LITTORAL CELLS, SAND BUDGETS, AND BEACHES: UNDERSTANDING CALIFORNIA'S SHORELINE

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EXECUTIVE SUMMARY

The coastline of California can be divided into a set of distinct, essentially self-contained littoral cells or beach compartments. These compartments are geographically limited and consist of a series of sand sources (such as rivers, streams and eroding coastal bluffs) that provide sand to the shoreline; sand sinks (such as coastal dunes and submarine canyons) where sand is lost from the shoreline; and longshore transport or littoral drift that moves sand along the shoreline. Sediment within each cell includes the sand on the exposed or dry beach as well as the finer-grained sediment that lies just offshore.

Beach sand moves on and offshore seasonally in response to changing wave energy, and also moves alongshore, driven by waves that usually approach the beach at some angle. Most beach sand along the coast of California is transported from north to south as a result of the dominant waves approaching the shoreline from the northwest, although alongshore transport to the north occurs in some locations and at certain times of the year in response to waves from the south. Average annual rates of littoral drift typically range from about 100,000 to 1,000,000 yds^3/yr along the California coast.

Sand budgets have been developed for many of California's littoral cells by calculating or estimating the amount of sand added annually from each source or lost to each sink, and by documenting the volume of sand moving alongshore as littoral drift by using harbor dredging records as proxies. It is the balance between the volumes of sand entering and leaving a littoral cell over the long-term that govern the long-term width of the beaches within the cell. Where sand supplies have been reduced through the construction of dams or debris basins in coastal watersheds, through armoring the seacliffs, by mining sand or restricting littoral transport through large coastal engineering structures, the beaches may temporarily or permanently narrow.

The impacts of human activities on the amount of sand supplied to California's beaches have been well documented. While there is a public perception that Southern California beaches have narrowed in recent years, fueled at least in part by the stormy 20-year El Niño dominated period that extended from 1978 to 1998 and severely eroded many beaches, long-term changes in beach width are still being studied.

Beach nourishment or beach restoration is the placement of sand on the shoreline with the intent of widening a beach that is naturally narrow or where the natural supply of sand has been significantly reduced through human activities. Nourished shorelines provide a number of benefits including increased area for recreation, increased revenue from tourism, habitat improvement for shore dependent species, greater protection of the coastline from coastal storms, reduced need for armor, and increased public access.

To date, opportunistic beach fill has provided the majority of sand historically used for beach nourishment in California. Over 130 million yds^3 of sand were added to the beaches of southern California between 1930 and 1993 as a by-product of several large coastal construction projects and from the dredging of existing harbors and new marinas. As a result, the beaches of Santa Monica Bay and the Silver Strand, for example, are much wider than they were under natural conditions. Although the amount of sand provided by these projects has dropped sharply, the use of sand retention structures, such as groins or offshore breakwaters, has been effective in stabilizing the sand and maintaining wider beaches at many locations.

Beach nourishment has emerged as an option in recent years for portions of the southern California coastline (northern San Diego County and portions of Santa Barbara and Ventura counties, for example) where beaches are narrow and back beach or cliff top development is being threatened. While nourishment may appear to be an attractive alternative to coastal armoring or retreat, there are a number of issues or considerations that need to be carefully considered and addressed. These include the source and method of obtaining appropriate sand, costs and impacts of removing and transporting large volumes of sand to the site, financial responsibility for the initial project and subsequent re-nourishment, the potential impacts of sand placement, and the lifespan of the nourished sand. Due to the high littoral drift rates that characterize most of the California coast, sand added to a beach that is narrow to begin with cannot be expected to remain at that location for any extended period of time. Sand retention systems have been used effectively at a number of sites in California, however, as a way to significantly extend the lifespan of a beach nourishment project.

Chapter 1

Introduction

People have been interested in beaches and coastal processes for many years. Researchers have observed that beach width can change significantly over a range of time periods, from hours and days to years and decades. Long-term erosion or narrowing of any California beach is of concern to coastal managers as well as the general public.

In an effort to better understand the processes that change beaches, scientists use the concept of sand budgets to identify and quantify, to the degree possible, additions and losses of sand that influence beach width. By the 1960's, researchers recognized that the coastline of California could be separated into distinct, essentially self-contained regions or cells that were geographically limited. For example, beach sand in the Santa Barbara area originated from the watersheds and the coastline in the Santa Barbara area, and beach sand in San Diego or Santa Cruz originated in those geographic areas.

Coastal geologists and engineers termed these essentially self-contained coastal units littoral cells. These cells are geographically bounded by specific physical features that act as barriers to sediment movement, and contain additional features that either provide or remove sand from the cell. Understanding this setting allows researchers to focus on the major elements influencing specific beach or shoreline areas. This report discusses the physical process (littoral drift) that moves sand from one location to another within littoral cells. Littoral cell boundaries, features within the cell that supply sand to the beaches (sources), or remove sand from beaches (sinks) are also explained.

The methods used to develop sand budgets are first illustrated and then summarized for California's major littoral cells. Information is provided on how development associated with California's urbanizing society has altered the sand budgets of many of California's littoral cells, generally by decreasing the input of sand into the cell. This report concludes with a discussion of how the state is attempting to replace the sand lost through human activities (dam removal and beach nourishment) and the issues raised by such restoration activities.

The California Coastal Sediment Management Workgroup (CSMW), a taskforce of state and federal agencies seeking to resolve coastal sediment management issues, and the University of California at Santa Cruz, have developed this report as part of their public outreach and education effort associated with the CSMW's Sediment Master Plan, or SMP. A more detailed report on specific sand budgets for California's major littoral cells has been completed and is a complement to and resource for this more general discussion (Patsch and Griggs, 2006). Funding for both studies was provided by the California Resources Agency as part of a Coastal Impact Assistance Program grant for the SMP. The document was prepared with significant input from CSMW members, but does not necessarily represent the official position of member agencies.

CHAPTER 2

AN OVERVIEW OF LITTORAL CELLS AND LITTORAL DRIFT

WHAT IS LITTORAL DRIFT?

Researchers have learned that sand is in constant motion along California's coastline, and only resides "temporarily" on an individual beach. An alongshore or littoral current is developed parallel to the coast as the result of waves breaking at an angle to the shoreline. This current and the turbulence of the breaking waves, which serves to suspend the sand, are the essential factors involved in moving sand along the shoreline. As waves approach the beach at an angle, the up-rush of water, or swash, moves sand at an angle onto the shoreface. The backwash of water rushes down the shoreface perpendicular to the shoreline or a slight downcoast angle, thus creating a zigzag movement of sand (Figure 2.1). This zigzag motion effectively results in a current parallel to the shoreline. Littoral drift refers to the movement of entrained sand grains in the direction of the longshore current.

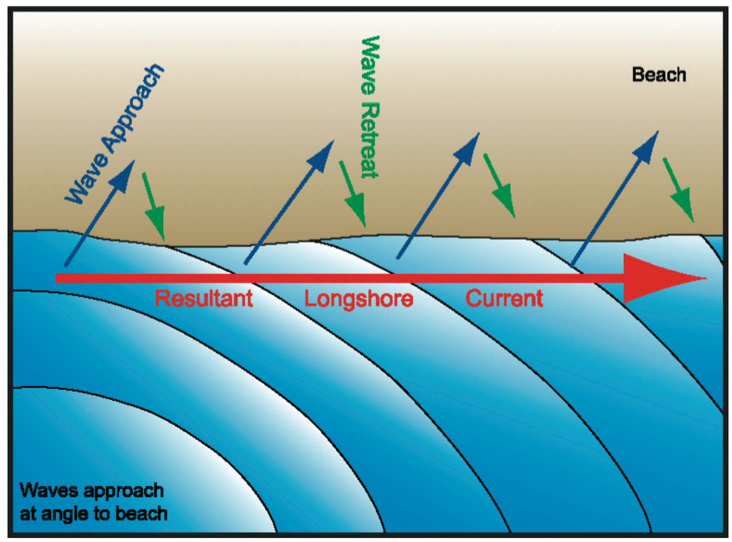

Figure 2.1: Development of longshore current as a result of waves approaching the beach at an angle. Littoral drift refers to the net movement of sand grains in the directions of the longshore current.

Littoral drift can be thought of as a river of sand moving parallel to the shore, moving sand from one coastal location to the next and so on until the sand is eventually lost to the littoral system. Littoral drift or transport in California can occur alongshore in two directions, upcoast or downcoast, dependent on the dominant angle of wave approach (Figure 2.2). Along the California coast, southward transport is generally referred to as downcoast and northward transport is considered upcoast. If waves approach perpendicular to the shoreline, there will be no net longshore movement of sand grains, no littoral current, and thus no littoral drift. Longshore transport for a reach of coast will typically include both upcoast and downcoast transport, often varying seasonally.

Gross littoral drift is the total volume of sand transported both up and downcoast, while net littoral drift is the difference between the two volumes. In other words, along a particular segment of coastline, there may be 200,000 yds^3 of sand transported in a southerly or downcoast direction each year, and 50,000 yds^3 transported in a northerly or upcoast direction. The gross littoral drift would be 200,000 + 50,000 or 250,000 yds^3, whereas the net drift would be 200,000 – 50,000 or 150,000 yds^3 downcoast.

For most of California, from Cape Mendocino south to San Diego, waves from the northwest have the greatest influence on littoral drift, and thus, a southward net littoral drift of sand dominates (Figure 2.2). The more energetic winter waves generally approach from the northwest direction, driving littoral drift southward or southeastward along the beaches. There are also areas such as southern Monterey Bay, and Oceanside, where longshore transport to the north may take place. During El Niño winters, waves generally come from the west or southwest and the predominance of southward transport is reduced. Transport may be to the northwest, or upcoast, in most of southern California during the summer months when southern swell dominates.

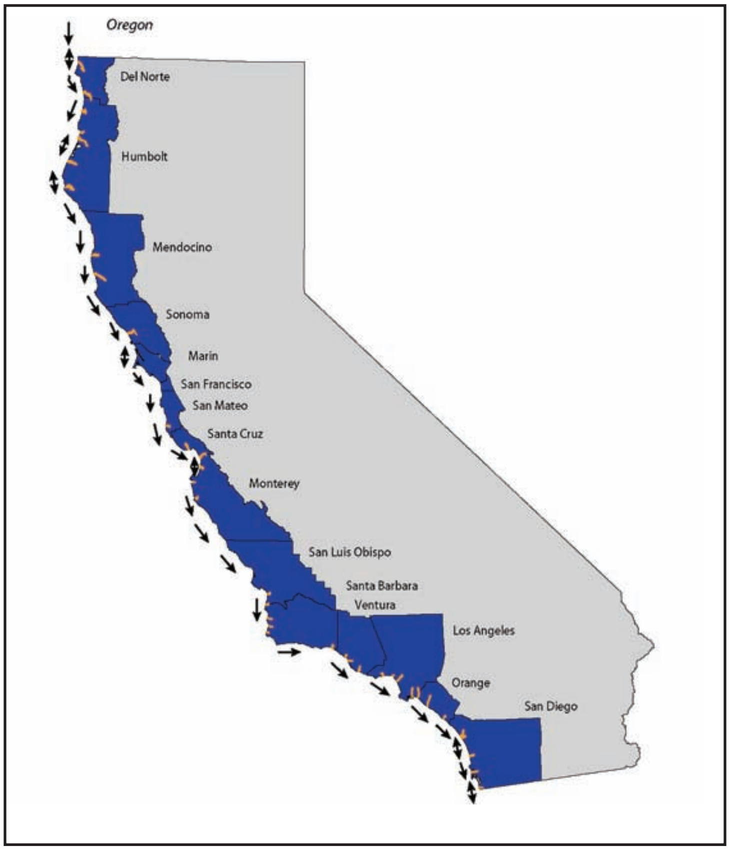

Figure 2.2: Net littoral drift directions in California

Coastal engineering structures designed to widen or stabilize beaches, such as groins, the construction of harbor entrance jetties and breakwaters, and also the stability or lifespan of beach nourishment projects, are all closely tied to littoral drift direction and rate. Interrupting or disrupting the littoral drift or "river of sand", in addition to the benefits of retaining sand and widening beaches, can have serious consequences to the downdrift shorelines, including increased beach or cliff erosion and, in the case of a harbor entrance, costly dredging. Erosion of downdrift properties may necessitate the emplacement of additional coastal armoring, which extends the disruptions to the shoreline farther downcoast.

WHAT CONSTITUTES BEACH SAND?

Whereas it is common practice to refer to most beach sediment as "sand", grain sizes on beaches in California range from very-fine grained sand to cobbles as a result of differences in the wave energy, and the material available to any particular beach. Geologists and engineers classify sediment by size (e.g. silt, sand, pebbles) because different size materials behave very differently and sediment of different sizes is stable on different beaches. The Wentworth scale is one of the classification schemes most commonly used and it groups sediment by grain diameter (millimeters) based on powers of two (Krumbein, 1936). According to this scale, sand is defined as all particles between 0.0625 mm and 2 mm in diameter, although sand is further broken down into fine-grained, medium-grained, etc. (Table 2.1). The phi scale was introduced as an alternate measure of sediment size based on the powers of two from the Wentworth scale and is commonly used in the coastal geology community. It is important to note that larger phi sizes correspond to smaller grain sizes (Table 2.1).

Wentworth Scale Size Description	Phi Units Φ	Grain Diameter (mm)
Boulder	-8	256
Cobble	-6	64
Pebble	-2	4
Granule	-1	2
Very Coarse Sand	0	1
Coarse Sand	1	0.5
Medium Sand	2	0.25
Fine Sand	3	0.125
Very Fine Sand	4	0.0625
Silt	8	0.004
Clay	12	0.00024

Table 2.1: Wentworth scale of sediment size classification–Note that larger Phi sizes indicate smaller grain size

LITTORAL CUT-OFF DIAMETER

Very fine-grained sand, ranging from 0.0625 to 0.125 mm in diameter (4ø to 3ø), typically doesn't remain on the exposed (dry) portions of most California beaches due to the high-energy wave environment. An investigation of littoral transport processes and beach sand in northern Monterey Bay (Hicks, 1985), discovered that there is a littoral cut-off diameter, or a grain-size diameter, characteristic of any particular segment of coast. The cut-off diameter serves as a functional grain size boundary in that very little material finer-grained than this diameter actually remains on the exposed beach. The cut-off diameter along any particular beach or stretch of coast is primarily a function of wave energy at that location.

Studies along the coast of northern Santa Cruz County, which is a relatively high-energy, exposed coast, determined a littoral cut-off diameter of ~0.18 mm (2.5ø) for this stretch of coast, with very little finer sand remaining on the exposed beaches. In southern California, where much of the coast is protected from strong wave action by the sheltering effect of the Channel Islands, the littoral cut-off diameter is smaller, typically around 0.125mm (3ø). When estimating or calculating inputs to a sand budget or planning a beach nourishment project, it is important to consider the littoral cut-off diameter. Sand placed on the beach or entering a littoral cell that is finer than the littoral cut-off diameter will not remain on the dry beach.

THE BEACH PROFILE

The exposed (dry) beach is the visual portion of a profile of sediment that extends from the back of the beach to some depth (commonly referred to as "closure depth") representing the point beyond which it is believed that there is little net seasonal movement of sand on- and offshore. The grain size distribution varies along this profile perpendicular to the shoreline, and the overall distribution of size can be represented by an "envelope" of grain sizes. The coarsest materials within this envelope reside on the beach itself; successively finer-grained materials are present further offshore along the profile. Materials within the nearshore are an important part of the beach and related system. . Sediment smaller than the cut-off diameter may move into the nearshore and help support the beach profile. It may also move alongshore as littoral drift.

We do not currently have the historical information needed to quantify changes in nearshore sand volumes. This report focuses on the changes and processes affecting beach sands, which provides an adequate surrogate for the total volume of sediment moving alongshore as littoral drift.

LITTORAL CELLS

The California coast can be divided into a number of individual segments within which littoral sediment transport is bounded or contained. These essentially self-contained segments have often been referred to as beach compartments (Figure 2.3; Inman and Frautschy, 1966) or littoral cells.

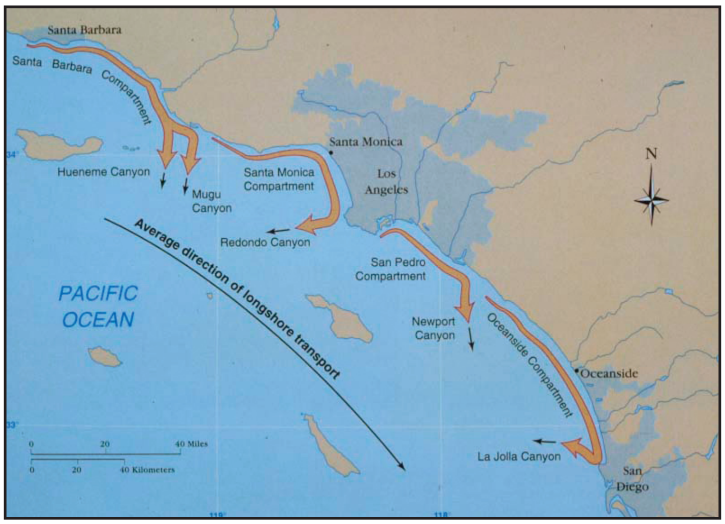

Figure 2.3: Littoral cells in southern California

Each cell has its own source(s) of sand, littoral drift, and ultimately, a sink or sinks where sand is lost permanently from the littoral cell (Figure 2.4). Sediment within a littoral cell consists of sand on the exposed or dry beach as well as the finer grained materials residing in and moving through the adjacent nearshore environment. Typical sources and sinks are described in detail in Chapter 3. The littoral cell concept has been perhaps the most important discovery in the field of coastal and beach processes in the last 50 years. It has enormous value in understanding coastal processes, sand input, output, storage and transport, and provides an extremely valuable and useful framework for assessing any human intrusions into the coastal zone.

The upcoast boundary of a littoral cell is typically a rocky headland, littoral barrier or sink such that littoral drift into the cell from the adjacent upcoast compartment is restricted or minimal. Sand enters the littoral cell primarily from streams and rivers draining to the shoreline and from bluff erosion, and is transported alongshore by littoral drift. Ultimately, sand is lost from the compartment offshore into the head of a submarine canyon or beyond the reach of longshore transport, onshore into coastal dunes, or in some cases, to sand mining.

CROSS-SHORE TRANSPORT

During large storm events, sand may be either transported offshore or onshore from the seafloor seaward of the surf zone. Thus the nearshore area may be either a source or sink for beach sand. However,

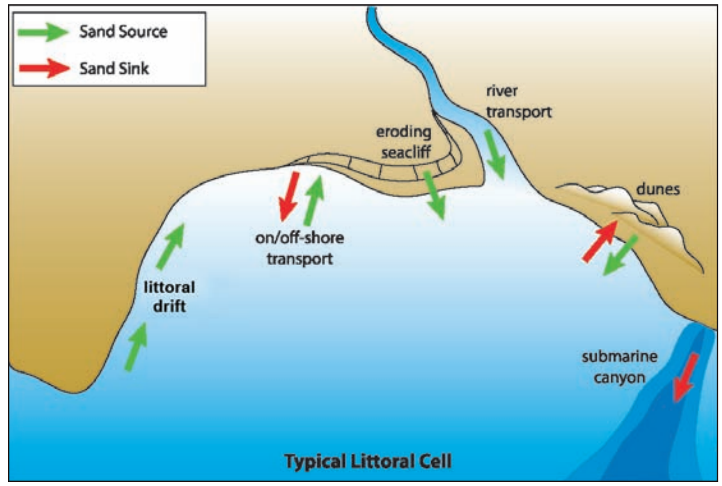

Figure 2.4: Sources and sinks in a typical littoral cell in California

for most littoral cells we simply don't have adequate information to quantify this cross-shore transport and, therefore, the importance of the sand in the nearshore area to littoral sand budgets is poorly understood.

LIMITATIONS TO THE LITTORAL CELL CONCEPT

Ideally, each littoral cell exists as a distinct entity with little or no transport of sediment between cells. It is believed that many headlands form nearly total barriers to littoral drift, but under particular conditions, such as during large storms, significant sand may be suspended and carried around points or across the heads of submarine canyons onto the beaches of adjacent cells. Fine-grained materials being transported in suspension behave differently than sand moving along the surface of the beach or nearshore zone, and the littoral cell boundary concept does not apply to these materials.

Nevertheless, while boundaries have been delineated for California's major littoral cells (Figure 2.5; also see Chapter 4), there are still uncertainties and information gaps on these often well-studied cells: Where are the actual boundaries of each littoral cell? Does significant sand transport take place around or across these "boundaries"? What is the dominant littoral drift direction throughout each cell? These are a few of the questions that remain partially unanswered.

The application of a budget to understand changes in and processes affecting beach sand is a useful tool in coastal land use management and coastal engineering. It is an essential step in understanding sand routing along the coast. One of the first sediment budgets for a littoral cell was created in the region from Pismo Beach to Santa Barbara, estimating each sand input and output along this portion of the central coast of California (Bowen and Inman, 1966). This budget has proven to be a valuable template for subsequent studies.

Our historic lack of understanding of littoral cells and their importance, or the failure to incorporate this type of information early on in the decision-making process in large watershed or coastal engineering projects has resulted in costly problems to society. For example, ongoing harbor entrance channel dredging is required where these projects were constructed in the middle or downcoast ends of littoral cells with high drift rates (Griggs, 1986). The reduction of sand delivery to beaches due to impoundment of sediment behind dams in coastal watersheds has contributed to cliff and beach erosion and the loss of recreational benefits. An improved qualitative and quantitative understanding of littoral cells and sand budgets can help us to resolve existing coastal sediment problems and also inform future planning so as to avoid the mistakes of the past.

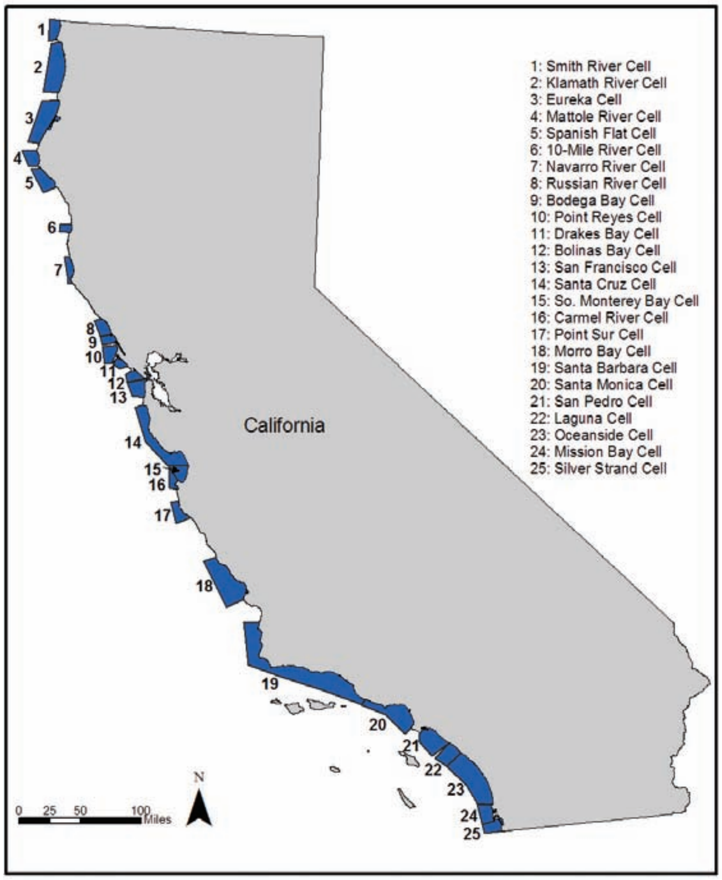

Figure 2.5. California's littoral cells (Habel and Armstrong, 1978)

SEASONAL AND DECADAL MOVEMENT OF SAND WITHIN A LITTORAL CELL

The shoreline within a littoral cell is dynamic, changing with the rhythms of the tides, seasons, and long-term climatic shifts, including fluctuations of sea-level. Beaches respond with great sensitivity to the forces acting on them, primarily wind and waves. Waves provide the energy to move sand both on- and offshore as well as alongshore. The beach is a deposit of well-sorted material that appears to be stable, but in reality, the beach and sand in the nearshore are in constant motion on-, off-, and alongshore. This motion occurs underwater and on both short term (individual waves) and long-term (seasonal and decadal) time scales.

As sea level changes with tidal cycles, so does the width of the exposed beach. In addition to daily variations, long-term fluctuations in sea level occur over hundreds and thousand of years as a result of global climate change. Sea level has been rising for about 18,000 years, and it is assumed by virtually all coastal and climate scientists that it will continue to rise into the foreseeable future. Over the past century, sea level has risen relative to the coastline in southern California by about 8 inches (20 cm), and at San Francisco by about 9 inches (23 cm).

Beach widths in California also change on a seasonal scale, due to changes in weather, storm intensity, and wave climate (Figures 2.6 and 2.7). Seasonal beach erosion is typically a recoverable process; beach width narrows each winter and generally widens the following summer. In the winter, the coast experiences an increase in storms and wave energy. The increased wave energy tends to erode the beach, and moves sand into the nearshore where it is stored in sand bars. These sand bars tend to reduce the wave energy hitting the shoreline because the waves will break farther offshore (over the bars), losing some of their energy before reaching the shoreline. As the winter storms pass and the wave intensity is reduced, the smaller, less energetic spring and summer waves begin to dominate. These smaller waves rebuild the beach with the sand moved offshore during the winter storms. Figure 2.7 shows a beach in central California (A) during the summer when smaller waves have moved sand onshore to build a wide beach, and (B) in winter when large storm waves have narrowed the beach by moving sand onto offshore bars.

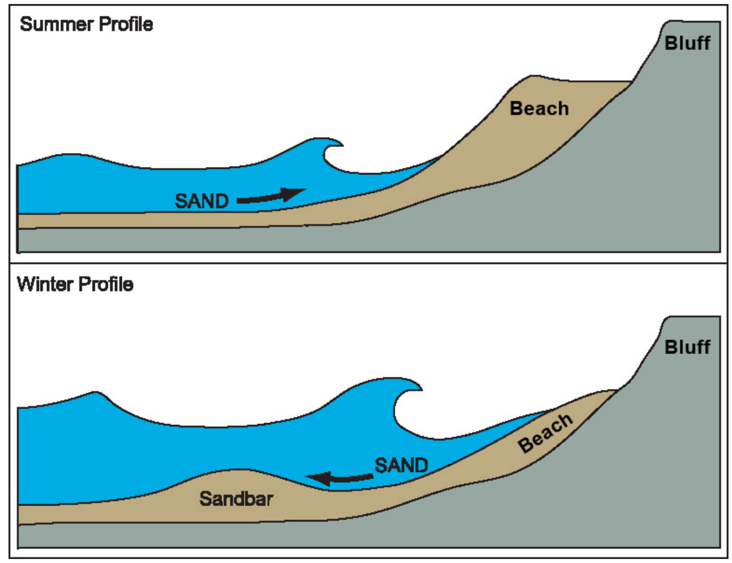

Figure 2.6: Summer profile (also known as the swell profile) results from waves with low heights, and long periods and wavelengths. The beach is characterized by a steep foreshore and a broad berm (a terrace formed by wave action along the backshore of a beach). The winter beach profile (also known as the storm profile) is a response to higher waves, shorter wave periods, and shorter wavelengths. Waves become erosive and cut away at the berm, transporting sand onto offshore bars where it is stored until the following summer.

Over years and decades, beaches can erode (narrow), advance (widen), or remain in equilibrium, as a result of available sand within a littoral cell. When sand supply is reduced through the construction of dams or altered by large coastal engineering structures such as breakwaters or jetties, affected beaches can experience permanent erosion or take years or decades to re-establish equilibrium. This loss of sand and beach width may be recoverable, however, if the sand supply is restored.

Large-scale ocean warming episodes related to El Niño occur in the Pacific Ocean when mean sea level in California can be elevated by up to 15 cm or more for several months to a year. El Niño winters are also characterized by more frequent and vigorous storms over the Pacific, and severe beach erosion can result when large waves approaching from the west or southwest arrive simultaneously with very high tides. Research on changing climate conditions has identified periods, sometimes lasting several decades, when El Niño events are much more severe than those occurring during La Niña periods (characterized by cooler temperatures, decreased storm intensity and rainfall), such as the period from the mid-1940's to 1978. Although the timing of these decadal-scale changes are not predictable, cycles of more frequent El Niño events have been recognized when increased storm intensity and duration result in increased beach loss and cliff erosion. The most recent cycle of intense El Niño events began in 1978. Winter storms of 1982-1983 and 1997-1998, in particular, caused severe beach erosion along California's shoreline and significant damage to oceanfront structures and coastal infrastructure.

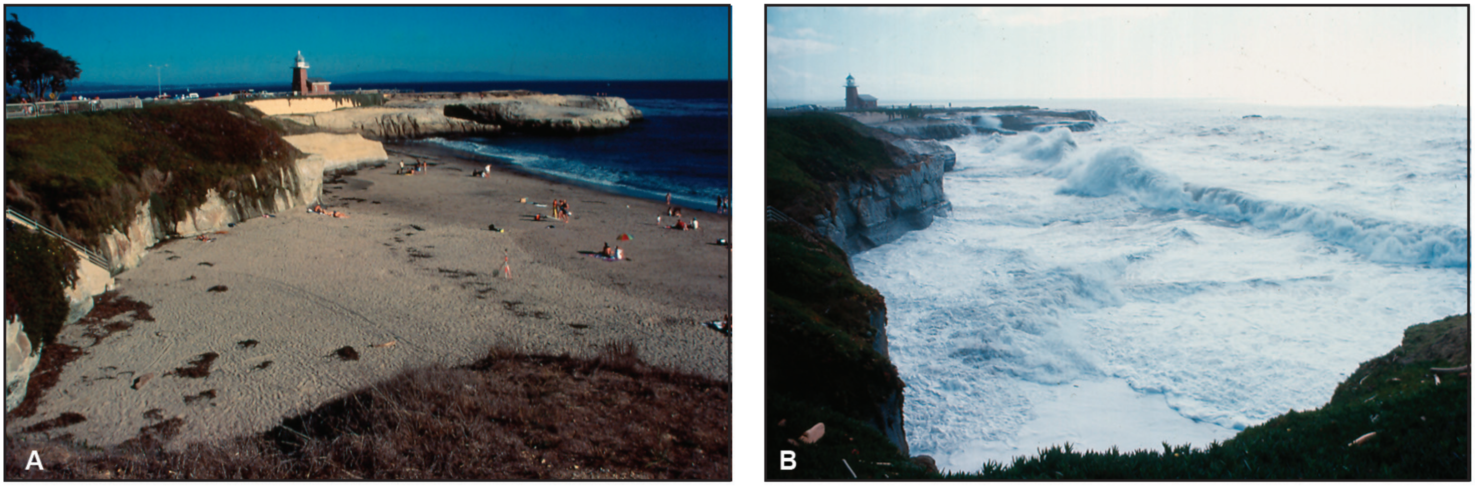

Figure 2.7: Seasonal beach changes
A. Wide, summer beach at Its Beach in Santa Cruz (October 1997) B. Narrow winter beach at Its Beach in Santa Cruz (February 1998)

Chapter 3

Elements Involved in Developing Sand Budgets for Littoral Cells

Beach sand is in a constant state of flux, moving on-, off- and alongshore under the influence of waves and currents. Sand is transported to beaches from a variety of sources, including rivers, seacliffs or dunes, updrift beaches and possibly offshore sources (Figure 2.4). Sand generally remains at a given location on a beach for only a short time before it is entrained and moved on as littoral drift. When the removal of sand (output) exceeds that being transported in (input), beach erosion or narrowing results. Conversely, beach widening results when sand input exceeds output, or when some barrier to littoral transport (a groin or jetty for example) is constructed that leads to sand storage (output is reduced). Beaches are said to be in equilibrium when sand inputs are approximately equal to sand outputs.

A sand budget is an attempt to quantify changes in the on-shore sand volume along a stretch of coast by applying the principle of conservation of mass. In order to develop a sand budget, estimates must be made of the primary sand sources (input) and sand losses (output) for a stretch of shoreline. Balancing or creating a sand budget for a reach of coast is similar to balancing a checkbook. Sand sources such as river inputs, seacliff or dune erosion, longshore transport from upcoast areas, beach nourishment and onshore transport from the nearshore can be thought of as deposits (inputs) into the account (Figure 2.4). Sand sinks (e.g., submarine canyons, dune growth, longshore transport out of an area, offshore transport and sand mining) represent outputs from the system or debits to the account (Figure 2.4). The difference between the total volume of sand provided by all sand sources and the volume lost to all sinks within a particular littoral cell will equal the change in sand volume or storage within that compartment and provide insight on the stability of the beach or particular stretch of coast (Table 3.1).

Sources of Sand	Sinks for Sand	Balance
Longshore Transport In	Longshore Transport Out	Accretion
River Inputs	Offshore Transport	Erosion
Seacliff or Bluff Erosion	Dune Growth	Equilibrium
Gully Erosion	Sand Mining	
Onshore Transport	Submarine Canyons	
Dune Erosion		
Beach Nourishment		

Table 3.1: Sources and sinks of sand and the resulting balance in the development of a sand budget.

A sand budget can be developed to represent short-term conditions, such as seasonal or yearly changes. However, when planning a large engineering, restoration or nourishment project or other alteration to the coast, it is best to construct a long-term sand budget that includes historic and present conditions. Many assumptions and errors involved in the data analysis and interpretation of a sand budget can be reduced when a budget spans a greater length of time and averages out year-to-year variations in the components.

It is the balance between sand sources and sinks within each littoral cell that govern the long-term width of beaches within a beach compartment. If there is a significant reduction in the amount of sand reaching a particular stretch of coast, the beach should gradually erode or narrow. Conversely, if there is an increase of sand in a particular area, the beach should advance seaward, or widen.

COMPONENTS OF A SAND BUDGET

The main challenge in developing a sand budget is quantitatively assessing all sources and sinks to a reasonable degree of accuracy. A thorough literature search should be performed to find the most up-to-date information on each component. Along the California coast, most of the naturally supplied beach sand comes from river and stream runoff with a lesser amount derived from the erosion of coastal cliffs and bluffs. Sand is lost from littoral cells predominantly to submarine canyons, to sand dunes to a lesser extent, and perhaps to offshore transport during extreme storm events. Sand mining directly from the beach historically was a major loss for some littoral cells, but most of this has now been eliminated.

Sand contributions from seacliff erosion, rivers, and dunes as well as other components of the budget, have been or can be quantified or calculated with some effort for many of the state's littoral cells (Patsch and Griggs, 2006; Patsch, 2005). The volume of materials dredged from harbors within the littoral cell can serve as a surrogate (or check point) for the volume of littoral drift at a specific location. The following sections give more specific information on the difficulties and limitations involved in calculating or estimating contributions and losses for a sand budget.

River Inputs (Source): Rivers contribute the majority of sand to most beaches in California. Physical and chemical weathering slowly breaks down the rocks from coastal mountains into smaller fragments. The broken-down boulders, cobbles, gravel, sand, silt and clay move into mountain streams and creeks through rainfall, runoff, and slope failures, and the sediments are sorted and transported downstream into larger streams or rivers. As sediments travel down stream, they break down and become smaller. Large cobbles and boulders are often left upstream because the river does not have enough energy to transport them downstream. Sediment is transported in streams either as suspended load (the finer-grained sediment which makes it look muddy), or as bedload (the coarser material that is transported along the bed of the stream). Most of the suspended load consists of clay and silt, except during high discharge events when significant volumes of sand can be transported in suspension and delivered to the shoreline. Although the total amount of sediment carried as bedload is much less than that carried in suspension, most of the bedload is sand and will contribute directly to the littoral sand budget.

Eventually, the smaller cobbles, sand, silt and clay will reach the shoreline. The finer silt and clay particles are too small to settle and remain on the beach, and consequently are carried offshore by coastal and offshore currents, and eventually deposited on the seafloor nearby or perhaps many miles away. Offshore mudbelts are fairly common, where much of the fine-grained sediment eventually ends up. Most sand-sized material will remain on the beach, and gradually be moved alongshore by littoral drift, thereby feeding down-coast beaches. The finer-grained sand may, however, move into the nearshore zone and also be transported alongshore.

Sand contributions for the majority of the coastal rivers and streams in California have been determined using daily measured values of water discharge, or probabilities of discharge events, to develop "sediment-rating curves". These curves show the relationship between the volume of water discharge and sand loads for individual streams.

Sediment rating curves can be used to estimate the annual sediment yield from individual rivers and streams. Using these curves, average sand loads (sediment sufficiently coarse to remain on the beach) have been calculated for most of the rivers and streams in California (Willis and Griggs, 2003; Slagel, 2005). Under historical or natural conditions about 13-14.5 million yds^3 of sand was being delivered annually to the coast of California from 37 major rivers and streams. This volume has been reduced about 23% statewide through impoundment behind dams, such that, on average, about 10,000,000 yds^3 of sand is presently delivered to the coast each year.

The methodology used in these two studies is believed to be the most reliable approach currently available for determining sand contributions to the shoreline from rivers; however it is not without error. Some gauging stations are often well upstream from the mouth of the river; thus, sediment loads may differ significantly between the gauging station and the shoreline due to deposition or erosion that may occur along the stream channel or flood plain between the gauging station and the river mouth.

Sediment delivery by rivers to California's littoral cells is extremely episodic. Most sediment discharged by any particular stream typically occurs during several days of high flow each year. Additionally, sediment discharge during a single year of extreme flood conditions may overshadow or exceed decades of low or normal flow. For example, the Eel River transported 57 million tons of suspended sediment on December 23, 1964, representing 18% of the total sediment discharged by the river during the previous ten years. This one-day discharge is greater than the total average annual suspended sediment discharge for all rivers draining into the entire California coastline. On some streams, however, little or no sediment discharge data may exist for the flood or large discharge events that transport the greatest volumes of sediment. As a result, rating curves may not adequately predict sand transport from water discharge records during the high discharge events. Data or calculations for sediment impounded behind dams can help fill such gaps or deficiencies in sediment discharge records (Slagel, 2005).

Fluvial sediment discharge has also been shown to vary widely from El Niño to La Niña periods (Inman and Jenkins, 1999), such that the length of historic streamflow record from any particular gage may or may not be representative of long-term conditions. In Southern California, mean annual stream flow during wet El Niño periods exceeded that during the dry periods by a factor of about three, while the mean annual suspended sediment flux during the wet periods exceeded the sediment transported during dry periods by a factor of about five (Inman and Jenkins, 1999).

At their best, data on fluvial sand discharge are believed accurate to within about 30% to 50% (Willis and Griggs, 2003). Yet, the amount of sand transported and delivered to the shoreline by streams is an extremely important component of all sand budgets for California.

Reductions to Fluvial Inputs: Damming of rivers or streams reduces sediment delivery to the coast by both trapping sand in the reservoirs and reducing peak flows that transport the greatest amount of sediment. Most of California's large dams, under good management, have reservoir capacities sufficient to absorb all incoming water during a normal winter, releasing low flows to downstream areas during the spring and summer months. The magnitude and frequency of peak flows are therefore reduced, decreasing the river's ability to transport material downstream (Figure 3.1). Dams act as complete barriers to bedload and trap most of the suspended sediment load, except during large flood events when flows overtop the dam or pass through the spillway. The average trapping efficiency (the amount of suspended sediment trapped by the dam) for most coastal dams in California is about 84% (Brune, 1953; Willis and Griggs, 2003).

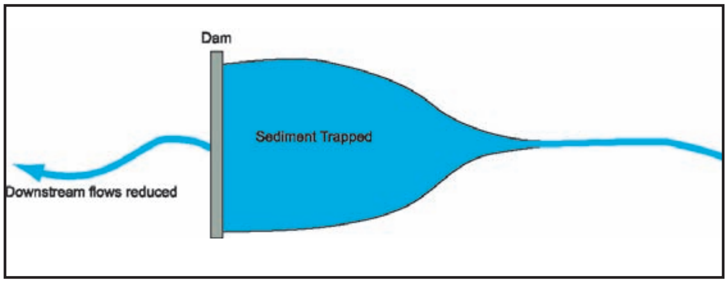

Figure 3.1: Dams trap sediment, preventing it from moving downstream to the shoreline, in addition to reducing the river's flow volume and thus its ability to transport sediment.

Recent work by Willis and Griggs (2003) and Slagel (2005) indicate that the present day delivery of sand to the shoreline has been reduced to about 10 – 11 million yds^3/year, or approximately a 23-25% reduction from natural conditions, due to the more than 500 dams on California's coastal streams. Approximately 3 million yds^3 of sand is trapped each year and a total of about 163 million cubic yds^3 of sand has now been deposited behind dams on the state's 21 major rivers (Slagel, 2005). The great majority of this reduction is concentrated in southern California (Tables 4.1 and 4.2; These two tables list only the amounts of sand provided to California's ten major littoral cells under natural and present-day conditions, and do not include all of the state's major coastal rivers and dams analyzed by Slagel [2005] and Willis and Griggs [2003])

Sand mining in Northern California coastal watersheds and along stream channels has removed an estimated 9 million yds^3 (11 million tons) of sand and gravel annually on average, and similar operations in Southern California have removed about 41.5 million yds^3 (55.8 million tons) annually on average (Magoon and Lent, 2005). It is unclear how much of this sand and gravel would naturally be delivered to the coast by rivers, but sand mining may play a major role in the reduction of sand delivery by rivers to the shoreline.

If sand supply from rivers is continually reduced through impoundment behind dams, as well as through sand and gravel mining from stream beds, then beaches should eventually be deprived of a significant portion of their predominant sand source. Over decadal time scales, beaches should, therefore, narrow or erode, assuming no change in littoral transport rates (Figure 3.2). Littoral drift rates are a function of the amount of wave energy, the angle of wave approach, and the sand available for transport. More wave energy and a greater angle of wave approach will generate larger littoral drift rates.

Seacliff erosion (Source): Seventy-two percent of California's 1,100-mile coast consists of seacliffs or coastal bluffs, which, when eroded, may contribute sand to California's beaches. Coastal cliffs that consist of materials such as sandstone or granite that break down into sand-sized grains will contribute directly to the beaches. Fine-grained rocks that consist of silt and clay (shales or mudstones), on the other hand, will not contribute significantly to beaches.

The geology of the seacliffs along the coast of California varies widely alongshore and, therefore, the amount of sand contained in the cliffs or bluffs also varies from place to place. Typically, where the coastal cliffs consist of uplifted marine terraces, there is

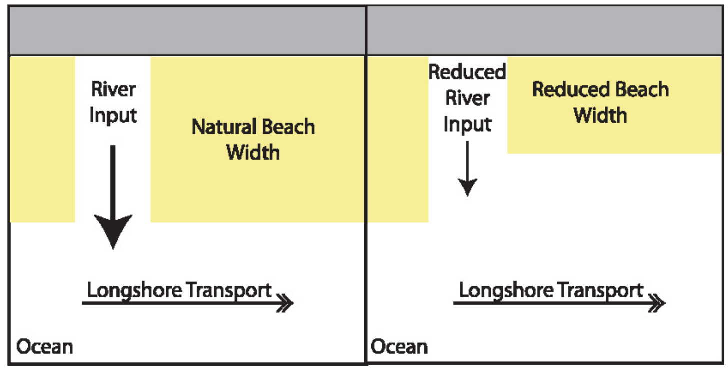

Figure 3.2 illustrates beach narrowing expected from a reduced sand supply. A simplified littoral cell is presented with a single river as the only sand source, thus ignoring sand contributions from cliffs and other budget components. If the amount of sand delivered by the river is reduced, and the littoral drift remains the same, then the downdrift beach volume or width should decrease over time.

an underlying, more resistant bedrock unit and an overlying sandy deposit, consisting predominantly of relict beach sand. Each unit will have its own particular sand content. In order to make qualitative assessments or quantitative measurements of the contribution of coastal cliff retreat to beaches, it is necessary to divide the coast into manageable segments somewhat uniform in morphology and rock type. Estimates of sand contributions from individual segments can then be combined to arrive at a total contribution of beach sand over a larger area, such as an individual littoral cell.

The annual production of sand coarse enough to remain on the beach resulting from seacliff erosion (Qs) along a segment of coastline is the product of: 1- the cross-sectional area of seacliff (Area = alongshore cliff length x cliff height); 2- the average annual rate of cliff retreat, and; 3- the percentage of material larger than the littoral cutoff diameter (Figure 3.3):

$$Qs\ (ft^3/yr) = Lc*E*(Hb*Sb + Tt*St)$$

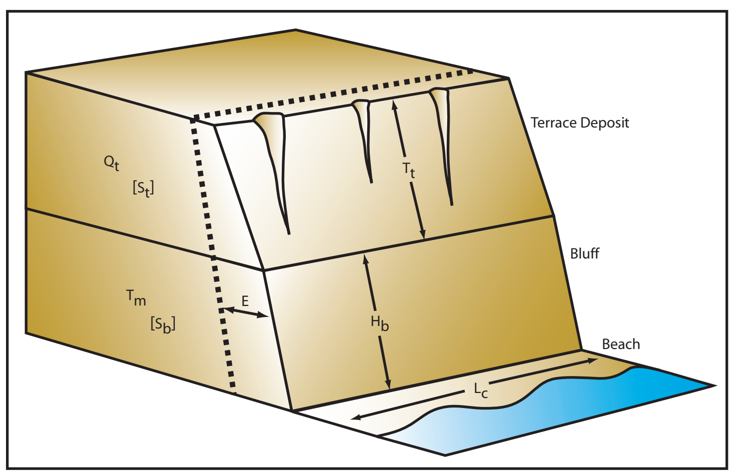

Figure 3.3: Seacliff showing the components involved in calculating sand contribution: Lc is the alongshore length of the cliff (ft); E is erosion rate (ft/yr); Hb is bedrock height (ft); Sb is percentage of sand size material larger than the cutoff diameter in bedrock; Tt is thickness of the terrace deposit (ft); and St is percentage of sand larger than the cutoff diameter in the terrace deposit. Tm (Tertiary Marine) represents geology of the bedrock, and Qt (Quaternary Terrace) represents geology of the capping terrace deposit.

The methodology for determining sand contributions from seacliff erosion is simpler than the process used to determine river contributions of sand. However, these calculations still have a high degree of uncertainty. The most difficult element of this methodology to constrain is the long-term seacliff erosion rates due to the high spatial variability and episodic nature of cliff or bluff failure. Seacliff erosion rates are typically determined by precisely comparing the position of the cliff edge over time on historical stereo aerial photographs (Griggs, Patsch and Savoy, 2005).

On a state-wide basis, contributions to beach sand from seacliff erosion tend to be much less than those from streams. However, such contributions may be very important locally where very sandy cliffs are rapidly eroding and there are no large streams (Runyan and Griggs, 2003). For example, while bluff erosion contributes less than one percent of the sand to the Santa Barbara littoral cell, bluff erosion is believed to contribute about 31% and 60% of the sand to the Laguna and Mission Bay littoral cells, respectively. Also, recent research in the Oceanside littoral cell, utilizing composition of sand in the bluffs and beaches, as well as very precise LIDAR (a very precise, laser-based, topography measuring system) measurements of coastal bluff retreat (over a relatively short 6-year period) concluded that bluffs may contribute 50% or more of the sand to beaches in this littoral cell.

Beach Nourishment (Source): Beach nourishment is used to describe sand artificially added to a beach and/or the adjacent nearshore that would not have otherwise been provided to the littoral cell. It is a way to artificially widen otherwise narrow or eroding beaches, and has occurred more frequently in southern California than in other region of the state. Historically, sand placed on the beach or just offshore has come from a variety of sources, including: dredging of coastal harbors, lagoons, bays, estuaries or river channels; coastal construction projects where dune or other excavated sand is placed on the beach; and, dredging of offshore areas. Most beach nourishment projects have served dual purposes, i.e., the primary purpose was to create a marina, clear a river channel for flood control, restore a coastal wetland or excavate a construction site, and the secondary purpose of the project was to nourish or widen the beach.

When developing a littoral budget, sand excavated from offshore, coastal or inland sources is considered to be an additional source of sand to the littoral cell, and thus labeled as nourishment. Harbor entrance bypassing operations or channel maintenance dredging do not represent new sources of sand, because they are simply moving the sand to a new location within the same cell, and so are not considered nourishment.

Cross-shore exchange (Source/Sink): Quantifying the potential movement of sand between beaches and the nearshore and offshore areas is the most challenging and poorly evaluated sand budget element. Cross-shore transport can result in either a net gain or loss for the beach. A comparison of sediment composition (e.g., distinct minerals contained in the sand) between beach, nearshore and shelf sand is often used as evidence for a net onshore or offshore transport; however, the similarity in composition only indicates that an exchange has taken place. It rarely indicates direction of transport or volumes of sand moved, which are necessary for development of a sand budget.

Whether or not sand is moved on- or offshore is controlled by factors such as wave energy and tidal range, bottom slope and the grain size of the sand. In order to thoroughly evaluate this component it would be necessary to have data on the precise thickness or depth of beach-sized sand over large offshore areas and to know how this has changed over time. With the large shelf areas typically involved, a small increase in the thickness of the sediment veneer over an extensive area can produce a large volume of sand in storage. We simply don't have these data, and it would require long-term studies to determine how the distribution of sand changes over time. In developing sand budgets, it is often assumed that net cross-shore exchange of sand is zero, such that the volumes of sand transported on- and offshore are balanced, unless sediment data are available on a particular area of interest. In other cases, however, unaccounted for losses are usually ascribed to offshore transport.

Offshore dredge disposal: There are several littoral cells where large volumes of beach size sand that have been dredged from harbors or channel entrances have been or continue to be transported offshore for disposal, thus removing this material permanently from the littoral system. Offshore disposal can, therefore, be a significant littoral sand sink.

Close to a million cubic yards of sand on average is dredged from the Humboldt Bay entrance channel every year and transported to EPA's Humboldt Open Ocean Disposal Site (HOODS; Tom Kendall, USACE). Sediment lost to the littoral cell from dredging and offshore disposal was also a major issue in San Diego. About two million cubic yards of sediment was scheduled for dredging as part of the deepening of San Diego Bay for larger U.S. Navy vessels. This sediment was originally intended for the SANDAG nourishment project, but was disposed of offshore due to ordinance found in the dredge spoils from the bay. These are very large volumes of potential beach sand that are being removed more-or-less permanently from the littoral system for different reasons. This is an issue that merits further investigation in order to document how extensive these losses are, where they are taking place, and what options exist for possible utilization of these materials in the adjacent littoral cells.

Dune Growth/Recession (Sink/Source): Sand dunes occur adjacent to and inland from beaches at many locations along the coast of California. Dunes are created where ample fine-grained sand is available with a persistent onshore wind and a low-lying area landward of the beach where the sand can accumulate. Typically, if the shoreline is backed by seacliffs, dunes can't accumulate or migrate, and thus will not grow to any significant size. In many areas of California, such as the area north of Humboldt Bay, Golden Gate Park in San Francisco, southern Monterey Bay, The Pismo Beach area, and areas along Santa Monica Bay, wind-blown sand has created large dune complexes.

Dunes commonly represent sand permanently lost from littoral cell budgets, constituting a significant sink to a cell. For example, it has been estimated that an average of 200,000 yd^3/yr of wind-blown sand is permanently lost from the beaches along the 35-mile coastline from Pismo Beach to Point Arguello (Bowen and Inman, 1966; Figure 3.4). On the other hand, in areas such as the Southern Monterey Bay littoral cell, dune erosion and recession play an important role as a sand source to the littoral budget. While uncommon, sand may be blown onto the beach from a coastal dune area (representing a source).

Dune migration, growth and erosion (or deflation) can be measured from aerial photographs or in the field and converted into sand volumes. Dune growth and deflation illustrate the need to introduce a time element into sand budgets. One major storm can erode the portion of dunes closest to the ocean (i.e., the foredune), which were previously considered a sink, returning the sand to the beach. However, many studies have concluded that this type of foredune erosion may occur for only a few days during a major storm event and is followed by a prolonged period (from years to decades) of foredune growth.

Figure 3.4: Pismo Dunes in San Luis Obispo County. Copyright © 2002 Kenneth & Gabrielle Adelman California Coastal Records Project, www.Californiacoastline.org.

Losses into Submarine Canyons (Sink): Submarine canyons that extend close to shore (e.g., Mugu, Redondo, Newport and Monterey submarine canyons) (Figure 3.5) serve as effective barriers to littoral drift and terminate most littoral cells in California. These canyons are the largest permanent sink for sand in California. Sand accumulates at the heads of these submarine canyons and, through underwater sand flows or turbidity currents, is funneled away from the shoreline and deposited in deep offshore basins.

Figure 3.5: Monterey Submarine Canyon

It is believed that an average of over a million cubic yards of sand is annually transported down into Mugu Submarine Canyon, thus terminating the littoral drift within the Santa Barbara littoral cell. Monterey Submarine Canyon (Figure 3.5), located in the center of Monterey Bay, is one of the world's largest submarine canyons and is over 6,000 feet deep. An average of at least 300,000 yds^3 of sand is annually lost down this canyon. As part of sand budget calculations, after all sand sources and other sinks are first accounted for, any remaining sand in the budget is assumed to be directed into a submarine canyon, where one exists and reaches close enough to the shoreline to trap littoral drift, and is permanently lost to the littoral cell.

Sand Mining (Sink): Sand and gravel removed from riverbeds, beaches, dunes and nearshore areas for construction and/or commercial purposes, represents a significant permanent sink for some of California's littoral cells. Sand mining along the beaches of California and Oregon began in the late 1800s when there seemed to be an overabundance of sand and no obvious impacts from mining. Overall in northern California, (i.e., from the Oregon border to the Russian River), about 8 million yds^3 (11 million tons) of sand and gravel are removed each year from the coastal streambeds (Magoon and Lent, 2005). In southern California, the annual total is nearly 41.5 million yds^3 (56 million tons), primarily in the greater Los Angeles and San Diego areas.

Beach or streambed sand mining has historically been a large sink for beach sand in some specific locations; however the volumes removed are difficult to quantify for the purposes of a sand budget. Due to the proprietary (and therefore publicly unavailable) nature of sand mining operations, gathering information on specific mining practices for a given river or beach within a littoral cell may not be possible. Information on mining should be included in long-term sand budgets when available. While there are still extensive sand and gravel mining operations along many streambeds in California, direct removal of sand from the beach along the coast of California was mostly terminated by the early 1990's. However, mining of the back beach still occurs at some sites (e.g., near Marina in southern Monterey Bay) (Figure 3.6).

Figure 3.6: Sand is still mined directly from the back beach in the Marina area of southern Monterey Bay (2005). Copyright © 2005 Kenneth and Gabrielle Adelman, California Coastal Records Project, www.Californiacoastline.org.

LITTORAL DRIFT CHECK POINTS

Direct measurement of the volume of sand moving as littoral drift would confirm estimated sand inputs from streams and bluffs; however, such direct measurement is unfortunately not feasible. However, California's four large ports and 21 small craft harbors (Figure 3.7) can serve as constraints, or check points, on this volume when developing sand budgets. Half of the littoral cells in California (10 of the 20 cells) contain at least one harbor that effectively traps the littoral drift. These coastal sand traps, however, are very different from dams and reservoirs, which keep sand from ever entering the littoral system.

Much of the sand moving along the coast as littoral drift is caught in either harbor entrances or designed trapping areas, dredged, and, with few exceptions, placed downdrift. The configuration and

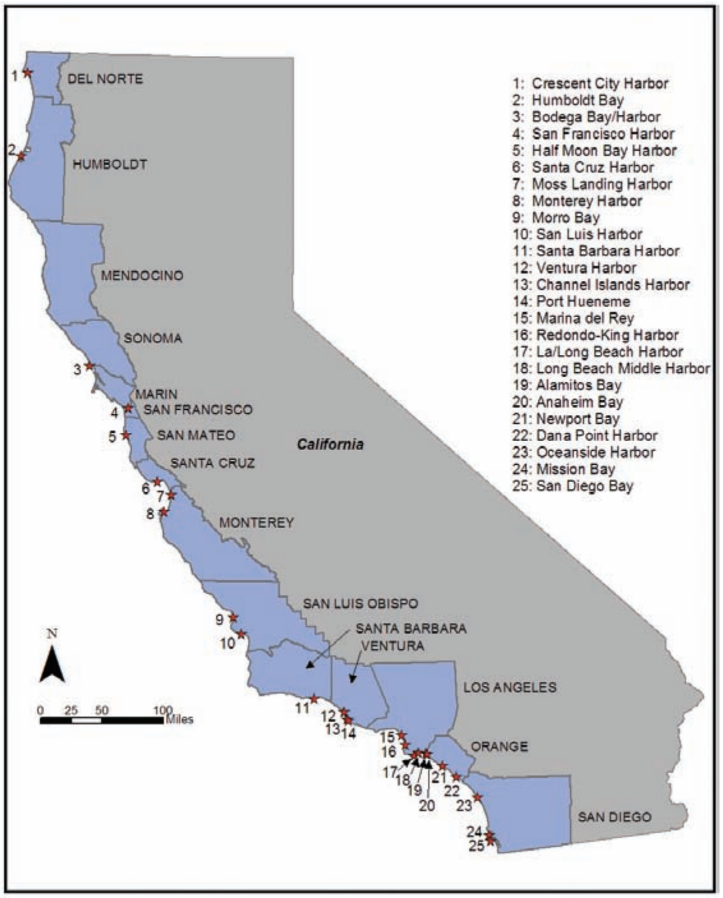

Figure 3.7: California's harbors and location by county.

geometry of some harbors (e.g., Ventura and Channel Islands; Figure 3.8) were designed to trap littoral drift before it enters the harbor's navigation channel. Sand resides in these sediment traps until it is dredged, typically once or twice a year. Other harbors (e.g., Humboldt Bay, Oceanside, and Santa Cruz harbors) were not designed with a specific sediment trapping area. Thus, once the sand residing upcoast of the first jetty reaches the jetty tip, littoral drift travels around the jetty and accumulates in the harbor entrance channel, often forming a sandbar. While some littoral drift may naturally bypass the entrance channel, especially at those harbors designed without a specific trapping area, harbor dredging records are the most dependable numbers currently available for estimating long-term annual gross and, occasionally, net littoral drift rates.

For purposes of sand budget calculations, there must be enough sand being added to the littoral cell to balance the average dredged volume. Some littoral cells have more than one harbor, and thus multiple check points for quantifying the cell's littoral drift. These cells provide optimum conditions for developing reliable sand budgets.

Inherent errors do exist when using harbor entrance dredging volumes to estimate littoral drift as checkpoints in the development of

Figure 3.8: Ventura Harbor: maintenance dredging in 1972. Copyright © Kenneth and Gabrielle Adelman, California Coastal Records Project www.Californiacoastline.org

littoral cell sand budgets, however. Errors involved in estimating dredging volumes include, but are not limited to, the type of equipment used to dredge, and the time frame of sand removal and placement. There can also be uncertainties involved in the pre-dredge conditions and the method used to determine the reported volume of sand dredged from a location.

Other uncertainties include: 1–harbors, (e.g., Oceanside) where detailed studies indicate that littoral drift reverses seasonally, such that sand can be dredged twice, and; 2- significant natural bypassing of sand beyond the dredging area can also occur (e.g., again at Oceanside, where sand appears to have been transported offshore and formed a permanent bar) (Dolan, Castens, et al., 1987; Seymour and Castel, 1985).

It is believed, however, that the margin of error involved in estimating dredged sand volumes is still significantly lower than the error associated with quantifying the annual volumes of most sand sources and sinks within littoral cells (such as the sand contribution from streams and cliff erosion and sand lost to submarine canyons). For most harbors, entrances or trapping areas form nearly complete littoral drift traps. Where long-term data exist, which tend to average out year to year fluctuations, harbor dredging records provide rational check points for littoral cell sand budgets.

Chapter 4

Sand Budgets for California's Major Littoral Cells and Changes in Sand Supply

The beaches of southern California are intensively used recreational areas that generate billions of dollars of direct revenue annually. Wide, sandy beaches, used by people playing volleyball, sunbathing, swimming, jogging and surfing, are the quintessential image of southern California. Wide, sandy beaches, however, were not always the natural condition. Many of these beaches have been artificially created and maintained through human intervention, including placement of massive amounts of sand and the construction of groins, jetties and breakwaters (Flick, 1993). The rate at which sand was added to these beaches, however, has diminished over the past 30 years, fueling the public's perception of erosion and the narrowing of the beaches. Sand sources for most of the littoral cells in southern California are minimal to begin with, and have been reduced further through stream channel sand mining and the damming of rivers, and, to a lesser extent, armoring of seacliffs and reduction in beach nourishment projects.

Sand is naturally supplied to the beaches of California's littoral cells from a combination of river discharge, seacliff erosion, and dune deflation or erosion. In addition, sand has been added to the beaches historically through various beach nourishment projects. These elements are included as inputs for the sand budgets presented in this summary for the major littoral cells in California. The cells described include (Figure 2.5) Eureka, Santa Cruz, Southern Monterey Bay, Santa Barbara, Santa Monica, San Pedro, Laguna, Oceanside, Mission Bay, and Silver Strand littoral cells.

Table 4.1 summarizes selected major littoral cells and the relative importance of individual sand sources to the total sand supplied to the cells. These data were developed for and derived from the more detailed companion study which quantified sand budgets for these littoral cells (Patsch and Griggs, 2006). Under present-day (i.e., dams in place) conditions (excluding beach nourishment), and based on all data published to date, fluvial inputs constitute about 87% of the sand entering California's major littoral cells and 90% of the sand provided to southern California beaches (from Santa Barbara to the Mexico border). Seacliff erosion contributes 5% of the sand to the major littoral cells statewide, and about 10% of the sand reaching the beaches in southern California. Dune recession statewide accounts for 8% of the sand in the statewide analysis but is 0% in southern California

When beach nourishment is taken into account as a contributing source of sand, the relative importance of rivers, bluffs, and dune erosion statewide drops to 72%, 4% and 7% respectively in California's major littoral cells, with beach nourishment accounting for the remaining 17% of the sand input. In southern California, beach nourishment represents 31% of the sand supplied to the beaches, thus reducing the importance of river and bluff inputs to 62% and 7% respectively.

Table 4.2 is a summary of the anthropogenic reductions to the sand supplied to the major littoral cells in California and to southern California from armoring of seacliffs and damming of rivers. In addition, these reductions are contrasted against the sand supplied through beach nourishment, and a net balance associated with these anthropogenic changes is shown. The greatest reduction in sediment supplied to southern California results from the damming of rivers. Such damming has reduced the apparent volume of sand

Littoral Cell	All Sand Volumes in yd3/yr	Rivers	Bluff Erosion	Dunes	Beach Nourishment	Total Sand Supply
Eureka	Total “Actual” sand contribution	2,301,000	0	175,000	0	2,476,000
	% of Budget	93%	0%	7%	0%	100%
Santa Cruz	Total “Actual” sand contribution	190,000	33,000	0	0	223,000
	% of Budget	85%	15%	0%	0%	100%
Southern Monterey Bay	Total “Actual” sand contribution	489,000	0	353,000	0	842,000
	% of Budget	58%	0%	42%	0%	100%
Santa Barbara	Total “Actual” sand contribution	2,167,000	11,000	0	0	2,178,000
	% of Budget	99%	1%	0%	0%	100%
Santa Monica	Total “Actual” sand contribution	70,000	148,000	0	526,000	744,000
	% of Budget	9%	20%	0%	71%	100%
San Pedro	Total “Actual” sand contribution	278,000	2,000	0	400,000	680,000
	% of Budget	41%	0%	0%	59%	100%
Laguna	Total “Actual” sand contribution	18,000	8,000	0	1,000	27,000
	% of Budget	66%	31%	0%	4%	100%
Oceanside	Total “Actual” sand contribution	133,000	55,000	0	111,000	299,000
	% of Budget	23%	9%	0%	19%	51%*
Mission Bay	Total “Actual”sand contribution	7,000	77,000	0	44,000	128,000
	% of Budget	5%	60%	0%	35%	100%
Silver Strand	Total “Actual”sand contribution	42,000	0	0	256,000	298,000
	% of Budget	14%	0%	0%	86%	100%
Total	Total “Actual” sand contribution	5,695,000	335,000	528,000	1,338,000	7,896,000
	% of Budget	72%	4%	7%	17%	100%
Southern CA Total: (Santa Barbara cell to Mexico)	Total “Actual” sand contribution	2,715,000	301,000	0	1,338,000	4,354,000
	% of Budget	62%	7%	0%	31%	100%
Total: Without Beach Nourishment	All	87%	5%	8%	N/A	6,558,000
	Southern CA	90%	10%	0%	N/A	3,016,000

Table 4.1: Summary of the average annual (post-damming and seacliff armoring) sand contributions from rivers, seacliff erosion, dune recession, and beach nourishment to the major littoral cells in California. * Gully erosion and terrace degradation accounts for the remaining 49% of the sand in the Oceanside littoral cell. This category is not accounted for in this table. Nourishment data is for the period 1930–1993. (For data sources see Patsch and Griggs, 2006)

reaching the beaches within the state’s major littoral cells and to southern California cells by about 43% and 47%, respectively. The reduction in southern California equates to nearly 2.4 million yds^3 of sand annually (Willis and Griggs, 2003). Seacliff armoring has reduced the sand supplied to the major littoral cells and southern California’s beaches by 11% and 10%, respectively. The southern California reduction is about 35,000 yds^3 annually, still less than 7% of the total sand input to all of these littoral cells.

Littoral Cell		Rivers (dams)	Bluff Erosion (armor)	Total Reduction	Beach Nourishment	Balance (nourishment-reductions)
Eureka	Reduction yd^3/yr	N/A	N/A	N/A	0	N/A
	Percent Reduction	N/A	N/A	N/A		
Santa Cruz	Reduction yd^3/yr	6,000	8,000	14,000	0	-14,000
	Percent reduction	3%	20%	6%		
Southern Monterey Bay	Reduction yd^3/yr	237,000	N/A	237,000	0	-237,000
	Percent reduction	33%	N/A	33%		
Santa Barbara	Reduction yd^3/yr	1,476,000	3,000	1,479,000	0	-1,479,000
	Percent reduction	41%	19%	40%		
Santa Monica	Reduction yd^3/yr	29,000	2,000	31,000	526,000	495,000
	Percent reduction	30%	1%	13%		
San Pedro	Reduction yd^3/yr	532,000	0	532,000	400,000	-132,000
	Percent reduction	66%	0%	66%		
Laguna	Reduction yd^3/yr	0	1,000	1,000	1,000	0
	Percent reduction	0%	13%	4%		
Oceanside	Reduction yd^3/yr	154,000	12,000	166,000	111,000	-55,000
	Percent reduction	54%	18%	47%		
Mission Bay	Reduction yd^3/yr	65,000	17,000	82,000	44,000	-38,000
	Percent reduction	91%	18%	50%		
Silver Strand	Reduction yd^3/yr	41,000	0	41,000	256,000	215,000
	Percent reduction	49%	0%	49%		
Total	Reduction yd^3/yr	2,540,000	43,000	2,583,000	1,338,000	-1,245,000
	Percent reduction	43%	11%	39%		
Southern CA Total	Reduction yd^3/yr	2,297,000	35,000	2,332,000	1,338,000	-994,000
	Percent reduction	47%	10%	44%		

Table 4.2: Summary of the anthropogenic reductions to the sand supplied to the major littoral cells in California and to southern California, due to seacliff armoring and the damming of rivers. In addition, sand supplied to the cells through beach nourishment is shown for the period 1930–1993. Note: sand bypassing at harbor entrances is not included in the nourishment volume.

Chapter 5

DISCUSSION OF BEACH NOURISHMENT IN CALIFORNIA

Beach nourishment or beach restoration is the placement of sand on the shoreline with the intent of widening beaches that are naturally narrow or where the natural supply of sand has been significantly reduced through human activities. Although there are several different approaches to beach nourishment, procedures are generally distinguished by methods of fill placement, design strategies, and fill densities (Finkl, et. Al. 2006; NRC, 1995; Dean, 2002). Types of nourishment according to the method of fill emplacement include the following (Figure 5.1; Finkl, et. al. 2006)):

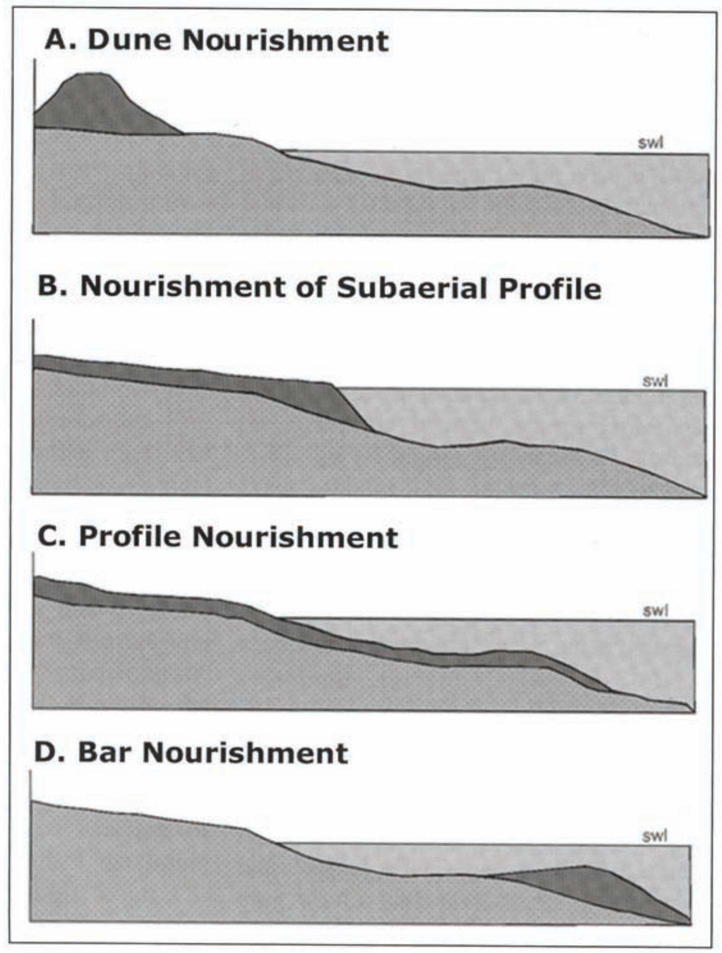

Figure 5.1. Methods of beach nourishment defined on the basis of where the fill materials are placed (from Finkl, Benedet and Campbell, 2006).

(a) Dune nourishment: sand is placed in a dune system behind the beach.

(b) Nourishment of subaerial beach: sand is placed onshore to build a wider and higher berm above mean water level, with some sand entering the water at a preliminary steep angle.

(c) Profile nourishment: sand is distributed across the entire beach and nearshore profile.

(d) Bar or nearshore nourishment: sediments are placed offshore to form an artificial feeder bar.

Nourished shorelines provide two primary benefits: increased area for recreation and greater protection of the coastline against coastal storms. Other potential benefits include, but are not limited to, increased tourism revenues, increased public access, reduced need for hard protective structures, higher property values, enhanced public safety and restored or expanded wildlife habitats.

Beach nourishment in California has been concentrated primarily in the southern part of the state. Flick (1993) summarized the history of beach nourishment in southern California and determined that over 130 million yds^3 of sand was added to those beaches between 1930 and 1993. About half of this amount was divided evenly between the Santa Monica and the Silver Strand littoral cells where the beaches widened significantly in response to this nourishment. Wiegel (1994) prepared a very thorough evaluation of ocean beach nourishment along the entire USA Pacific Coast; however, the report is mostly about Southern California because of the numerous beach nourishment projects that have taken place there.

What is clear is that there are major differences between the tectonic, geomorphic, oceanographic, climatic, and wave conditions along the Pacific Coast as compared to the Atlantic and Gulf Coasts. In addition to these inherent geological and oceanographic differences, there is a pronounced difference in the practice of beach nourishment (Finkl, et. al., 2006). Large nourishment projects using sand from offshore are common along the Atlantic and Gulf Coasts, but beneficial or opportunistic sediment (from coastal construction, channel maintenance and bypass operations) predominate on the West Coast (Herron, 1987; Flick, 1993; Wiegel, 1994).

The California Beach Restoration Study (2002) is a comprehensive assessment of California's beaches and their economic benefits, beach nourishment and restoration, as well as an evaluation of the major sources of sand to the state's beaches and how these have been impacted by human activity (http://www.dbw.ca.gov/beachreport.htm). The report concludes that continued loss of many public beaches could be substantially reduced by beach nourishment.

Opportunistic beach nourishment, which has provided the majority of sand historically used for beach nourishment in southern California, occurs when beach-compatible sand from a harbor development or expansion project, excavation for a large coastal construction project (e.g., El Segundo Power Plant or Hyperion Sewage Treatment Plant construction) or other construction or maintenance project is placed on nearby beaches. In other words, such sand is a byproduct of some construction or maintenance project that was not undertaken with beach replenishment or nourishment as a specific goal, but rather as an added benefit.

In addition to opportunistic beach nourishment there are other projects (the largest example being the 2001 SANDAG project in San Diego County) where sand has been delivered to the coastline with the sole purpose of widening the existing beaches. Sand may come from either terrestrial (stream channels or dunes, for example) or offshore sources (the inner shelf).

Beach nourishment, unless it takes place where there is a headland or other natural barrier to littoral transport, or unless it is accompanied by some structure or mechanism of holding the sand in place (e.g., groins), may not provide a long-term solution to narrow beaches or beach erosion in California, simply because the high to very high littoral drift rates that characterize most of California's shoreline will tend to move any additional sand added to the shoreline alongshore.

In the absence of any major reductions in littoral sand supply (due to either large-scale climatic fluctuations or human activities), beaches over the long-term will tend to approach some equilibrium size or width; e.g. a summer width that will vary about some mean from year to year. This width is a function of a) the available littoral sand, b) the location of barriers or obstructions to littoral transport (Everts and Eldon, 2000; Everts, 2002) c) the coastline orientation, and d) and littoral drift direction and rate, which is related to the amount of wave energy incident on the beach and the angle of wave approach.

In northern Monterey Bay, for example, because of the direction of dominant wave approach and the coastline orientation, those shorelines oriented northwest-southeast, or east-west (and where littoral transport barriers exist), such as the Santa Cruz Main Beach, Seabright Beach, or the inner portion of Monterey Bay, have wide well-developed beaches (A. Figure 5.2). In contrast, where the coastline is oriented essentially north-south (from Lighthouse Point to Cowell's Beach (B. Figure 5.2) and the Opal Cliffs shoreline between Pleasure Point and New Brighton Beach, for example), and where no significant littoral drift barriers exist, beaches are narrow to nonexistent because littoral drift moves the sand along this stretch of coast rapidly without any retention.

Figure 5.2. The coastline of northern Monterey Bay at Santa Cruz illustrating how the orientation of the coastline determines whether or not a beach forms. Where the shoreline is oriented essentially east-west and littoral barrier exist (A), wide stable beaches have formed. Where the coastline is oriented essentially north-south and there is no barrier, beaches rarely form (B). North is up in the photograph.

FACTORS AFFECTING THE LONGEVITY OF A BEACH NOURISHMENT PROJECT

It has often been assumed that the important parameters in the durability or longevity of a beach nourishment or replenishment project include the alongshore length of the nourishment project, the density or volume of fill placed, grain size compatibility with the native beach, the use of sand retention structures such as groins in conjunction with sand placement, and storm activity following nourishment. Those nourishment projects that had the greatest alongshore dimensions have been shown to last longer than shorter beach fills.

Fill Density: Density of the fill refers to the volume of sand per unit length of shoreline. The longevity of a nourishment project has often been assumed in the past to be directly related to fill density, with greater fill densities yielding longer life spans. In California, the initial fill densities range from 20,000 cubic yards per mile to 2,128,000 cubic yards per mile.

Grain Size: Grain size compatibility between the native beach and the fill material is also perceived to be an important factor in the longevity or durability of a nourished beach. Beach fill must be compatible with the grain sizes of the native sand (as coarse as or coarser than the native sand) such that the waves will not immediately carry the sand offshore. If the fill sand is to remain on the dry or exposed beach under prevailing wave conditions at the particular site, it must be larger than the littoral cut-off diameter.

Sand Retention Structures: Coastal structures aimed at retaining sand, such as groins or detached offshore breakwaters, have been successful in extending the life span of nourishment projects. For example, groins throughout the Santa Monica littoral cell and groins placed on beaches in Capitola, Ventura, Redondo Beach and Newport Beach have all been successful at stabilizing beach fill projects. However, if there is not enough sand in the system to begin with, groins will not be effective, as was the case at Imperial Beach where a series of groins has not been adequate to combat erosion. Groins will continue to trap littoral drift in the years following a beach nourishment project, thus maintaining the updrift beach. Groins must be considered on a regional scale, however. While beaches updrift of groins will be stabilized or widened, beaches downdrift of a groin may experience erosion once their sand supply is cut-off. A series of groins along the shoreline of interest in conjunction with beach nourishment may be an effective way to address downdrift beach erosion.

Offshore breakwaters have been widely used in Europe and in a few locations in the United States to stabilize or widen beaches by reducing wave energy and littoral drift in the lee of the breakwater. These offshore structures can be either slightly submerged, at sea level, or slightly above sea level. The offshore breakwater at Venice is a good example of the effects of such a structure in California, where the beach landward of the breakwater significantly widened (Figure 5.3). The Santa Barbara breakwater was completed in 1929 as a detached offshore structure. Although the purpose of the breakwater was to provide a protected anchorage for boats, accretion of littoral sand in the lee of the structure by the fall of 1929 had become so serious that the breakwater was extended to the beach at Pt. Castillo, a distance of about 600 feet. This was followed by rapid deposition of sand on the west or up-coast side of the structure (Griggs, Patsch and Savoy, 2005).

Detached offshore breakwaters can effectively reduce wave energy at the shoreline, thereby widening or stabilizing otherwise narrow or eroding beaches. They are not without their impacts, however: high construction costs, navigation hazards for vessels, dangers for recreational coastal water users, as well as a reduction in sand transport to down coast beaches are all important considerations.

Storm Intensity: The life span of beach nourishment projects has been correlated with storm intensity to which a fill is exposed. Large or extreme storms, such as those that have occurred during El Niño years, have caused increased beach erosion, whether nourished or not. Sand removed from the beaches during these large storm events is often deposited on offshore bars where it is stored until the smaller waves associated with the summer months carry the sand back to the beach. During conditions of elevated sea levels and very large waves, sand may be transported offshore into deep enough water where summer waves cannot move the sand back onshore. Longshore transport may also increase with the larger storm waves, thus reducing the residence time of the sand on a nourished beach.

During the strong 1997-98 El Niño, however, monthly beach surveys collected along 22 miles of Santa Cruz County coastline showed that although the beaches experienced extreme erosion during the winter months, by the end of the summer of 1998 all but one beach had returned to their original pre- El Niño widths (Brown, 1998).

Figure 5.3. Offshore breakwater at Venice where beach has widened in protected area behind breakwater (2004). Photo © Kenneth and Gabrielle Adelman, California Coastal Records Project, www.Californiacoastline.org

ISSUES INVOLVED WITH BEACH NOURISHMENT

While beach nourishment appears to be an attractive alternative to either armoring the coastline with seawalls, riprap or revetments, or to relocating threatened structures inland, as with any large construction project, there are a number of issues or considerations that need to be carefully evaluated and addressed. In California, littoral cells span large stretches of the coastline, from 10 miles to over 100 miles in length, and, in most locations, experience high net littoral drift rates (from 150,000 yd^3/yr to over 1 million yd^3/yr). As a result, the life span or longevity of sand placed on a particular beach may be short (less than a single winter, in some cases) due to the prevailing winter waves transporting the sand alongshore as littoral drift. Properly constructed and filled retention structures (groins, for example) can help increase the longevity of beach fill.

In addition, potential considerations associated with beach nourishment in California include costs, financial responsibility for the initial project and subsequent re-nourishment, the source and method for obtaining sand, transportation of large quantities of sand to the nourishment site, and the potential smothering or temporary loss of marine life or habitats when placing the sand.

The availability of large quantities of beach compatible sand is a significant issue that has not been completely explored. Sand exists offshore in large volumes but it may not always be beach compatible. In addition, there are environmental and habitat issues that need to be evaluated and possibly mitigated. Some offshore areas are protected, such as the 400 miles of coastline included within the Monterey Bay National Marine Sanctuary, and for which dredging sand from the seafloor is a complex issue with a long list of environmental concerns and probable opposition.

While consideration is being given to removing sediment from behind dams essentially completely filled (e.g., Matilija Dam on the Ventura River and Rindge Dam on Malibu Creek) and placing such sediment on the beach, there is not yet any agreed upon approach for accomplishing this objective. Dam removal followed by natural fluvial transport, trucking, and slurry pipelines have all been studied and each has their costs and impacts. Even though this sediment would have been delivered to the shoreline by these streams under pre-dam natural conditions, accomplishing the same "natural process" today is far more complex. The release of all of the impounded sediment would overwhelm any downstream habitats that are now being protected. In addition, the current USEPA guidelines do not normally allow any sediment to be placed on beaches when the amount of fines (silt and clay) is over 20% (the so-called 80:20 guideline, or acceptable sediment for beach nourishment must consist of at least 80% sand and no more than 20% silt and clay). Unfortunately, the sediment transported by streams and trapped behind dams doesn't follow this 80:20 guideline and contains far more than 20% silt and clay. As a result, most sediment impounded in reservoirs might not be acceptable to the EPA for beach nourishment under such criteria, even though these same streams naturally discharge such sediment every winter to the shoreline, where waves and coastal currents sort out all of this material. The USEPA has and is working with project proponents to identify appropriate conditions that allow the use of sediments with a fine-grained content greater than 20% to be used for beach restoration purposes. These conditions are described in CSMW's Sand Compatibility and Opportunistic Use Program (SCOUP) report. (http://www.dbw.ca.gov/csmw/csmwhome.htm).

If inland sources of beach compatible sand can be located, approved, and transported to the coastline, there are additional challenges of getting the material onto the beach and spreading it out in a timely manner. A 200,000-yds^3 beach nourishment project, for example, would require 20,000 10-yds^3 dump trucks.

In California, obtaining sand from an inland source to place on the beach is far more costly than sand from offshore sources, primarily due to significantly higher removal and transport costs. Inland sources provided by trucking would also have environmental impacts associated with the quarrying, transport, and placement of the sand. Estimates in the Monterey Bay area for truck delivered beach-quality sand in 2004 were around \$21/yd^3. The offshore area in this location is a National Marine Sanctuary such that dredging sand from the seafloor is not acceptable under existing policies. The estimated cost associated with delivering ~240,000 yd^3 of sand (to build a beach ~3,000 feet long and 100 feet wide) from an inland source from a recent proposal for a nourishment project in southern Monterey Bay would be ~\$5.5 million dollars (~\$23/yd^3) (O'Connor and Flick, 2002).

It is also important to look objectively at the logistics of a nourishment project of this scale. Placing 240,000 yd^3 of sand on the beach would require 24,000 10-yd^3 dump truck loads of sand. If a dump truck could deliver a load of sand to the beach and dump it every 10 minutes, 48 truckloads could be dumped in an 8-hour day. Keeping this process going 7 days a week could deliver 1440 truckloads or 14,400 yd^3 each month. At this rate, it would take over 16 months to complete this nourishment project. There are also issues of delivering sand in the winter months when high wave conditions might make truck traffic on the beach difficult; placing sand in the winter-months would also reduce the lifespan of the nourished sand. However, beaches are used the most during the summer months. While none of these are overwhelming obstacles, beach nourishment from inland sources by truck is not a simple or straightforward process. Smaller-scale maintenance projects would take proportionally less time to deliver smaller amounts of sand, and while more logistically feasible, don't have the impacts of larger projects.

Beach nourishment projects using terrestrial or inland sources of sand can be very expensive undertakings and any such project will probably have to be re-nourished on a regular basis unless the sand is retained. The limitations and costs associated with beach nourishment and re-nourishment must be balanced by the ultimate benefits of the project, including the recreational, environmental, and economic value of widening a beach, in addition to the back-beach protection offered to development by a wider beach.

NOURISHMENT HISTORY OF INDIVIDUAL LITTORAL CELLS

In California, beach nourishment (not including harbor bypassing) has historically provided on average ~1.3 million yd^3 annually to the beaches in southern California (Point Conception to the international border), representing 31% of the overall sand budgets in the area (Table 4.1). Large quantities of sand excavated during major coastal construction projects, such as the excavation associated with the Hyperion Sewage Treatment Facility (17.1 million yd^3 from 1938-1990) and Marina del Rey (~10 million yd^3 from 1960-1963) in the Santa Monica littoral cell, as well as the dredging of San Diego Bay (34 million yd^3 between 1941-1985) have provided millions of cubic yards of sand to the beaches of southern California (see comprehensive summary articles by Flick, 1993 and Wiegel, 1994 for detailed discussion of southern California beach nourishment projects.). Between 1942 and 1992 about 100 million yd^3 of material were placed on the beaches with approximately half of the sand derived from harbor or marina projects (Flick, 1993).

Santa Monica Littoral Cell: In the Santa Monica littoral cell, over 29 million yd^3 of sand has been placed on the beaches since 1938 for projects where the primary objective was not specifically beach nourishment. As a result, the shoreline in many areas of Santa Monica Bay advanced seaward from 150 to 500 feet from its earlier natural position. Although the majority of beach fill was placed prior to 1970, beaches in this area are still wider than their natural pre-nourished state, due, in large part, to the construction of retention structures to hold the sand in place. Currently, there are 5 breakwaters, 3 jetties and 19 groins along the nearly 19 miles of shoreline from Topanga Canyon to Malaga Cove, effectively retaining the sand before it is lost into Redondo Submarine Canyon. Sand retention structures have been very effective at maintaining the wide artificial beaches in the Santa Monica littoral cell because of the nearly unidirectional longshore transport to the southeast.

San Pedro Littoral Cell: In the San Pedro littoral cell, federal, state and local governments fund ongoing beach nourishment at Sunset Beach (just downcoast of Seal Beach) to maintain a wide enough beach to meet the recreational needs of the area and to mitigate for the erosion caused by the construction of the Anaheim jetties. The area is nourished with ~390,000 yd^3 of sand annually. Herron (1980) stated that 22,000,000 yd^3 of sand from harbor and river projects have been placed on the 15 miles of public beaches of the San Pedro littoral cell.

Oceanside Littoral Cell: Nearly 11.9 million yds^3 of sand were placed on the beaches of the Oceanside Cell between 1943 and 1993 (Flick, 1993). This represents an annual average rate of about 250,000 yd^3. Most of this sand has come from the dredging of Agua Hedionda Lagoon and Oceanside Harbor which each contributed about 4 million yd^3 in 1954 and 1961, respectively. About 1,300,000 million yd^3 were trucked from the San Luis Rey River bed to the Oceanside beaches in 1982. Two smaller projects, construction of the San Onofre Nuclear Power Plant and nourishment of Doheny Beach, each generated about 1,300,000 million yd^3.

Mission Bay Littoral Cell: The beaches in the Mission Bay littoral cell have also benefited from large construction projects along the coastline. Nearly 4 million cubic yards of sand dredged from Mission Bay to create the aquatic park and small craft harbor were placed on the beaches to create wider recreational areas. The upcoast jetty at

Mission Bay now holds the southern portion of Mission Beach in place. A concrete seawall about 13 feet above mean sea level backs the Mission Beach area but was overtopped during both the 1982-83 El Niño and the unusual storm of January 1988 (Flick, 2005).

Silver Strand Littoral Cell: The Silver Strand littoral cell is somewhat unique in the region in having an overall net littoral transport from south to north. The nearly 35 million yds^3 of sand placed on its beaches since 1940 represents the most highly altered stretch of beach in southern California (Flick, 1993). Much of this volume, about 26 million yds^3, was excavated from the massive expansion of naval facilities in San Diego Bay just after WWII. Prior to this effort, the Silver Strand had been a relatively narrow sand spit separating San Diego Bay from the ocean, which was occasionally overwashed by storm waves.

THE SAN DIEGO ASSOCIATION OF GOVERNMENTS (SANDAG) BEACH NOURISHMENT PROJECT

The most recent large-scale, non-opportunistic beach nourishment project in California with the sole purpose of widening the beaches was completed in San Diego County in 2001. Approximately 2-million yds^3 of sand were dredged from six offshore sites and placed on 12 beaches in northern San Diego County at a total cost of $12.25 million dollars or $5.83/$yd^3$ (Figure 5.4). This project was coordinated by local governments working together through SANDAG and was funded by $16 million in state and federal funds and about $1.5 million from the region's coastal cities. It was seen as an initial step in overcoming what has been perceived as a severe sand deficit on the region's beaches.

A total of six miles of beaches were nourished from Oceanside on the north to Imperial Beach on the south (Figures 5.4 & 5.5). Eighty-five percent of the sand went to the beaches of the Oceanside Littoral Cell. A comprehensive regional beach-profiling program had been in place since the 1983 El Niño event, which provided a baseline for monitoring the results or status of many of the individual nourished sites. Sixty-two beach profile lines were surveyed, typically in the fall and in the spring. Seventeen of these profile lines either already existed or were established at the individual beach nourishment sites (Coastal Frontiers, 2005).

While it is difficult to completely evaluate and summarize the vast amount of beach survey data that have been collected in this report, it is important to try and extract some overall measures of performance or behavior following the nourishment if we are to derive any useful conclusions from this large project.

At 14 of the 17 nourishment sites surveyed, the beach width (determined by the mean sea level shoreline position) narrowed significantly between the fall of 2001 (immediately following sand placement) and the fall of 2002. While the surveyed beaches showed initial increases in width of 25 to over 100 feet from the nourishment, most of these beaches narrowed 20 to 60 feet during the first year following sand emplacement. Twelve of the 17 sites showed further decreases in width over year two, and 13 of these sites continued to decrease in width in the 3rd year. Three of the beaches in the Oceanside Cell showed modest width increases (6 to 15 feet) in the first year following nourishment, but in the two following years all declined in width.

A very detailed study of the Torrey Pines State Beach fill project was carried out as part of the post-nourishment monitoring (Seymour, et al. 2005). This fill was 1600 feet long and included about 330,000 yds^3 of sand, one of the larger fills. Rather than being constructed as a sloping fill, the upper surface was level and terminated in a near-vertical scarp about 6 feet high. Profiles 65 feet apart were collected bi-weekly along 1.8 miles (9500 feet) of beach and extended

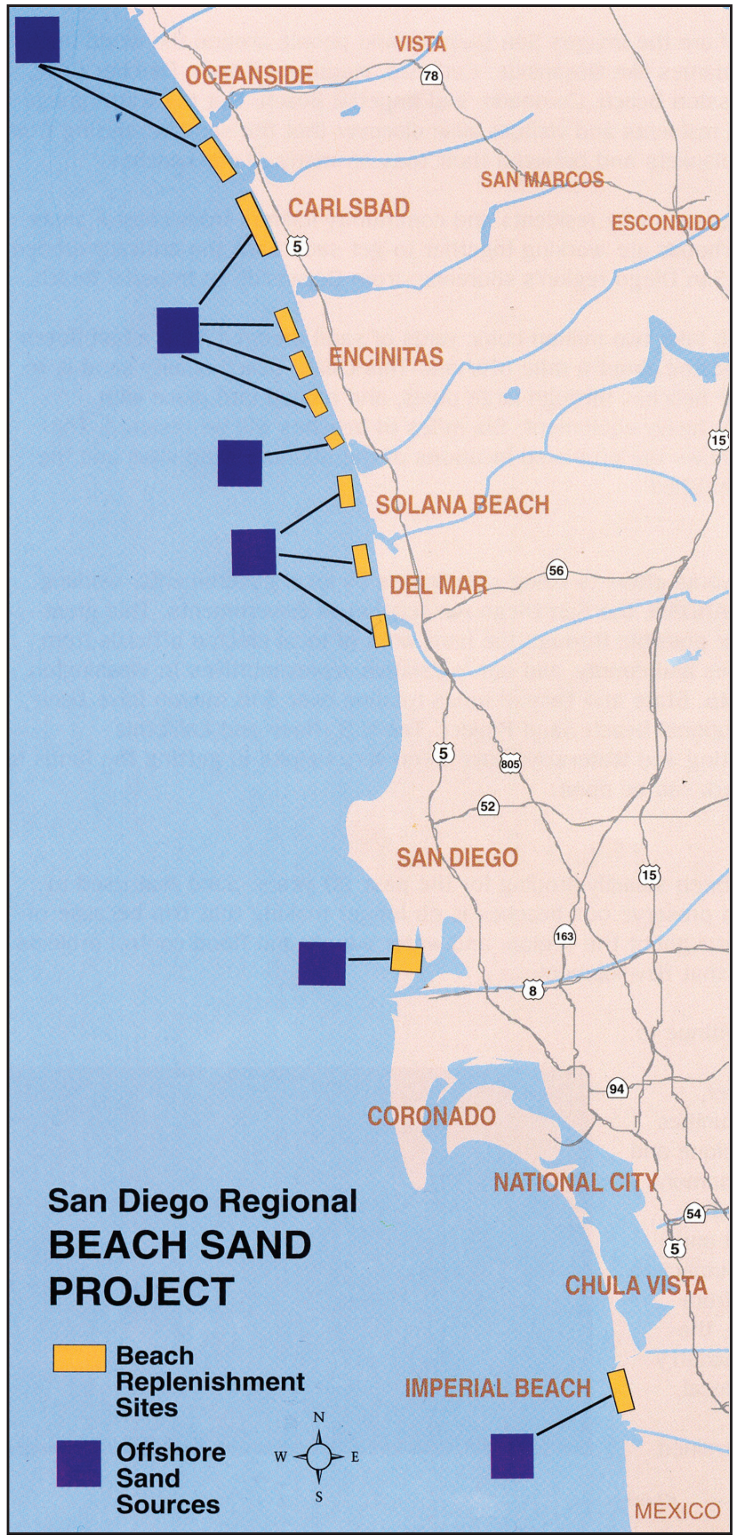

Figure 5.4. Offshore sand sources and nourishment sites for the 2001 SANDAG 2,000,000 yds^3 beach nourishment project.

offshore to a depth of 26 feet. The temporal and spatial resolution provided by this surveying program, in combination with offshore wave measurements, provided an exceptional database for documenting the relationship between wave conditions and the behavior of a beach fill (Seymour, et. al., 2005).

The fill was completed near the end of April, 2001 (Figure 5.6). Wave

Figure 5.5: Beach nourishment at South Carlsbad State Beach. In July 2001. 150,000 yds^3 of sand were placed on this beach in a fill that was 2000 feet long, 180 feet wide and up to + 12 feet msl.

Figure 5.6. Aerial view of the Torrey Pines beach fill project (from Seymour, et.al., 2005).

conditions during the summer and fall were mild, with significant wave heights (the average of the highest 1/3 of the waves) generally less than 3 feet except for a few incidents of waves as high as 5 feet. The front scarp of the fill remained intact and there were only modest losses at the ends of the fill.

At noon on Thanksgiving Day, November 22, 2001, significant wave heights reached nearly 10 feet and remained in the range of 9 to 10.5 feet for seven hours. The fill was overtopped and began to erode quickly. By daylight on November 23, the fill had been almost completely eroded to the riprap at the back of the beach (Seymour, et al., 2005). The fill was stable for approximately 7 months of low wave energy conditions, but was removed within a day when the first large waves of the winter arrived.

Some overall conclusions can be drawn from the four years of published beach surveys in the nourished areas (Coastal Frontiers, 2005). The performance of the individual beach fills varied considerably. At some sites, such as Del Mar, Moonlight, and South Carlsbad, the gains in the shorezone (defined as the subaerial or exposed portion of the beach as well as the nearshore sand out to the seasonal depth of closure) that occurred during placement of fill were short-lived. At other sites, such as Mission Beach and Oceanside, the gains in the shorezone persisted through the time of the Fall 2004 survey. In many cases, dispersal of the fill was accompanied by shorezone volume gains on the downdrift beaches. Both the grain size of the sand and the volume of the fill were important factors in how long nourished sand remained on the beach. For the smaller fills, erosion or losses from the ends of the fills were significant. One very small nourishment site in the Oceanside cell (Fletcher Cove) received a small volume of very-fined grained sand and it was removed very quickly.

Nearly all of the sand added to the beaches in the SANDAG project tended to move both offshore and also alongshore with the arrival of winter waves although much of this has persisted just offshore in the shorezone. This sand does provide some benefits including dispersing some of storm wave energy and flattening the beach profile. However, most of the general public expects to see a wider exposed beach as the benefit of a beach nourishment project. It is important to understand for the SANDAG project or any nourishment plan or proposal, that most beaches have some normal or equilibrium width, as discussed earlier. Without either regular or repeated nourishment or the construction of a retention structure, such as a groin, to stabilize or hold a beach fill, there is no reason why in an area of significant longshore transport and moderate to large winter wave conditions that the sand should stay on the exposed beach for any extended period of time. The considerations that need to be weighed prior to any beach nourishment project are whether the benefits of littoral cell or shorezone sand increases, and the potentially short-term or temporary beach width increases resulting from beach nourishment are worth the initial investment and continuing costs.

CHAPTER 6

CONCLUSIONS

Before large-scale human influence or interference, the majority of beaches in southern California were relatively narrow. Large coastal construction projects, the creation and expansion of harbors and marinas, and other coastal works found a convenient and cost-effective disposal site for excavated material on the beaches in southern California, thus creating the wide sandy beaches that people have come to expect in this region, particularly along the beaches of the Santa Monica littoral cell and the Silver Strand cell. The majority of sand was placed before the mid-1960's, however. Since then, the rates of nourishment have dropped sharply. In many cases, sand retention structures such as groins, built in conjunction with the placement of beach-fill, have been successful in stabilizing the sand and maintaining wider beaches. Carefully designed retention structures have been shown to extend the life of beach nourishment projects and should be considered when planning beach restoration projects in the future. A single episode of beach nourishment, however, will not provide a permanent solution to areas with naturally narrow beaches or to problems associated with beach erosion. Any potential California beach nourishment program should be viewed as a long-term and ongoing process.

When assessing the success or failure of a nourishment project, one must look beyond the individual beach where the nourishment took place and examine the regional effects throughout the entire littoral cell. Often the nourished site serves as a feeder beach, providing sand to be transported by littoral drift to "feed" or nourish the downdrift beaches.Where littoral drift rates have been documented they are typically in the range of about a mile-per-year (Bruun, 1954; Wiegel, 1964; Griggs and Johnson, 1976), although this will depend upon the wave energy, the orientation of the shoreline, and the angle of the dominant wave approach. Depending on the potential littoral drift in an area, as well as the coastline configuration and barriers to littoral transport, nourishment projects may or may not have a fairly short residence time on a particular beach. However, if well planned on a regional scale, the placed sand should feed the downdrift beaches until ultimately ending up in a submarine canyon, offshore, or retained behind a coastal engineering structure.

Because of California's high littoral drift rates, the emplacement of a well-designed, properly constructed and filled retention structure is also a very important consideration in the success or longevity of any beach fill or nourishment project. Groins and offshore breakwaters have been used successfully in a number of locations in California to widen or stabilize beaches (Ventura, Santa Monica and Newport Beach, for example). Retention structures can make the difference in the long-term success of a beach nourishment project. It is recommended that all existing retention structures and their effectiveness and impacts be evaluated so as to learn from past experiences and improve on their use in the future by mitigating any potential negative impacts.

When engineering a beach nourishment project in California, it is important to consider such elements as grain size compatibility, fill density, or the volume of sand per unit length, possible sand retention structures and the effects on down drift beaches, the rate and direction of littoral drift, and wave climate (including storm duration and intensity).

Harbor maintenance and large construction projects along the coast may be excellent sources of opportunistic beach nourishment. There are many difficulties associated with nourishing the beach with sand taken from an inland or terrestrial source including the 80:20 rule, cost, financial responsibility of the project, the source and method for obtaining sand, transporting large quantities of sand to the nourishment site, and the potential for covering over marine life or habitats when placing the sand. Offshore sand sources also have their limitations and impacts including costs, location of compatible sand offshore, permit issues such as environmental impacts associated with disturbing the seafloor habitat, transporting and placing large quantities of sand (Figure 5.5) increased turbidity, etc.

The limitations and costs associated with beach nourishment must be balanced by the ultimate benefits of the project including public safety and access, expanded wildlife habitat and foraging areas, the economic and aesthetic value of widening a beach, in addition to the back-beach or coastal protection offered by a wider beach.

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Dune erosion threatens the Ocean Harbor House apartment complex on Del Monte Beach, Monterey CA (October 2005). Copyright © 2005 Kenneth and Gabrielle Adelman, California Coastal Records Project, www.Californiacoastline.org.

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