California Regional Water Quality Control Board
San Francisco Bay Region

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Napa River Sediment Total Maximum Daily Load

Technical Report

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Cover Photo: Napa River near St. Helena
Photo by: Stillwater Sciences, Inc.

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CHAPTER 1: INTRODUCTION

Key Points

- Section 303(d) of the Clean Water Act requires states to compile a list of "impaired" water bodies that do not meet water quality standards.
- In 1990, the Regional Board listed Napa River as impaired by sedimentation based on evidence of widespread erosion, and concerns regarding adverse impacts to fish.
- This report contains Regional Water Quality Control Board staff analyses and findings pertaining to sediment impairment in the Napa River.

This document is an initial draft of the Napa River sediment TMDL. We prepared this draft report to provide an initial opportunity for interested parties to comment on the scientific basis for the TMDL and to provide a framework for beginning a discussion of the implementation actions that may be needed to resolve sediment impairment and conserve steelhead. We welcome your review and comments, and expect subsequent drafts of the TMDL report to be enhanced as a result of your input at this time. Although this draft report does provide an initial foundation for recommended policy actions by the Water Board, it is important to emphasize that no regulatory action is being considered at this time. This draft report will be revised in response to public review and comment, and independent scientific peer review. Ultimately, we will propose a draft regulatory policy, a Basin Plan amendment, to be considered by the Board. Prior to considering any changes in regulatory policy, we plan to conduct several public meetings in Napa Valley to present and discuss the proposed TMDL. We expect the technical report and proposed regulatory policy to be improved as a result of the knowledge and involvement of the stakeholders of the Napa River watershed.

1.1 Background

In 1967, the California Legislature established the State Water Resources Control Board (State Board), and the nine Regional Water Quality Control Boards (regional boards) to regulate and protect water resources for the use and enjoyment of the people of the state. The State Board administers water rights, water pollution control, and water quality functions as part of the California Environmental Protection Agency. The State Board provides guidance to the regional boards, which conduct regulatory planning, permitting, and enforcement activities to protect water resources from pollution. Water pollution control regulatory authorities of the State Board and the regional boards are shared and derived from the state Porter-Cologne Act and federal Clean Water Act. The California Regional Water Quality Control Board, San Francisco Bay Region (Water Board) regulates surface and groundwater quality throughout the Bay Area including Napa River and its tributaries. By law, the Water Board is required to develop, adopt, and implement a Water Quality Control Plan (Basin Plan) for the San Francisco Bay region. The Basin Plan specifies and describes:

- Designated beneficial uses of water;
- Water quality objectives, which are parameters that can be evaluated to determine whether the designated beneficial uses are protected; and
- Implementation plans and policies to protect water quality.

Designated beneficial uses of water for the Napa River include the following:

- Water supply (agricultural, municipal, and domestic);
- Recreation (fishing, swimming, boating, etc.);
- Navigation;
- Fish migration and spawning;
- Cold and warm freshwater habitats;
- Wildlife habitat; and
- Preservation of rare and endangered species.

Beneficial uses adversely affected by excess sediment in the Napa River are recreation (i.e., fishing), cold freshwater habitat, fish spawning, and preservation of rare and endangered species.

As designated in the federal Clean Water Act, the State Board and the regional boards share several water pollution control responsibilities, including establishment of ambient water quality standards. Ambient water quality standards include beneficial use protection and water quality objectives (described above), and an anti-degradation policy. The anti-degradation policy requires that where water quality is better than needed to protect beneficial uses, that such superior water quality be maintained. Furthermore, Section 303(d) of the Clean Water Act also requires biennial assessments to determine whether ambient water quality standards are being achieved in individual water bodies throughout the United States.

In 1990, based on evidence of widespread erosion and concern regarding adverse impacts to fish habitat, the Water Board listed the Napa River as impaired by sedimentation. The primary impetus for listing was a concern regarding substantial decline since the 1940s in abundance and distribution of steelhead and salmon in the Napa River and its tributaries. As a result of the sediment impairment listing, the Water Board is required to prepare a total maximum daily load (TMDL). A TMDL involves development of a pollutant budget and a control plan to restore the health of a polluted water body. Key components of a TMDL include the following:

- Problem statement;
- (Pollutant) Source analysis;

- Numeric targets (e.g., specification of water quality parameter[s] that can be measured to evaluate attainment of water quality standards);

- Linkage analysis (between pollutant sources and numeric targets);

- Pollutant load allocations;

- Implementation plan (to attain and maintain water quality standards); and

- Monitoring plan (to evaluate progress in achieving pollutant allocations and numeric targets).

To improve understanding of the significance of sediment pollution relative to other factors that may be limiting steelhead and salmon populations, the Water Board partnered with the State Coastal Conservancy to fund the *Napa River Basin Limiting Factors Analysis* (Stillwater Sciences and Dietrich, 2002). The limiting factors analysis documented two adverse impacts of erosion and sedimentation on salmon and steelhead habitat:

- Poor spawning habitat quality, related in part to the deposition of lots of fine sediment in the streambed; and

- Channel incision in mainstem Napa River.

Channel incision, which occurs in Napa River and lower reaches of its tributaries, has greatly reduced the quantity and quality of spawning and rearing habitat for salmon, and appears to be the primary factor limiting chinook salmon reproductive success and smolt survival under current conditions (Stillwater Sciences and Dietrich, 2002). Excessive amounts of fine sediment deposited at potential spawning sites for salmon and/or steelhead in Napa River and its tributaries causes high rates of egg and larval mortality during incubation. Although poor spawning habitat quality does not currently appear to be a primary factor limiting for steelhead, high mortality at during egg incubation may further depress what appears to be a very small run. Other factors including poor flow persistence during the dry season and poor habitat access, appear to be the primary factors that limit steelhead productivity and survival in the Napa River watershed at present (Stillwater Sciences, 2002). We conclude that progress towards resolution of all factors limiting steelhead productivity and survival in the Napa River watershed is needed to conserve and recover steelhead populations. Therefore, we recommend actions to address sediment and additional management and research actions to address the above limiting factors, as a component of the sediment TMDL implementation plan.

1.2 Document Organization

Chapter 1. Introduction. Provides background regarding the responsibilities of the Water Board, the TMDL program, and the problems of sediment and other limiting factors. The introduction also describes the purpose of the draft technical report, and outlines subsequent steps in the TMDL process.

Chapter 2. Problem Statement. Describes the relationships between the identified pollutant (sediment), applicable water quality objectives and beneficial uses, and current water quality conditions in Napa River and it is tributaries. The problem statement also describes primary factors limiting steelhead run-size in the Napa River watershed.

Chapter 3. Sediment Source Analysis. Presents the approach, methods, and results of the sediment source analysis.

Chapter 4. Numeric Targets. Presents the rationale to support proposed water quality parameters and numeric targets, and their relation to the attainment of applicable water quality standards.

Chapter 5. Linkage Analysis and Allocations. The linkage analysis describes hypothesized linkages between sediment loads and habitat conditions, and therefore provides the rationale for estimating the assimilative capacity for sediment in the Napa River. Allocations are amounts of sediment allocated to each source category, including a margin of safety to account for uncertainty in estimating loads and assimilative capacity, and allowance for future growth.

Chapter 6. Implementation Plan and Water Quality Attainment Strategy. Initial conceptual discussion of the actions that may be needed to attain water quality standards for sediment, and conserve steelhead in the Napa River watershed.

CHAPTER 2: PROBLEM STATEMENT

Key Points

- Fine sediment clogs spawning gravels and degrades rearing habitat contributing to decline of salmon and steelhead in the Napa River watershed.
- Channel incision is the key factor in the decline of chinook salmon.
- Channel incision is a controllable water quality factor.
- Low summer base flow and poor habitat access are key factors in the decline of steelhead.
- The Water Board is obligated under the Clean Water Act to develop a sediment TMDL for the Napa River.

2.1 Summary

The TMDL problem statement describes the relationships between the identified pollutant (sediment), applicable water quality standards, and current water quality conditions in the Napa River. Water quality standards are composed of three parts:

- A statement of designated uses for a specified body of water (beneficial uses).
- One or more water quality parameters that can be evaluated to determine whether beneficial uses are protected (water quality objectives).
- An anti-degradation policy, which requires that where water quality is better than needed to protect beneficial uses, those superior water quality conditions must be maintained.

Water quality standards for the Napa River and its tributaries are specified in the Water Quality Control Plan for the San Francisco Bay Basin (Water Board, 1995). Water quality objectives related to sediment and aquatic life and relevant beneficial uses are listed in Table 1.

Table 1. Water Quality Objectives and Sediment-Related Beneficial Uses		
Beneficial Uses	**Water Quality Objectives**	
Cold Freshwater Habitat Fish Migration Preservation of Rare and Endangered Species[1] Fish Spawning Warm Freshwater Habitat Wildlife Habitat	Turbidity	Increase from background <10% where natural turbidity is >50 NTU*
	Sediment	Should not cause a nuisance or adversely affect beneficial uses
	Settleable Material	Should not cause a nuisance or adversely affect beneficial uses
	Suspended Material	Should not cause a nuisance or adversely affect beneficial uses
Cold Freshwater Habitat Fish Migration Preservation of Rare and Endangered Species Fish Spawning	**Population And Community Ecology**	The health and life history characteristics of aquatic organisms in water affected by controllable water quality factors shall not differ significantly from those for the same waters on areas unaffected by controllable water quality factors
Note: Bold text indicates water quality objective is violated. *NTU Nephelometric Turbidity Unit		

With regard to the problem of sediment in Napa River, we find that:

- Populations of steelhead and salmon in the Napa River and its tributaries have declined substantially since the 1940s (USFWS, 1968; Leidy et al., 2003).

- There is evidence of accelerated erosion and sedimentation in the Napa River and its tributaries (Soils Conservation Service, 1985; White, 1985; St. Helena Star, 1989; WET, 1990; and Stillwater Sciences and Dietrich, 2002).

- The problem of sediment is expressed by excessive amounts of fine sediment deposited in the streambed at potential steelhead and salmon spawning sites. Excess fine sediment in the streambed can cause poor incubation conditions for fish eggs, resulting in high mortality prior to emergence. When excessive amounts of fine sediment are deposited, the streambed is also more vulnerable to deep scour during storms, which can wash away eggs and thereby further reduce survival during incubation. Excessive fine sediment in the streambed also decreases the growth and survival of juvenile salmon and steelhead.

[1] Preservation of rare and endangered species listed under state or federal law as rare, threatened, or endangered. Steelhead within the Central California Coast, including the Napa River and its tributaries, are listed as threatened under the federal Endangered Species Act (ESA). Fall-run chinook salmon in the Napa River are not listed as threatened or endangered under the state or federal ESA, however, they are rare in Bay Area streams. California freshwater shrimp have been found in the Napa River and a few of its tributaries. These shrimp are federally listed as endangered species.

- Rapid and active channel incision, or downcutting, in mainstem Napa River and in its lower tributary reaches causing significant adverse changes to salmon habitat and is a significant source of fine sediment in the Napa River (Stillwater Sciences and Dietrich, 2002). The discharge of sediment and the process of channel incision are occurring, in part due to controllable water quality factors.[2]

Regarding sediment impairment we conclude that the narrative water quality objectives for sediment and settleable material are violated because large amounts of fine sediment are deposited in the streambed with significant adverse affects to cold freshwater habitat, wildlife habitat, fish spawning, recreation, and preservation of rare and endangered species beneficial uses. We find that channel incision harms physical habitat structure of the river by reducing the quantity of gravel bars, riffles, side channels, and sloughs, which threatens chinook salmon, and other fish and aquatic wildlife species (Stillwater Sciences and Dietrich, 2002). Channel incision is a controllable water quality factor that results in a violation of the narrative water quality objective for population and community ecology (Table 1).

We have prepared a total maximum daily load (TMDL) for sediment in Napa River to quantify the impact of excess erosion and sedimentation on fish populations and to develop an implementation plan to achieve sediment-related water quality objectives to resolve threats to chinook salmon and steelhead. Resolution of sediment impairment in Napa River watershed is one of several factors that need to be addressed to conserve and recover steelhead. Other factors that appear to be even more important controls on steelhead growth and survival, include the following:

- Poor baseflow persistence occurring in combination with stressful water temperatures that appear to severely limit the growth of juvenile steelhead;

- Poor access to-and-from potential spawning and rearing habitat, as a result of human structures in channels and water uses that impede or block habitat access; and

- Habitat simplification, as a result of a reduction in the amount of large woody debris in the channels (Stillwater Sciences and Dietrich, 2002).

Therefore, to facilitate steelhead trout conservation and recovery, we provide additional management and study recommendations to address the key limiting factors listed above, as part of the sediment TMDL implementation plan.

2.2 Detailed Problem Statement

We reviewed available information to conclude that there has been a significant decline in the distribution and abundance of steelhead and coho salmon in the Napa River and its tributaries since the late 1940s (U.S. Fish and Wildlife Service, 1968; Anderson, 1969; and Leidy, 2003). The U.S. Fish and Wildlife Service (1968) estimates that the Napa River watershed once

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[2] Controllable water quality factors are those actions, conditions, or circumstances resulting from human activities that may influence the quality of the waters of the state and that may be reasonably treated.

supported runs of 6,000–8,000 steelhead and 2,000–4,000 coho salmon, and that by the late 1960s, coho salmon were extinct in the watershed, and the steelhead run had reduced to about 1,000 adults.[3] At present, the steelhead run is estimated at less than a few hundred adults (Emig and Rugg, pers. com., 2000 and Leidy et al., 2003).

Much less information is available to evaluate status and trends in population of chinook salmon in Napa River. We are not aware of any historical research that has been conducted to determine whether chinook salmon are native to Napa River. However, recent studies in Sonoma and Putah creeks, which border Napa River, document the historical occurrence of native fall-runs of chinook salmon in both streams (Dawson, 2002 and Yoshiyama et al., 2000). These streams have flow regimes that are similar to Napa River, and up until recent decades, Sonoma, Putah, and Napa all had gravel-beds and bar-pool channels that could have provided abundant spawning and rearing habitat for chinook salmon. Considering the above information, we conclude that it is likely that the Napa River also supported a native fall-run of chinook salmon. In recent years, we estimate that a few hundred or more chinook salmon spawned in the Napa River.[4]

In 1990, based on evidence of widespread erosion (USDA Soil Conservation Service, 1985; White, 1985; and St. Helena Star, 1989) and the resulting threat to fish habitat (Cordone and Kelly, 1961), the Water Board listed the Napa River as impaired by sedimentation. The primary impetus for listing was concern regarding the decline since the 1940s in abundance and distribution of steelhead trout.

To improve understanding of current fisheries habitat conditions and the significance of sediment pollution relative to other factors that may be limiting populations of steelhead and salmon, the Water Board partnered with the State Coastal Conservancy to provide funding for the *Napa River Basin Limiting Factors Analysis* (Stillwater Sciences and Dietrich, 2002). The limiting factors study documented two adverse impacts of sediment pollution on steelhead and salmon habitat. The first impact is due to excessive amounts of fine sediment deposited in the streambed, which adversely affects spawning and rearing habitat for both species. The second impact is due to channel incision, which occurs primarily in the mainstem and lower tributaries and affects chinook salmon primarily (because most steelhead spawn further upstream in the tributaries). These sediment-related impacts are discussed below:

- Excess fine sediment is clogging spawning gravels contributing to low permeability. Successful salmon and steelhead reproduction depends on adequate water flow through gravel in order for eggs to hatch and larvae to grow. If sediment clogs the gravels, flow is very slow, egg mortality can be very high, and few young fish (fry) may emerge from the streambed. Low gravel permeability is predicted to cause high rates of mortality at potential spawning sites in Napa River and its tributaries. Spawning habitat quality does

[3] Similarly, Anderson (1969) estimated that the steelhead run in the Napa River watershed numbered 1,000 to 2,000 in the late 1960s.

[4] The Napa County RCD conducted formal surveys to estimate number of adult chinook salmon entering the river to spawn, and to estimate number of spawning sites. These surveys were conducted in November and December of 2004 within a three mile long reach of the mainstem near Rutherford (J. Koehler, unpublished data). During the fall–winter of 2004, Napa County RCD documented over 100 adult salmon in the Rutherford sub-reach.

not currently appear to be a primary factor limiting steelhead or salmon run size. However, because the number of steelhead returning to spawn appears to be quite small, poor spawning habitat quality has the potential to further depress steelhead run size.

- Excess fine sediment in the streambed also can cause significant decreases in growth and survival of juvenile salmonids by reducing availability of vulnerable prey and increasing activity level, aggressive behavior, and attacks between juvenile salmonids (Suttle et al., 2004).

- Active and rapid channel incision in mainstem Napa River and lower reaches of its major tributaries has greatly reduced quantity of gravel bars, riffles, side channels, and sloughs, and has greatly decreased frequency of inundation of adjacent flood plains. These features and processes provide essential spawning and juvenile rearing habitat for chinook salmon, which reside primarily in the mainstem Napa River. Therefore, channel incision appears to be the primary factor limiting chinook salmon run size. Channel incision, and associated bank erosion in areas underlain by thick alluvial deposits, also appears to be a significant source of sediment delivery to Napa River (Figure 1).

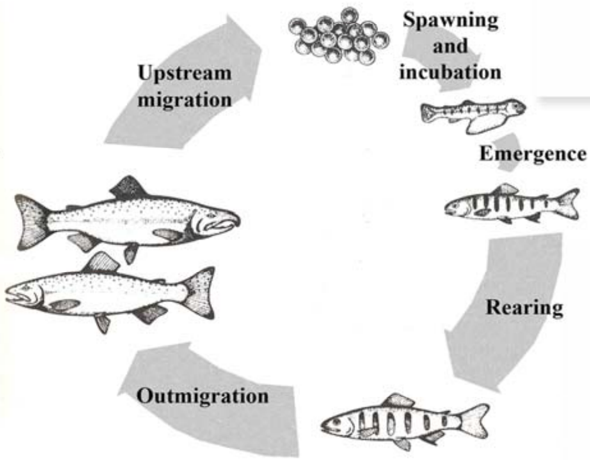
In addition to the threat excess sediment poses to fish populations, the Limiting Factors Analysis identified several other factors that are critically important to the health of steelhead populations. The following "primary factors" appear to limit steelhead population size (Figure 2) in Napa River watershed[5]:

Habitat Access: A large number of structures (dams, road crossings, weirs, etc.) have been constructed in Napa River tributaries (Dietrich et al., 2004). Many of these structures present barriers and/or impediments to adult steelhead spawning migration into the tributaries and/or the migration of juvenile steelhead (smolts) out of the tributaries on their journey to rear in the ocean.

Physical Habitat Structure: The occurrence and frequency of deep pools in the mainstem and lower tributaries has decreased during the historical period. Deep pools with good cover provide high quality holding habitat for adult steelhead during their spawning migrations, essential summer habitat for older juvenile steelhead, and may also provide important winter high-flow refuge habitat for older juvenile steelhead. The number of older and/or larger, juvenile steelhead that can be produced is quite important because there is a strong relationship between size of juvenile steelhead (smolts) when they migrate to the ocean, and proportion that successfully return to spawn. This is because larger fish are better able to evade predators and to survive the long migration to the ocean. Pools appear to be less frequent in tributaries than we would expect to have occurred under historical conditions, when large woody debris would have created obstructions in the channels and caused deep pools (with good cover) to be formed. The amount of large wood in channels also appears to be low when compared to similar streams draining watersheds covered by mixed evergreen forests. Large wood is a primary agent for the

[5] A primary factor is one that exerts a significant influence on the total population size.

Figure 1. Chinook salmon life cycle and potential limiting factors in the Napa River watershed

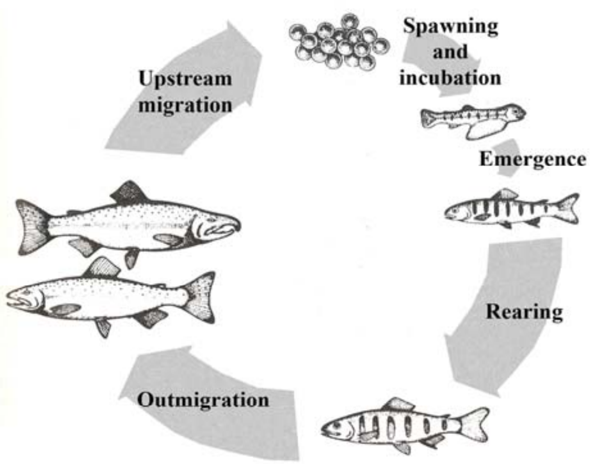


Loss of estuarine rearing habitat. The estuary of the Napa River has been dramatically altered by dredging and diking, as well as introduction of exotic species. These activities may have greatly reduced suitability of the estuary for rearing.

Fine sediment and channel incision. Channel incision greatly reduces riffle and gravel-bar habitat areas, which are the primary spawning sites for chinook salmon. Fine sediment clogs gravels in small spawning areas that remain. Riffle margins, side-channels and sloughs, and flood plains are primary juvenile rearing habitats. These habitats are obliterated or isolated as a result of incision. Incision also increases quantity of deep-slow run-pool habitats, favored by fish species that prey upon juvenile salmon. We hypothesize, at present, that channel incision is the primary factor limiting chinook salmon run-size. Once channel incision is remedied, fine sediment may become a primary limiting factor. Both impacts need to be resolved to conserve chinook salmon.

Figure 2. Steelhead life cycle and potential limiting factors in the Napa River watershed

Fine sediment clogs spawning gravels. Increases mortality of incubating eggs and larvae. Not hypothesized to exert a primary influence on steelhead run-size. With few adults returning to spawn, however, has potential to reduce steelhead run-size by moderate amount.



Habitat access. Over 400 dams, numerous road crossings, and other structures built in tributary channels, block or impede access to and from a significant amount of otherwise suitable habitat. Human uses of water also likely cause significant reduction in springtime baseflow and/or more rapid dry-up of lower reaches of tributaries. Poor habitat access hypothesized to exert a primary influence on steelhead run-size.

Poor flow persistence over riffles and stressful summer temperatures. Appears to greatly reduce summertime growth of juvenile steelhead. Hypothesized to exert a primary influence on steelhead run-size.

Lack of large wood in channels.
Greatly reduces quantity and quality of summer rearing habitat for larger/older juvenile steelhead.
Not hypothesized to exert primary influence on steelhead run-size under present conditions of poor baseflow and access.

formation of deep pools, complex cover, and retention of spawning gravels in channels that provide significant amounts of potential habitat for steelhead. Habitat in tributary streams draining mixed evergreen forests, primarily those located on the west side of the watershed and those draining Howell Mountain, have been simplified as a result of a reduction in amount of large wood in the channels (Stillwater Sciences and Dietrich, 2002).

Low Summer Flow and Elevated Temperature: Typical summer water temperatures are stressful to juvenile steelhead and flow persistence over riffles is poor. These conditions act in a synergistic fashion, and appear to severely limit growth of juvenile steelhead during the summer months. Reduction in growth rate is important because smaller juvenile trout experience much higher rates of mortality during all phases of freshwater rearing, ocean migration, and during ocean rearing life stages. Therefore, poor juvenile growth rate during the summer in the freshwater environment has the potential to greatly reduce the number of adult steelhead that ultimately return from the ocean to spawn in the Napa River watershed[6]

Following completion of the *Napa River Basin Limiting Factors Analysis*, University of California, Berkeley, in partnership with the University of Florida and with the assistance of Napa County, developed a high-resolution digital topographic map to accurately map the locations and extent of channels and reservoirs throughout the Napa River watershed. Dietrich et al. (2004) identified over 1,000 dams within the watershed, over 400 of which are located on tributary channels that drain approximately 30% of the total land area. These dams exert a significant influence on routing of physical products (water, heat, nutrients, sediment, and wood), and the movement of fish and aquatic wildlife through channels in the Napa River watershed. Because dams capture all of the coarse sediment delivered to channels above dams (and some of the fine sediment), it likely that dams are affecting or influencing the channel incision and associated bank erosion that has been documented in the mainstem of the Napa River and along the lower reaches of its tributaries.

Based on the results of the *Napa River Basin Limiting Factors Analysis* and the other sources cited above, we conclude that the narrative water quality standards for sediment, settleable material, and for population and community ecology are not attained as a result of erosion and sedimentation in the Napa River and its tributaries. As such we are required to develop a total maximum daily load (TMDL) for sediment.

In Chapter 3, we present, the sediment source analysis to further refine our description of current channel conditions with regard to erosion and sedimentation, and to address the following sediment-related questions:

- What are the relationships between sediment input to channels, channel sediment transport capacity, and streambed permeability values in Napa River and its tributaries?

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[6] We have not determined the extent to which poor baseflow persistence can be explained by natural conditions versus human water uses. However, considering the ecological significance of reduction in growth rate, further research should be conducted to confirm whether poor summer growth is a spatially extensive phenomena in some or all water year types, and whether poor summer growth can be offset by high rates of growth during the spring and fall.

- How important are natural processes and human alteration of the land with regard to input of fine sediment to channels?

- Are channel incision and associated bank erosion large sources of sediment input to channels? How do these sources compare/rank in relation to other natural and human generated (anthropogenic) sediment sources?

CHAPTER 3: SOURCE ANALYSIS

Key Points

- Sediment loads vary depending on geologic terrain, land uses, and dams.
- More than half of all sediment delivered to channels comes from grazing, vineyards, roads, and erosion of the bed and banks of Napa River and lower tributary reaches.
- 30% of the watershed drains into dams, capturing a significant fraction of all sediment input to channels, nevertheless fine sediment load remains substantially elevated in Napa River.
- In addition to being a significant sediment source, erosion of the river's bed and banks is degrading aquatic habitat.

3.1 Introduction

This section identifies sediment sources linked to three sediment problems: 1) low values of permeability at potential spawning and rearing sites for salmon and steelhead, caused, at least in part, by deposition of excess fine sediment in the streambed (Figure 3); 2) active-and-rapid incision of mainstem Napa River and lower reaches of its tributaries, which causes significant degradation of physical habitat structure and also appears to be a significant sediment source (Figure 4); and 3) as the streambed becomes finer at spawning sites in Napa River, scour of spawning gravel may be increased by a significant amount, exposing incubating salmon-and-steelhead eggs-and-larvae to high rates of mortality. These sediment problems are described in greater detail in the problem statement and numeric targets chapters.

A TMDL must identify pollutant source categories and estimated loads associated with each source. We used a "rapid sediment budget approach" to identify significant processes that deliver sediment to Napa River and its tributaries, and to estimates rates and sizes of sediment input to the channel network during the most recent decade.[7] Reid and Dunne (1996) define a sediment budget as follows:

> "A sediment budget is an accounting of the sources and disposition of sediment as it travels from its point of origin to its eventual exit from a drainage basin."

We chose the most recent decade (1994–2004) as our measurement period because it follows enactment of Napa County's Hillside Conservation Regulations and therefore reflects current land use practices.

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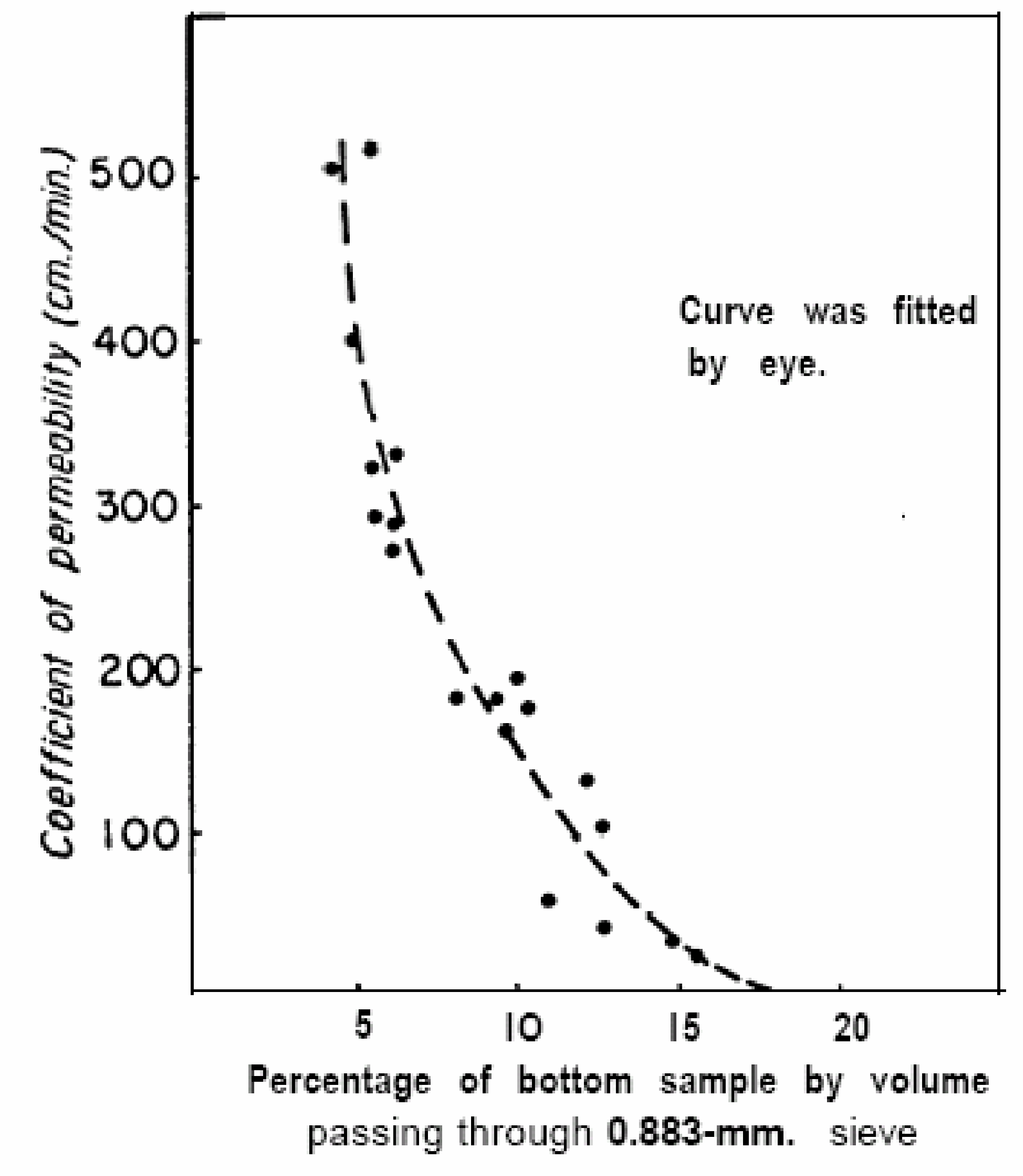
[7] A rapid sediment budget is a measurement technique that can be performed over a short period of time to provide approximate estimates of rates and sizes of sediment delivered to channels.

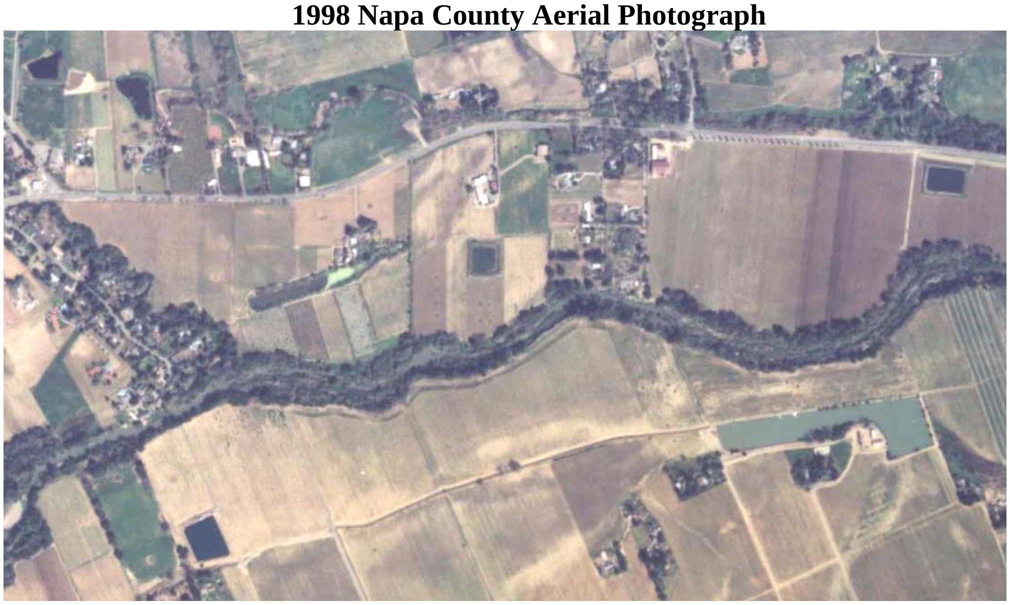


Source: McNeill and Ahnell (1964).

Figure 3. Relationship Between Fine Sediment Deposition and Streambed Permeability.

1940 Soils Conservation Service Aerial Photograph

1998 Napa County Aerial Photograph



Source: Stillwater Sciences and Dietrich (2002).

Figure 4. Channel Incision between 1940 and 1998 in the Napa River at Soda Creek.
In the 1940 photograph, the channel bed alternates between gravel bars (light colored arcs) and pools (dark areas). In the 1998 photograph, with the exception of the left edge of the photograph, no gravel bars are evident, the channel has narrowed, and it is straighter.

Complicating the analysis of sediment inputs to Napa River and its tributaries is the occurrence of over 400 dams located on tributaries to the Napa River (Dietrich et al., 2004; Maps 1 and 2). Considerable effort was expended by scientists at Stillwater Sciences and UC Berkeley to map locations of dams in relation to the channel network, which we then used to identify portions of the channel network located upstream of dams, and the effects of dams on sediment supply to downstream reaches.

The Napa River sediment source analysis identifies key sediment sources and sheds light on the following questions:

- What are the relationships between sediment input to channels, channel sediment transport capacity, and streambed permeability values in Napa River and its tributaries?

- How important are natural processes and human alteration of the land with regard to input of fine sediment to channels?

- Are channel incision and associated bank erosion large sources of sediment input to channels? How do these sources compare/rank in relation to other natural and human generated (anthropogenic) sediment sources?

In the following section we describe our approach, present data we collected, and report estimated rates of human caused and naturally occurring sediment inputs to channels.

3.2 Key Attributes that Influence Sediment Input into Napa River and its Tributaries

Primary controls on rates and sizes of sediment input to Napa River watershed channels are: 1) geology or the hardness of bedrock and sediment deposits; and 2) influences of land-use activities on vegetation cover, soil attributes, and topography.[8] The potential significance of these attributes on sediment supply is discussed below. An introduction to the recent history of mountain building in the watershed is first provided to set the stage for exploring why variability in bedrock hardness is particularly important in Napa and other parts of the California Coast Range.

Napa Valley and its surrounding ridges, the Vaca and Mayacama mountains, are geologically recent features, formed within the last three million years in response to slight shifts in the direction of movement of the Pacific Plate. This movement caused a small component of compression along the San Andreas fault system, and the formation of the California Coast Range (Swinchatt and Howell, 2004). The Vaca Mountains, Mayacama Mountains, and Napa Valley are being actively shaped and changed by ongoing movement along active faults and folds. In such active landscapes, hills underlain by erosion resistant bedrock types (hard rocks) maintain steep slopes and low erosion rates as uplift occurs. In contrast, bedrock types that have a low resistance to erosion (soft rocks) as they are uplifted respond much more rapidly, erode into gentle and more deeply dissected slopes, and deliver much greater quantities of sediment to the channels that drain them.

[8] Changes in vegetation cover, soil attributes (e.g., infiltration capacity and permeability), and topography (e.g., road cuts and inboard ditches) may cause significant changes in runoff rate and locations, and significant changes in the resistance of the landscape to erosion.

Hardness of common bedrock units found in Napa River watershed varies substantially in relation to texture and structure of the rock types, conditions under which the rocks were formed, and amount of subsequent weathering and tectonic deformation (faulting and folding of rocks). For example, lava flows of the Sonoma Volcanics Formation are hard because they are formed from molten rock (lava) that is rapidly cooled and hardened when it reaches the earth's surface. Also, these lava flows are hard because they are geologically recent deposits that have experienced low to moderate amounts of subsequent weathering and tectonic deformation. In contrast, another unit within the Sonoma Volcanics Formation, air-fall deposited volcanic ashes (ash-flow tuffs), although also recently deposited, are composed primarily of very fine-grained material that was erupted into the air, and then deposited shortly thereafter as unconsolidated air-fall deposits. Fine texture and poor consolidation, in contrast to lava flows, promotes much more rapid weathering of the ash flows into soft clays that are easily eroded when vegetation or soils are disturbed.

The importance of environmental conditions during bedrock formation in influencing hardness is also illustrated by examining the Franciscan mélange and sheared serpentinite units, which underlie most of the Sulphur Creek and Bear Canyon tributary watersheds. The fine-grained ocean-floor rock types that form the bulk of the mélange have been intensively sheared and they are composed of a mechanically incompetent matrix that engulfs occasional large pieces of hard rock referred to as blocks. Given the intensive tectonic deformation during the formation of the mélange and sheared serpentinite units, large deep-seated landslides are common features in these units, which we believe are caused primarily by the natural attributes of these bedrock types versus historical and/or recent disturbances from land-use activities.

In addition to bedrock, extensive areas of the watershed are underlain by thick deposits of sediment, derived from erosion of upland bedrock units and soils. Swinchatt and Howell (2004) suggest that most of these sediments were deposited during the past 10,000 to 15,000-years, in response to worldwide sea-level rise associated with the end of the most recent glacial epoch. These deposits are composed primarily of sand and coarser-grained sediments that typically are not cemented together, and hence are classified as soft deposits. Although most fan and valley fill deposits are soft, sediment accumulation was favored over erosion at these sites up until the historical era. As the watershed was developed, upslope disturbances of vegetation and soil likely increased runoff rates and sediment input to channels. These historical and recent impacts, in combination with direct alterations of channels and adjacent flood basins, have destabilized channels where they traverse alluvial fan and valley deposits. This has led to active and rapid channel down-cutting and accompanying bank erosion that is widespread along Napa River and lower reaches of many of its tributaries today.

Within a given bedrock or sediment deposit type, we hypothesize that land-use activities exert a significant influence on total rate and sizes of sediment input to channels (hereafter referred to as sediment supply). This point is illustrated by describing some specific mechanisms by which common land uses in Napa River watershed may increase erosion rates. For example, intensive grazing has the potential to reduce ground-cover vegetation density, change vegetation structure and species assemblage, and compact soils causing infiltration capacity and permeability to be reduced. The above effects of grazing, in turn, may greatly increase overland flow runoff during storms, leading to significant increases in the rates of surface erosion from sheetwash, rilling, and gullies. Gully erosion may also cause significant local changes in hillslope topography and mass, which may activate landslides.

Other common land uses also may cause significant changes in rate, volume, and locations of storm runoff. For example, where hillside vineyards replace mature mixed evergreen forests, peak runoff rate and volume from the vineyard site may be increased substantially because mature conifers intercept a significant proportion of the total rainfall in a storm, greatly reducing the rate of delivery (and in some cases total amount) of rainfall that is input into the soil. Furthermore, if vineyard development involves installation of subsurface drainage pipes, more storm runoff, at a faster rate, may be discharged off-site than under natural conditions. Finally, if discharges from drainage pipes are collected at a single point of discharge, there is the potential to further concentrate runoff volume (Figure 5). The above effects have the potential to cause off-site gully erosion and/or shallow landslide failures, most often at or near the points of discharge from the site, and in locations where hillslope soils and bedrock are soft (easily eroded).

Figure 5. Gully Formed by Discharge of Concentrated Runoff from Hillside Vineyard

A third example of the effects of land use on sediment supply is illustrated by examining the effects of roads. Road cuts intercept subsurface drainage, speeding up runoff rate. Roads also usually change the distribution of runoff from the hillslope. Inboard ditches and compacted road surfaces substantially increase the rate, volume, and locations of direct runoff from these areas, which can cause the road surfaces and ditches to rapidly erode (Figure 6). Road cuts and fills alter drainage pathways, and the distribution of mass on the hillslope, often contributing to greater rates of landslide activity. Also, road crossings (over channels), may be undersized for the conveyance of peak runoff rates, and/or may be easily plugged by large debris during storms causing overtopping and/or diversion of channel flows, with resulting channel crossing erosion, and/or gully erosion through diversion of channel flows to another channel or hillslope location.

Figure 6. Rills and Gullies on a Compacted Dirt Road
Gully forms where runoff depth and slope are sufficient to erode soft colluvium at this site, which is underlain by the mélange bedrock unit.

The above examples of potential influences of land-use activities on sediment supply are not intended to be exhaustive or definitive statements. Other outcomes are also possible in the above cases.

3.3 Definition and Delineation of Terrain Types

As described above, hardness of bedrock units and sediment deposits, and land-use activities exert primary influences on sediment supply to channels. To confirm this relationship and provide a basis for watershed-wide sediment supply extrapolation from a limited sample of sites, we defined and delineated a suite of sediment supply terrain types that occur within Napa River watershed. We hypothesize that within each defined terrain type, key attributes that influence sediment supply to channels are similar in response to natural disturbances and land-use activities. We then test our hypothesis by measuring sediment input rates to channels at sites grouped by terrain type, and within each defined terrain type, at sites that vary with regard to primary land-use activities.

We defined and delineated sediment supply terrain types based on review of existing information (WET, 1990; Ellen and Wentworth, 1995; Pacific Watershed Associates, 2001; and Stillwater Sciences and Dietrich, 2002), recent aerial photographs (Napa County, 1993 and 2002), and extensive field reconnaissance over much of the watershed during the summer and fall of 2003 to identify significant active processes that deliver sediment to channels, and relationships to land uses, topography, and underlying bedrock types and/or sediment deposits.[9] Based on field

[9] Field reconnaissance sites included Ritchie Creek, Mill Creek, Sulphur Creek, upper Conn Creek, Chiles Creek, Milliken Creek, Suscol Creek, Tulocay Creek, Dry Creek, Carneros Creek, and mainstem Napa River between Calistoga and St. Helena.

reconnaissance and review of available information, we identified four major categories of active and potentially significant processes that deliver sediment to channels[10]:

- Bank erosion, gullies, and shallow landslides formed by natural processes, and/or by land-use activities (e.g., concentrated or diverted runoff from roads, hillside vineyard runoff, intensive grazing, etc.);
- Channel incision where human actions have destabilized streams underlain by deep alluvial deposits;
- Sheetwash and rill erosion associated with natural processes (e.g., drought and fire), and land-use activities (e.g., vineyards and grazing); and
- Road surface and channel crossing induced erosion.

We then defined and delineated terrain types (Table 2) that are similar with regard to sediment supply to channels under similar natural processes and human disturbances. The terrain types we defined are derived from "hillside materials units" defined by Ellen and Wentworth (1995) based on analysis of engineering properties of mapped geological formations. We modified their classification by lumping together several units into four upland terrain types defined based on bedrock hardness and/or amount of tectonic deformation and weathering, and which we list below in order from lowest to highest predicted erosion potential:

- Hard rocks, primarily hard volcanic lava flows (low to moderate erosion potential);
- Sedimentary rocks of variable hardness and deformation (medium to high erosion potential);
- Ash-flow tuffs (medium to high erosion potential); and
- Intensively deformed Franciscan mélange and sheared serpentine (high to extreme erosion potential).

We also defined a lowland terrain type, which lumps together all gently sloping to flat lying alluvial fan and valley deposits. We predicted that the lowland terrain type has a high erosion potential based on frequent observation of deeply incised channels and steep poorly vegetated banks in alluvial valleys. Table 2 describes terrain types in further detail. Map 3 shows the aerial extent and location within the Napa River watershed of each of our terrain types.

[10] Although large, active deep-seated landslides are an important erosion process in some terrain units in Napa River watershed, they do not directly deliver sediment to channels. Instead, sediment delivery occurs, primarily through bank erosion, gullies, and shallow landslides that are located on the toes of deep-seated landslides.

Table 2. Terrain Types Defined Based on Predicted Sediment Supply

Terrain Type*	Hillside Materials Units¥	Drainage Area (km^2)	Percent Study Area	Key Attributes with Regard to Erodibility	Predicted Sediment Input Rate	Units Surveyed to Estimate Sediment Input Rates
Sonoma Volcanic Lava Flows (primarily hard lava flows)	202, 204, 218, 219, 220, 234, 238, 240, 253, 261, 262	257	26.3	Hard (little deformation and low to moderate modification by weathering	Low	218, 219, 234, 238, 240
Other Hard Bedrock Units	511 (Franciscan chert) 900 (Unsheared)	5.4	0.5	Hard (little deformation and low to moderate modification by weathering	Low	Not surveyed
Alluvial Valley Fills and Fans	N/A—Alluvial Lowlands	299	30.6	Flat lying or gently sloping, commonly unconsolidated and non-cohesive	High	Extensive surveys along mainstem and all major tributaries
Sonoma Volcanic Ash Flows and Tuffs (primarily air-fall ash, some welded tuff)	270, 272, 273, 290	112	11.5	Medium to low hardness	Medium	270
Sandstones and Clayey Rocks (variable hardness and deformation)	100, 123, 141, 153, 358, 381, 384, 410, 415, 417, 439, 470, 519, 683, 686, 703	239	24.5	100s are poorly consolidated; all other units are medium to low hardness and/or have moderate to high fracturing as a result of weathering and/or deformation	Medium	683/686§
Franciscan Mélange and Sheared Serpentinite	801, 802, 805	64.6	6.6	Intensively deformed	High	801, 805
	Total	**978**	**100.0**			

* Terrain types are defined by rock type (geological units) and slope category (upland or lowland)

¥ Hardness classification adapted from Ellen and Wentworth, 1995: hard - [rock] hammer bounces with solid sound; medium hardness - [rock] hammer dents material with thud, and pick point dents or slightly penetrates material; low - pick point penetrates material.

§ Units 683/686 - Great Valley Formation constitutes about 2/3 of the total land area in the sandstone and clayey rocks land type.

NOTE: Does not include urban land cover categories (commercial, residential, industrial, parks, roads, etc.), which cover about 116 km^2 or about 10% of the watershed.

3.4 Approach to Measurement of Sediment Input to Channels

Colluvial bank erosion, gully erosion, and shallow landslide erosion processes are active and potentially significant processes that deliver sediment to channels in all of the upland terrain types. Channel incision and accompanying stream terrace bank erosion occurs solely in the alluvial valley and fan deposits. Sheetwash erosion occurs in all terrain types, and appears to be a significant active process, where land uses such as livestock grazing and vineyards disturb soil and vegetation cover. Sheetwash erosion is also prevalent on earth-surfaced roads, ditches, and cut banks of roads. Roads crossing erosion, and gullies and landslides caused by road-related changes in hillslope runoff and/or distribution of mass, are also significant active processes that deliver sediment to channels.

We organized our approach to the measurement and/or modeling of sediment input rates by the above four major categories of active and potentially significant processes that deliver sediment to channels as described below.

1) Gullies, Shallow Landslides, and Bank Erosion in Uplands

We conducted upland field surveys at nineteen upland sites to measure rates of sediment input to channels during the most recent decade from erosion of gullies and shallow landslides. We also conducted reservoir sedimentation surveys that together with other field observations and measurements were used to estimate longer-term rates of total sediment input to upland channels (Table 3). We also measured depths of colluvium exposed in hillside channels to provide data for the calculation of colluvial bank erosion rates, which also involved measurement of channel network length using channel maps derived from the three-meter digital elevation model, and estimation of average rate of downslope movement of sediment on hillslopes based on review of literature (Fleming and Johnson, 1975, McKean et al., 1993). We assume over the long-term rates of downslope movement on hillslopes are equal to rates of colluvial bank retreat.

The location of field survey sites was not random, and constrained primarily by our ability to obtain permission for access to privately owned land, and by our available budget and schedule. Nevertheless, for three of the four upland terrain types we defined (Franciscan mélange and sheared serpentinite, lava flows and other hard rocks, sedimentary rocks) we surveyed one or more sites where natural cover, vineyards, and/or livestock grazing are predominant cover types or uses. At sites underlain by the ash-flow and tuff, we surveyed three sites, all of which are currently dominated by natural land cover.

We also measured reservoir sedimentation rates and estimated trap efficiency at ten sites that capture runoff from upland sites. Five of these sites are located immediately downstream of sites where we also measured or modeled sediment inputs to channels from colluvial bank erosion, gullies, and shallow landslides (Table 3). Because we did not observe any significant sediment storage sites in channels draining into the reservoirs, we assume that sediment yields to reservoirs match rates of sediment input to channels at the sites where we conducted surveys. Therefore, reservoir sites provide a basis for estimating total sediment yields from the defined terrain types under various combinations of land use.

Table 3. Upland Measurement Sites

Site	Da (km^2)	Time Period	Predominant Land Uses and intensity/disturbances	Type of Measurement Surveys	Key Upland Erosion Process(es)
Terrain Type: Hard Flow Rocks					
Spence Creek Pond	0.21	1958–2004	Natural grasslands	Reservoir sedimentation	Soil creep and sheetwash
Kreuse Creek	3.14	1994–2004	Natural grasslands; recent large fire	Upland sediment inputs	Soil creep, sheetwash, gullying
Milliken Reservoir	25.1	1926–2003	1981 Atlas Peak fire; very low road density, large cattle ranch in upper watershed; minor vineyard dev.	Reservoir sedimentation	…
Bell Canyon Reservoir	13.9	1959–2001	Minor amount roads and vineyards; historical logging	Reservoir sedimentation	…
Conn Creek stock pond	0.17	1977–2004	High intensity grazing over small portion of the site	Reservoir sedimentation, upland sediment inputs	Soil creep, gullying, sheetwash, shallow landslides
Redwood Pond 1	0.18	1981–2004	Vineyard	Reservoir sedimentation, upland sediment inputs	Gullies, shallow landslides, soil creep
Redwood V Creek	0.12	1994–2004	Vineyard	Upland sediment inputs	Gullies, shallow landslides, soil creep
South Creek	1.0	1993–2003	Low-intensity grazing	Upland sediment inputs	Soil creep and sheetwash
Central Creek	1.4	1993–2003	Low-intensity grazing	Upland sediment inputs	Gullying, sheetwash, soil creep
Terrain Type: Volcanic Tuff and Ash Flows					
Kimball Canyon Dam	7.8	1940–2003	Historical: logging/grazing Present-day: low intensity land uses, water supply	Reservoir sedimentation	Did not perform upland surveys
Ritchie Creek	6.4	1994–2004	Historical: logging Present-day: protected parkland with low-density of roads and trails	Upland sediment inputs	Deep-seated landslides, soil creep, channel incision, and bank erosion
York Creek—St. Helena Upper Dam	5.9	1993–2003	Historical: logging/grazing; Present-day: low-intensity roads, rural residential, and vineyard development	Reservoir sedimentation	Did not perform upland surveys
Terrain Type: Great Valley Formation and Associated Sedimentary Rocks					
Redwood Swale 2	0.37	1994–2004	Vineyard covers 100% of site	Upland sediment inputs	Gullying, soil creep
Redwood Swale 1 and Pond	0.16	1981–2004	Vineyard	Reservoir sedimentation, upland sediment inputs	Gullying, soil creep
Carneros—Scott Creek Dam	0.52	1949–2003	Intensive historical grazing; actively grazed at present	Reservoir sedimentation	Earthflows, gullying, soil creep, and shallow landslides
Carneros—Scott Creek Downstream of dam	1.9	1994–2004	Land-use as above; gullies primarily from historical grazing	Upland sediment inputs	Earthflows, gullying, soil creep, and shallow landslides
Terrain Type: Mélange and Sheared Serpentinite					
Conn (R pond)	0.03	1997–2004	Intensive grazing at present	Reservoir sedimentation, upland sediment inputs	Gullying, sheetwash, soil creep
Sulphur #1	5.1	1994–2004	Historical grazing; Present-day: low-intensity vineyard development	Upland sediment inputs	Deep-seated landslides, gullies, soil creep, shallow landslides
Sulphur #2	1.0	1994–2004	Historical grazing; roads traverse unstable slopes	Upland sediment inputs	Deep-seated landslides, gullies, soil creep, shallow landslides

Using all of the above information, we calculated:

- Median annual rates of cumulative sediment input to channels from colluvial bank erosion, gullies, and shallow landslides during the most recent decade, for each of the four defined terrain types;

- Median ratios of anthropogenic to total sediment input (A/T) by the above processes, during the most recent decade, and for each terrain type based on the range of land-use activities at the sites where we conducted surveys; and

- Total sediment input rates from all delivery processes (or sediment yields) to reservoirs over longer periods of time.

2) Channel Incision and Stream Terrace Bank Erosion in the Alluvial Valleys and Fans

In the alluvial valley and fan deposits, we conducted extensive field reconnaissance in stream channels, reviewed available information, and interpreted time-sequential aerial photographs (1940, 1998) to identify reaches where channel incision was initiated during the historical period. We use the term channel incision to refer to the progressive lowering of the streambed over multiple decades (or longer) that is often accompanied by rapid and intensive bank erosion. Based on field observations and measurements at representative locations in six reaches of the mainstem Napa River and 22 tributary reaches, we estimates rates of sediment supply to channels from channel incision. Our field surveys involved:

a) Interpretation of streamside vegetation (e.g., age classes and species of riparian trees, root exposures, etc.), landform attributes (e.g., terrace bank steepness, lack of soils, presence of distinct side channels on terraces, etc.), and/or observation of incision through a man-made structures of known or estimated age, to estimate approximate timing of the start of channel incision at each site; and

b) Estimation of the volume of sediment eroded by incision and accompanying bank erosion (calculated from measurement of average channel width, average terrace height minus average bankfull channel height, and length of incised reaches estimated from field reconnaissance and measurement on USGS 7.5 minute topographic maps).

3) Sheetwash Erosion from Land Uses

In the Napa River watershed, sheetwash erosion appears to be a significant active process for sediment delivery to channels, where livestock grazing and vineyards disturb soil infiltration capacity and/or vegetation cover. We used USGS land cover/use classification mapping, derived from 1992 satellite imagery, to identify locations of vineyards and grasslands and estimate land areas in each category. For each of these land use/cover types, we used the three-meter digital elevation model to subdivide each vineyard and grassland site into sub-areas based on slope steepness category (<5%, 5 to 30%, >30%). We then used the USLE model to estimate soil erosion rates, and field surveys to estimate sediment deliver ratios to channels. Most vineyards we observed during watershed reconnaissance, and at sites where we conducted upland surveys, had cover crops. Therefore, we apply a vegetation cover value equal 70% for vineyards in the USLE model. Similarly, based on conditions observed in rangelands, we apply a vegetation cover value equal to 60% for grasslands grazed by livestock. We assume that the vineyard and rangeland sites that we observed are representative of typical conditions throughout the watershed. In our analysis of sheetwash erosion caused by grazing, we also assume only one-third of delineated grassland areas are managed at present to provide forage for livestock. This assumption is based on comparison of known areas of cattle grazing to mapped areas of grasslands in Carneros Creek and Sulphur Creek watersheds, where mapped grassland areas appear to be 2 to 4 times greater than areas currently being grazed.

4) Road Erosion Processes

We reviewed and interpreted recent road erosion surveys conducted by Pacific Watershed Associates (PWA) in three Napa River tributary watersheds: Carneros, Dry, and Sulphur, where we applied the tributary specific rates developed by PWA. Elsewhere in the Napa River watershed, we estimated sediment delivery from road surface and crossing erosion, as follows.[11] We compared road length and crossing frequency estimated from overlap of the channel network map with the Napa County GIS layer for roads, which does not include most private roads, to the complete maps of roads developed by PWA in the above three tributaries. We found the Napa County road layer on average underestimates total road length by a factor of three, and total crossing frequency by a factor of 1.5. Therefore, in using the Napa County GIS road layer to estimate road surface and crossing erosion in other parts of the watershed, we multiplied road length by three and crossing frequency by 1.5. In our modeling of road surface erosion, outside of the three surveyed areas, we estimate that 20% of the road length is hydrologically connected to channels, which corresponds to the average value measured by PWA in the three tributary survey areas.

Size Distributions for Sediment Input from all Significant Delivery Processes

In addition to estimating rates of sediment input, We also collected and analyzed samples of sediment stored on hillsides adjacent to channels at 12 sampling sites to estimate percentages of coarse and fine sediment input to channels from colluvial bank erosion, gullies, shallow landslides, and road crossing erosion (Table 4). We also performed extensive field reconnaissance in mainstem Napa River and reviewed available information to estimate grain-size distribution of sediments input to channels as a result of channel incision through alluvial valley and fan deposits. Grain size distributions for sediment input from surface erosion processes on hillsides and roads were estimated qualitatively based on visual observation of coarse lags in rill channels on hillsides (e.g., coarse sand and granules), small alluvial fans deposited at breaks-in-slope, and based on review of the soil grain-size distributions described in the soil survey for Napa County. Based on these observations and our review of soils data, we estimate that sediment delivery for surface erosion processes on hillsides is composed of about

[11] Road-related gullies and landslides that are located downslope of the roads are tabulated within the upland gully, landslide, and colluvial bank erosion category.

Table 4. Terrain Type Sediment Size Distribution					
Terrain Type	**Samples**	**Coarse Bed Material > 64mm (percentage)**	**Spawning Gravel 64mm > X ≥ 11.2mm (percentage)**	**Fine Bed Material 11.2 mm > X ≥ 2mm (percentage)**	**Suspended Load <2mm (percentage)**
Sandstones and clayey rocks (Great Valley formation)	two samples; mean wt.= 108.1 kg	2	12	19	67
Sandstones and clayey rocks (Franciscan metagreywacke)	one sample; wt. = 224.7 kg	18	25	14	43
Franciscan mélange and sheared serpentinite	two samples; mean wt. = 197.3 kg	4	32	55	9
Sonoma Volcanic lava flows	two samples; mean wt. = 97.7 kg; Trso (2003)	12	17	6	65
Sonoma Volcanic ash flow and tuff	two samples; mean wt. = 30.9 kg	11	50	Not measured	Not measured
Alluvial fans and valley fills	Based on WET (1990)	10	20	40	30
NOTES: Considering small number of samples and small sample sizes, expected accuracy of estimated grain size distributions is poor. In the absence of additional data, we assume that Sonoma volcanic tuff/ash-flows have identical size distribution as Sonoma volcanic flows. We did not use our sample data because sample sizes were too small and sampling was truncated at 11.2 mm. We hypothesize that actual size distribution for tuffs/ash flows is richer in fine bed-material and poorer in spawning gravel than Sonoma volcanic flows.					

25% very fine gravel (> 2mm to 11.2 mm), and 75% sand and finer sizes (< 2mm). Similarly, we estimate that road surface erosion produces 25% fine gravel, and 75% sand and finer sizes.

Calculation of Total Sediment Input Rate to Mainstem Napa River

The distribution and frequency of terrain types and occurrence of dams varies by position along mainstem Napa River (Maps 1, 2, and 3). Therefore, to examine how geography of terrain types and dams influences sediment supply to Napa River, we calculated total sediment supply to the channel network upstream of four stations on Napa River: 1) Napa River near St. Helena, at the USGS streamflow gage near Zinfandel lane; 2) Napa River at its confluence with Conn Creek; 3) Napa River at its confluence with Soda Creek; and 4) Napa River at San Pablo Bay. Napa River near St. Helena was chosen because it corresponds to the USGS gage site, it occurs within the primary habitat area in Napa River for chinook salmon, and because the effect of dams on runoff and sediment delivery is low relative to downstream sites (20% of upstream drainage area drains into dams). Napa River at Conn Creek also occurs within the spawning and rearing habitat area for chinook salmon, however in contrast to the site near St. Helena, this site corresponds to the point of maximum influence of dams on runoff and sediment delivery (49% of upstream drainage area drains into dams). Napa River at Soda Creek corresponds approximately to the downstream boundary of spawning and rearing habitat for salmon, and it is located a short distance upstream of the tidal reach. Napa River at San Pablo Bay was chosen because it provides a basis for watershed-wide calculation of total sediment input into the channel network.

Calculation of Total Sediment Input Rate into Four Representative Tributaries

We also calculated total sediment input rates into the channel network from all sources into four tributaries at their confluences with the Napa River (Map 4): Carneros Creek, Milliken Creek, Sulphur Creek, and Ritchie Creek. We selected these tributary watersheds for analysis because:

- One defined upland terrain type predominates in each watershed (sedimentary rocks in Carneros; mélange and sheared serpentinite in Sulphur; ash-flows and tuffs in Ritchie; and volcanic lava flows in Milliken), from which we could examine influence of terrain type on sediment supply under varying land-use activities;

- Recent and/or historical fish census and/or habitat surveys suggest that all of these tributaries provide habitat for steelhead;

- Previous studies conducted in Carneros and Sulphur creeks, provide significant amounts of useful information; and

- We were able to obtain permission for access to extensive portions of each tributary watershed.

The four tributaries selected drain about 10% of the land area in the Napa River watershed. Grape growing, cattle grazing, rural residential development, reservoirs, and roads are common in these tributary watersheds.

In the tributary study areas, we measured or modeled all sediment input rates to channels as described earlier in this section. There was one difference in how we calculated sediment input rates into three of the tributaries we studied—Carneros, Sulphur, and Ritchie—as compared to the remainder of the Napa River watershed. In these three tributary study areas, within the predominant terrain type, we estimated sediment input from colluvial bank erosion, gullies, and shallow landslides, based on measurements made locally within sub-areas of these tributary watersheds, as compared to measurements made at sites elsewhere in the Napa River watershed. In Milliken Creek watershed, we did not conduct upland field surveys, and therefore, we used median values (for input from colluvial bank erosion, gullies, and shallow landslides) that are derived from field measurements at seven upland sites in other locations within the Napa River watershed. Upland survey areas totaled 1.9 km^2 in Carneros Creek watershed, 6.1 km^2 in Sulphur Creek watershed, and 5.9 Km^2 in Ritchie Creek watershed.

Relationship Between Fine Sediment Supply, Transport Capacity, and Streambed Permeability

To explore the relationship between fine sediment input to channels and streambed permeability, we compared average annual fine sediment input rates to reach-median values for streambed permeability measured in seven reaches of the four study tributaries, and in one reach of mainstem Napa River, located near Rutherford.

Streambed permeability values typically reflect a balance between fine sediment supply and transport capacity, therefore, we also estimated stream power. Stream power is defined as the rate of energy expenditure by water as it flows through a channel. Stream power is directly proportional to the product of streamflow discharge multiplied by water surface slope. In our analysis, we define a stream power index that is equal to streambed slope multiplied by drainage area, which we use as a proxy for streamflow discharge in our analysis.[12] We measured streambed slopes throughout the length of each reach where we measured permeability. All of the reaches we surveyed were greater than 40 bankfull channel widths long. We also calculated the land area draining into each reach using the three-meter digital elevation model. We did not estimate values for bankfull discharge because streamflow gaging data were not available at most of our sites.

[12] Our estimates of total stream power provide only a rough estimate of the fraction available to transport sediment. This is because flow energy is also expended through internal friction within the fluid, and friction along the channel boundaries caused by grain roughness, large obstructions (like debris jams, bedrock outcrops, bridge piers, etc.), and/or other changes in channel width, depth, and direction of flow encountered along the length of the channel.

3.5 Tributary and Mainstem Study Areas

Milliken Creek

Milliken Creek drains a 53-km^2 tributary watershed located on the east side of Napa River watershed. The City of Napa operates Milliken Reservoir, which captures runoff from almost half of the land area of the watershed, and a diversion located about two miles downstream to provide water supply within its service area. Other large on-channel dams are located on tributaries to Milliken Creek and in its lower reach within the Silverado Country Club. Altogether, dams capture runoff from about three-quarters of the land area of the watershed. Low density residential and resort development predominate in the lower part of the watershed, and natural cover and rangeland uses predominate in the upper and middle parts of the watershed. This watershed is underlain primarily by very hard volcanic flows of the Sonoma Volcanics Formation. 66% of the total land area is underlain by hard volcanic lava flows. A gently sloping plateau dominates the upper watershed, which then abruptly transitions into deep canyon in the middle reach of Milliken Creek, and which opens up again in its lower reach in the Napa Valley (Figure 7).

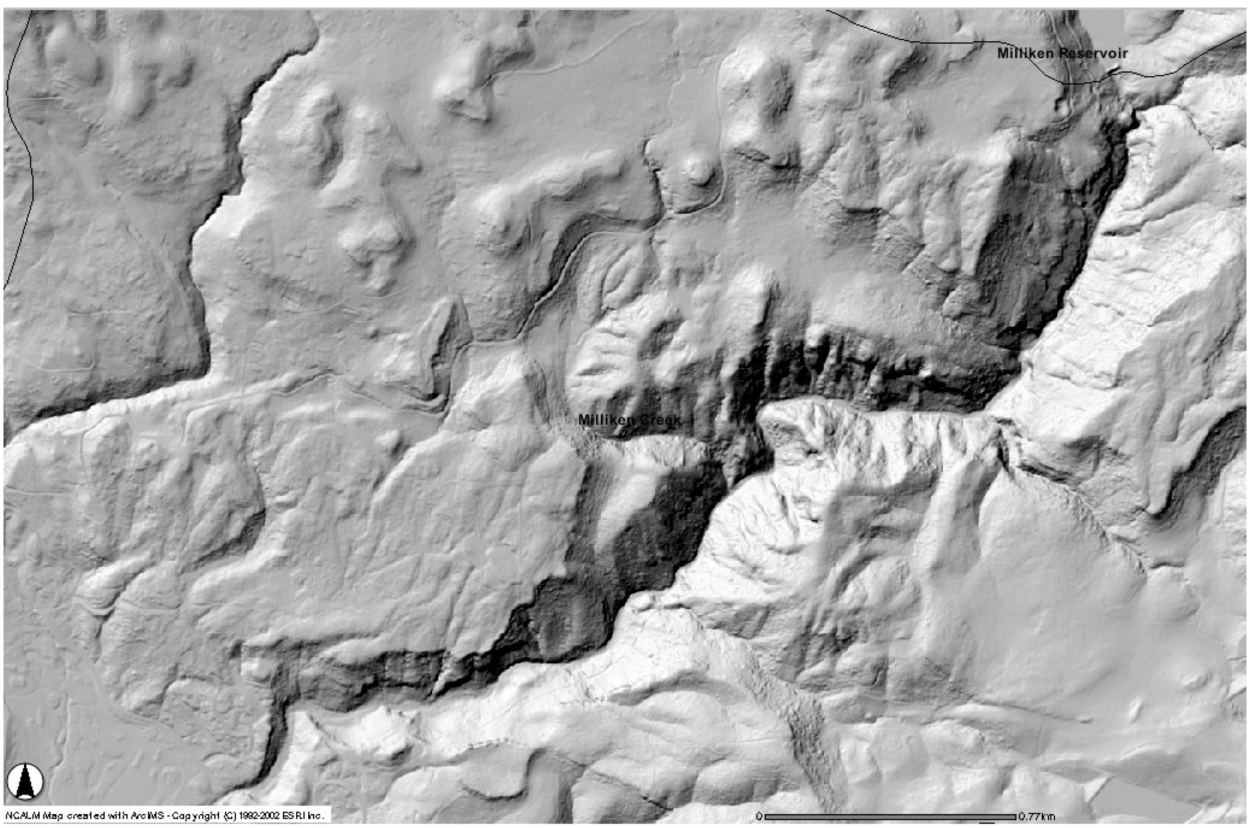


Figure 7. **Ground Surface Topography in Milliken Canyon** .
Generated using 1-meter laser altimetry (LIDAR) topographic data, and data filtering to remove most vegetation cover. Hard bedrock forms steep slopes in the canyon. Gentle plateau in upper watershed was formed during an earlier geologic period when uplift rates were much lower (Swinchatt and Howell, 2004).

In Milliken Canyon, boulder and cobble deposits predominate, in steep reaches that alternate between cascade and step-pool channel types (Figure 8). We measured streambed permeability at all potential spawning sites for steelhead and/or rainbow trout in two reaches located within the gorge, one located a short upstream of Milliken Dam (eight potential spawning sites within a 215 m reach; streambed slope = 0.035; upstream drainage are = 18.9 km^2), and the other reach located a short distance downstream of the diversion operated by the City of Napa (six potential spawning sites located within a 135 m reach; streambed slope = 0.058; upstream drainage are = 30.3 km^2). Based on geology (hard volcanic flow rocks), predominance of natural cover and low density of roads, and the steep and confined nature of channel reaches in Milliken Canyon, we hypothesized low values of fine sediment supply and high values of streambed permeability.

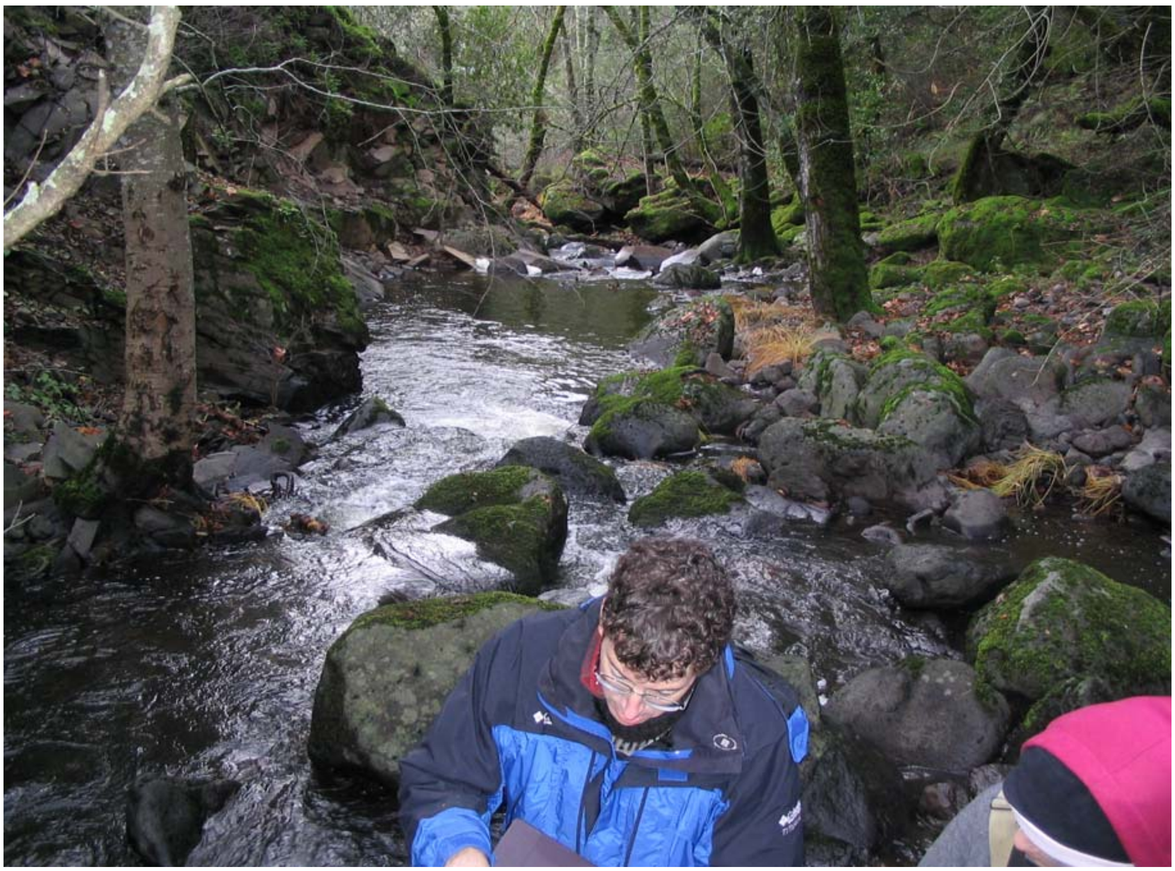


Photo by Bill Dietrich, UC Berkeley.

Figure 8. Alternating Boulder Step and Pool Bedforms in Upper Milliken Creek.
Photo taken upstream of Milliken Canyon Reservoir.

Other Napa River tributaries with similar land cover that are underlain primarily by hard volcanic flows, and where dams capture runoff from most of the watershed area, include Rector Creek, Tulocay Creek, and Sarco Creek. We would expect these tributary watersheds to have sediment budgets that are similar to that calculated for Milliken Creek watershed. Other east-side tributaries underlain primarily by hard volcanic flow rocks, and with similar land cover and uses include Soda Creek and Suscol Creek watersheds. These differ from Milliken and the above group of tributaries, in that no large on-channel dams have been identified on Suscol Creek or Soda Creek, and therefore, we would expect higher sediment supplies in these channels.

Carneros Creek

Carneros Creek drains a 23-km^2 tributary watershed located in the southwestern part of the Napa River watershed. Natural vegetation cover and vineyards predominate. Cattle ranching, low-density rural residential development, and wineries are also common. Intensive stocking of cattle and/or other types of livestock was common throughout large parts of the watershed from early nineteenth century up until recent decades (Grossinger et al., 2003). Sixty-six percent of the watershed is underlain by mechanically weak sedimentary rocks, which are distinguished by gentle slopes that are often hummocky where they are being sculpted by landslides and gullies (Figure 9). Lesser but significant sub-areas of the watershed are underlain by hard volcanic lava flows or thick alluvial fan and valley deposits that flank the mainstem of Carneros Creek throughout its course. Dietrich et al. (2004) identified 40 small to medium sized dams that have been constructed on intermittent and ephemeral tributaries to Carneros Creek, which capture runoff from 22% of the land area in the watershed. Mainstem Carneros Creek is a deeply entrenched gravel-bedded stream, which alternates between pool-riffle, bedrock, and plane-bed reaches within its perennial reach (Figure 10). Bedrock channel reaches are also common in the middle of the watershed (upstream of Dealy Lane).

We measured streambed permeability at all potential spawning sites for steelhead and/or rainbow trout in two reaches of Carneros Creek, one located in the middle of the watershed (five potential spawning sites within a 340-m reach; streambed slope = 0.013; upstream drainage area = 10.4 km^2), that maintains perennial surface water, and the second located downstream of Old Sonoma Road (six potential spawning sites within a 280-m reach; streambed slope = 0.006; upstream drainage area = 18.2 km^2), in a freshwater reach that usually goes dry in the spring or summer of each year. Based on our review of available information and extensive field reconnaissance, we hypothesized that Carneros Creek has a medium to high total and fine sediment supply in both reaches that we surveyed, and that stream power is moderate in the middle reach and low in the lower reach. Therefore, we predicted that typical values for streambed permeability would be fair to poor in the middle reach, and poor in the lower reach.

Other Napa River tributaries with similar land cover that are also underlain primarily by sedimentary rocks include Dry Creek and Redwood Creek tributary watersheds. These watersheds differ from Carneros Creek, however in that smaller proportions of their land areas drain into reservoirs, and average annual precipitation is higher. Erosion response to land use disturbances in Dry Creek and Redwood Creek watersheds may be similar to that described and measured in Carneros Creek.

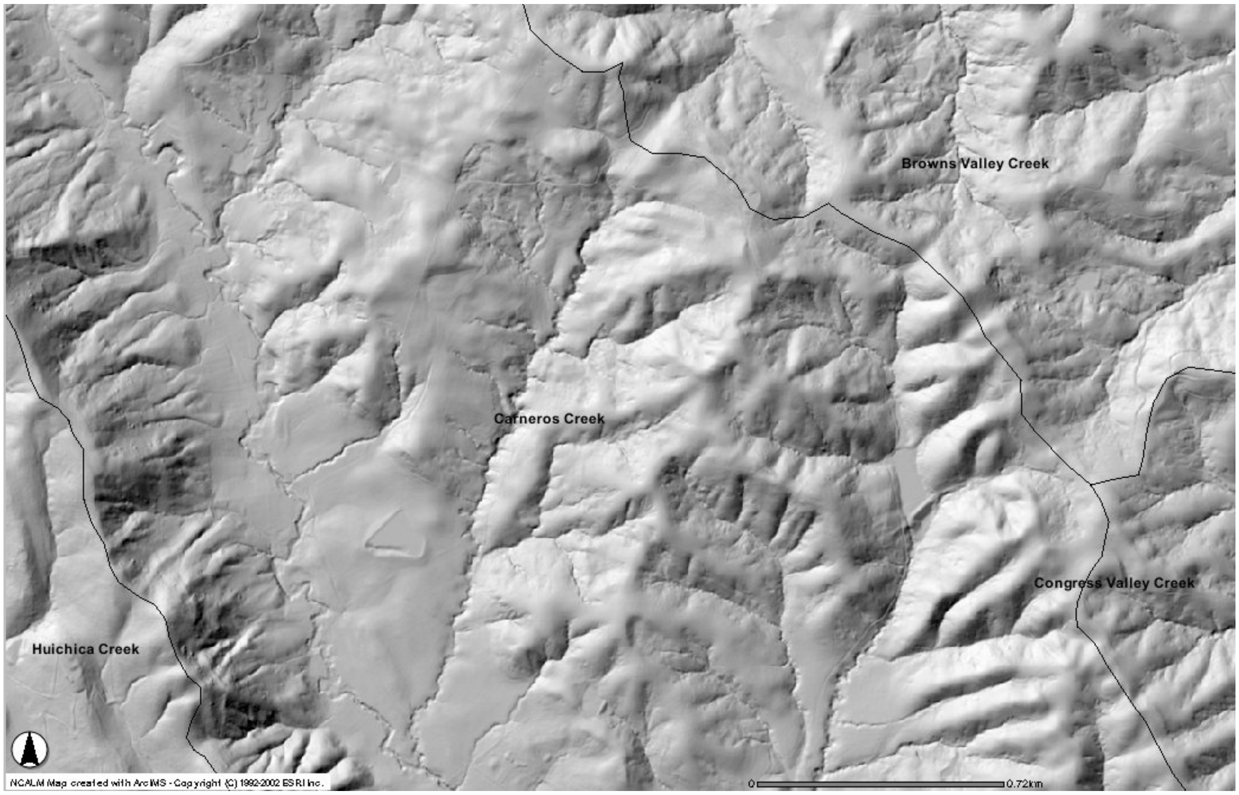


Figure 9. Ground Surface Topography in Carneros Creek Watershed. Generated using 1-meter resolution laser altimetry (LIDAR) data, and filtering to remove most vegetation cover. Gentle hummocky slopes developed on soft sandstones and clayey rocks that are being rapidly eroded by earthflows and gullies. Two dams can be seen on the image, one built on a channel (near center right-half of image), and the second, which is built off-channel (and visible at left center of image).

Ritchie Creek

Ritchie Creek drains a 6.4-km^2 tributary watershed underlain almost entirely by tuff and ash flow deposits of the Sonoma Volcanics Formation. Almost all of this watershed area has been in public ownership since the creation of Bothe State Park in 1960, and except for a very small amount of vineyard development in its headwaters and in its lower (Napa Valley) reach, the watershed is covered primarily by a natural mixed evergreen forest. Road density is also very low (1 km/km^2). Within Bothe State Park, Ritchie Creek typically is a steep cobble- or boulder-bedded channel that alternates between step-pool and cascade channel types within its canyon (Figure 11). Forced pool-riffle reaches also occur, primarily within the alluvial fan reach, which begins in the campground and extends downstream of the park boundaries into the Napa Valley. Based on reconnaissance of channel reaches and hillsides in the lower part of the watershed within Bothe Park, we classified Ritchie Creek as a medium to high sediment supply watershed with high channel sediment transport capacity, and consequently we predicted that streambed permeability values would be poor to fair. We measured streambed permeability at all potential spawning sites for steelhead in one stream reach located near in the uppermost reach of the mainstem of Ritchie Creek (4 potential spawning sites; streambed slope = 0.05; drainage area = 4.0 km^2).


Photo by Bill Dietrich, UC Berkeley

Figure 10. Extensive Bank Erosion and Deep Entrenchment Along Mainstem Carneros Creek.
Bar in foreground formed by obstruction of flow by large bay trees that recently fell into the channel. Flow direction is from background to foreground in the picture.

Sulphur Creek
Sulphur Creek drains a 23-km^2 tributary watershed underlain primarily by mélange and sheared serpentine types of the Franciscan Formation, that is renown for its high to extreme rates of erosion (Brown and Ritter, 1971; Kelsey, 1980; and Lehre, 1982). Natural vegetation cover, vineyards, and rural residential land uses predominate. Mixed evergreen forest is the most common vegetation cover type. Extensive grasslands and woodlands are located in the upper part of the watershed. Beginning in the mid-nineteenth century and up until the last few decades, most of this area was managed to provide forage for livestock. In recent decades many former rangelands and some forested areas have been converted to vineyards. During the mid to late nineteenth century, most of the large redwood trees in Sulphur Creek watershed were logged (Grossinger et al., 2003b).

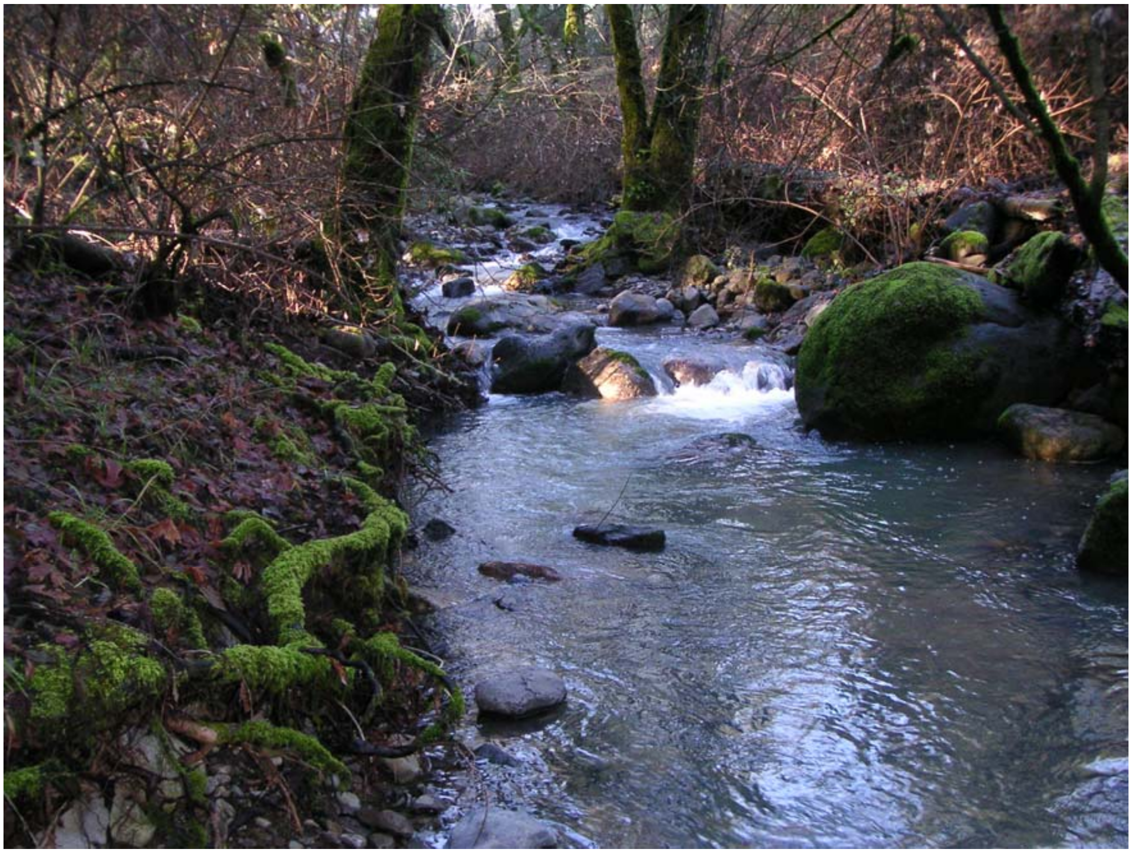


Figure 11. Step-Pool and Cascade Reaches Along Ritchie Creek.
The pool located in the foreground occurs at the boundary of channel-bridging boulder step (step-pool sequence). The steeper reach, in the background, where large boulders and cobbles are scattered about the channels and flow is turbulent throughout is referred to as a cascade.

Hillside topography alternates between steep slopes underlain by large hard blocks of bedrock and hummocky gentle slopes where intensively deformed rock types that form the bulk of the mélange and sheared serpentine deposits are sculpted by deep-seated landslides and large gullies (Figure 12). Perennial reaches of Sulphur Creek and its tributaries that provide potential habitat for steelhead trout are typically gravel-bedded with step-pool, plane-bed, or pool-riffle channels that are confined by adjacent slopes or moderately confined within narrow alluvial valleys (Figure 13).

Figure 12. Sulphur Creek in its Headwaters.
Sulphur Creek in its headwaters cutting through a large deep-seated landslide formed in the mélange.

Photo by Bill Dietrich, UC Berkeley

Figure 13. Plane-Bed Reach of Sulphur Creek
Long riffle and low-elevation gravel bar dominate this plane-bed reach of Sulphur Creek. Pools are spaced far apart and are shallow in plane-bed channels. A small and shallow pool occurs at the downstream bend in the background of the photo.

We conducted extensive field reconnaissance in three perennial tributaries of Sulphur Creek and in its mainstem channel within the canyon reach. Based on our reconnaissance and review, we hypothesized that Sulphur Creek provides high to extreme total and fine sediment supply to its channels. Based on channel conditions described above and field observations, we selected four reaches of Sulphur Creek which we classified as medium to high sediment transport capacity, and where we measured streambed permeability at all potential spawning sites for steelhead that were identified in each reach (35 potential spawning sites in four reaches that varied in length between 125 and 300 meters with streambed slopes that vary between 0.012 and 0.024; upstream drainage area varied between 4.5 km^2 and 9.6 km^2). Based on channel and watershed attributes, we predicted measured permeability values would be poor to fair.

Mainstem Napa River

Mainstem Napa River is a gravel-bedded channel upstream of the City of Napa. As a result of active and progressive down-cutting of the channel throughout much of its length during the past 40 to 50 years, the frequency of gravel bar, riffle, side channel, and slough habitat has been greatly reduced, and the frequency of long-deep pool-run habitats has increased substantially with significant adverse impacts to salmonids, and other native fish and wildlife species (Stillwater Sciences and Dietrich, 2002). Stillwater Sciences and Dietrich conducted extensive surveys throughout an approximately 15-kilometer reach of mainstem Napa River located between Calistoga and St. Helena during 2001 and 2002. We rely upon the data they collected in their extensive survey of mainstem Napa River, and also upon the data we collected for this study at several additional locations throughout the mainstem Napa River and in its tributaries to estimate channel incision rates. Based on field reconnaissance and review of available information, we hypothesized that mainstem Napa River had a medium total and high fine sediment supply, and a medium to high sediment transport capacity. Therefore, we predicted that streambed permeability would be poor to fair. To test this hypothesis, we used streambed permeability data collected by Napa County RCD staff at ten potential spawning sites for salmon and trout located in the 7-km long Rutherford Reach of the mainstem of the Napa River (streambed slope = 0.002; drainage area = 200 km^2).

3.6 Findings

- Streambed permeability values are influenced at least in part by rates of fine sediment input to channels (Figure 14), and where stream power available to transport sediment is relatively high, streambed permeability will rise by a greater amount in response to reduction in fine sediment supply than in reaches where stream power is relatively low.

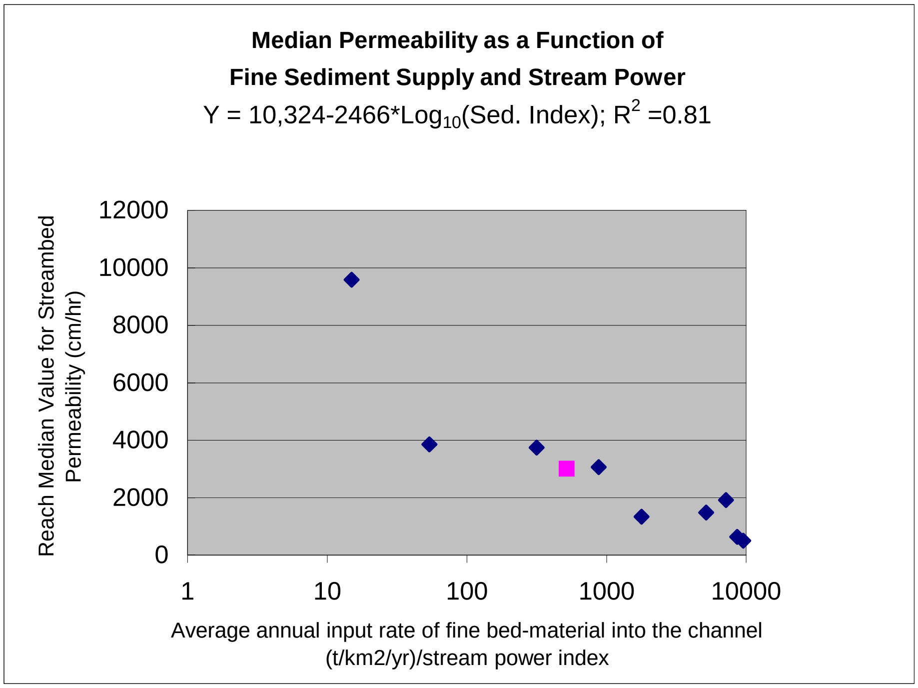


Figure 14. Streambed Permeability Is a Function of Fine Sediment Supply and Transport.
Fine sediment input rate in our analysis corresponds to all grains with intermediate diameters <11.2 to 2 mm to account for breakdown of gravel into fine sediment during transport through the channel network. Diamond symbol corresponds to tributary measurement site, and square corresponds to Rutherford Reach in mainstem Napa River.

- Bedrock hardness exerts a significant influence on total sediment supply to channels (Table 5). Total sediment supply was lowest at sites underlain by the hard lava flow, 50 to 400 t/km^2/year. At sites underlain by soft ash flow and tuff, and soft sandstones and clayey rocks, total sediment supply was about 500 to 1000 t/km^2/year. We measured the highest rates of total sediment supply at sites underlain by the intensively deformed Franciscan mélange and sheared serpentinite, where total sediment supply was about 900 to greater than 1700 t/km^2/year.

- Within defined upland terrain types, land uses have the potential to greatly increase rates of sediment input to channels. At sites underlain by hard lava flows and sedimentary rocks we conclude that more than half of sediment input to channels during the most recent decade was caused by land-use activities (Table 5). We reach this conclusion because we found most of the gullies and shallow landslides observed in these terrain types are caused by land-used activities. For example, we often observed direct spatial overlap between locations of discharge of concentrated runoff from roads and/or hillside vineyards and actively eroding gullies and/or shallow landslides. We also conclude that intensive grazing (current or historical) has caused the gullies and shallow landslides we observed at some rangeland sites to be formed, based on the association between the gullies and shallow landslides, widespread occurrence of clay-rich soils at these sites, and

Table 5. Sediment Supply from upland Terrain Types												
Site	**DA (km^2)**	**Time Period**	**Key Process(es)**	**Input Rate ($t/km^2/yr$)**	**Key Process(es)**	**Input Rate ($t/km^2/yr$)**	**Key Processes**	**Input Rate ($t/km^2/yr$)**	**Colluvial Bank Erosion, Gullies, and Landslides Input Rate ($t/km^2/yr$)**	**Colluvial Bank Erosion, Gullies, and Landslides A/T (1)**	**Total Input Rate(2) ($t/km^2/yr$)**	**Land Uses/Disturbances**
Land Type: Hard Flow Rocks												
Spence Creek Pond	0.21	1958–2004	…	…	…	…	…	…	56	0.00	56	Natural non-managed grasslands
Kreuse Creek	3.14	1994–2004	Colluvial bank erosion	53	Post-fire sheetwash and gullies	101	…	…	?	?	154	Recent large fire
Milliken Reservoir	25.1	1926–2003	…	…	…	…	…	…	…	…	74	1981 Atlas Peak fire; low-intensity land uses; Foss Valley stores substantial fraction of coarse input to upper watershed
Bell Canyon Reservoir	13.9	1959–2001	…	…	…	…	…	…	…	…	129	Low-intensity land uses
Conn Creek	0.17	1994–2004	Colluvial bank erosion	(50–80)	Grazing gullies and SLS	[131–161]	Grazing sheetwash	165	211	0.62 to 0.76		High intensity grazing
Conn Creek Stock Pond	0.17	1997–2004	…	…	…	…	…	…	…	…	376	High intensity grazing
Redwood—Pond 1	0.18	1981–2004	…	…	Vine drainage gullies and SLS	35	…	…	…	…	242	Vineyard
Redwood—V Creek	0.12	1994–2004	Colluvial bank erosion	80	Vineyard drainage gullies and SLS	104	…	…	184	0.57	…	Vineyard
South Creek	1.0	1993–2003	Colluvial bank erosion	46	…	…	Nat. grass. Sheetwash	24	46	0.00	…	Low-intensity grazing
Central Creek	1.4	1993–2003	Colluvial bank erosion	60	Grazing gullies and SLS	79	…		139	0.57	…	Low-intensity grazing
								Range.	46 to 211	0 to 0.76	55 to 375	
								Average	127	0.37		
								St. dev.	74	0.34		
								Median	**139**	**0.57**		
								N=	5	5	6	

Table 5. Sediment Supply from Upland Terrain Types (Continued)												
Site	**DA (km^2)**	**Time Period**	**Key Process(es)**	**Input Rate ($t/km^2/yr$)**	**Key Process(es)**	**Input Rate ($t/km^2/yr$)**	**Key Processes**	**Input Rate ($t/km^2/yr$)**	**Colluvial Bank Erosion, Gullies, and Landslides Input Rate ($t/km^2/yr$)**	**Colluvial Bank Erosion, Gullies, and Landslides A/T (1)**	**Total Input Rate(2) ($t/km^2/yr$)**	**Land Uses/Disturbances**
Land Type: Great Valley Formation and Associated Sedimentary Rocks												
Redwood—Swale 2	0.37	1994–2004	Colluvial bank erosion	79	Vineyard and road gullies	256	…	…	335	0.76	…	Present: 100% vine
Redwood—Swale 1 Pond	0.16	1981–2004	…	…	…	…	Vine Sheetwash	[318]	…	…	605	
Redwood—Swale 1	0.16	1994–2004	Colluvial bank erosion	87	Vineyard gullies	200			287	0.70		
Carneros—Scott Creek Dam	0.52	1949–2003	…	…	…	…	…	…	…	…	960	Intensive historical grazing; moderate at present
Carneros—Scott Creek Downstream of dam	1.9	1994–2004	Colluvial bank erosion	130	Grazing and road gullies and SLS	530			660	0.80		LU as above; gullies primarily from historical grazing
								Range	287 to 660	0.7 to 0.80	600 to 960	Sampled Great Valley; inferred for other
								Average	427	0.75	783	Sedimentary rocks
								St. Dev.	203	0.05		
								Median	**335**	**0.76**		
								N =	3	3	2	

Table 5. Sediment Supply from Upland Terrain Types (Continued)

Site	DA (km^2)	Time Period	Key Process(es)	Input Rate (t/km^2/yr)	Key Process(es)	Input Rate (t/km^2/yr)	Key Processes	Input Rate (t/km^2/yr)	Colluvial Bank Erosion, Gullies, and Landslides Input Rate (t/km^2/yr)	Colluvial Bank Erosion, Gullies, and Landslides A/T (1)	Total Input Rate(2) (t/km^2/yr)	Land Uses/Disturbances
Land Type: Mélange and Sheared Serpentinite												
Conn (R pond)	0.03	1997–2004	Colluvial bank erosion and channel network extension	400	Grazing gullies	[136]	Grazing sheetwash	383	536	0.25	919	Intensive grazing
Sulphur (NF)	5.1	1994–2004	Colluvial bank erosion	130	Deep-seated landslides	1474	SLS	133	1737	>0.01	…	Historical grazing; present-day: low-intensity vineyard
Sulphur (H)	1.0	1994–2004	Colluvial bank erosion	150	Road gullies and slides	354	Spillway gullies	21	1170	0.32	…	Road drainage problems
								Range	719 to 1737	0.01 to 0.32	919 to 1737	
								Average	1148	0.19		
								St. Dev.	601	0.16		
								Median	**1170**	**0.25**		
								N =	3	3	3	

40

Table 5. Sediment Supply from Upland Terrain Types (Continued)												
Site	**DA (km^2)**	**Time Period**	**Key Process(es)**	**Input Rate ($t/km^2/yr$)**	**Key Process(es)**	**Input Rate ($t/km^2/yr$)**	**Key Processes**	**Input Rate ($t/km^2/yr$)**	**Colluvial Bank Erosion, Gullies, and Landslides Input Rate ($t/km^2/yr$)**	**Colluvial Bank Erosion, Gullies, and Landslides A/T (1)**	**Total Input Rate(2) ($t/km^2/yr$)**	**Land Uses/Disturbances**
Land Type: Volcanic Ash-Flows and Turf												
Kimball Canyon Dam	7.8	1940–2003	…	…	…	…	…	…	…	…	494 to 618	Historical: logging/grazing; Present-day: low-intensity land use, water supply
Ritchie Creek	5.9	1994–2004	Colluvial bank erosion	150	Deep-seated landslides	670	Channel incision and bank erosion	85	905	0.09	913	Historical logging; Present-day: protected parklands
York Creek—St. Helena Upper Dam	5.9	1993–2004	…	…	…	…	…	…	…	…	570	Historical logging; Present-day: low-intensity roads, rural residential and vineyard
												Based on frequent occurrence of large deep landslides, we assume A/T in ash-flow = mélange
								Median	**520**	**0.25**		
								Range			494 to 960	
								N =	1		3	

Table 5. Sediment Supply from Upland Terrain Types (Continued)
Notes, Abbreviations, and Conventions. (1) A/T = ratio of anthropogenic (human-caused) to total sediment input to channels from colluvial bank erosion, gullies, and shallow landslides. (2) Total input rate = sum of all significant active processes that deliver sediment to channels. Typically estimated from measurement of reservoir sedimentation rate corrected to account for trap efficiency. Based on lack of large gravel bars or floodplains in upland channels, we assume that sediment input to the channel network is approximately equal to yield measured in reservoir. Conversions: area- 1.0 square kilometer = 247.1 acres = 0.39 square mile; sediment supply rates - 100 metric ton/square kilometer/yr. = 286 English tons/square mile/yr. = 0.45 tons/acre. SLS: shallow landslides; values in (parentheses) represent estimated range for rate; BE: bank erosion; N = number of sites; st. dev.: standard deviation; graz. = grazing; vine. = vineyard; ds - downstream; LU - land use. Sheetwash sediment input to channels: erosion modeled using USLE equation, and sediment delivery ratio estimated by delineating area of convergent topography and examination of coarse lag deposits. Values in [brackets] are residuals, which are not measured, and instead estimated by conservation of mass, as difference between sedimentation rate and sum of measured inputs. Residuals are only estimated where all other significant process rates have been measured. Colluvial bank erosion rates derived from measurement of total channel length and mean bank height, assuming typical downslope velocity of 0.01 m/yr., and assuming soil bulk density equals 1.6 metric tons per cubic meter. We set reservoir trap efficiency equal to 75% in all reservoirs except Kimball, where we assume 90% trap efficiency because of continuous pond in a large reservoir, and 67% in upper York, where dam has filled with sediment. Reservoir sedimentation volumes and landslide and gully scar volumes converted to mass assuming bulk density of 1.6 metric tons per cubic meter. **Input from Colluvial Bank Erosion, Gullies, and Landslides in Ash flows and Tuff.** We only conducted one upland field surveys at a site underlain by the ash-flow and tuff. Therefore median rate of input from colluvial bank erosion, gullies, and shallow landslides is calculated as follows: Given the dominance of deep-seated landslides in ash-flow and tuff, we applied A/T value estimated for mélange and sheared serpentinite (A/t = 0.25). Although A/T value is higher than estimated at Ritchie Creek (A/T = 0.09), we hypothesize that human influences on sediment supply are lower in Ritchie Creek than most other areas underlain by ash-flow and tuff. Median rate of sediment input from colluvial bank erosion, gullies, and landslides for ash-flow and tuff is calculated using York Creek sedimentation data, and assuming fraction of total input from colluvial bank erosion, gullies, and shallow landslides, in York Creek, is the same as estimated in Ritchie Creek (91%). Therefore, median estimated rate of input from colluvial bank erosion, gullies, and shallow landslides = 570 x 0.91 = 520 t/km2/yr.

documentation of intensive grazing during the historical period or present-day.[13] Also at two sites we surveyed (Spence Creek and South Creek), that do not have a history of intensive grazing, we document a lack of large actively eroding gullies and shallow landslides, which is consistent with our hypothesis. During the most recent decade, gullies and shallow landslides from roads, grazing, and/or hillside vineyards, collectively contributed about 50–150 t/km^2/year at sites underlain by hard lava flows, and about 200 to 500 t/km^2/year at sites underlain by the soft sandstone and clayey rocks (Table 5). Also, as indicated in Table 5, sediment input from sheetwash erosion caused by grazing and/or vineyards may contribute a few hundred or more tonnes/km^2/yr in the soft sandstone and clayey rock, and hard lava flow terrains.

- In contrast, we conclude that the large deep-seated landslides that dominate sediment input to channels in the mélange and sheared serpentinite are caused primarily by the intensive tectonic deformation of these units during their formation. Therefore, we conclude that only one-fourth to one-third of the sediment supplied to channels at sites underlain by the mélange and sheared serpentinite were human caused during the most recent decade (Table 5). Similarly, because large deep-seated landslides are also common in Ritchie Creek watershed, which is underlain by ash-flow and tuff terrain, we reach the same conclusion for this terrain type. Although the deep-seated landslides appear to dominate sediment input to channels in the above terrain types, we also identified several actively eroding gullies and shallow landslides formed by concentrated runoff from roads, vineyards, or on-channel dams in areas underlain by the mélange and sheared serpentinite (Table 5). Based on surveys at three upland sites in the mélange and sheared serpentinite, we estimate that land use-related gullies and shallow landslides contributed about 100 to 400 tonnes/km^2/yr to channels during the most recent decade. Also, based on modeling of sheetwash erosion rates at one intensively grazed site underlain by sheared serpentinite, it appears that sediment input rates to channels from grazing-related sheetwash can be very high (about 400 tonnes/km^2/yr).

- Valley fills and alluvial fans in the Napa River watershed are thick, recently deposited coarse-grained sediments derived from erosion of the uplands. Sediment accumulation was favored over erosion in alluvial fans and valleys in the Napa River watershed since the end of the most recent glacial epoch, 10 to 15 thousand years ago, up until the historical era. However, because fans and valley fills are composed primarily of coarse-grained recently deposited sediments, they are poorly consolidated and non-cohesive, and hence a soft terrain type. As such, valley fills and fans are quite vulnerable to erosion when vegetation is disturbed, or runoff is increased or concentrated by land use disturbances, as evidenced by rapid and active channel incision and bank erosion that we documented in several reaches of the Napa River and its tributaries (Table 6). During the

[13] Clayey soils are widespread in the Carneros region, and up until the last decade or two, much of the Carneros region was very heavily grazed (Grossinger et al., 2003). Heavy grazing in the wet season, would cause clayey soils to become severely compacted, and vegetation cover density to be substantially reduced. The above factors acting in combination would greatly increase the area, volume, and peak rates of overland flow runoff during storms, providing the impetus for gullies and shallow landslides to form. Soils developed on the hard lava flows are also clay-rich, and hence vulnerable to compaction. However, because cobbles and boulders are also abundant in these soils, and soils are typically very thin, gullies and/or shallow landslides formed in the hard volcanic flows are usually much smaller features.

Table 6. Sediment Supply From Channel Incision								
Watershed Subareas	**Stream Name**	**Incised Channel Length (M)**	**Channel Width (M)**	**Average Annual Incision (M)**	**Age (Yr.)**	**Mass Removed (Tonnes)**	**Annual Average Incision Rate (Tonnes/Yr.)**	**Notes**
Upstream of Saint Helena	**Mainstem Napa River 1**	7,700	15	3	54	554,500	10267	Between Lodi Ln. and St. Helena gaging station; 2 m of incision 1850-1900; rejuvenated after 1950.
	Upper Napa River 1	12,500	8	2.5	20	400,000	20000	Mainstem between Lodi Ln. and Myrtledale Ln., Garnet Creek (fan), Blossom Creek (fan), and Cyrus Creek.
	Upper Napa River 2	3,100	5	1.5	20	37,200	1860	Mainstem Myrtledale Ln. to Kimball Reservoir
	Fan Blossom Creek	3,500	3	1.5	20	25,200	1260	Incision only in fan; age estimated based on vegetation cues.
	Upland and Fan Simmons Canyon	2,400		none	none	0	0	
	Fan Bell Canyon Below Dam	3,100	8	3	45	119,040	2645	
	Fan Cyrus Creek	650	9	1.5	20	14,040	702	Incision only in fan.
	Upland and Fan Dutch Henry Canyon	2,650		0	0	0	0	
	Fan Garnett Creek	3,400		0	0	0	0	
	Upland and Fan Ritchie Creek	2,900	6	0.7	40	19,488	487	1.5 meters of incision, perhaps 100 yrs. Old
	Upland and Fan Mill Creek	1,900	6	0.5	20	9,120	456	1.5 meters of incision, perhaps 100 yrs. Old
	Fan Sulphur Creek	2,400	8	3	100	92,160	922	Incision only in fan, downstream of gravel mining; primarily an urban reach.
	Upland Sulphur Creek				100	32,000	320	
Saint Helena to Conn Creek	**Mainstem Napa River 2**	12,000	15	3	54	864,000	16000	Between St. Helena gaging station and Conn Creek; 2 meters of incision 1850-1900; rejuvenated after 1950.
	Fan Bear Creek	3,600	2.5	1	50	14,400	288	Age estimated based on vegetation cues
	Fan Rector Creek Below Dam	2,400	8	3	56	92,160	1646	Incision only in fan.

Table 6. Sediment Supply from Channel Incision (Continued)

Saint Helena to Conn Creek	**Upland Conn Creek Below Dam**	250	10	1.5	?	6,000	0	According to WET (1990), incision in this reach was prior to 1900; also after Lake Hennessey was built?
	Upland Conn Above Dam				50	97,700	1954	Not included in estimates of channel incision downstream of dams.
	Upland Chiles Above Dam				50	37,750	755	Not included in estimates of channel incision downstream of dams.
Saint Helena to Conn Creek to Napa	**Mainstem Napa River 3**	10,100	15	3	54	727,200	13467	Between Conn Creek and Soda Creek, we estimate 2 meters of incision between 1850-1900; incision rejuvenated after 1950.
	Upland and Fan Dry Creek	6,700	10	1.5	100	160,800	0	
	Upland and Fan Soda Creek	750	15	1	1850–1900	18,000	0	Incision prior to 1900?
Downstream of Napa	**Mainstem Napa River 4**	4,800	15	3	54	345,600	6400	Between Soda Creek and Trancas Avenue, we estimate 2 meters of incision between 1850-1900; rejuvenated after 1950.
	Upland Milliken Creek Below Dam	None	None	None	None	0	0	
	Fan Napa/ Redwood Creek	8,400	13	2	100	349,440	3494	includes an urban reach
	Upland Redwood/ Pickle Creek	None	None	None	None	0	0	
	Upland and Fan Tulucay Creek	None	None	None	None	0	0	
	Fan Suscol Creek				100			
	Upland/Fan Carneros Creek	9,000	10	3	100	432,000	4320	
	Fan Huichica Creek	2,200	8	2.75	100	77,440	774	Laurel Collins (personal communication, 2004; unpublished surveys, 1996)
Long-Term Average Rate of Sediment Supply:						Napa River (tonnes/yr.)	67993	
						Tributaries (tonnes/yr.)	18923	
						Total (tones/yr.)	***86916***	

In the absence of data to estimate rates during the most recent decade, we assume rates of sediment input from channel incision during the most recent decade equal are to one-half of long-term rates.

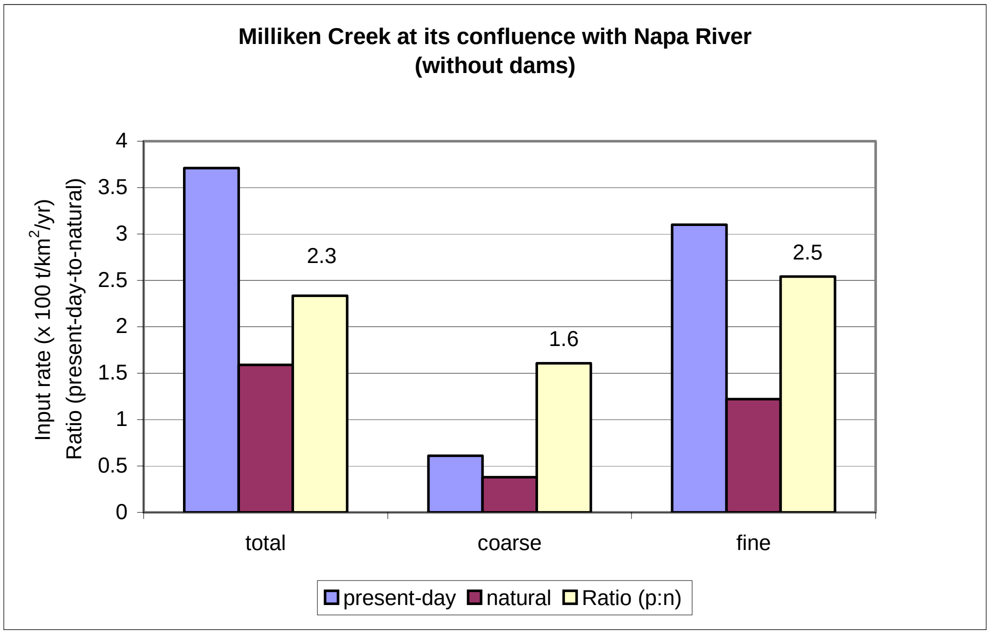
most recent decade, we found that channel incision, and associated bank erosion, in the alluvial valley and fan terrain contributed an average of about 45,000 tonnes per year into the Napa River. Because incision rate appears to vary substantially with location along the Napa River, total supply corresponds to a high local value of about 1,100 t/km^2/year adjacent to the upper Napa River, and a low value of about 100 t/km^2/year along the Napa River downstream of Soda Creek, where the river approaches sea level. The average rate of channel incision in mainstem Napa River over the past four decades (>5 cm/yr) was greater than 50 times the natural background rate of incision, which we found should be similar in magnitude to local uplift rate (<< 1 cm/yr). Almost all incision is found to be anthropogenic based on the very high estimated rate, and initiation during historical period, which is coincident with a period of intensive levee building and dam construction, filling of flood basins adjacent to channels, navigational dredging, intensive removal of debris jams, and historical gravel mining and channel straightening.

- We also calculated total sediment input rates into the channel network from all sources into four tributaries at their confluences with the Napa River—Carneros Creek, Milliken Creek, Sulphur Creek, and Ritchie Creek—to examine the influences of terrain type, land uses, and dams on sediment supply. In Milliken Creek, and much of the eastside of the Napa River watershed, the influence of dams is prominent (Maps 1 and 2). Although total sediment input rate into the channel network was more than twice the estimated natural background during the most recent decade, most of this sediment was not delivered to lower Milliken Creek or the Napa River, because about three-quarters of the Milliken Creek watershed drains into dams (Figure 15). In the other three tributaries where we calculated total sediment input rate into the channel network, dams are much less prominent, and therefore total sediment input should correspond approximately with total sediment yield at the confluence. Sediment yields however, will be richer in fine and poorer in coarse sediment, as a result of breakdown of coarse sediment during transport through the tributary channel network. Sediment input rates calculated for Carneros, Sulphur, and Ritchie creeks are consistent with influences of terrain types and land uses described above (Figure 16).

- During the most recent decade, on average and over the whole watershed more than half of all sediment input to channels was caused by human actions (Figure 17). However, a significant proportion of all sediment input to tributaries does not reach Napa River, however, because 30% of watershed drains into tributary dams (Maps 1 and 2; Figure 18). Tributary dams capture all coarse and most fine sediment delivered to channels upstream of the dams. Effect of dam sediment-capture is greatest in middle reach of Napa River, at its confluence with Conn Creek, where about half of upstream area drains into dams. In this reach, coarse sediment input to channels approximates natural input rate, and fine sediment input rate equals about 150% of natural input (Figure 18). In upper Napa River and in its lower reaches, where a smaller proportion of the land drains into dams, coarse sediment input rate is similar to natural rate, and fine sediment input rate is about 200% of natural rate.

- Four significant categories of human caused sediment sources are: 1) grazing lands, 2) vineyards, 3) roads, and 4) erosion of the Napa River bed and banks. Sediment erosion process that relate to these sources are: a) sheetwash from land uses (grazing and vineyards); b) road related erosion (surface erosion, crossings, and landslides and gullies caused by roads); c) gullies and shallow landslides caused by land-uses that concentrate runoff (grazing, roads, and hillside vineyards); and d) channel incision and associated bank erosion (Figure 19). Channel incision has the highest priority for treatment because sediment from channel incision is produced locally therefore, it likely has a greater effect on fine sediment deposition at spawning sites in the Napa River, than distal sources. Also, of greater importance than its role in the sediment budget, as the Napa River incises, it obliterates the basic physical habitat structure of the river (expressed by a substantial reduction in quantity of gravels bars, riffle margins, side channels, and sloughs, and a disconnection of the channel from its flood plain). The resulting increase in the quantity of homogeneous long, deep pool-run habitats, favors native and introduced fishes that prey upon juvenile salmonids and has likely reduced chinook populations. Stillwater Sciences and Dietrich (2002) postulate that the restoration of natural and complex physical habitat is a necessary prerequisite to facilitate a self-sustaining run of chinook salmon. Restoration of natural bar-pool topography and flood-plain connectivity may also be needed to protect other rare or threatened species, including California freshwater shrimp, that are distributed solely or primarily in the Napa River and lower tributary reaches. Additionally, streamside land uses and public works infrastructure also are threatened by the high rates of bank erosion associated with channel incision processes along the Napa River.

Addressing the problem of channel incision in mainstem Napa River and the lower reaches of its tributaries will be the primary focus of the Napa River sediment TMDL. Substantial reductions in the amount of fine sediment input from land-uses in upland areas will also be needed to improve the quality of spawning and rearing habitat for salmon in the Napa River, and to protect spawning habitat for steelhead in its tributaries. Proposed reductions in sediment load are described in Chapter 5 (Allocations and Linkage Analysis).



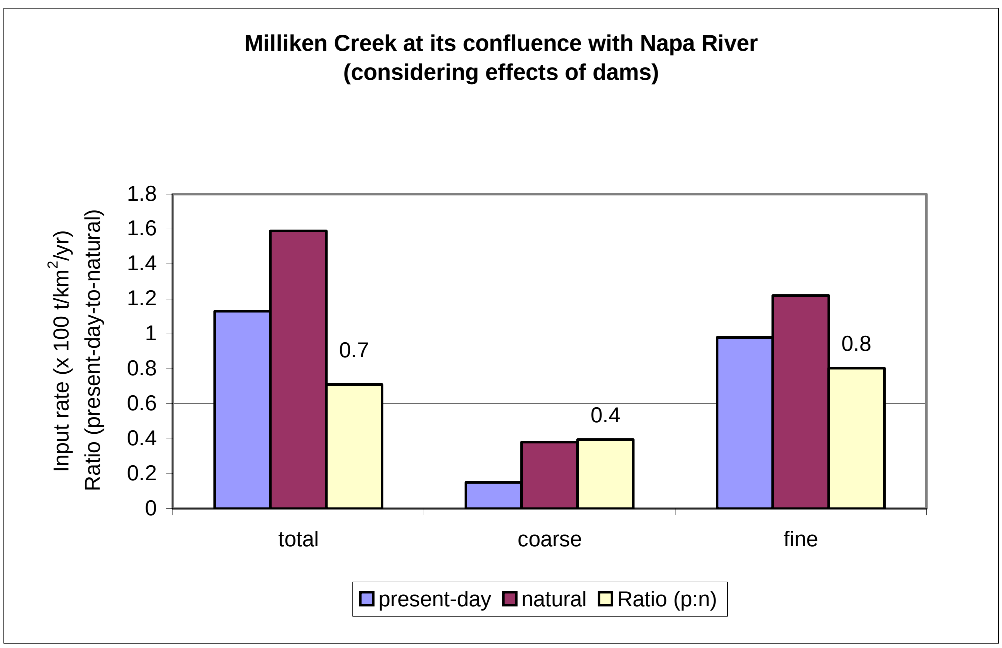


Figure 15: Dams Capture Most of the Sediment Input to Milliken Creek. Dams capture runoff from about three-quarters of Milliken Creek watershed. Therefore, although total sediment input rate into channel network was more than two-times natural background rate, we estimate that total sediment yield from Milliken Creek was only 70 percent of natural background rate during the most recent decade.

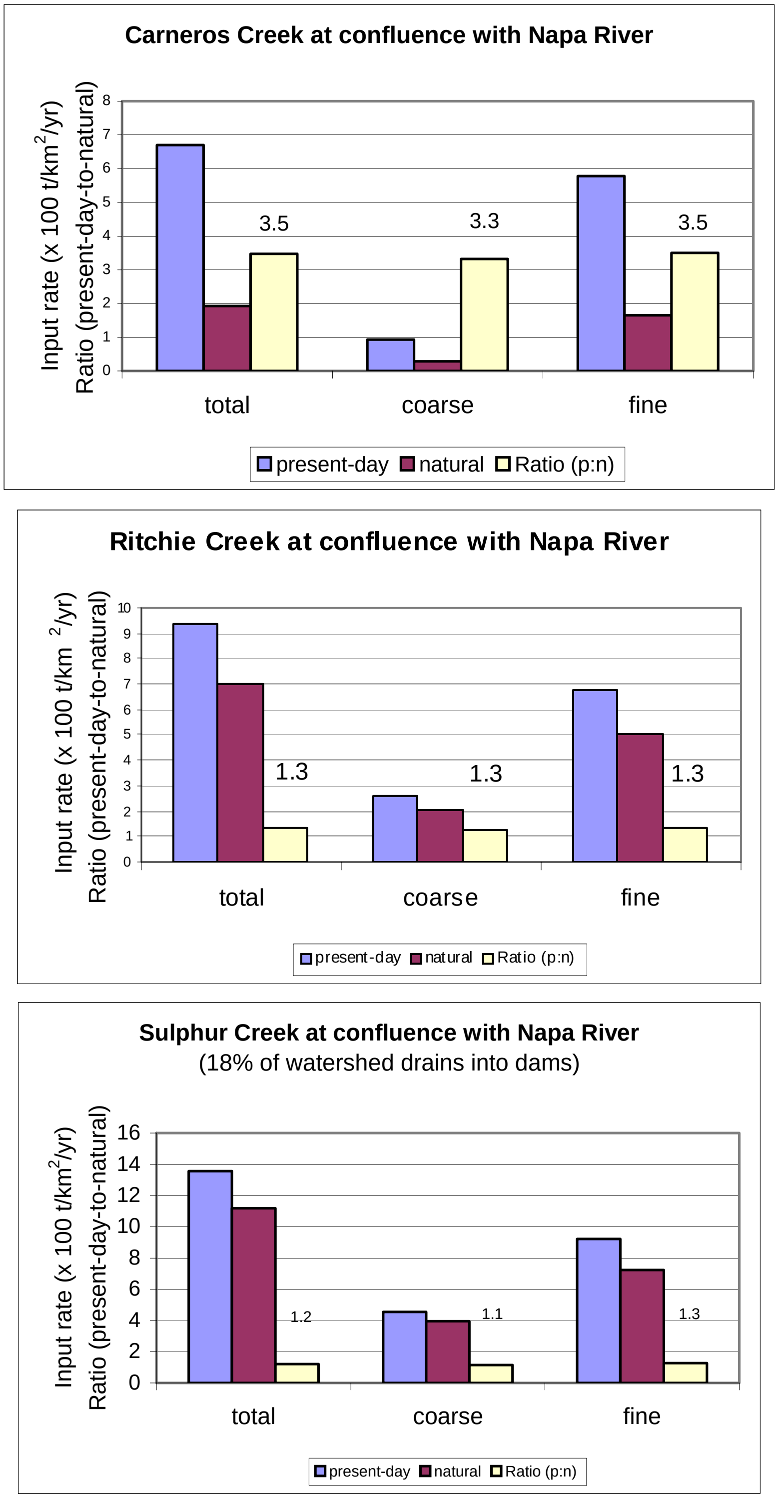


Figure 16. Total Sediment Input into Channels Network within Carneros Creek, Ritchie Creek, and Sulphur Creek. Total sediment input into the channel network in Carneros Creek, Ritchie Creek, and Sulphur Creek watersheds, tallied at their confluences with Napa River. Note: without dams on Sulphur Creek, ratio of present-day to natural input (total) equals about 1.5 to 1.

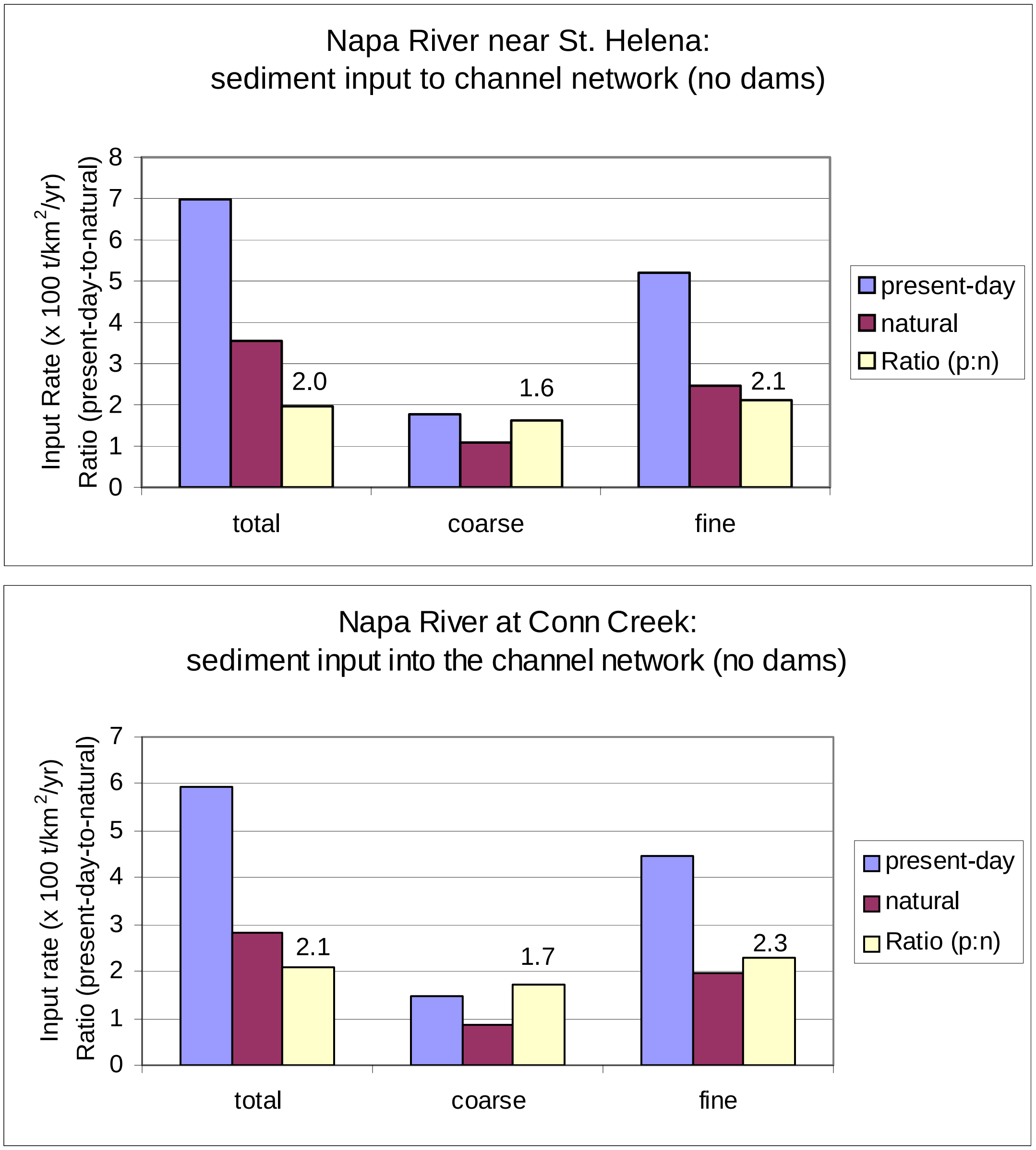
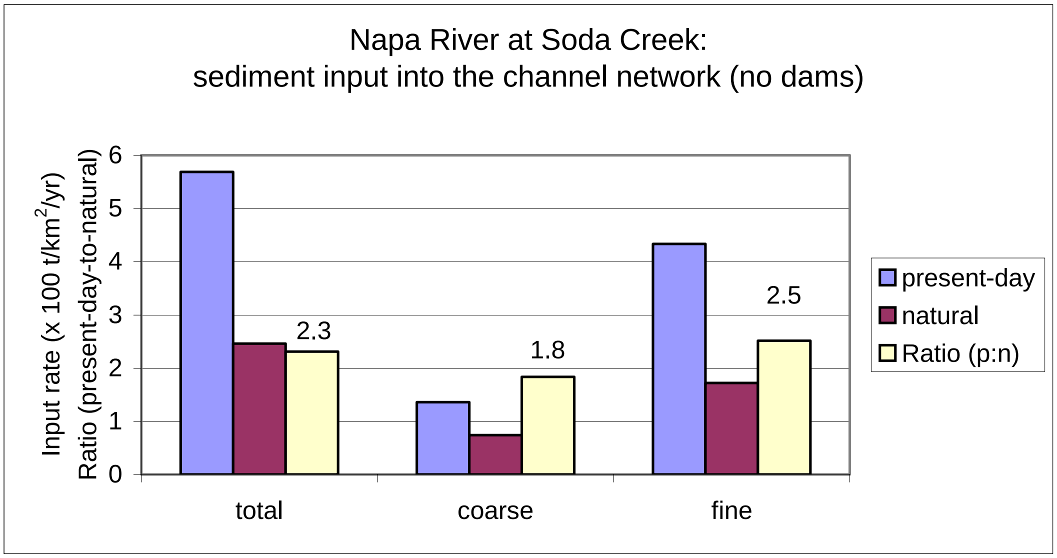


Figure 17. Present Versus Natural Rate of Total, Course, and Fine Sediment Input in Napa River (Without Dams).
Present-day versus natural rates of total, coarse, and fine sediment input into the channel network from all sources upstream of four measurement sites in the Napa River. Effect of dams in trapping sediment is not considered in the above figures.



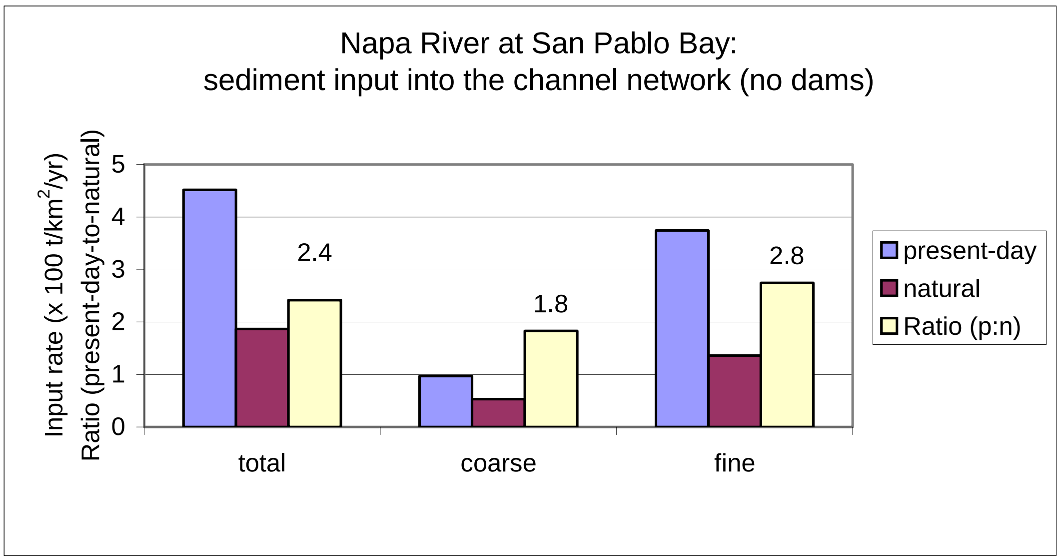
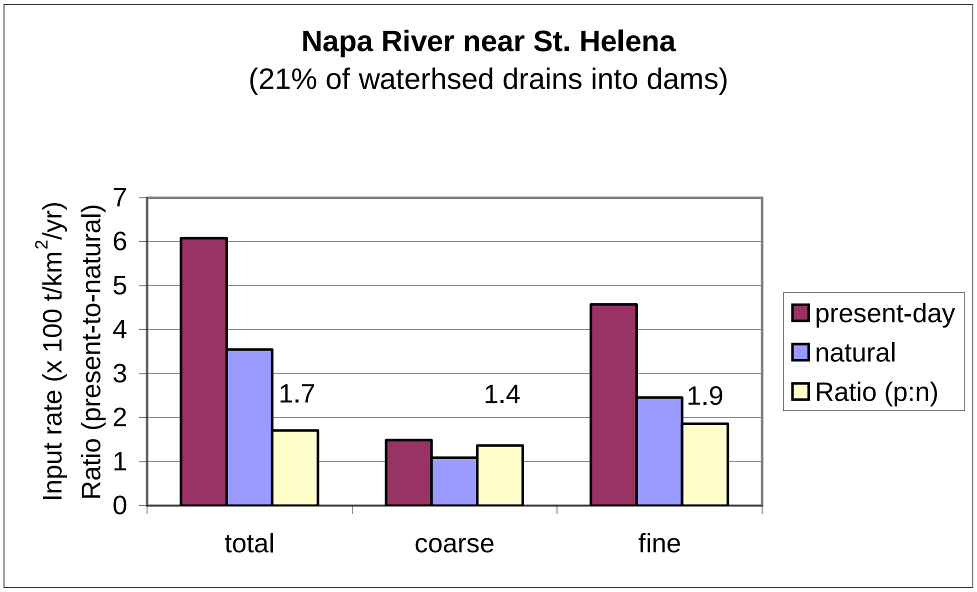


Figure 17. Present Versus Natural Rates of Total, Course, and Fine Sediment Input in Napa River (Without Dams) (Continued).
Present-day versus natural rates of total, coarse, and fine sediment input into the channel network from all sources upstream of four measurement sites in the Napa River. Effect of dams in trapping sediment is not considered in the above figures.



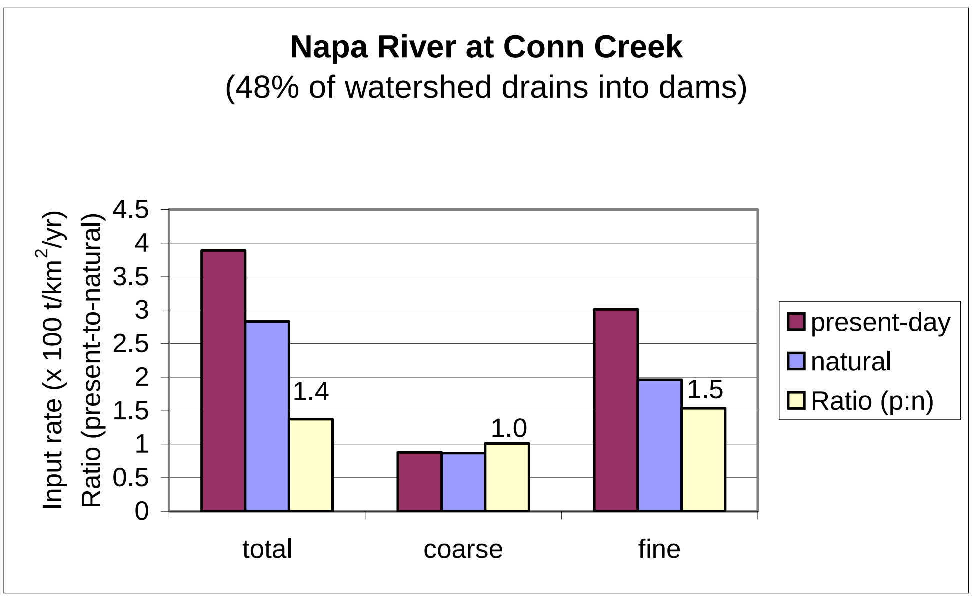
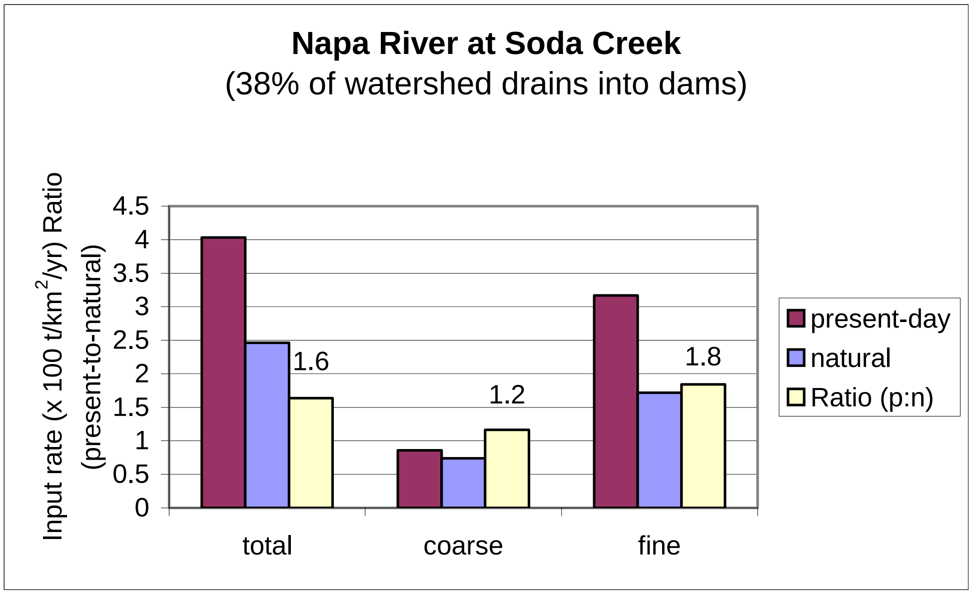


Figure 18: Present Versus Natural Rates of Total, Course, and Fine Sediment Input in Napa River (Downstream of Dams).

Present-day versus natural rates of total, coarse, and fine sediment input into channel network downstream of dams tabulated at four measurement sites in the Napa River. Dams capture much of sediment input to tributaries.



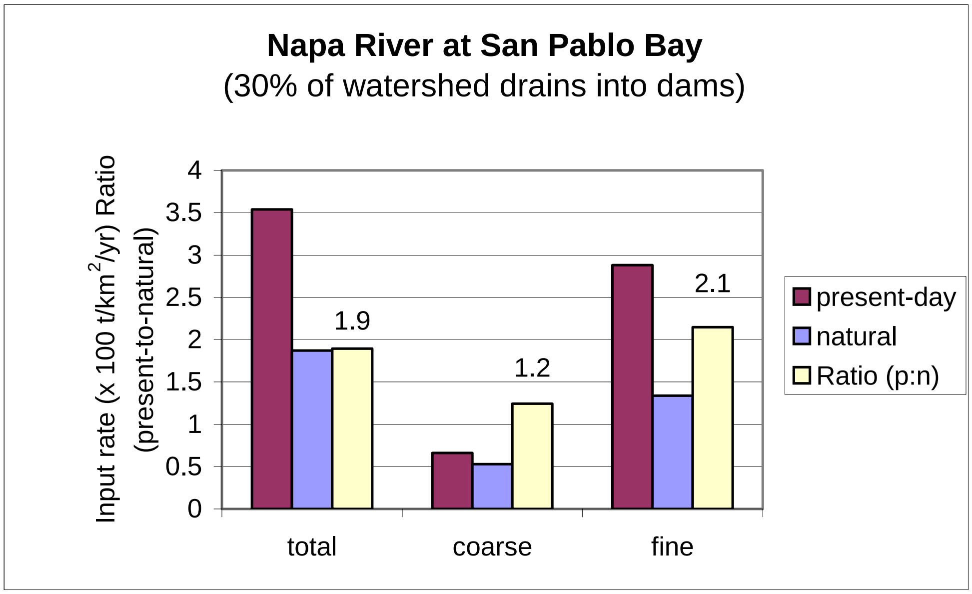


Figure 18: Present Versus Natural Rates of Total, Course, and Fine Sediment Input in Napa River (Downstream of Dams) (Continued).
Present-day versus natural rates of total, coarse, and fine sediment input into channel network from all sources upstream of four measurement sites in the Napa River. Effects of Dams are considered in above figures.

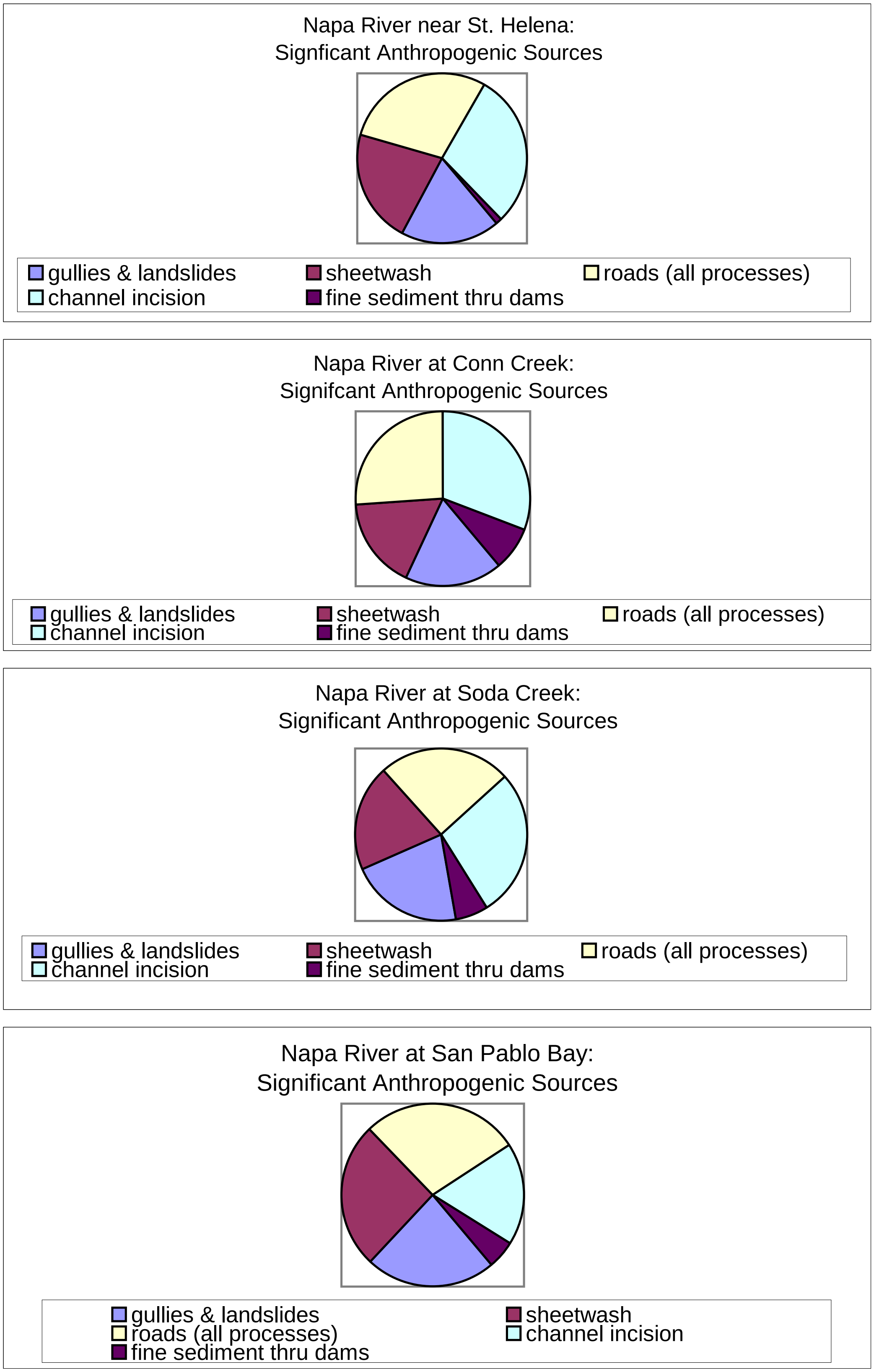


Figure 19. Primary Human-Caused Sediment Sources Tallied at Four Sites in Napa River.

CHAPTER 4: WATER QUALITY STANDARDS AND NUMERIC TARGETS FOR SEDIMENT

Key Points

- Water quality objectives for sediment, settleable material, and population and community ecology are not met .
- To protect chinook salmon and steelhead, rates of fine sediment supply and channel incision must be reduced in a manner that enhances aquatic habitat conditions.
- To protect spawning and rearing habitat, we propose numeric targets for streambed permeability, redd scour, and gravel bar spacing.
- The proposed targets are consistent with water quality objective and antidegradation policies.

4.1 Introduction

In order to develop a TMDL, a desired target condition must be established to provide measurable goals for management and a clear linkage to attaining applicable water quality objectives. In the case of sediment impairment in Napa River, we conclude that Napa River does not meet water quality standards for sediment, settleable material, and population and community ecology (see Problem Statement for additional details). Water quality objectives for settleable material and population and community ecology are as follows:

- **Settleable material**

  "Waters shall not contain substances in concentrations that result in deposition of material that cause nuisance or adversely affect beneficial uses."

- **Population and Community Ecology**

  "All waters shall be maintained free of toxic substances in concentrations that are lethal to or that produce significant alterations in population or community ecology or receiving water biota. In addition, the health and life history characteristics of aquatic organisms in waters affected by controllable water quality factors shall not differ significantly from those for the same waters in areas unaffected by controllable water quality factors."

Water quality objectives for sediment, settleable material, and population and community ecology are not met because human activities have increased the total supply of sediment delivered to mainstem Napa River and caused the supply to become much richer in fine sediment (sand, silt, and clay). As a result, excess fine sediment is deposited in the streambed at spawning sites, causing high levels of mortality between spawning and emergence for salmon and steelhead eggs and larvae. Also, as the streambed becomes finer at spawning sites, scour of spawning gravel is enhanced, exposing salmon and steelhead eggs and larvae to yet another significant source of mortality. Therefore, we have concluded that the water quality standard for settleable material is violated.

In addition, channel incision and associated bank erosion has been identified as a significant human-caused (anthropogenic) sediment source. Channel incision has high priority for control, not only because of its significance in the sediment budget, but also because it disconnects the channel from its flood plain, and causes physical habitat structure of the channel to be greatly simplified. Adverse habitat changes for salmonids, include substantial reduction in gravel bars, riffles, side channels, and sloughs that are needed for spawning and early juvenile rearing, and associated increase in deep pool-run habitats that favor fish species that prey upon juvenile salmonids. Reduction in bar and riffle bedforms, and narrower width to depth ratio, as a result of channel incision, also cause much more energy to be exerted on the streambed at potential spawning sites, further exacerbating redd scour risk. Channel incision appears to be controllable by actions to restore a state of dynamic equilibrium, through construction of modest flood plain, and rehabilitation of natural pool-bar habitat structure, as is being considered in the 4.5-mile long Rutherford Reach of the Napa River. Taking the above information into account, we conclude that the water quality standard for population and community ecology is violated.

To conserve native fish and aquatic wildlife species, we propose three numeric targets that relate sediment to the attainment of water quality standards and beneficial uses in Napa River:

1) streambed permeability at potential spawning sites; 2) redd scour; and 3) physical habitat structure.

4.2 Redd Scour

Target

The mean depth of scour (d_s) should be ≤ 15 cm below the level of the overlying streambed substrate at typical pool-tails/riffle-heads in all gravel-bedded reaches of mainstem Napa River and in the lower alluvial reaches of its perennial tributaries in reaches where the streambed slope is gentle (S= 0.001 to 0.01). The target applies in response to all peak flows ≤ bankfull discharge.

We propose the above numeric target for redd scour depth as a water quality and habitat indicator to relate rate and sizes of sediment delivered to the channel (and its physical habitat structure) to the survival of incubating chinook-salmon eggs-and-larvae in mainstem Napa River and the lower reaches of its gravel-bedded perennial tributaries. This target applies to the entire length of the mainstem of the Napa River, upstream of Trancas Road, and in the lower reaches of its perennial tributaries, where the slope of the streambed is between 0.001 and 0.01. Below find our rationale to support the proposed target.

Background and Rationale

Scour of spawning gravel during commonly occurring peak flows (e.g., bankfull) can be a significant source of mortality to the incubating eggs and larvae of salmon and trout species

(McNeil, 1966; Montgomery et al., 1996). The beds of natural gravel channels cut and fill during high flow events. How deeply they cut into their bed (scour depth) is a function of the force per unit area exerted by flowing water on the streambed, channel features that either concentrate or disperse flow energy (e.g., debris, vegetation, bedrock, gravel bars, etc.), and the abundance and sizes of sand and coarser sediment grains supplied to the channel (bedload). Human actions that increase the rate of bedload supply, and/or cause it to become finer, will cause the streambed to become finer, facilitating an increase in the rate of bedload transport through a channel reach (Dietrich et al., 1989). As bedload transport rate increases, so do the mean depth and/or spatial extent of streambed scour (Carling, 1987) (Figure 20). Similarly, land uses activities that increase storm runoff peak and/or volume (forest clearing, pavement, etc.), and/or increase the amount of energy that is focused on the streambed at potential spawning sites for a given runoff event (e.g., human constructed levees, straightened channel reaches, removal of large debris jams, etc.), also have the potential to increase bedload transport rate, and therefore, streambed scour.

Human activities have caused the total rate of bedload supply to become substantially finer and to increase about 50% in the gravel-bedded alluvial reaches of mainstem Napa River and the lower alluvial reaches of its larger perennial tributaries. Both of these changes likely have caused an increase in streambed scour. In addition, the widespread occurrence of constructed channel levees, channel straightening, and the intensive removal of large woody debris from the mainstem Napa River have likely increased the amount of energy that is focused on the streambed at potential spawning sites for salmon during peak flow events, which may further increase the amount of scour. In contrast, in steep reaches ($S = 0.02$ to 0.08) of tributaries to the Napa River, channel incision is not significant, and although the total rate at which bedload sediment is supplied to steep tributary reaches has increased and become finer, it appears that much of the additional bedload is transported rapidly downstream to the lower gradient alluvial reaches. Therefore, we hypothesize that redd scour is not a significant concern in most steep tributary reaches.

We chose chinook salmon as the index species for evaluating the potential impacts of redd scour because:

1) The distribution of their spawning habitat overlaps almost exactly with the distribution of gravel-bedded reaches in mainstem Napa River and the low gradient alluvial reaches of its larger tributaries, where human actions appear to have increased the amount of streambed scour; and

2) Fall-run chinook salmon typically spawn much earlier in the wet season than steelhead and, assuming similar temperature conditions, their eggs/larvae will remain in the streambed for a similar period of time.[14]

[14] In recent years, spawning of fall-run chinook salmon in Napa River has been documented in early November through late December (Koehler, 2005), whereas most steelhead spawning, although not well documented in the Napa River watershed, probably does not begin until early January or later in most years, assuming that timing in the Napa River watershed is similar to the timing documented for other local California coastal range streams. The amount of time from spawning to emergence is a function primarily of water temperature, with milder temperatures promoting more rapid incubation and development. For fall-run chinook salmon, this time period varies from about eight to sixteen weeks. For steelhead, the time period varies from about six to eighteen weeks.

Therefore, we conclude that the probability of a large runoff event coinciding with the incubation period for chinook salmon is much greater than for steelhead, and average amount of streambed scour, in such an event, is likely much greater in the stream reaches utilized by chinook salmon. As such, our redd scour target is applied to chinook salmon in gravel-bedded alluvial reaches of mainstem Napa River and the lower courses of its larger tributaries.

Our redd scour target is based on review of typical depths of egg burial by chinook salmon and data describing streambed scour in gravel-bedded alluvial channels where the sediment supply is in approximate equilibrium with transport capacity. Such equilibrium channels are neither incising nor aggrading. Egg burial depth is a function of the body size of the spawning salmon or trout, and the sizes and packing of rocks in the streambed (van den Berghe and Gross, 1984; Burner, 1951). Although we have not measured chinook salmon egg burial depths in the Napa River, studies conducted in other Pacific coastal streams provide some insight into this issue. DeVries (1997) reports published data for chinook salmon egg burial depth in several streams including the Columbia River located in the Pacific Northwest. In those streams, the depth of burial from the top of the egg pocket relative to the level of the overlying gravel varied from 10 to 46 cm (4 to 18 inches) with mean depths of burial varying from 19 to 28 cm. Similarly, Evenson (2001) reports chinook salmon egg burial depths at 28 spawning sites in the Trinity River in northwestern California, where egg burial depth, relative to level of overlying gravel, varied from 15 to 53 cm with a mean value equal to 26.5 cm.

Montgomery et al. (1996) report egg burial depths by chum salmon in relation to stream scour depths in a small gravel-bedded alluvial channel, Kennedy Creek, draining into Puget Sound. Their measurements, following a slightly greater than bankfull flow, reveal that scour depth was ≤ 10 cm at 65% of sites monitored (with a mean depth of scour = 13.4 cm), whereas less than 5% of chum salmon egg pockets were ≤ 10 cm below overlying gravel (mean depth of egg pockets = 22.6 cm). These observations lead them to hypothesize that the large-bodied salmon with spawning and incubation periods overlapping the period of maximum peak flows have adapted to the risk of redd scour by developing an ability to bury their eggs slightly deeper than the typical depth of scour. As such, salmon may be particularly sensitive to human disturbances of watershed and channel attributes that cause an increase in the rate of sediment supply and/or the amount of energy focused on the streambed at spawning sites.

Considering the above information, we propose that the target for depth of scour at potential spawning sites for chinook salmon in mainstem Napa River, and in the lower alluvial reaches of its perennial tributaries, shall be ≤ 15 cm in response to a bankfull or smaller peak flow event. We hypothesize that this target should be similar to natural reference value, in which mortality via redd scour would be low during most years in response to moderate flood events and moderate rates of sediment supply.

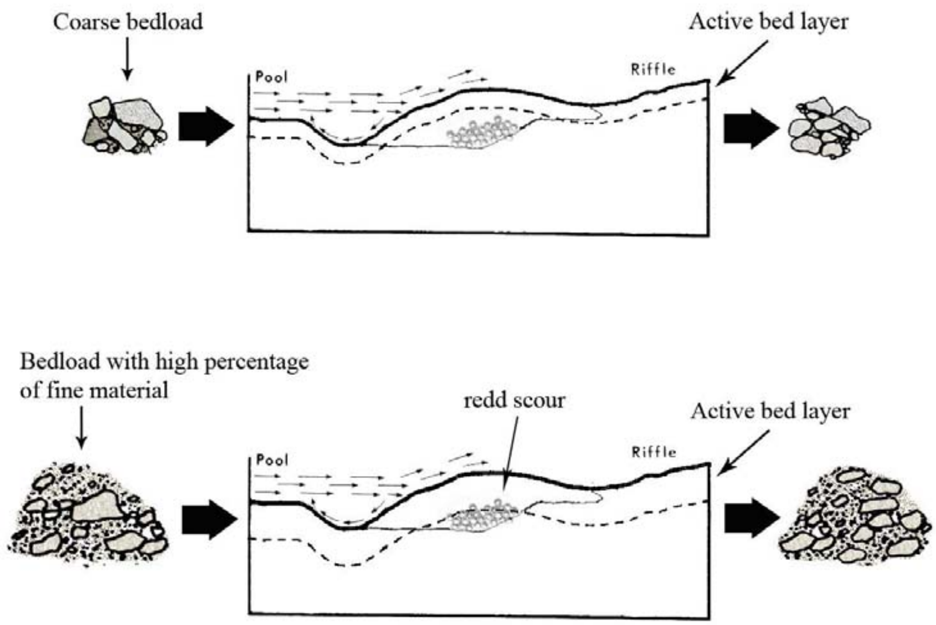


Figure 20. Influence of Sediment Supply on Streambed Scour at Spawning Sites (Redds)
When sediment supply increases and/or becomes richer in fines, depth of streambed scour is increased, exposing incubating eggs and larvae to increased risk of mortality via scour. **Figures reproduced with the American Fisheries Society, 1991.**

4.3 Streambed Permeability

Target
The median value for streambed permeability should be ≥ 7000 cm per hour at all potential spawning sites for steelhead and salmon in the Napa River watershed (Table 7). We estimate this target value corresponds to approximately 50% survival of eggs and larvae from spawning to emergence (Stillwater Sciences and Dietrich, 2002). Below find our rationale to support the proposed target.

Background and Rationale
Streambed permeability, or the flow rate of water through the streambed, is a key factor influencing the survival of incubating salmonid eggs and larvae. Streambed permeability is significantly and positively correlated with survival to emergence (Chapman, 1988). Cool, clean water flowing through the streambed is needed to provide and replenish dissolved oxygen and to remove metabolic wastes. Streambed permeability is a function of the size distribution and packing of coarse sediment (gravels) and finer sediment contained in the streambed. Streambed permeability is inversely related to fine sediment concentration, primarily sand grains with diameters ≤ 1 mm, that are deposited in the streambed (McNeil and Ahnell, 1964). When a large amount of fine sediment is deposited in the streambed, permeability can be reduced by a

substantial amount with consequent adverse impacts to the survival of incubating salmon and trout eggs and larvae.

Stillwater Sciences and Dietrich (2002) measured streambed permeability in January and February of 2002 at 69 potential spawning sites located in 28 reaches of 17 Napa River tributaries and at five potential spawning sites located in three reaches of mainstem Napa River. They concluded that permeability values at potential spawning sites for steelhead and salmon in the Napa River and its tributaries are low with a median value equal to 4800 cm per hour, which corresponds to a predicted value of approximately 44% survival for incubating eggs and larvae between spawning and emergence.[15] In June 2003 we resurveyed a subset of the above sites (22 sites in ten reaches of eight tributaries). Based on the results of our resurvey (median value = 2900; predicted survival = 35%), we conclude that low permeability is a spatially extensive phenomenon in Napa River tributaries. Although we estimate a lower value for median permeability, the difference between the medians is not statistically significant ($\alpha = 0.05$).

To explore the relationship between streambed permeability and fine sediment supply, we estimated rates of fine sediment delivery to channels during the most recent decade in four Napa River tributaries and four sites along mainstem Napa River (see source analysis). This involved the following:

- We measured streambed permeability at all potential spawning sites for steelhead and/or rainbow trout, in nine reaches of the same four tributaries, (64 potential spawning sites for steelhead in nine reaches of four tributaries). We then used permeability data collected by Napa County Resource Conservation District (Koehler, 2005) at ten potential spawning sites in three reaches of mainstem Napa River near Rutherford (Table 7);

- Because we also expected differences in stream power to influence fine sediment deposition, we surveyed longitudinal slope of the streambed.[16] From this we analyzed the energy gradient and calculated drainage areas into each reach in order to develop rough estimates of variability in stream power between measurement sites, and the influence of this attribute on permeability.

[15] We report and use median values in developing targets because standard deviations often approach or exceed the mean value.
[16] Stream power is defined as the rate of energy expenditure by water, as it flows through a channel. Stream power is directly proportional to the product of streamflow discharge multiplied by water surface slope. In our analysis, we use drainage area as a surrogate for streamflow discharge. Only a fraction of total stream power is available to transport sediment. This is because energy is also expended through internal friction within the fluid, and friction along the channel boundaries caused by grain roughness, large obstructions (like debris jams, bedrock outcrops, bridge piers, etc.), and/or other changes in channel width, depth, and direction of flow encountered along the length of the channel. In reaches where we measured permeability, channel form and substrate sizes varied substantially. Therefore our estimates of total stream power only provide a relative estimate of the fraction of stream power that is available to transport sediment.

Table 7. Streambed Permeability Measurements								
Reach Name	**Number of Potential Spawning Sites Where Permeability was Measured**	**Median Permeability (cm/hr)**	**Median Predicted Survival to Emergence (%)**	**Drainage Area (DA) (km2)**	**Streambed Slope (S)**	**Stream Power Index (DA x S)**	**Fine bed-material (<11.2 to 2 mm) input rate (t/km2/yr)**	**Sedimentation Index = Fine Bed-Material Input Rate/Stream Power**
Lower Carneros	6	1337	25	18.2	0.006	0.11	195	1783
Upper Carneros	5	3069	37	10.4	0.013	0.14	121	881
Upper Milliken	7	3856	41	18.9	0.035	0.67	36	54
Lower Milliken	7	9577	54	30.3	0.058	1.76	26	15
Sulphur 1	9	1913	30	4.7	0.024	0.12	829	7178
Sulphur 2	8	503	10	7.1	0.012	0.09	829	9545
Sulphur 3	8	640	14	4.5	0.019	0.09	738	8637
Sulphur 4	10	1481	26	9.6	0.018	0.17	895	5164
Upper Ritchie	4	3743	40	4.0	0.051	0.20	64	315
Rutherford	10	3011	37	200.0	0.002	0.4	207	518
Totals:	74	2461	34					
Range:	4 to 10	503 to 9577	10 to 54	4.7 to 200	0.002 to 0.058	0.09 to 1.76	26 to 829	15 to 9545

We found a strong negative relationship between median permeability and average-annual fine sediment supply divided by stream power (Figure 14). Although our R^2 value is high (0.81), we would caution against using the relationship to predict the magnitude of a permeability increase/decrease in a given channel reach in response to an increase/decrease by a given amount in fine sediment supply because:

- The stream power index we used provides only a crude estimate of energy expenditure on the streambed at potential spawning sites;

- Inter-annual and spatial variations in sediment supply in channels are large[17] in the Napa River watershed; and

- Our median permeability values used to develop the relationship are probably only accurate within a factor of two of actual values.

Based on our regression analysis presented in Figure 14 (described above), documentation that human actions have increased fine sediment supply in channels in the Napa River watershed (see source analysis), and the work of McNeil and Ahnell (1964) (Figure 3), we conclude that:

- Low permeability values at potential spawning sites in the Napa River and its tributaries are explained, at least in part, by the deposition of large amounts of fine sediment (primarily sands) in the streambed; and

- Current values for permeability at potential spawning sites for steelhead and salmon in the Napa River watershed are lower than natural reference values.

We propose a numeric target ≥ 7000 cm per hour as the reach-median value for streambed permeability at all potential spawning sites for salmon and steelhead in the Napa River and its tributaries. We hypothesize that this value corresponds to approximately 50% survival of incubating salmon and steelhead eggs and larvae between spawning and emergence (Stillwater Sciences and Dietrich, 2002).

For fall-run chinook salmon, we conclude that moderate to high rates of survival (≥ 50%) for eggs and larvae from spawning to emergence may be necessary to achieve a self-sustaining wild spawning run in the Napa River. This is because the total production of chinook salmon fry appears to be substantially reduced relative to natural reference values as a result of other inter-related impacts of fine sediment supply and/or channel incision, which include the following:

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[17] Channel form and sediment deposits reflect a temporal and spatial integration of sediment inputs to, and transport and storage in channels. In addition to sediment supply, channel transport capacity and storage are influenced by: a) magnitude, duration, and frequency of high flows; b) channel slope and depth; and c) channel roughness, or elements that concentrate or disperse flow energy. For these reasons, time lags between sediment input and discharge may be several years to decades or more, and specific channel responses to changes in sediment supply also may vary substantially. Spatial and temporal distributions of sediment inputs are also highly variable, further complicating analysis of relationships between sediment input and channel response.

- Risk of egg and larvae mortality, via redd scour during common peak flows (bankfull event), appears to be quite high as a result of human actions that have increased sediment supply and energy expenditure on the streambed at potential spawning sites in mainstem Napa River; and

- Spawning habitat quantity in mainstem Napa River is very small and appears to have decreased substantially between the 1940s and present as a result of channel incision.

With regard to steelhead, although spawning habitat quality and quantity does not presently appear to be a primary factor limiting steelhead or salmon run size (Stillwater Sciences and Dietrich, 2002), if the average number of steelhead returning to spawn is small under current conditions, then poor spawning habitat quality has the potential to further depress steelhead run-size. Therefore the risk of steelhead extinction in the Napa River watershed is increased. We propose implementing the 50% predicted survival target between spawning and emergence as a precautionary measure to reduce risk of steelhead extinction. We also propose implementing management actions to improve habitat access and rearing habitat for older juvenile steelhead in order to facilitate enhancement of steelhead run-size and distribution, and therefore, the long-term conservation of steelhead within the watershed.

4.4 Pool-Bar Structure

Numeric Target

The mean value for meander wavelength, comprised of two alternate bar units, in gravel-bedded reaches of mainstem Napa River, should be between 9 and 11 bankfull widths.

Background and Rationale

As described in Trush et al. (2000):

> The primary geomorphic and ecological unit of an alluvial river is the alternate bar sequence. Dynamic alternating bar sequences are the basic structural underpinnings for aquatic and riparian communities in healthy alluvial river ecosystems. The fundamental building blocks of an alluvial river is the alternate bar unit, composed of an aggradational lobe or point bar, and a scour hole or pool. A submerged transverse bar, commonly called a riffle, connects alternating point bars. An alternate bar sequence comprised of two alternate bar units, is a meander wavelength; each wavelength is between 9 and 11 bankfull widths (Leopold, Wolman, and Miller, 1964). Floods flowing through alternating bar sequences frequently rearrange the bar topography, producing diverse, high-quality aquatic and terrestrial habitat. (Figure 21.)

Active and rapid channel incision in mainstem Napa River and the lower reaches of its major tributaries between the 1940s (or more recently) and the present has greatly reduced the quantity of gravel bars, riffles, side channels, and sloughs, and has greatly decreased the frequency of inundation of adjacent flood plains (Stillwater Sciences and Dietrich, 2002). These features provide essential spawning and juvenile rearing habitat for chinook salmon, which reside primarily in the mainstem

Napa River. Therefore, channel incision appears to be the primary factor limiting chinook salmon run size. Channel incision, and associated bank erosion, also appears to be a significant source of sediment delivery to Napa River.

We therefore propose the numeric target for pool-bar structure to guide rehabilitation river habitat structure and functions.

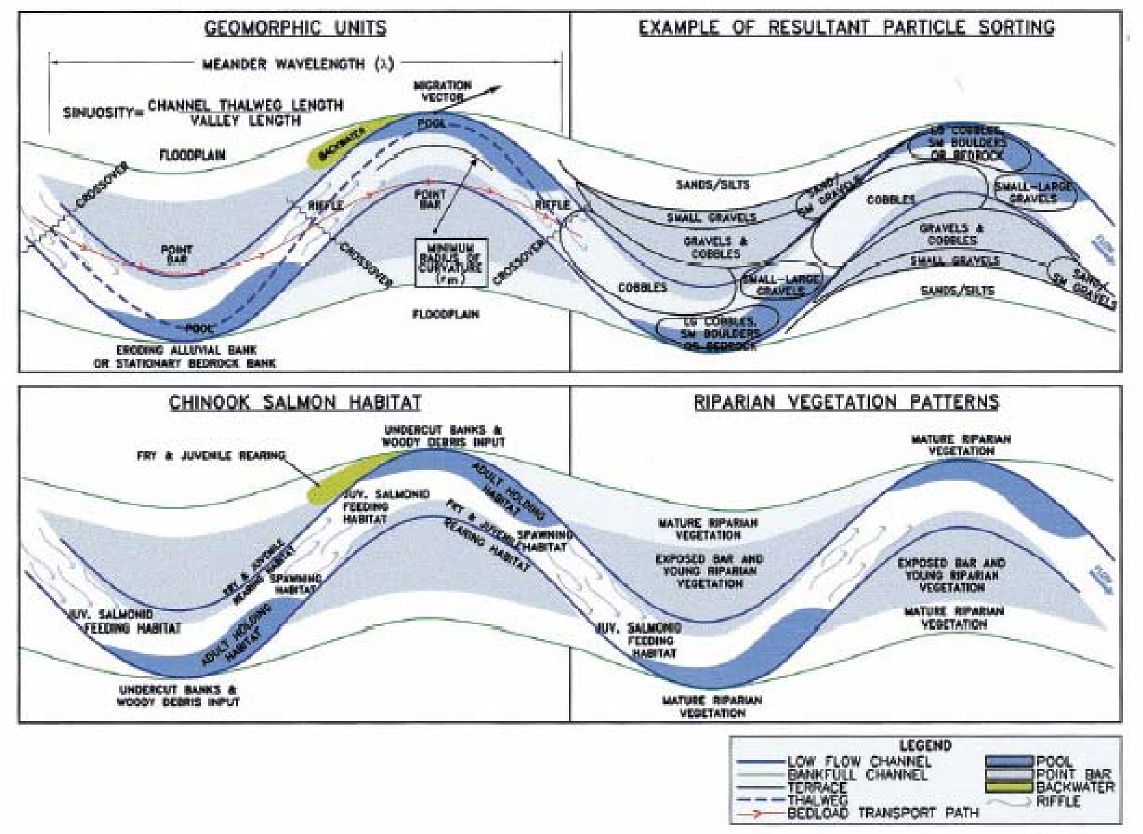

Figure 21. Idealized Alternate Bar Sequence
(Trush et al., 2000.)

CHAPTER 5. LINKAGE ANALYSIS AND ALLOCATIONS

Key Points

- We propose sediment TMDL of 125% of natural background.
- Attainment of the proposed TMDL will require human-caused sediment inputs to be reduced by 50%

5.1 Introduction

In this chapter, we evaluate linkages between sediment inputs and habitat conditions as needed to determine the total maximum daily load (TMDL) for sediment and allocations for sediment sources. The TMDL is the total sediment load that can be discharged into the Napa River and its tributaries without violating water quality standards.

5.2 Approach to Development of the Linkage Analysis

Linking channel conditions to sediment supply is challenging because channel form and sediment deposits reflect the temporal and spatial integration of sediment inputs to and transport through stream channels. In addition to sediment supply, channel transport capacity and storage are influenced by: a) magnitude, duration, and frequency of high flows; b) channel slope and depth; and c) channel roughness, or elements that concentrate or disperse flow energy. For these reasons, time lags between sediment input and discharge may be several years to decades or more, and specific channel responses to changes in sediment supply may vary substantially. Spatial and temporal distributions of sediment inputs are highly variable, further complicating analysis of relationships between sediment input and channel response. Considering these challenges, one or more of the following approaches to linking sediment inputs and channel attributes have been pursued for developing natural stream channel sediment TMDLs:

- Reference watershed;
- Reference time period;
- Direct comparison of sediment supply and numeric values for channel attributes; and
- Direct comparison of current and desired numeric values for channel attributes.

The allocation scheme for most sediment TMDLs developed for stream channels in northwestern California is based on a reference time period or watershed. Similar to Napa, the primary goal of these sediment TMDLs is the recovery of salmon and steelhead fisheries. In two northwestern California stream TMDLs for which a reference watershed or reference time-period approach has been used (e.g., Redwood Creek, and Noyo River), the reference time periods and/or watershed sediment load corresponding to desired steelhead and/or salmon fish populations equates to about 117% to125% of the calculated natural sediment load.

Lacking a reference watershed in Napa, we evaluated the relationship between attainment of numeric targets and reductions needed to achieve 125% of the calculated natural sediment load, as was done for similar sediment TMDLs. Attaining this reference condition TMDL during the most recent decade would have required a 30% reduction in total and fine sediment supply to Napa River. Assuming a 1 to 1 relationship between percent improvement in permeability and fine sediment reduction (30%), the median permeability of 5500 cm/hour would improve to 7200 cm/hour (Stillwater Sciences and Dietrich, 2002). Similarly, a 50% reduction in sediment input from channel incision, accomplished through re-establishment of dynamic equilibrium (stable streambed elevation) and natural bar-pool structure over half of the length of the Napa River would result in a several hundred percent increase in the quantity of salmon spawning and rearing habitat. Redd scour potential would also be reduced by an unknown but significant amount as a function of reduction in fine bed-material supply and restored gravel bars and flood plains, which would provide considerable amount of flow energy dissipation, greatly reducing the force exerted on the streambed at spawning sites.

5.3 Allocations

Therefore, consistent with the approached used in other northwestern California streams, we propose 125% of natural background rate as the Napa River sediment TMDL. Allocations by sediment delivery processes are expressed in terms of an estimated percent reduction and percent of total sediment load. The allocations apply to all source areas (grazing , vineyards, roads, channel bed and banks) to the degree in which these processes are active and influenced by human activities.

Table 8. Sediment TMDL and Allocations as measured in Napa River at Soda Creek

Sediment Delivery Processes	Reductions Needed (Percent)	Allocations (Expressed as a fraction of total natural load into channel network)
Natural inputs	0	0.70*
Gullies and landslides caused by land uses	50	0.13
Sheetwash caused by land uses	50	0.11
Road erosion	50	0.12
Channel incision	50	0.13
Sediment through dams	50	0.06
TMDL = Sum of allocations		1.25

*Dams capture runoff and sediment from approximately 38% of land area upstream of Napa River at Soda Creek.

Allocations expressed in terms of estimated percent reductions are consistent with the approved sediment TMDL for Deep Creek, Montana (Endicott and McMahon, 1996) as cited in the *Protocol for Developing Sediment TMDLs* (USEPA, 1999). The TMDL of 125% of the natural input rate into the channel network represents total sediment input absent dams and human-caused sediment inputs. Compliance with the TMDL will be evaluated at Napa River below the confluence of Soda Creek. This station approximates the downstream limit of mainstem Napa River salmon habitat. For the most recent decade, attainment of the TMDL equates to a sediment load in Napa River at Soda Creek of approximately 310 t/km^2/year.

We did not set mass based allocations because:

a) Inter-annual variation in sediment input rate to and transport rate in California coastal streams is extreme and governed primarily by the frequency, magnitude, and duration of precipitation events. A ratio between total and natural sediment load is superior, because the human caused sediment discharge effects are evaluated within the context of total supply, which is a function of the hydrologic driving forces.

b) By expressing allocations in terms of a ratio of total to natural, the focus of sediment measurement is on the measurement of human and natural inputs into the channel network. With this focus, it is possible to rapidly evaluate progress in attainment of the TMDL and effectiveness of management practices.

Costs of estimating sediment input rates to channel are similar to estimation of sediment loads in stream channels, and accuracy is of a similar magnitude.

CHAPTER 6: IMPLEMENTATION PLAN AND WATER QUALITY ATTAINMENT STRATEGY

6.1 Introduction

In this chapter we provide an initial outline of the actions that may be needed to resolve the sediment impairment (TMDL implementation plan), and we also provide an outline of a broader program to conserve steelhead in the Napa River watershed (water quality attainment strategy). Our intent in presenting an outline at this time is to encourage your constructive involvement over the next several months in the development of a detailed and specific plan to restore water quality and protect fisheries in a way that is fair and effective in achieving these objectives.

First, we provide an introduction to this topic. As suggested by definitions of the words *implement* and *plan*, a TMDL implementation plan is "a detailed description of a program of actions" (*plan*) to "ensure actual fulfillment by the performance of specific measures" (*implement)* that are needed to restore clean water.

USEPA has further recommended that TMDL implementation plans include each of the following elements: (USEPA, 1999):

- List of actions needed to achieve pollutant allocations and numeric targets specified by the TMDL, and a schedule, including interim milestones for implementation of those actions.

- Reasonable assurances (provided by the state water quality agency) that implementation actions specified in the plan will occur. These include being able to demonstrate that the specified actions will be effective, and that adequate resources will be available to successfully execute the program.

- A description of the legal authority (of local, state, and/or federal government agencies) under which the necessary actions will or could be required.

- Monitoring or modeling plan, including milestones for measuring progress, in achieving water quality standards.

- Adaptive management plan that includes a schedule for iterative update(s) of the TMDL in response to monitoring or modeling results, and/or other information that is new and relevant to the determination of whether water quality standards have been achieved.

- Estimated amount of time required to restore clean water including basis for estimate.

In the coming months, we will prepare and report a specific and complete implementation plan for review and comment. Before doing so we hope to receive constructive input from interested and knowledgeable parties. Crafting a plan that works on the ground will benefit tremendously from the input and involvement of local agency staff, land managers, and other individuals who are interested in and/or familiar with resource conditions, costs and effectiveness of erosion-control and habitat-restoration actions, the balancing of a various management priorities (on a roadway, vineyard, or ranch), and other practical management considerations. To this end, we are committed to participating in consultation with all interested parties.

In addition to actions needed to resolve sediment-related threats to steelhead and salmon, we conclude that progress is also needed toward resolution of all other factors limiting steelhead productivity and survival in the Napa River watershed (e.g., habitat access, instream flow protection, etc.). Therefore, we recommend additional management and research actions to address other significant factors limiting steelhead, as part of a broader water quality attainment strategy discussed at the end of this chapter. As per the sediment implementation plan, we present an outline at this point in time, and seek your constructive input in developing a fair and effective strategy.

In the discussion that follows, we describe our goals and intentions, legal authorities, and key considerations that may influence implementation actions. We then outline some of our initial concepts for how an effective and fair program might be developed.

Our overarching goal is to restore and protect beneficial uses of the Napa River and its tributaries. As described in the source analysis, significant sediment sources to the Napa River and its tributaries include: roads, grazing, vineyards, and channel incision. The Water Board recognizes the technical, institutional, and monetary challenges that each responsible party or group of dischargers (e.g., ranchers, grape growers, road owners, etc.) may face in designing and implementing measures to reduce fine sediment loads, and/or to rehabilitate physical habitat conditions in the Napa River. Because of this, we are trying to be as flexible as possible in developing an implementation approach to reduce sediment load, and begin to address other key factors limiting steelhead population.

6.2. Key Considerations Regarding Implementation

Key considerations that may influence implementation actions to resolve sediment impairment in Napa River and its tributaries may include the following:

- Total sediment delivery to channels from human activities needs to be reduced by 50 percent from contemporary values (1994-2004) in order to meet the proposed numeric targets and allocations for sediment. A fair approach, ideally, would involve 50 percent reductions, across the board, to each major human-caused source category (roads, vineyards, grazing, and mainstem incision). However, because some landowners and/or source categories already have implemented effective controls (e.g., hillside vineyards permitted under the Conservation Regulations have implemented measures to reduce sheetwash erosion), it appears actual goal for percentage reductions from other human-caused sources, where effective control actions have not been implemented yet, may need to be 60 percent instead of 50 percent.

- Based on review of previously approved sediment TMDLs for similar California streams (e.g., Garcia River and San Lorenzo River), typical timeframe for development and submittal of erosion control and management plans, and/or evidence documenting effective practices are already in place, is 3 years following adoption of the TMDL.

- Similarly, typical timeframes for achieving TMDL allocations and targets are 10-to-20 years following submittal of erosion control and management plans.

- We support exploring opportunities to optimize cost effectiveness of sediment source reduction through development of sediment source-control cooperatives that could be administered by local public agencies or other capable and interested groups. Conceptually, such cooperatives might be organized around a source category (roads, vineyards, etc.) and/or geographic region of the watershed (e.g., tributary, mainstem channel reach), allowing cooperative members to target the most cost effective sources for treatment that are within their responsibility. Local public agencies, including those with source control responsibilities (e.g., Napa County Public Works), and those with expertise in erosion control and landowner assistance (e.g., Napa County RCD and NRCS), probably would need to be involved to provide leadership, administrative and technical support for such a venture, should there be interest. Such partnerships would be in favorable positions for receipt of grant funding from state and federal agencies to support implementation actions, and emphasizing treatment of the most cost effective sources would result in significant cost savings to public and private landowners.

- We expect to define a minimum threshold, in terms of potential sediment delivery to channels caused by human activities from a given parcel that would trigger the requirement to prepare and implement a sediment control plan. In other words, we do not expect or intend to implement sediment control regulations or permit requirements on most small- or medium-sized landowners (e.g., < 40 acres) in the Napa River watershed, except where such parcels have the potential to deliver a significant amount of human caused sediment to the channel network (e.g., ground disturbing activities are occurring over large proportion or in sensitive areas of the property, extensive road network, etc.). We will work with knowledgeable and interested parties to study this issue over the next several months as needed to develop fair and defensible thresholds for responsibility to prepare and implement a sediment control plan.

- Our proposed sediment allocations are expressed as a ratio of total-to-natural sediment delivery to channels. Therefore, TMDL effectiveness monitoring will focus on measuring human and natural sources of sediment delivery to channels, and the response of the channels to management and natural events (e.g., streambed permeability and redd scour). With this focus, we will be able to rapidly evaluate effectiveness of a variety of management practices implemented to reduce sediment loads, and progress toward attainment of the TMDL. Furthermore, a ratio-based approach for sediment allocations may have another advantage over a mass-limits approach because human-caused sediment is always evaluated within the context of total supply, which is strongly influenced by hydrologic conditions encountered in the monitoring period.

- We expect individual landowners (or those participating in sediment cooperatives or stewardships) to perform monitoring to document that implementation actions have occurred (TMDL implementation monitoring). We do not expect individual landowners however, to perform effectiveness monitoring (e.g., post implementation monitoring of human-caused and natural sediment delivery to channels, and/or channel response to management and natural events). Ideally, such effectiveness monitoring should be coordinated and conducted by an agency or organization with appropriate scientific expertise and demonstrated capability to work effectively with property owners and other interested parties to gain permissions for access, as needed to collect the monitoring data.

- We support broadening the TMDL monitoring program to include census of steelhead and salmon populations, focused studies to improve understanding of limiting factors, and other relevant biological information. With such information, in hand, it may be possible to further prioritize management and restoration actions based on estimated costs and environmental benefits, and/or to adaptively update of sediment allocations, numeric targets, and/or schedule for sediment implementation actions.

- In crafting an effectiveness-monitoring program for the TMDL, we will work with the technical advisory committee to the Napa County Watershed Information Center and Conservancy and other interested and knowledgeable parties.

- State funding will be available to support (in part) the implementation of sediment source inventories and controls, the broader set of actions needed to conserve steelhead, and a monitoring program to evaluate progress in restoring water quality and conserving salmon and steelhead populations. Other incentives for pro-active participation may include permit waivers and more favorable implementation schedules.

- We believe there is substantial value in supporting and expanding tributary and/or mainstem-reach stewardships to achieve significant large-scale enhancements of stream and riparian conditions in the Napa River watershed.

6.3. Legal Authorities and Requirements

The Water Board's legal authorities to require water pollution control actions are derived from the state Porter-Cologne Act and federal Clean Water Act. The Porter Cologne Water Quality Control Act gives Water Board's the authority to issue waste discharge prohibitions, waste discharge requirements (WDRs), and/or waivers thereof, to control actual or potential discharges of pollutants from point-and-nonpoint sources[18] into the waters of the state (California Water Code 13000 et seq). The state has recently adopted a policy for implementation and enforcement of its nonpoint source pollution control program (NPS program)[19], which requires all current and future nonpoint sources to be regulated under waste discharge requirements or waivers, and/or waste discharge prohibitions (California Water Code Section 13369). Under the adopted NPS program, waivers of waste discharge requirements must be conditioned on a monitoring program to ensure that water quality is protected. Locally administered water quality protection programs (e.g., Napa Green) may provide an innovative and less intrusive means for landowners to qualify

[18] Point sources typically are discharges of pollutants from a discrete conveyance (or pipe). Nonpoint sources are everything else that has not been defined as a point source (e.g., vineyards, rangelands, roads, etc.).
[19] The policy can be obtained online at http://www.waterboards.ca.gov/nps/docs/oalfinalcopy052604.doc .

for waivers, and hence, a more attractive venue for achieving compliance with the TMDL and the state's nonpoint source pollution control program.

6.4. Implementation Strategy

The Source Assessment presented in Chapter 3 identified four significant categories of human caused sediment sources in the Napa River watershed. These sources are: roads, grazing, vineyards, and erosion from bed and banks of the Napa River. Erosion processes that relate to these sources are: a) sheetwash from land uses (grazing and vineyards); b) road-related erosion (surface erosion from roads, erosion at stream crossings, and landslides and gullies caused by roads); c) gullies and landslides caused by land uses that concentrate runoff (grazing, roads, and hillside vineyards); and d) channel incision and associated stream terrace bank erosion. Table 9 provides an overview of possible implementation actions to reduce sediment input to streams and to rehabilitate the physical habitat structure in the Napa River. Stakeholders in the Napa River watershed have a longstanding tradition of citizen involvement in watershed-scale planning, management, and restoration activities that has included a number of very impressive accomplishments including, but not necessarily limited to the following:

- Establishment of the Agricultural Preserve in Napa Valley in the 1960s.

- Formation of a community-based coalition to advocate and pass Measure A, the Living River Strategy, which now provides funding for local flood protection efforts via the creation of wetlands and restoration of linkages between the river and its floodplain.

- Establishment in May of 1998 of the Napa River Watershed Task Force, comprised of a representative group of stakeholders appointed by the County Board of Supervisors, that met over a two-year period ending in September 2000, to develop recommendations for sustainable land use and natural resource conservation in Napa County.

- Establishment and continuity of several watershed stewardships, many of which have developed management plans and/or have implemented, or are planning, large-scale projects to enhance water quality and stream-riparian habitat (Huichica Creek, Carneros Creek, Sulphur Creek, Rutherford, Murphy, Salvador, and others).

We commend these achievements, and your impressive work on the ground to control erosion and protect or restore habitat conditions (e.g., local voluntary efforts, Napa County Conservation Regulations, early implementation of a very strong municipal stormwater program, Napa Salt Pond Restoration, Napa Green, etc.). As a result of these and other successful, locally led conservation efforts, it will be much easier to achieve the proposed allocations and targets for sediment (and other pollutants), as needed to restore water quality.

There also are other programs that might provide useful templates or approaches toward the goals of restoring water quality and protecting fisheries in the Napa. For example, FishNet 4C - a coalition of six central California coastal counties (Mendocino, Sonoma, Marin, San Mateo, Santa Cruz, and Monterey) that formed in the late 1990s following the listings of coho salmon and steelhead in central California as threatened under the federal Endangered Species Act - has developed a road maintenance manual for public works agency staff to achieve the objectives of protecting water quality, aquatic habitat, and salmonids, while undertaking most routine and emergency road-related maintenance activities (FishNet 4C et al., 2004)[20]. It is our understanding that Napa County Public Works is interested in adapting and implementing the best management practices described in the FishNet 4C road maintenance manual for use in Napa County (T. Adams, personal communication, 2005). We applaud County staff for their interest and leadership in this area. Similarly, the Rangeland Advisory Program of UC Cooperative Extension (UCCE) has developed a program for inventory and implementation of erosion control practices on ranches in California that has been very well received by ranchers. It is our understanding that local staff of the US Natural Resources Conservation Service are already working with UCCE staff to assist interested ranchers in developing a water quality protect plans for their ranches in the Napa River and Berryessa watersheds. These efforts and stewardship practices of many local ranch owners should provide a solid foundation for implementation of effective sediment control plans at ranches throughout the Napa River watershed.

We also wish to acknowledge the accomplishments of the Rutherford DUST Society in building a coalition and obtaining resources to explore restoration of a 4-mile reach of the Napa River. Their leadership and success suggest that the larger goal of restoring complex physical habitat conditions and conserving fisheries and aquatic wildlife along a large portion of the Napa River is an attainable goal that could be accomplished at a reasonably foreseeable future date (e.g., 15-to-25 years). We strongly support the voluntary and cooperative restoration efforts, embodied by the Rutherford example, as a primary vehicle for addressing adverse impacts of channel incision on water quality and habitat conditions in Napa River and the lower reaches of its tributaries. The Water Board is committed to advocating for grant funding for the implementation of an ecologically superior restoration project in the Rutherford reach, and in other freshwater reaches up and down the length of the river.

[20] Best management practices covered include those to "preserve and protect (ecologically) important woody debris in creeks to the extent possible", and ecologically superior approaches to stream bank stabilization.

Table 9. Implementation Goals and Actions to Reduce Sediment				
Source Category	**Goals**	**Management Measures**	**Responsible Parties**	**Implementation Tools**
Roads	60% reduction from present-day rates of sediment delivery from roads. Regular inspection and maintenance of roads; Adoption of FishNet4C roads maintenance manual by Napa County.	Road erosion inventory and management plans, implementation actions.	County of Napa Private Road Associations All Large Landowners	WDRs/Waiver from State to County General WDRs/ Waiver for others Grants/waivers to provide incentives for early implementation.
Grazing Sheetwash Gullies and landslides	Residual dry matter targets developed by UCCE, NRCS, and/or RCD to reduce sheetwash. 60% reduction from present-day rates of sediment delivery from management-caused gullies and shallow landslides.	Rangeland inventory and management plan Sediment delivery inventory and management plan Implementation	Ranch Owners	General WDRs/ Waiver Grant program/waiver or WDRs
Vineyard Sheetwash Gullies and landslides	ECP equivalency Accelerate natural recovery of management-caused gullies and landslides.	ECP equivalency Hydromodification control plan Implementation, monitoring, and adaptive management	Vineyard Owners	General WDRs/ Waiver Green Certification, Expansion of Napa County Conservation Regulations
Erosion from the Napa River Bed and Bank	Rutherford example	Conceptual plan, design, regulatory approval, implementation, monitoring, and adaptive management.	Channel-reach stewardships on mainstem reaches	Non-regulatory cooperative restoration

Notes: UCCE: University of California Cooperative Extension; ECP = erosion control plan; WDRs: waste discharge requirements.

6.5 Discussion of Possible Approaches to Achieve Allocations
In the discussion that follows, we put forth some initial concepts about how a sediment TMDL implementation plan might be developed around each major source category (roads, grazing, vineyards, channel incision), hopefully to encourage a constructive dialogue over the next several months.

Vineyards
An effective means of reducing sediment delivery from sheetwash erosion would be for all vineyards to meet the performance standards specified under the Napa County Conservation Regulations (Chapter 18.108).[21] For hillside vineyards established prior to 1991, we think this could be accomplished by using the design and management practices that have been implemented on other hillside vineyards permitted under the Conservation regulations. Alternatively, at gently sloping or flatland sites, not currently regulated, it may also be possible to control sediment delivery to channels through establishment and maintenance of vegetated buffers adjacent to engineered and natural channels.

Hillside vineyard development at some sites, especially at those underlain by soft bedrock and/or where vineyards replace forest cover has also caused off-site channel enlargement (gully development) and associated shallow landslide failures[22] (see source analysis this document; MIG, 2000). To avoid this problem when new hillside vineyards are proposed, the design review process should incorporate rigorous hydrological analysis to predict potential change in peak runoff rates, and the potential for off-site channel enlargement (as appears to be the case with new hillside vineyards now undergoing permit review by Napa County). Effective design features should then be incorporated to reduce off-site erosion risk to an acceptable level. A possible approach to this problem is outlined on pages 31-37 of the *Phase II Final Report of the Napa River Watershed Task Force* (MIG, 2000). Similarly, the Science Advisory Group to the Napa Green Certification Program has recommended that peak storm runoff rates following hillside vineyard development (at all sites) should not increase by more than 10-to-15 percent above pre-project rates to reduce the risk of off-site channel enlargement to an acceptable level (Napa Green Certification Program, 2003). At all existing hillside vineyards, as part of a larger sediment source inventory and control plan, the potential for concentrated runoff from the vineyard or road network should be evaluated through site inspection and analysis by qualified registered professional scientists or engineers. The goal for management of existing vineyards should be to reduce peak storm runoff rates into actively eroding gullies or landslides or other potentially unstable areas, as needed to accelerate natural recovery.

Vineyard sediment control performance standards described above could be achieved through expanding the total vineyard acreage enrolled and independently certified under the Napa Green

[21] Assuming a 20-to-25 year period for sediment TMDL implementation, we predict that 95% or more of the total projected hillside vineyard acreage would be permitted under the Napa County Conservation Regulations or successor regulations that provide equal or greater levels of resource protection. At present, we estimate that approximately 55% of total hillside vineyard acreage is permitted under the Conservation Regulations.
[22] Potential mechanisms are discussed on page 18 of this document.

Certification Program[23], by application of existing state regulatory authorities (Waste Discharge Requirements or Waivers thereof), and/or by adoption of some of the revisions to the Conservation Regulations that were recommended by the Napa River Watershed Task Force (MIG, 2000).

Grazing

An effective means of reducing sheetwash erosion from livestock grazing, at sites where this is a problem, could involve adopting livestock and/or range management practices that result in sufficient plant material being left on the ground to effectively resist sheetwash erosion. One such approach of this type, that has been successfully applied to control soil erosion and nutrient losses at many rangeland sites in California is a residual dry matter standard or target, with residual dry matter being defined as "the old plant material left standing or on the ground at the beginning of a new growing season" (University of California, 2002).[24]

We would appreciate the opportunity to work with local staff of the University of California Cooperative Extension (UCCE), NRCS, and/or RCD to consider development of residual dry matter (RDM) targets based on variation in rainfall and vegetation cover at sites in Napa River watershed. We would also be interested in partnering with one or more of the above organizations and/or rancher member organizations to establish a grant program to fund technical assistance for the development of rangeland water quality inventories and management plans, and funding for implementation measures pertaining to accelerating the natural recovery of gullies and landslides caused by intensive historical grazing and/or active or abandoned roads and/or other human structures (e.g., channel incision and/or gullies downstream of stock ponds, etc.). Effective control actions to accelerate natural recovery of gullies and landslides might involve exclusion fencing, planting of native woody vegetation, diversion or dispersion of concentrated runoff from roads, modification of grazing strategies and locations, construction of alterative water supply for livestock, etc.)[25]. Possible incentives for pro-active participation of ranchers, within responsibility and means, may involve waivers of waste discharge requirements, grant funding for rangeland and sediment source inventories and implementation actions, and/or more favorable schedules for implementation. We look forward to the opportunity to discuss these and other ideas that might provide a basis for a fair and effective rangeland management program.

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[23] To-date, holistic and comprehensive farm plans to restore clean water, and to protect salmon, and steelhead have been prepared for about 6,000 acres of vineyards in Napa River watershed. With current funding through for the program, we estimate that it will be possible to enroll about 12,000 vineyard acres in the program, or about 25-to-30 percent of the total acreage within the Napa River watershed. To-date, the State Coastal Conservancy and Water Board have provided approximately $1.2 million to fund development and implementation the Napa Green Program. Department of Fish and Game, NOAA Fisheries, Napa County RCD, NRCS, and other groups and individuals have also provided significant additional resources for the program.

[24] For more information on this topic, this report (Rangeland Monitoring Series, Publication 8092) can be obtained online at http://anrcatalog.ucdavis.edu .

[25] Based on initial conversations with a local expert in the field of gully stabilization on Bay Area ranchlands (S. Chatham, personal communication, 2005), it appears that most rangeland gully stabilization efforts in the Napa River watershed may be quite cost effective to undertake, and may compare favorable in comparison to typical costs of vineyard surface erosion control and channel bank stabilization costs. Based on this input, we would estimate that typical costs may range between $15-to-$50 per ton of sediment that is prevented from future delivery into a stream channel.

Roads

Road-related sediment delivery to channels is a significant source to the Napa River. In comparison to other significant sources, erosion control and prevention actions for rural earth-surfaced roads, which are located primarily on private property, may be one of the most cost effective sediment sources to control within the Napa River watershed[26]. Also, most road-related sediment inputs are very rich in the fine sediments that are impairing the quality of spawning and rearing habitat for steelhead and salmon in the Napa River and its tributaries. Finally, strategic investments to control future road-erosion pay significant dividends to property owners in terms of large reductions in costs for maintenance and/or repair of roads.

In contrast to rural roads located on private lands, most rural public roads in the Napa River watershed are paved. Based on this difference, the need to satisfy other road design and safety standards, and additional costs associated with staging road reconstruction actions on public roads, typical costs to storm-proof paved rural public roads may be three-to-four-times the cost to storm-proof rural earth surfaced roads located on private property (PWA, 2001). Based on review of available mapping of roads and road ownership in Napa River watershed (PWA, 2001, 2003a, and 2003b; Napa County, 2003), we estimate that there are approximately 1400 miles of upland roads (that produce the vast majority of road-related erosion delivered to channels). We estimate that 12 percent of the total road length is owned and maintained by Napa County, and 88 percent is owned and maintained primarily by private landowners.

There may be several advantages to public agencies and private landowners exploring the possibility of entering into sediment-control cooperatives to reduce road-related erosion in a way that also substantially reduces costs and burdens to both parties. For example, Napa County Public Works would bring professional staff expertise in contract administration, road construction and maintenance, and ability to obtain and manage large grants. Private landowners would bring to the table what would appear to be some of the most cost effective sediment sources to treat. By working together within a larger group costs for road erosion inventories and execution of control actions would be substantially reduced because of the economies of scale. Finally, individual private landowners likely would be at a substantial disadvantage in attempting to obtain grants, and potential problems associated with run-on from adjacent properties (that are causing road-erosion) will be difficult to resolve without cooperation across property boundaries. Should there be interest in exploring such a cooperative, it also clear that such a cooperative would also benefit from the involvement of the RCD and/or NRCS, to provide professional expertise in erosion control and landowner assistance.

To this end, we strongly support providing several potential incentives to road sediment-control cooperative partnerships including prioritization of such efforts for grant funding, a general WDR waiver program, and a more favorable schedule for achieving load allocations.

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[26] Based on a review of recent road erosion control inventories conducted in three Napa River tributary watersheds (Carneros, Dry, Sulphur) and two similar watersheds located elsewhere in the Bay Area (Pescadero Creek in western San Mateo County, and Redwood Creek in western Marin County), we estimate that typical costs to storm-proof rural earth-surfaced roads in Bay Area watersheds, including road erosion inventories, are less than $20 per ton of sediment that is prevented from future delivery into a stream channel. For example, typical costs for erosion control for valley-floor vineyards in the Napa Valley region appear to be more than $300 per ton of sediment that is prevented from future delivery into a stream channel, and cost per unit sediment savings for hillside vineyard erosion control are much higher.

Channel Incision

Channel incision has the highest priority for treatment of any sediment source category because sediment from channel incision is produced locally, therefore it may have a greater effect on fine sediment deposition at spawning sites in the Napa River, than more remote sources. Also, of greater importance than its role as a sediment source, as the Napa River incises, it obliterates the basic physical habitat structure of the river, expressed by a substantial reduction in quantity of gravels bars, riffle margins, side channels, and sloughs, and a disconnection of the channel from its flood plain. The resulting increase in the quantity of homogeneous long, deep pool-run habitats also favors native and introduced fishes that prey upon juvenile salmonids and has likely reduced chinook salmon populations. Stillwater Sciences and Dietrich (2002) postulate that the restoration of natural and complex physical habitat is a necessary prerequisite to facilitate a self-sustaining run of chinook salmon in Napa River. Restoration of natural bar-pool topography and flood-plain connectivity also may be needed to protect other rare or threatened species, including California freshwater shrimp, that are distributed solely or primarily in the Napa River and lower tributary reaches. Additionally, streamside land uses, public works infrastructure, and utilities are threatened by the high rates of bank erosion associated with channel incision processes along the Napa River.

We strongly support the effort being undertaken by Rutherford DUST Society to design and implement actions to enhance ecological functions along the Napa River. Adopting a channel restoration approach at the reach scale for treatment of channel incision and associated bank erosion, has several potential advantages including, but not necessarily limited to the following:

- Higher cost effectiveness than hard engineering approaches;
- Greater likelihood of long-term success;
- Lower long-term maintenance costs;
- Enhanced aesthetic and recreational values;
- The potential to reverse some of the significant adverse ecological impacts of incision on stream-riparian ecosystems; and
- A much more favorable position with regard to regulatory permit reviews and approvals.

Furthermore, by working together on a large scale it would be possible to implement a design that balances sediment supply and transport capacity throughout the reach (e.g., one landowners bank and/or bed stabilization solution does not become another's problem). Also, by adopting a channel restoration approach on a large scale, there appears to be a very high potential to receive significant public funding to support the design and implementation.[27] From our standpoint as a potential funding agency, or in acting in an advisory capacity to others, we will be strong

[27] Public funding to-date from State Coastal Conservancy, Napa County Measure A funds, and CDFG to support development of a restoration design for the Rutherford reach has been over $500,000, or more than 90% of the total costs thus far.

advocates for the adoption of an ecologically superior design alternative in the Rutherford Reach that results in meaningful enhancement of the stream-riparian ecosystem. To this end, we support consideration of the adoption of standards to guide the design process and evaluate the ecological success of the river restoration project that is implemented, as have been put forward recently by Palmer et al. (2005).[28]

We do not intend to propose a regulatory permitting program to require channel restoration to resolve adverse ecological and water quality impacts of channel incision for the following reasons:

- Channel incision problems along Napa River and its lower tributary reaches reflect and integrate multiple historical and ongoing disturbances some of which are local and/or direct, and others that are indirect and distal. In this sense, with the exception of an individual who owns property on both sides of the river over a very long distance, it is not possible for an individual to effectively control or be responsible for the channel incision that may be taking place on his or her property.

- An effective program to control channel incision in a way that enhances habitat for fish and aquatic species (as outlined above) will require cooperative and coordinated actions by multiple landowners over significant distances along the river.

- Considering the state of the science for river restoration and ecological modeling, and the physical and biological information for the Napa River that is available to guide river restoration design and modeling, any design that may be developed and implemented in the near future needs to be considered an experiment for which we cannot predict with a high degree of certainty in advance that the project ultimately will be successful.

Although it may be feasible to explore and implement river restoration options that are effective in controlling incision and/or accelerated bank erosion, but are not effective with regard to ecological performance, there is a high probability that such projects would have a much poorer chance of receiving significant public funding, and therefore, design and implementation costs to private landowners would be much greater. Although this is a scenario under which it might be possible to resolve the sediment impairment listing, ecologically successful river restoration appears to be a preferable option for public and private parties.

6.6 Water Quality Attainment Strategy to Facilitate Steelhead Conservation

Table 10 provides an initial overview of what a broader program to conserve steelhead in the Napa River watershed might look like. Before developing even a conceptual outline of a broader implementation program to address other key limiting factors for steelhead (e.g., habitat access, instream flow protection, etc.), we need have an extended discussion of our initial ideas with the agencies that have primary statutory authority for the protection of steelhead (NOAA Fisheries and California Department of Fish and Game), and for the regulation of surface water rights (State Board, Division of Water Rights), so that we may act in a manner that coordinated and

[28] A copy of this paper can be obtained online at http://nrrss.umd.edu/Publications/Palmer_et_al_2005_JAE.pdf .

consistent with the intent of the other responsible agencies. We expect to complete consultations needed to prepare a conceptual plan by early fall of 2005.

6.7. Agricultural Water Quality Control Program Costs

Implementation actions to control discharge of pollutants from grazing lands and vineyards constitute an agricultural water quality control program and therefore, consistent with California Water Code requirements (Section 13141), the cost of such a program must be specified and considered prior to enactment. We expect to complete preliminary estimates by mid-July 2005 of the costs to agriculture of that might be associated with implementation of the sediment TMDL and a broader plan to protect steelhead. We will also estimate potential costs to other public and private landowners. High and low ranges for costs will be developed by source and land use category, including key assumptions and information used to derive cost estimates.

Table 10. Steelhead Habitat Protection and Enhancement Program

Key Element	Actions	Goals	Targets	Timeframe/ Critical Path Items	Regulatory Encouragement
Tributary Stewardships	**Establish and Support Stewardships**	Develop and sustain stewardships in all key tributaries for steelhead	Stewardships sustained in 10 key tributaries including Dry, Redwood, Milliken, Ritchie, Sulphur, and York.	Within five years of TMDL adoption Professional assistance (Estimated cost = $200,000/yr.)	Grants to provide partial support for stewardship start up.
	Baseflow protection and enhancement	Dial-up water-level gages and baseflow surveys in 10 key tributaries for steelhead.	Minimum depth of water (DMIN) at critical riffles (3/15-6/1) = 0.15 m; DMIN at riffles (perennial reaches u/s of alluvial fans) (6/1-10/15) = 0.05 m	Within five years of TMDL adoption Stewardship success Professional assistance (estimated cost = $200,000/yr.)	Grants to support start up of flow gaging and analysis; Eventually, if necessary consider requesting State Board to: a) add general permit provision to existing WR holders to analyze relationships between flow, water use, and beneficial uses; b) comprehensive compliance survey.
	Habitat access	Barrier surveys, enhancement plans, and implementation actions in 10 key tributaries for steelhead.	To be determined	Stewardship success Professional assistance Cost of surveys and priority plan (estimated cost = $500,000) Cost of implementation (unknown, but large)	Grants for barrier remediation; Grace period for cooperative resolution of violations related to illegal dams/barriers.
	LWD and shade enhancement	Reduce spatial and temporal extent of stressful water temperatures; substantial enhancement of habitat for older juvenile steelhead in 10 key tributaries for steelhead.	To be determined	Stewardship success Pilot project success Professional assistance Management plans (estimate cost = $500,000) Voluntary agreements re: setbacks	Consider revision of allocations and/or implementation schedule for legacy sediment sources, in the absence of tributary habitat enhancements.
	Municipal Water Purveyors	Agreements with municipal water agencies to enhance conditions for steelhead spawning, rearing, and migration in the context of enhanced water supply reliability.	To be determined	Regional Water Supply Management Program Planning and Implementation Grants	Pursue cooperative agreement to improve water supply reliability and steelhead habitat as first step.

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