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Boxes

Chapter Y. Sediment Management

Sediment definition:

1. Geology - Solid fragmented material, such as silt, sand, gravel, chemical precipitates, and fossil fragments, transported and deposited by water, ice, or wind or that accumulates through chemical precipitation or secretion by organisms, and that forms layers on the Earth's surface. Sedimentary rocks consist of consolidated sediment.
2. Chemistry - Particles of solid matter that settle out of a suspension to the bottom of the liquid.

Sediments can come from anywhere and be just about anything. Organic and inorganic material alike can become the bits of matter tiny enough to allow it to be picked up and carried along with a moving fluid. Organic sediments are mostly debris from trees, plants, grasses, and animals and fish and their waste products. Inorganic sediments are divided into two main groups, these being coarse-grained sediments and fine-grained sediments. Coarse-grained sediments are boulders, cobbles, gravel, and sand, while fine-grained sediments are silts and clays. A further important distinction of the sediments is whether they are "clean" sediments or contaminated sediments, as this greatly affects the manner in which they can be used as beneficial material or must be isolated from their surrounding environment. For this Resource Management Strategy the use of the term sediment will mean clean sediment, and if the sediment is contaminated the term contaminated sediment will be used.

Sediment management is an essential for integrated water management as the presence or absence of sediment will have significant impacts on water and its beneficial uses.

Sediment Management in California

Sediment management in California is critical for the entire watershed, beginning with the headwaters and continuing into the coastal shores. From a human perspective, sediment has a dual nature—desirable in some locations and unwanted in others. Sediment can be used for many beneficial uses such as to create or restore beaches and to renew wetlands and other coastal habitats. Sediment is also needed to renew stream habitat. Spawning gravels need replenishment, and fine sediment is also needed to maintain, enhance, or restore good quality native riparian vegetation. Historic flood deposits of sediment into floodplains are the source of much of California's richest farmland.

Sediments can also be used for land reclamation and construction material. Such activities are referred to as beneficial uses. Excessive sediment, above natural loads, can cloud water, degrade wildlife habitat, form barriers to navigation, and reduce storage capacity in reservoirs for flood and water conservation. Contaminated sediment can contaminate the food chain for marine plants, animals, and humans.

Surface water with high sedimentation may negatively affect beneficial uses by increasing turbidity. Sediment affects sight-feeding predators in their ability to capture prey, clogs gills and filters of fish and aquatic invertebrates, covers and impairs fish spawning substrates, reduces survival of juvenile fish, reduces fishing success, and smothers bottom dwelling plants and animals. It may also physically alter streambed and lakebed habitat.

PLACEHOLDER Box Y-1 Debris and Sediment

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

Nutrients (such as phosphorus) and toxic pollutants (contaminants such as trace metals and pesticides) are often associated with fine-grained sediment. In some cases suspended sediment particles increase growth of bacteria which can concentrate these nutrients from the water column. Toxic pollutants from storm water may also be absorbed onto sediments. Concentrated pollutants can greatly impair water quality if they are remobilized back into the environment.

Deposited sediment can reduce the hydraulic capacity of stream channels, causing an increase in flood crests and flood damage. It can fill drainage channels, especially along roads, plug culverts and storm drainage systems, and increase the frequency and cost of maintenance. Sedimentation can decrease the useful lifetime of a reservoir by reducing storage capacity. This loss in storage capacity affects the volume of stored water available for municipal supplies and the volume available for floodwater storage. Sedimentation of harbors and drainage systems results in higher maintenance costs and potential problems associated with disposal of removed material. The accumulation of sediment in recreational lakes affects boating activity in the shore zone, and can lead to demands for dredging to deepen marinas and channels.

Whether sediment is desirable or not, its location and movement can have large economic and ecological consequences. For example, excess sediment in shipping channels may cost ports millions of dollars in delayed or limited ship access, while in other locations insufficient sediment deposits could result in the loss of valuable coastal wetlands (source - http://www.oceancommission.gov/documents/full_color_rpt/12_chapter12.pdf).

Due to numerous factors, including geology, climate and population, sediment management issues vary significantly throughout the state. For that reason it is best done on a watershed-wide scale. A major goal in this management is to try to make the watershed as stable as possible for sediment production (meaning to try to mimic natural sediment production, not to eliminate it). Watershed stability is determined by performing geomorphic assessments of the waterways within that watershed. Then, for the sediment that is produced, make efforts to use this sediment most beneficially throughout the watershed using a concept termed “regional sediment management” (RSM).

A stream that has excessive erosion and sedimentation may be determined by the Water Boards to be unable to support its designated beneficial uses and may be listed as impaired under the Section 303(d) of the Federal Clean Water Act. A Total Maximum Daily Load is required to reduce the excess sediment load and is scheduled as part of the listing (Source- Betty Yee, CVRCB). The U.S. EPA has stated that excessive sediment in streams is the number one water quality problem in the country. The USACE, working with other agencies within the San Francisco Bay area, has a program for sediment management in the San Francisco Bay and Delta, termed the “Long-Term Management Strategy (LTMS) for handling dredged material and its beneficial uses with that area.

The USACE and the California Resources Agency have formed the California Sediment Management Workgroup to bring sand to California's beaches. Many local agencies along the coast are assisting in this effort. The California Regional Water Quality Control Boards are working to reduce excessive sediment within streams when it occurs within their regions.

Some goals and objectives of sediment management are:

- Maintain stable watersheds.
- Maintain infrastructure capacity.
- Achieve stormwater permit requirements.

Methods include supporting:

- Low Impact Development projects.
- Clean Sediment TMDLs.
- Use of land use BMPs.
- Regional Sediment Management Plans.

Sediment and Flood

Sediment management is a key consideration in flood management. When a river breaks its banks and floods, it leaves behind layers of sediment. These gradually build up to create the floor of the flood plain. Floodplains generally contain unconsolidated sediments, often extending below the bed of the stream. These are accumulations of sand, gravel, silt, and/or clay, and are often important aquifers, the water drawn from them being pre-filtered compared to the water in the river.

Geologically ancient floodplains are often represented in the landscape by fluvial terraces. Fluvial processes are the movement of sediment, organic matter, and erosion that deposits on a river bed, and the land forms this creates. Fluvial terraces are old floodplains that remain relatively high above the present floodplain and indicate former courses of a stream.

When floodplains are separated from the water source, through levees or other means, the natural process of equilibrium (which elevates the land through sediment deposits) is halted. This alters the historic flooding and sediment distribution patterns. In some cases sediments remain within the restrained channel, settling and reducing the capacity of the channel, increasing the likelihood of a water breach and flood. In many cases this is avoided by dredging of the channel and then mechanically depositing the sediment in desirable locations.

Alluvial fans develop where streams or debris flows gather speed in narrow passages then emerge into areas with greatly larger channel widths. A number of factors contribute to the severity including the degree of steep grades to flatter grades. Debris and water spill out in a fan shape depositing sediment and other debris on its way. The channels on these fans range from decimeters to several meters deep with the speed of the flows moving boulders sometimes taller than a house. In California these conditions are found at mountain fronts, in intermountain basins, and at valley junctions. Alluvial Fans are found where sediment loads are high, for example, in arid and semiarid mountain environments, wet and mechanically weak mountains, and environments that are near glaciers.

For example, in Los Angeles (LA) County, much sediment is the result of the naturally erosive mountains. The San Gabriel Mountains are mostly undeveloped because they are within the Angeles

National Forest. Other ranges (Santa Monica, Verdugos, Puente Hills) also have large areas of undeveloped land. The basins and valleys below these mountains are giant, relatively flat, alluvial plains. The depth of the sediment deposits indicates that a significant portion, and possibly the majority, of the sediment are from the mountains "parks."

The majority of LA County residents/businesses settled in these alluvial plains. These inhabitants were getting impacted by frequently fluctuating watercourse alignments resulting from high amounts of sediment deposition. They thus wanted more stable river/stream alignments. Development in LA County, starting with agricultural development, started altering the alluvial areas' surface and groundwater hydrology, prompting the need to capture stormwater for use and recharge. This situation led to the construction of dams, debris basins, channels and spreading grounds in LA County. The facilities were constructed to serve agricultural and urban areas. Most of the agricultural areas later became urbanized. Farms and subdivisions essentially planted themselves in the very sediment disposal areas Mother Nature set up.

Historic Context

Many California sediment management issues trace back to historic gold dredge activities beginning in the 1850's. California's Central Valley and Bay-Delta waterways experienced significant alteration caused by billions of tons of debris sent downstream from mining operations. Court action stopped these activities. However, impacts from these activities continue today.

The ditches used for mining are still in use for agriculture today. The channel infilling that occurred in many of the gold bearing streams is still also in evidence today, and many streams such as the Feather and Yuba, a hundred and fifty years later, are still adjusting their thalweg and profile. The thalweg is a line drawn to join the lowest points along the entire length of a stream bed or valley in its downward slope, defining its deepest channel. The thalweg thus marks the natural direction (the profile) of a watercourse. The thalweg is almost always the line of fastest flow in any river.

Some early reservoirs in the State (Clementine, Englebright, Camp Far West) were initially built to capture the sediment. There are still millions of tons of mining debris remaining on the floodplain. The USGS has measured the amount of sediment entering the SF Bay from numerous tributary streams and determined the historic changes in sediment yield over the long term.

Beyond the Delta and Central Valley, impacts from historic and current road building and land management practices continue to contribute to existing problems. Landslides are the major producer of sediment in the North Coastal and South Coastal areas. Road construction and poor timber harvesting techniques in the '50s and 60's resulted in an astronomical increase in sediment from the North Coast (almost wiping out the anadromous fishery), from which this part of the state is still recovering.

Additional system alterations also occurred as dams and channels were built for both water supply and flood protection. More and more structures changed what had been the natural hydrology, which then altered whatever system stability for sediments may have existed. So one of the normal functions of waterways to produce sediment, flush it through the system with some settling occurring in low areas (areas now typically used for farming or urbanization) and some moving to the sea to create shoreline replenishment, has also changed (Source- Craig Conner, USACE).

Management Focus

(Source - Brenda Goeden, BCDC)

California sediment management for water benefits typically focuses on three issues:

1. Source management - addressing the type and source of sediment.
2. Transport of sediment - addressing the systems transporting sediment.
3. Deposition of sediment - addressing the location where sediment deposits.

Management actions are tailored depending on the location they occur and the whether the management concerns involve a non-built environment (rivers, streams, creeks and flood plains) or a built environment (water control structures, flood levees, dams).

Source Management

Source management occurs to prevent soil loss and adverse sediment flows from land use activities that may, without proper management, cause erosion and excessive sediment movement. Routine source management activities prevent or mitigate excessive sediment introduced into waterways due to recreational use, roads and trails, grazing, farming, forestry and construction. Excessive flows affecting erosion and sedimentation may also result from land based events such as extreme fire incidents, high water volumes, wind, and other factors.

Farmers, transportation, planners, and recreation professionals are all aware that soil loss is an economic as well as an environmental and safety problem. Even so, many homeowners and other stakeholders may not be aware of sediment issues unless their homes and neighborhood streets are damaged by mudslides or stream bank or lakeshore erosion.

For example, in Los Angeles (LA) County, the original settlers were familiar with the problems posed by soil loss but the economic and environmental problems changed in nature as agricultural land was urbanized. At that point, the safety issue became more acute. Flood control facilities eventually lead to more inhabitants, especially those in the basins and valleys, becoming less aware of the sediment-induced safety problems the County used to face.

Understanding the cumulative impacts of all past, present, and proposed human activities in watershed is important in predicting the impacts of sediment on surface waters.

On the federal side, the US Department of Agriculture, Forest Service and Natural Resources Conservation Service, and the federal Bureau of Land Management and US Geological Survey all actively support California land management practices that incorporate erosion control and sediment management.

The US Fish and Wildlife Service, through its Landscape Conservation Cooperatives, is also engaged. Local entities, particularly Resource Conservation Districts, provide direct support for land managers as do stakeholder organizations such as the California and local Farm Bureaus and California Rangeland Trust. Other local and regional planning bodies, such as the Sierra Nevada Conservancy, Tahoe Regional Planning Agency and local planning commissions, support land use planning that in turn supports good sediment management.

Many State agencies and commissions are also actively engaged in sediment source management work, most notably CalFIRE and the Board of Forestry and Fire Protection (BOF). For over 20 years a group of advisors called the Monitoring Study Group (MSG) has, and continues, to: (1) develop a long-term program testing the effectiveness of California's Forest Practice Rules, and (2) provide guidance and oversight to the California Department of Forestry and Fire Protection (CAL FIRE) in implementing the program. The MSG has sponsored significant research on sediment management. This research informs CAL FIRE funded monitoring efforts designed to ascertain if forest practice rules, reducing unnatural sediment loads and protecting beneficial uses of water are being implemented and are effective.

Forestry and fire management for sediment, while more broadly a wildland concern, plays a unique role in the Tahoe Basin. In 2007, the devastating Angora Fire swept through the Basin burning approximately 3,000 acres and destroying 254 homes. At the time, there was confusion by property owners over the ability to manage fuel loads due to concern over the potential for these activities to cause erosion and sedimentation of Lake Tahoe. There were claims that due to this confusion, many property owners had not created defensible space around their homes. Investigations eventually found that a large number of houses burned due to firebrands from other burning houses rather than wildland fuel (United States Department of Agriculture 2007).

PLACEHOLDER Photo Y-1

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Nevertheless, the Lahontan Water Board subsequently adopted basin plan amendments and waivers of waste discharge requirements clarifying the water quality requirements related to fuel reduction activities.

Other state agencies, such as the Department of Food and Agriculture and the Department of Conservation provides significant leadership in this area through the development of Best Management Practices (BMPs). The University of California Extension Farm Advisors also play a critical role in supporting sediment management.

The Water Boards protect water quality through the issuance of waste discharge requirements which also serve as National Pollutant Discharge Elimination System (NPDES) permits for point source discharges subject to the Clean Water Act. NPDES permits related to sediment control include stormwater permits for municipal stormwater systems, highways and other thoroughfares and construction activities. Permits require the implementation of best management practices (BMPs) at constructions sites, outreach and education to residents, and consideration of the principles of low impact development for redevelopment and new development sites. The Water Boards provide guidance and training on the principles of low impact development to local government officials and permittees.

Dischargers that are not subject to NPDES permits are, by definition, nonpoint source (NPS) dischargers. NPS pollution is basically polluted runoff, which is diverse and each discharge may contribute only a small quantity of pollutants. Much of NPS pollution is sediment or pollutants carried by sediment. Federal guidance divides NPS pollution into the following six categories: (1) agriculture; (2) forestry; (3) urban areas; (4) marinas and recreational boating; (5) hydromodification activities; and (6) wetlands, riparian areas, and vegetated treatment systems. The Water Boards administer grant funding to develop and implement management practices to address NPS pollution such as development and implementation of the California Rangeland Water Quality Management Plan (http://www.waterboards.ca.gov/publications_forms/publications/general/docs/ca_rangeland_wqmgmt_plan_july1995.pdf).

A significant source of sediment is from urban run-off. The California Association of Storm Water Quality Agencies (CASQA) assists the Water Boards and municipalities throughout the state of California in implementing the National Pollutant Discharge Elimination System (NPDES) stormwater permits. One of the accomplishments of CASQA has been the development and dissemination of Best Management Practices (BMP) Handbooks. The BMPs help reduce unwanted delivery of sediment. These handbooks are designed to provide guidance to the stormwater community in California regarding BMPs for a number of activities affecting water quality and sediment management, including New Development and Redevelopment, Construction Activities, Industrial and Commercial Activities, and Municipal Activities (CASQA Web sites: http://www.casqa.org/ and http://www.cabmphandbooks.com).

Some local governments (city and county) have also begun to support Low Impact Development (LID), including it as part of their planning and development ordinances. LID features design elements, including hydromodification, that address sedimentation at the source. Resources, including model regulations, are available to help municipalities interested in incorporating sediment source management into their planning portfolios (http://www.epa.gov/owow/NPS/lidnatl.pdf, http://www.epa.gov/region1/topics/water/lid.html, http://efc.muskie.usm.maine.edu/docs/lid_fact_sheet.pdf, and http://www.huduser.org/publications/pdf/practlowimpctdevel.pdf, with model regulations at http://www.mass.gov/envir/smart_growth_toolkit/bylaws/LID-Bylaw-reg.pdf).

Road construction and maintenance in or near streams can also be a source of sediment. Photo Y-2 is a picture of the Caltrans I-5 Antlers Bridge realignment project on Shasta Lake. The photo shows the dramatic erosion and sediment controls required for a massive cut and fill project that threatens surface waters (Central Valley Regional Water Quality Control Board 2011).

PLACEHOLDER Photo Y-2

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Another transportation related source is Off-highway vehicle (OHV) use. OHV is a popular form of recreation in California and state, federal, local agencies and private entities provide recreational areas for this purpose. These OHV recreation areas need to implement a range of storm water best management practices to protect water quality. Additionally, unauthorized and unmanaged OHV areas can become erosion problems and discharge polluted storm water. With limited resources, maintaining and policing these areas can be a challenge.

Sedimentation can be a problem in the construction and operation of many mines. Increased potentials for erosion and sedimentation at mines are related to mine construction and facility location. Tailings dams, waste rock and spent ore storage piles, leach facilities, or other earthen structures are all potential sources of sedimentation to streams. Road construction, logging, and clearing of areas for buildings, mills, and process facilities can expose soils and increase the amount of surface runoff that reaches streams and other surface water bodies. These activities increase the potential for rill and interill erosion and can increase peak stream flows, increasing the potential for channel erosion. Unusually high peak flows can erode stream banks, widen primary flow channels, erode bed materials, deepen and straighten stream channels, and alter channel grade (slope) (U.S. Environmental Protection Agency 2003).

Sediment Transport Management

Sediment like water, flows downstream and supports both shorelines and habitats at the end of the line. Rivers and streams carry sediment in their flows. This sediment can be in a variety of vertical locations within the flow, depending on the balance between the upwards speed on the particle (drag and lift forces), and the settling speed of the particle.

In some cases, depending on the velocity, sediment will be transported downstream entirely as suspended load. In other cases it will move along the water bed as bed load by rolling, sliding, and saltating (jumping up into the flow, being transported a short distance then settling again). It may also move as a wash load.

PLACEHOLDER Box Y-2 Definitions

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There are generally a range of different particle sizes in the flow. It is common for material of different sizes to move through all areas of the flow for given stream conditions.

Sediment Transport management is the process of introducing or leveraging natural functions that create optimum sediment transport. This involves managing the speed and flow of the sediment conveyance and the natural or built structures to achieve a properly distributed balance of sediment types in the habitat. Properly managed transport of sediments will result in the best deposition of sediments.

For example, sand bypass structures in flood control channels are starting to see some use. Such structures placed into flood channels allow the coarse-grained sediments to be diverted to a settling pond where they can be excavated and used for construction, while the fine-grained sediments are diverted to a wetland where they add to the size of the wetland. (More on this method can be seen at the web site http://www.ocwatersheds.com/Documents/wma/LaderaRanch_HNouri.pdf and http://www.ocwatersheds.com/Documents/wma/Integrated_Mgmt_of_Stormwater_Sediment_and_Pollutants_in_Ladera_Ranch.pdf.)

Sediment Deposition Management

The goal of sediment deposition management is to achieve optimum benefits from sediment deposits and mitigate negative impacts. As noted previously, properly distributed sediment has numerous beneficial outcomes such as:

- Fine grain sediments supporting existing habitat and for adapting to sea level rise.
- Gravel remaining in rivers and stream beds for habitat and river bed stability.
- Sand to sustain beaches both for recreation and habitat.
- Fine silts and clays introduce nutrient rich materials and nutrient cycling.
- Deposits creating buffers (particularly offshore) that reduce climate change and storm surge impacts.

Deposition management also includes techniques to prevent and mitigate the negative aspects of sediment including

- Siltation impacting the capacity of floodways and water supply systems (including dams).
- Siltation impacting navigation.

The US Army Corps of Engineers maintains primary jurisdiction for waterway and navigational concerns and specific interests for many dams, with the Bureau of Reclamation also maintaining a significant federal role in this area. The state Department of Water Resources and the State Lands Commission serve as state counter-parts to the federal agencies with other agencies, such as the U.S. EPA and State Water Boards, and State and federal agencies responsible for fisheries and recreation.

Dredging

Dredging is a critical sediment management activity supporting commercial shipping, homeland security, fishing, recreation and more. In just the San Francisco Bay/Delta Estuary these activities fuel a substantial maritime-related economy of over $7.5 billion annually. However, the facilities supporting these activities are located around the margins of a bay system that averages less than 20 feet deep, while modern, deep-draft ships often draw 35 to 40 feet of water or more. Extensive dredging — in the range of 2 million to 10 million cubic yards (mcy) per year — is therefore necessary to create and maintain adequate navigation channels in order to sustain the region’s diverse navigation-related commercial and recreational activities. Effective management of the large volumes of dredged material generated throughout the Estuary is a substantial challenge (source: http://www.bcdc.ca.gov/pdf/Dredging/EIS_EIR/chpt3.pdf).

Dredging is also used to maintain the capacity of other infrastructure. For example, LA County Flood Control District has been undertaking sediment removal from its reservoirs since the 1930s, to protect system capacity.

Determining how the dredged material will be managed involves a variety of factors related to the dredging process including environmental acceptability, technical feasibility, and economic feasibility. More detailed descriptions of dredging equipment and dredging processes are available in Engineer Manual (EM) 1110-2-5025 (U.S. Army Corps of Engineers 1983), Houston (1970), and Turner (1984).

Dredging directly impacts water quality, sediment management and contaminant control. Dredging operations may also reduce water quality by introducing turbidity, suspended solids, and other variables that affect the properties of the water such as light transmittance, dissolved oxygen, nutrients, salinity, temperature, pH, and concentrations of trace metals and organic contaminants if they are present in the sediments (U.S. Navy 1990).

Depending on the location of the dredging, deepening navigation channels can increase saltwater intrusion (since saline water is heavier than freshwater), potentially impacting freshwater supplies and fisheries. Dredging can also increase saltwater intrusion into groundwater aquifers (e.g., the Merritt Sand/Posey formation aquifer in the Oakland Harbor area), with consequent degradation of groundwater quality in shallow aquifers (U.S. Navy 1990).

Dredging may reintroduce contamination into the water system by re-suspending pollutants. Metal and organic chemical contamination is widespread in urban shipping channels due to river run-off and municipal/ industrial discharges. Chemical reactions that occur during dredging may also change the form of the contaminant. These chemical reactions are determined by complex interactions of environmental factors, and may either enhance or decrease bioavailability, particularly of metals.

In California, dredged material, while potentially a dilemma to dispose of may also be repurposed for significant benefits when used for a variety of purposes as fill. When this occurs the economics of disposal may be altered. The introduction of benefit may also increase a real cost for sediment removal as the sediment may be a public trust asset and thus subject to mineral extraction fees and other restrictions. (Lands [including the minerals and sediment of those lands] under the ocean and under navigable streams are owned by the public and held in trust for the people by government. Because public trust lands are held in trust for all citizens of California, they must be used to serve statewide, as opposed to purely local, public purposes.)

Dam Removal

In addition to dredging of dams and sediment basins, there has been substantial interest in recent years related to dam removals. Analysis of dam removal proposals features significant discussion of sediment management. Over XXX dams (that are at least 6 feet in height) exist in California today, and they serve many different purposes. [Need reference for California Dam numbers.] These purposes include water supply for irrigation, municipal, industrial, and fire protection needs; flood control; navigation; recreation; hydroelectricity; water power; river diversion; sediment and debris control; and waste disposal (Heinz Center 2002, American Society of Civil Engineers 1997).

While the great majority of these dams still provide a vital function to society, some of these dams (source: http://www.usbr.gov/pmts/sediment/kb/ErosionAndSedimentation/chapters/Chapter8.pdf) may need to be decommissioned for various reasons including economics, dam safety and security, legal and financial liability, recreation, ecosystem restoration (including fish passage improvement), and site restoration (including to rehabilitate cultural or historic properties). Management of sediments behind such dams has been an important element of negotiations related to decommissioning.

Coastal Management

The California Coastal Sediment Management Workgroup (CSMW) was established by the U.S. Army Corps of Engineers (Corps) and the California Resources Agency (Resources Agency) in 1999 to develop regional approaches to protecting, enhancing and restoring California's coastal beaches and watersheds through federal, state and local cooperative efforts.

The mission of the CSMW is to identify and prioritize regional sediment management needs and opportunities along the California coast, and provide this information to resource managers and the general public. The goal is to assist in addressing coastal sediment management issues, and develop strategies to streamline sediment management activities. Such issues may include coastal erosion, recreational opportunities, dredging, and sediment flow through coastal watersheds.

The CSMW was formed in response to concerns about shore protection and beach nourishment needs in California. The consensus was that coastal sediment management is a key factor in developing strategies to conserve and restore California's coastal beaches and watersheds.

In addition to the Corps and the Resources Agency (including Agency departments and Commissions such as the Ocean Resources Management Program, Department of Boating and Waterways, Department of Park and Recreation, California Coastal Commission, State Lands Commission, State Coastal Conservancy, California Geologic Survey and Department of Fish and Game.), the California Coastal Coalition (CalCoast) participates. CalCoast is a non-profit organization comprised of cities, counties and regional government agencies along the coast. CalCoast advises the CSMW with local feedback and updates regarding projects and studies underway in coastal communities.

Other entities, including the federal Minerals Management Service and U.S. Geological Survey, and the California Department of Transportation (CalTrans), participate in an advisory capacity.

Together, the CSMW oversees the California Coastal Sediment Management Plan (SMP) (http://www.dbw.ca.gov/csmw/smp.aspx). The SMP will identify and prioritize Regional Sediment Management (RSM) needs and opportunities along the California coast, provide this information to resource managers and the general public, and streamline sediment management activities.

Tools, documents and RSM strategies developed to date are available on the CSMW website (www.dbw.ca.gov/csmw). Examples of assistance to Coastal managers from components of the SMP could include:

- Identifying and prioritizing sediment-related projects.
- Navigating though environmental and regulatory review.
- Developing opportunistic sand programs.
- Developing Environmental Impact Statements and Assessments.
- Developing governance needed for effective implementation of sediment management programs.

Connections to Other Resource Management Strategies

Many other resource management strategies in the Water Plan Update 2013 share a connection with Sediment Management. More information on each of these resource management strategies can be found in their respective chapter under the Resource Management Strategies section of the CWP Update 2013.

- **Land Use Planning and Management:** The way in which land is used—the type of land use, transportation, and level of use—has a direct relationship to sediment management. One of the most effective ways to reduce unnatural sediment loads is through land use planning that is fully abreast and reflective of applicable sediment and hydrology practices. This includes site design to reduce the introduction of unnatural loads of sediment into waterways.

- **Flood Management:** Floods have a major role in transporting and depositing unconsolidated sediment onto floodplains. Erosion and deposition help in determining the shape of the floodplain, the depth and composition of soils, and the type and density of vegetation. Sediment transport dynamics can cause failure of adjacent levees through increased erosion or can reduce the flood-carrying capacity of natural channels through increased sedimentation. Sediment is also a major component of alluvial fan and debris-flow flooding.
- **Watershed Management:** Watersheds are an appropriate organizing unit for sediment management. Restoring, sustaining, and enhancing watershed functions are goals of sediment management in the context of IWM.
- **Stormwater (Urban) Runoff Management:** Urbanization creates impervious surfaces that reduce infiltration of stormwater and can alter flow pathways and the timing and extent of sediment introduction into the system. The impervious surfaces increase runoff volumes and velocities, resulting in stream bank erosion, and potential unnatural sediment distribution downstream. Watershed approaches to urban runoff management attempt to manage sediments to mitigate negative impacts and support beneficial uses in a manner that mimics the natural hydrologic cycle.
- **Agricultural Lands Stewardship:** Agricultural land stewardship directly links to management of erosion and soils protection. Proper management in both private and public land ownership, prevents disruptive development patterns, and supports sediment aware farming and ranching practices.
- **Forest Management:** Forestation practices can influence sediment transport from upland streams. Wildfires can reduce surface water infiltration, which can cause additional erosion and debris flooding.
- **Conveyance:** Depending on design, conveyance facilities can either trap, scour or in result in other unnatural distribution of sediments. Sediment overload can significantly reduce system capacity.
- **Surface Storage:** Similar to conveyance, sediments may be trapped behind infrastructure or otherwise unnaturally distributed. This results in a loss of system capacity.
- **Outreach and Education:** Outreach is needed to regularly educate the public on sediment management concerns. Outreach is also needed to educate the public on the natural, beneficial functions of sediment.
- **Ecosystem Restoration:** Native riparian and aquatic animal and plant communities of California are dependent on effective sediment management. These ecosystems are dynamic in nature and highly productive biological communities given their proximity to water and the presence of fertile soils and nutrients. Many opportunities for improvement in both sediment management and ecosystem restoration occupy the same spatial footprint and are affected by the same physical processes that distribute water and sediment in rivers and across floodplains. Sediment management projects that result in protected and restored ecosystems will likely create increased effectiveness, sustainability, and public support.
- **Pollution Prevention:** Well designed pollution prevention efforts improve water quality by filtering impurities and nutrients, processing organic wastes, controlling erosion and sedimentation of streams.

- **Water-Dependent Recreation:** Water and land based recreational activities can contribute to unnatural erosion and sediment production. Conversely, high sediment loads can negatively impact recreation, particularly boating, fishing and swimming.

Potential Benefits of Sediment Management

It is essential to manage water and sediment with both in mind. Beneficial use of sediment is important because it is a limited and valuable resource.

As noted above sediment has a dual nature.

Too much sediment can lead to:
- Obstructed channels.
- Overflowing rivers.
- Smothered reefs.
- High turbidity that blocks sunlight.
- Smothered salmonid spawning beds.
- Water treatment plant filtration obstructions.

Too little sediment can lead to:
- Disappearing beaches.
- Eroded streambeds and riverbanks.
- Wetlands losses.
- Altered river profiles.

Sediment can also be used for:
- Construction material.
- Beach nourishment.
- Wetland restoration.
- Replacement of agricultural soil.
- Levee building.

The ultimate benefits of sediment management relate to preventing the negative results of too little or too much sediment and repurposing sediment for beneficial uses. As noted above, benefits associated with reducing impacts to navigation and commerce alone may achieve cost savings by millions of dollars. A similar statement can be made about the management of sediment that accumulates at reservoirs and debris basins and is prevented from flooding communities downstream.

Source Sediment Management

An average of 1.3 billion tons of soil per year are lost from agricultural lands in the U.S. alone due to erosion (http://landresources.montana.edu/SWM/PDF/Final_proof_SW3.pdf). Considering soil formation rates are estimated to be only 10–25% of these erosion rates (Jenny, 1980), loss and movement of soil by erosion is a major challenge for today's farmers and land managers. Soil erosion over decades can have detrimental effects on productivity and soil quality because the majority of soil nutrients and soil organic matter (SOM) are stored in the topsoil, the soil layer most affected by erosion. For these reasons and more, sediment management for soil sustainability has numerous multiple benefits far exceeding the scope of the Water Plan.

In the case of urban land management, use of LID and other sediment management practices can reduce negative impacts of storm water run-off, by maintaining the natural production of sediment and improving permeability of drainage areas. Land use goals for sediment may also improve flood management by improving the flood system hydrology.

Coastal Sediment Management

In the coastal waterways sediment can serve to furnish material needed to replenish the beaches along the coastal areas. If the sediment is dredged from navigation channels or harbors the dredged material can be used for such construction purposes as highway sub-base material and flood control levees. (This is a very rare occurrence at most locations because re-handling and transportation expenses make it cost-prohibitive.)

The dollar value of this improved protection is nearly incalculable, not just for those that own coastal structures, but for the stunning number of infrastructure improvements that support the state including power generation, major transportation assets, water systems, etc., and the dollar value of the recreation and tourism industries to the state's economy.

Fisheries

In terms of water management, natural amounts of coarse-grained sediment (sand and gravel) that has entered the stream and river system has many beneficial uses. In the inland waterways it can serve as a substrate for fish spawning areas. Enhancing the sustainability of the fishery benefits not only the State's fishing industry but is also a water supply benefit as a declining fishery may lead to reductions of water exports. Protection of listed fish (e.g., Santa Ana sucker) and wildlife (southwestern willow flycatcher) are also beginning to interfere with the exercise of rights to locally generated surface and ground water.

Regional Sediment Management

Regional Sediment Management (RSM) refers to a practice where sediment is managed over an entire region. Managing sediment to benefit a region potentially saves money, allows use of natural processes to solve engineering problems, and improves the environment. As a management method, RSM:

- Includes the entire environment, from the watershed to the sea.
- Accounts for the effect of human activities on sediment erosion as well as its transport in streams, lakes, bays, and oceans.
- Protects and enhances the nation's natural resources while balancing national security and economic needs.

This is a growing concept nationwide and has economic benefits. The Army Corps of Engineers has a primer on Regional Sediment Management at: http://www.spur.org/files/u35/rsmprimer.pdf

RSM is an approach for managing projects involving sand and other sediments that incorporates many of the principles of integrated watershed resources management, applying them primarily in the context of coastal watersheds. While the initial emphasis of RSM was on sand in coastal systems, the concept has been extended to riverine systems and finer materials to more completely address sources and processes important to sediment management. It also supports many of the recommendations identified by interagency working groups on improving dredged material management. Examining RSM implementation through demonstration efforts can provide lessons not only on improved business practices, techniques and tools necessary for managing resources at regional scales, but also on roles and relationships important to integrated water resources management.

More about RSM can be found in the American Society of Civil Engineers written Policy Statement 522, on Regional Sediment Management at: http://www.asce.org/Content.aspx?id=8638

Beneficial Uses for Dredged Material

(http://www.bcdc.ca.gov/pdf/Dredging/EIS_EIR/chpt3.pdf)

Beneficial uses include a wide variety of options that utilize the dredged material for some productive purpose. Dredged material is a manageable, valuable soil resource, with beneficial uses of such importance that they should be incorporated into project plans and goals at the project's inception to the maximum extent possible. For example:

- Habitat restoration/enhancement (wetland, source, island, and aquatic sites including use by fish, wildlife, and waterfowl and other birds).
- Beach nourishment.
- Aquaculture.
- Parks and recreation (commercial and noncommercial).
- Agriculture, forestry, and horticulture.
- Strip mine reclamation and landfill cover for solid waste management.
- Shoreline stabilization and erosion control (fills, artificial reefs, submerged berms, etc).
- Construction and industrial use (including port development, airports, urban, and residential).
- Material transfer (for fill, dikes, levees, parking lots, and roads).
- Multiple purposes (i.e., combinations of the above).

Detailed guidelines for various beneficial use applications for dredging are given in the USACE Engineering Manual 1110-2-5026 (1987) (http://140.194.76.129/publications/eng-manuals/EM_1110-2-5026/toc.pdf). The USACE also has a Sources Testing Manual (Evaluation of Dredged Material Proposed for Disposal in Waters of the U.S.—Testing Manual: Inland Testing Manual) that gives methods for determining what contaminants might result in a waterway following dredging and disposal of the dredged material into an upland dewatering. This manual can be found at: http://www.epa.gov/owow/oceans/regulatory/dumpdredged/pdf/itm_feb1998.pdf.

System Capacity and Materials Use

There are multiple benefits of managing the sediment that accumulates at reservoirs and debris basins. If sediment that accumulates in reservoirs is not removed, storage capacity for water is reduced. As an example, for those flood control reservoirs which have a water conservation purpose (and most of them do), water captured in the reservoirs is used to recharge local groundwater aquifers. Sediment that is sluiced from a reservoir may impact infiltration rates at spreading grounds used to replenish groundwater aquifers.

If sediment is not removed from reservoirs and debris basins, their ability to provide flood risk management and water supply benefits is diminished.

Maintaining Regulatory Requirements Related to Sediment

Many problems related to maintaining water quality and suitable physical habitats in streams is due to sediments, for reasons explained above. The State Water Resource Control Board is developing narrative and numerical objectives for the macroinvertebrates and algae, and for sediment composition of the streambeds themselves. A benefit of sediment management will be to help achieve these new biological and physical habitat objectives.

Special Situations

The battle to retain Lake Tahoe as a pristine visual jewel is an unusual sediment case study. Here the sediment concern is very fine sediment (that less than 20 microns) that affects the clarity (and people's aesthetic enjoyment) of Lake Tahoe. In this case, the problem may be unique and so the extensive costs of Basin-wide improvements would not translate to other situations. Even so, many best practices for sediment management have been pioneered in the Basin and these can translate to other programs. (The relatively gross estimates of capital costs for implementation for the entire Tahoe Basin for the first 20 years is estimated at $1.5 billion, with annual operation and maintenance at more than $10 million.) Additionally the benefits of the investment have been equally evaluated and considered of national interest.

Potential Costs of Sediment Management

The cost of implementing Sediment Management to achieve Water Benefits varies widely depending on the sector and purpose of the management. As a sample, significant resources are allocated as noted below.

Natural Resources Conservation Service (NRCS) - From 2007 to 2012 the NRCS obligated over 91 million dollars in California for conservation practices to address soil erosion and sedimentation on agricultural land. These practices are recommended to reduce erosion, prevent the transport of sediment, or trap sediment before it leaves the farm or field (Source - Rebecca Chandler, NRCS).

Forest Service - Overall watershed restoration project costs on National Forests are close to $2,000/acre, and most of these projects have benefits in terms of reducing erosion and sediment transport. Meadow restoration using the pond and plug approach is about $1,000/acre. Road decommissioning costs about $16/cubic yard of sediment (reduction in potential erosion) (source - Barry Hill, USDA Forest Service).

Water Boards—When the Water Boards adopt a basin plan amendment that includes an implementation program that affects agriculture, the Board must include the costs for agriculture to implement the control program. An example is the Garcia River (http://www.waterboards.ca.gov/northcoast/water_issues/programs/tmdls/garcia_river/).

The staff report estimated the cost to implement the sediment reduction efforts described in the Action Plan at $5 million plus unquantified costs which include inventory costs and the opportunity cost of the volume of unharvested timber, up to an additional $2 million.

LA County Flood Control District (LAFCD)- Based on the alternatives included in the LACFCD's Draft Sediment Management Strategic Plan (April 2012), the cost to manage the Strategic Plan's 67.5-MCY planning quantity could be as much as $1.2 Billion over the 20-year planning period (2012 to 2032).

Corps of Engineers San Francisco District—Staff costs for implementing the Long Term Management Strategy for Dredged Material in San Francisco Bay and Delta. - ?

Corps of Engineers San Francisco, Sacramento, and Los Angeles Districts - Staff costs for implementing the oversight of continuous navigation channel maintenance. ?

California Sediment Management Workgroup—Staff costs for implementing the California Sediment Management Master Plan - ?

California Construction Companies—Costs for implementing sediment control at construction sites, in compliance with SWRCB stormwater permit requirements - ?

Major Issues Facing Sediment Management

The issues facing implementation of Sediment Management are similar to those experienced by related Resource Management strategies, including the following:

- The need to balance environmental impacts, social impacts, feasibility, and cost.
- Different stakeholders have different needs and a different understanding of the need to manage sediment.
- Stakeholders and regulators lack understanding of the natural regional sediment regimes and attempt to address issues on a statewide basis.
- Urbanization and other structural limitations may preclude introduction of truly natural regimes.
- Conflicting Federal, State and local regulations and agency missions, and regulators' unwillingness to compromise to navigate these conflicts for the good of a region.
- Significant nimbyism.
- Budget constraints.

Issues facing the three management approaches follow.

Sediment Source Management

Lack of Techniques for Coarse-Grained Sediments Management

Additional efforts are needed to support availability of the coarse grained fraction of the natural supply of sediments (sand and gravel), but not the fine-grained sediments (silts and clays) from the watershed to enter the streams and rivers so they can replenish these sediments in fish spawning areas, and also move toward the ocean thereby replenishing the sand along the coastal beaches. Research is needed in this area, as not many techniques now exist for coarse-sediment bypassing in inland watersheds.

In particular, efforts must be made to keep coarse-grained sediments available and clean in salmon-spawning rivers and streams. Erosion in unstable watersheds brings fine-grained sediments into the channels which may settle and cover the coarse-grained sediments needed for spawning, thus elimination them from use in the spawning process. (A web site describing these needs is at: http://www.joewheaton.org/Home/research/projects-1/past-projects/spawning-habitat-integrated-rehabilitation-approach-shira-.)

Barriers to Supplying Coarse-Grained Sediments to the Coastal Beaches

Many of the beaches along the coastline are receding because their natural supply of coarse-grained sediments from inland rivers has been stopped by dams, covering of areas by impermeable pavements, stormwater controls, changes to the ground surface, and other land use practices. As noted above, the CSMW, a joint effort of the Army Corps of Engineers and the State of California Resources Agency, is working toward this effort but challenges remain as agencies aim to work collaboratively and overcome the traditional silos that create this dilemma.

Another challenge to beach replenishment is transporting sediment through beach neighborhoods in order to get to the beaches. Also, there appears to be a non-recognition that natural fluvial processes in some regions may not necessarily deliver the heavier coarse-grained sands (they drop out in upstream areas), but instead the lighter suspended silts to the coastlines. Such material is not as pleasing to beachgoers.

In some California locations, sandy beaches (primarily used for recreation) are manmade and require continual maintenance and support.

Controlling Excessive Sediment from Entering Eutrophic Waterways

Eutrophic waterways typically have a lot of minerals and organic nutrients that benefit plants and algae. They often appear dark and have poor water quality. This occurs when certain nutrients such as phosphorus are absorbed on fine-grained sediments and carried into the waterways and lakes. These nutrients can cause algae blooms in a lake which create a lack of oxygen resulting in fish kills. The sediments themselves result in a reduction in light clarity in lakes, thereby harming the food chain and also reducing the aesthetic quality of the lake. Controlling these conditions is challenging and a failure to do so, especially harmful at Lake Tahoe.

Implementation of Regional Sediment Management

Practical implementation of RSM, however, faces obstacles. RSM requires a long-term (multi-year) view; yet it may be difficult for stakeholders and regulatory agencies to adopt long-term views. Federal, State and local regulations are often in conflict with each other. Successful RSM requires compromise from everyone. Regulators do not compromise; reasons cited include non-recognition of others' public charge and fear of exposure to 3rd party lawsuits. Additional challenges RSM faces are: finding re-use projects/activities that occur at the same time sediment needs to be removed; long distances between potential users and the sediment source; and opposition from inhabitants/stakeholders along the sediment transport route.

Limited Options Due to Other System Requirements

In some cases, the optimum sediment management approach may be precluded due to other system requirements or previously implement decisions and goals.

As an example, a major shift in land use and population patterns may not be feasible. On a specific project level large amounts of sediment already accumulated behind reservoirs prohibit the immediate implementation of a different approach to sediment management (e.g. a reservoir may need cleanout out to its original condition before a sediment flow through approach can be implemented).

Sediment Transport Management

Lack of Monitoring on Stable (Reference) Sediment Conditions in Watersheds

There is benefit in achieving and maintaining watersheds in a stable condition as it relates to the generation and transport of sediments from the land surface to the surface streams. To do so requires understanding (assisted by geomorphic assessments on channels) and monitoring to determine when watersheds are stable or unstable. Management without these tools cause stream channels to degrade in their geomorphic form and not support the native aquatic biological habitat, and affect domestic water supplies (filtration). Unstable sediment conditions may also result in disruption of flood control structures.

Maintaining Clean Sediments

Clean sediments are those which have not been contaminated by hazardous substances. For a variety of reasons, including control of the source of the substances, keeping these substances out of the waterways and sediment is a challenge. Total Maximum Daily Load (TMDL) documents for clean sediment control in California's waterways are being written by the State Water Resource Control Board. (Info on the control of clean sediments is here: http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/upload/NSLReport17.pdf).

Achieving Broad Support for Establishing and Implementing Biological Objectives in Streams

Excessive sediment in streams, or lack of natural sediment loads can be detrimental to the aquatic life. Biological objectives for suspended sediment are being established because of their effect upon the fishery and algae. Efforts are being made to control the deposition and erosion of sediments from the stream channel bottoms because of their effects on aquatic invertebrates. Watershed efforts are needed to control sediment generation and runoff to the streams to meet biological objectives. The State Water Resources Control Board is establishing biological objectives, which will include those for suspended sediment as well as deposited sediments. (A web site containing this information is available at: http://www.waterboards.ca.gov/plans_policies/biological_objective.shtml.) Achieving broad support for establishing and implementing biological objectives is sometimes met with resistance.

Sediment Deposition Management

Securing Deposition Locations

Finding deposition locations has become increasingly difficult and expensive, due to regulatory constraints/ requirements or opposition from those adjacent or along the haul routes to the deposition sites.

Another challenge to disposing of/reusing dredged sediment on dry land is de-watering the sediment. Due to the high content of water, the de-watering areas need to be quite large, and a region may not have sufficient space available.

Most often the beneficial uses that can be made of dredged material from inland channels is not known until the Regional Water Quality Control Boards analyze the data collected during dredging and later make decisions on any potential beneficial uses that can be made of that material. Often these delays can be costly and tie up the emptying and use of the storage sites for future projects.

Additional challenges to using sediment for beneficial uses are: finding beneficial use projects that coincide with the timing of sediment removal; long distances between the sediment removal site and the beneficial use site; encountering regulatory obstacles to using the beneficial use site; and encountering steep disposal fees at the beneficial use site.

Handling Contaminated Sediments

Management of contaminated sediments can be challenging. There are limited resources for cleaning of the sediments and disposal or containment of contaminated ones. The USACE has a National Center of Expertise for handing contaminated sediments, at: http://el.erdc.usace.army.mil/dots/ccs/ccs.html.

Contaminated Sediment Impacts during Dam Removal

One potential problem in dam removal is when the sediments contain toxic constituents. For example, some of the reservoirs behind dams in the Central Valley acted as sediment catchment sites for mining activities and contain mercury and other toxic trace metals. The sediment in other reservoirs may contain toxic constituents resulting from pesticides or other organic chemicals originating in the watershed. Thus the sediments behind dams must first be analyzed for toxic constituents before the sediment can be considered for removal and disposal into the environment.

Regulatory Impediments

Regulatory and management frameworks involving sediment typically are designed to support specific uses. As a result they involve multiple agencies and jurisdictions not necessarily accommodating of the complexities of managing all the aspects of sediment sources, transport and deposition. As a result, sediment related projects and/or multiple benefit projects may not be feasible due to timing, costs and conflicts related to the desired deposition of the sediment.

Implementation of statewide standards do not consider that in some regions sediment is a natural component of runoff in watersheds that are by nature of their geology highly erosive. For some agencies sediment is looked on as a pollutant. Yet aquatic species native to such watersheds would be tolerant of high sediment flows.

Data Availability

A number of issues related to integrated management and better planning and coordination could be improved with better data availability. For example:

- Better planning and decision making could occur with coordinated mapping efforts to allow agencies to better consider upstream and downstream impacts prior to decision making.
- On-going monitoring would allow better adaptive management and an evaluation of management methods being used.
- Improved forecasting and modeling would support long term and strategic planning.
- Development of sand and sediment budgets would assist agencies in planning and reduce regulatory conflicts.

Sediment and Climate Change

Climate change is already occurring and is projected to continue to alter temperature and hydrology patterns in the State. Climate change studies project an increased frequency of extreme weather; higher temperatures, larger and more frequent wild fires, longer droughts and more precipitation falling in the form of rain than snow. These changes will bring shifts in vegetative species, heighten soil exposure and cause flooding to already vulnerable lands, adding a heavy mix of sediment and debris to storm waters. Coupled with sea level rise, which increases beach erosion and coastal flooding, climate change will amplify the already difficult task of sediment management.

Adaptation

Adaptation will necessitate projecting where excessive sediments will source and accumulate, and building controls that will allow for effective management of those sediments. With climate change expected to bring wetter winter and drier summers, erosion will become an even greater threat to California lands and sediment management. Two adaptation strategies would provide benefit in light of climate change. Floodplain restoration, which allows for natural deposits of beneficial sediment, would serve dual purposes of managing sediment and replenishing soil. Excess, clean sediment can be beneficially used on eroding beaches and agricultural lands, mimicking natural processes.

Warmer temperatures and higher levels of CO2 may, in some cases, lead to increased vegetation. Vegetation can minimize run-off and lessen erosion; preventing sediments from entering waterways. Effective management of landscapes including the planting of heat and drought tolerant native vegetation around waterways will minimize sediment loads.

Mitigation

Sediment management is a continuous process that can result in high GHG emissions. Dredging and channel clearing is necessary to ensure adequate capacity for flood protection, water supply and navigation, but is a constant source of GHG emissions from fossil-fuel powered equipment. Transporting sediment offsite can also be a large source of GHGs. It is important that projects managers are constantly scrutinizing the way they are doing things and staying up-to-date on the newest research and technologies to see if there are ways to reduce the impacts of these necessary projects.

(Source - Jennifer Morales, DWR)

Recommendations to Facilitate Sediment Management

Sediment Source Management

1. The Governor’s Office of Planning and Research should develop model General Plan Policies that support optimum sediment source management.
2. Federal, Tribal, State, Regional and Local agencies and stakeholders should support and participate in Regional Sediment Management—For those sediments which must be dredged to keep the waterways open to navigation or to support flood control efforts, support those efforts to use that sediment beneficially within the region. One possible use of the sediment is for levee construction that can direct the floodwater to the most desirable location.
3. The State Lands Commission and other responsible agencies should scrutinize in-stream and beach Sediment Mining Permits - On a case-by-case basis scrutinize, and challenge as necessary, sediment-mining permits which allow the removal of coarse-grained material directly from stream beds or from coastal beaches—While such permits may be satisfactory in some instances, in other instances such permits reduce the sediment needed for fish spawning beds and for beach replenishment along the coast.
4. The State should implement the requirements recommended by the California Association of Storm Water Quality Agencies (CASQA) for stormwater discharge control programs which are (1) technically and economically feasible, (2) provide significant environmental benefits and

protect the water resources, (3) promote the advancement of stormwater management technology, and (4) effect compliance with State and Federal laws, regulations and policies. Reducing or controlling stormwater discharges keeps watershed and industrial pollutants from running into the waterways, thereby improving water quality.

Sediment Transport Management

5. The State should support research and design of fine-grained and coarse-grained sediment bypass structures—This will allow the coarse-grained sediment to be separated and either enter the streams and serve its many beneficial uses there, such as for fish spawning grounds and the restoration of coastal beaches, or be trapped in detention ponds where it can be excavated and beneficially used. The fine-grained sediment will be separated and can be used for wetland establishment or other uses. The separation and removal of fine-grained sediment with their attached nutrients can help improve the water quality in lakes having excessive eutrophication.
6. The Water Boards should work with stakeholders to secure broader support of sediment "Total Maximum Daily Load" (TMDLs) and stakeholder based implementation plans.
7. The State should support the use of watershed mathematical models, when the occasion demands, which can track sediment from source to transport in the streams. Such models (such as SWAT, HEC-HMS, and HSPF) need adequate calibration and validation, but once done these models can help to manage the sediments throughout the watershed. The watershed model can also predict the concentrations of other water quality substances in the water.
8. The Resources and CA Environmental Agencies should implement an integrated approach to achieve the maintenance of stable watersheds—A stable watershed is one where sediment yield mimics the natural sediment production that would occur in the absence of anthropogenic conditions. If the watershed is not stable assist in efforts to make it so. Maintaining a stable watershed will have many benefits to downstream uses of the water. Excessive sediments are the number one cause of water quality violations in the nations streams, and having stable watersheds will reduce the number of these violations.

Sediment Deposition Management

9. The Water Boards Should develop regionally based sediment screening criteria so that agencies could know sooner what the use of the dredged material could be and plan accordingly. (One of the Boards does have this screening criteria developed.) Establish potential uses of dredged material, depending upon its quality in advance. The upland sites receiving dredged material can then be emptied sooner and be available for additional dredged material. This will assist in maintaining the shipping channel in operational condition.
10. The State should prepare Sand Budgets for each watershed. Comparisons of these sand budgets over time for each watershed will tell of the effect of source Best Management Practices in affecting sand transport, will be of use in determining how well sand is moving toward the coastal beaches, will allow comparison of sand generation in the watershed to that removed by instream sand removal permits, and will tell which watersheds are the best in generating sand.
11. The State should determine the Sediment Yields of Watersheds—These yields (such as in tons/square mile/year) can be determined at monitoring sites which have matching pairs of suspended sediment concentrations and instantaneous flow rate measurements. Knowing the sediment yields will help in managing dredging budgets for the navigation channels.
12. Dredging permit applicants should perform sediment testing prior to Dredging—Test the sediments before dredging begins to ascertain the water quality effects that may occur. The USACE

has a Sources Testing Manual that gives methods for determining what contaminants might result in a waterway following dredging and disposal of the dredged material into a source dewatering site. Knowing the quality to be expected can help in the design of the sources disposal site and thereby improve the water quality in the water body itself.

Data Acquisition and Management

13. The Federal and State government should support geomorphic assessments of streams—This is the method needed to determine if a watershed is stable as regards sediment production. If a watershed is unstable then regulatory agencies can issue stormwater NPDES permits and require BMPs to re-establish stability. An unstable watershed can affect sediment movement in such adverse ways as disrupting the physical habitat of the channel, thereby violating the biological objectives of the channel and affecting the fishery.
14. The Federal and State government should support monitoring programs that will measure suspended sediment concentrations and instantaneous flow rates—This will allow sediment yields from the watershed and sediment budgets for the downstream areas to be determined. They should also establish monitoring protocols that produce scientifically-defendable data of comparable quality throughout the State. Such monitoring will add to the water quality data base of the waterway.
15. The State should establish a Sediment Data Base and cooperate with others who may be obtaining sediment data in a watershed so that a common data base is used that is accessible to all users.
16. All responsible agencies should utilize a common GIS Mapping framework and use GIS to overlay maps relating sources of excessive sediment production in watersheds with areas having sediment problems in the stream in those watersheds.

Regulatory Reconciliation

17. The California Department of Agriculture, and State Resources and Environmental Agencies should convene a stakeholder working group to recommend methods to overcome sediment management regulatory conflicts.
18. The stakeholder group in recommendation #17 should also evaluate needs for outreach and education on sediment management and offer recommendations for next steps to address that need.

PLACEHOLDER Box Y-3 Case Study: Sediment Management Related to Recreational Use

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

PLACEHOLDER Box Y-4 Case Study: Los Angeles County Flood Control District — Impacts of the 2009 Station Fire

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

PLACEHOLDER Box Y-5 Case Study: California American Water Files Application for Removal of Silted-Up Dam — Dredging Not Feasible

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

PLACEHOLDER Box Y-6 Case Study: Clear Lake — Algae in Clear Lake

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

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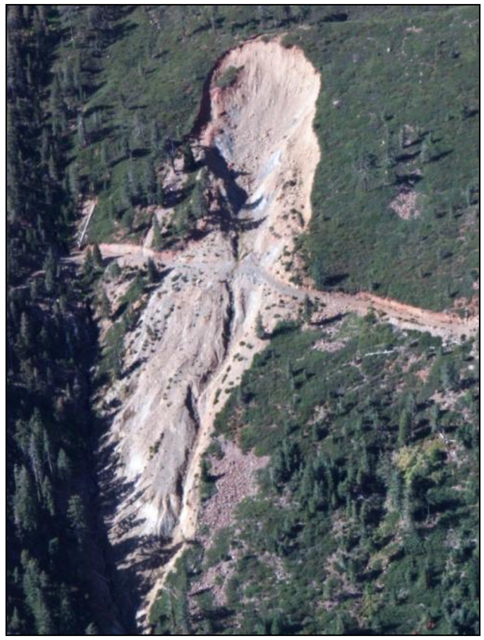
Personal Communications

Photo Y-1 Mass sediment movement in an upland watershed which destroyed a road in Siskiyou County



Source: [Source needed.]

Photo Y-2 Caltrans I-5 Antlers Bridge realignment project on Shasta Lake

This photo shows the dramatic erosion and sediment controls required for a massive cut and fill project that threatens surface waters.

Source: Central Valley Regional Water Quality Control Board. 2011. The State of the Central Valley Region Address. A Five-Year Review Reflection and Projection. December. Available at: http://www.waterboards.ca.gov/centralvalley/board_info/exec_officer_reports/state_of_cvrwqcb_dec_2011.pdf

[Additional photos may be included within this chapter. These are shown below.]

Possible Photos:

Oxbow Lake/ - Butte County - Sacramento River - http://creagrus.home.montereybay.com/CA-BUT.html

(Jeff Mount)

BRAIDED RIVER

Fig. 4.4. 1953 USDA aerial photograph of lower Cache Creek, Yolo County,

California. This steep-gradient, bedload-dominated river occupies multiple, actively migrating channels during bankfull discharge events, forming an extensive braid plain. Intense aggregate mining has greatly disrupted the sediment budget for this river, creating a number of land use issues.

http://www.ucpress.edu/excerpt.php?isbn=9780520202504

Fig. 4.3. 1952 aerial photograph of Sacramento River in Glenn County, north of Sacramento. Note meandering single channel pattern of river. Also note extensive point bar development and heavily vegetated riparian corridor.

Box Y-1 Debris and Sediment

The Sediment Resource Management Strategy (RMS) relates to organic materials. However sediment and debris are often comingles.

Approximately 80 percent of marine debris in the world's oceans originates from land-based sources- primarily trash and debris in stormwater and urban runoff. Studies have found that significant quantities of small plastic debris originating in urbanized land areas pollute the Pacific Ocean both near-shore and on beaches and segments of the ocean thousands of miles away from human habitation.

Studies of debris in Southern California coastal waters demonstrate that significant quantities of trash and debris originate from urban areas and are comprised of pre-production plastics from plastic industrial facilities, trash and litter from urban areas, and boating and fishing-related debris.

More about this topic may be found in the Pollution Prevention and Stormwater-Urban Run Off RMS chapters.

Source: http://www.plasticdebris.org/Trash_BMPs_for_Munis.pdf

Box Y-2 Definitions

Suspended load is the portion of the sediment that is carried by a fluid flow which settles slowly enough such that it almost never touches the bed. It is maintained in suspension by the turbulence in the flowing water and consists of particles generally of the fine sand, silt and clay size.

Bed load describes particles in a flowing fluid (usually water) that are transported along the bed of a waterway.

Wash load is the portion of sediment that is carried by a fluid flow, usually in a river, such that it always remains close the free surface (near the top of the flow in a river). It is in near-permanent suspension and is transported without deposition, essentially passing straight through the stream. The composition of wash load is distinct because it is almost entirely made up of grains that are only found in small quantities in the bed. Wash load grains tend to be very small (mostly clays & silts but some fine sands) and therefore have a small settling velocity, being kept in suspension by the flow turbulence.

Box Y-3 Case Study: Sediment Management Related to Recreational Use

Off-highway vehicle (OHV) use is a popular form of recreation in California. State and federal agencies provide recreational areas for this purpose. These OHV recreation areas need to implement a range of storm water best management practices to protect water quality. Additionally, unauthorized and unmanaged OHV areas can become erosion problems and discharge polluted storm water. With limited resources, maintaining and policing these areas can be a challenge.

In 2009, the Central Valley Water Board found that portions of the Rubicon Trail located in El Dorado County were severely eroded, erosion was accelerated by OHV use and sediment was being discharged to surface waters. (see following 3 photos provided courtesy Monte Hendricks) To address this problem as well as other OHV related water quality issues, the Central Valley Water Board issued a Cleanup and Abatement Order (Central Valley Regional Water Quality Control Board 2009) to El Dorado County and Eldorado National Forest to develop and implement plans to improve management of the trail and protect water quality.

PLACEHOLDER Photo A Rubicon Trail, U.S. Department of Agriculture Forest Service Land

[The draft photos follow the text of this box.]

PLACEHOLDER Photo B [Title Needed]

[The draft photos follow the text of this box.]

[see "Monte Hendricks photos.docx]

The Rubicon Trail Foundation, in response to critisms over OHV use of the Rubicon Trail, has been involved in restoration activities and, in testimony to the Central Valley Water Board, provided some photos of improvements. The following three photos (also see pdf of the actual slides from the testimony to the Central Valley Water Board) show before, during and after photos of an eroded site.

[See Rubicon Trail Foundation.docx and Rubicon Panel A 200904.pdf]

In 2012, the Central Valley Water Board found that sediment disturbed by recreational vehicle activity and transported in storm water runoff to Corral Hollow Creek was a water quality problem at the Carnegie State Vehicle Recreation Area. The Board also identified metals, such as copper and lead, as a potential concern. To address these problems, the Board issued a Cleanup and Abatement Order (Central Valley Regional Water Quality Control Board 2012) to the California Department of Parks and Recreation (State Parks). The Order recognized that State Parks had developed a Storm Water Management Plan that describes the best management practices that need to be implemented to address erosion and sedimentation. The Order required State Parks to and implement the Storm Water Management Plan update.

PLACEHOLDER Photo C Off-Highway Vehicle - Sediment Settling Pond

[The draft photos follow the text of this box.]

— Betty Yee, Central Valley Regional Water Quality Board

Photo A Rubicon Trail, U.S. Department of Agriculture Forest Service Land

Source: Rubicon Trail Foundation

Photo B [Title Needed]

Source: Rubicon Trail Foundation

Photo C Off-Highway Vehicle — Sediment Settling Pond

Source: Rubicon Trail Foundation

Box Y-4 Case Study: Los Angeles County Flood Control District — Impacts of the 2009 Station Fire

In the 1800s and early 1900s, the Los Angeles Region experienced catastrophic floods that resulted in loss of life and property. Consequently, in 1915, the California State Legislature adopted the Los Angeles County Flood Control Act. The Act established the Los Angeles County Flood Control District and empowered it to provide flood risk management and conserve flood and storm waters. The Flood Control District encompasses most of Los Angeles County, including the highly erosive San Gabriel Mountains as well as other mountain ranges. The Flood Control District operates and maintains 14 dams and reservoirs, 162 debris basins, 500 miles of open channel, and other infrastructure.

Given the region's highly erosive mountains and the existing system, managing flood risk and conserving water goes hand in hand with removing and managing the sediment that accumulates at the facilities. Sediment is delivered to the facilities as a result of runoff in the mountains picking up and carrying material eroded from the mountains. The amount of sediment that reaches a facility any given year depends on the size of the watershed, the watershed's vulnerability to erosion, watershed conditions (such as vegetated watershed versus burned watershed), and weather conditions (such as amount and intensity of rain).

Wildfires greatly increase the amount of runoff and erosion from mountainous watersheds. As much as 120,000 cubic yards of sediment and debris have been produced per square mile of a burned watershed after a major storm. The first four years after a fire have proven to be the most critical in terms of the potential for increased delivery of sediment and debris to the Flood Control District's facilities. The effects of wildfires were taken into consideration during the design of the dams under the jurisdiction of the Flood Control District and continue to be considered for today's operations.

The Station Fire of 2009 was the largest fire in Los Angeles County's recorded history, burning approximately 250 square miles. The fire started on August 26th and was not fully contained until October 16th. The burned watersheds resulted in a significant increase in the amount of sediment and debris eroding from the hillsides during storms and making its way into debris basins and reservoirs. After a short but powerful burst of rain in mid-November 2009, Mullally Debris Basin, which is located in the City of La Cañada-Flintridge and has a 9,400- cubic-yard capacity, filled up in 30 minutes. There were also storms in January and February 2010 that delivered tremendous amounts of sediment to the facilities. The images shown below illustrate the amount of sediment that reached Dunsmuir and Mullally Debris Basins as a result of the Station Fire and the storms of February 2010.

PLACEHOLDER Photos A-D Dunsmuir and Mullally Debris Basins

[The draft photos follow the text of this box.]

Immediately following the Station Fire and the 2009-2010 Storm Season, a total of approximately 1.2 million cubic yards (MCY) of sediment were removed from 38 debris basins in order to reduce flood risk for the communities downstream of those debris basins from subsequent storms that still had the potential to send overtopping flows into the debris basins. In addition, many k-rails were installed in the streets of the foothill communities to direct flows away from houses in the event of debris flows due to overtopped debris basins. Emergency operations involved day and night work and trucking of sediment through neighborhoods. The total amount of sediment removed that year is the largest amount removed in any year since the Flood Control District began managing sediment accumulation in debris basins in the 1930s. Notably, the amount of sediment inflow to debris basins is small compared to the amount of sediment that impacts the reservoirs the Flood Control District maintains.

The Station Fire burned significant portions of the watersheds of four reservoirs, as listed below.

- Big Tujunga Reservoir: 88 percent of the reservoir's watershed.
- Cogswell Reservoir: 86 percent of the reservoir's watershed.
- Devil's Gate Reservoir: 68 percent of the reservoir's entire watershed, 92 percent of the reservoir's undeveloped watershed.
- Pacoima Reservoir: 80 percent of the reservoir's watershed.

Based on the Flood Control District's records, 3 of the 4 reservoirs have had an additional 1 MCY of sediment accumulate in them, as detailed in the table below. The potential for high sediment inflows into both reservoirs and debris basins will continue until the watersheds recover.

Table A [Needs Title]

Reservoir	Date of last survey prior to or soon after Station Fire	Date of last survey [a]	Amount accumulated between subject surveys	Challenges
Big Tujunga	October 2009	August 2011	1.6 MCY	1,2,3,5
Cogswell	December 2009	August 2011	1.7 MCY	1,2,3,5
Devil's Gate	April 2009	March 2011	1.2 MCY	4,5
Pacoima	January 2009	September 2011	0.4 MCY	1,3,4,5

[a] As of June 2012

1 – Limited access ; 2 – Limited space at adjacent or nearby sediment placement sites; 3- Endangered species present downstream; 4- Conflicting environmental interests; 5- Long haul routes to facilities with available space

Another consideration at reservoirs is the amount of sediment already accumulated in them** and the capacity available for additional sediment accumulation that would not interfere with the dam's operations. Given the current volume of sediment and the high potential for large sediment inflows, the Flood Control District is planning sediment removal projects at the four reservoirs affected by the Station Fire. These projects are currently estimated to remove a total of 14 MCY of sediment over the next 8 years, with each project lasting 3 to 5 years and costing as much as $50 million.

** Significant amounts of sediment had accumulated in the subject reservoirs prior to the Station Fire (the same is true of other reservoirs operated and maintained by the Flood Control District). This is the result of a combination of issues, including the following:

- Diverse stakeholder interests, which result in different opinions on the "best" sediment removal, transportation, and placement alternative that should be used for a project.
- Conflicting regulatory requirements.
- Restrictions from other agencies.
- Costs.

— Greg Jaquez, LA Flood Control District

Photos A-D Dunsmuir and Mullally Debris Basins


Dunsmuir Debris Basin – Before Feb. 2010 Storms


Dunsmuir Debris Basin – After Feb. 2010 Storms


Mullally Debris Basin – Before Feb. 2010 Storms


Mullally Debris Basin – After Feb. 2010 Storms

Box Y-5 Case Study: California American Water Files Application for Removal of Silted-Up Dam — Dredging Not Feasible

Following is story about a proposal to remove a dam (http://www.sandandgravel.com/news/article.asp?v1=13621). While the San Clemente Dam no longer is providing the water supply function it was intended to meet, that may not be true for other dams in the State. For example, LA County has a lot of people (most of its 10 million population) depending on LACFCD's and Corps' dams for flood protection & water supply. This makes a discussion of sediment and dam removal essential to the water management discussion.

News - September 27, 2010

California American Water has filed an application with the California Public Utilities Commission requesting permission to remove the San Clemente Dam on the Carmel River in order to resolve seismic safety concerns associated with the dam and restore critical habitat for the steelhead trout.

"From an engineering and environmental perspective, this is a landmark project," said California American Water president Rob MacLean. "Our innovative method for dealing with the sedimentation behind the dam and the level of public-private cooperation which has made this plan a reality will serve as a template for the removal of other obsolete dams across the country."

California American Water is partnering with the National Oceanic and Atmospheric Administration's National Marine Fisheries Service and the California State Coastal Conservancy to implement the dam removal project while minimizing cost to its ratepayers. California American Water has committed $49 million and the dedication of 928 acres where the dam is located as parkland.

The Coastal Conservancy and NOAA committed to raise the additional $35 million needed for the removal project through a combination of public funding and private donations.

The San Clemente Dam is a 106ft high concrete-arch dam built in 1921, 18 miles from the ocean on the Carmel River, to supply water to the Monterey Peninsula's then-burgeoning population and tourism industry. Today the reservoir is over 90 percent filled with sediment and has a limited water supply function.

In 1991, the California Department of Water Resources, Division of Safety of Dams agreed with a California American Water consultant's assertion that San Clemente Dam did not meet modern seismic stability and flood safety standards.

The Department of Water Resources and Army Corps of Engineers studied many ways to ameliorate the safety issues including strengthening the dam and removing it.

The January 2008 Final Environmental Impact Report and Environmental Impact Statement ("EIR/EIS") regarding San Clemente Dam's stability contains analysis of a Reroute and Removal Project, which would address the seismic and flood safety risks associated with San Clemente Dam by permanently rerouting a portion of the Carmel River and removing the dam.

Under this proposal, the Carmel River would be rerouted to bypass the 2.5 million cubic yards of silt that have accumulated behind the dam thereby avoiding dredging, which has been deemed infeasible.

The primary benefits of the Reroute and Removal Project are that it improves the Carmel River environment by removing the dam, which serves as a barrier to fish passage, and satisfies government agencies' concerns that strengthening the dam, as opposed to removing it, could further threaten the South Central California Coast Steelhead and violate the federal Endangered Species Act.

— *http://www.sandandgravel.com/news/article.asp?v1=13621*

Box Y-6 Case Study: Clear Lake — Algae in Clear Lake

[NOTE TO REVIEWERS - THIS CASE STUDY IS FROM OFFICIAL GOVERNMENT SOURCES - I HAVE RECEIVED SOME PUSH BACK ON USING IT. LET ME KNOW.]

The Clear Lake Basin was shaped by a variety of processes over the last 1 to 2 million years. Scientists have recovered a nearly continuous sequence of lake sediments dating back 475,000. Other lake sediments in the region that date back to the Early Pleistocene, approximately 1.6-1.8 million years ago.

There is an excellent climate record from these cores for the last 127,000 years. The record documents a shift from pine dominated to oak dominated forests at the end of the Pleistocene Glacial Period 10,000 years ago, indicating a warming trend. The diatom sequence in these cores indicate that Clear Lake has been a shallow, productive system, essentially similar to the modern lake since the end of the Pleistocene Period.

The basin was created primarily from the stresses of the San Andreas Fault System, the eruption and subsidence of the Clear Lake Volcanics, and the erosion and deposition of the parent rock. The east-west extension of the fault system and vertical movements of the faults created and maintained the basin. Downward vertical movement within the basin created by these processes is at a rate approximately equal to the average sedimentation rate of 1/25 inch/year in the lake basin.

Since these rates are essentially equal, a shallow lake has existed in the upper basin for at least the last 475,000 years. If sedimentation rates were significantly different from the downshift, then either a deepwater lake or a valley would have resulted. Although the lake has changed shape significantly over this period, it has generally been located in the same area as the existing Upper Arm.

Clear Lake is a naturally eutrophic lake. Eutrophic lakes are nutrient rich and very productive, supporting the growth of algae and aquatic plants (macrophytes). Factors contributing to its eutrophication include a fairly large drainage basin to contribute mineral nutrients to the water, shallow and wind mixed water, and no summertime cold water layer to trap the nutrients. Because of the lake's productivity, it also supports large populations of fish and wildlife.

The algae in Clear Lake are part of the natural food chain and keep the lake fertile and healthy. Because of the lake's relative shallowness and warm summer temperatures, the algae serve another important purpose. They keep the sun's rays from reaching the bottom, thus reducing the growth of water weeds which would otherwise choke off the lake.

Along with Clear Lake's high productivity, algae in the lake can create a situation which can be perceived as a problem to humans. Algae are tiny water plants that cycle normally between the bottom and the surface, floating up and sinking down. During the day, algae generate oxygen within the lake; at night they consume oxygen.

Nuisance blue-green algae, however, can be a problem. From more than 130 species of algae identified in Clear Lake, three species of blue-green algae can create problems under certain conditions. These problem blue-greens typically "bloom" twice a year, in spring and late summer. The intensity of the blooms vary from year to year, and are unpredictable. The problem occurs when algae blooms are trapped at the surface and die. When this occurs, unsightly slicks and odors can be produced.

It does not appear that blue-green algae are a recent development in Clear Lake.

Sediment cores collected from the bottom of Clear Lake by the United States Geological Survey (USGS) indicate Clear Lake has been eutrophic with high algal populations since the last ice age, which ended approximately 10,000 years ago. The graph at http://www.co.lake.ca.us/Assets/WaterResources/Algae/Algae+Pollen+in+Core.pdf shows the change in algae pollen over time from a core in the Upper Arm.

Livingston Stone, a fisheries biologist, visited Lake County in 1873 and reported to Congress that Clear Lake had significant algal populations at the time.

> It is a singular fact, illustrating the inaptness with which names are often given to natural objects, that the water of Clear Lake is never clear. It is so-cloudy, to use a mild word, that you cannot see three feet below the surface. The color of the water is a yellowish brown, varying indefinitely with the varying light. The water has an earthy taste, like swamp-water, and is suggestive of moss and water-plants. In fact, the bottom of the lake, except in deep places, is covered with a deep, dense moss, which sometimes rises to the surface, and often to such an extent in summer as to seriously obstruct the passage of boats through the water.

He further describes water conditions in September as:

> Fish and fishing are about the same as in August. The weather is a little warmer. No one fishes during this month except the Indians, who still keep after the trout. The water this mouth is in its worst condition.

> It is full of the frothy product of the soda-springs. A green scum covers a large part of the surface, and it is not only uncleanly to look at, but unfit to drink; and yet, strangely enough, this lake, which one would think uninhabitable by fish, fairly teems and swarms with them.

These descriptions appear to describe blue-green algae and conditions similar to that in the last 20 years. The "moss" described in the first passage could be rooted plants or the filamentous algae *Lyngbya*, which behaves in a similar manner. Regardless, this moss indicates a relatively clear lake if sunlight is penetrating sufficiently to promote growth of "moss" on the bottom. The full text of Stone's writings about Clear Lake are available at http://www.co.lake.ca.us/Assets/WaterResources/Algae/Livingston+Stone.pdf.

Other historical accounts indicate the lake was relatively clear through 1925. Substantial declines in clarity and increases in scum forming algae (blue-green algae) occurred between 1925 and 1939. An increase in nutrient loading from increased erosion, fertilizer and wastewater discharges due to urban and agricultural development were the probable causes of increased blue-green algal growth.

The advent of powered earthmoving equipment increased the amount of soil disturbance and facilitated large construction projects, such as the Tahoe-Ukiah Highway (State Highway 20), the reclamation of the Robinson Lake floodplain south of Upper Lake, stream channelization and the filling of wetlands along the lake perimeter. To support the development, gravel mining increased within the streams , further increasing erosion and sediment delivery to Clear Lake. During this time period, mining techniques at the Sulphur Bank Mercury Mine changed from shaft mining to strip mining, resulting in the discharge of tens of thousands of yards of overburden directly into Clear Lake.

Limnological studies of Clear Lake began in the early 1960's to determine the causes of the high productivity in Clear Lake. It was found that the lake is nitrogen limited in the summer, with a great excess of phosphorus within the system. Phosphorus in the water column comes from both the annual inflows and nutrient cycling from the lake sediments. Nitrogen limitation does not affect many blue-green algae, as they were able to utilize (fix) nitrogen from the atmosphere, and consequently have an essentially unlimited supply of nitrogen. This gave these blue-green algae a competitive advantage, and *Anabaena* and *Aphanizomenon* dominated the lake during the summer. A third blue-green algae, Microcystis, also occurred in significant quantities. During this time period, it was also determined that iron was a limiting micro-nutrient.

Starting in the summer of 1990, lake clarity improved significantly. This improved clarity has continued until the present. The graph at http://www.co.lake.ca.us/Assets/WaterResources/Algae/Secchi+Depth$!2c+Upper+Arm.pdf shows the Secchi Depth (the depth into the water at which a black and white checked plate is visible) in the Upper Arm from 1969 through 2008.

During the 1991-1994 time period, University of California researchers led by Drs. Peter Richerson and Thomas Suchanek analyzed lake water quality data collected for the previous 15 years, conducted experiments and evaluated the Clear Lake system. Unfortunately, little data was available during the period of improved clarity since 1990. The "Clean Lakes Report" (http://www.co.lake.ca.us/Assets/WaterResources/Algae/Clean+Lakes+Report$!2c+1994.pdf) determined that excess phosphorus is a major cause, however, iron limits the growth of blue-green algae. The improved water clarity and reduced blue-green algal blooms continued into the new millennium. DWR data collected since the Clean Lakes Report was evaluated by Lake County staff in 2002. Surprisingly, phosphorus and total nitrogen concentrations in the lake did not change substantially when the lake clarity increased. Cursory review of the data did not provide evidence of chemical changes that led to the improved clarity and reduced blue-green algal blooms in Clear Lake.

— *http://www.co.lake.ca.us/Government/Directory/Water_Resources/Algae_in_Clear_Lake.htm*