SOUTH FORK EEL and NORTH FORK EEL RIVER

Sediment and Temperature Total Maximum Daily Load Reconnaissance Survey with Annotated Bibliography

REVIEW DRAFT

(Version 3.0)

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Table of Contents

List of Tables nested in text

Reconnaissance Survey of Information Pertaining to the Development of Total Maximum Daily Loads (TMDLs) for the South Fork and North Fork Eel River Basins.

Executive Summary

This document represents an effort to synthesize some of the information currently available in two sub-basins of the Eel River system. The Eel River has been listed as an impaired water body with respect to both sediment and temperature under section 303(d) of the Clean Water Act. This study describes the nature of past and present sediment and temperature-related research and monitoring efforts, identifies data gaps, and provides recommendations that will assist in the development and attainment of numerical targets for these water quality parameters. A brief overview of the various types of sediment and temperature related studies is presented in order to provide the reader with a sense of the wide range of approaches and methods used to characterize these complex phenomena.

Part I - Background

Introduction

Sediment and temperature related studies from the North Fork and the South Fork of the Eel River basin were reviewed in order to produce a summary and annotated bibliography describing the historic and current conditions in the study areas. These documents and data compilations were evaluated for purposes of determining the relevancy of existing studies to the task of establishing targets for sediment production and stream temperature. A list of the documents reviewed, including a brief summary of each and an assessment of their relevancy to the TMDL process is presented in Appendix A.

Many of the studies were conducted during the evaluation phase prior to widespread dam construction during the 1960's and 1970's. The studies were conducted with the primary goal of determining rates of sediment production in order to estimate rates of dam filling for the numerous proposed dams (Map 1). Relatively few of the studies were found to be highly relevant for the construction of TMDLs. Most of the studies were not conducted with the intent of answering some of the key questions we are faced with today, namely, assessing the linkages between land-use activities and accelerated rates of erosion and sediment delivery. Nonetheless, the historic studies provide general background information that is useful for watershed characterization. Large differences in rates of sediment production in the various sub-basins of the Eel River are clearly recognized by many of the studies. However many of the documents also address the inherent difficulties in trying to consistently measure or estimate rates of sediment production, transport and yield.

TMDL Applications to Watershed Processes

Efforts to apply the concept of Total Maximum Daily Loads (TMDLs) to watershed processes are bound to encounter numerous challenges. Quantitative descriptions of sediment-related phenomena and temperature patterns are filled with uncertainties. The processes related to sediment and water temperature are complex and strongly influenced by a multitude of factors, some of which are random or chaotic in nature. For the purposes of this review, we have made the assumption that the intent of the TMDL process is to establish numerical targets that maintain water quality conditions at a level that allows for the sustenance of beneficial uses. Specifically, we focus on the processes that influence habitat conditions for salmonids and other aquatic organisms. Determining the targets for the variety of basins and sub-basins in Northern California will involve a concentrated effort that requires synthesis of existing information and a dramatic increase in monitoring efforts aimed at describing current and future watershed conditions.

Watershed processes are the result of complex interactions between climatic, tectonic, and geomorphic processes operating under highly variable site conditions. In spite of the difficulties inherent in the TMDL process, the effort to develop TMDLs has been deemed a necessary step along the path to promoting land management practices that are compatible with the beneficial uses of water. The process will require careful thinking in order to establish targets that are realistic, measureable, and which are able to distinguish between natural and management related disturbances. The impacts of land-use activities over the past century contribute to make watershed processes more complex, both in the physical landscape and in socio-economic arenas.

Scientists engaged in the field of watershed restoration have emphasized the necessity of taking a systemic approach toward evaluating the conditions or health of a given area. In recent years, attention has shifted from efforts to restore specific habitat elements toward efforts that restore the processes that create healthy habitat. The increase in complexity associated with this paradigm shift is often daunting - conceptually and technically challenging to understand and describe - even more challenging to implement.

STATE OF KNOWLEDGE REGARDING SEDIMENT AND TEMPERATURE

Overview of types of sediment-related studies

The impacts on water quality resulting from accelerated rates of sediment production take many forms, and the methods used to assess these impacts are even more numerous. A comprehensive overview of early studies of sediment related water quality issues is presented in Iwamoto et al. (1978). This document summarizes over 300 papers on various biological and physical interactions, and lists an additional 100. The variety of topics summarized in this volume ranges from methods of assessing water quality, to specific impacts on individual species, habitats, etc. More recent summaries of interactions (bio-geophysical processes) are summarized in the technical literature of various individual disciplines. Klein (in preparation for EPA) has compiled an annotated bibliography of many recent studies that are relevant to the development of TMDLs in northern California.

Outline of Types of Sediment Studies

The different types of sediment-related studies can be broken down into a few basic categories. Types of studies are listed in outline form below, with examples of some specific approaches. *(note to reviewer: a great deal of literature exists on each of the following topics, however it is not within the scope of this project to conduct a detailed review or summary of these matters).*

- **Instream studies**
  Suspended sediment monitoring
  Turbidity monitoring
  Channel morphology studies
    stream channel cross-sections to evaluate changes in bed elevation
    changes in channel position and form
  Substrate conditions
    spawning gravel conditions
    bulk sampling; freeze cores; McNeil samples
    statistical sampling: Wolman pebble counts
    estimation of pool-tail embeddedness

- **Source analyses**
  Sediment source inventories
  Road inventories
  Streambank surveys
  landslide inventories

- **Process studies - detailed examinations of various issues related to accelerated erosion**
  Fluvial hillslope erosion
  Surface erosion
  Gully erosion
  Factors influencing landslide initiation

- **Integrative studies**
  Sediment Budgets
  Watershed Assessments
  Watershed Analyses

- **Mathematical / Computer Modeling**
  Erosion hazard models
  Landslide susceptibility models
  Sediment budget models
  Identification of unstable lands
  Surface erosion models (e.g. Universal Soil Loss Equation)
  GIS based erosion models

- **Land-use influences on sediment delivery**
  Evaluation of the impacts of logging and road construction
    - changes in landslide frequency
    - changes in hillslope runoff

  Impacts of burning, vegetation conversion
    - development of hydrophobic soils
    - changes in hillslope stability as a result of loss of root strength

- **Mitigation studies**
  Evaluations of erosion control programs
  BMP evaluations

- **Indicator studies**
  Cesium 137 and clay mineralogy studies to identify sediment sources
  Studies of the infiltration of fines into spawning gravels

- **Sampling and monitoring methodologies**
  Suspended sediment and bedload sampling
  Aerial photo analysis for erosion source inventories

Summary of the Impacts of Forest Management on Aquatic Resources

Numerous efforts have been made to describe the various impacts of forest management on aquatic resources. Salo & Cundy (1987) edited proceedings from a conference that presented detailed descriptions of the interactions between forestry activities, mass-wasting, sediment transport and fisheries requirements. Meehan (1991) edited a collection of technical papers in AFS special publication 19, and recently the ManTech report (Spence et al., 1997) was published by EPA/NMFS in order to address key issues raised by the listing of the coho salmon. Literature citations found in these documents provide access to vast amounts of information.

Key issues related to sediment - a clarification of the problems

In this study, we distinguish between erosion and sedimentation, but recognize that they are closely related facets of the same general problem. Erosion generally refers to the mobilization and loss of soil and inorganic material (sediment) from a site, while sedimentation is the result of deposition of mobilized material. Sediment transport is the intermediate step that often has the most direct impacts on aquatic habitats and channel morphology.

Chronic versus Pulse Sedimentation

In terms of volume, sediment delivery processes in northern California are dominated by mass wasting. The majority of the volume of sediment delivered to northcoast rivers occurs during peak magnitude storm events that initiate or reactivate large landslides and earthflows across the landscape. During peak storm events, very large land areas can fail suddenly, introducing a mixture of bedrock, colluvium, alluvium and soil. This type of sedimentation is often referred to as "pulse" or "catastrophic" sedimentation, as compared with "chronic" sedimentation. Pulse sedimentation was the dominant mode of material transport prior to widespread anthropogenic hillslope disturbance. Large hillslope failures deliver a mixture of sediments ranging in size from large boulders to fines. Since these failures generally occur during large storm events, most of the fines are entirely flushed from the system, leaving behind the coarser material as substrate for aquatic organisms. Surface erosion was likely very active on landslide surfaces, but large landslides tend to be widely spaced across the landscape, and the surface area of these slides is relatively small in comparison to undisturbed ground within a drainage basin.

Chronic sedimentation generally involves much smaller volumes of material, consisting primarily of fine sediment (sand size and smaller). Numerous studies have examined the harmful effects of fine sediment on aquatic organisms, most notably on the survival of juvenile salmonids just emerging from redds. Iwamoto (1973), and Klein (in preparation) provide critical reviews of a number of these studies.

One of the most common forms of chronic sedimentation results from road-related surface erosion. Instead of requiring peak events for sediment mobilization, surface erosion along roads and cutbanks occurs with even small rainstorms. The mobilization of fine sediment during low magnitude storm events or on the receding limb of the storm hydrograh leads to very deleterious sediment related impacts on spawning gravels, since much of the mobilized material often settles out rapidly, resulting in the filling of pools and the infiltration of fine sediment into gravels.

Cumulative Downstream Effects

In areas where mass-wasting processes dominate, large volumes of sediment introduced to the stream channel can have significant impacts on downstream areas. Severe aggradation of channels leads to increased rates of channel migration, altered channel geometry, and increased rates of streamside landsliding. As more volume is introduced to the channel, valley wall stability may be reduced, further destabilizing the riparian corridor. These processes combine to produce feedback loops where the results of upslope failures trigger additional failures along the stream corridor. The effects of these failures can become progressively larger in the downstream direction.

Slope instability is often the result of widespread alteration of hydrologic conditions. Vegetation removal and soil compaction from tractor logging, road construction and grazing leads to changes in runoff patterns. Watercourses diverted along roads and loss of root strength can lead to higher frequencies of mass wasting. The historically common practice of burning slash following logging can develop "hydrophobic soils" that prevent or reduce rates of infiltration during storms. The combination of these disturbance-related processes produce a cumulative effect that is difficult to treat. However, with shifts in management practices, many of these processes can be minimized. For example, road related channel diversions can be minimized with minor alterations in road drainage design; land-use activities in riparian areas and unstable lands can be avoided through the implementation of more stringent protective measure.

Sediment Studies

Various approaches have been taken in order to assess the sediment related processes operating within a watershed, ranging from detailed air-photo interpretation and modeling to intensive sampling and inventory. The type of study undertaken is generally a function of the time and resources available, and the nature of the question or problem posed. A brief overview of the various types of sediment-related studies is provided below in order to provide a background for the readers without a background in geomorphology or hillslope processes.

Source Analysis

Methods of measuring erosion and sedimentation can be broken down into a few general categories. Source analyses involve the counting and measurement of erosion features, estimation or calculation of the volume of material eroded, and application of a sediment delivery ratio (SDR) factor in order to estimate the amount of material actually delivered to a watercourse. In order to determine the nature of the impacts resulting from accelerated sediment production, it is necessary to identify the particle size distribution of material delivered. If rates of sediment production are desired, the age and activity of each source must be estimated or somehow determined.

Methods of source analyses depend on the nature and scale of the project. Direct field inventory is time consuming and costly, but provides the most detailed results. Aerial photos can be used in conjunction with field inventory, and often provide the only means of determining the age of a single feature. For aerial photos to be useful for identification and measurement of sediment sources, they must be at scales adequate for feature identification and measurement. Generally photos at a scale of 1:12,000 (1" = 1,000 feet) are the smallest scale adequate for inventory purposes. Photos enlarged to scales of 1:6,000 are preferable, and for detailed mapping for planning and design purposes, photos enlarged to a scale of 1:1,200 are ideal. For larger areas, it is often necessary to statistically sample photo-sets rather than conducting a full inventory, however the results of such inventories are always questionable due to the uncertainties introduced by various sampling methods. Again, if rates are of interest, it is necessary to evaluate multiple years of photos. This allows for comparison of features over time, and determination of the approximate timing of whatever type of disturbance is being measured, generally logging operations, road construction, fire or landslide features.

Source Analysis Limitations

Source analyses are generally limited by time, money, available resources and access. Thus, a great deal of attention is directed toward remote sensing methods, but many of these methods are limited by the resolution of remote sensing imagery. For example, aerial photographs are generally not capable of providing information about small scale landscape features, and it is often difficult to detect streamside landsliding along smaller order streams due to shading or blocking by riparian vegetation or steep inner gorge topography.

Synthesis: Sediment Budgeting Approaches

Sediment budget studies provide a context for the examination of various matters related to sediment mobilization, transport, and deposition or yield. The most current thinking on the application of sediment budgets to a wide variety of land-management considerations is summarized by Reid and Dunne (1996). This document provides a comprehensive overview of the variety of approaches, methods and limitations of the sediment budget approach. It also contains numerous literature citations and a number of examples of applications of sediment budget in land-management issues.

An overview of stream temperature issues

Introduction

Stream temperature is likely one of the most important factors influencing the health of aquatic ecosystems. Since most aquatic organisms are cold-blooded, their life history is largely determined by stream temperature conditions, and they require a range of temperatures for which they are evolutionarily adapted. Alterations in stream temperature patterns can lead to dramatic shifts in the community structure of various organisms, which in turn has profound effects on other parts of the food-chain. Fish community structure is also strongly influenced by stream temperature patterns, especially with the introduction of non-native fish species that are tolerant to warm water conditions. In the Eel River the Sacramento squawfish *(Ptychocheilus grandis)* and the California roach *(Hesperoleucus symmetricus)* are two introduced fish species that are currently in competition for resources with native salmonids.

Stream Temperature and Land Management Interactions

While the concepts pertaining to the physics of stream heating are fairly straightforward to understand, stream temperature continues to be a difficult parameter to describe due to dramatic spatial and temporal variability. Stream temperature patterns are the result of various climatic and site specific influences, and can be dramatically altered by both natural and anthropogenic disturbances. The primary variables influencing stream temperature and rates of stream temperature change are: local air temperature, canopy closure, relative humidity, and channel morphology. Each of theses parameters can be affected by forest management either directly, or as the result of cumulative impacts. Removal of trees from the riparian corridor allows for increased direct solar irradiance, while microclimatic variations resulting from vegetation removal can include changes in air temperature and relative humidity (Ledwith, 1996). Increased sediment loads and higher frequencies of streamside landsliding alters channel morphology and can influence riparian dynamics, sometimes preventing the establishment and growth of riparian vegetation.

Examination of the linkages between land-use and stream temperature initiated in earnest with the work of G.W. Brown in the late 1960's (Brown and Krygier, 1967, Brown, 1969, 1970). Brown and his coworkers examined the changes in stream temperature resulting from complete clearcutting adjacent to stream corridors. Later workers refined his models in order to evaluate the effects of partial removal of streamside shade (Cobb, 1988). Beschta et al.(1987) provide a comprehensive overview of the factors influencing stream temperature, and the typical impacts on stream temperature resulting from riparian forest management.

Many factors influence the resulting stream temperature at a site. Some of the key factors include: shading from topography and riparian vegetation; local air temperature and humidity; the quantity and magnitude of cold water inputs, either from groundwater or tributaries, and water depth and velocity. Land-use activities that are likely to influence any of these factors should be taken into account when trying to develop temperature TMDLs.

<u>Stream Temperature Monitoring</u>

Stream temperature data take the form of a time-series, with daily maximums and minimums corresponding to diurnal fluctuations in air temperature. Daily variations in stream temperature can range from two to three degrees in undisturbed streams with complete canopy closure to over fifteen degrees (celsius) in streams with no canopy closure. This characteristic of stream temperature makes spot measurements of stream temperature difficult to interpret, since the temperature at a site is constantly changing, and is largely a function of daily weather conditions and the time of day that the reading is taken.

Minimum/Maximum recording thermometers are slightly more reliable for providing an indication of the range of thermal extrema in the stream system. Recording thermographs provide the most accurate picture of stream temperature conditions and have been used for over 40 years. Early models were expensive and recorded information on rotating drums, producing analog chart records. In the past few years, digital temperature loggers (often referred to as Hobo-temps, or Stowaways) have become very popular because of their convenience, low cost, accuracy and ease of operation. . Figure 1 presents an example of temperature data collected with digital data loggers in "managed" and "late seral" watercourses, and the threshold value for harmful temperature effects on Tailed Frog eggs (Welsh, unpublished data).

As a result of the technological development in thermograph technology, the amount of stream temperature information being gathered today has increased exponentially. Temperature data are recorded digitally, allowing for various types of numerical analysis. To our knowledge, a thorough exploration of the large number of digital temperature records, including methods of analysis and typical short falls, has not yet been conducted.

<u>Stream Temperature Modeling</u>

Computer models have been developed to predict changes in stream temperature patterns resulting from different degrees of canopy removal. A detailed and comprehensive review of some of the most frequently used models is presented in Sullivan et al. (1990). One of the drawbacks of stream temperature modeling is the requirement for quantification of numerous parameters. However, if these parameters are known, then the results of the temperature models can be highly accurate, allowing for the prediction of the magnitude of temperature change resulting from any given management or conservation activity. It is likely that a combination of computer modeling and direct temperature monitoring with digital data loggers will be the most efficient means of documenting or describing stream temperature patterns from the regional to the site-specific scale.

Part II - Watershed Characterizations

Introduction

The Eel River system has long been recognized as having one of the highest sediment yields in the world (Brown and Ritter, 1971). The high rates of sediment production on the Eel River were defined on the basis of early suspended sediment monitoring projects and regional geologic assessments conducted by the USGS and the DWR in preparation for widespread dam construction. Nine major reservoirs were included in the 1968 "Master Plan" conducted by the State Interagency Group for Basin Planning (Map 1). Few of the proposed dams were ever constructed, and none of the dams proposed for the South Fork or the North Fork were constructed. The Benbow Dam, operated by the California State Park system is currently the only dam in the South Fork of the Eel. The Benbow Dam is a seasonal, low-height dam installed in the late spring, and removed in the late summer of every year.

The extreme sediment yields from the Eel River are generally attributed to a combination of factors including: unstable geology and active tectonics, high annual precipitation rates, and a history of intensive land-use which has dramatically disrupted the tenuous equilibrium developed during pre-disturbance conditions (Wahrhaftig and Curry, 1966). Cleveland (1977) asserts that suspended sediment yield per unit area in the Eel River is 15 times that of the Mississippi River, and 4 times that of the Colorado river, giving it the single largest sediment yield per square mile in the country. The study by Brown and Ritter (1971) showed that the great majority of sediment transport occurs during the relatively short time periods of peak flood events. For example, the amount of sediment transported during the ten day period of the 1964 flood, the flood of record in the basin, was more than one and a half times the amount of sediment transported during the preceding eight years.

Geologic Overview of the Eel River Basin

The Eel River basin lies within the Coast Range physiographic province, which is dominated by NW-SE trending ridges made up of rocks of the Franciscan Complex. (Map 2) The Franciscan Complex is divided into three broad belts, which become younger and generally less metamorphosed from east to west (McLaughlin et al., 1994). The three belts are known as the Eastern Belt, the Central Belt, and the Coastal Belt; each of these belts are further divided into tectonostratigraphic terranes (Map 3). The North Fork Eel is primarily underlain by rock of the Central belt, while the South Fork is underlain on the east by rocks of the Central belt, and on the west by rocks of the Coastal belt. The Coastal Belt is subdivided into three fault bounded terranes: the Yager terrane of Paleocene to Eocene age, the Coastal terrane of Late Cretaceous to Eocene age, and the King Range terrane of Late Cretaceous to mid-

Miocene age. The dominant NW-SE structural grain of the region is the result of two separate tectonic episodes. First, major lithologic belts were accreted to the North American continent during an E-W convergent tectonic setting, followed by NW-SE trending strike-slip deformation associated with the San Andreas Fault system.

Sub-basins of the Eel River

The basin is generally divided into 5 sub-basins: the Main Eel, the Middle Fork, the South Fork, the Van Duzen, and the North Fork (Map 4). The North Fork is the smallest of all of the Eel River tributaries, and is sometimes not even distinguished as a unique sub-basin. Many Eel River tributaries follow a modified trellis drainage pattern, strongly influenced by NW-SE trending shear zones, faults, and geologic contacts running approximately parallel to the San Andreas Fault system. Some of the basic physical characteristics of the South Fork and the North Fork Eel River basins are summarized below in Table I.

Table I - Physical Characteristics of the South Fork and North Fork Eel River Basins.

	South Fork	*North Fork*
Drainage Area		
Square miles	689	281
Square kilometers	1785	728
acres	440,572	180,020
proportion of Eel River basin	17%	7%
Stream Lengths (Reynolds, 1983)		
Mainstem Length (miles)	106	35
Miles of blue-line streams	713	171
Miles of intermittent streams	37.6**	115
Relief (in feet above sea-level)		
Low point in basin	155	600
High point in basin	4,491	5,900
Mean Annual Precipitation (inches)	60-70*	45-60

*see isohyetal map for South Fork Basin (Map 16)
** not all intermittent streams were counted

Climatic Overview

Climatic conditions in the North Fork and the South Fork are roughly similar to each other, with minor variations in annual precipitation accumulation and storm intensities due to local topographic influences (see Table I). The climatic setting is generally described as mediterranean, with warm dry summers and cool wet winters. Approximately 80 percent of the precipitation falls between the months of November and April (James, 1983). Brown and Ritter (1971) estimate that roughly 66 percent of the precipitation is delivered to watercourses as runoff, and the remaining 34 percent is lost to evapotranspiration or goes into groundwater recharge. These values are relative and dynamic, since removal of vegetation and forest cover alters forest hydrologic processes.

SOUTH FORK EEL RIVER OVERVIEW

The South Fork Eel River basin (South Fork) drains approximately 689 square miles and is nearly evenly divided between southern Humboldt County and northern Mendocino County. The headwaters of the South Fork begin near Laytonville, and flow for approximately 106 miles to the confluence with the Main Eel, near Dyerville. Reynolds (1983) estimates that there are approximately 713 miles of permanent flow streams and 38 miles of intermittent streams (Table I). Some of the major subwatersheds of the South Fork are listed below ~~(Table V),~~ and a more comprehensive list of tributaries, including names, river mile location and lengths of permanent and intermittent reaches is presented in Reynolds (1983). Elevations in the South Fork range from 155 feet above sea level at Dyerville to 4,491 feet at Iron Peak, northeast of Laytonville. USGS topographic map coverages of the South Fork (7.5 minute series) are presented as Map 5 of Appendix E.

U. S. Highway 101 passes through the entire length of the basin. Numerous communities and rural developments are present along this major transportation route. Most of these communities are listed in Table II.

Table II - List of principal communities and rural developments located within the South Fork Eel River basin.

Weott	Andersonia
Myers Flat	Piercy
Miranda	Reynolds
Phillipsville	Leggett
Redway	Cummings
Briceland	Empire
Garberville	Laytonville
Benbow	Branscomb
Cooks Valley	Laytonville Rancheria

Landownership Distribution in the South Fork Eel

Landownership in the South Fork is predominantly private, including large ranches, locally owned industrial timberland, and numerous rural subdivisions and remote homesteads. The distribution of landownership is presented in Table III. There are no Forest Service lands in the basin, and only a relatively small proportion of BLM lands (Map 6). The California State Park system is a major landholder, owning scattered tracts along the lower South Fork, and the entire Bull Creek watershed. Bull Creek has been the subject of numerous sediment studies due to damages to the Rockefeller Forest resulting from accelerated erosion following the 1955 and 1964 floods.

Table III - Distribution of Landownership in the South Fork Eel River Basin.

Land Ownership Distribution	*Acres*	*Proportion*	*Square miles*
South Fork Eel River			
Total Area	440,572	100 %	688
Forest Service	0	0 %	0
BLM	30,840	7 %	48
Private Lands	356,863	81 %	558
State Lands	52,869	12 %	83

Geologic Setting of the South Fork Eel

The South Fork Eel River Basin is underlain primarily by rocks of the Franciscan Complex, with lesser amounts of Tertiary and Quaternary sedimentary rocks and alluvial terrace deposits (James, 1983). In general, the southeast portion of the basin is underlain by the Central belt, which consists primarily of melange and scattered ultramafic rocks. The northwest portion of the basin is primarily underlain by the Coastal Belt, consisting primarily of the Yager terrane, with lesser amounts of Coastal terrane. The Yager terrane consists of massive greywacke, interbedded sandstone and shale, siltstone and conglomerate (McLaughlin et al., 1994). The southwest portion of the basin is underlain primarily by the Coastal terrane, which consists of greywacke, conglomerate and shale, with minor amounts of greenstone, serpentinite, schist, chert and limestone. Large alluvial terraces are present along portions of the South Fork, and weakly consolidated rocks of the late Tertiary Wildcat group are found in the vicinity of the towns of Redway, Garberville, and Piercy. James (1983) has compiled and summarized geologic mapping in Plate 1 of his report, entitled, *South Fork Eel Watershed Erosion Investigation*. The distribution of geologic units summarized by James (1983) in the South Fork is summarized in Table IV - (distribution of geologic units).

Table IV - Distribution of Geologic Types in the South Fork Eel (James, 1983)

Geologic Unit	Areal Coverage
Franciscan Complex	
Coastal Belt	35.7 %
Central Belt	25.1 %
Rattlesnake Schist	0.5 %
Leggett Peridotite	2.0 %
Cretaceous (undifferentiated)	6.1 %
Yager terrane	21.7 %
Tertiary Marine	3.5 %
Tertiary Mixed	0.9 %
Terraces and Alluvium	4.5 %

Special Designations in the South Fork Eel

The mainstem of the South Fork has been designated as a Wild and Scenic River, and certain federally owned portions of the upper basin are designated as Tier 1 Key Watersheds (FEMAT, 1993). Key Watersheds are recognized for their significance as biological refugia, and for their high priority for watershed restoration efforts.

Major Subwatersheds of the South Fork Eel

There are 158 named and 32 unnamed streams identified on USGS 7.5 minute topographic maps. Table V lists major tributaries with blue-line stream lengths greater than five miles. The longitudinal stream profiles of some of the major streams in the South Fork are presented as Figure 2.

Table V - Major Subwatersheds of the South Fork Eel River Basin (listed from confluence to headwaters).

Bull Creek	Indian Creek
Canoe Creek	Piercy Creek
Salmon Creek	Cedar Creek
Dean Creek	Rattlesnake Creek
Redwood Creek	Hollow Tree Creek
Sprowel Creek	Ten Mile Creek
East Branch South Fork	Elder Creek

Land-Use History in the South Fork Eel

The land-use history in the South Fork is extremely varied and complex due in part to the large variety of geomorphic and vegetation types within the basin, and to the lack of public ownership within the basin. Since 81% of the basin is in private ownership, there have been a wide variety of land-use activities in the basin, namely: ranching, the tanbark industry, redwood and Douglas fir logging, agriculture and tourism. Keter provides a concise overview of the history of the South Fork in the South Fork Watershed Analysis (USDA Forest Service/USDI BLM, 1996). Similar to other parts of northern California, early settlement began in the mid 1850's, immediately followed by a decade-long period of conflict with the indigenous populations. Most of the native peoples were killed or placed onto reservations during this period, thus allowing the ranching and homesteading period (1865-1900) to become established. Sheep and cattle ranching were the dominant land-use activity during this period, and redwood logging did not begin in earnest until the completion of the Redwood Highway and other road networks in the first decade of the 20^{th} century.

Intensive logging of Douglas fir forests did not begin until the post World War II era (1945 to present). Changes in the tax structure after 1946 provided irresistible economic incentives to large landholders and ranchers, who sold the rights to log their land to timber companies from outside of the area. Abuses to the landscape were widespread, and there was little consideration for forest regeneration or the impacts of widespread road construction and deforestation. The landscape is still recovering from the widespread impacts of this period. Documentation of the abusive land practices of the late 1940's and early 1950's is presented in Gleason (1956), who examined the impacts to the Bull Creek watershed following the 1955 flood.

As the timber-boom subsided in the late 1960's, the "back-to-the land" movement began. Ranches were subdivided, and urban refugees began migrating to the logged over lands of Humboldt and Mendocino Counties. Abandoned logging roads were upgraded or new roads were constructed to reach newly subdivided parcels, and a new subculture gradually established itself. Today, road systems associated with homestead access provide a chronic source of sedimentation to many parts of the South Fork.

Current Land-Use Activities in the South Fork Eel

The predominant land-use activities in the South Fork today include: transportation, timber production, ranching, farming, dispersed rural development, urban and suburban development, tourism, and recreation.

The proximity of Highway 101 opens the South Fork and some of its major tributaries to a variety of environmental hazards. Highway 101 is the major artery between the San Francisco Bay Area and northwestern California and southwestern Oregon. Toxic spills have resulted from vehicle accidents involving trucks hauling chemicals, fuel, asphalt, etc. In addition, large cuts into steep slopes have destabilized many portions of the Highway 101 corridor, and there are numerous large landslides that typically produced large volumes of sediment during peak winter storm events.

Timber production, ranching and rural development all require an elaborate network of roads in order to access various parts of the basin. An overview of the major roads in the South Fork is presented as Map 7. In portions of the basin not suitable to timber production, cattle and sheep ranching continue to be a prominent land-use activity although to a lesser extent than during the historic period.

Urban developments along the South Fork have historically introduced raw sewage into the South Fork during saturated ground conditions in the wintertime. Since 81% of the basin is in private ownership it is very difficult to regulate land-use activities in the South Fork at a watershed scale. The private ownership factor presents one of the single largest challenges to the implementation of TMDLs in the basin.

NORTH FORK EEL RIVER OVERVIEW

The North Fork Eel River is located primarily in southwestern Trinity County, with the extreme southern portion of the basin extending into Mendocino County (Map 8). The headwaters of the North Fork begin in Hettenshaw Valley, and the river runs approximately 35 miles to the Main Eel just south of the Mendocino/Trinity county line. The North Fork is the smallest of the major sub-basins in the Eel (281 mi^2). Elevation ranges from approximately 600 feet above sea level near the mouth of the North Fork, to 5,900 feet along the eastern crest of the basin.

Due to its remote nature and lack of proposed dams it has not been the subject of any detailed studies with respect to either sediment or temperature. In fact, very few focused research efforts of any sort have been conducted in the North Fork. The best general sources of information for this basin are the result of many years of research by Tom Keter, archaeologist for Six Rivers National Forest. However, the North Fork Eel is adjacent to the Middle Fork of the Eel, where the USGS conducted a long term suspended sediment monitoring study (Knott, 1971). It is possible that Knott's study, and other sediment source studies conducted by DWR in the Middle Fork and Main Eel are relevant to the North Fork. Kelsey's sediment budget (1980) for the Van Duzen River may also be relevant to the North Fork.

There are no major population centers within the North Fork, but there are a small number of homesteads and ranches: Zenia, Hettenshaw Valley, Kettenpom, Mina and Hoaglin Valley are some of the named rural developments. The distribution of landownership in the basin is presented in Table VI. Map 9 shows the jurisdictional boundaries of state and federal lands, and the distribution of tribal and private lands.

Table VI - Distribution of Landownership in the North Fork Eel River Basin.

Land Ownership Distribution	*Acres*	*Proportion*	*Square miles*
North Fork Eel River			
Total Area	180,020	100 %	281
Forest Service	73,230	41%	114
BLM	16,340	9%	26
Private/State	86,960	48%	136
Tribal Lands	3,480	2%	5

Special Designations in the North Fork Eel

The North Fork Eel has been designated as a key watershed in the FEMAT report. Different portions of the federal lands within the North Fork are designated by the FEMAT report as matrix and late successional reserves. Portions of the North Fork have been designated as a "Wild River" but a Wild River Management plan has yet to be written. Two wilderness areas exist within the basin: the North Fork Wilderness area and the Yolla Bolly Middle Eel Wilderness area.

Major Subwatersheds of the North Fork Eel

In the North Fork, there are 38 named and 35 unnamed streams identified on USGS topographic maps (Reynolds, 1983).

Table VII - Major Subwatersheds of the North Fork Eel River Basin (listed from confluence to headwaters).

Wilson Creek	Salt Creek
Asbill Creek	Kettenpom/Bluff
Hulls Creek	West Fork
Red Mountain	Soldier Creek

Geologic setting of the North Fork Eel

The geologic and geomorphic terranes of the Federal Lands within the North Fork are described by Theisen (1996). Portions of the rest of the basin have been mapped, but these maps remain unpublished (McLaughlin, personal communication, July, 1997). The North Fork is comprised of rocks from the Franciscan Complex, consisting of three geologic terrane types: melange, relatively competent greywacke and metagreywacke, and saprolitic (deeply weathered) greywacke and shale. Minor rock types make approximately 6% of the watershed area, and include: ultramafics, serpentinite, chert, metavolcanics and alluvium.

Table VIII - Distribution of Geologic Types on the Federal Lands of the North Fork Eel River Basin. (Theisen, 1996).

Geologic Unit	Areal Coverage
Greywacke and metagreywacke	47 %
Melange	31 %
Haman Ridge Saprolite	9 %
Valley Fill Deposits	7 %
Mixed argillite, serpentinite, chert and metavolcanics	6 %

USGS Stream Gages

Located near Mina (captures 86% of drainage area)
23 years of record (1953 - 1976)
Average discharge = 450 cfs
Peak flow = 130,000 cfs (Dec. 1964)
Lowest flow = 0.1 cfs (August 30, 1959)

Land-Use History in the North Fork Eel

The land-use history of the North Fork has been extensively researched and compiled by Tom Keter, Anthropologist at Six Rivers National Forest. Much of this information is summarized in Keter (1995), with more detailed historical and archaeological information presented in a series of published and unpublished manuscripts available from Six Rivers National Forest (Keter, 1988, 1990, 1993, 1994, Keter and Busam, 1997). He has conducted numerous interviews with long-time residents of the North Fork, and summarized land-use patterns from 1850 to present. This information provides a valuable context for assessing the linkages between land-use and physical processes. Keter breaks down the land-use history into 4 periods: the settlement and conflict period (1854-1865), the ranching period (1865-1905); the homesteading period (1905-1940) and the modern era (1940-1990's). During the ranching period, especially during the late 1870's, sheep ranching was at a maximum, and Keter estimates that there were approximately 40,000 to 60,000 sheep spending at least a portion of the year in the basin. The modern era includes the post World War II logging boom, and Keter notes that the majority of the Douglas Fir forests was harvested during the 1950's. Human populations in the North Fork reached a maximum during the 1950's timber boom.

Keter notes the profound effects of fire in the North Fork basin, first used by the indigenous populations and later by the ranchers as a tool for vegetation management. During recent years, the use of fire as a management tool has nearly ceased, and vegetation is responding rapidly. It should be noted that many of the land-use patterns described by Keter for the North Fork are also applicable to other parts of northern California.

Theisen (1996) notes that most of the forest road systems were constructed during the 1950's and 1960's, with fewer ranch access roads existing prior to that time. Major roads in the North Fork are presented in Map 10, with a summary of road densities in the North Fork presented as Table 1 in Appendix F. The intensive period of Douglas fir logging also occurred during the 1960's and consisted primarily of clearcutting on private lands. Grazing of sheep and cattle continue to be a dominant land-use in the North Fork. Very minor amounts of mining have taken place in the North Fork. Theisen notes only a couple of small manganese exploration pits as well as several borrow pits for obtaining road surfacing aggregate.

Part III - Synopsis of Recent and Current Studies

Introduction

Numerous proposed water development projects during the late 1950's and 1960's prompted an extensive regional assessment of the entire Eel River Basin. The results of these assessments are presented in a series of interagency reports, the most relevant of which is *USDA (1970) - Sediment Yield and Land Treatment*. Since the mid 1970's there have been relatively few directed studies dealing with sedimentation issues in the South Fork, and none located in the North Fork of the Eel. A list and partial description of the most relevant documents for the development of TMDLs is provided below. For further discussion of the specific relevance of each document, please refer to Appendix A.

South Fork Documents

Brown and Ritter, 1971
James, 1983
Gleason, 1956
Kubicek, 1977
Puckett and VanWoert, 1972
South Fork Watershed Analysis, 1996
BLM Road Assessment, PWA, 1997

North Fork Documents

Keter, 1997 et al.
Knott, 1971 (outside of basin)
Kubicek, 1977
Puckett and VanWoert, 1972
Theisen, 1996
North Fork Eel Watershed Analysis, 1996

Overview of Temperature Studies

Temperature monitoring in the Eel River and other parts of northern California have taken three basic forms: (1) periodic or continuous measurements of stream temperature using recording thermographs at USGS or DWR stream gaging sites, (2) spot checks with a hand held thermometer, and more recently (3) dispersed placement of electronic temperature data loggers

The USGS and DWR have operated stream gages on many northcoast streams, mostly starting in the early to mid 1950's. Selected stream gaging stations contained recording thermographs that measured stream temperature near the stream-gage. Depending on the station and the lead agency, temperature data were collected either on a continuous basis (drum type recorder), once or twice daily, or were measured periodically using hand-held thermometers. Data from these sites are summarized by the DWR in Puckett and Van Woert (1972), and by the USGS in Blodgett (1970). Puckett and Van Woert (1972) provide annual summaries of daily maximum and minimum temperatures for each gage and calculate averages for each month (Table 2 and 3). Blodgett (1970) presents only monthly minimums, maximums and averages, as well as the total days of record (Table 4). A map of USGS temperature monitoring sites is presented as Map 11. The location and duration of each of the temperature recording sites is presented in Table A-1 within the Annotated Bibliography (Appendix A

Spot checks of stream temperature have been conducted for many years by fisheries biologists and various stream surveyors. Paul Kubicek (1977) conducted a regional overview of stream temperatures in the Eel River by measuring stream temperatures at 179 locations throughout most of Eel River basin in the summer of 1973 (Map 12). Using a hand held thermometer, he attempted to estimate maximum temperatures for each of these locations by correlating his measurements with data from the nearest of 30 USGS or DWR thermograph sites(Map 13). An example of Kubicek's temperature data is presented as Table 5. Stream surveys conducted by the Department of Fish and Game also contain scattered observations of stream temperatures, but the data are not systematically recorded or summarized, and are therefore of limited use. They serve more as anecdotal observations of general thermal conditions within certain stream reaches. More recently, with the widespread application of the Habitat Typing Protocol (Flosi and Reynolds, 1994) spot stream temperatures have been recorded along many reaches of stream. While these measurements often describe thermal conditions in remote areas, they are difficult to interpret due to the uncertainties associated with spot measurements (see discussion of stream temperature variability in Part II).

In the early 1990's temperature data loggers have become more widely used due to their portability and general cost-effectiveness. Today they are used widely by agencies, timber companies and environmental organizations interested in monitoring stream and air temperature conditions. In the Eel River, a regional temperature monitoring effort is currently underway, under the direction of Gary Friedrichsen of the Humboldt County Resource Conservation District (discussed below in more detail).

Current Studies and Activities Related to Sediment or Temperature Monitoring in the North Fork and South Fork of the Eel River

Watershed Analyses

Interagency watershed analyses have been completed for both the South Fork and the North Fork basins. These documents provide a good general overview of basin conditions, but are severely lacking in detailed information regarding sediment or temperature conditions. The documents serve primarily to identify some of the key issues of concern in the basin, and to provide an overview of the status of threatened and endangered species. The historical overviews presented in both documents provide a detailed summary of past and present land-use activities. Dave Fuller, fisheries biologist at the Arcata Resource Area BLM office was the coordinator for both of these watershed analyses. He also has extensive field experience in the North Fork from prior stream survey and habitat restoration efforts.

Stream Surveys and Habitat Typing

The Department of Fish and Game (DFG) has been conducting general stream surveys in many northcoast basins since the early 1960's. These surveys are often very general in nature, and contain brief narratives describing general habitat conditions, species present and notable barriers to fish migration. Some surveys also include ground photos and/or oblique aerial photographs. While some of these surveys provide good general information about the basin, they are of little use for the development of TMDLs.

A semi-quantitative form of stream surveying known as "Habitat Typing" has become popular in recent years. Habitat typing has been conducted in many parts of the North Fork Eel River by DFG, under the direction of Scott Downie. Surveyors follow the protocols described in the *California Salmonid Stream Habitat Restoration Manual* (Flosi and Reynold, 1994). An example of the habitat typing form is presented in Appendix G. Digital copies of the surveys conducted in both basins and a copy of the program Habitat 8.4 are included on the digital data appendix (100 Mb Zip Drive Disk).

Some of the potentially valuable measurements taken during these surveys include visual assessments of channel substrate composition, pool-tail embeddedness and percent canopy. Embeddedness values are divided into 4 classes:

Embeddedness Class	Percent Embedded
1	0 to 25 %
2	26 to 50 %
3	51 to 75 %
4	76 to 100 %

Substrate characterizations simply identify the two most dominant components from the following size classes: silt/clay, sand, gravel, small cobble, large cobble, boulder and bedrock. Unfortunately, the subjective nature of these assessments makes them highly suspect.

Riparian canopy conditions are measured with a spherical densiometer, and recorded for the following categories: percent total canopy, percent deciduous canopy, and percent coniferous canopy. This information is potentially useful for making rough generalizations about the canopy conditions in various sub-basins, and for assessing changes from year to year.

Eel River Temperature Monitoring Project - Humboldt County Resource Conservation District

An extensive stream temperature monitoring effort is currently underway throughout much of the Eel River Basin. This effort is being coordinated by Gary Friedrichsen of the Humboldt County Resource

Conservation District (HCRCD), and involves cooperators from state and federal agencies, the timber industry, environmental organizations and Humboldt State University. The project formally began in the summer of 1996, but some prior years of thermograph data have also been compiled by the Department of Fish and Game and private timber corporations (Gregg Moody at Palco). Additional stream temperature data sets from industrial timber lands are being compiled in the offices of the Forest Science Project at Humboldt State University, under the direction of Tim Lewis. A list of cooperators in the HCRCD study is presented in Appendix C-2, and Map 14 shows the distribution of digital data logger deployed during the summer of 1996. Table 6 lists sites in the South Fork and the North Fork where digital data loggers have been deployed by California Department of Fish and Game (DFG) from 1991 to 1995..

GIS Coverages

Geographic Information System (GIS) coverages exist for features such as roads, watercourses, vegetation, ownership and special designations of land areas. A data dictionary of existing coverages as of July, 1997 is presented in Appendix F. This information was provided by Jan Werren, GIS coordinator at the USDA Watershed Analysis Center. Additional GIS coverages exist at Humboldt State University (HSU) in the Klamath Basin Ecosystem Restoration Office.

Sediment Studies and Source Analyses

Hydrologic monitoring

Basic hydrologic monitoring includes the measurement of precipitation and streamflow in order to produce descriptive relationships of runoff, flow duration and flood frequency. The USGS and the California Department of Water Resources (DWR) have operated stream gages in the Eel River basin since the 1950's, collecting information on river stage, water temperature, channel morphology, suspended sediment and bedload transport at the gage site (Brown & Ritter, 1971, Hickey, 1969, Blodgett, 1970, Hawley and Jones, 1969). A map of stream gages in the South Fork Eel is presented as Map 15. There is only one stream gage in the North Fork, located near Mina.

Precipitation records exist from some of the gage sites, in addition to other measurement sites scattered through the basin. An isohyetal map of precipitation in the South Fork is presented as Map 16, and summaries of annual records at six separate sites in the South Fork are presented as Figures 3, 4 and 5. A precipitation depth-duration-frequency analysis is presented as Table 7.

Data collected at stream gages provides some of the only systematic long-term monitoring information of hydrologic phenomena. These data provide the basis for information on the relative magnitudes of different flood events (Table 8), and for the calculation of basic hydrologic descriptors such as flood frequency and flow duration (Figures 6 and 7). These basic hydrologic descriptors play a critical role in planning, hazard assessment and monitoring of long-term climatic patterns.

Suspended sediment and bedload data were compiled in order to produce regional estimates of sediment production from various parts of the basin.(see Map 15, Map 16a and 16b). Due to the high costs and difficulties of sampling for suspended sediment, efforts were made to develop correlations between suspended sediment concentration and turbidity. Examples of turbidity measurements at various location in the South Fork and some of its major tributaries are presented as Tables 9, 10 and 11. Turbidity measurements and stream discharge are plotted for measurements taken in 1982-83 as Figure 8. Weak correlations between turbidity and stream discharge are likely the result of the important role that landslides and other forms of mass-wasting play in the processes that contribute sediment to the Eel River. Mass-wasting events introduce sudden pulses of sediment and debris to rivers that are not necessarily related to patterns of stream discharge. The chaotic or stochastic nature of landsliding and sediment transport processes has led to increased attention toward measuring sediment sources, rather than trying to measure the material as it passes through the fluvial system.

Landslide inventories

Unfortunately, relatively few upslope inventories have been conducted in either the South Fork or the North Fork Basins. In the South Fork, James (1983) compiled a detailed map of landslides based on analysis of 1981 aerial photographs. A summary of the results of this reconnaissance level survey is presented in Table 12. No field checking was conducted in order to assess the specific conditions of any of the mapped features.

Theisen (1996) conducted a similar analysis of geomorphic terranes in the North Fork, based primarily on aerial photo analysis. Again, very little field work was conducted to verify air photo interpretations (Theisen, pers. comm, 1997).

Road Inventories

Horns and LaVen (1986) conducted a general road inventory in the Bull Creek basin with the goal of prioritizing erosion control efforts in Humboldt Redwood State Park. Pacific Watershed Associates has conducted road inventories for the Bureau of Land on most of their holdings in the upper South Fork (see Form 2 in appendix G). The final report was sent to the BLM for review in September, 1997. There are no known road inventories in the North Fork Eel.

GIS coverages of road networks (derived from the 1:100,000 scale map series) are available from the USDA Watershed Analysis Center or the Teal Data Center. Small scale versions of these coverages are presented in Map 7 and Map 10 for the South Fork and the North Fork, respectively. Some of these coverages have been updated to include road information from the 1:24,000 scale map series. These layers provide a starting point from which to begin to develop a comprehensive road database for each basin.

Private timber corporations have also begun the process of conducting detailed inventories of their road systems, however none of this information is published. There are no known road inventories of private residential roads systems.

Local Watershed Efforts

Active involvement in watershed planning, monitoring and assessment at the local scale can dramatically improve the awareness of local residents regarding watershed processes and the impacts of various land-use activities (e.g. Mattole Restoration Council, 1989). The establishment of watershed councils and coordinators has been recognized as an important step in the processes of prioritizing and implementing watershed restoration plans. Local inhabitants often have the strongest long-term commitment to maintaining and improving watershed conditions where they live, but they are often lacking in the technical expertise that enables them to develop plans or implement projects that are effective at restoring watershed processes. Most local activist groups direct their attention at specific issues, such as the prevention of timber harvest plans, or the diversion of water from their watershed.

Summary of Organizations in the South Fork and North Fork Basins

There are currently no well established watershed organizations in either basin, however there are a handful of different special interest groups and recently established groups with interests in the field of watershed restoration and conservation. A list of the organizations is presented below; phone numbers for the listed contact people are found in Appendix C.

South Fork (or Eel River in general)

Friends of the Eel River - Nadananda
Environmental Protection and Information Center (EPIC) - Richard Gienger
Coho Salmon / Salmon Forever - Jesse Noel
Eel River Salmon Restoration Project - Harry Vaughn / Bill Eastwood
Eel River Watershed Improvement Group - Ruth Goodfield
Diane Higgins - curriculum development, monitoring
Bioengineering Associates - Evan Engber
Friends of Gilham Butte

North Fork: None found

Part IV - Data Gaps and Recommendations

Most of the sediment and temperature related information available for the North Fork and the South Fork is from the late 1960's and early 1970's. There have been relatively few directed studies following the early dam feasibility studies. Very little effort has been made to synthesize or analyze existing data. The lack of research conducted in the two basins is the result of different circumstances for each basin. The North Fork is remote and sparsely populated, with approximately 50% of the basin in private ownership. Over 80% of the South Fork Basin is in private ownership, making regional watershed studies logistically difficult.

The data gaps and recommended actions listed below are discussed in more detail in the Recommendations section that follows it.

Sediment related information gaps

- Recently completed geologic mapping needs to be published for sediment production modeling.
- Few upslope inventories of roads or sediment sources.
- No current information on suspended sediment, for purposes of comparison with studies of the late 60's and early 70's (e.g. Brown and Ritter, 1971).
- No analysis or synthesis of various studies and data.
- No sediment budgets for the basins aimed at distinguishing natural versus management induced erosion and sediment production.
- No quantitative, reliable information on channel conditions.

Temperature information gaps

- Digital summaries of recent and historic temperature data
- Numerical analysis of temperature data derived from digital data loggers
- Minimal attention to the causes of elevated water temperature.

Recommendations

1. 0 Compile and review existing temperature and sediment information

Historic temperature monitoring has taken place at many USGS and DWR gage stations. Currently, stream temperature data are being collected at numerous locations in the Eel River basin. There is a large need for a regional watershed information database and the establishment of consistent methods for data collection, analysis, and storage. Historic temperature data needs to be entered into a digital database in order to allow basic retrieval of information, and comparison with current stream temperatures at the same sites (if available).

1.1 Determine what level of watershed assessment has been conducted throughout the watersheds on both private and public lands.

Road inventories conducted by various workers and agencies should be collected and evaluated for inclusion in a regional watershed database. Most of the current studies exist only in the grey literature of final reports and field maps. Efforts should be made to synthesize and analyze existing road and sediment source inventories in order to develop a picture of historic and current watershed conditions. Wherever possible, map information should be incorporated into a Geographic Information System(GIS).

The search for information conducted for this study located only two upslope inventories in the South Fork Eel (Horns and LaVen, 1986, and Pacific Watershed Associates, 1997). The Pacific Watershed Associates report inventoried approximately 110 miles of maintained and abandoned dirt and gravel surfaced roads on public lands. These studies cover approximately 15% of the basin, leaving the remaining 85% of the basin as a data gap. No systematic road inventories were located for private timber, ranch or residential lands.

1.2 Compile existing streambed information

Channel cross-sections have been surveyed at USGS stream gage sites and at various other locations along the South Fork Eel and some of its major tributaries (Bull Creek and Elder Creek). Resurveying of selected cross-sections will provide insight into the trend of channel conditions at these sites. Extensive surveying of channel cross-sections occurs in lower portions of the mainstem of the Eel River due to extensive gravel extraction operations in these areas. However, due to the lack of such activities in the South Fork and North Fork, no such monitoring is currently taking place.

1.3 Publish geologic mapping currently in draft form

Sediment production is primarily a function of the geologic setting and climatic pattern, with land-use playing an important role in the acceleration of background sedimentation rates. Most of northern California has been geologically mapped in detail, yet many of these maps have never been published due to funding cuts and recent reorganization of the U. S. Geological Survey (USGS). The funding was cut to publish these maps after over a decade of field mapping by numerous geologists from the USGS, graduate students, and local researchers. Many of these maps have finished technical review and simply await updates by a GIS technician. Funding of a few salary positions is likely to go a long way toward the publication of these maps.

Contact:
Don Gautier - chief scientist - (415)329-4909
gautier@sierra.wr.usgs.gov
Dave Howell - project chief for SF Bay Region Project - (415) 329-5430

dhowell@octopus.wr.usgs.gov
John Pallister - project coordinator for National Geologic Mapping Program - (703) 648-6960
jpallist@usgs.gov

2.0 Establish regional data repositories at USDA Pacific Southwest Research Station (Redwood Sciences Laboratory) or at the Interagency Watershed Analysis Center.

There is a clear need for a central clearinghouse for watershed information that could be compiled into a series of digital databases. The magnitude of the database would require powerful computer capabilities and skilled database managers. Ideally all of the information contained in the regional watershed database would be available via electronic links on the Internet/World Wide Web.

3.0 Develop consistent protocols for data collection

Road and sediment source, temperature and stream inventories, as well as locations where channel morphology changes are measured would all be more useful if they were conducted using consistent methodologies that are internally consistent and based on scientifically sound principles. For example, all locations where temperature data have been collected over the years need to be reviewed in order to determine which sites are providing meaningful information. Based on the results of the review, a more permanent network of monitoring sites should be established, including a determination of which historic sites should be reoccupied. A consistent protocol should be established which allows for the collection of information on stream channel and riparian conditions (in the reach above the measurement site) which affect stream temperature. Summaries of such protocols are described in Spence et al. (1997) and MacDonald et al. (1991).

4.0 Continue or reinitiate regional monitoring programs

4.1 Maintain stream gaging and stream temperature monitoring at sites with long historic records

Many USGS gages are scheduled to be closed during the 1997/1998 water year due to state budget cuts. USGS stream gages provide continuous monitoring of river stage, from which river discharge can be calculated. Many sediment transport relationships are related to these parameters (depth and flow). Stream gages provide the only systematic source of information on the flow conditions in many northcoast rivers, and are often the primary source of information for various important decisions. Flood hazard assessments, sport fishing regulations and storm tracking analyses all rely on information provided by USGS/DWR stream gages. Without adequate streamflow data from gaging stations, it will be very difficult to monitor the effectiveness of any TMDLs for sediment in the Eel River watershed.

In recent years, many stream gages have been "uplinked" via satellite and streamflow data are now available on the Internet/World Wide Web. This availability of information is unprecedented, and will allow for more extensive usage and analysis of streamflow data.

4.2 Reinitiate suspended sediment monitoring at selected stream gages

Collection and analysis of suspended sediment at sites monitored during the 1960's and 1970's would provide valuable trend information. Suspended sediment monitoring is costly to carry out and difficuit to interpret, but it is the best technique available for measuring the overall sediment yield at a point. Without suspended sediment data, it will be difficult to measure success or failure of sediment TMDLs, requiring more attention be directed toward sediment source analyses.

5.0 Conduct additional field assessments (source analyses)

Various state and federal agencies, private corporations and non-profit groups have been conducting a wide variety of road and sediment source inventories across all land-ownerships in the Pacific Northwest.

Methods exist for formal accounting of sediment production from different types of activities. These methods involve simple field inventories conducted by trained personnel. Generally the work is conducted or overseen by a geologist with training in geomorphology. Recent efforts have been made to retrain displaced workers in the fishing and timber industries to evaluate road conditions (PCFWWRA, 1995, 1996 and 1997). These efforts have been valuable in various respects. Displaced workers are given meaningful work that give them direct experience with the linkages between land-use practices, geomorphic processes, fish habitat enhancement programs and development of on-site and off-site mitigation measures. These efforts need to be formally documented and evaluated, and all future efforts should require a standardized protocol.

6.0 Analysis of Recent Inventory Data.

Industrial timber companies have also recently begun detailed inventories of their lands. Some are conducting sediment source inventories, road inventories, and various types of biological inventories. Collation of some of these data could lead to a better representation of the current conditions. It would be valuable to know what the average road densities are on different types of lands, and to be able to subdivide these road densities based on hillslope position, type of construction, and potential to deliver sediment to watercourses. Some of this information is currently being compiled by the Forest Science

Project at Humboldt State University, and could also be contributed to the proposed regional watershed database.

7.0 Influence current and future land-use practices, especially with regard to riparian protection.

7.1 Support more effective implementation of forest practice rules and best management practices (BMPs)

During the course of this study, numerous individuals recognized and elaborated upon the need to direct attention to the upslope areas in order to achieve in-stream targets for sediment production. For mitigation of current land management activities, non-degradation policies, such as "zero net increase" in sediment delivery or temperature have been applied. However, these types of approaches can only be achieved with detailed prior evaluation of hillslope conditions and monitoring of conditions following "treatment." This type of approach directs attention towards anthropogenic disturbance activities, and reduces the uncertainties associated with establishing numerical targets for highly dynamic systems.

7.2 Formalize increased riparian protection measures.

Riparian buffers provide a means of dramatically decreasing temperature conditions, while reducing the amount of disturbance triggered slope-failures in the steep inner gorges found in many parts of northern California. The FEMAT report (1993) examined the potential impacts of increased buffer widths on federal lands. The fundamental goal in the establishment of riparian buffers should be to minimize disturbance in stream corridors.

7.3 Formalize land-use restrictions on unstable lands.

California Forest Practice Rules currently only require surface erosion estimates for their erosion hazard rating system. A more comprehensive review of additional types of erosion, including mass-wasting and fluvial hillslope erosion should be included in the timber harvest planning process. The results of such analyses would identify unstable areas during the planning phase, and could lead to more limited activities on steep headwalls and inner gorge slopes.

8.0 Support local monitoring efforts

8.1 Provide technical guidance to local watershed restoration groups (if they exist)

Technical guidance to local watershed groups will assist to focus attention on the most productive avenues of work. Information and technology transfer is a worthwhile investment in a watershed, and the benefits are reaped for many years to come.

9.0 Address sediment production associated with ranch and rural homestead road systems

Virtually no quantitative information exists on the degree of sediment-related problems existing on private, non-industrial timber lands. Rural homestead, residential access, and ranch road systems are frequently recognized as chronic sources of fine sediment, but very few studies have been conducted to quantify these inputs. While many of these road systems are similar to forest roads found on industrial timberlands, there are some very significant differences that make the management of residential roads problematic. In contrast to industrial forest roads, there are no seasonal restrictions on the use of residential roads, and there is no regulatory framework for overseeing the maintenance or implementation of proper erosion control measures. As a result, there remains a vast information gap on the magnitude of the problem associated with rural homestead access roads.

The magnitude of sediment production from rural homestead roads varies greatly, and depends largely on the financial and heavy equipment resources available to the landowner(s). Road associations, consisting of groups of landowners using the same road system can sometimes minimize the individual costs associated with proper road maintenance. Unfortunately, road associations are often plagued with petty disagreements that severely limit the effectiveness of the association.

Conducting road inventories on private residential and ranch roads is difficult due to landowner concerns over potential loss of "private property rights." Private landowners in northern California generally do not like to be told what to do on their lands and generally have a high level of distrust and disdain for government agencies. If any kind of analysis of rural homestead roads is conducted, it must either be done by remote means such as aerial photo analysis, or through the involvement of local Resource Conservation Districts. Any wholistic effort will require the cooperation of a large number of landowners.

In the late 1980's, an inventory of sediment sources was conducted by the Mattole Restoration Council (in the basin immediately to the west of the South Fork Eel) that included local landowners in the identification of landslide features on their own properties (MRC, 1989). While the level of technical analysis was somewhat lower in this study, the approach was successful in the manner in which local landowners were included in the process of contributing to the state of understanding regarding erosion and sedimentation problems. A similar type of approach could be developed for conducting a detailed road inventory on private lands, but would require substantial incentives (technical and financial support) in order to gain the cooperation of the wide spectrum of local landowners.

Part V - Conclusions

The types of studies located in this literature review are of limited value for defining TMDLs for sediment or temperature in the North Fork or South Fork of the Eel River. There are few detailed sediment source inventories, and very little recent synthesis of existing data. The key sediment transport studies (Brown and Ritter, 1971, Janda and Nolan, 1979, Lisle, 1981a) serve more as testimony to the natural variability of sediment transport processes in northwestern California. Most of the detailed studies of sediment transport processes took place over twenty to thirty years ago, and very few detailed studies have taken place since then.

It is clear that most of the sediment transport occurs in the high magnitude storm events. It is during these events that hillslopes experience widespread failure. Since many of these failures occur in the steep inner gorges of deeply incised channels, most result in direct delivery of the landslide material. Deep-seated landslides and earthflows are also mobilized during these prolonged saturation events, and the toes of these features become significant sediment sources. These are the chronic sediment sources that line the banks of the main Eel downstream of Dos Rios.

In spite of significant data gaps on current conditions, the greatest challenges facing those trying to develop and implement TMDLs on non-federal lands are likely to be encountered in the socio-political arenas rather than the technical arena. Over 80% of the South Fork of the Eel, and nearly 50% of the North Fork of the Eel are in private ownership, and the resistance to increased state and federal regulation is likely to be extreme. Many rural landowners in northern California share a characteristic "anti-regulatory" attitude that will make establishment of water quality standards very difficult to implement. Efforts to force landowners to achieve standards will likely be much less successful than efforts to assist landowners with technical and financial support for appropriate land use planning, road upgrade assessment and implementation, and proper road closure of high risk road routes with the re-location of the former routes to more stable locations on the hillslopes. Efforts leading to the development of watershed councils will promote landowner participation in community based watershed restoration, and may have some of the most direct influences on the attainment of water quality standards.

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Hickey, J. J., 1969, Variations in low-water streambed elevations at selected stream-gaging stations in northwestern California: U. S. Geol. Survey Water-Supply Paper 1879-E, 33 pp.

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Janda, R. J., and K. M. Nolan, 1979. Stream sediment discharge in northwestern California, *in* Guidebook for a Field Trip to Observe Natural an Management-Related Erosion in Franciscan terrane of Northern California: Geol. Soc. America, Cordilleran Section, pp.IV-1-27.

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PacificWatershed Associates, 1997. South Fork Eel River watershed assessment report for BLM lands. Prepared for USDI Bureau of Land Management, Arcata Resource Office, Calif. 100 p.
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Reid, L. M. and T. Dunne, 1996. Rapid evaluation of sediment budgets. Catena Verlag 164 pp.
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Salo, E. O. and T. W. Cundy (eds) Streamside Management: Forestry and Fishery Interactions. Contribution #57, Institute of Forest Resources, University of Washington, Seattle, Wash.
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USDA Forest Service and USDI Bureau of Land Management. 1996. North Fork Eel River watershed analysis. Ver. 1.0. Mad River Ranger District. 146 p.
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Wahrhaftig, C. and R.R. Curry, 1966. Geologic implications of sediment discharge records for the [northern Coast Ranges, California, unpublished report, 24 pp.

APPENDIX A

Annotated Bibliography for TMDL Literature Review: South Fork and North Fork Eel River Sediment and Temperature Related Studies

Eel River Basin (inclusive)

Bechtel Corporation. 1959. Report on Eel River Investigations, California. Prepared for the Metropolitan Water District of Southern California. San Francisco, CA.

Source: Not photocopied, report resides at: Humboldt County Department of Public Works, Natural Resources Division, Eureka, CA; Don Tuttle (707) 445-7741
Summary: Evaluation of water yield expectations and dam feasibility studies.
Relevancy to TMDL: Low

Blodgett, J. C. 1970. Water temperatures of California streams, north coastal subregion. USGS open-file report, Menlo Park. 50 p.
Source: From Humboldt County Collection, Humboldt State University (HSU) Library.
Summary: Partial photocopy of introductory text of the report, and data summaries from stations within the Eel River basin. Both periodic and continuous measurements were taken at many stations, with variable lengths of record. Data consist of mean monthly values for minimum, mean and maximum stream temperatures for a given water year.

Table A-1 - Location and duration of temperature monitoring stations

Gage Name/Location	USGS #	DWR #	Periodic measurements	Continuous measurements	Duration of Record
North Fork near Mina	11-4745	F-6-2100	134		Sept. 1953 to Oct. 1968
North Fork near Mina	11-4745	F-6-2100		yes	Oct. 1965 to Sept. 1966
Eel River @ McCann, a.k.a. Eel River @ S. Fork (DWR)	11-4752.5	F6115450	205	no	Apr. 1951 to Sept. 1968
SF Eel nr Branscomb	11-4755	F-6-4300	97		Jan 1950 to Sept. 1960
SF Eel nr Branscomb	11-4755	F-6-4300		yes	Oct. 1956 to Sept. 1968
Tenmile Ck nr Laytonville	11-4757	F-6-4400	16	no	Mar. 1953 to Aug. 1968
SF Eel @ Leggett	11-4758	none	38		Oct. 1965 to Nov. 1968
SF Eel @ Leggett	11-4758			yes	Oct. 1965 to Sept. 1968
E. Branch SF nr Garberville	11-4759.4	none	24	no	July 1966 to Nov. 1968
SF Eel @ Benbow dam	11-4759.5	none	none	yes	Oct. 1957 to Sept. 1959
SF Eel near Miranda	11-4765	F-6-4100	216		Mar. 1950 to Sept. 1960
SF Eel near Miranda	11-4765	F-6-4100		yes	Oct. 1960 to Sept. 1968
Bull Creek near Weott	11-4766	F-6-1150	65	no	Nov. 1960 to Nov. 1968

Relevancy to TMDL: High - summary of mean monthly temperatures, locations and durations of temperature monitoring stations.

Brown, L. R. and P. B. Moyle. 1989. Eel River survey: Third year studies. Department of Wildlife and Fisheries Biology, University of California, Davis, CA 95616.

Source: Not photocopied, report resides with Don Tuttle, Humboldt County Department of Public Works.
Summary: Overview of fish distribution through the Eel, including N. Fork, Bull Creek.
Relevancy to TMDL: Low

Brown III, W. M. and Ritter, J. R. 1971. Sediment transport and turbidity in the Eel River basin, California. USGS Water Supply Paper 1986. 70 p.

Source: From Humboldt County Collection. HSU Library.

Summary: This report provides a comprehensive overview describing the general setting of the Eel River basin, including: the Physical setting, Hydrography, Hydraulic Geometry, Fluvial Sediment Turbidity and References to prior and related studies. Summarizes results of sediment transport studies conducted at 22 locations between 1955 and 1967 (not all continuous). Recognizes the Eel River has having the "highest recorded average annual suspended sediment yield per square mile of drainage area of any river of its size or larger in the United states."

The purpose of the study was to quantify sediment production from several areas of the Eel River Basin, with the ultimate goal of evaluating water development alternatives.

This study describes the magnitude and timing of sediment transport from the different major subbasins, and along some of the major stream reaches of the Eel.

Recognizes the South Fork as a unique drainage in the context of the Eel basin (p.15): Distinctive geologic formations (relatively little earthflow terrain); much lower average stream gradient (24 feet/mile) compared to the other major tributaries.

Hydraulic geometry cooefficients (b, m, f, and Q) are given for numerous gages in the Eel, but not the North Fork or the South Fork. Suspended sediment transport curves are the lowest of the six sites evaluated (fig. 13).

Topics discussed include:

Variation in hydraulic geometry 1966-1967

Average Sediment yield, 1963-1967, and 1966-1967

Downstream variations in hydraulic geometry of the main Eel between Black Butte and Scotia

Definition of terms

Methods of computation

Flood effects - 1964

Detailed discussion of sediment studies at Eel River at Scotia: Sept. 1955 to 1967. Sediment Transport curves, (relation of suspended sediment to streamflow), particle size distributions

Detailed presentation of similar data from Black Butte, Fort Seward and South Fork at Branscomb, summary of suspended sediment and water discharge at SF - Branscomb, and SF near Miranda.

Summary of relationship between turbidity and suspended sediment concentration (concentration-turbidity plots). The South Fork consistently has the lowest suspended sediment concentration for a given turbidity rating (fig. 33), and the most scatter of any of the gages (fig. 32).

Relevancy to TMDL: High - describes the dynamics of suspended sediment discharge estimation in the Eel River.

California Department of Fish and Game. 1997. Eel River Salmon and Steelhead Restoration. (final review draft) Inland Fisheries Division. January 28, 1997. 100 p.

Source: Scott Downie, Fortuna

Summary: Current summary of fish habitat conditions in the Eel River basin. General descriptions of each of the subbasins in the Eel, and brief summaries of habitat conditions in each sub-basin are presented. Status of habitat typing and stream surveys are mentioned for each sub-basin. Appendix F, summarizes "streams inventoried for fish habitat."

Relevancy to TMDL: Moderate - mostly directed toward fish habitat, but stream inventories could be useful.

California DWR, 1974. Eel River Basin environmental studies - 1974 Progress Report. 93 p.

Source: DWR Northern District - Trisha Brasher - (916) 529-7356

Summary: This summary report contains the results of some of the more detailed geological memorandum reports, plus summaries of sediment transport estimates and stream temperature monitoring. The report also addresses numerous other topics such as fish, wildlife and recreation planning. This report represents the initiation of a 12 year study of the Eel River basin evaluating the suitability of the basin for Wild and Scenic River status, and/or the impacts of large-scale water development.

Contains summary table of highest suspended sediment yields from 1972-73, for Middle Fork, Main Eel, and North Fork.
Relevancy to TMDL: Moderate - good overview of multiple issues throughout the Eel River basin.

California Department of Water Resources. 1966. North coastal area investigation. Appendix A. Watershed management in the Eel River basin. Calif. Dept. Water Resour. Bull. No. 136. 143 p.

Source: copy on loan from A. K. Lehre, also available in Humboldt County Collection, HSU Library
Summary: General planning document for watershed management throughout the Eel River basin: general discussion of hydrologic, climatic and physical setting, landuse and vegetation types, problem areas and activities. Listing and map presentation of possible water projects (dam construction). General discussion of the role of state and federal agencies in watershed management.
Relevancy to TMDL: Low - very general. Most of the research was conducted prior to the 1964 flood, maps dated 1963, 1964.

California DWR. 1965. Land and water use in the Eel River hydrographic unit. Vol. I: Text. Bulletin No. 94-8. 113 p. plus appendices.

Source: Not photocopied, report resides at: Humboldt County Department of Public Works, Natural Resources Division, Eureka, CA; Don Tuttle (707) 445-7741
Summary: Overview of land-use and classification of lands; summary and descriptions of surface water diversions in Eel River Hydrographic Unit (ERHU)
Relevancy to TMDL: Low

California DWR. 1965. Land and water use in the Eel River hydrographic unit. Vol. II: Plate 2, Classification of Lands. Bulletin No. 94-8.

Source: Not photocopied, report resides at: Humboldt County Department of Public Works, Natural Resources Division, Eureka, CA; Don Tuttle (707) 445-7741
Summary: Collection of detailed maps describing land use and land classification. At scale of 1 inch = 4,000 feet. Classifications include: lands receiving full irrigation; lands receiving partial irrigation; lands usually irrigated, lands idle or fallow in 1958; naturally irrigated meadowlands; dry farmed lands; urban lands; recreational lands. Mapping conducted 1958. No text.
Relevancy to TMDL: Low

California DWR. 1963. Land and water use in the Eel River hydrographic unit. Vol. III: Plate 3, Classification of Lands. Bulletin No. 94-8.

Source: Not photocopied, report resides at: Humboldt County Department of Public Works, Natural Resources Division, Eureka, CA; Don Tuttle (707) 445-7741
Summary: Collection of detailed maps describing land use and land classification. At scale of 1 inch = 4,000 feet. Classifications include: smooth lying irrigable lands; gently sloping or undulating irrigable lands; steeply sloping irrigable lands; irrigable lands better suited for forest management; present urban lands; recreational lands. Mapping conducted 1958. No text.
Relevancy to TMDL: Low

California DWR. 1962. Branscomb project investigation (preliminary edition). Bulletin No. 92.

Source: Not photocopied, report resides at: Humboldt County Department of Public Works, Natural Resources Division, Eureka, CA; Don Tuttle (707) 445-7741
Summary: Water temperature data from South Fork Eel near Branscomb, Benbow dam site, and Fernbridge: 1957 and 1958, from US Fish and Wildlife Records.
Relevancy to TMDL: Moderate, contains raw temperature data

Cleveland, G. B. 1977. Rapid erosion along the Eel River, California. California Geology, September, 1977.

pp. 204-211.

Source: HSU Library
Summary: General overview of erosional processes active in the Eel. Focus on the extreme erosional activity in the Eel River Basin, and its sensitivity to land-use practices. Most of the data in the report are compiled from Hawley and Jones (1969), Knott, (1971), and Brown and Ritter, (1971). The author observes the highly variable nature of sediment production derived from different parts of the basin, and more specifically from different landscape elements within the basin. Thus different portions of the basins have their own unique erosional characteristics. Prudent land management requires that each individual slope be considered separately.
Relevancy to TMDL: Moderate to high - good background info.

Hauge, C. J., M. J. Furniss, and F. D. Euphrat. Soil erosion in California's coast forest district, Status report on the California Department of Forestry's continuing Soil Erosion Studies. California Geology, June, 1979. pp. 120-129.

Source: HSU Library
Summary: Overview of forestry-related erosion hazards, and suggestions for best management practices. Emphasis on soil properties and their relative sensitivity to different types of forestry activities and ground disturbance. This paper explores some of the general impacts of forest removal, road construction on varying slopes, rill and gully erosion, and erosion resulting from skid road construction. An inventory of landslides shows a strong relationship between frequency of events and road construction/hillslope gradient. The authors provide a concise overview of alterations to hillslope drainage.
Relevancy to TMDL: Moderate - useful for suggestions of best management practices.

Hawley, N. L. and B. L. Jones. 1969. Sediment yield of coastal basins in northern California, 1958-64. USGS open-file report. 19 p.

Source: HSU Library, CalDocs
Summary: A quantitative summary of suspended sediment monitoring efforts in northern California (Eel, Mad, Van Duzen and Trinity rivers). Includes ternary diagrams showing percentages of sand, silt and clay in suspended sediment samples. Figure 5 shows ranked distribution of sediment sources by major subbasins. A sediment transport curve is presented for the Van Duzen Basin. Bedload discharge estimates are made where possible, and the proportion of bedload relative to suspended sediment is estimated for the Dos Rios (30%) and Scotia (4%) gages. The authors note that sediment production is largely related to basin physiography (geologic setting).
Relevancy to TMDL: High - quantitative summary of sediment discharge.

Hickey, J. J. 1969. Variations in low-water streambed elevations at selected stream-gaging stations in northwestern California. USGS Waters Supply Paper 1879-E. 33 p. plus map of gage locations.

Source: From Humboldt County Collection, HSU Library.
Summary: A collection of plots of channel cross-sections at selected stream gaging stations. The largest elevation changes occurred during the low-water periods of 1964 and 1965. During this period, 42 of 51 gages showed signs of aggradation, with 25 of 51 sites showing elevation changes in excess of 1 foot. Measurements were taken at stream gaging sites during discharge measurements. 54 gages were evaluated, 46 with records that exceed 5 years in length (long-term).
Records exist for the North Fork gage, and in the South Fork, records exist for the following gages: Branscomb, Miranda, Tenmile Creek, and Bull Creek.
Relevancy to TMDL: Moderate - documentation of changes in mean bed elevation over time.

Irwin, G. A. 1976. Water-quality investigation, Eel River, California. USGS Water-resources investigation 76-5. 24 p. plus data appendix.

Source: Photocopy from Tom Lisle, Redwood Sciences Lab, Arcata.

Summary: Water-quality investigation, with attention on major inorganic chemical constituents; total organic carbon; trace elements; and pesticide compounds. Methods: specific conductance, chemical analysis and statistical analysis (regression).

Sampling sites include: Eel River: at Van Arsdale Dam, near Dos Rios, at Fort Seward, at South Fork, at Scotia. Sampling period ranges from 1971 to 1976, with a summary of data collected between 1951 and 1966.

Relevancy to TMDL: Only relevant for nutrient-related TMDLs.

Janda, R. J., and K. M. Nolan, 1979. Stream sediment discharge in northwestern California, <u>in</u> Guidebook for a Field Trip to Observe Natural an Management -Related Erosion in Franciscan terrane of Northern California: Geol. Soc. America, Cordilleran Section, pp.IV-1-27.

Source: From Humboldt County Collection, HSU Library.

Summary: A comprehensive overview of sediment discharge in numerous basins in northern California, with emphasis on the Russian River, Eel River, Mad River and Redwood Creek. Contains maps of USGS gage sites and a table summarizing gage stations: name, drainage area, period of record, and suspended sediment and bedload data in terms of daily, annual and long-term average.

The text provides a comparison of northern California suspended sediment data to national and worldwide averages. Factors leading to the high rates of sediment discharge include: 1) geologically recent tectonism 2) pronounced seasonal concentration of precipitation, and 3) major disruption of the ground surface by the activities of man.

Summarizes range of water discharges per unit area (WD/A) and Suspended Sediment Data per unit area (SSD/A) for stations.

Discusses sources of uncertainty for comparisons of SSD/A:

- measurement and computation techniques: Estimated long-term averages are most prone to uncertainties due to different computational methods. SSD/A values are more comparable due to consistent measurement techniques applied by the USGS.
- lengths and dates of observation: Uncertainties due to different period of record are important due to the event-related nature of sediment transport, e.g. 1.5 as much suspended sediment transported at the Scotia gage between Dec. 21-30, 1964 than in the preceding 8 years. (see Brown and Ritter).
- drainage basin sizes: SSD/A's appear to be inversely related to drainage area, but not universally so; gentler hillslopes in smaller basins; also more likely to be impacted by localized storm events. Smaller basins respond more dramatically to land-use activities .

Uncertainties attest to the difficulty of ranking or assigning mean values for the measured parameters.

Discussion of suspended sediment transport curves (SSTC's): steeper for tributaries than for larger streams.

Discussion of relationship between SSD/A and Runoff, and limitations of statistical measures as prediction tools.

Addresses the role of mass movements in SSD/A measurements, i.e. event dominated, direct supply of sediment to streams, exposure of mineral soil to further erosion.

Bedload Discharge: discussion of difficulties and errors, and very high uncertainties. In some locations, Helley-Smith samples have agreed well with predictive equations.

Approximately 20% of annual total load is transported as bedload; typically 15%; rarely less than 10%. These values can be used to approximate the underestimation of SSD/A measurements.

Discussion of implications: soil loss - non-uniform denudation, as evidenced by remnant Quaternary landforms and active landsliding.

Geologic Controls on SSD/A's: may ultimately override the influences of man in absolute magnitude. E.g. the localized distribution of shear zones, steep terrain, or alluviated valleys influence erosion rates. Rock types, e.g. crystalline basement versus sedimentary rocks also strongly influence erosional activity. Geologic parameters are critically important, but often not the emphasis of many studies of sediment production, partly due to institutional biases.

Relevancy to TMDL: High - relevant for both general concepts and summary of historic data and physical process relationships. Strong emphasis on the uncertainties associated with suspended and bedload sediment measurement and interpretation.

Kubicek, P. F. 1977. Summer water temperature conditions in the Eel River system, with reference to trout and salmon. Masters Thesis, HSU, 200 p.

Source: From Humboldt County Collection. HSU Library.
Summary: A spatially broad, but temporally narrow survey of temperature conditions in the Eel River Basin. Kubicek measured temperatures across nearly the entire Eel River basin in the summer of 1973, recording water temperatures with a hand-held thermometer. Daily maximum and minimum temperatures were estimated based on comparison of that days data with data from the nearest thermograph location. The author uses the information gathered to subdivide different portions of the basin into the following categories, with respect to suitability for salmonids: lethal (max. summer temp. estimated @ 28 degrees Celsius); marginal (max. temp between 26.5 and 28.0 C); and satisfactory (max. temp less than 26.5 C). Map on page 22 summarizes the distribution of these reaches.
Relevancy to TMDL: High - provides overview of temperature conditions throughout the entire basin. Results are limited, however by the "spot-check" nature of the sampling method.

Lamphear, D. 1997. DRAFT Map: Eel River Hobo Temp. Locations. 1 p.

Source: Dave Lamphear, Redwood Sciences Laboratory, Arcata, CA (707) 825-2928.
Summary: GIS map showing the locations of 1996 thermographs deployed by Gary Friedrichsen et al. of the Humboldt County RCD. One-page 8.5x11 map showing thermograph locations, based on the Latitude/Longitude coordinates provided by the individual surveyor. Some errors in the map, with some thermographs appearing out of the watershed.
Relevancy to TMDL: High - shows locations of current stream temperature monitoring efforts throughout the Eel River basin.

Lisle, T. E. 1981a. Channel recovery from recent large floods in north coastal California: rates and processes, in Coates, R. N., Proceedings, Symposium on Watershed Rehabilitation in Redwood National Park and Other Pacific Coastal Areas. August 25-28, 1981. Center for Natural Resource Studies, Sacramento, CA. p. 153-160.

Source: From Humboldt County Collection, HSU Library.
Summary: Overview of the processes leading to channel recovery, and their expected rates. Recognizes the linkage between riparian vegetation/large organic debris and channel recovery, with attention toward the rates of regrowth of riparian forests following scouring events. Minimal specific discussion of Eel River tributaries
Relevancy to TMDL: Low- general overview of geomorphic processes and riparian dynamics.

Lisle, T. E. 1981b. The recovery of aggraded stream channels at gauging stations in northern California and southern Oregon. In Erosion and Sediment Transport in Pacific Rim steeplands, I. A. H. S Publ.No. 132 (Christchurch, 1981). p. 189-211.

Source: From general collection, HSU Library, Arcata, California
Summary: A similar overview of the processes of channel aggradation and recovery following peak storm events. Emphasizes the importance of large, infrequent events in channel forming processes. This paper resembles that of Hickey (1969) but is more process-oriented.
Relevancy to TMDL: Low- general overview of geomorphic processes and riparian dynamics. No specific mention of South Fork or North Fork of the Eel.

Lisle, T. E. 1982. Effects of aggradation and degradation on riffle-pool morphology in natural gravel channels, northwestern California. Water Resources Research, vol. 18, no. 6, pp. 1643-1651.

Source: Reprint from Tom Lisle, Redwood Sciences Lab, Arcata, CA (707) 825-2930.
Summary: A similar, slightly more technical discussion of the rates and processes of channel recovery in northwestern California, than Lisle, 1981a and 1981b.
Relevancy to TMDL: low- general overview of geomorphic processes and riparian dynamics. No specific

mention of South Fork or North Fork of the Eel.

Lisle, T. E. 1990. The Eel River, northwestern California: high sediment yields from a dynamic landscape. In: M.G. Wolman and H.C. Riggs, ed., Surface Water Hydrology, v. O-1, The Geology of North America, Geological Society of America. p. 311-314. (draft manuscript).

Source: Tom Lisle. Redwood Science Lab

Summary: This paper identifies the Eel River as the basin with the highest recorded average suspended sediment yield per unit drainage area in the United States.

High sediment yields are due to a combination of erosive bedrock, rapid tectonic uplift high seasonal rainfall, and recent disturbances by man.

A concise overview of the hydrologic and geologic setting of the basin is presented. Suspended sediment per unit area increase due to the proportional increase of unstable lands in inner gorge areas. The variation in sediment production across different geologic terranes is as much as an order of magnitude, for example, estimated annual sediment yield from streams draining the melange (earthflow terrane) is 24,000 t/km^2, which is 10 times that of the yield for the whole basin. Certain portions of the basin produce a disproportionate amount of the total sediment yield, namely the reach between Dos Rios and the confluence of the South Fork. In contrast, in the more competent coastal belt terrane, stable forested basins may have sediment yields as low as 300 t/km^2. A brief summary of the effects of land-use is provided.

Peak climatic events are recognized as a highly significant player in channel forming processes, with emphasis on the influential role of extreme flood events on sediment transport rates, hillslope and channel processes. Cites study by Hawkins (1982) that concludes 87% of the suspended sediment load is carried in the highest 10% of daily discharges. Discusses some of the reasons why large storms transport so much sediment: higher sediment delivery ratios, high frequency of landslides and bank failures, causing positive feedback mechanisms.

Discussion of the persistence of certain channel alterations resulting from the 1964 flood.

High sediment yields are due to a combination of erosive bedrock, rapid tectonic uplift, high seasonal rainfall, and recent disturbances by man.

Relevancy to TMDL: Low to moderate - good overview of Eel River conditions, summary of processes.

Porterfield, G. 1972. An inventory of published and unpublished fluvial-sediment data for California. USGS open file report. ~45 p.

Source: HSU Library, Document section.

Summary: Partial photocopy of station locations, numbers, durations.

Relevancy to TMDL: Moderate - gage location information.

Puckett Larry K. 1976. Observations on the downstream migrations of anadromous fishes within the Eel River System. Memorandum Report. CDFG.

Source: Not Photocopied - Available from Steve Canatta (707) 826-2007

Summary: This report summarizes studies of the natural, downstream migrations of anadromous fishes from 1959 - 1970 in the Main Eel, Middle Fork Eel, South Fork Eel, Redwood Creek, Tenmile Creek, and Van Duzen Rivers. Water temperatures and streamflows are shown for each fish sampling date. (The water temperature data is also presented in Puckett and Van Woert. 1972).

Relevancy to TMDL: Low - spot measurements of water temperatures.

Puckett, Larry K. and William F. Van Woert. 1972. Water temperature observations in the Eel River system 1957-1969, A Data Report. Department of Fish and Game.

Source: Photocopy from the files of Steve Canatta, Fish Biologist (707) 826-2007.

Summary: A tabulation of stream temperatures within the Eel River System was assembled as part of the California Department of Fish and Game's (CDFG) investigation of the potential effects of water developments upon Eel River fishery resources. The following table presents the locations and period of record for each water temperature station listed in the report. Figure (in the report) shows a map of station locations.

Relevancy to TMDL: High - this document contains summaries of original data, consisting of daily min/max temperatures, and monthly averages in some cases.

Station Number	Location	Period of Record
USGS 11-476500	South Fork Eel River at Miranda	1960 - Sept 1969
CDFG	Eel River at South Fork	May-Oct 1966
CDFG	Redwood Creek at Whitmore Grove	Apr-Oct 1966
CDFG	South Fork Eel River near Benbow Dam	Jan 1958 - Sept 1959
CDFG	East Branch South Fork Eel River near rodeo grounds	Mar-Sept 1966
USGS 11-44758	South Fork Eel River at Leggett	Oct 1965 - Sept 1969
CDFG	Tenmile Creek USGS stream gage 6 miles northwest Laytonville	Mar-Oct 1966
USGS 11-4755	South Fork Eel River .4 miles upstream Jack of Hearts Creek near Branscomb	Jul 1957 - Jul 1958 Jan 1961 - Sept 1969
USFWS	North Fork Eel River at Mina Bridge	Apr-Aug 1966

Reynolds Forest L. 1983. 1983 Status report of California wild and scenic rivers salmon and steelhead fisheries. California Department of Fish and Game. 55 p. plus appendices.

Source: Partial photocopy from the files of Steve Canatta, Fish Biologist (707) 826-2007.
Summary: This report is the second in a series of fisheries status reports for California Wild and Scenic Rivers. Included in this report is a review of fiscal year 1982-83 fishery management activities and an update of the status of the system with notes on habitat conditions and management recommendations. Appendix G (photocopied) presents a river mile index for the location of the confluence of tributary streams within the major river reaches, and lists stream names and length of tributaries (permanent and intermittent). Appendix H lists data on miles of streams available for anadromous salmonids from 328 tributaries.
Relevancy to TMDL: Low - provides a concise summary of stream miles of tributaries and subreaches. Good general reference for tributary identification.

Ritter, J. R. 1972. Sand transport by the Eel River and its effect on nearby beaches. USGS open-file report. 17 p.

Source: HSU Library, Documents section.
Summary: Emphasis on sand transport in the Eel
Relevancy to TMDL: Low-attention on lower mainstem of Eel, below Scotia.

Smith, L. M. and D. M. Patrick. 1979. Engineering geology and geomorphology of streambank erosion; Report 1, Eel River Basin, California. Technical Report GL-79-7, U. S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Miss.

Source: Partial photocopy (pp. 22-27) obtained from Tom Lisle, Redwood Sciences Lab
Summary: Report deals primarily with general patterns of aggradation and degradation along the mainstem of the Eel. Includes a description of historical channels in the Lower Eel River and Eel River Delta: changes in longitudinal profile; summary of meandering patterns; estuarine morphology.
Relevancy to TMDL: Low, but other portions of the report may be more directly relevant. Whole report should be located for at least cursory review.

U. S. Army Engineer District, S. F. 1980. Eel River Basin Resource Analysis. U. S. Army Corps of Engineers, San Francisco, CA. ~300 p.
Source: Copy available in Eureka NRCS office, contact James Komar.
Summary: Partial Photocopy of table of contents, and extensive list of references on erosion/sedimentation. Also photocopied "Sources for Eel River Mapping," and "Agencies and Individuals Contacted," which provides a list of stakeholders as of 1980.

Report provides a broad overview of land-use and land-management and ownership patterns across the Eel River basin. Section 9.0 deals with Erosion and Sedimentation (approximately 115 pages). and summarizes basin geology. hydrology. climate: sediment transport and yield: basin terrain types: mass wasting and stream erosion processes: and basin sediment production sources.

Relevancy to TMDL: Low-moderate. Some of the information in Section 9 may be helpful. and should be looked at more closely.

U.S.C.E. 1965. High water mark data for Eel River, Flood of December 1964.

Source: Not photocopied, report resides at: Humboldt County Department of Public Works. Natural Resources Division, Eureka, CA; Don Tuttle (707) 445-7741.

Summary: Brief descriptions of hundreds of high water marks along the Eel river basin.

Relevancy to TMDL: Low

U.S.C.E. 1964. Interim Report for water resources development, Eel River, CA and appendix. Army Engineer District.

Source: Humboldt County Department of Public Works, Natural Resources Division, Eureka, CA; Don Tuttle (707)445-7741.

Summary: Land-use overview for Eel river basin, flood control projects, water resource development. Precipitation stations and streamflow stations.

Relevancy to TMDL: Low

U. S. Department of Agriculture. 1970. Sediment yield and land treatment. Appendix No. 1. Eel and Mad River Basing. 143 p. and maps.

Source: Copy on loan from D. K. Hagans, Pacific Watershed Associates. Also available in Humboldt County Collection, HSU Library

Summary: A comprehensive, reconnaissance-level background study on sediment production and land-use in the Eel River, Mad River and Redwood Creek basins. This study is a part of the "State Water Project," study to determine the feasibility of development of water resources in northern California and southern Oregon.

Objectives of the study include:

- To estimate the sediment yield by sources and causes under present conditions.
- To estimate the future sediment yield under the expected use and management.
- To formulate a land treatment program that would reduce the sediment yield and to estimate the costs of remedial measures.
- To evaluate the physical effects of the recommended program.
- To evaluate the potential development that could be obtained through U. S. Department of Agriculture programs.

Numerous maps are included in the report: Generalized Geologic Map; General Soil Map; General Land Capability Map; Hydrologic Soil Groups; Vegetal Cover Types; Land Ownership; Annual Sediment Yield Map; Locations of Suspended Sediment Gaging Stations and Reservoir Sedimentation Surveys. All maps are dated 1968.

Sediment yields are presented in units of acre-feet/sq. mile/year.

Numerous tables provide information about distribution of landslides, roads, and sediment yields from different causes, e.g. natural or anthropogenic.

Most of the information on sediment sources was based on sampling of 1:20,000 aerial photographs, i.e. not a complete inventory.

Relevancy to TMDL: Moderate - This report provides a good general overview of processes and issues. However, it is dated, and the maps are highly generalized. Data analysis was based on sampling rather than inventory, and therefore provide only rough estimates of rates and processes.

U. S. Department of Agriculture. 1972. Sediment yield and land treatment, Main Report. 135 p. and maps.

Source: Copy available in Eureka NRCS office, contact James Komar

Summary: Partial photocopy of table of contents.
Relevancy to TMDL: moderate

Waananan, A. O., P. P. Harris, and R. C. Williams. 1971. Floods of December 1964 and January 1965 in the far western states. Water Supply Paper 1866A—U. S. Geol. Survey. 225 p.

Source: Humboldt County Collection. HSU Library
Summary: Partial photocopy, including introduction, explanation of data, and data summaries for the North Fork Eel and South Fork Eel (and tribs). Data presented include: gage height, discharge, sediment concentration and load.
Relevancy to TMDL: Low-moderate

North Fork Eel River

Bickner. F. and R. G. Scott, 1975. Geologic reconnaissance study of Bell Springs Creek and Blue Rock Creek watersheds. California DWR Northern District. Memorandum Report. 22 p. map.

Source: DWR Northern District - Trisha Brasher -(916) 529-7356
Summary: Reconnaissance geologic report of these tribs., which drain into the main Eel. just upstream of the North Fork; Blue Rock Creek drains into the Main Eel, just above Bell Springs creek. This report represents the third year of geologic studies on the Main Eel below Dos Rios. Emphasis of report is on mass wasting processes and sediment production. Report contains detailed descriptions of geologic units. Numerous color photographs show the types of erosion features, characteristic geologic features, and some channel conditions. Hand colored geologic map and cross-sections show major shear zones, geologic contacts, landslides. Geologic mapping based largely on air photo interpretation.
Relevancy to TMDL: Moderate - detailed geologic study in area adjacent to the North Fork.

California DWR, 1973a. Geologic reconnaissance study of sediment sources, Chamise Creek drainage. California DWR Northern District. Memorandum Report. 14 p., map.

Source: DWR Northern District - Trisha Brasher -(916) 529-7356
Summary: This is a brief reconnaissance level geologic report, with attention to mass wasting. Chamise creek drains into the main Eel; the creek contains a USGS sediment sampling station.
Relevancy to TMDL: Low to moderate; brief, basin-specific report.

California DWR, 1973b. Geologic reconnaissance study of sediment sources, Dobbyn Creek drainage basin. California DWR Northern District. Memorandum Report. 32 p.

Source: DWR Northern District - Trisha Brasher -(916) 529-7356
Summary: A geologic reconnaissance of the Dobbyn Creek Basin (enters Main Eel from east at Fort Seward), with emphasis on mass wasting and sediment delivery processes. This basin is extremely active in terms of large landslide and earthflow activity.
Relevancy to TMDL: Moderate - studies not located directly in the NF, but processes may be similar.

California DWR,1974. Geologic progress report on landslides and sedimentation, Eel River. California DWR Northern District. Memorandum Report. 53 p.

Source: DWR Northern District - Trisha Brasher -(916) 529-7356
Summary: Summary report of geologic investigations. Contains results of numerous prior studies, as well as a photographic overview of slide types (also presented in Dwyer and Scott, 1971). Gradation curves (particle size analysis) presented for six landslides located in the main Eel. The study areas are located outside of the North Fork, but processes are likely comparable.
Relevancy to TMDL: Moderate - good summary document.

Dwyer, M. J, and R. Scott 1971. Middle Fork Eel River Development. Reconnaissance study of landslide conditions and related sediment production on a portion of the Eel River and selected tributaries. California Department of Water Resources. Memorandum Report. 69 p.

Source: DWR Northern District - Trisha Brasher -(916) 529-7356
Summary: A photographic documentation of different types of landsliding common in the Middle Fork Eel. Emphasis on landslide classification and distributions.
Relevancy to TMDL: - Moderate - good review of the different types of landslides and erosion features present some parts of the Eel River basin.

Keter, T. S. 1995. Environmental history and cultural ecology of the North Fork of the Eel River Basin, California. USDA Forest Service, Pacific Southwest Region, R5-EM-TP-002.

Source: Tom Keter, Anthropologist, Six Rivers National Forest, Eureka, CA (707) 442-1721
Summary: A well-written overview of cultural, biological and physical conditions in the North Fork, from an anthropologist's perspective. Substantial attention paid to paleoclimatic conditions of the past few thousand years of time, based on archaeological and pollen research. Potential fish habitat is presented in Table IV-B.
Relevancy to TMDL: Low to moderate - mostly cultural and paleo-climatic information. Good overview of the linkages between land-use, physical processes and biological processes.

Knott, J. M. 1971. Sedimentation in the Middle Fork Eel River Basin, California. U. S. Geological Survey Open-File Report. Menlo Park, CA. 60 p.

Source: from files of T. Lisle, also available in Humboldt County Collection, HSU library.
Summary: Detailed study of sediment transport in the Middle Fork Eel sub basin. Not closely reviewed due to lack of direct information from the North Fork, however this is the closest basin, with conditions similar to those in the North Fork.
Report shows the location of 8 stream gaging sites where sediment measurements were taken, as well as three US Bureau Weather Stations.
Suspended sediment plots (versus discharge) for the different gages are presented. Various measures of suspended sediment are presented, including: Daily Suspended Sediment; Instantaneous Suspended Sediment; Average Daily Suspended Sediment.
Plots of Roughness; Grain Size Distribution, and Instantaneous Bedload Discharge are also presented.
Hydraulic Geometry for the different gage sites.
Analysis of sediment transport data is presented with respect to reservoir sedimentation rates.
Sedimentation rates increased dramatically following the 1964 flood, and will likely take 5-10 years to return to pre-flood rates.
SSD/A = highly variable (777 to 25,000 tons/square mile)
Long-term total sediment discharge for sampling sites range from 625 to 3760 ton/square mile, with a basin average of 2870 tons/square mile.
Relevancy to TMDL: High - detailed sedimentation study in an adjacent sub-basin that may be analogous to North Fork.

Rogers, D., J. Horton, and L. Puckett. 1968. A stream survey of the Van Duzen River system and the North Fork Eel River. Calif. Dept. Fish and Game. Water Proj. Br. Mimeograph. 75 p.

Source: Not photocopied - Archival copy reviewed in the DFG office in Eureka, CA. Contact Larry Preston (707) 441-5736. The file number for this document is F4-912. Relevant pages are in the second volume, pages 19 and following.
Summary: This report is a general summary of stream survey efforts during 1967 in the Van Duzen River and the North Fork of the Eel River. The report comes in at least two separate documents, the second of which contains information about the North Fork. The report contains nice oblique aerial photographs of certain stream reaches, and ground photos of channel conditions, barriers to fish migrations, etc. Very general descriptions of basin characteristics are provided; simple line drawings of survey reaches are also provided. Mention is made in a few of the surveys of mainstem temperatures exceeding 80 degrees F.
Relevancy to TMDL: Low. Photographs are the most valuable part of the document. The rest is too general for any specific use.

Scott, R. G. 1973. Geology and sediment production for ten Eel River landslides. California Department of Water Resources. Memorandum Report 29 p.

Source: DWR Northern District - Trisha Brasher - (916) 529-7356
Summary: Concise summary of 10 landslides along the Main Eel extending from above Dos Rios, near Outlet Creek to the confluence of the South Fork. A brief description of each slide is give, along with the mapped extent of the slide (scale: 1"=2000')
Relevancy to TMDL: Moderate - good overview of large landslide features along one of the highest sediment production reaches of the Eel. Some slides are very close to the North Fork.

Scott, R. G., and G. D. Cox. 1972. Landslide aspects of alternative plans, Eel River Development, California DWR Northern District. Memorandum Report 25 p.

Source: DWR Northern District - Trisha Brasher - (916) 529-7356
Summary: An overview of landslide impacts on proposed dam developments, with specific attention to five separate problems created by landsliding: reduction of storage capacity; reservoir blockage; wave generation; scenic degradation; and hazards to recreational sites and reservoir developments.
Relevancy to TMDL: moderate - report deals mostly with the Main Eel, and the proposed dams along it. Most directly relevant to North Fork studies.

Six Rivers National Forest, 1995. Transitional watershed restoration assessment - North Fork Eel River. Unpublished report. 23 p.

Source: USDA Interagency Watershed Analysis Center, McKinleyville, CA - (707) 839-6277
Summary: FEMAT driven, preliminary report on the status of watershed analysis being conducted in the basin. Much of the report consists of boilerplate rationale and justification for conducting the watershed analysis. This document identifies some of the key issues with respect to prioritizing restoration efforts in the North Fork Eel, namely: anadromous fish habitat, riparian corridor conditions, and water quality/quantity. The report contains a general discussion of desired future conditions.
Relevancy to TMDL: Low with respect to specifics in the North Fork. Moderate with respect to describing desired future conditions.

Theisen, S. 1996. Geology and Geomorphology of the North Fork Eel EUI Area and Upper Mad WA Area. Unpublished report. 31 p., plus S. Theisen's list of references.

Source: Copy obtained from Stan Theisen, Six Rivers National Forest, Eureka
Summary: Synthesizes USGS geologic mapping (in press) by McLaughlin et al., and breaks down different geologic types based on aerial photo analysis. Discussion of major geologic units in the N. Fork, as well as geomorphic terranes and erosion hazard units. Color GIS maps and shaded relief maps are presented of geologic and geomorphic types on Forest Service lands within the North Fork. Tables provide a breakdown of acreages of different geologic types. Unit descriptions are provided for each of the 18 units identified. It seems that some of the units are unnecessarily split out, for example, there are 4 separate graywacke units and 4 separate metagraywacke units.

The geomorphic analysis covers multiple categories including feature identification, location, origin (timing), activity, mass wasting hazard, erosion hazard and cause. Polygons of different geomorphic types were identified and codes were assigned for each of the categories listed above. Tallies are provided for each of the categories.
Relevancy to TMDL: Moderate to high - good overview of geologic setting and geomorphic terranes, vegetation relations to geologic setting, and sensitivity of different geomorphic terranes to different types of land use. It is important to note that very little direct field work was done for this study, rather it is the compilation of prior unpublished mapping, and lots of aerial photo analysis.

USDA Forest Service and USDI Bureau of Land Management. 1996. North Fork Eel River Watershed Analysis Version 1.0. 146 p.

Source: USFS, Mad River Ranger Station, Star Route Box 300, Bridgeville, CA 95526
Summary: Attention is directed toward wildlife and vegetation distributions, threatened and endangered species, fire hazards, and cultural history. Very little information is presented on physical processes and basin characteristics. Some restoration prioritization is discussed.
Relevancy to TMDL: Moderate. Although there is relatively little information directly relevant to sediment or temperature studies, the document contains a number of useful maps, tables, and regional descriptions. Some tables and maps are inconsistent in nomenclature, making sub-basin identification difficult.

USDA, Soil Conservation Service, Soil survey of Mendocino County, eastern part, and Trinity County,

southwestern part, California, 1991.

Source: Natural Resource Conservation Service. Ukiah. CA. Contact: Tom Schott (707) 468-9223
Summary: Published soil survey for portions of the North Fork Eel. The report contains detailed descriptions of soil series and reproductions of USGS orthophotos with soil units outlined. Generalized soil series descriptions are also available on the World Wide Web at the NRCS website.
Relevancy to TMDL: Moderate - primarily useful for identifying surface erosion hazards based on soil series.

South Fork Eel River

Bickner, F. R. 1984. Geology and alluvial history in the South Fork Eel River basin, Humboldt County, Northern California, in Lamberson, R. H., ed., Proceedings of the Humboldt conference on environmental systems and natural resources. HSU, Arcata, CA, pp. 33-51.

Source: From HSU Math Department.
Summary: Regional overview of South Fork system, with respect to alluvial terrace formation.
Relevancy to TMDL: Low

Harris, L. 1995. Summer 1995 salmonid survey through Benbow Lake State Recreation Area. Final Report presented to Calif. State Dept. of Parks and Recreation, by Fisheries Department, HSU, Arcata, CA. 26 p. plus 30 p. of appendices.

Source: From the files of Terry Roelofs, HSU Fisheries
Summary: Fish counts, and evaluation of thermal refugia at Benbow dam site.
Relevancy to TMDL: Low to moderate

James, S. M. 1983. South Fork Eel watershed erosion investigation, Calif. Dept. of Water Resources. 95 p. 2 maps (plates).

Source: DWR Northern District - Trisha Brasher - (916) 529-7356
Summary: Reconnaissance level erosion study for the South Fork Eel: landslide investigation, turbidity study, generation of database for purposes of comparison with past and future studies.
Many figures and are presented that summarize precipitation patterns, local seismicity, gage locations, stream profiles. Photographs of erosion features and flood impacts.
Maps include 1) Geology of the South Fork; 2) Landslide map with turbidity sample sites.
Relevancy to TMDL: Moderate - high. This is the most comprehensive overview of geologic and geomorphic condition of the South Fork.

Harris, L. and W. Pinnix. 1994. Summer 1994 salmonid survey through Benbow Lake State Recreation Area. Report presented to Calif. State Dept. of Parks and Recreation, by Fisheries Department, HSU, Arcata.

Source: From the files of Terry Roelofs, HSU Fisheries Department
Summary: Fish counts, and evaluation of thermal refugia at Benbow dam site.
Relevancy to TMDL: Low

Roelofs, T. S. and W. Trush. 1991. Evaluation of juvenile salmonid passage through Benbow Lake State Recreation Area. Progress Report.

Source: From the files of Terry Roelofs, HSU Fisheries Department
Summary: Evaluation of the impacts of the Benbow Dam on anadromous salmonids. Temperatures were monitored with a hand thermometer at the hottest part of the day at approximately 6 locations in the lake. In addition, thermographs (chart recorders) were installed between August 15 and September 13. Vertical temperature and oxygen profiles were measured at 5 locations. These profiles are presented graphically.
Relevancy to TMDL: Low

Jager, D., and R. LaVen. 1981. Twenty years of rehabilitation work in Bull Creek, Humboldt Redwoods State Park, in Coates, R. N., Proceedings, Symposium on Watershed Rehabilitation in Redwood National Park and Other Pacific Coastal Areas. August 25-28, 1981. Center for Natural Resource Studies, Sacramento, CA. pp. 26-49.

Source: From Dick LaVen. Fortuna CA (707) 725-4974
Summary: Summary of rehabilitaition efforts in Bull Creek.
Relevancy to TMDL: Low

LaVen, R. D., F. R. Bickner, and D. A. Short. (1986) Late Pleistocene and Holocene erosional cycles in the South Fork Eel River watershed, northwestern California, in Wang, S. Y. et al. (eds.) Proceedings of the Third International Symposium on River Sedimentation, University of Mississippi. pp. 724-733.

Source: From Dick LaVen, Fortuna CA. (707) 725-4974
Summary: Examines prehistoric patterns of channel evolution, based on reach-level analysis of channel patterns. Special emphasis on Bull Creek, with attention to changes in the configuration of the Bull Creek delta, and changes in channel storage capacity.
Examination of historic gage records and hydraulic geometry indicate a decrease in the sediment transport capacity of the stream.
Discussion of prior erosion cycles.
Relevancy to TMDL: Low - provides valuable geologic and geomorphic perspective

LaVen, R. D. 1984. South Fork Eel River Bank Protection Project (excerpt). pp. 3-9.

Source: From Dick LaVen, Fortuna CA. (707) 725-4974
Summary: Summary of sediment yields for a hypothetical year for both the South Fok and Bull Creek, as well as for other major rivers for comparison purposes.
Relevancy to TMDL: Moderate

LaVen, R. D. 1984. Channel Changes over time in the South Fork Eel River and Bull Creek system, in Lamberson, R. H., ed., Proceedings of the Humboldt conference on environmental systems and natural resources. HSU, Arcata, CA, pp. 97-109.

Source: From HSU Math Department.
Summary: Presentation of changes at the mouth of Bull Creek, hydraulic geometry, and watersurface profiles during high and low flows.
Relevancy to TMDL: Low

May, C. and J. Britton. (n. d. ~1994). Summertime use of thermal refugia by juvenile steelhead (Oncorhynchus mykiss) in the South Fork Eel River. Unpublished class project final report, Department of Fisheries, HSU, Arcata, CA

Source: Copy on loan from Terry Roelofs, HSU Fisheries Professor.
Summary: Identifies, maps and classifies thermal refuges along a four mile stretch of the South Fork Eel river mainstem.
Relevancy to TMDL: Low

Short, D. 1993. A sediment budget for a small northcoast drainage basin, Humboldt County, California. Masters Thesis, HSU. 69 p.

Source: Not photocopied - Humboldt County Collection
Summary: Detailed sediment budget study for Cuneo Creek, a tributary to Bull Creek with one of the highest total sediment discharge values in northwestern California.
Relevancy to TMDL: Moderate - an example of a sediment budget for a small basin in the Eel.

Short, D. A. 1984. Cuneo Creek land-use history and changes in channel morphology, in Lamberson, R. H., ed., Proceedings of the Humboldt conference on environmental systems and natural resources. HSU, Arcata, CA, pp. 97-109.

Source: HSU Math Department
Summary: Summary of land-use and devastating landsliding in the Cuneo Creek Basin.
Relevancy to TMDL: Low to moderate

Steiner, W. P., R. Krugaer, C. Watson, and I. Noell. 1983. Cedar Creek habitat management plan.

Source: Partial photocopy, Received from Sam Morrison, from files at BLM, Arcata Resource Area.
Summary: Discussion of vegetation conditions, soils, and erosional processes in this tributary to the S. F. Eel.
Relevancy to TMDL: Low

U. S. Army Corps of Engineers. 1969. Flood Plain Information, South Fork Eel River, Phillipsville to Garberville, Humboldt County California.

Source: James Komar, NRCS, Eureka, CA. (707) 444-9708
Summary: Partial Photocopy of Table of Contents, introduction, Table I: Relative flood heights and drainage areas, SF Eel; Table III: Stream gaging stations, SF Eel; Table IV: Floods - South Fork Eel River near Miranda - Date, Order of Magnitude of the highest ten, crest elevation and peak discharge, 1940 - 1967; Table V: Outstanding floods - Eel River at Scotia; Storm Data Summary for 1955 and 1964. Large format (11x17) figures include:
Plate 1: South Fork Eel River Basin watershed map;
Plate 2: Eel River basin: public and private lands;
Plate 4: Index of flooded areas - inundation areas;
Plates 5, 6: Detailed maps of flooded maps, Phillipsville to Garberville;
Plate 15: SF Eel High Water Profiles (longitudinal);
Plates 20, 21, 22: SF Eel cross-sections with flood elevations from 1955 and 1964, and the "standard project flood" elevation;
Relevancy to TMDL: Low - provides detailed overview of extreme climatic events, and the impacts to floodplains.

U. S. Army Corps of Engineers. 1967. Flood Plain Information, South Fork Eel River, Eel River-Stafford to Holmes Humboldt County California.

Source: Humboldt County Department of Public Works, Natural Resources Division, Eureka, CA; Don Tuttle (707) 445-7741
Summary: overview of flooding impacts within the denoted reach.
Relevancy to TMDL: Low

U. S. Army Corps of Engineers. 1968. Flood Plain Information, South Fork Eel River, Weott to Myers Flat, Humboldt County California.

Source: Not photocopied. report resides at: Humboldt County Department of Public Works, Natural Resources Division, Eureka, CA; Don Tuttle (707) 445-7741
Summary: Contains maps and photographs of flood damage, hydrographs. Similar to 1969 report in general contents.
Relevancy to TMDL: Low

USDA Forest Service and USDI Bureau of Land Management. 1996. South Fork Eel River watershed analysis, Ver. 1.0. Arcata Resource Area. ~150 p.

Source: Bureau of Land Mangagement, Arcata Resource Area (707) 825-2300

Summary: A draft collection of miscellaneous issues related to land-use and land-management in the South Fork. Emphasis on endangered species (birds, fish, amphibians) and human history in the basin. Very little information pertaining to physical watershed conditions. Good watershed and land-ownership maps. No sediment transport or sediment source information. Lacking in general watershed maps or road maps. The lack of substantial information in this report is partially due to the relatively small proportion of public land in the South Fork.
Relevancy to TMDL: Low

USDA Forest Service and USDI Bureau of Land Management. 1996. North Fork Eel River watershed analysis. Ver. 1.0. Mad River Ranger District. 146 p.

Source: Mad River Ranger District (707) 574-6233
Summary: Another boiler-plate watershed analysis, replete with colorful GIS maps. Emphasis is on threatened and endangered species, cultural history, fire management and agency approaches to future management. Includes identification of key issues and concerns for watershed management. Very little information on sediment transport, or sediment source information. The single paragraph on landsliding and sedimentation (p.101) states: "Sediment derived from human disturbance of the landscape appears to be a relatively small percentage of sediment loads in the North Fork Eel River. Landslide inventories are mentioned as 'scheduled for fiscal year 1996.' " There is reference to two appendices that are not included with this document: 1) Geologic Controls on Riparian Processes and Function (see Craven, 1996), and 2) Bedrock Geology Map Legend (see Theisen, 1996).
Relevancy to TMDL: Low to moderate - marginally relevant for works in progress and current issues.

USDA, Natural Resource Conservation Service survey of Mendocino County, Western part, and Trinity County, southwestern part, California. Interim Document, (unpublished).

Source: Natural Resource Conservation Service, Ukiah, CA . Contact: Tom Schott (707) 468-9223
Summary: Unpublished soil survey that covers the portion of the South Fork Eel in Mendocino County. While the report remains unpublished, it is available for review in the Ukiah office of the NRCS. It is contained in 4 three ring binders, each approximately 3 inches thick. The report contains detailed descriptions of soil series and reproductions of USGS orthophotos with soil units outlined. Generalized soil series descriptions are also available on the World Wide Web at the NRCS website.
Relevancy to TMDL: Moderate - primarily useful for identifying surface erosion hazards.

USDI, BLM. 1990. River management plan and environmental impact statement- South Fork Eel wild and scenic river.

Source: Not photocopied, report resides at: Humboldt County Department of Public Works, Natural Resources Division, Eureka, CA; Don Tuttle (707) 445-7741
Summary: Planning document - no specific temperature or sediment data. Study area focuses on reaches downstream of the Angelo Reserve.
Relevancy to TMDL: Low