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WASHINGTON STATE DEPARTMENT OF ECOLOGY

Southwest Washington Coastal Erosion Workshop Report 1998

Editors
Guy Gelfenbaum[1] and George Kaminsky[2]

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Prepared in cooperation with
Washington State Department of Ecology

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U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

[1]U.S. Geological Survey, Menlo Park, CA
[2]Washington Department of Ecology, Olympia, WA

Cover Photograph: As a result of net northward littoral transport, the Copalis River flows north along the coast until it turns west to enter the Pacific Ocean. During summer months, the littoral transport reverses, turning the river back to the south before it enters the ocean.

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INTRODUCTION

This report contains the abstracts and group discussion reports that were presented at the second Fall technical workshop of the Southwest Washington Coastal Erosion Study. The workshop was held at the Department of Ecology Headquarters building in Olympia, WA during Wednesday, November 18 through Friday, November 20, 1998. The workshop assembled the entire multi-disciplinary group of scientists working on the study or on related projects within the study area, including investigators from the USGS and the Washington Department of Ecology, college and university professors and students, senior scientist advisors, and consultants.

The workshop was designed for scientists and engineers associated with the study to collaborate and review research results, exchange ideas, and discuss recent data, fieldwork, progress with ongoing tasks, and plans for future research on the Columbia River littoral cell. Investigators were therefore encouraged to present preliminary results and interpretations, and to speculate on their significance. In addition, presentations were made in such a way as to encourage discussion about data development, collection techniques, and analysis methods.

Much of the data and information provided in this report has not yet been extensively peer reviewed or published, therefore the reader is advised that its contents are preliminary and subject to change.

BACKGROUND

The Southwest Washington Coastal Erosion Study, now in its third year, is a five-year multi-disciplinary investigation of a 165-km long coastal region between Tillamook Head, Oregon and Point Grenville, Washington (Figure 1). The study is co-sponsored by the US Geological Survey and the Washington Department of Ecology. The study has been initiated in response to several coastal erosion crises that collectively identified a lack of basic data and information on coastal morphodynamics and the regional sedimentary system needed for planning and decision-making on coastal projects having multi-million dollar costs or implications.

Preliminary results of the study are already being used by state and local governments to aid in mitigating existing erosion problems, as well as in long-term planning for future coastal development. For example, the preliminary results of the monitoring data, shoreline change analysis, and modeling efforts are supporting the City of Ocean Shores in developing long-term alternatives to erosion problems. Study scientists have been involved with advisory committees, public workshops, local conferences and educational events. Public education materials have been produced, including a video (Wessels *et al.*, 1998), a glossary of terminology (Voigt, 1998), brochures, and an internet home page. The study is continuing to produce public information and facilitate the transfer of knowledge and integration with the decision-making process of coastal managers (Voigt, 1998).

The primary 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). The study tasks include: an assessment of previous studies; establishing a geodetic control network; investigating the evolutionary sequences of the coastal barriers; analyzing historical shoreline and bathymetric change; determining the sediment budget for the littoral system; mapping the inner shelf and Holocene stratigraphy; monitoring active beach and shoreface processes; conducting shoreline change modeling; developing a project database; and providing outreach and educational information. An overview of the study and initial results are presented in Kaminsky *et al.* (1997).

The Southwest Washington Coastal Erosion Study has a principal focus on applying knowledge gained from research to practical management and decision-making. Two major objectives of the collective research effort are to:

- Predict coastal behaviour at scales relevant to management. Initially, this work involves producing realistic scenarios of future coastal change based 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 continue in order to improve on predictive capabilities, especially those associated with quantifying shoreline change and accurately defining future positions of the shoreline and its dynamic range over temporal and alongshore spatial scales.
- Provide decision-support products that directly link with coastal management needs. Most importantly, this work requires the identification of sections of the coast that are susceptible to erosion, flooding, and impacts from coastal changes. Information on vulnerable areas will need 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 the acceptable levels of risk. A principal challenge will be to manage the inherent uncertainties in identification of the vulnerable areas.

In order to develop these predictive capabilities and decision-support products, the study necessarily takes a systems analysis approach that involves:

- Geomorphic description based on features and changes that is obtained from mapping the evolution of the Columbia River littoral cell, and developing a conceptual model of system functioning.
- Derivation of sediment budgets through the identification of compartments and pathways, sources and sinks, and net fluxes from volume change analysis.
- Nested data collection/monitoring and modeling that cover a wide range of spatial and temporal scales.
- Combined approaches for management scale predictions that integrate a variety of data and models, scaling down from geological observations and scaling up from processes measurements.

STUDY PROGRESS AND RESULTS

The Study has developed a geological framework (*e.g.* Wolf *et al.*, 1998; Woxell, 1998;Cross *et al.,* 1999) and a historical base of information to initiate quantitative modeling of coastal change at a variety of scales. A morphology monitoring program has been established and short-term beach changes are being documented (Ruggiero *et al.*, 1998).

Several study accomplishments and work in progress are worth highlighting at the outset of this workshop.

- **Prehistoric timelines** – The study has successfully conducted ground penetrating radar (GPR) surveys, drilling, and coring to confirm shoreline scarps and dates associated with earthquake-induced subsidence events. In addition, seismic surveys and drilling have identified Holocene transgression surfaces. The identification of these timelines has been an important accomplishment for constraining the evolution of the littoral cell and determining bulk sediment budgets.
- **Geological scale evolution** – Large signals of change over relatively short time that have been preserved in the stratigraphy of the prograded barriers that have been mapped with GPR, and the barrier sequences have been documented from well log data and drilling data. New cores on the shelf have been collected to yield recent sediment accumulation rates. Geological scale modeling is just beginning to work out the uncertainties in initial conditions, sea level rise rates, and sediment budgets.
- **Shoreline behaviour modeling** – Preliminary results of shoreline change modeling are beginning to reveal possible long-term tendencies of future shoreline change. Modeling improvements will continue to be made as more historical shorelines are mapped, better sediment budget numbers that document changes through time are derived, and wave refraction modeling results are refined. Historical barrier accretion volumes have been obtained and are expected to be improved in the future with a LIDAR-derived digital elevation model.
- **Variability of shoreline and profile change** – The beach morphology program is documenting the scales of short-term alongshore and cross-shore fluctuations in beach morphology. The study has also collected nearshore bathymetric data to compare with the only other data set in the region collected over fifty years ago. Work is already in progress to upgrade the collection of nearshore bathymetry.
- **Response to a strong El Niño event** – Both the beach morphology monitoring program and two airborne LIDAR surveys have provided a synoptic view of the regional response to the 1997/98 El Niño. These data sets should help determine the relative influence of these events on long term changes and enable comparisons with changes driven by typical seasonal variability.
- **Bathymetric change** - Initial results show large magnitude of change throughout the region. These changes are especially pronounced at the entrances to the Columbia River and Grays Harbor that demonstrate offshore migration of the ebb shoals just seaward of the jettied entrances and onshore migration of the flanks of the shoals. These changes have resulted in nearshore shoreface steepening and a decoupling of ebb deltas with the adjacent coasts. Significant bathymetric changes have been revealed at water depths up to 100 m. Data suggest that the lower shoreface along this coast may be as deep as 20 m - 40 m, and the upper shoreface shallower than 15 m.

There are a number of significant study results and observations that summarize our understanding of the evolution of the Columbia River littoral cell:

Geological Observations

- Tillamook Head, OR and Point Grenville, WA have confined the beach sand discharged from the Columbia River for the last several thousand years.

- North Head and Cape Disappointment are prominent geologic features that aligned littoral currents to form the Long Beach Peninsula and Willapa Bay.

- The coastal barriers have prograded for some 4,000 to 5,000 years along the Long Beach Peninsula and Clatsop Plains, and only about 1,500 years along the northern end of the North Beach sub-cell. Barrier progradation rates are on the order of 0.3 to 0.6 m/yr over the last 4,000 years.

- The beaches have experienced severe shoreline retreat caused by sudden 1 m to 2 m drops in land elevation along the coast associated with large subduction-zone earthquakes that occur about every 500 years.
- The shelf is the largest sink of Columbia River sediment, followed by the deep sea slope, canyons and fans, the bays, and the barriers and beaches.

Historical Observations

- Following construction of jetties at the Columbia River and Grays Harbor in the early 1900's, the beaches have grown seaward by many meters per year for several decades.

- The jetties have influenced accretion and possibly erosion patterns on the beaches over alongshore distances of 20 km or more.

- The carrying capacity of beach sands of Columbia River to the estuary has been reduced by approximately two-thirds over the last century.

- Accretion rates along the coast have slowed dramatically over the past few decades.

- High rates of erosion are occurring along sections of beach that had previously accreted most rapidly.

- Local erosion sites appear to have either increasing erosion rates or an expanding spatial scale of erosion along the shoreline.

Processes Observations

- There are large regional gradients of change in shoreline progradation and recession patterns, as well as in sediment size, beach slope, and elevation change.

- The shoreline position can migrate landward by as much as 100 meters during a winter season and is typically on the order of 33 m.

- Seasonal beach elevation change is on the order of 0.5 m and rip currents scour as much as 2 m depth of sand from the upper beach face, causing local embayments.

Some of these basic observations yield additional questions, particularly as to their implications on the future state and evolution of the Columbia River littoral cell. However, these observations combined with preliminary analysis and synthesis of other data enable the formulation of a conceptual model of historical (century) scale sediment flux and morphological change (Figure 2).

The behaviour of the shoreline over the historical period is coupled with the evolution of the shoreface and ebb-tidal deltas. The jetties have constricted the tidal flow and increased the velocities at the inlets resulting in erosion of the broad and shallow ebb-tidal deltas. These features migrated offshore directly in front of the entrances, but much of the sediment in the ebb deltas moved onshore, resulting in massive post-jetty beach accretion rates. After the initial large flux of onshore sediment movement, the ebb-tidal deltas diminished as a sediment source. In recent decades, shoreline recession has corresponded with a reduced exchange of sand across these inlets and shoreface deepening, possibly a combined effect of jetties and Columbia River sediment source reduction.

New regional bathymetry will be essential to determining the exchange of sediment between the inner shelf and the upper shoreface, and to the role of the lower shoreface in long-term nearshore morphology and shoreline dynamics. Further analysis and synthesis of other study results will refine this conceptual model in both time and space. This historical scale model of coastal evolution will need to be combined with both shorter- and longer-term conceptual models and extrapolated to the future to develop realistic scenarios and predictive capabilities of coastal change at management scale.

QUESTIONS FOR FURTHER INVESTIGATION

Major questions remain that are important to addressing the principal goals and objectives of the study. A few primary questions include the following:

1. What is the role of the lower shoreface in beach accretion and erosion processes and how might it influence the overall beach morphology? For example, the north beach subcell has a lower sediment input and an exposed transgression surface. To what extent can the lower shoreface along the north beach subcell serve as a proxy for the other sub-cells? Do the changes suggest feeding of sediment from the lower shoreface to the beach? What is the seaward limit (zone) of active change?
2. What are the mechanisms of coastal progradation? What is the relative contribution from cross-shore feeding versus longshore transport and deposition of sediment? Does net progradation result from summer conditions that drive onshore sediment transport and swash bar migration? What is the relative contribution from aeolian transport and deposition?
3. How do the estuaries influence coastal evolution? Can we determine their relative importance as a sediment sink or source, and/or as a pathway of transport to the shelf? How have the jetties affected the sinks and pathways? Can we quantify the evolution of the flood tidal deltas? What is the role of channels and deltas for sediment dispersion?

4. What is the role of episodic events, pulses of sediment discharge/transport, and how can these be evaluated? Are the fluctuations of large-scale morphologic changes related to sediment discharge? Can we adequately identify the signatures of episodic events, interannual variability, and cyclical fluctuations? What are the appropriate response parameters to measure, and what are the time-response properties associated with the forcings?

Although these questions are specific to the Columbia River littoral cell, many of them can be posed as important research problems in their own right, requiring perhaps years of study. In an effort to obtain input from scientists working on similar research questions either from a theoretical perspective or as applied to other case studies, this workshop included the participation of principal investigators involved with the European Union-sponsored project, Prediction of Aggregated-scale Coastal Evolution (PACE) (see abstract by deVriend in this report). Because of the complementary alignment of the goals of the Southwest Washington Coastal Erosion Study with the aims of the PACE project, the sharing of expertise has been a value-added benefit to the study. In particular, some of the concepts and models developed in the PACE project are being applied in this study and the morphodynamic scales of change within the Columbia River littoral cell are being compared with those of different coastal settings.

The principal investigators from the PACE project that participated in this workshop included: Dr. Peter Cowell, Dr. Huib deVriend, Dr. Josė Jiménez, and Dr. Marcel Stive. The abstract by deVriend provides an overview of the PACE project and recent progress on predicting large scale coastal behaviour. The abstract by Cowell demonstrates the application of the Shoreface Translation Model to the Washington coast. The abstract by Jiménez illustrates both similarities and differences with the Ebro delta coast in Spain, and the abstract by Stive provides a framework for investigation of long-term changes as applied to the Holland coast. These contributions were solicited for their unique approaches to the systematic investigation of large scale coastal behaviour.

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ACKNOWLEDGEMENTS

We would like to thank Brian Voigt for helping to organize the workshop, and the assistance of Steve Eykelhoff, Emily Lindstrum, and Josh McInnis. Thanks also to Britt Argow and Brian Voigt and Michael Hamer for their help in preparing this workshop report. Finally, we would like to thank Robert Morton for his thorough review of this report.

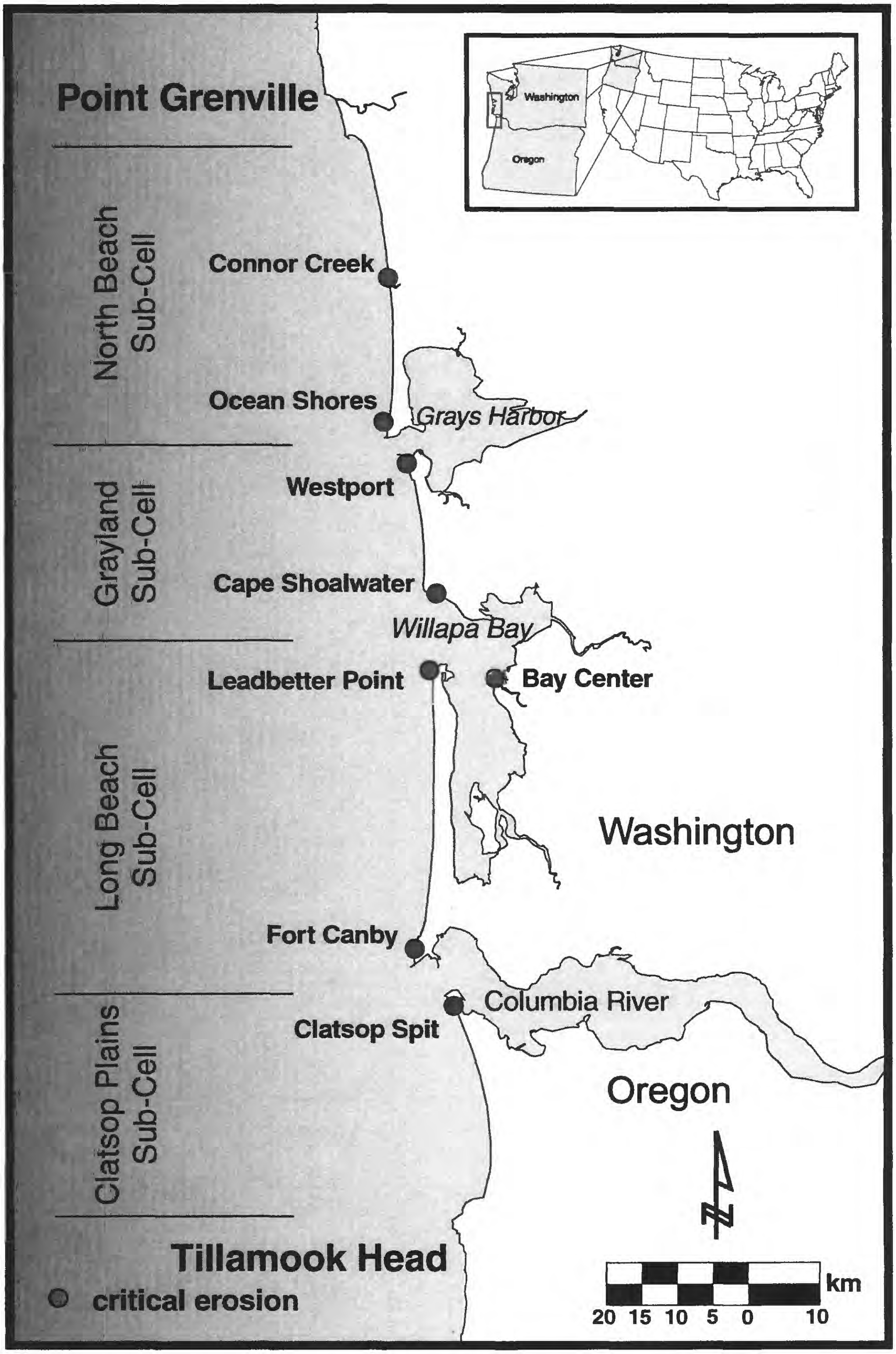


Figure 1. Columbia River littoral cell map.

Conceptual Model
Sediment Flux and Morphological Change

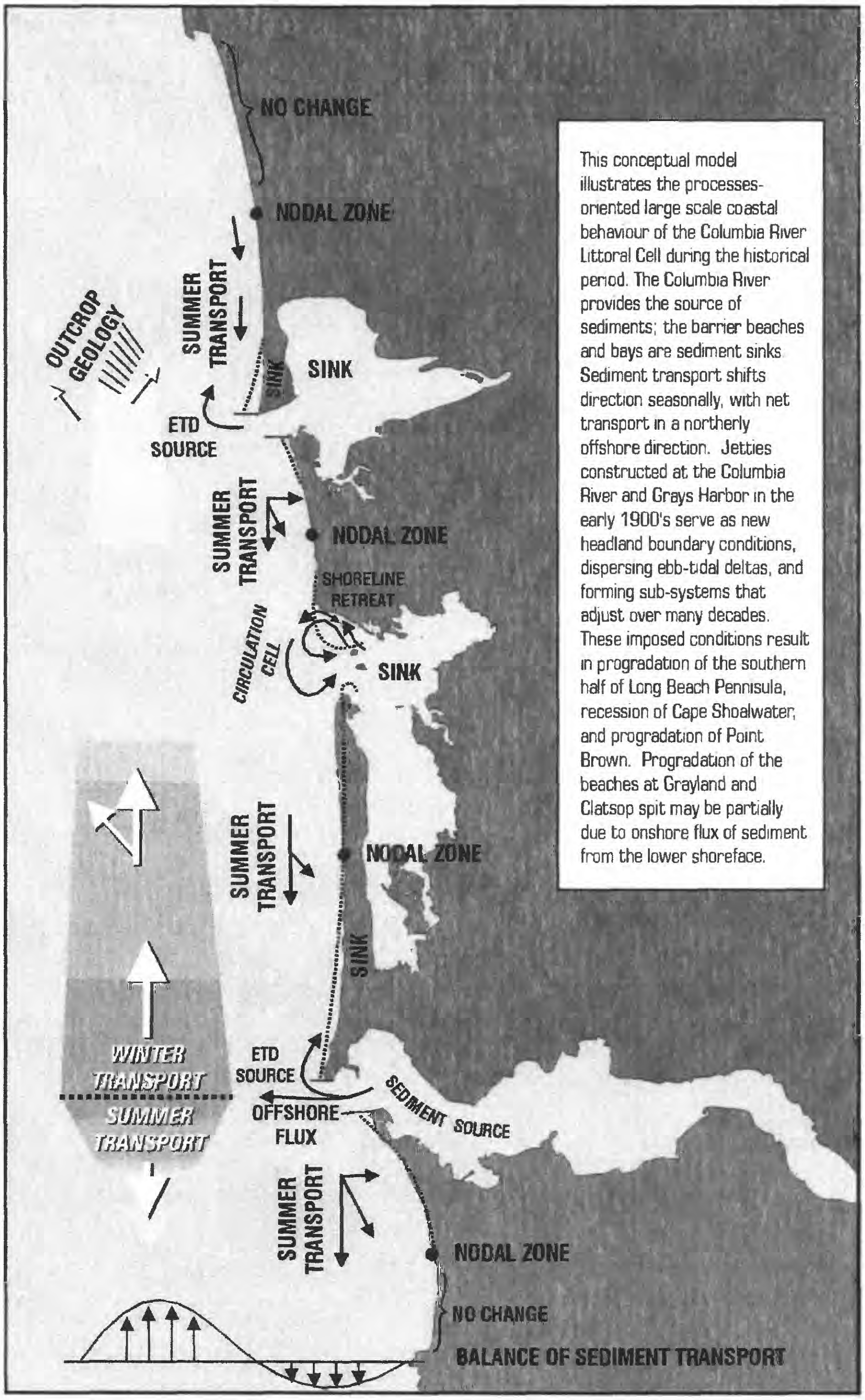


Figure 2. Conceptual model: Sediment flux and morphological change.

THIRD SOUTHWEST WASHINGTON COASTAL EROSION STUDY WORKSHOP

Olympia, Washington
November 18-20, 1998

WORKSHOP AGENDA

Wednesday, November 18

0800	*PICK-UP AT HOTEL FOR SHUTTLE TO WORKSHOP*	
0815	Welcome	G. White, Program Manager, DOE
0830	Status of USGS/DOE cooperative study	G. Gelfenbaum, USGS
0900	Review of progress and current events	G. Kaminsky, WA Dept of Ecology
0945	BREAK Erosion Study Video	
1015	Evolution of SW WA inner shelf since the last lowstand of sealevel	D. Twichell, USGS
1045	Deep borehole at the Columbia R mouth	C. Peterson, Portland St U
1115	Sedimentation summary of 1998 gravity cores from the southwest WA shelf	L. Phillips, USGS
1145	Pre-historic sediment budget study – Geologic-scale modeling	M. Buijsman, DOE
1215	Discussion	
1230	LUNCH	
1330	Introduction to barrier accretion studies	C. Peterson, Portland St U
1345	Compilation of geotechnical and water well borehole data for the barrier beaches	A. Herb, Portland St U
1400	Vibracoring of surfzone deposits in Col R cell	C. Peterson, Portland St U

1430	Drilling results and interpretation	S. Vanderburgh, UCFV
1500	GPR correlation to drilling and coring	H. Jol, UWEC
1515	BREAK Geologic data GIS demonstration	 V Cross, USGS D. Percy, Portland St U
1600	Origin and interpretation of sand dunes in the Grayland plains	J. Phipps, Grays Harbor CC
1630	Modeling shoreface translation	P. Cowell, U of Sydney
1700	Discussion	
1900	DINNER (optional – Cactus on the Bay)	

Thursday, November 19

0800	*PICK-UP AT HOTEL FOR SHUTTLE TO WORKSHOP*	
0815	Post-jetty Clatsop plains sand accumulation	F. Reckendorf
0830	Update of historical shoreline mapping	B. Huxford, R. Daniels, DOE
0845	Shoreline change analysis	G. Kaminsky, DOE
0915	Bathymetric volume change analysis	A. Gibbs, USGS M. Buijsman, DOE
0945	Linking nearshore depth & shoreline change around Grays Harbor	D. Simpson, PIE
1015	BREAK	
1045	Recent beach progradation & GPR	H. Jol, UWEC G. Kaminsky, DOE
1100	Shoreline modeling	M. Buijsman, DOE
1130	Regional wave modeling to predict shoreline change	J. Haines, USGS
1200	Discussion	
1230	LUNCH	
1330	Prediction of large-scale coastal change	H. de Vriend, University of Twente
1400	Surface geology of and annual change to the inner shelf	D. Twichell, USGS

1430	Role of lower shoreface in sediment budgets	M. Stive, Delft Univ
1500	BREAK	
1530	Holocene Columbia R sediment source	H. Nelson, USGS
1600	Columbia River and estuary sediment budget	H. Moritz, COE
1615	Comparative analysis of Ebro delta coast (Spain) with the Washington coast	J. Jiménez, Catalonia UT
1645	Discussion	
1900	DINNER (sponsored by SWCES – Louisa)	

Friday, November 20

0800	*PICK-UP AT HOTEL FOR SHUTTLE TO WORKSHOP*	
0815	Update on Willapa Bay projects	E. Nelson, COE
0845	Willapa Bay wave-current interactions	H. Bermudez, PIE
0900	Processes off the mouth of the Columbia R	H. Moritz, COE
0930	Morphological length scales of beach change	P. Ruggiero, DOE
1015	BREAK	
1045	Beach morphology using GPR	H. Jol, UWEC
1100	Nearshore bathymetry	J. Cote, Oregon St U P. Ruggiero, DOE
1130	Aerial video system for measuring large-scale shoreline, beach width, and sand bar variability	G. Gelfenbaum, USGS
1145	Lidar mapping of coastal change	A. Gibbs, USGS R. Daniels, DOE
1215	LUNCH	
1315	Education and product development	B. Voigt, DOE
1345	Break-out groups	
1515	BREAK	

1530 Break-out group reports

1615 Summary

1630 End of Workshop

The Southwest Washington Coastal Erosion Study: Status and Update

Guy Gelfenbaum, U.S. Geological Survey
George Kaminsky, WA Department of Ecology

The Southwest Washington Coastal Erosion Study is a cooperative study funded by the U.S. Geological Survey and the Washington State Department of Ecology. The primary goal of this study is to better our understanding of regional coastal processes and the resulting coastal evolution in the Columbia River littoral cell with an aim toward predicting future change. The study is addressing both oceanographic and geologic processes over time scales of several thousands of years, centuries, decades and inter-annual periods. Results of this study are being used by federal, state and local governments to aid in mitigating existing erosion issues, as well as in long-term planning for future coastal development.

The underlying strategy used to develop the detailed objectives and study tasks includes: a strong federal-state-local cooperative effort, a regional perspective, unbiased, objective and scientifically defensible analysis, a long-term approach, and incorporation of both fundamental and applied studies. This strategy resulted in a study plan that takes a systems approach to coastal evolution and includes information on ocean processes, regional and local sediment budgets, sea-level rise, climatic variability, and human influences (Figure 1).

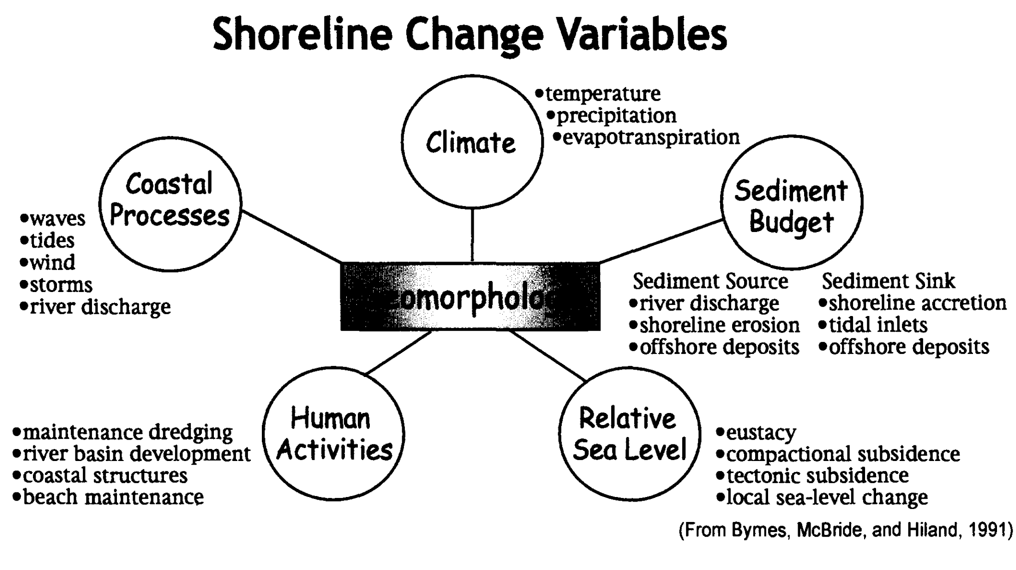
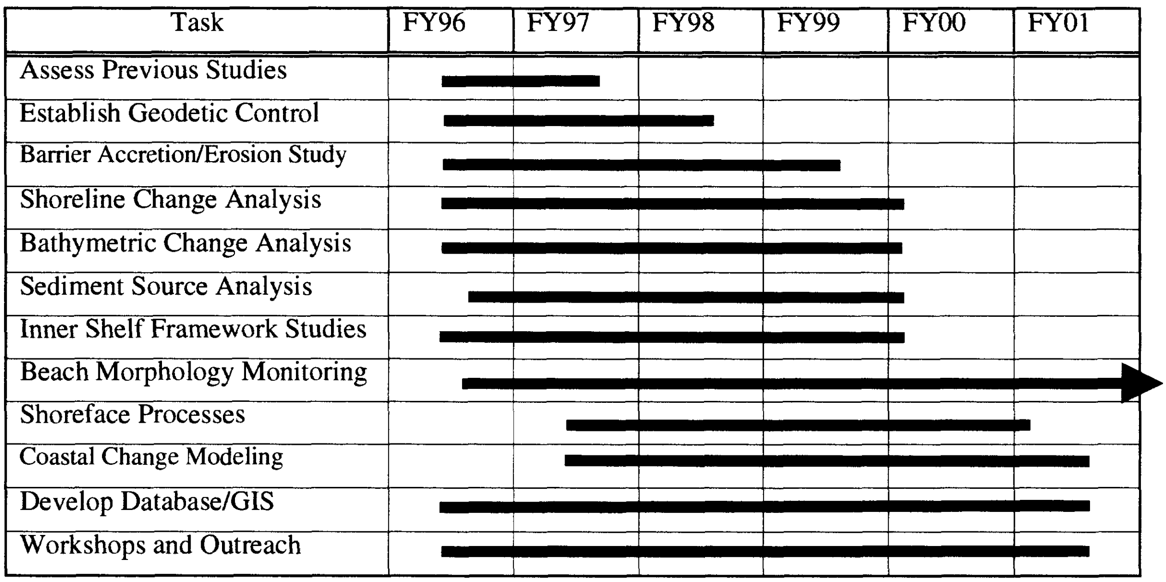


Figure 1. The SW Washington Coastal Erosion Study is taking a systems approach to understanding the processes responsible for shoreline change over a variety of time scales.

A variety of study tasks were initially identified as essential in order to reach the overall goals and objectives of the study. Overall study tasks are shown in the timeline below. Some tasks involve one or two people and limited field-work, whereas other tasks involve numerous participants and multiple field efforts. The study, as originally planned, will take five years to be completed. Since initiation of funding for the project was delayed in its first year, some tasks will continue into FY01. The Beach Morphology Monitoring task should be continued beyond the end of the study to assure the State and locals have access to continued, accurate assessment of the state of the beaches.



Each of the tasks listed in the timeline above are described briefly below. In some cases, significant accomplishments are listed, whereas in other cases continuing efforts or future efforts are listed. A common purpose behind many of the tasks is to obtain information that will lead to an understanding of the sediment budget of the Columbia River littoral cell system. Based on the idea that large-scale coastal evolution, such as shoreline change, occurs over many time scales, the sediment budget will be evaluated over several time scales. Where possible, the sediment sources, pathways, and sinks of sand in the littoral cell will be evaluated over geological, historical, and seasonal time scales.

Assess Previous Studies
- Workshop to assess state of knowledge
- Acquired maps & digital data
- Report from 1st workshop
- Established library database of over 900 references

Establish Geodetic Control
- Field effort to establish 3D geodetic control
- 13 new coastal control monuments, 77 total

- Accurate control for mapping & monitoring
- Used extensively by private & government agencies
- Report to NGS, meet "Blue-Book" standards

Barrier Accretion/Erosion Study
- Mapping & dating linear dune ridges
- Cross-shore GPR profiles
- Soil profiles, dating scarps
- Auger coring, vibra-coring, drilling
- Pre-historic accretion rates & episodic erosion events

Shoreline Change Analysis
- Historical shorelines from NOS T-sheets & aerial photos: 1870's, 1920's,1950's, 1974, 1995
- Ocean Shores: 1970, '76, '80, '85, '90
- Error analysis of shoreline position
- Regional historical shoreline change rates and accumulation volumes
- Orthophotos produced and distributed
- "Mapping Erosion Hazards in Pacific Co", JCR Special Issue #28

Bathymetric Change Analysis
- Regional historical bathymetry from 1870's & 1920's
- More historical data at estuary inlets
- Bathymetric change maps
- Additional funds for new regional bathymetry

Sediment Source Analysis
- Historical dredge disposal analysis at Columbia River
- Analysis of "Mid Shelf Silt Deposit" (MMSD) & deep-sea cores
- Re-analyze mid-shelf mud deposition rates
- Plan to assess reservoir accumulation

Inner Shelf Framework Studies
- High-resolution seismic & side-scan sonar across inner shelf and bays
- Surface sediment samples & video
- Sediment cores
- History of shelf & bays sediment accumulation

Beach Morphology Monitoring
- 47 cross-shore profiles (2/yr)
- 4 sediment samples/profile
- 16 3D (4 km) surface mapping sites (2/yr)
- 4 nearshore bathymetric grids (2/yr)
- Shoreline scarps
- "Beach Morphology" annual report

Shoreface Processes

- Analysis of historical wave data
- Analysis of wave hindcast data
- Initiate regional wave refraction models
- Estimate seasonal littoral transport
- Deploy profiling current meters
- Plan wave refraction experiment

Coastal Change Modeling

- Geologic-scale ADM for shelf evolution
- Shoreface Translation Model
- UNIBEST Shoreline change model

Develop Database/GIS

- MS ACCESS
  - 900 references; 250 maps
  - 525 contacts
  - 175 news articles
- GIS Database
  - metadata development
  - 25 layers
  - orthophoto mosaics

Education and Outreach

- Annual study participants & users workshop
- Presentations for local organizations (Beach Combers Fun Fair, Willapa Science Fair)
- Displays at Ocean Shores Interpretive Çenter & Pacific Co Historical Society
- Ocean Shores Technical Committee
- Governor's Task Force on Coastal Erosion
- Coastal Erosion video, fact sheets, posters, etc.

Participants in the study have included USGS and DOE staff, and numerous academic faculty, staff, and students. In addition, other federal, state, and local agencies have contributed to the overall effort. In all, the study has benefited from the efforts of over 40 participants, including several undergraduate and graduate students. Funding for the study began in early 1996, and has continued with nearly equal contributions from the USGS and DOE. In 1998/1999, funding has been increased to allow for the collection of new regional bathymetric data.

Evolution of the SW Washington Inner Shelf since the Last Lowstand of Sealevel

Dave Twichell, VeeAnn Cross, Ken Parolski
U.S. Geological Survey

A grid of seismic profiles from the inner continental shelf (innermost 20 km) off southern Washington and northern Oregon (Cross et al., 1998) have been used to map the stratigraphic development of this area since the last lowstand of sea level (Figure 1). Well information from the Grays Harbor area (Peterson and Phipps, 1992) were used to calibrate the interpretation which will be further refined by drill hole results from the 1998 field season.

Sediment accumulation since the last lowstand of sea level can be divided into two parts: estuarine deposits and marine deposits (Figure 2). Estuarine deposits completely fill large, well-developed valleys extending offshore from Grays Harbor and the Columbia River and a smaller valley, originating in Willapa Bay (?), that extends from near Klipsan Beach on Long Beach Peninsula to the head of Astoria Canyon. The Grays Harbor valley is not straight; its path controlled by several anticlines and faults that disrupt the shelf in this part of the study area (McCrory, 1996). The Columbia River and Willapa Bay valleys are straighter as they cross a part of the shelf that is less deformed tectonically. Seismic profiles show the estuarine fill in the Columbia River valley as acoustically featureless (Figure 3) while Grays Harbor paleo-valley fill is characterized by shoreward dipping reflectors (Figure 4). The Columbia River estuary is the deepest of the three, was connected to the head of Astoria Canyon which extended closer to shore than as present, and, because of its greater depth, is interpreted to have been the first of the three estuaries to fill. Figure 3, for example, shows the ravinement surface that cuts the top of the estuarine fill is at –70 m on this profile which suggests that at this location on the shelf the Columbia River estuary was completely filled by 11,000-12,000 yr BP. Grays Harbor and Willapa Bay estuaries were primarily filled by the shoreward transport of sediment from offshore rather from local rivers. The shoreward dipping foreset beds in the Grays Harbor paleo-valley (Figure 4) are interpreted to represent flood tidal delta deposits. Peterson and Phipps (1992) suggest that the Grays Harbor estuary was largely filled by 8,000 BP. A topographic high mapped in Willapa Bay that runs parallel to Long Beach immediately on its shoreward side (Wolf et al., 1998), is shallower than the Columbia River or Grays Harbor estuaries and may have served to shelter this bay from shelf sediment input until the latest Holocene. The crest of the ridge, where it could be mapped is at about –25-30 m, and passages through this ridge cut to about –40 m. Using the sea level curve from Grays Harbor (Peterson and Phipps, 1992), sediment accumulation would have started in Willapa Bay at about 8,000 BP.

A pronounced ravinement surface, which was cut during the Holocene transgression, separates the older estuarine deposits from the overlying, younger marine deposits (Figure 3). The marine deposits, mapped by Wolf et al. (1997), are more extensive in coverage (in map area, but volumes have not yet been calculated) than the estuarine deposits. They reach 45 m thickness on the middle shelf immediately north of the Columbia River, thin southward to Tillamook Head, and pinch out to the north off Grayland (Wolf et al., 1997). This deposit is thickest on the middle shelf and thins both onshore and offshore (Figure 5). Exposed gravel patches on the inner shelf off Grayland and north of Grays Harbor indicate that here the marine deposits are thin and discontinuous. The Holocene marine deposits show as acoustically transparent on the seismic profiles except off the Columbia River where three overlying packages of foreset beds, two of which are shown in Figure 2, appear to indicate the locations of ebb-tidal deltas associated with earlier locations of the river mouth. The oldest is on the outer shelf, and the youngest is on the inner shelf immediately seaward of the modern ebb tidal delta. The foreset sequences are separated by thin packages of flat-lying reflectors which suggests punctuated rather than continuous sedimentation during the formation of this marine deposit. Correlative conformities can be traced away from some of the ebb tidal delta packages, and may help subdivide the Holocene marine deposit into several subunits.

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FIGURES AND FIGURE CAPTIONS:

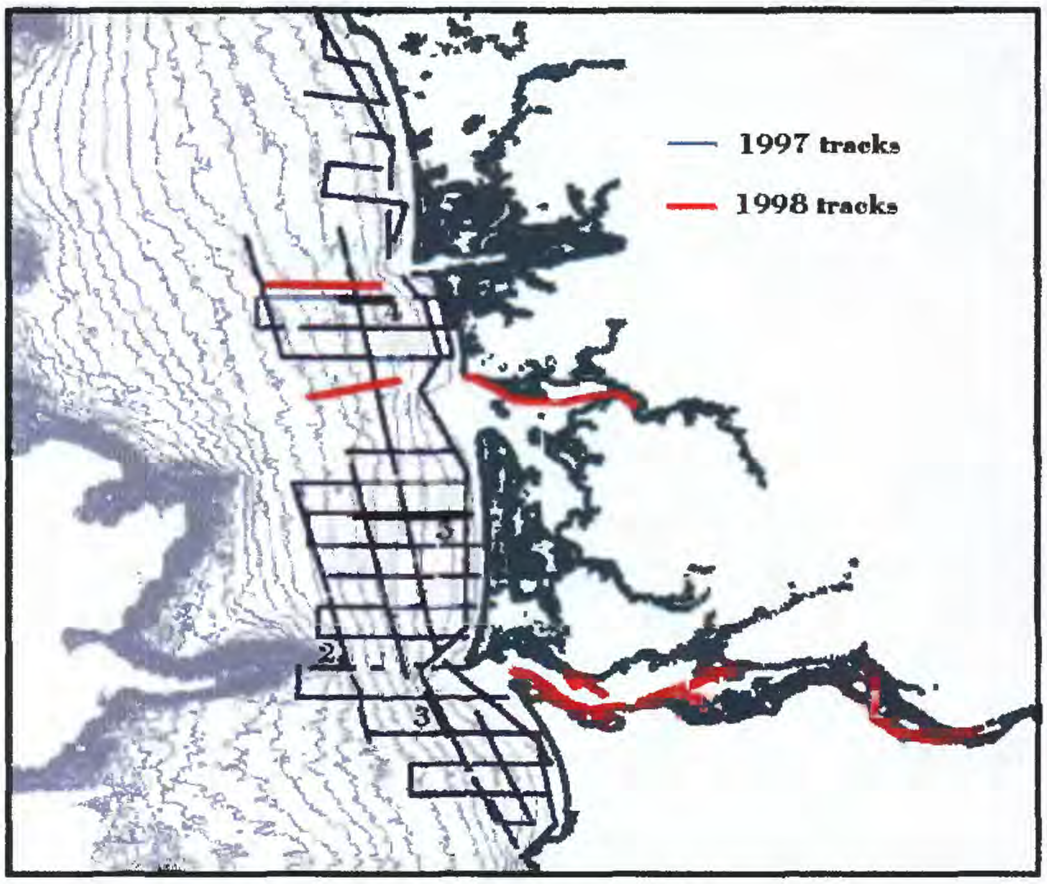

Figure 1. Track map showing the locations of seismic profiles collected aboard the R/V Corliss during 1997 (blue lines) and 1998 (red lines). Numbered black lines show locations of profiles shown in the following figures.

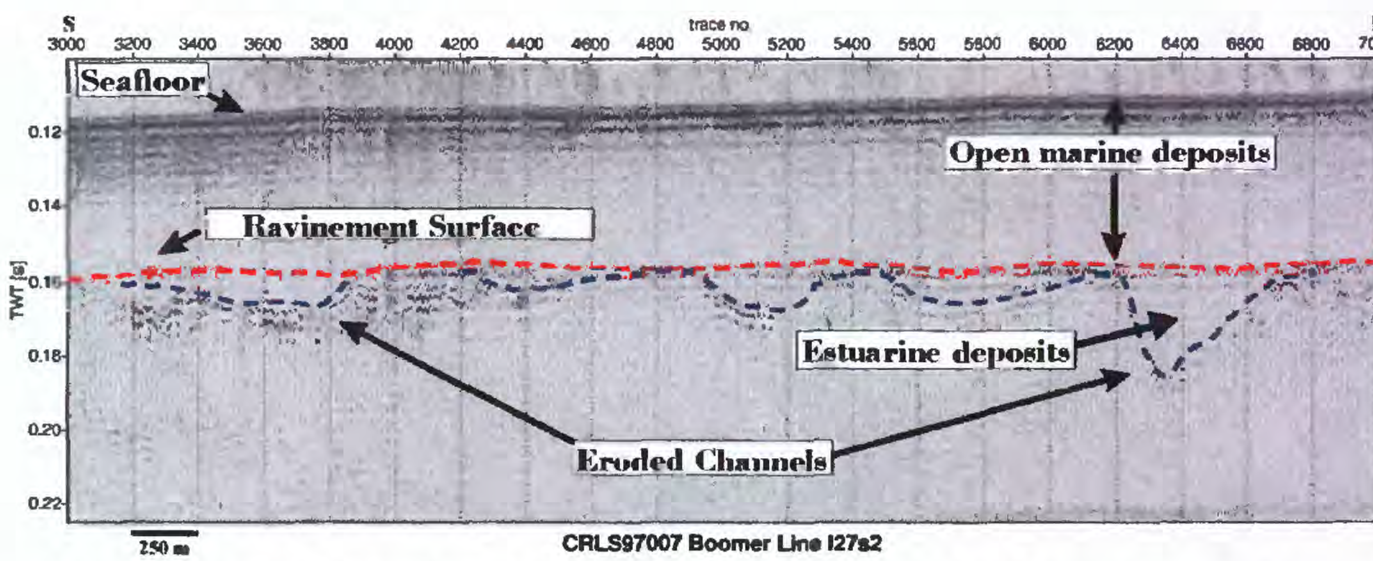

Figure 2. Boomer seismic profile collected on the middle shelf off Cape Disappointment showing the inferred Holocene aged estuarine and open marine deposits. Both deposits are time transgressive, but the older estuarine deposits are separated from the overlying open marine deposits by an erosional ravinement surface. Figure modified from Cross et al., 1998. Profile location shown in Figure 1.

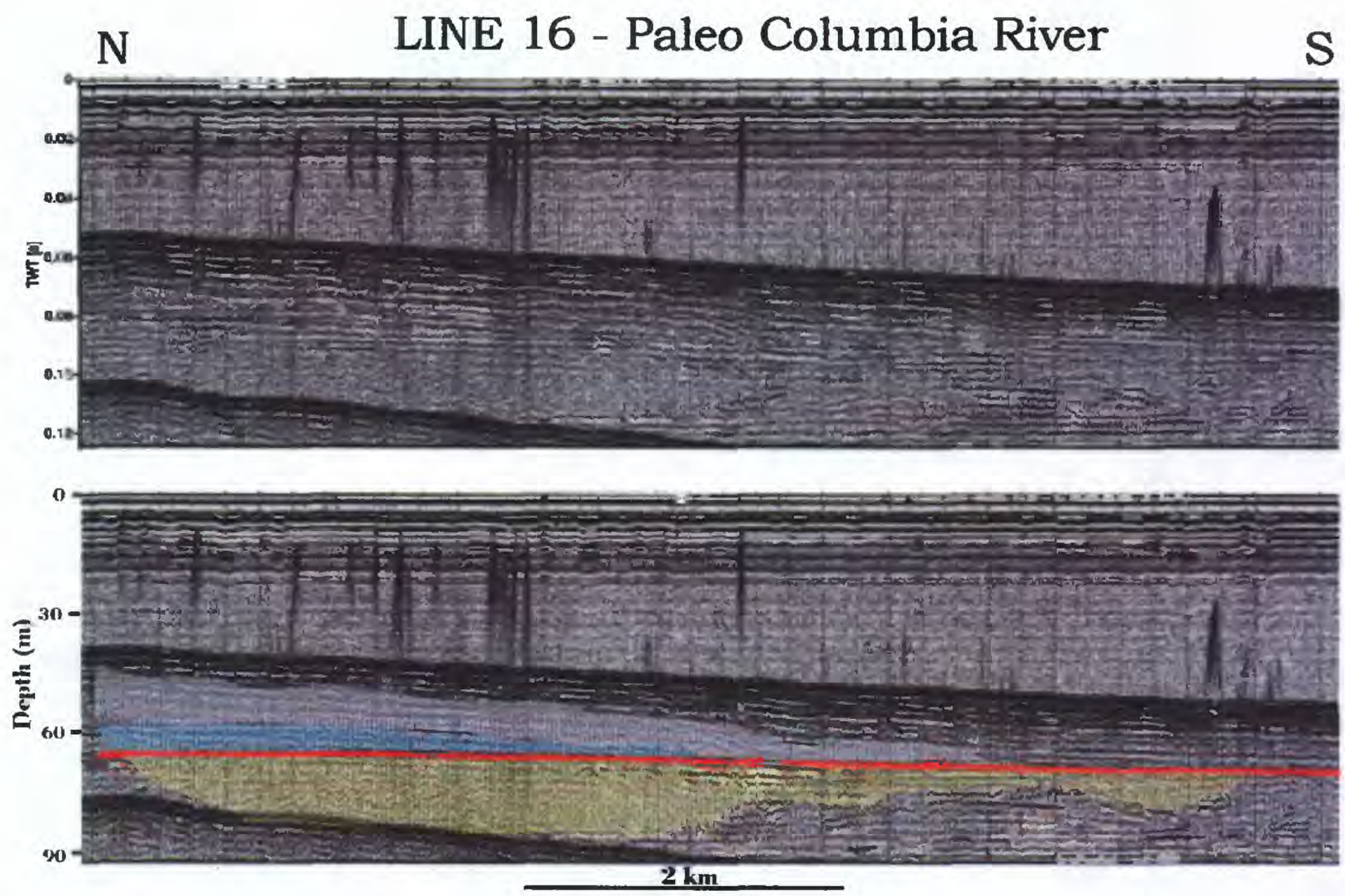

Figure 3. Boomer seismic profile showing the paleo Columbia River valley that was cut during the last lowstand of sea level, the acoustically chaotic sediments that fill the channel (highlighted in yellow), the flat ravinement surface that cuts across the top of the channel fill (red line), and two ebb tidal shoal units that overly the ravinement surface and accumulated in an open marine setting. Profile location shown in Figure 1.

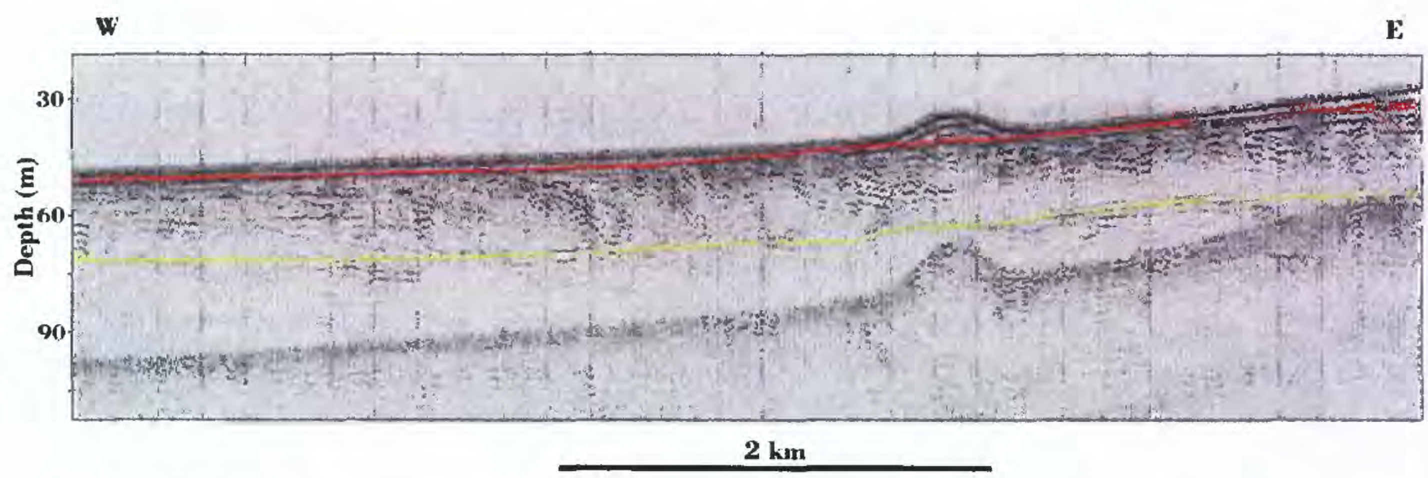

Figure 4. Seismic profile collected in the paleo-river valley offshore of Grays Harbor. The yellow line marks the floor of the river valley that was cut during the last lowstand of sea level, and the red line marks the ravinement surface. Note the shoreward dipping reflectors in the estuarine fill (the interval between the yellow and red lines) which are interpreted to be associated with infilling of the estuary by flood tidal shoals. Location shown in Figure 1.

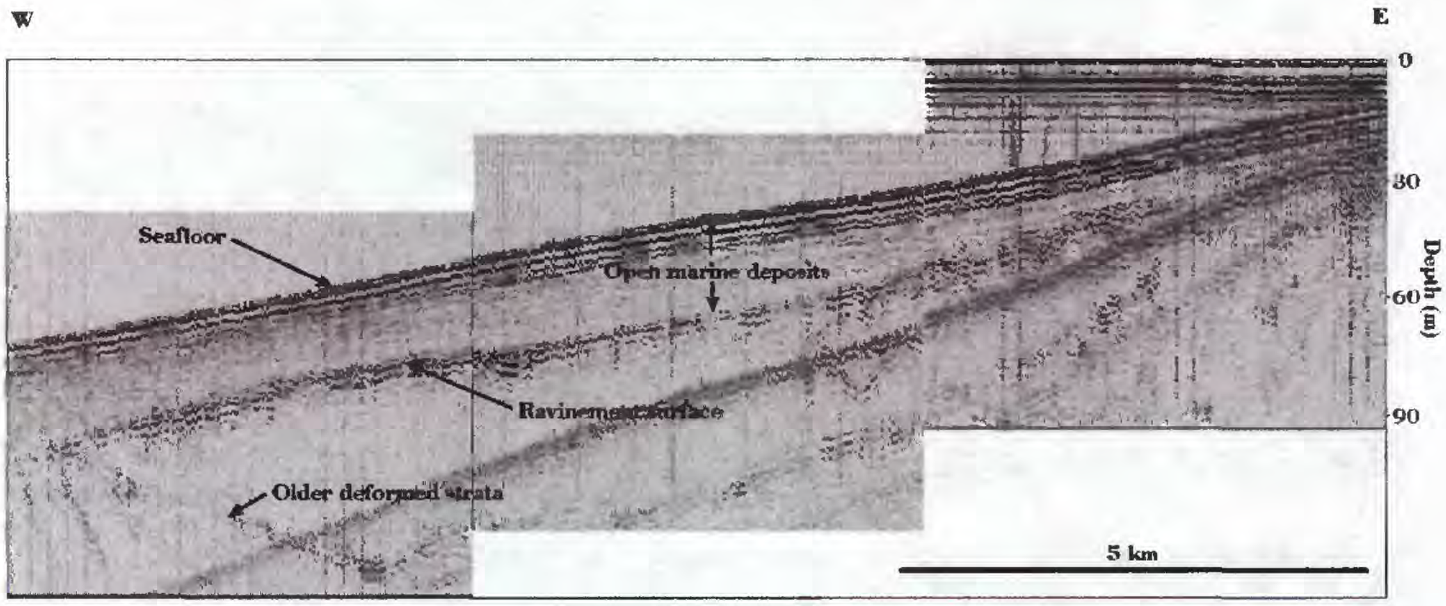

Figure 5. Seismic profile across inner shelf part of the Holocene open marine deposit. Note that it is thinnest nearshore, thickens on the middle shelf, and starts to thin farther offshore. Older deformed strata have largely been planed off by the ravinement surface. Profile location shown in Figure 1

Deep Borehole at the Columbia River Mouth

Curt Peterson, Portland State University
Sandy Vanderburgh, University College of the Frasier Valley
Larry Phillips, U.S. Geological Survey
April Herb, Portland State University
Dave Twichell, U.S. Geological Survey

Rotary mud drilling and split-jar sampling were performed by industry drillers (Geotech Inc.) at a deep bore-hole site near the mouth of the Columbia River, NW Warrenton, Oregon, in September of 1998. The bore hole site was selected on the basis of offshore seismic records (Corliss Cruise 1997) and a nearby geotechnical bore-hole that indicated the proximity of the ancestral valley thalweg. Subsequent seismic lines taken across the Columbia River (Corliss Cruise 1998) further constrain the bore-hole position to the southern side of the low-stand thalweg at a depth of 110-115 m below present sea level. The bore hole site is located about 0.25 km seaward of the oldest beach ridge preserved in the Warrenton area. Spit jar samples (7.5 cm x 75 cm) were taken at five-foot intervals to 100 ft depth, then at ten foot intervals to 370 ft depth. The hole was terminated in low-stand debris flow deposits at 372 ft subsurface depth. The semi-consolidated debris flow is overtopped by river cobble (-365 ft), which is overtopped by river sand (-340 ft), which is overtopped by alternating units of sand and mud to the ravinement surface (-35 ft).

The alternating units of mud and sand (10-30 ft in thickness) imply lateral channel migration during the river-tidal-valley filling (-35 to 250 ft). Potential time lines occur at 75 ft Mazama ash, and at two anomalous flood silt layers (-200 ft and –300 ft). Wood, shells and peat in recovered samples should yield C-14 AMS dates for Columbia valley sediment-level and sea-level curves extending back to low-stand conditions, possibly 14-15 ka. The bore-hole demonstrates throughput of river sand throughout the transgression but, a coarsening upward sequence above –70 ft suggests significantly decreased trapping efficiency after 7 ka. This trend is consistent with extensive ravinement surfaces in early-mid-Holocene time and shoreline progradation in late Holocene time.

Stratigraphy and Tephra Occurrences in Cores from the Southwest Washington Shelf

R. Lawrence Phillips, Gita Dunhill, Steve Wolf
U.S. Geological Survey

Ten gravity cores obtained on the Washington-Oregon shelf from west of Grays Harbor to south of the Columbia River were collected from depths of 63 to 132 m during a cruise of the *R/V Wecoma* (Figure 1). The cores ranged in length from 16 to 151 cm. All cores are intensely bioturbated and contain organic-rich sediment with rare to abundant glass shards. The sand size fraction varies in abundance ranging from 78 to 82 percent in the south changing to 23 to 79 percent in the northern cores. The deepest core, core 4 at 132 m depth, is remarkably uniform in sand composition ranging from 71 to 80 percent (Figure 2). Cores 4, 6, and 7, contain distinctive "green sand" composed of abundant green mica and glauconite.

The sand fraction consists of well-sorted fine sand containing glass shards, shells and shell fragments, diatoms, radiolaria, benthic and rare planktonic foraminifers, brown to black fibrous lignite, and wood fragments. The glass shards, which based on heavy liquid separations form up to 60 percent of the sand fraction, consist of rare black and clear bubble wall shards, and white, cream to yellowish tan very abundant vescicular shards. The shards are found throughout all cores to depths of 151 cm (our longest core, C-3 at 84 m depth) taken northwest of Willapa Bay. The multiple types and varying colors of the shards suggest multiple tepha sources that after deposition have been mixed by intensive bioturbation.

Directly west of the Columbia River at 65 m depth and 60 cm below the sea floor a 45 cm thick bioturbated mud bed, rich in glass shards, represents a major depositional event of Mt. St. Helens (?) tephra deposited on the shelf that may correlate with glass-rich strata found to the north. The highest concentration of glass shards occurs in sediment found 23 to 60 cm below the seabed in a bioturbated stratigraphic interval ranging in thickness from 40 to 75 cm (Figure 3). The greatest abundance of glass shards is found in core 6 (106 m) located west of Grays Harbor where the shards form up to 60 percent of the sand fraction. Glass shards are also found in surficial sediments on the outer shelf to at least 130 km north of the Columbia River (our northern most sample) but are absent or very rare in the inner shelf samples. Based on surface samples, Harmon (1972), identified a "pumice" belt associated with wood fragments on the mid-shelf to north of Willapa Bay showing that shards are a common feature in the shelf sediments. Ridge and Carson (1987) documented on the Washington shelf the rapid northward transport of silt-size glass particles derived from the 1980 Mt. St. Helens eruption showing that currents as well as airfall tephra can disperse the volcanic sediments.

Physical structures within the cores are rare with possible storm deposits identified by truncated strata, shell lags, horizontal laminations, and a local increase in the sand-size fraction. The storm deposits are only identified in three cores at depths of 65, 84, and 106 m. The intense bioturbation of the strata suggests slow sedimentation rates on the shelf.

Sedimentation rates of 3.3 cm/yr are determined for core 1 west of the Columbia River mouth decreasing northward to 2.2 cm/yr (core 8) to 1.3 cm/yr (core 7). This assumes that the strata containing the abundant glass shards represents the initial Mt. St. Helens tephra deposit from the 1980 eruption. The assumption that the strata containing the major glass shard abundance represents the 1980 Mt. St. Helens eruption is tentative. A thin surficial glass shard concentration may only represent sediment from the 1980 eruption with the deeper glass shard occurrences representing an older, possible the 3,500 year Mt. St. Helens Smith Creek eruptions where tephra was transported to the west or an older event as the 6,760 year Mt. Mazama tehpra? The occurrence of at least two glass shard peaks in core 4 suggests more than one major tephra deposit may be present on the shelf. Until the tephra beds are identified as to source the conclusions presented here are speculative. However, the rapid northward dispersion of the tephra confirms the dominance of the northward flowing currents and sediment transport on the Washington shelf.

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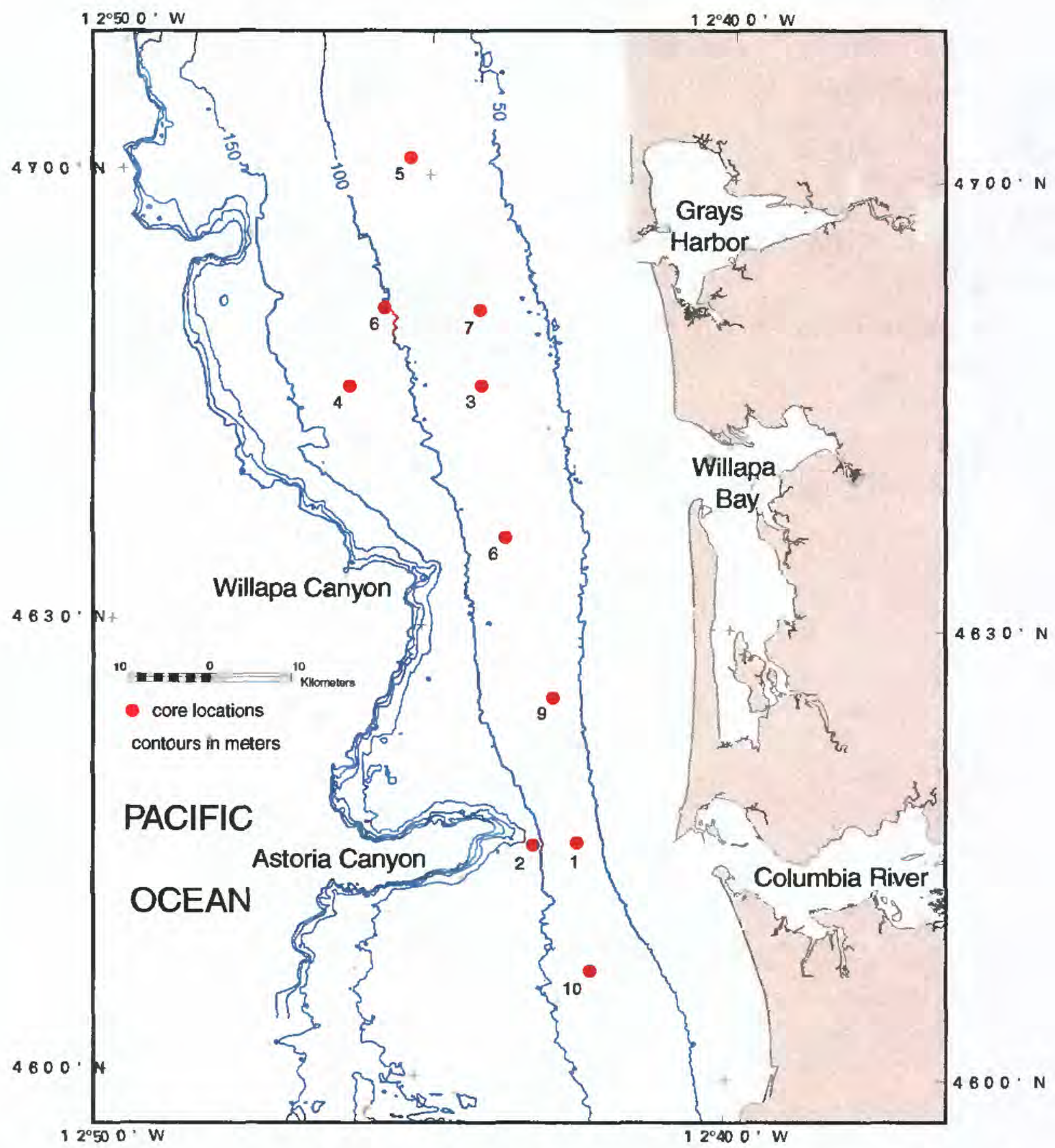

Core No.	Latitude	Longitude	Bottom Depth	Core Length	Core No.	Latitude	Longitude	Bottom Depth	Core Length
1	46°14.92'N	124°14.02'W	65m	1.35m	6	46°49.98'N	124°35.96'W	106m	0.06m
2	46°15.02'N	124°20.66'W	133m	0.16m	7	46°49.93'N	124°25.89'W	75m	0.80m
3	46°45.00'N	124°25.40'W	84m	1.51m	8	46°35.81'N	124°22.14'W	81m	0.95m
4	46°44.96'N	124°39.90'W	132m	1.15m	9	46°24.01'N	124°17.04'W	63m	0.61m
5	46°59.94'N	124°32.01'W	75m	0.47m	10	46°08.02'N	124°12.99'W	85m	0.52m

Figure 1. Core locations

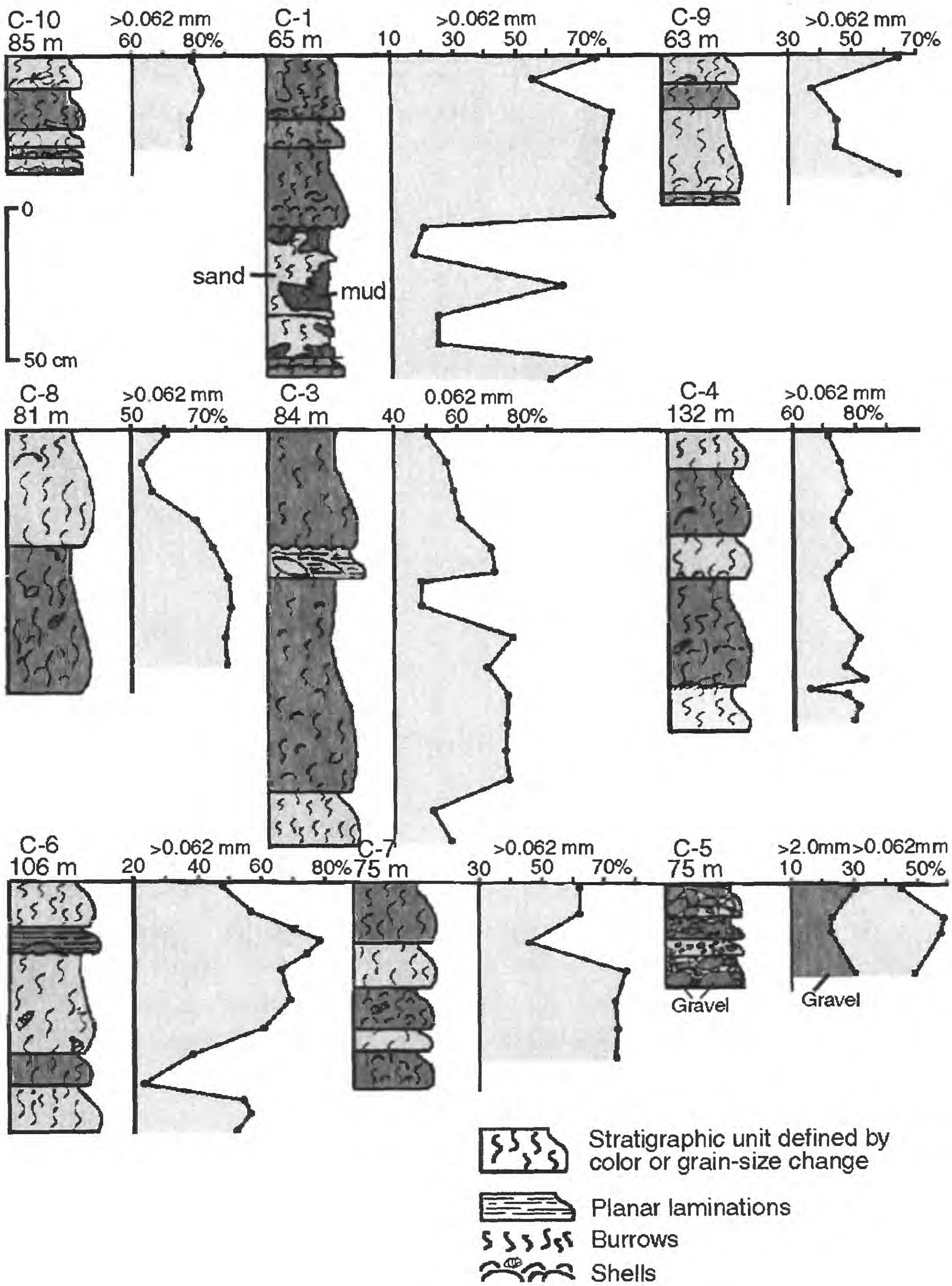

Figure 2. Stratigraphy and sand fraction distribution in cores from the southwest Washington and northern Oregon shelf. Core 1 contains a bioturbated mud bed in the basal 50 cm.

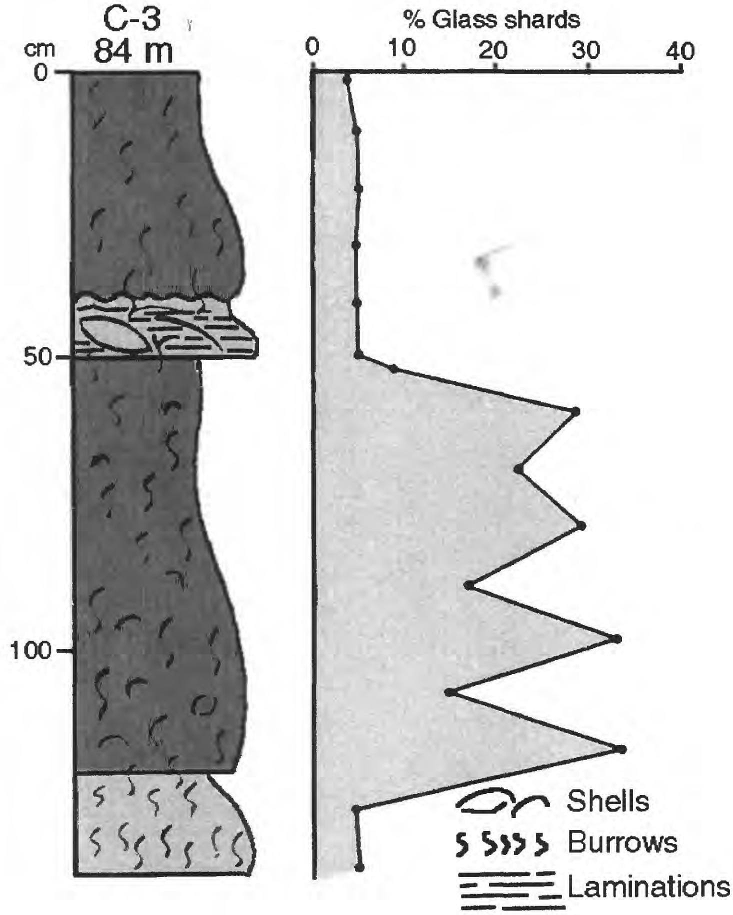

Figure 3. Glass shard weight percent in sand fraction in core C-3. The glass fraction was separated (floated) with heavy liquids.

Prehistoric Sediment Budget Study - Geological-Scale Modeling

Maarten Buijsman, WA Department of Ecology
Curt Peterson, Portland State University
Guy Gelfenbaum, U.S. Geological Survey

In this study the prehistoric sediment budget data has been tested using the Advection-Diffusion-Model (ADM) (Niedoroda et al., 1995). The main question in this case is: How large was the sediment source of the Columbia River during prehistoric times? The ADM model describes the onshore advection and the offshore diffusion of sediment on a cross-section of the shoreface including the shelfbreak. The fundamental forcing is sea-level rise, littoral bypassing and shoreface-shelf coupling. The modeled period is from 7000 BP to present and describes the progradation of the Columbia littoral cell.

The data used for this initial test is very scarce and contains many uncertainties. Various studies including Sternburg (1986) and Peterson et al. (1997) present different figures about the sources and sinks determining the (pre) historic sediment budget. These figures are:

Values*10^6 m^3/yr	Columbia river (source)	Tidal basins (sink)	Shelf break (sink)	Net input
Sternberg (1986); low	4.5	0.7	0.6	3.2
Sternberg (1986); high	17.5	0.7	2.4	14.4
Peterson et al (1997)	24.5	0.7	3.3	20.5

Another uncertainty is the rate of sea-level rise. The only available sea-level curve is that of Peterson and Phipps (1992) which was derived for Grays Harbor. Because of the tectonic variability within the littoral cell, there is a question of how representative this curve is for the rest of the coast. The parameters used to determine the advection and diffusion in the model are based on default settings. For most of the parameters it is hard to determine a representative value for the modeled period. The littoral cell as a whole has been mapped to one representative cross-shore profile. All the figures describing the sources and sinks are averaged over the length of the littoral cell, approximately 150 km in length. This reduction from 2D to 1D is inherent to the model concept. However it introduces an error. Another important question is: What is the shape of the initial shelf profile 7000 years ago?

All these questions and uncertainties result in various scenario's. Calculations with the ADM model show that the Columbia River source can range between 3.2 and 14.6 million cubic meters per year (closer to 14.6 than to 3.2 10^6 m^3/yr). The net input based on the study of Peterson et al.

(1997) seems too large. More study is needed to overcome the uncertainties mentioned in the above.

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Historical Sediment Budget Study

Maarten Buijsman, Richard Daniels, Steve Eykelhoff
WA Department of Ecology

INTRODUCTION

During the last 100 years the coast of the Columbia River littoral cell has gained a huge amount of sediment. These morphological changes have been quantified using a Digital Elevation Model (DEM), and shorelines from 1870, 1885, the 1950's and 1995. The DEM and shorelines have been used to calculate the gain and loss of sediment onshore. In this particular study we consider the theory, the results, conclusions and some remarks.

THEORY

The Digital Elevation Model used was derived from USGS and Forest Service 7.5 minute DEMs originally obtained from the USGS. The composite DEM has a grid size of 30 x 30 m. It is based on topography obtained from the period 1950 to 1970. The original datum was NGVD 29. For our purpose the DEM has been translated to NAVD88, which is approximately 1 m below NGVD 29 within the study area. Between these two datums there is no data.

The original DEM data was processed by the USGS and organized into three classification levels (Maune. 1996). Level-1 DEMs are elevation data created by scanning and photo-interpreting National High Altitude Photography (NHAP)/NAPP photography. A vertical RMSE (root mean square error) of 7 meters is the desired accuracy standard. A RMSE of 15 m is the maximum permitted error. Level-2 DEMs elevation data sets have been processed or smoothed for consistency and edited to remove identifiable systematic errors. A RMSE of one-half contour interval is the maximum permitted error. In our study area this equates to 3 m. Level-3 DEMs are derived from Digital Line Graph data by incorporating selected elements from both hypsography (contours, spot elevations) and hydrography (lakes, shorelines, drainage). A RMSE of one-third of the contour interval is the maximum permitted. All the 7.5-minute DEMs used in this study are Level-1 or 2 DEMs.

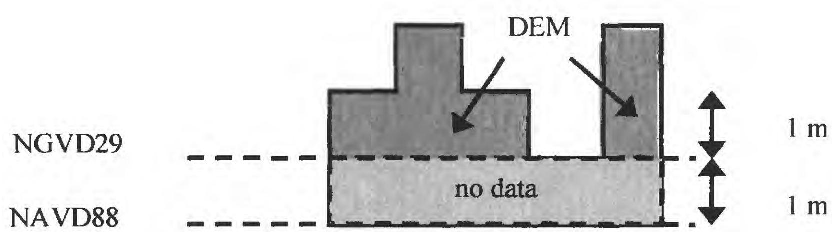

Figure 1. Schematic representation of the DEM volume.

All elevations contained within the original data sources were rounded to the nearest meter. Thus, the minimum elevation shown is 1 m. For that reason we determine the 2-m NAVD88 contour as the shoreward boundary of our modified DEM. The DEM is schematized in Figure 1.

The Columbia River littoral cell mainly consists of two coastal systems: the inlets with the ebb-tidal deltas and the straight coast in between. For the major part of the coast the 1870/1885 shoreline lies landward, the 1995 shoreline lies farthest offshore and the 1950's coastlines lie in between. For most of the coast the historical shape of the profiles is not known (profiles were collected by DOE in the years 1997 and 1998). Therefore we assume a Bruun-like behaviour of the coast between the deltas (Bruun, 1962). In this theory it is assumed that the shape of a profile remains constant. Any sediment loss or gain affects the profile from closure depth up to the top of the first dune. By neglecting sea-level rise the profile can only move horizontally without loosing its shape. In Figure 2 we see the application of this rule to a cross-section of the littoral cell. The shaded area is equal to the volume between the 1870/1885 and the1950's profiles.

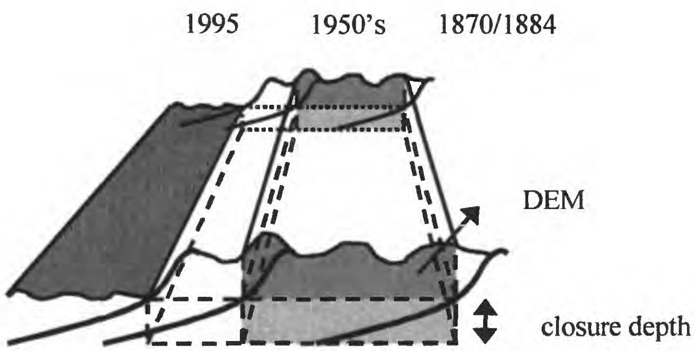

Figure 2. Application of the Bruun-rule to the DEM.

The position of the shorelines is average high water (Kaminsky et al., 1997), except for the 1885 Oregon coastline, which indicates the toe of the primary dune, equivalent to the storm high water line (Reckendorf, 1998). We will consider this in the next section as well.

In the DEM there is no data below the level of NGVD 29, implying that the actual volume changes below NGVD 29 are not known. To assess the volume below NAVD88 we need to calculate the depth of closure. The depth of closure is determined with formulas of Hallermeier (1981):

$$h_c \cong 2.28 \cdot H_e - 68.5 \cdot \left(\frac{H_e^2}{g \cdot T_e^2} \right) \quad (1)$$

$$h_c \cong 2 \cdot \overline{H_{sig}} - 11 \cdot \sigma \quad (2)$$

and Birkemier (1985), who adjusted formula (1):

$$h_c \cong 1.75 \cdot H_e - 57.9 \cdot \left(\frac{H_e^2}{g \cdot T_e^2} \right) \quad (3)$$

and who derived the simple relation :

$$h_c \cong 1.57 \cdot H_e \qquad (4)$$

Where:

h_c	=	depth of closure;
H_e	=	nearshore storm wave height that is exceeded only in 12 hours each year;
T_e	=	the associated wave period;
g	=	acceleration due to gravity;
$\overline{H}_{sig}$	=	mean significant wave height;
σ	=	standard deviation of the mean wave significant wave height;

To determine the depth of closure, we used wave data from the Grays Harbor buoy from September 1993 to August 1998 and data from Ruggeiro et al. (1997). Wave heights and periods used in equations (1), (3) and (4) are ballpark figures. The results are presented in Table 1.

Table 1.

Formula	h_c (MSL) (m)	H (m)	T (s)	σ (m)
Hallermeier (1)	16.25	8	15	
Hallermeier (2)	16.93	2.04	9.46	1.17
Birkemeier (3)	12.32	8	15	
Birkemeier (4)	12.56	8		

The Hallermeier formulas calculate a closure depth of 16-17 m below MSL (15-16 m below NAVD88). The adjusted Birkemeier formulas give an answer ranging between 12-13 m below MSL (11-12 m below NAVD88). There is not an unambiguous value of the closure depth. The difference between the answers is about 4.5 m. In regard to the calculation of the volumes below NAVD88 the adjusted Birkemeier formulas give a more realistic answer than the Hallermeier formulas.

RESULTS

The whole cell is divided in sections of approximately 5 km alongshore in length (Figure 3). Some sections are larger or smaller because they show erosion since the 1950's (WP, LBDs) or 1870's (LBC7) or they are near an inlet. For all the sections a best volume has been calculated. This method is explained in the following. In a large part of the cell the DEM 2 m contour (which is close to average high water) is close to the 1950's shoreline position. The coverage of the DEM between the 1950's and 1995 shorelines is moderate. The total area between the 1995 and 1870 (1884) shorelines has approximately 60% DEM coverage. The total area up to the 1950's shorelines is covered by about 80%. The volume of the non-covered area in each section is estimated by multiplying this area with the

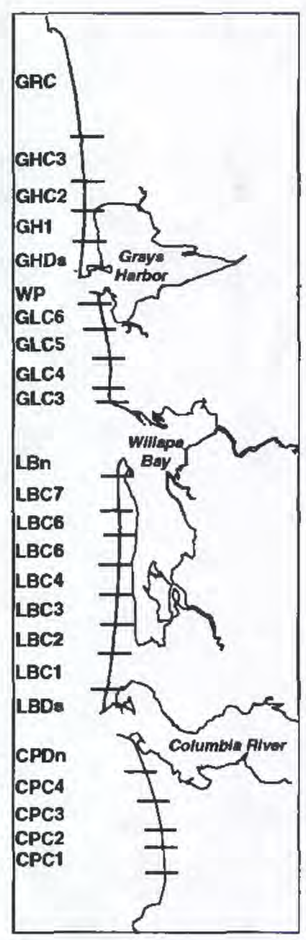

Figure 3. Sections

average height of the covered area of that section. In all these sections there is less coverage in the offshore direction. In some sections (WPnd, GLC3, LB7 and LBC6, LBDs and CPDn) the DEM coverage is very scattered. In these areas there is no data above NGVD29 (+1 m NAVD88) and below the DEM 2 m. In these cases the no-data areas are given a volume of 1 m^3/m^2 above NAVD88 (see Figure 1).

It is not possible to calculate an accurate volume of Cape Shoalwater, because elevation data for the period 1870-1995 is not available. At the end of this section we will present some estimated figures. The most southern 5 km of Clatsop Plains is not taken into account. The historical shorelines for this area are not available. In CPC1 the data of the 1950's shoreline is not available. The volumes of 1950-1885 and 1995-1950 for CPC1 are not included in the figures.

The 1950's and 1995 shorelines in Oregon are at AHW. The 1885 shoreline however is the storm high water line (bluff of dune). In fact we are comparing different kinds of shorelines. Therefore it is not completely correct to use those shorelines in the Bruun-rule procedure.

The accreted and eroded volumes above NAVD88 are presented in Figure 4. See Table 2 for an overview of all the volumes. The largest accreted volume in the period from 1870 (1885) to 1995 can be found in section GHDs (~39 million m^3). The largest changes occurred before the 1950's. The changes after 1950 are significantly smaller. The most accreted sub-cells are North Beach, Long Beach and Clatsop. In the Results section we will discuss possible causes of the volume changes.

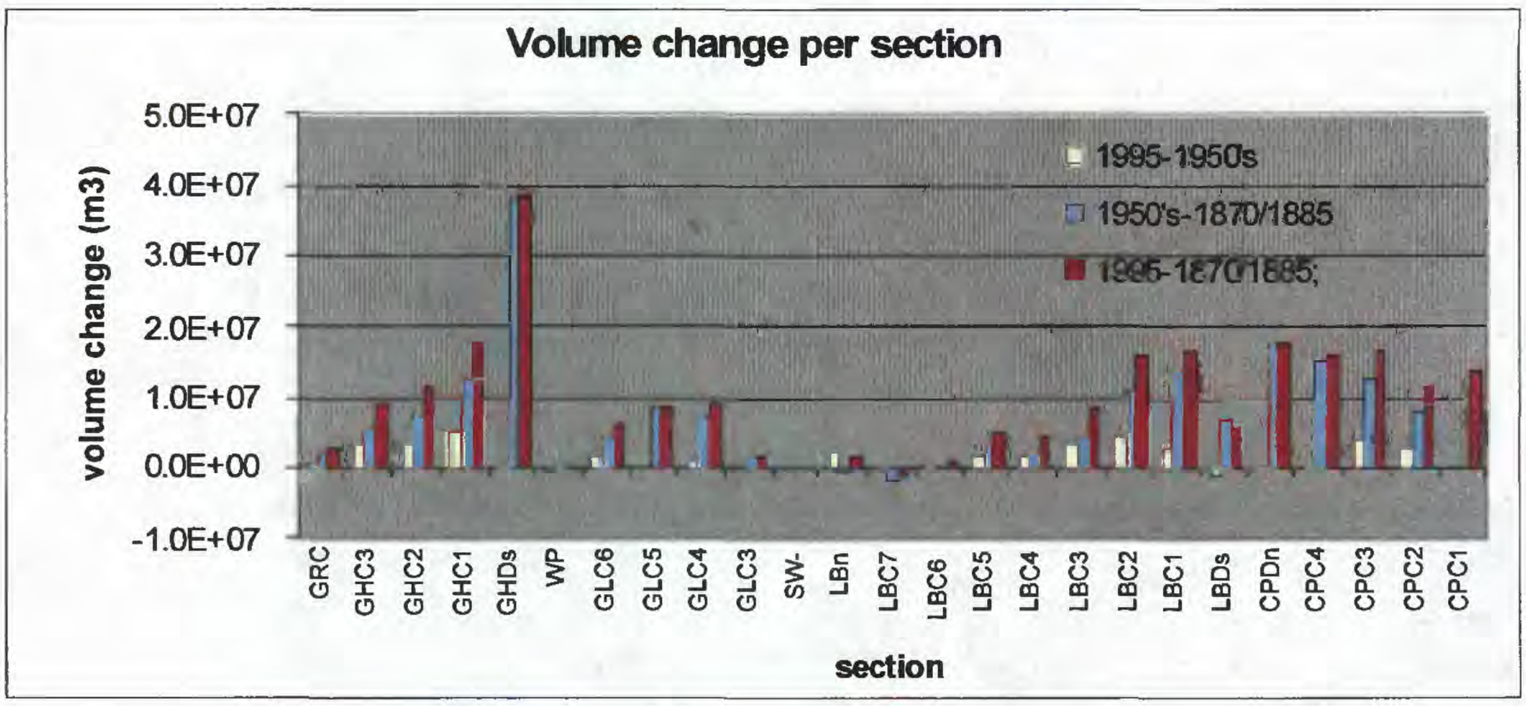

Figure 4. Volume change above NAVD88 per section.

The volume change above NAVD88 per sub-cell is listed in Table 3. The net gain of the Columbia River littoral cell up to 1995 above NAVD88 is about 247 million m^3 (DEM volume).

Table 2. Overview of the areas and volumes for each section.

	DEM								active depth				DEM + <NAVD88						
	1995-1870/1885;		1950's-1870/1885		1995-1950's				50-1870	50-1870	95-50	95-50	1950-1870/1885;	1995-1950;	1995-1950	1995-1870/1885,	1995-1870/1885;	%DEM 1996	%DEM 1950
	area	vol	area	vol	area	vol	h1950	length m					12 m	12 m	16 m	12 m	16 m	0	0
GRC	1.21E+06	3.25E+06	1.01E+06	2.62E+06	1.99E+05	6.27E+05	2.59E+00	19000	12.0	16.0	12.0	16.0	1.48E+07	3.01E+06	3.81E+06	1.78E+07	2.27E+07	100	100
GHC3	2.28E+06	9.40E+06	1.46E+06	5.98E+06	8.20E+05	3.42E+06	4.09E+00	7000	12.0	16.0	12.0	16.0	2.35E+07	1.33E+07	1.65E+07	3.68E+07	4.59E+07	73	100
GHC2	2.71E+06	1.16E+07	1.80E+06	7.71E+06	9.07E+05	3.88E+06	4.28E+00	5000	12.0	16.0	12.0	16.0	2.93E+07	1.48E+07	1.84E+07	4.41E+07	5.49E+07	65	98
GHC1	3.76E+06	1.84E+07	2.66E+06	1.30E+07	1.10E+06	5.38E+06	4.89E+00	5000	12.0	16.0	12.0	16.0	4.49E+07	1.86E+07	2.30E+07	6.35E+07	7.86E+07	70	99
GHDs	8.33E+06	3.87E+07	8.21E+06	3.82E+07	1.19E+05	5.54E+05	4.65E+00	6200	2.4	2.4	12.0	16.0	5.77E+07	1.98E+06	2.46E+06	5.97E+07	6.02E+07	82	84
WP	2.52E+05	4.13E+05	6.21E+05	1.00E+06	-3.69E+05	-5.88E+05	1.61E+00	1900	1.0	1.0	12.0	16.0	1.62E+06	-5.02E+06	-6.49E+06	-3.39E+06	-4.87E+06	30	28
GLC6	1.41E+06	6.69E+06	9.64E+05	4.58E+06	4.46E+05	2.12E+06	4.75E+00	4200	12.0	16.0	12.0	16.0	1.61E+07	7.47E+06	9.26E+06	2.36E+07	2.93E+07	68	99
GLC5	1.66E+06	9.18E+06	1.65E+06	9.07E+06	1.28E+04	1.03E+05	5.49E+00	5000	12.0	16.0	12.0	16.0	2.89E+07	2.57E+05	3.08E+05	2.91E+07	3.58E+07	100	100
GLC4	2.11E+06	9.19E+06	1.72E+06	7.51E+06	3.85E+05	1.68E+06	4.36E+00	5000	12.0	16.0	12.0	16.0	2.82E+07	6.30E+06	7.84E+06	3.45E+07	4.29E+07	81	99
GLC3	1.31E+06	2.20E+06	1.03E+06	1.93E+06	2.79E+05	2.79E+05	1.86E+00	2200	2.5	2.5	2.5	2.5	4.51E+06	9.75E+05	9.75E+05	5.49E+06	5.49E+06	32	40
SW-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4200	0.0	0.0	0.0	0.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0
LBn	2.03E+05	2.15E+06	-1.28E+05	-1.28E+05	1.70E+06	2.72E+06	0.00E+00	3000	2.1	2.1	2.1	2.1	-4.00E+05	6.35E+06	6.35E+06	5.51E+06	5.51E+06	19	0
LBC7	-9.09E+05	-9.09E+05	-1.45E+06	-1.45E+06	5.42E+05	5.42E+05	0.00E+00	6100	12.0	16.0	12.0	16.0	-1.89E+07	7.04E+06	9.21E+06	-1.18E+07	-1.55E+07	0	0
LBC6	4.46E+05	1.15E+06	6.08E+04	3.28E+05	3.85E+05	9.89E+05	0.00E+00	4000	12.0	16.0	12.0	16.0	1.06E+06	5.61E+06	7.15E+06	6.49E+06	8.28E+06	36	100
LBC5	1.13E+06	5.57E+06	6.56E+05	3.44E+06	4.77E+05	2.14E+06	5.25E+00	5000	12.0	16.0	12.0	16.0	1.13E+07	7.86E+06	9.77E+06	1.92E+07	2.37E+07	76	100
LBC4	1.50E+06	4.63E+06	7.91E+05	2.45E+06	7.07E+05	2.19E+06	3.09E+00	5000	12.0	16.0	12.0	16.0	1.19E+07	1.07E+07	1.35E+07	2.26E+07	2.86E+07	50	95
LBC3	2.19E+06	8.87E+06	1.24E+06	5.06E+06	9.50E+05	3.81E+06	4.07E+00	5000	12.0	16.0	12.0	16.0	2.00E+07	1.52E+07	1.90E+07	3.52E+07	4.39E+07	60	100
LBC2	3.06E+06	1.63E+07	2.10E+06	1.12E+07	9.62E+05	5.13E+06	5.33E+00	5000	12.0	16.0	12.0	16.0	3.64E+07	1.67E+07	2.06E+07	5.30E+07	6.53E+07	54	79
LBC1	3.81E+06	1.68E+07	3.13E+06	1.38E+07	6.82E+05	3.01E+06	4.41E+00	5900	12.0	16.0	12.0	16.0	5.14E+07	1.12E+07	1.39E+07	6.26E+07	7.79E+07	50	61
LBDs	2.77E+06	5.93E+06	3.89E+06	7.05E+06	-1.12E+06	-1.12E+06	1.81E+00	3500	3.2	3.2	3.2	3.2	1.95E+07	-4.71E+06	-4.71E+06	1.48E+07	1.48E+07	30	22
CPDn	7.52E+06	1.82E+07	7.20E+06	1.79E+07	1.11E+04	1.11E+04	0.00E+00	5100	2.4	2.4	12.0	16.0	3.53E+07	1.44E+05	1.89E+05	3.58E+07	3.58E+07	64	67
CPC4	3.02E+06	1.65E+07	2.85E+06	1.56E+07	1.89E+05	9.21E+05	5.46E+00	5000	12.0	16.0	12.0	16.0	4.98E+07	2.94E+06	3.62E+06	5.28E+07	6.48E+07	91	96
CPC3	2.31E+06	1.72E+07	1.76E+06	1.31E+07	5.50E+05	4.10E+06	7.44E+00	5000	12.0	16.0	12.0	16.0	3.43E+07	1.07E+07	1.29E+07	4.58E+07	5.43E+07	70	92
CPC2	1.25E+06	1.17E+07	9.03E+05	8.43E+06	3.46E+05	3.23E+06	9.33E+00	3200	12.0	16.0	12.0	16.0	1.93E+07	7.39E+06	8.77E+06	2.86E+07	3.16E+07	62	86
CPC1	1.47E+06	1.41E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.61E+00	4500	12.0	16.0	12.0	16.0	0.00E+00	0.00E+00	0.00E+00	3.17E+07	3.76E+07	62	0

Table 3. Volume change per section

($*10^6\ m^3$)	1995-1870 (1885)	1950-1870 (1885)	1995-1950
Ocean Shores	81	67	14
Grayland	28	24	4
Long Beach	61	42	19
Clatsop	78	55*	8*
Sum	247	188*	45*

The results do not change much when calculating the volume change per section length (shore-parallel length of section). The volume change per section length is presented in Figure 5.

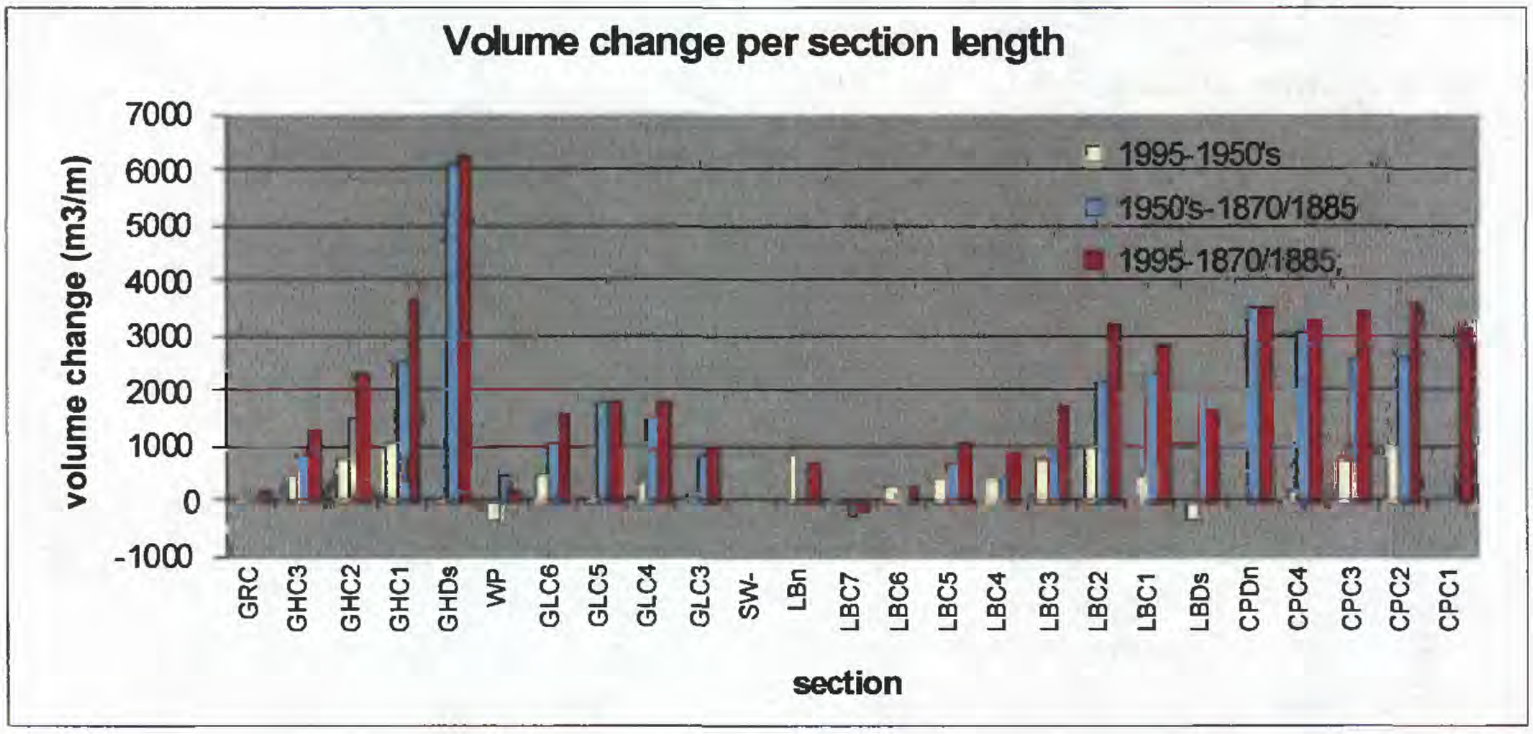

Figure 5. Volume change above NAVD88 per section length

So far only the changes above NAVD88 have been considered. For the changes below NAVD88 the depth of closure is needed. The Bruun-rule is applied for the sections in between the deltas. The sections GHDs, WP, GLC3, LBn, LBDs and CPDn are treated differently. Those sections are part of ebb-tidal delta system. For the period up to the 1950's, the volumes of all sections closest to the inlets are calculated by multiplying the accreted areas with the average accreted depth below NAVD88. The average depth for all these cases lies around 2-3 m below NAVD88. The general trend of the sections adjacent to the inlets with jetties is upper-shore accretion and offshore erosion. After the 1950's, the volumes of these particular sections are calculated by applying the Bruun-rule and depth of closure. The reason to do this is that in particular for the sections GHDs, WP and CPDn the ebb-tidal delta is no longer attached to the beach system. This does not apply for the sections GLC3, LBn and LBDn. They are treated the same as in the period before the 1950's. The total volume change is calculated for the case with a depth of closure of 12 and 16 m relative to NAVD88.

* CPC1 not included

In Table 4 an overview is given of the total (DEM + volume below NAVD88) volumes for several periods and for closure depths of 12 and 16 m. As a comparison the DEM volume from 1870-1995 is mentioned as well. The volume determined with the closure depth 12 m determines about 65% of the total volume. The total volume for the case of closure depth 16 m is about 20% larger than the one for closure depth 12 m.

Table 4.

($*10^6$ m^3)	1995-1870/1885 DEM	1995-1870/1885 Total; 12 m	1950-1870/1885 Total; 12 m	1995-1950 Total; 12 m	1995-1870/1885 Total; 16 m
Ocean Shores	81	222	170	52	262
Grayland	28	89	79	10	109
Long Beach	61	208	132	76	252
Clatsop	78	192	139*	21*	224
Sum	247	711	521*	159*	848

In Figure 6 the total volume changes per section are presented. In Figure 7 it can be seen that the global trends do not change much when divided by section length.

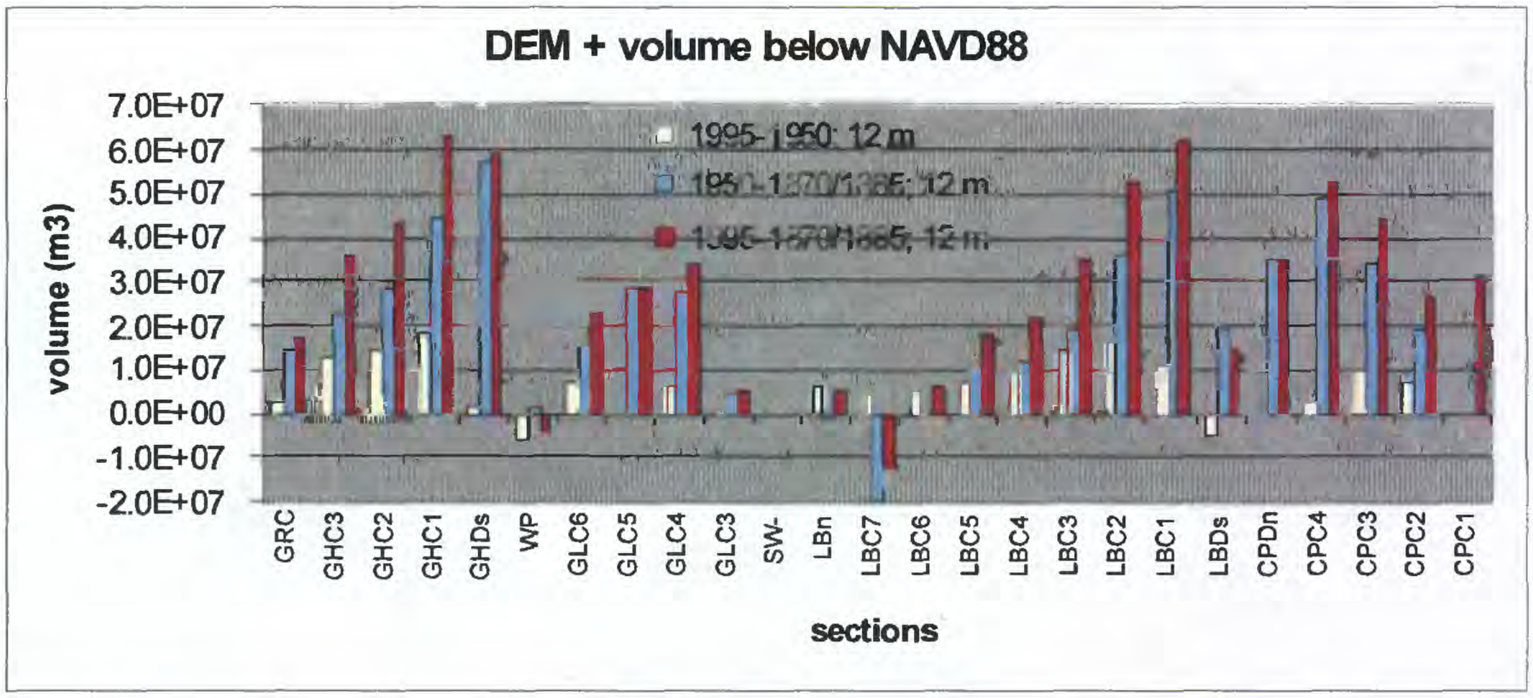

Figure 6. Total volume for the case closure depth equals 12 m.

* CPC1 not included

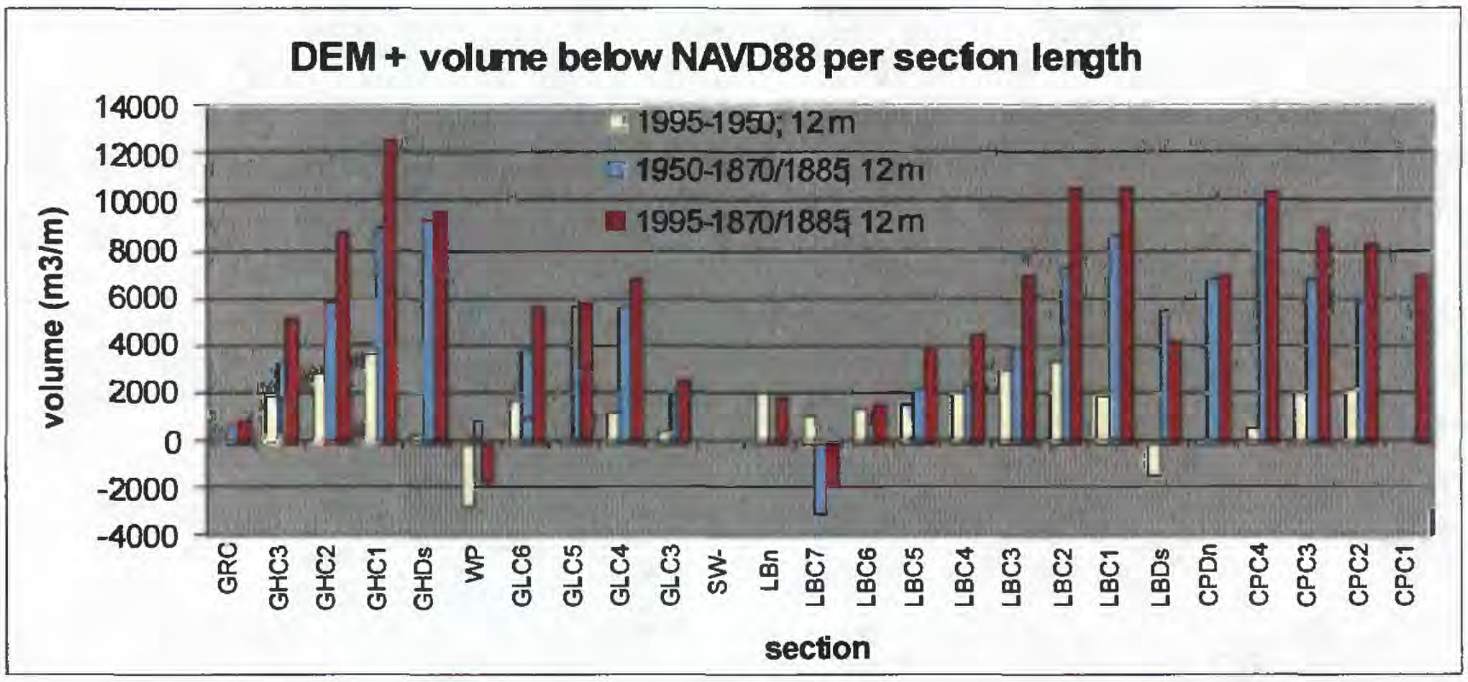

Figure 7. Total volume per section length for the case closure depth equals 12 m.

Looking at the trend we see several differences between the graphs representing total volume (Figure 4) and only DEM volume (Figure 6). The peaks in the DEM results have been smoothened out (compare GHDs). In the case of the total volume we see erosion in WP over the whole period from 1870 to 1995. As regards the DEM we only see accretion for the same period. The reason is that after the 1950's the assumed active depth has increased (from 1 to 12 (16 m)), and thus the total eroded volume (see Table 2).

The total volume change per section per year is presented in Figure 8. The same volume changes per section length are presented in Figure 9. In both graphs the depth of closure equals 12 m. In this analysis the changes are calculated since the last year of jetty construction. It is assumed that the largest changes occurred after jetty construction. The construction years are listed in Table 5.

Table 5. Construction dates of the Columbia River and Grays Harbor jetties.

	Columbia River		Grays Harbor	
	South Jetty	**North Jetty**	**South Jetty**	**North Jetty**
Started	1885	1913	1898	1907
Finished	1895	1917	1902	1913

Another important aspect to calculate the rates is the length of the period between the shorelines. These dates are presented in Table 6. There is a lot of fluctuation between and even within the sub-cells.

Table 6. Dates of shorelines

	1800's	**1950's**	**1995**
Ocean Shores	1886/87	1950/51	1995
Grayland	1896	1950/51	1995
Long Beach	1871/72/73,	1950/57	1995
Clatsop	1885	1948/57	1995

The third aspect that is included in this analysis is the pre-historical shoreline change rates (Woxell, 1998). These rates are used for the period from the pre-jetty shoreline to the last year of jetty construction. For example, the change rate for Ocean Shores for the period 1886-1913 is about 2.7 m/yr (9.12 m/yr post-jetty). The average rate fluctuates between 0.1 m/yr and 1 m/yr. The volumes calculated with these rates are subtracted from the volumes calculated with the DEM and depth of closure analysis. The impact of this analysis is not very large, but significant.

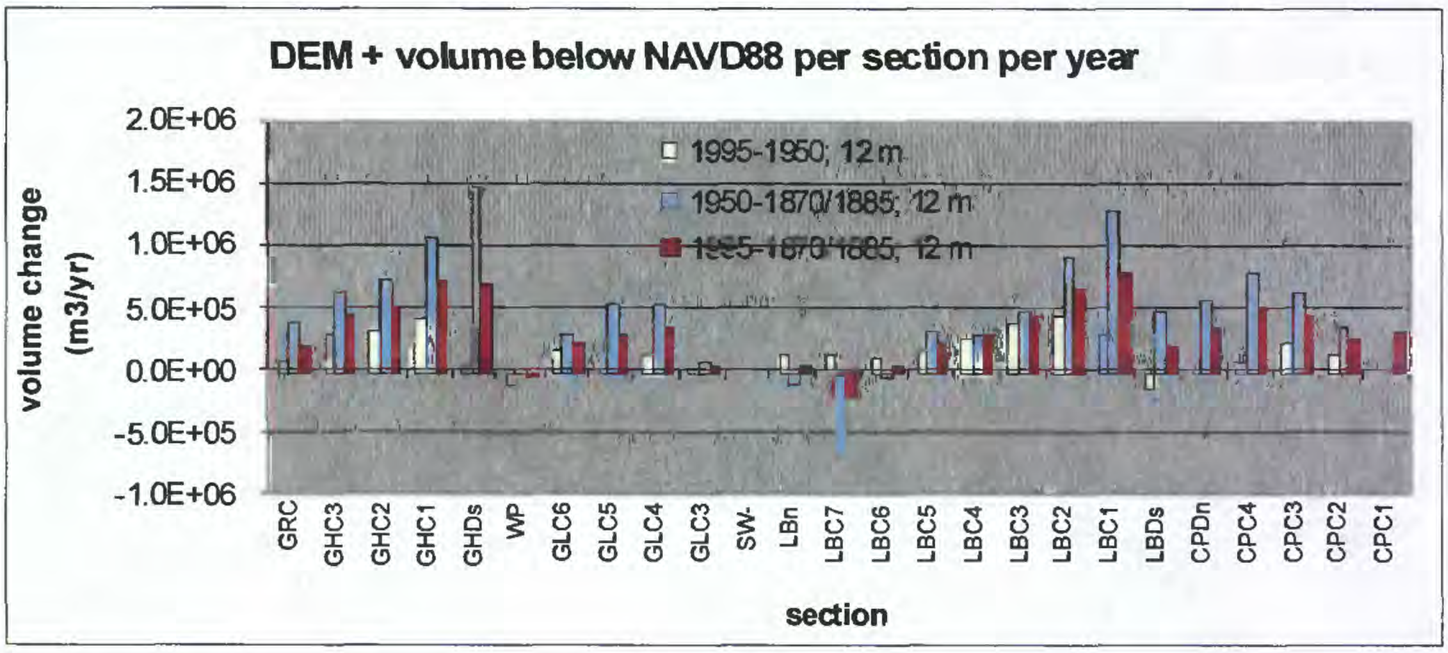

Figure 8. Volume change per section per year.

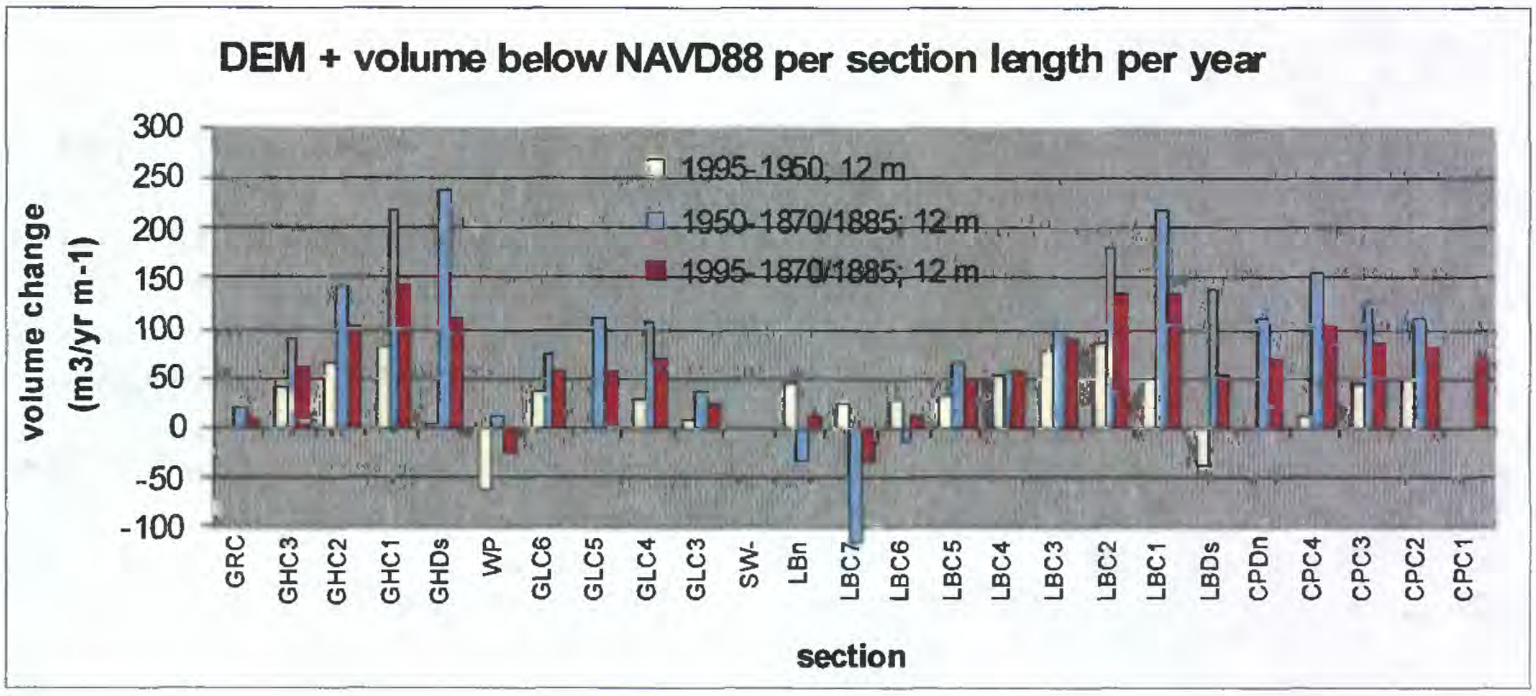

Figure 9. Volume change per section length per year.

As it can be seen the rates decrease after the 1950's. The biggest changes occur close to the delta. Farther away the rates remain relatively high (Ocean Shores and Long Beach). There is little recent accretion in Grayland and Clatsop.

The main cause of the erosion of Cape Shoalwater is the northern migration of the North Channel of Willapa Bay. This sediment is mainly eroded during ebb and deposited on the ebb-tidal delta. On the ebb-tidal delta the waves and currents distribute the sediment. The sediment can be transported back to the inlet or to the adjacent coastal systems. It is possible that most of the sediment accretes south of the North Channel. The height of this area varies around MLLW (~NAVD88 – 0.5 m). The eroded volume of Cape Shoalwater is the volume above this level. The average height of all the accreted land in the whole littoral cell above NAVD88 is about 4.5 m. This value is used to estimate the historical volume of sand at Cape Shoalwater. The volumes are presented in the table below.

Table 7. Total volume of Cape Shoalwater for different periods of time.

	1995-1870	1950-1870	1995-1950
Area (*10^6 m^2)	-12.2	-7.2	-5.1
Volume above NAVD88 (*10^6 m^3)	-55	-32	-23
Volume below NAVD88 (*10^6 m^3)	-6	-4	-3
Sum of volumes	-61	-36	-25

It seems that in the period from 1950 to 1995 the erosion has increased about 20% (comparison of horizontal areas). The volumes that are mentioned in Table 4 might underestimate the total erosion. The eroded Cape Shoalwater consisted of several coves with flats and channels. The volumes of the flats and channels below the average high waterline are not included in this analysis.

CONCLUSIONS

The jetties, which were constructed in the early 1900's at the Columbia and the Grays Harbor inlet, had a large impact on the morphodynamics. Our hypothesis is as follows: the central part of the deltas was jetted off-shore. The wings were no longer part of the tidal prism system and its sediment was transported onshore by waves. In Figure 4 to Figure 9 we see two "pyramids". The center of the left pyramid is located at Grays Harbor inlet, and the center of the right one is located at the Columbia River inlet. The delta of Grays Harbor mainly supplied the beaches of Ocean Shores (totally 222 million m^3) and to a lesser extent the beaches of Grayland (89 million m^3). The Columbia River delta equally supplied both the beaches of Long Beach (208 million m^3) and Clatsop (192 million m^3). Note that the shorelines of the last southern 5 km of Clatsop are not available. Assuming the total accreted volume of CPC1 is representative for this last 5 km, the total accretion up to 1995 is about 35 million m^3 for the last 5 km (depth of closure 12 m) and 16 million m^3 for the DEM only. Making the total for Clatsop 227 million m^3 (depth of closure 12 m) and 94 million m^3 for the DEM only.

Looking at the configuration of the deltas relative to the inlet we can conclude the following. The center of the pre-jetty Grays Harbor delta lies north of the inlet. The Grays Habor jetties were built across the southern part of the delta. This explains why there is more accretion at North Beach compared to Grayland. The pre-jetty configuration of the Columbia River delta is slightly north of the main channel in the inlet. The jetties were built across the northern part of the delta, leaving a larger area (compared to the area north of the inlet) to supply the beaches of Oregon. However the supply of sand to Long Beach in the complete period is not significantly smaller than the supply to Clatsop. The northern part of the "new" ebb-tidal delta is closer to

LBDs than the southern part to CPDn. A possible feeding of Columbia River sediment to Peacock spit (LBDs) is more obvious than to CPDn. This feeding may have contributed to the supply of the Long Beach beaches. The feeding may consist of Columbia River sediment and/or sediment from the Corps of Engineers disposal sites E and maybe B (Moritz, 1997). Up to 1955 about 18 million m^3 was dumped in ocean or estuarine disposal sites. In the period from 1956 to 1997 about 170 million m^3 was placed in ocean disposal sites. About 50 million m^3 was dumped on site E and about 68 million m^3 on site B. The other disposal sites are considered too deep to contribute to any nearshore feeding. When looking at Table 3 and Table 4 we see that since the 1950's more accretion has occurred at Long Beach than at Clatsop (76 versus 21 million m^3). But the figures for Clatsop may be too small since CPC1 and the southern 5 km have not been included. However the total accretion up to the 1950's is larger at Clatsop (DEM: 55 million m^3; total: 139 million m^3; CPC1 and southern 5 km not included) than at Long Beach (DEM: 42 million m^3; total: 132 million m^3). It should be mentioned that the 1885 Reckendorf shoreline indicates the toe of the dune and not the AHW position. This gives a larger estimate of the volume between the 1885-1950's shorelines. The historical Oregon shoreline is less accurate as well. In this comparison the period for the Long Beach sections is 15 years longer. Assuming that the largest changes occurred after jetty construction this difference should not be any problem. The contribution of the feeding seems obvious, but further improvement of the data is needed to underpin this statement. A fact that contradicts the feeding hypothesis is the erosion of Peacock Spit since the 1950's. It is possible that the actual morphology causes more erosion and that the supply of sediment from the eroding delta before the recession was bigger than the actual feeding from the dredging sites.

The general trend in the sub-cells since the 1950's is less accretion near the delta, more accretion closer to the center of the sub-cells and less accretion farthest away from the delta. Due to the influence of the ebb-tidal delta the development of Leadbetter Point (LBn) and LBC7 is very erratic. The accretion after the 1950's in the littoral cell has decreased and the center of the accretion has moved away from the deltas. The post 1950's rates in the middle of Ocean Shores and Grayland remain relatively high. The accretion at Grayland and Clatsop has decreased more significantly than at the other two sub-cells. The sections adjacent to the deltas have started to erode. As a result of the diminishing feeding from the deltas the shorelines are reorienting themselves. The concave shape of the shorelines of all the sub-cells causes higher transports at the edges than in the center. For the future we may expect more erosion closer to the deltas and accretion farther away.

REMARKS

This study contains many uncertainties and assumptions. For the period from 1870 to 1995 about 60% of the total accreted area is covered by DEM data. All the volumes below NAVD88 are based on active depth calculations. Since these are raw estimates the uncertainty in the related answers may be large. There may be a lot of variance in the total volumes (Figure 9) but the trends do not differ much. This is reflected by the developments of the areas through time (Figure 10).

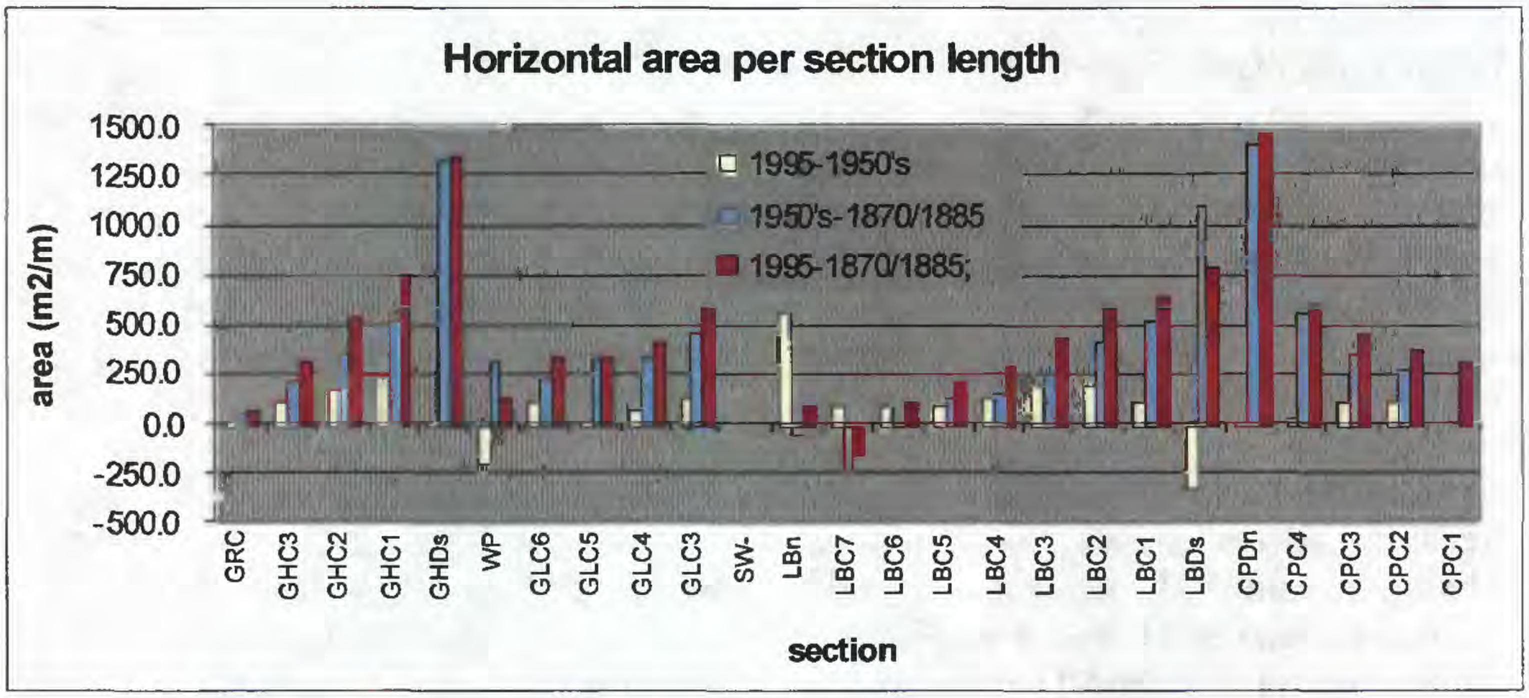

Figure 10. Area change per section length.

To get a better understanding it would be good to include the 1927 shorelines in this study. More study is needed to find out about volume changes on the ebb-tidal deltas. In the nearby future the DEM will be improved with recent LIDAR data. Hopefully these actions will lead to a better defined sediment budget.

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Compilation of Geotechnical and Water Well Borehole Data for the Columbia Cell Barrier Beaches

April Herb, Portland State University

Geotechnical and water well data are being used to augment the auger hole data collected during the summer of 1998. Currently, about 200 borehole logs have been selected from state Water Resource databases in both Oregon and Washington. The geotechnical and water well borehole logs are compiled in spreadsheet format including depth to facies change and lithology. Sand to mud ratio and Standard Penetration Test curves as well as minor constituents such as gravel, shell material, peat layers are being used to interpret lithology in the boreholes. In addition, lithologic interpretations from auger hole drilling during the summer of 1998 are being used. The resulting data set will be used to create isopach maps of shelf, beach and dune sand thickness for the barrier beaches. The data set will also be used to test hypotheses of facies description and longshore continuity.

Vibracoring of Surf Zone Deposits in the Columbia River Littoral Cell

Curt Peterson, Dave Qualman, April Herb, Portland State University
Harry Jol, University of Wisconsin - Eau Claire

Vibracoring of about two dozen shoreface sites was performed in the Columbia littoral cell during extreme low-tide sequences, June-August 1998. Target sites include lower beach face, beach toe, inner-rough zone, and the tops of the 1st or 2nd swash bars offshore of the inner-rough zone. Vibracores were taken to depths of penetration refusal, e.g., subsurface depths of 2-5 m, using a high-powered vibrator and tripod assembly mounted on a trailer. Preliminary results demonstrate uniform fine sand with rare laminae of mica, shell fragments, and/or heavy minerals in the inner-surf zone deposits. Primary structures, are variably bioturbated but, include landward dipping swash bar foresets (0.5-1.5 m amplitude), alongshore dipping megaripple foresets (0.1-0.5 m amplitude), and weakly developed planar beds. This lithofacies likely corresponds to the chaotic Ground Penetrating Radar GPR facies that occur immediately below seaward-dipping foreshore reflectors. Penetration refusal was abrupt in all surf zone sites, and it corresponds to basal units of 'hard sand', containing rare planar beds and granule laminae. The high-density of the 'hard sand' unit(s) probably results from subsurface cyclic-shear compaction by winter storm surf. The thickness of the overlying 'soft-sand' unit generally increases towards northern subcell boundaries, and thins towards southern subcell boundaries. The 'soft-sand' unit apparently reflects onshore sand transport following northward sand displacement from the 1996-98 El Nino, as indicated by corresponding beach face erosion or accretion. Very-thin 'soft-sand' units at Leadbetter Point and Twin Harbor-South Jetty surf zones indicate a northward bypassing of sand to adjacent tidal inlets, thereby reflecting ineffective boundaries to northward transport in the Long Beach and Grayland subcells over short (interannual) time scales.

1998 Drilling Program on the Columbia River Littoral Cell: SW Washington Coastal Erosion Study

Sandy Vanderburgh, University College of the Fraser Valley
Mike C. Roberts, Simon Fraser University
Curt Peterson, Portland State University
Harry M. Jol, University of Wisconsin – Eau Claire
Jim Phipps, Grays Harbor Community College

The 1998 field season involved the collection of drill cores from the Columbia River littoral cell for the determination of nearshore sand geometry and mapping of the prehistoric and geologic processes of this coastal system. A total of 25 cores, ranging from 2 m to 27 m depth, were drilled near the base of the Pleistocene sea cliff, on mid-barrier beaches, and on the modern beach. A 6" diameter, solid-stem flight auger technique was employed to maximise data recovery and drilling efficiency (Figures 1 and 2). Cores were logged in the field for facies characteristics, composition, and texture. Samples were collected at critical depths and stratigraphic transitions for later laboratory analysis and chronological determinations.

Figure 1. SFU drill rig on beach near Gearhart, Oregon.

Figure 2. View of 6″ diameter solid-stem flight auger used for beach coring.

Preliminary analysis of the core data shows, firstly, a strong correlation with the GPR profiles and secondly, a reduction in barrier beach thickness towards the north and south margins of the littoral cell (Figures 3 and 4). A gravel lag, possibly indicative of a wide spread sea level transgressive phase, was observed throughout the littoral system (Figure 5). The thickness of each barrier-beach system above the Pleistocene boundary was determined for the North Beach, Grayland Plains, and Clatsop Plains sub-cells. Drilling also lithologically confirmed the continuation of the earthquake-produced, buried scarp-dune ridge relationship into the Clatsop Plains sub-cell (Figure 6).

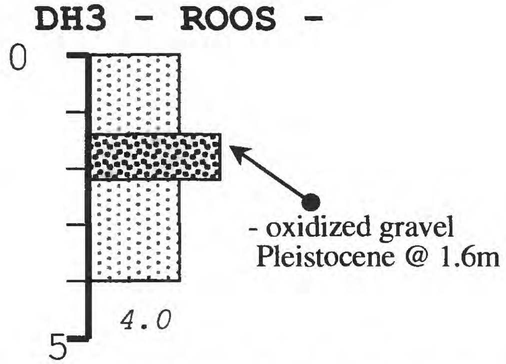

Figure 3. Core from Roosevelt Beach, North Beach sub-cell, showing fine sand overlying Pleistocene contact at approximately 1.6 m depth.

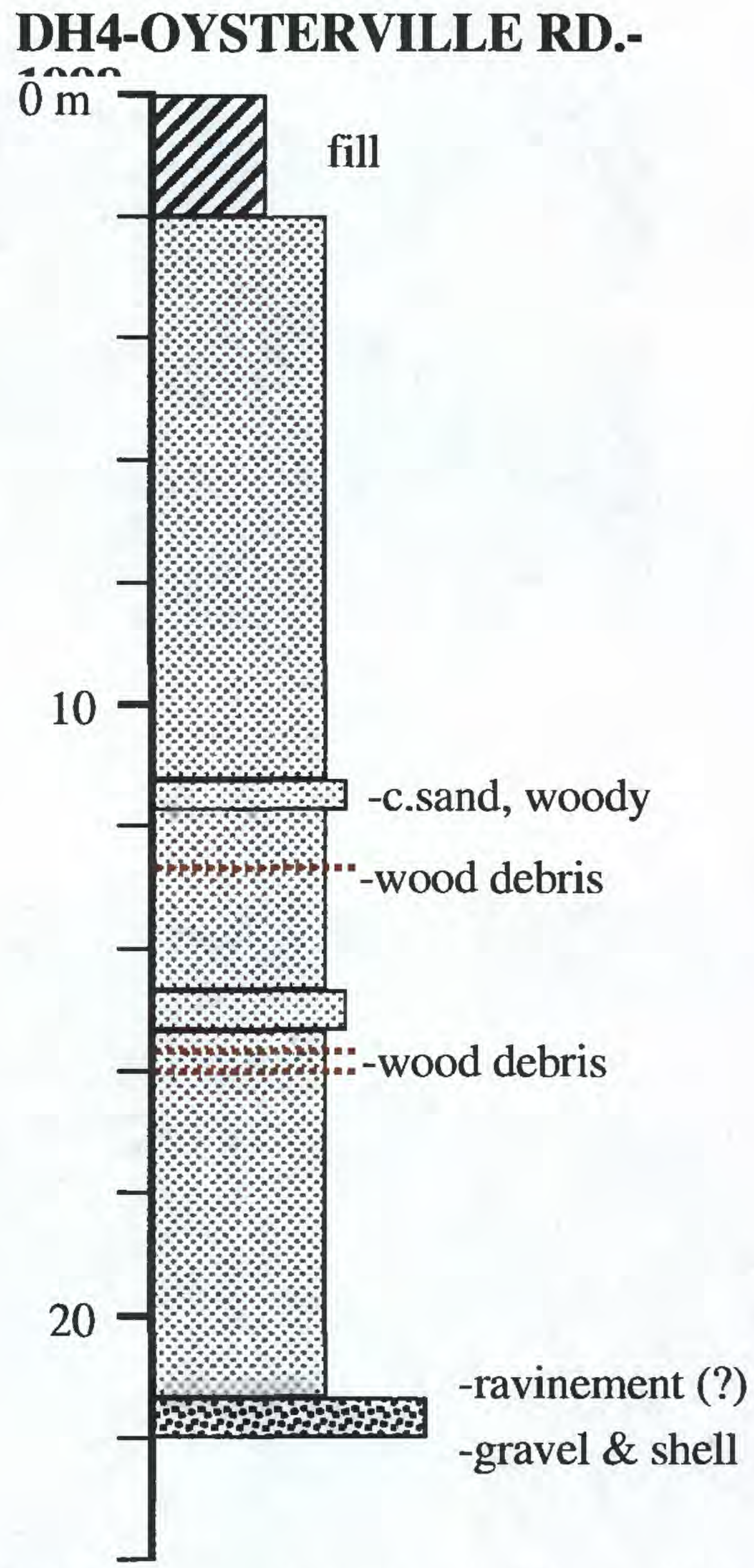

Figure 4. Core from Long Beach Peninsula near the west end of Oysterville Road. Log shows fine to coarse sand overlying a gravel contact at ≈ 20.8 m.

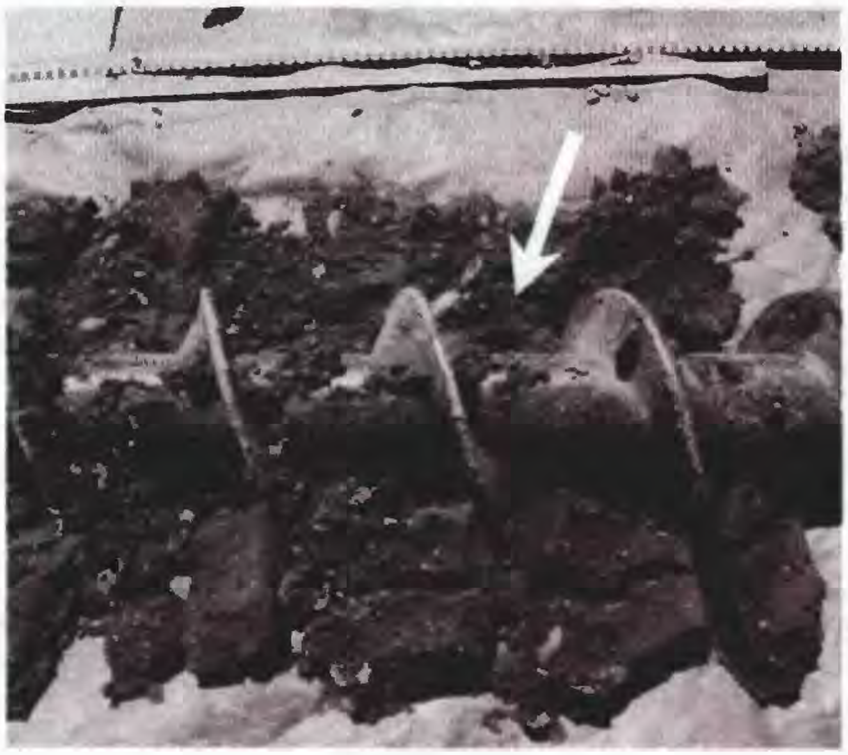

Figure 5. Top of gravel layer observed in drill core DH1-Oyhut, North Beach sub-cell, at about 12 m depth. White arrow is pointing to top of gravel contact. Distance between auger flights is approximately 6″.

Figure 6. Buried placer observed in drill core Section-1 at 7.6 m to 9.2 m depth from Camp Rilea, Clatsop Plains sub-cell. Placer confirms buried scarp – dune ridge correlation throughout the Columbia River littoral cell. Top of core is to left side of figure.

Drill Core Correlation with Ground Penetrating Radar Profiles

Harry M. Jol, University of Wisconsin - Eau Claire
Curt Peterson, Portland State University
Michael Roberts, Simon Fraser University
Sandy Vanderburgh, University College of the Fraser Valley
Jim Phipps, Grays Harbor College

Much of the data collected during the summer of the 1998 was tied to the drill core and vibracore records. GPR profiles were collected along all drill site locations where possible. For consistent GPR data collection 100 MHz antennae with a 1000 volt transmitter were used. Where interesting sedimentary structures existed, other antennae frequencies were utilized. The topographically corrected GPR lines imaged the upper 4-6 meters and allowed for correlation of GPR profiles with sedimentary packages revealed in the drill/vibra core. The drill cores also confirmed previous GPR interpretations (1996 and 1997) of paleo-scarps where augering and vibracoring could not penetrate.

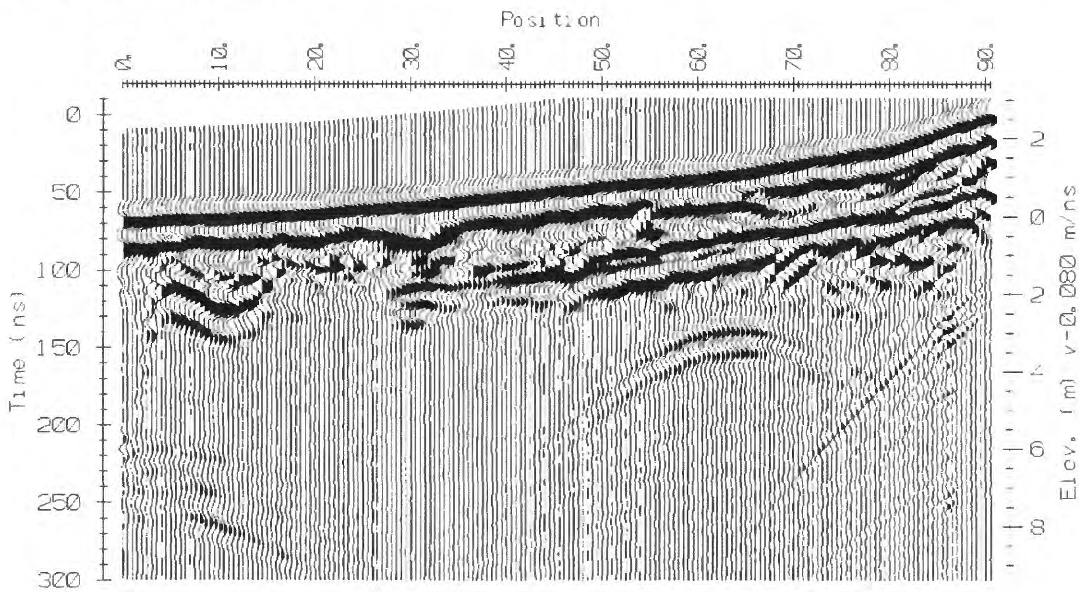

Figure 1. 100 MHz GPR profile (W-E) shot in 1998 at Rossevelt Beach. Drilling confirmed shallow sand/beach deposit above a Pleistocene bench seen at ~ 1.5 m depth. Note the small channel like feature center on 10 m.

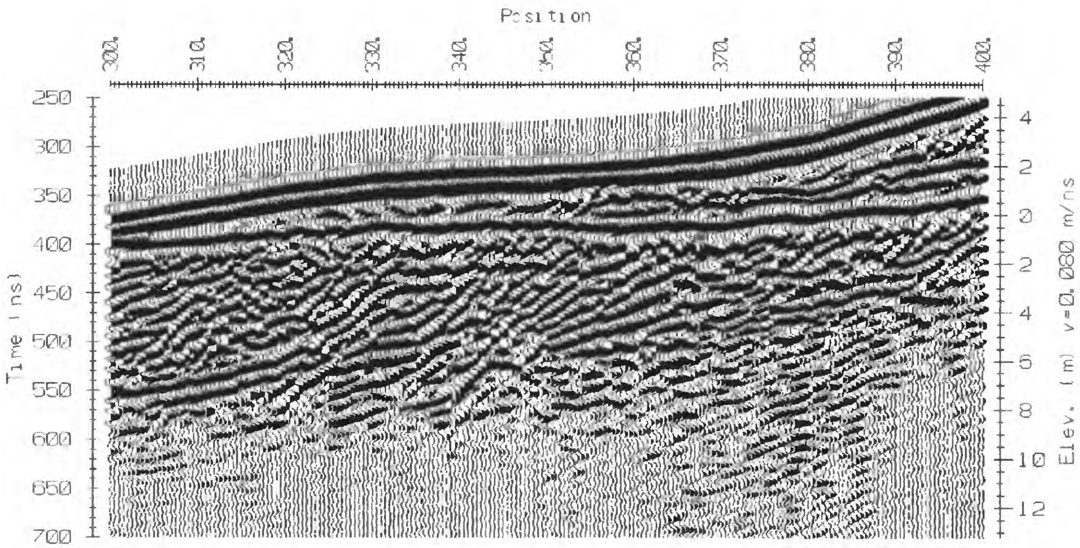

Figure 2. 100 MHz GPR profile (W-E) shot in 1996 and 1998 on the Camp Rilea Military Base. A placer deposit was detected on the GPR profile between positions 325-350 m but due to the depth of the target augering and vibracoring could not reach it. Drilling confirmed the predicted placer deposit which allows more confidence in other predicted targets.

ACKNOWLEDGEMENTS

The major support for this project comes from the Southwest Washington Coastal Erosion Study - United States Geological Survey (USGS). Further support comes from Sensors and Software, University of Wisconsin-Eau Claire, Portland State University, University College of the Fraser Valley and Grays Harbor College. We would also like to acknowledge the support of the Washington Department of Ecology (DOE), and Grays Harbor, Pacific, and Clatsop counties. Able bodied field assistance was provided by Brian Thayer, Mark Newman-Bennet, David Qualman, April Herb and Andrew Zachery (your long days in the field are appreciated!). We thank Rilea Armed Forces Training Center, the Cranberry Research Foundation, and the communities within the study area for their aid in this project.

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Origin and Interpretation of Sand Dunes in the Grayland Plains

Jim Phipps, Grays Harbor College

Linear dune ridges characterize the entire Columbia cell sand sheet. They form at the edge of the sea where sand is trapped by vegetation and thus can be used as proxies for shorelines. Many of the larger, more continuous dunes are associated with scarp-placer deposits, and these deposits have been associated with beach erosion occurring during subduction zone earthquakes. There are more dunes in the older part of the sand sheet (Clatsop plains) and fewer in the northern end of the sand sheet (North Beach).

There are at least two kinds of dunes. One type is those that form in response to wind and vegetation as the beach progrades. A rapidly prograding beach produces a series of relative low shore parallel ridges. The height of the ridge depends on the supply of sand and the ability of pioneer grasses to move into bare sand environments and trap the wind driven sand. These ridges are rarely associated with scarp-placers. A second kind of dune ridge is one whose height has been enhanced by aeolian sand freed during a subduction zone event. Such dune reactivation increases the height of the dune, often entombs a buried soil profile, and in the case of the Big Dune at North Cove, buries a forest.

The mapping of these dunes is in progress. Preliminary findings show dune truncations near the inlet mouths and to lesser degree along the 13 miles of open coast. These truncations imply erosion at North Cove further north than the existing shoreline as well as oscillations at the mouth of Grays Harbor. The general pattern for most of the shoreline away from the inlets is that the oblique trending older dunes appear to be truncated by the Big Dune, but there seem to be few if any truncations west of the Big Dune.

Modeling Shoreface Translation

Peter J.Cowell, University of Sydney

The Shoreface Translation Model (STM) is a mass-budget geometric profile model that is driven by sea-level change, littoral transport budgets, and changes in the active elements of the morphology such as the shoreface or barrier dimensions. Unlike other geometric models of this type, the STM includes sediment-accommodation controls both in the lagoon as well as on the shoreface, and it incorporates time-dependent changes in active morphologies. That is, the STM does not assume equilibrium for the shoreface or other morphological elements. Instead, the geometric parameters are varied through time to simulate observed behaviour in coastal evolution.

These qualities allow the STM to simulate complex changes on the SW Washington coast such as the response to episodic downthrust faulting and subsequent rebound, which manifest as roughly 500 year cycles of sudden sea-level rise followed by a gradual sea-level fall, all of which is superimposed upon a mean-trend coastal progradation driven by a constant infeed of littoral sediments supplied by the Columbia River (Kaminsky *et al.*, 1997). Experimental designs used in simulations of these processes included a rotational deepening of the shoreface. Such rotation might be expected during periods following sudden submergence, and seems evident in available bathymetric-change data. Amongst other things, the model results show simulated condensed beds corresponding to the heavy-mineral lenses observed in the field (Figure 1).

Other prospective experimental designs using the STM relevant to the SW Washington coast include a generalized evolution of the entire coastal cell spatially averaged to a representative 1D profile. Inverse simulations (e.g., sensitivity analysis) can be conducted on this data model to evaluate general responses of the shoreline to the range of possibilities regarding the sediment budget (e.g., variations in Columbia sediment discharge and different estimates for fine: coarse sediment ratio, and supply from lowering of the shoreface). Similar designs are possible for sub-cells within the study region; e.g., these sub-cells could comprise shoreline segments between the estuaries. At the most localized scale, site specific scenario modeling can be undertaken using discrete profiles or sets of adjacent profiles coupled through littoral sediment exchanges.

The STM also permits variation in experimental design with respect to cross-shore scale. More specifically, two designs present themselves. The first involves simulation of the inner continental shelf and coastal plain in relation only to the coarse (sand) fraction of the sediment budget. Alternatively, the STM can be applied to the entire continental shelf and upper slope to simulate the gross effects of the full sediment supply from the Columbia (coarse and fine fractions). Such simulations entail setting shoreface parameters to the continental-shelf dimensions.

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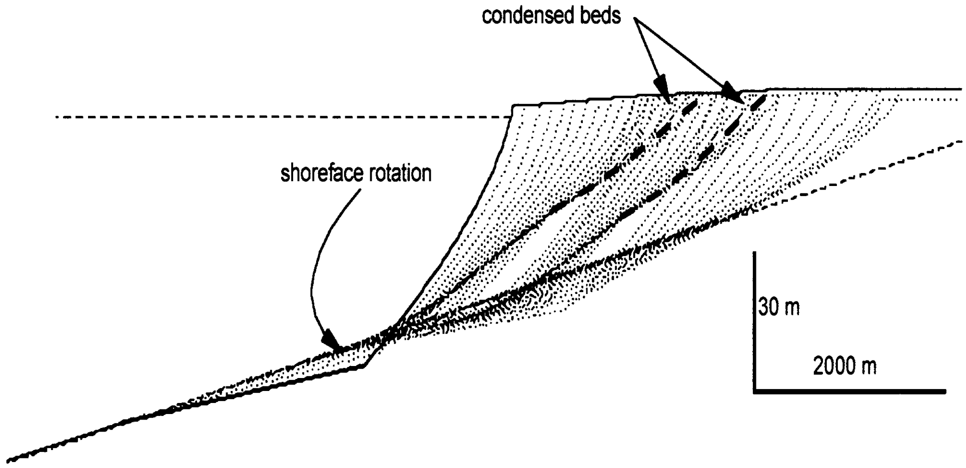

Figure 1. A prograded sequence showing simulated cycles of heavy-mineral fractionation (condensed beds) due to major erosion events on the upper shoreface attributable to rapid tectonic subsidence on the rapidly prograding Columbia River coast, NW USA. The simulation entailed 2 m subsidence events in a single step followed by rebound in a series of 0.2 m steps. Each step is accompanied by shoreface relaxation (deepening) at a rate of 1 m per step over 10 steps, with a constant supply of littoral sediment of 3000 m^3 per step.

Estimating Post Jetty Sand Volumes in Clatsop Plains Dunes in Oregon

Frank Reckendorf, Reckendorf & Associates
Curt Peterson, Portland State University

This study was undertaken to establish how much of the historical sand volume that accumulated south of the South Jetty of the Columbia River in Oregon has blown landward to be constrained in the sand dunes of the Clatsop Plains. This sand is no longer available for movement within the Columbia River cell, and in particular to prograde beaches between Tillamook Head, Oregon and the South Jetty of the Columbia River. As part of the study an overview was made of when, since about 1885, sand began to accumulate at the southern end of the cell, near Seaside.

The study used 1936 and 1937 vertical and oblique photographs for initial establishment of the eastern boundary of post, about 1885, sand accumulation. A 1939 oblique aerial photo taken after a very high storm-water event showed that ocean flooding had moved all loose sand from behind the newly formed foredune (1936 -1937) inland onto the pre-1885 foredune or further inland. The new foredune that was over topped was only about one to two meters high in 1939. The photograph helps to suggest that all the later sand in the new foredune and to the east, accumulated because of the presence of European Beachgrass, except for the sand on the pre-existing high (> 20 meter) dunes shown on the 1937 photograph. This sand on the pre-existing dunes (and shown on the 1936-1937 photographs) was deposited before the European Beachgrass was introduced in the area.

Using an Australian sand auger holes were dug to find pre-1885 soils that had been buried by the historical sand increment. In addition, the depth to the paleosol was correlated to the 1997 auger holes, GPR, and survey lines, made by Jol, Vanderburgh, Peterson, Phipps, and Woxell. Preliminary results show depths of about 1.5 m to the pre-jetty foredune paleosol, and depths around 4 to 5 m above the paleosols on the top of the preexisting topography. However preliminary results show that local areas and side slopes might have burial depths to at least 8 m.

At many locations the auger holes do not encounter the color and organic matter change associated with the pre-jetty soil profiles, but may show sufficient textural change to reflect the same time horizon. We hypothesize that the coarser deposits reflect a closer shoreline and as the shoreline progrades, associated with post 1885 accumulation, the deposits fine upward reflecting a more distant source. Field textural analysis suggest a fining upward sequence. but this needs to be confirmed at select locations by laboratory grain-size analysis.

The pre-existing topography is being established by subtracting the depths to the paleosol from the 1973 topography (1:1200). These large-scale maps (one inch equals 100 ft) have the disadvantage of being 25 years old, so the dune accumulation occurring in the last 25 years is not reflected. This is especially a problem in the area from the modern foredune back to and including the pre 1885 foredune. After the modern foredune became a few meters high the strong winter winds would come over the dune and transport the loose sand down to the winter water table eastward and on to the pre-jetty foredune and older dunes. Later when the modern foredune began to reach its maximum height of about 9 to 10 m the winter winds transported some sand over the top of the dune to accumulate in the former deflation plain. However by this time the deflation plain had grown sufficient vegetation to trap the sand. Therefore the deflation plain began to fill back in. A considerable amount of this sand accumulation on the deflation plain has occurred in the last 25 years.

Examination of the landscape in the Seaside area using aerial photographs and field observations reveals little accumulation of sand dunes on the gravel ridges in the past few thousand years. In addition the first soil survey (USDA, 1947) made in the area in 1937, showed only a few hundred feet of sand at the northern end of the Necanicum Spit. In other words, the roughly 10,000 feet of sand area paralleling the beach accumulated after 1937, suggesting that the sand moved down from the north, probably by longshore transport rather than being derived from the Necanicum River.

The study area was divided up into a series of sub-areas thought to be representative of the dunes. The area from the modern foredune to and including the pre-jetty foredune was also separated. Preliminary estimates of sand volume were made by the Washington Department of Ecology using a Digital Elevation Model (DEM). The DEM could not correct for the pre-existing dune topography, and is based on 40 ft contours. However, the preliminary data using height above MLLW indicates that roughly 64.6 million cubic meters of sand exists between the modern foredune and the pre-jetty foredune. MLLW is probably too low a datum to represent the dune increment separate from the beach increment so the volume may be too high. However, the volume is adequate as a preliminary number, and it is quite large. As indicated, this volume represents the sand that has accumulated since the introduction of European Beachgrass. In other words, the European Beachgrass allowed the modern foredune to grow essentially cutting off erosion of the land eastward. The small amount of historical erosion that has occurred in the cell is at the north end within a few thousand feet of the jetty. A very rough estimate of the post-1885 sand volume above the preexisting dune topography, is about 50 million cubic meters, but this needs to be confirmed by the dune cross section and auger hole part of the study. Therefore, a rough value of 113 million cubic meters needs to be accounted for in the sand budget for the mouth of the Columbia River.

It would be difficult for the Columbia River to provide 113 million cubic meters of sand even if all the dredged sand (about 4.0 million cubic yards/yr) ended up south of the south jetty. Since most of the sand is thought to go to the north and not to the south, a preliminary conclusion might be that there is more sand accumulation in the dunes south of the south jetty than can readily be accounted for by just historical runoff in the last 100 years. This then raises the issue that the historical sand in the dunes may not have been accumulated historical Columbia River sand. Other reasons than just filling in the Columbia River embayment should be considered, such as, (1) there would be a rebound period after the 1700 earthquake and sand could be returning to the shoreline that was deposited offshore at the time of the 1700 earthquake; (2) the sand making up the Columbia River ebb-tidal delta could have transported offshore after construction of the jetties and some of this sand may have moved to the south; (3) anthropogenic changes in the basin due to forestry, grazing and agriculture added higher sediment yields after the turn of the century and prior to dam construction; and (4) a transgressive shoreline is just adding more sand from the shelf in the last 100 years.

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PRELIMINARY AREA AND VOLUME CALCULATIONS

SUB-UNIT	AREA (m^2	AREA (m^2)	VOLUME (MLLW) (m^3)	VOLUME (?) (M^3)
SPIT	5,268,184		13,928,968	
K1	2,226,282		4,795,185	
J1	784,035		2,576,176	
J2		285,658		2,691,031
I1	782,270		3,022,192	
I2		391,853		3,528,961
H1	1,165,971		6,092,326	
H2		1,403,352		10,436,875
G1	791,866		5,483,885	
G2		1,411,426		13,985,683
F1	1,129,392		6,485,028	
F2		1,819,584		23,954,478
E1	696,313		3,700,655	
E2		1,174,296		12,842,782
D1	1,231,714		7,445,994	
D2		1,923,403		22,660,568
C1	843,880		5,857,675	
C2		1,608,364		21,638,208
B1	444,283		2,352,063	
B2		1,180,423		13,265,483
A1	491,981		2,896,176	
A2		1,412,143		17,226,144
	15,856,179	12,610,507	64,636,329	142,230,214*

* Overstated, as it includes volume from pre-existing topography.

NOAA, Topographic Sheets: Vectorization and Error Analysis - Update

Robert H. Huxford, Richard C. Daniels
WA Department of Ecology

The National Oceanic and Atmospheric Administration (NOAA) and the Washington Department of Ecology have undertaken a data rescue project to convert historical and contemporary topographic sheets (T-sheets) from paper or cloth to a digital format. The original maps have been scanned at 400 dpi, saved as raster images, and vectorized to obtain X, Y coordinate pairs that describe the location of historical shorelines depicted on the original maps. A methodology has been developed for vectorization of NOAA topographic sheets and for the analysis of errors on the sheets. The error assessment methodology utilizes coordinates obtained for survey markers shown on the scanned T-sheets and compares these coordinates to those published by the National Geodetic Survey for the same markers. Differences between the measured and published coordinates are then computed and several descriptive statistics are obtained. This year's update includes an error analysis on the 192x T-sheets and the completion of shoreline data sets. These new shoreline data sets now include Oregon.

Coastal Change Rates for Southwest Washington and Northwest Oregon

Richard C. Daniels, Diana McCandless, Robert H. Huxford
WA Department of Ecology

Historical shorelines for the 1870s, 1926-27, and the 1950s have been digitized from National Ocean Service (NOS) topographic sheets (T-Sheets). Contemporary shorelines for 1974 and 1995 have been obtained from air photography flown at scales of 1:6,000 (Oregon 1995) 1:12,000 (Washington 1995) and 1:24,000 (Washington 1974). Six additional shorelines have been obtained for the erosion hot spot located near the North Jetty of Grays Harbor in Ocean Shores, WA. The photos have been scanned using an Agfa Horizon Ultra scanner at 600 to 1,200 dpi to obtain a nominal cell size of 0.5 m by 0.5 m. This resolution was selected based on two factors, the expected maximum accuracy in determining a shoreline and the desire to minimize file size (22 Mbytes at 600 dpi, vs. 122 Mbytes at 1,200 dpi). Over 250 photos have been scanned and archived to CD-ROM.

ERDAS Imagine™ and Orthomax™ are used to georeference, orthorectify, and mosaic the photography. The final mosaics cover the entire ocean shoreline in 1974 and 1995 for the Washington portion of the Southwest Washington Coastal Erosion Study area. About 90% of the Oregon portion of the study area is covered by 1995 photography. The final orthophoto mosaics have mean locational errors of 1.5 to 3 m. Near Leadbetter Point errors ranged from 3 to 8 m. These larger errors are due to the difficulty in identifying pass points and ground control points in the flat undeveloped topography of the area.

Change rates are being calculated for the study area based on the average high water lines (AHWL) digitized from the air photography and the mean high water lines (MHWL) obtained from the NOS T-Sheets. Possible error in the identification of the AHWL and MHWL has been estimated to be less than ±10 m. Thus, in the 1974 to 1995 time period (21 years), change rates greater 0.95 m/yr or less than –0.95 m/yr are significant. In comparison, rates over a ten-year period would need to be greater than 2.0 m/yr or less than –2.0 m/yr to be significant.

Historical Shoreline Change Interpretations

George Kaminsky, WA Department of Ecology

INTRODUCTION

The Study has accurately derived shoreline position data from historical aerial photos and U.S. Coast & Geodetic Survey topographic sheets (NOS T-Sheets) from 1868 to present. The methodology used typically captures historical shorelines within ±5 m of true position from these sources (Daniels et al., this volume; Kaminsky et al., in press). Regional trends in shoreline behaviour for the sub-cells can be readily observed from a data set of nominally 4 timelines (1870s, 1920s, 1950s, and 1995). The influence of short-term variability in shoreline position on long-term shoreline change rates is still being evaluated.

The major shoreline mapping tasks for the Study include:

- Deriving historical shorelines from NOS T-Sheets and aerial photography at decadal scale
- Obtaining shoreline position data and change rates for selected sites at 2-6 year intervals
- Combining analysis of shoreline change with topographic and bathymetric change
- Densifying and extending time slices of shoreline position with GPR data
- Analyzing the error and short-term variability of shorelines derived from aerial photography

Much of the work on these tasks is still in progress. However, the results to date are already providing a wealth of information to document the historical evolution of the Columbia River littoral cell. These results are also providing the baseline data for shoreline change modeling.

Analyses of the shoreline data so far reveal that:

- The historical shoreline changes throughout the Columbia River littoral cell have been governed by the installation of jetties in the early 1900s.
- The post-jetty shoreline changes have manifested over decade to century time scales and appear to have resulted in fundamentally different patterns of erosion and accretion throughout most of the littoral cell.
- The shoreline changes adjacent to the jetties have reversed from progradation to recession over the last few decades.

A SYNOPSIS OF HISTORICAL SHORELINE CHANGES

The calculated shoreline change rates reveal large alongshore gradients in shoreline orientation and progradation rates over tens of kilometers associated with the installation of jetties at the mouth of the Columbia River and Grays Harbor during the early 1900s. In effect, the jetties have imposed new headland boundaries to enhance sub-cell development and functioning within the littoral cell. Rates of shoreline progradation are typically one to two orders of magnitude larger than pre-jetty rates, being highest adjacent to the jetties for decades following jetty construction (see Figure 1). Over the latter half of the century, the shoreline progradation rates for the region have substantially declined. More recently, the shorelines immediately adjacent to the jetties have reversed in trend to recession, likely related to local and regional sediment budget constraints and long-term morphologic response to the imposed boundary conditions.

The largest fluctuations in shoreline change rates and direction over the historical period are generally closest to the estuary entrances. The jetties at both the Columbia River and Grays Harbor were built on shallow delta plains to constrict the inlet flow and scour the entrance channel for navigation improvements. Over the course of several decades, the increased tidal flows pushed the center of the deltas farther offshore, and waves forced large volumes of sediment onshore from the flanks of the ebb-tidal deltas, where tidal inlet currents were no longer present. The onshore movement of sediment and its dispersal along the coast away from the jetties explains much of the historical shoreline evolution in the Columbia River littoral cell.

SHORELINE CHANGE WITHIN THE SUB-CELLS

During the few decades following installation of the Columbia River south jetty (1885 to 1895) and its extension (1903 and 1913), the adjacent shoreline rapidly accreted, transforming Clatsop Spit from a broad shallow shoal to a foreland point, to align the beaches to the south. An exponentially decreasing rate of shoreline progradation occurred towards the south to Tillamook Head (Figure 1). Since the jetties were constructed, Clatsop Spit accreted over 7 km^2 of land within 5 km of the south jetty. Since 1936, a southerly translation of the accreting region over time is apparent, as is a diminishing rate of shoreline progradation. Mean shoreline change rates range from approximately 10 m/yr during 1885 – 1936, to 4 m/yr during 1936 – 1954, to –1 m/yr during 1954 – 1995. Note that shoreline change rates are more regionally uniform during the most recent period than during the early post-jetty period as shown in Figure 1.

Along the southern half of the Long Beach sub-cell, the shoreline progradation rates were among the lowest in the littoral cell during the late Holocene, and among the highest during historical time. During the late Holocene, this region appears to have been in dynamic equilibrium, acting as an efficient longshore sediment transport corridor. Once the Columbia River north jetty was constructed (1913 – 1917), the northern expansion of Peacock Spit likely served as a point source of sediment to feed the Long Beach Peninsula. Just north of the Columbia River, Fort Canby developed quickly following jetty construction, accreting nearly 4 km^2 of land between the Columbia River north jetty and North Head, 3.5 km to the north. Long Beach Peninsula experienced a major accretionary period, prograding at rates of 4-6 m/yr. During the period 1926 – 1950s, the Long Beach Peninsula accreted rapidly at rates approaching 14 m/yr at the southern end with a nearly linear decrease to a nodal point 20 km to the north. The northern 20-km of Long Beach Peninsula eroded substantially during this period in contrast to the moderate accretion that occurred in later periods. In total, the shoreline change rates appear as a 35-km linear gradient along Long Beach Peninsula during this post-jetty period. Since the 1950s, the shoreline change rates have been greatly reduced as shown in Figure 1.

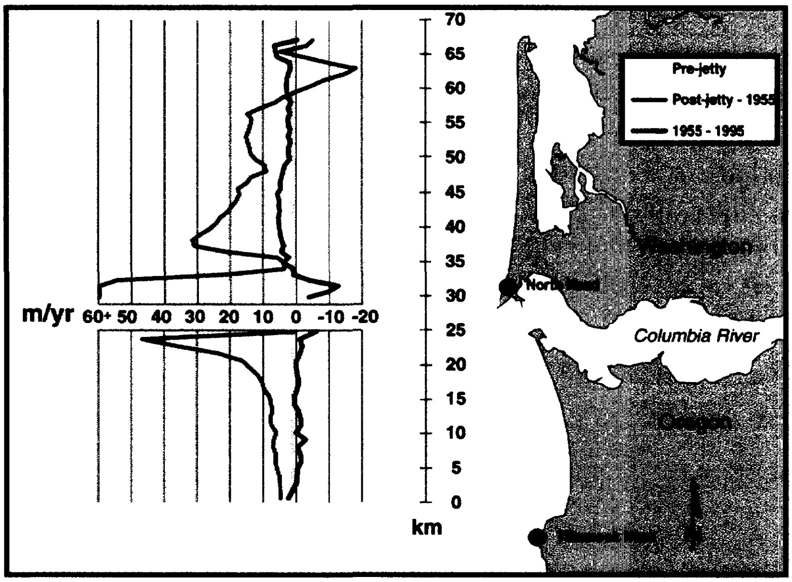

Figure 1. Changes in shoreline change rates for the southern portion of the Columbia River littoral cell. Positive values indicate progradation. Note nearly no change in shoreline position at North Head, a rocky promontory.

In the Grayland Plains sub-cell, the shoreline change rates are more spatially uniform than in other sub-cells. Except for sections of coast within a few kilometers of either the Grays Harbor south jetty or the Willapa Bay entrance, most of the shoreline prograded at a rate of 10 m/yr during the early 1900s. Shoreline change rates calculated from various data sets from 1926 to present reveal lower rates of change that fluctuate between ±5m/yr along most of the sub-cell, with a tendency of lower rates of change in the middle of the sub-cell, and higher rates toward each end. After an initial large pulse of shoreline progradation immediately adjacent to the south jetty, there appears to be a longer-term trend of shoreline recession within 2 km of the jetty. At Cape Shoalwater, the early NOS T-Sheets suggest that Cape Shoalwater was a southerly prograding spit until 1891, which than began eroding sometime between 1891 – 1911. The major cause of the shoreline recession is attributed to a nearly continual migration of the deep ebb channel along the northern entrance. North of this severely eroding spit, an inflection point in shoreline change direction is well defined. This inflection point moved northward at an average rate of 64.5 m/yr during 1926 – 1950, and migrated at an average rate of 35 m/yr during 1950 – 1995. These inflection point migration rates exceed the maximum rate of shoreline recession at Cape Shoalwater by about 35 percent (Kaminsky et al., in press).

In the North Beach sub-cell, the seaward growth of the barrier resulted in a nearly 2 km offset of the once co-linear shorelines across the Grays Harbor entrance. The North Beach sub-cell prograded rapidly along its southern end, accreting approximately 8 km^2 of land within 6 km of the Grays Harbor north jetty, with decreasing rates of accretion over tens of kilometers toward Point Grenville. Within 15 km of the Grays Harbor north jetty, there is a large gradient in shoreline progradation rates in the early post-jetty period that averages roughly 50 m/yr. During 1927 – 1951, the progradation rates in this section fluctuate between 14 m/yr and 8 m/yr, with no obvious alongshore gradient. However, between 10-20 km north of the jetty, the progradation rates are approximately double their earlier rates, suggesting the northward dispersal and accumulation of sediment over time. The most recent period from 1951 – 1995 reveals a reversed gradient in shoreline change rates that ranges from approximately 0 m/yr at the jetty to 6 m/yr at a distance 7 km to the north, where the progradation rates begin to taper to approximately 4 m/yr over the next 15 km. North of this region the change rates are complicated by creek and river migration.

DISCUSSION AND QUESTIONS

The recent decrease in shoreline progradation rates and the onset or acceleration of shoreline recession is likely a result of decreased sediment supply from the ebb-tidal deltas. Along the Clatsop and Long Beach sub-cells, this change in shoreline behaviour may also be directly related to a decrease in regional sediment supply from the Columbia River. A reduced sand supply from the lower shoreface may also account for slower shoreline progradation along the North Beach and Grayland sub-cells. In the North Beach sub-cell, the lower shoreface may become depleted of fine sediment because of a reduced feeding of Columbia River sand from the south. Due to the deepening of the ebb-tidal delta and shoreface steepening near the Grays Harbor south jetty, the sediment pathway across the inlet may be diverted to deeper water whereby the sediment accumulates on the outer ebb-tidal delta, rather than migrate northward along the coast. The North Beach sub-cell may therefore function as a closed system regardless of the Columbia River sediment supply. Along the Grayland Plains sub-cell, sediment transported northward during the winter months may be at least partially lost to the outer ebb-tidal delta at Grays Harbor, rather than accumulate along the lower and upper shoreface. The overall changes in shoreline orientation and inlet morphology at both Grays Harbor and the Columbia River, and the deepening of the adjacent shoreface therefore appears to have significantly affected the distribution of Columbia River sediment throughout the littoral cell. The modern sediment pathways, fluxes, and compartment volumes that comprise the littoral cell sediment budget may in fact be quite different from that of the late Holocene.

A number of principal questions can be asked of these historical shoreline change interpretations:

- Why are there hot spot erosion sites and what does a regional slowing of progradation rates indicate, aside from a reduced sediment supply from the ebb-tidal deltas or the Columbia River? Have the jetties imposed boundary conditions and shoreline configuration changes to significantly alter the dominant processes and sediment pathways, and hence the mechanisms responsible for shoreline progradation of 0.5 m/yr (the approximate background rate) throughout the Columbia River littoral cell?

- Has the behaviour of Long Beach Peninsula fundamentally changed since the pre-jetty era? Is this sub-cell more cross-shore or longshore dominated and has this changed over time? Why was there nearly no net change in shoreline position along the southern Long Beach Peninsula during 1700 – 1900s and to where was the sediment supplied from the Columbia bypassing? If the Long Beach Peninsula did not significantly grow in length or width during 1700 – 1900s, perhaps the sediment was accumulating in Willapa Bay and/or along the Grayland Plains and North Beach sub-cells. This situation would imply that the Long Beach sub-cell was also functioning as an open system.
- Has Cape Shoalwater and the Willapa Bay entrance been affected by jetties and sub-cell development? While at first consideration it is difficult to imagine how jetties that are on the order of 2 km long could possibly affect sedimentation patterns along the coast at distances of tens of kilometers away. However, as observed along the Long Beach sub-cell, the coast abruptly prograded at large magnitudes along its southern end following jetty construction. This large accumulation of sediment suggests that the distal sediment sinks would have experienced a reduction in supply. If Willapa Bay and Cape Shoalwater were those distal sinks, than there may be a linkage to the onset of the rapid channel migration at the entrance to Willapa Bay and the erosion of Cape Shoalwater. Likewise it may have been possible that the change in shoreline orientation near the Grays Harbor south jetty and the imposed northern boundary condition could have reduced southerly transport of sediment that supplied Cape Shoalwater.
- What is the relative contribution of jetty-induced inlet morphology and ebb-tidal delta supply versus Columbia River sediment supply to the resulting shoreline changes? This question is of fundamental importance to answer in order to link shoreline change with the sediment budget. If the assumption is made that the jetties induced all the shoreline changes, than how critical is Columbia River sediment supply to shoreline stability? What other factors may be important in influencing the regional sediment budget? For example, how important is the introduced dune vegetation to the barrier sediment sink? Was historical shoreline progradation influenced by a pulse of sediment from a large deposit left by the 1700-subsidence event or a pre-historic flood?
- Are the ebb-tidal deltas and adjacent shorelines of Grays Harbor and the Columbia River approaching an equilibrium condition or are these features continuing to evolve under changing conditions such as changes in the sediment budget, climate, relative sea level, or shoreface translation/rotation? Are the sub-cell systems forced or feedback dominated? Have the jetties affected regional bathymetric changes?
- Where will the shoreline be in the future? This question is the most important of all, because it relates directly to the principal goals of the Study. How predictable is large-scale coastal behaviour? A simple extrapolation of historical shoreline change trends to the future in this region may be wrong in both magnitude and direction. This observation signals a need for more detailed investigation of the historical shoreline changes and more sophisticated techniques for predicting future shoreline position (Kaminsky et al., in press). It may be of critical importance to analyze shoreline changes in context with bathymetric changes in order to infer future shoreline behaviour. A basic but perhaps difficult question to answer is whether recent regional-scale shoreline change rates suggest a long-term trend of slowing shoreline progradation rates that will manifest as a future erosion trend or if the shoreline will adjust to a dynamically stable position.

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Regional Bathymetric Change off the Washington-Oregon Coast

Ann Gibbs, Guy Gelfenbaum
U.S. Geological Survey

INTRODUCTION

The southern Washington and northern Oregon coast has experienced a long history of sediment accretion and high-energy conditions. During the Holocene, large amounts of sediment carried down the Columbia River were deposited on the beaches, the continental shelf, and in flood and ebb deltas at the mouths of the rivers and estuaries. During the 1800s the region became an important hub of commerce and shipping, and navigation projects such as jetties at the Columbia River Mouth and the entrance to Grays Harbor were established. In the mid-1900s many dams were built across the Columbia River for flood control and generation of hydroelectric power. Within the last decade the trend of sediment accretion on the Washington/Oregon coast has reversed and, in many areas, resulted in severe coastal erosion. The Southwest Washington Coastal Erosion Study, a Federal/State/Local cooperative, is investigating the regional aspect of these changes in erosional patterns. One component of this project is to understand the historical change in regional bathymetry in order to define the large-scale, long-term changes in offshore sediment behavior and availability to the coast and how these factors may or may not correlate with changes in the position of the coastline.

HYDROGRAPHIC DATA

As part of the historical bathymetric change analysis, all existing US Coast and Geodetic Survey (USC&GS) and National Ocean Service (NOS) hydrographic surveys collected between Tillamook Head, Oregon and Point Grenville, Washington were compiled into an ArcInfo GIS data base. The surveys span over 100 years (1851 - 1958), and are grouped into three time periods based on temporal and regional coverage: 1800s (regional coverage from Cape Falcon, OR to Pt. Brown, WA); Pre-1950s (regional coverage from Cape Falcon, OR to Pt. Grenville, WA); and Post-1950s (limited to the Columbia River Mouth, Willapa Bay, and Grays Harbor estuaries and their respective offshore ebb-tidal delta complexes) (Figure 1).

The Portland and Seattle Districts of the U.S. Army Corps of Engineers (COE) have collected hydrographic survey data in and around the Columbia River, Grays Harbor, and Willapa Bay since the mid-1800s. These agencies continue to collect surveys almost annually in areas of local concern to navigation projects. In addition, an area extending approximately 20 km north of the 1998 Portland District COE Mouth of Columbia River Approach Survey was surveyed during the summer of 1998 by the Portland District COE for the Southwest Washington Coastal Erosion Study (Figure 2).

ERRORS AND ACCURACY

Uncertainties inherent to the data set limit the precision of our results. Several of the 1800s surveys have unknown and/or unshifted horizontal datums resulting in potential horizontal errors of up to 250 m. The selection of a large grid cell size (250m) minimizes this error. Vertical errors are more problematic. Although, historically, tectonic uplift has nearly kept up with sea-level rise (Hicks 1972; Komar 1998), questions regarding the vertical datum used during a particular survey, the precision of collection techniques (lead line vs. echo sounder), tidal corrections (tidal range on this coast is about 3-4 m), and sea-state conditions, all contribute to the absolute error associated with bathymetric change analysis (List et al., 1994).

USC&GS hydrographic survey accuracies, established by 1894 (Shalowitz, 1962), evaluation of available survey logs, and selected survey trackline crossing comparisons, have led us to determine an error envelope of +/- 1.5m for the SW Washington/NW Oregon coast, 1877-1926 bathymetric comparisons (Gibbs and Gelfenbaum, in prep.)

REGIONAL BATHYMETRIC CHANGE: 1877-1926

Comparison between 1877 and 1926 bathymetry shows large areas of both erosion and deposition, on the order of several meters, throughout the entire study area (Figure 3). This suggests that the nearshore region is an extremely dynamic sediment transport system, with large-scale sediment transport occurring across the entire shelf, even to depths of -100 m.

The most significant change in the study area is evident at the Mouth of the Columbia River (MCR). Between 1877 and 1926, the MCR ebb-tidal delta shifted approximately 5 km north and 5 km offshore. The cause of this movement is likely the emplacement of jetties on both the north and south side of MCR around the turn of the century.

Bathymetric change off the Grayland Plains area is represented by a very thin band of deposition close to shore, changing to a band of moderate or no erosion between -3 and -20 m water depth, and deposition dominating in water depths greater than -20 m. This is the only region within the study area where the classic "depth of closure" scenario, where sediment interaction between the nearshore/shelf and the littoral zone becomes negligible, can be interpreted. This observation may be a result of the denser data coverage of the 1877 survey in this area.

The origin of large accumulations of sediment offshore of north Long Beach and southern Clatsop Plains is unknown at this time. Recent AVHRR photography suggests that sediment plumes extending north from the Columbia River during winter months may be responsible for the deposition, at least off north Long Beach.

NEW HYDROGRAPHIC SURVEYS

Unfortunately, regional offshore data exist only for the 1877-1926 times series, making it difficult to establish how representative the changes observed during this time period are, or, whether similar conditions exist in the area today. To address this lack of modern data coverage, the USGS contracted with the Portland District of the U.S. Army Corps of Engineers to collect new regional hydrographic surveys on the inner shelf. The surveys are designed to cover the region from Tillamook Head to Willapa Bay, at a trackline spacing of 500m, to water depths of -60 m. Nearly 600 km of new hydrographic data north of the Columbia River were collected by the Portland District COE during the summer of 1998. Preliminary analysis of the data shows significant changes in both the amount and distribution of sediment both north and south of the Columbia River. Whether this is due to an actual decrease in sediment supplied by the river, or the loss of the ebb-tidal delta as a sediment source, is still to be determined.

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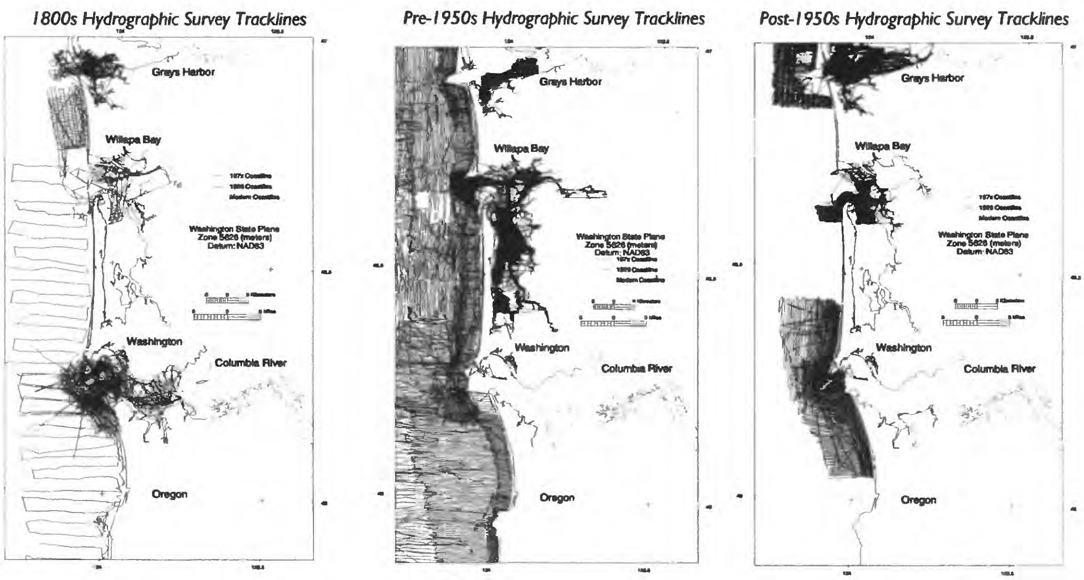

Figure 1. Existing NOS (formerly US Coast and Geodetic Survey) hydrographic data used for the regional change analysis.

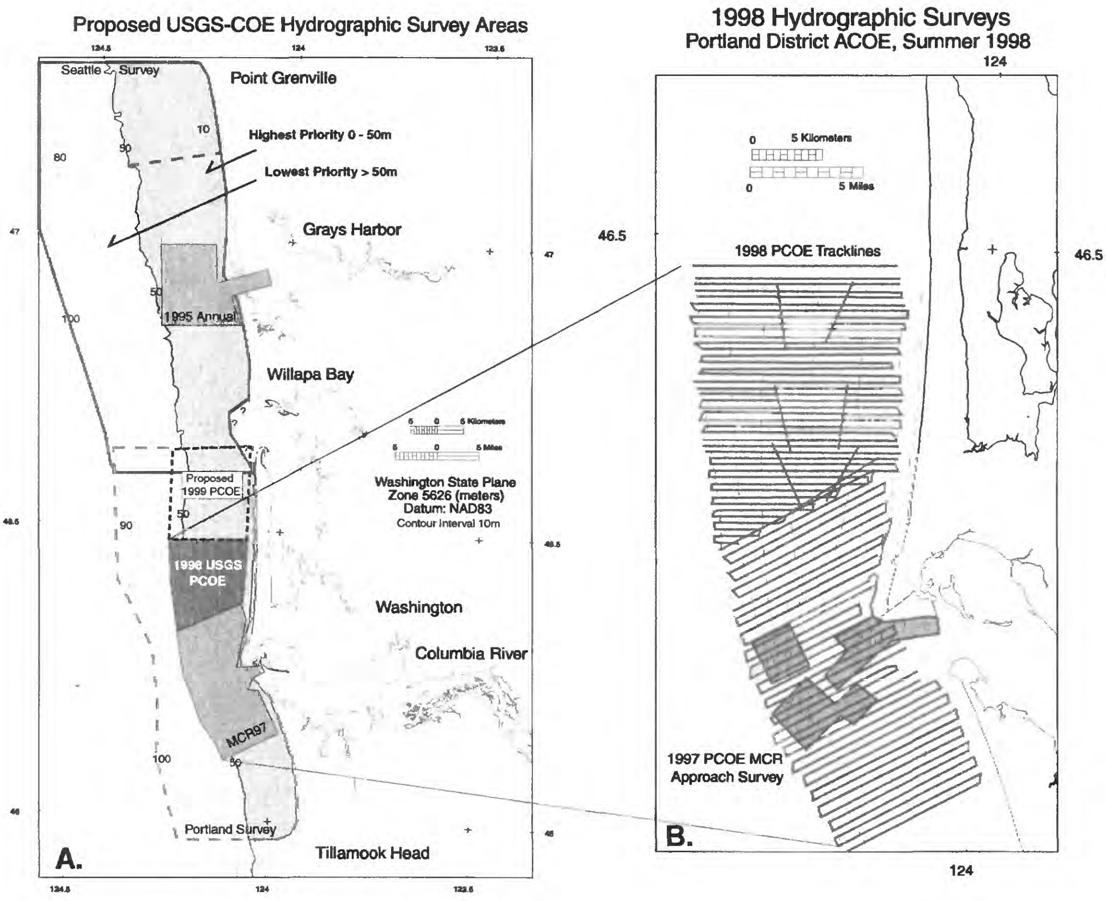

Figure 2. A. Proposed area of additional hydrographic data collection. B. Hydrographic data collected by Portland District Army Corps of Engineers during the summer of 1998.

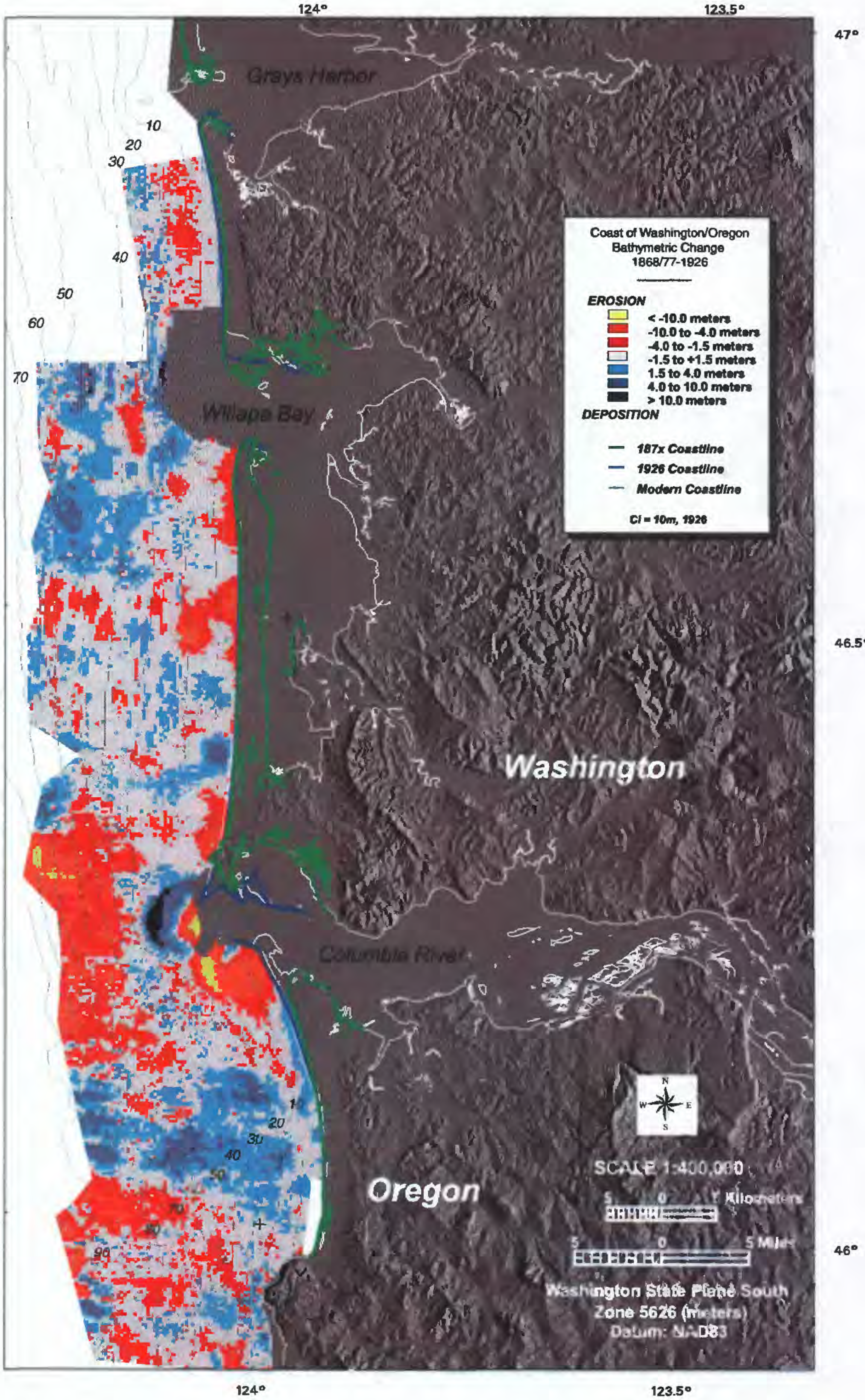

Figure 3. Preliminary regional bathymetric change map, 1868-1927.

Linking Nearshore Depth and Shoreline Change around Grays Harbor

Dave Simpson, Pacific International Engineering

Morphology and morphologic changes around Grays Harbor entrance were analyzed to develop engineering responses to shoreline recession at South Beach (Westport) and at North Beach (Ocean Shores). Figure 1 is a location map of the study area. Figure 2 illustrates the change in morphology of the ebb-tidal shoal, entrance, and adjacent shorelines in the past 100 years. Quantifying nearshore bottom changes revealed several facts that are important to improving understanding of processes responsible for coastal change at this location and projecting future trends:

- Patterns of shoreline movement developed immediately after construction of the Grays Harbor navigation project in the early part of the century
- The ebb-tidal shoal at the entrance diminished to the point of being indistinguishable in recent decades
- The ocean bottom in the vicinity of the entrance lowered many feet since navigation project construction
- Loss of material volume occurred first on the south side of the ebb-tidal shoal, and later on the north side
- Shoreline retreat occurred first at South Beach, and later at North Beach
- Erosion in these two shoreline reaches began nearest the entrance and progressed away from the entrance over a period of years

Figure 3 illustrates the relief in the nearshore bottom due to the ebb-tidal shoal early in the century and the change in shoal height through time. Wave transformation studies showed that the higher waves that approached the coast broke on the former tidal shoal and waves of much lower height reformed and traveled to shore. Under today's conditions, those waves travel farther inshore before breaking and dissipate energy over a much narrower surf zone than previously. The profiles in the figure were measured at a transect on the south side of the tidal shoal, but also represent the kind of change that occurred on the north side.

Figures 4 and 5 show the trend in lowering of the crest of the ebb tidal shoal through time, as measured at transects just south of the south jetty and north of the north jetty, respectively. The graphs indicate that bottom lowering at the crest of the ebb-tidal shoal was completed in about 1960 at the transect on the southern side of the entrance, and in about 1970 on the northern side of the entrance.

Literature exists documenting the beginning of noticeable shore erosion at South Beach at about 1970, and at North Beach in the mid 1980's. Although the timing of events fits the supposition that changes in the tidal shoal lead to the changes at the shore near the entrance, the physical link between the two observations is not established by this information alone.

Nearshore bottom profiles oriented perpendicular to shore were analyzed by fitting depth data surveyed from 1950's through 1998 to an equation for the theoretical equilibrium profile. Extrapolating the resulting best-fit curve to the profile origin for each survey year provided a basis for comparing the horizontal shift in the theoretical shoreline position from year to year. This position was extrapolated from profile data that extended from one to three and one-half kilometers from shore; no data exist for documenting bathymetry of the inshore one kilometer or the exact shoreline position for these survey years. Figure 6 plots the theoretical shoreline position through time, relative to an arbitrary but fixed baseline, for a transect just south of the south jetty. The retreat of this profile origin is shown to start at about 1965. Figure 7 plots the comparable theoretical position for North Beach, and shows that retreat began at about 1975. Theoretical shoreline movement can be connected to observed shoreline movement by both the mathematical significance of the profile origin and the timing of the beginning of recession. Ten to fifteen years separates the time when the tidal delta lowering was completed and when shoreline recession is observed to begin. Theoretical shoreline retreat precedes the observed retreat by five to ten years. Cross shore transects were similarly analyzed at distances up to three kilometers north and south from the entrance. At these limits, the theoretical shoreline position did not show progressive retreat, nor did the actual shoreline retreat during this time.

Trend lines established through the theoretical shoreline positions calculated near the entrance allow the projection of future shoreline movement. A second-order polynomial curve fitted to the calculated points extends to a point of zero change at about year 2000 for South Beach, and at about year 2020 for North Beach. This particular function was chosen because it describes a process of approaching an equilibrium state at a declining rate and represents well the rate of change in the plotted points. (The trend line was terminated at the point of zero change.)

The method of representing the theoretical shoreline position by extrapolating shoreward from the inshore limit of profile data, and the method of projecting these positions into the future yields three important findings. The first is the consistency of the timing of these events of tidal shoal disappearance, observed shoreline recession, and stabilization of the projected profile origin. The sequence shown to occur at the south side of the entrance is repeated at the north side, but offset in time by roughly 20 years.

The second important finding is the consistency with results of beach profile measurements. South Beach profiles have been surveyed for the City of Westport at eight locations over a distance of two kilometers south from the south jetty monthly from April 1995 through the end of 1998. Sand volume in the profile and position of the mid tide elevation on each profile were calculated for each survey and compared over time. Sand volume plots show no net change within about one and one-half kilometers south of the south jetty. The position of the mid tide elevation reflects similar variation, and is plotted for two transects within 1.3 kilometer of the south jetty in Figures 8 and 9. The figures represent seasonal variability in the sand volume in the upper profile, but a mean trend of essentially no net change until the fall of 1997. South of this reach, the trend in sand volume change is negative until the fall of 1997. El Nino effects are interpreted to be responsible for the large sand accumulation in this survey reach. If that is the case, the trend in sand volume is expected to return to the mean trend direction after El Nino effects subside. The shoreline position at transects showing net sand volume loss is aligning with the adjusted, but now stabilized, shoreline position closer to the south jetty.

The third finding is that theoretical shoreline positions calculated with this profile analysis method can reveal the response of the nearshore profile at northern boundaries of littoral sub-cells to past El Nino events. Figure 6 shows plotted points that deviate from the trend line and which correspond to El Nino events of 1972-73 and 1982-83. The deviations are consistent with the effects of those respective events; erosion accompanied the 1972-73 event and sand accumulated in the 1982-83 event. The analysis indicates that sand that accumulated adjacent to the south jetty starting in 1982 remained in the profile for 5 years.

Conclusions from this analysis are that shoreline change experienced at South Beach and North Beach is a response to changed nearshore conditions resulting from loss of the ebb-tidal shoal. Shoreline recession due to this mechanism is limited to those reaches near the Grays Harbor entrance. Recession may occur up to a few kilometers north and south from the entrance, as the shoreline realigns to the more landward position of the shoreline adjacent to the jetties. After adjustment of the shoreline to these changed conditions is completed, net change in shoreline position due to this mechanism is expected to be near zero. Cessation of shoreline retreat by this mechanism is projected to be at about year 2000 at South Beach and year 2020 at North Beach.

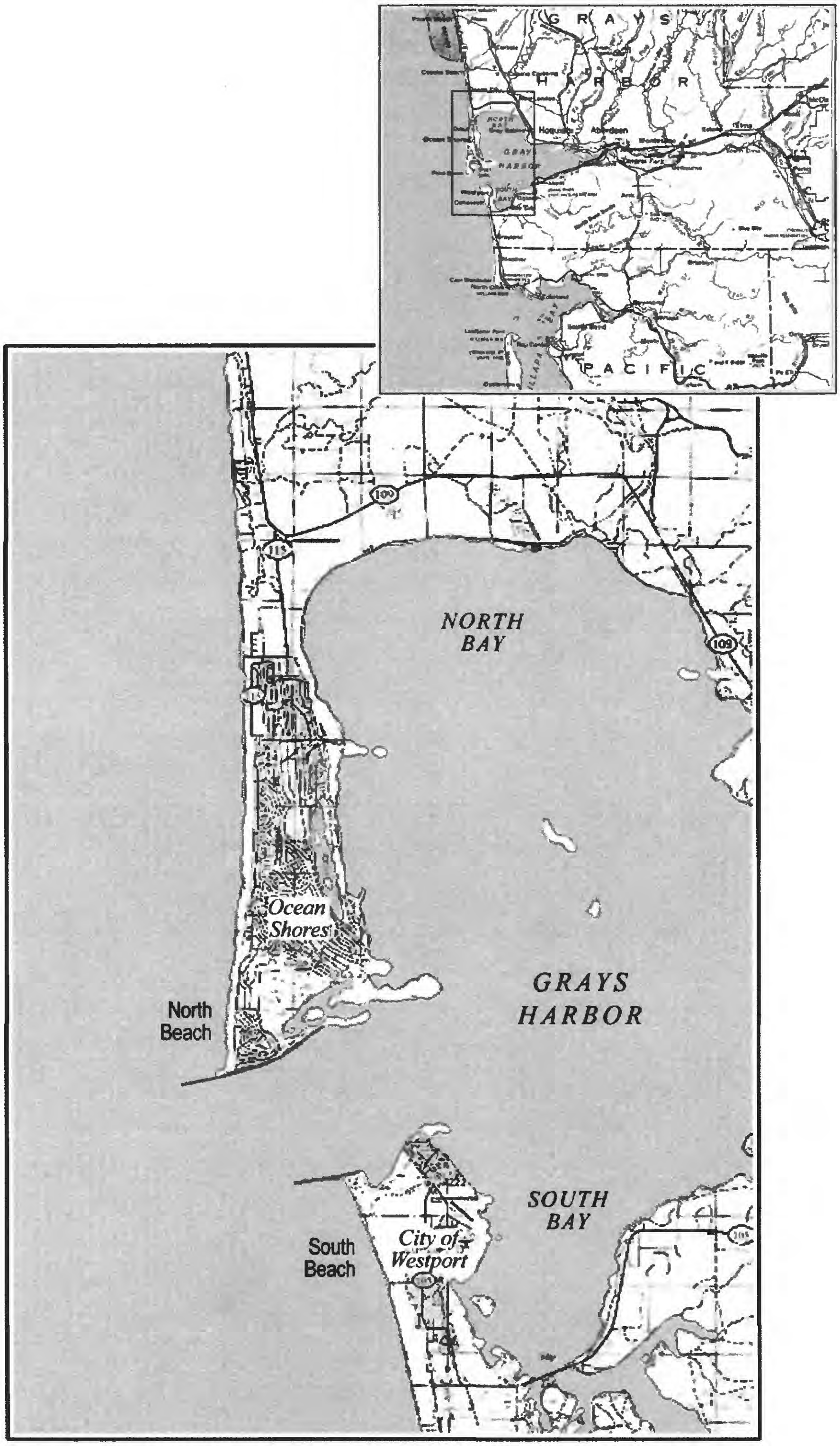

Figure 1. Grays Harbor South Beach and North Beach analysis areas

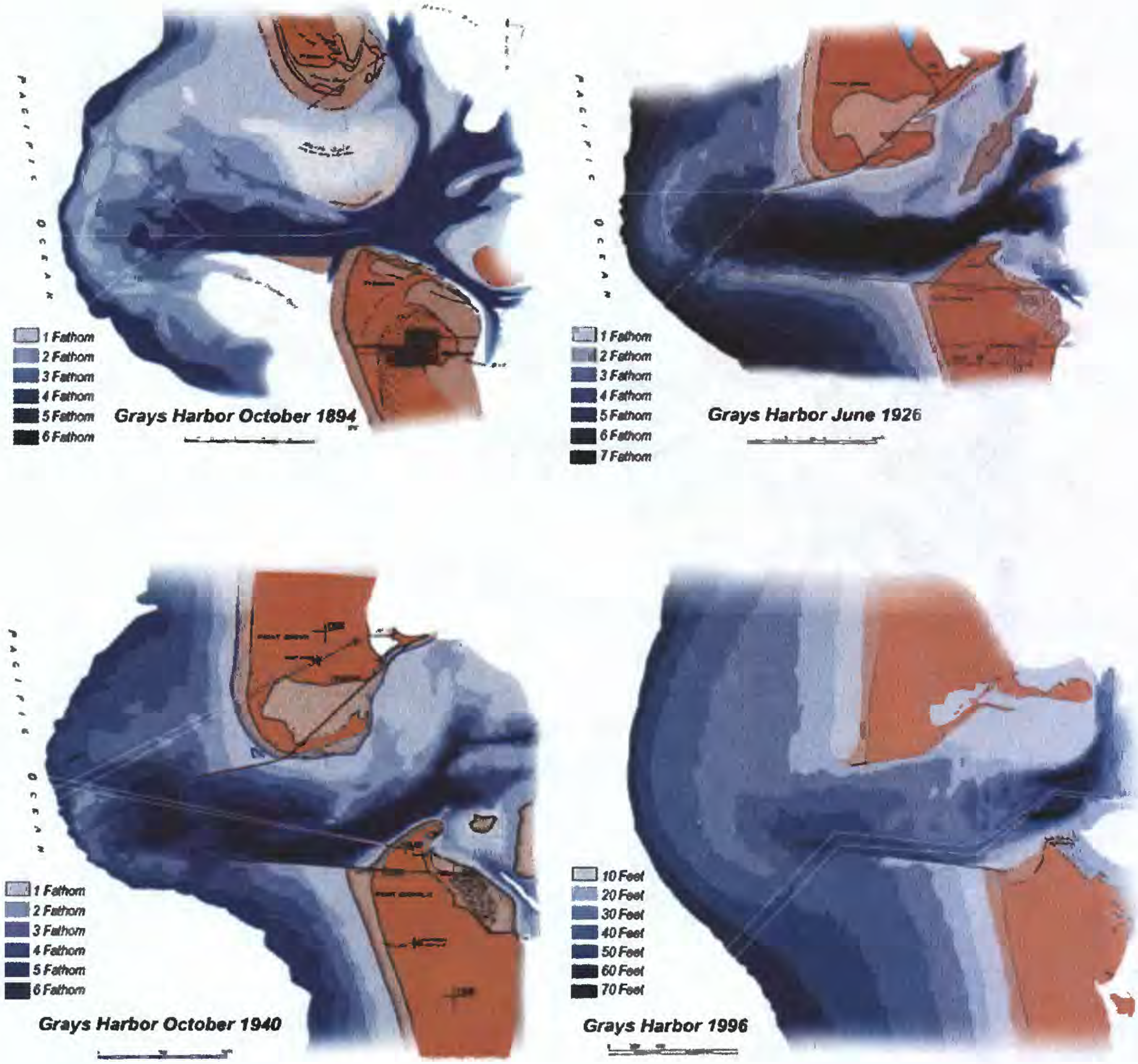

Figure 2. Grays Harbor Bar and Entrance Morphology, 1894 to 1996

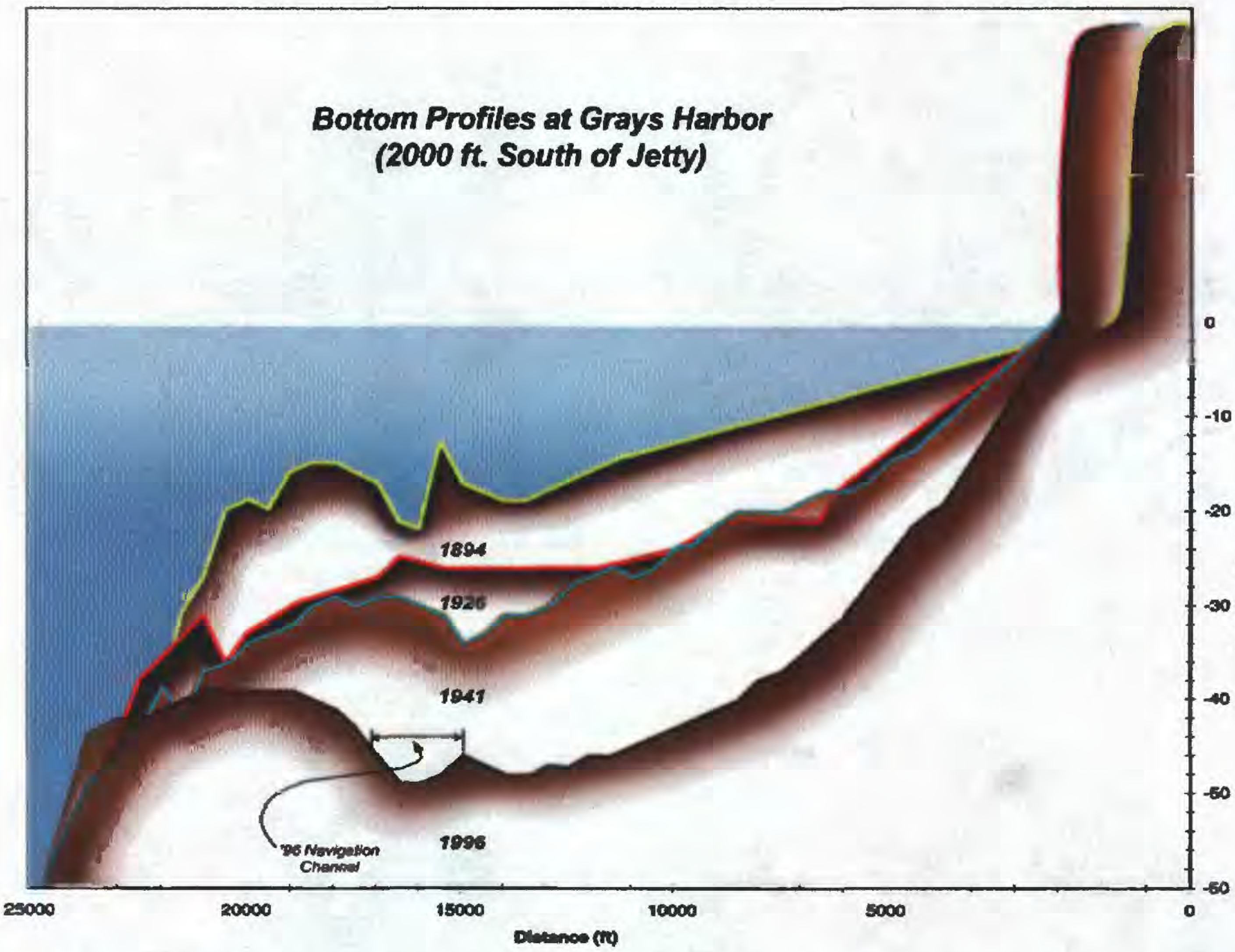

Figure 3. Bottom Profiles, South Side of Grays Harbor Entrance, 1894 to 1996

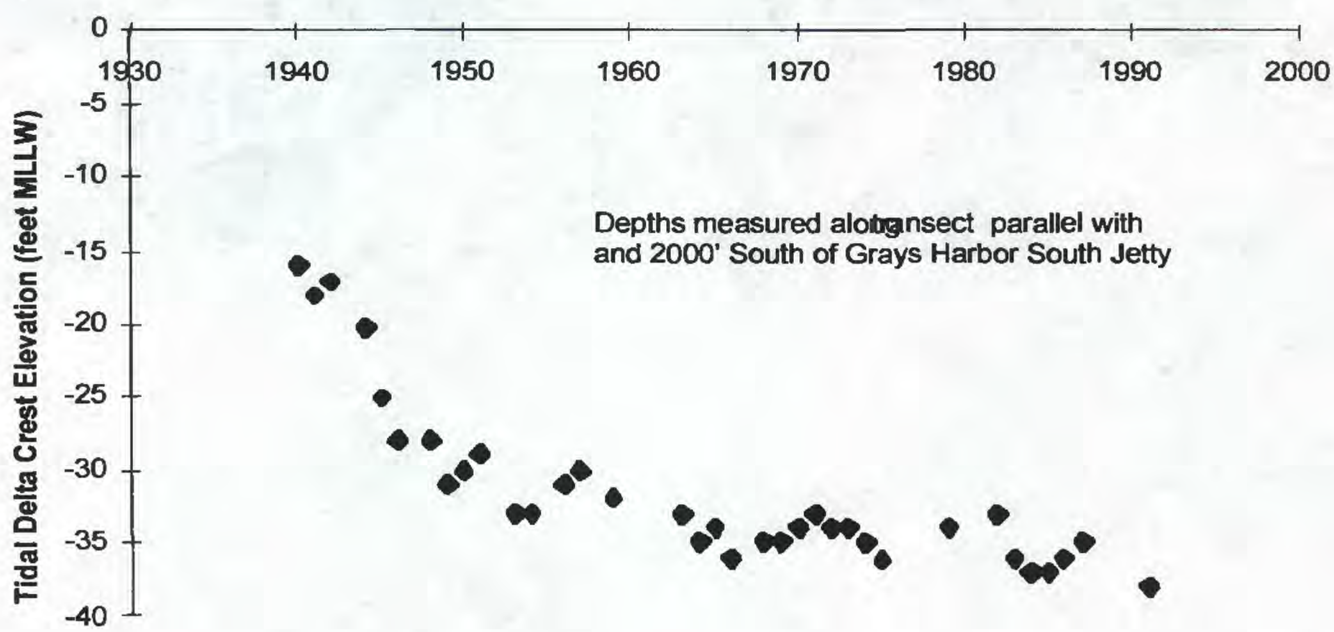

Figure 4. Tidal Delta Crest Elevation South Side of Grays Harbor 1930 to 1998

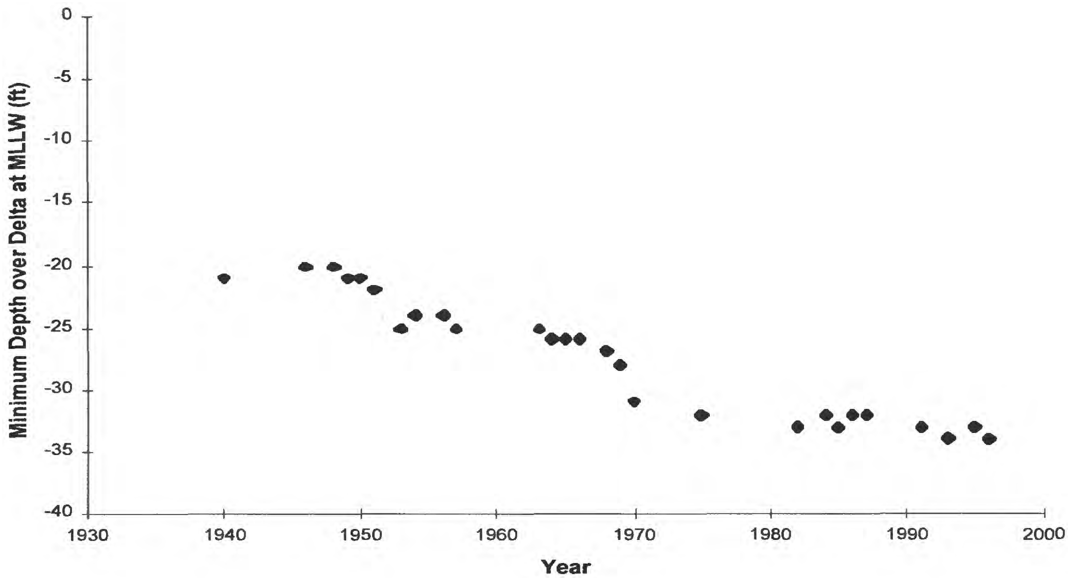

Figure 5. Tidal Delta Crest Elevation North Side of Grays Harbor 1940 to 1996

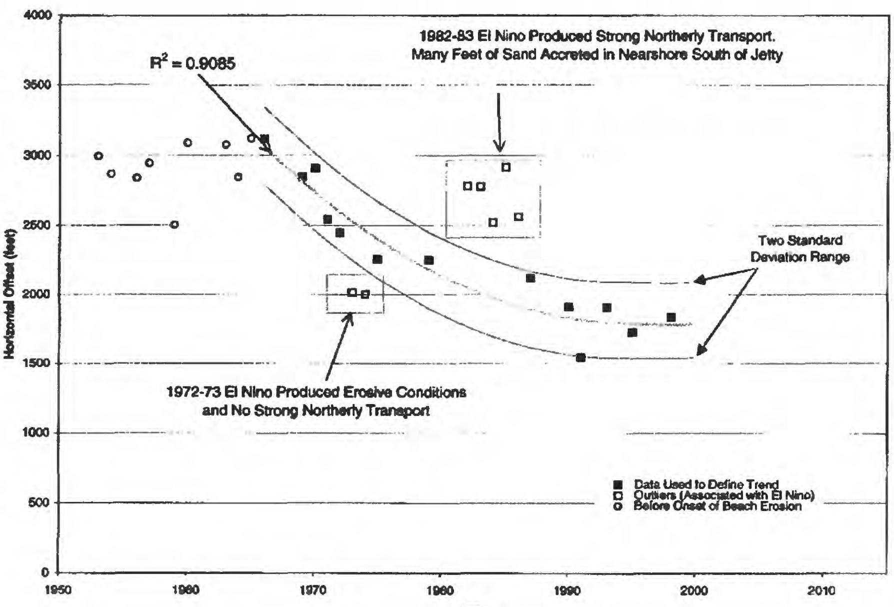

Figure 6. Trend of Variation of Theoretical Shoreline Position with Time, South of Grays Harbor South Jetty

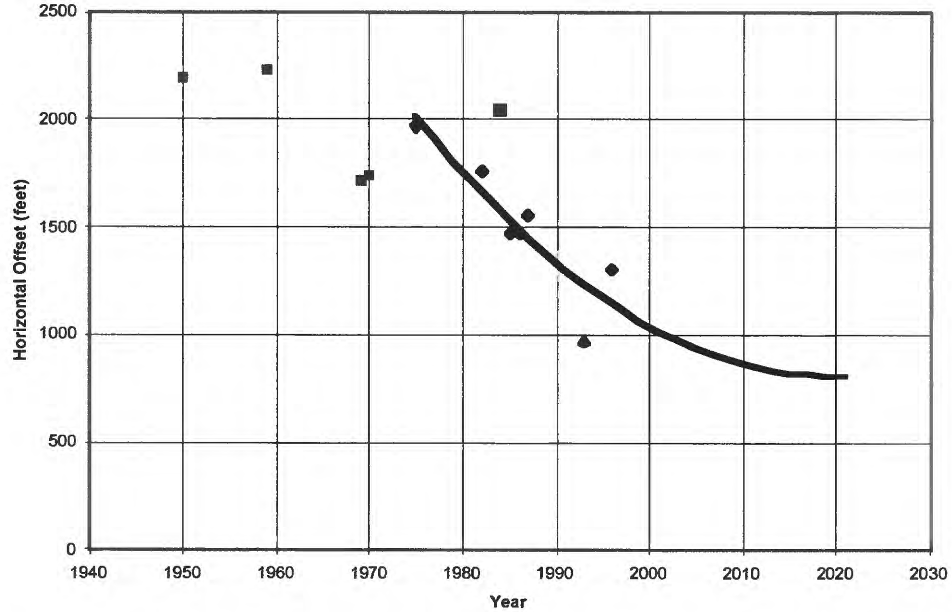

Figure 7. Trend of Variation of Theoretical Shoreline Position with Time, North of Grays Harbor North Jetty

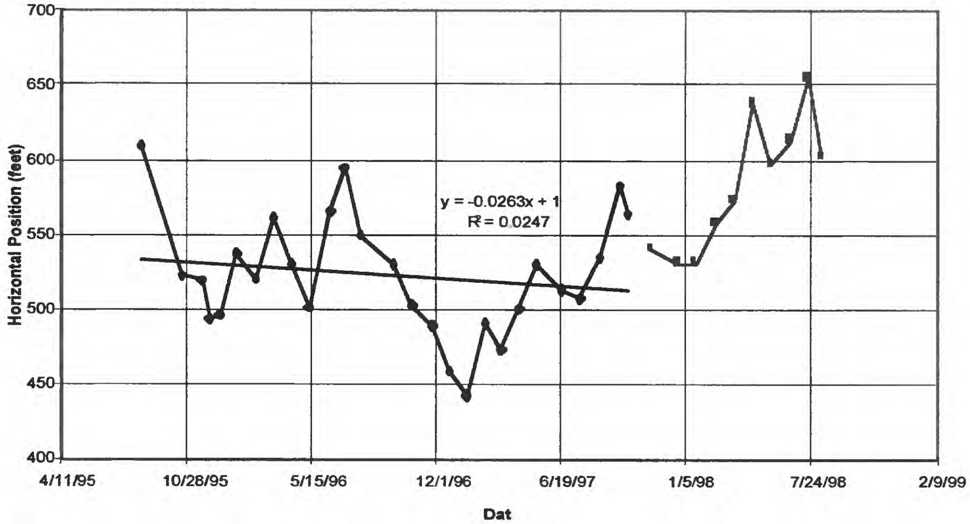

Figure 8. Variation of Mid-Tide Point on Profile, 443 Meters South of South Jetty, 1995 to 1998

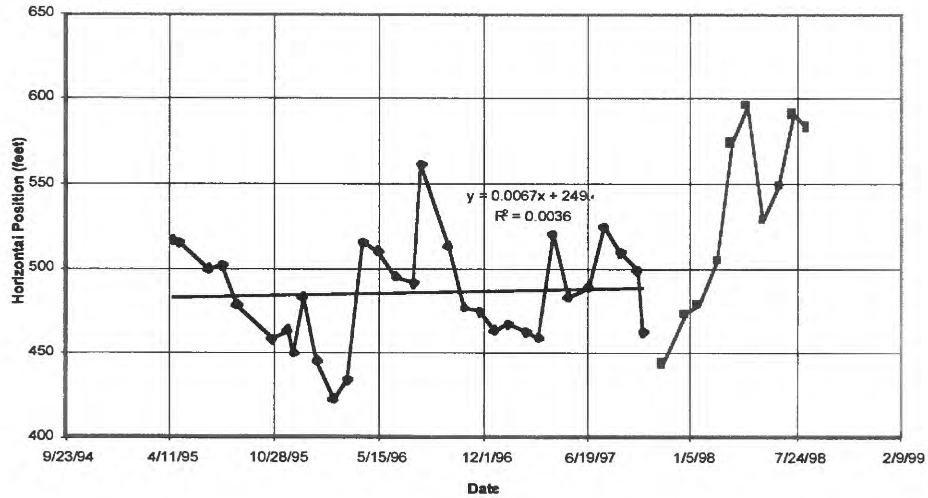

Figure 9. Variation of Mid-Tide Point on Profile, 1,373 Meters South of Jetty

Recent Beach Progradation and High Resolution Ground Penetrating Radar Lines

Harry M. Jol, University of Wisconsin - Eau Claire
George Kaminsky, Peter Ruggerio, WA Department of Ecology

During the summer of 1998, three high resolution ground penetrating radar (GPR) profiles were collected in coordination with global position system (GPS) data. A line was run in each of 3 sub-cells located within the larger Colûmbia River littoral cell – Ocean Shores (North Grays Harbor), Warrenton (South Grays Harbor) and Long Beach. These profiles were shot using 200 MHz antennae with 0.5 m step to allow for detailed imaging (<0.5 m resolution) of the subsurface. The processed profiles were topographically corrected using the GPS data and at each location, a common mid-point survey was collected to calculate velocity of the subsurface material so that depth calculations could be made. The data were collected in areas that the geographic information systems database reveals constant progradation over the time period of available topographic information. Further processing and interpretation will aid in understanding rates of recent progradation and possible anomalies.

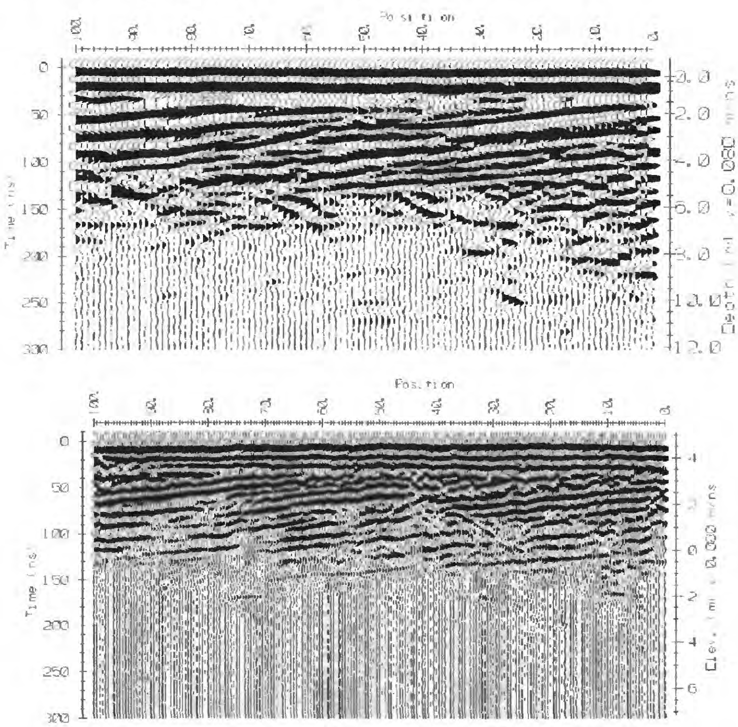

Figure 1. *Upper:* 100 MHz GPR profile (W-E) shot to show dipping foresets at Ocean Shores. *Lower:* 200 MHz GPR profile shot over same site showing higher resolution stratigraphy. The 1884 shoreline is located at the east end of the profile.

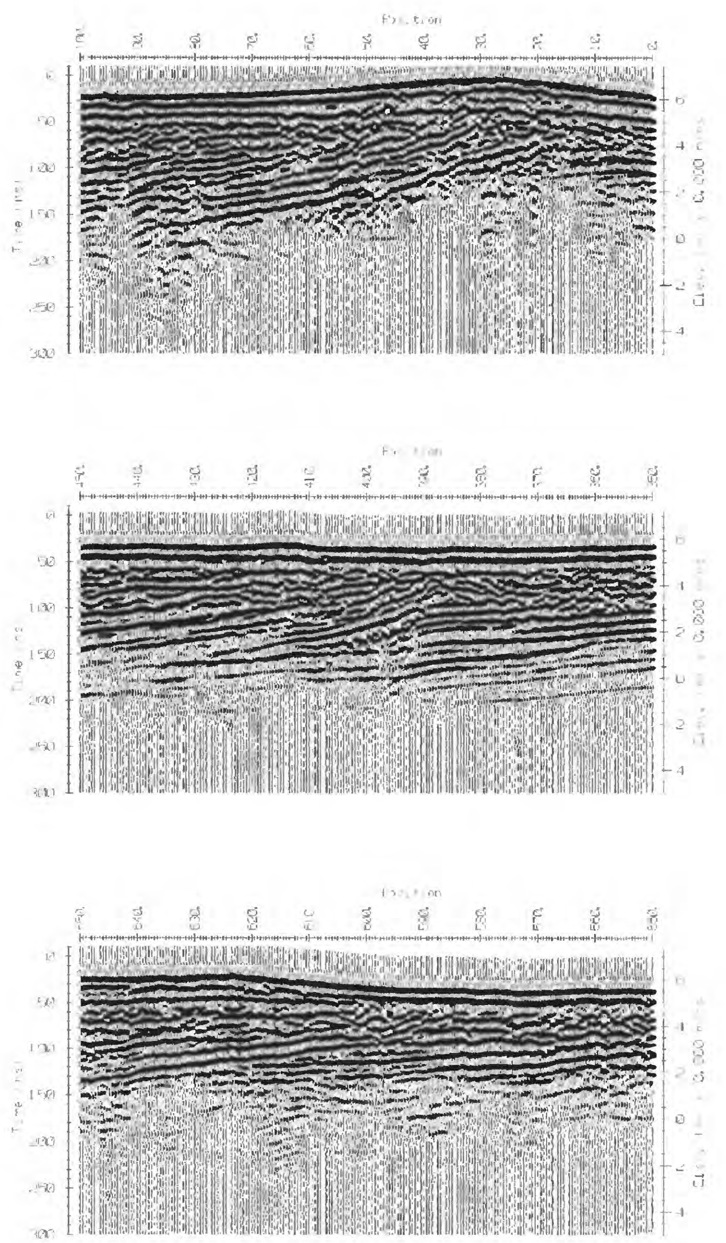

Figure 2. 200 MHz GPR profile (W-E) shot in 1998 along Warrenton-Cannery Road in the South Grays Harbor Cell. *Upper:* 1200 yr BP scarp (placer) is located at 20-40 m, *Middle:* 300 Yr BP scarp (placer) is located at 385-400 m, *Lower:* Further west along the line is an erosional scarp located at 585 – 606 m. The feature is in front of the last known earthquake event and could possibly be the 1886 El Nino event.

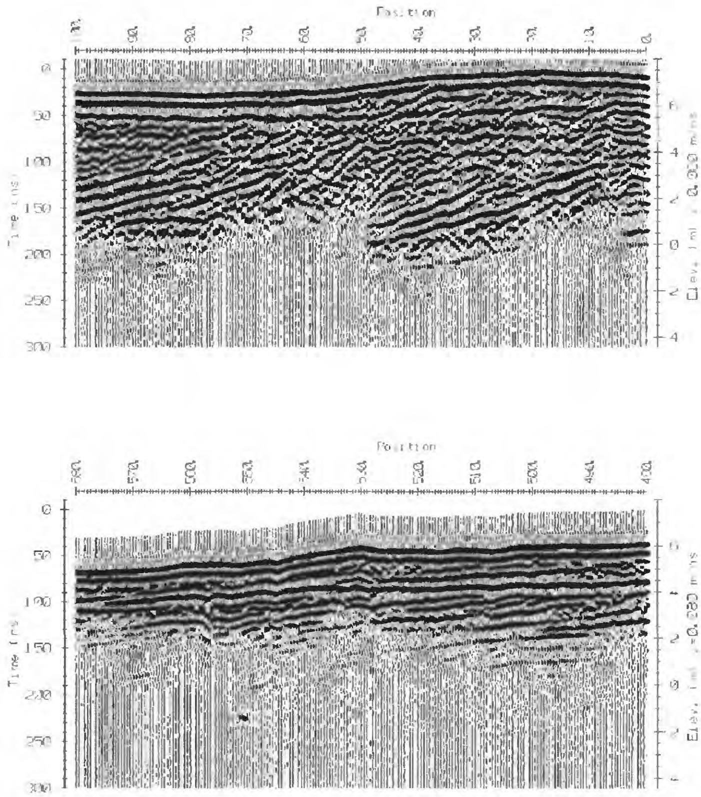

Figure 3. 200 MHz GPR profile (W-E) shot in 1998 on the Long Beach Peninsula. *Upper:* 300 Yr BP scarp (placer) is located at 40 – 60 m. The 1873 shoreline is located at the same location. *Lower:* Further west along the line dunes are apparent in the topography as well as salt-water intrusion attenuates the radar signal. The 1924 shoreline is located at approximately position 540.

ACKNOWLEDGEMENTS

The major support for this project comes from the Southwest Washington Coastal Erosion Study - United States Geological Survey (USGS). Further support comes from Sensors and Software, University of Wisconsin-Eau Claire, Portland State University, University College of the Fraser Valley and Grays Harbor College. We would also like to acknowledge the support of the Washington Department of Ecology (DOE), and Grays Harbor, Pacific, and Clatsop counties. Able-bodied field assistance was provided by Brian Thayer. We thank Rilea Armed Forces Training Center, the Cranberry Research Foundation, and the communities within the study area for their aid in this project.

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Shoreline Modeling

Maarten Buijsman, WA Department of Ecology

INTRODUCTION

One of the most important forcing conditions governing the behaviour of the coast are the waves. Incident waves determine the littoral transport and the angle of the coast normal. For example in a closed system, where net input equals zero, the coastline strives for an equilibrium angle. The pocket beach cells in Oregon are a good example (Komar, 1997). Today we see that most of the accretion of the sandy beaches of the Columbia River littoral cell has come to a hold. The beaches seem to be developing towards a new equilibrium of pocket beach systems. The boundaries of these sub-cells are Point Grenville, the Grays Harbor jetties, Willapa Bay inlet, the jetties of the Columbia River and Tillamook Head. In this particular study, the UNIBEST model of Delft Hydraulics has been applied to some of the sub-cells of the Columbia River littoral cell to simulate and extrapolate actual and future shoreline positions.

MODEL APPROACH

The general hypothesis is as follows: The construction of the jetties in the early 1900's across the deltas of Grays Harbor and the Columbia River changed the tidal flow. The jetties have restricted the ebb flow to a narrow channel. As a result, the wings of the deltas, which were no longer part of the tidal system, started to erode. This sediment was brought onshore by waves and caused the beaches to accrete. The accretion has been simulated with UNIBEST.

The model UNIBEST has been applied for three sub-cells: Ocean Shores, Grayland and Long Beach. The calibration period is from the 1950's to 1995. During this period the accretion slowed down and the first erosion appeared. In the calibration process the results for Ocean Shores are most promising. Therefore an extrapolation has been made from 1995 to 2020.

The approach is described in the following. The total accreted volume per sub-cell has been calculated by multiplying the horizontal area between the 1950's and 1995 shorelines with the active height. The active height comprises the average dune height to the depth of closure (about 13 m below MSL (Buijsman et al., 1999)). For the modelled beaches, the active height varies between 15 and 19 m. The volume distribution along the coast has been determined in increments of 1 km. The total volume is used as a boundary condition for each modelled sub-cell. Ocean Shores is the only sub-cell with one boundary condition. The Grayland and Long Beach sub-cells have two boundary conditions. Therefore they are more difficult to model.

To improve the calibration and extrapolation, input values like coast angles are based on 1995 or more recent data. These values remain constant of shape or value during the calculations.

UNIBEST

UNIBEST is a computer model, which describes shoreline and profile behaviour. UNIBEST is the acronym for Uniform Beach Sediment Transport. This software package consists of 4 modules. Two of them describe the longshore transport (UNIBEST-LT) and coastline change (UNIBEST-CL). These two modules have been used in this study.

In UNIBEST-CL the cross-shore profiles are defined. For each cross-section the sediment transport (S [m^3/yr]) is calculated as a function of the coast angle (θ [degrees]). The most important input of UNIBEST-CL consists of wave statistics based on time series of H_{sig}, T_{peak} and θ in combination with current conditions. The sediment transport formulas used in this study are the formulas of Van Rijn and Bijker (Delft Hydraulics, 1994). The effects of refraction and shoaling are incorporated in the model. The model is not able to calculate diffraction. The active part of the model is the part affected by the volume calculations. It comprises the active height from the top of the dune to the depth of closure (offshore boundary). The input of the waves in the model is at the offshore boundary. The waves are shoaled from this point towards the coast using linear refraction. The waves are shoaled from the data source location towards the UNIBEST boundary by applying linear refraction or a sophisticated shoaling model.

In UNIBEST-LT the dynamics of the coastline are considered through time. In this module the initial coastline, boundary conditions, sources and sinks, jetties and revetments are defined. Changes in coast angle cause changes in sediment transport. The sediment transport is calculated using the S(θ) curve determined in UNIBEST-CL. UNIBEST-LT is a one-line model. All of the horizontal changes are averaged over the active height.

INPUT

In this section we discuss the input needed for the model UNIBEST. This input consists of waves, profiles, sediment sizes, initial position of the shoreline and sediment input.

The shoreline change and transport rates are calculated applying buoy data from the Grays Harbor (CDIP) buoy and the Long Beach array (CDIP). WIS hindcast data from the U.S. Army Corps of Engineers has not been used. The WIS data seem to overestimate the measured buoy wave height up to a maximum value of 45%.

The characteristics of the buoys for only the directional data are listed in the table below. This directional data is used for this study.

Table 1. Characteristics of the Long Beach and Grays Harbor buoys

Buoy ID	Period (year)	Position (long-lat)	Depth below MLLW(m)
Long Beach 05401	1983 – 1987	46:23:5 124: 4:7	11.3 m
	1991 – 1996	46:23:2 124: 4:3	9.8 m
Grays Harbor 03601	1993 – 1995	46:51:2 124:14:9	42.7 m
	1995 – 1997	46:51:4 124:14:7	40.2 m
	1997 – present	46:51:5 124:14:7	40.2 m

The monthly means of the wave height, period and direction of the Grays Harbor and Long Beach wave gages are presented in figures below.

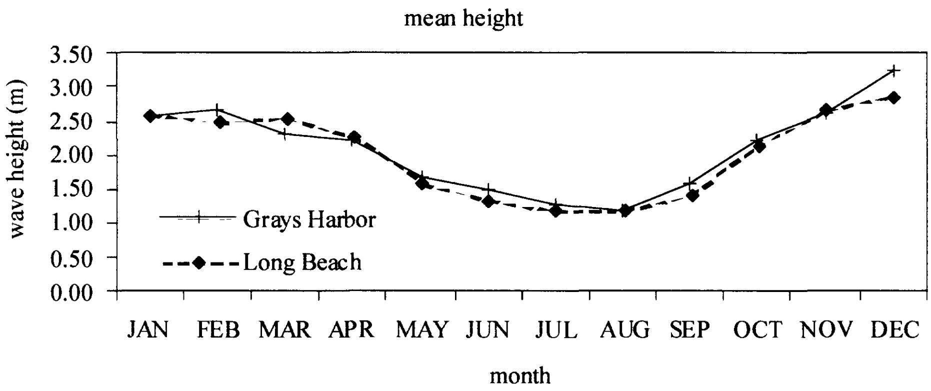


Figure 2. Mean wave height

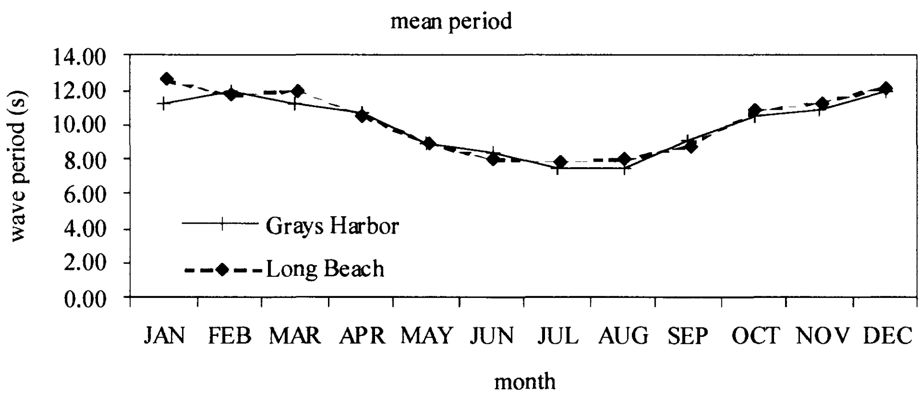


Figure 3. Mean wave period

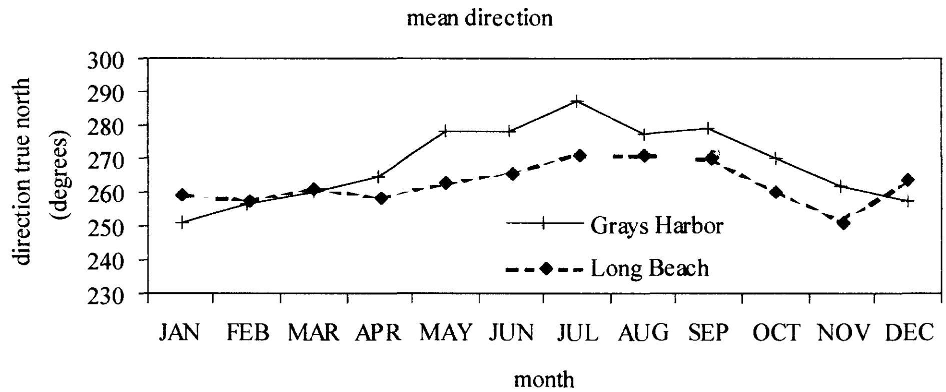


Figure 4. Mean wave direction

The seasonal fluctuation is clearly reflected by the data. During the winter season the waves come from the southwest (250°-270°) and have a mean height of 2.5 m and a period of about 12 s. In the summer months the wave height is about 1.25 m, the period 8 s and the mean direction varies from 270°-285° (all values from Grays Harbor buoy).

The monthly means are directly derived from the data. A direct comparison between the two stations is difficult, because they are not in the same water depth. The waves at the Long Beach array have approximately the same height and period as the waves at the Grays Harbor buoy. Looking at the monthly mean directions we see differences between Grays Harbor and Long Beach. The amplitude of the wave direction at Long Beach is smaller than the amplitude at Grays Harbor. This is a characteristic of shoaling: in shallower water the wave directions get closer to the coast normal. The data of the Long Beach array has a lot of gaps. The period from 1983 to 1996 combined has 5 years of usable data. Wave data from the Grays Harbor buoy has been used for the Ocean Shores and Grayland sub-cells. The Long Beach wave array has been used for Long Beach.

The distribution of the sediment for D50 and D90 is shown in Figure 5. The "D50 database" is data from Peterson et al. (1994). The other data has been collected and analyzed by the Department of Ecology as part of the study. The general trend in the data is a decreasing sediment size going from the Columbia River towards the north. A peak occurs around the south of the Grays Harbor jetties. This sediment mainly consists of gravel that may be relict.

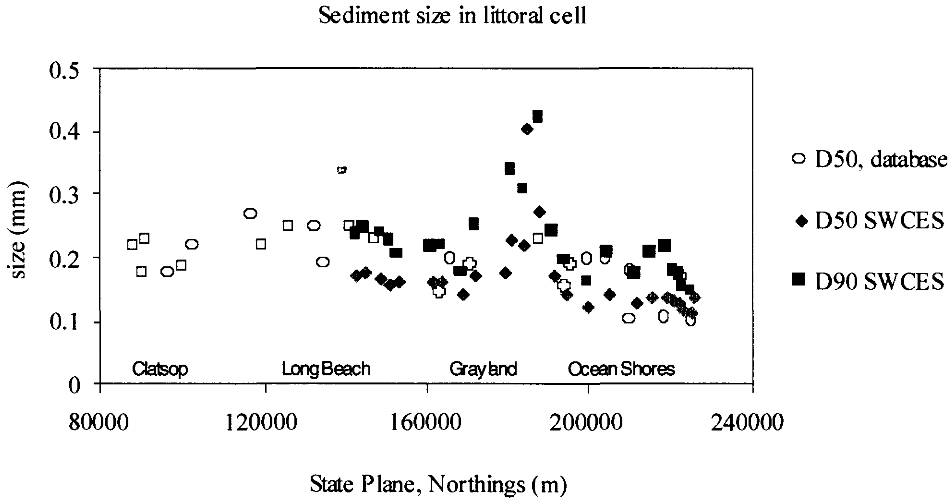


Figure 5. Sediments size distribution

Several different profiles are used for the modelling. Some profiles are compiled from 3 different data sets: U.S. Army Corps of Engineers bathymetry data around the inlets, waverunner data (Coastal Profiling System (CPS)) and beach profile data (Ruggiero et al., 1998). As an example, the compilation of the profile Pro-cop (near Copalis Beach) is shown in Figure 6.

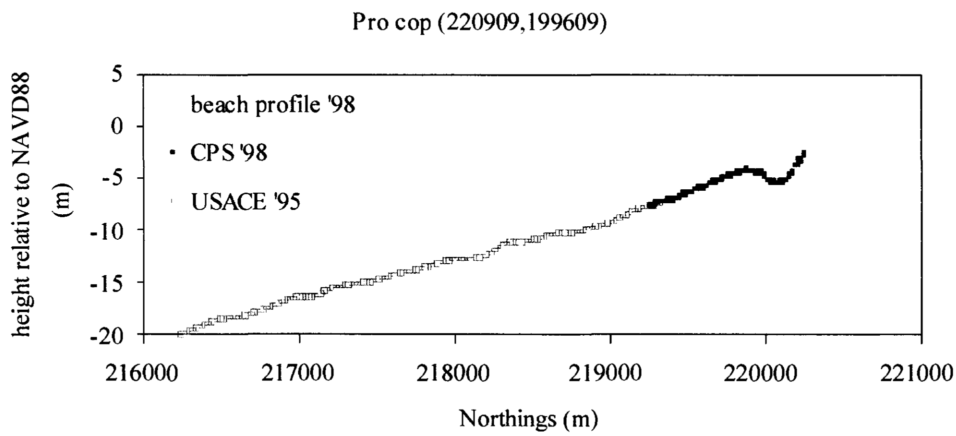


Figure 6. Beach profile near Copalis Beach, WA from combined data sources

RESULTS

Ocean Shores

The model is calibrated for the period from 1950 to 1995. The calibrated model is used to extrapolate from 1995 to 2020/2025. The Ocean Shores sub-cell is approximately 43 km long. The southern boundary is the Grays Harbor North Jetty and the northern boundary is Point

Grenville. It is assumed that both boundaries are closed, with no exchange of sediment across these boundaries. All the accreted sediment is assumed to have come from the ebb-tidal delta of the Grays Harbor inlet from onshore cross-shore transport. Subsequently the waves transported the sand further to the north. The total accreted volume for the period 1950-1995 is about 58 Mm^3. This volume (Figure 7) is calculated by summing all volume changes per kilometer going from Point Grenville to Ocean Shores. This value is close to the volume (52 Mm^3) calculated in Buijsman et al. (1999). In the model, the feeding is represented by point sources. The feeding from the delta decreases linearly with time, and becomes zero in 1995. Dividing the cumulative volume by the time gives the average sediment transport (maximum 1.3 Mm^3/yr in northern direction). The 1950 and 1995 shoreline positions are presented in Figure 7. All the accretion occurred in the southern part of the cell.

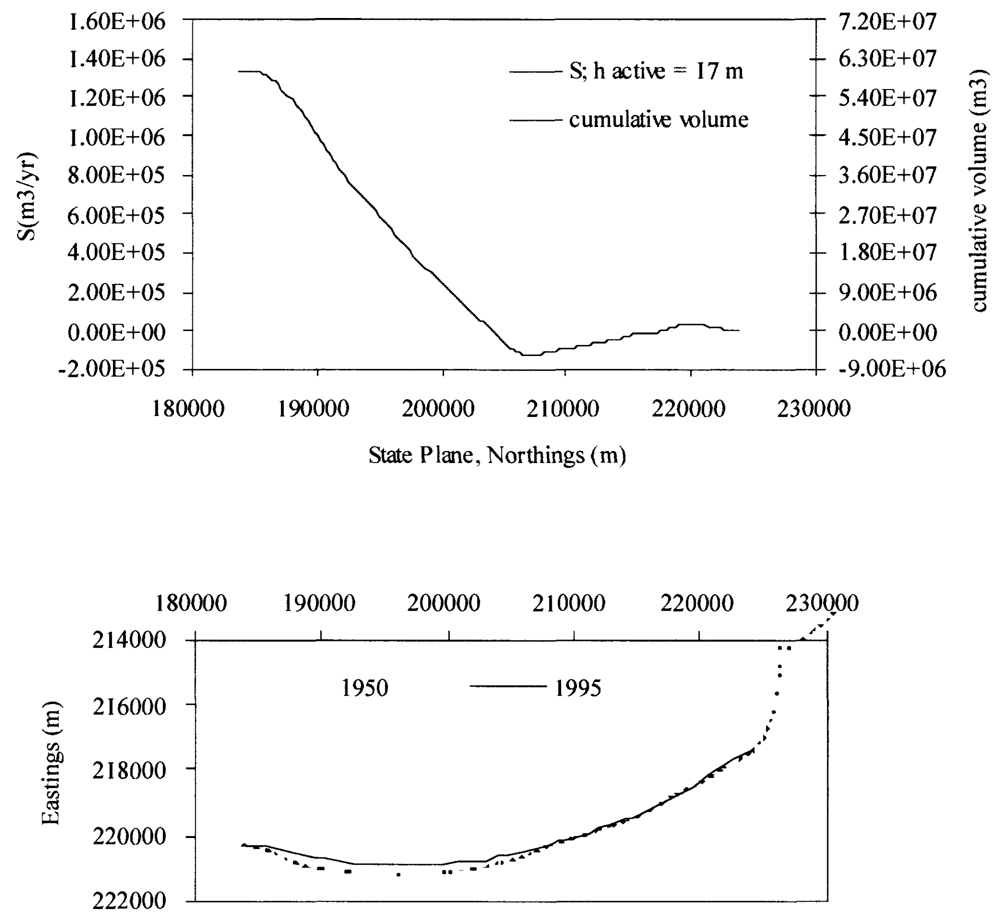


Figure 7. Sediment transport, cumulative volume and coastline positions. Ocean Shores (1950-1995)

A sensitivity analysis has been performed for different shoaling routines (linear and quasi 2D) and for various sediment transport formulas (Bijker and van Rijn). In the theory about linear shoaling the waves are shoaled and refracted according to Snell's law and linear wave theory (assuming parallel depth contours). In the quasi-2D wave shoaling and refraction the bathymetry is included and the wave refraction and shoaling is more sophisticated. The quasi-2D shoaling routine is part of the software package SCATTER by Delft Hydraulics. The disadvantage of the quasi-2D shoaling is that it takes a lot of time and manual labor to derive the angles and profiles from a map. The results for the linear and quasi-2D shoaling are presented in Figure 8 and Figure 9. The presented results are obtained with the Bijker formula.

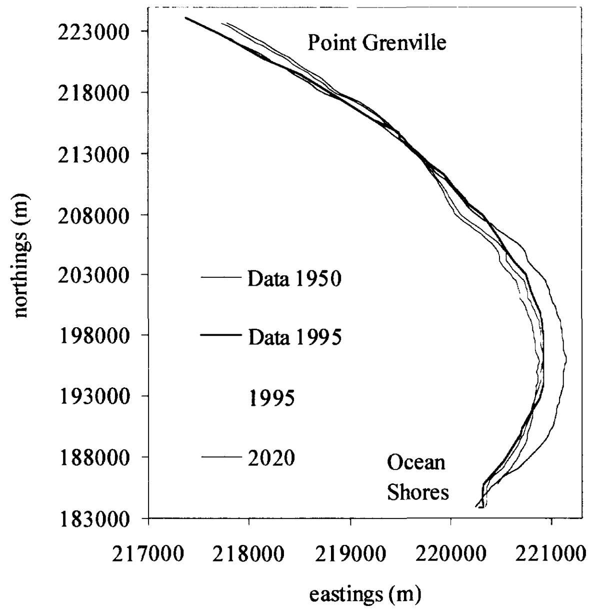


Figure 8. Ocean Shores 1950-2020; linear shoaling; Bijker

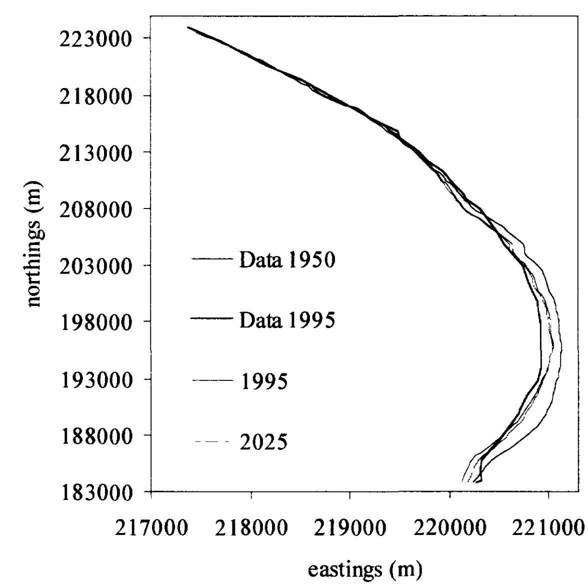


Figure 9. Ocean Shores 1950-2025; quasi 2D shoaling; Bijker

The best results in the calibration phase are obtained in the case of linear shoaling in the south, and in the case of quasi-2D shoaling in the North. Both simulations reflect the southerly sediment transport as presented in Figure 7. A large amount of accreted sediment around Northing 208000 m in Figure 8 comes from the eroded north side of the sub-cell. The shoreline south of this point matches the data fairly well. The ebb-tidal delta is included in the quasi-2D analysis, and affects much of the behaviour in the south. Small errors in measured angles directly affect the results. The results in the north are better because of the more uniform bathymetry. The results for the van Rijn formula are not presented. The transports calculated by the van Rijn formula are larger, and result in increased accretion and erosion.

In both cases an extrapolation to the future has been made. After 1995 it is assumed that feeding from the delta no longer exists. As it can be seen, the coast starts to erode. This erosion slows down in time until the coast reaches a "dynamic" equilibrium position. To illustrate this behaviour the model has been extrapolated to 2050. This year may fall outside the range where the extrapolation is considered accurate, but the extrapolation to 2050 demonstrates this process very well (Figure 10). The erosion affects the coast up to 9 km north of the jetty. The erosion for this stretch of 9 km equals about 16 Mm^3 for the period 1995-2050 (0.3 Mm^3/yr).

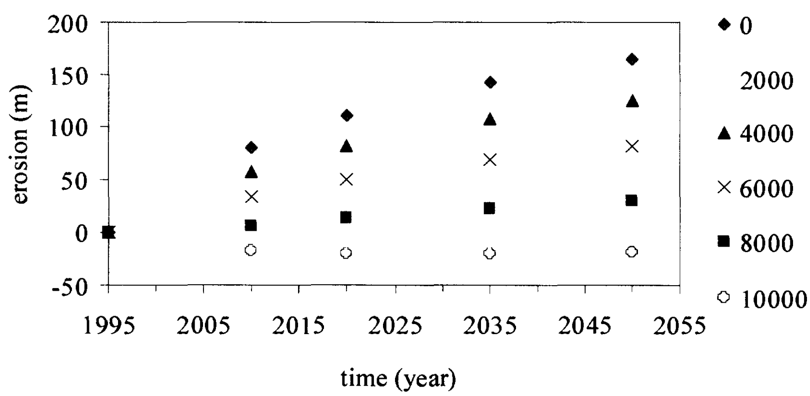


Figure 10. Relative shoreline erosion for several points up to 10 km north of the Garys Harbor North Jetty (assuming linear shoaling and Bijker sediment transport).

Grayland

The results for Grayland are not as satisfying as the results for Ocean Shores. The results presented here are very preliminary. They are based on the first model simulations. The modelled period is from 1951 to 1995. The sub-cell is about 20 km long. The northern boundary is the South Jetty of the Grays Harbor inlet and the southern boundary is the North Channel in the Willapa Bay inlet. All the sediment that accreted in Grayland since the 1950 's equals 14 Mm^3. This value was derived before the DEM study (10 Mm^3 in Buijsman et al. (1999)). The shoreline positions, transport and cumulative volume are presented in Figure 11. The cumulative volume has been calculated starting at Westport. Dividing the accumulative volume by year does not show a clear transport pattern. The "transport" curve shows erosion in the north and accretion south of the erosion. The coast remains stable in the center and shows accretion again in the south. Does the curve show a southerly transport in the north and a northerly transport in the south? Or does it show southerly transport for the whole sub-cell? Linear shoaling was applied for the first run. A constant input for the northern boundary is used of 0.34 Mm^3/yr (yearly average derived from 14 Mm^3). The Corps data (USACE, 1997) show about 44 Mm^3 of erosion of the foreshore near the South Jetty. In the case of the quasi-2D modelling it is assumed that this amount is transported southward. This volume is used as input for the northern boundary. The remaining 30 Mm^3 is transported across the southern boundary. In Figure 12 the results for both linear and quasi-2D shoaling are shown. For both cases the Bijker transport formula has been used.

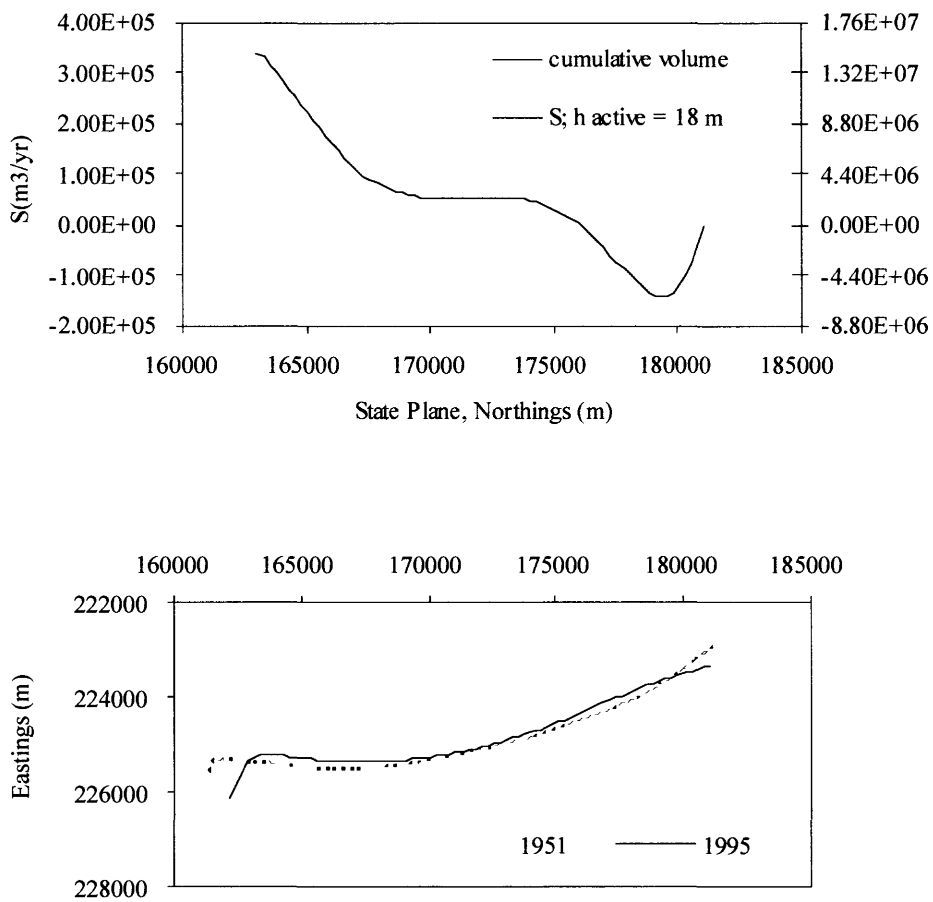


Figure 11. Sediment transport, cumulative volume and coastline positions. Grayland (1951-1995)

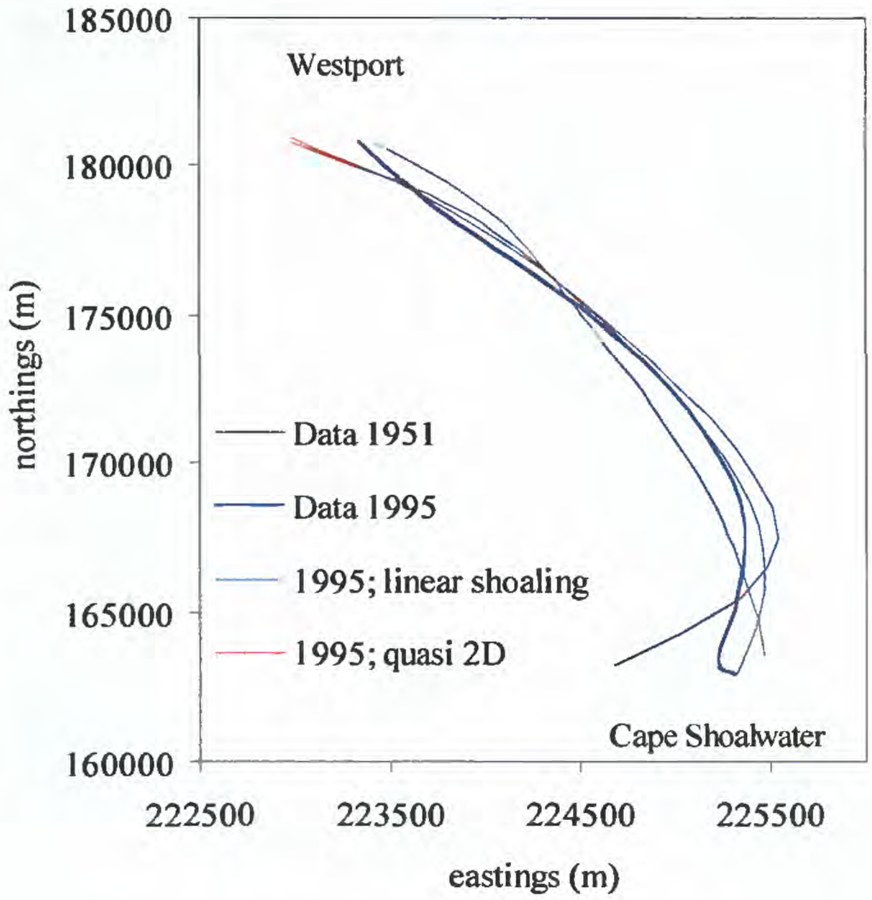


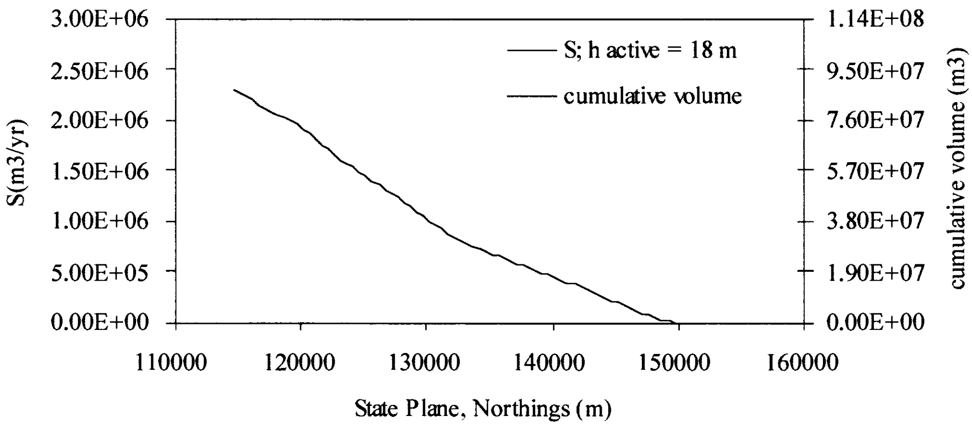
Figure 12. Grayland 1951-1995; Bijker.

In the case of linear shoaling the effect of the Willapa and Grays Harbor delta has not been included. The graph in Figure 12 shows erosion in the north, accretion in the middle and erosion again in the south. The transport in this case is from north to south in the north and from south to north in the south. All the sediment is transported to the center of the cell. The results of the quasi-2D shoaling are slightly better. In this case the bathymetry of the Willapa and Grays Harbor delta is included. The model shows a tendency for northerly transport close to the South Jetty and a southerly transport for the rest of the cell. But because of the large feeding the littoral transport is to the south. The waves in the southern part of the sub-cell are strongly refracted across the delta. As it can be seen the shoreline reorients itself towards the waves. The transport here is larger than the sediment output at the boundary and as a result accumulation occurs. The input in the north of the sub-cell is so large that it prevents erosion. It can be seen that there is a small tendency for erosion and accretion in that area. In both simulations diffraction by the jetty is not included.

Long Beach

The Long Beach sub-cell is about 40 km in length. The northern boundary is near Leadbetter Point, the southern boundary is North Head. The total accreted volume for the period 1951/1957–1995 equals about 87 Mm^3 versus about 75 Mm^3 (Buijsman et al. (1999)). It is assumed that this sediment originated from the Columbia River delta. It can be seen in Figure 13 that most of this sediment accreted in the south. The sediment transport is towards the north. The fluctuations of Leadbetter Point in the north are not included in the model calculations.

The wave data used for Long Beach is from the wave array. This array is no longer in service. Its position was close to the beach at a depth of 10 m MLLW. The wave data from this gage is only representative of a small part of Long Beach. The waves that arrive at the array have undergone a significant amount of shoaling and refraction. The refraction and shoaling will be different for other parts of the sub-cell because of different shoreline angles and geometry. In this simulation it is tested if it is possible to apply the wave data for the whole sub-cell. The data are used without any modification like linear or quasi-2D shoaling. The depth at the seaward boundary in UNIBEST is equal to the depth of the wave array.



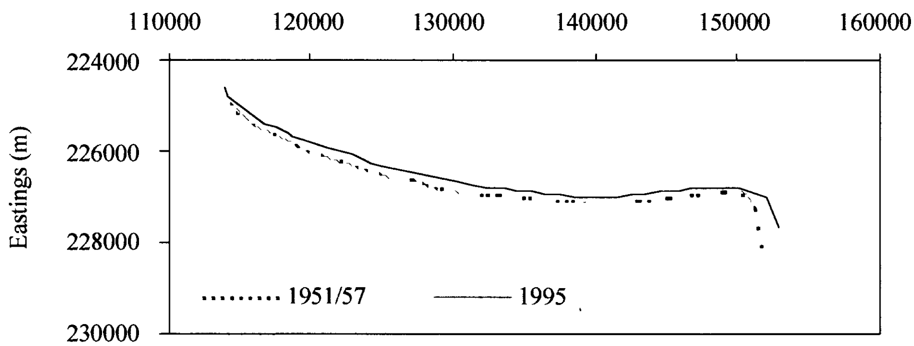


Figure 13. Sediment transport, cumulative volume and coastline positions. Long Beach (1951/1957-1995)

The duration of the calculations is about 38 years. The transport at the beach opposite of the wave array is very high: 4.8 Mm^3/yr (van Rijn: D50 = 200 μm, D90 =300 μm, assumed for the whole sub-cell). The transport generated by the waves at the south boundary is about 6.5 Mm^3/yr and at the north boundary about 3.1 Mm^3/yr. The input is too high and/or the output too low to generate the 87 Mm^3 of accretion. Therefore, two cases have been considered: input south 5.4 Mm^3/yr and output north 3.1 Mm^3/yr, and input south 6.1 Mm^3/yr and output north 3.8 Mm^3/yr. The results are presented in Figure 14. The DOE has not analyzed sediment samples for two-thirds of Long Beach. The sediment transport calculated with extrapolated sediment sizes (which are smaller than the default 200/300 µm) can be twice as large! The results of these calculations are not presented.

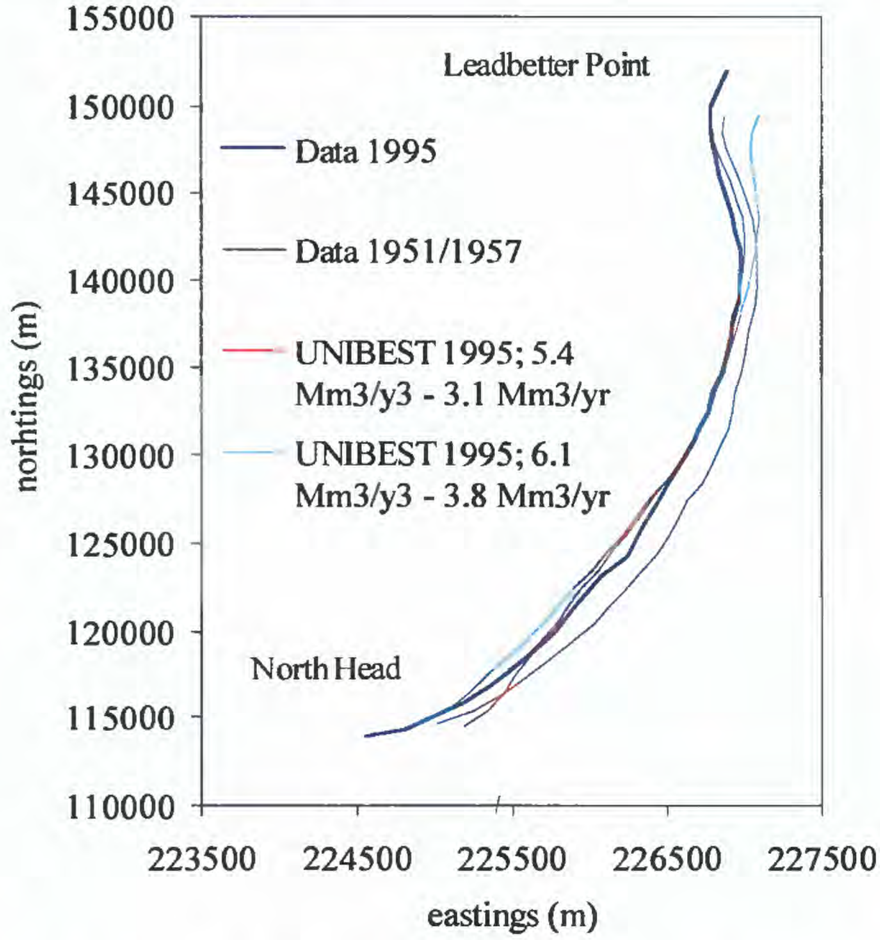


Figure 14. Long Beach 1957-1995; Van Rijn (D50 = 200 µm, D90 =300 µm); input south 5.4 (6.1) Mm^3/yr, output south 3.1 (3.8) Mm^3/yr.

As can be seen, it is difficult to fit the data very well. If the fit in the south is fine than there are problems with the fit in the north and vice versa. The results show that the wave data cannot be used for the whole cell.

CONCLUSIONS

In comparison to the results for Grayland and Long Beach the results for Ocean Shores are most promising. The hypothesis stated earlier in this report is represented best in the case of Ocean Shores.

In the case of Ocean Shores both the north and the south boundary conditions are known. This makes it easier to model. This does not apply for Grayland and Long Beach. The boundary conditions for these cells are based on eroded volumes of the ebb-tidal deltas or they have been roughly estimated. The southern boundary of Grayland causes the coastline to prograde. The transports are higher than the sediment output.

Apart from boundary conditions the waves largely determine the behaviour of the coast. The majority of the waves come from the west. Small changes in angles cause the transport to switch direction. The influence of the bathymetry on the shoaling is very important as well. It seems that wave refraction across the Willapa Bay delta and to a lesser extent across the Grays Harbor delta has a large influence on the transports. Although the SCATTER (quasi 2D) routine is more sophisticated than linear shoaling, the obtained results still need more improvement. The SCATTER results for the northern half of Ocean Shores are better than the results for the southern part. The shoaling generated by SCATTER for the southern part of Grayland causes the coast normal to turn in the clockwise direction. Tidal currents, which are not used in the modelling, may play a role as well for the southern part of Grayland. Looking at the results for Long Beach it can be concluded that the data from the wave array is not representative for the whole sub-cell.

The differences between the transport formulas of Bijker and van Rijn are not very large. In general the van Rijn formula shows a larger transport, implying more erosion and accretion.

REMARKS

It is expected that the modelling can be improved when applying a wave model like SWAN to better model the refracted waves. Furthermore, the results can be improved by using the volumes as derived in the Historical Sediment Budget Study (Buijsman et al., 1999). A more detailed analysis of the volume changes of the ebb-tidal deltas would also help in defining better boundary conditions. The shorelines of 1974 for the whole littoral cell will soon be integrated in the modelling.

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Wave Modeling of the SW Washington Coast with SWAN

Kurt Hanson, John Haines, U.S. Geological Survey
Peter Howd, University of South Florida

INTRODUCTION

Recent advancements in coastal wave modeling promise to greatly improve the understanding of nearshore sediment transport and regional shoreline change. These models provide a central link between wind and offshore wave data and the characterization of sediment dynamics. The wind and wave conditions specified as inputs to a wave model are freely selected by the user. They may represent a specific time period or an element of a long-term climatology, and they may be derived from either observations or some larger-scale numerical model. Recently developed wave models are run using realistic, 3-D bathymetry and they describe wave evolution based on fundamental theory. The result of a simulation is a detailed description of the wave field. The description may then be used as the input to a sediment transport model, which characterizes sediment dynamics such as shoreline change.

MODEL BACKGROUND

The wave model used in this study is the SWAN model of Ris et al (1999) of the Delft University of Technology. SWAN accounts for nearly all of the physical processes, which modify the wave field in the shelf and nearshore regions. The most important advancement of this and other recent models is that the spectrum of waves is described as the net effect of a number of waves of different frequencies. Models of this type are called "third generation." Contrastingly, the older "second generation" models considered only the spectrum as a single, undivided entity. It is advantageous to model waves on a frequency-by-frequency basis because the evolution of a single wave (having one frequency) is a more fundamental and better understood concept than is the evolution of the entire spectrum. Furthermore, the wave spectrum -- which describes wave height as a function of frequency -- has a shape that varies considerably in space and time. This shape cannot be exactly described by the short list of parameters used in second-generation models. The collection of waves described by third generation models is free to describe a far wider range of spectral shapes.

SWAN characterizes most processes influencing waves in the coastal zone. It describes the modifications to wave kinematics due to refraction, shoaling and wave-current interactions. Modeled processes that change the energy content of waves include the coastal-specific processes of bottom friction and wave breaking, and the more universal processes of wind generation and whitecapping. Nonlinear wave-wave interactions influence both wave generation and shoaling, and their effects are included in SWAN. Diffraction and reflection are not modeled, however. SWAN is thus inappropriate in areas very near to engineering structures such as breakwaters, jetties and seawalls. The implementation of the numerical algorithms in SWAN leads to another limitation: the propagation of wave energy is slightly too diffuse. This "numerical diffusion" is small over short distances but its effects become significant over scales larger than roughly 25 km.

An alternate class of wave models designed for the coastal zone is termed "phase resolving." These models attempt to fully describe the time- and space-varying sea surface, and are capable (unlike SWAN) of accounting for the effects of diffraction and reflection. These models, however, do not include the effects of wave generation by wind. REF DIF S, written by James Kirby of the University of Delaware, is a prominent phase-resolving model. SWAN and models like it are "phased-averaged," meaning that the shape of the wave trains is ignored in favor of modeling the spectral energy. Phase-averaged models are more computationally efficient than phase-resolving ones, so that for the same computational time, the phase-averaged model can handle a larger domain.

STUDY AREA

The study area extends from approximately the mouth of the Columbia River in the south to Point Grenville in the north. Construction of a bathymetric data set for use with SWAN required several steps. First, all data in the National Ocean Service (NOS) database for the region was extracted. For offshore contours (offshore of roughly the 50 m contour), this data is from the years 1926 and 1927. The NOS data was then projected from geographic coordinates to the plane using the Universal Transverse Mercator (UTM) projection for zone 10. The last step was interpolation onto a regular grid with resolution 750 m; the result is shown in Figure 1, where the mouth of the Columbia River and Point Grenville are located at roughly 5120 and 5240 km Northings, respectively. Contours offshore of about 5 m are depicted with acceptable accuracy. However, the shoreline is poorly reproduced since the NOS database has essentially no data more shallow than 5-m depth.

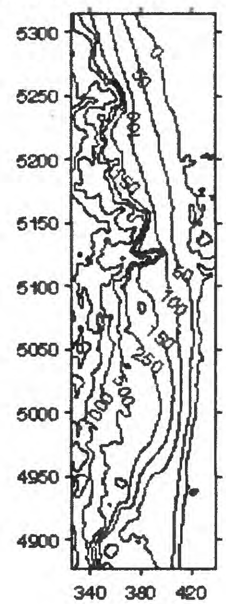

Figure 1. Large-scale bathymetry in UTM zone 10. Ordinate and abscissa are Eastings and Northings in km. Contour levels are in m.

Selection of the area to model (as shown in Figure 1) followed from several considerations. Foremost was that the longest modeled waves should be deep-water waves over the offshore boundary. The longest waves we chose to consider were 0.04 Hz (25 sec). A comparison between the arbitrary-depth and deep-water dispersion relationships (from linear wave theory) revealed that these waves experience a 2% change in wavelength at about 350 m. This depth was chosen as the most shallow depth allowed on the offshore boundary. A second consideration in selecting the model domain concerns the so-called null boundary effect. In a SWAN model run, wave conditions are imposed along the offshore boundary but not along the lateral (i.e. East-West) boundaries. This is equivalent to specifying that no waves exist on the lateral boundaries. These wave "shadows" influence the results over triangular regions next to the lateral boundaries. Therefore, the alongshore (i.e. North-South) extent of the domain must be large enough so that these null boundary effects do not influence the study area. The last consideration in making a grid was that it should have axes parallel to the cardinal directions. The result is that depicted in Figure 1.

WAVE CLIMATOLOGY

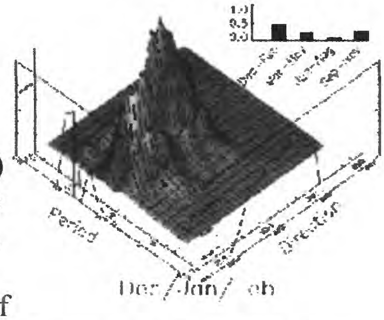

Figure 2. WIS wave height climatology (winter).

In order to characterize the temporal variability in the wave state offshore of the study area, several data sources were investigated. A NOAA National Data Buoy Center (NDBC) buoy named 46005 has been collecting wave data during the 1990's at a location about 500 km offshore of the study area. Unfortunately, it does not acquire wave direction data. Another data source is the Wave Information Study (WIS) of the Army Corps of Engineers. It is a hindcast wave modeling study for the years 1956-1975. A third source is the results of the basin-scale Wave and Atmospheric Model (WAM) for the years 1994-1998, as computed by the Navy's Fleet Numerical division. We computed probability density functions (PDF's) of wave height based on data from all three sources. These PDF's describe frequency of occurrence as a function of wave height, and were computed for the entire data records and also for each season. Even though the time of record differed dramatically, the PDF's based on WIS and NDBC agreed closely, whereas the WAM and NDBC results showed far less similarity. Accordingly, the WIS results were chosen to characterize not only wave height but also wave direction for our study region. One of the WIS-derived seasonal PDF's of wave height is shown in Figure 2. Results such as these will allow us to select wave conditions to include in our modeling study based on their frequency of occurrence.

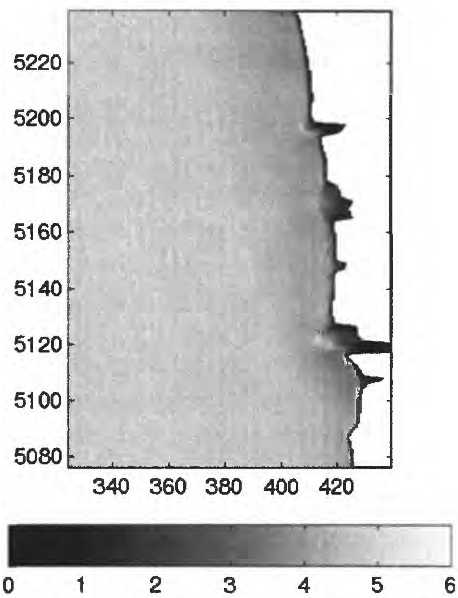

Figure 3. SWAN-modeled wave height (m). Offshore conditions are $H_{sig} = 4.7$ m, peak period of 13 s and waves coming from 290° relative to true N.

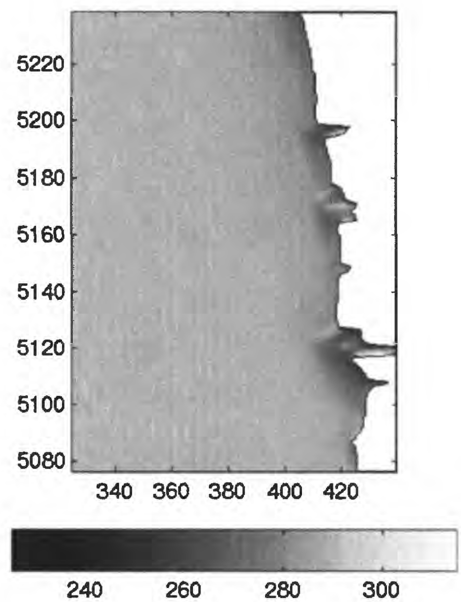

Figure 4. SWAN-modeled wave direction (rel to true N) for the case described by Fig. 3.

MODEL RESULTS

Preliminary modeling of the wave conditions described by the WIS climatology is underway. Typical wave height and direction results are shown in Figures 3 and 4. However, before beginning a complete modeling study of the WIS wave climatology, the accuracy of the SWAN model must be investigated. This analysis can be divided into two parts: sensitivity and validation. A sensitivity study will determine which SWAN parameters produce significant change in the results. These parameters are the means by which the formulation of the model physics may be modified. One example of a sensitivity study is shown in Figure 5, where the effects of triad nonlinear interactions are investigated. These "triads" influence the steepening of waves in shallow water and Figure 5 shows that their effect is significant.

The other half of SWAN accuracy analysis is validation. In this stage, SWAN runs will be performed under measured wave conditions and its results compared to observations acquired by an array of traditional instruments including pressure sensors and current meters. This is the subject of an upcoming field experiment.

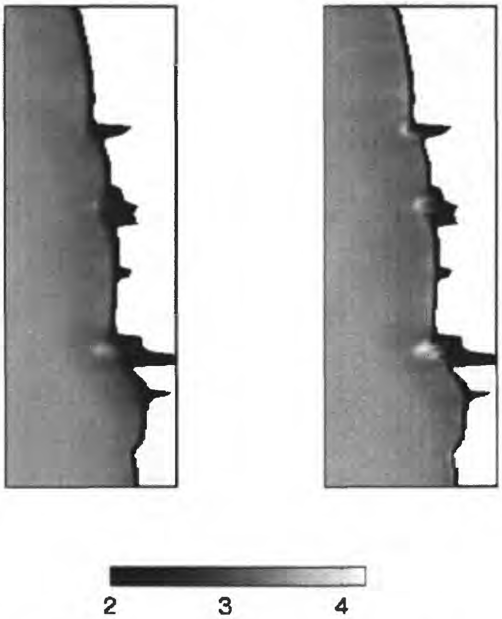

Figure 5. SWAN-modeled significant wave height (m) for two cases. Left: triad nonlinear interactions are modeled. Right: triads are not modeled.

CONCLUSIONS

The SWAN wave model is a useful tool for estimating wave evolution on the coast. Preliminary modeling of the SW Washington coast is ongoing. Model runs will be initialized using a wave climatology computed from the Wave Information Study of the Army Corps of Engineers. This modeling will be performed following a detailed analysis of parameters affecting the SWAN model itself. When coupled with observations acquired in a planned wave experiment, this analysis will determine the parameter settings, which correspond to the best possible accuracy. Subsequently, SWAN modeling of the SW Washington wave climatology will be used in conjunction with sediment transport models in order to best understand the sediment dynamics of the SW Washington coast.

Prediction of Aggregated-Scale Coastal Evolution

Huib de Vriend, University of Twente / Delft University of Technology, The Netherlands

INTRODUCTION

This contribution is meant to be a report on recent progress in knowledge, know-how and views on the prediction of large-scale coastal behaviour (LSCB), primarily from the EU-sponsored project PACE, which involves 20 research institutes and some 60 scientists from Europe, Australia and the USA. Further see De Vriend (1998).

PREDICTABILITY

Coastal behaviour is a manifestation of the dynamic interaction between water motion (wind waves, tides, surges, currents), sediment motion and bed topography in the coastal zone. Coupled via the sediment balance, the elements form a nonlinear dynamic system, which manifests itself at a very wide range of spatial and temporal scales. The behaviour of such a system can either be forced or free. If a system is forced by an external input, the variations in its response may be correlated to the variations in the forcing factor, directly or via some complex transfer function. Such a response is called forced behaviour. Examples are the response of a coastline to the construction of groynes, or that of a beach to a nourishment, or that of a coast to sea-level rise. In the case of free behaviour, the variation of the system's state cannot be correlated to variations in the forcing. Free behaviour can only occur in specific modes, comparable to eigenmodes in linear systems. In the case of coastal morphology, it results from a positive feedback between bed topographical features and the water and sediment motion around them. Well-known examples are small-scale bedforms (bed ripples), beach cusps, breaker bar systems, shoreface-connected ridges, etc. In numerical modelling, linear instability is a notorious example of (erroneous) free behaviour.

The distinction between free and forced behaviour is an issue in the prediction of large-scale coastal behaviour, not only because it is impossible - by definition - to find a transfer function between this behaviour and the forcing, but also because free behaviour of nonlinear dissipative systems with a continuous energy input, such as the coast, may become inherently unpredictable. Deterministic chaos is a widely accepted phenomenon in other fields of science (turbulence research, meteorology), but much less so in coastal dynamics. Although its existence remains to be proven formally, there is some circumstantial evidence that we have to reckon with the possible occurrence of predictability limits in LSCB, as well.

This becomes even more compelling if we include in the definition of predictability not only the *fundamental possibility* of phenomena to be predicted, but also *our ability* to predict them. Especially multi-dimensional process-oriented morphological models, i.e. models based on detailed descriptions of waves, currents and sediment transport, are so computationally demanding, that using them for probabilistic predictions is still beyond our reach.

SCALE AND MODEL CASCADES

In spite of the possible existence of predictability limits, modelling of LSCB is not a hopeless task, because these limits can usually be overcome by aggregation to larger spatial and temporal scales. Clearly, this goes at the expense of the spatial and temporal resolution, but the remaining information can still be of great practical value. A well-known example of overcoming a predictability limit by aggregation is the modelling of turbulent flow: one can integrate the Navier Stokes equations over the turbulent fluctuations, to yield the Reynolds equations. When combined with a turbulence closure model, which relates the nonlinear residual terms to the mean flow parameters, they constitute a mean flow model, which can be solved without going into the details of turbulence. Thus the inherent predictability limit associated with turbulence is overcome.

Another well-known example of such an aggregation step concerns the wave-averaged flow equations, in which the radiation stresses are the nonlinear residual terms. Formally speaking, there is no inherent predictability limit involved, but running an intrawave flow model is very time-consuming and therefore seldomly feasible.

Other forms of aggregation which are widely accepted in coastal modelling are the use of sediment fluxes, instead of individual grain motion, and the use of a bed roughness estimator, instead of describing the interaction between the flow and individual small-scale bedforms. Figure 1 maps the scale range of interest to LSCB and indicates the various scale levels at which predictability limits may occur. The boxes indicate scale ranges at which certain phenomena occur. The fact that the set of boxes, so the area of interest, is concentrated around the diagonal expresses the assumption that spatial and temporal scales are more or less coupled (larger-scale morphological features evolve more slowly). The upward transition between two consecutive boxes involves an aggregation step, in order to overcome the predictability limit. Thus the boxes form a sort of cascade: planes of predictable behaviour, separated by aggregation steps.

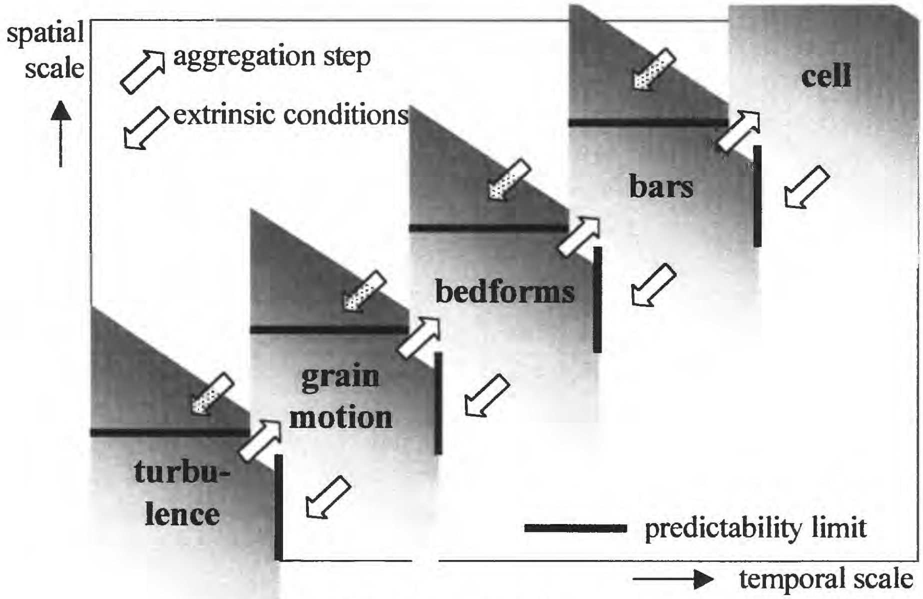

Figure 1. Scale and model cascade

If the physical phenomena in coastal morphology are ordered in this way, there is no scope of a single model covering the entire scale range, whatever computer power we have at our disposal. The gamut of models should rather reflect the above cascade: one model at every scale level. The consecutive models in the cascade are coupled in two ways: upwards via aggregation and downwards via the transfer of environmental conditions (higher-scale developments act as an environment for lower-scale phenomena).

PACE - GENERAL

The idea behind the PACE-project is to verify or falsify the existence of predictability limits at scale levels which are of interest to LSCB, and to come up with model concepts which fit into the above cascade-concept. There are basically four research themes, *viz.* data, decadal-scale behaviour, very-large-scale behaviour and rhythmic features.

A special Data Task Force has identified a number of potentially useful datasets, investigated how to get access to them, collected the relevant metadata, and compiled this information into a report (Hamm et al., 1998).

PACE – DECADAL SCALE

The work on the decadal-scale behaviour consists of data analysis , data reduction, process-oriented modelling and behaviour-oriented modelling. The data analysis involves analyses and interpretations of coastal profile behaviour (depth of closure, input/output correlation, fractal analysis), but also analyses of nearshore bar patterns (analysis of depth soundings, video data and data taken from surfzone vehicles). The data originate from various sites, such as the Holland coast, the Lincolnshire beaches, Duck, Ocean City and various other sites around the world. One striking result is the identification, by Southgate and Möller (1998), of time-windows of fractal behaviour of the coastal profile at Duck, NC. For the inner bar zone, for instance, this window is 20-40 months, for the outer bar 15-30 months, and for the upper shoreface 1-12 months.

Data reduction addresses the question how the large amount of data can be mapped onto an essentially smaller dataset without losing the essence of the behaviour. Techniques such as EOF, PCA, POP, PIP and random sine functions are applied together, partly to the same datasets. One example, though from before PACE, is the EOF-map of the development of the Holland coast during the last 30 years (Wijnberg and Terwindt, 1995).

The process-oriented modelling efforts at the decadal scale level concern the effects of graded sediments, deterministic and probabilistic coastline modelling, probabilistic profile modelling, and an auxiliary model of surfzone whiteness as a function of bed topography and input wave conditions, to support the interpretation of the video data. The extension to probabilistic modelling is thought to be of paramount importance to practically useful predictions of LSCB, and a rather severe test to the predictive capability of models.

Behaviour-oriented modelling is conceptually different from process-oriented modelling, in that there is no reference to the detailed processes, but only to their net effect: the observed coastal behaviour. The approach is largely empirical, though the sediment balance is usually observed.

Linear relaxation is favourite when describing transient processes. Examples of behaviour-oriented models investigated in PACE are a diffusion-type profile model (in fact a continuum-version of the n-lines model), a hinged-panel model of the Ebro Delta coast, a multi-line model including tidal inlets, and a box model of the Wadden Sea barrier-island coast.

PACE – VERY LARGE SCALE

The reference frame for the term 'very-large-scale' is the time-scale which is considered for engineering works, i.e. decades up to a century. The term refers to time-scales of millennia and spatial scales of typically a coastal cell. The work in this compartment of PACE includes the gathering and analysis of geologic data from various sites around the world, such as the Haarlem and Ameland transects (NL), various Australian sites. The well-documented long-term evolution of the Washington coast would fit very nicely into this set.

At this scale level, data and modelling are intimately coupled. It is widely recognised that a model that cannot fall back on data is bound to be of little use here. Within PACE, a variety of very-large-scale models are studied. Three different concepts of models with more or less the same functionality, viz. coastal profile evolution, are compared (cf. Stive et al., 1995). In addition, a new box-type sediment balance model of tidal inlets was developed, and an existing multi-line model of barrier-island coasts was underpinned and extended.

PACE – RHYTHMIC FEATURES

This part of PACE is typically the realm of free behaviour. In this subproject, linear and nonlinear stability analyses are applied to more or less simplified mathematical models (= sets of coupled mathematical equations), in order to identify and explain modes of free behaviour. Examples are: certain combinations of edges waves and beach cusps, sandbanks and sandwaves in tidal shelf seas, shoreface-connected ridges (Falqués et al, 1998), and tidal inlet channels. This constitutes the formal approach to the verification/falsification of the existence of inherent predictability limits in coastal morphodynamics within practically relevant scale ranges.

SUMMARY

The work in PACE and the ideas behind it can be summarized as follows:

- Coastal systems may be unpredictable at certain practically relevant scale levels.
- Model aggregation is the way to overcome predictability limits, but the price is a loss of resolution.
- The existence of predictability limits within practically relevant scale ranges remains to be proven/falsified.
- The potential implications of their existence are such, that it is worth spending part of our research means to finding them, or showing that they don't exist.
- In the meantime, process-oriented research should go on, since at every scale level the models are still open to major improvement.
- In order to deal with the uncertainty which is inherent to coastal morphodynamics, we have to go down the avenue of probabilistic prediction.

- In order to cope with predictability limits, inherent or practical, we have to develop a cascade of interlinked models, each at its own scale level.

ACKNOWLEDGEMENTS

The views described herein have been developed within the PACE-project, an international research project on large-scale coastal prediction, which is funded partly by the European Union's MAST-III programme, under contract no. MAS3-CT95-0002. The author is greatly indebted to the partners in this project, who have participated in the discussions which have led to these views.

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Surficial Geology of and Annual Changes to the SW Washington Inner Shelf

Dave Twichell, VeeAnn Cross, Ken Parolski
U.S. Geological Survey

Bathymetry profiles and sidescan sonar images were collected in 1997 to expand the understanding of the surficial geology of the SW Washington inner shelf which previously had been based primarily on surface sediment sample information (Gross et al., 1967; Venkatarathnam and McManus, 1973; Roberts, 1974; Nittrouer and Sternberg, 1981; Sternberg, 1986). In 1998 bathymetry and sidescan sonar data were collected along several of the 1997 lines to determine if there had been changes to the inner shelf surface during the year (Figure 1). Sediment samples and bottom photos were also collected in 1998 to determine the causes of backscatter differences on the sidescan imagery.

The regional survey in 1997 showed a shore-parallel, high-backscatter band in 10-15 m water depth along the length of the study area except around the tidal inlets. The origin of this high-backscatter band and whether it represented the seaward limit of the shoreface could not be determined from the imagery alone. Bottom photographs, however, indicate that the high-backscatter, shore-parallel band corresponds with an area where sand dollars are abundant (Figure 2). Visual observations of sediment samples suggest that the surface sediment within the belt of sand dollars is the same as that found along its shoreward and seaward sides. The sidescan images show that offshore of this band, the shelf has mostly a uniform, low-backscatter signature except north of Grayland. Here the low-backscatter signature was interrupted by discontinuous high-backscatter patches. Seismic data show that some of these high-backscatter patches are associated with exposures of older Tertiary strata (Wolf et al., 1997). In other places bottom photographs show these high-backscatter areas to be exposures of well-rounded gravel. The gravel is interpreted to be glacial outwash that was deposited during the last lowstand of sea level (Venkatarathnam and McManus, 1973). The gravel patches represent areas where the recent shelf deposits are too thin to completely cover these relict deposits. South of Grayland, the silt content of the surface sediment increases, and bottom photographs show that the shelf surface is rippled out to at least 66 m depth and that the surface sediments become more heavily bioturbated on the middle shelf (Figure 3).

The sidescan and bathymetry data show remarkably few differences between 1997 and 1998. The sections of lines that were rerun were in water depths of 5-35 m.

Comparison of the bathymetry profiles mostly showed changes less than 1 m, the resolution allowed by the survey conditions and equipment. One exception was a line over a dredge-spoil mound near the mouth of the Columbia River. The crest of the mound was 1.5 m deeper in 1998 than in 1997 while the surrounding sea floor remained unchanged (Figure 4). The sidescan imagery showed that the location of the seaward edge of the band of sand dollars remained virtually unchanged between the two surveys along most of the transects (Figure 5). North of Grays Harbor, gravel patches and areas of outcrop remained unchanged between the two surveys. One area of change shown by the sidescan imagery was along one line off Grayland. Here several high-backscatter patches were present in the 1998 data in water depths of 15-30 m that were not there in 1997 (Figure 6). Samples and photographs showed these to be patches of gravel and semi-lithified clay. Apparently a thin veneer of sand was removed between the two surveys. Why erosion is focussed on certain localized sections of the shelf while other areas, many of them being considerably shallower, remain unchanged needs to be explored further.

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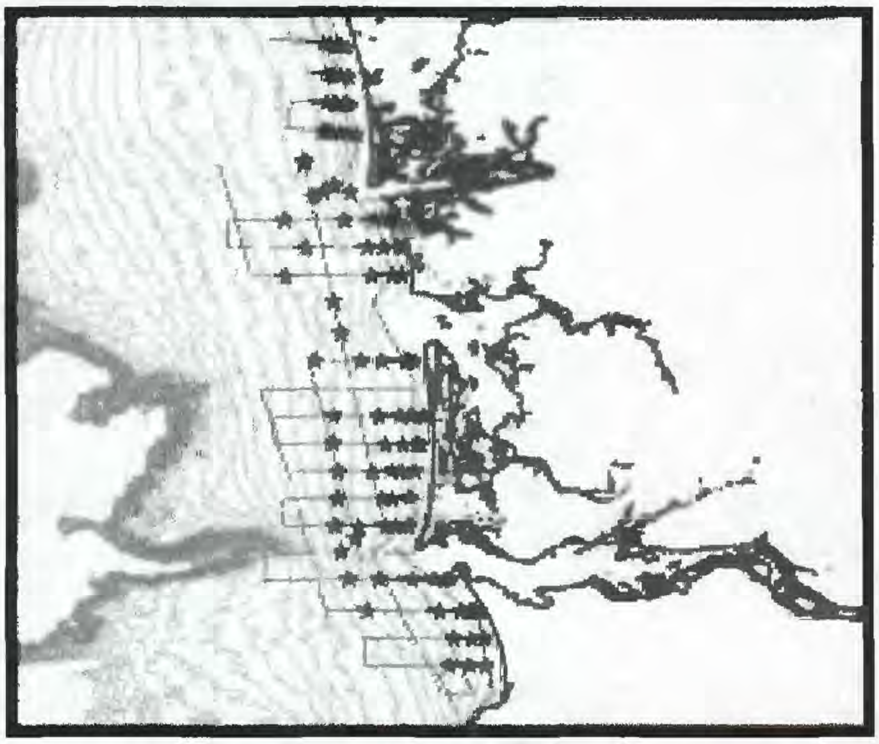

Figure 1. Map showing locations of sidescan sonar images collected in 1997 (blue lines), 1998 (red lines), and the locations of stations where surface sediment samples and video or still photographs were taken (yellow stars).

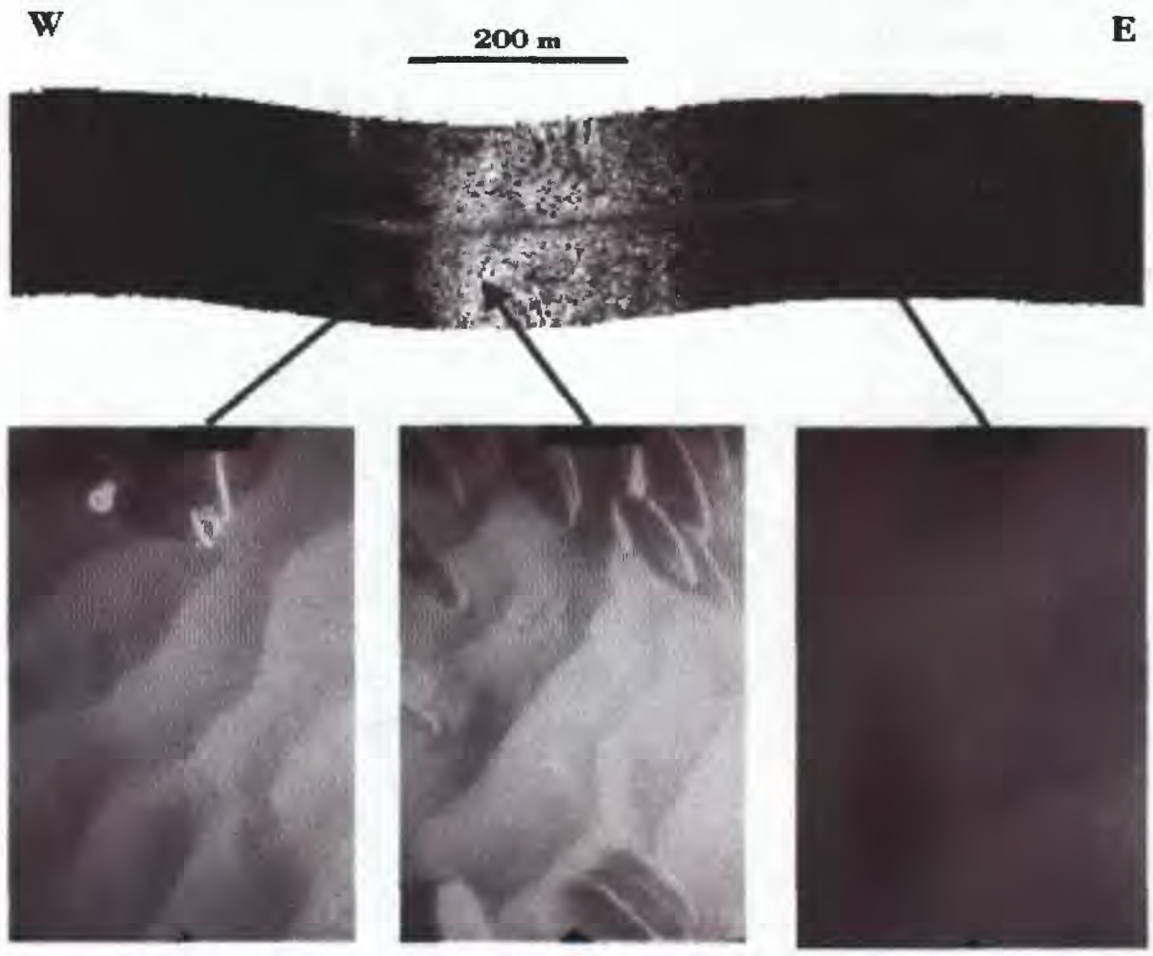

Figure 2. Sidescan sonar image and bottom photographs off the northern tip of Long Beach showing the relationship of backscatter intensity to sea floor geology. Note that the high-backscatter stripe coincides with the occurrence of sand dollars.

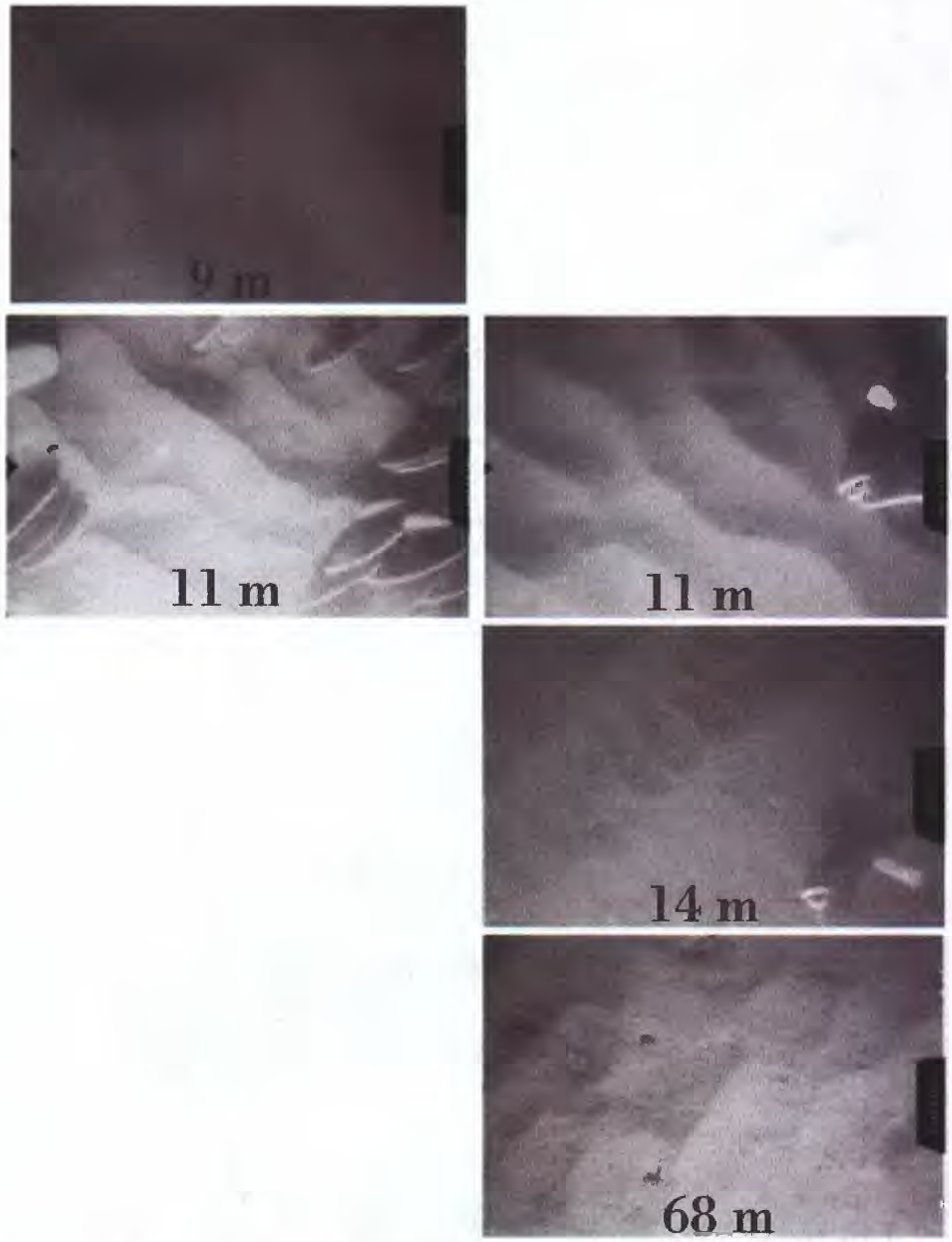

Figure 3. Transect of photographs from onshore to offshore showing the progression from rippled sand shoreward of the belt of sand dollars, the band of sand dollars with the abrupt transition on the seaward side to clean, rippled sand, and farther offshore the silty, bioturbated, rippled sand.

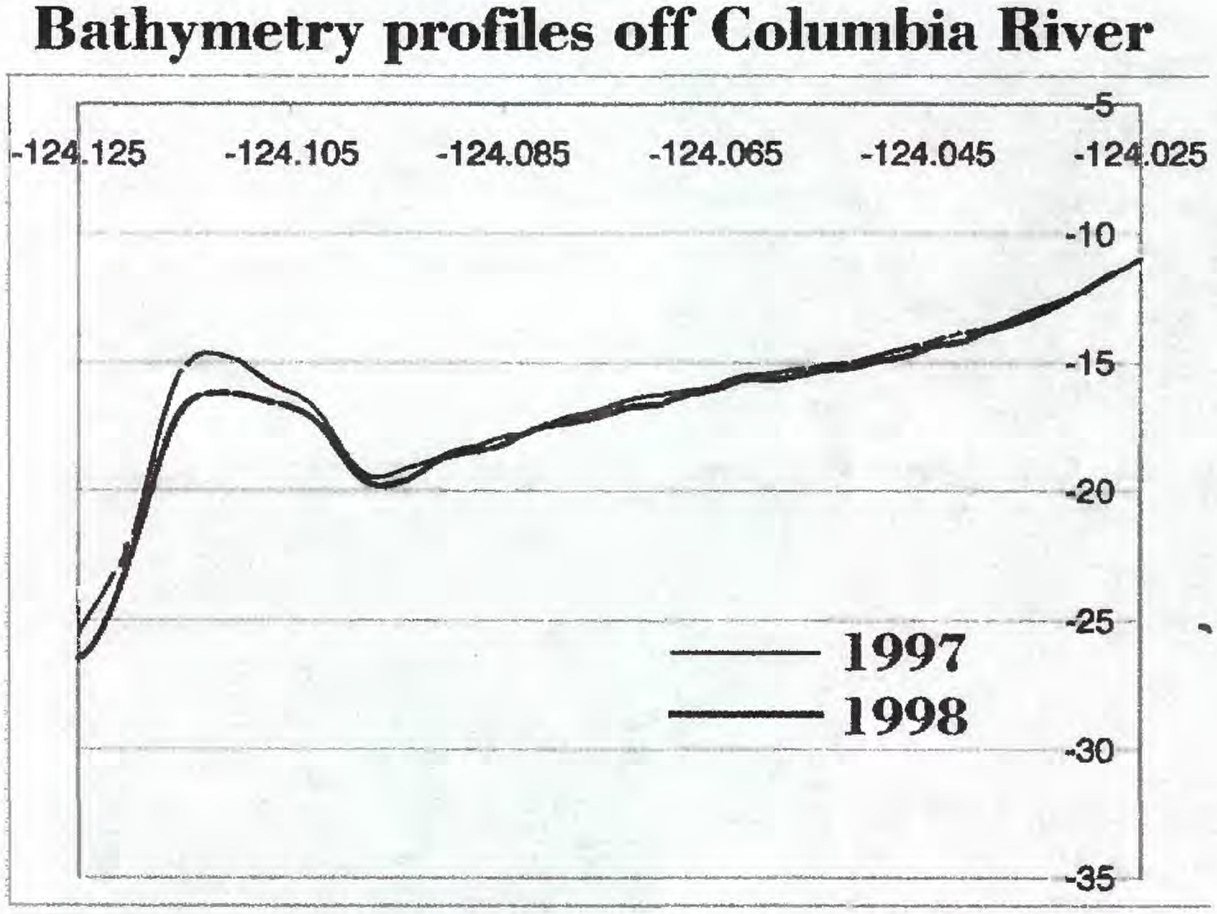

Figure 4. Bathymetry profiles across a dredge-spoil site immediately south of the mouth of the Columbia River showing that the mound has lost approximately 1.5 m height between the two surveys.

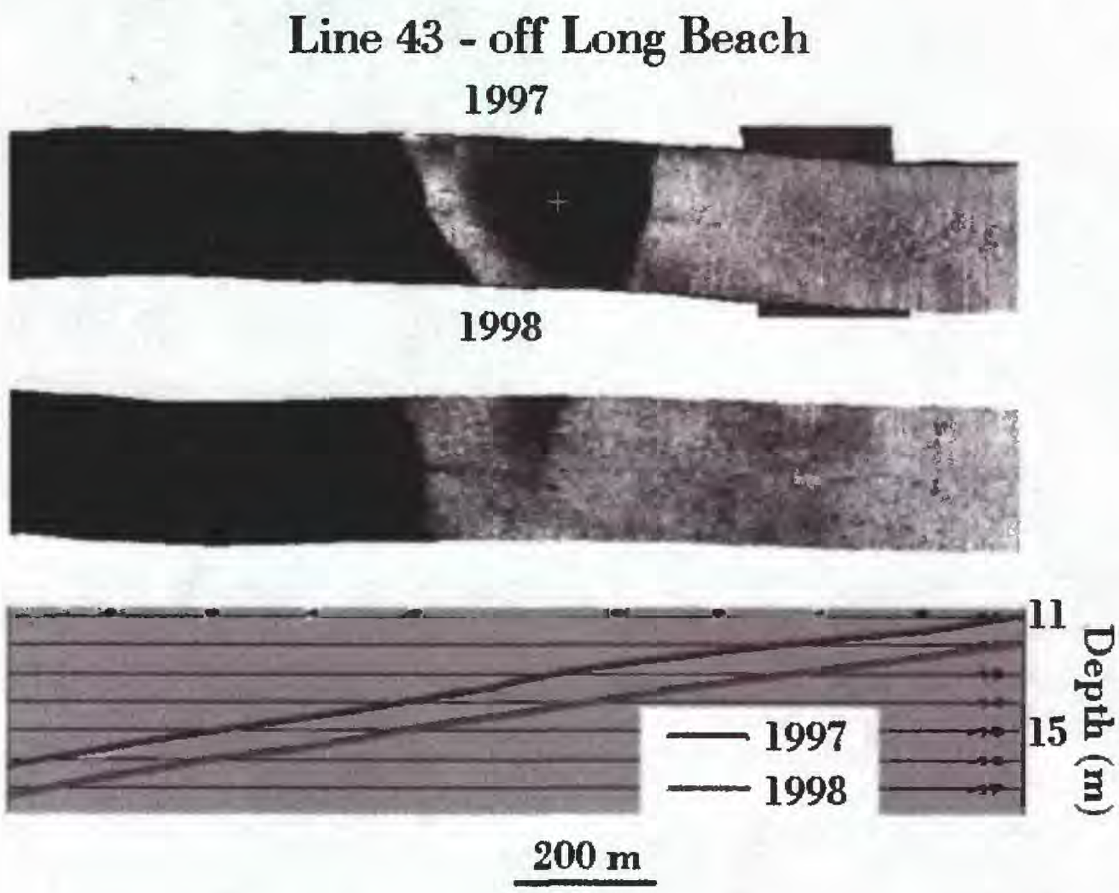

Figure 5. Sidescan sonar images collected in 1997 and 1998 off Long Beach showing no change in the location of the sand dollar field. The apparent difference in the bathymetry between the two years probably is due to errors in data collection techniques.

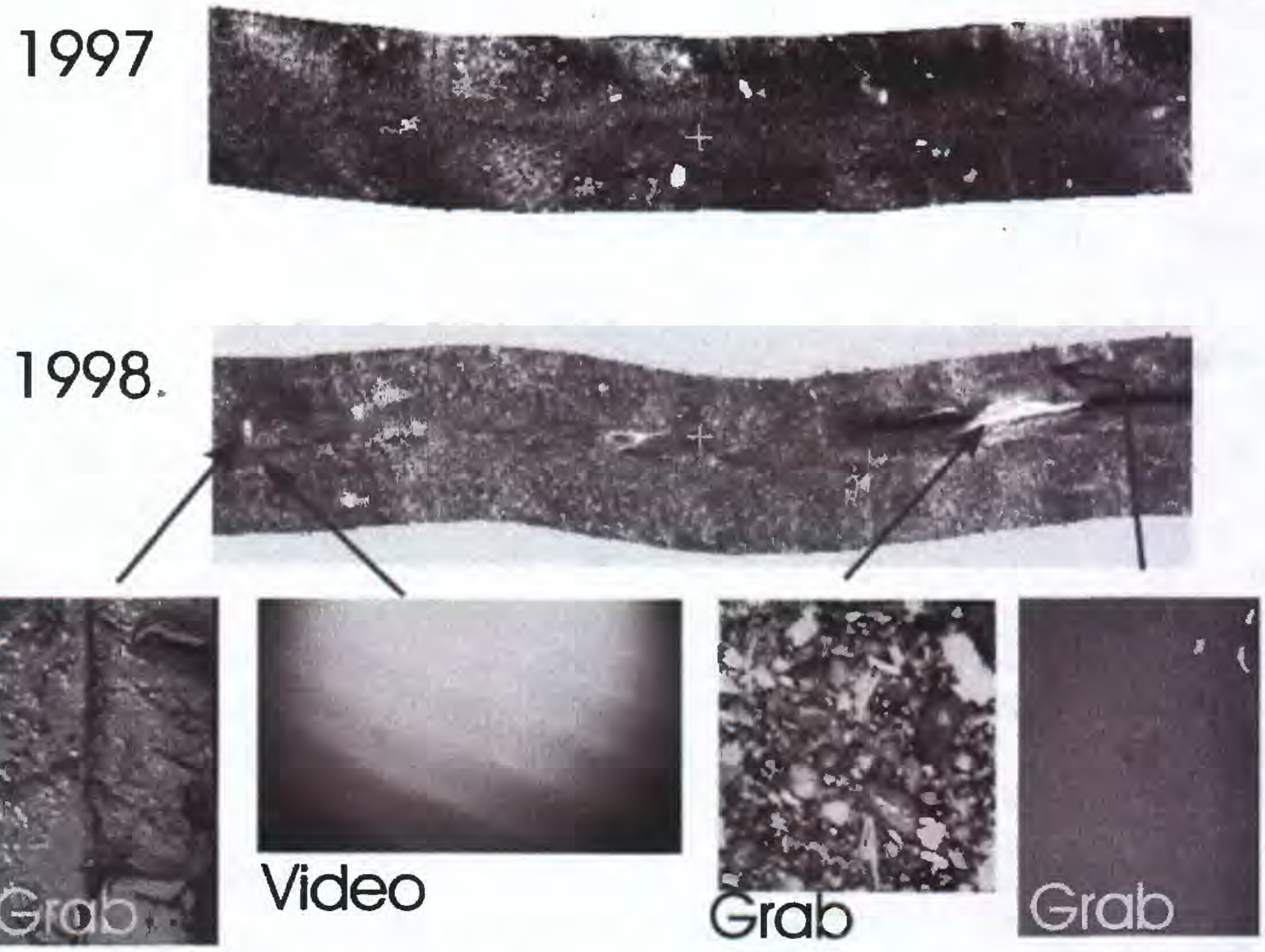

Figure 6. Sidescan sonar images collected along the same line in 1997 and 1998 off of Grayland. Locations of photographs of the grab samples and a video image are shown on the 1998 sidescan image. The westernmost grab sample (from the small high-backscatter patch) recovered a semi-lithified silt, the grab sample farthest to the east from a low-backscatter area recovered very-fine sand. The grab sample from the large high-backscatter patch recovered gravel and shell hash. The video image shows that the low-backscatter, fine sand which is representative of most of the area, is covered by linear ripples.

Long-term Holland Coast Evolution

Marcel JF Stive, Delft University

INTRODUCTION

Temporal shoreline variability may easily be observed by plotting a particular shoreline position against time. Two examples of this are given in Figure 1a and 1b, the former for a shoreline position along the coast of the Waddensea barrier island Schiermonnikoog, unaffected by human-induced interference, and the latter along the Zeeland barrier island of Goeree, affected by this. As indicated in these figures, temporal variations on different scales may be discerned. On the centennial scale the shoreline shows a clear trend of progradation and retrogradation respectively. Note that the centennial trends of the LW, HW and duneface position are not necessarily the same. On the decadal scale the LW and HW shoreline of Schiermonnikoog shows a clear oscillation, associated with 'horizontal sand waves' induced by coastal inlet channel cycles. Note that this is not reflected in the dunefoot behaviour. One such natural oscillation is also apparent in the Goeree shoreline, which in contrast is also reflected in the dune foot. The construction of the Brouwersdam closing off the coastal inlet to its south causes a perturbation of the trend. Generally, we may observe that shorter, annual variations of the LW line are strongest and of the dunefoot the weakest.

The above mentioned examples from Schiermonnikoog and Goeree indicate that the variability of shorelines displays itself differently in space and in time and differently in the LW, HW and dunefoot position. By looking more closely at the causes and effects we may try to understand and thereby quantify the variability more precisely. For this purpose Table 1 lists natural and human causes and factors and associated typical evolutions on the various scales. This scale division rests upon the idea that nature can be partitioned into 'naturally ocurring' levels that share similar time and space scales, and that interact with higher and lower levels in systematic ways (Capobianco et al., 1998). Each level in the hierarchy or cascade sees the higher levels as constraints and/or boundary conditions and the lower levels as noise[1]. In the following we present and discuss the case example of the Holland coast on the timescale of millenia to centuries.

LATE HOLOCENE VARIABILITY DUE TO SEA LEVEL RISE AND SEDIMENT AVAILABILITY

Based on observations of large scale Holocene coastal behaviour Cowell et al. (1999) consider a coastal tract system to form the highest or first-order level in the hierarchy of coastal evolution scales, i.e. on the larger time-scales (centuries to millenia) the periphery of the shelf, which includes e.g. deltas, shorefaces, dunes and (tidal) lagoons, responds in a morphologically coupled sense to higher level related forcing conditions, such as relative sea-level rise and shelf determined hydrodynamic conditions, and to higher level constraints, such as a geologically inherited substrate (the zero-th order system). On these larger time-scales the coastal tract is a sediment sharing system, within which sediment is conserved, taking into account external

[1] Depending on the physical character of the system, however, 'noise' at the lower level could be turned into significant perturbations on the higher level.

sediment sources (such as river input) or sediment sinks (such as submarine canyons) and taking into account substrate movements (tectonics, subsidence).

In order to deal with the complexity of a coastal tract system there is a need to further partition the system. We therefore introduce a lower, second-order level at which we attempt to describe the spatial and functional complexity of the coastal tract system. This may be referred to as the level of 'physiographic units'. Examples of the coastal physiographic units we may distinguish are a river delta, an inletfree shoreface, a beach barrier, a coastal inlet or a backbarrier system (lagoon, bay or estuary).

The evolution of the Holland coastline over the late Holocene is here introduced to describe the potential variability in the shoreline trend over time of an initially inletfree shoreface under a variable sea-level rise rate and sediment availability situation.

Table 1. Natural and human-induced causes and factors and associated evolutions for shore and shoreline variability (based upon and adapted from Stolk, 1989 and Stive et al., 1990) (following page).

very long term (time scale: centuries to millenia; space scale: ~ 100 km and more)	
natural causes/factors	relative sea-level changes
	differential bottom changes
	plate tectonics
	long-term climate changes
	'sediment availability'
	paleomorphology
human causes/factors	climate change
	large river regulation
	large coastal structures
	large reclamations & closures
	structural coastal (non)management
typical evolutions	(quasi-)linear trend
	trend changes & reversals
	fluctuating
	asymptotic
long term (time scale: decades to centuries; space scale: ~ 10 - 100 km)	
natural causes/factors	relative sea-level changes
	regional climate variations
	coastal inlet cycles
	'horizontal sand waves'[2]
	extreme events
human causes/factors	river regulation
	coastal structures
	reclamations & closures
	coastal (non)management
	natural resource extraction
typical evolutions	(quasi-)linear trend
	trend changes & reversals
	fluctuating
	asymptotic
middle term (time scale: years to decades; space scale: ~ 1-5 km)	
natural causes/factors	wave climate variations
	surfzone bar cycles
	extreme events
human causes/factors	surfzone structures
	shore nourishments
typical evolutions	cyclic
	damping
short term (time-scale: hours to years; space scale: ~ 10 m - 1 km)	
natural causes/factors	wave- and surge states
	seasonal climate variations
typical evolutions	(rhythmic) fluctuations

[2] This phenomenon is not so much a factor or cause, but rather the result of an often not well-understood cause.

From approximately 5000 BP to 2000 BP the first order "sediment sharing" system concerns the central Holland coast flanked by the Rhine Meuse Delta in the South and the Texel High in the North. Both the delta and the high are assumed to have an alongshore sediment divergence point in the transport at their -inferred- location of maximum protrusion. Before 5000 BP the Pleistocene depression between the Rhine Meuse Delta and the Texel High was a sheltered tidal basin or lagoon like area in which during strong sea-level rise the sea transgressed and marine sedimentation occurred. Several larger inlets developed which stored sediments in their ebb and flood tidal deltas. As sea level rise rates started to drop the lagoon inlets choked and a strongly prograding barrier system came into being, storing some 6 billion m^3 of sediments between 5000 and 2000 BP (Beets et al., 1992). It is estimated that somewhat less than half of this amount was laterally fed by the Rhine Meuse Delta and to a lesser extent by the Texel High. The remainder is estimated to have been reworked from the shoreface, primarily from the subaquous tidal deltas and secondarily from the deeper shoreface. Since 2000 BP the role of the delta as a southern source, although decreasing in magnitude, has not basically changed. The Texel High, however, started to loose its integrity by breaktroughs and washovers, and instead of being a source towards the south it developed into a source for the Waddensea barrier islands and tidal basins.

The above leads to the distinction of three second-order systems over the late Holocene along the Holland coast:

1. Scheveningen-Bergen transect between 5000 and 2000 BP:

   The barrier system between Scheveningen and Bergen (some 75 km in length) can be considered as a subsystem of the above first-order system. As illustrated by a number of isochrons of this barrier sequence (Figure 2) we are dealing here with a rather uniform prograding shoreface between 5000 and 2000 BP. Shoreline evolution and sea-level rise rates for this transect are given in Table 2. The sediment sources for this system appear to be far greater than the sinks due to sea-level rise and possibly dune formation.

Table 2. Data for Scheveningen-Bergen transect between 5000 and 2000 BP

Period		Sea level rise rate	Shoreline evolution
C^{14} years BP	Calendar years		
~ 5000 - 4000 BP	~ 4000 - 2700 BC	~ 2 mm/yr	~ 2.1 m progradation/yr
~ 4000 - 2000 BP	~ 2700 BC- 0 AD	~ 1 mm/yr	~ 1.6 m progadation/yr

   Based on the method of Cowell et al. (1999) an estimate of the contribution to the shoreline movement due to sea level rise in the cross-shore direction (the 'direct' effect of sea level rise) can be made. The method rests on the concept that the morphologically active part of the shoreface remains invariant relative to mean sea level. This yields a absolute contribution of the sea level rise component of less than 5%.

2. Hoek of Holland-Haarlem transect between 2000 BP and present:

   The southern part of the original Scheveningen-Bergen transect, although not being fed as strongly by the delta, initially continued its progradation. At a later stage it experienced strong cross-shore redistribution by the formation of the Younger dunes

(~1000 to 1650 AD), and retrogradation occurred. Supported by dune management and since the construction of the harbours of Rotterdam and IJmuiden (after 1850 AD), the upper shoreface of this transect is accretive where the sources are decreasing net longshore transport from the south and erosion of the lower shoreface, compensating for the sinks due to sea-level rise and dune formation. Table 3 gives an estimate of an average shoreline evolution and associated sea-level rise rates over the various periods.

Table 3. Data for Hoek of Holland-Haarlem transect between 2000 BP and present

Period Calendar years	Sea level rise rate	Shoreline evolution
~ 0 - 1000 AD	0.5 - 1 mm/yr	~ 0.3 m progadation/yr
~ 1000 -1500 AD	0.5 - 1 mm/yr	~ 1.1 m retrogradation/yr
~ 1500 - 1850 AD	0.5 - 1 mm/yr	~ 0.6 m retrogradation/yr
~ 1850 - present	1.5 - 2 mm/yr	~ 0.45 m progadation/yr

Here, the estimate of the contribution to the shoreline movement due to sea level rise yields an absolute contribution of this component of 10% for the period 0 - 1000 AD, 4% for the eperiod 1000 - 1500 AD, 7% for the period 1500 - 1850 AD, and 17% for the period of 1850 to present.

3. Haarlem-Den Helder transect between 2000 BP and present:

As indicated above the northern part of the original Scheveningen-Bergen transect and the adjacent Texel High started to play a role as sediment source for the North-Holland breaktroughs and the adjacent Waddensea system. These sediment losses were aggravated by the formation of the Younger dunes resulting in strong retrogradation, which insists until present. Table 4 gives an estimate of an average shoreline evolution and associated sea-level rise rates over the various periods.

Table 4. Data for Haarlem - Den Helder transect between 2000 BP and present

Period Calendar years	Sea level rise rate	Shoreline evolution
~ 0 - 1000 AD	0.5 - 1 mm/yr	~ 1.7 m retrogadation/yr
~ 1000 -1500 AD	0.5 - 1 mm/yr	~ 3.9 m retrogradation/yr
~ 1500 - 1850 AD	0.5 - 1 mm/yr	~ 2.7 m retrogradation/yr
~ 1850 - present	1.5 - 2 mm/yr	~ 1.65 m retrogadation/yr

Here, the estimate of the 'direct' contribution to the shoreline movement due to sea level rise yields an absolute contribution of this component of less than 5% in all cases. However, as highlighted by Stive et al. (1990), there exists an 'indirect' impact of sea level rise due to the sediment accomodation space created by this rise in the adjacent Waddensea tidal basin. This component is shown to become dominant in recent times.

The above example is introduced to give an insight into long term shoreline trends and its variations on centennial scales, against the background of sea level rise rates. Important lessons are that the 'direct' effect of sea level rise (known as the Bruun-effect; Bruun, 1962) is fairly modest under late Holocene sea level rise as are known to occur in stable areas, and that the importance of lateral sources and sinks is high and dominated by the 'indirect' effect of sea level rise when the coast is under the influence of an adjacent tidal basin. It is finally stressed though that for lateral sources and/or sinks for an inlet-free shoreline to exist requires that either the coast displays a curvature relative to the offshore wave climate or that there exist protrusions such as due to a delta.

ACKNOWLEDGEMENTS

These results are largely based on work in the PACE and SAFE projects, in the framework of the E.U. sponsored Marine Science and Technology Programme (MAST-III), under contract no. MAS3-CT95-0002 and MAS3-CT95-0004.

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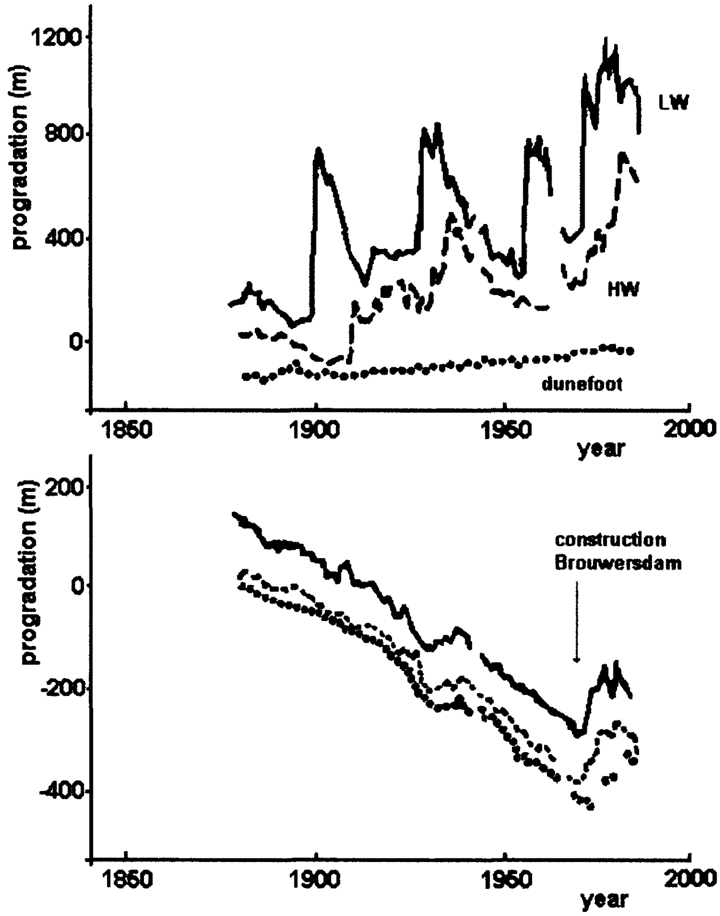

Figure 1. Evolution of the mean LW, HW and dunefoot shoreline since 1880; (a) northwest location of Schiermonnikoog, (b) west location of Goeree

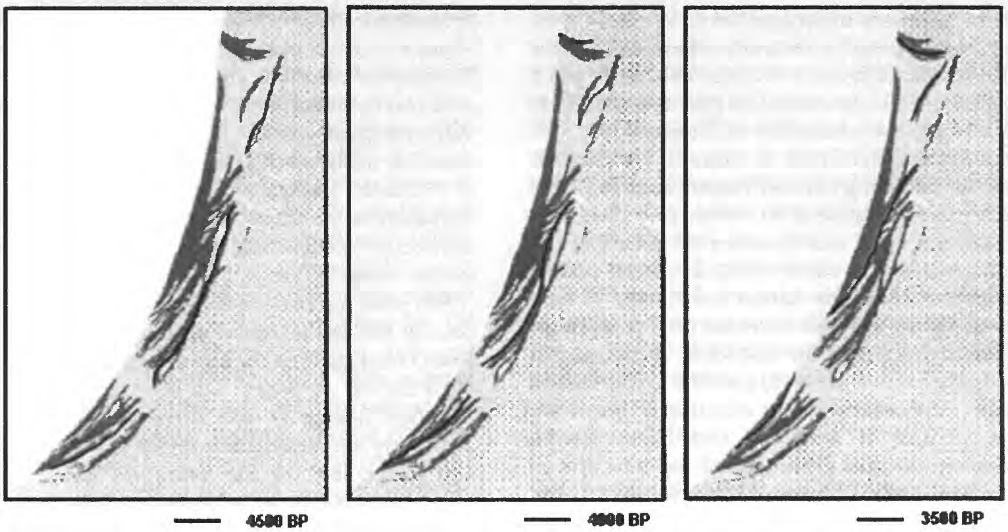

Figure 2. Isochrons of the Holland Coast barrier sequence

The Washington and Oregon Mid-Shelf Silt Deposit and its Relation to the Late Holocene Columbia River Sediment Budget

Stephen C. Wolf, C. Hans Nelson, Carol C. Reiss, Michael R. Hamer
U.S. Geological Survey

Nittrouer (1978) interprets and describes a sediment unit on the continental shelf as a Mid Shelf Silt Deposit (MSSD) which on seismic records is represented by a dense, dark band of reflectors at the seabed overlying an acoustically transparent unit which he describes as a transgressive sand unit (TSL). He observed the MSSD on the continental shelf west of the Columbia River mouth to as far north as the Juan De Fuca Canyon which incises the shelf. We recognize the MSSD unit, as defined, on the seismic profiles southwest, west, and northwest of the Columbia River mouth to as far north as Grays Harbor. North of Grays Harbor the acoustic signature becomes less obvious and difficult to trace. MSSD thickness, as described by Nittrouer, thins in this region and to the north. The thickness of total unconsolidated sediment in this region (Wolf et al., 1997) is similar to that described for the MSSD by Nittrouer. We thus combined the USGS data for this region with what we interpret as the MSSD sequence to the south to formulate an isopach map of the Mid Shelf Silt Deposit.

The thickness of the MSSD was contoured at 5 m intervals to 10 meters thickness and at 10 m intervals thereafter. A maximum sediment thickness of 35 m was observed 10-15 km northwest of the Columbia River mouth. Nittrouer (1978) indicates that the MSSD is a product of Columbia River discharge and thus we should be able to relate it to overall sediment budgets for the region. The volume of the total MSSD unit (48.5 cu km), as shown in Wolf et al, 1998, was determined to facilitate calculations of the Columbia River sediment budget.

Sediments transported directly westward from the Columbia River mouth form two thick lobes bisected by the Astoria Canyon. The northwest lobe is composed of silt and sand (Nittrouer, 1978) and has the greater sediment accumulation. It diminishes in thickness northwestward toward Quinault Canyon (Nittrouer, 1978). Nittrouer (1978) interprets the MSSD to represent a modern sediment accumulation of age 3,000 to 7,000 years. The southern lobe, not described by Nittrouer, thins to the southwest, suggesting that this lobe formed from sediments transported southward from the Columbia River mouth along the Oregon continental shelf.

The bifurcation of the lobes may reflect seasonal control of sediment transport by surface currents flowing north during winter and south during the summer and autumn (Carlson and others, 1975; Conomos, 1968). The winter phase is the period of high river discharge and high sediment load, consistent with greater sediment accumulation in the northern lobe. Seismic data is lacking near the head of Astoria Canyon, nonetheless, the limited available data suggest that the sediments thicken greatly towards the head of the Astoria Canyon. This thickening suggests that Columbia River-derived sediment intersects the canyon head and is transported down the canyon to make up another component of the Columbia River sediment budget.

Sediments on the continental shelf to the west and north of Grays Harbor thin to 10 meters or less. Sediment transported northwesterly across the outer shelf is intercepted by Quinault Canyon which cuts to within 25 km of the coast. Nittrouer (1978) and Sternberg (1986) show that part of the sediment is captured by Quinault Canyon and transported down the canyon to the abyssal plain.

Sternberg (1986) has investigated modern sediment transport and dispersal patterns of sediment over the Washington continental shelf. Based on modern sediment accumulation rates from Pb^{210} activity and an assumed Columbia River sediment load of 21 million tons/yr, he estimates approximately 67% of the total Columbia River sediment discharge accumulates on the shelf in the MSSD. He also estimates that 6% of the annual sediment discharge is transported over the shelf edge and 11% of the sediment is deposited in the Quinault (3%), Grays (1%), Willapa (2%), and Astoria (5%) canyon systems.

Based on sediment volumes deposited during the past 5,000 years, we estimate that 62% of the late Holocene Columbia River sediment deposits in the MSSD, 6.4% deposits in Astoria Canyon, 7 % in Washington canyons, 5.3% on the Washington-Oregon slope excluding canyons, and 19.3% deposits in the Cascadia abyssal basin floor and channel systems. We calculate that the minimum average sediment load of the Columbia River is 17.9 million metric tons each year in the late Holocene. Our budget does not include the paralic deposits (inner shelf, shoreline, and estuarine) of the southern Washington and northern Oregon margin that also appear to be mainly derived from the Columbia River sediment source. Because the best estimate of the present-day sediment load of the Columbia River is 5 million tons/yr (Sherwood et al., 1990), our data suggest that anthropogenic effects have caused a minimum 72% reduction in the normal late Holocene sediment load of the Columbia River.

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Dams and Potential Effects on Delta and Coastline Erosion

C. Hans Nelson, Stephen C. Wolf, Gita Dunhill
U.S. Geological Survey

Sediment budgets of the Ebro (Spain) and Columbia (USA) rivers, derived by calculating the volume of river sediment deposited in continental margin depocenters, suggest that anthropogenic effects of dams may be linked to delta- and coastal- erosion problems. Changes in river sediment budgets due to natural environmental variation and anthropogenic effects can be compared using data from studies of seismic stratigraphy, radiometric ages, stratigraphic time markers and mineral dispersal patterns. Sea-level highstand budgets of the Ebro River, (6.5×10^6 t/y [tons/year]) for the early Pliocene and (6.2×10^6 t/y) for the Holocene, are in close agreement when the natural drainage basin was well forested during warm climatic regimes. In contrast, during the Pleistocene time of glacial climatic deforestation, the average annual budget of the Ebro River increased to 15.7×10^6 t/y. This compares with sediment budgets of 21×10^6 t/y taken in the early 1900's during times of deforestation by humans. Within the post-dam era (past 50 y), the Ebro sediment load has decreased to $<0.3 \times 10^6$ t/y and the previous average coastline progradation of 370 cm/y for the Ebro delta has reversed to net coastline erosion of 4 cm/y.

Based on sediment volumes deposited during the past 5,000 years, we calculate that the minimum average sediment load of the Columbia River is 17.9×10^6 t/y in the late Holocene. 62% of this load progrades from the river mouth northwestward across the southern Washington shelf. Additional Columbia River sediment, which is the dominant late Holocene source for Washington inner-shelf and shoreline deposits, are not yet included in the budget calculation. Based on previous studies, the best estimate of the present-day sediment load for the Columbia River is 5×10^6 t/y. Thus, our data suggest that anthropogenic effects of dams have caused a minimum 72% reduction in the natural late Holocene sediment load. Similar to the Ebro system, the significant reduction in the Columbia load appears to be caused by sediment entrapment behind numerous dams. Decrease in sediment supply now seen may be a key factor in the enhanced coastal erosion that has been observed over the past two decades.

Activities at the Mouth of the Colombia River

Hans R. Moritz, U.S. Army Corps of Engineers - Portland District

This abstract and corresponding workshop presentation will provide a brief overview of the U.S. Army Corps of Engineers (USACE), Portland District's investigative activities at the Mouth of the Columbia River (MCR). The Portland District is currently engaged in three levels of investigation at the MCR. These investigative efforts include:

- Normal USACE Monitoring of dredged material disposal at ocean disposal sites.
- Enhanced (short-term) USACE and EPA Monitoring of the Oceanographic Environment at MCR.
- USACE Activities in Support of the USGS-Southwest Washington Coastal Erosion Study.

NORMAL USACE MONITORING OF DREDGED MATERIAL DISPOSAL AT OCEAN DISPOSAL SITES

To maintain a project depth of –55 ft MLLW for the 5 mile-long entrance channel at the MCR, the Portland District dredges about 4 million cubic yards of sand per year. The dredged sand has been placed in four EPA-designated ocean dredged material disposal sites (ODMDS) ranging in water depth from 50 ft to 180 ft, and located within 6 miles from the MCR entrance channel. Approximately 2/3's of all sediment dredged at MCR has been placed within ODMDSs shallower than 80 ft deep or within the Columbia Estuary disposal sites. The Portland District routinely conducts bathymetric surveys at ODMDSs to monitor placed dredged material. Recently, the Portland District has expanded and increased the use of ODMDS E (a nearshore disposal site located at the seaward end of the north jetty) to promote the return of dredged material to the littoral environment. A principal assumption for the above management action is that dredged material placed at ODMDS E will be transported northward along the coast of Washington. The dredging and disposal practices at MCR must continually balance the competing interests of: A) Providing safe navigation through the MCR, B) Minimizing adverse impacts to the environment, C) Optimizing dredging and disposal efficiency, and D) Maximizing dredged material as a littoral resource. For further information regarding dredging/disposal at MCR, please contact Mr. Eric Braun at (503-808-4348 or email at *eric.p.braun@usace.army.mil*)

ENHANCED USACE AND EPA MONITORING OF THE OCEANOGRAPHIC ENVIRONMENT AT MCR

To improve the long-term management of ODMDS at MCR and ocean entrances nation-wide, USACE is conducting a 5-year study at MCR to determine the short- and long-term behavior of dredged sediment when placed into ODMDSs. The data collection effort involves support from USACE and EPA to measure oceanographic processes at 4 locations on or near the ebb-tidal delta of MCR. Process measurements for waves, tide, currents (complete vertical structure), and bottom sediment concentration have been made at each location using a suite of sensors. The goal of the data collection effort at MCR is to concurrently measure oceanographic processes at all deployment sites so that each "season" of an entire oceanographic year can be described. Data has been collected for Aug-Oct 1997 and Apr-Aug 1998. Instruments have been re-deployed to collect data for Nov-Jan 1998-99. The process measurements will be used to calibrate sediment FATE models that will be used to improve ODMDS site management practices. For further information regarding oceanographic data collection at MCR, please contact Ms. Heidi Moritz at (503-808-4893 or email at *heidi.p.moritz@usace.army.mil*)

USACE ACTIVITIES IN SUPPORT OF THE USGS-SOUTHWEST WASHINGTON COASTAL EROSION STUDY

The Portland District (in coordination with the Seattle District) is performing bathymetry surveys offshore MCR: Northward along the Long Beach Peninsula of Washington and southward along the Clatsop Plains of Oregon. The completed survey could potentially extend from Seaside, Oregon to the mouth of Willapa Bay, Washington (45 mile extent). To date, Portland District has conducted bathymetric surveys 8 miles northward from Long Beach, WA. Combined with existing bathymetric data, the full alongshore extent of the present survey effort is about 23 miles. The Portland District (NWP) is also compiling existing Columbia River hydrologic data to be used in USGS sediment budget estimates for MCR. NWP will provide interpretation of the supplied hydrologic data. NWP will provide recommendations for potential USGS sedimentation studies for select Columbia River, Cowlitz River (SRS), and Willamette River Dams. Based on the recommendations, the Portland District may assist the USGS with potential sedimentation studies. Work will be completed in a series of milestones with an interagency funding agreement during FY98 and FY99. Funding will be incremental based on milestone completion. For further information regarding Portland District's activities in support of the USGS-Southwest Washington Coastal Erosion Study, please contact Mr. Rod Moritz at (503-808-4892 or email at *hans.r.moritz@usace.army.mil*)

Comparative Analysis of the Ebro Delta Coast (Spain) with the Washington Coast

José A. Jiménez, Laboratori d'Enginyeria Marítima, Universitat Politécnica de Catalunya

The Ebro delta is located in the Spanish Mediterranean coast about 200 km southwards of Barcelona. It has a subaerial surface of 320 km^2 and a sandy coastline length of about 50 km (Figure 1). Although until the beginning of this century the delta was behaving as such as depositional environment (continuous progradation), during the last decades a change in its evolution trend has been detected: from an intermediate river-wave dominated delta (as it has been usually classified in classical deltaic-related literature) to a wave dominated one, in such a way that reshaping processes are the dominant ones along the coast. This results in an alternation of accretion/erosion zones along the coast with maximum shoreline retreats located in its central part (a recession of about 1.5 km in 30 years) and accretion at the apex of both spits (800 m and 700 m in the south and north respectively). This change in the evolutionary trend is usually related with the management in the drainage basin which is highly regulated (the 97% of the basin is controlled by more than 100 dams). All these features makes the Ebro delta a good "small scale" example of large scale coastal behaviour to extract some knowledge to be applied (or to test) in a real large scale case, the Columbia River littoral cell. In the presentation, emphasis will be put in processes/behaviour along the Ebro delta within the context of the SWCES (e.g. hot spots in the Ebro delta and reasons for them, river management influence, role of the different driving agents inducing sediment transport, etc.).

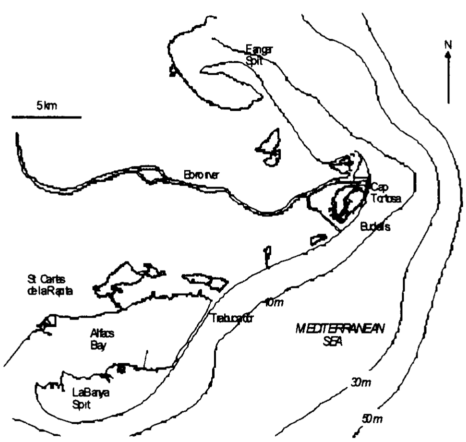

Figure 1. The Ebro delta.

Wave Spectra Transformation in Willapa Bay, Washington

S. Fenical, H. Bermudez, Pacific International Engineering

ABSTRACT

This paper presents the preliminary results of an ongoing study on wave transformation at the entrance to Willapa Bay, Washington. The study is based on collection, processing and analysis of field data. Wave data have been collected in Willapa Bay for two coastal projects: The State Road (SR) 105 Emergency Stabilization Project and the Willapa Bay Navigation Project. The SR 105 project data is part of project design procedure and pre-construction and post-construction monitoring efforts. The data collected under the navigation project is part of a feasibility study.

A total of ten wave data collection stations have been deployed at the entrance of Willapa Bay since September 1997. Wave data station locations are presented in Figure 1. Collected wave data were processed in order to obtain statistical wave parameters (water surface time series, significant and maximum wave height, peak period, direction in some cases, and wave steepness) and wave energy density spectra. The objective of this paper is to present the wave energy density spectra transformation phenomenon observed for waves which have propagated from offshore, over the outer bar, and along the tidal channels.

Deep-water waves in the Pacific Ocean, as well as in most other water bodies, are typically represented by narrow-banded (frequency) energy density spectra (Dean and Dalrymple, 1991). Narrow-banded energy density spectra imply that wave energy is concentrated within a small wave frequency range. Existing field data and theoretical studies have reported that deep-water wave energy spectra generally conserve this narrow-banded shape during transformation over shoals and bars and during interaction with tidal currents. The data obtained from Willapa Bay demonstrate that the narrow-banded deep-water wave spectra change shape to wide-banded spectra while propagating from the outside of the Willapa Bay outer bar into the bay along the tidal channels.

Deep-water waves entering Willapa Bay experience transformation mostly due to reflection, refraction and diffraction on the outer bar, and wave-current and wave-wave interaction. Analysis of the data shows that wave transformation is followed by changes in the shape and configuration of the wave spectra (Figures 2 and 3). Wave energy at Station 1 (deep-water waves) is represented by narrow-banded energy density spectra, with peaks generally located at approximately 0.08-0.09 Hz and several secondary wave energy components at slightly higher frequencies. The majority of the wave energy is concentrated between frequencies of 0.06 and 0.16 Hz.

The Station 2 spectra (transformed waves inside of the bay) contain a widely spread distribution of wave energy unlike a Rayleigh distribution, as previously observed in wave breaking over shallow reefs (Gerritsen, 1980). The majority of the wave energy in the Station 2 spectra is concentrated between frequencies of 0.10 and 0.26 Hz. These spectra show that low-frequency wave energy measured at Station 1 (incident swell energy) is dramatically reduced over the outer bar, while high-frequency energy remains approximately the same between Stations 1 and 2. In some cases, the high-frequency energy levels at Station 2 are larger than at Station 1.

Based on the study, it has been concluded that waves propagating from deep water into Willapa Bay are subjected to non-linear transformation effects. Non-linear wave transformation effects have been known to cause a transfer of energy from low frequency to high frequency harmonics (Beji and Battjes, 1993). The results of the study presented in this paper demonstrate the specifics of wave spectra transformation at different tide elevations and stage (flood and ebb).

The analysis will continue as a theoretical interpretation of the observed phenomena is developed. It is believed that the theoretical interpretation will be completed and prepared for publication upon completion of the study.

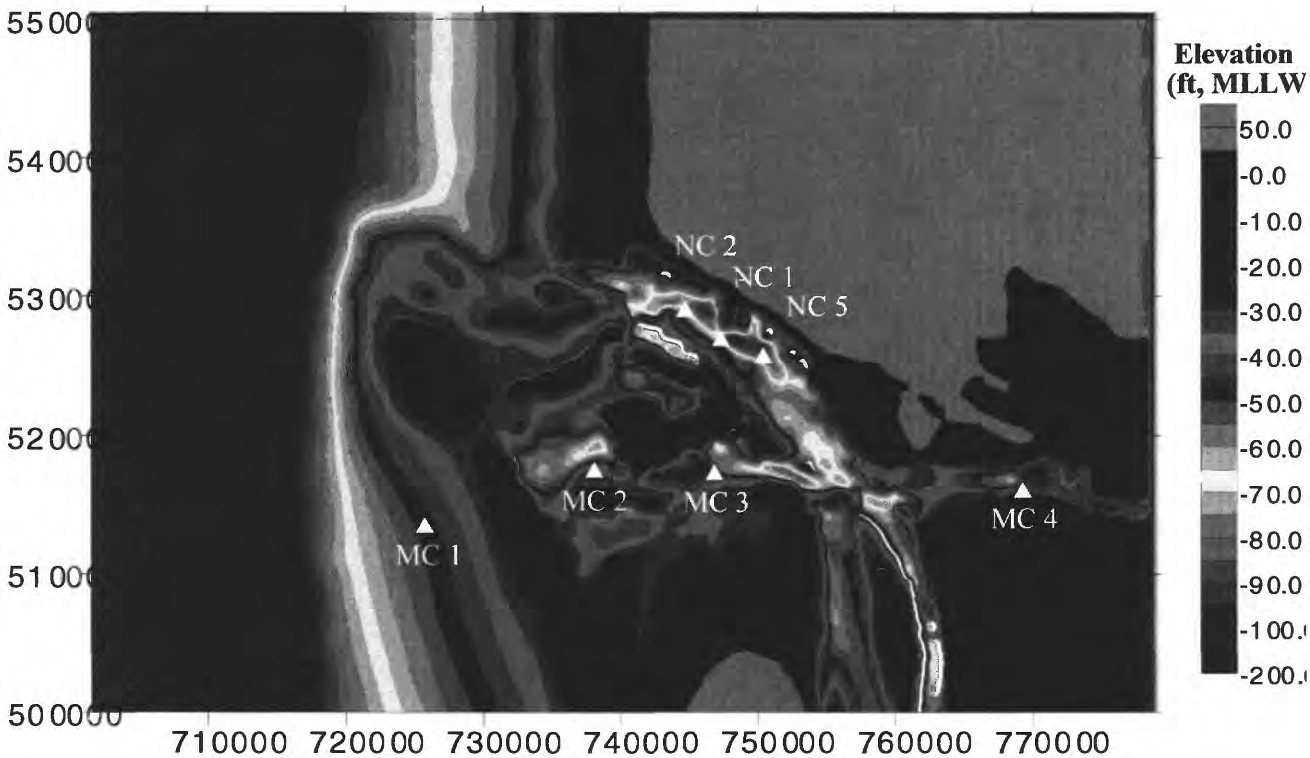

Figure 1. Willapa Bay Bathymetry and Wave Data Measurement Station Locations

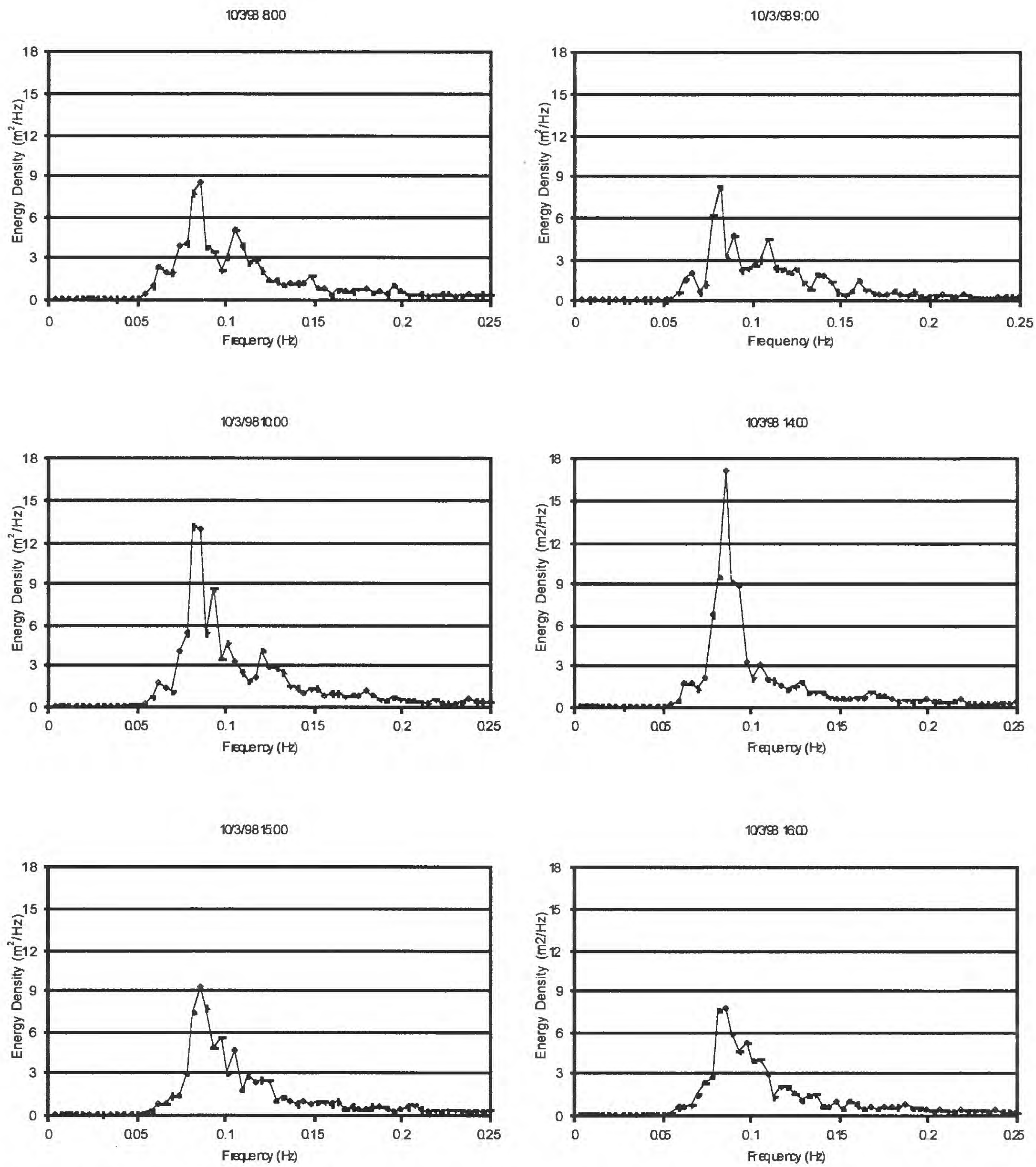

Figure 2. Energy density plots for Station 1 (offshore of outer bar)

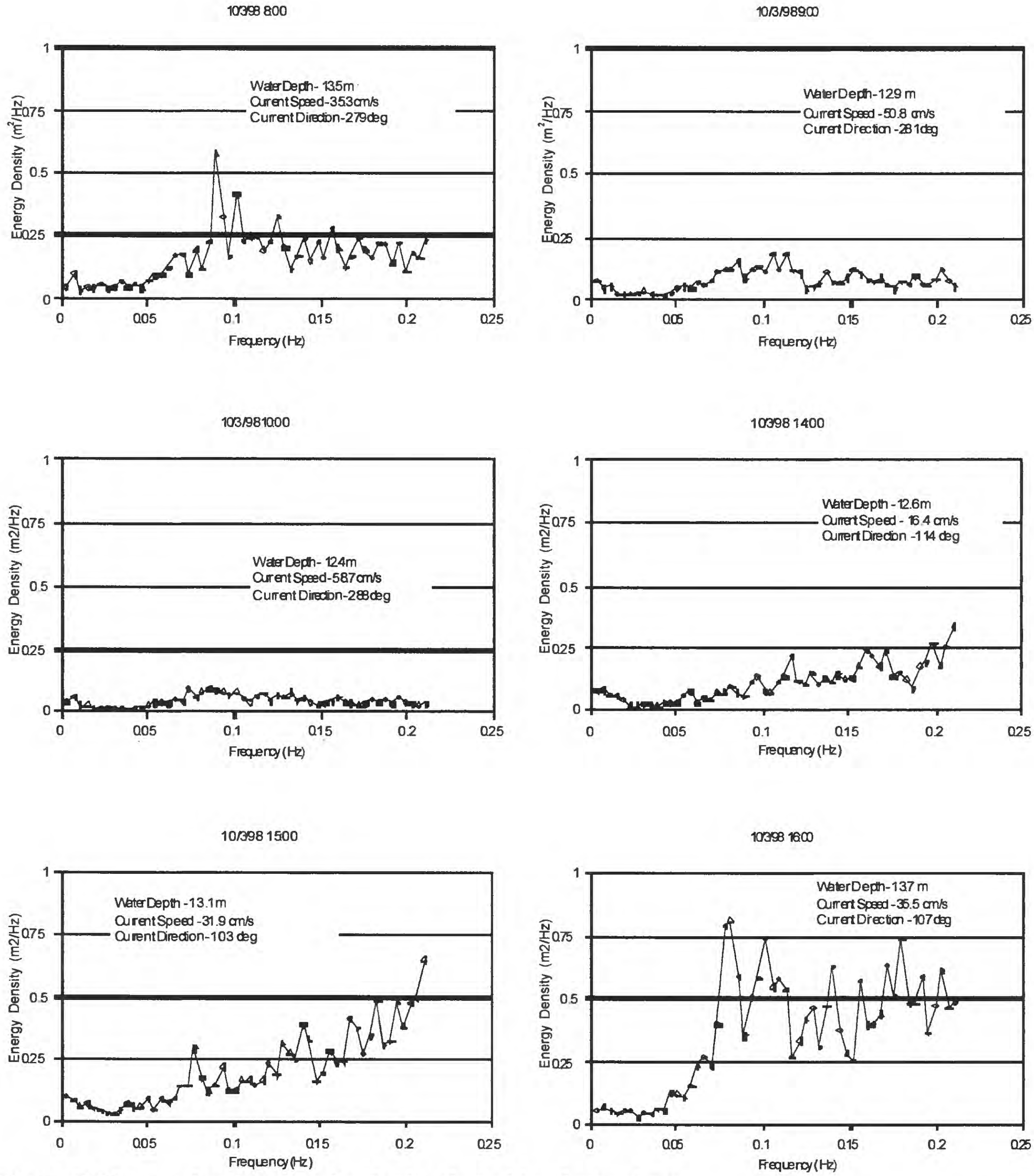

Figure 3. Energy density plots for Station 2 (inside of outer bar).

Morphologic Length Scales of High Energy Dissipative Beaches

Peter Ruggiero, George Kaminsky
WA Department of Ecology

A regional beach morphology monitoring program, designed to document short to medium-term coastal variability (event - seasonal - decadal scale), is being implemented along the high-energy, meso-tidal beaches of the Columbia River littoral cell (CRLC). Following the installation of a dense geodetic control network, a nested sampling scheme of detailed three-dimensional surface mapping, cross-shore beach profiles and shoreline change monitoring was initiated in the summer of 1997 (Figure 1). Approximately 160 km of U.S. Pacific Northwest shoreline are being examined as part of the Southwest Washington Coastal Erosion Study (Kaminsky *et al.*, 1997). Beaches within the littoral cell are highly dissipative, characterized by fine Columbia River sediment, $D_{50} \approx 0.10$ - 0.20 mm, with typical beach slopes between 1:10 and 1:100. Within the CRLC the inner surf zone and swash zone is typically dominated by infragravity wave energy.

The beach morphology monitoring is conducted via Real Time Kinematic Differential Global Positioning System (RTK-DGPS) surveying techniques. Beach topographic surfaces are generated biannually (to resolve seasonal cycles) at 16 sites, nominally 4-km in length, by obtaining dense three-dimensional beach measurements with a DGPS antennae mounted to a six-wheel drive all-terrain vehicle. Individual measurements are dense enough, O(10 m) spacing, to resolve relatively small scale features such as beach cusps, and exist over large enough alongshore distances to resolve larger scale features such as rip-current embayments and mega-cusps. Cross-shore beach profiles are collected biannually at 47 locations, spaced roughly 3-4 km throughout the coastal corridor, to examine two-dimensional beach change with higher resolution.

Figure 2 provides a regional inventory of two physical beach state parameters derived from the monitoring program (Ruggiero *et al.*, 1999). Both median sediment diameter, sampled at approximately MHW, and mean foreshore beach slope are presented for each of the 47 beach profile locations. A regional gradient in grain size exists along the CRLC with a fining of sediments with distance from the Columbia River. This trend is interrupted only near the mouth of Grays Harbor where a relic coarse sediment lag is evident. Mean foreshore beach slopes are obtained by averaging slopes from each of the three surveys, summer 1997, winter 1998 and summer 1998 between the 1.0 m and 3.0 m (NAVD 88) contours. Beach slopes are typically steeper near estuary entrances, lowering in slope with distance from the estuaries. The most dissipative beaches can be found in the North Beach sub-cell with slopes as mild as 1:100.

During the 1997/1998 winter, the littoral cell was influenced by one of the most significant El Niño events on record. Steeper than typical southerly wave angles forced alongshore sediment transport gradients that were evident in seasonal morphology on a regional scale. The morphologic data from the monitoring program are being integrated with other geophysical data sets to develop a conceptual model of the region and to begin shoreline change modeling to predict coastal evolution at a management scale (*ie.*, decades and tens of kilometers). The magnitudes of both the environmental forcing and morphologic variability of the beaches along the Columbia River littoral cell are greater than the better understood, lower energy and more reflective beaches of, for example, Duck, North Carolina and the central Dutch coast (Holland) (Table 1). Table 1 lists several parameters and gives ranges and mean values from the CRLC as well as typical values for Duck and the central Dutch coast (Plant, 1998; Wijnberg, 1995). The CRLC features higher energy than the other two coastlines and the morphology is more dissipative with finer sediment sizes and lower beach slopes, ß, both on the foreshore and within the surf zone (from the +1 m contour to 750 m seaward). At least for the winter of 1997/1998, the seasonal morphologic variability (average change in elevation across a profile, ΔZ, and the average 2.0 m contour recession, ΔX) appears to be greater in the CRLC than at Duck or in Holland. Future work will include the collection of data to improve the temporal resolution of morphologic variability and existing models will continue to be tested, identifying modifications necessary for application to the CRLC.

Table 1. Scales of environmental forcing and morphologic change.

Parameter	Range (CRLC)	Mean (CRLC)	Duck, NC	Holland
H_s (m)	1.0 – 8.0+	2.0	1.1	1.2
T (s)	5.0 – 20.0	11.0	8.4	5.0
Tide (m)	2.0 – 4.0	3.0	1.5	1.6
β (foreshore)	0.01 – 0.095	0.02	0.10	0.03
β (surf zone)	0.0067 – 0.0095	0.008	0.01	0.0065 – 0.017
D_{50} (mm)	0.13 – 0.23	0.18	0.50	0.26
ξ_o (surf similarity)	0.10 – 0.75	0.19	0.5 – 2.5	0.20
Bar Height (m)	1.0 – 2.8	2.0	0.9	2.0
ΔZ (m)	-1.92 – 0.55	-0.45	-0.3 – -0.1	-0.3
ΔX (2.0 m)	-109.0 – -0.6	-33.0	-15.0 – -10.0	-15.0 – -10.0

Annual morphologic change is considered for the sub-aerial beach profiles and surface map data. Between the summer 1997 and summer 1998 surveys, 25 of the beach profiles experienced a net loss of sediment while 22 profiles experienced a net gain (Figure 3a). For the year, 17 profiles featured less than 0.10 m of vertical change (averaged over the cross-shore distance between the location of the 1.0 m and 4.0 m contours during the summer 1997 surveys) and 9 profiles had less than 0.05 m of vertical change, the approximate limit of our ability to resolve beach change (Ruggiero *et al.*, 1998). Therefore, 26 of the 47 beach profiles experienced only a minor net change for the year. However, many profiles exhibited larger trends with 7 profiles experiencing greater than 0.4 m of net elevation gain and 7 profiles experiencing greater than 0.4 m of net elevation loss.

Of the four sub-cells, only profiles along the Long Beach sub-cell experienced more net loss than net gain for the year, with 13 of the 17 profiles revealing net beach elevation lowering. Beach profile data for both this sub-cell and the northern portion of the North Beach sub-cell show evidence of re-alignment with the anomalous acute southerly wave angles that occurred during the 1997/1998 El Niño. Results from the surface mapping data illustrate this trend for each of the sub-cells. Figure 3b presents the net change of the 2.0 m contour line averaged over each 4-km long surface map. Each sub-cell shows maximum net erosion or minimum net accretion at the southern end of the sub-cell and maximum net accretion at the northern boundary of the cell. Kaminsky *et al.* (1998) discusses the processes and morphologic response to the 1997/1998 El Niño in more detail. The average net change, derived from the surface map data, was 3.9 m of recession, however much of this is associated with the North Cove erosion "hot spot." Eliminating North Cove from the analysis reveals a mean net progradation of 3.5 m over 60 km of sampled beach surface.

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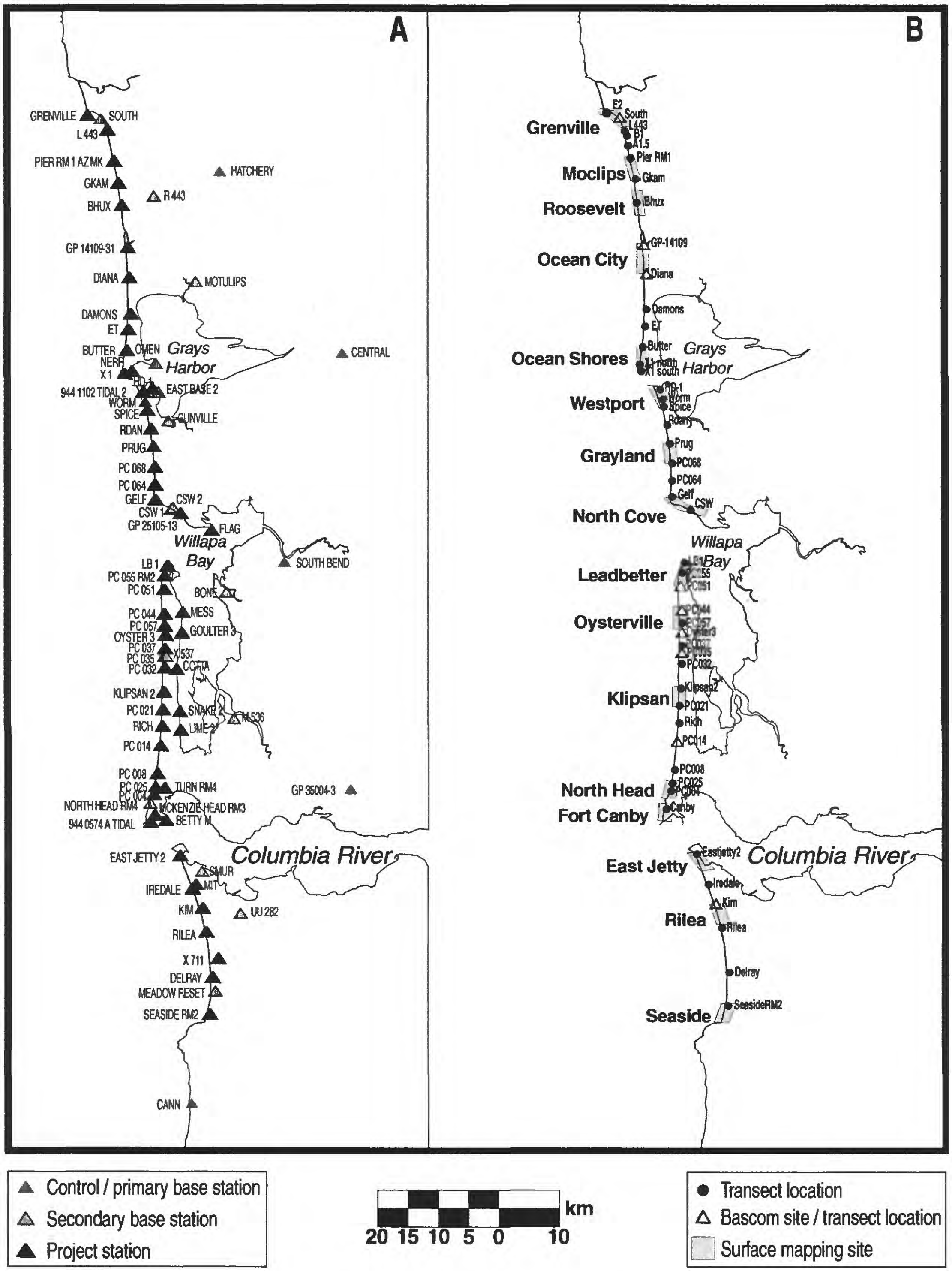

Figure 1. a) Locations of geodetic control monuments and b) locations of beach profiles and 3-dimensional surface maps.

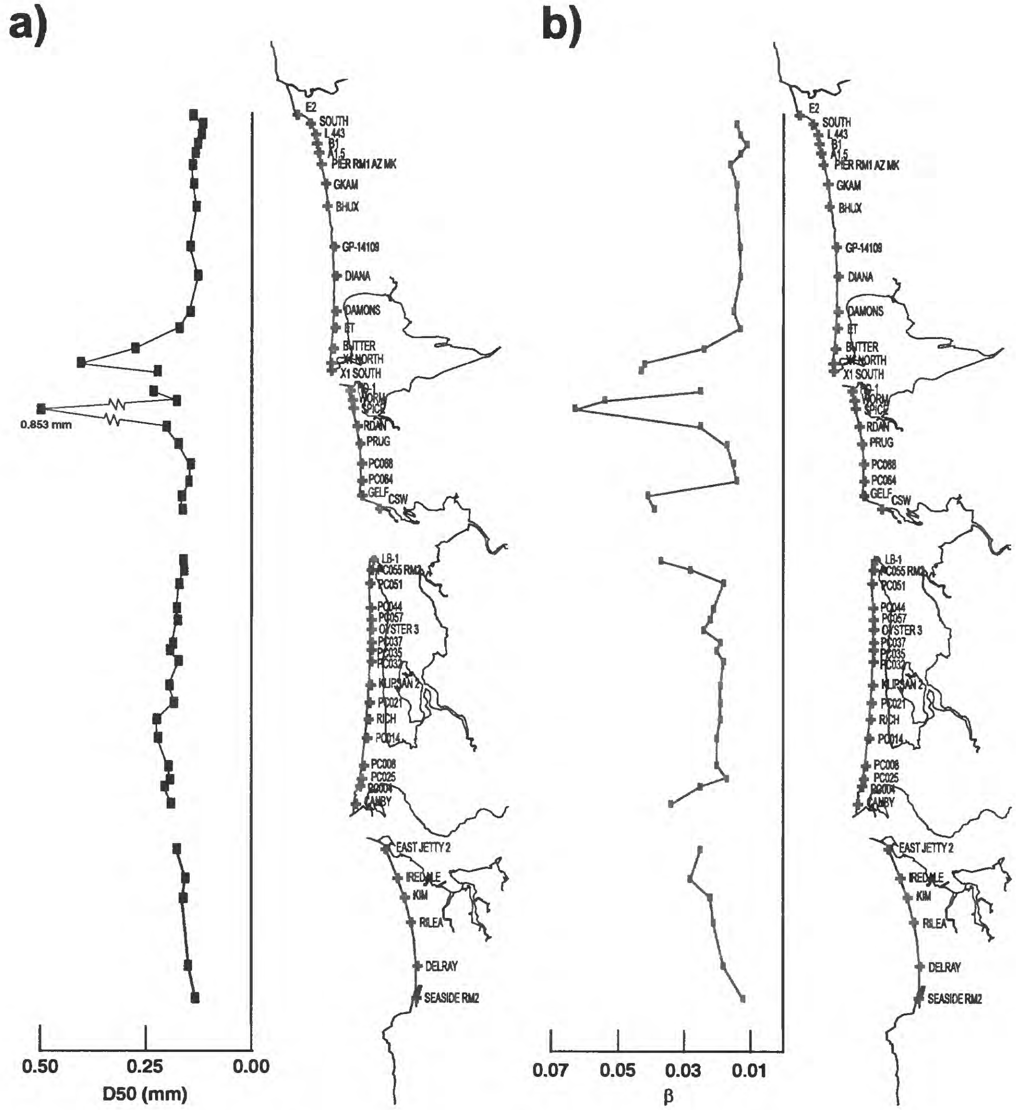

Figure 2. a) Median grain size, D_{50} (mm) and b) mean beach slopes, β (radians), at each of the 47 beach profile locations. Beach slopes are foreshore slopes, calculated between the 1.0 and 3.0 m contours (NAVD 88), and are averaged from 3 surveys, summer 1997, winter 1998 and summer 1998.

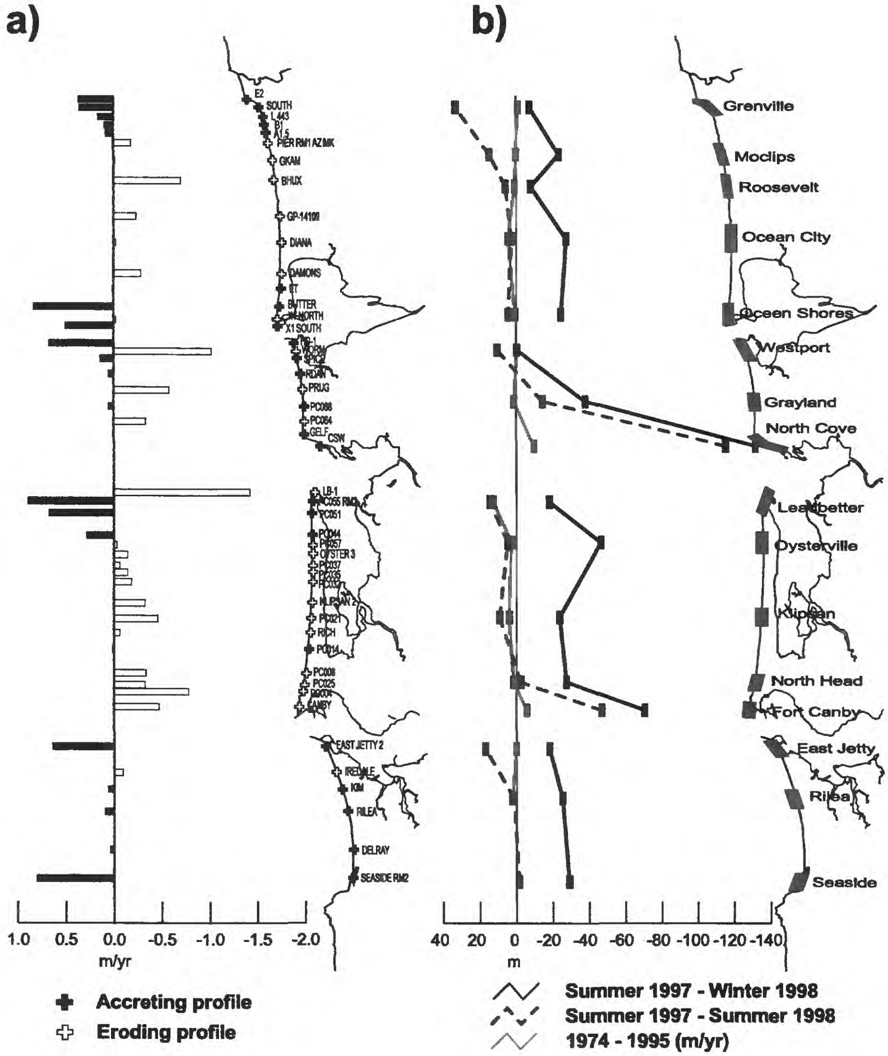

Figure 3. a) Mean beach profile lowering between the 1.0 m and 4.0 m contours at each of the 47 beach profiles from summer 1997 to summer 1998. b) Seasonal, summer 1997 to winter 1998, and annual, summer 1997 to summer 1998, variability of the 2.0 m contour as averaged over each of the 4.0 km long surface maps. Also shown is the alongshore averaged long-term shoreline change rates at each of the surface map locations as derived from 1974 and 1995 aerial photography.

Beach Morphology using Ground Penetrating Radar

Harry M. Jol, University of Wisconsin - Eau Claire
Curt Peterson, Portland State University
Peter Ruggerio, WA Department of Ecology
Sandy Vanderburgh, University-College of the Fraser Valley
Jim Phipps, Grays Harbor College

Several ground penetrating radar (GPR) datasets that were requested by the participants of the research group were collected during the summer of 1998. 100 MHz topographically corrected GPR lines were surveyed to fill in gaps of previous data collection (1996 and 1997), particularly in the north section of the Columbia River littoral cell. The northern lines confirmed our hypothesis that deposition in the northern portion of the cell has not been occurring for a long period (as compared to lower portions of the cell).

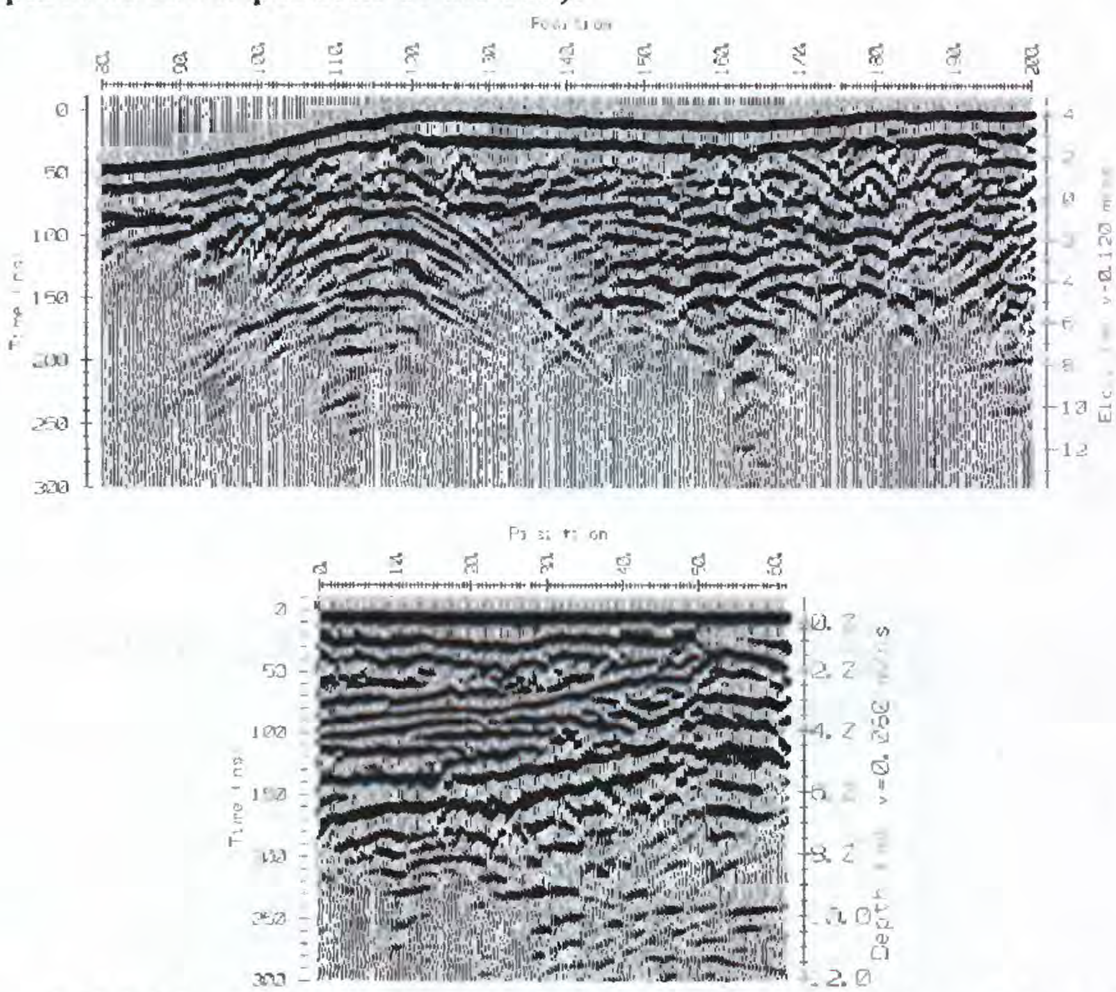

Figure 1. *Upper:* 100 MHz GPR line shot in Moclips – northern portion of the cell. Paleo-scarp located at 100-110 m. *Lower:* 100 MHz GPR line shot as a continuation of a 1997 line to confirm paleo-beach cliff location and lower Holocene – Pleistocene contact (35-55 m)

Field experiments that compared radar frequencies and transmitter powers were carried out at several locations within the cell. Antennae frequencies tested were 25, 50, 100 and 200 MHz. The transmitter powers used were 400 and 1000 volt (maximum allowable by federal government regulations). All lines were topographically corrected. The experiment allowed for both higher resolution datasets to be collected so that better insight into the sedimentological structures could be achieved, as well as deeper penetration, particularly into the large dunes of the Clatsop area of the study.

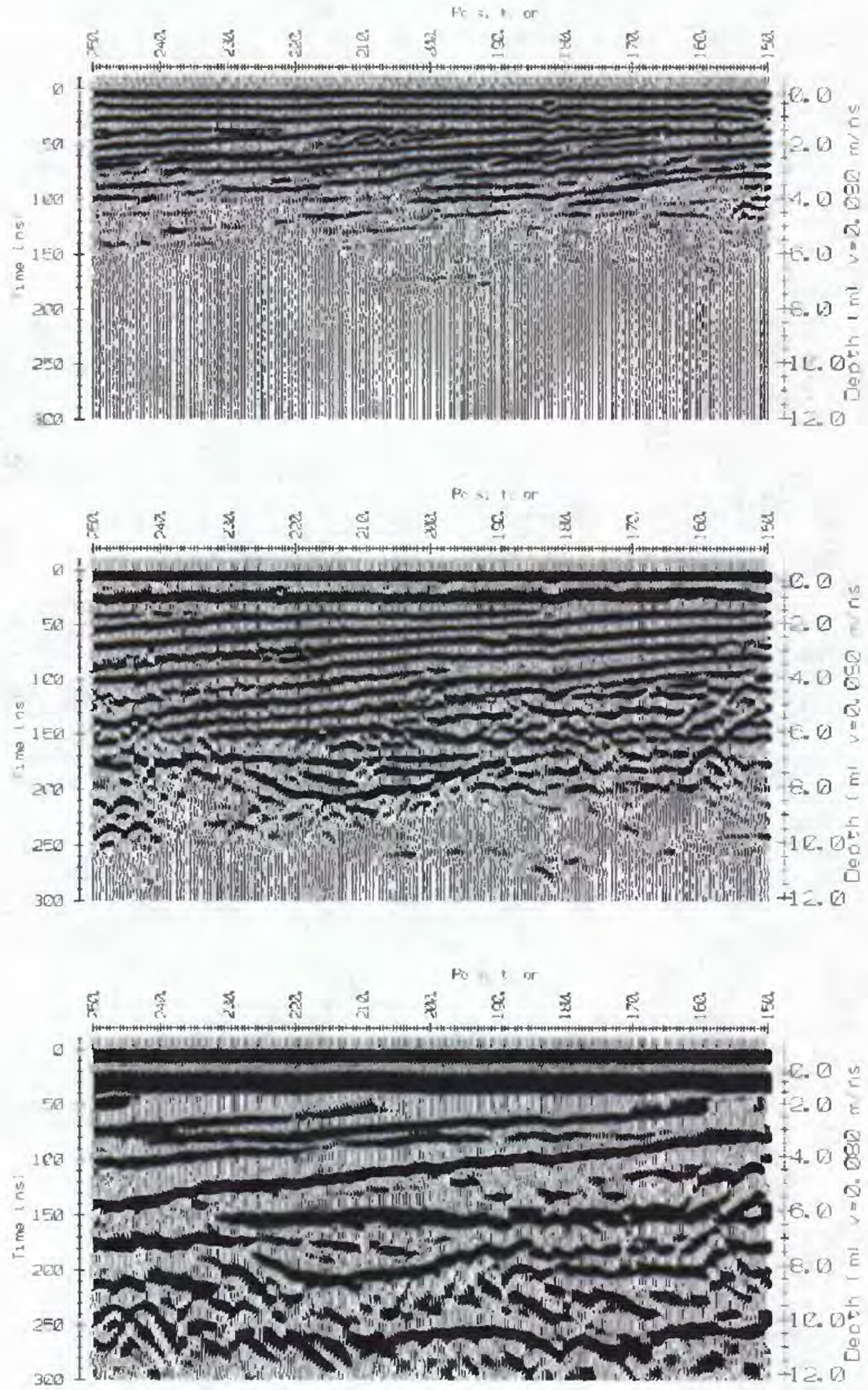

Figure 2. A frequency comparison of 3 GPR antennae frequencies. The site was located on the south end of Ocean Shores. The profiles are plotted with similar parameters. *Upper:* 200 MHz antennae – note higher resolution stratigraphy, *Middle:* 100 MHz antennae – note deeper penetration and lower resolution, *Lower:* 50 MHz antennae – note much deeper penetration (off this scale) but a loss of much of the near surface stratigraphy.

Two three-dimensional grids were collected, one in the north Grays Harbor area and one in the Long Beach area. The datasets were collected to image recent paleo-beachface (shoreface) deposits and compare the results to present beachfaces. A GPS grid was collected at the same time as the high-resolution (200 MHz) GPR grid was collected. The dimension of the grid was 25 m by 25 m with datapoints collected every 0.5 m (0.5 m antennae step along lines separated by 0.5 m). Initial processing and interpretation reveals several paleo-beach layers that will be compared to the present GPS beachface surveys.

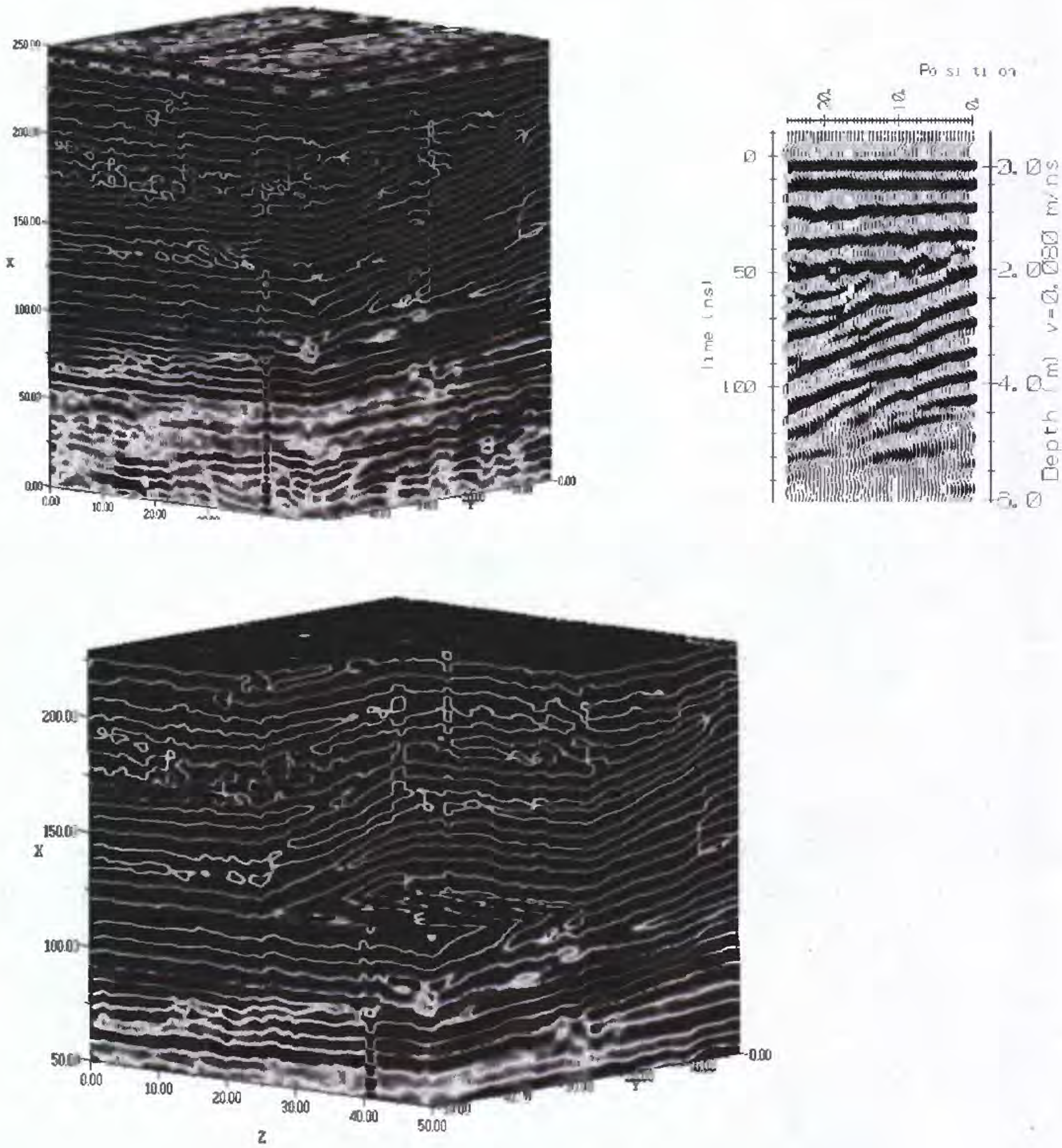

Figure 3. 200 MHz 3D Grid shot to map paleo-beachfaces. Grid shown is located in the Long Beach portion of the cell. *Upper Left:* Three dimensional perspective of the dataset (red lines indicating shorefaces). *Upper Right:* One of the 51 GPR lines shot – each dipping reflection is interpreted as a paleo-beachface, *Lower:* The cube shown here has been cut away to show the internal stratigraphy of the shoreface. Note the continuity of the beachfaces.

ACKNOWLEDGEMENTS

The major support for this project comes from the Southwest Washington Coastal Erosion Study - United States Geological Survey (USGS). Further support comes from Sensors and Software, University of Wisconsin-Eau Claire, Portland State University, University College of the Fraser Valley and Grays Harbor College. We would also like to acknowledge the support of the Washington Department of Ecology (DOE), and Grays Harbor, Pacific, and Clatsop counties. Able bodied field assistance was provided by Brian Thayer, Mark Newman-Bennet, David Qualman, April Herb, Chad Bartz, Lorraine Woxel, Nick Zerr and Andrew Zachery (your long days in the field are appreciated!). We thank Rilea Armed Forces Training Center, the Cranberry Research Foundation, and the communities within the study area for their aid in this project.

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Nearshore Bathymetry within the Columbia River Littoral Cell

Jessica M. Côté, U.S. Geological Survey
Peter Ruggiero, WA Department of Ecology

The Coastal Profiling System developed by Beach *et al.* (1995) at Oregon State University has been used to characterize nearshore bathymetry at selected sites within the Columbia River littoral cell. The system is comprised of a Yamaha Waverunner III equipped with a real time kinematic differential global positioning system (RTK DGPS) and an echo sounder to measure depth. The data is collected and stored in an onboard computer system with a daylight readable LCD providing the waverunner driver with valuable GPS and depth readings to monitor the data collection.

Beach *et al.* (1995) developed the profiling system to provide bathymetry as a tool for understanding the morphology that drives fluid motions in the nearshore zone as well as the associated morphology changes that are driven in return by the fluid motions. In October 1997 extensive testing and ground truthing of the system took place at the SandyDuck '97 field experiment in Duck, NC (Côté, 1999). Nearshore bathymetric surveys were taken simultaneously by the Coastal Resource Amphibious Buggy (CRAB) and the Coastal Profiling System (CPS). The CPS data interpolated to a gridded surface of the CRAB survey demonstrates errors of less than 0.2 m in the vertical. In July & August 1998, the system was tested as a tool for long-term morphology monitoring by the Southwest Washington Coastal Erosion Study in a regional Coastal Monitoring & Analysis Program (Kaminsky *et al.,* 1997). For comparison, , the only historic nearshore bathymetric surveys in the U.S. Pacific Northwest were taken by Willard Bascom and associates over the course of 1945-1947 (Kraus *et al.*, 1996).

A 2-3 km section in approximately the center of each of the four sub-cells of the Columbia River littoral cell was surveyed to characterize each region (Figure 1). A fifth site was surveyed just north of the North jetty at the mouth of the Columbia River in Fort Canby, WA. All five sites were surveyed once over 5 weeks during the months of July and August, 1998. Environmental conditions permitting, the surveys were conducted from 1m depth at high tide to 12 m. The nearshore profiles surveyed by the CPS were merged with sub-aerial beach profiles to provide complete coverage of much of the active zone of sediment movement. A series of surveys in April, June, and October 1998 were taken at the northern most site, Ocean City, WA to estimate sand bar response to seasonal variability in incident wave conditions. The three beach profiles shown in Figure 2, surveyed by the CPS and the CLAMMER at Ocean City, WA during April, July, and October 1998 reveal seasonal morphologic variability. Poor resolution of the inner surf zone is due to high wave or wind conditions during the surveys. The well defined outer bar, O(2 m) in height, evident in the April survey lowered by July as the crest moved onshore with deposition in the trough. An inner bar in 3 m water depth is evident during the July survey. Even with the occurrence of a few minor storms in late September, the outer bar continued to decrease in amplitude with movement onshore between July and October and the trough became only weakly defined. No appreciable change in profiles is seen beyond the 6 m depth contour, however these surveys only span a short time period.

Historic profiles surveyed by Willard Bascom were reoccupied at three of the study sites. The example profiles illustrated in Figure 3 suggest that recent beach slopes are similar to those of Bascom's profiles collected over a half century ago. However, dramatic shoreline change has occurred during this period, with 1 - 2 m of beach elevation gain along most of the profile. The earlier surveys show substantial short-term fluctuations of the upper beach profile associated with either seasonal variability or alongshore sediment transport gradients. The modern Ocean City profile is different than the Bascom data in that the sand bar is broader and contains more sediment volume. The Oysterville data is remarkable, as the form of the profiles, separated by over 50 years, is almost identical with 3 distinguishable bars of similar magnitudes in the same cross-shore position.

Figure 4 illustrates the nearshore planform of the Oysterville site, located on the Long Beach Peninsula, as measured in August 1998. The data spans 2.5 km in the cross-shore and almost 4 km in the longshore (Figure 4a). Figure 4b reveals a distinctly linear outer bar in approximately 6.0 m water depth and a crescentic inner bar in 4.0 m of water with an alongshore wavelength O(1500 m). In shallower water, the alongshore wave length of swash bars decreases and morphologic complexity increases. Above the 1.0 m contour the morphology again resumes patterned behaviour with large-scale rhythmic mega-cusps.

Figure 5a features the merged topographic and nearshore bathymetric data collected at Fort Canby, a site bounded by the Columbia River North Jetty to the south and North Head to the north. After accreting over 1 km in the first half of this century, Fort Canby is currently experiencing rapid shoreline recession (Kaminsky *et al.*, in press). This site has a steep foreshore slope O(1:50), but quickly flattens to 1:100. The North Jetty of the Columbia River lies approximately 250 m south of the southern end of the survey and the onshore limits of the ebb-tidal delta extend to the offshore limits of the survey data. The beach profile close to the jetty exhibits a concave shape, absent of bars or troughs. To the north, a longshore bar develops with its amplitude increasing with distance from the jetty. This bar eventually becomes similar in magnitude and length to the Oysterville site approximately 30 km to the north, but is located in shallower water. This kilometer scale gradient in bar morphology is almost certainly related to the proximity of the jetty, the ebb-tidal delta and the nearshore circulation associated with these boundary conditions. Shorelines derived from GPS measurements during the winters of 1998 and 1999 indicate that this site also experienced strong alongshore gradients in shoreline change rates during the past year (Figure 5b). The large gradients in sand bar position and height are thought to be of first order importance in driving these gradients in shoreline erosion.

In Figure 6, an alongshore-averaged beach profile from each of the survey sites illustrates the variability of bar size, bar position, and beach slope among sub-cells (Côté, 1999). The CPS nearshore profiles are merged with sub-aerial profiles and the origin of the coordinate system is horizontally adjusted to begin at the 1.0 m contour (NAVD 88), an elevation approximately equal to MSL. The resulting beach profiles were then averaged across a 1 km alongshore distance to produce a spatial mean profile at each of the five survey sites. The beach profiles are presented with extreme vertical exaggeration (1V:125H) to emphasize subtle variations in shoreface morphology. All sites are characterized by a multiple barred profile, however, poor resolution of the swash zone (+1 m to -1 m) as a result of high wave and/or wind conditions occasionally hindered the connection of nearshore profiles to sub-aerial beach profiles.

To represent the basic shape of the profile, the alongshore-averaged data were fit to an equilibrium profile. The shape factor, A, and the exponent, m, of the equilibrium profile were calculated through a least squares fit by the Gauss-Newton method and are given in Table 1. A beach slope, β (1.5 km), spanning from 0 m to -1500 m in the cross-shore has been calculated from the equilibrium mean profile. The Ocean City profile has the shallowest slope (0.0059) and Rilea the steepest (0.077). A foreshore slope, β (fs), calculated from the alongshore-averaged profile, reveals Ocean City has the mildest sloping beach (0.013) but Fort Canby has the steepest foreshore slope (0.034).

Sand bars are identified based on deviations from the least squares fit equilibrium profile. The presence of a sand bar is indicated by a zero-down-crossing in the deviation profile, marking the change from a positive to negative anomaly, *ie.* the seaward flank of the bar. The position of the bar on the profile is identified as a local profile maximum, h_{bc} at the bar crest and measured relative to 0.0 m at the cross-shore position x_{bc}. Likewise, the trough occurs as a local minimum, h_{bt}, also determined from the local profile slope. With these parameters the height of the sand bar, H_b, and the length of the bar, L_b, are derived from the deviation profile. The volume of sediment contained in a bar, V, from the landward trough to the seaward trough is also calculated from the deviation profile.

A minimum of two well-defined sand bars were present at all five survey sites. With the exception of Ocean City, there is a swash bar located between +0.76 and -0.74 m at 50 to 175 m from the origin. Four of the five survey sites exhibit both inner and outer bars. Fort Canby is anomalous with only two bars, a swash bar and an inner bar. At three of the five locations the outer bar is in approximately 6.5 m water depth. The sand bars range in height from 0.2 to almost 2 m, in length from 164 to 949 m and in volume from 48 to 535 m^3/m.

Table 1. Results of equilibrium profile fit and sand bar identification methods to quantify the variability between sub-cells (Côté, 1999).

Site	Equilibrium profile				Sand bar statistics					
	A	m	β(fs)	β(1.5km)	bar #	x_{bc}	h_{bc}	H_b	L_b	V_t
Ocean City	0.031	0.699	0.013	0.0059	1	-326	-1.36	0.731	596.7	423.4
					2	-750	-4.30	0.845	352.7	99.1
					3	-1215	-6.60	0.203	553.9	48.0
Grayland	0.027	0.789	0.015	0.0073	1	-50	0.76	0.566	232.7	130.0
					2	-342	-2.14	0.666	225.8	105.2
					3	-567	-3.81	1.145	949.1	534.9
Oysterville	0.037	0.660	0.024	0.0064	1	-175	-0.45	1.076	429.5	429.5
					2	-613	-3.79	1.602	359.0	359.0
					3	-1088	-6.32	1.249	409.0	409.0
Fort Canby	0.039	0.562	0.034	0.0075	1	-157	-0.74	1.417	217.3	217.3
					2	-426	-4.11	0.962	322.2	322.2
Rilea	0.030	0.780	0.021	0.077	1	-90	0.38	0.797	164.2	193.6
					2	-244	-1.12	1.132	184.2	126.4
					3	-516	-3.17	1.913	317.1	208.8
					4	-887	-6.46	0.412	647.4	141.1

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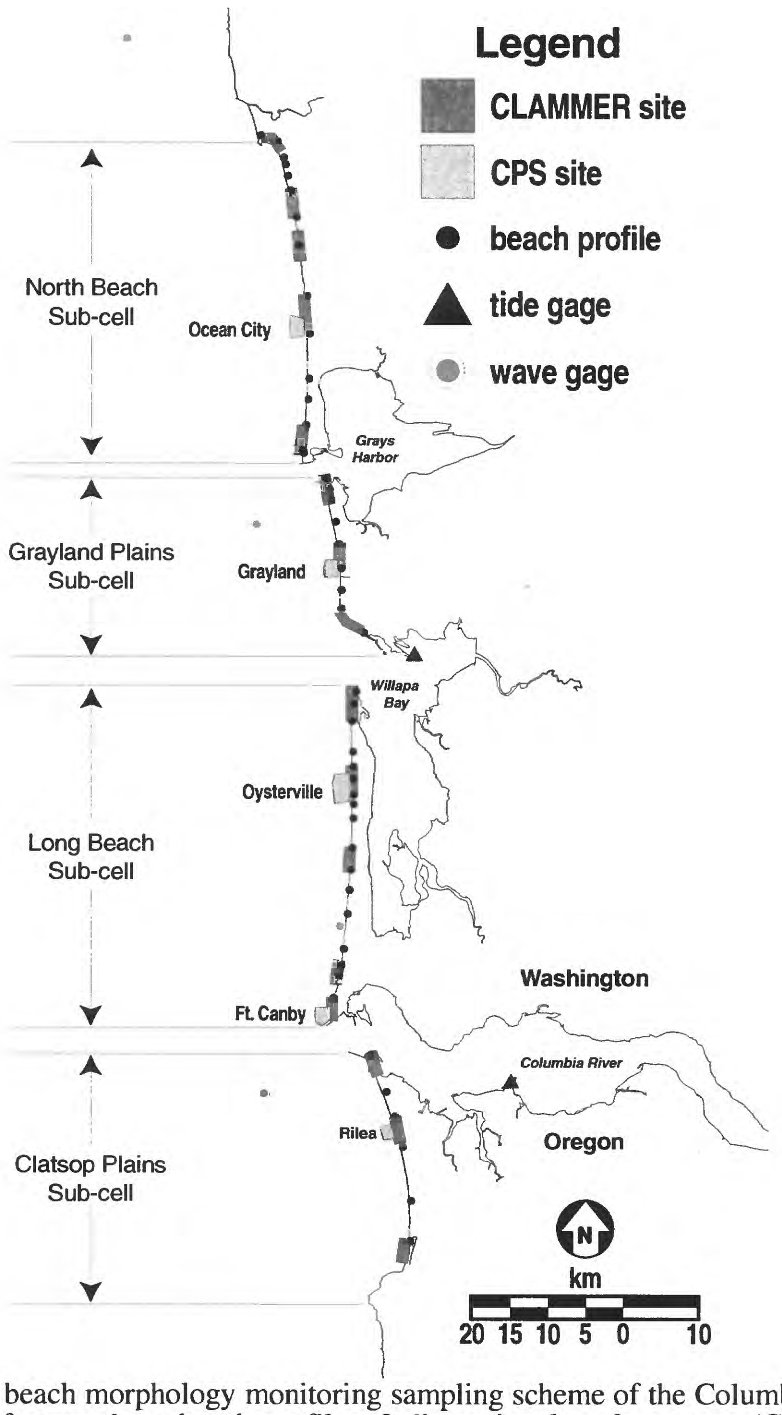


Figure 1. Nested beach morphology monitoring sampling scheme of the Columbia River littoral cell consisting of cross-shore beach profiles, 3-dimensional surface maps (CLAMMER) and nearshore bathymetry (CPS).

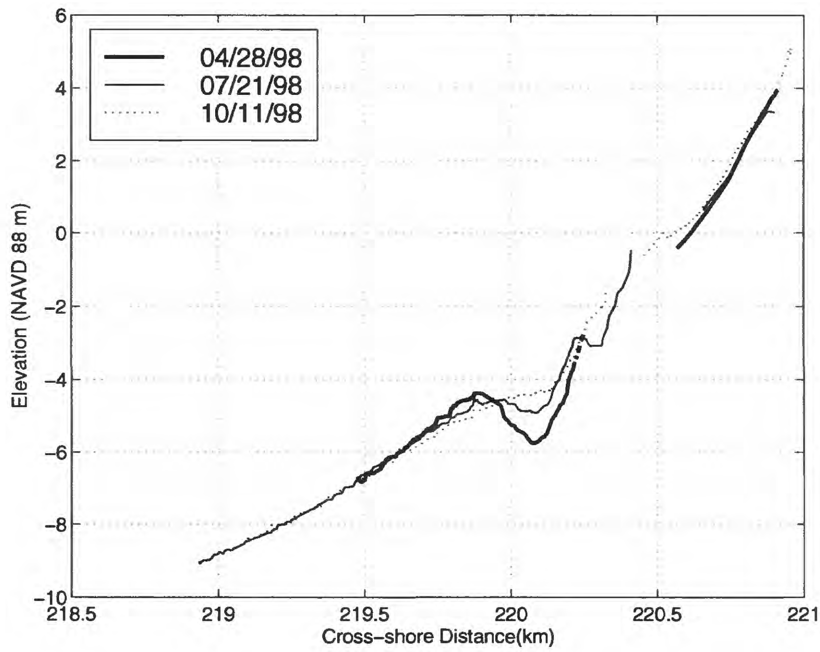


Figure 2. The seasonal comparison of beach profiles surveyed at Ocean City, WA during April (dark line), July (light line), and October (dashed line) 1998 by the CPS and the CLAMMER. MLLW is approximately -0.5 m NAVD 88.

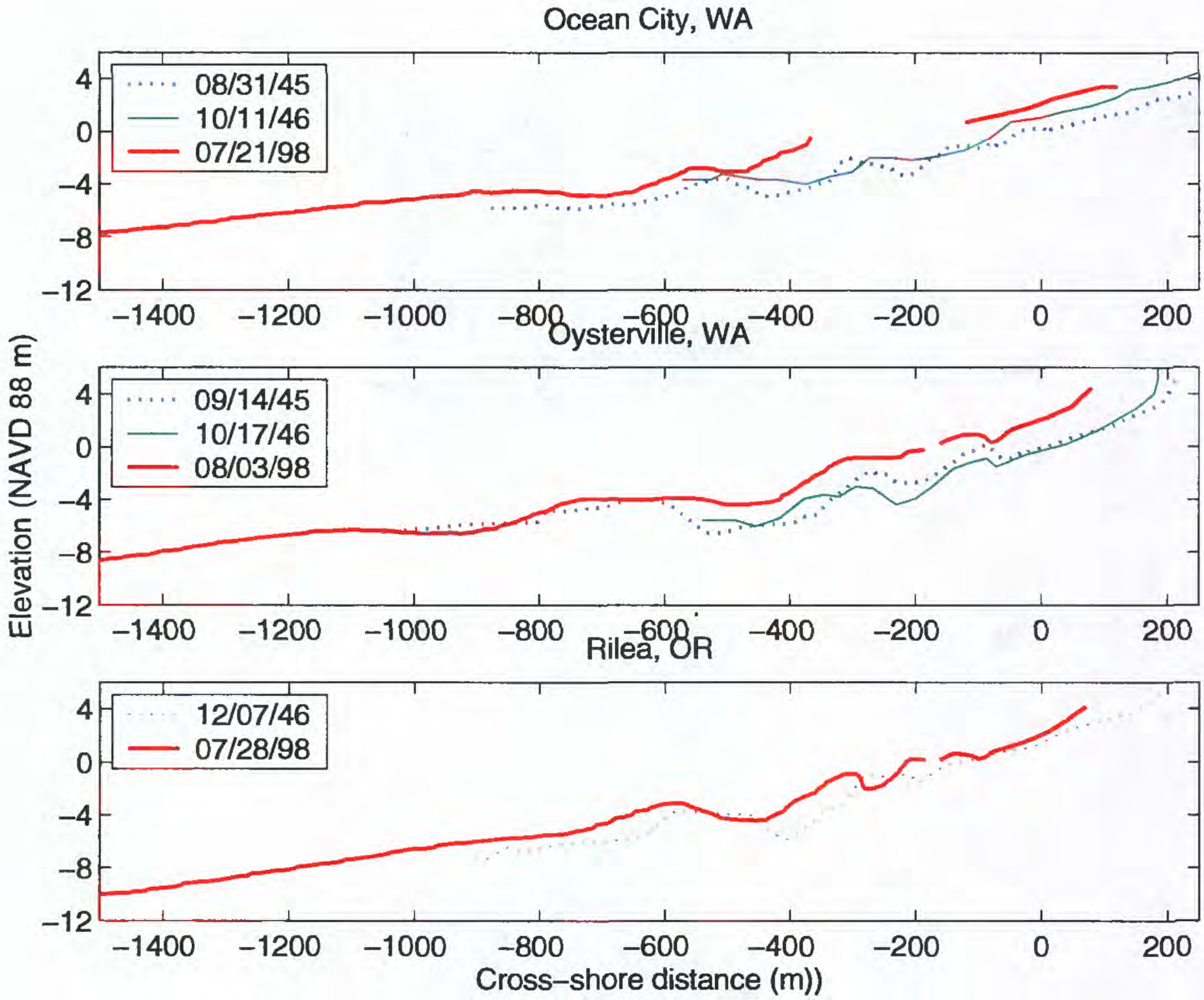
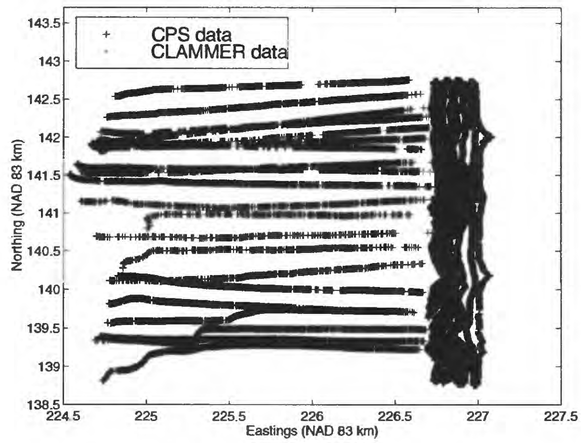


Figure 3. Beach profiles at a) Ocean City, WA, b) Oysterville, WA and c) Camp Rilea, OR comparing data collected by Bascom and associates in the 1940's with modern profiles collected with the Coastal Profiling System and the CLAMMER. Note the multiple bar and trough system at Oysterville, WA.



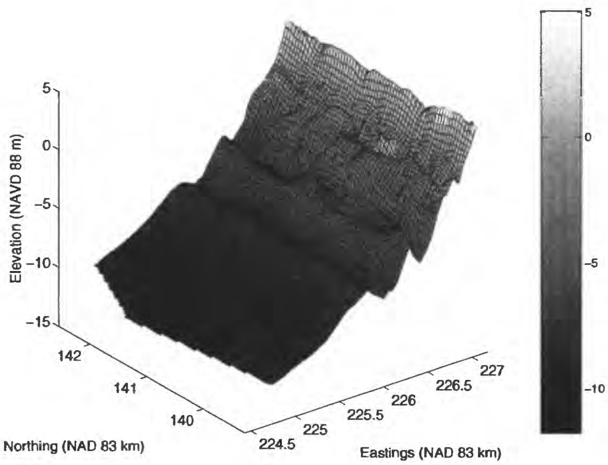


Figure 4. (a) A plan view of topographic, alongshore transects collected by the CLAMMER, and nearshore bathymetric data, cross-shore transects collected with the CPS, surveyed to produce the b) 3-dimensional surface map of the Oysterville, WA nearshore planform during August 1998 (Côté, 1999).

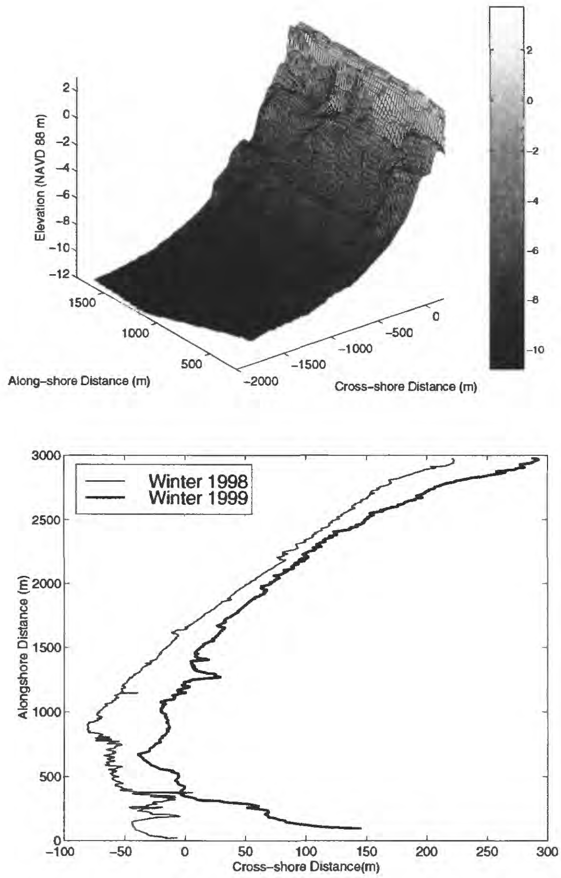


Figure 5. a) Merged topographic and nearshore bathymetric data at Fort Canby, WA and b) GPS derived shorelines at Fort Canby, Washington during the winter of 1998 and the winter of 1999.

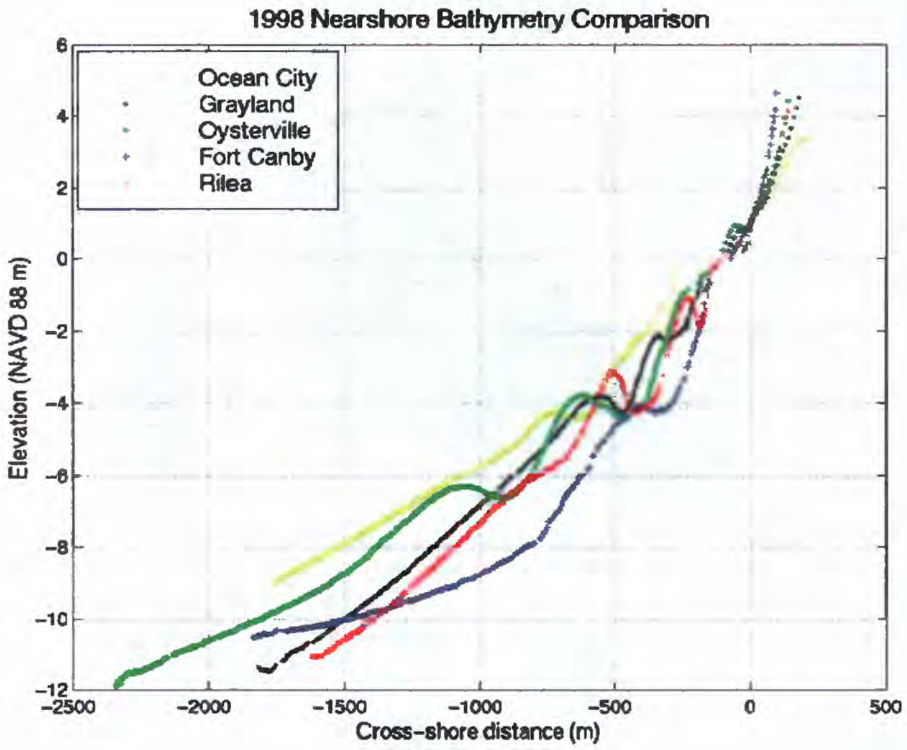


Figure 6. The five survey regions are represented by a 1 km alongshore-averaged profile. The coordinate system origin has been set to the 1.0 m contour NAVD 88. Differences in morphology and slope demonstrate the variability within the CRLC (Côté, 1999).

An Aerial Video System for Measuring Large Scale Coastal Features along the NW U.S. Coastline

Tom C. Lippmann, Chuck R. Worley, Scripps Institution of Oceanography
John W. Haines, Abby H. Sallenger, Guy Gelfenbaum, U.S. Geological Survey
Peter Ruggiero, George Kaminsky, WA State Department of Ecology

ABSTRACT

Accurately measuring the changes in position of nearshore sand bars and the shoreline coincident with antecedent offshore regional wave conditions allows quantitative analysis of large-scale coastal evolution and beach erosion. As part of a cooperative research program supported by the U. S. Geological Survey, we have developed a unique aerial video system that can be used to accurately (order 5 m resolution) and rapidly (order 1-5 hours) sample the location of nearshore sand bars (inferred from average wave breaking patterns), as well as the shoreline and dune position (which provides a measure of beach width), over alongshore distances ranging up to several hundred kilometers along the coastline. In further cooperation with the Washington State Department of Ecology, the aerial system has been deployed along the SW Washington coast over the past year during the winter and summer of 1998 and the winter of 1999. The surveys provide a base to observe morphological changes that have occurred during the fall storms over the past year, and for comparison with future surveys.

AERIAL VIDEO SYSTEM AND FIELD METHODS

The dynamic interaction of waves and nearshore morphology occurs over 5 decades of scale, with spatial variability ranging from wave- and mega-ripples to large scale sand bars, and temporal response from a single wave cycle to months or even years. This wide range of scales presents difficult sampling problems that must be overcome. Commonly used nearshore surveying techniques are limited in spatial and especially temporal resolution, require an enormous resource of manpower, and are feasible only during moderate or small wave conditions. For most scientific, engineering, or coastal management applications it is of interest to sample the bathymetry as quickly and as often as possible to resolve phenomena such as rapid, large changes in beach topography and sand bar morphology that occur during single storm events, or over a series of several to many storm cycles. One remote sensing technique which has successfully resolved the horizontal spatial and temporal scales is sub-aerial video measurements of large scale sand bar morphology. Time-averaged video images detect the horizontal scales of the average wave breaking patterns. Because waves preferentially break over shallow regions, the large scale morphologic features associated with bars are revealed. Recent advances in aerial videography developed by the principal investigator have shown that the rapid acquisition of the spatial patterns of sand bar morphology spanning 100's of kilometers along the coast can be done.

A schematic of the aerial video system is shown in Figure 1. The modular, low-cost system was configured so that it could be quickly deployed in easily accessible, inexpensive Cessna 172 or 182 aircraft at locations where forecasted weather predictions indicated the development of large storm systems. The system utilizes a gyro-stabilized compass and inclinometer to maintain the camera in a vertically downward orientation within a walk-circle of 1 degree diameter. The azimuthal angle of the camera view and altitude (measured with a pressure sensor) is recorded on a lap-top PC and is synchronized with the video using timing obtained from a hand-held GPS receiver. The horizontal real-world UTM coordinates and vertical elevation of the aircraft are measured using an independent differential GPS system with reliable positioning and very high accuracy (0.05-0.5 m depending on distance to the base station). Assuming precise positioning, and for a typical deployment using a 2/3 inch format video camera with wide angle lens, the expected image resolution ranges between 1.1-5.9 (1.6-8.8) m in the cross-shore (longshore) directions, depending on flight altitude ranging 1500-8000 ft. With a typical aircraft ground speed of 80-100 knots (~50 m/s) we expect sampling periods and averaging times in one flyby to be about 17-89 seconds for the same flight altitudes. The averaging time can be increased linearly by making several flybys of the same ground area.

The approximately 200 km of coastline from Newport OR to Pt. Grenville can be sampled in less than 5 hours, the time to fly the entire coast round-trip in the aircraft (Figure 2). The sand bar morphology is measured from time-exposure images created digitally using image processing and video hardware already in hand at Scripps. The position of the bars, shoreline, and dune are determined from the contrast in the images between the dark vegetated back-dune, the higher intensity sand on the subaerial beach, the nearly white breaking regions at the shoreline and over the bars, and the darker, non breaking regions in the trough and offshore (Figures 3a-3c).

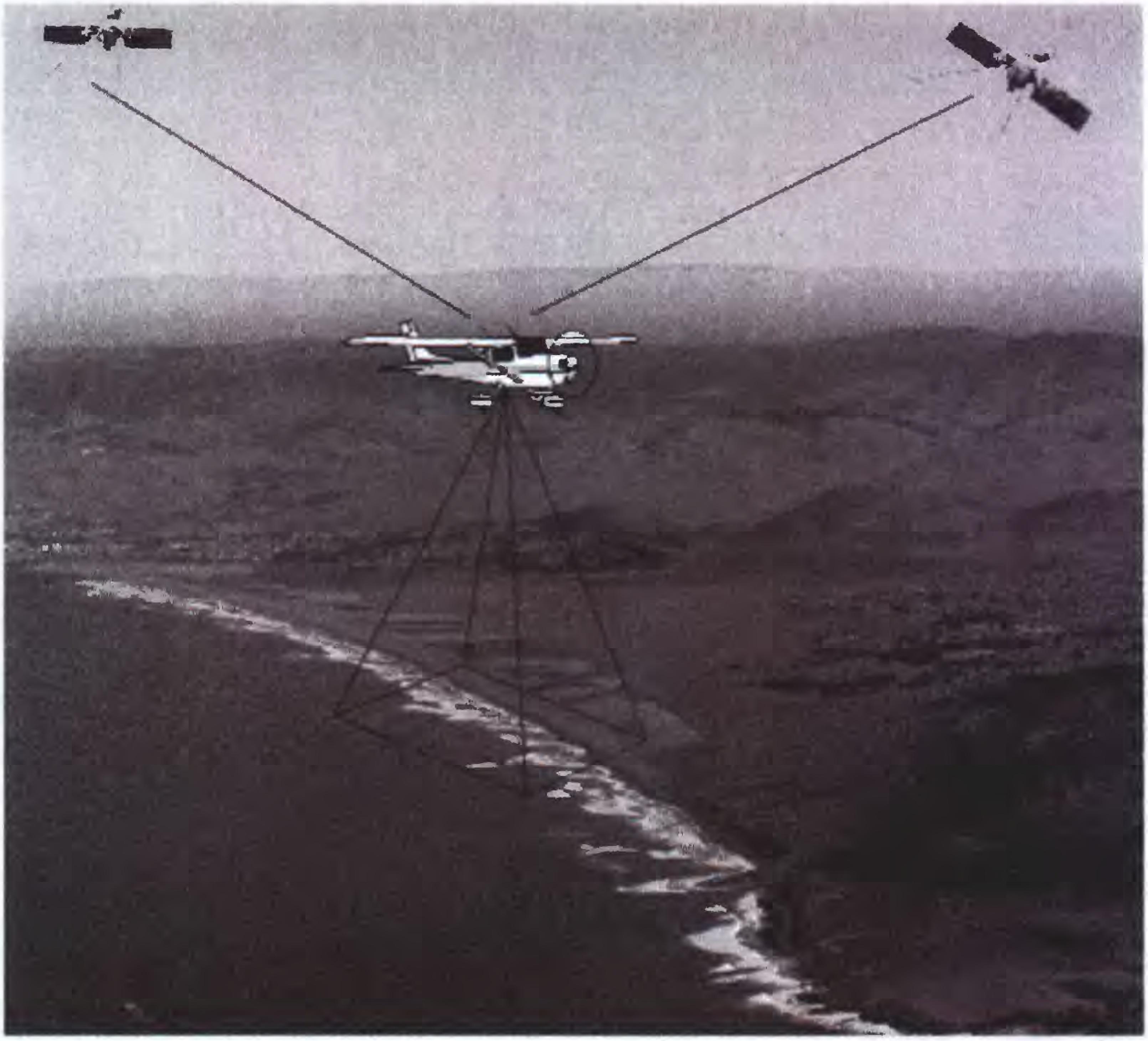


Figure 1. Schematic of the aerial video system technique used to sample the position of the shoreline, dune, and offshore sand bars over alongshore distances spanning up to several hundred kilometers of coastline. Video image coordinates are transformed into real world UTM coordinates using the differentially corrected GPS position, measured with an onboard GPS satellite antenna and receiver, and the horizontal orientation (yaw) of the video cameras measured with a fluidic gyro-stabilized KVH compass. Successive, over-lapping rectified (ortho-normal) images are digitally averaged together to make a time-exposed image of typical duration 35-60 seconds. The position of the shoreline is determined from the contrast between wet and dry sand or the shoreward edge of the breaking patterns (depending on the characteristics of the shore break, beach slope, and wave conditions). The position of sand bars are inferred from the location of average breaking patterns. Large-scale alongshore variability in the shoreline and the position of multiple sand bars can be deduced from the large expanse of the video coverage.

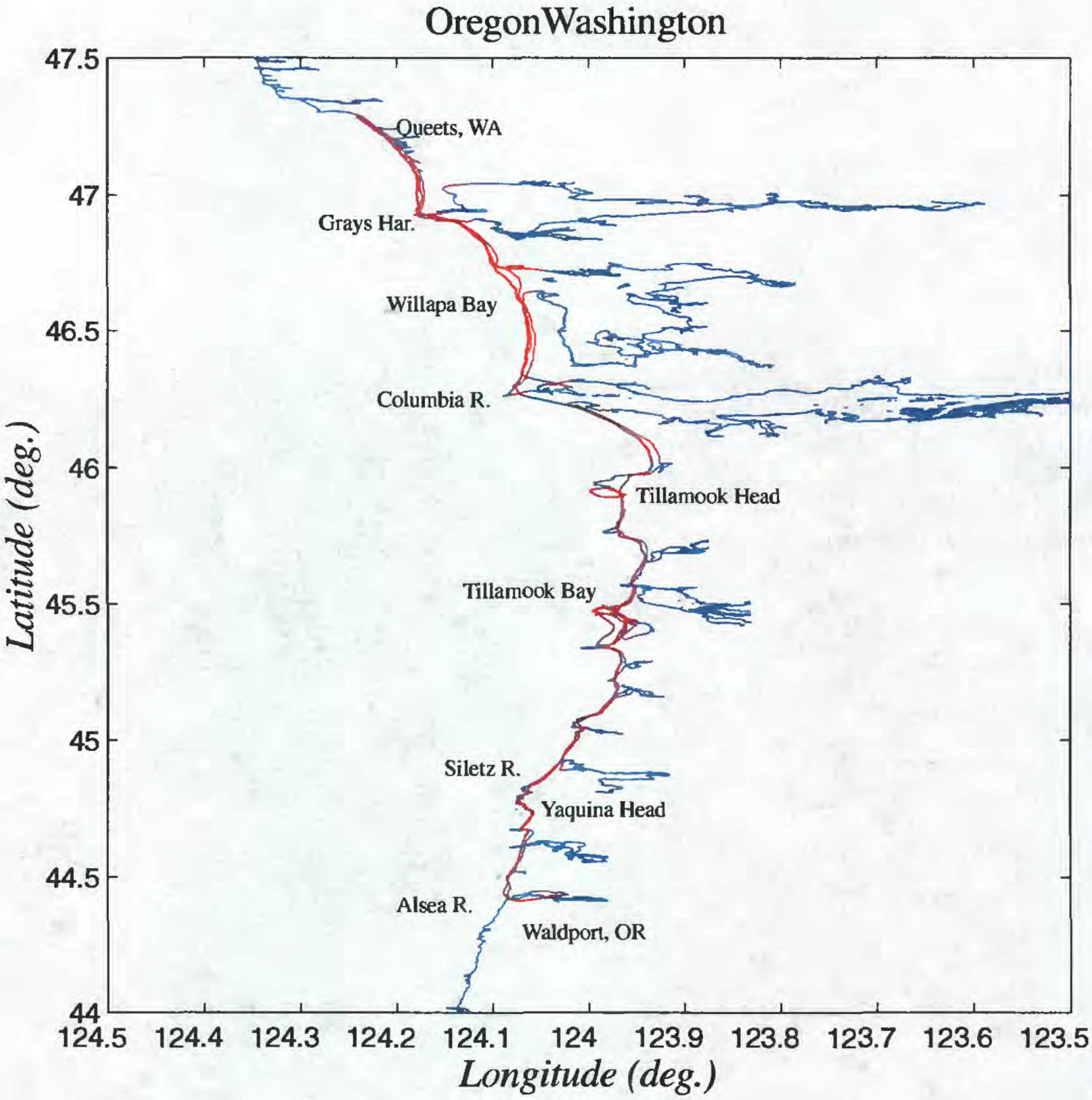
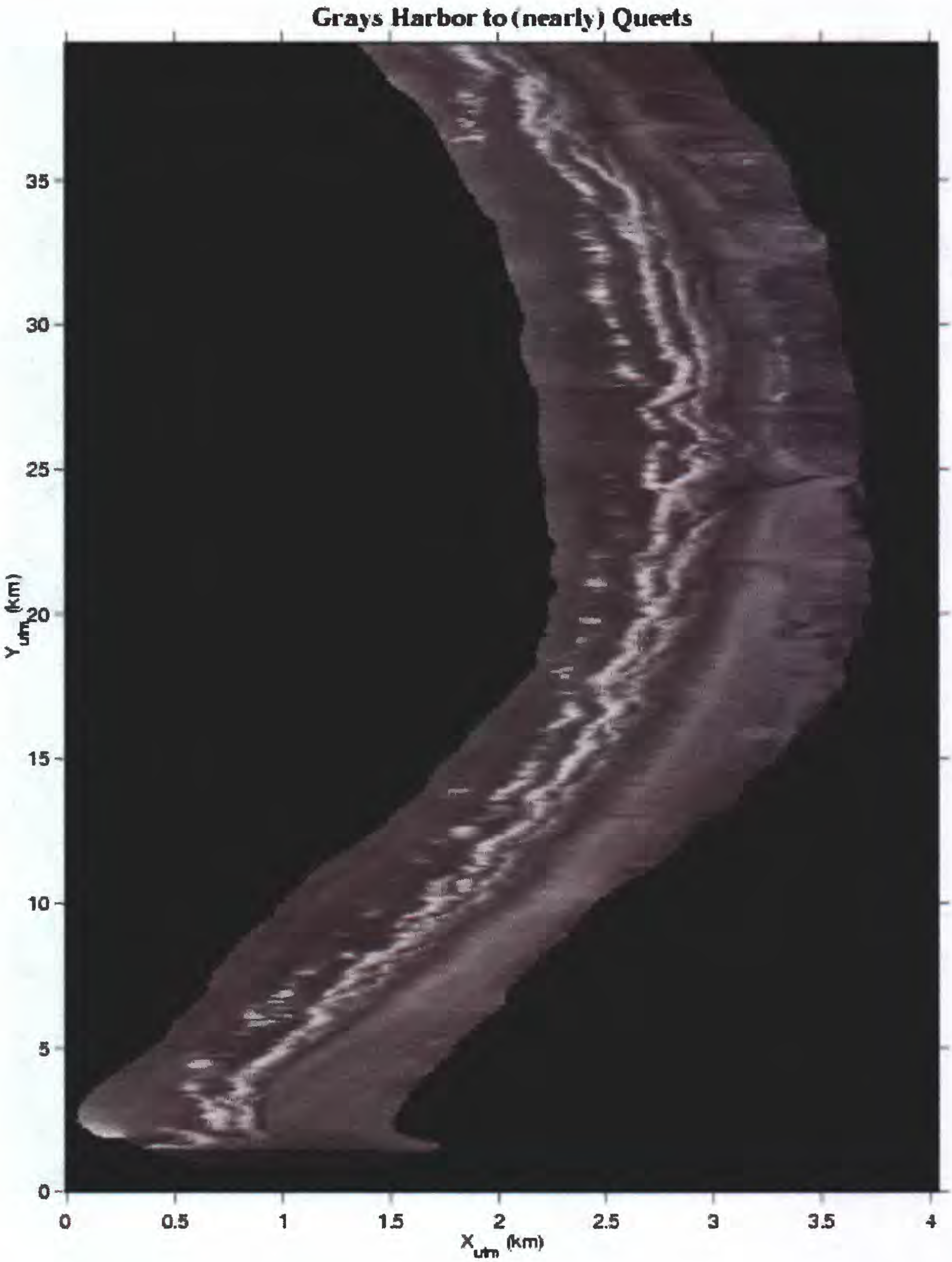
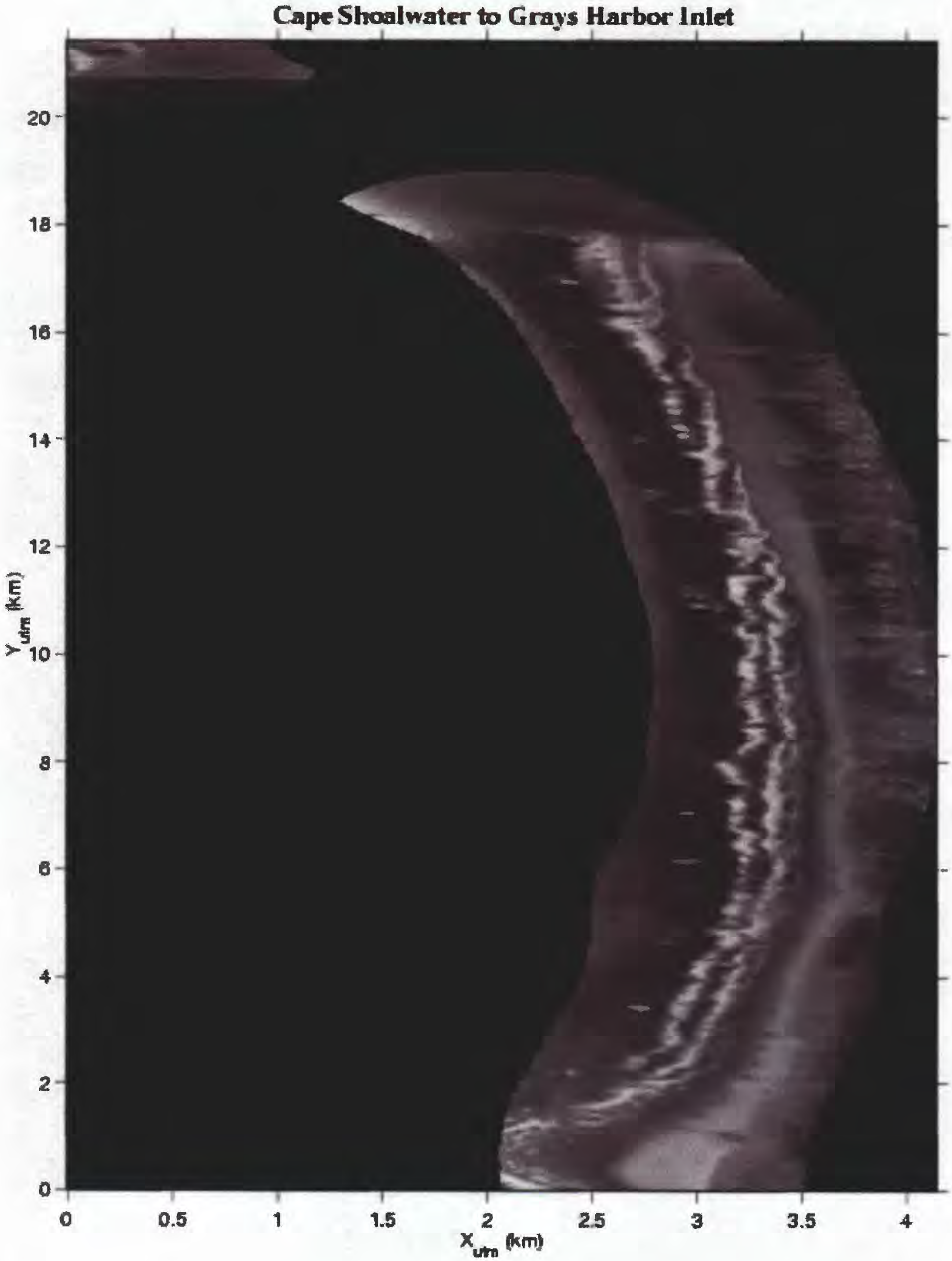
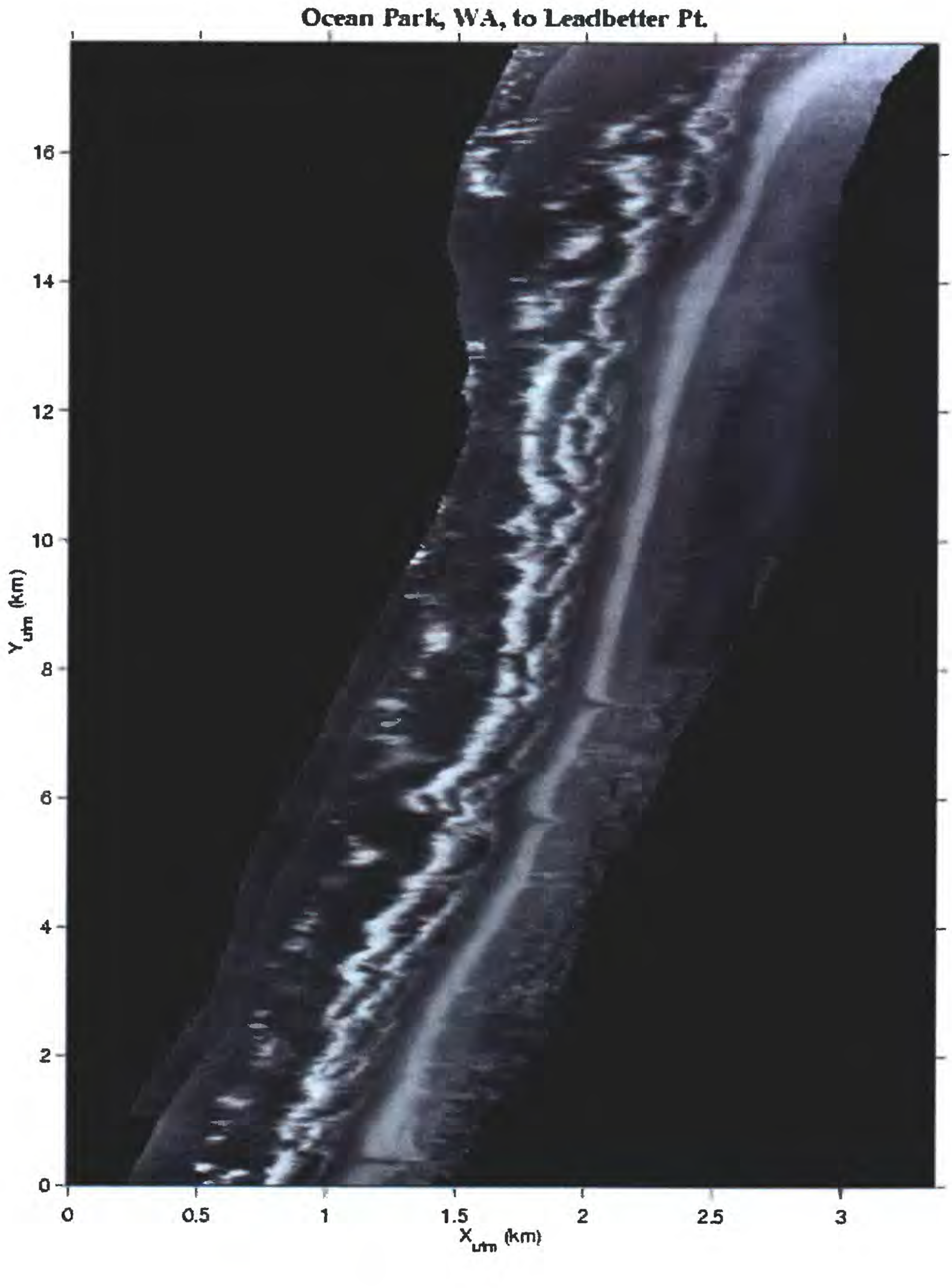


Figure 2. Flight track (red line) of the aerial mission flown on 2 June 1998 which spanned the NW Oregon/SW Washington coast (blue lines) from about Newport, OR, to Moclips, WA. One stop was required (in Astoria), and the round-trip flight took approximately 5 hours to complete the survey.

Figure 3. Time-exposed images of the coast from the aerial over-flight conducted on 2 June 1998 along the SW Washington coastline. (a) 40 kilometers of coast from Grays Harbor to (nearly) Moclips. (b) 21 kilometers of coast from Cape Shoalwater to Grays Harbor inlet. (c) 21 kilometers of coast from Ocean Park, WA, to Leadbetter Pt. The horizontal and vertical axes are in kilometers in UTM coordinates. The time-exposures were made over 35 second duration, with image resolution of about 3 m (following pages).


Grays Harbor to (nearly) Queets
0
5
10
15
20
25
30
35
Y_utm (km)
0
0.5
1
1.5
2
2.5
3
3.5
4
X_utm (km)


Cape Shoalwater to Grays Harbor Inlet
Y_{utm} (km)
X_{utm} (km)
0
2
4
6
8
10
12
14
16
18
20
0
0.5
1
1.5
2
2.5
3
3.5
4


Ocean Park, WA, to Leadbetter Pt.
0
2
4
6
8
10
12
14
16
Y_utm (km)
0
0.5
1
1.5
2
2.5
3
X_utm (km)

Use of Light Detection and Ranging Data for Volume and Elevation Change Calculation at Connor Creek, Washington

Richard C. Daniels, Peter Ruggiero
WA Department of Ecology

Light Detection and Ranging (LIDAR) is a radar-like methodology that uses an active remote sensing system. The system uses light pulses to illuminate the terrain. Distance is measured based on the elapsed travel time for the light reflected from the surface. This technology provides a rapid, highly accurate method for the generation of both digital elevation models (DEM) and the calculation of water depths in small to medium sized project areas. The Department of Ecology, in cooperation with U.S. Geological Survey, sought the assistance of the Coastal Services Center (CSC), NOAA to obtain LIDAR coverage for the Southwest Washington Coastal Erosion Study area. The data will be used build a digital data set of beach and dune field topography for the study area.

LIDAR data was obtained for the study area in October 1997 and April 1998 as part of the Airborne LIDAR Assessment of Coastal Erosion (ALACE) Project -a collaboration with the CSC, NASA Wallops Flight Facility (WFF), the U.S. Geological Survey (USGS), and the NOAA Aircraft Operations Center (AOC). The LIDAR system (the Airborne Topographic Mapper) collected 3,000 to 5,000 spot elevations per second as the aircraft traveled over the study area at approximately 60 m/s (135 mph). Using the ATM and global positioning system (GPS) satellite receivers, beach elevations were surveyed to a vertical accuracy of 10 to 15 cm.

A 5.22 km^2 subset of this data has been obtained for the Connor Creek area of the study area for analysis prior to receipt of the entire data set. The 1997 data covers one 500 m swath and comprised about 1 million data points. The 1998 data covers two swaths and contains about 2 million data points. This data has been imported into a geographic information system (GIS) and converted into triangular irregular networks (TIN) with a weed spacing of one meter. With this spacing the total number of points was reduced by about 50%. The TIN structures are used to calculate the total sediment volume change between the two data years, calculate contours, and to generate raster data sets. The raster data sets are being compared to rasterized RTK GPS data obtained by the Department of Ecology's Coastal All-Terrain Morphology Monitoring and Erosion Research Vehicle (CLAMMER-V). Once the accuracy of the LIDAR data has been verified based on comparison with the CLAMMER data a suitable raster cell sized will be determined and the data appended to the DEM currently used by the study in the orthophoto generation process. The data will be used for several other applications, including a quantitative analysis of the effects of the 1997/1998 El Niño within the region.

Communicating Study Results through Education and Product Development

Brian Voigt, WA Department of Ecology

Erosion along the southwest coast of Washington State is a major management issue for state and local agencies. Recent reversals in shoreline change trends at several locations along the coast are resulting in erosion crises threatening a range of local and statewide interests. A coastal management response to erosion in this region has not been well defined and has been based on general policies with little substantive basis. In response to escalating costs of coastal crises and the long-term potential for lost property and infrastructure, coastal communities, the Washington Department of Ecology (Ecology) and the U.S. Geological Survey, Coastal and Marine Geology Program (USGS) sought funding to study the regional coastal sedimentary system (Kaminsky, *et al.*, 1999). Ecology established the Coastal Monitoring & Analysis Program (CMAP) to conduct the Southwest Washington Coastal Erosion Study (Study), initiate beach morphology monitoring in the Columbia River littoral cell (CRLC) and provide technical assistance to coastal communities. A Coastal Information Clearinghouse has been developed as the repository for research and monitoring data and to facilitate the transfer of information and integration of research results with the coastal management and decision-making processes.

The communities along the southwest Washington coast feature some of the fastest growth rates in the Pacific and Grays Harbor Counties, yet none has a year-round population in excess of 5,000. In the past, most communities relied heavily on the lumber and fishing industries for income. The recent decline in productivity and increased legislation governing these industries has led to an upsurge in tourism and tourism related development. Recent coastal community growth patterns mark the onset of the transition from fishing villages to tourist destinations, complete with hotels, condominiums and the commercial capacity to support a rapidly increasing part-time population. The combination of a dynamic coastal region and increased development pressure present unique challenges for planners to develop economically feasible and environmentally sensitive long-term plans that protect existing economic investment while preserving the pristine coastal environment that initially drew residents and tourists to the coast.

Over the past year a strong emphasis has been placed on communicating Study results with the general public and developing educational material to help facilitate an understanding of the dynamic coastal environment. Study information sheets have been distributed at more than 35 locations throughout Washington and Oregon, including state parks, tourism and travel information centers, and Chambers of Commerce. The educational component has in large part been accomplished through the installation of displays at the Ocean Shores Interpretive Center and the Pacific County Historical Society. Coordination with the Willapa Alliance on a variety of projects, including the Student Institute, Willapa Science Fair, and a proposed GIS Information Clearinghouse has led to additional contacts and opportunities for increased communication.

THE COASTAL INFORMATION CLEARINGHOUSE

Ecology also serves as the liaison between the coastal communities and the USGS and has an integral role in translating Study results and beach monitoring data into coastal management tools to facilitate crisis management and long-term planning. A Coastal Information Clearinghouse collects information and results generated through CMAP activities. The Clearinghouse has several milestones, including:

- Identify coastal hazards and appropriate management response measures,
- Identify barriers to science and management integration, and develop support products to help overcome these barriers,
- Develop a coastal database and information management system to present coastal change at appropriate time/space scales for integration with coastal planning and management,
- Develop a GIS database and facilitate a collaborative GIS access plan to enhance geographically-based management,
- Develop and maintain a project Internet site to highlight ongoing research efforts and assist in the transfer of data products, and
- Facilitate community participation and educational outreach to ensure research efforts and deliverables have local value and provide necessary technical information for decision-making.

These milestones will serve as the foundation and framework for building improved coastal management capacity at the state and local level. The information, products and systems developed in this project will be an important component of coastal zone management along the southwest Washington coast into the future.

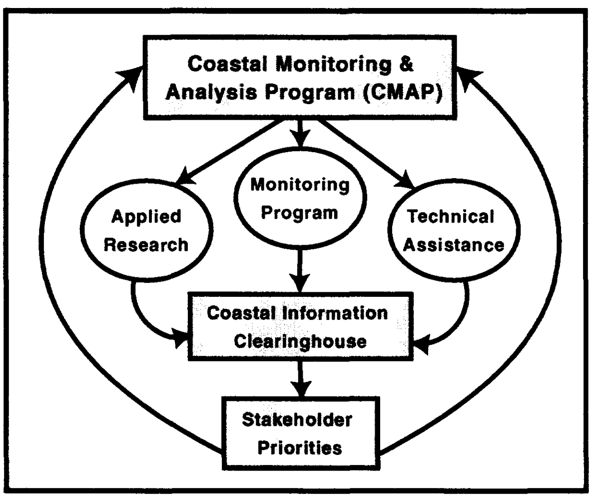


Figure 1. Coastal Monitoring & Analysis Program information-flow schematic. Data and results from Study efforts feed directly into the Clearinghouse to be developed into management and educational products.

Information and products contained in the Clearinghouse are distributed to a number of stakeholder groups, including local planners, state resource managers, environmental organizations, developers and interested public citizens. A list of contacts has been established through public meetings, personal communication and mail-in registration forms which can be found at a variety of locations along the coast, including state parks, city offices, libraries, hotels and restaurants. Although many of the publications that result from the research are scientific in nature, the primary purpose of other products such as maps, the Study web site, brochures and progress reports is to communicate research results to lay audiences.

PRODUCT DEVELOPMENT AND EDUCATIONAL OUTREACH

The Clearinghouse draws from a multi-disciplinary data set that includes physical beach parameters, wave and water level data, subsurface stratigraphic profiles, shoreline change rates, topographic and bathymetric surveys, sediment budget estimates, a GIS database of more than 150 coverages, and a library of more than 2000 references. Individual products are diverse in nature with product types ranging from publications or posters to GIS data or ArcView projects. One of the first accomplishments of the Study was the development of a geodetic control network. Recognized as a critical component of the coastal research for spatially referencing data, the geodetic control network has also been utilized by state and local agencies. The control network coordinates have been published on the Internet by the National Geodetic Survey and an Ecology publication describing the project, survey techniques, maps and monument locations is currently in review.

Efforts to overcome barriers to the integration of science and management focused on developing a common language for all user groups and defining the appropriate time scales of interest for both the research and management communities. The research activities attempt to bridge time and space scales ranging from days to millennia and meters to 100 km, respectively, and modeling efforts will develop scenarios of future coastal conditions that will feed into the planning horizon. *A Glossary of Coastal Terminology* (Ecology Publication # 98-105) was released as a tool to help support the communication between the science and end-user communities. This publication is intended to serve as a companion reference for Study reports and coastal literature.

The beach monitoring program has combined a variety of global positioning system (GPS) and remote sensing techniques to document short- to medium-term coastal variability throughout the CRLC at a scale relevant to coastal managers and planners (Ruggiero, *et al.*, 1999). Results of the beach monitoring program will be published in a forthcoming Ecology publication and will be available as a paper document or on the Internet at the Study web site.

A majority of the products are developed as maps or publications, but alternative formats are also sought to capture the interest of a larger public audience, including the Internet, television, museums and interpretive centers. An Internet site has been developed to provide improved access to Study findings, data and information products (http://www.wa.gov/sea/swces/index.htm). Improvements to the web site are made as new Study information becomes available. As metadata is completed for the GIS data layers, geographic data and maps will also be available on-line. In autumn 1998, the Study released *At Ocean's Edge: Coastal Change in Southwest Washington* (Ecology Publication #98-116), a 20 minute video that presents the research activities of the Study. The video is currently being broadcast on 17 cable access television stations throughout Washington and is available from the Department of Ecology Publication's Office for a nominal fee. Copies of the video have also been distributed to coastal libraries, city, county and state government agencies, schools and museums. More than 500 copies have been distributed to date.

Finally, Study displays at the Ocean Shores Interpretive Center and the Pacific County Historical Society Museum attracted several thousand visitors over the past year. Last year more than 3,000 people visited these displays which offer current Study information in the form of maps, posters, brochures and reports, and are an invaluable way to solicit public input and enhance outreach and communication to interested parties. A number of requests have been filled as a result of the installations and the list of contacts has grown to include more than 650 interested parties. Currently, the displays are being updated with new maps and graphics in preparation for the summer tourism season, and arrangements with a third location are underway.

SUMMARY

Research and data collection for CMAP is being synthesized in a Coastal Information Clearinghouse for distribution and integration with state and local coastal zone management efforts. The development of future change scenarios will facilitate improved coastal management options to accommodate shoreline change by encouraging appropriate land use commensurate with acceptable public risk and environmental stewardship ideals. These scenarios can be utilized to develop long-term coastal management strategies that are economically feasible, represent statewide interests and are based on the best available science.

REFERENCES

Kaminsky, G.M. and Gelfenbaum, G., 1999. The Southwest Washington Coastal Erosion Study: Research Supporting Coastal Management. *Proceedings of Coastal Zone '99*, July 1999, San Diego, California.

Ruggiero, P., Cote, J., Kaminsky, G.M., Gelefenbaum, G., 1999. Scales of Variability Along the Columbia River Littoral Cell, *Proceedings of Coastal Sediments '99*, June 1999, Long Island, New York

DISCUSSION GROUP SUMMARIES

INTRODUCTION

Near the end of the workshop, the participants were divided into four small groups, with the aim of encouraging input from every group member and facilitating discussion across sub-disciplines. Each break-out group consisted of 6-9 people. Study participants were separated randomly into the four groups. Each group was responsible for taking notes and presenting them at the completion of the workshop.

Each group discussed scientific issues or questions that need to be addressed as a priority to achieve the study goals and objectives. The issues raised included data collection, analysis, synthesis, modeling efforts, and other research tasks. Special attention was given to research work that determines scales of change (magnitude, variability, geometry, direction) of the system, which will help define possible change scenarios and improve the development of our predictive capability.

The charge for each group was to prepare a written summary that:

1) Provides a comprehensive list of unresolved issues and tasks,

2) Prioritizes the top 2-3 items, and explains why they are priorities,

3) Describes a research strategy to address the top issues and tasks,

4) Provides suggestions for future tasks, and

5) Identifies questions that may require additional research beyond the scope of this study.

BREAK-OUT GROUP REPORTS

Each group approached their charge slightly differently. Moreover, not all groups covered each of the items above. The content of each of the group reports remains essentially as they were submitted at the conclusion of the workshop. They have been edited primarily for consistency in formatting, and for clarity.

Group 1:

Jessica Cote, Scott Fenical, Guy Gelfenbaum, Diana McCandless, Rod Moritz, David Simpson, Marcel Stive, Sandy Vanderburgh, Huib deVriend.

The charge for the group is to discuss what tasks are still needed to be completed to be able to satisfy the objectives of the study. In order to discuss this, the group first listed some general ideas and questions to help us focus in on our task.

- Is the type of data collection and interpretation that we are doing going to get to where we want to go?
- What are the things we need to do? We want to convey to the coastal managers and public the spatial and temporal scales of shoreline change
- Who is the customer? The public
- We need to INTEGRATE - Are we spread too thin to develop a cohesive concept?
- Concentrate on different products at different stages, for example: public workshop, group different disciplines together more to enable the layman to keep track of what we are talking about.
- Don't be afraid, just use a wide pencil, meaning form working hypotheses.
- What is our end product? Shoreline prediction, sediment budgets, pre-historic documentation/investigation

Tasks requiring further work:

- Need the framework of analysis, need to integrate the ideas
- Inlets and bays need more attention; Columbia River, Willapa Bay, Grays Harbor
- Processes work; currents, waves
- Sediment budget; changes in sediment discharge over time. Date accumulation in barriers over time as a record of source. Is the system just redistributing the sediment
- Depth of closure, active zone, sediment mobility, sediment fluxes
- Longshore sediment fluxes - from shoreline positions, instrument, calculated from wave forcing?
- Problems at hot spots
- Modern bathymetry, bays, everywhere
- Decadal variability; can it be estimated.
- Eolian transport, flux of sediment to the dunes
- Mapping tidal basin prism for the bays
- Relative sea-level change, subsidence, tilting, radioactive sediment tracer study?
- Variations in shoreline position
- Sediment volumes, budgets.

Group 2:

Hugo Burmudez, Peter Cowell, John Haines, Bob Huxford, Harry Jol, George Kaminsky, Peter Ruggiero

Unresolved issues:

- Potential Sinks: Columbia River, Willapa? Source or neutral; CR? sink or source?
- Shoreface-zones of different behaviour.
    - Sediment budget
    - Profile dynamics
- Dunes- budget & processes

- Data analysis and distribution of results
- Data integration with quality control. Collaborative work sessions 1-1 and small group
- Feedback to data collection efforts
- Data set availability, distribution among team, METADATA!
- Set of questions should drive priorities/tasks. Follow through with development of hypothesis and conceptual models.
- Local new bathymetry for engineering projects
  - inside bays
  - nearshore
- Accommodation space in bays
  - Coring versus bathymetry
  - Identify ravinement surfaces-depositional sequences
- Dating
  - Map out geologic timelines for entire cell
  - Dispersal system (prehistoric)
- High resolution GPR
- Climatology
- Collaborative work sessions throughout, small group sessions
- Processes measurements for model calibration
  - Waves, currents
  - After development of hypotheses for modelling
- Grain size, color, texture offshore and nearshore, dunes and barriers, i.e. sediment descriptions
- Offshore vibracores; direct tasks based on seismic work
- Estuary evolution modelling
- Synthesis/coherence
  - Working system hypothesis ("Our best guess")
  - Evaluate scenarios, reconcile differences
- Long-term monitoring
- What's essential? Best return?
- Recent trends of erosion and present day observations. Are they important, significant in the long-term sense?
- How do historical changes influence today (future)?

Of the above tasks, ideas, and questions, the highest priorities are:

1) Develop a set of questions that focus the collection, the interpretation, and the synthesis of data.
2) Get the most synthesis, value, and utility, out of the existing data.
3) Get a better understanding, both qualitatively and quantitatively, of the sediment sinks, sources, and accommodation spaces within the littoral cell.

Additional research beyond scope of study:

- Long-term wave climatology

- Earthquakes – rebound

Group 3:
VeeAnn Cross, Rich Daniels, Peter Howd, Larry Phillips, Jim Phipps, Dave Twichell

Overview comment:

Finish the geologic work that's been started – complete interpretations and write it up. Time is needed to mine what we have and understand what we have already collected. Money should be set aside for smaller groups (for example geologists, modelers, or GIS specialists) to get together and start getting products out.

1. Process studies

- Is it broken? Is the erosion we are seeing in parts of the study area, for example, part of the way the system naturally works?
- Process studies could become huge and expensive, but we are not sure we are at the point where we would get the maximum benefit out of them.
- Is cross-shelf transport important? Are other processes besides waves important (eg, tides)? What are the time scales that need to be addressed?
- Scales of processes and changes we're seeing – are annual frequency things being incorporated into or need to be incorporated into models.

2. Geology studies

- Sediment budget – what are sources and sinks – long shore versus cross shore. Understanding sediment budget is important for both geologic and modeling purposes.
- Need an understanding of dates and sedimentation rates in different areas – estuaries, barriers, shelf and reservoirs behind dams.
- What time scale to do this sediment budget. Need to look at a variety of time scales.
- Century time-scale should include climatology and find where the sediment goes during the subsidence events.
- Which way is the sand on the shelf going – Pb210 dates on box core samples
- Climatology – look at historic tide gauge information, waves, precipitation, tree ring information
- Importance of tidal inlets – Much of this project has not focused on the tidal inlets – do we need to look at this and how should that be done?
- Cores provide temporal but not necessarily spatial data for some areas – look at historical geologic variation
- Sedimentation rate – both on the shelf, in the inlets, and in the bays.
- Need better carbon 14 dates on linear dunes onshore.
- Constrain the date on the ravinement surface
- Need strong constraint on dating to determine sedimentation rate which ties in to the sediment budget.

- Reservoirs haven't really been looked at as far as their influence and amounts in sources and sinks. Reservoir study would be very useful in trying to quantify the recent decrease of sediment input from this source to the system.
- Where did the Mt. St. Helen's sediment go? Could it be used as a tracer of sediment dispersal?
- Better understanding of the role the ebb-tidal deltas play in supplying or preventing sand to the estuaries.
- Look at different scales of variability – sort of a signal to noise study – therefore what variability can the models see and what do we expect them to see
- Importance of lower shoreface – if it is of significance to what's happening onshore, much more work will need to be done to collect current data – use sediment budget data to determine if this is an important factor
- Need physical properties work to quantify and determine what is causing the reflectors seen in the GPR.

3. GIS

- Communicate and distribute the data – amongst ourselves and to the public
- Data exchange, archival and management, metadata.
- How do we proceed because of being spread all over the place – need time and money for the smaller groups that work together to get together and exchange ideas and information. Need to set aside money for subgroups to get together.
- Aid in sharing and communication
- Data management meeting is needed. It is recognized that there is some danger in subgroup meetings (specifically the danger of the subgroups getting isolated from each other). Individuals getting together is not intended to replace a workshop like the one we just had.

Group 4:

Eric Braun, Steve Eykelhoff, Josh Fisher, April Herb, Jose Jimenez, Emily Lindstrum, Curt Peterson, Frank Reckendorf

The following list is non-prioritized:

- Upper shoreface budget; tidal basins, Columbia River estuary, prehistoric river sediment supply
- Eolian dune sediment budget
- Modern Beach GPR in potential problem areas
- Scale of "hotspots" and regional conditions, linking regionally? or localized phenomena?
- Is time scale of interest decadal?
- Compile geologic history of area--for general public and education, teaching
- Objective background information
- Need setback lines (red zone, yellow zone, green zone)
- Tracer studies (localized)
- Use modelling to predict tracer study sites
- Predict appropriate borrow areas for beach nourishment
- (in bays, offshore and Columbia River sites)

- Columbia River estuary throughput rates and dam retention rates
- Modelling needs more ground-truthing
- 75% effort for background data collection, 25% modelling effort

SUMMARY OF BREAK-OUT GROUP DISCUSSIONS

People were divided randomly into the four break-out groups, and all four groups were given the same charge. The groups were asked to assess what work, or analysis needed to be undertaken to help satisfy the overall objectives of the Study. The lists that were developed were based, in large part, on the talks and discussions held over the previous few days.

Several themes emerged that were common to the different groups. In particular, the groups emphasized the need for integration and summation of data and analysis from the previous two years work. Recall, there was a paucity of reliable data and lack of a general understanding of how the Columbia River littoral cell functioned at the beginning of the study. The first two years of the Southwest Washington Coastal Erosion Study produced a substantial increase in our understanding of the littoral cell, and participants feel it is incumbent upon us to relay that information to others. Several participants reiterated that there were management decision being made that could benefit from the recent findings of the study. It was noted, also, that the need to integrate our results would benefit study participants as well as clients and users. Study scientists and engineers would benefit from the development of working hypotheses, or conceptual models of the littoral cell, as our understanding could then be tested with further work. Moreover, the models developed by one sub-group in the study could be useful to another group. Because the project is taking a systems approach to studying the littoral cell, many of the tasks of the project are interrelated. For example, the offshore framework studies should be integrated with the onshore framework studies. While this seems obvious, it is noted that because the two groups use different tools that "see" differently into the geologic record, the integration and synthesis will require the two groups working closely together over a period of time. This need for synergy can be found within several aspects of the study. A strong recommendation from several of the groups was that resources be made available for sub-groups to get together to discuss and integrate their data and results.

Another recommendation that was repeated in several of the break-out groups was the need to better understand the filling of the sinks of Columbia River sediment. Major sinks include the continental shelf, deep-sea channel, canyon, fans, and slope, the beaches and barriers, and the three major estuaries, Grays Harbor, Willapa Bay, and the Columbia River estuary. Enough data have been collected to begin to estimate the volumes of fill in each of the sink areas, as well as the fill rates. Several of the groups specifically focused on the question of the filling of the estuaries. In particular, there were questions about how the fill rates of the estuaries may be changing over time. Given the significant changes in sea level over the last 10,000 years, as well as the human-induced changes in inlet morphology as a result of the jetties at Grays Harbor and the Columbia River, the fill rates have likely changed as well. Moreover, whether or not the estuaries are presently filling with Columbia River sediment could be important to predictions of shoreline change.

Related to the filling of the estuaries is the question of the possible filling of the reservoirs behind the dams in the Columbia River watershed. Over 200 dams have been built in the watershed and flow regulation has resulted in a record of decreasing peak river discharges. Since the peak flows are responsible for the majority of the sediment transport down the river, there is speculation that the dams are responsible for a decreased sediment discharge to the estuary. In addition, some of the dams may be trapping sediment. Two of the four break-out groups recommended assessing whether or not dams in the Columbia River watershed were trapping sediment.

Also mentioned in the break-out groups was the need to conduct more processes and modeling studies. The Coastal Erosion Study emphasized geologic studies in the first two years of effort, and those tasks were coming to completion. Following the strategic plan set forth in the Tasks and Timelines, the Study would transition into more processes studies and more studies modeling shoreline and morphological change. The groups cautioned, however, not to conduct processes studies without specific questions in mind that could be answered by those studies. Processes studies can be very expensive and could easily use a large percentage of study funds. There also was an acknowledgement that it probably would not be feasible to conduct bottom-up integration of instantaneous sediment fluxes to obtain long-term shoreline or morphological change predictions with any real degree of certainty. Thus, experiments that tested or calibrated model parameters would be the most useful types of processes studies.

Finally, there was discussed the need for more modern bathymetry. Except near the entrances to Grays Harbor and the Columbia River, which the Corps of Engineers surveys regularly, there is a lack of modern bathymetric data. The most recent regional bathymetric data were collected by NOS in 1926-1927. Since dramatic changes in the shoreline change rates during historic time have extended for 10s of kilometers away from the jetties and estuary inlets, then it is anticipated that the shoreface profile has also experienced significant changes. This hypothesis could be tested with modern bathymetric data collected regionally.

LIST OF ATTENDEES

Mr. Hugo Bermudez
Pacific International Engineering
144 Railroad Avenue
Edmonds, WA 98020 USA
tel (425) 744-7700
fax (425) 624-1388
e-mail hugob@piengr.com

Mr. Eric Braun
U.S. Army Corps of Engineers,
Portland District
P.O. Box 2946
Portland, OR 97208-2946 USA
tel (503) 808-4348
fax (503) 808-4875
e-mail eric.p.braun@usace.army.mil

Mr. Maarten C. Buijsman
Washington State Department of Ecology
Coastal Monitoring & Analysis Program
P.O. Box 47600
Olympia, WA 98504-7600 USA
tel (360) 407-7125
fax (360) 407-6535
e-mail mbui461@ecy.wa.gov

Ms. Jessica Cote
Oregon State University
835 NW 27th Street
Corvallis, OR 97330 USA
tel (541) 737-3251
e-mail cote@engr.orst.edu

Dr. Peter J. Cowell
Coastal Studies Unit
University of Sydney, NSW 2006
Australia
tel 61-2-9351-2189
fax 61-2-9351-3644
e-mail P.Cowell@csu.usyd.edu.au

Ms. VeeAnn Cross
U.S. Geological Survey
384 Quissett Campus Woods Hole Rd.
Woods Hole, MA 02543-1598 USA
tel (508) 457-2251
fax (508) 457-2310
e-mail vatnipp@usgs.gov

Mr. Richard Daniels
Washington State Department of Ecology
Coastal Monitoring & Analysis Program
P.O. Box 47600
Olympia, WA 98504-7600 USA
tel (360) 407-6427
fax (360) 407-7162
e-mail rdan461@ecy.wa.gov

Ms. Gita Dunhill
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025 USA
tel (650) 329-5261
fax (650) 329-5197
e-mail gita@octopus.wr.usgs.gov

Mr. Steve J. Eykelhoff
Washington State Department of Ecology
Coastal Monitoring & Analysis Program
P.O. Box 47600
Olympia, WA 98504-7600 USA
tel (360) 407-6436
fax (360) 407-6535
e-mail seyk461@ecy.wa.gov

Mr. Scott Fenical
Pacific International Engineering
144 Railroad Avenue
Edmonds, WA 98020 USA
tel (425) 744-7700
fax (425) 624-1388
e-mail scottf@piengr.com

Dr. Guy R. Gelfenbaum
U.S. Geological Survey
345 Middlefield Road MS 999
Menlo Park, CA 94025 USA
tel (650) 329-5483
fax (650) 329-5190
e-mail gelf@octopus.wr.usgs.gov

Ms. Ann E. Gibbs
U.S. Geological Survey
345 Middlefield Road MS 999
Menlo Park, CA 94025 USA
tel (650) 329-5060
fax (650) 329-5197
e-mail agibbs@octopus.wr.usgs.gov

Dr. John W. Haines
U.S. Geological Survey
600 4th Street South
St. Petersburg, FL 33701 USA
tel (813) 893-3100 ext. 3022
fax (803) 893-3333
e-mail jhaines@wayback.er.usgs.gov

Ms. April Herb
Portland State University
P.O. Box 751
Portland, OR 97207-0751 USA
e-mail aherb@hotmail.com
tel (503)725-3375
fax (503)725-3025

Dr. Peter Howd
Department of Marine Science
University of South Florida
140 7th Avenue South
St. Petersburg, FL 33701-5016
tel (727) 553-1158
fax (727) 553-1189
e-mail phowd@marine.usf.edu

Mr. Robert H. Huxford
Washington State Department of Ecology
Coastal Monitoring & Analysis Program
P.O. Box 47600
Olympia, WA 98504-7600 USA
tel (360) 407-6780
fax (360) 407-6535
e-mail bhux461@ecy.wa.gov

Dr. José A. Jiménez
Laboratori d'Enginyeria Maritima,
Universitat Politecnica
c/ Jordi Girona 1-3, Campus Nord Ed. D1
Barcelona, Spain 08034

tel +34 93 401 64 68
fax +34 93 401 73 57
e-mail jimenez@etseccpb.upc.es

Dr. Harry Jol
University of Wisconsin--Eau Claire
Department of Geography
Eau Claire, WI 54702-4004 USA

tel (715) 836-3472
fax (715) 836-6027
e-mail olhm@uwec.edu

Mr. George M. Kaminsky
Washington State Department of Ecology
Coastal Monitoring & Analysis Program
P.O. Box 47600
Olympia, WA 98504-7600 USA

tel (360) 407-6797
fax (360) 407-6535
e-mail gkam461@ecy.wa.gov

Ms. Emily Lindstrum
Washington State Department of Ecology
Coastal Monitoring & Analysis Program
P.O. Box 47600
Olympia, WA 98504-7600 USA

tel (360) 407-7218
fax (360) 407-6535
e-mail emli461@ecy.wa.gov

Mr. Jamie MacMahan
University of Florida
336 Weil Hall
Gainsville, FL 32608 USA

tel (352) 392-1480
e-mail macmahan@coastal.ufl.edu

Ms. Diana C. McCandless
Washington State Department of Ecology
Coastal Monitoring & Analysis Program
P.O. Box 47600
Olympia, WA 98504-7600 USA

tel (360) 407-6104
fax (360) 407-6535
e-mail dimc461@ecy.wa.gov

Mr. Josh McInnis
Washington State Department of Ecology
Coastal Monitoring & Analysis Program
P.O. Box 47600
Olympia, WA 98504-7600 USA

tel (360) 407-6436
fax (360) 407-6535
e-mail jofi@ecy.wa.gov

Mr. Rod Moritz
U.S. Army Corps of Engineers,
Portland District
P.O. Box 2946
Portland, OR 97208-2946 USA

tel (503) 808-4892
fax (503) 808-4875
e-mail hans.r.moritz@usace.army.mil

Mr. Eric E. Nelson
U.S. Army Corps of Engineers,
Seattle District
P.O. Box 3755
Seattle, WA 98124-3755 USA
tel (206) 764-3557
fax (206) 764-6795
e-mail eric.e.nelson@nps.usace.army.mil

Mr. Hans Nelson
U.S. Geological Survey
345 Middlefield Road MS 999
Menlo Park, CA 94025 USA
tel (650) 329-5286
fax (650) 329-5299
e-mail hans@octopus.wr.usgs.gov

Dr. Joan Oltman-Shay
Northwest Research Associates, Inc.
300 120th Ave. NE
Bellevue, WA g 98005-3020 USA
tel (206) 453-8141
fax (206) 646-9123
e-mail 'oan@aurora.nwra.com

Mr. Dave Percy
Portland State University
P.O. Box 751
Portland, OR 97202-0751 USA

Dr. Curt D. Peterson
Portland State University
P.O. Box 751
Portland, OR 97202-0751 USA
tel (503) 725-3375
fax (503) 725-3025
e-mail curt@ch1.ch.pdx.edu

Dr. Larry Phillips
U.S. Geological Survey
345 Middlefield Rd. MS 999
Menlo Park, CA 94025 USA
tel (650) 329-5738
fax (650) 329-5197
e-mail larryp@octopus.wr.usgs.gov

Dr. Jim B. Phipps
Grays Harbor College
1620 Edward P. Smith Drive
Aberdeen, WA 98520-7599 USA
tel (360) 538-4200
fax (360) 538-4299
e-mail jphipps@ghc.ctc.edu

Mr. Dave Qualman
Portland State University
P.O. Box 751
Portland, OR 97202-0751 USA

Dr. Frank Reckendorf
Reckendorf & Associates
950 Market Street NE
Salem, OR 97301 USA
tel (503) 364-6681
fax (503) 399-9421
e-mail frecken@open.org

Dr. Peter Ruggiero
Washington State Department of Ecology
Coastal Monitoring & Analysis Program
P.O. Box 47600
Olympia, WA 98504-7600 USA
tel (360) 407-6230
fax (360) 407-6535
e-mail prug461@ecy.wa.gov

Ms. Renee Shadel
Washington State Department of Ecology
Coastal Monitoring & Analysis Program
P.O. Box 47600
Olympia, WA 98504-7600 USA
tel (360) 407-7162
fax (360) 407-6535
e-mail rsha461@ecy.wa.gov

Dr. Vladimir Shepsis
Pacific International Engineering
144 Railroad Avenue
Edmonds, WA 98020 USA
tel (425) 921-1703
fax (425) 744-1400
e-mail vladimir@piengr.com

Mr. David Simpson
Pacific International Engineering
144 Railroad Avenue
Edmonds, WA 98020 USA
tel (425) 744-7700
fax (425) 624-1388
e-mail dsimpson@piengr.com

Dr. Marcel J.F. Stive
WL/Delft Hydraulics
Rotterdamseweg 185
Delft
The Netherlands
tel +31 15 2858585
fax +31 15 2858582
e-mail marcel.stive@wldelft.nl

Dr. Nels Sultan
Pacific International Engineering
144 Railroad Avenue
Edmonds, WA 98020 USA
tel (425) 744-7700
fax (425) 624-1388
e-mailnsultan@piengr.com

Dr. Dave C. Twichell
U.S. Geological Survey
384 Quissett Campus Woods Hole Rd.
Woods Hole, MA 02543-1598 USA
tel (508) 457-2266
fax (508) 457-2310
e-mail dtwichell@usgs.gov

Dr. Sandy Vanderburgh
University College of the Frasier Valley
Department of Geography
33844 King Road
Abbotsford, Brittish Columbia, CAN
tel (604) 853-7441
fax (604) 855-7558
e-mail vanderburghs@smtpgw.ucfv.bc.ca

Mr. Brian Voigt
Washington State Department of Ecology
Coastal Monitoring & Analysis Program
P.O. Box 47600
Olympia, WA 98504-7600 USA
tel (360) 407-6568
fax (306) 407-6535
e-mail bvoi461@ecy.wa.gov

Dr. Huib J. de Vriend
University of Twente
P.O. Box 217
The Netherlands
tel (31) 53-489-4320
fax (31) 53-489-4040
e-mail h.jdevriend@sms.utwente.nl

Mr. Steve M. Wessells
U.S. Geological Survey/CVO
5400 MacArthur Blvd.
Vancouver, WA 98661 USA
tel (360) 696-7941
fax (360) 696-7866
e-mail smwess@mailvan.wr.usgs.gov

GROUP PHOTOGRAPH

(From left to right):

Front Row: J. McInnis, A. Gibbs, L. Phillips, D. Simpson, M. Buijsman, H. Jol, S. Vanderburgh, V. Cross, A. Herb, F. Reckendorf.

Second Row: B. Voigt, G. Gelfenbaum, P. Ruggiero, S. Eykelhoff, J. Oltman-Shay, J. Haines, J. MacMahan, C. Peterson.

Third Row: G. Kaminsky, R. Shadel, J. Jimenez, H. de Vriend, D. Percy, R. Daniels, R. Huxford, J. Phipps, J. Cote.

Back Row: M. Stive, D. McCandless, N. Sultan, E. Braun, E. Nelson, D. Qualman, P. Howd, D. Twichell, R. Moritz, P. Cowell.