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THE SOUTHWEST WASHINGTON COASTAL EROSION STUDY: A SCIENTIFIC RESEARCH PROJECT TO ADDRESS MANAGEMENT-SCALE OBJECTIVES

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ABSTRACT

The Southwest Washington Coastal Erosion Study is a five-year, multi-disciplinary research project designed to build a knowledge foundation as a sound basis for addressing coastal management objectives. The purpose of the Study is to gain an understanding of a regional coastal sediment system, the Columbia River littoral cell, in order to support local, state, and federal decision-making in land-use planning, resource allocation, and hazards reduction. In particular, the Study intends to obtain sufficient information so that future coastal conditions, particularly shoreline change and its associated impacts, can adequately be anticipated or predicted. The Study has developed products based on significant findings to assist coastal managers, including preliminary predictions of future shoreline positions. Many types of data and information covering a cascade of temporal and spatial scales are now being integrated to derive vulnerability assessments that consider the probabilities, uncertainties, and constraints of the various factors that influence coastal change. However, due to the inherent complexity of the coastal system, some scientific questions relevant to specific management questions will remain unanswered without additional investigation and/or long-term monitoring.

Background

For some five thousand years the beaches along the southwest coast of Washington and northwest coast of Oregon accumulated Columbia River sediment, creating broad coastal barrier plains and dune fields. Coastal management issues along the Columbia River littoral cell have historically dealt with problems associated with accreting and drifting dunes that interrupted homeowner views and restricted public access. Incidents of coastal erosion were viewed as localized or temporary problems with minimal societal implications. Questions regarding the permanence and safety of development on the rapidly accreting barrier plains were rarely if ever raised as a management concern, due in part to the high rates of sand accumulation along with relatively sparse and inexpensive development patterns. However, within the past few decades the growth of coastal communities has accelerated while accretion rates have generally slowed and several areas became recognized as exhibiting an erosional trend. Since December 1993, erosion at several sites has struck as community crises, threatening or destroying community infrastructure, resource-based industries, public parks and access, and public and private property. In response to recent erosion problems, over $70 million has been invested in coastal stabilization projects.

Land-use planning and coastal permitting decisions in Washington State are primarily made at the local level, and the combined local and state capacity, whether scientific or management-oriented, has been inadequate to address growth and development pressures along the southwest Washington coast. Local governments have lacked basic data and information needed for sound decision-making and long-term coastal planning, and as a result, communities have been relatively unprepared to deal with the magnitude of the problems associated with recent coastal erosion trends. Coastal communities would rarely get beyond informed crisis management (Gale, 1997). Local communities have been grappling with basic questions such as: when or where will the erosion stop?; what constitutes responsible action?; are there feasible interim measures?; what are the appropriate long-term solutions?; and where might other erosion problems occur in the future? The lack of answers to these fundamental questions provided the motivation to initiate the Southwest Washington Coastal Erosion Study in May 1996.

Littoral Cell Science and Management

The Columbia River littoral cell is bounded to the south by Tillamook Head, Oregon and by Point Grenville, Washington to the north. The beaches, barriers, coastal plains, estuaries, and inner-shelf along this stretch of coast contain nearly all of the sand discharged from the Columbia River over the last several thousand years (roughly 80 to 90 percent of the total sediment load is silts and clays that accumulate on the mid-shelf and in the deep sea). The littoral cell presently features four major concave-shaped, offset sections of accreted land separated by the Columbia River and two large coastal plain estuaries, Willapa Bay and Grays Harbor (Figure 1). Together, these four beach segments, or sub-cells, make up the major geographical components of the littoral system.

The definition of littoral cell boundaries is essential for calculating a sediment budget and analyzing changes in the coastal system. For example, sediment may be added or removed from a littoral system, and/or sediment may be redistributed between the various compartments within the system. Over timescales of millennia, the Columbia River contribution has resulted in a net increase of sediment in the littoral cell, despite potential external losses to the mid-shelf and submarine canyons. Knowing the external inputs to and outputs from the system is necessary for quantifying possible volumetric changes of the internal compartments. Once the total sediment budget is quantified, including the sediment volumes of the internal compartments, it is possible to determine the extent to which a beach might accrete, based on the quantity of sediment available from sources such as the inner-shelf and ebb-tidal deltas. Likewise, the extent to which a beach might erode could be determined based on the capacity of and transport potential to sediment sinks such as estuaries, and the barrier dunes. Details of the Columbia River littoral cell sediment compartments and budgets are provided in Gelfenbaum *et al*., (1997 and 1999).

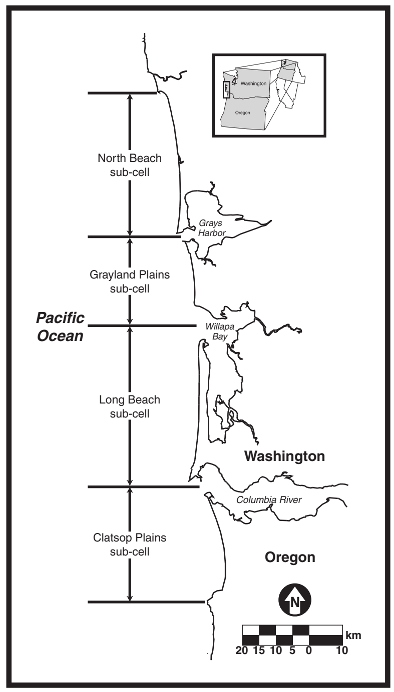

Figure 1. The Columbia River littoral cell spans a 165-km coastline in the Pacific Northwest, USA.

The concept of the littoral cell is also useful to coastal management. In coastal management, the concept emphasizes the inter-connections among the various compartments, whereby human intervention and natural perturbations within one part of the littoral cell may affect the other parts as well. This concept is especially important in consideration of shoreline stabilization measures where sediment retention at one location may lead to a downdrift sediment deficit, resulting in beach erosion. The utilization of dredged material to maintain sediment budgets and natural sediment dispersal pathways within the littoral cell is another key management application of the littoral cell concept. Although neither Washington State nor the local communities in southwest Washington have adopted a littoral cell management scheme, coordination of efforts to deal with coastal erosion issues among the Washington communities has been greatly enhanced since the inception of the Study. In Oregon, littoral cell management planning has been strongly encouraged and implemented on a voluntary basis. Motivation and detailed guidelines for developing littoral cell management plans in Oregon is provided in Shoreland Solutions (1995).

The Study Design

Initially conceived by the recognition of a lack of basic understanding of coastal processes and resulting changes, the Southwest Washington Coastal Erosion Study is now entering its final year of a five-year investigation of the 165-km long Columbia River littoral cell. The Study is jointly sponsored and directed by the US Geological Survey Coastal and Marine Geology Program and the Washington Department of Ecology Coastal Monitoring & Analysis Program, with active participation by local communities. Kaminsky and Gelfenbaum (1999) provide details about the development of this federal-state-local partnership. An overview of the Study elements and initial results is provided in Kaminsky *et al*., (1997). The present paper emphasizes the Study approach that has been specifically designed to address management objectives. Principally, the research plan has been devised to be applicable to planning horizons covering distances of tens of kilometers and time frames of decades, scales often neglected in scientific endeavors.

The research plan was developed in recognition of the need to provide information for resolving coastal erosion crises and reducing future impacts of coastal hazards. At the outset of the Study, temporary measures were being implemented to mitigate the initial impacts of erosion in order to gain sufficient time and information to plan actions leading towards long-term solutions. The recognition of the need to know future shoreline positions (decades) in order to develop viable management alternatives over the long term became a driving influence on the design of the Study. Secondly, sparse information at isolated project locations provided the impetus to develop regional and long-term data establishing a context to address site-specific problems. A basic understanding of where, why, and the extent to which erosion problems would occur in the future was largely unknown. Moreover, because remedial actions, whether implementation of shoreline stabilization, relocation of infrastructure, or a decision to do nothing would result in costs of several million dollars, a basic need developed for reliable information and prediction of future conditions in order to proceed in an acceptable manner.

The Study has therefore been designed to investigate this coastal region from a systems perspective and include assessments of the relevant factors that influence coastal change, such as sediment budget, regional tectonics, climatic forcing, and human intervention. Major goals of the study are to: understand regional sediment system dynamics; determine natural and anthropogenic influences on the littoral system; and predict coastal behaviour at a management scale (*i.e.* decades and tens of kilometers).

Because the Study has a principal focus on applying knowledge gained from research to practical management and decision-making, two priority efforts are emphasized here:

1. Predict coastal behaviour at scales relevant to management. Predictive modeling at scales of decades and tens of kilometers rely heavily on the concept of nested hierarchical scales of coastal systems whereby it is possible to scale down from geological-based models and scale up from processes-based models. Initially, the work involves producing realistic scenarios of future coastal change based on an integrated understanding of the coastal evolution of the Columbia River littoral cell. Probable scenarios and first-order predictions are now being developed. Combined monitoring and modeling efforts will be essential to continued improvements of predictive capabilities, especially those associated with quantifying shoreline change and accurately defining future positions of the shoreline and its dynamic range over relevant temporal and alongshore spatial scales.
2. Provide decision-support products and technical assistance that directly link scientific research with coastal management needs. Most importantly, this work requires the identification of sections of the coast susceptible to erosion, flooding, and impacts from coastal changes (Voigt *et al*., these proceedings). Information on vulnerable areas needs to be developed to mitigate coastal hazards, guide land-use planning, and enable prudent investments in community infrastructure. A variety of diagnostic tools can be developed to determine what is at-risk and help communities define acceptable levels of risk. A principal challenge will be to manage the inherent uncertainties in identification of the vulnerable areas and to provide a variety of products to support the decision-making process of coastal managers.

In order to develop these predictive capabilities and decision-support products, the Study necessarily takes a systems analysis approach that involves multiple tasks grouped into the following categories:

1) **Coastal Change:** analyses of past and present changes in geomorphic features that include barrier evolution, shoreline behaviour, beach monitoring, and bathymetric change. These efforts involve mapping the evolution of the littoral cell over a continuum of scales ranging from days and meters to millennia and hundreds of kilometers in order to understand the system functioning. The observed coastal changes are being related to environmental forcing, climatological events, sediment budgets, and other influences, including human intervention and tectonic activity.

2) **Sediment Budget:** analyses of the littoral system that includes assessment and quantification of the Columbia River source, and sediment sinks including the barriers, bays, and shelf. Related tasks involve identifying the internal sediment compartments and the pathways and magnitudes of sediment flux between compartments.
3) **Coastal Processes:** studies that measure, monitor, and/or model currents, waves, sediment transport and other climatic conditions that drive coastal response over a wide range of spatial and temporal scales.
4) **Predictive Modeling:** predictions of shoreline change and shoreface translation based on integrated input data sets derived from the analysis of coastal change, sediment budgets, coastal processes, and other environmental forcing conditions and geological constraints. The initial predictions are refined through iteration with nested data collection/monitoring.
5) **Management Support:** tasks that involve susceptibility analyses, development of Decision Support Systems and databases and application of Study results to case studies.

These research categories are designed to obtain information on most of the factors needed to predict coastal change over a variety of temporal and spatial scales (Figure 2). Nevertheless, quantitatively accurate prediction of coastal changes should be recognized as inherently complex and exceedingly difficult at any scale. Determining the correct process-response relationships in coastal change is confounded by time-dependent initial conditions, variable sensitivities, time lags in response, and variable duration of transient periods between states. Even if it were possible to obtain all the information at the required accuracy and develop it into a coherent understanding, long-term predictions may remain elusive. This difficulty is due to the fact that natural phenomenon such as the magnitude and frequency of storms, climatic fluctuations, and tectonic events are stochastic processes, meaning that they depend on random variables that can not be predicted with certainty. At best, stochastic processes can be associated with probabilities of occurrence and levels of uncertainty. Therefore, probabilities and uncertainties are integral components to the most advanced decision-support products. A combination of approaches is needed to confine and integrate both predictions and uncertainties in order to overcome the natural complexity of coastal system evolution. The development and use of expert knowledge and experience is a fundamental requirement in this process.

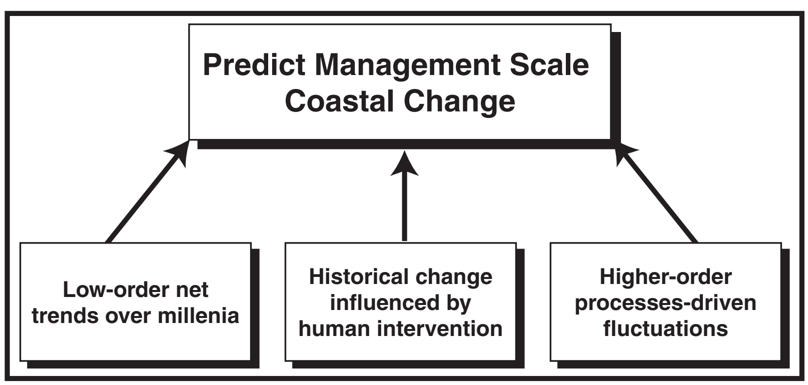

Figure 2. Schematic representation of the Study approach to develop predictive models for the Columbia River littoral cell. The trends, patterns, and variability of coastal change are determined based on the combined influences of: a) the inherited geological framework and processes that govern long-term trends; b) century-scale perturbations (often human-induced) that affect regional changes in coastal configuration; and c) interannual-scale morphodynamic behaviour driven by short-term, small-scale processes.

While coastal change predictions, Decision Support Systems, and other results relevant to management are under development, the Study has engaged in efforts to provide technical assistance to the management community. Technical assistance to local communities occurs in a number of ways, such as data sharing, information transfer, product development, technical consultation, site monitoring and mapping, proposal review, and educational outreach. Some of the ways the Study serves federal, state and local agencies include:

- identifying and monitoring coastal environmental indicators
- developing a state-wide perspective on coastal hazards and land-use management
- providing information to support non-regulatory solutions to coastal problems
- providing best available science as a basis for regulatory and management decisions
- providing expertise for specific projects, policy options, and environmental assessments

Study scientists have been involved with advisory committees, briefings to elected officials, public workshops, conferences and educational events. Some specific public outreach and education products include a video (Wessels *et al*., 1998), a glossary of terminology (Voigt, 1998a), an internet web site, brochures, fact sheets, local displays and exhibits, public presentations, and newspaper articles. The Study is continuing to generate new products to facilitate the integration of scientific knowledge with the decision-making process of coastal managers (Voigt, 1998b).

Scientific Findings of Significance to Coastal Management

Geological data from the Study show that the beaches in the Columbia River littoral cell have grown seaward at rates on the order of 0.5-1.0 m per year averaged over the last few thousand years (Peterson *et al*., 1999). This net beach accretion has occurred despite massive episodic shoreline retreat on the order of a few hundred meters associated with large Cascadia subduction zone earthquakes (Doyle, 1996). The last major earthquake along the coast occurred on January 26, 1700 (Satake, *et al*., 1996), and the average return interval for these large-scale events is approximately 500 years (Atwater and Hemphill-Haley, 1997).

In contrast, historical shoreline change analysis from topographic surveys and aerial photos has revealed high rates of beach accretion following jetty construction at the Columbia River and Grays Harbor during the early 1900s. The highest rates of beach accretion (tens of meters per year) occurred adjacent to the jetties during the first few decades following their construction. Over several decades, the shorelines at distances of up to 20 km from the jetties also advanced seaward, while accretion rates next to the jetties tended to decrease.

Combined bathymetric change and shoreline change analysis has revealed that much of the historical accretion patterns and rates are primarily due to sediment redistribution from the ebb-tidal deltas of the Columbia River and Grays Harbor to the adjacent coasts (Kaminsky *et al*., 1999a). After an initial flux of onshore sediment movement, the ebb-tidal deltas have diminished as a sediment source corresponding to slowing accretion rates and/or the onset of shoreline erosion adjacent to the jetties in more recent decades. In addition to the decrease in sediment supply to the beaches from the ebb-tidal deltas, river flow regulation via dam and reservoir construction has diminished the sediment carrying capacity of the Columbia River by approximately two-thirds over the historical period (Gelfenbaum *et al*., 1999). The decrease in peak flood flows, which reduces the amount of sand carried by the Columbia River, may also reduce the discharge of sand from the estuary entrance to feed the adjacent coast.

These recent research findings have important management implications. As the sediment supply to the beaches from both ebb-tidal deltas and the Columbia River continues to decline, it is apparent that coastal communities will likely be faced with increased potential for shoreline retreat. It is anticipated that the shoreline will continue to evolve over several decades in response to the declining sediment budget, and shoreline sections that advance will tend to do so as a result of shoreline retreat elsewhere in the littoral system. Therefore, the coastal management community will need to deliberate on both short-term responses and long-term planning to deal with these anticipated changes.

The strategic use of dredged material from the estuary entrances will be increasingly important to coastal communities in mitigating erosion trends. In fact, coastal communities and the US Army Corps of Engineers, in cooperation with many state and federal agencies, are actively engaged in developing ways to enhance the beneficial use of dredged material at the mouth of the Columbia River. The Corps of Engineers moves an average of 3.4 x 10^6 m^3 per year of sand from the navigation channel in the lower estuary. Investigations by the Study suggest a relationship between the offshore steepening of the beach profile and shoreline change at Fort Canby, just north of the Columbia River entrance. These findings may help optimize innovative placement of dredged materials to reduce coastal erosion.

In consideration of the relatively low-elevation barrier plains that have grown seaward since the early 1900s, it is apparent that development on these accreted lands is at increasing risk from the next Cascadia subduction zone earthquake. Coastal communities may decide that all development is within the level of acceptable risk. However, information from the Study, such as the location of previous earthquake scarps (e.g. Peterson, *et al*., 1999), land elevation data, and modeling results could be factored into land-use plans that recognize areas of greater and lesser susceptibility to future damage or destruction from these events.

Presently there is no specific policy to guide coastal development on accreted lands for structures located landward of local set-back requirements, which typically range from 30 m to 120 m from the seaward limit of vegetation. Existing flood zone maps of the Federal Emergency Management Agency that are intended to guide development in 100-year flood zones along the Washington coast can be grossly inaccurate. Kaminsky *et al*., (1999b) found that flood zone boundaries along the coast may not accurately delineate current flood zones because of large shoreline position discrepancies in excess of 600 m in two locations. Shoreline monitoring and mapping must be an ongoing activity in order for these kinds of products to be useful for long-term coastal planning and hazard mitigation.

Study results have enabled the formulation of conceptual models of future shoreline change that will continue to be tested and refined with additional data as part of the scientific research process. However, these conceptual models are already useful tools for generating a dialogue with the management community to consider both management responses to the suggested implications and to identify the particular questions that need to be addressed to assist the decision-making process. It is important that the Study and management community grapple with these findings and implications during the preliminary stages so those priority scenarios can be developed to a more precise level.

Likewise, improved prediction of coastal change will require continued monitoring to provide an accurate record of local shoreline conditions and promote a better understanding of the cause and effect relationships behind coastal change scenarios. Combined monitoring and modeling programs are important for validating shoreline change predictions and enhancing predictive capabilities and thus, long-term planning (Ruggiero *et al*., these proceedings). In addition, the collection of other data sets may be necessary to address specific science or management questions. For example, high-resolution bathymetric surveys could reveal transfers of sand between the inner-shelf and the beach, having implications for assessments of future coastal change, the use of dredged material, and the influence of coastal structures on sediment entrainment or deposition.

Concluding Discussion

A primary goal for the final year of the Study is the development of products and the transfer of data and knowledge from Study investigators to local managers, government staff and officials responsible for coastal planning and decision-making. Effective strategies must be developed from a broad understanding of the problem and by careful study of alternatives through a collaborative process of the affected parties. The Southwest Washington Coastal Erosion Study has generated extensive data and knowledge to enable more informed choices regarding coastal development, resource protection, and hazard mitigation activities along the southwest Washington coast.

As Study investigators develop tools and information in collaboration with the management community, it is up to that community to determine if and how they incorporate the information into their planning and decision-making activities. Regardless, the improved ability to anticipate future hazards associated with this dynamic coastline should enhance the long-term sustainability of coastal communities.

References

Atwater, B., and Hemphill-Haley, E. 1997. Recurrence intervals for great earthquakes of the past 3,500 years at northeastern Willapa Bay, Washington: US Geological Survey Professional Paper 1576, 108p.

Doyle, D.L. 1996. Beach response to subsidence following a Cascadia subduction zone earthquake along the Washington-Oregon coast, M.S. Thesis, Portland State University, Portland, Oregon, 113p.

Gale, C. 1997. Communities and coastal erosion, pp. 24-28, In Southwest Washington coastal erosion workshop report, Gelfenbaum, et al., (eds.), *U.S. Geological Survey Open File Report 97-471,* 102p.

Gelfenbaum, G., Kaminsky, G.M., Sherwood, C.R., and Peterson, C.D. 1997. Southwest Washington coastal erosion workshop report, *U.S. Geological Survey Open File Report 97-471,* 102p.

Gelfenbaum, G., Sherwood, C.R., Peterson, C.D., Kaminsky, G.M., Buijsman, M., Twichell, D.C., Ruggiero, P., Gibbs, A.E. and Reed, C. 1999. The Columbia River littoral cell: a sediment budget overview, *Coastal Sediments '99*, Long Island, NY, pp. 1660-1675.

Gelfenbaum, G., and Kaminsky, G. M. (editors) 1999. Southwest Washington coastal erosion workshop report, 1998. *U.S. Geological Survey Open File Report* 99-524, 182 p.

Kaminsky, G.M., Buijsman, M., Gelfenbaum, G.R., Ruggiero, P., Jol, H.M., Gibbs, A. and Peterson, C.D. 1999a. Synthesizing geological observations and process-response data for modeling coastal change at a management scale, *Coastal Sediments '99,* Long Island, NY, pp. 1708-1723.

Kaminsky, G.M. and Gelfenbaum, G. 1999. The Southwest Washington coastal erosion study: research in support of coastal management, *Coastal Zone '99.* San Diego, CA, pp. 737-739.

Kaminsky, G.M., Daniels, R.C., McCandless, D. and Ruggiero, P. 1999b. Mapping erosion hazard areas in Pacific County, Washington, *Journal of Coastal Research, Special Issue #28,* pp. 158 - 170.

Kaminsky, G.M., Ruggiero, P., Gelfenbaum, G., and Peterson. C. 1997. Long term coastal evolution and regional dynamics of a US Pacific northwest littoral cell, *Proceedings of Coastal Dynamics '97*, pp. 614-623.

Peterson, C.D., Gelfenbaum, G.R., Jol, H.M., Phipps, J.B., Reckendorf, F., Twichell, D.C., Vanderburg, S., and Woxell, L.K. 1999. Great earthquakes, abundant sand, and high wave energy in the Columbia cell, USA, *Coastal Sediments '99*, Long Island, NY, pp. 1676-1691.

Ruggiero, P., Voigt, B., and Kaminsky, G. 2000. Beach monitoring for enhanced decision-making, *these proceedings*.

Satake, K., Shimazaki, K., Tsuji, Y. and Ueda, K. 1996. Time and size of a giant earthquake in Cascadia inferred from Japanese tsunami records of January 1700, *Nature*, v. 378, pp. 246-249.

Shoreland Solutions 1995. Littoral cell management planning along the Oregon Coast, report prepared for the Oregon Coastal Zone Management Program, Oregon Department of Land and Conservation and Development, Salem, Oregon, 39p.

Voigt, B., Ruggiero, P., and Kaminsky, G. 2000. Towards the development of a decision support system for the Columbia River littoral cell, *these proceedings*.

Voigt, B. 1998a. *Glossary of Coastal Terminology*, Washington State Department of Ecology, Coastal Monitoring & Analysis Program, Publication No. 98-105, 89p.

Voigt, B. 1998b. Merging coastal research and policy for improved coastal hazard management, *Proceedings of the 16th International Conference of The Coastal Society,* Williamsburg, Virginia, p. 160a.

Wessels, S.M., Gelfenbaum, G., and Kaminsky, G. 1998. *At ocean's edge: coastal change in southwest Washington*, Washington State Department of Ecology, Coastal Monitoring & Analysis Program, Publication No. 98-116, video, 23 min.

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