U.S. Environmental Protection Agency
Region IX

Ten Mile River Total Maximum Daily Load for Sediment

Approved by:

______________________ ____________

Alexis Strauss
Director, Water Division

Date

FIGURE 1

TEN MILE RIVER WATERSHED

TMDL Planning Areas and Sub-Watersheds

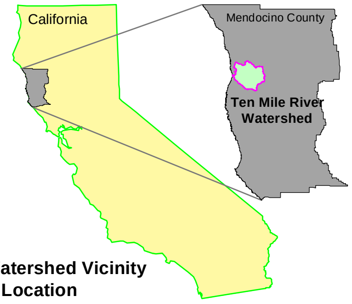
Watershed Boundary

Planning Watersheds	Streams
North Fork	Perennial
Middle Fork	Intermittent
South Fork	Ephemeral
Mainstem	

Sub-Watersheds

8 **Former USGS Gauge**

Basemap Data Source: Ca. Dept. of Forestry



Watershed Vicinity & Location

TMDL Planning Area

Sub-Watershed	Acres	Sq. Miles
North Fork	**24,943**	**38.97**
Upper North Fork Ten Mile River	6,655	10.40
Middle North Fork Ten Mile River	5,748	8.98
Bald Hill Creek	3,289	5.14
Little North Fork Ten Mile River	4,960	7.75
Lower North Fork Ten Mile River	4,291	6.70
Middle Fork	**21,414**	**33.45**
Upper Mdl. Fork Ten Mile River	7,452	11.64
Middle Mdl. Fork Ten Mile River	4,126	6.45
Little Bear Haven Creek	1,922	3.00
Bear Haven Creek	4,224	6.60
Lower Mdl. Fork Ten Mile River	3,689	5.76
South Fork	**24,567**	**38.39**
Upper South Fork Ten Mile River	5,236	8.18
Redwood Creek	5,038	7.87
Churchman Creek	2,537	3.96
Middle South Fork Ten Mile River	3,531	5.52
Campbell Creek	2,720	4.25
Smith Creek	3,511	5.49
Lower South Fork Ten Mile River	1,994	3.12
Mainstem	**5,653**	**8.83**
Mainstem Ten Mile River	2,737	4.28
Mill Creek	1,737	2.71
Ten Mile River Estuary	1,179	1.84

4

Scale: 1 = 130,000

Presented By

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Prepared By

Trinity County Resource Conservation District

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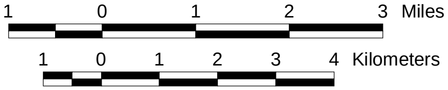

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EXECUTIVE SUMMARY

The Ten Mile River drains 120 square miles of forested, coastal watershed in Mendocino County, California. Its history is largely defined by timber harvest, which began in the lower basin about 1870. Old growth logging continued into the first half of the 20th century. Second growth logging began in the 1960s and continues today. Most of the watershed is managed by Campbell Timberland Management, LLC. It was purchased by Hawthorne Timber Company, LLC, from Georgia-Pacific West, Inc. in 1999. A handful of small rural residential and non-industrial timber ownerships are also in the watershed.

The U.S. Environmental Protection Agency (EPA) is establishing the Ten Mile River Total Maximum Daily Load (TMDL) for sediment to identify sediment loading allocations that are necessary to implement water quality standards for sediment, established to protect the beneficial uses of the Ten Mile River. EPA is establishing the TMDL in order to meet its obligations under a consent decree *(Pacific Coast Federation of Fishermern's Associations, et al., v. Marcus, No. 95-4474 MHP, March 11, 1997).* The primary beneficial use of concern in the Ten Mile River watershed is the salmonid fishery, particularly the coho salmon (*Oncorhynchus kisutch*) fishery.

SECTION 303(d) AND THE TEN MILE RIVER WATERSHED

The Ten Mile River watershed was listed on the 1998 303(d) list by the State of California pursuant to Section 303(d) of the Clean Water Act. This list describes water bodies that do not meet water quality standards. It also describes the pollutant(s) for each water body that limit(s) its use or prevent(s) attainment of its water quality objectives. As required by Section 303(d), a TMDL must be developed for water bodies on the list. For the Ten Mile River watershed, the listing was the result of water quality problems related to excess sediment throughout the watershed. Sediment was determined to be impacting the cold water fishery, a beneficial use of the Ten Mile River watershed, including the migration, spawning, reproduction, and early development of cold water fish such as coho salmon and steelhead trout. Cold freshwater and estuarine habitats are also designated beneficial uses of the Ten Mile River watershed.

ENDANGERED SPECIES ACT CONSULTATION

EPA has initiated informal consultation with the U.S. National Marine Fisheries Service and the U.S. Fish and Wildlife Service (the Services), on this action, under Section 7(a)(2) of the Endangered Species Act (ESA). Section 7(a)(2) states that each federal agency shall ensure that an action authorized, funded, or carried out by such agency is not likely to jeopardize the continued existence of any endangered or threatened species. EPA's consultation with the Services has not yet been completed. EPA believes it is unlikely that the Services will conclude that the Total Maximum Daily Load (TMDL) that EPA is establishing violates Section 7(a)(2), since the load allocations are calculated in order to meet water quality standards, and water quality standards are expressly designed to "protect the public health or welfare, enhance the quality of water and serve the purposes" of the Clean Water Act, which are to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters." Additionally, this action will improve existing conditions. However, EPA retains the discretion to revise this action if the consultation identifies deficiencies in the allocations requiring remedial action by EPA.

COMPONENTS OF THE TMDL

The TMDL includes:
- Problem statement;
- Numeric targets;
- Source analysis;
- Linkage analysis and loading capacity;
- TMDL and load allocations;
- Discussion of the margin of safety, seasonal variation and critical conditions.
- Implementation and monitoring recommendations; and
- Discussion of public participation.

There are two significant sources of information and analysis for this TMDL. The first is an assessment of aquatic conditions (Clyde and Mangelsdorf 2000), which analyzes all the data that could be found about instream conditions and the relationships to salmonid distribution and abundance in the Ten Mile watershed. The second is a sediment source analysis (GMA 2000), which also includes considerable analysis of hydrologic and geomorphic data. The watershed is divided into four Planning Watersheds (PW): North Fork, Middle (Clark) Fork, South Fork, and Mainstem Ten Mile River (see Figure 1). These are further divided into 22 subwatersheds for the purposes of the source analysis.

Problem Statement

The problem statement includes a summary of existing conditions that led to the 303(d) listing of the water body. Coho salmon, steelhead trout, and chinook salmon are native to the Ten Mile River. Coho and chinook salmon populations have declined significantly in recent years. High concentrations of channel-bottom fine sediment, excessive gravel embeddedness, inadequate pool frequency and depth, and lack of large woody debris appear to be factors directly and indirectly related to sediment that are currently limiting the success of salmonids, especially coho salmon, throughout the watershed. It is likely that chinook were also native to the basin, but were locally extirpated prior to the 1950s (Shapavalov 1948, in Mangelsdorf and Clyde 2000; L. Clyde pers.comm. 2000, G. Bryant pers.comm. 2000). Steelhead populations appear to have remained stable (suggesting that conditions are not as critical for steelhead as in other basins, where populations have plummeted). Chinook salmon were re-introduced to the watershed in large numbers beginning in 1979. Coho and steelhead were also planted, in lower numbers, beginning in the 1950s. Because steelhead populations appear to be stable and chinook data are lacking, this assessment concentrates on the water-quality conditions that would support coho, which are still found in the watershed, although in diminished numbers. Nevertheless, the water quality improvements addressed in this document are expected to lead to conditions supporting cold freshwater habitats and beneficial uses generally, including those for chinook and steelhead.

Water Quality Targets

The water quality targets interpret water quality standards and provide indicators of watershed health and achievement of water quality standards. In particular, they describe in-stream and watershed conditions suitable for the successful migration, spawning, rearing, and over-wintering of coho salmon in the freshwater environment. The indicators and targets are listed in Table 1.

The target for substrate quality ($\leq$14% (mean) fines <0.85 mm) provides a good instream indication of sedimentation problems, and it would be valuable to have additional information on this indicator in tributaries that may also be subject to upcoming management activities. V* is also recommended (value $\leq$ 0.21). Other targets (thalweg profile, and several aquatic habitat characteristic indicators) are expressed as improving trends, because there is no inherent target value that indicates adequate water quality, and because the literature does not suggest that a particular value is appropriate. The habitat characteristic indicators include: distribution of pool habitat (including scour pools and backwater pools) and large woody debris-formed habitat; embeddedness, and seven-day running average of maximum daily temperatures. These habitat characteristics indicators are included as a group, primarily because the existing data for the basin suggests conditions that would facilitate coho support, consistent with reduced sediment loads. Thus, they are also derived from apparent correlations with the presence or absence of coho, rather than just from an interpretation of water quality standards. They are also good integrators of multiple stressors, including sediment loads.

Road and hillslope indicators (stream crossings with diversion potential or significant failure potential, hydrologic connectivity, disturbed area, activity in unstable areas, annual pre-winter road inspection/maintenance, and road location, surfacing and sidecasting) are also established to define watershed conditions needed to protect water quality. They relate directly to the delivery of sediment to a watercourse.

EPA recommends that the indicators be incorporated into the ongoing monitoring program in the basin, and that the Regional Water Board will coordinate with landowners to develop a monitoring plan that includes these indicators. Substrate composition and V* are relatively simple to monitor, and should be monitored regularly. Thalweg profiles are better monitored on an infrequent basis, potentially after large floods.

Source Analysis

The source analysis includes an assessment of sources of sediment historically and/or presently impacting water quality. Several management-related factors have contributed to the elevated sediment delivery rates throughout the watershed. The most important include high rates of timber harvest and associated road building, both historically (particularly prior to institution of the Forest Practice Rules) and currently (particularly in the South Fork Planning Watershed); high road densities; and, historically, high densities of skid trails. While overall rates have declined in the 67-year study period from 1933-1999, sediment generation from road surface erosion has increased. Current sediment delivery from all sources is estimated at 629 tons/mi^2/yr, with about 50% of that background and the rest management-related.

Linkage Analysis and Loading Capacity

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

Determining the loading capacity entailed estimating a sediment delivery rate for the watershed at a period when salmonids were abundant and comparing this to an estimated rate of natural sediment delivery. There are no sediment delivery data for the Navarro watershed at a time when salmonids were abundant. Therefore, data for a nearby watershed, the Noyo River watershed, was used in this analysis. Salmonids were abundant in the Noyo and its tributaries during the 1933-1957 period, so the corresponding sediment yield during this period must have been sufficiently low to allow salmonid habitat of suitable quality to persist (EPA 1999). In the Noyo River Total Maximum Daily Load for Sediment, the total sediment yield during this period was estimated at 470 tons/mi^2/yr and the natural sediment yield was estimated at 370 tons/mi^2/yr (EPA 1999). The loading capacity for the Noyo is 125% of the background load. This ratio is then applied to the background levels in the Ten Mile River, because the two basins are close in proximity, and have similar characteristics of geology, vegetation, orientation, and land use history. Thus, the loading capacity for the Ten Mile basin is determined to be 125% of the estimated background rate. The background rate for the Ten Mile is 311 tons/mi^2/yr. Loading capacity for the Ten Mile is determined to be 125% of background levels, or 390.

TMDL and Load Allocations

EPA is setting the TMDL equal to the loading capacity, which is expected to result in attainment of water quality standards for sediment. EPA has decided that the most appropriate load allocation is one based on a loading capacity of 125% of background, based on the Noyo River TMDL. Under this alternative, overall reductions of 75% from current (1988-1999) sediment loading levels would be needed from management-related sources to meet the allocations. Reductions of 85% would be needed from road surface erosion and nearly 76% of road-related landsliding. Landsliding reductions from all sources would average about 56%, and reductions from skid roads would average about 20%.

In its draft TMDL, EPA proposed two alternative methods for calculating the TMDL. One was to use the actual loading capacity established for the Noyo, or 470 tons/mi2/yr. The other was to use the methodology used for calculating the Noyo TMDL of 125% background, or 390 tons/mi2/yr. EPA has determined that the more conservative loading capacity is most appropriate. Using the conservative loading capacity serves as a Margin of Safety in protecting and improving habitat for endangered salmonids in the basin.

The proposed TMDL and Load Allocations are expressed as an average annual loading rate, and are intended to be interpreted as a 10-year rolling average, which more appropriately describes sediment loadings that can achieve water quality conditions than if it were expressed as a daily load. This is because variations in sediment loads are normal, tending to fluctuate with fluctuating precipitation and stream flow conditions.

In summary, the TMDL = loading capacity = the sum of waste load allocations (from point sources), load allocations (from nonpoint sources) and background loads:
TMDL = ' WLA + ' LA + Background loading = 390 tons/mi^2/yr

' WLA (Waste Load Allocation) = 0, as there are no point sources in the basin.
' LA = 79 tons/mi^2/yr (management-related loads would be at about a 75% reduction below current estimates)
Background = 311 tons/mi^2/yr

Margin of Safety, Seasonal Variation and Critical Conditions

The Margin of Safety is implicit, and is based on several different factors. Choosing the more conservative calculation of the loading capacity (TMDL) is one example of this implicit Margin of Safety. In addition, because sediment production within a watershed does not always coincide with sediment delivery to streams, which is inherently variable, both temporally and spatially, the sediment allocations are designed to apply to the sources of sediment, not the movement or delivery of the sediment to the streams. In addition, the hillslope targets are specifically designed to describe watershed conditions that are directly responsible for preventing additional sediment delivery prior to the time of delivery.

Regarding seasonal variations and critical conditions, hillslope targets were developed with variations in rainfall and peak flows in mind. Furthermore, they are defined as 10-year rolling averages, as are the loading capacity and load allocations in the TMDL.

The approach used in this TMDL to account for critical conditions is to include indicators that can address sediment sources and watershed conditions, addressing lag times from production to delivery, and which are reflective of the net long-term effects of sediment loading, transport, deposition, and associated receiving water flows. Instream indicators may be effectively measured at lower flow conditions at roughly annual intervals, and hillslope indicators can assist in tracking the implementation of measures to improve water quality conditions.

Public Participation

EPA provided opportunities for comment on the TMDL and development process for landowners, community groups, public agencies, and the general public. In addition to direct communication with members of the public, EPA held two public meetings in the city of Fort

Bragg. At the first meeting, the supporting documents to the TMDL were presented and discussed. At the second, the public review draft of the TMDL was presented and discussed. The public was provided a 30-day official comment period in which to review and submit written comments regarding the document. Several changes were made to the final document as a result of public comment. These include: a brief discussion of the informal consultation with the Services under the Endangered Species Act; clarification of the text related to the status of coho salmon in the basin; changes to the habitat characteristics targets to strengthen water quality protection; additional habitat characteristics indicators; clarification of the temperature-related habitat characteristics indicator; clarification of one hillslope indicator; two additional hillslope indicators; additional detail of the source analysis; and selection of the more conservative of two proposed allocations methods. Tables 1 (Water Quality Targets), 3 and 4 (Habitat Characteristics Target Values and Current Values), 11 and 12 (Sediment Input Summary and Annual Unit Area Rates), and 13 (TMDL and Allocations) were modified to reflect the chosen TMDL and allocations levels, and additional detail from the source analysis. Table 14 (alternative proposed TMDL) was deleted.

Table 1: Summary of Water Quality Targets

Indicator	Target	Monitoring *	References^
Substrate Composition	#14% (mean, as wet volume) fines <0.85 mm, in pool tail-outs or potential spawning areas	Expand use to other tributaries; monitor frequently	Burns 1970; CDF 1994, Mangelsdorf & Lundborg 1998
V*	#0.21 (mean) in pools	Monitor frequently, throughout basin.	Knopp 1993
Thalweg profile	Increasing variation in thalweg elevation around the mean thalweg slope	Monitor infrequently, to determine gross changes.	Trush 1999; Madej 1999
Aquatic Insect Production	Improving trends in indicdes for EPT (mayflies, caddisflies, and stoneflies), percent dominant taxa and species richness.	NCRWQCB to determine appropriate protocols	Bybee 2000, letter to USEPA dated 12/1/00
Habitat Characteristic Indicators	Increasing trends, toward Little North Fork values, in: -distribution of pools (lngth, scour pool lngth/area, backwater pool lngth) and LWD-formed habitat lngth; -No. reaches where 7-day rning avg max. daily temp #16.8EC; -No. of reaches where embeddedness # 25%	Monitor new habitat areas as appropriate. Monitor summer temp frequently.	Flosi et al. 1998; DFG 1995a, 1995b (In Mangelsdorf & Clyde 2000)
Road/Hillslope Indicators			
Stream crossings w/ diversion or significant crossing failure potential	#1% of all stream crossings, as a result of a storm with a 100-year recurrence interval or less	Annually inspect, evaluate, correct	Weaver and Hagans 1994; Flanagan et al. 1998
Hydrologic connectivity	Decrease in the miles of road hydrologically connected to a watercourse		Ziemer 1998; Furniss 1999
Disturbed area	Decrease in the area disturbed by facilities[+]		Lewis, 1998
Activity in unstable areas	No activities (e.g., roads, harvest, yarding, etc.) in unstable areas (e.g., steep slopes, headwall swales, inner gorges, streambanks, etc.) unless a detailed geological assessment is performed by a certified engineering geologist that shows there is no potential for increased sediment delivery to a watercourse as a result.		Dietrich et al. 1998; Weaver and Hagans 1994; PWA 1998
Annual road inspection & maintenance	All roads would be inspected annually prior to winter. Conditions that are likely to deliver sediment to streams would be corrected, otherwise roads will be hydrologically closed/disconnected (fills and culverts removed, natural hydrology of hillslope largely restored).		EPA 1998
Road location, surfacing and sidecasing	1) All roads alongside inner gorge areas or in potentially unstable headwall areas should be removed unless alternative road locations are unavailable and need for road is clearly justified. 2) Road surfacing, drainage methods and maintenance are appropriate to their use patterns and intensities. 3) hydrologic connectivity is assessed and reduced to the extent feasible. 4) Sidecast/fill on steep or potentially unstable slopes pulled back/stabilized		EPA 1998

*Suggestions for Regional Water Board use. ^References as cited in EPA 1998/1999, unless noted as cited elsewhere.

[+] A facility is defined as any management-related structure such as a road, railroad roadbed, skid trail, landing, harvest unit, animal holding pen, or agricultural field (e.g., pasture, vineyard, orchard, row crops). For the purpose of this target, a harvest unit or agricultural field that retains its natural characteristics with respect to rainfall interception, rainfall infiltration, and soil protection, is not considered a "facility." References as cited in EPA 1999, unless noted as cited elsewhere

CHAPTER I
INTRODUCTION

TMDL PURPOSE

The purpose of the Ten Mile River TMDL for sediment is to identify sediment loading allocations that are necessary to implement the applicable water quality standards for sediment, as required by Section 303(d) of the Clean Water Act. Standards are established in order to protect beneficial uses. The most sensitive beneficial use of concern is the cold water fishery, particularly for the coho salmon (*Oncorhynchus kisutch*) fishery.

The Ten Mile River watershed was included on the State of California's list of impaired waterbodies (also known as the "303(d) list") due to sediment, which was determined to be impacting the cold water fishery, including migration, spawning, reproduction, and early development of cold water fish such as coho salmon and steelhead trout. Cold freshwater and estuarine habitats are also designated uses of the Ten Mile River watershed, which are listed in the North Coast Basin Plan. Nonpoint source silviculture was identified as the probable cause of the impairment in the 303(d) list. EPA is establishing the sediment TMDL for the Ten Mile River in order to meet EPA's obligations under a consent decree *(Pacific Coast Federation of Fishermen's Associations, et al., v. Marcus, No. 95-4474 MHP, March 11, 1997).*

Pursuant to Section 303(d) of the Clean Water Act and associated regulations, this TMDL uses best available information to describe the water quality problem, define conditions that would indicate achievement of water quality standards, analyze sources of sediment, describe the linkages between aquatic conditions, watershed conditions and sediment loads, determine the maximum sediment loading that the water body appears capable of assimilating while still meeting water quality standards (i.e., the loading capacity and TMDL), and allocate that load amongst known sediment sources. Because the state of scientific knowledge defining these linkages is limited, and because there is uncertainty associated with that knowledge, the analysis relies on conservative assumptions where appropriate.

One of the benefits of this TMDL is to bring together all available information on water quality conditions in the basin. EPA hopes that the Regional Water Board, landowners and community members will be able to use the information summarized in the TMDL and associated documents (Mangelsdorf and Clyde 2000, GMA 2000) to implement the most effective water quality improvements in the basin, and to revise the TMDL if necessary in the future.

ENDANGERED SPECIES ACT CONSULTATION

EPA has initiated informal consultation with the U.S. National Marine Fisheries Service and the U.S. Fish and Wildlife Service (the Services), on this action, under Section 7(a)(2) of the Endangered Species Act (ESA). Section 7(a)(2) states that each federal agency shall insure that an action authorized, funded, or carried out by such agency is not likely to jeopardize the continued existence of any endangered or threatened species.

EPA's consultation with the Services has not yet been completed. EPA believes that it is unlikely that the Services will conclude that the Total Maximum Daily Load (TMDL) that EPA is establishing violates Section 7(a)(2), since the load allocations are calculated in order to meet water quality standards, and water quality standards are expressly designed to "protect the public health or welfare, enhance the quality of water and serve the purposes" of the Clean Water Act, which are to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters." Additionally, this action will improve existing conditions. However, EPA retains the discretion to revise this action if the consultation identifies deficiencies in the allocations requiring remedial action by EPA.

CHANGES TO THE FINAL TMDL FROM THE PUBLIC REVIEW DRAFT

EPA provided opportunities for comment on the TMDL and development process for landowners, community groups, public agencies, and the general public. In addition to direct communication with members of the public, EPA held two public meetings in the city of Fort Bragg. At the first meeting, the supporting documents to the TMDL were presented and discussed. At the second, the public review draft of the TMDL was presented and discussed. The public was provided a 30-day official comment period in which to review and submit written comments regarding the document. Several changes were made to the final document as a result of public comment. These include: a brief discussion of the informal consultation with the Services under the Endangered Species Act; clarification of the text related to the status of coho salmon in the basin; changes to the habitat characteristics targets to strengthen water quality protection; additional habitat characteristics indicators; clarification of the temperature-related habitat characteristics indicator; clarification of one hillslope indicator; two additional hillslope indicators; additional detail of the source analysis; and selection of the more conservative of two proposed allocations methods and additional detail in the allocations. Tables 1 (Water Quality Targets), 3 and 4 (Habitat Characteristics Target Values and Current Values), 11 and 12 (Sediment Input Summary and Annual Unit Area Rates), and 13 (TMDL and Allocations) were modified to reflect the chosen TMDL and allocations levels, and additional detail from the source analysis. Table 14 (alternative proposed TMDL) was deleted.

WATERSHED CHARACTERISTICS

The Ten Mile River drains about 120 square miles of forested, coastal watershed in Mendocino County, California (see Figure 1). The mouth of the Ten Mile River is about 10 miles north of Fort Bragg. The watershed elevation ranges from sea level to 3,240 feet at Strong Peak. It is entirely privately owned, with Hawthorne Timber Company, LLC (managed by Campbell Timberland Management, LLC), the successor to Georgia-Pacific West, owning about 85% of the watershed. Three small non-industrial timber owners and a handful of other residences are in the watershed. Average annual precipitation ranges from about 40 inches near the coast to greater than 70 inches at higher elevations in the northern and eastern portions of the watershed. Most precipitation occurs as rainfall. The terrain varies from the flat estuary and broad river floodplain to rugged mountainous topography with high relief (GMA 2000).

PLANNING WATERSHEDS

For the purposes of the analysis, four Planning Watersheds (PW) have been defined, which correspond to the North, Middle and South Fork tributaries and the Lower Mainstem Ten Mile. They are similar in size, ranging in area from 33 to 39 square miles. The Lower Mainstem Planning Watershed is smaller, about 9 square miles. These Planning Watersheds have been further divided into 20 subwatersheds (SW), as shown in Figure 1.

The Ten Mile River has three main forks: the North Fork, Middle Fork (also known as the Clark Fork), and the South Fork. Each of these tributary watersheds form an approximately equal size planning watersheds, with an additional 9-square mile lower Mainstem Planning Watershed. Most of the basin, aside from the northeast grasslands area, is characterized by steep, narrow drainages bordered by steep to moderately steep slopes leading to the headwaters of the tributaries. The lower portion of the South Fork Planning Watershed, like the lower Middle Fork and much of the lower Mainstem, has broad alluvial valleys bordered by high relief terrain. The headwaters of the North Fork are characterized by relatively gentle terrain, while the headwaters of the Middle and South Forks are characterized more by summits and ridgelines. Inner gorge topography (oversteepened slopes adjacent to stream courses) locally characterizes portions of the tributaries. Fluvial cut terraces are also present locally, except along the Middle Fork. Most of the drainages are narrow, with 60-80% of the basin area in steep to moderately steep slopes (15-35%). Less than 3% of the area has slopes greater than 40% (GMA 2000).

The bedrock geology of the watershed is dominated by rocks of the Franciscan Complex, primarily the relatively coherent and stable Coastal Belt Terrane. Relatively incoherent Central Belt Terrane rocks crop out in the northeastern area in the headwaters of the North Fork, and are responsible for the subdued topography in that area. These rocks are overlain by a variety of surficial deposits, varying locally from beach sand, marine terrace deposits, dune sands, estuary deposits, landslide debris, alluvium, and soil and colluvium (GMA 2000).

WATERSHED HISTORY

The history of the Ten Mile River watershed is largely defined by timber harvest, which began in the lower basin about 1870. The first railroad in the area was developed in the 1910s, connecting the South Fork Ten Mile with the sawmill in Fort Bragg. Railroads were extended into the Middle and North Forks by the early 1920s. Until about 1940, the South Fork Ten Mile provided the major log supply to the Fort Bragg mill. In the 1930s, tractor yarding began to replace railroad yarding, and most of the railroad grades were converted to roads. Major portions of the watershed were harvested between the mid 1940s and the mid 1960s, using tractor yarding, with its associated road, skid trail and landing construction. Since the passage of the Forest Practices Act in 1973, tractor logging has been restricted primarily to gentler slopes (although it still accounts for 40-80% of the harvest), and the use of cable yarding has increased on steeper slopes. Relative to the 1940-1960 period, harvest levels were apparently far lower between the late 1960s and the mid 1980s, because the forest was fairly well depleted and was left to regenerate. Current harvest levels have increased, particularly in the South Fork, with the maturity of second growth forests. Most of the watershed is managed using about a 60 year average rotation age (GMA 2000).

Information Sources

Information for this TMDL came from a variety of sources. Much of the analysis is summarized from an assessment of watershed conditions conducted by staff of the North Coast Regional Water Quality Control Board (Mangelsdorf and Clyde 2000), and a sediment source analysis developed by GMA (2000), who conducted the analysis for EPA as a subcontractor to Tetra Tech, Inc. Primary sources of data for the studies were: the California Department of Fish and Game (DFG), California Department of Forestry and Fire Protection (CDF), U.S. Geological Survey (USGS), and Campbell Timberlands Management and its predecessor, Georgia-Pacific West, Inc. (Campbell/GP). DFG provided historic aquatic surveys as well as some fish distribution and aquatic habitat data. CDF provided Timber Harvest Plan (THP) data. Campbell/GP provided monitoring data on substrate conditions, aquatic habitat and fish populations. USGS provided stream flow and topographic data. Most sources cited in this TMDL were originally cited in Mangelsdorf and Clyde (2000) and GMA (2000). This TMDL does not include the same level of detail found in the two supporting documents.

This TMDL includes:

- Problem statement, including a discussion of existing water quality requirements;
- Water quality targets;
- Source analysis;
- Linkage analysis;
- TMDL and load allocations;
- Discussion of the margin of safety, seasonal variation, and critical conditions;
- Recommendations pertaining to implementation and monitoring; and
- Discussion of public participation.

The problem statement includes an assessment of existing in-stream and watershed conditions. The numeric targets interpret water quality standards and provide indicators of watershed health, and compare existing and target conditions. The source analysis includes an assessment of sources of sediment historically and/or presently impacting water quality. The linkage analysis provides the basis for estimating the assimilative capacity of the water body and determining the maximum sediment loads allowable consistent with that capacity that are protective of water quality standards and beneficial uses (the loading capacity, or TMDL). The load allocation(s) are the assignment of maximum sediment loads from different source categories. The margin of safety and seasonal variation discussions summarize the means by which the final load allocations account for any uncertainty in the data or data analysis, and temporal effects in the load allocation(s). A discussion of recommendations for the future development of implementation measures and monitoring plan is included. A discussion of public participation is also included.

CHAPTER II
PROBLEM STATEMENT

This chapter lists the water quality standards applicable to sediment problems in the Ten Mile River basin, describes the sediment problem and summarizes its relationship to beneficial uses, particularly coho population and abundance.

WATER QUALITY STANDARDS

Water quality standards (WQS) adopted for the Ten Mile River basin are contained in the Water Quality Control Plan for the North Coast Region (the Basin Plan, NCRWQCB, 1994). The WQS for the Ten Mile river are comprised of the beneficial uses of water and the water quality objectives designed to protect the most sensitive of the beneficial uses. The Basin Plan identifies municipal, industrial, agricultural and recreational uses of the Ten Mile River watershed, including the following beneficial uses related to the Ten Mile River's cold water fishery:

- Commercial and sport fishing (COMM);
- Cold freshwater habitat (COLD);
- Migration of aquatic organisms (MIGR);
- Spawning, reproduction, and early development (SPWN); and
- Estuarine habitat (EST).

The COMM beneficial use applies to water bodies in which commercial or sport fishing occurs or historically occurred for the collection of fish, shellfish, or other organisms, including, but not limited to, the collection of organisms intended either for human consumption or bait purposes. The COLD beneficial use applies to water bodies that support or historically supported cold water ecosystems, including, but not limited to, the preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates. The MIGR beneficial use applies to water bodies that support or historically supported the habitats necessary for migration or other temporary activities by aquatic organisms, such as anadromous fish. The SPWN beneficial use applies to water bodies that support or historically supported high quality aquatic habitats suitable for the reproduction and early development of fish. The EST beneficial use applies to water bodies that support or historically supported estuarine ecosystems, including, but not limited to, the preservation or enhancement of estuarine habitats, vegetation, fish, shellfish, or wildlife (e.g., estuarine mammals, waterfowl, shorebirds). The RARE beneficial use, while not yet designated for the Ten Mile River, applies to protection of endangered species habitat, and appears to be an appropriate designation as well. The Regional Water Board is taking this into consideration, and will be updating the Basin Plan in the near future to reflect endangered species listings that have occurred since the last update (D. Leland, pers. comm., 2000).

As with many of the North Coast watersheds, the primary beneficial use of concern in the Ten Mile River watershed, as described in the *Water Quality Control Plan, North Coast Region* (Basin Plan), is the cold freshwater fishery, which supports coho salmon (*Oncorhynchus kisutch*), steelhead trout (*Oncorhynchus mykiss*), and chinook salmon (*Oncorhynchus tshawytscha*). In particular, the coho salmon fishery appears to be the most sensitive use, on which beneficial use support can be gaged. Accordingly, protection of the coho fishery is presumed to protect any of the other beneficial uses that might also be harmed by sedimentation.

Water Quality Objectives

The Basin Plan establishes four water quality objectives pertaining to suspended material, settleable material, sediment, and turbidity:

> “Waters shall not contain suspended material in concentrations that cause nuisance or adversely affect beneficial uses.”
>
> “Waters shall not contain substances in concentrations that result in deposition of material that causes nuisance or adversely affect beneficial uses.”
>
> “The suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.
>
> “Turbidity shall not be increased more than 20 percent above naturally occurring background levels. Allowable zones of dilution within which higher percentages can be tolerated may be defined for specific discharges upon the issuance of discharge permits or waiver thereof.”

In addition to the water quality objectives, the Basin Plan includes two discharge prohibitions specifically applicable to logging, construction and other associated activities:

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

SEDIMENT PROBLEMS

The cold water fishery is the most impaired beneficial use in the basin. Fish populations in the basin depend on a number of internal and external factors, including: habitat availability and quality (determined by stream flow, channel form and structure, and physical barriers); water temperature; water chemistry; food supply; and predation. For anadromous salmonids, these factors are important at the spawning and rearing sites as well as along migration routes and into the ocean. While all these factors can affect salmonid populations, this TMDL addresses only those factors related to sediment discharge in the Ten Mile basin.

Timber harvest activities have been identified by the North Coast Regional Water Quality Control Board (Regional Water Board) as the probable cause of the sediment problem within the Ten Mile River basin. In particular, the concentration of fine sediments in many stream channel reaches appears to be too high to support egg survival and fry emergence: excess fine sediment can prevent adequate water flow through salmon redds, or nests, which is critical for maintaining adequate oxygen levels and removing metabolic wastes. Deposits of these finer sediments can also prevent the hatching fry from emerging from the redds, resulting in smothering. Gravels in the basin are also generally embedded (i.e., fine sediment surrounds and packs in against the gravels, which effectively cements them into the channel bottom), which can prevent redds from being constructed: the spawning fish essentially slap their tails against the channel bottom, which lifts unembedded gravels, removes some of the fine sediment, and leaves the cleaner gravel in a pile. Embedded gravels do not generally lift easily, which prevents spawning fish from biulding their nests, or redds, to lay eggs.

In addition, the total sediment load to the Ten Mile River and its tributaries is too high. Consistently high influxes of sediment can result in large changes in aquatic habitat: lower water depths, which decreases the amount of protective shelter for the fish and potentially can increase temperatures; decreased numbers and depths of pools, which become filled with sediment; decreased variety in the types of pools, such as those formed by large woody debris ("LWD"), which provide essential shelter for coho. Decreased availability of large woody debris in the stream from timber harvest activity (i.e., removing it from streamside areas) can also decrease shelter for fish directly, and can indirectly result in decreased pool habitat, since the LWD also provides a geomorphic function of sediment metering in the stream. Many of these factors interact with sediment loading to provide a crucial influence on the water quality of the stream. (Mangelsdorf and Clyde 2000).

While some sediment load in the stream is natural, much of the excess sediment is directly and indirectly caused by management activities. For example, timber harvest activities can result in excess sediment loads in the stream as a result of road construction and use (sediment discharged into the basin from road crossing failures, surface erosion and deposition, and landsliding associated with road location and construction) as well as the actual harvesting of timber (which causes ground disturbance and surface erosion or could trigger landslides and other ground failures that deliver directly to the stream).

SALMONID DISTRIBUTION AND ABUNDANCE

Brown et al. (1994, in Mangelsdorf and Clyde 2000) report that coho salmon previously occurred in as many as 582 California streams from the Smith River near the Oregon border to the San Lorenzo River on the central coast. There are now probably less than 5,000 native coho salmon spawning in California each year, many in populations of less than 100 individuals. Coho populations today are probably less than 6% of what they were in the 1940s, and there has been at least a 70% decline since the 1960s. Brown et al. (1994 in Mangelsdorf and Clyde 2000) conclude that the reasons for the decline of coho salmon in California include: stream alterations brought about by poor land-use practices and by the effects of periodic floods and drought, the breakdown of genetic integrity of native stocks, introduced diseases, over-harvest, and climatic change. Many factors may have contributed to the decline in salmonid populations, but this TMDL focuses on impacts to freshwater habitat from an overabundance of sediment in the basin.

In the early 1960's, the Ten Mile River was estimated to have a coho run of 6,000 fish, according to the California Wildlife Plan, published by the Fish and Game Commission in 1965 (Mangelsdorf and Clyde 2000). The California Wildlife Plan also noted that fishery habitat conditions in the Ten Mile River were severely degraded by logging activity and associated with an over-abundance of sediment.

Mangelsdorf and Clyde (2000) assessed aquatic conditions in the Ten Mile watershed relative to salmonid populations. This discussion is largely abstracted from that report. In conducting their assessment, they examined a wide variety of information sources, including: spawning surveys, outmigration studies, presence/absence surveys, electrofishing surveys, population estimates, habitat inventories, fine sediment data and temperature data. Relative to other basins in the Mendocino Coast, there is a considerable quantity of data available, some of it stretching over a several-year period. The data are primarily helpful in describing qualitative relationships between coho presence and habitat characteristics such as pool frequency and type, large woody debris-formed habitat frequency, and weekly average stream temperature. These relationships are also discussed in Chapter III.

Coho Population

Salmonid abundance has declined dramatically throughout the Mendocino Coast Hydrologic Unit. In the Ten Mile River watershed, coho populations have declined sharply during the past 3-4 decades. Available information indicates that chinook have also declined since their re-introduction to the watershed beginning in 1979, although the native population may have been extirpated prior to the 1950s, since chinook apparently were present in the basin in the early part of the century but were not observed naturally by mid-century (Shapavolov 1948, in Mangelsdorf and Clyde 2000). The steelhead trout population, however, has been fairly stable and may be now surpassing the population numbers identified in the 1960s. Accordingly, this assessment focuses primarily on coho.

The California Department of Fish and Game's unpublished records indicate that coho were planted in the Ten Mile River dating back as far as 1955. The effort to restore this run by artificial propagation appears to have been unsuccessful. The Oregon coho stocks planted in the Ten Mile River basin may have been inappropriate to this watershed and habitat problems and the limitations that exist may have contributed as well (Maahs, 1994 in Mangelsdorf and Clyde 2000).

In an assessment of coho stocks for the Central California Coast ESU (Ecologically Significant Unit) population of coho salmon, Weitkamp et al. (1995 in Mangelsdorf and Clyde 2000) estimate, using data from Brown et al. (1994, in Mangelsdorf and Clyde 2000), that the recent (1980s) coho salmon spawner abundance in Mendocino County includes approximately 160 presumed native coho salmon in the Ten Mile River, which Weitkamp et al. (1995, in Mangelsdorf and Clyde 2000) defined as "lacking a history of supplementation within non-native stocks." Although the Ten Mile River basin was supplemented with Oregon coho stocks (and possibly other sources, though they are not documented) beginning in the mid 1950s and continuing almost without a break through the mid 1990s, other factors such as genetic analysis and run timing point to the remaining stock being native, as opposed to simply naturalized (G. Bryant, pers. comm., 2000). Still, Higgins et al. (1992, in Mangelsdorf and Clyde 2000), as cited by NMFS (1995, in Mangelsdorf and Clyde 2000), characterizes the coho salmon run in the Ten Mile River watershed as one of "special concern."

The most recent estimates of the coho population, from 1989 to 1996, indicate a population range of 14-351 fish, with the highest population estimates in the 1995-96 season. (Maahs and Gilleard 1994, Maahs 1995-96, Maahs 1997a, in Mangelsdorf and Clyde 2000). These fish have been found in the Little North Fork Ten Mile River, Clark Fork Ten Mile River, Bear Haven Creek, South Fork Ten Mile River, Smith Creek, Campbell Creek, and Churchman Creek. The spawning survey data indicate that the Little North Fork is the best coho stream in the basin (J. Dillon, pers. comm., 2000), with Bear Haven Creek and South Fork Ten Mile River also good locations for spawning coho.

OTHER FACTORS RELATED TO SEDIMENT PRODUCTION AND HABITAT CONDITIONS

Gravel mining

Although gravel mining is another management activity in the basin, it does not appear to have contributed significantly to the sediment problems. There is no record of gravel mining impacts in the basin. Currently, Watkins Sand & Gravel is permitted by Mendocino County to remove up to 2,500 cubic yards of gravel per year from several sites in the South Fork of the Ten Mile River. Watkins and Baxman Gravel Company are both permitted to mine gravel from hillside quarries. Two earlier gravel mining operations in the basin prior to these permitted operations were unpermitted, and no record of their location, size or impact has been found.

Stream Improvement Activities

Some efforts have been made at improving water quality and aquatic habitat conditions for support of salmon in the basin. From 1991-92, the Center for Education and Manpower Resources, Inc. (1993a, 1993b, 1993c, 1995a, and 1995b, in Mangelsdorf and Clyde 2000) conducted stream restoration work for G-P, installing habitat structures (e.g., logs intended to induce pool scour or to provide cover) and removing or modifying barriers to fish migration in the North Fork, Middle Fork, South Fork, Redwood Creek, and North Fork Redwood Creek. G-P estimates that 6.83 km (4.24 mi) of stream were made accessible to salmonids as a result of barrier modifications (Ambrose, et al., 1996).

G-P has also conducted stream restoration and hillslope work of their own, with the intention of reducing sediment delivery and improving salmonid habitat (Ambrose et al., 1996, Ambrose and Hines, 1997, in Mangelsdorf and Clyde 2000). G-P uses a substrate composition target of 20% fines (<0.85 mm) as the basis for identifying locations requiring sediment-related corrective action. The North Fork Planning Watershed was targeted for corrective action due to the number of sites in which fines exceeded this target, but some work was also conducted throughout the basin, including:

- Approximately 117 km (73 miles) of road were rocked from 1993-1997
- Additional installation of waterbars to direct runoff to the hillslope, mulching and silt barriers to filter sediment from water.
- Replacement of an old failing bridge.
- Installation of new and upgraded culverts and other in-stream crossing structures, and removal of other fish migration barriers.
- In the North Fork Planning Watershed, 3 dirt bridges were replaced.
- Rip-rap was placed at the toes of three stream bank erosion sites near the main haul road in the North Fork Ten Mile River.
- Vegetation was planted along the stream banks of newly constructed bridges and crossings.

G-P's efforts at restoration have probably improved habitat conditions for salmonids at certain locations; however, this alone has not been adequate to alleviate the excessive stream-delivered sediment that has resulted in not meeting water quality standards. EPA concludes that reducing the overall sediment loading rate, particularly fine sediment, is needed to facilitate achievement of water quality standards in the basin, although continued stream improvement activities will probably hasten the recovery process.

CHAPTER III
WATER QUALITY TARGETS

Water quality targets interpret narrative water quality standards, provide indicators of watershed health and achievement of water quality standards, and represent habitat conditions adequate for the success of salmonids. The water quality standards of concern are narrative standards for suspended material, settleable material, sediment, and turbidity. In addition, two prohibitions on sediment discharge from logging, construction and related activities further define water quality-related requirements. These targets allow resource managers and others to assess the degree to which positive changes are occurring in the watershed that, over time, will result in a greater abundance and quality of habitat necessary to support the cold water fishery.

A TMDL is intended to result in pollution reductions necessary to attain water quality suitable to support beneficial uses. To this end, it is important to monitor in-stream parameters to determine if water quality is in fact improving over time. EPA anticipates that the Regional Water Board will coordinate with landowners in the basin to conduct monitoring in conjunction with its implementation of this TMDL.

Many in-stream parameters, identified in the scientific literature as critical to coho success, vary as a result of both natural and anthropogenic changes. Furthermore, instream targets alone would not be adequate to ensure achievement of adequate water quality, as sediment-producing changes in hillslopes and watershed conditions could take years to decades to be reflected in stream conditions, when it might be too late to correct the problem. Thus, hillslope targets are included to define watershed conditions associated with watersheds that function well and do not deliver sediment to streams in quantities that result in impairment. These are needed to ensure achievement of water quality standards and assist in assessment of sediment control. Thus, both in-stream and hillslope targets are identified for the Ten Mile River watershed.

Although the Ten Mile River was included on the 303(d) list for sediment and its threat to water quality and the salmonid fishery, many factors indirectly affected by sediment also affect salmonid populations. Regional Water Board staff evaluated existing sediment, habitat and temperature data to determine how and where sediment was limiting to the beneficial use, and how other factors might interact with sediment factors. To do this, staff compared data with coho population data and criteria cited in Flosi et al. (1998, in Mangelsdorf and Clyde 2000) and Mangelsdorf and Lundborg, 1998 (in Mangelsdorf and Clyde 2000). This site-specific data as well as literature sources were used to identify indicators and targets.

Summary

Table 1 (p. 6) lists water quality targets. Targets are intended to be evaluated on a weight-of-evidence approach. In other words, the water body can still be considered to be meeting its targets if the majority of targets, and particularly those that are critical to beneficial uses, such as coho, are met. Targets have been developed for the following, which are described in more detail in the next sections:

Instream Targets

- Substrate composition: ≤ 14% fines <0.85 mm (mean wet volume)
- V* ≤ 0.21
- thalweg profile (increasing variation of elevation around the mean slope)

Habitat Characteristics Targets: improving trends in of inventory reaches where:

- pool length ≥ 44%
- scour pool length ≥ 27% and area ≥ 32%
- backwater pools length ≥ 2%
- large woody debris-formed habitat length ≥ 18%
- large woody debris-formed habitat length ≥ 19%
- gravel embeddedness at pool tail-outs ≤ 25%
- seven-day running averages of maximum daily temperatures is ≤ 16.8EC

Hillslope Targets

- number of stream crossings with diversion or significant failure potential (≤1%, estimated for a 100-year or smaller storm)
- hydrologic connectivity (decreasing length)
- disturbed areas (decrease)
- activity in unstable areas (none)
- annual pre-winter inspection, maintenance and correction of roads
- roads location, surfacing, and side casting.

INSTREAM TARGETS

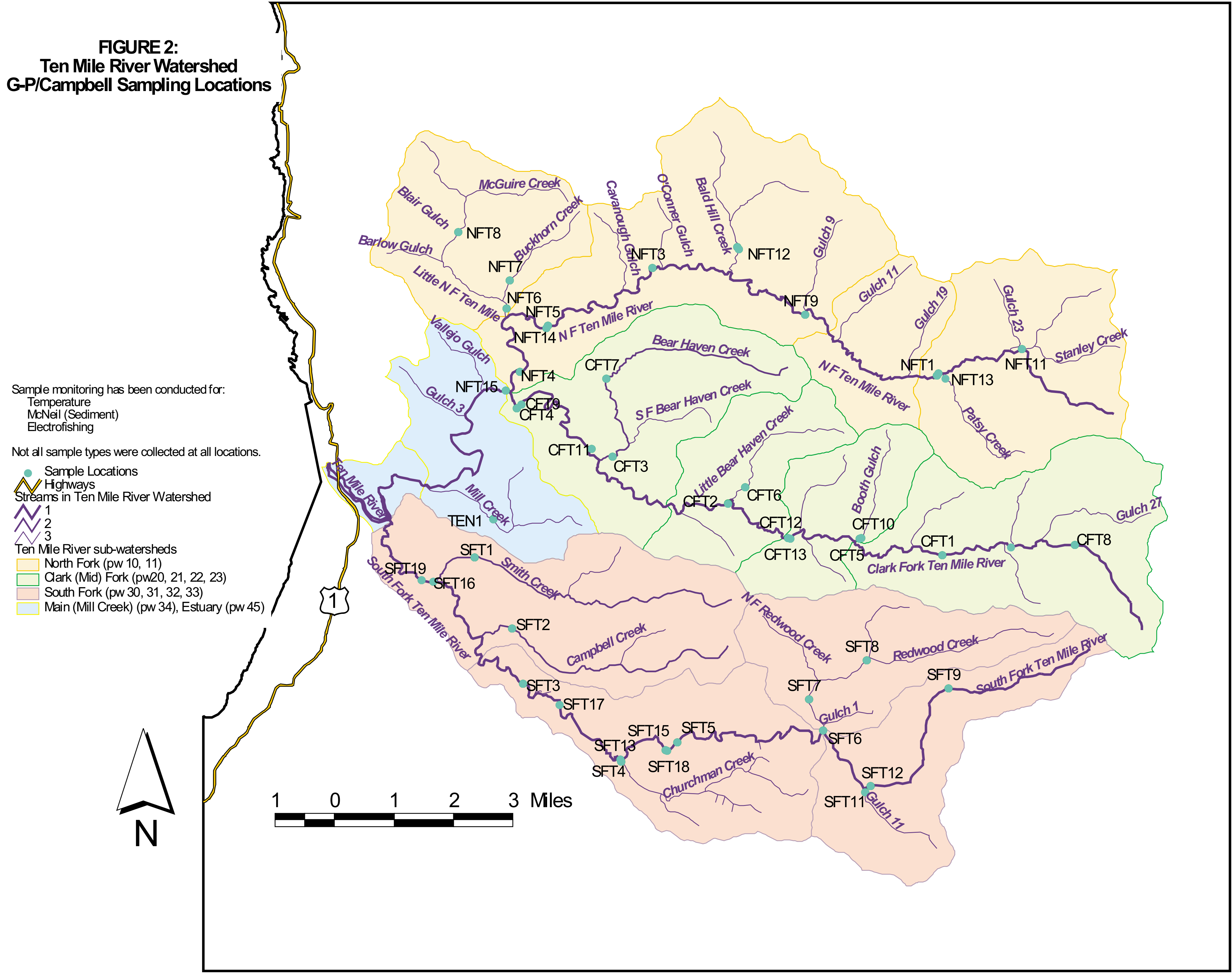
Sediment Substrate Composition

Target: ≤ 14% fines <0.85 mm (mean wet volume)

The indicator and target selected to represent adequate spawning, incubation and emergence conditions relative to substrate composition is as follows: channel substrate samples should contain less than or equal to 14% fine sediment (by mean wet volume) in the <0.85mm size class (Mangelsdorf and Lundborg, 1998, in Mangelsdorf and Clyde 2000). Excess fine sediment can prevent adequate water flow through salmon redds, or nests, which is critical for maintaining adequate oxygen levels and removing metabolic wastes. Deposits of these finer sediments can also prevent the hatching fry from emerging from the redds, resulting in smothering.

Since 1993, G-P has sampled substrate composition of streambed gravels at the pool/riffle juncture of locations throughout the Ten Mile River watershed, using a McNeil sampler and following the protocol recommended by Valentine (1995, in Mangelsdorf and Clyde 2000). G-P established 23 instream substrate sampling stations (see Figure 2): one in the Lower Ten Mile Planning Watershed, seven in the North Fork Planning Watershed, six in the Middle Fork Planning Watershed and nine in the South Fork Planning Watershed. Sampling was conducted during low flow conditions of late summer or early fall.

FIGURE 2:
Ten Mile River Watershed
G-P/Campbell Sampling Locations



None of the three main forks of the Ten Mile River watershed meets the target value on an average basis (see Table 2). All but three of the stations (Upper South Fork, South Fork at Churchman, and Bald Hill Creek) have 5-year averages exceeding the target value. At one-quarter of the sample locations (TEN1, NFT7, NFT9, NFT10, CFT5, and SFT2), the average values over a five-year period are greater than 20% (representing values that are 50-70% higher than the target), which may significantly impair spawning success. Sampling sites are located throughout the watershed, but are found predominantly in the North Fork Planning Watershed. The high concentrations of fines may be most problematic in locations where spawning activity is critical. For example, Bear Haven Creek, Campbell Creek, Smith Creek, South Fork Ten Mile, and Little Bear Haven Creek appear to be important spawning areas. Spawning has also been observed in Patsy Creek, and Middle Fork Ten Mile. Unfortunately, spawning observation sites and sediment sample locations are not necessarily correlated.

G-P (Hines, 2000, in Mangelsdorf and Clyde 2000) conducted a trend analysis and found trends at 10 of the 23 sampling locations (NFT2, NFT5, NFT6, NFT9, NFT10, CFT4, CFT6, SFT1, SFT2, and SFT13 in Table 2). All of these locations are stable or decreasing in fine sediment concentrations, except SFT1, which is increasing. The increase at this site may reflect the recent intensive harvest activity. Three sampling locations in the Middle Fork Planning Watershed and one in the South Fork Planning Watershed (CFT1, CFT3, CFT5, and SFT6) appear to have increasing trends, though the data are not statistically conclusive (Hines 2000, in Mangelsdorf and Clyde 2000) .

Hines (2000, in Mangelsdorf and Clyde 2000) suggests, from his trend analysis, that fines concentration in the North Fork Planning Watershed are generally decreasing while those in the South Fork and Middle Fork Planning Watershed, while still elevated, appear relatively stable from 1993-1999. Hines hypothesizes that the previous era of intensive logging happened more recently in the North Fork than elsewhere in the basin, which would have provided adequate time for the tributary areas to recover. Hines further suggests that monitoring of sediment data in the other planning watersheds may have begun too late to catch their previous downward trends, and are now simply measuring post-disturbance stabilization.

Five-year averages in the South Fork Planning Watershed are generally lower than the other planning watersheds. This Planning Watershed was also harvested more intensively than the other planning watersheds over the past decade. It is possible that the “signal” from the current disturbance has not yet reached the stream, or it may also be that the broader valleys and generally greater distances between the roads and the streams could effectively buffer the impacts from the erosion, or it could be a combination of effects that result in these currently lower substrate values. Given the intensive second growth harvesting in the South Fork Planning Watershed over the past decade, however, future increases in the delivery of sediment to important spawning and rearing reaches are of concern.

It is important to note that increased timber harvest is likely in the North Fork and Middle Fork Planning Watersheds in the near future, given the historical and recent trends in the South Fork, and given that the growth in the North and Middle Fork Planning Watersheds may now be at harvestable age. Thus, it is even more important to protect the already strained water quality and

Table 2: Substrate Composition

Location				**Percent fines less than 0.85 mm**					
		1993	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**5-year mean**
LOWER TEN MILE PW									
TEN1	Mill Creek			**22.6**	**23.7**	**17.4**	**19.1**	**20.7**	**20.7**
NORTH FORK PW Average:		**19.8**	**20.5**	**22.3**	**18.4**	**18.3**	**18.7**	**15.3**	**19.4**
NFT1	NFT at Patsy Creek			20.7	18.4	14.7	23.3	14.4	**18.3**
NFT2	Bald Hill Creek			16.2	13.7	14.2	12.6	10.7	**13.5**
NFT5	NFT at Camp 5			20.8	15.5	16.5	16.3	16.6	**17.1**
NFT6	Lower Little North Fork			18.9	17.3	17.1	17.6	11.2	**16.4**
NFT7	Buckhorn Creek			23.7	16.2	20.8	22.5	19.9	**20.6**
NFT9	NFT at Gulch 9			26.5	20.7	23.9	19.1	19.2	**21.9**
NFT10	Patsy Creek			28.8	27.1	21.7	19.3	21.8	**23.7**
MIDDLE FORK PW Average:		**16.7**	**18.3**	**19.1**	**17.4**	**17.6**	**16.8**	**18.5**	**17.8**
CFT1	CFT at Reynold's Gulch			17.0	15.1	20.0	19.8	21.1	**18.6**
CFT2	CFT at Little Bear Haven Creek			16.5	19.7	14.2	8.8	14.4	**14.7**
CFT3	Lower Bear Haven Creek			18.6	12.9	11.4	23.2	18.1	**16.8**
CFT4	Lower CFT			20.9	16.9	17.2	15.6	18.5	**17.8**
CFT5	Booth Gulch			22.2	22.5	26.7	20.6	22.9	**23.0**
CFT6	Little Bear Haven Creek			19.6	17.4	16.2	12.5	16.1	**16.4**
SOUTH FORK PW Average:		**17.0**	**16.5**	**17.0**	**17.3**	**16.5**	**17.6**	**15.4**	**16.6**
SFT1	Smith Creek			14.7	17.2	16.6	21.1	19.1	**17.7**
SFT2	Campbell Creek			23.1	22.8	22.0	18.7	22.5	**21.8**
SFT3	SFT at Brower's Gulch			16.5	21.8	18.4	16.1	13.5	**17.3**
SFT4	Churchman Creek			15.8	19.2	12.4	13.6	16.4	**15.5**
SFT5	SFT at Buck Mathew's Gulch			16.6	16.9	12.9	28.2	16.1	**18.1**
SFT6	SFT at Camp 28			18.4	16.2	15.4	20.3	16.9	**17.4**
SFT8	Upper Redwood Creek			19.5	16.0	22.7	17.1	15.2	**18.1**
SFT9	Upper SFT			14.0	13.2	13.6	12.0	9.9	**12.5**
SFT13	SFT at Churchman Creek			14.2	12.4	14.5	11.2	9.2	**12.3**

Note: 1993 and 1994 data were reported only as averages.
Shaded areas show where targets are currently met.
Source: Ambrose et al. (1996, in Mangelsdorf and Clyde 2000), Ambrose and Hines (1997, 1998, in Mangelsdorf and Clyde 2000)

fishery from further degradation potential. Furthermore, the most critical habitat areas for coho (e.g., Little North Fork and Bear Haven Creek), which may serve as local refugia, are located in these planning watersheds. Fine sediment levels in these tributaries are already somewhat elevated, and further degradation could cause significant damage to the coho fishery.

The substrate composition target is the most directly descriptive and easily repeatable indicator of target conditions. The fact that most of the tributaries are very rich in fine sediment suggests one reason why the salmon population is depressed. EPA anticipates that the Regional Water Board will continue to coordinate with landowners to continue data collection on a regular (i.e., annual) basis, and possibly to expand data collection to other areas where timber harvest may take place in the future or where potential for salmonid habitat exists.

V*

Target: ≤ 0.21

V* is a measure of the fraction of a pool's volume that is filled by fine sediment and represents the in-channel supply of mobile bedload sediment (Lisle and Hilton, 1992, in Mangelsdorf and Clyde 2000). It also reflects the quality of pool habitat, since coho particularly prefer cool, deep pools, which offer protection from predators, a food source and resting location. A study conducted on over 60 streams representing different levels of disturbance in the North Coast found that a mean V* value of ≤ 0.21 (21%) represented good stream conditions (Knopp, 1993, in Mangelsdorf and Clyde 2000). This is the target value for this indicator. This target is included in this TMDL as a potential indication of beneficial use support because the data available in the Ten Mile River watershed indicate that pool depth and frequency are factors limiting success of salmonids throughout the basin. This is directly related to sediment transport and deposition, and V* is a relatively easy way to measure sediment in pools. Knopp (1993, in Mangelsdorf and Clyde 2000) collected V* measurements from sites in both the South Fork Ten Mile River and Churchman Creek. Both sites were identified as representing highly disturbed watersheds. The V* measurement was 0.27 in the South Fork, and 0.73 in Churchman Creek (A. Mangelsdorf, pers. comm. 2000). While there were only two data points, they indicate that significant reductions in sediment loading may be required in individual subwatersheds within the Ten Mile River basin. EPA recommends that this indicator will be monitored regularly.

Thalweg Profile

Target: increasing variation of elevation around the mean slope

Fish need a variety of habitat types to be available in relatively close proximity. For example, eggs are laid at the downstream end of pools (the tail-out of the pool); the young fry that emerge from the gravels then require slow-moving water (the pools themselves) with an abundant supply of food. Fish at various life stages and times of year may rest in pools, darting into riffle sections (faster moving water) to feed where insects are abundant. However, they may also need to make a quick escape from predators, for example, into a deep pool, an overhanging bank, under a log, etc. In short, variety and complexity in habitat is more likely to serve the needs of the fish at different times in the year or in its life cycle.

Measuring the thalweg profile and the variation of the elevation around the mean slope is one indicator of that habitat complexity. The thalweg profile is a survey of elevations along the stream length, parallel to stream flow, of the deepest point in the stream (the thalweg). As a stream descends from its headwaters to its mouth, the thalweg profile slope also descends. When the elevations of the thalweg at locations along the descent are plotted against stream length, the profile would appear as a jagged but descending line. The line would be relatively flat at pool areas, and would descend sharply at cascades. An overall trend in the descending line could also be defined, as the mean of the profile slope. As the number of pieces and volume of large woody debris increases as well as the number and depth of pools, the thalweg profile develops more pronounced variation around the mean profile slope, which indicates better habitat conditions.

The inadequate availability (distribution and quantity) of large woody debris and deep pools appear to be two of the main factors limiting the success of salmonids in the Ten Mile River watershed (Mangelsdorf and Clyde 2000). The techniques proposed by the Forest, Fish and Farm Committee at its 1999 Workshop ("Using Stream Geomorphic Characteristics as a Long-term Monitoring Tool to Assess Watershed Function," cited in Mangelsdorf and Clyde 2000) include the measurement of the channel thalweg to determine the variation around the mean thalweg profile slope. Not enough is yet known about channel structure to establish a specific number that reflects a satisfactory degree of variation. Therefore, the numeric target is simply an increasing trend in variation from the mean thalweg profile slope.

EPA anticipates that the Regional Water Board would coordinate with landowners to include this parameter in a monitoring plan. Selected "response" reaches (generally lower gradient stream reaches whose profiles tend to change in response to sediment movement through the system) could be monitored infrequently, e.g., every 5-10 years and/or in the summer season following large floods.

Aquatic Insect Production

Target: improving trends in EPT, % dominant taxa and species richness indices

Benthic macroinvertebrate populations are greatly influenced by water quality and are often adversely affected by excess fine sediment. Ambrose et al. (1996, in Bybee 2000) completed a 1995 macro-invertebrate study that could serve as a baseline. This TMDL recommends several indices be calculated, following the Califonia Department of Fish and Game Water pollution Control laboratory stream bioassessment procedures (1996, in Mangelsdorf and Clyde 2000):

1) EPT Index, which is the number of species within the orders Ephemeroptera, Plecopter, and Trichoptera (EPT), more commonly known as mayflies, stoneflies and caddisflies. These organisms require higher levels of water quality and respond rapidly to improving or degrading conditions (EPA 1999, Bjornn et al. 1997, in Bybee 2000).

2) Percent Dominant Taxa: Calculated by dividing the number of organisms in the most abundant taxa by the toal number of organisms in the sample. Collections dominated by one taxa generally represent a disturbed ecosystem.

3) Richness Index: The total number of taxa represented in the sample. Higher diversity can indicate better water quality.

Target conditions are expressed as improving trends, since appropriate thresholds have not been developed.

HABITAT CHARACTERISTICS TARGETS

Considering that the maximum population estimate in the most recent decade has been 351 fish, it is reasonable to assume that the coho population in the basin is not thriving. Although factors outside the watershed may be contributing to the decline, excess sediment in the basin is clearly a factor, and probably has also caused the habitat to decline.

Hines and Ambrose (1998, in Mangelsdorf and Clyde 2000) analyzed measurements of juvenile coho habitat in individual tributaries and concluded that the data only reliably indicated the presence of coho, not the sustainability of the populations or the habitat. Ambrose et al.(1996, in Mangelsdorf and Clyde 2000) reported the results of habitat inventories in 109 miles of stream in the basin. These inventories consisted of walking lengths of stream and identifying a set list of descriptive features for that reach. Mangelsdorf and Clyde (2000) identified several habitat indicators for which the mean measurement values correlated with coho presence in at least 80% of the cases. From that group, EPA selected indicators that were most appropriate to define water quality conditions and to conduct monitoring. These indicators were related to the distribution of scour pools and LWD-formed habitat and areas where temperature conditions were below a 16.8EC threshold (see explanation below). In response to public comments concerning habitat indicators, EPA added two other pool descriptors (total pool distribution and backwater pool distribution) and embeddedness.

Although the original habitat characteristic indicators did appear to correlate strongly with coho presence, it is important to note that they did not necessarily correlate with a sustainable population or habitat features. For most indicators, it is not generally known what target level would represent achievement of water quality standards. Thus, because the Little North Fork is the best coho stream, and may represent sustainable conditions, the values for those habitat indicators in that tributary are selected as targets. For the habitat characteristics indicators that were added, this same relationship holds true for the two additional pools indicators; however, values for embeddedness throughout the basin are poor, so the target is obtained from literature recommendations. All indicators are essentially defined as improving trends toward the value. For temperature, Ambrose et al. (1998, in Mangelsdorf and Clyde 2000) concluded that coho presence correlated well with monitoring locations where the 7-day running averages of daily maximum temperatures generally does not exceed 16.8EC also

Target values for those indicators are listed in Table 3. These indicators have both direct and indirect relationships to sediment. These indicators and target values are included because they were developed using site-specific data, and provide important information on the multiple factors affecting water quality conditions that support coho salmon.

It is important to emphasize that while these indicators were developed using local, site-specific data, coho presence was all that was required to assign an indicator as “meeting targets,” and target values are somewhat qualitative and are locally relative. This is why the indicator characteristics are taken from the best coho stream in the basin, and why the target value is generally for improving trends. Again, this does not definitively determine what would be suitable characteristics to identify a sustainable salmonid population. Due to this factor, as well as the primarily indirect nature of their relationship to sediment and the limitations of using habitat inventories as a monitoring tool, this group of indicators are intended primarily as qualitative descriptors, with monitoring repeated only every 5 to 10 years (hopefully incorporating at least one large storm), or new locations monitored added to the database. Furthermore, the targets are set as increasing trends. These indicators are intended to facilitate a broad-scale view of the basin and the influences on water quality conditions and salmonid populations.

Table 3: Habitat Characteristic Target Values

Habitat characteristics	**Target Value for Coho Streams**
% of habitat inventory reach length in pools	increasing no. of locations $ 44%
% of habitat inventory reach length in scour pools	increasing no. of locations $27%
% of habitat inventory reach area in scour pools	increasing no. of locations $32%
% of habitat inventory reach length in backwater pools	increasing no. of locations $2%
% of habitat inventory reach length formed by large woody debris	increasing no. of locations $18%
% of habitat inventory reach area formed by large woody debris	increasing no. of locations $19%
% embeddedness at pool tail-outs in habitat inventory reach	increasing no. of locations ˜25%
% of 7-day runing average of maximum daily temperatures < 16.8EC	increasing no. of locations

Table 4 lists the current values of the indicators for selected stream reaches. Shaded values indicate that targets are being met and shaded stream reaches indicate where coho are generally present. The habitat indicators and their current values in the sampled stream segments are discussed below.

Pool Distribution

Target: increasing inventory reaches where length ≥ 44%

Good coho streams generally contain > 40% of their habitat length in pool habitat types (Flosi et al. 1998). However, EPA has selected a more conservative target of 44%, which is derived from the Little North Fork values, consistent with the other habitat indicators. Frequent pools are important for providing food and shelter, and may also serve as localized refugia. In general, pools make up more than 40% of the habitat by length in only three surveyed reaches: mainstem North Fork, Little North Fork, and mainstem Middle Fork.

Lateral Scour Pools

Target: increasing inventory reaches where length ≥ 27% and area ≥ 32%

Flosi et al. (1998, in Mangelsdorf and Clyde 2000) describe lateral scour pools (pools formed near either bank, which tend to scour out a deeper pool area along the edge) as the most widely used habitat. Of the little pool habitat that does exist throughout the rest of the watershed, lateral scour

Table 4: Current Values of Habitat Characteristics Indicators

Stream	% Pool length	% Scour pool length	% Scour pools area	% BW pool length	% LWD-formed habitat length	% LWD-formed habitat area	% of WMT ≤ 16.8 EC	% Pool tail-outs ≤ 25% embedded
Lower Ten Mile River								
Mill Creek	20	8	10	0.0	4	3	100	0
North Fork Ten Mile River								
North Fork Ten Mile River	47	28	39	0.4	8	9	35	2
Little North Fork Ten Mile River	44	27	32	1.8	18	19	100	0
Blair Gulch	19	5	12	0.2	1	2	NS	0
Barlow Gulch	11	3	5	0.0	1	2	NS	0
Buckhorn Creek	11	3	6	0.2	0	0	100	0
McGuire Creek	16	6	19	0.1	2	3	NS	0
Cavanough Gulch	7	4	7	0.7	1	2	NS	4
O'Connor Gulch	12	8	7	0.0	0	0	NS	0
Bald Hill Creek	26	14	19	0.3	5	7	95	12
Gulch 8	23	5	1	0.5	1	1	NS	3
Gulch 11	8	6	7	0.0	0	0	NS	0
Gulch 19	18	9	15	1.4	0	0	NS	5
Patsy Creek	19	7	9	0.0	2	3	NS	11
Gulch 23	9	3	9	0.0	0	0	NS	0
Middle Fork Ten Mile River								
Clark Fork Ten Mile River	44	26	26	0.4	7	9	65	2
Bear Haven Creek	33	21	32	0.3	12	19	100	0
Little Bear Haven Creek	33	14	12	0.1	2	2	100	0
Booth Gulch	13	5	10	0.1	0	0	100	0
Gulch 27	22	8	9	0.0	3	4	NS	0
South Fork Ten Mile River								
South Fork Ten Mile River	31	22	23	0.0	9	10	65	0
Smith Creek	21	17	23	0.0	11	16	100	0
Campbell Creek	25	19	25	0.0	12	16	75	0
Churchman Creek	8	6	12	0.2	4	9	100	0
Redwood Creek	19	11	17	0.4	5	8	80	0

Note: represents the % of the inventoried reach length or area that contained the given habitat type (i.e., lateral scour pool or LWD-formed habitat. For temperature, it is the % of time below the target value. WMT is the 7-day running average weekly maximum temperature
Shaded stream reaches indicate where coho are generally present; shaded values indicate that targets are being met.

pools are the predominant type in Mill Creek, mainstem North Fork, Little North Fork, Cavanough Gulch, Bald Hill Creek, Gulch 11, Gulch 19, mainstem Clark Fork, Bear haven Creek, Mainstem South Fork, Smith Creek, Campbell Creek, Churchman Creek and Redwood Creek. Of those, coho have been observed only in North Fork, Little North Fork, Clark Fork, Bear Haven Creek, South Fork, Smith and Campbell Creeks. The Little North Fork, North fork and Clark Fork are the only stream study reaches that currently meet the target values for scour pool length and area.

Backwater Pools

Target: increasing inventory reaches where length ≥ 2%

Backwater pools are used by salmonids as overwintering habitat (Flosi et al. 1998, in Mangelsdorf and Clyde 2000). In particular, they provide shelter from high storm flows. Backwater pools are not prevalent anywhere in the basin, and are non-existent in several reaches. Even in the Little North Fork, they comprise only two percent of all habitat types, which is more than any other reaches. As a proportion of pool lengths, backwater pools have relatively higher values in Cavanough Gulch, Gulch 19 and Little Bear Haven Creek (Mangelsdorf and Clyde 2000).

Habitat Formed by Large Woody Debris (LWD)

Target: increasing inventory reaches where length ≥ 18% and area ≥ 19%

California coastal streams are especially dependent on the presence of large woody debris to provide ecological functions, such as sediment metering, sediment grading, pool formation, and shelter. Large pieces of woody debris in streams influence the physical form of the channel, the movement of sediment, the retention of organic matter and the composition of the biological community (Bilby and Ward 1989, in Mangelsdorf and Clyde 2000). Debris can be instrumental in forming and stabilizing gravel bars (Bilby and Ward 1989, Lisle 1986, in Mangelsdorf and Clyde 2000) or in accumulating fine sediment (Zimmerman et al. 1967, Megahan 1982, in Mangelsdorf and Clyde 2000). Debris also can form pools by directing or concentrating flow in the stream in such a way that the bank or bed is scoured or by impounding water upstream from the obstruction (Lisle and Kelsey 1982, in Mangelsdorf and Clyde 2000). Large woody debris plays a more significant role in routing sediment in small streams than in large ones (Bilby and Ward 1989, in Mangelsdorf and Clyde 2000).

LWD is particularly important for pool habitats. Ambrose et al. (1996, in Mangelsdorf and Clyde 2000) conclude that the South Fork Planning Watershed has the highest percentage of pools formed by large woody debris (42%), followed by the Middle Fork (19%) and North Fork (18%). A possible association was also found between coho sites and the occurrence of pools formed by LWD: coho were found only in creeks where there was a large percentage of LWD. This suggests that a low percentage of LWD-formed pools could adversely affect juvenile coho populations. The four creeks where coho were found had over 30% of their pools formed by LWD.

Embeddedness

Target: increasing pool tail-outs ≤ 25%

Throughout the Ten Mile River basin, gravels that are otherwise available for spawning are apparently so heavily embedded (i.e., fine sediment surrounds and packs in against the gravels, which effectively cements them into the channel bottom) that they may impede or prevent spawning. When constructing its redd (generally at a pool tail-out, or the downstream end of the pool), the spawning fish essentially slaps its tail against the channel bottom, which lifts unembedded gravels, removes some of the fine sediment, and leaves cleaner and more permeable gravel, more suited to nurturing of the eggs, in a pile. Embedded gravels do not generally lift easily, which prevents spawning fish from building their nests, or redds, to lay eggs. Flosi et al. (1998, in Mangelsdorf and Clyde 2000) indicate that gravels that are less than 25% embedded (i.e., fine sediment surrounds and effectively cements the gravel into the bed) are preferred for spawning. There are no locations in the basin where gravels are less than 25% embedded. In fact, most locations are greater than 75% embedded. This is true even of the Little North Fork. Thus, the target that is chosen is for increasing locations where pool tail-outs have the predominance of gravels that are less than 25% embedded. Because embeddedness is so high in the Little North Fork, it is not appropriate to use the value at that location.

Temperature conditions

Target: increasing locations where seven-day running average of maximum daily temperatures ≤16.8EC
Stream temperatures are influenced by many factors, among them water depth, which can decrease with excess sediment. While the Ten Mile River is not listed by the Regional Water Board for temperature, Regional Water Board staff nonetheless analyzed the temperature data that G-P provided, and a summary of the analysis is included here because of the indirect relationship with sediment, and because it is one of the factors that clearly affects coho distribution.

Ambrose and Hines (1998, in Mangelsdorf and Clyde 2000) conclude that a seven-day running average of daily maximum temperatures of 16.8EC predicts whether or not coho will be present in a stream. G-P collected temperature data from 36 pools and 9 riffles. 31% of the pools sampled in the North Fork Planning Watershed, 45% of the pools sampled in the Middle Fork Planning Watershed, and 27% of the pools sampled in the South Fork Planning Watershed exhibit weekly average summer temperatures regularly below a 16.8EC MWAT. On average, 36% of the pools sampled in the basin as a whole exhibit suitable weekly average maximum summer temperatures.

HILLSLOPE TARGETS

The hillslope targets (Table 1, p. 6) are established to define watershed conditions needed to protect water quality. Sediment impairment in the Ten Mile River basin is influenced by episodic events. Linkages between hillslope sediment production and instream sediment detection are complicated by time lags from production to delivery, instream storage, and transport through the system. In limited areas, the linkages can be clarified somewhat. For example, where diversion of water from the road drainage system is possible, sediment can be carried from the road drainage and diverted into the stream. In addition, the crossing itself can fail, potentially delivering the volume of the crossing fill to the stream and possibly adding to this volume by triggering a debris flow. Measuring instream water and substrate conditions, for example, is simply an indirect measurement of an assumed cause-and-effect relationship which probably does not accurately reflect the source of the impairment; more importantly, it is an after-the-fact measurement of impairment, which may prevent adequate protection of the beneficial uses of water. In many cases, timely road inspection and maintenance can prevent many of the failures and associated sediment deliveries from occurring. Appropriate location, design, construction and maintenance of roads can frequently result in minimal sediment delivery. Likewise, some timber harvest activities can result in additional sediment delivery to streams, but appropriate practices can eliminate that delivery.

Moreover, these hillslope and road-related sediment production sources effectively represent potential or temporarily modified existing impairments. Measures of water conditions do not reflect this *existing* but temporarily "controlled" water quality impairment, which need only be triggered by a particular quantity and quality of precipitation and runoff. These indicators relate directly to the MIGR beneficial use, particularly in locations where sediment from failed crossings impair migration routes. They also relate indirectly to the COLD and SPAWN beneficial uses in association with additional sediment inputs that fill pools or provide excess fine sediments in spawning areas.

Hillslope targets supplement instream targets by providing measurable goals that are not subject to the variability of climatic conditions. Hillslope and road targets are also easier to measure and are more controllable, and have the advantage to landowners of being easier to carry out and evaluate than instream targets. In addition, including these targets will address the problem of instream indicators suggesting that conditions are good while the hillslopes are "loaded guns" of sediment to be delivered in the next large storm event, resulting in immediate consequences as well as potentially irreversible aquatic habitat degradation. Without addressing these hillslope sources, the cycle of degradation could potentially be repeated until some species of aquatic life could no longer recover.

Roads are the biggest source of controllable sediment delivery in the basin (see Chapter IV). Thus, in a system that may be slowly recovering from previous land management and storm-triggered sediment delivery, controlling the potential for future land management and storm-triggered sediment delivery will ensure that water quality standards are attained for the foreseeable future. In basins where sediment impairment does exist, reduction or elimination of hillslope delivery potential will facilitate recovery.

Roads disrupt the natural drainage pattern of the watercourse, and can become part of the drainage system if improperly designed or maintained. This can result in considerable sediment delivery directly to a stream channel. Many existing and potential road sediment deliveries can be corrected relatively easily, resulting in decreased sediment delivery. EPA's analysis indicates that in most cases it will be feasible continue use of well-constructed and well-maintained roads while protecting water courses fro the adverse effects of sediment. In many cases, lower road maintenance costs result as the roads are made to be "hydrologically maintenance free," retaining or re-establishing natural drainages and avoiding the potential for creation of diversion potential.

Hillslope targets are developed for management-related parameters identified in Chapter II (Problem Statement) that are important to the delivery of sediment to a watercourse. The stream crossing targets are intended to focus directly on road-related sediment delivery, particularly sediment delivery that is highly controllable. The hydrologic connectivity target is intended to focus on the problem of an expanded channel network associated with roads, particularly the accompanying issues of elevated sediment (such as scour) and flow. The disturbed area target is intended to focus on the problem of increased erosion and flow potential accompanying unvegetated and/or compacted soil surfaces. The unstable area target is intended to focus on the problem of the increased risk of erosion and sediment delivery that is likely from unstable areas.

The road inspection/maintenance target and road location, surfacing and side-casting targets also relate to direct deposits of sediment in the stream that can be avoided.

Stream Crossing with Diversion Potential and Stream Crossings with Significant Failure Potential

Target: ≤ 1% of all stream crossings, estimated for a 100-year or smaller flood

Most truck roads, skid roads, and railroad roads cross ephemeral or perennial streams. Stream crossing structures are built to capture the stream flow and safely convey it through, under, or around the roadbed. The California Forest Practice Rules require that: (1) the number of watercourse crossings be minimized; (2) crossing structures allow for unrestricted passage of fish, where fish are present; (3) crossings be constructed or maintained to prevent the diversion of stream overflow down the road; (4) crossings be constructed to accommodate a 50-year flood flow; and (5) trash racks be installed to prevent debris from reducing the flow capacity of the crossing structure.

There is no existing data in the Ten Mile River watershed regarding the current rate of stream diversions or stream crossing failures or the contributions of sediment to the watercourse from these processes. In other North Coast basins (e.g., Rolling Brook, a tributary of the Garcia River, and Redwood Creek in Redwood National Park), sediment from stream diversions and other sources associated with haul road and skid trail crossings have been estimated to contribute from 25-38% of the overall sediment budget. Thus, this sediment process is likely to be a significant component of the Ten Mile River watershed sediment budget as well.

Diversion potential is the potential for a road to divert water from its intended drainage system across or through the road fill thereby delivering road-related sediment to a watercourse. As described in the South Fork Trinity River TMDL (EPA, 1998), the potential delivery of sediment to a watercourse can be eliminated from almost all potential road diversions by identifying and correcting sites with diversion potential. Correction measures include eliminating inboard ditches, outsloping roads, and/or installing rolling dips at crossings. No more than 1% of potential road diversion sites are expected to be either physically impossible to correct or of such a nature that their correction would make the road unsafe for travel.

Stream crossing failures are generally related to undersized, poorly placed, plugged or partially plugged culverts. When a culvert fails, the sediment associated with the crossing is delivered directly into the watercourse. Indeed, in most crossing failures, the total sediment volume delivered is the volume of road fill associated with the crossing as well as sediment from collateral failures such as debris torrents that scour the channel and stream banks (EPA, 1998). The Forest Practices Act requires that road crossings be designed to pass a 50-year flood and be protected from damage by debris with trash racks. Given the large percentage of seasonal roads in the Ten Mile River watershed, however, maintenance of culverts and trash racks following storm events is likely to be irregular. The target, therefore, is being established based on the 100-year flood. No more than 1% of all culverts are expected to fail as a result of a 100-year flood or less, if all the culverts are properly sized, installed, and maintained. Only those crossings where modification would endanger travelers, or where there are other physical constraints, should fall within this 1%.

Hydrologic Connectivity

Target: decreasing length

Increased intensity, frequency and magnitude of flood flows are accompanied by increased suspended sediment discharge and can result in the destabilization of the stream channel. This can have a have a devastating effect on salmonid redds and growing embryos (Lisle, 1989, in Mangelsdorf and Clyde 2000). Hydrologic connectivity refers to the extent that the road drainage is connected to watercourses. The connectivity can be reduced by outsloping roads, creating road drainage that mimics natural drainage as much as possible, and other facotrs (M. Furniss, pers. comm. 1998, and Weaver and Hagans 1994, in EPA 2000).

The reduction of road densities and the reconstruction of roads to reduce the miles of inboard ditches, for example, can reduce the amount of water that is directly delivered to watercourses, including any associated sediment load. Current research appears insufficient to identify a specific number of miles of road or road with inboard ditch that would adequately prevent excessive stream flows and sediment discharge. Accordingly, the target calls for a reduction in the hydrologic connectivity of roads to watercourses.

Disturbed Area

Target: decrease

Studies in Caspar Creek (Lewis, 1998, in Mangelsdorf and Clyde 2000) indicate that there is a statistically significant relationship between the difference in the disturbed areas and the corresponding suspended sediment discharge rate (Lewis, 1998; J. Lewis pers. comm. w/ A. Mangelsdorf as reported in Regional Water Board, 1999, in Mangelsdorf and Clyde 2000). In addition, studies in Caspar Creek indicate that clearcutting causes greater increases in peak flows (and by extension suspended sediment loads) than does selective harvest (Ziemer, 1998, in Mangelsdorf and Clyde 2000). As with the “hydrologic connectivity” target above, increases in peak flows, annual flows, and suspended sediment discharge rates negatively affect the potential survivability of ova in redds (Lisle, 1989, in Mangelsdorf and Clyde 2000).

The available information is insufficient to identify a threshold below which effects (such as increases in peak flows, annual flows and suspended sediment discharge) on the Ten Mile River watershed would be insignificant. Accordingly, the target calls for a reduction in the amount of disturbed area. With respect to this target, “disturbed area” is defined as the area covered by management-related facilities of any sort, including: roads, landings, skid trails, firelines, harvest areas, animal holding pens, and agricultural fields (e.g., pastures, vineyards, orchards, row crops, etc). The definition of a facility is intentionally made broad to include managed agricultural areas, such as pastures and harvest areas, where the management activity (e.g., logging or grazing) results in substantially enough removal of vegetation to significantly reduce important rainfall interception and soil protection functions. Agricultural fields or harvest areas in which adequate vegetation is retained to perform these ecological functions can be excluded from consideration as “facilities.” Dramatic reductions in the amount of disturbed area, then, can be made by reducing road densities, skid trail densities, clearcut areas, and other management-induced bare areas.

Activity in Unstable Areas

Target: none, unless detailed geologic assessment by a Certified Engineering Geologist concludes there is no additional potential for increased sediment loading

Unstable areas are those areas that have a high risk of landsliding and include: steep slopes, inner gorges, headwall swales, stream banks, existing landslides, and other locations identified in the field. Because of the high risk of landsliding inherent in these features, any activity that might trigger an erosional event should avoided, if possible, and be kept to a minimum if unavoidable. Such activities include: road building, harvesting, yarding, terracing for vineyards, etc.

An analysis using a predictive model of chronic landsliding in the Noyo River basin, based on the ratio of effective precipitation to soil transmissivity (q/T), indicates that landslides observed on aerial photographs largely coincide with predicted chronic risk areas. Chronic risk areas include steep slopes, inner gorges and headwall swales, as well as other locations (Dietrich et al. (1998, in Mangelsdorf and Clyde 2000). Studies in the lower Eel River basin suggest that landslides in recently harvested second growth areas underlain by Franciscan geology are larger and more common than those in areas of unharvested second growth (PWA, 1998, in Mangelsdorf and Clyde 2000). In Redwood Creek basin, Pitlick (1982, in Mangelsdorf and Clyde 2000) found that slides in harvested inner gorge areas were no more common but were much larger than those in uncut inner gorge slopes. Thus, the target calls for avoiding activities such as road building, harvesting, or yarding in unstable areas (e.g., steep slopes, headwall swales, inner gorges, streambanks, etc.) unless a detailed geological assessment is performed by a certified engineering geologist that shows there is no potential for increased sediment delivery to a watercourse as a result. Weaver and Hagans (1994, in Mangelsdorf and Clyde 2000) also suggest methods for eliminating or decreasing the potential for road-related sediment delivery.

Road Inspection/Maintainance or Closure

Target: annual inspection, maintenance and correction

EPA's analysis indicates that in watersheds with road networks that have not experienced excessive road-related sedimentation, road networds are regularly inspected, maintained, and hydrologically closed as necessary. Roads that will not or cannot be adequately inspected and maintained are potentially large sources of sediment unless constructed to be hydrologically maintenance free (D. Hagans, pers. comm., 1998, in EPA 1998). Inspection and maintenance of roads that are not hydrologically maintenance free—i.e., that continue to alter the natural hydrology of the stream and represent a potential sediment delivery—is one way of delaying and/or reducing the potential for sediment impairment. Alternatively, the roads can be upgraded to become hydrologically maintenance free. In general, road inspection should be undertaken annually, and could in most cases be accomplished with a windshield survey. The areas with the greatest potential for sediment delivery should be corrected, prior to the onset of winter conditions.

This target calls for all roads to be inspected annually prior to winter, and potential sediment deliveries corrected, or the road should be decommissioned or hydrologically closed or disconnected (fills and culverts removed, natural hydrology of hillslope largely restored).

Road Location, Surfacing, Hydrologic Connectivity, Sidecast
Target: prevent sediment delivery
This target calls for: 1) All roads alongside inner gorge areas or in potentially unstable headwall areas to be removed unless alternative road locations are unavailable and need for road is clearly justified. 2) Road surfacing, drainage methods and maintenance be appropriate to their use patterns and intensities. 3) Hydrologic connectivity be assessed and reduced to the extent feasible. 4) Sidecast/fill on steep (greater than 50%) or potentially unstable slope, that could deliver sediment to a watercourse slopes, be pulled back/stabilized

These factors reflect the highest risk of sediment delivery from roads, and should be the highest priorities for correction (C. Cook, M. Furniss, M. Madej, R. Klein, G. Bundros, pers. comm., 1998, in EPA 1998) Roads located in inner gorges and headwall areas are more likely to fail than roads located in other topographic locations. Other than ephemeral watercourses, roads should be removed from inner gorge and potentially unstable headwall areas except where alternative road locations are unavilable and the need for the road is clearly justified. Road surfacing and use intensity directly influences sediment delivery from roads. Rock surfacing or paving is appropriate for frequently used roads. Hydrologic connectivity refers to the extent that the road drainage is connected to watercourses. The connectivity can be reduced by outsloping roads, creating road drainage that mimics natural drainage as much as possible, and other factors (M. Furniss, pers. comm., 1998; Weaver and Hagans 1994, in EPA 1998). Sidecast on steep slopes can trigger earth movements, potentially resulting in sediment delivery to watercourses. This indicator is intended to address the highest risk sediment delivery from roads not covered in other targets.

CHAPTER IV
SOURCE ANALYSIS

The purpose of this chapter is to analyze sediment production information for the Ten Mile River watershed, to determine the sources of sediment loading. The information for this analysis is abstracted from GMA (2000).

ANALYSIS METHODS

Existing data were compiled from a variety of sources, including the Georgia-Pacific Fort Bragg Timberlands Sustained Yield Plan (Jones & Stokes Associates, Inc. 1997, in GMA 2000), as well as TMDL and/or sediment source analyses for similar basins such as the Noyo (GMA 1999), Navarro (Entrix et al. 1997, in GMA 2000) and Garcia Rivers (PWA, 1997, in GMA 2000). GMA analyzed a series of historic aerial photographs and made field visits to calibrate the air photo analysis and to collect field data, to the extent permitted by landowners.

The sediment source analysis involves three primary components: 1) evaluation of the dominant geomorphic processes that deliver sediment to the various stream channels in the Ten Mile River watershed through limited field reconnaissance, review of existing data, and consultation with those who are familiar with basin conditions; 2) measurement of various parameters, such as landslide size/type/associated land use, road length and harvest areas from sequential aerial photography and existing data bases; and 3) selection of factors to complement or modify the photo-based measurements where other data or information exist, and/or to estimate conditions where no data exist, thus allowing computation of results. The approach is primarily an indirect, office-based approach.

Time Period of Analysis

Historic aerial photographs were used to evaluate changes in sediment storage. Coverage was available for 1942 (partial coverage), 1952, 1965, 1978, 1988, and 1999. GMA assumed that features observed in the 1942 photographs covered approximately a 10-year period (i.e., no earlier than 1933), generally similar to the length of the subsequent study periods. Thus, the sediment budget covers a 67-year period, extending from 1933 to 1999. Sediment source data were developed for all six of these time intervals, capturing different periods of sediment-producing events, including both the largest storms this century (water years 1938, 1956, 1965, 1974, 1993) and changes in harvest practices and road building techniques.

Hydrology and Geomorphology Methods

Existing precipitation data were collected from the National Weather Service NCDC database on CD-ROM and from James Goodridge, former state climatologist and now consultant to the California Department of Water Resources. The limited streamflow and gaging station records available were obtained from USGS . The only stream gage in the basin operated on the Middle Fork from 1965-1973. A correlation process was used to extend the short record available on the Middle Fork Ten Mile using the longer record from the Noyo River. Data were supplemented using additional data collected during winter 1999-2000 for the nearby Big and Albion Rivers.

Access was not provided by the landowner for additional instream data collection in most parts of the Ten Mile River watershed. Using available data, synthetic streamflow records were developed for the North, Middle, and South Forks independently. These data were analyzed for magnitude, frequency, and duration. Bedload and suspended sediment load were also estimated over the time period.

Gaging station records were also used to evaluate changes in mean streambed elevation (MBE) at the gage. The cross section at the cableway of the former USGS gaging station was resurveyed to evaluate bed elevation changes since 1973. Historic records of timber harvest, railroad construction, and early photographs from a variety of sources were examined to provide a glimpse of conditions in the watershed from 1870-1940. Field reconnaissance visits to limited portions of the lower watershed were made to assess changes in channel-stored sediment and bank erosion at the USGS gage. However, similar conditions were also evaluated from field data for the Noyo, Big and Albion Rivers.

Mass Wasting Source Methods

Analysis of landslides and debris slides was conducted for photo years 1942, 1952, 1965, 1978, 1988, and 1999. Each photo covered the period from the previous photo up through the photo date. A 10-year period was assumed for the 1942 photos. The total period is thus 67 years. 1942 coverage was incomplete, as previously noted, but probably still included most of the slides that would have been seen on the photos. Only landslides greater than about 75-100 feet in width or length were included, which included most of the failures. Landslides were classified as rotational/translational, earthflow, debris slide, or debris flow/torrent. Rotational/translational and earthflow slides are characterized as relatively deep-seated, slow-moving or static slides, and it is generally assumed that such failures contributed little sediment except that derived from sheetwash or gullying processes. Debris slides, however, are short-term, active failures that contribute relatively modest to large volumes of sediment to the drainage. Over time they revegetate and eventually heal so that, in many cases, sediment input is reduced to similar levels as adjacent undisturbed areas. Debris flows/torrents are fast-moving and relatively shallow (in most, but not all) failures. For this study, cutslope and fillslope failures and rock avalanches are also included in this classification.

Certainty that the landslides observed were, in fact, landslides, were noted as “definite,” “probable,” or “questionable.” Those identified as “questionable” were eliminated from further analysis. Those that were not delivering sediment to a stream or watercourse were eliminated as well. The geologist then estimated the proportion of the landslide volume that was likely to be delivering to the stream, as either less than 33% delivering, 33-66%, or greater than 66%. The midpoint of each of these ranges (0.166, 0.50 and 0.833) were used for volume calculations. Delivery proportions were also adjusted for the type of slide: debris torrents were reduced by a factor of 0.5 because mapped portions of run-out areas probably were not delivering; earthflows were adjusted by 0.02 to account for slow movement and a relatively small delivery rate; and deep-seated rotational/translational slides were adjusted by 0.005 to account for even slower movement and delivery. Slides that were labeled as relic or dormant were assumed to be no longer delivering sediment.

Surface area of each feature was derived from Geographic Information System (GIS) mapping of the slide feature. Depth estimates were based in part on Mendocino Redwood Company's (MRC's) watershed investigations for the Noyo River watershed, which suggested that forest or harvest non road-related slides had a mean thickness of 3.0 ft. GMA's field investigations in the Ten Mile River basin suggested that this thickness was also appropriate to be assigned to road-related slides as well. Earthflows were assigned a thickness of 10 ft, and rotational/translational slides were assigned a thickness of 25 ft. A few larger slides were assigned thicknesses greater than 3 ft, but only when large scarps were clearly visible.

If a slide could be seen on a later photo, it was determined whether the slide had healed, was continuing to deliver sediment, or had re-initiated. If it was either continuing to deliver or re-initiated, the volume of sediment was estimated for that period as well.

Land uses associated with landslides were assigned based on what was visible in the air photo: road cut or fill, skid trail, railroad cut or fill, timber harvest (clear cut, partial cut, recent selective cut or selective cut greater than 20 years old) and forest, which represented apparently undisturbed conditions (i.e., no apparent disturbance within the previous 40 or so years). This was estimated visually.

Each landslide was thus identified in a data base, with associated information, including: GIS location, photo date, type, associated land use, area, volume, position (e.g., inner gorge v. hilltop), and certainty. Volumes were converted to tons using 1.48 tons/yd3.

Limited field reconnaissance in June of 2000 was focused mainly on slides located along main roads, parallel to tributaries, and the subdued topography in the headwaters of the North Fork. As expected, sediment delivery neared 100% parallel to watercourses for fill failures. A conversation with a long time employee of the major landowner confirmed that prior to institution of the FPRs, slide debris on roads was pushed into streams. Since 1973, debris is either spread out along the roadway or end-hauled to an appropriate location.

Surface Erosion Source Methods

Surface erosion was estimated for background rates, timber harvest, skid trails, roads, and railroads for the various period. Surface erosion from roads and skid roads was estimated by developing a road construction history and a harvest history. Prior to 1988, the history was developed primarily from interpretation of aerial photography. From 1988 to present, road and harvest history was obtained from California Department of Forestry (CDF) GIS coverages which had been developed by directly inputting information provided as part of submitted Timber Harvest Plans (THPs). Data from the pre-1988 mapping efforts were shown on overlays and simply record road or harvest activity during the period between years of photographs reviewed.

For roads, only main roads or haul roads were mapped. Adjustments were made to the GIS to match the CDF GIS coverages with air-photo mapping. The various CDF GIS classes were combined into 4 categories for simplicity: highway (paved), permanent (rocked but not paved), seasonal (native surface), and temporary. Because of revegetation over time, probably not all haul roads were mapped. Furthermore, their importance could be misinterpreted because of lack of use, being overgrown, or being incorporated into harvest units and lost in a maze of skid trails. Because the 1942 photos did not cover the eastern portions of the North Fork and a small portion of the Middle Fork, roads for that period may have been slightly underestimated, but it is unlikely that it is a large effect since little timber harvest took place in that part of the watershed prior to 1942.

Surface erosion from skid trails and harvest was estimated by estimating the aerial extent and type of harvest. In tractor-logged harvest units, road and skid trail density was characterized as low, moderate, or high, and erosion factors were applied to estimate the amount of erosion from each type over time.

Data from the overlays was digitized into the GIS database for subsequent mapping and analysis.

Road Erosion

The method used to estimate sediment production from roads is based on a procedure developed by Reid (1981, in GMA 2000) for industrial timber roads and associated use and sediment production in the Clearwater (Washington) basin. This procedure was also recently undertaken on the Navarro River and Noyo River watersheds. Although its use has limitations in that the similarity between the Mendocino watersheds and the Clearwater basin is unknown, it provides the best practical method for this TMDL, because any other method would require detailed information on road characteristics and use that can only be developed through a detailed road inventory.

The first step involves converting the observed road mileage by year into cumulative road miles by period to allow for road surface erosion calculations. The total road mileage in a given sub-watershed is then stratified into use categories by application of a “use function” which proportions the road miles into four use categories (high, moderate, low, none) based on fixed percentages (high use - 5%, moderate use - 5%, low use - 40%, and no use - 50%). These percentages are based on the patterns of log-truck usage observed by Reid (1981, in GMA 2000), with the percentages rounded to the nearest 20% to simplify the computation (high from 6% to 5%, low from 39% to 40%).

The next step involves application of the sediment production rates for each use class. Reid (1981, in GMA 2000) found that sediment production rates for each use class in the Clearwater basin declined by approximately an order of magnitude (i.e. 800 tons/mi for high, 80 tons/mi for moderate, 8 tons/mi for low, and 0.8 tons/mi for no use). These rates are used to indicate the relative number of trips that are likely for each class of use. The product of each use class by the applicable sediment rate gives annual sediment yield by class. The yields in the various classes are then summed to obtain sub-watershed production from roads. This procedure was followed for all years with road mileage data. There was one significant modification to this computation process: to account for improved road practices in recent years, overall factors of 0.8 and 0.6 were applied to the total computed sediment yield by sub-watershed for the 1979-1988 and 1989-1999 periods, respectively.

Hillslope Harvest/Skid Trail Surface Erosion Methods

There is considerable variation in estimates from the literature in the role of skid roads in sediment production and delivery to stream channels. Since skid roads are generally not linked as directly to stream channels as roads typically are, drainage practices (proper installation of water bars, etc.) are of primary importance in determining whether significant sediment production and delivery will occur. As a result of these site specific characteristics that control sediment generation, extensive direct field observations would be the only way to obtain comprehensive information on the role of skid roads.

GMA (2000) evaluated sediment production and delivery from skid trails using indirect methods. Harvest areas were identified on the historic aerial photographs and assigned a high, medium, or low rating regarding the density of skid roads. The area of the different types was computed by GIS methods for each sub-watershed. For the 1999 budget period, harvest areas were not mapped, but rather computed from the GIS database based on annual THP's submitted to CDF.

All harvest areas in the 1942 photos were considered to have a high density of skid roads. In 1952 and 1965 the majority of harvesting still used a high density of skid trails. Harvest rates were very low in 1978 and 1988, and by 1988 there were not any harvest areas mapped as high density, apparently reflecting changes in the Forest Practice Rules. In 1999, areas that were mapped were all assigned low skid road density, along with a number of new categories from the CDF database, including clear cuts, narrow clear cuts, and cable cuts. Typically, few if any skid roads were seen on these areas, as much effort was apparently spent to obliterate the skid trails developed during harvest operations.

To compute surface erosion rates from the harvest acreage data requires selection of a yield function for each class and selection of a time function to characterize the change in sediment yield over time, as revegetation occurs and the site stabilizes. GMA used yield and time functions developed by Mendocino Redwoods Company (MRC 1999, in GMA 2000) for their holdings in the Noyo River watershed. Based on a review of the literature, MRC selected 50 tons/mi^2/yr as a current mean rate for skid road sediment production for current management methods. They applied these rates over a 12-year period for each harvest area, with two years at the initial high rate, and 10 years thereafter at a reduced, or base rate (C. Surfleet, pers. comm. 1999, in GMA 2000). To extrapolate their method to the various density classes that GMA mapped, GMA used 600 tons/mi^2/yr for high densities, 450 tons/mi^2/yr for medium densities, and 300 tons/mi^2/yr for low densities. These higher values were estimated to reflect earlier, pre-Forest Practice Rules operations. GMA used a 10-year period to simplify the calculations, since a 12-year period would have overlapped many of the period lengths, necessitating more complex calculations. The first two years were at the rates listed above, and then reduced to 25% of that rate for the remaining eight years. For periods 1979-1988 and 1989-1999, the rate was adjusted downward to an average of 100 tons/mi^2/yr to reflect the combination of improved management practices post-1974 FPR, and the advent of cable skyline yarding and greatly improved buffering practices. Unfortunately, GMA had no site-specific information on vegetation cover establishment in the Ten Mile watershed with which to adjust our calculations, and therefore no adjustments were made.

Fluvial Erosion Methods

GMA used fluvial erosion rates developed for the Noyo River, which had been extrapolated from preliminary data from Mendocino Redwoods Company (C. Surfleet, pers. comm. 1999, in GMA 2000) to arrive at a value of 200 tons/mi^2/yr. These values were then multiplied by the drainage area and the period length in years to estimate of the period fluvial erosion total. This is the best information that is currently available.

Change in Channel Storage Methods

GMA examined historical aerial photographs to determine visible changes in channel width, considered channel cross section configuration from gaging station records, and the hydrologic and management histories. GMA inferred that due to management practices and high flow years between 1938 and 1974, a substantial amount of alluvial storage was lost as the channel widened. GMA approximate this change by estimating that the channel widened by an average 40 feet over a 10.5 mile reach including 4.5 miles of the Mainstem Ten Mile above the estuary, the lower three miles of the Middle Fork, and the lower three miles of the North Fork. GMA furthermore assume that the average height of floodplain lost was five feet. From this, GMA estimated likely changes in channel storage.

RESULTS

Hydrology and Geomorphology Results

Average annual precipitation in the basin ranges from about 40-45" per year in the western portion of the basin, to 75-85" in the eastern portion. Most of the precipitation occurs as rainfall from October through April, with the largest storms frequently occurring in mid-winter. The largest floods resulting from these storms occurred in Water Years 1938, 1956, 1965, 1974, and 1993. The 1942, 1965, 1978 and 1999 air photos would all record the most visible effects of those storms. The 1952 and 1988 air photos reflect periods of relative quiescence related to low water years and, in the case of the 1988 photos, a period of drought. The photo years prior to 1978 reflect intensive timber harvest with no regulation, while 1988 and 1999 reflect timber harvest under the California Forest Practices Act, which was passed by the California State Legislature in 1973. The effects of the heavy precipitation and flood flows were more pronounced in the earlier years, prior to establishment of the Forest Practice Rules (FPRs). Considerable lengths of roads and skid trails had been built, and the railroad had been constructed and was operational. The storms apparently had a significant effect on the watershed. Effects were less pronounced in the 1999 air photos, probably reflecting both the effects of the FPRs and the fact that many of the landslide areas had already been triggered in earlier years.

The data developed for the Ten Mile River watershed indicates an average annual sediment discharge of 1,135 tons/mi^2/yr for the period 1952-1997 (GMA 2000, p. 18). Of the 6.24 million tons transported during that period, 12% was estimated to have been transported in 1974 alone, while the top 10 flow years accounted for 58% of the total load. This occured in WY 1974, 1965, 1956, 1993, 1995, 1983, 1952, 1986, 1953, and 1958 (GMA 2000).

Mass Wasting Results

Landslide Frequency

A total of 2,008 total slides were mapped as delivering within the 1933-1999 budget period. Of those features, 1,649 were unique, and the rest were continuing previously-mapped features that continued to deliver or re-initiated in a later period. This averages out to 13.8 unique slides per mi^2 for the 67-year period, or 16.8 features/mi^2 including those that also delivered in later periods. Of the 1,649 unique slides, 1,527 or 92.6% were debris slides, 110 or 6.7% were debris flows/torrents, five or 0.3% were earthflows, four or 0.2 % were gullies, and three or 0.2% were Rotational/Translational slides.

Highest slide frequencies occurred in the 1965 photo period, undoubtedly triggered by the intensive timber harvest and the heavy rainfall and flood flows. The periods through 1965 account for 73% of all the delivering landslides, whereas the most recent period accounts for only 6%. It is not surprising that the earlier periods account for the largest proportion of the landslides, since these periods include some of the largest storm events, in December 1965, December 1955 and December 1937. However, the incidence of landslides in the 1943-1952 period seem anomalously high, given the absence of large floods in the 1942-1952 period, and it must be attributed to the high level of disturbance. Likewise, the most recent period seems low, and may be attributed both to improved management practices as well as the fact that earlier periods probably triggered most of the likely failures already.

Landslide Frequency Differences by Subwatershed

Smith Creek subwatershed, in the South Fork Planning Watershed, had the greatest number of slides for two consecutive periods, with 166 occurring in the 1933-1952 periods, out of a total 198 slides for the 67-year period. Only nine slides occurred in that watershed in the 1953-65 period, possibly because such a large number of failures had already been triggered in the previous two periods. Overall frequency of slides in this subwatershed (averaging 36.1/mi^2 for the total period) was higher than for any other subwatershed. Other subwatersheds in the South Fork Planning Watershed also had relatively higher numbers of slides: Churchman, Middle Fork South Fork and Campbell Creek all averaged 22-25/mi^2.

In the Lower Ten Mile Planning Watershed, a large number of slides in a smaller area also resulted in higher frequencies, particularly in Mill Creek (33.6/mi^2). By contrast, the lowest number of slides for any subwatershed during the entire period (25) occurred in the Ten Mile River Estuary subwatershed, probably reflecting the subdued topography and smaller aerial extent of timber harvest in the subwatershed.

The North Fork Planning Watershed generally had lower frequencies of landslides, with the lowest frequency rate in the Upper North Fork subwatershed (3.8/mi^2). However, the Lower North Fork subwatershed totaled 170 landslides, corresponding to a frequency rate of 25.3/mi^2. Of the total, 136 occurred in the first 3 photo periods. Bald Hill Creek subwatershed also had a high frequency rate (18.7/mi^2).

In the Middle Fork Planning Watershed, high landslide frequencies occurred in the Lower Middle Fork subwatershed (170, or 30.4/mi^2 for the period), but these were distributed fairly evenly thoughout all periods. The Middle Middle Fork subwatershed also had relatively high landslide frequency (18.6/mi^2).

Landslide Frequency Relationship to Timber Harvest

Generally speaking, landslide frequency is correlated with the aerial extent of timber harvest (see Figure 3). Most noteworthy is that the landslides in the 1953-1965 period are well above the expected frequency, while the 1989-1999 period is well below. In 1965, this is probably due to the intensive timber harvesting and effects of the December 1964 flood. The low frequency in the most recent period probably reflects changes in FPRs as well as previous triggering of landslides.

Landslide Frequency Legacy Effects

Landslides initiated in earlier periods continue to have an effect today, despite the lower overall rates of landsliding. Approximately 1/5 of all landslides are re-initiated or continued to deliver in future periods. This has had a relatively larger effect in recent periods (Table 5). Up through 1978, 77-95% of all landslides observed were unique features, initiated in that period. In the most recent 20 years, that has dropped to 52-60%. In other words, 40-48% of slides that are observed today were initiated in the previous period, and are continuing to deliver sediment to watercourses.

Inner Gorge Landslide Frequencies

In many forested watersheds of the northern California coast, inner gorge topography (i.e., very steep slopes immediately adjacent to the watercourse) is the greatest source of sediment delivery to streams. This is usually important because of the high delivery rate. This type of landslide does account for nearly half of the slides in the lower North Fork and Middle Fork mainstem areas, and also dominates the lower South Fork mainstem. However, for the basin as a whole, this process accounts for only a quarter of all landslides, primarily because the slopes exceed 40% in only a relatively small portion of the basin (less than 2%).

Landslide Frequency/ Land Use Associations

The greatest associations with landslides are timber harvest, particularly legacy effects, and skid trails. Although the analysis initially suggests that only 2% of slides and debris torrents were associated with landslides in forested areas (i.e., no visible harvest) and would be classified as "background" rates, this figure is underestimated, since portions of the unharvested areas in the 1942 air photo coverage was unavailable (underestimating the 1933-1942 period slightly), and since some landslides identified as "harvest > 20 yrs" are probably not management-related.

The fact that this is an underestimate is supported by further data analysis. Although background rates can vary somewhat, for example by the effect of "event hardening," i.e., when the landslides that were on the threshold of being triggered have already been triggered (such as in the 1964 flood season) (L. Reid, pers. comm., 2000), a true "background" rate should be somewhat constant over time. The data for the Ten Mile show that the landslides in the "forest" category actually decreased following 1965, with the three most recent periods having none or very few

FIGURE 3

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

Harvest Acreage vs. Number of Slides for Analysis Periods

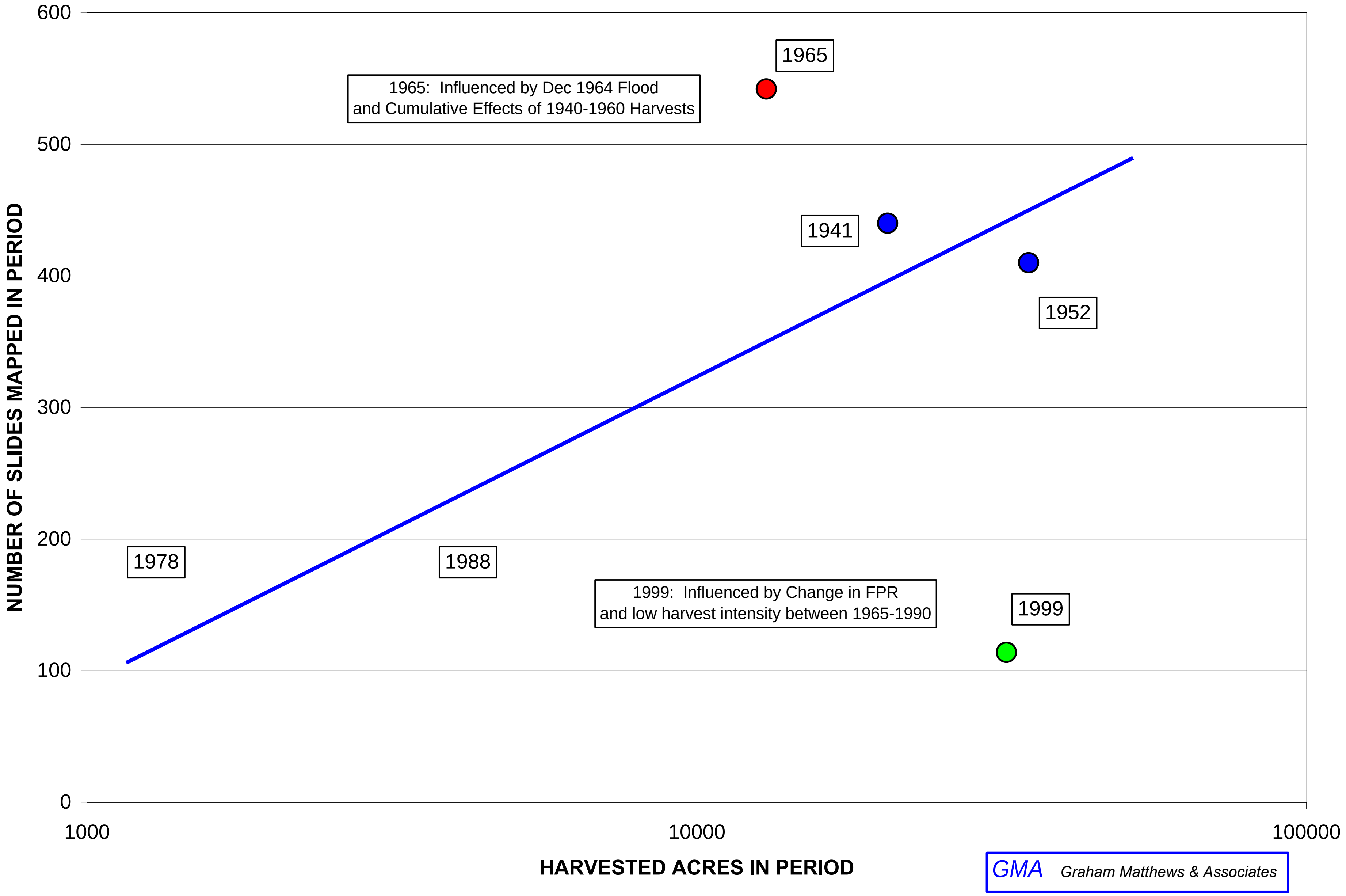


Table 5: Delivering Landslides Initiated by Period

Total Slides	1933-1942		1943-1952		1953-1965		1966-1978		1979-1988		1989-1999		Notes
	#	%	#	%	#	%	#	%	#	%	#	%	
2,008	449	100%	451		575		230		181		122		All Delivering Slides
1,649	449	100%	349	77%	456	79%	219	95%	108	60%	64	53%	Proportion Initiated in that Period
		0%		23%		21%		5%		40%		47%	Proportion Initiated in Earlier Period

landslides. It seems more likely that the first two periods are more representative of non-management, i.e., background landsliding (averaging 36 tons/mi^2/yr). EPA believes this is a better estimate of the non-management landsliding rate. Thus, about 95% of landslides over the entire 67-year study period would be management-related, and 70% of landslides in the current period. Current management-related inputs would comprise about 49% of the total.

It is possible that more landslides in the “harvest > 20 yrs” category are non-management related, but the degree of underestimate of the non-management landsliding is not known. If all of the landslides in that category were actually non-management related, then 1,987,000 tons or 248 tons/mi^2/yr would be non-management related landslides. Total non-management inputs would average 311 tons/mi^2/yr over the 67-year period, or 28% of the total. Using the average of the “forested” category landslides for the first two periods also yields a value of 311 tons/mi^2/yr for the 1988-99 period, which suggests that the estimate is reasonable.

In reality, it is not possible to state precisely how much of the landsliding in the harvest > 20 years category may be attributable to background rates. It is clear, however, that harvest activities do show an association with landslides; in Figure 3, a clear correlation can be seen between the number of acres harvested and the number of landslides by period. Two periods are exceptions: the 1953-1965 period shows a higher-than-expected number of landslides, and the 1989-1999 period shows fewer. This may be the result of improved forest practices in the recent period.

There is also some non-management related sediment input that is probably actually caused by management. Of the 200 tons/mi^2/yr attributed to fluvial erosion, some portion is probably caused by management activities. This is even more difficult to quantify.

Overall, two-thirds of the failures are harvest-related (primarily related to older harvest), while 29% are road- and railroad-related, (primarily related to road fills). Less than 2% are associated with grazing or other undetermined sources. While most harvest-related slides are associated with older harvest units, the number of slides associated with roads has increased in recent periods, and the number of slides associated with skid trails has also increased, accounting for less than 4% up through 1965, and 25% in 1966-99. The association peaked in the 1966-78 period (82 of 227), declining to 13 (of 115) in the 1989-99 period.

Land Use Frequency Associations by Subwatershed

As shown in Table 6 , harvest-related landslides are dominant in the South Fork Planning Watershed (92% of all slides, whereas 8% are related to roads, railroads and skid trails). Subwatersheds with large harvest-related landslide associations include the Upper South Fork, Middle South Fork, Campbell and Smith Creeks. A notable exception to the pattern is the Lower South Fork subwatershed. In the other Planning Watersheds, harvest-related landsliding comprises 50-61% of the total volume, and 65% overall. In those Planning Watersheds, road-related landslides are 36-46% of the total volume. Non-management related landslides are responsible for only 2% of total landslides.

Because associations are assigned visually based on aerial photo analysis, it is likely that some degree of error exists, particularly in the assignment of non-management (i.e. forest) landslides versus those related to harvest >20 yrs old. It is likely that some of those areas represent forest regrowth, and some of the landslides in that category probably are not caused by management activities. However, it is likely that the error is small (J. Coyle, pers. comm., 2000).

In the North Fork and Middle Fork Planning Watersheds, road-related landslides are dominant. This is probably partly related to the topography, as the canyons tend to be narrower and steeper, and roads were initially constructed immediately adjacent to the water courses, and are more subject to failure. In the North Fork Planning Watershed, the Middle North Fork, Bald Hill Creek and Lower North Fork subwatersheds have the largest number of road-related slides. In the Middle Fork, the Upper Middle Fork, Middle Middle Fork and Lower Middle Fork subwatersheds have the most road-related slides. The South Fork Planning Watershed generally tends to have broader valleys, so that early road construction was not generally immediately adjacent to the stream course.

In the Lower Ten Mile Planning Watershed, the Mill Creek subwatershed also has a high number of road-related and harvest-related slides, relative to the size of the watershed.

Landslide Volume and Unit Area Volume

In the 1933-1942 period, 832,000 tons, or 61% of the total for the period, was delivered to watercourses in the South Fork Planning Watershed, with 20% of the total each coming from Campbell Creek and Smith Creek subwatersheds. The Middle South Fork and Redwood Creek subwatersheds together contributed 16% of the total. This period accounted for over half of the sediment production for the 67-year period, for the South Fork Planning Watershed. This probably reflects the intensive harvest practices for that Planning Watershed in the period. On the whole, sediment delivery from landslides in the South Fork Planning Watershed averaged 2,167 tons/mi^2/yr (again, assuming 1933 as the beginning of the period). Delivery in the Campbell Creek and Smith Creek subwatersheds averaged 6,300 and 4,905 tns/mi^2/yr, respectively (Table 7).

TABLE 6

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

VOLUMES OF DELIVERING SLIDES BY LAND USE BY WATERSHED AS PERCENTAGE OF PW OR SW TOTAL
(ALL VALUES IN TONS)

PLANNING WATERSHED	Drainage Area	FOREST	HARVEST						ROADS					GRAZING	TOTAL
Sub-Watershed	(mi^2)		Clear Cut	Partial Cut	Harvest (<20 yrs)	Harvest (>20 yrs)	Skid Trails	TOTAL	Road Cut	Road Fill	RR Cut	RR Fill	TOTAL		
NORTH FORK TEN MILE	**38.97**	2.8%	2.7%	2.3%	6.7%	32.0%	6.5%	50.2%	6.3%	37.4%	2.4%	0.3%	46.4%	0.5%	38.3%
Upper North Fork Ten Mile River	10.40	6.5%	0%	0%	16.2%	3.8%	1.4%	21.4%	2.9%	54.9%	0%	0%	57.8%	14.4%	1.5%
Middle North Fork Ten Mile River	8.98	0.3%	0%	2.2%	0.3%	47.3%	0.6%	50.4%	3.1%	46.2%	0%	0%	49.3%	0%	21.4%
Bald Hill Creek	5.14	10.2%	0%	2.3%	23.1%	5.3%	23.1%	53.8%	7.9%	28.0%	0%	0%	36.0%	0%	3.9%
Lower North Fork Ten Mile River	6.70	5.9%	6.4%	1.8%	14.1%	12.7%	6.4%	41.3%	16.7%	28.3%	6.1%	1.6%	52.7%	0%	8.0%
Little North Fork Ten Mile River	7.75	1.3%	14.6%	4.8%	7.0%	24.0%	26.7%	77.2%	1.3%	7.4%	12.9%	0%	21.5%	0%	3.5%
MIDDLE FORK TEN MILE	**33.45**	3.6%	5.2%	2.9%	10.0%	21.7%	17.0%	56.7%	13.2%	19.3%	3.9%	3.3%	39.6%	0.0%	24.6%
Upper Middle Fork Ten Mile River	11.64	11.2%	0.2%	0%	11.3%	22.7%	16.6%	50.8%	0.9%	25.2%	0%	11.8%	37.9%	0%	6.3%
Middle Middle Fork Ten Mile River	6.45	2.6%	5.2%	1.3%	0%	45.5%	12.8%	64.7%	2.6%	30.1%	0%	0%	32.7%	0%	5.6%
Little Bear Haven Creek	3.00	0%	0%	0%	9.0%	38.3%	32.8%	80.0%	0.3%	19.7%	0%	0%	20.0%	0%	1.6%
Bear Haven Creek	6.60	0.2%	0.5%	12.3%	50.3%	13.6%	1.6%	78.3%	16.5%	1.8%	1.1%	2.3%	21.6%	0%	2.7%
Lower Middle Fork Ten Mile River	5.76	0.5%	11.7%	3.6%	2.6%	4.0%	22.2%	44.1%	31.1%	13.2%	11.1%	0%	55.5%	0%	8.3%
SOUTH FORK TEN MILE	**38.39**	0.1%	0.6%	1.3%	25.3%	63.6%	0.6%	91.5%	2.9%	5.0%	0.3%	0.0%	8.2%	0.1%	30.2%
Upper South Fork Ten Mile River	8.18	0%	0.1%	0%	4.8%	83.1%	1.2%	89.2%	1.4%	9.4%	0%	0%	10.8%	0%	3.9%
Redwood Creek	7.87	0%	0%	0%	55.9%	40.4%	0%	96.3%	0.3%	3.4%	0%	0%	3.7%	0%	2.8%
Churchman Creek	3.96	0%	1.5%	11.5%	12.0%	46.0%	2.2%	73.1%	6.0%	20.8%	0%	0%	26.9%	0%	3.5%
Middle South Fork Ten Mile River	5.52	0%	2.0%	0%	21.4%	64.3%	1.0%	88.7%	5.7%	5.6%	0%	0%	11.3%	0%	5.2%
Campbell Creek	4.25	0%	0.1%	0%	13.4%	86.6%	0%	100.0%	0%	0%	0%	0%	0.0%	0%	6.7%
Smith Creek	5.49	0.4%	0.3%	0%	40.2%	54.6%	0.2%	95.2%	4.3%	0.1%	0%	0%	4.4%	0%	7.2%
Lower South Fork Ten Mile River	3.12	2.1%	0.7%	0.6%	68.5%	10.1%	0%	79.9%	0%	3.8%	9.9%	0%	13.7%	4.3%	0.8%
LOWER TEN MILE	**8.83**	3.2%	26.7%	0.0%	8.7%	16.9%	8.3%	60.6%	11.0%	18.9%	5.6%	0.0%	35.5%	0.7%	6.9%
Mainstem Ten Mile River	4.28	3.2%	41.0%	0%	4.6%	20.7%	6.6%	73.0%	9.1%	10.8%	3.8%	0%	23.7%	0.1%	4.3%
Mill Creek	2.71	3.7%	4.2%	0%	17.8%	10.0%	13.0%	44.9%	14.5%	36.9%	0%	0%	51.4%	0%	2.3%
Ten Mile River Estuary	1.84	0%	0%	0%	0%	15.2%	0%	15.2%	11.4%	2.6%	59.3%	0%	73.4%	11.5%	0.4%
TEN MILE RIVER WATERSHED	**119.64**	2.2%	4.3%	2.0%	13.3%	38.0%	7.4%	65.0%	7.3%	21.9%	2.4%	0.9%	32.5%	0.3%	100%

Source: GMA 2000

TABLE 7

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

AVERAGE ANNUAL UNIT AREA VOLUMES OF SLIDES BY STUDY PERIOD BY WATERSHED

PLANNING WATERSHED	Drainage Area	1942	1952	1965	1978	1988	1999	AVG
		10 years, 1933-1942	10 years, 1943-1952	13 years, 1953-1965	13 years, 1966-1978	10 years, 1979-1988	11 years, 1989-1999	1933-99
Sub-Watershed	(mi^2)	(t/mi^2/yr)	(t/mi^2/yr)	(t/mi^2/yr)	(t/mi^2/yr)	(t/mi^2/yr)	(t/mi^2/yr)	(t/mi^2/yr)
NORTH FORK TEN MILE	**38.97**	**690**	**565**	**1,811**	**244**	**1,062**	**144**	**768**
Upper North Fork Ten Mile River	10.40	0	153	395	27	21	9	109
Middle North Fork Ten Mile River	8.98	44	523	5536	115	4129	411	1865
Bald Hill Creek	5.14	14	1094	988	858	439	66	600
Lower North Fork Ten Mile River	6.70	2863	1244	1149	284	161	92	930
Little North Fork Ten Mile River	7.75	933	229	512	246	96	110	353
MIDDLE FORK TEN MILE	**33.45**	**419**	**836**	**1,335**	**351**	**267**	**126**	**575**
Upper Middle Fork Ten Mile River	11.64	0	583	1258	280	188	53	422
Middle Middle Fork Ten Mile River	6.45	87	724	2209	245	422	139	683
Little Bear Haven Creek	3.00	0	883	725	551	248	41	423
Bear Haven Creek	6.60	226	734	737	112	88	33	327
Lower Middle Fork Ten Mile River	5.76	2078	1565	1517	781	468	409	1127
SOUTH FORK TEN MILE	**38.39**	**2,167**	**745**	**588**	**171**	**131**	**77**	**614**
Upper South Fork Ten Mile River	8.18	225	357	1009	302	207	22	376
Redwood Creek	7.87	1206	227	203	82	21	25	276
Churchman Creek	3.96	416	1770	926	532	338	207	694
Middle South Fork Ten Mile River	5.52	2340	769	1104	57	137	148	734
Campbell Creek	4.25	6300	1289	370	99	74	31	1240
Smith Creek	5.49	4905	1263	247	104	142	109	1028
Lower South Fork Ten Mile River	3.12	1152	70	13	13	0	72	199
LOWER TEN MILE	**8.83**	**1,445**	**420**	**802**	**536**	**398**	**91**	**612**
Mainstem Ten Mile River	4.28	2432	635	1269	308	41	73	782
Mill Creek	2.71	234	308	611	1239	1221	181	652
Ten Mile River Estuary	1.84	935	87	0	33	18	0	162
TEN MILE RIVER WATERSHED	**119.64**	**1,144**	**688**	**1,211**	**272**	**492**	**113**	**653**

Source: GMA 2000

Other areas also experienced high landslide volumes during this period. The Lower Ten Mile Planning Watershed delivered 35% of its load for the 67-year period during 1933-1942. For the same period, the Middle South Fork, Lower Middle Fork, Lower North Fork and Mainstem Ten Mile subwatersheds all averaged between about 2,100-2,900 tns/mi^2/yr, which were about twice the basin average for the period. Over one-quarter of the total volume of sediment delivered to the basin was delivered during that period.

Sediment production decreased only slightly in the 1943-1952 period, despite the absence of large storms. 16% of the total delivery for the basin occurred in that period, although it was somewhat more evenly distributed amongst all the Planning Watersheds. Subwatersheds with the highest unit area volumes (1,000-1,800 tons/mi^2/yr) included Bald Hill Creek, Lower North Fork, Lower Middle Fork, Middle South Fork, Campbell Creek and Smith Creek.

The 1953-1965 period saw a combination of some of the largest storms and the greatest harvest intensities, resulting in well over a third of the total sediment delivery during that period. This effect was even more pronounced in the North Fork and Middle Fork Planning Watersheds, where nearly half of all the sediment production for those Planning Watersheds occurred in that period. The unit area production volume averaged 1,211 tons/mi^2/yr for that period, and the volumes were unevenly distributed, skewed in part by both a high number of slides and one particularly large slide in the Middle North Fork subwatershed, where the resulting unit area volume averaged 5,536 tons/mi^2/yr for the 1953-1965 period. In the Middle Middle Fork subwatershed, the unit area volume averaged 2,209 tons/mi^2/yr for the period. Several other subwatersheds that produced over 1,000 tons/mi^2/yr in the 1953-1965 period included the Lower North Fork, Upper Middle Fork and Lower Middle Fork (1,149-2209 tons/mi^2/yr). Volumes in the South Fork were relatively lower overall, although the Upper South Fork and Middle South Fork subwatersheds still averaged 1,009 and 1,104 tons/mi^2/yr, respectively.

From 1978-1999, the volume of landslides decreased noticeably, with the basinwide average of 492 tons/mi^2/yr in 1978-88 and 113 in 1989-99. Only Mill Creek subwatershed continued to produce over 1,200 tons/mi^2/yr during the 1966-1989 periods, and the Middle North Fork subwatershed averaging 4,129 tons/mi^2/yr during 1979-1988, largely because a single large slide was reactivated. For the entire 1933-1999 period, sediment production from landsliding averaged 653 tons/mi^2/yr.

Surface Erosion Results

Roads

According to the GIS road coverage developed in this study, there are currently 940 miles of roads in the Ten Mile Watershed, which translates to a basinwide road density of 7.86 mi/mi^2 (including includes the former railroads, which were converted to roads). Table 8 shows the existing road network distributed by Planning Watershed and sub-watershed. The highest road density in the basin is in the Little North Fork subwatershed, with a density of 11.61 mi/mi^2, followed closely by Lower North Fork (10.98 mi/mi^2), Bear Haven Creek (10.99 mi/mi^2, in the Middle Fork Planning Watershed), and Middle South Fork (10.23 mi/mi^2). The other subwatersheds in the North Fork and Middle Fork Planning Watersheds are all under the watershed average. Lower Ten Mile and South Fork Planning Watersheds had the highest Planning Watershed densities at 8.29 and 8.46 mi/mi^2, respectively.

Not surprisingly, seasonal roads (native surface) were 87.7% of the total, followed by permanent roads (rocked) at 8.5%, temporary (native surface 4WD) at 3.6%, and highway (paved) at 0.1%. Only a very small portion of Highway 1 is contained in the watershed. The Lower Ten Mile Planning Watershed has the highest road density (8.46 mi/mi^2) of the 4 planning watersheds. The South Fork Planning Watershed has the largest amount of road miles at 318, followed by the North Fork Planning Watershed at 291 miles. There is a higher percentage of permanent roads in the Lower Ten Mile Planning Watershed (16.2%) and South Fork (13%) than in the North Fork (5.9%) or Middle Fork (3.7%) Planning Watershed. The Middle Fork Planning Watershed contains the largest proportion of seasonal and temporary roads (96%).

Railroads

Railroads played an important role in the transportation of harvested timber between about 1910 and 1950. Main tracks extended far up the South Fork, with spur lines up Smith Creek, Campbell Creek and Redwood Creek (also in the South Fork Planning Watershed). Tracks were extended a much shorter distance up the Middle and North Forks. Table 9 demonstrates that the South Fork Planning Watershed contained most of the railroad network in 1942. Beginning in the 1940s, railroads were replaced by trucks and the railroad grades were converted to road beds. This conversion appears to have been complete by the early 1950s. Railroad trestles are still visible at a number of sites thoughout the watershed, particularly at abandoned river crossings.

Road History

The miles of roads constructed by period for each Planning Watershed and subwatershed is shown in Table 10. Of the current total of 940 miles of roads, 10% were existing in 1942, 21.5% were added in the 1943-1952 period, 13.1% were constructed in the 1953-1965 period, another 11.6% were built in the 1966-1978 period, only 5.4% were added in the 1979-1988 period, while 37.9% were created in the most recent period (1989-1999). The latter period probably includes some roads that were actually constructed earlier, mainly in 1979-1988, but it is still evident that nearly half of the roads were constructed in the last 20 years.

The road construction and railroad history largely mirrors the history of timber harvest through the watershed, with most concentrated in the Lower Ten Mile and South Fork Planning Watersheds in the 1930s and 1940s, although the largest mileage during the 1933-1940 period (30 miles) was constructed in the Little North Fork subwatershed. It seems likely that the South Fork Planning Watershed would have had even more road construction during the 1940s and 1950s if the railroad network had been less extensive in that Planning Watershed.

TABLE 8

EXISTING ROAD TYPES BY PLANNING WATERSHED AND AND SUB-WATERSHED

PLANNING WATERSHED		MILES OF INDICATED ROAD TYPE				TOTAL BY PW	TOTAL BY SW	ROAD DENSITY
Sub-Watershed	Drainage Area	Highway	Permanent	Seasonal	Temporary	(mi)	(mi)	(mi/mi^2)
NORTH FORK TEN MILE	**38.97**	**0**	**17.17**	**257.77**	**16.70**	**291.63**		**7.48**
Upper North Fork Ten Mile River	10.40	0	0	55.40	6.67		62.07	5.97
Middle North Fork Ten Mile River	8.98	0	0	34.27	2.64		36.91	4.11
Bald Hill Creek	5.14	0	2.04	25.99	1.06		29.09	5.66
Lower North Fork Ten Mile River	6.70	0	5.78	63.23	4.54		73.54	10.98
Little North Fork Ten Mile River	7.75	0	9.35	78.88	1.79		90.01	11.61
MIDDLE FORK TEN MILE	**33.45**	**0**	**9.53**	**243.50**	**2.80**	**255.83**		**7.65**
Upper Middle Fork Ten Mile River	11.64	0	0	84.90	1.24		86.14	7.40
Middle Middle Fork Ten Mile River	6.45	0	1.76	31.28	0.79		33.83	5.24
Little Bear Haven Creek	3.00	0	0.06	19.31	0		19.37	6.46
Bear Haven Creek	6.60	0	0.04	72.32	0.16		72.52	10.99
Lower Middle Fork Ten Mile River	5.76	0	7.66	35.70	0.61		43.96	7.63
SOUTH FORK TEN MILE	**38.39**	**0**	**41.53**	**266.79**	**9.90**	**318.21**		**8.29**
Upper South Fork Ten Mile River	8.18	0	4.00	50.87	1.38		56.2	6.88
Redwood Creek	7.87	0	4.30	59.68	3.78		67.8	8.61
Churchman Creek	3.96	0	1.96	27.35	0		29.3	7.40
Middle South Fork Ten Mile River	5.52	0	13.65	42.14	0.70		56.5	10.23
Campbell Creek	4.25	0	4.87	32.54	2.88		40.3	9.48
Smith Creek	5.49	0	4.82	36.92	0.59		42.3	7.71
Lower South Fork Ten Mile River	3.12	0	7.93	17.29	0.57		25.8	8.26
LOWER TEN MILE	**8.83**	**0.96**	**12.07**	**57.06**	**4.62**	**74.70**		**8.46**
Mainstem Ten Mile River	4.28	0	6.19	28.88	2.88		37.96	8.87
Mill Creek	2.71	0	0.59	21.44	1.74		23.78	8.77
Ten Mile River Estuary	1.84	0.96	5.28	6.73	0		12.97	7.05
TOTAL TEN MILE WATERSHED	**119.64**	**0.96**	**80.29**	**825.11**	**34.02**	**940.38**		**7.86**
% of Total Roads		**0.10%**	**8.54%**	**87.74%**	**3.62%**	**100.00%**		

Source: GMA 2000

Notes: Base road data from CDF, substantially added to and corrected to aerial mosaic by GMA.

TABLE 9

LENGTH OF RAILROADS IN THE TEN MILE WATERSHED 1942

PLANNING WATERSHED	Length (miles)
North Fork Ten Mile River	5.96
Middle Fork Ten Mile River	2.60
South Fork Ten Mile River	25.84
Lower Mainstem Ten Mile River	5.93

Major road construction in the 1943-1952 period occurred in Bear Haven Creek (20.7 miles) and Upper Middle Fork (34.6 miles) subwatersheds in the Middle Fork Planning Watershed and in many of the subwatersheds in the North Fork Planning Watershed. In the 1953-1965 period, most road construction occurred in the North Fork Planning Watershed with 65 miles of roads built, primarily in the Upper, Middle and Little North Fork subwatersheds. In the 1966-1978 period, road construction was concentrated primarily in one subwatershed in each of the Planning Watersheds: Campbell Creek in the South Fork Planning Watershed, Mill Creek in the Lower Ten Mile Planning Watershed, Bear Haven Creek in the Middle Fork Planning Watershed, and the Lower and Upper North Fork subwatersheds, with only small amounts in the remaining areas. Relatively little construction occurred in the 1966-1978 and 1979-1988 periods. During the 1979-1988 period, almost all of the road building was in Smith Creek, Redwood Creek and Middle South Fork subwatersheds in the South Fork Planning Watershed and the Upper Middle Fork and Upper North Fork subwatersheds.

Widespread construction occurred in the 1989-1999 period, as harvest rates rose considerably. The road construction rate in the South Fork Planning Watershed was double that of the other Planning Watersheds; over half the roads constructed in that Planning Watershed were built in the most recent period. In the Middle and North Forks, 30-34% of the total roads in the Planning Watershed were constructed in the period (about 88 miles each).

Despite the significant increase in road density, the advantage of recently constructed roads is that construction standards have markedly improved in the past 25 years, thereby reducing the overall impact of these features compared to those built in earlier periods. In addition, many of these recent roads are ridgetop roads, which generally yield less sediment to watercourses than roads near stream courses or mid-slope roads. Unfortunately, the scope of this road investigation could not take the location of the road into account.

TABLE 10

ROAD CONSTRUCTION HISTORY BY PLANNING WATERSHED AND AND SUB-WATERSHED

PLANNING WATERSHED		MILES OF ROAD CONSTRUCTED IN PERIOD						TOTAL BY PW OR SW	% TOTAL WATERSHED ROAD MILES	PW or SW Road Density
Sub-Watershed	Drainage Area	**1942**	**1952**	**1965**	**1978**	**1988**	**1999**	(mi)	(mi)	(mi/mi2)
NORTH FORK TEN MILE	**38.97**	**34.47**	**59.58**	**65.20**	**35.24**	**8.75**	**88.40**	**291.63**	**31.0%**	**7.48**
	% of PW Total	**11.8%**	**20.4%**	**22.4%**	**12.1%**	**3.0%**	**30.3%**			
Upper North Fork Ten Mile River	10.40	0	10.58	23.50	12.10	7.05	8.83	62.07	6.60%	5.97
Middle North Fork Ten Mile River	8.98	1.30	13.77	16.47	1.38	0.84	3.16	36.91	3.93%	4.11
Bald Hill Creek	5.14	0	15.10	3.36	1.70	0.39	8.53	29.09	3.09%	5.66
Lower North Fork Ten Mile River	6.70	3.10	11.91	8.73	17.07	0.03	32.70	73.54	7.82%	10.98
Little North Fork Ten Mile River	7.75	30.06	8.21	13.15	2.99	0.43	35.17	90.01	9.57%	11.61
MIDDLE FORK TEN MILE	**33.45**	**11.85**	**85.36**	**28.03**	**33.97**	**9.25**	**87.37**	**255.83**	**27.2%**	**7.65**
	% of PW Total	**4.6%**	**33.4%**	**11.0%**	**13.3%**	**3.6%**	**34.2%**			
Upper Middle Fork Ten Mile River	11.64	0	34.60	8.98	4.22	9.25	29.10	86.14	9.16%	7.40
Middle Middle Fork Ten Mile River	6.45	0.39	15.17	4.40	2.72	0	11.15	33.83	3.60%	5.24
Little Bear Haven Creek	3.00	0.52	5.89	0	6.40	0	6.55	19.37	2.06%	6.46
Bear Haven Creek	6.60	3.22	20.69	5.50	16.17	0	26.95	72.52	7.71%	10.99
Lower Middle Fork Ten Mile River	5.76	7.72	9.01	9.15	4.46	0	13.62	43.96	4.67%	7.63
SOUTH FORK TEN MILE	**38.39**	**30.31**	**42.19**	**16.80**	**31.74**	**26.54**	**170.64**	**318.21**	**33.8%**	**8.29**
	% of PW Total	**9.5%**	**13.3%**	**5.3%**	**10.0%**	**8.3%**	**53.6%**			
Upper South Fork Ten Mile River	8.18	1.82	7.61	0.78	7.29	0.16	38.59	56.2	5.98%	6.88
Redwood Creek	7.87	3.97	12.03	3.67	0	7.94	40.16	67.8	7.21%	8.61
Churchman Creek	3.96	0.34	7.20	2.92	0	0	18.84	29.3	3.12%	7.40
Middle South Fork Ten Mile River	5.52	7.46	11.15	2.27	0.25	6.20	29.16	56.5	6.01%	10.23
Campbell Creek	4.25	4.29	1.00	0	16.97	1.48	16.57	40.3	4.28%	9.48
Smith Creek	5.49	5.18	1.84	4.84	1.34	8.77	20.35	42.3	4.50%	7.71
Lower South Fork Ten Mile River	3.12	7.23	1.36	2.32	5.89	2.00	6.98	25.8	2.74%	8.26
LOWER TEN MILE	**8.83**	**21.53**	**14.72**	**13.02**	**8.52**	**6.56**	**10.36**	**74.70**	**7.9%**	**8.46**
	% of PW Total	**28.8%**	**19.7%**	**17.4%**	**11.4%**	**8.8%**	**13.9%**			
Mainstem Ten Mile River	4.28	11.61	8.98	5.65	0.80	6.22	4.69	37.96	4.04%	8.87
Mill Creek	2.71	0.77	5.74	4.89	7.59	0.34	4.45	23.78	2.53%	8.77
Ten Mile River Estuary	1.84	9.15	0	2.48	0.12	0	1.22	12.97	1.38%	7.05
TOTAL TEN MILE WATERSHED	**119.64**	**98.15**	**201.84**	**123.05**	**109.47**	**51.10**	**356.76**	**940.38**	**100.0%**	**7.86**
% of Total Roads		**10.44%**	**21.46%**	**13.08%**	**11.64%**	**5.43%**	**37.94%**	**100.00%**		

Source: GMA 2000

Notes:
Base road data from CDF, substantially added to and corrected to aerial mosaic by GMA.
Eastern portion of watershed not covered by 1942 aerial photographs.
Road segments not codified by year by CDF or mapped into specific period by John Coyle are all included in 1999 period.

Road Surface Erosion

The analysis indicates that surface erosion from roads has increased significantly over the course of the study period (Figure 4). However, the adjustment factors in recent years, predicated on substantially improved practices, result in a much lower rate of increase overall in recent years and in decreases for certain sub-watersheds. Providing the assumptions regarding improved road construction and maintenance practices are adequate, the rate of increase has slowed considerably, though the amount of road construction in the past 20 years has still led to increases in the overall load. Existing conditions are estimated to produce an overall average yield of 225 tons/mi^2/yr, which is estimated to be an almost 6-fold increase over 1942 rates, though with almost a 10-fold increase in the mileage of roads during the period.

Current road surface erosion rates are computed to vary between 117 tons/mi^2/yr for the Middle North Fork to 331 tons/mi^2/yr for the Little North Fork. The eastern (upper watershed) portions of the North Fork and Middle Fork Planning Watersheds typically had rates below the watershed average, while the lower portions of all three forks and all of the South Fork and Lower Mainstem had rates greater than the watershed average.

Skid Trail (Hillslope Harvest) Surface Erosion Results

The largest harvest rate occurred in the 1942 period, when 35,030 acres or 46% of the watershed area was cut. Since then, harvest rates declined steadily between 1942 and 1988, and then jumped dramatically in the 1989-1999 period, when 42% of the watershed was harvested, as shown in Figure 5. The most intensive harvest has been in the South Fork Planning Watershed: 76% of the entire Planning Watershed was harvested, and in the Campbell Creek subwatershed, multiple entries during the 11-year period resulted in the equivalent of 110% of the subwatershed harvested. Over 80% of Smith Creek, Redwood Creek, and the Middle South Fork subwatersheds were harvested during that period. The total harvest in the watershed for the 58 year period from 1942 to 1999 was 106,154 acres or 139% of the total watershed area, reflecting that a number of areas have been harvested several times.

The computed surface erosion from skid roads in harvest units suggests a peak in surface erosion coinciding with high harvest rates in the 1942 period, with declining amounts since then. Currently, it is estimated at 15 tons/mi^2/yr. Very little surface erosion was generated in the 1979-1988 period (1,927 tons), but the amount increased to 16,439 tons in the 1989-1999 period due to the major increase in harvest rates. During the 67-year period, GMA estimates that 270,387 tons of sediment eroded from harvest area skid trails, nearly half of this prior to 1942, and one quarter during the 1943-1952 period. This reflects an overall average unit rate of 33.7 tons/mi^2/yr for the 67 year period. The highest rates were in the 1933-1942 period (110 tons/mi^2/yr), with the greatest production and unit rates in the South Fork Planning Watershed (over 80,000 tons or 209 tons/mi^2/yr). High production was also seen in the North and Middle Fork Planning Watersheds, although about one quarter of that produced in the South Fork Planning Watershed. High unit rates were also seen in the Lower Ten Mile Planning Watershed (101 t/m^2/yr). These high rates were also seen in the Lower Ten Mile Planning Watershed in the 1943-1952 period. Skid road erosion increased in the Middle Fork Planning Watershed in the 1943-1952 period, then decreased slightly in 1953-1965.

FIGURE 4

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

Computed Road Surface Erosion by Study Period

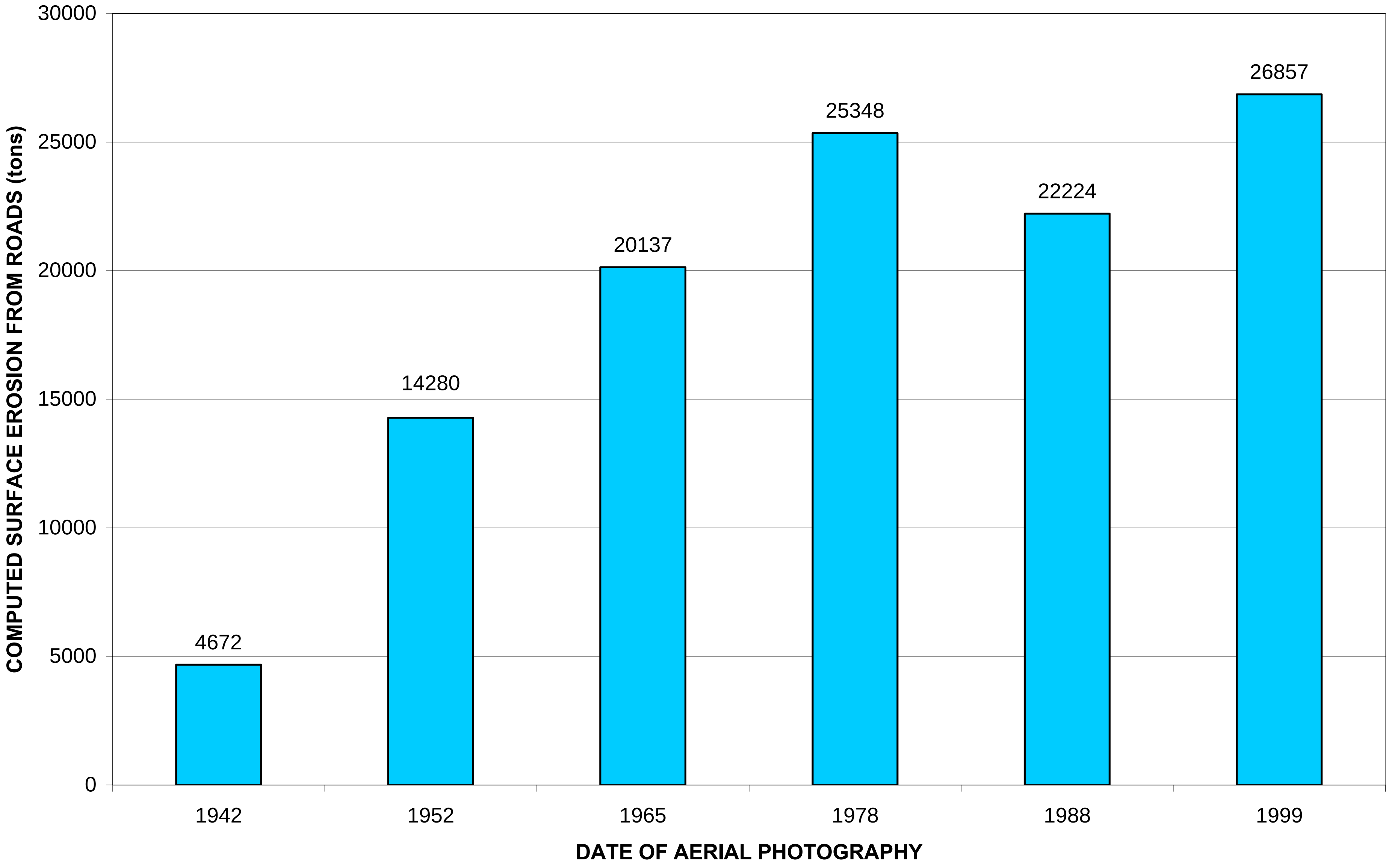
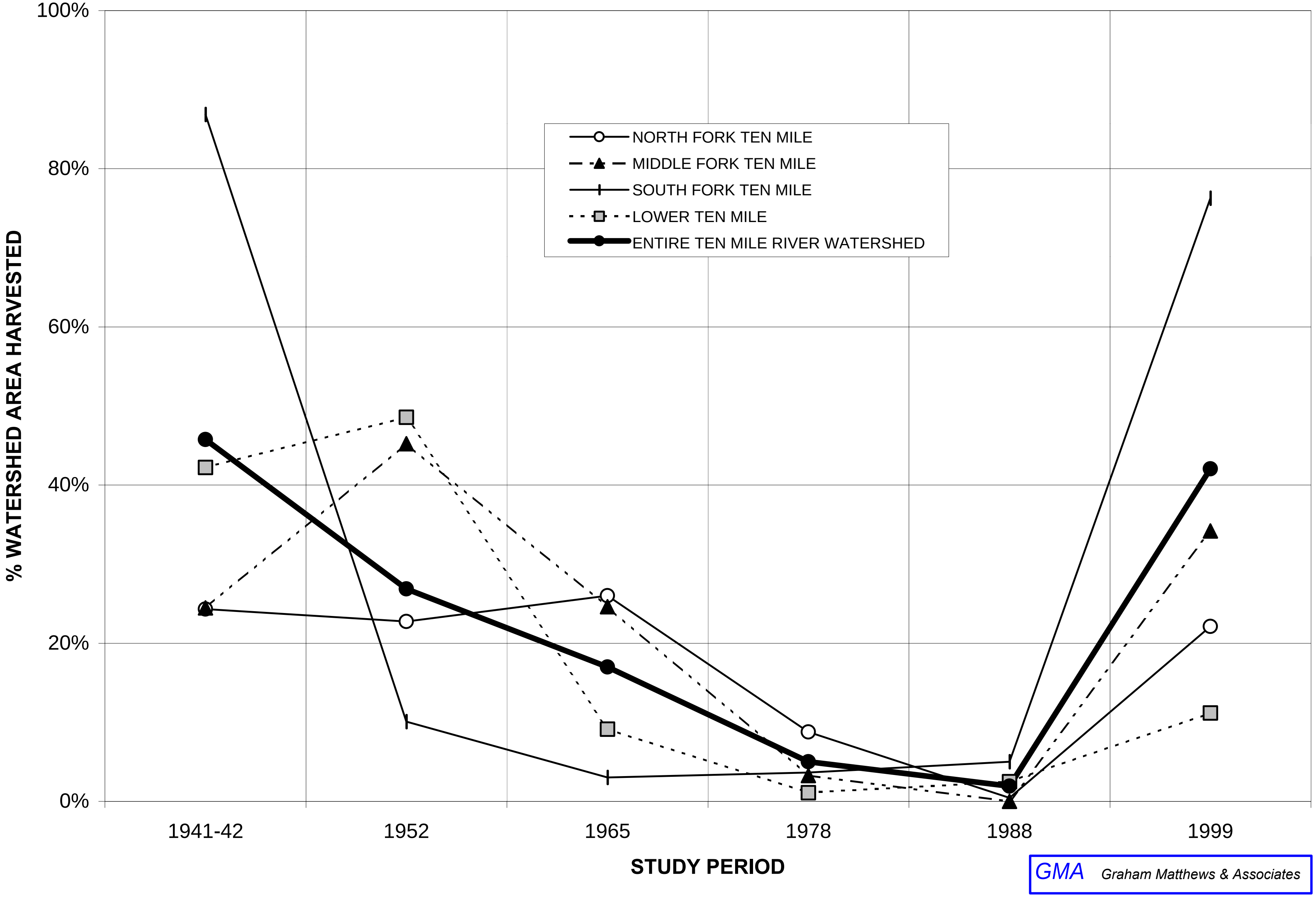


FIGURE 5
TEN MILE RIVER SEDIMENT SOURCE ANALYSIS
Harvest History of Planning Watersheds by Study Period



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Erosion was still somewhat high in the North Fork Planning Watershed through 1965. Skid road erosion dropped off considerably in the next two periods, from a high of nearly 8,000 tons in the 1966-1978 period in the North Fork Planning Watershed, to a high of 1,600 tons in the 1979-1988 period in the South Fork Planning Watershed. During the most recent period, production increased substantially, with the majority of the erosion in the South Fork Planning Watershed (nearly 12,000 tons, or 28 tons/m^2/yr). During the 1989-1999 period, over 20,000 tons of sediment was produced, which was about 7.5% of the total for the 67-year period.

Fluvial Erosion Results

GMA used fluvial erosion rates developed for the Noyo River, which had been extrapolated from preliminary data from Mendocino Redwoods Company (C. Surfleet, pers. comm. 1999, in GMA 2000) to arrive at a unit area factor of 200 tons/mi^2/yr, which is the best information currently available for the watershed. Over the 67 year budget period, this accounts for about 1.6 million tons.

Change in Channel Storage Results

Due to the confined nature of most of the main channels of the three forks of the Ten Mile River, fluvial-induced change in alluvial storage in these areas (i.e., bank erosion or channel deposition) is considered a relatively small portion of the sediment budget for these portions of the watershed. This is not the case for the lower reaches of the North Fork, South Fork, and the entire mainstem, where much more extensive alluvial deposits are present. Little change in the position or vegetation characteristics of the South Fork were seen between 1942 and 1999, suggesting that lower precipitation and lower slopes combine in a more stable floodplain setting. This may also have resulted from less intensive activities right in or adjacent to the channel, as was clearly the case in the North and Middle Forks. Along much of the Lower South Fork, the valley floodplain was wide enough for the early railroads to be set well back from the channel on relatively gentle land and materials excavated in construction of the grades were not dumped directly into the channel.

Compared to landsliding volumes, change in storage volumes are likely to be rather small. GMA estimate that 608,000 tons of sediment were removed from the channel when it widened between 1938 and 1974. Assuming that most of this floodplain has been recreated since 1974, as suggested by the dense riparian corridor currently existing along almost the entire channel, then storage increased by an approximately equal amount during the period 1975-1999.

TOTAL SEDIMENT LOAD AND SEDIMENT YIELDS

Overview

Typically, 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 a gaging station over a designated time frame or several time periods (Reid and Dunne, 1996, in GMA 2000). 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 Ten Mile River watershed, these can be divided into four primary processes or sediment delivery mechanisms: 1) mass movement (landslides), 2) fluvial erosion (i.e., stream bank erosion), 3) surface erosion (rills and sheetwash) and 4) land management activities which directly place sediment in stream channels.

The first three processes can deliver sediment to stream channels both naturally and as a result of land use activities. Sediment production by mass movement processes occurs commonly during large, infrequent storm events, whereas fluvial and surface erosional processes can occur during small storms in virtually every water year or as a result of large storms. Direct sedimentation into stream channels by heavy equipment involved with road/railroad construction and timber harvest was commonplace in the Ten Mile River watershed prior to 1974. After passage of the California Forest Practices Act in 1973, the practice of yarding logs down stream channels, which resulted in direct sedimentation into stream channels, was prohibited. However, many areas are still experiencing elevated sediment yields as a legacy of the former practices. The residence time of such introduced sediments is highly variable, but on the order of years to decades.

Inputs

Table 11 summarizes the Ten Mile River sediment budget, and Table 12 shows the average annual unit area rates. Overall sediment loading rate averaged 1,124 tons/mi^2/yr from 1933-1999. The sediment loading rate was much higher in the early periods, dropping to a current (1989-1999) rate of 629 tons/mi^2/yr (See Figure 6). Management inputs comprise about three-quarters of all the current inputs. Road erosion is currently the largest single component of the current loading rate (225 tons/mi^2/yr), as well as 38 tons/mi^2/yr for road-related landslides in the 1989-99 period, and it is the only component that has increased over the budget period. This represents about 42% of the current loading rate. Fluvial erosion is the next largest current component (200 tons/mi^2/yr), which represents about 32% of the current loading rate.

In previous time periods, the role of sediment delivery from landslides was much more significant, ranging from 40% to 77% of the estimated total sediment inputs. It comprises about 18% in the current period. Under current conditions, sediment loading from road surface erosion is estimated to be almost double that of total landsliding (225 tons/mi^2/yr v. 113 tons/mi^2/yr).

Nearly 70% of the landsliding is management-related under current conditions (or about 12% of the current input total). Over the entire budget period, it averaged about 95%. About half of the sediment inputs for which estimates were developed are management-related under current conditions.

Figure 6 illustrates the changes in input rates over the study period. With the exception of the 1953-1965 period, the overall trend is one of decreased sediment inputs.

TABLE 11

TEN MILE RIVER WATERSHED SEDIMENT SOURCE ANALYSIS

Sediment Input Summary

PERIOD YEAR	INPUTS														AVERAGE INPUT RATE (tons/mi2/yr)
								SURFACE EROSION							
	BKGRND LANDSLIDES* (tons)	TOTAL MGMT LANDSLIDES (tons)	HARVEST-RELATED LANDSLIDES (tons)	SKID TRAIL-RELATED LANDSLIDES (tons)	ROAD/RR-RELATED LANDSLIDES (tons)	GRAZING/ UNDETMD. LANDSLIDES (tons)	TOTAL LANDSLIDES (tons)	BKGRND* (tons)	SKID TRAILS (tons)	ROAD (tons)	FLUV/BANK EROSION* (tons)	TOTAL NON-MGMT INPUTS* (tons)	TOTAL MGMT INPUTS (tons)	TOTAL INPUTS (tons)	
1933-1942	31,886	1,338,112	1,042,403	42,330	250,289	3,090	1,369,998	89,700	131,361	46,270	239,200	360,786	1,515,743	1,876,529	1,569
1943-1952	53,078	769,651	427,045	29,246	302,033	11,327	822,729	89,700	60,876	142,800	239,200	381,978	973,327	1,355,305	1,133
1953-1965	26,474	1,857,203	903,814	72,952	880,047	390	1,883,677	116,610	43,025	261,781	310,960	454,044	2,162,009	2,616,053	1,683
1966-1978	389	423,010	154,865	175,416	91,935	794	423,399	116,610	12,983	329,524	310,960	427,959	765,517	1,193,476	768
1979-1988	5,525	582,934	398,891	57,823	126,220	-	588,459	89,700	1,927	222,240	239,200	334,425	807,101	1,141,526	954
1989-1999	-	149,370	87,030	11,810	50,005	525	149,370	98,670	20,215	295,427	263,120	361,790	465,012	826,802	628
	2%	98%	58%	7%	32%	0%	100%								
TOTAL	117,352	5,120,280	3,014,048	389,577	1,700,529	16,126	5,237,632	600,990	270,387	1,298,042	1,602,640	2,320,982	6,688,709	9,007,000	1,124
	1%	57%	33%	4%	19%	0%	58%	7%	3%	14%	18%	26%	74%	100%	

Source: GMA 2000

Notes:
- -- Mass Wasting derived from landslides mapped from aerial photographs taken at the end of each budget period Eastern portions of the watershed were not covered by the photographs in 1942, though the area was relatively undisturbed. See text for details.
- -- Background rates (containing creep, surface erosion by sheetwash and rilling, and deep-seated landslide components) based on work of Roberts and Church (1986) and Cafferata/Stillwater Sciences (pers. Comm. 1999). Rate used is 75 tons/mi2/yr.
- -- Skid roads based on measured harvest areas on the 1942, 1952, 1965, 1978, 1988 and 1999 aerial photographs, delineated into 3 classes of skid road density. Harvest areas after 1988 are computed from GIS coverages developed by CDF.
- -- Road erosion computed from measured road miles in 1942, 1952, 1965, 1978, 1988, and 1999 aerial photographs. Roads after 1988 are based on GIS coverage developed from THP submitted to CDF, corrected to 1999 aerial mosaic developed by GMA.
- -- Bank erosion is based on a rate of 200 tons/mi/yr. This category includes bank erosion and smaller streamside mass movements under the canopy and generally not visible on aerial photography.
- -- Change in storage represents estimates of net change in channel dimensions based on aerial photographs, multiplied by length of alluvial reach
- -- Sediment Outflow computed from regional suspended sediment and bedload transport equations developed as described in the text and applied to combined synthetic flow records for the period 1952-1997. Pre-1952 values based on correlation with annual precipitation.
- -- Non Management Landsliding includes only "forest" categories. Actual non-management related landsliding could be higher: some landslides classified as >20 yr ol d harvest may be non management related
- -- *Non Management inputs include non management landsliding, background rates), and bank erosion. Some bank erosion is probably management related, but it is not possible to identify quantities.

TABLE 12

TEN MILE RIVER WATERSHED SEDIMENT SOURCE ANALYSIS

Sediment Input Summary-Average Annual Unit Area Rates

PERIOD YEAR	INPUTS													
	NON-MGMT LANDSLIDES* (tons/mi2/yr)	MGMT LANDLSIDES (tons/mi2/yr)	HARVEST-RELATED LANDSLIDES (tons/mi2/yr)	SKID TRAIL-RELATED LANDSLIDES (tons/mi2/yr)	ROAD/RR-RELATED LANDSLIDES (tons/mi2/yr)	GRAZING/ UNDETMD. LANDLSIDES (tons/mi2/yr)	TOTAL LANDSLIDES (tons/mi2/yr)	SURFACE EROSION BKGRND* (tons/mi2/yr)	SURFACE EROSION SKID TRAILS (tons/mi2/yr)	SURFACE EROSION ROAD (tons/mi2/yr)	FLUV/BANK EROSION (tons/mi2/yr)	TOTAL NON-MGMT INPUTS* (tons/mi2/yr)	TOTAL MGMT INPUTS (tons/mi2/yr)	TOTAL INPUTS (tons/mi2/yr)
1933-1942	27	1,119	872	35	209	3	1,145	75	110	39	200	302	1,268	1,568
1943-1952	44	644	357	24	253	9	688	75	51	119	200	319	814	1,133
1953-1965	17	1,194	581	47	566	0	1,212	75	28	168	200	292	1,391	1,683
1966-1978	0	272	100	113	59	1	272	75	8	212	200	275	492	767
1979-1988	5	487	334	48	106	-	492	75	2	186	200	280	675	953
1989-1999	-	114	66	9	38	0	114	75	15	225	200	275	353	629
1989-1999**	36	78	30	9	38	0	114	75	15	225	200	311	318	629
AVG 33-99	15	639	376	49	212	2	654	75	34	162	200	290	834	1,124
AVG 33-99**	36	618	355	49	212	2	654	75	34	162	200	311	814	1,124
	using average 1933-1952 rate													

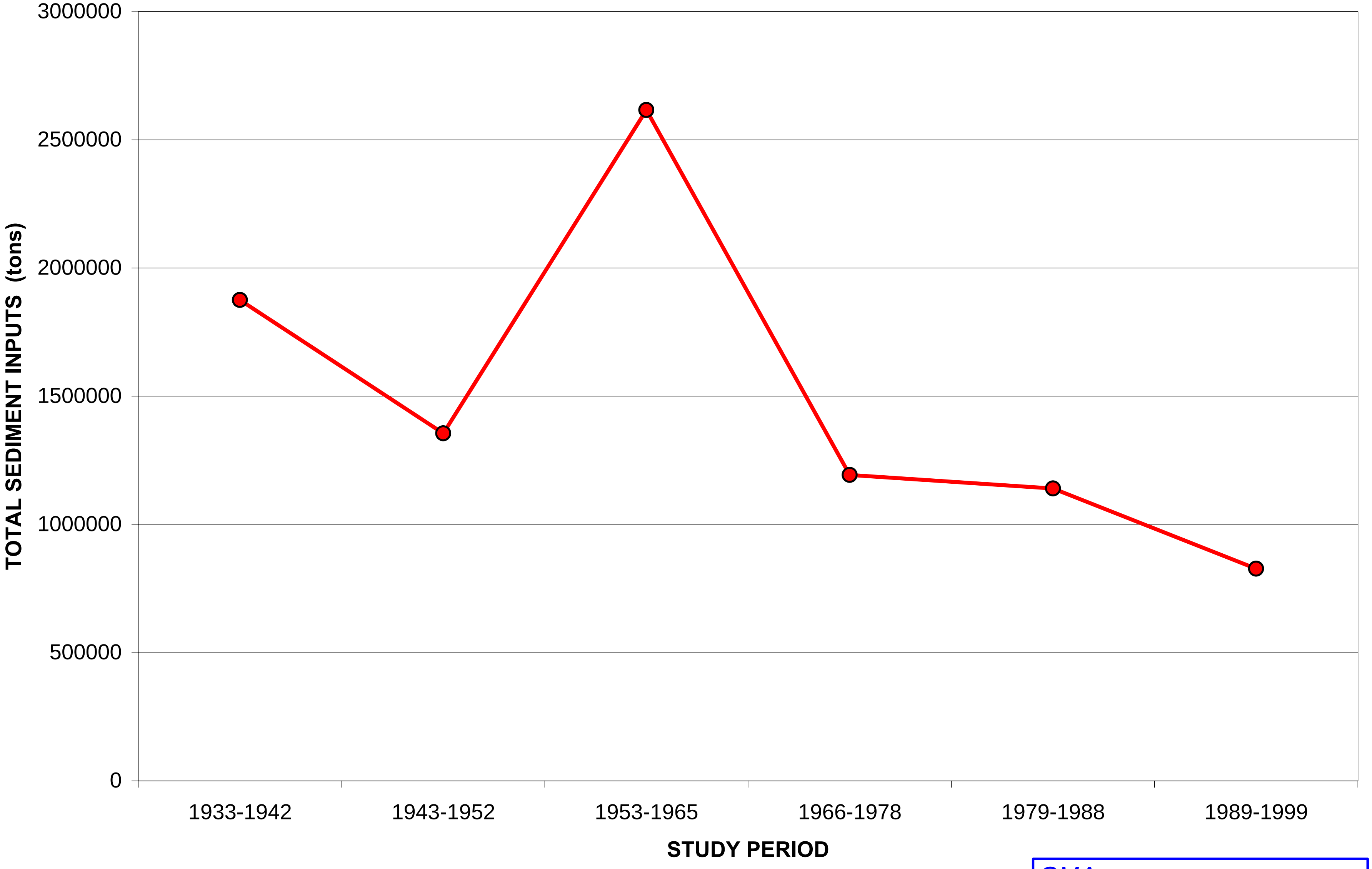
Source: GMA 2000

Notes:
See also notes to Table 11.
Non-Management inputs are the sum of non-management landsliding, background rates and bank erosion.
Some fluvial erosion is probably management-associated, but it is not possible to assign an amount to management v. non-management.
**Some management landsliding is probably non-management associated. In particular, some landsliding in the "harvest > 20 yrs" category is probably non-management associated (second-growth forest)
**Actual value of non-management landsliding is probably more accurately estimated at the average of the 1933-1952 rates, or 36 t/mi2/yr.

FIGURE 6

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

Estimated Total Sediment Inputs by Study Period



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Outputs and Sediment Budget

The output side of the sediment budget essentially estimates the amount of sediment that has been or carried through the stream flow and exported from the basin. The estimate was based on regional sediment transport equations, which were developed in this study through evaluation of other basins in the general area of roughly similar characteristics. This process provides data only slightly better than an order of magnitude estimate. Available evidence suggests that our sediment yield estimates may be low, but well within the likely range. It is provided primarily to provide a way of thinking about channel erosion and aggradation: if outputs are lower than inputs, then the leftover is stored in the channel; if outputs are greater than inputs, then the channel storage is being lost–that is, the banks and channel are eroding. Over time, this roughly balances when the channel storage component is considered, but it only provides a rough estimate.

Computed sediment yields (outputs) for the 67-year study period average 1,015 tons/mi^2/yr. In general, yields of this magnitude would be considered low in northern California, compared to values from the Eel, Mad, or Redwood Creek basins. However, available information on sediment yields for watersheds in the Mendocino coast suggests that these values are reasonable and perhaps slightly higher than nearby basins. Long-term yields for the Noyo River, with very similar characteristics, were 979 tons/mi^2/yr (GMA 1999, in GMA 2000) while for those for Caspar Creek fall in the same general range, with adjusted estimates of 793 tons/mi^2/yr (Cafferata/Stillwater Sciences, pers. comm. 1999, in GMA 2000). While it is possible that regional sediment transport data somewhat overestimate the sediment transport characteristics of the Ten Mile watershed, it is probable that the method used (involving mean daily flows instead of typically 15-min instantaneous flows) underestimates sediment transport due to the power relationship between flow and sediment.

The preliminary sediment budget for the Ten Mile River watershed between 1933 and 1999 is shown in Table 11. Detailed explanations for the various input and output elements can be found in GMA (2000). Estimated inputs total 9,007,000 tons over the 67-year period, while computed outflow is 8,093,000 tons. Although these values are surprisingly similar, evidence suggests that the sediment outflow may be over-estimated by the regional approach and underestimated by the computational method, with a net result to the output calculations that is unknown. At the same time, various input sources are likely to be underestimated, both because of information available and the limitations of the analytic techniques. Assigning a great deal of confidence to the sediment budget numbers because they are quite similar, would a mistake given the uncertainties in certain methods and assumptions used. What the sediment budget may suggest, since the numbers are nearly balanced, is that much of the sediment generated during the 1940s-1970s pre-Forest Practice Rules period has likely flushed through the system (GMA 2000).

CHAPTER V
LINKAGE ANALYSIS

This chapter analyzes the relationships between hillslope processes and in-stream effects. In Chapter III, water quality targets are defined that interpret the applicable water quality standards for sediment. Load allocations are established in Chapter VI that establish limits on the allowable sediment loading from various watershed sources. The linkage analysis provides the basis for calculating the loading capacity of the water body (the TMDL) and the load allocations that, when met, will result in the reductions in sediment that are needed to attain water quality standards for sediment.

Although the best available science does not yet provide for a mathematical linkage between sediment loadings and instream water quality, there is a clear qualitative basis for the linkage. EPA is describing this linkage for the Ten Mile River using best available information in a weight-of-evidence approach. There are correlations between timber harvest and landsliding rates and between watershed disturbance in the basin and the proportion of fine sediment in the stream channel bottom. Correlations are also apparent between the water quality indicators and coho presence/absence.

Little information is available to select an appropriate reference period in the Ten Mile River basin to determine loading capacity. Management activities were intensive and occupied much of the basin in the early part of the century, but we do not have adequate information to determine any appropriate loading rate based on water quality conditions at the time. Existing information is limited to a single source suggesting that there were over 6,000 coho in the early 1960s, while there are only somewhere between 14-351 today. Furthermore, it appears that chinook were native to the basin, but were extirpated well before the period for which we have any loading rates, which suggests that the loading rates may have been too high for the fishery at a very early time. Thus, EPA is not determining a loading rate based on an historical period in the Ten Mile River basin. In addition, there is no currently-unmanaged basin in the Ten Mile watershed that can serve as a reference condition.

Salmonids were still abundant in the Noyo and its tributaries during the 1933-1957 period, so the corresponding sediment yield during this period must have been sufficiently low to allow salmonid habitat of suitable quality to persist (EPA 1999). In the Noyo River TMDL for Sediment, the total sediment yield during this period was estimated at 470 tons/mi^2/yr and the natural sediment yield was estimated at 370 tons/mi^2/yr (EPA 1999). The loading capacity for the Noyo is 125% of the background load. This ratio is then applied to the background levels in the Ten Mile River, because the two basins are close in proximity, and have similar characteristics of geology, vegetation, orientation, and land use history. Thus, the loading capacity for the Ten Mile basin is determined to be 125% of the estimated background rate. The background rate for the Ten Mile is 311 tons/mi^2/yr. Loading capacity for the Ten Mile is determined to be 125% of background levels, or 390.

In summary, the linkage analysis for the Ten Mile River TMDL is based on the following:

- The correlation between substrate quality (% fine sediment < 0.85 mm) and watershed disturbance.
- Decreased sediment loading is expected to improve salmonid habitat
- Comparison with the Noyo River Basin
- Road-related sediment

Correlation Between Substrate Quality and Watershed Disturbance

Excess sediment loading from management activities is an important cause of water quality decline on the Mendocino Coast. Decreased sediment loading is expected to improve water quality conditions, which should also result in improved salmon habitat, and potentially increased salmon populations.

The correlation between substrate quality (% fine sediment < 0.85 mm) and watershed disturbance suggests that decreased watershed disturbance will result in decreased fine sediment concentrations. As has been true in the past, based on the source analysis, it is expected that the decreased loading required by the TMDL will result from decreased disturbance in the future, which will in turn result in increased substrate quality.

Substrate quality is one of the few direct sediment measurements that is available in the Ten Mile basin. In an effort to determine whether a correlation exists between substrate quality and relative level of watershed disturbance, GMA (2000) analyzed the data from each of the 20 G-P/Campbell Timberlands sediment monitoring stations. GMA defined “watershed disturbance” as a product of road density, percent of subwatershed that had been harvested in the 1989-1999 period, and the unit area volume of landslides mapped for the 1989-1999 period.

Figure 7 shows the relationship between relative disturbance index and substrate quality for the subwatersheds for which data were available. Although there is a considerable amount of scatter in this relationship, the correlation is apparent. Further review of the relationship suggested that two distinct groupings of subwatersheds appeared to exist. Figure 8 subdivides these groupings, which may represent areas with different sensitivities to disturbance. Thus, the analysis suggests that certain subwatershed areas may be less sensitive to disturbance than others (GMA 2000).

The Ten Mile River sediment source analysis (GMA 2000) shows that decreasing rates of disturbance and improved practices over time in the Ten Mile basin have resulted in lower sediment delivery rates. Hines (2000, in GMA 2000) hypothesizes that, where fine sediment concentrations are decreasing, it is the result of continuing long-term recovery from previous intensive disturbances. EPA anticipates that additional reductions in disturbance and continued improvements in practices and restoration projects will result in additional sediment reductions, which will improve instream conditions. Development of a more sophisticated disturbance index utilizing improved road and fluvial erosion sediment delivery values could well result in a stronger correlation, which could provide a basis for prioritization of sediment reduction efforts throughout the watershed (GMA 2000).

FIGURE 7

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

RELATIVE DISTURBANCE INDEX VS. SUBSTRATE QUALITY

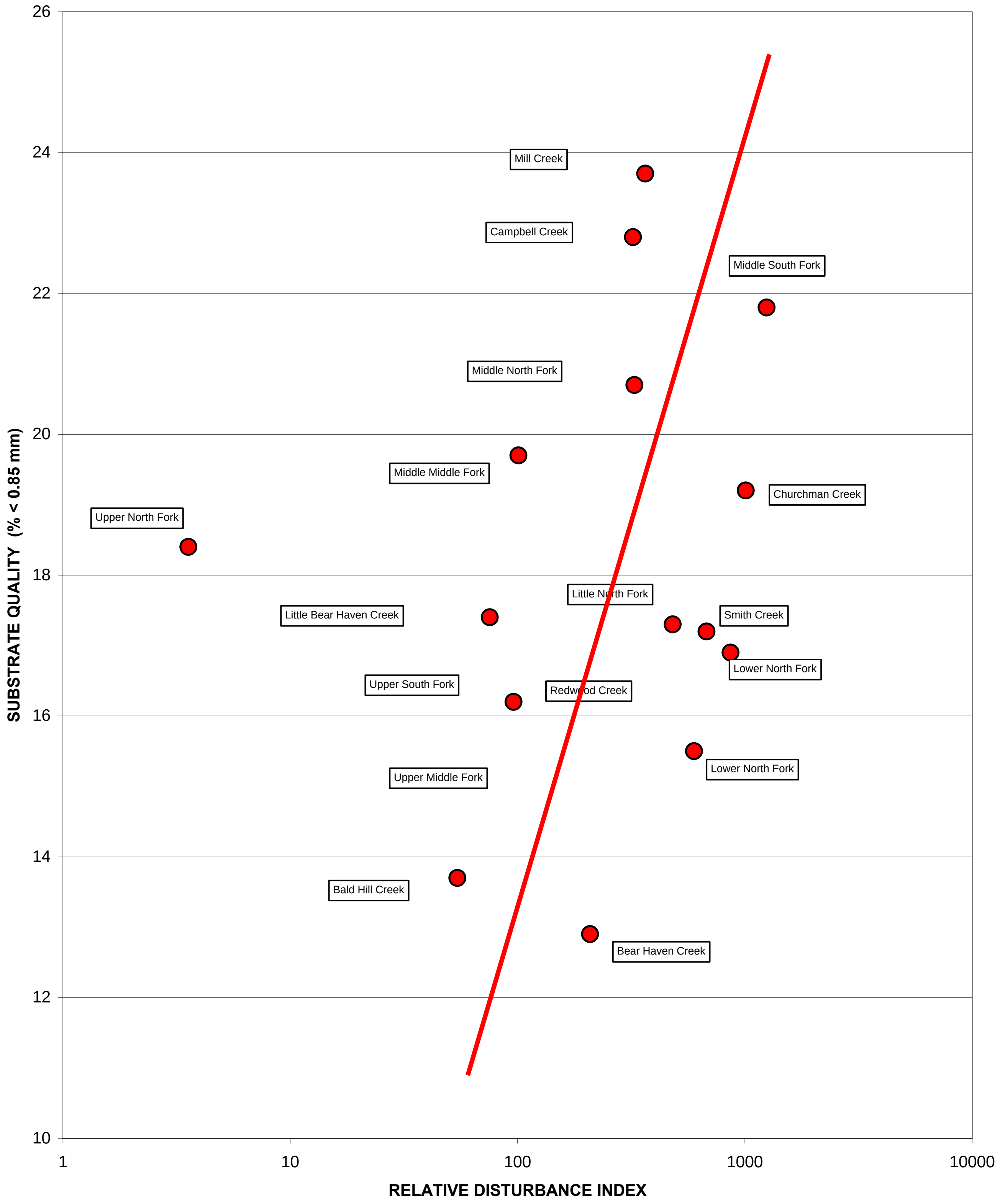

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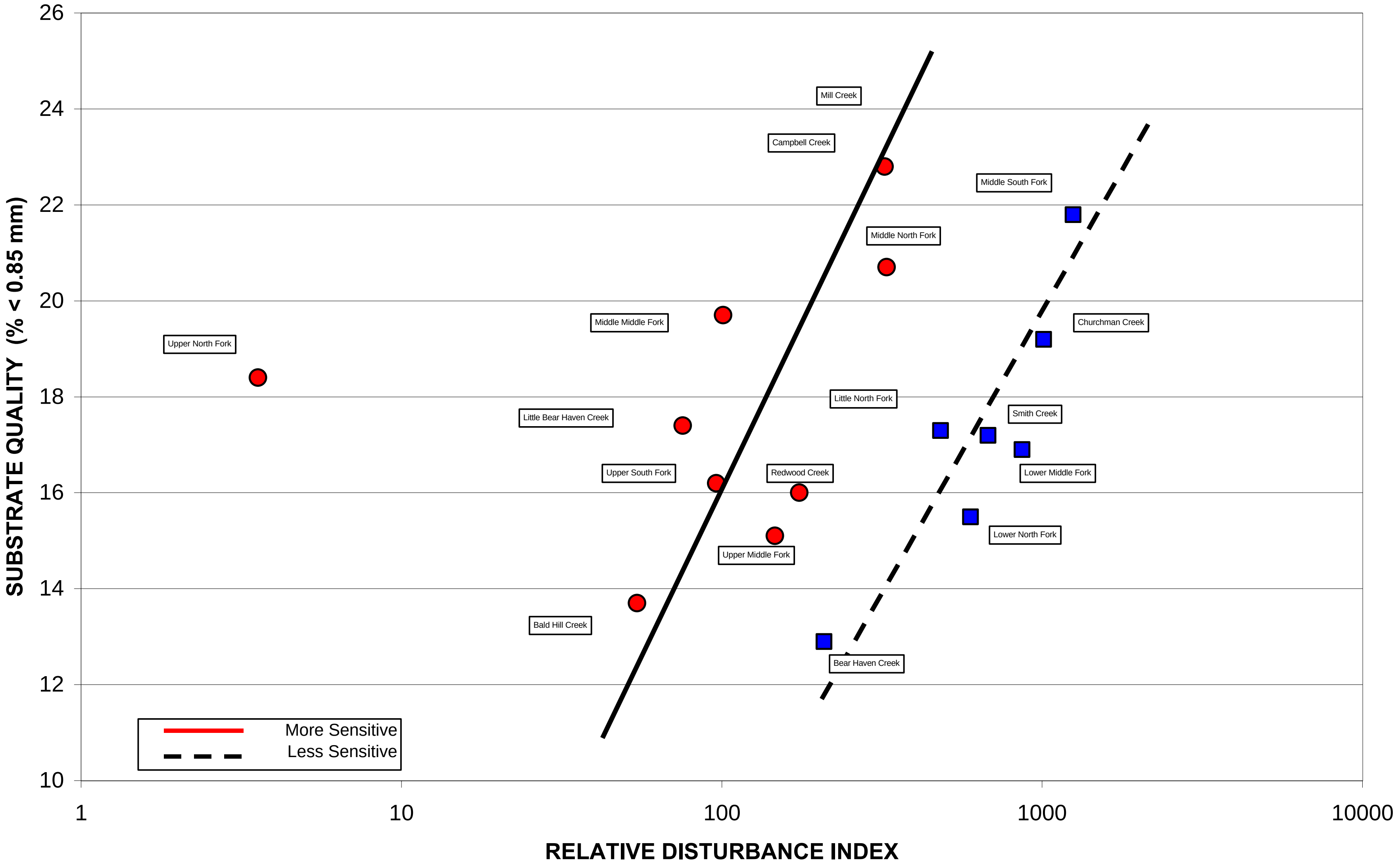
FIGURE 8

TEN MILE RIVER WATERSHED

RELATIVE DISTURBANCE INDEX VS. SUBSTRATE QUALITY



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Critical Habitat Parameters and Coho Abundance

Mangelsdorf and Clyde (2000) compared habitat and other conditions with coho presence/ absence information, where available for stream reaches within the Ten Mile. Coho are generally present in Little North Fork, Bear Haven Creek, Smith Creek, Campbell Creek, the Middle Fork and South Forks, and Churchman Creek. With the exception of Churchman Creek, all of these streams shared habitat characteristics. In general, the subwatersheds that contain the better coho streams (i.e., those in which salmon have been observed spawning and/or rearing with some recent consistency), tend to have lower sediment loading rates than most of the other subwatersheds in the basin over the past decade (see Table 7, p. 46). For example, Bear Haven Creek and Little North Fork, which are two of the best coho streams (i.e., coho are consistently found) have among the lowest loading rates over the 67-year study period, and lower than average for the past decade. Bear Haven Creek's loading rate in the recent decade is a third of the average. Loading rates for the past decade in Campbell Creek and Smith Creek are less than one-third average and just below average, respectively. The loading rates for these two subwatersheds has been consistently lower than average beginning in 1953. High rates in earlier periods may be related to the more intensive harvest during those periods, and lower rates since then may be related to recovery.

Coho are found in both the mainstem Middle and South Forks, though it is not clear exactly where in the mainstem they are found, and which subwatersheds this would correspond to. Overall, loading rates in the Middle and South Fork Planning Watersheds are just below average for the 67 year period. The Upper Middle Fork subwatershed is below average, while the Middle Middle Fork subwatershed is about average, and the Lower Middle Fork is above average. It may be that the Upper and Middle Middle Fork reaches are the better areas, but this is not known. In the South Fork, the Upper and Lower South Fork subwatersheds have loading rates well below average. The Middle South Fork subwatershed is slightly above average, but it may be within the range of tolerance, or this may be an exception, or it may be that coho are not found as consistently in this reach of the South Fork. Similarly, Churchman Creek has slightly higher than average loading rates. These two areas may be an exception, as is Churchman Creek an exception relative to habitat data.

Additional data and analysis may reinforce the linkage, or may suggest other factors that influence the linkage. For example, Lower North Fork, Little Bear Haven Creek and Redwood Creek subwatersheds have lower than average loading rates, but surveys have been inconsistently conducted in those stream reaches.

Comparison with the Noyo River Basin

Geology and land use conditions in the Ten Mile basin are similar in many ways to those in the Noyo River basin. The reference time period used to calculate sediment loading capacity for the Noyo River TMDL was based on a period when salmonids were still relatively abundant, so sediment loads were apparently low enough that loading capacity had not been exceeded. There is no similar time period for the Ten Mile, since chinook were apparently extirpated prior to the 1950s. In the Noyo River TMDL, the period of 1933-1957 was chosen as a reference period, despite the watershed impacts associated with earlier old growth logging, due to several factors.

First, anecdotal information suggested that coho were well represented in the basin in this period. It was a relatively less disturbed period in the basin history. Second, it was assumed that good coho populations were accompanied by adequate instream habitat. Third, aerial photos existed for this period from which to estimate sediment delivery. Fourth, the analysis of sediment delivery allowed for the development of a relationship between management and background sediment delivery rates. The loading rate during this period was approximately 470 t/m^2/yr. The background loading was estimated at 370 tons/mi^2/yr. The loading capacity of 470 tons/mi^2/yr is approximately 25% higher than background.

EPA is estimating the loading capacity for the Ten Mile river based on the judgement that a water body can assimilate a certain proportion of load over its background rate while still meeting water quality standards. In the Noyo River, that rate is 125% over background. Because the basins are so close in location and so similar in vegetation, climate, geology and land use history, it is appropriate to assume that the rate of 125% over background levels would also be appropriately protective for the Ten Mile River.

Road-Related Sediment

Road-related sediment may be the largest current (and potentially future) source of sediment, and may be affecting the concentration of fine sediment in stream channels. GMA (2000) determined that sediment loading rates related to surface erosion from roads have generally continued to increase during the past several decades. This may also be associated with the generally high proportions of fine sediment found in stream bottom samples, since surface erosion from roads probably contributes more sediment in the finer size fractions. This increase appears to be generally related to the sheer number of roads, since road construction techniques have undoubtedly improved over past practices. In addition, more roads were built in the last decade, particularly in the South Fork, where harvest levels increased significantly as an approximately 50-year harvest rotation came on line. It is possible that affects from recent road building and timber harvest activities in the South Fork Planning Watershed have not yet been evident in the stream channel. This would be important to monitor over time. However, given that the Middle and North Fork Planning Watersheds are apparently still recovering from earlier harvest practices (Hines 2000, in GMA 2000), it may be more critical to protect hillslope conditions in those areas prior to and during timber harvest activities that may be expected within the next decade.

CHAPTER VI
TMDL AND LOAD ALLOCATIONS

This chapter establishes the loading capacity of the Ten Mile River for sediment and apportions it among the sources, after accounting for background loading. The TMDL and the load allocations are expressed as 10-year rolling averages due to the considerable year-to-year variability in sediment loading rates. Thus, although the annual TMDL could be converted into daily loads, expressing it as a rolling annual average more appropriately describes sediment loadings that can achieve water quality conditions than if it were expressed as a daily load.

CALCULATION OF THE TMDL AND LOAD ALLOCATIONS

For the Ten Mile River, EPA is defining the TMDL as the current loading capacity (i.e., the total loading of sediment that can be delivered to the river and still attain the applicable water quality criteria for sediment). The loading capacity (i.e., the TMDL) is apportioned among the various sources of the pollutant so as to focus attention on the sources that are influenced by human activities. In establishing TMDLs, EPA generally apportions the loading capacity among: (1) the background loading; (2) the wasteload allocations for point sources; and (3) the load allocations for non-point sources. For this TMDL, there are no point sources, so the wasteload allocations equal zero. Therefore, the TMDL for the Ten Mile River can be divided into the background loading and the load allocations.

Load allocations are expressed as an average over the entire watershed; however, the Regional Water Board may determine that its implementation measures could benefit by a distinction among the different Planning Watersheds, especially if additional information from other studies becomes available at a future time.

As discussed in the previous chapter, EPA is estimating the loading capacity as 125% of the background loading. EPA estimates that the bckground loading for the Ten mile River is 311 tons/mi^2/yr (see Table 12, p. 57). Thus, the TMDL (i.e., the loading capacity) is 390 tons/mi^2/yr, or 125% of 311, the background level. The amount available for load allocations, is 79 tons/mi^2/yr (390-311). The TMDL and load allocations are shown in Table 13. Because the allocations are lower than the estimated current loads, reductions of the current loads are likely. For informational purposes, Table 13 identifies the percentages of sediment reduction from existing estimated sediment loading rates which appear needed to implement each load allocation.

Summary

In summary, the TMDL = loading capacity = the sum of waste load allocations (from point sources) and load allocations (from nonpoint sources):

TMDL = ' WLA + ' LA + Background loading = 390 tons/mi^2/yr
' WLA (Waste Load Allocation) = 0, as there are no point sources in the basin.
' LA = 79 tons/mi^2/yr (management-related loads about a 75% reduction over current estimates)
Background = 311 tons/mi^2/yr

TABLE 13:
TMDL AND LOAD ALLOCATIONS

Based on 125% of background loading.

Source	Load Allocation tons/mi^2/yr	Current Load Estimate (1989-1999) tons/mi^2/yr	Percent Reduction Needed
LOAD ALLOCATIONS (MANAGEMENT-ASSOCIATED LOADS)	**79**	**318**	**75%**
TOTAL MANAGEMENT LANDSLIDING	34	78	56%
Harvest*	18	30	40%
Skid Trails	7	9	22%
Roads	9	38	76%
SKID TRAILS	12	15	20%
ROAD SURFACE EROSION	33	225	85%
BACKGROUND (NON MANAGEMENT-ASSOCIATED LOADS)	**311**	**311**	**0%**
NON-MANAGEMENT LANDSLIDING*	36	36	0%
SOIL CREEP	75	75	0%
FLUVIAL EROSION	200	200	0%
TMDL (LOADING CAPACITY)	**390**	**629**	**38%**

---

*Includes an adjustment to the estimate to more accurately reflect background rate, based on an average rate in the 1933-1952 period. See Tables 11/12 and text.

Load Allocations

EPA considered several factors in setting load allocations for various source categories, including the effectiveness of available methods of controlling sediment from the particular source category, the likelihood of future sediment delivery growth, the type of sediment that is likely to be delivered from a particular source, and the feasibility of monitoring to determine compliance with the allocations.

Load allocations are expressed for management-associated landsliding (harvest, skid trails, roads), road surface erosion, and surface erosion from harvest/skid trails. They are also expressed as percentage reductions from the current loads (based on the 1989-99 sediment delivery rates) to illustrate the estimated decrease needed to attain water quality standards. (See Table 13).

The allocations suggest that most of the needed reductions would come from road surface erosion. EPA estimates that a reduction of 85% is needed, based on estimates of current road surface erosion. This is currently the largest cause of sediment inputs to the system, and the only input that has continuously increased during the entire study period, and may likely increase further without additional controls as more harvest activity takes place in the North and Middle Fork Planning Watersheds. Increased surface erosion from roads would certainly contribute to continued decline in water quality conditions, particularly those related to fine sediment and sediment embeddedness, which relates directly to spawning and emergence success for salmonids. Additional sediment inputs would also contribute to the decline of the other identified critical habitat parameters. Improved methodologies for conducting road inventories and “storm-proofing” roads are now available to land managers which, if implemented, will lead to dramatic reductions in sediment from historic road-related loading rates (Weaver and Hagans, 1994). EPA has identified roads as a source amenable to aggressive sediment reduction efforts in other North Coast TMDLs as well. Thus, EPA has determined that aggressive treatment of road-related erosion is most appropriate for the allocations.

A reduction of about 75% in road-related landslide loads is also needed. For both road surface erosion and landsliding, some reductions can be made with continued treatment of roads, careful placement of new roads, maintenance of roads and stream crossings, upgrading roads and stream crossings to prevent hydrologic connectivity to watercourses, and potential for failure and diversion. New roads should also be constructed to these high standards (Weaver and Hagans 1994). Furthermore, attainment of the water quality targets will also lead to lighter sediment roads from these sources.

Harvest-related landsliding loads, which are more difficult to treat, need to be reduced by about 40%. Nevertheless, continued or expanded emphasis on cable yarding and minimization of tractor yarding, as well as avoidance of geologically unstable areas can result in minimization of landslides from harvest activities. Surface erosion from harvest areas/skid trails also needs to be reduced. Based on the load allocation of 10 tons/mi^2/yr, erosion from harvest areas/skid trails would need to be reduced by 20% below current levels.

CHAPTER VII
MARGIN OF SAFETY, SEASONAL VARIATION AND CRITICAL CONDITIONS

Section 303(d) of the Clean Water Act and the regulations at 40 CFR 130.7 require that TMDLs 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 regulations also require that TMDLs account for critical conditions for stream flow, loading, and water quality parameters. The margin of safety can be incorporated into conservative assumptions used to develop the TMDL or added as a separate, quantitative component of the TMDL (USEPA, 1991).

MARGIN OF SAFETY

As set forth in EPA guidance (EPA, 1991) the margin of safety can be incorporated into conservative assumptions used to develop the TMDL or added as a separate, quantitative component of the TMDL. This TMDL incorporates an implicit margin of safety through use of the conservative assumptions discussed in this chapter.

Targets

Water Quality Targets were chosen that consider a range of factors for the protection of water quality related to sediment. These include:

- Including a wide range of targets that are both primarily and secondarily related to sedimentation, such as substrate composition (primary), V* (primary), thalweg profile variation and habitat indicators (secondary);
- Selection of conservative water quality targets where the scientific literature supports them (e.g., percent fines);
- Conservative assumptions, where data are sparse, regarding which limiting factors are potentially affecting coho salmon; and
- Conservative assumptions with respect to the nature of the relationship between hillslope sediment production and in-stream effect.
- Because existing in-stream data are limited, the targets represent the optimal conditions for beneficial use support for salmonids.
- Inclusion of targets for watershed conditions (hillslope and roads), which will hinder additional sediment delivery into the water bodies.

Source Analysis

Conservative assumptions were made in the source analysis to account for uncertainty, as described by GMA (2000). In general, the assumptions resulted in attributing more of the observed sediment loads to management activities than is actually taking place. This reduces the amount estimated for background sources, and thus, the amount available for load allocations

TMDL and Load Allocations

EPA determined that historical loading rates analyzed for the study period in this basin were not appropriate to use as a reference period within the basin. There was no data that suggested a period during which water quality standards were apparently being met. A loading capacity and TMDL was selected that is lower than the sediment loading rates estimated for all periods within the basin between 1933-1999.

In the public review draft TMDL, EPA proposed two alternative approaches for establishing the TMDL and load allocations. The TMDL for Alternative 2 was is 80 tons/mi^2/yr less than Alternative 1, which was already based on conservative assumptions. By selecting alternative 2, EPA is effectively increasing the Margin of Safety.

Background loading from fluvial erosion is probably underestimated, since it is all assigned to non-management causes, and some bank erosion is probably management-related. Thus, no allocation is made for management-caused bank erosion, which essentially functions as a margin of safety for that particular source.

Annual and Seasonal Variation

Sediment delivery to stream varies annually and seasonally as a result of variation in precipitation and stream flow. There is also considerable spatial variation resulting from numerous factors, including: slope, geology, aspect, vegetation, soil type, etc. Surface erosion, including erosion from roads, occurs on an annual basis, but primarily as a result of winter rains. Surface erosion from ridge top roads, however, is much less likely to enter a watercourse than that from stream-side roads. Mass wasting occurs as a result of large storms, but is more likely in inner gorges and headwall swales, for example, than on gently sloping terrain. Because of the large temporal and spatial variation in precipitation, streamflow, erosion and sediment delivery, the sediment load allocations are designed to apply to the *sources* of sediment, not the movement of sediment across the landscape or delivery of sediment to the stream channel. Also, the load allocations are to be applied as 10-year rolling averages. Inherent annual and seasonal variation in the condition of the in-stream environment results from variation in sediment delivery, flow, and the longevity of large woody debris, for example. In addition, there is considerable spatial variation resulting from variation in channel slope, geology, aspect, vegetation, topography, etc.

The in-stream and hillslope targets established as part of this TMDL take into account this variation. The in-stream targets are indicators that are generally assessed during the summer months when stream flows are low and field crews can safely enter the stream for monitoring. The indicators are directly and indirectly related to factors potentially limiting the success of coho salmon in the Ten Mile River watershed. And they are all related to the issue of sedimentation, either as a primary factor (e.g., sediment composition) or as a secondary factor (e.g., large woody debris-formed habitat). Hillslope targets are specifically designed with variation in rainfall and peak flows in mind. Road crossing failure and flow diversion targets will require regular assessment of road facilities before and after the effects of storms of a specific recurrence interval (e.g., 10 years). Conformance with the disturbance area and hydrologic connectivity targets can be assessed remotely via GIS, for example. However, they specifically track critical changes in the landscape over time that influence the rates of erosion and peak flows resulting from variable climatic events.

It is difficult to accurately predict the specific impacts of sediment loading at particular times and places on particular salmonid life stages as they occur throughout a watershed. There are substantial and poorly defined spatial and temporal lags between sediment delivery and the occurrence of sediment–related impacts on beneficial uses. Therefore, the approach taken in this TMDL is to:

- Establish conservative in-stream targets that interpret narrative water quality standards and address the factors potentially limiting the success of salmonids in the Ten Mile River watershed, including factors that are secondarily related to sedimentation;
- Select hillslope indicators that are directly related to management-induced sedimentation, including targets associated with sediment delivery and hydrologic modification;
- Establish conservative hillslope targets based on scientific literature, reference streams, and best professional judgement; and,
- Establish conservative load allocations based on estimates of current and historic rates of sediment delivery.

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 the Ten Mile River basin. Therefore, the approach used in this TMDL to account for critical conditions is to include indicators that can address sediment sources and watershed conditions, addressing lag times from production to delivery, and which are reflective of the net long term effects of sediment loading, transport, deposition, and associated receiving water flows. Instream indicators may be effectively measured at lower flow conditions at roughly annual intervals, and hillslope indicators can assist in tracking the implementation of measures to improve water quality conditions. 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 changing the channel configuration so dramatically and suddenly that it effectively “recalibrates” the relationships between channel size and flow and sediment conditions for decades to follow. It may be appropriate for the State to reconsider the TMDL and associated allocations following such an event.

CHAPTER VIII
IMPLEMENTATION AND MONITORING RECOMMENDATIONS

Federal regulations require states to identify measures needed to implement TMDLs in state water quality management plans (40 CFR 130.6). EPA has established policies which emphasize the importance of timely development of measures to implement TMDLs that address nonpoint source discharges (memorandum from Robert Perciasepe, Assistant Administrator for Water, to EPA Regional Division Directors, August 8, 1997). EPA expects the State of California to develop and ensure the prompt implementation of source control measures adequate to achieve the allocations in this TMDL.

EPA expects that the State of California will develop implementation measures, and incorporate the TMDL and implementation measures into the Basin Plan, as required by 40 CFR 130.6. The State of California should also establish a monitoring and evaluation plan that identifies parties responsible for implementation and monitoring and establishes a time frame for Regional Water Board review of monitoring results. EPA encourages the Regional Water Board to employ an adaptive monitoring approach.

As part of the basin plan amendment process, EPA recommends that the State involve the National Marine Fisheries Service (NMFS), to review the actual implementation and monitoring measures to ensure that they are protective of salmonids.

Specific Recommendations for the Ten Mile River Basin
Achieving the TMDL would also be facilitated by continued improvements in management practices, including harvest practices that minimize ground disturbance, continued watershed and stream restoration, such as closing roads that are no longer needed, hydrologically disconnecting temporary roads, upgrading road crossings, including larger culvert sizes and decreasing diversion potential, upgraded road surfacing and upgraded drainage on older roads that are still needed.

The Regional Water Board's implementation of the TMDL could include additional site-specific inventories of roads and other sediment delivery areas, so that if particular locations are already found to be meeting load allocations, then additional sediment reductions will not be necessary. Alternatively, inventories might serve to further identify sources of sediment that are producing greater than the designated load allocations, and can readily be corrected.

Mangelsdorf and Clyde (2000) determined that coho salmon habitat in the Ten Mile River watershed could be significantly improved with reductions in sediment delivery, protection and improvement in riparian functions, increases in large woody debris for sediment metering and habitat, and modification of stream channel type.

Mangelsdorf and Clyde (2000) identified potential watershed improvements below for each of the tributaries of the Ten Mile River watershed, divided by priority. High priority streams are refuge streams or streams tributary to refuge streams. Moderate priority streams are non-coho streams with habitat characteristics that could be improved for coho salmon or streams that are tributary to restorable coho streams. The main forks are low priority streams since improvements in upstream sediment delivery, sediment metering, and stream temperature are necessary before significant instream changes can be expected.

High priority streams

1. The Little North Fork Ten Mile River is one of the watershed's strongest coho streams. It appears that were sediment delivery rates reduced, habitat conditions could be significantly improved: lower percentage of fines (<0.85 mm) in the substrate, lower embeddedness, and deeper pools. The tributaries to Little North Fork Ten Mile River may be significant sediment contributors.

2. Bear Haven Creek is another of the strongest coho streams in the watershed. With the exception of limited backwater pools, the primary issue of concern in Bear Haven Creek appears to be aggradation. Sediment delivery reductions in the Bear Haven Creek basin should be a high priority. Improvements to LWD volumes may also improve sediment metering and backwater pool formation.

3. Smith Creek and Campbell Creek are two other strong coho streams in the Ten Mile River watershed. Habitat conditions could potentially be improved by reducing fine sediment loading and improving the sediment metering and scouring functions of the stream channels with an increase in LWD volume. Temperatures in Campbell Creek could potentially be improved by increasing the streamside canopy.

4. Habitat conditions in Churchman Creek could potentially be improved by reducing fine sediment loading and improving sediment metering and scouring functions of the stream channel with an increase in LWD volume.

5. In Blair Gulch, Barlow Gulch, and Buckhorn Gulch, most reported habitat characteristics are not favorable to coho salmon. Only the streamside canopy and stream temperatures of these tributaries favor the presence of coho. These tributaries may also be significant contributors of sediment to Little North Fork Ten Mile River. Thus, they should be a high priority for sediment delivery reduction. A major conversion of channel type from F-type channel to C-type channel might provide greater salmonid habitat (if this is gemorphically appropriate). However, the significance of the effort would make this a low restoration priority. Coho salmon have been observed in Buckhorn Creek once before. As such, instream restoration work in Buckhorn Creek may take precedence over the others in this list.

6. McGuire Creek does not appear to offer significant potential coho habitat. It does, however, appear to be substantially aggraded and may be contributing to elevated sediment downstream in the Little North Fork Ten Mile River. As such, McGuire Creek should be a high priority for sediment delivery reduction.

Moderate priority streams
Bald Hill Creek is in many respects similar to the Little North Fork except for the absence of C-type channel. It may be possible appropriate to modify conditions and convert some of the F-type channel found in Bald Hill Creek to C-type channel, but it will not regain access to its former floodplain, which is now a defined terrace. Most significantly, Bald Hill Creek could benefit from LWD placement for improved scouring. Sediment delivery reduction does not appear to be a high priority here. Coho salmon have been observed here once before.

Habitat conditions in Little Bear Haven Creek could potentially be improved by reducing sediment delivery and improving sediment metering and channel scouring abilities with an increase in LWD volume. Little Bear Haven Creek has C-type channel and thus may have potential as a coho stream.

Habitat conditions in Redwood Creek could potentially be improved by reducing sediment delivery and improving sediment metering and channel scouring abilities with an increase in LWD volume. Improvements to streamside canopy may improve instream temperatures, as well. Coho salmon have been observed here once before.

Bald Hill Creek, Little Bear Haven Creek and Redwood Creek are streams in which coho currently appear to be absent but in which coho may have spawned and reared in the recent past. As such, the restoration of these streams as coho streams is a relatively important endeavor.

Cavanough Gulch, O'Connor Gulch, Gulch 8, Gulch 11, Gulch 19, Gulch 23, and Patsy Creek do not appear to offer significant potential coho habitat. They do, however, appear to be substantially aggraded and may be contributing to elevated sediment downstream in the North Fork Ten Mile River.

Booth Gulch and Gulch 27 do not appear to offer significant potential coho habitat. They do, however, appear to be substantially aggraded and may be contributing to elevated sediment downstream in the Clark Fork Ten Mile River.

Additional Monitoring Needs

Mangelsdorf and Clyde (2000) also identified additional data needs in the basin. The habitat inventories available for the Ten Mile River watershed provide an extraordinary snap shot of habitat conditions. Similarly, the population data, temperature data, and substrate composition data are incredibly useful for understanding conditions and trends in the basin. The availability of each of these data sets in electronic form for each of the years in which they were collected would vastly improve the ability of Regional Water Board staff to analyze it. Some additional parameters that would help better understand changes in sedimentation in the basin include: longitudinal profiles, cross-sections, V*, and LWD volume and distribution, analysis of aquatic invertebrate indices, and embeddedness. Locations where substrate data could confirm suspected aggradation include: Blair Gulch, Barlow Gulch, McGuire Creek, Cavanough Gulch, O'Connor Gulch, Gulch 8, Gulch 11, Gulch 19, Gulch 23, and Gulch 27.

Continued and improved spawning, rearing, and outmigrant salmonid population studies are necessary to keep close track of the success of the few remaining native coho salmon. In addition, expansion of the habitat inventory procedures may provide additional insight.

Most critical are the roads indicators, which, if target conditions are met, could result in significant reductions in sediment delivery to the streams. Investigating current conditions and potentially conducting site-specific sediment source analyses will provide a sense of the scope of the additional sediment reductions that can be made.

Most of these suggestions would also facilitate tracking the water quality targets.

CHAPTER IX
PUBLIC PARTICIPATION

Federal regulations require that TMDLs be subject to public review (40 CFR 130.7). The State of California and EPA have provided for public review through several mechanisms.

To date, EPA has solicited the following public involvement.

- Telephone and face-to-face meetings were conducted with landowners in the watershed and citizens groups concerned with the watershed and with the Mendocino Coast (1999-2000).

- A public meeting, advertised in local media as well as by directly contacting interested participants, was held in the Fort Bragg Town Hall. EPA provided an overview of the TMDL process for the Ten Mile River, Regional Water Board staff described the results of their Aquatic Conditions Assessment, and Graham Matthews, of Graham Matthews & Associates (GMA) presented the results of his sediment source analysis. The public was encouraged to comment on the findings. (August 2000).

- A public notice of the availability of the TMDL was directly mailed to a broad group of individuals and organizations, and was made available on EPA Region IX's web site.

- The draft TMDL and supporting documents were also placed at local libraries and public agencies. The supporting documents are: The NCRWQB's Ten Mile River chapter of its Mendocino Coast Assessment of Aquatic Conditions (Mangelsdorf and Clyde 2000) and Graham Matthews & Associates Sediment Source Analysis (GMA 2000).

- A formal 30-day public comment period was provided, and the public was invited to submit comments.

- When the draft TMDL was completed, it was directly mailed, along with supporting documents, to a small group of people, primarily watershed residents and managers, and others who requested it. The draft TMDL was also posted on EPA Region IX's web site during the formal comment period.

- A public meeting, advertised in local media as well as by directly contacting interested participants, was held November 21, 2000 to present the proposed TMDL and to answer questions. This meeting was also widely announced.

Several changes were made to the final document as a result of public comment. These include: a brief discussion of the informal consultation with the Services under the Endangered Species Act; clarification of the text related to the status of coho salmon in the basin; changes to the habitat characteristics targets to strengthen water quality protection; additional habitat characteristics indicators; clarification of the temperature-related habitat characteristics indicator;

clarification of one hillslope indicator; two additional hillslope indicators; additional detail of the source analysis; and selection of the more conservative of two proposed allocations methods. Tables 1 (Water Quality Targets), 3 and 4 (Habitat Characteristics Target Values and Current Values), 11 and 12 (Sediment Input Summary and Annual Unit Area Rates), and 13 (TMDL and Allocations) were modified to reflect the chosen TMDL and allocations levels, and additional detail from the source analysis. Table 14 (alternative proposed TMDL) was deleted.

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GLOSSARY

Aggradation	To fill and raise the elevation of the stream channel by deposition of sediment.
Alternative prescriptions	Timber harvesting methods, including site-specific regeneration or intermediate treatment methods, that accomplish the goals of the Forest Practices Act in a more effective or more feasible way than the standard silvicultural methods.
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, as designated in the Basin Plan, of waters of the state that may be protected against quality degradation including, but not limited to, domestic, municipal, agricultural and industrial supply; power generation; recreation; aesthetic enjoyment; navigation; and the preservation and enhancement of fish, wildlife and other aquatic resources or preserves.
Basin Plan	The *Water Quality Control Plan, North Coast Region-- Region 1.*
Cable yarding	That system of skidding (transporting) logs by means of cable (wire rope) to the yarding machine (yarder) or a landing while the yarder remains stationary.
CDF	The California Department of Forestry and Fire Protection.
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-laden debris, commonly caused by debris sliding or road stream crossing failure in the upper part of a drainage during a high intensity storm.
Deep seated landslide	Landslides involving deep regolith, weathered rock, and/or bedrock, as well as surficial soil. Deep seated landslides commonly include large (acres to hundreds of acres) slope features and are associated with geologic materials and structures.
DFG	The California Department of Fish and Game.
DMG	The California Department of Conservation, Division of Mines and Geology.
Drainage structure	A structure or facility constructed to control road runoff, including (but not limited to) fords, inside ditches, water bars, outsloping, rolling dips, culverts or ditch drains.
EPA	The United States Environmental Protection Agency.
Embeddedness	The degree that larger particles (boulders, rubble or gravel) are surrounded or covered by fine sediment. It is usually measured in classes (<25%, 25-50%, 50-75%, and >75%) according to percentage of random large particles that are covered by fine sediment.

Evenaged management	Timber harvesting techniques, including clearcut regeneration, seed tree regeneration, and shelterwood regeneration. In a clearcut, timber is removed in one harvest and regeneration is accomplished by direct seeding, planting, sprouting or by natural seed fall. In seed tree regeneration, timber is removed in one harvest; but, seed trees are left distributed throughout the harvest area for natural regeneration. In shelterwood regeneration, timber is removed in three harvests: the preparatory step improves crown development; the seed step promotes natural reproduction from seed; and the removal step removes timber, including the protective overstory trees.
Facility	For purposes of the target for disturbed area, a facility is defined as any management-related structure such as a road, railroad roadbed, skid trail, landing, harvest unit, animal holding pen, or agricultural field (e.g., pasture, vineyard, orchard, row crops). A harvest unit or agricultural field that retains its natural characteristics with respect to rainfall interception, rainfall infiltration, and soil protection, is not considered a facility.
Flooding	The overflowing of water onto land that is normally dry.
Fluvial erosion	Essentially synonymous with gully erosion, it includes: downcutting in roadside ditches, streams diverted out of culverts and through road fill as a result of plugged culverts, gullies resulting from “shot gun” culverts, etc.
Fry	A young juvenile salmon after it has absorbed its egg sac and emerged from the redd.
GIS	Geographic Information System.
Grilse	A young salmon which returns early to fresh or brackish waters.
Habitat inventory	The identification of individual habitat units (e.g., pool, riffle, or flatwater) that are further defined by their origin and/or orientation (e.g., backwater pool, boulder-formed), as described by Flosi and Reynolds (1994). A basin-level habitat inventory is designed to produce a thorough description of the physical fish habitat.
HAA	Headwaters Assessment Area
Habitat length	The entire length of stream surveyed during a habitat inventory.
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.
Intermediate treatments	Timber harvesting techniques, including commercial thinning and sanitation salvage logging. Commercial thinning is the removal of trees in a young-growth stand to maintain or increase average stand diameter, promote timber growth, and/or improve forest health. Sanitation salvage logging is the removal of insect attacked or diseased trees in order to maintain or improve the health of the stand.
Landslide	Any mass movement process characterized by downslope transport of soil and rock, under gravitational stress by sliding over a discrete failure surface-- or the resultant landform.
Large woody debris	A piece of woody material having a diameter greater than 30 cm (12 inches) and a length greater than 2 m (6 feet) located in a position where it may enter the watercourse channel.

MAA	Mainstem Noyo River Assessment Area.
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.
NFAA	North Fork Noyo River Assessment Area.
Numeric targets	A numerical expression of the desired in-stream or hillslope environment. For each pollutant or stressor addressed in the problem statement, a numeric target is developed.
Permanent drainage structure	A road drainage structure designed and constructed to remain in place following active land management activities while allowing year round access on a road.
Permanent road	A road planned and constructed to be part of a permanent all-season transportation facility. These roads have drainage structures, if any, at watercourse crossings that accommodate the fifty-year flood flow and have a surface that is suitable for hauling forest products throughout the winter period. Normally they are maintained during the winter period.
Planning Watershed	The uniform designation and boundaries of sub-basins within a larger watershed. These watersheds are described by CDF 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.
Regional Water Board	Regional Water Quality Control Board, North Coast Region.
Seasonal road	A road planned and constructed as part of a permanent transportation facility; but has a surface adequate for hauling forest products only in non-winter periods and extended dry periods or hard frozen conditions occurring during the winter period. It has drainage structures, if any, at watercourse crossings that will accommodate the fifty-year flood flow. Some maintenance usually is required.
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 (usually mass) passing a watercourse transect in a unit of time.
Sediment erosion	The group of processes whereby sediment (earthen or rock material) is loosened, dissolved and removed from the landscape surface. It includes weathering, solubilization and transportation.
Sediment source	The physical location on the landscape where earthen material resides which has or may have the ability to discharge into a watercourse.

Sediment yield	The sediment yield consists of dissolved, suspended and bed loads of a watercourse channel through a given cross section in a given period of time.
SFAA	South Fork Noyo River Assessment Area.
Shallow seated	A landslide produced by failure of the soil mantle on a steep slope (typically to a depth of one or two meters; sometimes includes some weathered bedrock). It includes debris slides, soil slips and failure of road cut-slopes and sidecast. The debris moves quickly (commonly breaking up and developing into a debris flow) leaving an elongated, concave scar.
SHALSTAB	A coupled, steady-state runoff and infinite-slope stability model that can be used to map the relative potential for shallow landsliding across a landscape.
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.
Special prescriptions	Timber harvesting techniques, including: (1) site-specific treatments for special areas such as ecological reserves, historical sites, or archaeological sites and (2) the rehabilitation of understocked areas. Rehabilitation includes the harvesting of an understocked area and subsequent restocking to meet stocking standards.
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. Etc.
Sub-basin	A subset or division of a watershed into smaller hydrologically meaningful Watersheds. For example, the North Fork Noyo River watershed is a sub-basin of the larger Noyo River watershed.
Swale	A channel-like linear depression or low spot on a hillslope which rarely carries runoff except during extreme rainfall events. Some swales may no longer carry surface flow under the present climatic conditions.
Tail-out	The lower end of a pool where flow from the pool, in low flow conditions, discharges into the next habitat unit.
Temporary road	A road that is to be used only during the timber operation. It must have a surface adequate for seasonal logging use and have drainage structures, if any, adequate to carry the anticipated flow of water during the period of use.
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.
THP	Timber harvest plan.
TMDL	Total Maximum Daily Load.
Tractor yarding	That system of skidding (transporting) logs by a self-propelled vehicle, generally by dragging the logs with a grapple or chokers.
Transition regeneration	Timber harvesting method used to create an unevenaged stand from a stand with an unbalanced, irregular or evenaged structure.
USGS	The United States Geological Survey.
Unevenaged management	Timber harvesting techniques whose attributes include the establishment and/or maintenance of a multi-aged, balanced stand structure, promotion of growth on leave trees throughout a broad range of diameter classes, and encouragement of natural reproduction. Unevenaged management techniques include the selection regeneration method and transition regeneration method. In the selection method, trees are removed individually or in small groups sized from 0.25 to 2.5 acres. The transition method is used to create an unevenaged stand from a stand with an unbalanced, irregular or evenaged structure.
Unstable areas	Characterized by slide areas, gullies, eroding stream banks, or unstable soils. Slide areas include shallow and deep seated landslides, debris flows, debris slides, debris torrents, earthflows and inner gorges and hummocky ground. Unstable soils include unconsolidated, non-cohesive soils and colluvial debris.
V*	A numerical value which represents the proportion of fine sediment that occupies the scoured residual volume of a pool. Pronounced “V-star.”
Watercourse	Any well-defined channel with a distinguishable bed and bank showing evidence of having contained flowing water indicated by deposit of rock, sand, gravel, or soil.
Waters of the state	Any ground or surface water, including saline water, within the boundaries of the state.
Watershed	Total land area draining to any point in a watercourse, as measured on a map, aerial photo or other horizontal plane. Also called a basin, drainage area, or catchment area.
Water quality criteria	Limits or level of water quality constituents or characteristics which are established for the reasonable protection of beneficial uses of water or the prevention of nuisance within a specific area.
Water quality objective	Water quality criteria as described in the Basin Plan.
Water quality standard	Consist of the beneficial uses of water and the water quality objectives as described in the Basin Plan.
Water Year	An annual period used to record rainfall, beginning on 1October and ending on 30 September of the following year. For example, Water Year 1999 began on 1 October 1998 and ended 30 September 1999.