ANNUAL REPORT

ASSESSMENT OF OFFSHORE SAND RESOURCES FOR POTENTIAL USE IN RESTORATION OF BEACHES IN CALIFORNIA

Year-One Activities

Prepared by the California Geological Survey

Under

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2005

Oceanside Pier, San Diego County

INTRODUCTION

This report summarizes activities performed during the first year of a project funded by two cooperative agreements between the U.S. Minerals Management Service (MMS), California Department of Boating and Waterways (CDBW), and California Geological Survey (CGS). The purpose of the project was to assess sand resources on the continental shelf beyond the 3-nautical mile State/Federal boundary for potential use in beach replenishment along the coast of California. The agreement with the MMS was part of a national program to assess offshore sand and gravel resources. The agreement with the CDBW was to provide additional cost-share funding to support the MMS agreement. In addition, activities of the project were integrated into goals and activities of the California Coastal Sediment Management Workgroup (CCSMW). The CCSMW is a consortium of federal and state agencies responsible for preparing a master plan and companion GIS to study and manage sediment issues along the entire coast of the state. The workgroup offered guidance on what segments of the coast may be in most need of beach replenishment in the near future.

Year One of the project involved three main tasks, which are presented below in this summary as Parts A, B, and C. In brief, the parts consisted of the following activities:

Part A – literature review of seven technical issues of interest to the CCSMW in its preparation of the statewide sediment master plan.

Part B – collection of information on current and future feasibility of offshore sand dredging, including technologies and maximum water depths.

Part C – collection, integration, and interpretation of available data and information on the occurrence and nature of Quaternary sediments in offshore areas determined to be high priority by the CCSMW. These activities are leading to specific definition of areas of potential sand resources and indicate where additional work, including high-resolution geophysical surveys and sediment sampling, will be needed to demonstrate the volume and suitability of the resources for beach replenishment.

The three sets of tasks were conducted over the period of late 2003 to early 2005. The expectation was that results from Parts B and C would lead to selection of specific sites of sand deposits that would be more intensively investigated in subsequent years.

GEOGRAPHIC FOCUS OF ACTIVITIES

In the Year-One phase of the project, the CGS worked with the CCSMW, MMS, CDBW, and other organizations to select priority areas along the coast of California on which to focus study for offshore sand deposits. After a brief reconnaissance of the entire coast of the state, the focus of the project was narrowed to the coastal segment in southern California from Point Conception to the border with Mexico. Criteria used to define the focus included distribution of population and coastal development, economics, distribution of current and anticipated projects in beach replenishment, and sites of problems with erosion. Specific areas of most interest to the State of California for beach replenishment included local segments in Orange County (Surfside/Sunset Beach to San Clemente), San Diego County (Oceanside to Imperial Beach), and Santa Barbara and Ventura counties (Carpinteria to Ventura region).

TYPES OF ACTIVITIES

Activities during Year One consisted largely of research on the location and content of technical data for coastal and offshore California. Methods of this research mainly comprised investigation of library holdings and Internet resources as well as interviews with experts in government, academia, and private industry. We compiled part of this research through a GIS inventory, which is described below under Part C.

Ancillary activities included attendance/presentations at various meetings of the CCSMW and technical conferences. We also participated in a research cruise conducted by the U.S. Geological Survey on San Pedro Shelf to collect seafloor samples and arranged to have 20 additional samples collected during that campaign.

SUMMARY OF RESULTS

Research on current capabilities of the U.S. dredging industry to extract sand from offshore California for beach replenishment indicates that maximum water depths for economical operation of hydraulic dredges (cutterhead-suction and trailing-suction hopper, which are standard for offshore sand extraction) are typically limited to about 100 feet. One U.S.-based trailing-suction hopper dredge reportedly can operate in 140 feet of water. Outside of the U.S., there are larger hopper dredges, termed “jumbos,” one of which is claimed to operate in up to 500 feet of water. Reportedly the jumbos cannot be used in the United States because of legal requirements on construction and ownership of dredges allowed to operate in navigable U.S. waters (Federal Dredging Act and Jones Act).

The continental shelf off California is notable for its irregularity in width and its general narrowness compared to the East and Gulf coasts of the U.S. Along much of the shelf, water depths drop off rapidly inshore of the 3-nautical mile limit that separates the jurisdiction of the Federal government (MMS) and the State of California. Furthermore, based on the technological, economic, and legal conditions related to dredging in the U.S. discussed above, there are currently few areas under MMS jurisdiction along the coastal shelf in southern California that would be accessible to potential extraction of sand <u>under the present conditions</u>. The most promising of these areas include:

- San Pedro Shelf, particularly near the Surfside/Sunset Beach area (Long Beach-Huntington Beach area in Orange and Los Angeles counties)
- Imperial Beach to Pacific Beach, particularly near Imperial Beach because of beach erosion there (San Diego County)

- Ventura Shelf, particularly near the Carpinteria area (Oxnard to Santa Barbara in Ventura and Santa Barbara counties)
- Santa Monica Shelf (Los Angeles County)
- San Onofre area (San Diego County)

Details on the first four areas are presented in Part C presented below. All five areas are in proximity to past, current, or potential future projects of beach replenishment of high interest to the State of California and local jurisdictions. These areas also comprise the widest sections of the continental shelf along the southern California coast, which translates to larger areas of relatively shallow water depths under jurisdiction of the MMS compared to adjacent segments of the shelf. Consequently, we recommend that the next phase of study focus on these areas because they are ones that could most likely be targets of extraction under the present or very near-future conditions for offshore dredging.

Because technology, economics, and legal aspects could change in the future, other areas of the coast of California could become candidates for extraction of sand for beach nourishment.

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The California Geological Survey thanks the following individuals for their assistance and guidance through various aspects of this project: John Smith, Tony Giordano, and John Rowland of the U.S. Minerals Management Service; Kim Sterrett of the California Department of Boating and Waterways; and Clif Davenport, project manager for the California Coastal Sediment Management Workgroup.

We also thank the numerous specialists in marine and coastal studies and issues who generously shared their time and knowledge in providing information during research for the project.

PART A

LITERATURE SEARCH AND REVIEW OF SELECTED TOPICS RELATED TO COASTAL PROCESSES, FEATURES, AND ISSUES IN CALIFORNIA

Prepared for the
California Coastal Sediment Management Workgroup

By

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California Geological Survey
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SECTIONS

TABLES
(as separate .xls files)

OVERVIEW OF ASSIGNMENT

INTRODUCTION

In 2004, the California Coastal Sediment Management Workgroup (CSMW) requested that the California Geological Survey (CGS) conduct research and prepare brief summaries of literature on various topics and geographic locations related to physical properties of sediment management along the coast of California. The CSMW, a consortium of state and federal agencies, is charged with preparing the Coastal Sediment Management Master Plan, a dynamic document that will guide the future coordination of local, regional, state, and federal approaches to coastal sediment management in California. The goal of the plan is to manage regionally, from a natural-systems approach, rather than locally, from a site-specific approach.

As prepared and prioritized by Clif Davenport, the state's project manager for the CSMW, this research was divided into seven tasks, which are listed below. The tasks were distributed among three staff geologists of the CGS. Because of the interest of the CSMW in completing this research quickly so that other phases of the Master Plan could move forward, the assignment was limited to a few months for research and preparation of results. Correspondingly, the research on the seven tasks was neither intensive nor comprehensive. Nonetheless, the results of the research should provide foundations for follow-up detailed research and direction for the CSMW Master Plan.

The results of this literature search are symptomatic of what the CSMW Master Plan will attempt to resolve, namely, that the studies and reports related to coastal activities have historically been done largely from a local, project-by-project approach. There is abundant information and documentation, but much of it has been accomplished and presented in piecemeal, isolated (rather than integrated) fashion.

There are many hundreds of published and unpublished technical reports and documents pertinent to the topics addressed in the seven tasks of this assignment. Many of those listed in the attached bibliographies were not reviewed. Nonetheless, they are presented here as examples of the literature as well as what we interpreted to be potentially the most important sources of information on the respective topics. We have not attempted to cull all pertinent data and information from these many reports. Rather, the bibliographies are presented as starting points for future detailed research on each of the topics as needed.

We researched literature and information for this project from the following sources:

- Standard hard-copy reports and maps
- Visits to libraries
- On-line search engines (e.g., GEOREF, ASCE, USACE, NTIS, AGU, Google)
- Web sites (e.g., NOAA, USGS, CERES)
- Personal interviews and correspondence

At the end of this overview are lists of selected Web sites for information on marine and coastal topics. We used some of these regularly to aid our research. Regarding search engines, we found many instances where journal articles were missed by on-line searches.

Within the main body of this report, we have broken each task into two sections: results and bibliography. For some of the tasks, we have included recommendations for continued related work to assist the Master Plan. For the tasks that are geographically oriented, we have divided the bibliographies into two sections. The first lists general references that the reader may want to use for related background or further education. The second lists references that apply directly to the coast of California. Several of the tasks include accompanying tables (Tables 1-5), which are included here as separate Excel spreadsheet files. Some of the tables have blank columns for latitude and longitude, which will allow the data in the tables to be georeferenced in GIS format. Values for latitude and longitude were not determined during this assignment.

Finally, we greatly appreciate the information and assistance provided by many individuals, particularly those at the California Coastal Commission, California Geological Survey Library, California Department of Boating and Waterways, California State Lands Commission, Orange County Public Facilities and Resources Department, U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, U.S. Geological Survey, U.S. Minerals Management Service, and several academic institutions. We especially thank Melanie Coyne for sharing insights on her table of beach-nourishment projects in California.

SUMMARIES BY TASK

The following sections list the seven tasks and briefly summarize findings for each of them:

Task 1 - Compile available and known beach nourishment needs along the entire California coast (locations, reasons, severity of need, and consequences); identify critical beaches that would benefit most from beach nourishment and compile a list of known erosion hot spots.

Erosion along the coast of California manifests itself through two types of processes: natural and man-induced. The former is expected because of the dynamic geology of the state. The latter has resulted from many coastal and inland modifications that have disrupted or exacerbated the natural processes. Coastal erosion in the state affects beaches, cliffs/bluffs, and steep mountain slopes adjacent to the ocean; overall, the first two are of most concern.

The severity of erosion can be viewed from a purely geologic perspective or a cultural perspective. From a cultural perspective, many factors affect the need for intervention to reduce or halt erosion. They fall into the categories of public safety and economic/recreation. These are largely driven in California by the disparate distribution of population and associated development along the coast. The two segments of the coastline with the greatest need for intervention to protect the public from erosion are from the Santa Barbara area to the border with Mexico and from the San Francisco Bay region to the Monterey area.

There appears to be no consistent definition of the term “erosion hot spot.” Although the National Research Council has defined it in one of its technical publications, how the term is used can depend on context and need.

Literature on coastal erosion in California covers from statewide to the local site-specific level. Some reports are published and widely available; others are more obscure and require more effort to locate and obtain. The documentation of locations and features of erosion are probably greater for cliffs and bluffs than for beaches.

An up-to-date, systematic, detailed inventory of rates and locations of erosion along the entire coast is warranted. A database for cliff/bluff erosion is in preparation, but one for beach erosion remains to be developed.

Task 2 - Gather studies that investigate the transport and depositional fate of fine-grained materials associated with natural and anthropogenic turbidity plumes; focus on what’s currently known about the densities and duration of “natural” turbidity plumes, and similar information on plumes associated with beach nourishment or other sediment management activities.

“Turbidity” as related to marine/coastal environments falls into two main categories, natural and anthropogenic. If the subcategory of turbidity currents is excluded from the natural category, then the volume of research and literature for the anthropogenic category by far exceeds that for the natural category.

Natural turbidity plumes in the marine environment generally fall into one of three categories: 1) classical turbidity currents, which transport sediment from the shelf slope to the deep abyssal environment, 2) hypopycnal (surface) and hyperpycnal (bottom-flowing) turbidity plumes at river mouths, and 3) storm-related turbidity plumes.

The primary sources of anthropogenic, open-water turbidity are channel-maintenance dredging, disposal of dredged material, beach replenishment, mining of aggregate by dredge, and coastal construction activities. Many studies have been conducted by the U.S. Army Corps of Engineers (USACE) on maintenance dredging and disposal activities in enclosed waters such as estuaries and embayments, locations where the presence of a high fine-sediment fraction is conducive to elevated turbidity. Studies have demonstrated that most dredge-induced turbidity plumes are localized, spreading less than a thousand meters from their source; the plumes are short-lived, dissipating to ambient water quality within several hours after dredging is completed. In many cases, suspended-sediment concentrations are less than those generated by commercial shipping operations or during severe storms. In some infrequent cases involving high fine-sediment content and strong tidal or riverine currents, surface plumes can be visible for distances of many kilometers.

Considerably less research has been conducted in unprotected marine waters where most of the literature has focused on the effect of turbidity on specific marine species and biosystems or on the transport dynamics of coarse sand, rather than on the temporal or spatial characteristics of re-suspension of fine sediment.

Few attempts have been made to quantify turbidity conditions during beach-nourishment activities. Nonetheless, it is generally agreed that turbidity that results from placement of sand on the beach face is even more localized and transitory than that during offshore or enclosed-water operations. In some studies, elevated turbidity was rarely observed outside the surf zone and was not discernable from normal turbidity caused by waves in the surf zone. In another study, elevated turbidity was limited to a narrow swath in the swash zone in the immediate vicinity of the operation. These results are largely attributable to the use of nourishment material that is low in clay and silt and resembles as closely as possible the indigenous beach sand.

Recent efforts have concentrated on modeling to predict suspended-sediment behavior. Most notable of these are the USACE PLUme MEasurement System (PLUMES) model, which documents the movement of sediment plumes using sediment concentrations and three-dimensional fluid velocity data; the Short-Term FATE (STFATE) model which evaluates the short-term behavior of surface discharges in open water; the Long Term FATE (LTFATE) model designed to assess the long-term fate of seabed accumulations of disposed material; and more recently, the Suspended Sediment FATE (SSFATE) numerical modeling system, which allows the running of multiple simulations to determine those scenarios with the least potential for adverse environmental impact.

Task 3 - Compile known and available information on: the types and grain size distribution of sands that have been used for nourishment projects along the important California beaches; observed end results of nourishment projects; the basis for limitation placed on the percentage of allowable finer grained materials in nourishment projects. Include any information gathered on existing grain size distributions at those important beaches.

Beach nourishment began in the early 1900s in California and has since encompassed hundreds of episodes at dozens of beaches along the coast. Most of the projects have been in southern California from Santa Barbara County to the Mexico border.

Data and information on the physical character of sediment (fill and native materials) involved in these projects range from sparse to well documented. This range results

largely from the purpose and time period of the individual projects; those designed as purely nourishment (rather than disposal) projects and that are relatively recent tend to have more data and information. Sources of data include academic studies as well as site-specific reports prepared by government agencies and private consultants.
To date, the overall results of beach nourishment in California have been mixed. Regarding documentation of results, it appears that early projects were either not monitored or monitoring was more qualitative in nature; documentation of results in the literature has been spotty. Rigorous quantitative monitoring (e.g., beach profiling, fill-volume measurements) of fill performance has become more routine in the last 10-20 years.

Various parameters can affect the performance of beach fills. There is some question as to the importance of the continued use of grain-size comparisons between fill and native materials as measures of beach performance.

Task 4 - Compile available information which identifies the presence of fine-grained “mud belts”, potential sand source areas, and sandy and rocky bottom habitats in the offshore vicinity of potential beach nourishment locations.

Because of its diverse and dynamic setting along an active plate margin, the seafloor off California is underlain by a complex distribution of geologic materials. Areas of mud, sand, and bedrock are interspersed, with sand prevalent along most of the coast at shallow depths.

The available data and information on the locations and character of these materials ranges from very sparse to highly detailed. There are a few statewide compilations of offshore geology. These were prepared from many historic observations, geophysical surveys, and samples collected by numerous institutions, both public and private. At the regional and local level along the coast, many academic and government groups have conducted studies of seafloor materials. The density and scale of coverage of these studies vary from place to place depending on funding and purpose. The most-detailed studies have been done in the San Francisco-Monterey Bay region and along the Southern California Bight from Santa Barbara County to the Mexico border.

Volumes of sand deposits using hypothetical thicknesses have been estimated for sand deposits along the entire coast of the state. Many sand deposits have been studied locally along the coast of southern California through direct sampling and vibracoring. Such deposits have served and could continue to serve as sources of sand for beach-nourishment projects nearby.

Task 5 - Research any studies assessing the 80/20 coarse-to-fines “rule-of-thumb” ratio used by various regulatory agencies to determine whether potential source sands are compatible with a given beach. Identify the origin of the rule-of-

thumb and nourishment projects where variances from the rule of thumb were allowed, including the basis for each variance.

There is a common misperception that beach-nourishment operations must conform to an 80/20 coarse-to-fines ratio, which prohibits the use of material containing more than 20% fines (silt and clay). This arises from the U.S. Corps of Engineers' (USACE) and U.S. Environmental Protection Agency's (EPA) use of this arbitrary cut-off for applying testing exclusions to marine disposal projects regulated under the Marine Protection, Research, and Sanctuaries Act (MPRSA). Beach nourishment is considered a fill activity and thus jointly regulated by the USACE and EPA under the under Section 404 of the Clean Water Act (CWA), which imposes no specific limits on sediment grain size. Instead, the 404(b)(1) guidelines require site-specific determinations that dredged material be demonstrably compatible with the receiving beach. Compatibility of dredged material is determined through a tiered testing protocol outlined in the Inland Testing Manual of the USACE and EPA.

It is necessary to proceed through the tiers only until enough information is obtained to make factual determinations. Tier-one testing evaluates the compatibility of grain-size distribution. If there is a reason to believe that the dredged material might contain contaminants, which are commonly adsorbed to the fine-clay fraction, then a second, and possibly third, tier of testing is required to identify potential adverse chemical and biological impacts. In California, to preclude second- and third-tier chemical and biologic testing, the USACE generally requires that the overall percentage of silt and clay in the dredged material be no more than 10% higher than that of the finest beach sample. Sediments containing more than this can be approved for beach nourishment provided that the additional testing demonstrates they pose no adverse environmental or health effects.

In recent years, there have been some beach nourishment projects in California that have been approved to use dredged material with greater than 20% fines, but only after complying with the 404(b)(1) guidelines and Inland Testing Manual protocols.

We were unable to determine why the values of 80% and 20% were originally selected.

Task 6 - Compile known information on debris-basin locations, contacts, volumes, and cleanout frequencies. Focus efforts outside of Ventura and Los Angeles Counties, since debris basins in those counties are already included within the SMP GIS.

We contacted officials in San Diego, Orange, San Luis Obispo, and Monterey counties to collect information on debris basins. Of these, only Orange County has debris basins, which are classified by local officials as retarding basins to trap fines and slow runoff during storms.

We did not collect information from Santa Barbara, Ventura, Los Angeles, San Bernardino, and Riverside counties because these were documented in detail in a study published in 2002.

Task 7 - Document known information (i.e., case studies, etc.) regarding the natural seasonal movement of sand from the beach to nearshore and back.

Numerous morphological studies of beach profiles and the hydrologic and hydraulic conditions that form them have demonstrated the phenomenon of seasonal cross-shore (onshore-offshore) transport of beach sediments on wave-dominated beaches. Seasonal beach erosion and accretion are natural mechanisms that allow the beach profile to adjust itself to the prevailing wave forces in order to effectively dissipate wave energy.

In winter, California’s beaches are subjected to pounding by tall, high-energy short-wavelength “storm waves” generated by local storms. Beaches respond by reducing their overall slope through erosion of the beach face and berm and the transport and redeposition of the sand in an offshore bar. This shifts the breaker zone farther offshore and produces a “winter” beach profile. At this point, the surf zone is at its widest and the breaker heights greatest. In summer, low, long-wavelength “swell waves”, generated by distant storms, reverse this process by eroding and redelivering the sand stored in the offshore bar to the beach face and berm (summer profile). Decreasing wave energy also causes beaches to narrow and steepen. The critical wave conditions that govern the shift between summer and winter profiles are largely a function of critical wave steepness (ratio of wave height to wavelength). Storm waves have high steepness values, while long swell waves have low steepness values. Up until the late 1990s, it appeared that no study had yet identified critical wave-steepness values that would dictate when a summer profile would revert to a winter profile and vice versa.

While the complete cycle between fully developed seasonal profiles is uncommon, southern California beaches are examples that generally experience the full sequence.

SELECTED WEB SITES FOR INFORMATION ON MARINE AND COASTAL TOPICS

Presented here are lists of Web sites that contain pertinent information and avenues for additional research on the seven tasks.

Web sites for marine and coastal data:

http://www.ngdc.noaa.gov/mgg/mggd.html (repository for marine geophysical and geologic data – NOAA National Geophysical Data Center – free)

http://www.nodc.noaa.gov/ (site for ocean data – NOAA National Oceanographic Data Center – free)

http://ceres.ca.gov/ocean/ (site for ocean and coastal data and information – California Environmental Resources Evaluation System – free)

http://www.netlobby.com/beachapprops05_table.htm (proposed 2005 funding for beach nourishment projects in California)

http://www.ngdc.noaa.gov/mgg/geology/mmdb.html (database for marine minerals - NOAA National Geophysical Data Center – free)

http://geopubs.wr.usgs.gov/dds, IN REVIEW (a Web-based GIS project that covers the central California coast from Cape Mendocino to Point Conception – U.S. Geological Survey: contact Mimi D'Iorio at mmdiorio@usgs.gov)

Web sites for bibliographic references for marine and coastal studies:

http://webspirs.silverplatter.com/cgi-bin/login.cgi (GEOREF database - highlights geologic studies - American Geological Institute – subscription service for CGS, not free)

http://www.spn.usace.army.mil/library.html (listing of holdings for technical library - U.S. Army Corps of Engineers – free)

http://www.lib.noaa.gov/ (list of library holdings and NOAA publications – NOAA Central Library – free)

http://www.csc.noaa.gov/ (list of library holdings and publications of Coastal Services Center – NOAA Coastal Services Center – free)

http://www.ntis.gov/search/index.asp?loc=3-0-0 (list of miscellaneous publications since 1990 – National Technical Information Service – free search, but charge for download of document) http://grc.ntis.gov/daypass.htm (list of miscellaneous publications since 1964 – National Technical Information Service - $15 per day charge plus download costs)

http://www.pubs.asce.org/chrhome2.html (list of journal articles since 1970 – American Society of Civil Engineers – free)

http://www.mms.gov/library/ (list of publications – U.S. Minerals Management Service – free – many publications on-line, but appear to be limited to fairly recent) plus http://www.mms.gov/itd/pacpubs.htm

http://scilib.ucsd.edu/sio/ (information and services – Scripps Institution of Oceanography Library – free and cost?)

http://www.coastalconservancy.ca.gov/Publications/pubs.htm (list of agency publications some of which are about California beaches and wetlands) Also on CCC Web site are two pages for "Southern California Wetlands Recovery Project" and "Southern California Wetlands information Station"

http://gis.ca.gov/catalog/BrowseRecord.epl?id=1532 (catalog of publications held by CDBW related to coastal hazards – California Department of Boating and Waterways – free)

Miscellaneous Papers on Beach Erosion, Nourishment, and Performance

http://www.coastal.ca.gov/pgd/pgd-mon.html (main text)

http://www.coastal.ca.gov/web/pgd/pgd-mon2.html (appendix)

http://resources.ca.gov/ocean/html/chapt_5c.html

http://bigfoot.wes.army.mil/6720.html (Orange County 1998)

http://ceres.ca.gov/ceres/calweb/coastal/beaches.html (General discussion of California beaches)

http://cdip.ucsd.edu/SCBPS/Torrey/homepage.shtml#top (Torrey Pines Beach nourishment project)

http://www.eurekalert.org/pub_releases/2000-12/UoCS-Hrrl-1612100.php (UCSC studies on coastal erosion related to storms)

http://www4.nationalacademies.org/onpi/oped.nsf/0/25D22ABB0CCB005F852566750073B95C?OpenDocument (General on eroding beaches) http://www.beacon.dst.ca.us/goleta_beach_restoration.htm (Goleta Beach restoration project)

RESULTS FROM CSMW TASK 1

(Coastal Erosion – Needs for Beach Nourishment)

TASK 1 – Compile available and known beach nourishment needs along the entire California coast (locations, reasons, severity of need, and consequences); identify critical beaches that would benefit most from beach nourishment and compile a list of known erosion hot spots.

BACKGROUND

The issues of coastal erosion and beach replenishment/nourishment are commonly related. Coastal erosion manifests itself through two processes: natural and man-induced. An important challenge is our capability to separate the two for a given geographic location or episode. Beach replenishment or nourishment has increasingly become a preferred method of reducing or halting erosion along coastlines throughout the world. The reasons can range from purely economic (e.g., recreation; tourism) to public safety (e.g., collapse of cliffs above occupied beaches; destruction of houses and businesses).

One of the first steps to manage sediment along a regional coastline is to identify the physical locations and rates of erosion from a geologic perspective only, regardless of cultural conditions and influences. After this identification is complete, a next step would be to then overlay the cultural conditions and influences. These could include such variables as population, development, jurisdiction (public, private), economics, safety, and anticipated future conditions, among others. These variables could be weighted and then combined in a quantitative fashion to rank "severity of need" for intervention with beach replenishment/nourishment.

An issue related to severity of need is that of "erosion hot spots." Erosion hot spots can be defined from a scientific perspective (high erosion rates with no "value" assigned) or from a cultural perspective (erosion is causing economic or safety hardships even though actual amount of erosion may not be severe compared to other locations).
The National Research Council (1995) defined an "erosion hot spot" as one or more areas along a beach project that will erode more rapidly than their neighbors and more rapidly than predicted using accepted methodologies. Indeed, the definition of an erosion hot spot can be different depending on one's purpose and interests. Is it based on purely geologic variables such as measured erosion rates? Is it based on economic losses? Is it based on jurisdictional location (public land or private property)?

The "benefit" of beach replenishment/nourishment is also an important part of ranking locations along a coastline for intervention. If considering economic benefits (tourism, recreation), King's study (California Department of Boating and Waterways and State Coastal Commission, 2002, Part 1, Chapter 3) provides an example of a monetary benefit/cost approach to ranking. If considering public safety benefits (which do not as easily lend themselves to monetary benefit/cost analysis), the approach would have to consider human exposure at sites (e.g., potential injuries or fatalities from collapse of cliffs or structures because of erosion).

EROSION ALONG THE COAST OF CALIFORNIA

Because of its dynamic geologic setting, the coast of California is subject to the natural processes of erosion along its entire length. Uplift of the coastal land mass by geologic forces in combination with rising sea level since the last ice age have created a complex interplay of erosion and deposition of sediment that varies from place to place. This coastal environment differs substantially from the more passive environments of the U.S. Atlantic and Gulf Coasts.

With the advent of man's intense settlement and development of the state since the 1800s, this natural condition has been significantly modified: the rate of erosion has been exacerbated in many places by the construction of inland dams and artificial channeling of rivers (which block or hinder movement of sediment to the ocean) and of coastal structures such as harbors, jetties, and seawalls/revetments.

Whether natural or man-induced, erosion along the coast of California affects beaches; cliffs and bluffs associated with terraces; and steep mountain slopes that front the ocean. The first two categories of features are by far the most important to humans because they are the sites where many people live, work, and pursue recreation. The coastline from the Oregon border to Point Conception is characterized generally by short, narrow beaches and rocky shorelines; the segment from Carmel to San Simeon is notably rugged. The coastline from Point Conception to the Mexico border is generally more subdued with longer, wider beaches, and bluffs and terraces interspersed with alluvial plains.

The significance of erosion along the coast largely correlates with the location of population centers. Population is relatively sparse north of the San Francisco Bay region. From the San Francisco Bay region to Monterey, population and development are much higher. The segment from the Monterey area to the San Simeon region is sparsely populated. Farther south, there is a cluster of population centers and associated development in the Morro Bay-San Luis Obispo region. The most intensively populated and developed part of the coast is from the Santa Barbara area to the Mexico border. Correspondingly, concerns and complaints about erosion are greatest along this part. To the north, concerns about erosion are less overall, with most expressed in the San Francisco Bay and Monterey Bay regions.

Statewide Documentation of Erosion

Documentation and interpretation of erosion along the entire coast of California are summarized in inventories published inventories by the U.S. Army Corps of Engineers and Dames and Moore (1971), Habel and Armstrong (1977), and Griggs and Savoy (1985). Each of these reports provides observations and interpretations of erosion plotted on base maps for the entire length of the coastline. Each has an advantage of observation at different periods of time, which can be important because of changes in coastal development. These reports represent relatively consistent “baseline” views of the coastline of the state.

Our research did not reveal a detailed systematic statewide survey of erosion done subsequently to the inventory of Griggs and Savoy (1985). In the last few years, however, two reports (Noble Consultants, 2000; California Department of Boating and Waterways and State Coastal Commission, 2002) have documented the locations of several dozen sites of critical erosion that are threatening the economic/recreational well-being and/or public safety of citizens along the coast of California. These sites include both beach and cliff/bluff erosion and are briefly summarized in Table A1. This list is not comprehensive, but it does give an idea of the distribution of erosion problems based on a cultural perspective.

Currently, the California Coastal Commission is developing a database of cliff and bluff erosion rates and locations of armoring along the entire state coastline. The database, which is being prepared by Jennifer Dare (jdare@coastal.ca.gov), a National Oceanographic and Atmospheric Administration (NOAA) Fellow with the Commission, is being designed in a GIS format. One of the main sources of data being researched for data on erosion rates is the large collection of consultant reports in the files of the Commission. As of April 2004, detailed research and population of the database was underway for San Diego County, which is serving as a template for the project. When completed, this GIS layer will be a valuable source of information for incorporation into the statewide Coastal Sediment Management Master Plan.

Concerning erosion of beaches in California, there is relatively poor understanding of both this phenomenon and the character of sediment budgets along the coast (Griggs and others, 2003). To improve understanding of these phenomena, Gary Griggs at the University of California, Santa Cruz, is researching beach erosion and sediment budgets along selected segments of the coast of California (Gary Griggs, personal communication, 2003).

Regional and Local Documentation of Erosion

Coastal managers and researchers have increasingly recognized the importance of studying and managing the coast of California from a regional and statewide approach, with focus on natural (system) boundaries rather than jurisdictional boundaries. Correspondingly, relatively recent reports reflect this perspective. Among the most noteworthy are those associated with the Coast of California Storm and Tidal Wave Study prepared by the U.S. Army Corps of Engineers (e.g., 1991, 1993, 2002). The first two installments of this study cover the San Diego and Orange County coastlines. In particular, the 1991 report for San Diego County identified the coastal segments from Oceanside to La Jolla and from Imperial Beach to the border with Mexico as locations of “critical erosion.” Another important study is that of Flick (1994), which is a detailed atlas of erosion along the coast from Dana Point in southernmost Orange County through all of San Diego County to the Mexico border.

Historically, academic researchers have studied some topical issues related to coastal erosion as exemplified by some of the references included in the accompanying bibliography. More recently, local government, as exemplified by the San Diego Association of Governments (SANDAG) and the Beach Erosion Authority for Central Operations and Nourishment (BEACON) in Santa Barbara and Ventura Counties, have embraced the concept of regional management of sediment and correspondingly prepared reports that identify locations of erosion and strategies to manage them (Noble Consultants, 1989; San Diego Association of Governments, 1993).

At the local, or project, level, numerous published and unpublished reports and information are available that document beach and cliff/bluff erosion along the coast of California. The three main sources of this literature are the U.S. Army Corps of Engineers (some are readily available; others are difficult to obtain), private-consultant reports (the California Coastal Commission has a large holding related to permit applications), and academic/professional journals (generally readily available at university libraries where coastal and marine studies are emphasized). Examples from each group are in the accompanying bibliography.

Compilation of Information from Reports

Because of the short length of the present study, detailed research and compilation of information from the wide array of literature and files on coastal erosion was beyond the scope of this study. Not only must the information be located, it must be evaluated for its timeliness; commonly, present conditions are not the same as when the information was gathered and reported for the individual studies.

The importance of compiling the available information on statewide beach and cliff/bluff erosion from the sources described above into a GIS format cannot be overestimated. The integration of the observations and interpretations, particularly those of the three state inventories published between 1971 and 1985, can significantly aid a modern systematic compilation and evaluation of erosion along any segment of the coast of California. The systematic compilation for cliff/bluff-erosion locations and rates is already underway through Jennifer Dare’s project. The systematic, detailed compilation for beach-erosion locations and rates remains to be accomplished.

NEED FOR BEACH NOURISHMENT

Coastal managers and researchers of the coast of California are increasingly looking to replenishment/nourishment as a way to maintain the size of beaches and to protect the landforms and associated development behind the beaches. The progressive diminishment of beaches along the coast, particularly in southern California, can negatively affect recreation and tourism as well as lead to hazardous cliff/bluff failure and flooding that affects public safety.

The need for replenishment/nourishment at any particular beach in the state depends on many variables as described previously. To establish a list of beaches requires evaluation and weighting of these variables. As one approach, Coyne (2000) presented a GIS-based decision-support tool for identifying potential sites of beach nourishment, with examples focused on southern California. Also, the “need” of many beaches in California has been met by a history of successive nourishment episodes (e.g., Surfside/Sunset). These beaches are either on a prescribed schedule of nourishment or may be irregularly nourished because they depend on receiving fill from sources that are defined as “opportunistic” (e.g., harbor dredging or channel maintenance, which must dispose of the excavated material). Need can also be “performance-dependent.” In other words, timeliness of the next nourishment episode can depend on how well the fill from the previous episode has performed according to design specifications.

For the coast of California, Table A1 lists selected beaches identified in previous reports as having a critical need for replenishment/nourishment. Also listed are the potential consequences if there is no intervention. Nearly all sites are in southern California, from Point Conception to the Mexico border. The main reason for this geographic bias is the distribution and density of coastal population and development. This list is not necessarily comprehensive, but represents sites evaluated and selected by consulting specialists and government officials in recent years. To prepare a comprehensive list would require research and evaluation of many published and unpublished reports and documents on all individual beaches along the coast. Furthermore, we believe at this point in development of the Master Plan that severity of need cannot be rigorously established for individual sites along the coast of California until a protocol for ranking is established. Consequently, we have not made judgments on severity of need for the sites listed in Table A1.

RECOMMENDATIONS

- For the CSMW Master Plan, prepare a clear definition of the term “erosion hot spot.”

- For the CSMW Master Plan, prepare a set of criteria to clearly define and rank needs for beach nourishment according to severity. To identify and rank based on economic effects, a benefit/cost analysis could be one approach. To identify and rank based on public health and safety will require other criteria such as previous fatalities or injuries.

- As part of CSMW Master Plan, annually maintain a GIS-based list of beach-nourishment needs, perhaps categorized by littoral cell.

- Digitize and attribute in GIS-format the data and interpretations from the following reports to establish baselines to aid interpretation of beach erosion and needs for nourishment. This process should be coordinated with the current project of Jennifer Dare at the California Coastal Commission.

  U.S. Army Corps of Engineers and Dames and Moore (1971)
  Habel and Armstrong (1977)
  Griggs and Savoy (1985)

CSMW TASK ONE

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RESULTS FROM CSMW TASK 2

(Natural and Anthropogenic Turbidity)

TASK 2 – Gather studies that investigate the transport and depositional fate of fine-grained materials associated with natural and anthropogenic turbidity plumes; focus on what's currently known about the densities and duration of "natural" turbidity plumes, and similar information on plumes associated with beach nourishment or other sediment management activities.

BACKGROUND

The issue of "turbidity" related to marine/coastal environments falls into two main categories, natural and anthropogenic. If the subcategory of turbidity currents is excluded from the natural category, then the volume of research and literature for the anthropogenic category by far exceeds that for the natural category. Our research revealed little information for turbidity in the nearshore environment caused by the artificial placement of sand on beaches.

NATURAL TURBIDITY

Natural turbidity plumes in the marine environment generally fall into one of three distinct categories: 1) classical turbidity currents, which transport sediment from the shelf slope to the deep abyssal environment, 2) hypopycnal and hyperpycnal turbidity plumes at river mouths, and 3) storm-related turbidity plumes.

Classical turbidity currents are submarine phenomena that are responsible for transporting the majority of sediment to the oceanic basins. Usually triggered by earthquakes and slumping of oversteepened delta fronts or submarine canyon walls, bottom sediment is re-suspended increasing the density of the nearby water, which then flows down the continental slope, entraining more sediment as it goes. When it encounters a decrease in slope, its velocity slows allowing the suspended particles to settle. Since a large portion of the world's petroleum reserves occur in these mixed clastic deposits (turbidites), voluminous research and literature exist. Therefore, turbidity currents and turbidites are excluded from this literature search.

When sediment-laden river water enters the ocean, it can generate a "hypopycnal" plume (overflowing surface plume) or "hyperpycnal" plume (bottom-flowing plume). Hypopycnal plumes are more common since river outflows are typically fresh and warm relative to the ocean. Hyperpycnal plumes occur when the density of sediment-laden river water exceeds that of the ambient seawater and descends to the sea floor as a result of the excessive sediment load (Mulder and Syvitski, 1995; Parsons and others, 2001). Hyperpycnal plumes are predominantly seasonal and require unusually high sediment concentrations exceeding 40 kg m^3.

Smaller-scale storm-related turbidity plumes can also be generated by storm-wave re-suspension of either fine seafloor sediments in shallow marine environments or sediments along a wave-dominated beach or other shoreface.

ANTHROPOGENIC TURBIDITY

The primary sources of anthropogenic open-water turbidity are channel-maintenance dredging, disposal of dredged material, beach replenishment, aggregate mining, and coastal construction activities. The main environmental effects of increased turbidity levels from these operations are a reduction in penetration of light into the water column and suspended-sediment impacts on filter-feeding organisms and fish. Most studies have focused on maintenance dredging and disposal activities in enclosed waters such as estuaries, embayments, and navigational channels where there is a high percentage of fine-grained sediment (often 75% or more), which results in larger dispersion plumes than similar activities in offshore waters. Hitchcock and others (1999) cite numerous dredge-related plume studies from around the world in their report on benthic and surface plumes prepared for the U.S. Minerals Management Service. However, the largest inventory of research and literature on dredge-induced turbidity, was produced by the U.S. Army Corps of Engineers (USACE) through its Dredging Research Program (DRP), Dredged Material Research Program (DMRP), and Dredging Operations and Environmental Research Program (DOER) administered through the U.S. Army Engineer Research and Development Center (ERDC) and its predecessor, the U.S. Army Engineer Waterways Experiment Station in Vicksburg, Mississippi.

Considerably less research has been conducted in unprotected offshore waters. Most of the available literature regarding suspended-sediment studies in the swash, surf, and nearshore zones has dealt with either the effect of turbidity on specific marine species and biosystems or on coarse-sand transport dynamics. This focus is largely because offshore disturbances generally produce fewer turbidity-related impacts since offshore sands tend to be coarser, cleaner, and have been winnowed of most clay and silt. In California and many other parts of the world, sands in high-energy offshore areas commonly contain less than 5 percent clay and silt (Nielsen, 1997). This is one reason beach-nourishment projects favor offshore borrow sites. The offshore hydrodynamic environment also favors prompt plume dispersion. Additionally, offshore organisms are more adapted to higher-energy natural sediment transport processes, which can create turbidity under normal conditions (storms, waves, etc).

Dredge and Material-Disposal Turbidity

Turbidity from marine dredging and disposal arises from disturbance of bottom sediments (benthic plumes), overspill of surplus or screened sediment mixtures from the surface dredge (surface plumes), and open-water disposal of dredged sediments (surface and benthic plumes). Generally overspill from spillways, screening, and open-water disposal generates a far greater quantity of suspended material and larger plumes than bottom disturbances (Herbich and Brahme, 1991; LaSalle and others, 1991; Herbich, 2000).

Turbidity is generally not an issue when dredging deposits of clean offshore sands with little fine-grained material. Studies also suggest that dredge-induced turbidity is of little concern in areas with high natural background levels of turbidity, such as at the mouth of estuaries, or in high-energy areas close to eroding coastlines since ecosystems are well-adapted to naturally high loads of suspended sediment caused by tides and wave action.

The majority of studies and monitoring efforts of dredge-induced turbidity has demonstrated that turbidity plumes are, more often than not, localized, spreading less than a thousand meters from their sources and dissipating to ambient water quality within several hours after dredging is completed (Schubel and others, 1978; Byrnes and others, 2003, LaSalle and others, 1991; McClellan and others, 1989; Pennekamp and Quaak, 1990). These results are characteristic of both offshore operations and those in enclosed waters.

Numerous observations and models by the USACE support the conclusion that dredge plumes are localized and of short duration. In one model of a turbid plume of re-suspended sediment generated by an operating hopper dredge in 90 meters of water in San Francisco Bay, a benthic plume extended 700-730 meters downcurrent from the dredge. In the immediate vicinity of the dredge, an overspill surface plume merged into the lower plume, becoming a single plume about 300 meters behind the dredge.

Infrequently, surface plumes can be visible for distances of many kilometers. In these cases, plumes are usually associated with enclosed waters with high fine-sediment content and strong tidal or riverine currents, which carry the plume marineward. In an instance of peak spring tidal velocities of 1.75 m/s, H.R. Wallingford reported that very fine sand could be carried up to 11 km from a dredging site (Hitchcock and others, 1999). Another extreme case was reported by Hitchcock and others (1999) wherein detailed monitoring associated with construction of the Storebaelt Link Bridge in Denmark detected suspended sediment up to 35 km from the source.

Measurements around properly operated dredges show that elevated levels of suspended bottom sediments can be confined to several hundred meters from the cutterhead location and dissipate exponentially towards the surface with little turbidity actually reaching surface waters (Herbich and Brahme, 1991; LaSalle and others, 1991; Herbich, 2000). In many cases, the suspended sediment concentrations are no greater than those generated by commercial shipping operations or during severe storms. Storms, floods, and large tides can increase suspended sediments over much larger areas and for longer periods than dredging operations, which makes it very difficult to distinguish between dredging-induced turbidity and that generated by marine natural processes or normal navigation activities (Pennekamp and others, 1996).

Both surface and benthic plumes are usually associated with marine disposal of dredged material (open-water pipeline discharges or hopper dredge releases). Upon release, the fines can behave either as a density current (dynamic plume), or mix with the water increasing turbidity throughout the water column (passive plume). In passive plumes, concentrations are generally low and sediment falls at the settling velocity of the single particles. In dynamic plumes, the bulk density of sediment-water mixture, relative to the ambient water, determines the rate of fall.

A dense, sediment-laden dynamic plume descends rapidly through the water column as a well-defined jet of high-density fluid, entraining ambient seawater as it falls. At the same time, a passive plume arises from turbidity-induced entrainment of sediment along the perimeter of the dynamic plume. It has been estimated that 95-99 percent of most discharged sediment loads descend to the bottom within 30 meters of the point of discharge with only the remaining few percent being stripped from the outside of the dynamic plume (Schubel and others, 1978; Neal and others, 1978).

In extremely strong current velocities and/or in deep water, where the bottom may be thousands of feet down, a descending dynamic plume may entrain so much water that it mixes entirely with the surrounding water and loses its integrity, thus becoming a passive plume. When this occurs, sediment concentrations become relatively low and fine particles usually stay in the water column for several hours, but may remain for as much as several days before settling out. The settling zone of the passive plume can cover several kilometers resulting in no significant bottom buildup.

Passive plumes will move away from the point of discharge by three separate mechanisms, all of which are a function of hydrodynamics and particle size and shape: advection by tidal currents; diffusion by turbulence; and settling. The fine particles in a plume are advected by the current and also undergo settling. Coarser sediments will be transported a lesser distance away from the point of discharge. Non-cohesive sediments, or those greater than sand size (>2mm) are generally considered to fall to the seabed immediately (Hitchcock and others, 1999). As the current velocity increases, advection becomes relatively more important in spreading the suspended sediment. Concentrations rapidly decrease with increasing distance downstream or downcurrent from the discharge point and laterally away from the plume center line due to settling and horizontal dispersion of the suspended solids (Bernard, 1978). Barnard (1978) presents a plot showing the relationship of suspended-solids concentrations along the plume centerline and distance down-current from several open-water pipeline disposal operations.

The duration of turbidity in water is largely based on the fall velocity of the sediment particles. Fall velocity depends on size, shape, and density of the particles as well as the fluid density, viscosity, and several other parameters. When a particle falls through water, it accelerates until it reaches its fall velocity, or the terminal velocity that a particle reaches when the retarding drag force on the particle just equals the downward gravitational force. While low concentrations of silt and clay (with diameters <0.03 mm) settle very slowly and cause more persistent plumes, under certain conditions, clay particles may collide to form aggregates or flocs with diameters of 0.1 to 2.0 mm. The formation of flocs increases settling velocity, which results in a more rapid decrease in suspended-sediment concentration with distance from the source (Barnard, 1978).

When a dynamic plume impacts the seafloor, it causes a horizontal, radially-spreading bottom surge outward across the seabed as a density underflow plume until its velocity and turbulence are sufficiently reduced to permit deposition. The greater the thickness and solids content of the layer, the greater the density flow effect. Generally, these underflow plumes originate as turbulent flows, characterized by chaotic motions and a billowing head just behind the leading edge and decay with deceleration to laminar underflow after spreading a short distance (Thevenot and others, 1992). Since turbulent underflows generally entrain ambient water, they grow vertically and tend to have lower concentrations than laminar underflows (Teeter, 2000a). The sediments ultimately form a low-gradient circular or elliptical fluid mud mound consisting of high-density (nonflowing) mud overlain by a surface layer of low-density (flowing) fluid mud (Barnard, 1978). Depending on the volume of material, these mounds can measure several feet thick (Holliday, 1978).

Tides also affect plume dispersion with plumes extending landward and seaward during the incoming flood tides and the outgoing ebb tides, respectively (Barnard, 1978).

Beach-Nourishment Turbidity

Suspended-sediment related issues are often a concern during beach-nourishment activities and afterward, while the new beach responds to the prevailing wave regime. Surprisingly, few attempts have been made to actually monitor and quantify turbidity conditions. Most of the literature regarding suspended sediments in the swash, surf, and nearshore environments addresses sand-transport dynamics and faunal effects rather than the distribution of re-suspended fine sediments. However, based on observations and the available studies, it is generally agreed that turbidity resulting from placement of sand on the beach face in beach nourishment and other sediment management projects is even more localized and transitory than offshore or enclosed-water operations. This is largely attributable to the use of nourishment material that is low in clay and silt and resembles as closely as possible the indigenous beach sand.

Generally, beach-nourishment projects on high-energy beaches quickly equilibrate with the current wave regime. Finer sediments are promptly winnowed from the nourishment material, causing only a short period of elevated turbidity. Parr and others (1978) noted that the silt and clay fractions were quickly winnowed from the nourishment material placed on Imperial Beach, California, and that after four months, the grain-size distribution of the nourishment fill was comparable to the indigenous beach sand.

In another study of beach nourishment on North Carolina beaches during 2001 and 2002, it was concluded that plumes caused by sand placement and de-watering on the beach face were small, short-lived, and did not create large increases in turbidity over background conditions (Versar, Inc., 2004). Sampling conducted immediately following nourishment and again one year later, demonstrated that turbidity generated by the pipeline discharge hugged the shoreline following the long-shore currents. While elevated turbidity spikes were associated with the discharge pipe itself, in most cases the plumes were not discernable from turbidity created by breaking waves in the surf zone a few hundred meters away or turbidity when dredging operations were temporarily shut down. Elevated suspended-sediment loads outside of the surf zone were rarely observed. Increases in turbidity detected during the second year of sampling were attributed to storm events and high surf conditions.

Perhaps one of the more definitive studies was conducted by the USACE between 1997 and 1999. During this period, the Corps completed one of the largest beach-nourishment projects on record, placing 19.39 million cubic meters of sand (<10% silt and clay) on 47 km of high-energy New Jersey beaches. Detailed sampling revealed little evidence of short-term elevated turbidity in the nearshore environment. Elevated turbidity was limited to a narrow swath (less than 500 m) in the swash zone in the immediate vicinity of the operation with a lateral extent on the order of several hundred meters. While discharge effluents ranged as high as 1048 g/l, observed concentrations decayed rapidly with dispersal through the surf zone to concentrations between <10mg/l to 34 mg/l, which are levels that many of the indigenous fish and invertebrate species experience in estuaries or during storm-induced turbidity (Burlas and others, 2001).

Post-storm monitoring of the swash, surf, and nearshore zones after hurricanes Dennis and Floyd in 1999 indicated that beach sediments at both recently filled and undisturbed beaches were equally susceptible to re-suspension. Suspended-sediment concentrations were generally comparable to slightly higher in the swash, surf, and near shore zones adjacent to the newly restored beaches as compared to undisturbed reference beaches. Only in a few samples from the swash zone of the nourished beach were suspended solids concentrations markedly elevated (Burlas and others, 2001).

DIFFICULTIES IN PLUME-PREDICTION AND MODELING

While many turbidity plumes have been qualitatively described both during and after dredging and beach-nourishment activities, it is difficult to ascribe the results of many studies in more than a general way. Few quantitative studies of short- and long-term plume behavior have been conducted. As a result, development of an accurate and universally applicable model of turbidity induced by dredging, beach nourishment, or other activities associated with largely cohesive sediments is considered nearly impossible (Pennekamp and others, 1996). This is largely because plumes, driven by tidal, wave, and current forces, can change dynamically over large spatial scales (both horizontally and vertically) and short time scales. Data collected at points in time at fixed locations are generally insufficient to rigorously assess the potential dispersion of suspended sediments. The development of widely applicable models is also hindered by the large number of parameters involved and the complications introduced by the dynamic temporal and spatial nature of plumes. Suspended-sediment dispersion is controlled by both operational parameters (dredge type and technique, method of overboard returns, speed) and the interaction of environmental parameters and physical properties. Water properties include depth, temperature, viscosity, stratification, and salinity; sediment properties include background levels of suspended solids, material composition, density, size, particle size distribution (individual grains or flocs), and solids concentration of the slurry; hydrodynamic forces include currents, waves, turbulence, all of which cause horizontal and vertical mixing; and other influences include buoyancy (entrapped air or gas), initial momentum on entering the water body, etc. The behavior and characteristics of a turbidity plume can only be evaluated if the complex interactions between the parts are taken into consideration.

Barnard (1978) offered one of the earlier methods of prediction of turbidity plumes from open-water sediment disposal activities requiring only six input parameters including dredge size, water depth, current velocity, sediment diameter or settling velocity, diffusion velocity, and the “age” of the plume to determine the worst case dimensions of the plume.

More recently, the USACE developed models and software in an effort to evaluate several aspects of suspended sediment behavior. The Dredging Research Program developed the PLUme MEasurement System (PLUMES) model (Kraus and Thevenot, 1992), which utilized commercially available broad-band acoustic Doppler current profiling equipment to measure sediment concentration and three dimensional (3-D) fluid velocity at dredging sites and to document the actual movement of sediment plumes.

The Dredging Research Program also developed the Short-Term FATE (STFATE) model (Johnson and others, 1993; Johnson and Fong 1993) as one module of the Automated Dredging and Disposal Alternatives Management System (ADDAMS) (Schroeder and Palermo, 1990). The STFATE software evaluates the short-term behavior of dredged material discharges in open water during and immediately after a surface discharge. The model was primarily designed to model disposed hazardous material mounds on the seafloor, but it can also be used to predict what portion of the discharge is dispersed as a passive plume. The model output includes a time history of the descent and collapse phases of the discharge and suspended-sediment concentrations for various particle-size ranges as a function of depth and time. At the conclusion of the model simulation, the thickness of the deposited material on the bottom is given.

The STFATE model was followed by development of the Long Term FATE (LTFATE) model (Scheffner and others, 1995). LTFATE modeling software was designed to assess the long-term fate and stability of dredged material disposal sites with an emphasis on seabed accumulations of disposed material.

More recently, the USACE, in conjunction with Applied Science Associates (ASA), developed the Suspended Sediment FATE (SSFATE) numerical modeling system to model suspended sediment plume behavior from dredging operations (Johnson and others, 2000). The software allows the running of multiple simulations in a short period of time so that alterative scenarios can be evaluated to determine those with the least potential for adverse environmental impact. The program evaluates sediment sources resulting from the operation of cutterhead, hopper, or clamshell dredges and differentiates the relative contribution of each type of suspended sediments to the water from bottom re-suspension and surface discharges. While this application is available to USACE staff, ASA has retained the distribution and marketing rights for non-USACE users. The model is currently undergoing upgrading following field testing, after which ASA intends to market the application.

Our research of the literature did not reveal reliability or success of these models as determined by any field-testing.

RECOMMENDATIONS

- Follow up on the field testing and potential availability of the updated SSFATE model.

CSMW TASK TWO

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RESULTS FROM CSMW TASK 3

(Beach Nourishment Projects – Performance and Sediment Characteristics)

TASK 3 – Compile known and available information on: the types and grain size distribution of sands that have been used for nourishment projects along the important California beaches; observed end results of nourishment projects; the basis for limitation placed on the percentage of allowable finer grained materials in nourishment projects. Include any information gathered on existing grain size distributions at those important beaches.

BACKGROUND

There are many variables that affect the success or failure of beach replenishment/nourishment projects. One of the main criteria for defining the "success" of such projects is the longevity of the "fill," or borrow material, placed during individual episodes of nourishment. For example, given a volume of fill emplaced in a beach system, managers and engineers want to know what percentage of that fill is retained in the littoral cell after a given period of time. How a fill performs with time is a function of the interaction of several conditions and properties. Some of these include local wave and current conditions; technique and location of fill placement; and the reliability of the monitoring method. The interactions will determine if a fill remains in the system longer or shorter than expected.

One property of interest in the performance of fills is the physical compatibility between the fill material and the "native" material of the beach where the fill is to be placed. "Compatibility" refers to the degree of similarity of the two materials and includes the size, type (mineralogy), color, density, and shape of the component sediment grains. Typically, size is the most commonly evaluated in trying to match a fill material with a native material mainly because of its potential mechanical performance within the dynamics of the beach environment. Grain type and color can locally be important because of aesthetic or health/safety concerns. A textbook on beach nourishment and protection published by the National Research Council (1995) presents a brief discussion of sand compatibility; various papers are cited that discuss the pros and cons of continued use of grain-size comparisons between fill and native materials as measures of beach performance. Also, the Coastal Engineering Manual (U.S. Army Corps of Engineers, 2002) has sections on beach-fill design and performance.

There are three main concerns with grain size. First, if the percentage of fines (clay- and silt-sized grains) in the fill is too high, a correspondingly larger volume of fill material must be emplaced in the beach system to allow for loss of the fines with time caused by winnowing action of the waves. Second, too high of a percentage of fines in a beach sand is recreationally undesirable – there may be clumping of the material, for example.

Third, fines can harbor or attract contaminants, which may be hazardous to humans and sea life; placement of a contaminated material on a beach system can be detrimental.

Beach Replenishment/Nourishment in California

Beach replenishment/nourishment began in California at least as early as 1919 (Coyne, 2000). Several hundred episodes of replenishment and periodic nourishment have occurred at several dozen beach systems along the coast. Most of these have been in southern California, particularly in the Santa Barbara and Ventura areas, and along the coastlines of Santa Monica Bay, Orange County, and San Diego County.

Currently (2004), there is reportedly only one beach replenishment/nourishment project currently underway in the San Francisco District of the U.S. Army Corps of Engineers, which extends from the Oregon border to just north of the San Luis Obispo-Monterey County line. This project consists of disposal of dredge material at Ocean Beach in San Francisco. In the Los Angeles District, which covers the remainder of the coast to the Mexico border, there are many on-going projects. Some are related to harbor maintenance: those at Santa Barbara, Ventura, Channel Islands, and Oceanside are done annually, while those at Morro Bay, Playa del Rey, and Mission Beach are done infrequently. As an example unrelated to disposal of dredged material, nourishment was recently accomplished at Goleta in Santa Barbara County.

Tracking the history and performance of these projects and individual episodes of replenishment/nourishment is a challenge largely because of the inconsistent documentation and because the information is commonly in unpublished files or reports. Through sponsorship of the California Coastal Commission and California Department of Boating and Waterways, Melanie Coyne, a National Oceanographic and Atmospheric Administration (NOAA) Fellow, researched and compiled the most comprehensive list of beach nourishment projects along the coast of California (Coyne, 2000). Presented here in modified form as Table A2, this list covered projects up to the year 2000. Also included here as Table A3 is Coyne's list of references that she consulted to compile the data and information. As an update to the list since 2000, we have added the individual replenishment/nourishment episodes of the SANDAG Regional Beach Sand Project as documented by Coastal Frontiers Corporation (2004).

Historically, most of the replenishment/nourishment activities in California have been pursued as local, rather than regional, projects. They have been dominantly "opportunistic" projects, meaning that beach restoration was not the primary purpose of the placement of fill. Rather, the beach systems were the receiving (disposal) sites for dredged material from other primary activities such as harbor construction or channel maintenance. Only in recent years has the number of "deterministic" projects become more common. In these projects, beach restoration through replenishment and nourishment is the primary purpose. The recently instituted Regional Beach Sand Project of the San Diego Association of Governments (SANDAG) is the first regional deterministic beach-nourishment program on the Pacific Coast of the United States.

CHARACTER OF FILL MATERIAL AND NATIVE MATERIAL

Data and information on the physical character of sediment involved in beach replenishment/nourishment projects along the coast of California range from sparse to well-documented. One of the main influences on documentation is whether a project is deterministic or opportunistic. Deterministic projects generally have greater testing of materials because of regulatory or economic considerations and requirements; the fill materials are commonly taken for a fee from virgin sources, which have unknown or poorly known characteristics. In contrast, testing is commonly less rigorous in opportunistic projects, particularly if a source for the fill material has been used previously and there are few or no reported problems of compatibility with the native material. The receiver beaches are generally very close to the sources of fill (e.g., bypassing operations) because of the desire to minimize transportation costs. Consequently, the fill material may be very similar in character to what would have been deposited naturally at the receiver beach.

Another factor that affects documentation of the physical character of sediment is the age of the projects. Older projects were under less regulation and thus may not have the quantity and quality of test data like those of modern projects.

Types of information reported for replenishment/nourishment projects can include size, type, color, density, and shape of the component grains. Grain size is by far the most dominant characteristic analyzed and reported; results are typically presented as percentage distribution of sizes within each sediment sample based on sieve analysis. In some reports, the percentage composition by mineral type is presented.

Regarding the character of native material on beaches, many pure- and applied-research studies have been conducted at several sites along the coast of California. Some of these studies are published and thus readily available (e.g., Hutton, 1959; Trask, 1952), Other sources include more-obscure or less-easily obtained reports (e.g., Straughan, 1981; reports of the Hydraulic Engineering Laboratory at the University of California, Berkeley) As a group, this category of studies is neither systematic nor consistent in content and presentation because of differences in researchers' purposes and interests. Nonetheless, they can provide background and baseline information, particularly at beaches that have not yet been replenished.

Regarding the character of both fill materials and native materials, much data and information are also available in geotechnical reports prepared for specific replenishment/nourishment projects. For example, data on grain characteristics are commonly presented in documents, such as environmental impact reports, submitted to the California Coastal Commission as part of its permit process. Also, the U.S. Army Corps of Engineers conducts detailed sampling and analyses of sediments, which are presented in its geotechnical reports (e.g., U.S. Army Corps of Engineers, 1989; 1995; 2002b). Some of its reports are readily available, while others are not; some reside in the project files of the geotechnical branches of both the Los Angeles and San Francisco District offices, while others are at archive centers in Laguna Niguel (Los Angeles District) and San Bruno (San Francisco District).

The character of fill material and, to a much lesser extent, native material at some of the replenishment/nourishment projects in California is summarized in Table A2 (modified from Coyne, 2000) under the column heading of "dredge/fill characteristics." These entries were extracted from research of a few hundred reports. Most are qualitative descriptions rather than quantitative data.

It is worth noting that at many southern California beaches (Santa Barbara County to the Mexico border) there is probably not much truly pristine, "native" material still present. Episodes of nourishment have diluted the original natural character of the beaches, particularly where nourishment has taken place frequently over many decades. Also, because of the inherent variability in the physical nature of natural sediments, it is difficult to generalize or define representative grain characteristics for individual beaches and fill material.

To prepare a comprehensive list of grain characteristics of fill material and native material will require systematic, detailed research of published literature as well as unpublished reports and files in agencies such as the U.S. Army Corps of Engineers and the California Coastal Commission, among others.

RESULTS OF BEACH REPLENISHMENT/NOURISHMENT IN CALIFORNIA

Of paramount importance in a replenishment/nourishment project is how well the emplace material performs compared to the engineering specifications of the project. To make reliable comparisons requires the use of systematic, quantitative monitoring of the performance of beach fills. Unfortunately, it was not until about 10-20 years ago that monitoring became more routine (Leonard and others, 1989; Komar, 1997). Up to the end of the 1980s, performance data for projects on the Pacific Coast of the U.S. were less prevalent than for those for the Atlantic Coast (Leonard and others, 1989). Since then, agencies in California have been taking more coordinated, regional approaches to protecting beaches. Part of this process has been institution of monitoring programs. One example is the Regional Beach Monitoring Program of the San Diego Association of Governments (SANDAG), which began in the middle 1990s (Coastal Frontiers Corporation, 2004). Associated with this project is the Southern California Beach Processes Study (Guza and others, 2002) at Torrey Pines State Beach, which is attempting to improve understanding of how and where a recent beach fill there is being transported by waves and currents. What is learned here could be applied to design and maintenance of replenishment/nourishment projects else where along the coast of California.

Historically, written documentation of the results of beach replenishment/nourishment projects along the coast of California has been inconsistent. Commonly, results have been reported from a site-specific perspective, with an emphasis on qualitative rather than quantitative observation and measurement. Examples are presented in Cahill (1989), Clayton (1989), Leonard and others (1989), Leidersdorf and others (1993, 1994), Mesa (1996), California Department of Boating and Waterways and State Coastal Conservancy (2002), U.S. Army Corps of Engineers (2002b), and Coastal Frontiers Corporation (2004). Important overview papers for results and performance in California include those by Hall (1952), Shaw (1980), Herron (1987), Clayton (1989), and Leonard and others (1989).

The performance of beach fills at various sites in the state is briefly summarized in Table A2 (modified from Coyne, 2000) under the column heading “duration of fill.” Similar to the entries in the table for “fill characteristics” described earlier, the reported results are largely qualitative descriptions rather than quantitative measurements. Many cells in this column are blank, either because monitoring was not conducted or because the research did not discover pertinent documents with recorded results.

To date, the overall results of beach nourishment in California have been mixed. As a current example of performance and monitoring of beach fills, Coastal Frontiers Corporation (2004) recently reported results of monitoring of a major nourishment program in San Diego County. In this program, administered by the San Diego Association of Governments, twelve beaches received nourishment in 2001. During the 2003 monitoring year, the performance of the individual fills at the twelve beaches reportedly varied considerably; at some beaches, previous gains in shorezone volumes persisted, while at others, the gains were short-lived.

Despite the spotty record of documented results of replenishment/nourishment projects in California, Leonard and others (1989) attempted to determine the overall success of various projects as of the late 1980s. As part of this determination, they also evaluated how five physical parameters might influence the success of fill episodes as measured by longevity, or “durability,” of the emplaced fills. Some of their major conclusions for Pacific Coast beaches (nearly all are evidently in southern California) were:

- Longevity of fills at Pacific Coast beaches has overall been higher than those at Atlantic Coast and Gulf Coast beaches.
- Of those beaches measured, 48% were successfully maintained, 15% were not, and 36% were unknown.
- The Pacific Coast management philosophy of nourishment by periodic “maintenance” was advantageous over the Atlantic/Gulf Coast management philosophy of nourishment by “crisis.”
- Project monitoring must be a mandatory part of each replenishment project.

Regarding replenishment parameters:

- **Length:** There was no relationship between longevity of replenished beaches and their lengths.

- **Density:** Pacific Coast beaches had higher cumulative densities of fill than Atlantic Coast and Gulf Coast beaches. For the Pacific Coast, there didn't appear to be a correlation between fill density and fill durability.

- **Grain Size:** The data suggested that grain size was not of particular importance in determining durability.

- **Groins:** These structures have aided stabilization of certain nourished beaches on the Pacific Coast.

- **Storms:** There was a correlation between high erosion rates on nourished beaches of the Pacific Coast and the passage of major storms.

RECOMMENDATIONS

- With some editing and modification, use Coyne's (2000) spreadsheet (Table A2) as a foundation to annually compile data and information on all beach replenishment/nourishment projects along the coast of California. Georeference this table so that it can be incorporated into the GIS of the CSMW Master Plan.

- Determine if the influence of grain-size on fill performance is significant enough to devote CSMW resources to the task of compiling detailed data on grain-size characteristics of fill materials and native materials for beach-nourishment projects along the coast of California.

CSMW TASK THREE

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RESULTS FROM CSMW TASK 4

(Offshore Materials for Beach Nourishment)

TASK 4 – Compile available information which identifies the presence of fine-grained “mud belts”, potential sand source areas, sandy and rocky bottom habitats in the offshore vicinity of potential beach nourishment locations.

BACKGROUND

The observation and mapping of the geologic materials on the ocean floor can lead to discovery of deposits of sand. Where of acceptable grain characteristics, volume, degree of consolidation, depth of submergence, and distance from shore, such deposits have been and will continue to be sources of material for beach replenishment/nourishment. The most desirable deposits are unconsolidated, have large volumes, are similar in physical character to the material on the receiving beaches, are in shallow water close to the receiving beaches, and are free of contaminants and debris. Also, mining of them would produce minimal environmental disturbance.

Typically, the identification and characterization of submarine geologic materials relies on both direct and indirect observation and measurement. Direct methods include visual observation, via submersible vehicles or cameras, and collection of samples through diving, dredging, or coring. Indirect methods include various geophysical techniques that can characterize the seafloor as well as the material beneath it. These data lead to maps and calculations that determine the locations, areal extents, volumes, and physical properties of the materials at and below the ocean floor. Furthermore, because of economic and technological limitations, the depth of sand deposits below the sea surface is of major interest, which requires reliable bathymetric measurements.

The identification and characterization of materials is also important for understanding and management of benthic habitat for marine organisms. The mapping of such habitats, which has become common in recent years, relies on the same techniques for exploration and characterization of sand deposits. Consequently, submarine geologic mapping and benthic habitat mapping are complementary and in some ways might be considered one and the same.

OVERVIEW OF OFFSHORE GEOLOGY OF CALIFORNIA

The complex geology that makes up onshore coastal California continues offshore beneath the continental shelf. In contrast to the U.S. Atlantic and Gulf Coasts, the shelf off California is notably narrow and irregular, a reflection of the active geologic forces there. It is commonly dissected by submarine canyons and, in some places, is only 1-2 miles wide. In simplified view, offshore California is underlain by diverse types of bedrock covered or surrounded by mantles of unconsolidated sand, mud, and gravel.

Available geologic mapping of offshore California is spotty as to areal coverage and detail. Some areas have been intensively studied and mapped, while others have been covered only by limited reconnaissance. Generally, areas close to shore and near large harbors and population centers have received more attention than those near less-developed parts of the coast.

At the statewide level, there are two sets of published maps that cover the entire offshore length of the state. The first, by Welday and Williams (1975), portrays at a scale of 1:500,000 the surficial geology of the offshore, with the greatest detail limited generally to within five miles of the coastline. The strength of this map is that the authors interpreted geologic bottom-types based on thousands of direct and indirect geologic observations made by various organizations. Especially noteworthy was use by the authors of the many historic observations of bottom type made during a suite of hydrographic surveys by the U.S. Coast and Geodetic Survey. Despite its age, this map is still a valuable aid to studies along many parts of offshore California. The second publication, a collaboration between the California Division of Mines and Geology (CDMG, now the California Geological Survey) and the U.S. Geological Survey, consists of seven map sheets that portray at a scale of 1:250,000 details of local geology among other geologic-related information for the continental margin (see Kennedy and others, 1987). The sheets that cover the offshore north of San Francisco have very little geologic detail, while those south of San Francisco have much greater detail. This distribution mainly reflects the focus, intensity, and availability of offshore study by different institutions. Also, the CDMG-USGS map series does not display the mapping of Welday and Williams (1975), therefore, investigators should consult both sets of maps when studying all or part of offshore California. The digitized version of the CDMG-USGS map series can be downloaded from the Seafloor Mapping Lab Website at California State University, Monterey Bay (http://seafloor.csumb.edu/).

In addition to the statewide maps discussed above, the California Geological Survey (CGS) and U.S. Geological Survey have published or are nearing publication of several regional geologic maps at a scale of 1:100,000 that include offshore areas. Some of these have newly compiled offshore geologic data, others do not. A few examples include the following quadrangles, from north to south: Monterey (CGS – published, new offshore data), Long Beach (CGS – in preparation, some new offshore data), and Oceanside (CGS – in preparation, no new offshore data).

Maps of surficial geology along portions of the coast are presented in Howard (1974), but we were unable to obtain and evaluate this report at the time of the CSMW study.

At local levels, various institutions and agencies have conducted detailed ocean floor surveys and mapping. These studies have been mainly in the Monterey Bay-San Francisco area in northern California and at several localities along the Southern California Bight, which extends from Point Conception to the Mexico border and includes the Channel Islands. In recent years, seafloor mapping in California has focused on benthic habitats. Much of this work has used multibeam mapping systems to produce “backscatter” images that display seafloor properties such as areas of mud and bedrock (e.g., Gardner and Dartnell, 2002). Although generally not termed “geologic” mapping, these activities have collected information on the geologic character of the seafloor through their qualitative descriptions of materials as “sand,” “mud,” and “bedrock.” The U.S. Geological Survey, Moss Landing Marine Laboratory, Seafloor Mapping Lab, and Scripps Institution of Oceanography as well as private companies are some of the groups that have conducted this type of work in California. Examples of benthic habitat mapping for the nearshore zone of San Diego County can be viewed or downloaded on-line at http://sccoos.ucsd.edu/nearshore/. The U.S. Geological Survey has published several reports on its offshore mapping in the Monterey Bay-San Francisco and southern California regions. Several are listed in the accompanying bibliography (e.g., Wong and Eittreim, 2001; Gardner and Dartnell, 2002).

DISTRIBUTION OF SEAFLOOR MATERIALS ALONG THE COAST

The geologically active and diverse interior coast of California has profoundly influenced the geologic character of the adjacent seafloor. The high topographic relief, numerous watersheds that drain into the ocean, and the great variety of rock types all have contributed to the many types and complex distribution of materials that make up the coastal seafloor from Oregon to Mexico. This diversity is apparent from the geologic maps of Welday and Williams (1975) and the CDMG-USGS continental margin series.

Documentation of seafloor materials along the coast is available for many local areas. Again, we emphasize that this information was most commonly collected from the Monterey Bay-San Francisco region and the segment of coast from Santa Barbara County to San Diego County. Except for the semi-reconnaissance work of Welday and Williams (1975), there has been no attempt to consistently map in detail the distribution of offshore geologic materials from Oregon to Mexico. This situation is more a result of insufficient resources (funds and time) rather than lack of interest. Correspondingly, the documentation of details has been mostly limited to local projects conducted through government and academic groups and, in some cases, private industry. Government reports and data are generally produced by agencies such as the U.S. Geological Survey, U.S. Army Corps of Engineers, and the National Oceanic and Atmospheric Administration (NOAA). Products from the academic community are typically in the form of theses and dissertations, and papers in technical journals. Studies by private industry typically are prepared as consulting reports to clients (public and private). Examples of some of these categories are presented in the accompanying bibliography.

Mapping of seafloor materials along the California coast has been greatly aided by collection of samples. These include surficial sediment and rock and shallow cores. The U.S. Geological Survey maintains a Website (http://coastalmap.marine.usgs.gov/regional/contusa/westcoast/usSEABED/) that catalogs offshore sample sites and associated data as part of a national database; the data can be viewed on-line through a map server. The U.S. Army Corps of Engineers has data from numerous vibracore samples taken to assess potential borrow sites for beach replenishment/nourishment. NOAA maintains a Website (http://www.ngdc.noaa.gov/mgg/mggd.html) that can be visited to obtain digitized seabottom observations collected during hydrographic surveys conducted between 1851 and 1965 as well as offshore geophysical and geological data. Academic institutions also have bottom sample and core data, some of which have been published. Examples include data collected by the University of Southern California in the Southern California Bight and by the Hydraulic Engineering Laboratory at the University of California, Berkeley, from various coastal localities. Still other data are available in disparate, sometimes obscure, published and unpublished documents.

Together, the technical reports and sets of data portray a pattern of distributed materials that reflect such things as source areas, geologic structure, variations in dynamics of transportation, energy conditions and geomorphology of the depositional areas, and variations of all of these factors with time. For example, deposits of sand are common in the nearshore regions of the state and where rivers have discharged material at their mouths (Welday and Williams, 1975). Mud belts are concentrated farther away from the shoreline or in nearshore areas where the energy of waves and currents are less because of protective coastal settings (e.g., Monterey Bay). Bedrock areas are often nearshore extensions of onshore features or where either relief is positive or current patterns do not favor deposition of sediment. Many of the sand deposits farther offshore are probably paleo-beaches, which originated when the shoreline was much farther west than today; since the last ice age the shoreline has migrated eastward from these locations as sea level has risen.

Finally, the techniques of mapping seafloor materials off the coast of California are evolving. Traditional mapping techniques (e.g., Welday and Williams, 1975) emphasize manual interpretation and drawing of map-unit boundaries based on data from sampling and/or backscattering properties of seafloor materials. Currently, there are attempts to map the boundaries of materials based on image-processing techniques (e.g., classification), which use the same sorts of datasets as the manual approaches. An example is the work in progress by the U.S. Geological Survey on the San Pedro shelf in southern California (Peter Dartnell, U.S. Geological Survey, personal communication, 2003).

POTENTIAL OFFSHORE SOURCES OF SAND

Historically, the sources of sand for beach replenishment/nourishment along the coast of California have predominantly been provided from non-offshore locations (see column labeled “fill source/site” in Table A2 (modified from Coyne, 2000). Included among these are inland sources as well as coastline sources, which have been related to such activities as harbor construction and channel maintenance or by-passing and back-passing operations. Interest in and use of offshore sand resources has generally occurred more recently in California.

Largely because of the abundant contributions from inland source areas and the prevailing southward-directed littoral drift along the entire coast, deposits of sand are prevalent in the offshore of California. Welday and Williams (1975) show numerous linear belts of sand that are dominantly fine-grained, with local areas that are medium- to coarse-grained as well. It is important to recognize, however, that these observations are for the seafloor surface only. Evaluation of sand deposits for potential beach replenishment/nourishment must also consider thickness of the deposits, which may or may not be known for any given location along the coast. To address this issue, Martindale and Hess (1979) and Luken and Hess (1979) used assumed thicknesses to calculate estimated volumes of sand and gravel deposits along the entire coast. The deposits they used for calculation were largely taken from the individual bottom-type areas shown on the maps of Welday and Williams (1975) and Howard (1974).

Because of the preponderance of historic beach replenishment/nourishment projects there, nearly all regional and local exploration and evaluation of offshore sand deposits have occurred in southern California from Santa Barbara County to the Mexico border. Also, because of limitations on dredging (cost, technology), most of this work has been done in shallow water close to shore. Some offshore borrow sites are used more than once because the excavations may be re-filled by natural sedimentation. Consequently, virgin borrow areas are not necessarily required for every episode of replenishment/nourishment, which lessens the overall need for their exploration and evaluation.

Various studies have identified many local offshore sand deposits in southern California that could serve as borrow sites for replenishment/nourishment. A list of selected sites is presented in Table A4. This list is not comprehensive, but gives an idea of the distribution and volumes of the deposits. Details of exploration, sampling, and analytical results for the deposits can be found in published and unpublished technical reports. The report by Osborne and others (1983) and many internal reports by the Geotechnical Branches of the U.S. Army Corps of Engineers (e.g., U.S. Army Corps of Engineers, 1989; 1995; 2002) are good examples of detailed study of individual deposits by use of vibracore data.

RECOMMENDATIONS

- Unless already accomplished, digitize and attribute the map of Welday and Williams (1975) for inclusion in the GIS of the CSMW Master Plan. Research files of the California Geological Survey to determine if the original 1:125,000-scale geology worksheets used to prepare the map are still available; these could be used for digitizing. Despite its age, this map is still a valuable statewide reference.

- Unless already accomplished, digitize and attribute the maps of Martindale and Hess (1979) and Luken and Hess (1979) for inclusion in the GIS of the CSMW

Master Plan. Original files for these reports may still be available in archives of the U.S. Geological Survey. This GIS product would be a companion layer to that for the Welday and Williams (1975) map discussed above.

- Unless already accomplished, digitize and attribute the maps associated with detailed studies of local sand deposits for inclusion in the GIS of the CSMW Master Plan. Examples of such reports would be those by Osborne and others (1983) and the U.S. Army Corps of Engineers (1989).

CSMW TASK FOUR

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RESULTS FROM CSMW TASK 5

(80/20 Coarse-to-Fines Rule of Thumb)

TASK 5 - Research any studies assessing the 80/20 coarse-to-fines "rule-of-thumb" ratio used by various regulatory agencies to determine whether potential source sands are compatible with a given beach. Identify the origin of the rule-of-thumb and nourishment projects where variances from the rule of thumb were allowed, including the basis for each variance.

80/20 COARSE-TO-FINES "RULE-OF-THUMB" RATIO

It appears that there is a widespread misperception, within both regulatory agencies and the regulated community, that an 80/20 coarse-to-fines "rule-of-thumb" ratio is an inviolate rule prohibiting the use of dredged material containing more than 20% fines for beach nourishment purposes. In actuality, the 80/20 ratio is merely a consensus view among regional offices of the U.S. Environmental Protection Agency and the Interagency National Dredging Team of what constitutes "predominantly" sand, for the purpose of applying the testing exclusion criteria of the Marine Protection, Research, and Sanctuaries Act (MPRSA or "Ocean Dumping Act") to the disposition of dredged material (memo from Brian Ross to Laura Johnson, April 2000). Specifics of the exemption are codified in 40 CFR –Part 227, Section 227.13 (b)(1) (U.S. Code of Federal Regulations, 2003a). When the 80/20 ratio is applied under MPRSA, dredged material that is less than 20% silt and finer material (i.e., "composed predominantly of sand") is deemed environmentally acceptable for ocean dumping or beach replenishment without further chemical or toxicity testing. Nonetheless, grain-size analysis of the dredged material must be done to make this determination. The desire to impose an upper limit of fine sediment content is premised on the fact that silts and clays, as opposed to coarser sediments, commonly contain adsorbed chemical contaminants that may have adverse impacts on marine environments or human health.

The U.S. Army Corps of Engineers (USACE) and U.S. Environmental Protection Agency (EPA) share regulatory responsibility for all discharges of dredged material in waters of the United States under Section 404 of the Clean Water Act (CWA), and section 103 of the MPRSA. Officials with both agencies agree that the 80/20 ratio is a "rule of thumb" only and that there is no statutory authority for its enforcement nor any known definitive studies or research from which a 20% cut-off was selected. Instead, it represents a national consensus value based on experience that such sediments are unlikely to be contaminated to an extent that would cause environmental damage (Brian Ross, "Beach Nourishment Questions", e-mail to author, June 7, 2004; Gregory Dombrosky, U.S. Army Corps of Engineers, personal communication, April 9, 2004). More importantly, the MPRSA testing exclusion in no way prohibits the use of material containing more than 20% silt and clay for beach nourishment. To the contrary, both the MPRSA and CWA 404(b)(1) guidelines (40 CFR – Part 230, U.S. Code of Federal

Regulations, 2003b) actually provide the means by which sediments containing a greater percentage of fines can be approved for beach replenishment on a site-specific basis. The EPA and USACE recognize a critical need for beach replenishment and encourage the use of dredged material (which might otherwise be disposed of) for beneficial nourishment projects. Both agencies also recognize that there is significant flexibility in allowing material with higher percentages of fines provided it meets the requirements of the 404(b)(1) guidelines that dredged material be demonstrated to be compatible with the receiving beach (memo from Brian Ross to Laura Johnson, April 2000).

Both the USACE and EPA define dredged material for beach replenishment as “fill” when the basic project purpose is beneficial beach nourishment and the project is determined to be necessary. In this case, regardless of whether the material is specifically dredged from borrow sites or is dredge waste material, it can be regulated under the 404(b)(1) guidelines rather than the MPRSA. This eliminates the need for a lengthy and formal designation as an official ocean disposal site for each and every receiving beach (memo from Brian Ross to Laura Johnson, April 2000). Hence, the guidelines become the primary criteria used by the USACE and EPA in evaluating beach nourishment projects. If no real need for nourishment can be demonstrated or if most of the material will not serve the intended purpose, the activity would be considered disposal (and thus regulated under MPRSA).

The 404(b)(1) guidelines allow for site-specific determinations regarding compatibility of dredged-sediment grain sizes with receiving beaches. Dredge or fill discharges must satisfy the requirements of sec 230.10 of the guidelines which, among other things, mandate that 1) the discharge site must be the least environmentally damaging alternative, 2) discharge will not result in significant degradation of ecosystems based on factual determinations, and 3) that all practicable means must be employed to minimize for adverse environmental impacts.

The Inland Testing Manual (Manual) was prepared by the USACE and EPA as a guidance document for implementing compliance with the 404(b)(1) Guidelines. It sets out the recommended protocols for three levels of tiered testing of dredged materials. It is necessary to proceed through the tiers only until information sufficient to make factual determinations has been obtained. Subpart G of the 404(b)(1) guidelines requires the use of available information to make a preliminary determination whether additional tiered chemical or biological testing of the material is necessary. Tier 1 emphasizes grain-size compatibility and chemical similarity of the dredged material to the receiving beach. If a first-tier analysis demonstrates grain-size compatibility with the receiving beach, dredged material can often be excluded from second- and third-tier chemical or biological testing. Such situations are most likely when the dredged material is composed primarily of sand, gravel and/or inert materials from a high-energy environment, the sediments are from locations far removed from contaminant sources, or the sediments are from pre-industrial age deposits not exposed to modern pollution sources (40 CFR Sec. 230.60(a), U.S. Code of Federal Regulations, 2003b). Additional testing is based on the concept of “reason to believe.” If there is a reason to believe that contaminants may be present, further evaluation is required.

From a regulatory standpoint, the physical compatibility of dredged material with the beach is the USACE’s primary basis for its decision regarding whether additional tiered chemical or biological testing is necessary. To make this decision, first-tier analysis of the dredged material grain-size distribution must be first be conducted and compared with the grain-size “envelope” of the receiving beach. When the material is determined to have an incompatibly high fine-sediment fraction, the second- and possibly third-tier chemical and biological testing are required to ascertain the degree of contamination in the fine fraction and the natural resources that might be impacted by the discharge or deposition of the fine-sediment fraction. Only then can the EPA and the USACE decide whether a relatively higher percentage of fines can be approved.

The Los Angeles District of the USACE regulates most California beach replenishment projects. In order to approve the use of dredged material for beach nourishment, the District requires the tiered testing approach as described in the Manual. The District’s tier-one testing is designed to determine if the dredged material is composed predominantly of sand, gravel, rock, or any other material greater than silt size and if the dredged material is compatible with the material on the receiving beach. Specific protocols for number and selection of dredge area and receiving beach sample sites, sampling methods, and data analysis methods are described in the District’s “Requirements for Sampling, Testing, and Data Analysis of Dredged Material Guidelines” (U.S. Army Corps of Engineers, undated; copy is available from CGS). To demonstrate compatibility with a given beach, the Los Angeles District requires that the overall percentage of silt and clay (grains less than 0.074 mm) in the dredged material must not exceed that of the finest beach sample by 10 percentage points. When a definitive determination of compatibility cannot be made, or, the dredged material contains a higher percentage of silt and clay, the tiered testing is then required. Satisfactory second- and third-tier test results may provide the USACE with the factual information from which it could approve using dredged material with 20% or more clay and silt for beach nourishment projects.

80/20 COARSE-TO-FINES “RULE-OF-THUMB” RATIO VARIANCES

Since the 80/20 ratio is an unenforceable rule of thumb, and applies to provisions of the MPRSA rather than the CWA, it becomes a futile exercise to identify beach nourishment projects that were permitted under a variance to this rule. While there may be isolated cases where the ratio was used to approve dredged sediment for replenishment, it is clear that most, if not all, projects that were implemented after enactment of the CWA in 1977 and development of the Inland Testing Manual required testing as required under the 404(b)(1) guidelines. Further, since it is agreed that the 80/20 ratio applied to provisions of the MPRSA, it could not have been applied to projects preceding enactment of the MPRSA in 1972.

In fact, in recent years there have been some beach nourishment projects in California that have been allowed to use dredged material with greater than 20% fines, but only after compatibility testing under the 404(b)(1) guidelines. In no case, however, has material exceeding 50% fines been approved. In one case, Santa Cruz Harbor was approved to use a maximum of 3,000 cubic yards per year of inner harbor material with fines ranging between 20-50%. It should be noted that this represents only 1% of the total material (generally 90%+ sand) placed on the beach every year (Brian Ross, “Beach Nourishment Questions”, e-mail to author, June 7, 2004).

Since records indicate that perhaps hundreds of site-specific nourishment episodes have been undertaken in California over the years (some as early as the 1920s), it would be a daunting task requiring many hours of research to identify all projects involving the use of sediments containing more than 20% fines. Consequently, it is considered beyond the scope of this project.

RECOMMENDATIONS

- Research the numerous beach-nourishment project files to identify projects that actually used a higher percentage of fines than 20%. Also research any post-nourishment monitoring of these beaches to determine the fate of the fine-sediment fraction and the long-term effects on beach profiles.

CSMW TASK FIVE

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RESULTS FROM CSMW TASK 6

(Debris Basins)

TASK 6 – Compile known information on debris-basin locations, contacts, volumes, and cleanout frequencies. Focus efforts outside of Ventura and Los Angeles Counties, since debris basins in those counties are already included within the SMP GIS.

INFORMATION ON DEBRIS BASINS

To identify debris basins in San Diego, Orange, San Luis Obispo, and Monterey counties, the public works departments/flood control districts in each county were contacted. Additionally, the California Department of Transportation was contacted regarding debris basins in San Luis Obispo and Monterey counties. Representatives of the public works departments/flood control districts in San Diego, San Luis Obispo, and Monterey counties stated that those counties do not have debris basins.

Orange County does not have debris basins like those in Los Angeles or Ventura counties that collect coarse material. However, it does have several retarding basins that are intended to slow runoff from storm events and reduce the amount of silt reaching Upper Newport Bay. These retarding basins are usually built by developers and turned over to the County for operation and maintenance. The retarding basins typically trap only silt and fines. Information on seven of these retarding basins is included in Table A5. Information for retarding basins in Orange County was provided by Mr. John Gietzen of the Orange County Public Facilities and Resources Department.

No efforts were made to collect information for Santa Barbara, Ventura, Los Angeles, San Bernardino, or Riverside counties as information on debris basins in these counties is summarized in a report prepared by the California Department of Boating and Waterways and State Coastal Conservancy (2002).

RECOMMENDATIONS

None

CSMW TASK SIX

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California Department of Boating and Waterways (CDBW) and State Coastal Conservancy (SCC), 2002, California beach restoration study: Sacramento, California.

RESULTS FROM CSMW TASK 7

(Seasonal Cross-Shore Movement of Sand)

TASK 7 – Document known information (i.e., case studies, etc.) regarding the natural seasonal movement of sand from the beach to nearshore and back.

OVERVIEW

Numerous investigators and authors have documented and described the phenomenon of seasonal cross-shore transport of sand from the beach to nearshore and back again, a process that is particularly common along the coast of California. Most of what is known comes from morphological studies of beach profiles over time and the hydrologic and hydraulic conditions that form them. Little attention has been paid to differentiating between the transport patterns of the various sediment fractions, with the emphasis instead being focused on the effects of bulk coarse sediment transport.

Two types of sediment transport, determined by waves and currents, influence beaches and nearshore environments. "Cross-shore" transport describes the sediment transport perpendicular to the shoreline (onshore-offshore) and is the dominant mechanism by which beaches erode and accrete; it creates distinctly different seasonal beach profiles. "Longshore" transport carries sand parallel to the shoreline.

Excellent recent examples of seasonal cross-shore transport and the resultant change in beach profiles are described in the Regional Beach Monitoring Program Annual Reports of the San Diego Association of Government (Coastal Frontiers Corporation, 2000; 2004). During the 1999 one-year cycle, offshore sediment transport during the winter months resulted in beach transects exhibiting shoreline retreat of from 10 feet to 100 feet at transects on Imperial Beach, La Jolla, and Carlsbad. During the following summer season, the shoreline advanced more than 10 feet at 29 of 33 transects. Advances of more than 100 feet were recorded at locations near the Tijuana River mouth, La Jolla, Torrey Pines, and Carlsbad (Coastal Frontiers Corporation, 2000).

Beaches exist in a constant state of change undergoing both erosion and accretion in an attempt to come to equilibrium with the varying energy of the attacking waves. The beach profile is a natural mechanism that causes waves to break and dissipate their energy, in effect, adjusting itself to the prevailing wave forces. Faced with increasingly larger waves, a beach responds by reducing its overall slope and shifting the breaker zone farther offshore, thereby enhancing the dissipation of the waves before they reach the shore (Komar, 1997). Conversely, as wave energy decreases, beaches narrow and steepen. Average sediment size also impacts beach slope with finer material producing gentler slopes than coarse material. Short (1979) presented a model of beach erosion and accretion showing the various stages of this continuum whose end members are the winter "storm" profile and summer "swell" profile ("dissipative" and "reflective" profiles of Short, “bar” and “berm” profiles of Komar). Where a beach resides in the spectrum of beach profiles and the speed at which erosion and accretion remove and replace sand are largely a function of changes in wave height, period, and grain size (Short, 1999).

A total understanding of the critical wave conditions that govern the shift between summer and winter profiles is still incomplete. There are many field studies that demonstrate an increasing wave height leads to offshore sand transport and a bar profile, while low wave conditions cause a shoreward return of sand to the beachface and berm. However, no study has identified a critical wave steepness (ratio of wave height to wavelength, described below) that dictates when a summer profile will revert to a winter profile or vice versa (Komar, 1997).

Seasonal cross-sand transport is driven by major differences in the waves impinging on a beach. Waves are classified as either “storm” waves or “swell” waves. Storm waves are generated in the vicinity of a coast by storms and the interaction of strong winds on the ocean surface, while swell waves are generated by distant storms (Johnson, 1956; Silvester and Hsu, 1993). The two types of waves generally coexist simultaneously. Swells, however, can be completely obscured by local storm waves.

One of the most important factors in determining the character of a beach profile and the cross-shore transport of sand is the ratio of wave height to wavelength, or "wave steepness" (Johnson, 1949). Wave steepness is the ratio of deep-water wave height to wavelength, which is related to the wave period. Storm waves have high steepness values while long swell waves have low steepness values. Wave steepness can be increased either by an increase in the wave height or a decrease in the wave period. Physical parameters of the beach (i.e., grain-size distribution, cohesiveness, beach slope) also play an important role. In general, high, steep waves move beach sediments offshore, while low waves of long period (low steepness) move material onshore (USACE, 1989).

The process of winter marineward sand transport can be illustrated by studies of pre- and post-storm event beach profiles. During winter storms, higher wind velocities generate high and steep storm waves that assail the beach, which is largely near equilibrium with the milder summer swell waves. The beach begins to rearrange itself to accommodate the larger waves. Storm “surges” (water pushed toward shore by winds associated with the storm) also raise water levels and expose higher parts of the beach to wave action (USACE, 1989). When the waves break, their excess energy is expended on erosion of the beach. The eroded material is carried offshore in large quantities and deposited on the nearshore bottom in the form of an offshore bar. The bar eventually grows large enough to break the incoming waves farther offshore, forcing the waves to expend their energy farther seaward (USACE, 1989). In simplistic terms, larger storm waves erode the beach berm and redeposit the sand offshore in the form of a bar. Once the bar is fully formed and is breaking the majority of incoming storm waves, the surf zone is at its widest and the breaker heights greatest. It is at this time that the littoral current plus littoral drift are at a maximum (Silvester and Hsu, 1993).

The milder swell waves remobilize the bar sand and sweep this material back from the bar redepositing the sand back onshore and reforming the beach. Littoral current and littoral drift decrease as the bar is removed, and the profile reverts back to the swell-built curve. Also, the surf zone is at its narrowest width. While the sand is stored in the beach berm, the waves can only re-suspend sand on the beach face or a small fraction of the total volume of sand available during a storm profile, and hence, littoral drift becomes negligible (Silvester and Hsu, 1993).

BEACH RESPONSE TO STORM WAVES

When a swell profile beach is subjected to the increasing wave height and decreasing period of storm waves it responds with erosion and offshore transport of sand. The high wind velocities of local storms can produce large waves and a wide spectrum of wave trains of varying period and height (Silvester and Hsu, 1993). Storm waves are steep and powerful, containing more water above the mean sea surface than swell waves. Storm waves break on a beach almost every second, much more frequently than during quiescent times. Erosion first occurs with beach material being placed into suspension by the strong plunging vertical motion of the breaking storm waves. The plunging motion creates sediment suspension and offshore sand transport over the seabed.

The repeated onslaught of storm waves quickly saturates the beach face and raises the water table until it is almost coincident with the beach face itself (Short, 1999). With the beach face saturated, there is nowhere else for the water to go and the downrush becomes almost equal to the uprush dragging much of the sand that was suspended in the breaking waves back down the beach face. Contributing to the downrush return of sand is the flow of excess groundwater back to the sea. At the waterline, it is moving vertically, which causes liquefaction, placing more sand in suspension and causing wave-induced slumping. This phenomenon undermines the toe of the beach face, which progressively retreats landward (Silvester and Hsu, 1993). The disappearance of the berm can happen rather quickly and can be removed in one or two days of unusually heavy erosional activity.

As wave heights increase, the combined action of berm-overwashing, berm-breaching, and strong swash action results in the slumping and collapse of the lower beachface. The sediment removed from the berm and beachface is deposited immediately seaward of the beach face where it begins to form an attached bar (Short, 1999). The increase of storm wave-heights accelerates beach erosion. which drives the beach profile to the fully erosional, winter, beach type and the offshore bar moves seaward, separated from the beach by a broad trough (Short, 1999).

BEACH RESPONSE TO SWELL WAVES

Swell waves are generated from far-away storms and continue to propagate radially outward across the ocean, dissipating their energy over an ever-increasing area. The energy dissipation associated with the radial wave front reduces wave heights to only 5-10% of their original height and increases wave period (Silvester and Hsu, 1993). Along the west coast of North America the largest storm waves and predominant swell travel in an east and southward direction towards the equator.

As swell waves replace storm waves, they dismantle the offshore bar and transport its sand shoreward infilling the trough and building the beach face. Swell waves are refracted at the continental shelf where their path becomes normal to the coast. During their traverse of the nearshore and surf zone, bottom material is suspended, most of it from the offshore bar (Silvester and Hsu, 1993). As each wave breaks and swashes up the beach face, its water percolates into the sand. The infrequent arrival of swell waves (often many seconds) relative to the higher frequency of storm waves allows much of the water to percolate to the water table before making its way back out to sea (Silvester and Hsu, 1993). The resulting downrush is smaller then the uprush and can't carry much of the sediment load back down the beach face, hence, the beach accretes (Silvester and Hsu, 1993).

As wave heights continue to drop, increasing swell-wave dominance continues to move sand shoreward. The bar moves shoreward, and the width of the surf zone decreases. As more sand moves onto the beach, a berm crest develops which is characterized by a slightly landward sloping berm. The accretion of the beach face and berm will continue only so long as there is material available in the offshore bar to be fed into the breaking waves. By this time the bar has moved completely on to the beachface and a relatively deep, barless nearshore zone fronts the beach. In this fully accreted state, a beach will take on a parabolic curve characteristic of a summer swell-beach profile. The slope of the beach face depends on the size of available sediment: fine sand produces gentler slopes than coarse materials.

In nature, the complete erosional/accretional sequence is not common, since waves rarely stay low long enough to achieve the full transition. However, the southern California beaches are considered an example of beaches that generally experience the full sequence (Short, 1999).

IMPACT OF LONGSHORE CURRENTS

On most beaches, cross-shore sand transport is impacted by longshore currents, which are largely responsible for the net erosion of beaches that results in the need for beach replenishment. Wave-induced longshore currents are related to angle of incidence of the breaking wave fronts to the shoreline and become superimposed on the oscillatory nature of wave motion perpendicular to the shore. When a wave breaks at an angle to the shoreline, the longshore current it produces carries in a zigzag pattern some of the sand suspended by the breaking waves a short distance downshore in a process called littoral drift.

RECOMMENDATIONS

None

CSMW TASK SEVEN

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PART B

PRELIMINARY OVERVIEW OF DREDGING TECHNOLOGY FOR OFFSHORE SAND RESOURCES, WITH APPLICATION TO CALIFORNIA

INTRODUCTION

The use of offshore sand deposits for nourishment of beaches along the coast of California relies directly on dredging technology. Such technology is currently the only means of moving sufficient quantities of sand to shore in a timely manner. This technology is used worldwide and is highly developed in several countries, particularly The Netherlands, Belgium, Japan, and Great Britain.

Those areas of sand resources that fall under Federal jurisdiction (Minerals Management Service) cover the offshore area beyond the 3-nautical-mile State-Federal boundary. Because the width of the continental shelf of California is very irregular and very narrow in many places, the water depths at this boundary vary significantly. Dredging technology and economics have various limitations dependent on water depths and distances from nourishment projects; consequently, shelf properties have an important influence on the practicality of dredging operations.

BACKGROUND ON OFFSHORE DREDGING

Dredges are classified under two main categories, hydraulic and mechanical. For production of offshore sand, especially in waters beyond the 3-nautical-mile limit, hydraulic dredges are used almost exclusively. This type of dredge is self-contained, meaning that it can both excavate the sand and dispose of it at the receiving site. Because of these two capabilities, such dredges are more efficient, versatile, and economical to operate than the mechanical type of dredges (Herbich, 2000).

Hydraulic dredges operate by pumping sand as slurry through a pipe that has either a cutterhead or draghead mounted at the end of the pipe where it meets the seafloor. Pumps to extract the sand are mounted in-board within the vessel or submerged as part of the dredge pipe itself.

Cutterhead-Suction Dredges

Cutterhead-suction (CS) dredges operate from a stationary site, pumping the sand slurry through a floating or submerged pipeline to a barge or to the actual site of nourishment along the shoreline.

In 2004, the largest cutterhead-suction dredge in the world was the JFJ de Nul, operated by the Jan de Nul Group of Belgium. It had a discharge pipe diameter of 1000 mm (40 inches) and a total power capacity of 27,240 kW (36,500 hp). The largest cutterhead-suction dredge in the U.S. in 2004, based on power capacity, was the Texas, operated by Great Lakes Dredge & Dock Company. It had a discharge pipe of 30 inches and a power capacity of 20,300 hp.

Table B1 lists the larger cutter-suction dredges operating in the U.S. as of 2004, as well as an example of the largest international dredges for comparison.

Trailing-Suction Hopper Dredges

Trailing-suction hopper (TSH) dredges operate as self-propelled units that sweep back and forth across a sand deposit in contrast to the stationary operation of the cutterhead-suction type of dredge. They also store the sand onboard in a hopper, which allows them to extract sand at distances farther from shore. They discharge their sand through on-board pumping systems, through bottom doors ("split-hull" design), or by mechanical removal at docks. These dredges overall are the best suited for offshore work (Herbich, 2000).

The most significant technological advancement in TSH dredges over the last 10-15 years is the development of submersible pumps that are mounted at the draghead. The design of increasingly larger pumps has allowed such dredges to dredge material from correspondingly greater water depths in the ocean.

Standard hopper dredges operate throughout the coastal United States. Currently, the largest ocean-going TSH dredge operational in the U.S. is the *Stuyvesant*, operated jointly by Bean Dredging and Royal Boskalis Westminster as the Bean-Stuyvesant Company. This dredge has a hopper capacity of about 11,000 yd^3, which is relatively small by international standards. The largest-capacity TSH dredge in the U.S. is the *Long Island*, operated by the Great Lakes Dredge & Dock Company; hopper capacity is 16,000 yd^3, but this vessel is no longer ocean going. In 2004, Manson Construction was building a TSH dredge of about 12,000-yd3 capacity, which is expected to be completed in another 1-2 years (Leonard Juhnke, Manson Construction, personal communication, 2004).

"Jumbo" hopper dredges are currently the largest dredges in operation internationally. In 2004, the largest dredge in the world was the *WD Fairway*, operated by Royal Boskalis Westminster of The Netherlands. It has a hopper capacity of about 36,500 m^3 (47,750 yd^3), with a total power capacity of 27,567 kW (36,984 hp). In the future, the Jan De Nul Group expects to retrofit its *Vasco da Gama* to a hopper capacity of 40,000 m^3 (52,320 yd^3).

Table B1 lists the larger trailing-suction hopper dredges operating in the U.S. as of 2004, as well as a few examples of the largest international dredges for comparison.

Offshore Dredging in Southern California

Offshore dredging for sand in California has historically been confined to State waters within the 3-nautical-mile State-Federal boundary. The two main goals of such projects are to dredge in shallow water and to be near the site of beach nourishment (as long as the dredging does not adversely affect the beach profile). In southern California, the site of most historic activity, dredging of offshore sand deposits generally takes place in water depths of about 30-60 feet. The greatest water depth reached during a project in California, as determined during research for this report, was about 80 feet, near the Port of Los Angeles (Mo Chang, U.S. Army Corps of Engineers, personal communication, 2004).

In 2001, the TSH dredge *Sugar Island* (see Table B1), operated by NATCO, a subsidiary of Great Lakes Dredge & Dock Company, was used to nourish 12 individual beaches along the coastline of San Diego County. A total of approximately two million cubic yards of sand were placed in a single campaign that moved from one beach to the next. This project extracted sand from six separate offshore borrow sites within State waters. As of 2004, it was the largest regional beach-nourishment project ever accomplished in California.

In late 2003, Manson Construction Company used the TSH dredge *Westport* (see Table B1) to move sand about 10 miles from a site at Santa Barbara Harbor to Goleta for nourishment of Goleta Beach (James Bailard, BEACON, oral communication, 2004). The dredge site was chosen after an initial offshore site only one mile from the beach was rejected because of the presence of kelp on the sand deposit. A cutterhead dredge was to be used at the initial site, but selection of the alternate site required use of a TSH dredge because of the long distance of transport to Goleta Beach. Approximately 59,000 yd^3 were moved by the *Westport* at a cost of about \$23/yd^3 (the cutterhead at the original site was projected to cost about \$4/yd^3). The *Westport* was unable to complete the project because it eventually encountered cobbles, which it could not remove. As a result, an additional 18,000 yd^3 of sand were trucked to Goleta Beach at a cost of about \$8/yd^3 from onshore sources to complete the nourishment. This project was reportedly the first beach-nourishment project in either Santa Barbara or Ventura counties other than those projects conducted by the U.S. Army Corps of Engineers (USACE).

LIMITATIONS AND RESTRICTIONS ON DREDGING

Although sand deposits may be present at many locations in the offshore beyond the State-Federal boundary, various issues will determine whether or not an individual deposit can be excavated for use in beach nourishment.

Technological Issues

- **Depths of Water** – the water depths at which dredges can pump sand are limited by the physics of pumps (barometric pressure in-board, cavitations). As of 2004 the greatest depth that was feasible was 155 meters (508 feet) on the TSH dredge *Vasco da Gama* (see Table B1); the greatest known actual depth reached was 134 meters (440 feet) in 2003 off Canada using this same vessel. The next near-term goal in design by one company is to develop a submerged pump of 10,000 kW (13,400 hp) that will allow dredging at 200 meters (656 feet) depth of water.

- **Length of Discharge Pipeline** – this issue applies mainly to cutterhead-suction dredges in that these dredges must pump the sand from dredge site to nourishment site via a floating or submerged pipeline. In 2004, a pipeline length of 25,000 feet (4 nautical miles) was commonly achievable in coastal areas of the U.S. other than California. Longer distances are possible, but booster pumps are needed (see economic issues).

- **Seafloor Characteristics** – the physical character of the seafloor material to be produced will in some instances determine what type of dredge is most appropriate. Cutterhead-suction dredges can be fitted with a variety of cutterheads that can produce from harder material.

- **Stability in Open Ocean** – swell and waves can significantly affect operations of a dredge. High swell, for example, can cause the dredge to rise and fall enough that it disrupts the efficiency of the cutterhead on the seafloor.

- **Draft of Trailing-Suction Hopper Dredges** – the draft of a trailing-suction hopper dredge determines how close it can approach the site of sand discharge. By virtue of their size, the largest hopper dredges have a large draft, which means they must anchor farther offshore from sites of beach nourishment to discharge their cargo of sand.

- **Structural Obstructions** – this category includes such features as infrastructure (seafloor pipelines, cables, drilling platforms), archeological sites (shipwrecks), and fish havens. Such features should be avoided by dredging activity.

Economic Issues

- **Depths of Water** – according to several individuals involved in dredging in southern California, dredging is economical in depths of water up to about 100 feet. This figure may be largely affected by the physical configurations and capabilities of the U.S. dredging fleet.

- **Distance to Nourishment Sites** – pertinent here are 1) the distance of transport when using trailing-suction hopper dredges and 2) pipeline lengths between nourishment-site and dredge-site when using cutterhead-suction dredges. Regarding TSH dredges, the most important costs result from travel time between dredge-site and nourishment-site, and from fuel used. Regarding CS dredges, the economic threshold of pipeline length is about 25,000 -30,000 feet (about 4-5 nautical miles). When these lengths are reached, however, it is probably more economic to use TSH dredges.

- **Size of Dredges** – to be most economical for a specific job of nourishment, a dredge must be of an appropriate size and capability. “Larger” does not necessarily translate to “cheaper” because of operating costs (e.g., mobilization, size of crew, fuel, etc.); the international jumbo TSH dredges can move large quantities of sand per trip, but they generally require large-scale projects to make their use economic. On the other hand, a small-capacity TSH dredge may have to make too many round trips to supply the required sand or may not have the capability to reach bottom in the desired offshore sand deposit.

- **Overall Cost to Dredge Sand** – the common standard for comparing costs of dredging offshore sand is the overall cost per cubic yard of sand. Listed below are some estimates of overall costs per cubic yard of sand as reported from different sources. Direct comparison of them is not justified, however, because of their different time periods, geographic locations, and uncertainty as to what factors were used to derive them.

  USACE (1990) (http://el.erdc.usace.army.mil/elpubs/pdf/drp4-02.pdf): $1.50 - $3.50 for USACE contracts on the Gulf and East Coasts.

  UNESCO (1998) (http://www.unesco.org/csi/pub/source/ero19.htm): $5.00 - $16.00 for projects in the Caribbean, plus mobilization costs.

  BEACON (2003) (James Bailard, BEACON, oral communication, 2004): $4.00 for a CS dredge one mile offshore; $23 for a small TSH dredge deployed about 10 miles from the nourishment site.

Legal Issues

Dredging in the United States is fundamentally governed by two pieces of federal legislation enacted in the early 1900s to protect the domestic maritime fleet from unfair foreign competition. The first piece is the Act of May 28, 1906, which is informally referred to as the Dredging Act. Most importantly, this act originally established requirements that all dredges engaged in dredging activities in navigable waters of the U.S. had to be U.S.-constructed and U.S.-documented (U.S. House of Representatives, 2003). The second piece of legislation is Section 27 of the Merchant Marine Act, 1920, which is informally referred to as the Jones Act. Provisions of this broad act originally resulted in the requirement that hopper dredges engaged in dredging activities in navigable waters of the U.S. also had to have at least 75% ownership by U.S. citizens (U.S. House of Representatives, 2003; U.S. Department of Transportation, 2003a). This requirement did not apply to non-hopper (e.g., cutterhead-suction) dredges because they did not transport dredged material ("merchandise") between two points along the coastal U.S. as do hopper dredges.

In 1992, the Dredging Act was amended through the Oceans Act of 1992 to apply the 75% citizenship requirements of the Jones Act to all dredges engaged in dredging in the navigable waters of the United States (U.S. House of Representatives, 2003). An exception to the requirements of U.S. citizenship was granted to the Bean-Stuyvesant Company to operate the TSH dredge *Stuyvesant*, a U.S.-constructed and U.S.-flagged vessel chartered to the company, which at the time of the amendment did not meet the U.S.-ownership requirements.

Provisions of the Jones Act have been controversial for a number of years, and there were attempts to modify or repeal the act during the 1990s. There has also been litigation during this period that stems from the 1992 amendment.

The importance of these two acts for present-day dredging of sand in waters offshore of the United States, and particularly California, is that they significantly restrict the pool of available dredges that can operate here. For example, it eliminates the use of foreign-owned jumbo hopper dredges, which are capable of producing sand from deeper shelf waters.

Other limitations on offshore dredging concern its exclusion from marine sanctuaries (protection of marine habitat), certain military and navigational zones (safety), and disposal sites (potential contaminants/debris and high variation in physical properties).

DREDGING COMPANIES AND DREDGES IN THE UNITED STATES

There are hundreds of dredging companies based throughout the world (Placer Management Corporation, 2004). Outside the United States, several countries have companies that operate dredges that are much larger than any in use in the U.S. Within the United States, most companies are small, local concerns that specialize in inland or coastal activities rather than offshore operations. Their most common work is in harbor and channel maintenance and in reclamation of shore areas for new construction projects. Relatively few companies engage in production of offshore sand deposits specifically for nourishment of coastal beaches. Generally, these companies are large, well-established enterprises that own or charter dredges capable of operation in ocean conditions.

In addition to private companies, the USACE has its own fleet of dredges, which are manned by members of the civil service (see Table B1).

There are two companies that currently conduct the majority of offshore dredging projects for beach nourishment in southern California: Operations for Manson Construction Company, which is headquartered in Washington State, is locally based in Long Beach, while Great Lakes Dredge & Dock Company is headquartered in Illinois. The other two largest U.S. companies, Weeks Marine (New Jersey) and Bean Dredging (Louisiana), have had little or no involvement in California.

PERMITTING OF DREDGE OPERATIONS

Offshore dredging is under jurisdiction of the U.S. Army Corps of Engineers (USACE) and U.S. Environmental Protection Agency (National Oceanic and Atmospheric Administration, 2004). Between the shoreline and the 3-nautical-mile State-Federal offshore boundary, the California State Lands Commission is also involved in the process of permitting of dredging.

THE FUTURE OF DREDGING IN THE U.S.

Other countries, most notably The Netherlands and Belgium, are sites of much of the leadership and innovation in the dredging industry. Much of the modern advancement of dredging technology has occurred outside the U.S.

To allow dredging at water depths greater than the current 100-150 feet maximum in the U.S. will require 1) changes in the present Dredging Act and Jones Act and/or 2) construction of U.S. dredges that can produce from greater water depths.

Regarding the first requirement, some experts do not see near-future repeal or modification of the current legal restrictions that are in place under the Dredging Act and Jones Act; changes to the acts could allow foreign-based vessels, capable of producing at greater water depths, to operate in the U.S.

Regarding the second requirement, it is commonly believed that the U.S. dredging industry will construct larger ocean-going vessels if there is a demand. As onshore and nearshore sand resources are locally depleted, there may be demand to extract sand that is farther offshore in waters under Federal jurisdiction. This situation is more common on the East and Gulf Coasts where the physical characteristics of the continental shelf offer more potential targets than do those of the West Coast, particularly in southern California.

An additional consideration is that the conventional dredging technology in place now could change in the future. As reported in a document published by the U.S. Minerals Management Service (1999), advances in the industry have been largely modifications of existing technology. Nonetheless, one example of an innovation is the “punaise” system developed in The Netherlands. In this technology, the punaise is a remotely operated dredge that resides on the seafloor and pumps sediment to the site of beach nourishment.

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PART C

PRELIMINARY INVENTORY OF DATA PERTINENT TO OFFSHORE SAND DEPOSITS IN SOUTHERN CALIFORNIA

(Portions of this report were extracted and modified/expanded from summaries prepared for PART A)

INTRODUCTION

One of the Year-One activities begun by the California Geological Survey (CGS) during the MMS/CGS/CDBW offshore sand project included research and inventory of studies and data related to the geologic characteristics at and below the seafloor along the continental shelf of California. It also included research on cultural features that might affect where sand could or could not be extracted in the future for beach nourishment.

Many sources were researched and consulted to determine the types, breadth, residence, and geographic extent of data and information available. These sources generally came under the following categories:

- Libraries/Archives (Hard-Copy Holdings)
- World Wide Web (On-Line Services and Web Sites)
- Personal Interviews

BACKGROUND

The observation and mapping of the geologic materials on the ocean floor can lead to discovery of deposits of sand. Where of acceptable grain characteristics, volume, degree of consolidation, depth of submergence, and distance from shore, such deposits have been and will continue to be sources of material for beach replenishment/nourishment. The most desirable deposits are unconsolidated, have large volumes, are similar in physical character to the material on the receiving beaches, are in shallow water close to the receiving beaches, and are free of contaminants and debris. Also, mining of them would produce minimal environmental disturbance.

Typically, the identification and characterization of submarine geologic materials relies on both direct and indirect observation and measurement. Direct methods include visual observation, via submersible vehicles or cameras, and collection of samples through diving, dredging, or coring. Indirect methods include various geophysical techniques that can characterize the seafloor as well as the material beneath it. These data lead to maps and calculations that determine the locations, areal extents, volumes, and physical properties of the materials at and below the ocean floor. Furthermore, because of economic and technological limitations, the depth of sand deposits below the sea surface is of major interest, which requires reliable bathymetric measurements.

The identification and characterization of materials is also important for understanding and management of benthic habitat for marine organisms. The mapping of such habitats, which has become common in recent years, relies on the same techniques for exploration and characterization of sand deposits. Consequently, submarine geologic mapping and benthic habitat mapping are complementary and in some ways might be considered one and the same.

OVERVIEW OF OFFSHORE GEOLOGY OF CALIFORNIA

The complex geology that makes up onshore coastal California continues offshore beneath the continental shelf. In contrast to the U.S. Atlantic and Gulf Coasts, the shelf off California is notably narrow and irregular, a reflection of the active geologic forces there. It is commonly dissected by submarine canyons and, in some places, is only 1-2 miles wide. In simplified view, offshore California is underlain by diverse types of bedrock covered or surrounded by mantles of unconsolidated sand, mud, and gravel.

General Characteristics of the Offshore Regions of California

Presented here are some general characteristics about offshore California (shelf and coast) as divided into the seven regions portrayed in the CGS-USGS California Continental Margin Geologic Map Series (Figure C1). References to shelf-width are for the 90-meter (~300-foot) contour of water depth. This contour represents an intermediate water depth that is greater than the capability of current dredging in the U.S., but less than the capability of international dredging. The contour along the entire coast of California is displayed in Figure C2 along with other contour values (30-m, 40-m and 150-m) for the coast. The 30-m contour represents the current general economic limit for dredging off the coast of California. The 40-m contour represents the current technological limit of deepest operating dredge allowed to operate in the U.S. The 150-m contour represents the current deepest dredging capability of any international dredge operating today (the actual greatest depth reached was 440 feet in 2003). Also shown is the 3-nautical-mile boundary that represents the State/Federal jurisdictional boundary offshore of the state.

Overall, available geologic mapping of offshore California is spotty as to areal coverage and detail. Some areas have been intensively studied and mapped, while others have been covered only by limited reconnaissance. Generally, areas close to shore and near large harbors and population centers have received more attention than those near less-developed parts of the coast.

Inner-Southern (Region 1): From Newport Canyon to Point La Jolla, the shelf at 90-meter water depth is relatively narrow (less than 2 nautical miles, although it widens

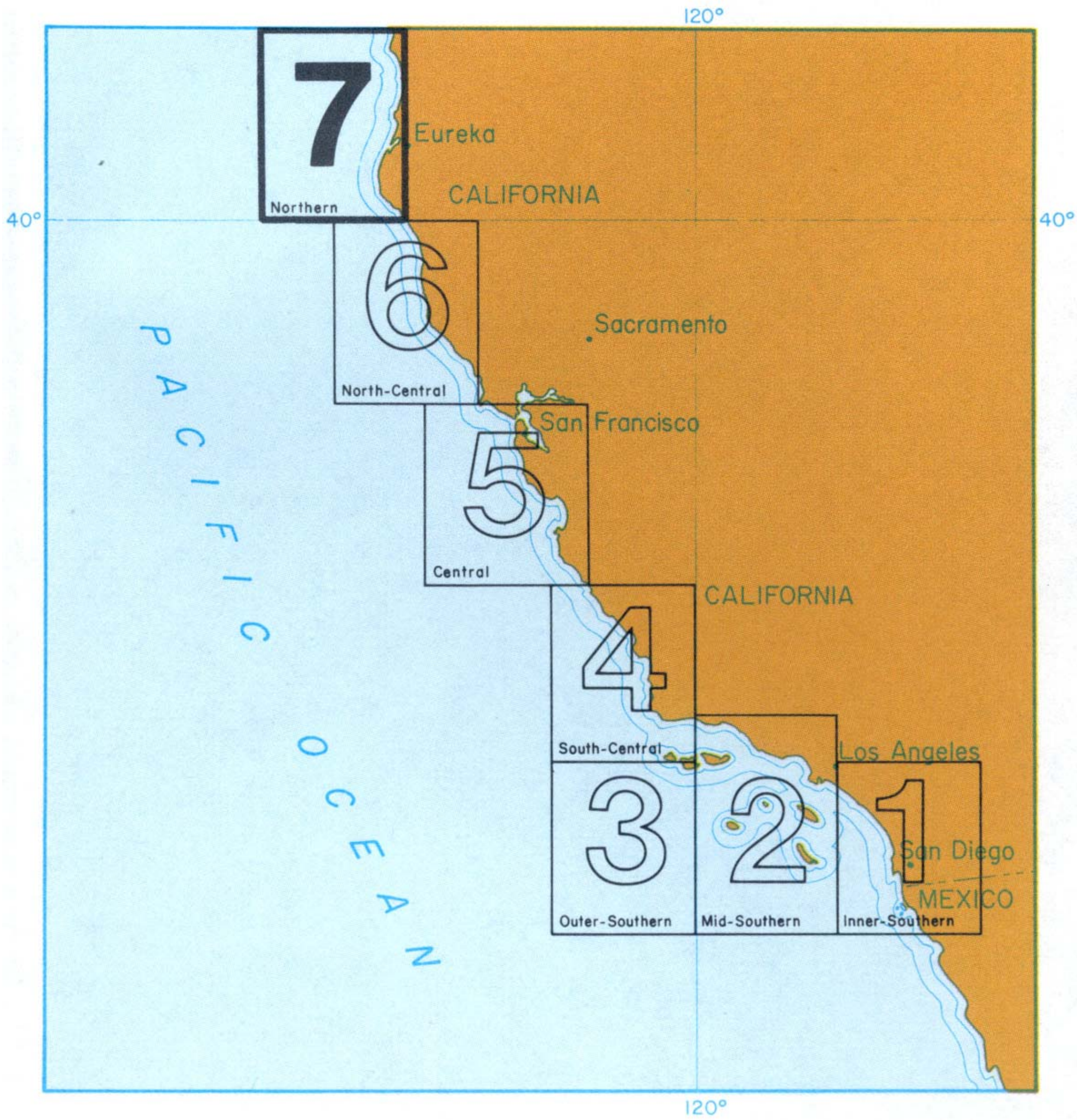


Figure C1 – Seven offshore regions discussed in text (graphic taken from the California Continental Margin Geologic Map Series published by the California Geological Survey/U.S. Geological Survey in 1986-1989).

somewhat north of Carlsbad Canyon to about 4 miles. South of Point La Jolla to the border with Mexico, there is a broadening of the 100-m shelf, particularly off Imperial Beach where it is up to about 8 miles wide. Geologic information about the shelf is extensive locally; it is probably one of most intensively studied areas because of proximity to marine labs. Many important recreational beaches are present along this map region; it probably has highest proportion of beach per unit length of coast of the seven map regions. The photograph below shows a typical beach (Oceanside) along this segment of the coast.

Photo by C. Higgins

Mid-Southern (Region 2): Much of the 90-m shelf from Newport Beach to just west of Santa Barbara is relatively narrow (less than 3 miles) except for areas at Ventura-Carpinteria, Santa Monica Bay, and San Pedro Bay where the shelf widens to as much as 10-11 miles. Geologic information is fairly extensive for selected local areas. Similar to Region 1, this region has numerous important beaches, some of which have been nourished.

Outer-Southern (Region 3): This region includes the islands, banks, and deep water of the continental borderland, away from the mainland coast. Although there is extensive geologic information for areas around the islands and banks, this region appears to be too far from the main coastline to be of interest for beach nourishment at this time.

South-Central (Region 4): The 90-m shelf from Cape San Martin in the north to San Luis Obispo Bay is fairly narrow (less than about 3 miles), but then widens from there south to Point Conception to as much as about 10 miles in places. Important recreational beaches are present between San Luis Bay and Point Sal. From Point Arguello to the south edge of the map the 100-m strip again narrows significantly. Geologic information is given for much of the immediate coastal area.

Central (Region 5): Within this region, broad shelf areas are present in the vicinity of both San Francisco Bay and northern Monterey Bay. The area from Point Reyes to Pescadero Point is very wide (nearly 25 miles off the Golden Gate) and may have potential if dredging technology at 90-m water depth is considered. From southern Monterey Bay to the southern map boundary (Big Sur coastline) the shelf is very narrow. Extensive geologic information is available for local areas, particularly for Monterey Bay to San Francisco Bay. Important beaches are in the Point Reyes area, along the San Francisco Peninsula, and along Monterey Bay. The photograph below shows a typical rugged portion (Big Sur coastline) of this segment of the coast.

Photo by C. Higgins

North-Central (Region 6): The 90-m shelf is very narrow over this segment of the coast, which extends from Point Reyes nearly to Point Delgada. With the exception of a wider section between Point Reyes and Fort Ross, the shelf is mostly less than 3 miles in width. The entire length is sparsely populated, and beaches are generally small and less used than those in southern California. This part of the coast, except at the Russian

River in the south and near Point Delgada in the north, is less affected by artificial restriction of sediment replenishment. Geologic information is relatively sparse compared to that along the central and southern California segments of the coast.

Northern (Region 7): The 90-m shelf from Point Delgada to Cape Mendocino is very narrow, but it broadens significantly from Cape Mendocino north to the border with Oregon; off the mouth of the Klamath River it is nearly 15 miles wide. This change is probably due in part to the large influx of sediment from the Eel, Mad, Klamath, and Smith rivers. Geologic information is sparse along this segment. Small population centers are at Eureka and Crescent City, and beaches are less used than those in central and southern California.

Based on information gathered for each of the seven regions summarized above and in consultation with various government agencies, the CGS decided at this time to limit its study of potential offshore sand resources to the Southern California Bight, which extends from Point Conception to the border with Mexico. The main reasons for this decision included the high percentage of beaches (and associated current and potential need for beach nourishment) and the distribution of population centers (tourism, residential and commercial development) in proximity to beaches in this region.

At the statewide level, there are two sets of published geologic maps that cover the entire offshore length of the state.

The first set, by Welday and Williams (1975), portrays at a scale of 1:500,000 the surficial geology of the offshore, with the greatest detail limited generally to within five miles of the coastline. The strength of this map is that the authors interpreted geologic bottom-types based on thousands of direct and indirect geologic observations made by various organizations. Especially noteworthy was use by the authors of the many historic observations of bottom type made during a suite of hydrographic surveys by the U.S. Coast and Geodetic Survey. Despite its age, this map is still a valuable aid to studies along many parts of offshore California. Figure C3 displays that portion of the map in southern California from Point Conception to the border with Mexico.

The second set, termed the California Continental Margin Geologic Map Series (CCMGMS), is a collaboration between the California Division of Mines and Geology (CDMG, now the California Geological Survey) and the U.S. Geological Survey. It consists of seven map sheets that portray at a scale of 1:250,000 details of local geology among other geologic-related information for the continental margin (see Kennedy and others, 1987). The sheets that cover the offshore north of San Francisco have very little geologic detail, while those south of San Francisco have much greater detail. This distribution mainly reflects the focus, intensity, and availability of offshore study by different institutions. Also, the CDMG-USGS map series does not display the mapping of Welday and Williams (1975), therefore, investigators should consult both sets of maps when studying all or part of offshore California. The digitized version of the CDMG-USGS map series can be downloaded from the Seafloor Mapping Lab Website at California State University, Monterey Bay (http://seafloor.csumb.edu/). Figure C4 displays that portion of the map in southern California from Morro Bay to the border with Mexico.

In addition to the statewide maps discussed above, the California Geological Survey (CGS) and U.S. Geological Survey have published or are nearing publication of several regional geologic maps at a scale of 1:100,000 that include offshore areas. Some of these have newly compiled offshore geologic data, others do not. See the discussion below under "Data Layers Pertinent to the Project."

Maps of surficial geology along portions of the coast are presented in Howard (1974) as part of a report by the U.S. Bureau of Reclamation to evaluate the feasibility of placing an undersea aqueduct that would carry fresh water from northern California to southern California. This mapping was based largely on the original Welday and Williams (1975) maps in their draft form. The original mylars for the Howard (1974) study are still available at a scale of 1:125,000. Although compiled many years ago like the Welday and Williams (1975) map, these maps are still valuable for highlighting possible regions of sand deposits. They could be scanned and digitized to capture the linework as a GIS layer (the Bureau of Reclamation is willing to scan them through a cost-share arrangement).

At local levels, various institutions and agencies have conducted detailed ocean floor surveys and mapping. These studies have been mainly in the Monterey Bay-San Francisco area in northern California and at several localities along the Southern California Bight, which extends from Point Conception to the Mexico border and includes the Channel Islands. In recent years, seafloor mapping in California has focused on benthic habitats. Much of this work has used multibeam mapping systems to produce "backscatter" images that display seafloor properties such as areas of mud and bedrock (e.g., Gardner and Dartnell, 2002). Although generally not termed "geologic" mapping, these activities have collected information on the geologic character of the seafloor through their qualitative descriptions of materials as "sand," "mud," and "bedrock." The U.S. Geological Survey, Moss Landing Marine Laboratory, Seafloor Mapping Lab, and Scripps Institution of Oceanography as well as private companies are some of the groups that have conducted this type of work in California. Examples of benthic habitat mapping for the nearshore zone of San Diego County can be viewed or downloaded on-line at http://sccoos.ucsd.edu/nearshore/. The U.S. Geological Survey has published several reports on its offshore mapping in the Monterey Bay-San Francisco and southern California regions. Several are listed in the accompanying bibliography (e.g., Wong and Eittreim, 2001; Gardner and Dartnell, 2002).

DISTRIBUTION OF SEAFLOOR MATERIALS ALONG THE COAST

The geologically active and diverse interior coast of California has profoundly influenced the geologic character of the adjacent seafloor. The high topographic relief, numerous watersheds that drain into the ocean, and the great variety of rock types all have contributed to the many types and complex distribution of materials that make up the coastal seafloor from Oregon to Mexico. This diversity is apparent from the geologic maps of Welday and Williams (1975) and the CDMG-USGS continental margin series.

Documentation of seafloor materials along the coast is available for many local areas. Again, we emphasize that this information was most commonly collected from the Monterey Bay-San Francisco region and the segment of coast from Santa Barbara County to San Diego County. Except for the semi-reconnaissance work of Welday and Williams (1975), there has been no attempt to consistently map in detail the distribution of offshore geologic materials from Oregon to Mexico. This situation is more a result of insufficient resources (funds and time) rather than lack of interest. Correspondingly, the documentation of details has been mostly limited to local projects conducted through government and academic groups and, in some cases, private industry. Government reports and data are generally produced by agencies such as the U.S. Geological Survey, U.S. Army Corps of Engineers, and the National Oceanic and Atmospheric Administration (NOAA). Products from the academic community are typically in the form of theses and dissertations, and papers in technical journals. Studies by private industry typically are prepared as consulting reports to clients (public and private). Examples of some of these categories are presented in the accompanying bibliography.

Mapping of seafloor materials along the California coast has been greatly aided by collection of samples. These include surficial sediment and rock, and shallow cores. The U.S. Geological Survey is developing a Website (http://coastalmap.marine.usgs.gov/regional/contusa/westcoast/usSEABED/) that catalogs offshore sample sites and associated data as part of a national database called usSEABED; the data will be viewable on-line through an interactive map server. The U.S. Army Corps of Engineers has data from numerous vibracore samples taken to assess potential borrow sites for beach replenishment/nourishment. NOAA maintains a Website (http://www.ngdc.noaa.gov/mgg/mggd.html) that can be visited to obtain digitized seabottom observations collected during hydrographic surveys conducted between 1851 and 1965 as well as offshore geophysical and geological data. Academic institutions also have bottom sample and core data, some of which have been published. Examples include data collected by the University of Southern California in the Southern California Bight and by the Hydraulic Engineering Laboratory at the University of California, Berkeley, from various coastal localities. The Southern California Coastal Water Research Project (SCCWRP), a consortium of public agencies responsible for water quality along the Southern California Bight, has periodically collected many sediment samples offshore through its survey program that began in 1977. Still other data are available in disparate, sometimes obscure, published and unpublished documents.

Together, the technical reports and sets of data portray a pattern of distributed materials that reflect such things as source areas, geologic structure, variations in dynamics of transportation, energy conditions and geomorphology of the depositional areas, and variations of all of these factors with time. For example, deposits of sand are common in the nearshore regions of the state and where rivers have discharged material at their mouths (Welday and Williams, 1975). Mud belts are concentrated farther away from the shoreline or in nearshore areas where the energy of waves and currents are less because of protective coastal settings (e.g., Monterey Bay). Bedrock areas are often nearshore extensions of onshore features or where either relief is positive or current patterns do not favor deposition of sediment. Many of the sand deposits farther offshore are probably paleo-beaches, which originated when the shoreline was much farther west than today; since the last ice age the shoreline has migrated eastward from these locations as sea level has risen.

Finally, the techniques of mapping seafloor materials off the coast of California are evolving. Traditional mapping techniques (e.g., Welday and Williams, 1975) emphasize manual interpretation and drawing of map-unit boundaries based on data from sampling and/or backscattering properties of seafloor materials. Currently, there are attempts to map the boundaries of materials based on image-processing techniques (e.g., classification), which use the same sorts of datasets as the manual approaches. An example is the work in progress by the U.S. Geological Survey on the San Pedro shelf in southern California (Peter Dartnell, U.S. Geological Survey, personal communication, 2003).

POTENTIAL OFFSHORE SOURCES OF SAND

Historically, the sources of sand for beach replenishment/nourishment along the coast of California have predominantly been provided from non-offshore. Included among these are inland sources as well as coastline sources, which have been related to such activities as harbor construction and channel maintenance or by-passing and back-passing operations. Interest in and use of offshore sand resources has generally occurred more recently in California.

Largely because of the abundant contributions from inland source areas and the prevailing southward-directed littoral drift along the entire coast, deposits of sand are prevalent in the offshore of California. Welday and Williams (1975) show numerous linear belts of sand that are dominantly fine-grained, with local areas that are medium- to coarse-grained as well. It is important to recognize, however, that these observations are for the seafloor surface only. Evaluation of sand deposits for potential beach replenishment/nourishment must also consider thickness of the deposits, which may or may not be known for any given location along the coast. To address this issue, Martindale and Hess (1979) and Luken and Hess (1979) used assumed thicknesses to calculate estimated volumes of sand and gravel deposits along the entire coast. The deposits they used for calculation were largely taken from the individual bottom-type areas shown on the maps of Welday and Williams (1975) and Howard (1974).

Deposits of offshore sand that may be most attractive for potential use in beach nourishment consist of two main types: 1) Those of relatively recent age (“modern” facies) that were deposited under submarine conditions and 2) those of older age (“relict” facies) that were deposited as beach sands or stream-channel deposits when the coastline was much farther west than at present because of decreased sea level associated with continental glaciation. Fischer and others (1983) believed that mainland shelf sediments form an elongated prism that parallels the coast of southern California. Maximum thickness of the prism is generally about 10-30 meters and is present near mid-shelf. Features that are sites of the greatest thicknesses are bases of relict sea cliffs, relict stream channels, and tectonic depressions.

The old beach sands and channel deposits are distributed to a farther extent offshore and thus have a higher chance of being present in Federal waters. Because of their age and different dynamics of formation, they may (or may not) have had different source areas than those of the modern streams that discharge into the ocean today. Thus may have different physical properties from the modern sands and associated beach deposits that are present along the present coastline.

Because of the preponderance of historic beach replenishment/nourishment projects there, nearly all regional and local exploration and evaluation of offshore sand deposits have occurred in southern California from Santa Barbara County to the Mexico border. Also, because of limitations on dredging (cost, technology), most of this work has been done in shallow water close to shore. Some offshore borrow sites are used more than once because the excavations may be re-filled by natural sedimentation. Consequently, virgin borrow areas are not necessarily required for every episode of replenishment, which lessens the overall need for their exploration and evaluation.

Various reports have identified many local offshore sand deposits in southern California that could serve as borrow sites for replenishment/nourishment. A list of selected sites is presented in Table C1. This list is not comprehensive, but gives an idea of the distribution and volumes of the deposits. Most of the deposits described in these reports do not extend into the Federal waters beyond the 3-nautical mile boundary, however. Details of exploration, sampling, and analytical results for the deposits can be found in published and unpublished technical reports. The two companion reports by Fischer and others (1983) and Osborne and others (1983) are still the most comprehensive regional reports for sand deposits along the mainland portion of the southern California Bight. The report by Osborne and others (1983) and many internal reports by the Geotechnical Branches of the U.S. Army Corps of Engineers (e.g., U.S. Army Corps of Engineers, 1989; 1995; 2002) are good examples of detailed study of individual deposits by use of vibracore data.

Candidate Areas in Federal Waters for Potential Future Study

Because of the irregularity and relative narrowness of the continental shelf off California, the locations of potential sites for dredging of sand deposits is restricted at present. Figures C5, C6, C7, and C8 respectively display statewide maps of areas beyond the 3-nautical-mile State/Federal boundary that are less than 30-, 40-, 90-, and 150-meter water depths as dictated by the limitations of the current dredging industry. As calculated from each of these four maps, the list below gives the offshore areas under federal jurisdiction that are less than the four selected water depths.

Water Depth	Area in Square Nautical Miles	Area in Square Statute Miles
<30 meters	97	128
<40 meters	232	307
<90 meters	1,727	2,287
<150 meters	3,584	4,747

From these mapped shelf areas and based on various technical and cultural criteria, we have selected four localities in southern California that are candidates for future detailed study. Characteristics of each are described below:

Ventura Shelf: This area is directly offshore from the cities of Ventura and Oxnard, but extends farther northwest toward Carpinteria and Santa Barbara (Figures C9, C10). Here, a lobe of the continental shelf extends broadly outward beyond the 3-nautical mile State/Federal boundary. At least in part , this lobe was probably formed from deltaic deposits built up by discharge from the Santa Clara and Ventura rivers, the mouths of which converge near the City of Ventura. The deeper portions of the shelf extend northwestward to the Carpinteria-Santa Barbara area. Much of the length of segment of the coastline has extensive public beaches.

Within the area of Federal jurisdiction, the map of Welday and Williams (1975) displays a complex distribution of surficial units including extensive sand deposits, although it is not indicated what the sand-size distribution is in many of these areas. The Continental Margin Geologic Map Series shows most of the shelf area as undifferentiated Quaternary and Tertiary sediments and sedimentary rock. The unpublished report by Field (1974) is the first known systematic study of the offshore sand resources of the Ventura Shelf. It was reconnaissance in nature, but served as a foundation for subsequent studies. The regional study by Fischer and others (1983) was the next to cover this area. These authors interpreted the sediment distribution in part of this shelf area to be controlled by active east-west-trending structures. They also showed thicknesses of Late Quaternary sediment reaching over 50 meters just offshore of the city of Ventura, which “may be predominantly sand.” Green and others (1978) show thicknesses to be at least 30 meters over most of the shelf in this area. Noble Consultants (1989a, b) followed up on the study by Fischer and others (1983) with a detailed study of potential offshore sand resources from Goleta to Point Mugu. Various geophysical and vibracoring surveys were conducted to define nearshore deposits of potential use for beach replenishment. The original datasets generated by this study were stored by Noble Consultants pending instructions by BEACON, which was the client for the project. Contact of either Noble Consultants or BEACON will likely determine if these datasets are still available for review by outside parties.

Various other studies conducted over the Ventura Shelf are listed in the accompanying bibliography.

Santa Monica Shelf: This area is offshore of a portion of the Los Angeles Basin that extends from the city of Santa Monica in the north to the city of Redondo Beach in the south, which is adjacent to the hilly coastal prominence known as the Palos Verdes Hills (Figures C11, C12). Although the 40-meter contour is entirely shoreward of the 3-nautical mile State/Federal boundary, there is a prominent east-west projecting lobe, informally called "Short Bank," that extends into Federal jurisdiction off El Segundo for at least another 6 miles to the 90-meter contour. Essentially the entire segment of the coastline adjacent to the shelf consists of public beaches.

Much of Short Bank is interpreted to be composed of exposed bedrock interspersed with unconsolidated sediments that are dominantly by sand of varying size distribution (Welday and Williams, 1975; Map Sheet 2A of the CCMGMS; and Dartnell and Gardner, 2004). The studies by Fischer and others (1983) and Osborne and others (1983) only marginally extended into Federal waters beyond the 3-nautical mile boundary and thus do not address the features of Short Bank. Sediment and bedrock characteristics of Short Bank have been documented in earlier studies (see references in Dartnell and Gardner, 2004), but the recent study by Dartnell and Gardner (2004) has led to a better understanding of the seafloor facies of this local feature of the continental shelf. Thicknesses of the facies are less well known, however.

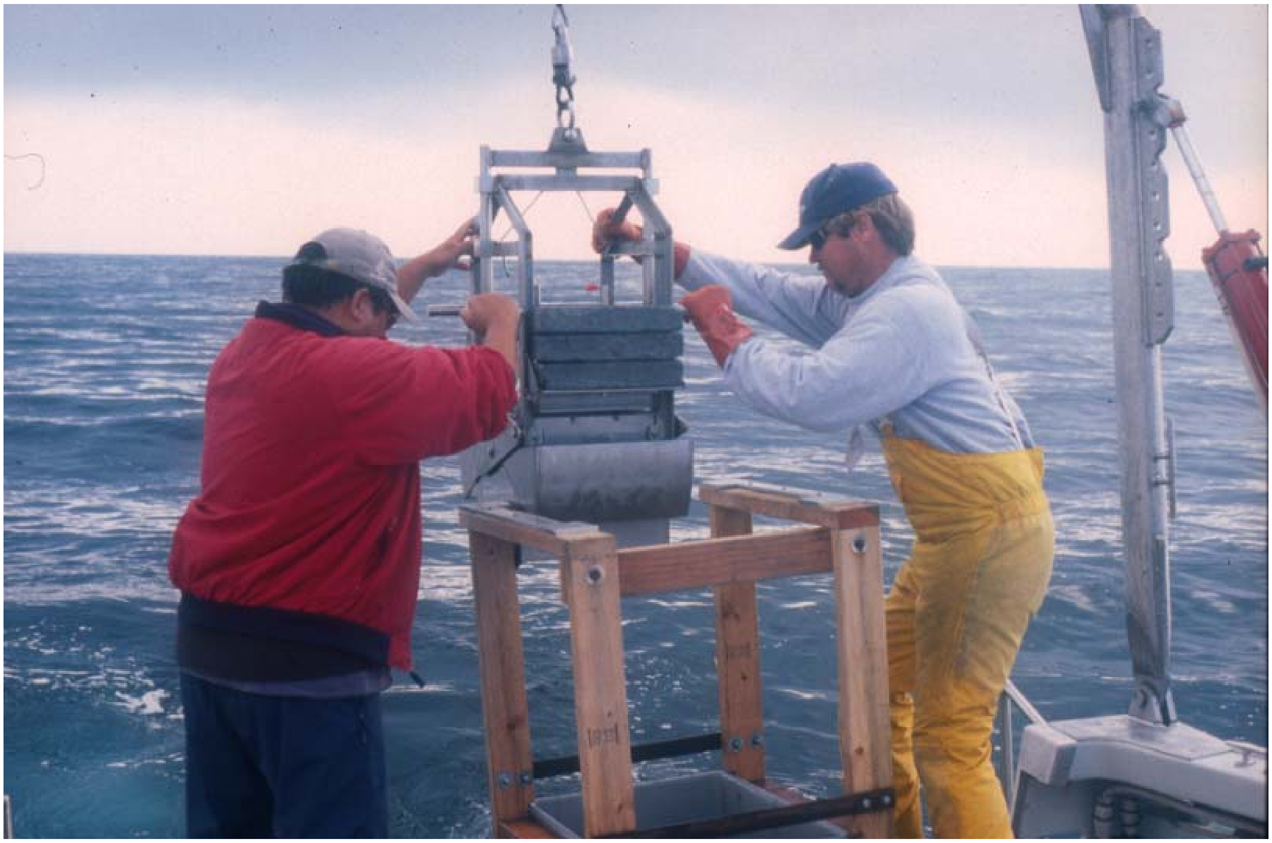
San Pedro Shelf: This area is offshore of the southern portion of the Los Angeles Basin, adjacent to a cluster of cities that extend from Long Beach in the northwest to Newport Beach in the southeast (Figures C13, C14). The shelf extends as much as 6 nautical miles beyond the 3-nautical boundary to where the continental slope begins to drop off rapidly at about the 90-meter contour. Much of the coastline consists of public beaches.

Because of both the complex, still-active tectonics and the convergence of three major rivers (Los Angeles, San Gabriel, and Santa Ana) that discharge into San Pedro Bay, the San Pedro Shelf has been the site of abundant sedimentation for thousands of years. These conditions and geophysical evidence led to the interpretation by Fischer and others (1983) that the San Pedro Shelf has a greater volume of Holocene sediment than that of any comparable area of the southern California shelf. Indeed, they calculated this amount to be 40% greater than that present over the entire shelf from Newport Beach to the border with Mexico. Of the total volume of Holocene sediment calculated by these authors for the San Pedro Shelf, over 80% is present in water deeper than the 30-meter contour. Most is within the "Wilmington Graben," a NW-trending structural basin in the center of the shelf. Much of the graben is within Federal jurisdiction.

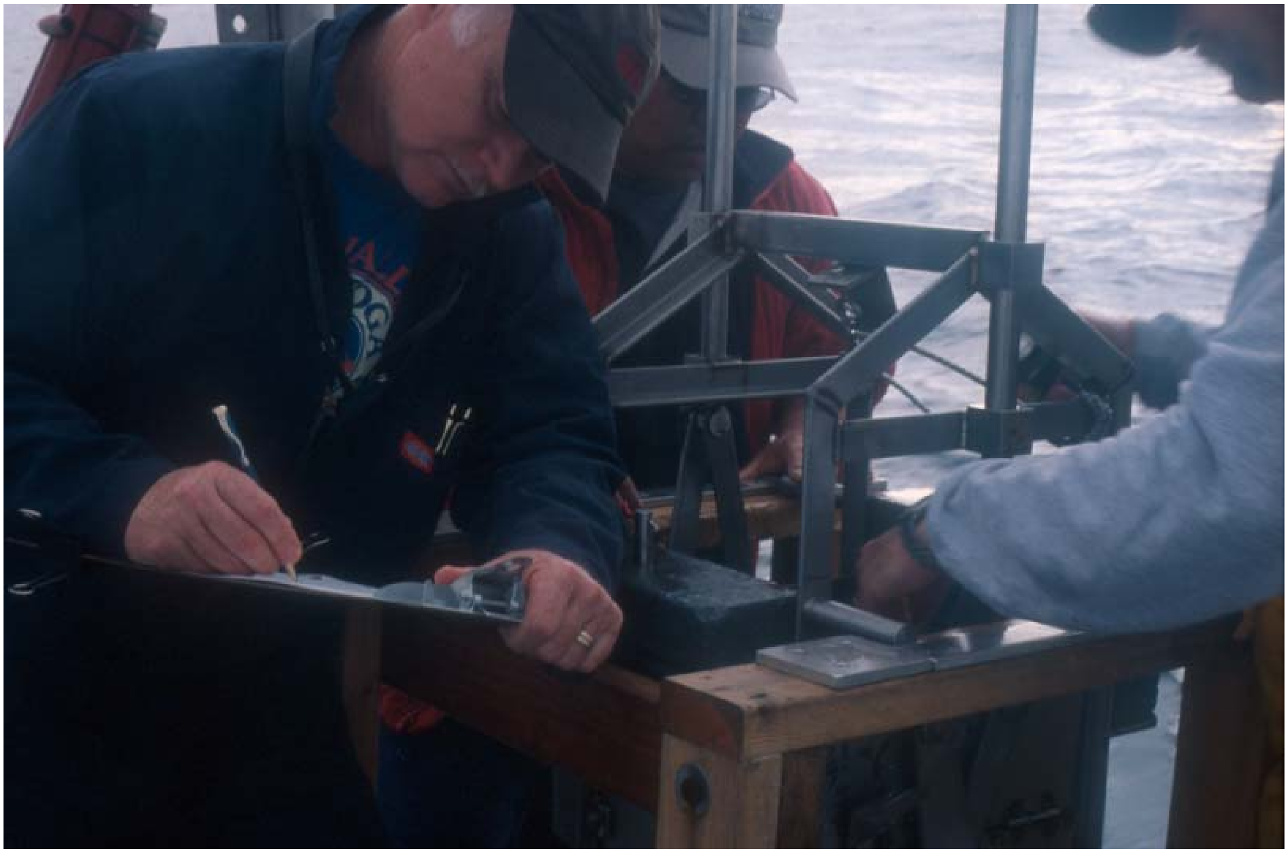
Because of its geologic and cultural importance, the San Pedro Shelf has been intensively studied by many groups for various purposes. The USGS alone has had many technical studies, some of which are still in progress. One project is use of multibeam surveys to map seafloor facies of the shelf similar to that described above on the Santa Monica Shelf. As part of the first phase of the CGS/MMS/CDBW study, the

CGS began working collaboratively with the USGS on this project as a means of aiding the CGS definition of sand deposits on the shelf. In December 2004, a major seafloor-sampling campaign was conducted on San Pedro Shelf by the USGS aboard the R/V Early Bird to aid the multibeam facies mapping. Approximately 200 bottom samples were collected; the USGS generously allowed CGS to research and define locations for twenty of the sampling sites. The following four photographs are from that sampling campaign.

Customized box-core sampler used for the USGS sampling campaign on San Pedro Shelf in December 2004. *Photo by C. Higgins*



Deployment of the box-core sampler by staff of the Orange County Sanitation District aboard R/V Early Bird during the sampling campaign on San Pedro Shelf. *Photo by C. Higgins*



USGS scientist recording observations of a retrieved sample during the sampling campaign on San Pedro Shelf. *Photo by C. Higgins*

Partially oxidized sand retrieved in box-core sampler during USGS sampling campaign on San Pedro Shelf. *Photo by C. Higgins*

Osborne and others (1983) defined several large areas of sand deposits on the San Pedro Shelf. As with the Santa Monica Shelf, however, these areas are mostly confined to the shoreward (State) side of the 3-nautical mile boundary. The USACE also defined specific borrow areas for offshore sand, but these are very near-shore in shallow water. In contrast to Santa Monica Shelf, Fischer and others (1983) prepared isopach contours that extend well into the waters under Federal jurisdiction on San Pedro Shelf. Areas of sand and gravel have been mapped in various other studies both in the graben area and as structurally ponded sediments on the uplifted bedrock high southwest of the graben. Correspondingly, it appears that knowledge about the overall distribution, thickness, and character of sand deposits in this shelf area may be better here than at Short Bank. A major task will be to build a composite facies map that draws on data and interpretations from all the previous sediment maps for this area in a manner that resolves differences in those interpretations.

San Diego Shelf: This area is offshore of several communities of the San Diego metropolitan region, extending from the La Jolla-Mission Bay area in the north to Imperial Beach near the border with Mexico in the south (Figures C15, C16). Of the four candidate shelf areas for future detailed study, this area is the smallest. Over much of its length, the shelf area between the 3-nautical mile boundary and the 90-meter contour is less than one mile in width. Only offshore of Imperial Beach does it broaden to about 4 miles. A sequence of public beaches extends over much of the length from La Jolla to the border with Mexico.

Welday and Williams (1975) mapped much of the San Diego Shelf area beyond the 3-nautical mile boundary as mud (silt and clay). Map Sheet 1A of the CCMGMS shows the area as mostly underlain by Quaternary and Tertiary sediments. Osborne and others (1983) have defined several deposits along the coast from La Jolla to Imperial Beach, but as previously, these deposits are almost entirely shoreward of the 3-nautical mile boundary. Fischer and others (1983) prepared isopach maps of the Late Quaternary sediment for most of the San Diego Shelf. Evans and others (1982) built on the work of Sprague (1971) to define a sand and gravel area directly west of Imperial Beach in waters under Federal jurisdiction. This area is generally in the 40-50-meter contour area and at this time represents the most likely site on the San Diego Shelf for future detailed investigation. In recent years, multibeam surveys (SANDAG, Neal Driscoll at SIO) have covered the nearshore parts of the shelf largely shoreward of the 3-nautical mile boundary. Multibeam surveys by the USGS were farther offshore in deeper water well beyond the shelf. An offshore-sand investigation conducted in the late 1990s for SANDAG (Sea Surveyor, Incorporated, 1999) included side-scan sonar, subbottom profiling, and vibracore sampling, but was confined to shallow waters shoreward of the 3-nautical mile boundary. The USACE also conducted study of sand deposits near those investigated for SANDAG (U.S. Army Corps of Engineers, 2002).

DATA LAYERS PERTINENT TO THE PROJECT

Part of the research and inventory during Year-One involved an initial compilation of a list of thematic digital layers that would form a GIS foundation for the mapping of sand deposits along or beyond the 3-mile State/Federal boundary. Some of these layers are readily available in digital form, while others are either not in digital form at all or only partially so. We expect that this compilation will continue in subsequent phases of the study.

Table C2 is a listing of data layers pertinent to the project. They are divided into two main categories: Base/Cultural and Geological. The Base/Cultural category includes themes such as geographic features of reference, jurisdictional boundaries, infrastructure, and controlled areas; many of these might influence whether or not a given sand deposit could be extracted or not. The Geological category includes technical themes that are restricted to the offshore marine environment – either in the water, on the seafloor, or beneath the seafloor. Themes such as sample sites, geophysical tracklines, and seafloor surface materials are included in this category and will be used to identify sites that are either lacking or are sparse in data and to map sand deposits. Comments on each thematic data layer are presented below.

BASE/CULTURAL DATA LAYERS

Bathymetry: Presented in 10-meter contour intervals. Aid in evaluation of where dredging could take place based on economic and technological limits.

Beaches: Locations are significant because they represent potential future locations of need for nourishment.

Cities: Important because the density of population can affect priorities of locations for beach nourishment and thus exploration for offshore sand resources. The location of cities/patterns of urbanization reflect the density of population.

Coastline: A means of geographic reference for determination of location.

Contaminants: This layer could represent the location of potentially serious hindrances to production of sand from offshore deposits. The extent of offshore contamination is unknown both as to type and location. An example of contamination is the DDT sediment material off the Palos Verdes Peninsula. There are two potential problems with removal of sands that are contaminated. First, the disruption of the deposit itself could spread the contamination to a larger physical area. Second, the placement of contaminated sand on a beach for nourishment purposes can pose health risks to humans.

Counties: A means of geographic reference for determination of location.

Disposal Sites: There are several officially regulated offshore disposal, or “dump,” sites in southern California. These are portrayed on nautical charts as circular or polygonal areas. Some are active, while others are abandoned. Many are in deeper water beyond areas of interest for production of sand. They contain various debris that should be avoided during any production of sand for beach nourishment.

Drilling Platforms: The Southern California Bight contains a few dozen offshore drilling platforms for the production of oil and gas. They are dispersed within two main areas, Santa Barbara Channel (Point Conception to Ventura) and San Pedro Bay. Some are in deeper water beyond areas of interest for production of sand, while others are in the inner shelf regions in both State and Federal waters. A radius of safety around these structures is advisable when defining areas for potential production of sand.

Federal/State Boundary: This line extends the entire coast of California and represents the boundary between State and Federal jurisdiction. It measures 3 nautical miles from the shoreline and around islands. Production of sand from beyond this 3-mile boundary is under regulatory authority of the U.S. Minerals Management Service.

Geographic Points: A means of geographic reference for determination of location. These consist of named physical landmarks on the coastline.

Highways: A means of geographic reference for determination of location.

Infrastructure: This theme is a mixture of man-made structures that are on the seafloor. It includes pipelines, electrical cables, and sewer outfalls from coastal municipalities. As with drilling platforms, a minimum distance of safety adjacent to these features is advisable when defining areas for potential production of sand. These features are mapped on NOAA navigational charts.

International Boundary: Consists of a single line that defines the offshore boundary between the U.S. and Mexico.

Leases (developed): Consists of areas of developed offshore oil and gas leases that are under administration by the Federal government (Minerals Management Service). They coincide largely with the locations of the offshore drilling platforms described above.

Leases (undeveloped): Consists of areas of undeveloped offshore oil and gas leases that are under administration by the Federal government (Minerals Management Service). These are dominantly in the vicinity of Point Arguello, with a few in the Santa Barbara Channel; they are adjacent to the active leases described above.

Marine Sanctuaries: These may have restrictions or prohibition of any dredging, therefore their locations are important for determination of where any future exploration for or exploitation of sand deposits can take place. There are two extensive sanctuaries in southern California. One surrounds the northern Channel Islands, while the other is south of Santa Barbara. The largest off the coast of the state is the Monterey Bay National Marine Sanctuary, which extends from San Simeon to San Francisco.

Military Exercise Areas: As with marine sanctuaries described above, these may have restrictions or prohibition of any dredging, therefore their locations are important for determination of where any future exploration for or exploitation of sand deposits can take place. The Southern California Bight has various locations of military bases, particularly in San Diego County. Some of these have offshore zones for training activities.

Shipping Lanes/Areas: Similar to the military exercise areas described above, there are several designated areas along the Southern California Bight where navigational rules, restrictions, or warnings are in effect. The most extensive are shipping lanes in the San Pedro Shelf area and along the offshore areas of Santa Barbara and Ventura counties. Some of these designated areas have no restrictions on dredging, while others prohibit it. Commonly, the areas are designated because of congestion in ship traffic. All are mapped on NOAA navigational charts, and any rules or restrictions can be obtained from the Coast Guard Headquarters in Alameda (we have a contact there if research is needed on any particular designated area).

Shipwrecks: Submerged wrecks may present local problems for dredging operations. Also, wrecks may be treated as archeological sites that are protected from disturbance. There are a few databases that cover locations in California, but we do not know at this time the quality of the locations presented (they could be poorly known, or purposely obscured to protect the artifact in question).

Submerged Obstructions: Exclusive of shipwrecks, this category includes features that may be hazardous for dredging operations. These are identified in part on NOAA navigational charts and are largely within the 3-nautical-mile limit, but some may be present in Federal waters.

Submarine Topography: This theme can be generated from bathymetric data as shaded relief imagery, which can aid characterization of the seafloor both as to potential dredging environment and in definition and mapping of seafloor materials.

Urban Coastal Areas: This theme covers both identity and extent of urbanized areas along the coast of California, which can be useful in defining priorities of beach areas for potential remediation. Those beaches within or near densely developed segments of the coastline are more likely candidates for remediation because of the greater use of those beaches.

Watersheds: Represent the coastal drainage areas that supply sediment to coastal beaches. Where rivers and streams discharge into the ocean may be sites of larger volumes of sediment including sand. We have not decided at this time whether to use small-scale watersheds, rivers and streams, or both. Concerning exploration for sand deposits, only the larger streams that discharge along the coast would be used for interpretation.

GEOLOGICAL DATA LAYERS

Core-Sample Sites: Locations of cores (e.g., vibracores) that give information on the subsurface of the seafloor potentially to a depth of about 40 feet, although most are less than 20 feet. The data are from a variety of surveys and periods of time, so quality and consistency can be in question. Core data are available from academic institutions, the USACE, and published technical reports from other government agencies such as SANDAG and CDBW. The distribution of core sites is irregular along the coast; the highest densities of cores are typically concentrated within identified sand deposits of interest for potential exploitation.

Currents: Although there may be little data for this layer, the data can be useful in determination of where periodic influxes or removal of sediment may occur in given areas. Of most interest are bottom currents, but this category has the fewest recorded observations. This theme is pertinent to answering the question of how stable are seafloor sediments through time. Do certain deposits remain stable while others are eroded? Read Inman's work.

Geology (CGS/USGS Continental Margin Series): Divided into seven separate sets of 1:250,000-scale maps, this series varies in its level of geologic detail. All seven sets of maps were digitized by CSUMB and are on that university's Web site for Internet mapping and downloading. Figure C---- shows the mapping for southern California with bathymetric contours that are pertinent to dredging superimposed. In some locations, these maps are useful, but in others there is insufficient mapping or units are not differentiated sufficiently to aid interpretation of potential deposits of sand.

The CGS also has a 1:100,000-scale series of geologic maps, which includes integration of offshore geologic data with the adjacent onshore mapping for quadrangles that overlap the coastline of the state. The status of the CGS and USGS 1:100,000-scale maps completed or in progress to date for California is as follows:

Long Beach:	CGS	In progress	New plus previous mapping	
Los Angeles:	USGS	Released	No offshore mapping included	OF 97-483
Monterey:	CGS	Released	New plus previous mapping	
Oceanside:	CGS	Ready for release	Previous mapping only	
San Diego:	CGS	Ready for release	Previous mapping only	
Santa Ana:	USGS	Released	No offshore mapping included	OF 99-172

The offshore area of Santa Barbara County is expected to be compiled by CGS starting in another year.

Geology (CGS MS 26): The Welday and Williams statewide map of seafloor surficial materials, published in 1975, is still the only map that shows interpreted surficial seafloor geology for the entire coastline of the state. This mapping also formed the foundation of the mapping presented in the U.S. Bureau of Reclamation report on a proposed offshore aqueduct as described in Howard (1974).

Geophysical Surveys (Subbottom): Numerous geophysical surveys have been conducted over the continental shelf for different purposes. Seismic reflection surveys generally fall into two categories: Low-frequency techniques that penetrate to great depths in the subsurface, typically for oil and gas exploration, and high-frequency, high-resolution techniques that penetrate only to shallow depths. Because of their high resolution at shallow depth, the latter are of more utility for identification and characterization of sand deposits that can be dredged.

A useful resource for location of previous USGS geophysical surveys (as well as other marine surveys) off the coast of California is the on-line database called "InfoBank." Other sources of geophysical data include Geological Data Center at the Scripps Institution of Oceanography (http://gdc.ucsd.edu/requests.html) and the Center for Los Angeles Basin Subsurface Geology at California State University, Long Beach (http://seis.natsci.csulb.edu/deptweb/CLABSG.html).

Habitat Classification: This theme involves mapping of seafloor environments and materials that provide habitat for marine animals and plants. It relates in some instances to the multibeam backscatter and sidescan sonar categories described elsewhere, but these represent final derivative products that are equivalent to geologic maps that portray seafloor materials. Map units include such materials as mud, sand, bedrock, and gravel plus mixed categories. Gary Greene's group at Moss Landing Marine Laboratory and other organizations have conducted such mapping at various sites along the California coast.

Littoral Cells: The coast of California has been subdivided into a set of a few dozen self-contained irregular segments, or "cells," that are defined by supply and loss of sediment through longshore, or "littoral," drift.

Multibeam Backscatter: The "roughness" characteristics recorded in these datasets, in combination with the companion bathymetry, can be valuable for interpretation and mapping of seafloor materials at the time of the surveys. Backscatter imagery has been collected by several institutions along the Southern California Bight including, among others, USGS, MLML, MBARI, NOAA, CSUMB, SIO, and consultants for local government (e.g, SANDAG). Imagery is known to cover most of the shelf areas except for a gap between Port Hueneme and Point Dume, and in the region around Dana Point. The data were collected at different times and different resolutions.

Oil and Gas Seepage: Natural seeps of oil and gas have been mapped at a few locations in shelf areas of the Southern California Bight. Such seeps present two issues related to sand deposits and associated dredging. First, the hydrocarbon residue may or may not have degraded any sand deposits at these locations. Second, any dredging at these sites may disrupt the equilibrium of the seeps, perhaps increasing flow rates.

Sand Resources: Several studies have been conducted along the Southern California Bight to define sand resources for potential use in beach replenishment (Table C1). The study by Field (1974) appears to be the first attempt at identification and quantification of sand resources off the coast of southern California. This work was built upon by the Osborne-Fischer studies for CDBW in the early 1980s, which were the first systematic reconnaissance of this region. Locally, BEACON (Santa Barbara-Ventura counties) in the late 1980s and SANDAG (San Diego County) in the1990s conducted studies of resources adjacent to their jurisdictions. Maps with outlines and estimated quantities of sand are presented in each of these reports. The USACE has conducted resource assessments in small areas adjacent to beaches designated for nourishment. Likewise, these reports, which date from the 1980s, contain maps and data on sand resources. It appears that the scopes of these studies, and the resources identified by them, rarely overlapped into Federal waters beyond the 3-nautical-mile limit. Areas of sand bodies outlined in each of these studies can be digitized with varying degrees of effort. Some reports include data on the physical characteristics of the sand. It appears that many of the identified resources are not rigorously mapped, with some based on relatively few core holes and geophysical surveying.

Seabed Materials (NOAA): Distribution of materials on seafloor as historically mapped by NOAA hydrographic surveys. This dataset may be replaced by the “Seabed-Sample Sites” layer described below.

Seabed-Sample Sites: These datasets contrast with the categories of core-sample sites by representing samples collected only at the seafloor-water interface. Many of these have been documented in usSEABED, a USGS database system

Sediment Thickness (isopachs): Various studies have presented maps that show contour thickness of unconsolidated sediment in local shelf areas. These studies include those described above under the category of sand resources.

Sidescan Sonar: The traditional seafloor mapping technique before the advent of the multibeam version, there are many datasets for coastal California.

OVERALL COVERAGE OF TECHNICAL DATA ALONG THE COAST

During initial statewide reconnaissance for this project, discussion with Gary Greene at the Moss Landing Marine Laboratory and other sources produced a general summary of relative coverage of technical data for the shelf of California. From south to north:

Mexico Border to Oceanside: Interests of San Diego Association of Governments (SANDAG) and Scripps Institution of Oceanography (SIO) have spawned a number of offshore studies and surveys ranging from multibeam sonar to vibracore sampling. Much of this work is within the State waters, however.

Oceanside to Newport Beach: This segment has not been covered as well as the segment to the south. Some studies have been done by the USACE in the San Clemente area.

Newport Beach to Ventura: Extensive studies from Newport Beach to Santa Monica particularly on the San Pedro and Santa Monica shelves. Much less from Santa Monica to the Port Hueneme area, but increases again in the Oxnard-Ventura area.

Ventura to Point Conception: Studies and data are common over this segment.

Point Conception to Morro Bay: Some multibeam and side-scan data are available, but overall an area of less intensive study.

Morro Bay to Sur Canyon: Very sparse data over this segment.

Sur Canyon to Golden Gate: Many studies and data particularly related to the Monterey Bay National Marine Sanctuary and the area around the Farallones Islands (Gulf of the Farallones).

Golden Gate to Eel River: Very sparse data over this segment.

Eel River to Oregon Border: Various studies by Federal agencies and others over this segment particularly because of the tectonic significance of this area and the presence of an offshore spreading center.

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