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BEACH MONITORING FOR ENHANCED DECISION-MAKING

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ABSTRACT

Coastal zone management practices, regulatory decisions, and land-use planning activities along the southwest Washington coast have historically been made with insufficient information concerning the dynamic coastal environment. This lack of information can and has resulted in a mix of costly problems, legal disputes, risks to public health and safety, damages to resources and industry, and losses of critical facilities. To help address these problems, a regional beach monitoring program was implemented to collect coastal change data on a regular basis to enable decision-making based on up to date, technically sound information in order to more effectively manage a host of complex coastal problems. The monitoring program is quantifying recent beach trends and fluctuations as well as the spatial variability associated with short-term, seasonal, and annual environmental forcing. Data from this fledgling (begun in 1997) monitoring program is already being used by local and state governments for decision-making. Integrating this monitoring data with other data (long-term coastal evolution and geological inheritance) from the Southwest Washington Coastal Erosion Study to develop products that can be used for local coastal planning is a complex task involving communication and feedback between the scientific and management communities.

INTRODUCTION

The coastal management community uses scientific data in at least three ways; planning coastal communities, permitting and reviewing shoreline stabilization projects, and developing a conceptual understanding of the coastal system. The ideal scientific data collection program would provide information to support each of these functions. A detailed understanding and predictive capability spanning all time and space scales would allow for optimally informed decision-making. However, this is beyond the current state of the knowledge of coastal science. Coastal change occurs temporally from seconds (e.g., individual waves) to decades (e.g., climate variability such as the Pacific Decadal Oscillation) and spatially from centimeters (e.g., ripples) to hundreds of kilometers (e.g., littoral cells). Therefore, scientific efforts need to be explicitly directed towards understanding coastal change at scales relevant to the management community (decades and tens of kilometers). Fiscal and scientific tradeoffs are required to develop the most appropriate knowledge of coastal systems for decision-making. One approach to these tradeoffs is to employ a nested sampling scheme in which multiple techniques are used to measure morphologic change over a variety of scales.

The evolution of the sub-aerial beach is often of principal interest in coastal management due to its proximity to valuable coastal properties and infrastructure. The most common measure of long-term change is the seaward or landward migration of the shoreline (Figure 1) over time, where the shoreline position is typically defined in terms of a horizontal reference feature delineated from topographic maps or aerial photographs. A long time series of shoreline position is often used to project future coastal change. The sub-aerial beach is also one of the most dynamic within the active coastal zone where tens of meters of shoreline recession can result from a major storm occurring in just a few hours. Therefore, predicted future shoreline positions are of limited value without a detailed understanding of the short-term variability of sub-aerial morphology. Fortunately, this portion of the active coastal zone is readily available for measurement, and as a result, most beach monitoring programs focus on measuring the temporal variability of the visible beach.

The sub-aerial beach, however, comprises only a small percentage of the active coastal zone (Figure 1). In order to develop reliable predictive capabilities of shoreline change, an understanding of the sub-aqueous beach variability is also necessary. Since offshore sandbars dissipate wave energy and provide a buffering capacity that protects the sub-aerial beach, the temporal variability of nearshore morphology (i.e., position and height of sandbars and overall beach slope) may affect the susceptibility of the shoreline to the erosive power of waves. This portion of the active coastal zone is much more difficult and expensive to measure and only a relatively few quality data sets exist worldwide.

Most of the world's beaches are inherently three-dimensional; implying that knowledge of alongshore variability of the coastal planform is also important to coastal decision-makers. For example, a coastal property may be fronted by a chronic rip current and embayment and often impacted by waves, while only tens of meters on either side of the embayment the beach may be stable. Alongshore gradients in offshore bar position and geometry may be responsible for such alternating regions of vulnerability and resilience along the coast. Figure 1 illustrates the relationships between temporal and spatial scales of morphologic change across the coastal planform. This paper describes a monitoring program aimed at quantifying these relationships at scales relevant to coastal management.

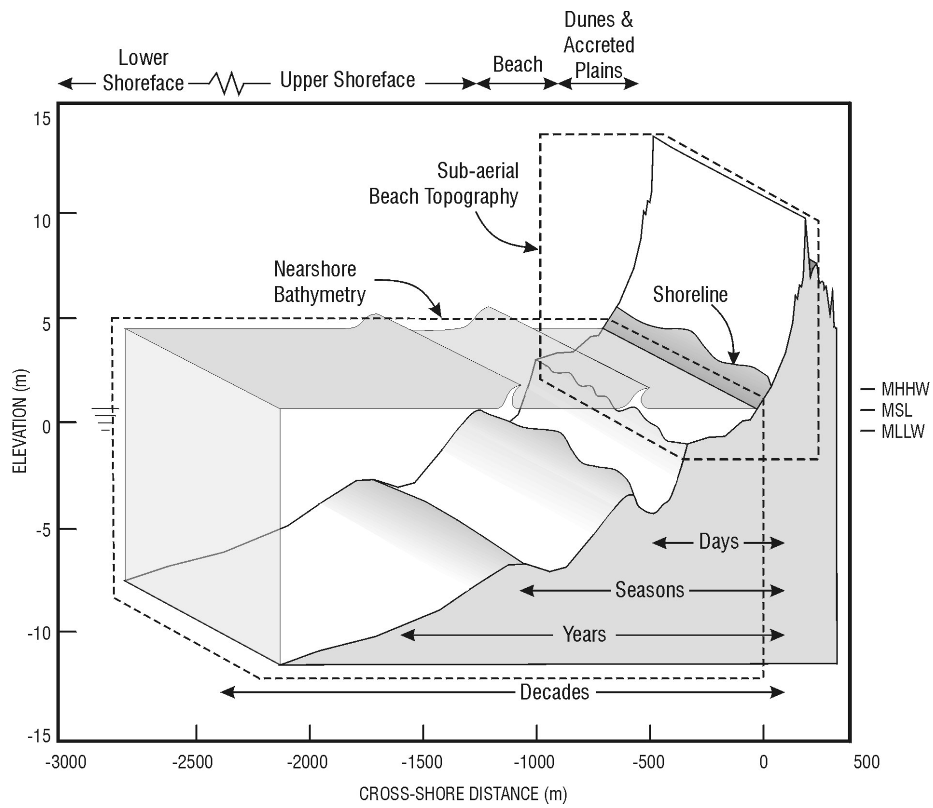

Figure 1. Conceptual diagram illustrating the motivation for a nested sampling scheme for monitoring beach change. The evolution of the shoreline is of primary interest from a coastal management perspective. However, for accurate predictions of shoreline evolution, nearshore bathymetry and the inherent three-dimensionality of the coastal system must also be considered. The horizontal arrows represent time scales for cross-shore morphologic change.

BEACH MONITORING IN THE COLUMBIA RIVER LITTORAL CELL

A regional beach morphology monitoring program was initiated along the Columbia River littoral cell (CRLC) in August 1997. The CRLC extends for approximately 165 km, from Tillamook Head, Oregon to Point Grenville, Washington (Figure 2). The monitoring program is one component of the Southwest Washington Coastal Erosion Study (SWCES), a federal-state-local cooperative aimed at developing the knowledge foundation to support decision-making, management strategies, land-use planning, resource allocations, and hazard-reduction solutions (Kaminsky *et al.*, 1997). The goals of the monitoring program include:

- Quantify the short- to medium-term (event-seasonal-interannual) morphologic variability of the Columbia River littoral cell.
- Develop the input data to enhance conceptual understanding and predictions of coastal change.
- Compare and contrast the scales of environmental forcing and beach change with other coastlines of the world.
- Provide relevant beach change data in an appropriate format to coastal managers.

Beach monitoring is being conducted by a variety of innovative surveying techniques utilizing Real Time Kinematic Differential Global Positioning Systems (RTK-GPS) (Ruggiero *et al.*, 1999). Components of the program include cross-shore beach profiles, three dimensional topographic surface maps, shoreline change feature delineation and nearshore bathymetric surveys. The spatial distribution of the sampling locations is shown on the right side of Figure 2. The following sections describe the monitoring program components and their relevance to decision-making.

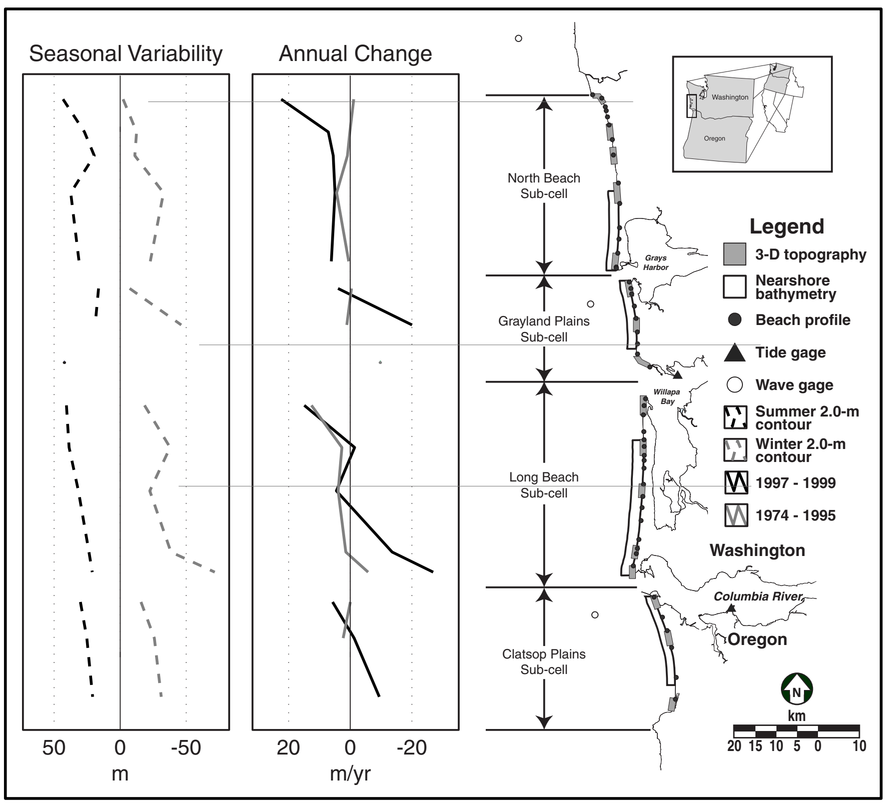

Figure 2. Nested beach morphology monitoring sampling scheme of the Columbia River littoral cell consisting of environmental forcing, cross-shore beach profiles, 3-dimensional surface maps and nearshore bathymetry. The mean winter erosion (change of the 2.0-m contour line, shown as the light dashed line) and subsequent summer recovery (dark dashed line) for each of the surface map sites for 1997-1999 are shown in the first panel. This large seasonal variability results in a relatively small net shoreline change. The second panel compares short-term shoreline change rates from the monitoring program (1997-1999, dark line) and long-term change rates derived from aerial photography (1974-1995, light line).

Wave and water level climatology

Maintaining a database of the environmental forcing responsible for beach change and variability is crucial in modeling future shoreline positions and coastal flooding probabilities. Fortunately there are national networks of both wave and water level gages maintained by outside agencies, e.g. the Coastal Data Information Program (CDIP), the National Data Buoy Center (NDBC) and the National Ocean Service (NOS) that make data available via the internet. However, time series of wave direction, which are often the most vital to shoreline change models, are typically short and sometimes not existent. Figure 2 shows the location of the three wave buoys currently operating in the CRLC. These buoys alone can not resolve the differences in wave climate along the coast that occurs primarily due to wave focussing or divergence as waves refract over irregular bathymetry. Therefore, models that consider the alongshore distribution of wave energy need to be used in conjunction with available buoy data.

Seasonal cycles in environmental forcing influence seasonal cycles in beach response. In the CRLC, seasonal variability in wave height and direction generally results in northerly offshore sediment transport in the winter (beach erosion) and southerly onshore sediment transport in the summer (beach accretion). Interannual climatic variability also affects waves and water levels, which in turn can influence beach response. For example, during the 1997/1998 El Niño event the CRLC experienced mean water levels up to 40 cm higher than typical, mean winter wave heights up to 1.0 m higher than usual, and wave directions from a steeper southerly angle (Kaminsky *et al*., 1998). This change in environmental conditions resulted in increased deposition of sediment along the northern boundaries of each of the sub-cells. Longer-term climate change signals are also evident in wave and water level data. A recent study by Allan and Komar (2000) suggests that wave heights have increased by almost 1.0 m off the Washington coast in the last three decades.

Beach topography

The most common method for measuring beach topographic change is the beach profile. The beach monitoring program collects profiles using a GPS mounted on a backpack. Cross-shore profiles are collected at 49 sites in the CRLC (Figure 2) by walking from the landward side of the primary dune, over the dune crest, across the beach and out to wading depth at low tide. “Beach state” variables such as slope, dune toe and crest elevation, beach width, and sand volume above a specified datum can be extracted from the beach profiles. These variables are used as inputs to models that predict coastal change and flooding. Cross-shore beach profiles can also provide an assessment of the current shoreline position at one alongshore location. Bi-annual or quarterly surveys make it possible to calculate the seasonal variability of shoreline position. Beach profiles are relatively simple and inexpensive to collect and are extremely accurate. However, care must be taken to maintain consistency when comparing shorelines extracted from beach profiles (specific elevation contours) to shorelines derived from aerial photographs or topographic maps (interpreted features based on visual queues). One limitation of beach profiles is that they are only two-dimensional representations of beach form and do not resolve alongshore variability.

In lieu of multiple closely spaced cross-shore profiles, three-dimensional beach surface maps are being generated by mapping the beach surface with a GPS antenna mounted to a six-wheel drive amphibious all-terrain vehicle called the CLAMMER (CoastaL All-terrain Morphology Monitoring and Erosion Research vehicle). CLAMMER data is collected at 16 sites throughout the littoral cell (Figure 2) between the base of the primary dune and the swash zone. Using the CLAMMER, beach surfaces, typically 4-km in length, can be mapped in only a few hours. Data sampling is dense enough and over long enough reaches to resolve beach cusps, rip current embayments, sand waves and regional trends. Figure 2 shows contour line changes derived from the CLAMMER data from the first two years of the SWCES monitoring program. The average winter shoreline recession (change of the 2.0-m contour extracted from gridded surfaces) is shown for each of the 4-km sites in the first panel. Although there is alongshore variability, the data reveal an average of approximately 35 m of seasonal shoreline recession. Also shown is the amount of beach recovery that has taken place during the last two summer seasons. These large seasonal beach change magnitudes tend to yield a relatively small net shoreline change rate over an annual period. The dark solid line in the second panel of Figure 2 represents the average shoreline change rate for each of the 16 surfaces. The mean change rate for the entire littoral cell during this two-year period is approximately 3 m per year of net erosion, however, the alongshore variability of shoreline change is large. For example, the northern portion in each of the 4 sub-cells experienced the most accretion in this two-year period, whereas net erosion occurred in the southern ends of three of the four sub-cells. These observations may be primarily due to the major 1997/1998 El Niño event and indicate the interannual nature of beach change due to climatic variability that should be taken into account by coastal managers.

Also shown in the second panel of Figure 2 is the average shoreline change rates from 1974-1995 as derived from aerial photography. Three main differences important to coastal decision-making become apparent when comparing monitoring data to long-term shoreline change trends. First, there is an increase in accretion rates in the northern portion of the North Beach sub-cell, a phenomenon probably explained by the aforementioned El Niño event. Secondly, there is an increase in erosion rates in the southern portion of the Long Beach sub-cell. This may also be explained in part by El Niño but may also imply the onset of a long-term erosion trend in this region. A third and surprising difference is the 20 m per year of shoreline retreat measured in the middle of the Grayland sub-cell, a historically stable region. The monitoring program may be revealing a new trend towards erosion at this location.

Nearshore bathymetry

As mentioned above, the visible beach comprises only a small portion of the active coastal zone. Variability in nearshore morphology dictates how much energy impacts the shoreline to cause beach change. It has historically been very difficult and expensive to collect data in this highly dynamic region and only a few coastlines in the world have sufficient nearshore morphologic data. A new system, based on the Coastal Profiling System developed by Oregon State University (Côté *et al*., in review), is now being used in the CRLC. This system was designed to collect bathymetric data in energetic, nearshore environments. It consists of a highly maneuverable watercraft (a waverunner) that is equipped with an echo sounder, GPS receiver and antenna, and an onboard computer. Kilometer spaced cross-shore transects (Figure 2) have been collected for most of the littoral cell revealing important information about variability in beach slope, sandbar size and sandbar location.

Initial results indicate strikingly different nearshore planforms among the four sub-cells of the CRLC. Nearshore sandbars along the North Beach and Long Beach sub-cells are large and three-dimensional while along the Grayland Plains and Clatsop Plains sub-cells sandbars are more linear and smaller. These observations are surprising in that the deep-water wave climate is fairly uniform throughout the region. The variations in nearshore morphology suggest that other factors such as sediment supply, sediment characteristics, or antecedent morphology may play a role in forcing these regional differences. These observations have significant implications for management-scale predictive capability.

Sediment size and composition

For a given set of environmental forcing conditions the rate of sediment transport is primarily determined by sediment size distribution. Therefore, knowledge of sediment characteristics is important for shoreline change modeling. Sediment samples collected at each of the 49 beach profile sites in the CRLC reveal a trend of fining with distance from the Columbia River. Beaches with the smallest mean grain size have the flattest beach slopes. Beach slopes in turn influence how a beach responds during storms, how high wave runup impacts the beach, and the probability of coastal flooding.

Regional shoreline determination

The primary methodology used to understand historical coastal evolution and often to predict future coastal change has been shoreline change analyses. The shorelines used in these analyses are typically derived from aerial photographs or topographic maps. Advantages to this approach include the regional and long-term coverage of the data. However, the errors and uncertainties associated with these techniques are larger than GPS-based approaches. Another limitation is that shorelines derived from photography are two-dimensional interpreted features. It is recommended that coastal monitoring programs begin the transition from these traditional techniques and towards more robust techniques that resolve the three-dimensionality of beaches and allow for objective shoreline determination. LIDAR data is presently the state of the art in regional three-dimensional data collection, however, in the near future high-resolution satellite data may be employed for shoreline change analysis.

INTEGRATING DATA INTO DECISION-MAKING

For scientific data and information to be successfully used for coastal planning it must, at the very least, reveal the susceptibility of coastal lands to natural hazards. The process by which a suite of beach monitoring data translates into the physical susceptibility of the coastline is not at all straightforward (Voigt *et al.*, these proceedings). The following example illustrates how some of the monitoring data collected by the SWCES is being used to help manage the coastline.

The city of Ocean Shores, WA has recently authored a Draft Environmental Impact Statement (DEIS) to help identify a management approach to deal with an immediate coastal erosion and ocean storm surge flooding problem (Hastings, these proceedings). As part of this process, the SWCES provided the city with preliminary shoreline modeling results to use as a planning tool. Each of the five aforementioned components of the beach monitoring program were utilized. Wave data, nearshore bathymetry and sediment size data were used as inputs into the shoreline change model. Historical shorelines derived from aerial photography were used to calibrate the model. The seasonal variability in beach change derived from topographic data was used to account for short-term variability and event response in shoreline predictions. Each of these data sets and the model results are being used in context with a conceptual model formulated from other components of the SWCES to help determine the appropriate long-term response to the erosion problem. Continued beach monitoring will refine and verify the process-based models as well as assess the flooding potential of the upland properties. SWCES scientists will present coastal susceptibility as a set of probabilities for encountering certain natural hazard zones rather than as single "lines in the sand." It will ultimately be up to the local managers and citizens to define levels of acceptable risk. However, if the scientific data is presented in an appropriate form, this process will enable rational choices for appropriate coastal management decisions.

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