of erosional processes operating within the watershed. For the Redwood Creek watershed, these can be divided into 2 general processes or sediment delivery mechanisms: 1) mass movement (of which landslides are most important) and 2) fluvial erosion (road and skid trail crossing failures, gullies, and surface or sheetwash erosion, and stream bank erosion). Erosional processes in the watershed range from the removal of individual soil particles by raindrops to extensive landslides that cover entire hillslopes. In general, erosion caused by obvious large-scale earth movement has been better documented than erosion caused by dispersed small-scale processes. The smaller-scale processes, however, may also be of great importance in generating sediment because they are more widespread. Past studies indicate that streamside landsliding and fluvial hillslope erosion may be the most important processes delivering sediment to Redwood Creek (Harden and others, 1978; 1995; Kelsey and others, 1981a; 1981b, cited in RNP, 1997). The Watershed Analysis discusses different erosional processes of interest in Redwood Creek in detail; a brief summary of those processes is presented here.

Landslides

Streamside landslides are clearly an important source of sediment in the Redwood Creek watershed, because of their number and volume, and because they deliver sediment directly to channels. Streamside landslides include debris slides, debris avalanches, and earthflows; however, debris slides account for most of the streamside landslide volume (Kelsey and others, 1995, cited in RNP, 1997). Streamside landslides may be caused in part by channel aggradation (Janda and others, 1975, cited in RNP, 1997). Sediment deposited in the channel raises water levels during storms, resulting in undercutting of hillslopes that subsequently fail as debris slides.

Most streamside landslides identified for the 1954-97 period occurred between 1962 and 1966. Between 1970 and 1976, the number of new streamside landslides decreased in the upper basin, but increased in the middle and lower basins. Few streamside landslides have been initiated during the relatively dry period since 1975, although the 1997 storm activated a substantial number of new slides.

The most aerially extensive mass movement features in the watershed are earthflows; however, they contribute relatively little sediment to Redwood Creek (RNP, 1997). Landslides other than streamside landslides include debris avalanches and debris, slumps, forested block slides, and some large and relatively inactive earthflows. These landslides are much less significant as sediment sources than are streamside landslides.

Fluvial Hillslope Erosion

Fluvial hillslope erosion in the Redwood Creek watershed is apparent in both natural and disturbed settings. On unlogged forested hillslopes, fluvial erosion is related to interactions between subsurface piping through root channels and gully and rill. On logged hillslopes, extensive networks of rills and gullies have developed from streamflow diversions and washouts at road and skid trail stream crossings, from ditches and cutbanks, and from interception of subsurface flow along roads and trails. Surface erosion of logged areas may also have increased as a result of decreased interception of rainfall by the forest canopy following harvest. Prairies are particularly susceptible to gully erosion, and road runoff has carved numerous large gullies in the Bald Hills area, near Berry Summit on Highway 299, and other areas within the watershed. Previous studies have documented large increases in fluvial erosion on lands where timber has been harvested or where roads have been constructed (Janda and others, 1975; Nolan and others, 1976; Walter, 1985; Hagans and Weaver, 1987, cited in RNP, 1997).

Channel Storage

Massive amounts of coarse sediment were deposited in tributaries and the upper and middle reaches of the mainstem during the flood of 1964. During subsequent floods, particularly in 1972 and 1975, coarse sediment was scoured from tributaries and the upper mainstem and re-deposited in lower reaches.

Sediment stored within the channel system continues to move in wave-like fashion downstream (Madej and Ozaki, 1996). As of 1990, peak aggradation was about 5 miles downstream from the Tall Trees Grove and about 4 miles upstream of Orick (fig. 3-5). Channel cross section surveys in 1995 indicated that, for the first time since measurements began in 1973, the channel bed between the Tall Trees Grove and Orick was scouring. However, cross section surveys from 1996-97 document continued channel aggradation or infilling for several miles below the Tall Trees Grove (public comments of Redwood National Park, November 18, 1998). It seems clear that sediment discharged into Redwood Creek during major storm runoff events remains in storage for decades or longer. High flow events can remobilize these stored sediments and cause adverse impacts through channel modification and sediment redeposit in downstream habitat areas.

Sediment Budget Adjustments

Sediment budget estimates of tributary streamside landslides were further subdivided for the TMDL in order to reflect different likely causative mechanisms. Pitlick's study of landslide associations with pre-failure site conditions (Pitlick, 1982) provides information which can be used to estimate the relationship between landslides and land uses. Pitlick showed that for Redwood Creek tributaries, 40 percent of stream side slope failures in tributary canyons were logging related, and 80 percent of the total landslide volume came from slopes logged prior to failure. Based on Pitlick's analysis, tributary streamside landslides were divided into three categories: natural (corresponding to Pitlick's unlogged category), road- related (corresponding to Pitlick's road-related failures category) and harvest-related (corresponding to Pitlick's clear cut and selection cut categories). Landslides were divided based on the percent of total inventoried slide mass measured by Pitlick for each category. This approach assumes that the distribution of landslide volumes associated with roads, harvesting, and natural conditions for the basin as a whole is the same as measured in Pitlick's sample of several hundred landslides.

A 1980 study of sediment sources and sediment transport in Redwood Creek evaluated 586 mainstem landslides. The study revealed that approximately 50 % of the slides had one or more associated roads (Kelsey, et. al., 1981) The evaluation of mainstem landslides recognizes that the volume of each slide may be variable. However, the volume of mainstem landslides associated with roads, or other management activities may represent more than 50 percent of the total load.

Table 9 reports the results of the modified sediment budget. Annual average loading rates were estimated by calculating the percentage of the total estimated loads associated with each source mechanism, then multiplying that percentage by the estimated total average annual sediment load for 1954-1997, as discussed above.

Table 9: Sediment Source Category Estimates

	a	b	c
1	Source Mechanism	54-97 Average Annual Sediment Load (t/mi^2/yr)	Percentage of Total Load Estimate
2	Roads and Skid Trails (Including silvicultural activities, agriculture, and public roads.)	690	14.6%
3	Gully Erosion (Mostly road related)	1020	21.4%
4	Bare Ground Erosion	400	8.4%
5	Stream Bank Erosion	590	12.4%
6	Tributary Landslides: Natural	210	4.4%
7	Tributary Landslides: Road Related	360	7.6%
8	Tributary Landslides: Harvest Related	390	8.3%
9	Mainstem Landslides	810	17.0%
10	Debris Torrents	100	2.2%
11	Other Mass Movements: - earthflows - block slides	180	3.7%
12	TOTAL ESTIMATED LOADS	4750	100%

Note: Calculations are rounded to the nearest 10.
Average annual loads are calculated by multiplying the percentage in column c by 4750, the total estimated annual loading rate for the watershed between 1954-97.
Source: Percentages of total loads in column c are derived from Redwood Creek Watershed Analysis, 1997, Appendix C.

Explanation of Sediment Budget

About 54% of the overall budget was from fluvial and surface erosion, and about 46% of the budget is associated with mass wasting processes. Road-related erosion processes account for approximately 50% of the total budget, including significant proportions of the loadings associated with both fluvial and mass movement processes. It is difficult to estimate the proportion of total loading associated with timber harvesting (road-related impacts aside), but it probably exceeds 10% of the total. Natural background erosion accounts for roughly 30-40% of the total loadings. As discussed above, it is assumed that approximately 10% of average annual sediment loads were stored instream during the period 1954-97.

This sediment budget is expected to be accurate within a factor of about +/- 40%. As such, it should be adequate for purposes of estimating the relative share of loadings from different source categories and establishing a baseline loading level for purposes of calculating needed load reductions. EPA expects that opportunities will arise in the future to evaluate the accuracy of the sediment budget and associated TMDL loading allocations, and make adjustments as necessary.

Conclusion

For the period 1954-1997, long term average annual sediment production rate for the entire basin is estimated to be approximately 4750 tons/mi^2/yr. Approximately half was from mass wasting and half from fluvial erosion sources, including surface erosion processes. About half the sediment production was associated with roads and skid trails and roughly 10%-20% was associated with timber harvesting (not including harvest related roads and skid trails). Perhaps 30%-40% of total loads were naturally occurring, or at least were not associated with specific land management causes.

It is important to emphasize that average annual loading rates provide useful information for planning only when a long term monitoring and analysis horizon is applied. Evaluation of sediment loading dynamics over short time periods (e.g., less than 10 or more years) is unlikely to yield reliable results, given that Redwood Creek sediment loading is dominated by infrequent, high magnitude events. For example, the key sediment loading events of the past 40 years were believed to be storms expected to occur perhaps once every 25-50 years. Just as important, stream recovery from high magnitude sediment loading events may take decades or longer to occur.

Although average annual sediment loading rates for the period 1981-97 were substantially lower than the period 1954-1980, it is not clear that the recent lower loading rates indicate that the sediment loading problems in the basin are a thing of the past. The 1980s and early 1990s were marked by lower than normal precipitation and relatively few high magnitude events. Thus sources on the hillslope could be triggered by future high rainfall/flow events. However, the lower loading rates may be also be attributable, to some extent, to improvements in timber harvest practices. This period coincided with a tightening of California Forest Practice Rules and the use of more protective harvest practices; however the amount of logging in the basin has not declined during the period since Redwood National Park was established. Rather, logging has been moved upstream into the middle and upper parts of the basin. Analysis of future loadings and associated land management practices will be needed to evaluate the degree to which lower loading rates for the 1980-97 period were associated with improvements in forest practices.

The early analysis of the effects of the 1997 "New Year's" storm (approximately an 11 year storm) indicates that a large amount of unaddressed erosion potential remains (NPS 1997 and written comments by Redwood National Park, November 18, 1998). Over 100 large landslides were triggered or reactivated, and multiple road failures occurred both within the Park and on lands outside the park. It was estimated that over 900,000 tons of sediments were discharged into Redwood Creek or its tributaries, or moved into unstable hillslope positions and are perched to fail. The erosion response to this storm indicates that additional action is needed to prevent ongoing, destructive sediment loading in the basin.

Section 3.4. Loading Capacity Linkage Analysis

In order to determine the TMDL, it is important to assess the magnitude of instream sediment problems and the associated levels of sediment source reductions needed to address instream problems. The result of this assessment is an estimate of "loading capacity" -- the amount of sediment the Creek can assimilate and still meet its water quality standards. This section assesses the degree to which sediment reductions are needed from sources in the Redwood Creek watershed to alleviate the instream sediment problems discussed in the Problem Statement section and quantified in the Numeric Targets section. The analysis is based on two methods of comparing existing and desired conditions for the watershed:

1. quantitative comparison of average sediment loading rates per square mile in more highly impacted and relatively unimpaired areas of Redwood Creek watershed, and
2. qualitative comparison of existing and historical conditions with target levels for the instream indicators selected in the numeric targets section.

It is recognized that inferring linkages between prospective hillslope erosion sources and instream impacts based on these methods will produce uncertain results. However, it is necessary to estimate the level of sediment reductions needed in the future to meet water quality standards. Because there are no reliable direct linkages to evaluate (i.e., the sediment-impact relationships tend to be separated in time and space) and no reliable methods for modeling those linkages, it is necessary to rely on these less certain inferential methods. EPA believes that through future monitoring and evaluation, it will prove more feasible to evaluate these cause-effect linkages with greater certainty than was feasible for this TMDL.

Comparison of Sediment Loads in Redwood Creek to Reference Streams

As discussed in the preceding sections, Lacks Creek, Panther Creek, and Little Lost Man Creek provide the best local candidates for estimating historical reference watershed loading rates. Adjusted average annual loading rates were estimated for each of these tributaries (see Source Analysis chapter for details), and the results are reported along with the average annual loading rates estimated for Redwood Creek at Orick.

To allow a comparison of historical loading rates for the Redwood Creek watershed as a whole with "reference watershed" loading rates, it was necessary to weight the loading rates for the reference watersheds in accordance with how representative their underlying geologies are of the entire basin. For this adjustment, it was assumed that Panther Creek loading rates would be representative of "reference" loading rates for all of the basin area underlain by schist-- about 42% of the basin. It was further assumed that Little Lost Man Creek loading rates were representative of "reference" loading rates for the Prairie Creek area-- about 14% of the basin. Finally, it was assumed that Lacks Creek loading rates were representative of "reference" loading rates for the remainder of the basin-- about 44% of the basin. The Lacks Creek assumption is reasonable because that tributary is underlain by both of the most common remaining geologic types present in the basin, a combination of resistant sandstones and less resistant mudstones and siltstones.

The weightings were calculated as follows to yield a single estimated reference loading rate for the entire Redwood Creek basin (see table 10). First, the sediment loading rates for each reference stream (column b) were multiplied by the corresponding percentage (expressed as a decimal, i.e., 42% becomes 0.42) of the whole basin underlain by the reference stream geologic type (column c) to yield loading rate factors for each reference. The three loading rate factors were added together to yield the overall estimated loading for the entire basin. The weighting of the "reference" loadings yields an overall composite estimate of loadings associated with reasonably well functioning watersheds which are not experiencing excessive human-caused erosion. This calculation yields an estimate for a basin-wide reference loading rate of 1962 tons/square mile, which is 59% lower than the estimated basin loading rate for 1954-1997 of 4750 tons/square mile. While considering the assumptions made on calculating the reference loading rate, the result suggests that a reduction of approximately 60-% might be needed in order to achieve "reference watershed" conditions over a long time horizon.

Table 10: Reference Stream Comparison Loading Information

	a	b	c
1	Reference Stream	Estimated Sediment Loading Rate (t/sq mi/yr) *	% of Watershed Representative of Reference Stream Geology
2	Panther Creek	1925	42%
3	Lacks Creek	2520	44%
4	Little Lost Man Creek	301	14%
5	Estimated Reference Loading Rate for Redwood Creek Basin	(weighted loading value = 1960)	100%

*Redwood Creek Watershed Analysis, RNP,1997

Although some land management activity was occurring in Panther Creek and Lacks Creek several decades ago, this average annual loading estimate (1960 t/sq mi/yr) based upon reference streams is considered conservative because it includes the use of Little Lost Man Creek- a nearly pristine tributary -- as a reference stream for 14% of the basin. EPA does not expect that it would be necessary to attain the near pristine levels of sediment loading associated with Little Lost Man Creek in order to restore a functioning aquatic habitat in the watershed as a whole.

Qualitative Analysis of Instream and Hillslope Conditions

Linkages between sediment sources in the watershed and instream conditions are generally indirect and highly variable. However, over the long term, reductions in sediment inputs to the stream system are expected to result in reduction in sediment distributions in the channel. Over time, the instream indicators identified in the Numeric Targets section should reflect changes in response to reduced sediment loading and transport. Because of historical data limitations, it was infeasible to prepare a quantitative comparison between historical and target conditions for instream indicators. However, Table 11 summarizes the qualitative comparisons reported in the Numeric Targets section. This qualitative comparison appears to indicate that instream conditions remain inadequate to support healthy habitat, but that conditions may be improving. Recently observed improvements in conditions may be associated with improved land management or with lower sediment loading rates during a relatively dry period. Significant continued sediment loading reductions appear to be necessary to address the instream problems associated with sediment. Large storm events of the magnitude seen prior to 1980 have not occurred since. When such events occur, higher sediment loading rates may result and consequently reveal deterioration of instream target conditions.

Table 11: Comparison of Existing/Historical Levels for Instream Indicators with Target Levels

Indicator	Qualitative Comparison
Fines <0.85mm	historical levels may exceed target levels to moderate extent; may be improving in upper watershed
Fines <6.5mm	historical levels may exceed target levels to moderate extent; may be improving in upper watershed
Median surface particle size (d50)	historical levels appear lower than target levels indicate elevated fine sediment; some improvement in upper basin
Surface fines <2 mm	may be approaching target range, but no data post-1984 available
Percent Riffles	riffle percentage exceeds target in many locations but appears to be improving
Pool Depth	possibly nearing target levels in mainstem

Conclusion: Estimate of Sediment Loading Capacity in Redwood Creek

Both the reference stream analysis and instream indicator analysis indicate that some sediment reductions and reductions in future erosion potential are necessary. In EPA's judgement, reductions should be based primarily on the quantitative results of the reference stream analysis as this provides a more rigorous basis for estimating loading capacity. EPA estimates that reductions of about 60% are needed in order for Redwood Creek to meet water quality standards for sediment in the future. This suggests that allowable loading capacity is on the order of 40% of historical loading rates. This figure also compares with the estimation from the sediment budget that natural background erosion accounts for roughly 30-40% of the total estimated load for the period 1954-1997. By multiplying the historical average annual loading rate (4750 tons/square mile) by the 40% allowable annual loadings, it yields an overall loading capacity estimate at Orick of 1900 tons/square mile/year .

The Loading Capacity meets the regulatory definition at 40 CFR 130.2(f) which states that the loading capacity is "the greatest amount of loading that a water can receive without violating water quality standards." In addition, the Load Allocations meet the regulatory requirements at 40 CFR 130.2(g) in that they are "best estimates of the loading, which may range from reasonably accurate estimates to gross allotments..."

Section 3.5. Total Maximum Daily Loads and Allocations

The requirements of a TMDL are described in 40 CFR 130.2 and 130.7 and Section 303(d) of the Clean Water Act, as well as in various guidance documents. A TMDL is defined as the sum of the individual wasteload allocations for point sources, and load allocations for nonpoint sources and natural background pollutants, such that the loading capacity of the receiving water is not exceeded. The allocations indicate the amount of pollutant reduction from individual source categories that is required to attain water quality objectives. Allocations may be assigned based on land use, land area, or erosional process. In addition, the regulations at 40 CFR 130.2(g) state that "Load allocations are best estimates of the loading, which may range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading." The Redwood Creek allocations have been developed for erosion processes (associated with land use activities where feasible) based on the source analysis of the various erosional processes. The load allocations have been developed as long term annual average loads per square mile at the basin-wide scale. As discussed in the source analysis chapter, sediment storage was not factored into the TMDL, loading capacity, and allocation calculations.

Total Maximum Daily Load Calculation

The TMDL for Redwood Creek is being expressed as long term annual average sediment loading per square mile, as applied at the Orick gauging station at the downstream end of the watershed. This meets the regulatory definition that "TMDLs can be expressed in terms of either mass per time, toxicity, or other appropriate measure." (40 CFR 130.2) This annual TMDL could be converted into daily loads, but expressing the TMDL as an annual average yield better reflects the dynamic nature of sediment movement throughout a watershed over time. The annual average loading rate for this TMDL will be measured in terms of 10 year rolling annual averages. The longer term annual average timestep is an appropriate approach to account for the large interannual variability in sediment loading and the long term timeframe in which beneficial use impacts occur and change. This annual average loading per square mile will be referred to as the TMDL for Redwood Creek. The TMDL is calculated by applying the loading capacity range from the previous section, which was estimated at 1900 tons/square mile/year (rounded). **The TMDL for Redwood Creek is therefore estimated to be 1900 tons/square mile/year, expressed as 10 year rolling annual averages.**

Load Allocations and Wasteload Allocations

The following are the load allocations (column e in Table 12 on the following page). The wasteload allocation for Redwood Creek is zero as there are no permitted point sources of sediment discharge to the watershed. Explanation is provided below under Explanation of Allocations and Calculations.

Table 12: Summary of TMDL and Allocations for the Redwood Creek watershed.

a	b	c	d	e
Source Mechanism	**Historic Sediment Load[1] ($t/mi^2/yr$)**	**Percent Controllable[2]**	**Controllable Load[3] ($t/mi^2/yr$)**	**Remaining Load (Allocation)[4] ($t/mi^2/yr$)**
Roads, Landings and Skid Trails erosion	690	85%	580	110
Gully Erosion (~90% road related)	1020	85%	870	150
Bare Ground Erosion	400	85%	340	60
Stream Bank Erosion	590	35%	210	380
Tributary Landslides: Naturally Occurring	210	0%	0	210
Tributary Landslides: Road Related	360	80%	290	70
Tributary Landslides: Harvest Related	390	50%	190	200
Mainstem Landslides (Human Induced and Naturally Occurring)	810	40%	320	490
Debris Torrents	100	50%	50	50
Other Mass Movements (Naturally Occurring): - earthflows - block slides	180	0%	0	180
Totals	4750		2850	1900

[1] The estimated historic sediment load for each source.
[2] The percent of that historic load that is estimated as controllable. Controllable discharges are those discharges resulting from human activities that can influence the quality of the waters of the State and that can be reasonably controlled.
[3] The load that is estimated as controllable (the percent controllable multiplied by the historic load), rounded to the nearest 10.
[4] The difference between the historic load estimate and the controllable load estimate, rounded to the nearest 10. This is the estimated load at which salmonids in the Redwood Creek watershed would no longer be limited by sediment.

Explanation of Allocations

The Allocations divide the TMDL among key source categories, including natural background sources. (The method for addressing natural background is discussed below.) The allocations are derived from the adjusted sediment budget presented in the source analysis section, which was based primarily on the sediment budget in the Redwood Creek watershed analysis.

The individual load allocations are based on EPA's assessment of the degree to which loadings from different source categories can actually be controlled or prevented. The controllable fraction of total loads from each source category was estimated, and the remaining loads by category were summed and compared with the TMDL. This analysis found that application of reasonable practices to control and prevent future loading would result in reductions adequate to meet the TMDL.

"Controllable" sources of sediment are defined as those which are associated with human activity *and* will respond to mitigation, altered land management, or restoration. The percentages are based on an understanding of the available mitigation, land management and/or restoration measures which have been developed for a variety of situations. The percentages reflect professional judgment of how successful the various best management practices (BMPs) generally are in controlling these sources. These assessments of source control potential are generally consistent with those used for the Garcia River sediment TMDL established in 1998.

Estimates of controllable percentage of loads for road-related sources are derived from field work in basin and nearby basins by Weaver and Hagans (see, e.g., Weaver and Hagans, 1994). The estimate that about 90% of gully erosion is road-related comes from Hagans, et al., 1986 and RNP, 1997).

Estimates of controllable percentage of loads from bare ground were derived from a conservative reading of results of bare ground sediment control practices in Redwood Creek basin documented in Kveton, et al. (1983) and Hagens, et.al. (1986).

Estimates of controllable percentage for streambank erosion were based on EPA's judgment summarized as follows: A significant portion of bank erosion is believed to be associated with higher flow elevations caused by changes in channel shape, which in turn are associated with sediment loads which exceed the stream's natural transport capacity (Rosgen, 1996). As sediment loading is reduced in the future, it is assumed that the frequency and magnitude of bank erosion will decline, and that the volume of eroded bank sediments will decline as well. In addition, it is expected that some streambank erosion will be addressed through stream restoration projects in some parts of the basin. Finally, it is expected that some reduction in bank erosion will occur in response to improvements in livestock management practices and, potentially, timber harvesting practices in riparian zones.

Estimates of controllable percentage of harvest related mass wasting are based on Pitlick, 1982, EPA and Regional Board staff judgment and experience, and are consistent with control rates estimated for the Garcia River sediment TMDL.

The available analysis concerning associations between landslides and roaded, harvested, or unlogged areas focused upon landslides in tributaries (Pitlick, 1982). Because the patterns and causes, and associated ability to prevent landslides along the mainstem of Redwood Creek are not well understood, this analysis assumed that mainstem landslides would not be as amenable to control as tributary landslides. Following this reasoning, it is estimated that about 40% of loads from mainstem landslides could be prevented, about half the amount of load prevention which could be expected for tributary landslides which are road related.

The sediment budget description inferred that most debris torrents are road-related. Because road-related debris torrents can usually be avoided through proper road siting and maintenance (e.g., through avoidance of side-casting), the estimated 50% control level is realistic.

Natural background is addressed in the allocations in two ways. First, explicit estimates of natural background loading levels are provided for different mass wasting processes, and it was assumed these sources are not controllable. Second, it is inferred that a portion of fluvial erosion would be naturally occurring, although the proportion of uncontrollable loads for the fluvial erosion categories which are related to natural sources versus uncontrollable anthropogenic sources is not distinguished. Control percentages for these sources are more modest as a result.

Allocations for road-related sediment applies to all land use activities including roads for timber, agricultural, residential, and park management activities as well as state and county roads.

Calculations

Table 12 summarizes the information used to calculate the individual allocations. The total historical loads estimated for each category (column a) are provided in column b. Column c provides data on the percent of the total loads for informational purposes. The estimate of controllable load in column d was calculated by multiplying the loads from column b by the controllable percentages in column c. Column e is the remaining load, calculated by subtracting the controllable load (column d) from the historical load (column b). Thus column e becomes the load allocation. There are no point sources in the watershed; nor are any expected to be proposed in the near future. Therefore, the wasteload allocation for point sources is zero.

Agriculture

As noted above, the allocation for road related sediment applies to all land use activities including agriculture (principally ranching in Redwood Creek basin). In addition, the allocations for the following categories also apply to agricultural activity: gully erosion, bare ground erosion, streambank erosion, mainstem landslides, and debris torrents. The sediment budget prepared by Redwood National Park does not separately estimate erosion associated with agriculture, although the existing categories account for agriculture related erosion to some degree. Overall, this approach is acceptable because agriculture-related erosion is not believed to be a major source in Redwood Creek watershed. Separate Load allocations are only required for significant source categories. If subsequent erosion source inventories find that agriculture-related sources are significant, it may be appropriate to revise the allocations accordingly in the future.

Conclusion

The Loading Capacity and Allocations of Loads are developed for all major sources of sediment in Redwood Creek. As part of the supporting documentation, all sources were considered. Certain sources were not quantified including sediment related to certain agricultural activities. These were accounted for in the margin of safety. The sum of the load allocations plus the natural background is less than or equal to the estimated loading capacity and associated TMDL.

Section 3.6. Margin of Safety

Section 303(d) of the Clean Water Act and the regulations at 40 CFR 130.7 require that TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numerical water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality. The margin of safety can either be incorporated into conservative assumptions used to develop the TMDL or added as a separate component of the TMDL (EPA, 1991). In every one of the components used to develop the TMDL, assumptions were made where sufficient data was lacking. Conservative assumptions have generally been made in each case as a way of addressing the uncertainty associated with the data.

EPA has identified these conservative assumptions more specifically to fully account for the implicit margin of safety.

Selection of Instream Numeric Target Levels

The relationship between physical measures of cold water aquatic habitat characteristics and the actual future health of salmonid populations is poorly understood. Available research results, which provide the information base from which target values are selected, vary widely with respect to the physical characteristics believed to be associated with well-functioning cold water aquatic habitats. No specific information concerning the relationship between physical measures of aquatic habitat and aquatic ecosystem health was available for Redwood Creek watershed.

Instream numeric targets were selected for the Redwood Creek TMDL based on a review of available literature sources which evaluate the relationship between salmonid health and various physical habitat measures. Target values for each measure were generally established at levels which were associated with successful salmonid reproduction and survival in carefully designed research settings, or which were associated with actual stream ecosystems which support healthy cold water aquatic habitat. Where available research results report a range of possibly acceptable levels of different physical habitat characteristics, values were selected for numeric target levels for the TMDL which were associated with higher salmonid survival rates or with stream conditions more favorable for healthy cold water ecosystem function.

In the case of measures of fine sediment in stream riffles, target values were set at levels associated with high levels of salmonid reproductive success in streams in the Pacific Northwest. Salmonids in California may have adapted to be able to thrive in settings where fine sediment levels are higher than found in comparable settings in Washington, Oregon, Alaska, or British Columbia. However, because this possibility has not been fully verified through reliable research results based on work in California streams, the target levels for fine sediments used in the TMDL were set at lower levels associated with research results from other locations in the Pacific Northwest. This is a conservative assumption because the numeric targets for fine sediments were set closer to the low end of the range of "acceptable" fine sediment levels reported in the literature.

Use of Hillslope Targets

It will take a substantial period of time (at least 10 years) before it will be appropriate to assess whether instream targets and associated water quality standards are being attained. During the period before this assessment can be conducted, significant uncertainty will remain concerngint the effectiveness of the TMDL and associated implementation actions. In addition to instream targets, the TMDL includes hillslope targets which identify desired conditions with respect to key land use management practices which could contribute to unacceptable increases in sediment loading rates. It will be possible to monitor whether these hillslope targets are being attained over short periods of time (i.e., less than 10 years). If it is determined that the hillslope targets are not being attained, it will be possible to evaluate whether the TMDL and/or implementation plan require immediate revision. Provision of hillslope factors provides an additional margin of safety to account for the lag time between establishment and implementation of the TMDL and evaluation of its effectivness.

Proportion of Bedload in Total Sediment Load

Total sediment load is comprised of suspended load and bedload. Much of the sediment data for Redwood Creek in recent years is available for suspended sediment only. It was important to used these data in the TMDL analysis to evaluate recent trends in sediment loading. In order to make recent data comparable with historical data for total sediment loading, it was necessary to assume the bedload fraction of total sediment loading in Redwood Creek. The loading analysis assumes a bedload proportion at the high end of the range (25%) estimated for the basin in available literature sources. (10-30%).

Sediment Storage in Mainstem of Redwood Creek

After sediment is discharged into North Coast California streams, it may be deposited in the stream bottom or floodplain, causing stream aggradation. It may take decades for excessive sediment loads deposited in the stream to be remobilized and transported out of the basin. The stream itself may therefore act as both a sink for sediments (a temporary storage location) and a source for sediment (through resuspension and transport of previously discharged sediments). Streams may have some capacity to absorb excess sediment loadings without impairing beneficial uses under some circumstances; however, this "buffering" effect is poorly understood. Moreover, in streams such as Redwood Creek which experienced massive discharges of sediment following major storms over the past 40 years, the stream may be unable to absorb temporary discharges of excessive sediment in this manner. Therefore, the TMDL was developed through a conservative approach which gives no "credit" for instream storage as a consideration in TMDL determination since current excessive levels of instream stored sediment are significantly impairing beneficial uses. The TMDL is approximately 10-25% lower than would be the case if instream storage credit were provided.

Comparison of Sediment Loading from Reference Streams with Redwood Creek as a Whole

The analysis of loading rates from three "reference" tributaries found that historical sediment loading rates were about 59% lower than for the Redwood Creek watershed as a whole. Some researchers and commenters have observed that, other factors being equal, sediment loading rates per unit of area appear to increase as watershed size increases. In comparing the loading rates from the smaller reference tributaries to the whole watershed, EPA made the conservative assumption that the loading rates could be compared directly, without attempting to compensate for scale differences which could explain (to some degree) why sediment loading rates from the watershed as a whole were much higher than for the reference tributaries. The Redwood Creek TMDL contains no compensating corrections to account for this phenomenon because it is poorly understood and because it was infeasible to evaluate the extent to which it actually exists in Redwood Creek watershed. This is a conservative assumption which may result in an overestimate of amount of sediment loading reductions needed to address sediment problems in Redwood Creek as a whole.

Association of Hillslope Sources With Human Causes

Where possible, the source analysis distinguishes human-caused sediment discharge sources from naturally occurring sources. Available research provides information on several types of hillslope sediment sources which are "associated" with land management activities. The TMDL source analysis makes the conservative assumption that hillslope sources identified as "associated" with land management activities are *caused* by the associated land management activities. This assumption results a higher estimate of human-caused discharges which are amenable to some degree of control or avoidance, and lower TMDL and associated load allocations as a result.

Estimation of Loading Capacity

The estimate of sediment loading capacity in the TMDL was based on a quantitative comparison of historical sediment loading rates in "reference" tributaries with the watershed as a whole, and a qualitative comparison of observed values for instream habitat indicators with the target values for those indicators. The quantitative comparison indicated that "reference" loading rates were about 40% of the loading rates for the watershed as a whole (suggesting that significant load reductions would be needed in the watershed as a whole). The qualitative comparison of instream parameters indicated that instream conditions may be improving, particularly in the upper watershed (implying that the system is recovering and may not require significant sediment discharge reductions. However, rather than raising the loading capacity estimate to account for the possible improvements in instream conditions, the TMDL makes the conservative assumption that the potential improvements in instream conditions have not been verified by adequate monitoring over an adequate monitoring period. This assumption results in the establishment of a lower loading capacity estimate which is more protective of aquatic habitat.

Conclusion

As the margin of safety discussion points out, there are a number of uncertainties associated with the supporting documentation, most notably in the source analysis and linkage analysis to estimate loading capacity. Given these uncertainties, conservative assumptions have been made regarding the amount of loading reductions that are needed to attain water quality objectives . This approach is warranted and meets the statutory requirements that a margin of safety take into account any lack of knowledge concerning the relationship between the effluent limitations and water quality.

Collection of site-specific data in the future will help to reduce the uncertainty associated with the current assessment and will therefore allow for a reduction in the degree of conservatism associated with the current assumptions. Thus, it is possible, depending on the quality and quantity of the site-specific data which is collected over time, that adjustments to the TMDL in the future will result in less stringent allocations as the margin of safety is reduced.

Section 3.7. Seasonal Variation

There is inherent annual and seasonal variation in the delivery of sediment to stream systems. Surface erosion occurs on an annual basis, but primarily as a result of winter rains. Fluvial erosion and mass wasting, on the other hand, occur as a result of big storms and thus may not be significantly active processes every year. For this reason, the allocations are designed to apply to the sources of sediment, themselves, not the movement of sediment across the landscape or delivery of sediment directly to the stream channel. If implemented as envisioned, potential and existing sediment delivery sites will be identified and the quantity of sediment associated with each site measured or estimated. Then, as a result of mitigation or altered land management, the amount of potential sediment saved from delivery to receiving water State will be measured or estimated. The relationship between the original measurement or estimate of potential sediment delivery and the amount saved by mitigation will indicate the degree to which the allocation has been achieved.

It is difficult to accurately predict specific impacts of sediment loading at particular times and places on particular salmonid life stages given spatial and temporal lag time between sediment delivery and the occurrence of sediment related impacts on beneficial uses. In addition, it is infeasible to predict or control sources at fine spatial and temporal scales in many cases. Therefore, the approach in this TMDL is to select indicators to interpret narrative water quality objectives which are believed to provide a good composite picture of instream sediment-related conditions and changes over time. Then, targets and associated TMDLs are set at levels believed to be protective of beneficial uses at key life stages taking into account the lag time effects. In addition, the numeric targets generally represent summer flow conditions. This TMDL accounts for seasonal variation through the careful articulation of likely cause and effect relationships between sediment loadings and effects on salmonid habitat at different key life stages, and its consideration of lag time effects.

Normal winter rains and larger storms will nonetheless have an effect on the assessment of allocations. Storm events which occur after mitigations have been achieved will provide a test of the success of the mitigation. For this reason, the monitoring plan will propose follow-up inventories of hillslope sources which will help assess post-mitigation success.

Section 3.8. Critical Conditions

The regulations at 40 CFR 130.7 state that TMDLs shall take into account critical conditions for stream flow, loading and water quality parameters. This TMDL does not explicitly estimate critical flow conditions for several reasons. First, unlike many pollutants (e.g. acutely toxic chemicals) sediment impacts on beneficial uses may occur long after sediment is discharged, often at locations far downstream from the point of discharge. Second, sediment impacts are rarely correlated closely with flow over short time periods. Third, it is impractical to accurately measure sediment loading, transport, and short term effects during high magnitude flow events which usually produce most sediment loading and channel modification in systems such as Redwood Creek. Therefore, the approach used in this TMDL to account for critical conditions is to use indicators which are reflective of the net long term effects of sediment loading, transport, deposition, and associated receiving water flows. These indicators may be effectively measured at lower flow conditions at roughly annual intervals. Inclusion of a large margin of safety helps to ensure that the TMDL will result in beneficial use protection during and after critical flow periods associated with maximum sedimentation events.

Critical conditions concerning stream habitat status and recovery may change substantially following major storms (e.g., storms with a recurrence interval of approximately 50 years or more). Such storms and the associated floods and huge sediment loads can have the effect of "recallibrating" the stream channel morphology for decades to follow. It may be appropriate to reconsider the TMDL and associated allocations following such an event.

Section 4. Public Participation

Federal regulations require that TMDLs be subject to public review (40 CFR 130.7). The State and EPA have provided for public participation through several mechanisms. The State has held several formal and informal public workshops during 1998 to discuss the State's TMDL and implementation plan proposals. EPA has participated in two of these workshops. The State and EPA have worked together to assure that the EPA TMDL for Redwood Creek is very similar to the TMDL proposed by the State.

EPA invited public comment on the EPA draft TMDL in a public notice dated October 19, 1998. That public notice was published in several North Coast newspapers and was mailed out to a mailing list of interested parties provided to EPA by the RWQCB. EPA hosted a public hearing on the Redwood Creek and South Fork Trinity River TMDLs in Eureka, CA on November 19, 1998. EPA reviewed public comments received in writing during the comment period as well as oral comments made at the public hearing in reaching its final decision on the TMDL. EPA has prepared a comment responsiveness summary which shows how EPA considered public comments in its final decision. The final TMDL incorporates changes in the following areas:

- clarification of instream numeric targets
- addition of hillslope numeric targets
- minor clarifications of the source analysis, linkage analysis, TMDL, and allocations
- restructuring of the margin of safety discussion, and
- additional detail in the implementation and monitoring recommendations.

Section 5. Implementation and Monitoring Recommendations

Federal regulations require the State to identify measures needed to implement TMDLs in the state water quality management plan (40 CFR 130.6). EPA has established policies which emphasized the importance of timely implementation of measures to implement TMDLs which address nonpoint source discharges (EPA, 1997b). EPA expects the State to promptly develop implementation measures and ensure the implementation of source control and erosion prevention measures which are adequate to achieve the allocations in the TMDL.

EPA expects that the State will incorporate the TMDL and associated implementation measures in the State water quality management plan (in California, the RWQCB Basin Plan) upon approval by EPA , as required 40 CFR 130.6. This requirement may be met through EPA's approval of the TMDL and implementation plans already added to the Basin Plan by the State, or through incorporation of an EPA-established TMDL and State-adopted implementation measures in the Basin Plan following EPA's establishment of the TMDL.

Implementation Plan Recommendations

Concurrent with its effort to develop the Redwood Creek TMDL, the RWQCB has drafted an Implementation Plan (Plan) for the TMDL (November 10, 1998) and is continuing to refine the Plan in consultation with interested stakeholders. EPA strongly supports the draft Implementation Plan and offers the following recommendations to further strengthen that Plan:

1. Promote and facilitate cooperative public-private implementation and monitoring efforts. The draft Plan recognizes that measures developed under the auspices of other planning mechanisms may be recognized by the Regional Board if they contain all the required elements of the erosion control plans. An MOU between the park and interested private landowners provides a potential existing mechanism for planning implementation actions and monitoring programs at a scale broader than individual ownerships. The Regional Board Plan would be improved if it more actively promoted cooperative efforts by Redwood National Park and interested private landowners to inventory roads and other potential erosion sites, plan erosion control and prevention actions, carry out those actions, and conduct instream and hillslope monitoring activities. The Plan should urge agencies and private landowners to share all data concerning instream water quality and hillslope practices with the State to assist in future review of the TMDL.

The Plan should also note that significant funding for implementation planning and action as well as monitoring may be available from outside sources (e.g., President's Forest Plan funds, Clean Water Act Section 319 nonpoint source and Clean Water Action Plan grant funds, NRCS cost share funds, and possibly state funding sources). If the park and local landowners are interested in obtaining such funds, the Regional Board should actively facilitate efforts to do so. EPA recommends that if outside funding is obtained to support implementation activities in the basin, preference for spending these funds should be targeted to smaller landowners who may be less able to carry out the necessary planning and implementation activities.

2. Clarify focus on potential erosion sites as well as existing sites. Although the text of the Plan indicates that landowner inventories should address both potential and active erosion sites, the Plan should be clarified to place greater focus on detection of potential erosion sites and implementation of measures to prevent activation of erosion from these sites. It is often cost-prohibitive to address erosion sites which have already begun to erode. In addition, if initial erosion site inventories are designed to identify all sites with future erosion potential based on the presence of characteristics indicating instability or vulnerability, it may prove unnecessary to conduct repeated detailed inventories every few years as proposed. If done well the first time, it may be necessary to follow-up these detailed initial inventories only with periodic cursory inspections of potential erosion sites and erosion control practices and structures.

3. Clarify the 10 year implementation timeframe and urge quicker implementation. The Plan calls for implementation of needed erosion prevention and control measures within 10 years after the baseline inventory is developed. The baseline inventory is scheduled for submission by 2003. EPA supports the 10 year implementation timeframe. However, the State should consider requiring submission of the baseline inventory and initiation of the 10 year implementation timeframe sooner than 2003. It should not have to take landowners 5 years to complete the inventory. EPA recommends a tighter timeframe for submission of the baseline inventory-- perhaps 2-3 years from the date of TMDL adoption. If the 2003 submission schedule is retained, the Plan should strongly encourage the implementation of erosion prevention and control measures as soon as is practicable, beginning now.

4. Improve protection of Class 3 watercourses. Existing forest practice rules appear to provide inadequate measures to protect Class 3 watercourses from disturbances which can trigger significant erosion and sediment delivery to Class 1 and 2 watercourses. The Regional Board plan should explicitly require inventories and action plans to address potential erosion sites near Class 3 watercourses.

Monitoring Recommendations

EPA guidance concerning the development of TMDLs through the phased approach emphasizes the importance of establishing rigorous monitoring and evaluation plans and associated schedules which will guide the review and potential revision of the TMDLs and implementation activities (EPA, 1991). The State should establish a monitoring and evaluation plan which identifies parties responsible for implementation and timeframes for RWQCB review of monitoring results. The monitoring plan should describe how and when monitoring results will be reviewed to evaluate the need for TMDL or implementation plan revisions. Finally, the monitoring plan should provide for data sharing among landowners, agencies, and interested stakeholders.

The Regional Board Plan should describe a more detailed approach to developing a comprehensive monitoring plan. EPA recommends the following monitoring provisions:

1. Actively lead the development of a comprehensive monitoring plan. EPA commends the State for its plan to work with other agencies and landowners to develop the monitoring plan, we suggest that the Regional Board develop a specific agreement with Redwood National Park (and perhaps with other agencies) to jointly lead the development of this plan. The Plan should recognize the opportunities to dovetail TMDL monitoring activities with ongoing monitoring conducted by Redwood National Park, USGS, other agencies, and private landowners. The Regional Board and Redwood National Park should describe a specific mechanism through which interested agencies and landowners can work together to develop and implement this monitoring plan. As discussed above, it may be appropriate for the Regional Board to facilitate acquisition of outside funds to support future monitoring efforts.

2. Distinguish monitoring needs in different stream types and hillslope locations. Different monitoring approaches will be appropriate in different locations. With respect to instream monitoring, it would be appropriate to establish monumented monitoring sites distributed throughout the mainstem and lower portions of key tributary watersheds. Priorities for monitoring tributaries and mainstem reaches which include potential spawning/rearing habitat include (in priority order):

- pebble counts at riffle crests,
- large woody debris inventories,
- thalweg and cross section measures which facilitate measurement of pool indicators,
- suspended sediment and possibly bedload sediment at mouths of key tributaries, including Lacks Creek, Prairie Creek, Panther Creek, Coyote Creek, Bridge Creek, and Little Lost Man Creek, and
- bulk sampling of substrate composition at riffle crests in a subset of established monitoring sites.

Priorities for monitoring in the larger portions of Redwood Creek should include the following:
- thalweg profiles and cross sections,
- large woody debris inventories,
- suspended and bedload sediment loads at Orick and Okane.

Additional indicators which should be considered for addition to monitoring programs include:
- substrate permeability,
- turbidity, and
- bed mobility measures (e.g. scour chains)

Hillslope monitoring will also be an important component of the monitoring plan. In addition to the implementation monitoring and reporting requirements in the Plan, the hillslope monitoring plan should provide for information collection adequate to update the sediment budget about once every 10-15 years. EPA recommends the use of rapid sediment budgeting methods described in Reid and Dunne (1996).

All monitoring plans should include specific descriptions of the monitoring protocols and data management efforts to be followed in adequate detail to guide monitoring and data recording by different field workers. Agreement at the outset on monitoring protocols and data management methods is crucial to ensure that data collected at different times and locations by different parties will be comparable in the future. If feasible, provision should be made to record and report data in electronic formats.

Section 6. Glossary

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

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.

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: Human-made watercourses, which usually supply downstream established domestic, agricultural, hydroelectric supply or other beneficial uses.

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 an intense 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. These structures include but are not limited to fords, inside ditches, water bars, outsloping, rolling dips, culverts or ditch drains.

Flood event: Flood frequency analysis defines the event which can be expected once every "Y" years, on the average. This does not imply that a "Y-year event" will occur regularly every "Y" years. Return periods, as well as flood magnitudes, are subject to analysis. For example, there is a two percent chance that a 50-year event will occur I any one year.

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 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.

Numeric targets: A numerical expression of the desired instream environment. For each stressor or pollutant addressed in the problem statement of the Strategy , a numeric target is developed based on the numeric or narrative State water quality standards which are needed to recovered the impaired beneficial use.

Permanent drainage: A road drainage structure designed and constructed to remain in place following active structure land management activities while allowing year round access on a road.

Planning Watershed: The uniform designation and boundaries of sub basins within a larger watershed (designated by the California Department of Forestry as Cal Water Watersheds).

Redd: A gravel nest or depression in the stream substrate formed by a female salmonid in which eggs are laid, fertilized and incubated.

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: 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 passing a point in the stream 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 the failure of the soil mantle (typically to a depth of 1-2 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.

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.

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, and so forth.

Sub basin: A subset or division of a watershed into smaller hydrologically meaningful Watersheds. For example, the North Fork Redwood Creek is a sub basin of the larger Redwood Creek 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.

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.

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.

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.

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 on 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.

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