# RESULTS FROM CSMW TASK 7

## (Seasonal Cross-Shore Movement of Sand)

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

## OVERVIEW

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

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

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

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

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

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

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

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

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

**BEACH RESPONSE TO STORM WAVES**

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

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

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

## BEACH RESPONSE TO SWELL WAVES

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

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

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

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

## IMPACT OF LONGSHORE CURRENTS

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

## CGS RECOMMENDATIONS TO THE CSMW

None

**CSMW TASK SEVEN**

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