

# Sediment Management



## A Resource Management Strategy of the California Water Plan

California Department of Water Resources

July 29, 2016





## Table of Contents

<b>Sediment Management .....</b>	<b>4</b>
Sediment Management.....	5
Management Framework .....	7
Sediment Management and Flood Management.....	8
Historic Context.....	9
Management Approach.....	11
Source Management.....	11
Agencies and Organizations Involved in Source Sediment Management .....	13
Sediment Transport Management .....	18
Sediment Deposition Management .....	19
Dredging and Sediment Extraction .....	19
Dam Retrofit, Reoperation, and Removal.....	22
Regional Sediment Management .....	22
Connections to Other Resource Management Strategy Reports .....	24
Potential Benefits.....	25
Source Sediment Management.....	25
Coastal Sediment Management.....	26
Fisheries.....	26
Beneficial Uses for Extracted Sediment .....	26
System Capacity and Materials Use.....	27
Potential Costs .....	27
Special Situations.....	28
Major Implementation Issues.....	29
Sediment Source Management.....	29
Lack of Techniques for Coarse-Grained Sediments Management.....	29
Barriers to Supplying Coarse-Grained Sediments to the Coastal Beaches .....	30
Cost Allocation .....	30
Controlling Excessive Sediment from Causing or Entering Eutrophic Waterways.....	31
Implementation of Regional Sediment Management.....	31
Limited Options Resulting from Other System Requirements .....	31
Sediment Transport Management .....	31
Lack of Monitoring on Stable (Reference) Sediment Conditions in Watersheds .....	32
Protecting Aquatic Life.....	32
Sediment Deposition Management .....	33
Securing Disposal/Placement Locations.....	33
Handling Contaminated Sediments.....	33
Contaminated Sediment Management .....	33
Reuse Challenges .....	33
Regulatory Requirements.....	34
Data Availability.....	34
Sediment and Climate Change.....	34
Adaptation.....	35
Mitigation.....	35
Recommendations to Facilitate Sediment Management.....	35
Policy and Regulatory Reconciliation.....	35
Sediment Source Management.....	36
Sediment Transport Management .....	36

Sediment Deposition Management ..... 37  
Data Acquisition and Management ..... 38  
References ..... 39  
References Cited ..... 39  
Additional References ..... 40

**Tables**

Table 1 Agency Roles and Activities in Sediment Management ..... 17

**Photos**

Photo 1 Caltrans I-5 Antlers Bridge Realignment Project on Shasta Lake ..... 15

**Boxes**

Box 1 Sediment and Debris ..... 4  
Box 2 Case Study: L.A. County Flood Control District and Impacts of the 2009 Station Fire ..... 9  
Box 3 Case Study: Sediment Management Related to Recreational Use ..... 11  
Box 4 Types of Sediment Loads ..... 17  
Box 5 Case Study: California American Water Files Application for Removal of Silted-Up Dam —  
Dredging Not Feasible ..... 20  
Box 6 Case Study: Prado Basin Sediment Management Demonstration Project ..... 25  
Box 7 Case Study: Clear Lake — Algae in Clear Lake ..... 29

## Acronyms and Abbreviations

BCDC	San Francisco Bay Conservation and Development Commission
BLM	U.S. Bureau of Land Management
BMP	best management practice
BOF	Board of Forestry and Fire Protection
CAL FIRE	California Department of Forestry and Fire Protection
California State Parks	California Department of Parks and Recreation
CASQA	California Association of Storm Water Quality Agencies
CO <sub>2</sub>	carbon dioxide
CSMW	California Coastal Sediment Management Workgroup
CWA	Clean Water Act
Delta	Sacramento-San Joaquin Delta
DFW	California Department of Fish and Wildlife
DOI	Department of Interior
DWR	California Department of Water Resources
EPA	U.S. Environmental Protection Agency
GHG	greenhouse gas
GIS	geographic information system
LACFCD	Los Angeles County Flood Control District
LTMS	Long-Term Management Strategy for the Placement of Dredged Sediment in the San Francisco Bay Region
Mcy	million cubic yards
MPRSA	Marine Protection, Research, and Sanctuaries Act
NED plan	National Economic Development Plan

## Sediment Management

NOAA	National Oceanic and Atmospheric Administration's
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
OCWD	Orange County Water District
OHV	off-highway vehicle
PG&E	Pacific Gas & Electric Co.
pH	acidity
RCD	resource conservation district
RSM	regional sediment management
RWQCB	regional water quality control board
SMP	California Coastal Sediment Master Plan
TMDL	total maximum daily load
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation

# Sediment Management

The management of sediment in river basins and waterways has been an important issue for water managers throughout history — from the ancient Egyptians managing sediment on floodplains to provide their crops with nutrients, to today’s challenges of siltation in large reservoirs. The changing nature of sediment issues, due to increasing human populations (and the resulting changes in land use and increased water use), the increasing prevalence of man-made structures such as dams, weirs and barrages and recognition of the important role of sediment in the transport and fate of contaminants within river systems has meant that water managers today face many complex technical and environmental challenges in relation to sediment management.

—*International Sediment Initiative, Technical Documents in Hydrology 2011*

Sediment in California is a valuable resource when it is properly managed, which results in multiple water benefits, environmental health, economic stability, and coastal safety. Sediment definitions vary among the professional disciplines. Sediment, as reflected in this resource management strategy report, is composed of natural materials and used contextually as follows:

1. Geology considers sediment to be the solid fragmented material, such as silt, sand, gravel, chemical precipitates, and fossil fragments, which has been 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. The U.S. Environmental Protection Agency (EPA) and U.S. Army Corps of Engineers (USACE) regard sediment as material, such as sand, silt, or clay, suspended in or settled on the bottom of a water body.

Sediments can come from anywhere and be just about anything. Organic and inorganic material alike can become bits of matter tiny enough to be picked up and carried along with a moving fluid. Organic sediments are made up of mostly plant and animal debris. Inorganic sediments are divided into two main groups — coarse-grained sediments and fine-grained sediments. Coarse-grained sediments are boulders, cobbles, gravel, and sand. Fine-grained sediments are silts and clays. Sediment deposits, like tree rings, can serve as a record of natural history.

A further important distinction 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 if they must be isolated from their surrounding environment. For this resource management strategy report, the term *sediment* will mean clean sediment, and if the sediment is contaminated, the term *contaminated sediment* will be used.

Debris management is also associated with sediment management. Debris may contain sediment, but it is not entirely composed of sediment. Likewise, debris is not trash. Debris consists of fragmented materials that are organic (trees, brush, and other vegetation) and are inorganic (soil, rocks, boulders, and other sediment) that is primarily moved by floodwaters. Large woody material is key to sorting material and creating scours and pools. Pools provide an important habitat for juvenile fish, as well as refugia during flood events. Large woody debris also creates turbulences that clean spawning gravels. Debris basins are

built-in areas subject to debris flows to save lives and protect property. Trash consists of discarded human-made products (e.g., litter) that sometimes comingles with debris. Typically, trash racks are placed on critical equipment, such as pump stations, to prevent mechanical failure caused by litter build-up during a flood. Trash racks also are placed at debris basins and dams for the same purpose.

Debris management is critical in flood management and includes the post-disaster removal of materials — natural and human-made — generated by a flood and extreme weather events. Debris in these situations can range from boathouses to gravel bars to zoo enclosures.

While debris management is related to issues of sediment management, this resource management strategy report focuses primarily on sediment management. Sediment management tools are essential for successful integrated water management as the presence or absence of sediment has a significant impact on water and its beneficial uses.

## Sediment Management

Sediment, like fresh water, is limited in supply and is a valuable natural resource. Sediment management is critical for the entire watershed, beginning with the headwaters and continuing into the coastal shores and terminal lakes. However, from a human perspective, sediment has a dual nature; it is desirable in some quantities and locations and unwanted in others. Sediment contributes to many positive outcomes and has many positive uses, such as beach restoration and renewal of wetlands and other coastal habitats. Sediment also is needed to renew stream habitat. Spawning gravels need replenishment from coarse-grained sediment, and fine-grained sediment is needed to maintain, enhance, or restore good quality native riparian vegetation and wetlands.

Flood deposits of fine-grained sediment into floodplains are the source of much of California's richest farmland. Sediment, particularly sediment adjacent to hot springs, has been considered for centuries as having healing properties. Sediments also can be used for habitat restoration projects, beach nourishment, levee maintenance, and construction material.

The key to effective water-sediment management is to address excessive sediment in watersheds.

Potential impacts of excessive sediment, generally associated with fine-grained sediments, are:

- Clouded water; degraded wildlife habitat; barriers to navigation; and reduced storage capacity in reservoirs, which affects flood protection and water supply.
- Increased turbidity and suspended sediment concentrations; negative effects on the ability of surface water to support recreation, drinking water, habitat; etc.
- Reduced ability of sight-feeding predators to capture prey.
- Clogged gills and filters of fish and aquatic invertebrates, covered and impaired fish spawning substrates, reduced survival of juvenile fish, reduced fishing success, and smothered bottom dwelling plants and animals.
- Physically altered streambed and lakebed habitat.

Other excess sediment issues sometimes include:

- Reduced hydraulic capacity of stream and flood channels, causing an increase in flood crests and flood damage. Sediment can fill drainage channels, especially along roads; plug culverts and storm drainage systems; and increase the frequency and cost of maintenance.



- Decreased useful lifetime of a reservoir, as a result of 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.
- Higher maintenance costs and potential problems associated with excess sediment in shipping channels, harbors, and drainage systems and disposing removed sediment. Excess sediment, which accumulates in ports, marinas along the coast, working rivers, and recreational lakes, affects boating and shipping activity and can lead to demands for dredging to restore or increase depths.

Pollutants, including those from stormwater, may also be absorbed onto fine-grained sediments and complicate management of contaminated sediment. Concentrated pollutants can greatly impair water quality and aquatic life if they are remobilized from this sediment back into the environment. Potential contamination issues are:

- Immediate direct effects on aquatic life from pollutants.
- Long-term effects as contaminants in sediments bioaccumulate or magnify in the food chain, and cause problems for aquatic plants, animals, and humans.
- Suspension of fine-grained sediment containing such nutrients as nitrates, phosphorous, and potassium; and toxic contaminants, such as trace metals and pesticides. In some cases, suspended sediment particles increase algal growth, causing nuisance conditions in waterways.

An effective strategy for managing sediment is to address the sediment at its source before it is mobilized. This strategy prevents contaminated sediments from entering waterways. Sediments and debris may have to be managed together, as discussed in Box 1. Management of watershed sediment location and movement can also have positive and negative consequences, as well as 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, beaches, recreation, and tourism, which are worth billions of dollars. The term *regional sediment management* has been developed to address this condition.

Sediment processes are important components of the coastal and riverine systems integral to environmental and economic vitality. Sediment management relies on knowledge about the context of the sediment system and forecasts about the long-range effects of management actions when making local project decisions. A strategy to stabilize and/or restore the watershed for sediment production, by mimicking natural sediment production, would maintain and enhance the various ecological and beneficial uses.

Numerous factors including geology, climate, development and population, and the location of littoral cells affect sediment management issues. The transport of coarse-grained sediments from the inland watersheds and from local coastal erosion areas into the near-shore coastal waters of California is important in maintaining the beaches. The near-shore coastal area running the entire length of the state contains littoral cells. Littoral cells are self-contained sections, or a compartment, along the coast wherein sand enters (streams, cliff erosion) temporarily resides (beaches), and exits (submarine canyons, offshore shelf). These factors vary significantly throughout the state. For that reason, sediment is best managed on a watershed-littoral cell basis, taking into consideration the sediment source and needs from the top of the

### Box 1 Sediment and Debris

The sediment resource management strategy relates to organic materials. However, sediment and debris are often considered commingles.

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 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 these resource management strategy reports, *Pollution Prevention* and *Urban Stormwater Runoff Management*.

Source: California Coastal Commission and Algalita Marine Research Foundation, n.d.

watershed to the coast where sediment will ultimately end. Adjacent littoral cells do not typically share sand whereas fine-grained sediments exhibit different behavior along the coast (e.g., turbidity plumes cross over cell boundaries). Regional sediment management recognizes sediment as a valuable resource and supports integrated approaches to achieve balanced and sustainable solutions for sediment related needs.

### Management Framework

The regional water quality control boards (RWQCBs) provide regulatory oversight for water quality problems associated with sediment. The USACE, EPA, State Lands Commission, and San Francisco Bay Conservation and Development Commission also have authority for aspects of sediment management and dredging in their respective jurisdictions.

A stream that has excessive erosion, suspended sediments, and/or sedimentation may be determined by a RWQCB to be unable to support its designated beneficial uses with regard to water quality and may be listed as impaired under the Section 303(d) of the federal Clean Water Act. The RWQCBs are working to reduce excessive sediment within streams when it occurs within their regions, by establishing total maximum daily load (TMDL) requirements. *The National Water Quality Inventory: Report to Congress, 2004 Reporting Cycle* shows that sediment is a major water quality problem in the nation's streams (U.S. Environmental Protection Agency 2009).

Partnerships have been formed throughout California to better manage sediments in a variety of ways. For example, the USACE, EPA, San Francisco Regional Water Quality Control Board, San Francisco Bay Conservation and Development Commission (BCDC), and State Lands Commission formed a partnership to address the disposal and beneficial reuse of sediment dredged from the San Francisco Bay. The Long-Term Management Strategy for the Placement of Dredged Sediment in the San Francisco Bay Region (LTMS) reduces in-bay aquatic disposal of sediments in favor of reusing that sediment beneficially in habitat restoration projects, levee maintenance, agricultural enhancement, and construction projects. LTMS emphasizes using sediment as a resource while simultaneously reducing impacts from aquatic disposal in the bay.

This program coordinates and manages approximately 110 maintenance-dredging projects, regulated by eight State and federal agencies under a common set of goals and policies. The LTMS policies and management practices also enable streamlining the permitting process, including coordinating programmatic consultations with the resource agencies, standardizing testing protocols, and increasing predictability for organizations in obtaining their permits. There is also a quasi-LTMS process in the Sacramento-San Joaquin Delta (Delta).

On a statewide basis, the California Coastal Sediment Management Workgroup (CSMW) was established to develop regional approaches to restore coastal habitats, such as beaches and wetlands, which have been affected by human-induced alterations to natural sediment transport and deposition through federal, State, and local cooperative efforts. CSMW is comprised of many State, federal, and local interests whose mission is to identify, study, and prioritize regional sediment management needs and opportunities along the coast and provide this information to resource managers and the public.

The CSMW was formed in response to concerns that shore protection and beach nourishment activities were being conducted on a site-specific basis, without regard to regional imbalances that could exacerbate the local problem. The consensus was that a regional approach to coastal sediment management is a key factor in developing strategies to conserve and restore California's coastal beaches and watersheds. The CSMW's main objectives include reducing shoreline erosion and coastal storm damages, restoring and protecting beaches and other coastal environments by reestablishing natural sediment supply from rivers, impoundments and other sources to the coast, and optimizing the use of dredged sediment from ports, harbors, and other opportunistic sources.

The CSMW oversees the development of the California Coastal Sediment Master Plan (SMP) (Coastal Sediment Management Workgroup 2014). The SMP will identify and prioritize regional sediment management (RSM) needs and opportunities along the coast, provide this information to resource managers and the public, and streamline sediment management activities. A series of Coastal RSM Plans (strategies) are being developed for one or more individual littoral cells focusing on issues specific to each region. Tools, documents, and resource management strategies developed to date are available on the CSMW Web site ([www.dbw.ca.gov/csmw](http://www.dbw.ca.gov/csmw)).

## **Sediment Management and Flood Management**

Sediment management is a key consideration in flood management. Sediment deposition in a channel, floodplain, or behind a dam can decrease flood capacity/flood management. Sediment-starved channels can increase velocity. High-velocity flows can scour soft-bottom channel banks, which can damage channel structures and increase flooding.

When a river breaks its banks and floods, it leaves behind deposits of sediment. Bank overtopping also results in depositions of sediment in the floodplain, which affects flood management. Sediment deposition within the river channel itself raises the bed elevation of the river and allows overtopping of the banks to occur more easily. These depositions can reduce flood capacity. Rivers can also erode their banks and potentially erode levees or flood control structures. The deposited sediments gradually build up to create the floor of floodplains. 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 to aquifers because the water drawn from them is pre-filtered compared with the water in the river.

Geologically ancient floodplains are often represented in the landscape by fluvial terraces. Fluvial processes include erosion and the movement of sediment and organic matter, which are deposited on a riverbed and the landforms this process creates. Fluvial terraces are old floodplains that remain relatively high above the present floodplain and indicate former courses of a floodplain or 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 interrupted. 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, and increasing the likelihood of flooding. In many cases, this can be avoided by dredging the channel and then mechanically depositing the sediment in desirable locations.

Alluvial fans are another form of flood sediment deposit. Over geologic time, sediment, debris, and water emerge from the mountain front along different courses. Alluvial fans are found where these materials gather speed in narrow passages then emerge into less confined areas where they can change course. A number of factors contribute to the dynamics of these flows, including the differential between the steep mountain grades and the flatter depositional surface. Sediment, debris, and water spill out in a fan shape, settling out and depositing on its way. The channels on these fans range from shallow to very deep (several meters) with a flow speed that can move boulders that are sometimes taller than a house. These conditions are found in California 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.

### **Historic Context**

A combination of both natural and human-made impacts to California waterways has led to today's sediment management challenges and solutions. Historically and prior to California becoming a state, sediment flowed naturally from the mountains into streams, meadows, rivers, lakes, and the ocean. California Native Americans understood the seasonal and climate impacts of waterway flows and drought, which affected levels of sediment. This environment provided a wide variety of flora and fauna that was useful as food and tool manufacturing sources for native people (Theodoratus and McBride 2009). As Europeans encountered the territories that became California, they altered this landscape by dredging passages of interior waterways for navigation, and captured a reliable water supply for their new settlements.

In addition to alterations to facilitate agrarian settlements, many of California's current sediment management issues also can be traced to historic gold dredge activities in the 1850s. California's Central Valley and Bay-Delta waterways experienced significant alteration caused by billions of cubic yards of sediment and debris sent downstream from hydraulic mining operations. Court action stopped these activities. However, impacts from these activities continue today. Ditches used for mining are still in use for agriculture and public water supply. The channel infilling that occurred in many of the gold bearing streams is still in evidence and many streams, such as the Feather and Yuba rivers, and these are still adjusting their watercourses 150 years later.

Some early reservoirs (e.g., 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 U.S.

Geological Survey has measured the amount of sediment entering the San Francisco Bay from numerous tributary streams and determined the historic changes in sediment yield over the long term. Today, scientists have concluded that much of the hydraulic mining sediments have moved through the Delta and potentially through much of San Francisco Bay. However, multiple institutions, laws, and human settlement patterns created during this era remain, and, ironically, wetlands that were established as a result of the inundation are now undergoing erosion.

Beyond the Delta and Central Valley, impacts from historic and current road building and land management practices continue to contribute to existing problems. Landslides resulting from natural and human processes are a major producer of sediment.

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 system stability for sediments. As a result, the normal function of waterways has also been changed to produce sediment, move it through the watershed, with some settling occurring in low areas that are now typically used for farming or urbanization, and ultimately depositing it at the shoreline, replenishing the coastline or terminal lakes. In addition to sediment being trapped in flood control structures, peak velocities during storm events has also been reduced, limiting the ability of the stream to move coarse-grained sediment downstream to the coast.

Many ports and harbors were constructed in the 1940s and 1950s along the coastline without regard to the natural process of sand transport along the coast. This natural transport activity has been interrupted by the entrance channels to the harbors, such that the sand being transported down the coast is deposited instead within the entrance channels. This shoaling results in shallower depths and potentially hazardous conditions within the channel, necessitating the ongoing dredging of the channels to restore function and safety. Beneficial reuse of the dredged material is an opportunity for regional sediment management.

Due to the desire to work, live, and play along the coast, significant development along the shoreline has occurred without consideration of the impacts to such development by natural processes. As a result, much of the shoreline has been armored to reduce erosion at specific locations to protect specific structures. Such armoring has reduced the natural supply of sediment to the beaches from bluff erosion. This causes beaches to become narrower and there is an associated loss of habitat and access from passive erosion and accelerating erosion of adjacent areas due to wave focusing.

Land use has also altered patterns of natural alluvial fans and plains. As one example, much sediment in Los Angeles County is the result of the naturally erosive mountains. The San Gabriel Mountains are mostly undeveloped because they are within the Angeles National Forest. Other mountain ranges (e.g., Santa Monica, Verdugos, Puente Hills) also have large areas of undeveloped land. The basins and valleys below these mountains are large, relatively flat, alluvial plains. The depth of the sediment deposits indicates that a significant portion, and possibly the majority, of the sediments are from the adjacent mountains.

Starting in the late 1800s and early 1900s, many Los Angeles County residents and businesses moved into these naturally occurring sediment disposal areas. The settlers and newcomers, experiencing the impacts of frequently fluctuating watercourse alignments caused by high amounts of sediment deposition, wanted more stable river and stream alignments to accommodate the agricultural and urban development that was

occurring. The inhabitants also started moving into the highly erosive foothills and were directly affected by sediment flows. These inhabitants also wanted to capture stormwater to meet their water needs. This situation led to the construction of dams, debris basins, channels, and spreading grounds in Los Angeles County. Many inhabitants are unaware that they are sitting on still-active alluvial fans that require the upkeep of infrastructure to protect them from most of the worst effects of the region's natural sediment transport processes.

### **Management Approach**

Understanding the cumulative impacts of all past, present, and proposed human activities in a watershed (and/or littoral cell) is important in predicting the impacts of sediment on surface waters. Sediment management in water bodies typically focuses on addressing three issues:

1. The type and source of sediment.
2. The systems transporting sediment.
3. The location where sediment deposits.

Management actions are tailored to the situation, depending on where the management actions will occur and whether the management actions involve a natural environment (e.g., rivers, streams, creeks, floodplains) or a built environment (e.g., water control structures, flood levees, dams).

### **Source Management**

Source management is preventing 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 weather, fires, high water volumes, wind, and other factors. The Station Fire, a large fire in the mountains near Los Angeles, caused a significant increase in debris and sediment, which filled debris basins the following rainy season (see Box 2).

Poor farming practices, such as those that led to the Dust Bowl of the 1930s, can create substantial soil loss. Fortunately, soil conservation practices can prevent this type of catastrophic situation and its impacts.

In many regions, land-disturbance activities associated with urban development are a major source of sediment disturbance. The RWQCBs regulate related construction activities occupying one acre or more to mitigate for sediment-related issues.

Road construction and maintenance in or near streams can also be a source of sediment. Photo 1 depicts 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).

## Box 2 Case Study: L.A. County Flood Control District and Impacts of the 2009 Station Fire

The Los Angeles County Flood Control District (LACFCD) was created in 1915 after a series of catastrophic floods resulted in loss of life and property during the 1800s and early 1900s. Encompassing most of Los Angeles County, including the highly erosive San Gabriel Mountains and other mountain ranges, the LACFCD provides flood risk management, conserves flood waters and stormwaters, and operates and maintains 14 dams and reservoirs, 162 debris basins, 500 miles of open channel, and other infrastructure.

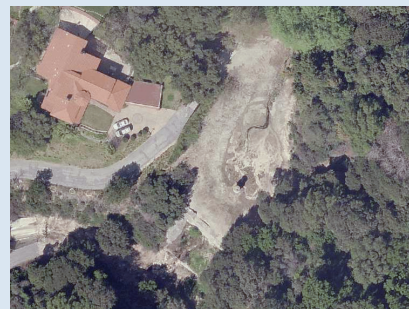
Given the region's highly erosive mountains, managing flood risk and conserving water go hand in hand with removing and managing the sediment deposited at the LACFCD facilities. Sediment accumulates as mountain runoff picks up and carries eroded material. The amount of sediment reaching a facility in any given year depends on the size of the watershed, its vulnerability to erosion, watershed conditions (e.g., vegetated versus burned area), and weather conditions.

Wildfires greatly increase the amount of runoff and erosion from mountainous watersheds. As much as 120,000 cubic yards of sediment and debris can be produced per square mile of a burned watershed after a major storm. The Station Fire of 2009 was one such fire; it burned for over 50 days and covered approximately 250 square miles. The burned watersheds created a mass of sediment and debris, which eroded from the hillsides and made its way into debris basins and reservoirs. After a short but powerful burst of rain in mid-November, 2009, Mullally Debris Basin, in La Cañada-Flintridge, filled up in 30 minutes. Storms in January and February, 2010, also delivered tremendous amounts of sediment to the facilities.

**Photo A Mullally Debris Basin Before Feb. 2010 Storms**



**Photo B Mullally Debris Basin After Feb. 2010 Storms**



Emergency operations involved day and night work and trucking of sediment through neighborhoods. The total amount of sediment removed that year was the largest removed in any year since the LACFCD began managing debris basin sediment accumulation in the 1930s. Notably, the amount of sediment inflow to the debris basins was small compared with the amount of sediment that affects LACFCD's reservoir operations. Here sediment concerns were compounded because significant amounts of sediment had accumulated before the Station Fire.

High sediment inflows into both reservoirs and debris basins will continue until the watersheds recover, usually a minimum of four years. Given the current volume of sediment and the high potential for continued large sediment inflows, the LACFCD plans to remove sediment at the four reservoirs affected by the Station Fire. They aim for a reduction of 14 million cubic yards of sediment over the next eight years, with each project lasting three to five years and costing as much as \$50 million.

The wildfire-sediment nexus is a major concern for LACFCD. Besides operational costs, other management factors include incorporating diverse stakeholder interests on the best methods of sediment removal, transportation, and placement that should be used for a project. Because a project of this scale involves so many other jurisdictions, LACFCD will also need to navigate sometimes conflicting regulatory requirements and restrictions imposed by other agencies.

— Data courtesy of Los Angeles County Flood Control District

**Photo 1** 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

Another transportation-related source is off-highway vehicle (OHV) use. OHV use is a popular form of recreation in California. State, federal, and local agencies, as well as private entities, provide recreational areas for this purpose. These OHV recreation areas are required to implement a range of sediment management and stormwater best management practices (BMPs) to protect water quality. Unfortunately, unauthorized and unmanaged OHV areas can become erosion problems and discharge sediment-laden stormwater (see Box 3). 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 potential 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 the clearing of areas for buildings, mills, and process facilities can expose soils and increase the amount of sediment-laden surface runoff that reaches streams and other surface water bodies.

#### ***Agencies and Organizations Involved in Source Sediment Management***

Many agencies and organizations contribute to sediment source management as land managers, land use planners, advisors, and regulators, and through training, technical and financial assistance, and promotion of good policy. An overview of some of those key entities and their activities are in Table -1.



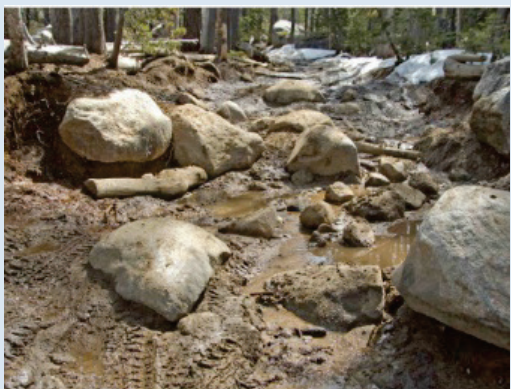
### Box 3 Case Study: Sediment Management Related to Recreational Use

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 stormwater best management practices (BMPs) to protect water quality. In addition, unauthorized and unmanaged OHV areas can become erosion problems and discharge polluted stormwater. With limited resources, maintaining and policing these areas can be a challenge. Central Valley RWQ

In 2009, the Central Valley Regional Water Quality Control Board (CB) found that portions of the Rubicon Trail located in El Dorado County were severely eroded, the erosion having been accelerated by OHV use, and as a result sediment was being discharged to surface waters. (See the following photos, provided courtesy Monte Hendricks.) To address this problem, as well as other OHV-related water quality issues, the Central Valley RWQCB 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.

The Rubicon Trail Foundation, in response to criticisms over OHV use of the Rubicon Trail, has been involved in restoration activities and, in testimony to the Central Valley RWQCB, provided some photos of improvements. These photos (see also the actual slides from the testimony to the Central Valley RWQCB) show the “before” and “after” states of an eroded site.

#### Photos A and B Rubicon Trail, before and after cleanup



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

— Betty Yee, Central Valley Regional Water Quality Board

**Table 1 Agency Roles and Activities in Sediment Management**

Type	Agency	Role	Sample Activities
Federal	U.S. Department of Agriculture (USDA) USDA Forest Service Natural Resources Conservation Service Dept. of Interior (DOI) Bureau of Land Management U.S. Geological Survey National Park Service Dept. of Defense U.S. Army Corps of Engineers (USACE)	Land managers Advisors	Support California land management practices that incorporate erosion control and sediment management.  Provides technical and financial assistance directly to farmers for the planning and implementation of conservation practices on agricultural lands for the protection of natural resources, including soil erosion and sedimentation.
Federal	Dept. of Interior (DOI) U.S. Fish and Wildlife Service Dept. of Commerce National Oceanic and Atmospheric Administration (NOAA) U.S. Environmental Protection Agency (EPA) USACE	Regulators Advisors	Oversight for dredging, fisheries and total maximum daily load (TMDL) issues
Tribal	Tribal Governments	Land managers Planners	Plans and manages for sediment management considerations.
State	California Department of Forestry and Fire Protection (CAL FIRE) Board of Forestry and Fire Protection (BOF) State Lands Commission California Dept. of Parks and Recreation (California State Parks) California Dept. of Fish and Wildlife (DFW)	Land managers Advisors Planners Regulators	Promotion of sediment management through best forest management practices. For over 20 years a group of advisors called the Monitoring Study Group (MSG) has continued to: (1) develop a long-term program testing the effectiveness of California's Forest Practice Rules, and (2) provide guidance and oversight to the 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, as well as measures to reduce unnatural sediment loads and protect beneficial uses of water, are being implemented and are effective.
State	California Department of Food and Agriculture California Department of Conservation DFW The University of California Extension Farm Advisors	Advisors Grant administrators Training & technical assistance	Provide significant leadership in source sediment management through the development of best management practices (BMPs)

Type	Agency	Role	Sample Activities
State	State Water Resources Control Board and Regional Water Quality Control Boards	Regulators Training & technical assistance	Protects water quality through the issuance of regulations and permits, which also serve as National Pollutant Discharge Elimination System (NPDES) permits for point-source discharges subject to the Clean Water Act. Permits related to sediment control include stormwater permits for municipal stormwater systems, highways and other thoroughfares, and construction activities. The Water Boards administer grant funding to develop and implement management practices to address non-point-source pollution, such as development and implementation of the California Rangeland Water Quality Management Plan ( <a href="http://www.waterboards.ca.gov/publications_forms/publications/general/docs/ca_rangeland_wqmgmt_plan_july1995.pdf">http://www.waterboards.ca.gov/publications_forms/publications/general/docs/ca_rangeland_wqmgmt_plan_july1995.pdf</a> ).
Regional	Sierra Nevada Conservancy	Planning Financial Assistance Training & technical assistance	Promotion of land use practices that support optimum source sediment management.
Regional	Tahoe Regional Planning Agency	Planning Regulation	Promotion of land use practices that support optimum source sediment management.
Local	Local Governments, Districts, Water Agencies, Reclamation Districts and Planning Commissions	Planning Regulation	<p>Promotion of land use practices that support optimum source sediment management.</p> <p>Some local governments (city and county) support low-impact development (LID), including it as part of their planning and development ordinances. LID features design elements, including hydromodification, which address sedimentation at the source. Resources, including model regulations, are available to help municipalities interested in incorporating sediment source management into their planning portfolios.</p> <p>Local governments may also be involved in flood protection and water supply. For more information, visit these Web sites:</p> <p><a href="http://www.epa.gov/owow/NPS/lidnatl.pdf">http://www.epa.gov/owow/NPS/lidnatl.pdf</a></p> <p><a href="http://www.epa.gov/region1/topics/water/lid.html">http://www.epa.gov/region1/topics/water/lid.html</a></p> <p><a href="http://efc.muskie.usm.maine.edu/docs/lid_fact_sheet.pdf">http://efc.muskie.usm.maine.edu/docs/lid_fact_sheet.pdf</a></p> <p><a href="http://www.huduser.org/publications/pdf/practlowimpctdevel.pdf">http://www.huduser.org/publications/pdf/practlowimpctdevel.pdf</a></p> <p><a href="http://www.mass.gov/envir/smart_growth_toolkit/bylaws/LID-Bylaw-reg.pdf">http://www.mass.gov/envir/smart_growth_toolkit/bylaws/LID-Bylaw-reg.pdf</a></p>
Local	Cities Counties Joint Power Authorities Commissions	Advisors	Develop a land stewardship ethic that promotes long-term sustainability of the state's rich and diverse natural resource heritage.

Type	Agency	Role	Sample Activities
Local	Resource Conservation Districts (RCDs)	Planning, technical and financial assistance	<p>RCDs implement projects improving sediment management on public and private lands and educate landowners and the public about resource conservation. They work together to conduct:</p> <ul style="list-style-type: none"> <li>• Watershed planning and management.</li> <li>• Water conservation.</li> <li>• Water quality protection and enhancement.</li> <li>• Agricultural land conservation.</li> <li>• Soil and water management on non-agricultural lands.</li> <li>• Wildlife habitat enhancement.</li> <li>• Wetland conservation.</li> <li>• Recreational land restoration.</li> <li>• Irrigation management.</li> <li>• Conservation education.</li> <li>• Forest stewardship.</li> <li>• Urban resource conservation.</li> </ul>
NGO	California and local Farm Bureaus	Advisors Advocates	Information development and dissemination, policy advocacy
	California Rangeland Trust	Training & technical assistance	Land holding services
	The Nature Conservancy	Training & technical assistance	
NGO	California Association of Storm Water Quality Agencies (CASQA)	Advisors Advocacy Training & technical assistance	<p>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 BMP handbooks.</p> <p>The BMPs help reduce unwanted delivery of sediment. The 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. For more information, visit these CASQA Web sites:</p> <p><a href="http://www.casqa.org/">http://www.casqa.org/</a></p> <p><a href="http://www.cabmphandbooks.com">http://www.cabmphandbooks.com</a>.</p>

Type	Agency	Role	Sample Activities
Private Interests and Land Managers	Pacific Gas & Electric Co. (PG&E), Southern California Edison, and other major private utilities with large land and water holdings and infrastructure. Tejon Ranch. Irvine Ranch, etc. Timber & Rail companies (e.g. Sierra Pacific, Catellus Corporation, a successor to the Southern Pacific Land Company and affiliated with Santa Fe Pacific) Agriculture	Land management	Pacific Forest and Watershed Lands Stewardship Council (PG&E) Irvine Ranch Conservancy Tejon Ranch Conservation and Land Use Agreement

Notes: DOI = Dept. of Interior, CAL FIRE = California Department of Forestry and Fire Protection, BOF = Board of Forestry and Fire Protection, DFW = California Dept. of Fish and Wildlife, NOAA = National Oceanic and Atmospheric Administration, NPDES = National Pollutant Discharge Elimination System, RCD = resource conservation district, CASQA = California Association of Storm Water Quality Agencies, PG&E = Pacific Gas & Electric Co.

### Sediment Transport Management

Sediment, like water, flows downstream and supports both shorelines and habitats through the length of the riverine system to the end of the line. Rivers and streams carry sediment in their flows. Different size sediment particles can settle throughout a waterway, based on the energy and flow of the water and the size and weight of the particle, resulting in similar size sediments being located together, as in sand or gravel bars in creeks and rivers. Three types of sediment loads are described in Box 4.

Sediment, primarily sand, also moves along the coastline as littoral drift. This “river of sand” is driven by wind and waves interacting with the shoreline and its orientation. Sand enters the littoral cell from streams and rivers, moves downcoast picking up additional contributions from eroding bluffs, and leaves the littoral cell when it reaches a submarine canyon. Some sand is also lost off shore during large storm events. The sand resides temporarily along the coast as beaches, and fluctuations in the supply, or the loss, of sand to the system will affect beach widths.

Sediment transport management is the process of introducing or leveraging natural functions that create optimal 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 optimal sediment deposition.

For example, sand bypass structures in flood control channels are starting to be used. Such structures placed into flood channels allow the coarse-grained sediments to remain in the channel and continue downstream toward the coast, while fine-grained sediments are diverted to a settling pond where they can be excavated and used for construction or diverted to a wetland where they add to the size of the wetland. More information on this method is available in the *California Beach Restoration Study* (California Department of Boating and Waterways and California Coastal Conservancy 2002).

Sand transport management along the coast includes dredging harbor entrance channels that have become clogged with the migrating sands, and transporting the dredged materials to some other location. In some areas, sand traps have been constructed to facilitate such transport prior to the sands entering the harbors. Elsewhere along the coast, retention structures (e.g., groins) have been constructed to slow the alongshore transport, maintaining beach widths for longer periods. If the area upcoast of the groins is not properly filled with sand, beaches downcoast of the groins can experience accelerated erosion.

### **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-grained sediments supporting existing habitat and adapting to sea level rise.
- Gravel remaining in rivers and streambeds for habitat and riverbed stability.
- Sand sustaining beaches for recreation and habitat.
- Fine silts and clays introducing nutrient-rich materials and nutrient cycling.
- Deposits creating buffers, particularly offshore, which reduce climate-change and storm-surge impacts. Coastal areas that benefit from sediment can also include offshore mudbelts.

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

- Siltation, creating an impact on the capacity of floodways, reservoirs, and water supply systems, including dams.
- Siltation, creating unsafe shipping and transportation channels and having an impact on other commercial and recreational navigation.
- Siltation, inundating wetlands.
- Deposition, filling pools and embedding riffles, which reduces stream habitat.

The USACE maintains the primary federal permitting and operational responsibility over waterway and navigational dredging, flood control, and the operation of many dams. The EPA oversees USACE's implementation of its Clean Water Act and its Marine Protection, Research, and Sanctuaries Act (MPRSA) responsibilities, establishes water quality criteria, and implements certain TMDLs. Additionally, the U.S. Bureau of Reclamation maintains a significant federal role in maintenance, construction, and even deconstruction of dams.

The California Coastal Commission, California Department of Water Resources (DWR), State Lands Commission, State Water Resources Control Board, RWQCBs, and BCDC serve as State counterparts. Additional federal and State resource agencies are responsible for fisheries and recreation.

### **Dredging and Sediment Extraction**

Dredging is an excavation activity or operation usually carried out, at least partially underwater, in shallow water areas with the purpose of gathering up bottom sediments and disposing of them at a different location. This technique is often used to keep waterways navigable.

#### Box 4 Types of Sediment Loads

**Suspended load** is the portion of the sediment that is carried by a fluid flow that 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 to 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 and silts, but some fine sands) and thus have a small settling velocity, being kept in suspension by the flow turbulence.

Other forms of sediment extraction can be completed by various methods including scraper, dragline, bulldozer, front-end loader, shovel, and sluicing. Sluicing is a sediment removal method that employs water flow to remove smaller particle sediment (i.e., sands and silts) to remove sediment accumulated in reservoirs. Sluicing is one of the two methods the Los Angeles County Flood Control District has used since the 1930s to remove sediment from its reservoirs. Extraction methods are often used to maintain the capacity of flood and water supply infrastructure and mine sediment, sand, and gravel for multiple purposes such as commercial construction, levee stabilization, and environmental restoration. Determining how the extracted sediment will be managed involves a variety of factors including environmental acceptability, and technical and economic

Dredging is a critical sediment-deposition management activity supporting commercial shipping, homeland security, fishing, recreation, and environmental restoration. 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; Turner 1984).

In San Francisco Bay alone, dredging facilitates a substantial maritime-related economy of more than \$7.5 billion annually. By necessity, maritime facilities 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 50 feet of water or more. In order to sustain this region's diverse navigation-related commercial and recreational activities, extensive dredging — in the range of 2 to 4 million cubic yards (mcy) per year — is necessary to maintain adequate navigation channels and berthing areas. Effective management of the large volumes of dredged material generated throughout this estuary is both a substantial challenge and an opportunity for beneficial reuse. Both are addressed by the Long Term Management Strategy for Dredging (see [http://www.bcdc.ca.gov/pdf/Dredging/EIS\\_EIR/chpt3.pdf](http://www.bcdc.ca.gov/pdf/Dredging/EIS_EIR/chpt3.pdf)) and the interagency Dredged Material Management Office. Navigational dredging in Southern California is similarly managed to encourage beneficial reuse wherever possible under the Los Angeles Basin Contaminated Sediment Management Strategy's Master Plan and the interagency Dredged Materials Management Team.

There are some known issues related to dredging and other forms of sediment extraction:

- Dredging and sediment extraction can directly affect water quality, habitat quality, and contaminant distribution. Operations may 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, acidity (pH), and

concentrations of trace metals and organic contaminants if they are present in the sediments (San Francisco Bay Conservation and Development Commission 2001).

- Depending on the location of the dredging, deepening navigation channels can increase saltwater intrusion because saline water is heavier than freshwater, and this may cause a net movement upstream of the deeper waters, potentially resulting in an impact on freshwater supplies and fisheries (e.g., deepening of the Sacramento and Stockton deep-water ship channels in the Delta). 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.
- Sediment removal operations may also reintroduce contaminants into the water system by re-suspending pollutants. Metal and organic chemical contamination is widespread in urban shipping channels due to river runoff and municipal/industrial discharges. Chemical reactions that occur during removal 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 those of metals. At the same time, dredging can aid in overall reduction of pollutants in a water body when contaminated sediments are removed from the system or sequestered in habitat restoration projects.

Many things have been done to address these existing issues. There are pre-dredging and real-time monitoring programs that have been developed to test the quality of sediments to be dredged, and there are alternative disposal sites where different quality sediments can be taken. Time windows for when some dredging can occur have been established to accommodate certain ecological cycles. Upland sediment-disposal sites can be designed to mitigate for many contaminants, and extremely contaminated sites can be capped in-place underwater. Evaluation of dredged material for ocean disposal under the Marine Protection, Research, and Sanctuaries Act (MPRSA) relies largely on biological (bioassay) tests. The ocean testing manual, *Evaluation of Dredged Material Proposed for Ocean Disposal — Testing Manual*, commonly referred to as the Green Book, provides national guidance for determining the suitability of dredged material for ocean and near-coast disposal. Evaluation of dredged material for inland disposal under the Clean Water Act (CWA) relies on the use of physical, chemical, and/or biological tests to determine acceptability of material to be disposed. The USACE's inland testing manual, *Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. — Testing Manual*, provides national guidance on best available methods.

Beneficial reuse of dredged and extracted sediments can solve what can otherwise be a dilemma of how to dispose of dredged and extracted sediments as a waste by repurposing it in a variety of ways. These can be used to raise subsided lands to allow restoration as an agricultural supplement and to support levees. When this occurs, the economics of disposal may be altered. In particular, the initial cost to the dredger for sediment removal and placement may be increased. For example, reusing the sediment may require different equipment, the transportation distance to the reuse site may be greater than to the traditional disposal site, and the amount of time needed to complete the dredging work may be extended.

Many sediment management activities involve public trust lands. Because these lands are held in trust for all citizens of California, they must be used to serve statewide, as opposed to purely local, purposes. In these cases, sediment as a trust asset may be subject to State mineral extraction fees and other restrictions.



## Dam Retrofit, Reoperation, and Removal

Dams are an important part of California's water and flood management and will remain so for the foreseeable future. Sediment deposits naturally behind dams and reservoir sediment management includes a range of options including sluicing of sediment, dredging, redesign, retrofit, and removal.

Dam retrofit is an option for deposition management. The Natural Heritage Institute, a non-governmental and non-profit organization, has been a pioneer in this area. They are investigating the feasibility of re-operating some dams in order to restore a substantial measure of the formerly productive floodplains, wetlands, deltas, and estuaries located downstream in ways that do not significantly reduce — and can sometimes even enhance — the irrigation, power generation, and flood control benefits for which the dams were constructed.

In addition, having the ability to re-operate reservoirs without the need to retrofit existing infrastructure (i.e., the ability to adjust hydraulic gates) could include sediment pass-through during stream forming flow events. Allowing coarse and finer sediments to pass through a reservoir during a stream-forming event can provide many benefits. Using sediment pass-through as a sediment management strategy can functionally create and/or maintain storage capacity; significantly decrease the frequency of sluicing or dredging; increase power generation efficiency (e.g., increased head); reduce debris intrusion and accumulation at intake structures; and restore to some degree the natural recruitment of coarse and finer sediments essential for the support of a diverse benthic community, thus resulting in a healthy aquatic environment.

Dam removal is sometimes a result of sediment management, or it creates a need for sediment management. As noted earlier, sediments trapped behind dams or in reservoirs may require periodic sediment removal to maintain function and capacity. However, this is sometimes extremely challenging owing to the facility's location and the lack of disposal or beneficial reuse opportunities at nearby locations. In recent years, there has been increased interest in dam removal for sediment-related reasons, such as the loss of capacity of the facility to hold water due to accumulated sediment (see Box 5 on the removal of San Clemente Dam). In other cases, the reasons may be unrelated, such as a need to upgrade hydrogeneration or improve a stream fishery. Analysis of dam removal proposals requires significant discussion of sediment deposition management. Management of sediments behind such dams has been an important element of negotiations related to dam decommissioning.

## Regional Sediment Management

Regional sediment management (RSM) refers to the 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. RSM as a management method:

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

RSM is an approach for managing projects involving sediment that incorporates many of the principles of integrated watershed resources management, applying them primarily in the context of coastal

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

Dams that have filled with sediment over the decades create management dilemmas. This news article about San Clemente Dam on the Carmel River describes some of the possible solutions and costs.

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 (NOAA’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 106 feet 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 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.

*Source: Dredging News Online 2010*

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 completely address sources and processes important to sediment management. It also supports many of the recommendations identified by interagency working groups for improving dredged material management. Examining RSM implementation through demonstration efforts can provide lessons regarding not only improved business practices, techniques, and tools necessary for managing resources at regional scales, but also roles and relationships that are important to integrated water resources management.

This is a growing concept nationwide, which also has economic benefits. The USACE has a primer on regional sediment management at <http://www.iwr.usace.army.mil/Portals/70/docs/nsms/rsmprimer.pdf>.

More information 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>.

## Connections to Other Resource Management Strategy Reports

Many other resource management strategies in the California Water Plan share a connection with sediment management. More information is in these resource management strategy reports:

- *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.
- *Conveyance — Delta and Conveyance — Regional/Local*. Depending on design, conveyance facilities can trap, scour, or result in other unnatural distribution of sediments. Sediment overload can significantly reduce system capacity.
- *Municipal Recycled Water*. Municipal recycled water is increasingly being utilized for irrigation. An emerging concern in some areas is that sodium loading may be found in soils irrigated with recycled waters. The sodium, through a chemical interaction, can alter the permeability of the soil and reduce its capacity for infiltration. Reduced infiltration rates cause increased run-off and, consequently, increased sediment transport.
- *Surface Storage — CALFED and Surface Storage — Regional/Local*. Similar to conveyance, sediments may be trapped behind infrastructure or otherwise unnaturally distributed. This results in a loss of system capacity.
- *Pollution Prevention*. Well-designed pollution prevention efforts improve water quality by filtering impurities and nutrients, processing organic wastes, controlling erosion, and sedimentation of streams.
- *Urban Stormwater 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.
- *Ecosystem Restoration*. Native riparian, aquatic, animal, and plant communities are dependent on effective sediment management. These ecosystems are dynamic and are 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.

- *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.
- *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 excessive 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 excessive loads of sediment into waterways.
- *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 integrated watershed management.
- *Outreach and Engagement.* Outreach is needed to educate the public regularly on sediment management concerns. Outreach is also needed to educate the public on the natural beneficial functions of sediment.
- *Water and Culture.* Sediment is used in traditional ceremonies and considered to contain healing, and in some cultures, it has spiritual properties. Mud structures are important to native peoples; for some, mud has ties to the creation story. See Tribal Water Stories at [http://www.waterplan.water.ca.gov/docs/tws/TribalWaterStories\\_FullBooklet\\_07-13-10.pdf](http://www.waterplan.water.ca.gov/docs/tws/TribalWaterStories_FullBooklet_07-13-10.pdf).
- *Water-Dependent Recreation.* Water and land-based recreational activities can contribute to unnatural erosion and sediment production. Conversely, high sediment loads can negatively affect recreation, particularly boating, fishing, and swimming. Adequate supply of sand and gravel sediments is essential for many beach recreational activities.

## Potential Benefits

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 just to navigation and commerce may achieve cost savings of millions. 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 is lost from agricultural lands in the United States because of erosion (McCauley and Jones 2005). Considering that soil formation rates are estimated to be only 10–25 percent 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 are stored in the topsoil, which is 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 California Water Plan.

In the case of urban land management, use of low-impact development and other sediment management practices can reduce negative impacts of stormwater runoff, 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, sediment management results in improved safety and environmental and economic outcomes.

### **Coastal Sediment Management**

Sediment in the coastal waterways can furnish material needed to replenish the beaches and marshes along the coastal areas. If the sediment is removed from navigation channels or harbors, the extracted material can be used for beach or marsh nourishment, construction purposes such as highway sub-base material, and flood control levees.

Widening the shoreline, either via beach nourishment or marsh restoration, improves storm surge and flood protection. The dollar value of this improved protection is nearly incalculable, not just for those who own coastal structures, but for the extraordinary number of infrastructure improvements that support the state, including power generation, major transportation assets, water systems, and the dollar value of the recreation and tourism industries that are large part of the state's economy. Restoring eroded coastlines also improves habitat for coastal biota and improves access safety to the shorelines.

### **Fisheries**

In terms of water management, natural amounts of coarse-grained sediment (sand and gravel) in the stream and river system has many beneficial uses. It can serve in the inland waterways 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 or use of some water rights.

### **Beneficial Uses for Extracted Sediment**

Extracted sediment is a manageable, valuable soil resource with beneficial uses of such importance that it should be incorporated into project plans and goals at the project's inception to the maximum extent possible. For example, extracted sediment can benefit:

- Habitat restoration/enhancement (wetland, source, island, and aquatic sites, including use by fish, wildlife, 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.).
- 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).
- Coastal access.
- Storm surge protection.

The applicability of uses is subject to the demand for materials. An issue or barrier might be matching disposal to uses and the composition of the sediment (course grained versus fine- grained). A detailed

discussion about various beneficial uses for extracted material can be found at [http://water.epa.gov/type/oceb/oceandumping/dredgedmaterial/beneficial\\_use.cfm](http://water.epa.gov/type/oceb/oceandumping/dredgedmaterial/beneficial_use.cfm).

### System Capacity and Materials Use

Multiple benefits come from managing the sediment that accumulates at reservoirs and debris basins. If sediment that accumulates in reservoirs is not removed, storage capacity is reduced. If sediment is not removed or passed through, then the storage capacity for floodwater, water supply, or hydropower is reduced. If sediment is not removed from reservoirs and debris basins, the ability to provide flood risk management, water supply, or hydropower is diminished.

As an example, a pilot project in the Santa Ana River Watershed is being designed by the USACE and the Orange County Water District to manage sediment in the Santa Ana River. The Prado Basin Sediment Management Demonstration Project will remove 500,000 cubic yards of sediment behind Prado Dam and re-entrain the sediment in the river below the dam (see Box 6).

### Potential Costs

Many agencies and organizations engage in sediment management activities. The cost of implementing sediment management to achieve water benefits varies widely depending on the sector and purpose of the management. When looking at the overall costs of sediment management, managers should consider and quantify the beneficial uses of the sediment and the ecosystem services, flood protection, storm surge protection, and water quality improvements associated with the benefits as a balance in comparison to the up-front financial investments. While the financial investment is often a one-time cost, the benefits are regularly long term, such as creating a wetland that provides habitat and water quality improvements in perpetuity.

A few sample investments in sediment management include:

**Natural Resources Conservation Service (NRCS).** From 2007 to 2012, the NRCS obligated more than \$91 million 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.

**U.S. Department of Agriculture Forest Service.** Overall, the cost of watershed restoration projects on national forests is close to \$2,000/acre, and most of these projects have the benefits 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).

**Los Angeles County Flood Control District (LACFCD).** 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 (County of Los Angeles Department of Public Works 2012).

**U.S. Bureau of Reclamation (USBR) and U.S. Bureau of Land Management (BLM).** Gravels are added to Northern California rivers to aid in the anadromous salmon run each year. The amount of gravels added depends on the budget allocated each year. Such gravel additions are occurring in the upper Sacramento River area (i.e., Clear Creek), and in other rivers such as the American River, Yuba River,

### Box 6 Case Study: Prado Basin Sediment Management Demonstration Project

The Santa Ana River watershed is the largest in coastal Southern California, covering 2,450 square miles. The Santa Ana River flows 75 miles from headwaters in the San Bernardino Mountains through Orange County to the Pacific Ocean. Upon the completion of Prado Dam in 1941, the sediment transport mechanics of the Santa Ana River watershed were altered dramatically. Ninety-two percent of the watershed drainage flows through the dam. As sediment-laden water enters Prado Basin, the water velocity decreases, sediment settles out of the water, and relatively sediment-free water is released through Prado Dam.

Disruption of natural sediment transport has numerous negative impacts upstream and downstream of the dam. Above the dam, sedimentation reduces the dam's storage and water conservation capacity, threatens infrastructure, and degrades valuable habitat in Prado Basin and along the river upstream of the basin. Downstream of the dam, a lack of sediment in the water released from the dam erodes the river bottom and banks; reduces the infiltration capacity of the river bottom; threatens infrastructure, such as bridges and flood control structures; and reduces sand replenishment at beaches.

The U.S. Army Corps of Engineers (USACE) is partnering with the Orange County Water District (OCWD) on a pilot project to remove up to 500,000 cubic yards of sediment behind the dam and re-entrain the sediment in a controlled manner back into the river downstream. One purpose of the Prado Basin Sediment Management Demonstration Project is to provide data, conclusions, and recommendations to design and implement a comprehensive, long-term sediment management program at Prado Basin, which may serve as a model for implementation of similar projects elsewhere. Key issues to be evaluated at a field scale in the project include sediment removal and conveyance measures, the rate at which sediment can be re-entrained into the river, and potential environmental impacts.

Removal of sediments would restore lost storage capacity behind Prado Dam and enhance water reuse and recharge capabilities. A cooperative agreement between the USACE and OCWD provides for the temporary storage of stormwater behind the dam to allow stored water to be released at rates that enable OCWD to divert stormwater to recharge basins for infiltration into the groundwater basin. Sediment accumulation reduces the volume of available storage. This project has the potential to significantly increase this important water supply for Orange County.

Re-entraining sediments removed from Prado Basin into the river below the dam will allow the sediments to migrate downstream and replenish eroded streambed sediments, provide sand to beaches, and encourage restoration and creation of habitat.

and Stanislaus River. The costs per ton of gravel added depends upon such factors as the method of placement, tonnage of gravel placed, and how the gravel is placed (e.g., dump trucks dumping gravel directly into river, lateral berms laid alongside the streambed at low water, or sluicing a mix of water and gravel directly into the river). Typical tonnages added may vary from 5,000 to 10,000 tons and more per application. In addition, the National Fisheries Service specifies the amount of cleaning (washing) that has to be done to the gravels prior to application, and the grain size distribution of the gravels, which adds to the cost.

### Special Situations

The battle to maintain Lake Tahoe as a pristine and visual jewel is an unusual sediment case study. The sediment of concern is very fine-grained sediment (less than 20 microns) that affects the clarity and people's aesthetic enjoyment of Lake Tahoe. In 2010, the Lahontan RWQCB developed TMDL allocations for sediment and nutrients to Lake Tahoe to control the impacts on lake clarity. To support the new requirements, the Lahontan RWQCB analyzed the costs of implementing controls in urban areas and stream channels and estimated the necessary capital investment at approximately \$1.5 billion in 2007-2008 equivalent dollars.

In this case, the problem may be unique and the extensive costs of basin-wide improvements would not translate to other situations. Even so, there have been many new and innovative best practices for sediment management in the basin and these can translate to other programs.

Additionally the benefits of the investment have been equally evaluated and are considered to be of national interest.

### Major Implementation Issues

The issues for implementing 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 is important.
- Availability and affordability of land often play a role.
- Different stakeholders have different needs and different understandings of the need to manage sediment.
- Local managers sometimes implement site-specific solutions without considering the regional backdrop or how regional processes affect the local conditions.
- Stakeholders and regulators lack a complete understanding of the different natural regional sediment regimes and attempt to address issues on a statewide basis.
- Urbanization and other structural limitations may preclude introduction of natural regimes.
- Supply/demand is a factor with extracted sediment in terms of quantity and timing, sediment type, and use. Beneficial use is contingent upon recipients for managed sediment.
- Conflicting federal, State, and local regulations, coupled with conflicting agency missions, make it difficult for the agencies to view projects holistically from a regionwide perspective.
- Significant resistance has come from some local interests concerned with siting and transfer of impacts. There is a lack of advocacy to counter negative attitudes (e.g., “don’t see, don’t care”).
- Budget constraints weigh, including the need to find a funding source to pay for the incremental costs of RSM.

Sustainability issues facing the three management approaches — sediment source management, sediment transport management, and sediment deposition management — follow.

### Sediment Source Management

#### Lack of Techniques for Coarse-Grained Sediments Management

Often there is a desire for 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 that 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 because so few techniques currently exist for implementing coarse-sediment bypassing in inland watersheds. Flood Control 2.2 — a joint project of the San Francisco Bay Estuary Partnership, San Francisco Estuary Institute, San Francisco Bay Joint Venture, Bay Area Flood Protection Association, and San Francisco Bay Conservation and Development Commission, which is funded by the EPA Water Quality Improvement Fund grant program — is examining this question. The project, which began in September, 2012, and will extend until December, 2016, is examining the coarse-grain load in Bay Area flood channels, characterizing the channel configurations and constraints, and identifying ways to move coarse-grain sediment through the channels to



the shoreline or to develop bypass areas where the sediment is diverted into habitat areas where it is much needed.

In particular, efforts must be made to keep coarse-grained sediments available and clean in fish 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 eliminating them from use in the spawning process. This web site, published by Joseph M. Wheaton, describes these needs: <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, extracted for use, deposited on impermeable pavements, coastal armoring, in-stream sand and gravel mining, stormwater controls, changes to the ground surface contours, and other land use practices.

Instream sand and gravel mining removes a resource that downstream environments need. This situation is anticipated to become worse and accelerate with sea level rise. As noted above, the CSMW is working toward this effort, but challenges remain as agencies aim to work collaboratively, identify the necessary funding, and overcome the traditional jurisdictional conflicts that create misalignment of policy and regulation. Current USACE policy for placement of dredge materials is the lowest-cost alternative, which is not always where the material could best be used. Sediments can also be used to restore the template of flood protection and, in some cases, sand and gravel mining operations can be moved out of the stream or a mitigation fee can be imposed.

Along the coast, beach nourishment has usually been undertaken by combining the USACE's or other dredgers' maintenance dredging of sandy areas and pumping it or placing adjacent to or directly on the shoreline for distribution either via wave action or by mechanical means. This practice has been well received; however, funding remains minimal. Even with these successes, a challenge to beach replenishment occurs when material must be transported over land through beach neighborhoods in order to get to the beaches. In some California locations, sandy beaches, primarily used for recreation, are human-made and require continual replenishment, maintenance, and support.

### **Cost Allocation**

The issue of whose budget pays is a major barrier to reuse of any kind. Often reuse is not only environmentally beneficial, but also presents the optimal use of society's funds. Even then, if the dredging budget will not pay for any increase in placement costs compared to disposal, and if the reuse site will not share some of the costs for receiving otherwise free material from the dredging project, the reuse does not occur. A USACE publication addresses this problem, which is available at <http://water.epa.gov/type/oceb/oceandumping/dredgedmaterial/>.

Additionally, current USACE policy for placement of dredged material, which requires the lowest cost alternative for the placement of dredged material, typically means transport to the location (e.g., beach) closest to the dredge area. Lack of broader policy discussion of this general issue is a lost opportunity to recommend to the Legislature that the body accomplish a number of things. For example, the Legislature

should encourage congressional action to revise how the Harbor Maintenance Trust Fund is distributed and to continue support or even increase funding to entities, such as the California Coastal Conservancy, to share costs with USACE for dredging projects. A cost-benefit ratio for dredge disposal incremental determinations (the NED plan, or national economic development plan, per the USACE]) is needed.

### **Controlling Excessive Sediment from Causing or Entering Eutrophic Waterways**

Eutrophic waterways typically have a lot of minerals and organic nutrients that are used by 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 algal blooms to go out of control in a lake, a condition that then creates a lack of oxygen resulting in fish kills. The sediments also result in a reduction of light and clarity in lakes, thereby harming the food chain and reducing the aesthetic quality of the lake. Controlling these conditions is challenging, and failing to do so is especially harmful to Lake Tahoe. Clear Lake struggles to manage sediment and resulting algal blooms (see Box 7).

### **Implementation of Regional Sediment Management**

There are obstacles to the practical implementation of RSM. RSM requires a long-term, multi-year watershed view for planning. Yet, it may be difficult for stakeholders and regulatory agencies to adopt long-term views and without the necessary scale. Federal, State, and local regulations sometimes conflict with one another. Successful RSM requires compromises from everyone. Regulators often do not offer a compromise due to statutory requirements, not recognizing others' jurisdiction, and fear of exposure to third party lawsuits. Additional challenges for RSM are finding re-use projects/activities that occur at the same time that the sediment needs to be removed, long distances between potential users and the sediment source, and opposition from inhabitants/stakeholders. CSMWs Coastal SMP program aims to address many of these issues by providing a cogent, strategic methodology to address sediment imbalance issues

### **Limited Options Resulting from Other System Requirements**

In some cases, the optimal sediment management approach may be precluded, owing to other system requirements or previously implemented 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 to be cleaned out to its original condition before a sediment flow-through approach can be implemented).

Also important is the instream sand and gravel mining industry, which, according to some authors (e.g., Magoon) may represent the largest source of downstream loss, but is also providing important benefits to the local economy and source materials for multiple critical uses.

### **Sediment Transport Management**

The discipline of sediment transport management is emerging. Much remains to be learned about the best ways to manage for instream sediment quality objectives to prevent aquatic organisms from being smothered by sediment while also providing sediment for downstream processes and needs.

### Box 7 Case Study: Clear Lake — Algae in Clear Lake

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 years. Other lake sediments in the region date back to the Early Pleistocene, approximately 1.6-1.8 million years ago.

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 the lake's 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 that would otherwise choke off the lake.

Along with Clear Lake's high productivity, algae in the lake can create a situation that can be perceived as a problem to humans. 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 varies from year to year and is unpredictable. The problem occurs when algae blooms are trapped at the surface and die. When this occurs, unsightly slicks and odors can be produced.

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.

Starting in the summer of 1990, lake clarity improved significantly. This improved clarity has continued until the present. 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](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. California Department of Water Resources 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.

*Source: County of Lake 2010*

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

Altered channels have changed natural hydrogeomorphology and natural sediment processes. There is a 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. This requires understanding (assisted by geomorphic assessments on channels) and monitoring to determine when watersheds are stable or unstable. Management without these tools causes stream channels to degrade in their geomorphic form and they will not support the native aquatic biological habitat. This affects domestic water supplies (filtration). Unstable sediment conditions may also result in disruption of flood control structures.

### Protecting Aquatic Life

The State Water Resources Control Board is establishing biological objectives, which will include those for suspended sediment and deposited sediments (California Environmental Protection Agency 2014). Excessive sediment in streams, as well as lack of natural sediment loads, can be detrimental to the aquatic life.

## **Sediment Deposition Management**

Sediment impacts through turbidity, dredging, or burial are also of concern in the coastal environment. Dredging has the potential to destroy habitat and biota currently residing in that habitat, while placement of sands has the potential to bury biota at the placement area or downcast from it. Both of these activities have the potential to create turbid conditions that if not abated, could create adverse conditions for filter feeders, visual predators, and photosynthesis. The CSMW's Biological Impacts Analysis and Resource Protection Guidelines discuss these potential impacts in detail, as well as recommending methodologies to minimize such impacts.

## **Securing Disposal/Placement Locations**

Finding disposal locations has become increasingly difficult and expensive due to development of nearby land, 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 dewatering the sediment. Due to the high content of water if the sediment is hydraulically dredged, the dewatering areas need to be quite large and a region may not have sufficient space available.

When dredged material is placed at an upland dewatering or stockpile site, often reuse options are not known until a particular reuse is proposed and the RWQCBs analyze the sediment quality data that was collected during dredging. This is because sediment that may be chemically suitable (considered to be "clean enough") for one kind of reuse may not be suitable for other kinds of reuse. Often this results in delays for projects wanting to reuse the sediment, and can also constrain the emptying and use of the storage sites for future projects. Some have suggested it would help if the coastal RWQCBs had sediment screening criteria that dredgers could have access to before dredging activities.

## **Handling Contaminated Sediments**

Management of contaminated sediments may be challenging. There are limited resources for cleaning of the sediments and disposal of containments taken from contaminated sediments. The USACE has a National Center of Expertise for handling contaminated sediments at <http://el.erdc.usace.army.mil/dots/ccs/ccs.html>.

## **Contaminated Sediment Management**

The potential for contamination is a consideration whenever dealing with sediments, whether these are in upper watersheds or in ports and harbors. When a project or a watershed has to contend with contaminated sediment, special considerations need to be applied. Even contaminated sediment can often be reused, but a more limited set of potential uses for that sediment may be available.

## **Reuse Challenges**

Appropriate reuse is sometimes cost-prohibitive. Challenges to using sediment for beneficial uses include finding beneficial use projects that coincide with the timing of sediment removal, long distances between the sediment removal site and the beneficial use site, offloading equipment needs, encountering regulatory obstacles, and potentially steep disposal fees at the beneficial use site.

## Regulatory Requirements

Regulatory and management frameworks involving sediment typically are designed to support specific uses. As a result, they involve multiple agencies and jurisdictions that are 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. Regionally, the LTMS program previously described provides a cooperative framework for testing, permitting, and beneficial reuse projects. The Los Angeles Region Contaminated Sediments Task Force is a similar interagency regulatory group.

Significant effort and energy is required to maintain such cooperative and collaborative efforts when dealing with dredging and beneficial reuse projects. CSMW also functions as a clearinghouse for member agencies to identify sediment-related activities of interest to other agencies.

## 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 more fully consider upstream and downstream impacts before making decisions.
- Ongoing monitoring would allow better adaptive management and an evaluation of management methods being used. Sediment monitoring should follow suitable quality assurance/quality control features, so that the data collected are scientifically defensible, are derived from field and laboratory methods acceptable to all users statewide, and are entered into a database accessible to all users. Improved forecasting and modeling would support long-term and strategic planning. Sediment transport modeling is becoming an increasingly important tool in watershed sediment considerations. The USACE and the EPA, as well as others, have been developing sediment transport models.
- Development of sand and sediment budgets would assist agencies in planning and reduce regulatory conflicts. The development of sand budgets is one of the most important aspects of regional sediment management.

Data challenges can be addressed. For example, CSMW maintains a Web site designed to make as much information as possible to coastal sediment managers. In addition, there are many Web sites devoted to specific topics that CSMW has been involved with since 2003. These range from a topical library containing links to relevant reports to a searchable database of references. A spatial database containing numerous data layers can be found at <http://www.dbw.ca.gov/CSMW/default.aspx>.

## Sediment and Climate Change

Climate change is already occurring and is projected to continue altering temperature and hydrology patterns in the state. Climate change studies project an increased frequency of extreme weather, higher temperatures, larger and more frequent wildfires, 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 will cause flooding to already vulnerable lands and coastlines, adding a heavy mix of sediment and debris to stormwaters. Coupled with sea level rise and surge, which increases coastal erosion, beach erosion, and coastal flooding, climate change will amplify the already difficult task of sediment management. Drought and climate change alter permeability and other physical characteristics of sediment, and increased carbon dioxide (CO<sub>2</sub>) levels may influence soil chemistry.

## **Adaptation**

Adaptation will necessitate projecting where excessive sediments will source and accumulate as a result of flooding. Effective management of those sediments for habitat, floodplains, and shoreline stability will improve resiliency.

With climate change expected to bring wetter winters and drier summers, erosion will become an even greater threat to California lands and sediment management. Several adaptation strategies may provide benefits in light of climate change.

Where floodplain restoration is feasible, this will allow for natural deposits of sediment and serve dual purposes of managing sediment and replenishing soil. Excess, clean sediment can be used beneficially on eroding beaches, marshes, and agricultural lands, augmenting natural processes. As an example, State and federal agencies, including the California Coastal Conservancy, have provided funding for the Hamilton/Bel Marin Keys Wetlands Restoration near Novato, California. In this project, dredged excess sediment was used to create habitat that will aid in storm surge protection.

Warmer temperatures and higher levels of CO<sub>2</sub> may, in some cases, lead to increased vegetation. Vegetation can minimize runoff and lessen erosion, preventing sediments from entering waterways. Effective management of landscapes, including planting heat- and drought-tolerant native vegetation around waterways, can minimize sediment loads. In other cases, where there is high fuel loading in an extreme fire hazard zone, excess vegetation could increase damage caused by fire, leading to post-fire erosion and excess sediment loading. Management for vegetation should be considered on a case-by-case basis.

## **Mitigation**

Removing sediment for navigation, flood control, and reservoirs, among other uses, is a continuous process that can result in high greenhouse gas (GHG) emissions from fossil fuel- powered equipment.

There is a growing opportunity for GHG offsets through the use of renewable energy in sediment management operations, such as harbor maintenance dredging. Potential may also exist for sequestration in the reuse of dredged sediment in wetland and vegetated habit restoration, but more research is needed before this can be determined.

## **Recommendations to Facilitate Sediment Management**

New recommendations for sediment management may increase costs and/or the amount of time needed to obtain permits. All new sediment recommendations should be strongly evaluated to determine to what extent they could inhibit important water/flood projects and activities. If impacts may occur, some form of mitigation for these effects should be included when implementing any given recommendation.

## **Policy and Regulatory Reconciliation**

1. The State and USACE should convene a stakeholder working group that includes flood protection and water supply entities to recommend methods to overcome sediment management regulatory conflict and encourage long-term thinking, including the issuing of permits that match the time horizon for any established sediment management plan. The stakeholder

working group should consult and build upon the successes of the CSMW. The stakeholder group should also developed recommendations for consideration by the State Legislature and Congress to address conflicting statutory requirements and facilitate flexibility among the agencies to develop sediment management approaches to meet regional needs.

2. The USACE, Natural Resources Agency, California Environmental Protection Agency, Department of Finance, Governor’s Office of Planning and Research, and the California Water Commission should convene a task force or stakeholder working group to recommend methods for sediment management cost allocation. Often reuse is not only environmentally beneficial, but also presents the optimal use of funds.
  - A. The stakeholder group should also evaluate needs for outreach and education on sediment management and offer recommendations for next steps to address those needs.
  - B. Specific focus should be given to cover the incremental costs of RSM.

### **Sediment Source Management**

3. The Governor’s Office of Planning and Research should develop model general plan guidelines that support optimal sediment source management.
4. Federal, tribal, State, regional, and local agencies and stakeholders should support and participate in RSM for those sediments that must be dredged to keep the waterways and other facilities open for navigation or to support flood control efforts. In addition, there should be support of those efforts to use that sediment beneficially within regions. One possible use of the sediment is levee construction that can direct the floodwater to the most desirable location.
5. The State Lands Commission and other responsible agencies should scrutinize instream and beach Sediment Mining Permits. The Commission should evaluate impacts of sediment-mining permits on a case-by-case basis, which allow the removal of coarse-grained material directly from streambeds 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.
6. The State should implement the requirements recommended by the California Association of Storm Water Quality Agencies for stormwater discharge control programs associated with sediment management, which
  - A. Are technically and economically feasible.
  - B. Provide significant environmental benefits and protect the water resources.
  - C. Promote the advancement of stormwater management technology.
  - D. Are compliant 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.
7. The Regional Water Quality Control Boards should work with stakeholders to secure broader support of sediment water quality requirement efforts and promote development of stakeholder-

### **Sediment Transport Management**

8. 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 used beneficially. 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. This work will need to account for water quality requirements and other interests, such as fishing and recreation.

9. The State should encourage the use of remote sensing as a tool for sediment transport management, 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 calibration is 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.
10. The Natural Resources Agency and California Environmental Protection Agency should implement, as much as possible, 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.

### **Sediment Deposition Management**

11. Where feasible, the State in cooperation with the local sediment management agencies should determine the Sediment Yields of Watersheds when downstream sediment problems are becoming an issue. This type of monitoring may not be feasible in undeveloped, highly erosive mountain areas. 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 to manage extraction and dredging budgets for the navigation channels and other non-navigation facilities.
12. The Regional Water Quality Control Boards in cooperation with the local sediment management agencies should expand use of regionally-based sediment screening criteria so that agencies could know sooner what the use of the dredged material could be and plan accordingly. Establish potential uses of dredged material, depending upon its quality, in advance. The upland sites receiving dredged material can then be emptied sooner and become available for additional dredged material. This will assist in maintaining the shipping channel in operational condition.
13. The State Lands Commission and DWR should prepare sand budgets for each watershed when downstream sand availability issues are occurring. Comparing these sand budgets for each watershed over time will reveal the efficacy of source BMPs' effect on sand transport, be of use in determining how well sand is moving toward the coastal beaches, allow comparison of sand generation in the watershed to that removed by instream sand removal permits, and show which watersheds are best generating sand. These sand budgets should include the sand budgets developed for coastal areas, including the regional sediment budget studies conducted by University of California, Santa Cruz for CSMW.
14. All affected jurisdictions should work with or through the CSMW, because it is preparing coastal RSM plans for most of the littoral cells along the coast.
15. The State should support and provide incentives for expanding successful interagency models to cover dredging projects throughout the state. Identifying beneficial reuse opportunities that support RSM goals should be a key objective of the State's involvement.
16. The State should develop a funding source to encourage and support beneficial reuse projects, specifically those that enhance, restore, or support habitat including beach nourishment and



wetland restoration projects. State funding can be partnered with federal and private funds to support these efforts.

17. The State may also consider ways to encourage beneficial reuse of sediment without State funding. Specific ideas include providing a tax credit or widely and flexibly applied mitigation credit when sediment is reused beneficially rather than treated as a waste product.
18. The State should enable funding for special districts and local governments to undertake sediment management actions. This could include the ability to levy taxes for sediment management, similar to infrastructure districts.
19. For sediment removal projects from facilities that capture sediment from undeveloped watersheds (e.g., some dams and debris basins), State agencies should allow pre-testing to facilitate deposition of sediment at solid waste landfills, inert landfills, and other potential deposition sites, which otherwise may require testing and affect beneficial use of sediment, especially in emergency situations.

### **Data Acquisition and Management**

20. Federal and State governments should allow for the installation of data collection and transmitting equipment and stations in all State- and federally-owned lands, even in designated wilderness and Wild and Scenic rivers, when the collection of data on such lands is necessary to provide a complete and accurate geomorphic assessment of streams and watershed stability. State and federal governments should also encourage the development of data collection and transmitting equipment that can be installed and operated with minimal impacts on habitat.
21. Federal and State governments should support development of guidelines to identify when geomorphic assessments of streams for watershed stability are appropriate to prevent undue delays in processing permits and ensure that studies are scaled to project size.
22. Federal and State governments should support sediment and flow monitoring programs of others if needed to determine the sediment yields from a watershed and sediment budgets for downstream areas. They should also establish monitoring protocols that produce scientifically defensible data of comparable quality throughout the state. Such monitoring will add to the water quality database of the waterway.
23. Federal and State governments should support modeling and monitoring for sediment dynamics in estuarine and near-shore (littoral cell) environments when understanding estuarine and near-shore sediment transport issues is key to adaptive management, infrastructure protection, and habitat restoration.
24. The State should expand efforts for a sediment data exchange and cooperate with others who may be obtaining sediment data in a watershed so that a common database is used that is accessible to all users. Stakeholders should be convened to establish data needs and requirements. CSMW has developed a geographic information system (GIS) database and associated web viewer, and is working with the Ocean Protection Council to incorporate their spatial data into the State Geoportal, currently under development. The State Geoportal is envisioned as a one-stop location for most of California agencies' geospatial database.
25. 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.

## References

### References Cited

- California Department of Boating and Waterways and State Coastal Conservancy. 2002. *California Beach Restoration Study*. Sacramento (CA): Viewed online at: <http://www.dbw.ca.gov/PDF/Reports/BeachReport/FULL.pdf>.
- California Environmental Protection Agency. 2014. "Proposed Policy for Biological Objectives for (Perennial Streams & Rivers of) the State of California." Sacramento (CA): State Water Resources Control Board. [Web site.] Viewed online at: [http://www.waterboards.ca.gov/plans\\_policies/biological\\_objective.shtml](http://www.waterboards.ca.gov/plans_policies/biological_objective.shtml).
- Central Valley Regional Water Quality Control Board. 2011. *The State of the Central Valley Region Address: A Five-Year Review Reflection and Projection*. Viewed online at: [http://www.waterboards.ca.gov/centralvalley/board\\_info/exec\\_officer\\_reports/state\\_of\\_cvrwqcb\\_dec\\_2011.pdf](http://www.waterboards.ca.gov/centralvalley/board_info/exec_officer_reports/state_of_cvrwqcb_dec_2011.pdf).
- Coastal Sediment Management Workgroup. 2014. "Sediment Master Plan." California Department of Boating and Waterways. [Web site.] Viewed online at: <http://www.dbw.ca.gov/csmw/smp.aspx>.
- County of Los Angeles Department of Public Works. 2012. "Sediment Management Strategic Plan." [Web site.] Viewed online at: <http://dpw.lacounty.gov/lacfed/sediment/stplan.aspx>.
- McCauley A and Jones C. 2005. *Managing for Soil Erosion*. Bozeman (MT): Montana State University Extension Service. Soil and Water Management Module 3. 12 pp. Viewed online at: [http://landresources.montana.edu/SWM/PDF/Final\\_proof\\_SW3.pdf](http://landresources.montana.edu/SWM/PDF/Final_proof_SW3.pdf).
- San Francisco Bay Conservation and Development Commission. 2001. *Chapter 3.0, Authorization Process for Dredging and Dredged Material Disposal Projects*. Viewed online at: [http://www.bcdc.ca.gov/pdf/Dredging/LTMS/Mgt\\_Plan/chpt3.pdf](http://www.bcdc.ca.gov/pdf/Dredging/LTMS/Mgt_Plan/chpt3.pdf).
- Theodoratus D and McBride K. 2009. "California Tribal Environmental Justice Collaborative Grant Project. Report for California Tribal Environmental Justice Collaborative Grant Project." [Web site.] Viewed online at: <http://www.catribalej.com/reporting.html>. Accessed: June 6, 2010.
- United Nations Educational Scientific and Cultural Organization. 2011. *Sediment Issues & Sediment Management in Large River Basins Interim Case Study Synthesis Report*. International Sediment Initiative, Technical Documents in Hydrology. Viewed online at: <http://unesdoc.unesco.org/images/0021/002128/212891e.pdf>.
- U.S. Environmental Protection Agency. 2009. *National Water Quality Inventory: Report to Congress, 2004 Reporting Cycle*. Washington (DC): Viewed online at: [http://water.epa.gov/lawsregs/guidance/cwa/305b/upload/2009\\_01\\_22\\_305b\\_2004report\\_2004\\_305Breport.pdf](http://water.epa.gov/lawsregs/guidance/cwa/305b/upload/2009_01_22_305b_2004report_2004_305Breport.pdf).

## Additional References

- American Society of Civil Engineers. 1997. *Guidelines for Retirement of Dams and Hydroelectric Facilities*. ASCE Publications. [Book.]
- . 2014. “Policy Statement 522— Regional Sediment Management.” ASCE American Society of Civil Engineers. [Web site.] Viewed online at: <http://www.asce.org/Content.aspx?id=8638>.
- Bridges TS. 1999. “Center for Contaminated Sediments.” U.S. Army Corps of Engineers. [Web site.] Viewed online at: <http://el.ercdc.usace.army.mil/dots/ccs/ccs.html>.
- California Regional Water Quality Control Board Central Valley Region. 2009. Cleanup and Abatement Order No. R5-2009-0030 for El Dorado County and the United States Department of Agriculture, Forest Service, Eldorado National Forest, Rubicon Trail, El Dorado County. Viewed online at: [http://www.waterboards.ca.gov/centralvalley/board\\_decisions/adopted\\_orders/el\\_dorado/r5-2009-0030\\_enf.pdf](http://www.waterboards.ca.gov/centralvalley/board_decisions/adopted_orders/el_dorado/r5-2009-0030_enf.pdf).
- . 2012. Cleanup and Abatement Order No. R5-2012-0700 for California Department of Parks and Recreation Carnegie State Vehicle Recreation Area, Alameda and San Joaquin Counties. Viewed online at: [http://www.waterboards.ca.gov/centralvalley/board\\_decisions/adopted\\_orders/alameda/r5-2012-0700\\_enf.pdf](http://www.waterboards.ca.gov/centralvalley/board_decisions/adopted_orders/alameda/r5-2012-0700_enf.pdf).
- California Stormwater Quality Association. 2014. “California Stormwater Quality Association.” [Web site.] Viewed online at: <http://www.casqa.org/>.
- Coastal Sediment Management Workgroup. 2014. “Coastal Sediment Management Workgroup.” California Department of Boating and Waterways. [Web site.] Viewed online at: <http://www.dbw.ca.gov/CSMW/default.aspx>.
- County of Lake State of California. 2010. “Algae in Clear Lake.” [Web site.] Viewed online at: [http://www.co.lake.ca.us/Government/Directory/Water\\_Resources/Algae\\_in\\_Clear\\_Lake.htm](http://www.co.lake.ca.us/Government/Directory/Water_Resources/Algae_in_Clear_Lake.htm).
- Dredging News Online. 2010. “California American Water Files Application for Removal of Silted-up Dam — Dredging Not Feasible.” [Web site.] Viewed online at: <http://www.sandandgravel.com/news/article.asp?v1=13621>.
- Gordon M and Zamist R. 2006. *Municipal Best Management Practices for Controlling Trash and Debris in Stormwater and Urban Runoff*. California Coastal Commission and Algalita Marine Research Foundation. Viewed online at: [http://www.plasticdebris.org/Trash\\_BMPs\\_for\\_Munis.pdf](http://www.plasticdebris.org/Trash_BMPs_for_Munis.pdf).
- Houston J. 1970. *Hydraulic Dredging Theoretical and Applied*. 1st Edition. Cambridge (MD): Curnell Montime Press. 318 pp. [Book.]
- Jenny H. 1980. *The Soil Resource: Origin and Behavior*. New York (NY): Springer-Verlag. 377 pp. [Book.]

- Kuhnle RA and Simon A. 2000. *Evaluation of Sediment Transport Data for Clean Sediment TMDLs*. NSL Report No. 17. Oxford (MS). [Web site.] Viewed online at: <http://water.epa.gov/lawsregs/lawguidance/cwa/tmdl/upload/NSLReport17.pdf>.
- Martin LR. 2002. *Regional Sediment Management: Background and Overview of Initial Implementation*. Prepared for: U.S. Army Corps of Engineers Institute for Water Resources Policy Studies Program. Viewed online at: [http://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/02ps2sed\\_man.pdf](http://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/02ps2sed_man.pdf).
- Murphy K, Rich T, and Sexton T. 2007. *An Assessment of Fuel Treatment Effects on Fire Behavior, Suppression Effectiveness, and Structure Ignition on the Angora Fires*. United States Department of Agriculture. Viewed online at: <http://www.cnpsd.org/fire/angorafireusfsfullreport.pdf>.
- New England Environmental Finance Center. n.d. *Promoting Low Impact Development in Your Community*. Viewed online at: [http://efc.muskie.usm.maine.edu/docs/lid\\_fact\\_sheet.pdf](http://efc.muskie.usm.maine.edu/docs/lid_fact_sheet.pdf).
- Prince George's County, Maryland, Department of Environmental Resources and Programs, and Planning Division. 1999. *An Integrated Design Approach: Low-Impact Development Design Strategies*. Viewed online at: <http://www.epa.gov/owow/NPS/lidnatl.pdf>.
- San Francisco Bay Conservation and Development Commission. 1998. *Chapter 3.0, Dredging and Dredged Material Characteristics — An Overview*. Final Environmental Impact Statement/Environmental Impact Report. Viewed online at: [http://www.bcdc.ca.gov/pdf/Dredging/EIS\\_EIR/chpt3.pdf](http://www.bcdc.ca.gov/pdf/Dredging/EIS_EIR/chpt3.pdf).
- Science Applications International Corporation. 2012. *Review of Sediment Management Impacts and Issues Relevant to Protection of California Coastal Biota*. Volume 2. User's Guide and Resource Protection Guidelines. Viewed online at: [http://dbw.ca.gov/csmw/pdf/BIA\\_Vol\\_2\\_SAIC\\_Nov2012.pdf](http://dbw.ca.gov/csmw/pdf/BIA_Vol_2_SAIC_Nov2012.pdf).
- Smart Growth/Smart Energy Toolkit. 2007. *Model Low Impact Development (LID) Bylaw*. Viewed online at: [http://www.mass.gov/envir/smart\\_growth\\_toolkit/bylaws/LID-Bylaw-reg.pdf](http://www.mass.gov/envir/smart_growth_toolkit/bylaws/LID-Bylaw-reg.pdf).
- The Heinz Center. 2002. *Dam Removal: Science and Decision Making*. Washington (DC): Viewed online at: [http://water.epa.gov/polwaste/nps/upload/Dam\\_removal\\_full\\_report.pdf](http://water.epa.gov/polwaste/nps/upload/Dam_removal_full_report.pdf).
- Trippsmith K. 2010. *Tribal Water Stories*. California Tribal Water Summit Planning Team. Viewed online at: [http://www.waterplan.water.ca.gov/docs/tws/TribalWaterStories\\_FullBooklet\\_07-13-10.pdf](http://www.waterplan.water.ca.gov/docs/tws/TribalWaterStories_FullBooklet_07-13-10.pdf).
- Turner TM. 1984. *Fundamentals of Hydraulic Dredging*. 1st Edition. Centreville (MD): Cornell Maritime Press. 214 pp. [Book.]
- U.S. Army Corps of Engineers. 1983. *Engineering and Design Dredging and Dredged Material Disposal*. Engineer Manual No. 1110-2-5025. Washington (DC): Viewed online at: [http://140.194.76.129/publications/eng-manuals/EM\\_1110-2-5025/EM\\_1110-2-5025.pdf](http://140.194.76.129/publications/eng-manuals/EM_1110-2-5025/EM_1110-2-5025.pdf).

- . 1987. *Engineering and Design: Confined Disposal of Dredged Material*. Engineer Manual No. 1110-2- 5027. Washington (DC): Viewed online at:  
[http://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM\\_1110-2-5027.pdf](http://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-5027.pdf).
- . 2004. *Regional Sediment Management*. Washington (DC): Viewed online at:  
<http://dbw.ca.gov/csmw/pdf/rsmprimer.pdf>.
- U.S. Commission on Ocean Policy. 2004. *Chapter 12, Managing Sediment and Shorelines. An Ocean Blueprint for the 21st Century*. Final Report. Washington (DC): Viewed online at:  
[http://govinfo.library.unt.edu/oceancommission/documents/full\\_color\\_rpt/12\\_chapter12.pdf](http://govinfo.library.unt.edu/oceancommission/documents/full_color_rpt/12_chapter12.pdf).
- U.S. Department of Housing and Urban Development. 2003. *The Practice of Low Impact Development*. Upper Marlboro (MD): NAHB Research Center, Inc. Viewed online at:  
<http://www.huduser.org/publications/pdf/practlowimpctdevel.pdf>.
- U.S. Department of the Interior and Bureau of Reclamation. 2006. *Dam Decommissioning and Sediment Management. Erosion and Sedimentation Manual*. Denver (CO): Viewed online at:  
<http://www.usbr.gov/pmts/sediment/kb/ErosionAndSedimentation/chapters/Chapter8.pdf>.
- U.S. Environmental Protection Agency. 1991. “Proposed for Ocean Disposal (Testing Manual). Water: Dredged Material Management.” [Web site.] Viewed online at:  
[http://water.epa.gov/type/oceb/oceandumping/dredgedmaterial/gbook\\_index.cfm](http://water.epa.gov/type/oceb/oceandumping/dredgedmaterial/gbook_index.cfm).
- . 2009. “Managing Stormwater with Low Impact Development Practices: Addressing Barriers to LID.” New England. Viewed online at:  
<http://www.epa.gov/region1/npdes/stormwater/assets/pdfs/AddressingBarrier2LID.pdf>.
- . 2013. “Beneficial Use of Dredged Material.” [Web site.] Viewed online at:  
[http://water.epa.gov/type/oceb/oceandumping/dredgedmaterial/beneficial\\_use.cfm](http://water.epa.gov/type/oceb/oceandumping/dredgedmaterial/beneficial_use.cfm).
- . 2013. “National Dredging Team (NDT).” [Web site.] Viewed online at:  
<http://water.epa.gov/type/oceb/oceandumping/dredgedmaterial/>.
- U.S. Environmental Protection Agency and Hardrock Mining. 2003. *Appendix H. Erosion and Sedimentation. EPA and Hardrock Mining: A Source Book for Industry in the Northwest and Alaska*. Viewed online at: [http://yosemite.epa.gov/R10/WATER.NSF/840a5de5d0a8d1418825650f00715a27/e4ba15715e97ef2188256d2c00783a8e/\\$FILE/ATTU303P/appendix%20h.pdf](http://yosemite.epa.gov/R10/WATER.NSF/840a5de5d0a8d1418825650f00715a27/e4ba15715e97ef2188256d2c00783a8e/$FILE/ATTU303P/appendix%20h.pdf).
- U.S. Environmental Protection Agency and U.S. Army Corps of Engineers. 1998. *Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. – Testing Manual*. Viewed online at:  
[http://water.epa.gov/type/oceb/oceandumping/dredgedmaterial/upload/2009\\_10\\_09\\_oceans\\_regulatory\\_dumpdredged\\_itm\\_feb1998.pdf](http://water.epa.gov/type/oceb/oceandumping/dredgedmaterial/upload/2009_10_09_oceans_regulatory_dumpdredged_itm_feb1998.pdf).

- . 2007. “Identifying, Planning, and Financing Beneficial Use Projects Using Dredged Material: Beneficial Use Planning Manual.” Washington (DC): Viewed online at: <http://water.epa.gov/type/oceb/oceandumping/dredgedmaterial/upload/Identifying-Planning-and-Financing-Beneficial-Use-Projects-Using-Dredged-material-pdf.pdf>.
- U.S. Fish and Wildlife Service, National Marine Fisheries Service, U.S. Army Corps of Engineers, and U.S. Environmental Protection Agency. 2006. *Sediment Removal from Active Stream Channels in Oregon: Considerations for Federal Agencies for the Evaluation of Sediment Removal Actions from Oregon Streams*. Version 1.0. Viewed online at: <http://www.fws.gov/oregonfwo/ExternalAffairs/Topics/Documents/GravelMining-SedimentRemovalFromActiveStreamChannels.pdf>.
- U.S. Navy. 1990. *Final Environmental Impact Statement for Proposed New Dredging*. Draft *Environmental Impact Statement for Proposed New Dredging*: U.S. Navy Military Construction Projects ; P-202 Naval Air Station, Alameda, P-082 Naval Supply Center, Oakland, San Francisco Bay, California. [Book.]
- UNESCO and IRTCES. 2011. *Sediment Issues & Sediment Management in Large River Basins*. Interim Case Study Synthesis Report. UNESCO (Beijing): Prepared by the International Sediment Initiative. Technical Documents in Hydrology. Viewed online at: [http://www.irtces.org/isi/isi\\_document/2011/ISI\\_Synthesis\\_Report2011.pdf](http://www.irtces.org/isi/isi_document/2011/ISI_Synthesis_Report2011.pdf).
- Wheaton JM. 2013. “Spawning Habitat Integrated Rehabilitation Approach (SHIRA).” Joseph M. Wheaton Research Linking Fluvial Geomorphology & Ecohydraulics. Logan (UT): [Web site.] Viewed online at: <http://www.joewheaton.org/Home/research/projects-1/past-projects/spawning-habitat-integrated-rehabilitation-approach-shira->.