Conceptual Approach for Developing Sediment TMDLs for San Francisco Bay Area Streams

Pescadero Creek at Homestead Flat (photo by Matt Cover)

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This report describes the problem of too much sediment in Bay Area streams, our approach to technical analysis, and implementation actions to resolve the problem. We also provide a status update and schedule for active sediment TMDL projects.

I. Problem Statement

Populations of steelhead, salmon, and other native aquatic species have declined substantially during the past half-century in Bay Area streams. Too much fine sediment in streams appears to be one of the factors contributing to fish population declines. Other important factors may include low baseflow, substantial habitat degradation and loss, and human-made barriers to fish migration (e.g., some road crossings, diversions, and dams). Conservation and recovery of native fish and aquatic wildlife populations is the primary issue driving development of sediment TMDLs in the Bay Area. Nine Bay Area streams and their tributaries are on the 303(d) list as impaired by too much sediment: Walker Creek, Lagunitas Creek, Petaluma River, Sonoma Creek, Napa River, San Gregorio Creek, San Francisquito Creek, Pescadero Creek, and Butano Creek (Figure 1). These streams drain watersheds with a combined land area of 1100 square miles, or about one quarter of the total land area within the jurisdiction of the San Francisco Bay Regional Water Quality Control Board (Regional Board). The nine streams are listed because: 1) habitat is degraded by fine sediment deposits; and 2) these streams are regionally significant from a conservation biology standpoint – they provide critical habitat for steelhead, salmon and other at-risk native fish and wildlife species.

<u>Decline of Bay Area Steelhead and Salmon Runs</u>

Three ocean-going (anadromous) species of salmon and trout are native to Bay Area streams: fall-run chinook salmon, coho salmon, and steelhead trout. Although their specific habitat requirements vary, populations of all three species have declined substantially during the past fifty years within the Bay Area.

Steelhead trout are federally listed as threatened throughout Central California. Historically they probably spawned in most Bay Area streams. At present, however, small remnant runs are only known in nineteen streams that drain into San Francisco Bay (Leidy, 2000) including all four Bay streams listed for sediment: Petaluma, Sonoma, Napa, and San Francisquito. Present-day steelhead runs in Bay streams probably range in size from a few to a few hundred adults (Leidy, 2000). Several Bay streams including Sonoma Creek, Coyote Creek, Guadalupe River, Alameda Creek, Napa River, and Petaluma River, probably had very large steelhead runs during the first half of the twentieth century. For example, the Napa River steelhead run was estimated at 6,000-to-8,000 adults prior to the 1940s (USFWS, 1968), 1,000-to-2,000 adults in the late 1960s

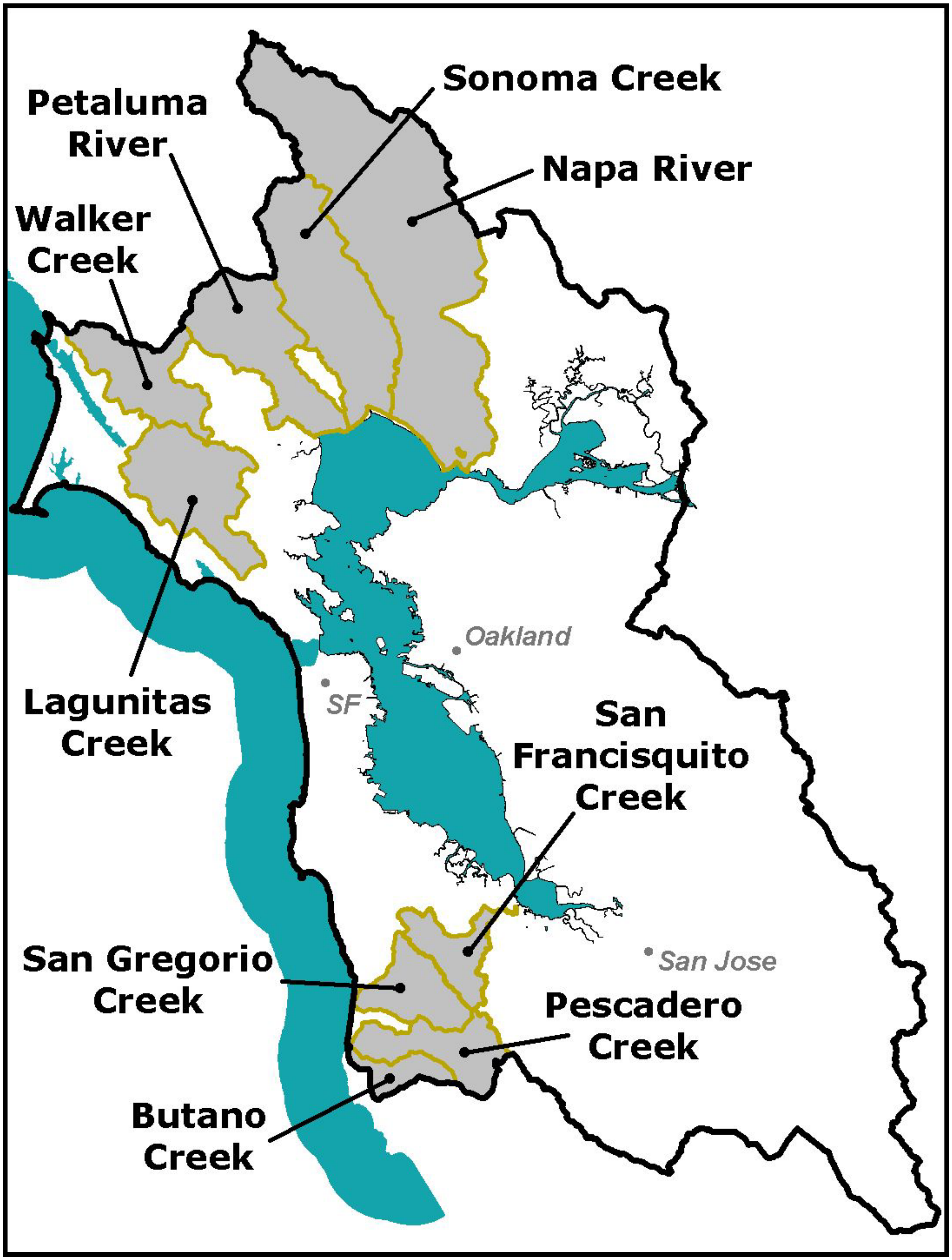

Figure 1. Watersheds areas for streams listed as impaired by sediment (shaded). These streams drain about one quarter of the total land area within the jurisdiction of the San Francisco Bay Regional Water Quality Control Board.

(Anderson, 1969), and is now believed to be less than a few hundred adults (Emig and Rugg, 2000).

The largest remaining steelhead runs in the Bay Area are found in Marin and San Mateo County coastal streams including Lagunitas, Olema, Redwood, San Pedro, Pescadero, and San Gregorio creeks. At present, these streams support runs of a few-to-several hundred steelhead. Even in these streams, population declines have been substantial during the last half century, and extreme during the past 150 years. For example, the California Department of Fish and Game (CDFG) estimates that the annual steelhead run in Pescadero Creek was about 1,500 fish as recently as the mid-1970s (Elliot, 1975), and much larger during the late nineteenth century, when a commercial fishery was able to harvest a wagonload of 2-to-30 pound steelhead and salmon each day between October and March of 1870 (Skinner, 1962). Other coastal streams, including Walker, Frenchmans, Pilarcitos, and Pomponio creeks, are believed to support small steelhead runs at present. Historically, Walker Creek supported a large steelhead run.

Overall, the historical and present-day abundance of chinook salmon is poorly documented for Bay Area streams. Our knowledge of historic conditions is summarized as follows. Spawning fall-run chinook salmon have been documented in recent years in Walnut Creek, Napa River, Sonoma Creek, Lagunitas Creek, Guadalupe River, and the Petaluma River (Leidy, 1997). The historical presence of coho salmon has been documented in several Bay streams including Sonoma Creek (Dawson, 2002), Napa River (Emig and Rugg, 2000), San Pablo Creek, Walnut Creek, Alameda Creek, Corte Madera Creek, and Mill Valley Creek (Brown, Moyle, and Yoshiyama, 1994). Historically, coho salmon probably used almost all coastal streams in San Mateo County and Marin County (CDFG, 1998; 2002). At present, coho salmon are state listed as endangered in Central California and federally listed as threatened. Coho salmon are now believed extinct in all streams draining into San Francisco Bay (Leidy and Becker, 2001). A handful of coastal streams in Marin County including Lagunitas, Olema, and Redwood creeks still support remnant coho salmon runs. Lagunitas Creek supports one of the largest remnant runs in California, with 500-or-more adults returning to spawn in recent years. Although the Lagunitas run has increased somewhat since the 1980s, available information suggests it supported a spawning run of few thousand or more coho as recently as early 1950s. CDFG estimated that Pescadero and San Gregorio creeks supported a combined average coho run of about 1,000 adults as recently as the early 1960s (CDFG, 2002). At present, few- if any- coho spawn in San Gregorio and Pescadero creeks (Smith, 2000). CDFG has listed San Gregorio and Pescadero creeks as top priority streams for rehabilitation in its coho recovery plan for Central California (CDFG, 1998). Historically, Walker Creek supported a large run of coho salmon (Worsely, 1972), but coho have only been observed sporadically and in small numbers since the mid-1950s (CDFG, 2002).

Other Native Fish and Aquatic Wildlife Species in Decline

Several other fish and aquatic wildlife species native to Bay Area streams are now endangered, threatened, or species of special concern, these include (but are not limited to): Pacific and river lamprey, green sturgeon, hardhead, hitch, tule perch, Sacramento splittail, Sacramento perch, tidewater goby, foothill yellow-legged frog, southwestern pond turtle, San Francisco garter snake, and California freshwater shrimp. Although less information is available about the decline of these species, we believe that habitat protection and restoration for salmon and steelhead, founded upon an understanding of natural physical and biological processes in Bay Area watersheds, will also benefit these species.

Factors Affecting Fish Populations

There are a number of ways in which sediment may impair fish and aquatic wildlife habitat. When sediment supply is high compared to a streams ability to transport sediment, fine sediment can be deposited in a gravel streambed smothering spawning sites and filling pools. Increases in the amount of fine sediment in the streambed also causes the streambed to be more frequently and deeply scoured during storms leading to direct mortality of incubating eggs and juvenile fish. High sediment load can also cause streams to remain cloudy for longer periods after storms. This can be an important problem for steelhead and salmon because they need to see their prey in order to capture it, and thus longer periods of moderate or high turbidity may reduce feeding opportunities. Reduced feeding opportunities during the wet season may result in smaller juvenile fish, and consequently higher mortality during outmigration and ocean rearing.

Habitat conditions in natural channels are influenced by more than sediment load. They are shaped by the interactions of streamflow, sediment, large woody debris, and streamside vegetation. This implies that a broader, more holistic, analytical framework is needed when the principle objective of a TMDL is fish recovery. Such a framework usually is referred to as a watershed assessment, in which features and processes important to fish habitat and water quality are identified, and the role of natural processes and human activities is distinguished (Washington Forest Practices Board, 1997; Watershed Professionals Network, 1999). Watershed assessment often includes a fish limiting factors analysis, which identifies significant physical and/or biological attributes in stream and riparian habitats that control fish population size.

Fishery declines are not the only concerns associated too much sediment. Other sediment-related management problems include: loss of municipal water supply because sediment has rapidly filled reservoirs or is causing prolonged high turbidity; and flooding problems in urban and rural residential areas along many of the listed streams (e.g., San Francisquito Creek in East Palo Alto, Pescadero and Butano Creeks in Pescadero, Sonoma Creek in Shellville area, etc.). Sediment reduction measures that may be proposed in the TMDL implementation strategy should also reduce economic and social impacts of flooding and water resources management in impaired streams.

II. Technical Tools and Approaches for Developing Sediment TMDLs

Our primary objective in developing and implementing sediment TMDLs is to protect and enhance fish habitat. Therefore TMDL analysis and implementation will include the following components:

1) Confirming the nature of impairment by identifying and ranking significant limiting factors for fish (using limiting factors analyses);
2) Evaluating sediment inputs and sources (using sediment budget analyses);
3) Evaluating causes of other limiting factors, such as habitat degradation, lack of baseflow, barriers, through watershed assessment;
4) Establishing narrative and numeric targets for water quality and habitat attributes needed to support fish in good condition (Moyle, 1998); and
5) Implementing measures to control sediment delivery to streams, enhance habitat conditions by increasing shade and habitat complexity and baseflow, and modifying or removing human-made structures to restore access for steelhead and salmon to suitable habitat areas.

1) These steps satisfy TMDL requirements, and provide additional information and actions needed to conserve and enhance native fish and aquatic wildlife populations in Bay Area streams.

The first step in the sediment TMDL process is to identify factors that contribute to reductions in fish population and assess the relative importance of these factors. The next step is to understand the causes for the identified limiting factors. Where sediment is confirmed as a limiting factor, we use a sediment budget analysis to quantify sediment input to streams. Watershed assessment may also be conducted to evaluate how natural processes and human activities are influencing other identified limiting factors such as water temperature, habitat complexity, and baseflow. We will develop appropriate narrative and numeric targets to protect water quality and habitat attributes for fish. A load allocation for sediment will be determined for each watershed, source reduction goals will be defined as the TMDL allocation, and an implementation plan to reduce sediment loads and to enhance other fish habitat attributes will be developed.

Limiting Factors Analysis

Limiting factors analysis can be used to: 1) evaluate sediment impacts; 2) identify and rank the importance of significant limiting factors (e.g., fish migration barriers, lack of flow, too much sediment, etc.); 3) establish initial priorities for management and restoration; and 4) determine the focus of subsequent watershed assessment on significant pollutant and pollution problems[1] identified in the limiting factors study.

[1] For example, sediment, nutrients, and heat input into a body of water are defined as potential pollutants under the 1987 revision of the Clean Water Act. Human activities that alter streamflow regime (hydrologic modification) and habitat structure and/or form (habitat degradation) are defined as pollution.

Limiting factors analysis involves repetitive process of hypothesis development, testing, and refinement to identify and describe specific physical and biological properties of water quality and riparian habitat that control fish population size. Such studies focus on identification of the most important "effects" or habitat attributes (e.g., stressful temperatures during summer, too much fine sediment) controlling fish population size. In June 2002, we completed the *Napa River Basin Limiting Factors Analysis* (Stillwater Sciences and Dietrich, 2002), which provides an example of this approach (available at http://www.swrcb.ca.gov/rwqcb2/napariversedimenttmdl.htm). Based on this study, we confirmed that sediment is a contributing factor in the decline of the steelhead run. We also identified other significant limiting factors including: 1) stressful summer water temperatures and very low flows that act together to severely limit fish growth; 2) lack of complex habitat caused by several factors including scarcity of large wood in channels; and 3) a very large number of human-made barriers across channels that prevent or impede access by steelhead to a large amount of potentially suitable habitat. Also, we recommended several priorities for interim management and additional research. The Napa County Farm Bureau, Napa Valley Grape Growers Association, Friends of the Napa River, and CDFG provided positive comments and/or letters of support regarding the study.

Sediment Budget Analysis

When sediment is confirmed as a limiting factor, we will conduct sediment budget analyses. A sediment budget is defined as follows:

> "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 (Reid and Dunne, 1996)."

We will use rapid sediment budget techniques to quantitatively estimate rates of sediment delivery to streams, and to distinguish natural and human contributions (Reid and Dunne, 1996). In some cases, we will also analyze what happens to sediment once it enters channels in order to predict in greater detail how changes in sediment load will affect where, how much, and what sizes of sediment are deposited and how this in turn affects channel form and functions. The rapid sediment budget methodology which has been in wide use for more than a decade, has proven scientifically defensible and cost efficient. A sediment budget takes into account the type and location of major natural and management-related sediment sources, the magnitude of the sources, grain-size distribution of sediment, the volume of sediment in storage and the transport rate through streams and valleys.

A sediment budget analysis involves the following five steps:

1. *Compile Existing Information.* The first step is to identify and compile existing information regarding erosion processes and rates in the watershed being analyzed, and/or other watersheds with similar geology, topography, vegetation, and land uses.

2. *Define Terrain and Channel Types.* The next step is to define and delineate land area and channel reach types within the watershed being studied that are similar with regard to potential sediment input rates and channel sediment transport capacity. Geology, topography, soils, vegetation, and land use activities are the primary controls on erosion and sediment transport that need to be identified. Maps and aerial photos can be reviewed to identify a manageable number of terrain types where erosion and sediment transport processes and rates are likely to be similar. Field surveys are then performed to confirm accuracy of defined land area and channel reach types, and develop conceptual model of sediment input to and transport through channels.

3. *Determine Sediment Sources.* After identifying the geology and ground cover of the watershed and gaining an understanding of terrain and channel types, the central work of the sediment budget analysis can begin. In this step, the amount of sediment contributed to the stream channel is estimated. Aerial photos can be interpreted to identify the first appearance and changes over time in the size of erosion features, and to measure the extent of some types of erosion features (e.g., gullies in grasslands, large landslides, and bank erosion on large channels).

4. *Determine Sediment Production Rate.* The size and occurrence of other erosion features, such as smaller landslides or gullies located under tree cover, and bank erosion rates on small streams typically cannot be detected on most aerial photographs, and therefore their dimensions must be measured in the field, unless they are small enough to be insignificant. After completing photo measurements, all types of erosion sites are surveyed in field (or existing data is used) to establish an erosion area-to-volume relationship. Sediment is also sampled (or soil survey data is used) to characterize sources with regard to percentage by major grain size classes (boulders, gravel, sand, fines), as needed to estimate sediment delivery to and transport through channels (in terms of mass per unit area per year).

5. *Compare Sediment Production Rate with Other Estimates.* Once an estimate of sediment delivery to channels is determined, estimated rates can be compared to downstream sedimentation rates, channel sediment transport data, and/or previously completed sediment budgets for local and/or similar watersheds. Because the rapid sediment budget approach uses retrospective historical analysis to estimate the age of erosion features and sediment deposits, it is possible to complete studies in a single field season and still have a reasonable estimate of long-term mean rates of erosion processes.

Watershed Assessment

When other limiting factors are identified besides sediment, a watershed assessment can be conducted to further identify how human activities and natural processes influence water quality and habitat attributes. The States of Washington and Oregon have developed approved methodologies for watershed analysis or assessment in rural watersheds (Washington State Forest Practices Board, 1997; Watershed Professionals Network, 1999). The California Resources Agency is currently developing an advisory document regarding approaches and tools for conducting watershed assessment in

California that is intended to address the broad array of land use activities, physical settings, and social and biological communities found in California (Schilling, 2003). This document is projected for completion in December 2003. The San Francisco Estuary Institute has developed the Bay Area Watershed Science Approach (SFEI, 1998) that has proven quite useful for assessment and management of small Bay Area watersheds (drainage area ≤ 20 mi^2) including several tributaries to the Napa River and Sonoma Creek.

Numeric Targets and Load Allocations

The Regional Board regulates discharge of pollutants to protect beneficial uses including the establishment of water quality criteria to protect uses. In the case of sediment and fish populations, we are examining the linkages between sediment delivery (i.e., rate, sizes, durability), water column attributes (e.g., turbidity), and streambed attributes (e.g., substrate sizes and arrangement, and channel topography) needed to provide favorable habitat for fish. The Clean Water Act specifies that a TMDL include numeric targets to provide measurable criteria for evaluation of whether or not impairment has been resolved and beneficial uses are protected. Because our objective is conservation of native fish and aquatic wildlife species, we also intend to develop additional water quality targets as needed to holistically evaluate attainment of suitable habitat and watershed conditions to conserve and enhance native fish and aquatic wildlife populations.

Table 1 provides example numeric and/or narrative targets for sediment and fish habitat attributes.

Table 1. Examples of Sediment and Habitat Targets and Water Quality Indicators

Category of Indicator	Example of Possible Targets	Example of Water Quality Indicators
Upslope	Reduce road sediment delivery by 75%	Roads erosion control and prevention
In-Channel	Median predicted mortality during incubation (from fine sediment) ≤ 40%.	Spawning gravel permeability
Habitat Restoration	All stream crossings on public roads shall be inventoried, and barriers to steelhead or salmon corrected within 10 years.	Fish migration barriers
Fish population	1000 adult steelhead return to spawn in 10 consecutive years. On average, no more than 2/3 of the total run spawns in any tributary or the mainstem channel.	Steelhead population and distribution

- Where sediment budgets have been completed for coastal watersheds in Northern and Central California, human activities typically contribute 50 percent or more of total sediment delivery to streams. Proposed or approved sediment TMDLs for coastal streams in California typically require very large reductions in the amount of sediment contributed from human sources. In these basins, each significant human and natural sediment source was allocated a load that is expressed in terms of average annual mass of sediment per unit area of land. In addition to establishing mass load allocations, we recommend that allocations be based on a ratio of human-to-total sediment delivery (Dietrich, 1998) because year-to-year variation in sediment delivery to and transport through channels is often extreme in California and governed primarily by substantial variation in character of a given wet season and preceding watershed disturbances. Therefore, a ratio of human-to-total delivery is superior to a fixed sediment delivery rate, because human inputs are always examined within the context of the climatic and hydrologic driving forces.

III. Implementation Planning

While undertaking analytical tasks, we will also begin working on implementation strategies. As significant limiting factors are identified, control measures will be proposed to reduce adverse water quality and habitat impacts. For example, if elevated erosion from roads is identified as a significant limiting factor for fish, then comprehensive road erosion control and prevention measures will be recommended as best management practices (BMPs). TMDL program staff will work with other Regional Board staff to coordinate implementation of these measures through existing and/or new water quality permit programs.

Relationships between common fish limiting factors, land use activities, and management actions to restore fish populations are summarized in Table 2. The overall goal is to protect and enhance spawning, rearing, and refuge habitats as needed to support "fish in good condition" at the individual, population, and community levels (Moyle et al., 1998). Therefore, although we will require actions to control sediment, we will also promote actions to address other identified limiting factors, such as fish migration barriers, stream and riparian habitat degradation, and low baseflow. Regulatory incentives may be recommended to encourage dischargers to participate in holistic management programs that consider erosion and sediment control as one of several habitat and water quality enhancement actions. We will also encourage the use of state and federal grant funds (Proposition 13, 40, and 50; CalFed; Clean Water Act 319h) to match local contributions to such projects.

We are working closely with local governments to facilitate the development of effective erosion control and stream setback ordinances to protect habitat and water quality. We also participate on the FishNet 4C Steering Committee, a coalition of Central California County Governments (including Marin, San Mateo and Sonoma), established to promote effective environmental permitting and management practices to protect salmonids in central California. FishNet recently completed a comprehensive review of County land use planning and management practices that included recommendations to: a) strengthen stream setback, erosion control, and storm runoff ordinances; b) implement holistic management practices to manage riparian vegetation, large woody debris, and bank stability associated with road and channel maintenance activities; and c) identify and correct impediments and/or barriers to fish migration caused by public road crossings (Harris et al., 2000).

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Stakeholder Involvement

Stakeholder involvement is needed throughout the TMDL process to: 1) educate stakeholders and regulators about land use practices, regulations, watershed problems, and potential solutions; 2) communicate the intentions of our agency; 3) share scientific information as it becomes available; 4) resolve disputes; and 5) provide incentives for pro-active problem solving by local entities. This is the most important element influencing the success of all watershed programs.

Many local, state and federal agencies are engaged in efforts to restore water quality and endangered species populations including City and County Governments, FishNet 4C, Watershed Councils, Resource Conservation Districts, California Department of Fish and Game, California Coastal Conservancy, California Department of Forestry and Fire Protection, California Department of Water Resources, USEPA, National Marine Fisheries Society, and US Fish and Wildlife Service. Where possible, we would like to approach the TMDL in a broader watershed context and promote regulatory coordination in order to: 1) avoid redundant and/or inconsistent regulatory directives; 2) accomplish a holistic and scientifically defensible analysis; and c) use scare resources in an efficient manner.

Stakeholders we currently work with include the Napa Farm Bureau, Napa Resource Conservation District, Napa County, Sonoma Ecology Center, Sonoma Valley Vintners and Growers, North Bay Agricultural Alliance, Southern Sonoma County Resource Conservation District, and the city and county governments in each watershed. Other stakeholders we work with include environmental groups, landowners, and interested members of the public.

IV. Schedule and Funding

We are taking a proactive approach to funding sediment TMDLs. We have aggressively pursued grant funding through Proposition 13 and federal grant programs such as the 319(h) and 205(j) programs. These grants have brought resources both to scientific investigation and to early on-the-ground implementation projects. We have allocated contract resources to ensure that high quality, scientifically sound studies form the basis for our water quality policies related to sediment and fish habitat. We are currently contracting with University of California at Berkeley and the San Francisco Estuary Institute. Major active TMDL contracts are listed in Table 3. Our Proposition 13 grants are with the Napa County Resource Conservation District, Sonoma Ecology Center and the Southern Sonoma County Resource Conservation District, and the San Francisquito Creek Joint Powers Authority.

Table 3. Currently Funded Sediment TMDL Studies

Watershed	Funding Level	Source of Funding
Napa River	$290,000	TMDL Contract
	$500,000	Prop. 13
Sonoma Creek	$200,000	TMDL Contract
	$650,000	Prop. 13
San Francisquito Creek	$200,000	TMDL Contract
	$250,000	Federal Grant

Schedule

TMDL development and early implementation is high priority for staff. We are working to meet our short-term completion dates for technical studies to ensure that projected Basin Plan amendment dates will be achieved. The sediment TMDLs that we are actively working on are Napa River, Sonoma Creek, and San Francisquito Creek. We are working with stakeholders in Pescadero and Butano creeks, and the Petaluma River to establish foundations for future studies. Next fiscal year, we will begin working on sediment TMDLs in Walker and Lagunitas creeks.

Our schedule for completing major TMDL tasks and proposing Basin Plan language to formally establish each TMDL is presented in Table 4.

Table 4. Sediment TMDL Schedule

Water Body	Proposed Basin Plan Amendment Date	Status (project completion date)
Napa River	June 2005	Limiting Factors Study (Complete) Sediment Budget (June 2004)
San Francisquito Creek	June 2005	Sediment Budget Study (Dec. 2003) Aquatic Resource Study (June 2004)
Sonoma Creek	June 2006	Limiting Factor Study (June 2004) Sediment Budget Study (June 2005)
Pescadero/Butano Creeks	June 2006	Problem statement (June 2003) Watershed assessment (Dec 2003)
San Gregorio Creek	June 2007	Problem statement (June 2003).
Petaluma River	June 2007	Preliminary stakeholder contact
Walker Creek	June 2007	Preliminary stakeholder contact
Lagunitas Creek	June 2007	Preliminary stakeholder contact

REFERENCES

Anderson, K.R., 1969. Steelhead Resource - Napa River Drainage, Napa County. Memorandum to File, California Department of Fish and Game, Region 3, December 23, 1969.

Brown, L.R., Moyle, P.B, and R.M. Yoshiyama, 1994. Historical Decline and Current Status of Coho Salmon in California. North American Journal of Fisheries Management, Volume 14 (2): 237-261.

California Department of Fish and Game, 1998. (Draft) Restoration Plan for the Endangered Coho Salmon South of San Francisco Bay. July 1998.

California Department of Fish and Game, 2002. Status Review of California Coho Salmon North of San Francisco. Report to the California Fish and Game Commission. Candidate Species Status Review Report 2002-3. April 2002.

Dawson, A., 2002. The Oral History Project: a Report on the Findings of the Sonoma Ecology Center's Oral History Project, Focusing on Sonoma Creek and the Historical Ecology of Sonoma Valley. Sonoma Ecology Center, Sonoma, California.

Dietrich, W.E., 1998. Personal communication from Professor Bill Dietrich, Department of Earth and Planetary Sciences, University of California at Berkeley to Mike Napolitano, RWQCB, Oakland, CA.

Elliott, B. G., 1975. The Natural Resources of Pescadero Marsh and Environs. California Department of Fish and Game, Coastal Wetland Series No. 13 (Draft).

Emig, J. and M. Rugg, 2000. Personal communication from John Emig and Mike Rugg, Senior Fisheries Biologists with CDFG, Yountville, CA to Mike Napolitano, RWQCB, Oakland, CA.

Harris, R.R. et al, 2000. Effects of County Land Use Policies and Management Practices on Anadromous Salmonids and their Habitats: Sonoma, Marin, San Mateo, Santa Cruz, and Monterey Counties, California. Prepared by the University of California at Berkeley, Department of Environmental Science, Policy, and Management. Prepared for FishNet 4C Program.

Leidy, R.A., 1997. Native Fishes in Bay Streams. PP. 16-19 in "State of the Estuary, 1992-1997." San Francisco Estuary Project, Oakland, California.

Leidy, R.A., 2000. Native Fish in Streams. PP. 19-21 in "State of the Estuary 2000 – Restoration Primer." San Francisco Estuary Project, Oakland, California.

Leidy, R., and G. Becker, 2001. Letter to Dennis McEwan, California Department of Fish and Game.

Moyle, P.B. et al, 1998. Fish Health and Diversity: Justifying Flows for a California Stream. Fisheries, Volume 23 (7): 6-15.

Reid, L.M., and T, Dunne. Rapid Evaluation of Sediment Budgets. Geo-Ecology Texts. Catena-Verlag, Reiskirchen, Germany.

Schilling, F., 2003. Personal communication via email from Fraser Schilling, Department of Environmental Science and Policy, University of California at Davis to Mike Napolitano, RWQCB, Oakland, CA.

Skinner, J. E. 1962. An historical review of the fish and wildlife resources of the San Francisco Bay area. California Department of Fish and Game, Water Projects Branch Report No. 1.

Smith, J., 2000. Personal communication from Dr. Jerry Smith, Professor of Fisheries Biology, San Jose State University, CA, to Mike Napolitano, RWQCB, Oakland, CA.

Stillwater Sciences and W. Dietrich, 2002. Napa River Basin Limiting Factors Analysis – Final Technical Report. Prepared for California Coastal Conservancy, Oakland, CA and San Francisco Bay RWQCB, Oakland, CA. June 14, 2002.

US Fish and Wildlife Service, 1968. Analysis of Fish Habitat of Napa River and Tributaries, Napa County, California, with Emphasis Given to Steelhead Trout Production. October 21, 1968. Memorandum to File.

Worsely, P.F., 1972. The Commercial and Sport Fishery in Tomales Bay. PP: 135-141 in Tomales Bay Study Compendium of Reports. Editors: David Walker and Rowan Rountree. Companion volume to "Summary Report- Tomales Bay Environmental Study. Prepared for the Conservation Foundation, Washington, D.C.

Watershed Professionals Network, 1999. Oregon Watershed Assessment Manual. June 1999. Prepared for the Governor's Watershed Enhancement Board, Salem, Oregon.

Washington State Forest Practices Board, 1997. Standard Methodology for Conducting Watershed Analysis. Department of Natural Resources, Forest Practices Division, Olympia, Washington.