Prepared in Cooperation with the Washington State Department of Ecology

Beach Morphology Monitoring in the Columbia River Littoral Cell: 1997–2005

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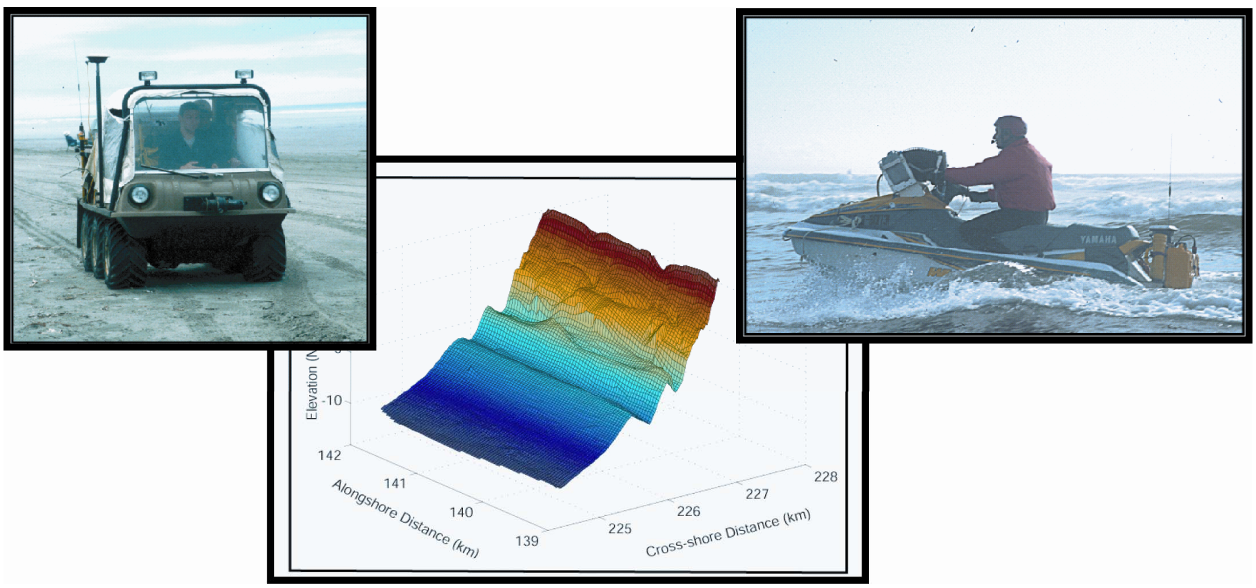

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SUMMARY

This report describes methods used, data collected, and results of the Beach Morphology Monitoring Program in the Columbia River Littoral Cell (CRLC) from 1997 to 2005. A collaborative group primarily consisting of the US Geological Survey and the Washington State Department of Ecology performed this work. Beach Monitoring efforts consisted of collecting topographic and bathymetric horizontal and vertical position data using a Real Time Kinematic Differential Global Positioning System (RTK-DGPS). Sediment size distribution data was also collected as part of this effort. The monitoring program was designed to: 1) quantify the short- to medium-term (seasonal to interannual) beach change rates and morphological variability along the CRLC and assess the processes responsible for these changes; 2) collect beach state data (*i.e.*, grain size, beach slope, and dune/sandbar height/position) to enhance the conceptual understanding of CRLC functioning and refine predictions of future coastal change and hazards; 3) compare and contrast the scales of environmental forcing and beach morphodynamics in the CRLC to other coastlines of the world; and 4) provide beach change data in a useful format to land use managers.

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1. INTRODUCTION

1.1 Southwest Washington Coastal Erosion Study

The Southwest Washington Coastal Erosion Study (SWCES) is a multidisciplinary investigation of the Columbia River Littoral Cell (CRLC, Figure 1). The study, initiated in 1996, is co-sponsored by the US Geological Survey and the Washington State Department of Ecology. The primary goals of the study are to improve scientific understanding of coastal morphodynamics and sedimentary processes, to determine natural and anthropogenic influences on the littoral system, and to provide information and predictions of coastal behavior at temporal and spatial scales of decades and tens of kilometers, respectively (Kaminsky et al., 1997; Gelfenbaum et al., 1997; Kaminsky et al., 1999; Ruggiero et al., 2005).

The Columbia River littoral cell extends approximately 165 km between Tillamook Head, OR and Point Grenville, WA and consists of four concave-shaped prograded barrier plain sub-cells separated by estuary entrances of the Columbia River, Willapa Bay, and Grays Harbor (Figure 1). Wide, gently sloping beaches characterize the region with sands having been derived from the Columbia River, the third largest river in the United States by discharge. Broad surf zones with multiple sandbars characterize the fully dissipative (Wright and Short, 1983), infragravity energy dominated nearshore zone of the CRLC. The beaches are backed predominantly by prograded dune fields and swales and by seacliffs along the northern half of the North Beach sub-cell (Figure 1). The prograded barrier beaches along this tectonically active coastal margin have experienced episodic erosion (Meyers et al., 1996) and sudden 1 to 2 m subsidence events associated with large earthquakes of approximately 500 year recurrence intervals (Atwater et al., 1995), the last such event occurring in 1700. Anthropogenic influences, including jetty construction in the late 1800s and early 1900s at the entrances to the Columbia River and Grays Harbor (Kaminsky et al., 1999; Gelfenbaum et al., 2001; Buijsman et al., 2003) and dam construction on the Columbia River during the 20th century (Gelfenbaum et al., 1999), resulted in significant impacts to the natural sedimentary dynamics of the CRLC coastal system.

1.2 Beach Morphology Monitoring Program

A beach morphology monitoring program was initiated in the CRLC during the summer of 1997 as one component of the SWCES (Ruggiero et al., 1998; Kaminsky et al., 1998; Ruggiero et al., 1999; Ruggiero and Voigt, 2000; Ruggiero et al., 2005). The field program is designed to document the short- to medium-term morphological variability of the high-energy dissipative beaches within the littoral cell over spatial scales ranging from meters to kilometers in the cross-shore and tens of meters to kilometers in the alongshore. Following the installation of a dense network of geodetic control monuments (Daniels et al., 1999), a nested sampling scheme consisting of cross-shore topographic beach profiles, 3-dimensional topographic beach surface maps, shoreline change reference feature surveys, sediment size distributions, nearshore bathymetry, and site specific special projects was initiated. Monitoring is being conducted using Real Time Kinematic Differential Global Position System (RTK DGPS) survey methods that combine both high accuracy and speed of measurement (Morton et al., 1993).

The primary objectives of the monitoring program are to:

1) Quantify the short- to medium-term (seasonal to interannual) beach change rates and morphological variability along the CRLC and assess the processes responsible for beach change at these and other scales;
2) Collect beach state data (*i.e*., grain size, beach slope, and dune/sandbar height/position) to enhance the conceptual understanding of CRLC functioning and refine predictions of future coastal change and hazards;
3) Compare and contrast the scales of environmental forcing and beach morphodynamics in the CRLC to other coastlines of the world;
4) Provide beach change data in an appropriate format to land use managers.

Components of the monitoring program include:

- data retrieval from wave and water level gages
- geodetic control

- topographic beach profiles and surface maps
- sediment size distributions
- shoreline reference feature mapping, and
- nearshore bathymetry

The data from the monitoring program are being integrated with other data sets, including those that document the long-term coastal evolution and geological framework of the CRLC, to develop conceptual and predictive models of coastal evolution at scales relevant to coastal planning and decision-making (Kaminsky et al., 1999; Kaminsky et al., 2001; Buijsman et al., 2001, Ruggiero et al., in press). This report describes the techniques used in the monitoring program, the data sets collected, and some initial results serving as an update to the beach monitoring report published by Ruggiero and Voigt in 2000. This report is only available in digital format and is accompanied by links to data files and associated metadata.

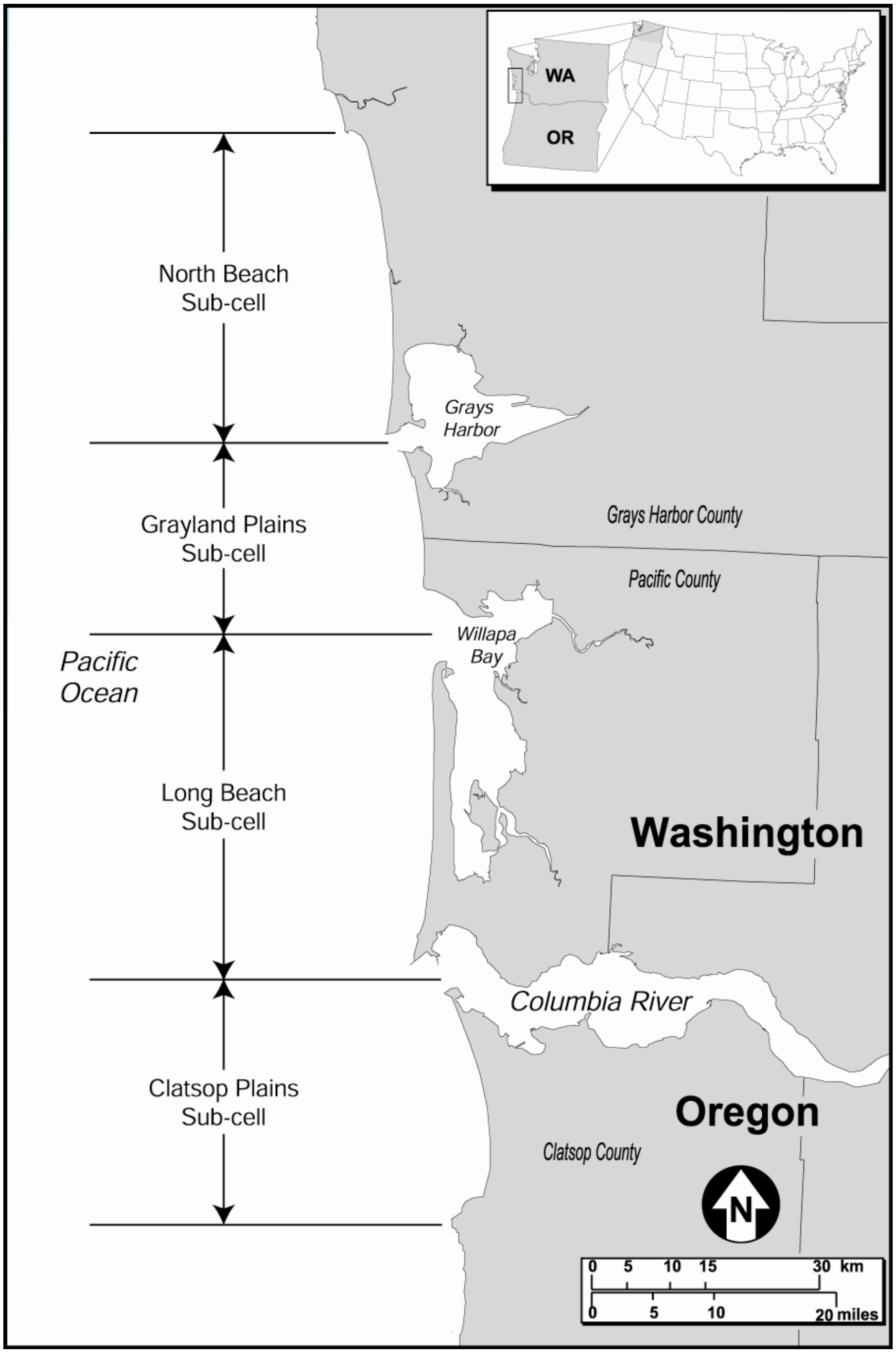

Figure 1. The Columbia River Littoral Cell stretches approximately 165 kilometers between Tillamook Head, Oregon and Point Grenville, Washington. The littoral cell is divided into four sub-cells, including the Clatsop Plains, Long Beach, Grayland Plains and North Beach. The sub-cells are separated by estuary entrances at the Columbia River, Willapa Bay and Grays Harbor and are bounded by rocky headlands at the northern and southern extents.

2. DATA COLLECTION AND PROCESSING METHODS

2.1 Waves and Water Levels

Maintaining a database of the environmental forcings responsible for beach change and variability is critical for modeling future shoreline positions and quantifying the probability of coastal flooding. Fortunately there are national networks of both wave and water level gages (Table 1) maintained by various federal agencies (*e.g.*, the Coastal Data Information Program (CDIP), the National Data Buoy Center (NDBC), and the National Ocean Service (NOS)) that make data available via the internet (http://cdip.ucsd.edu/; http://www.ndbc.noaa.gov/index.shtml; http://tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Tide%20Data&sort=A.STATION_ID&state=&id1=). At present, there are three wave buoys and two tide gages operating in the CRLC (Figure 2).

Table 1. Description of wave buoys and tide gages currently operating within the Columbia River Littoral Cell.

Type	Station Name	Location	Water Depth (m)	Period of Operation
Waves	NDBC-46029	Lat. 42°07’00’’N; Long. 124°30’00’’W	128	1984-present
Waves	CDIP-036	Lat. 46°51’24’’N; Long. 124°14’40’’W	~40	1981-present
Waves	NDBC-46041	Lat. 47°20’24’’N; Long. 124°45’00’’W	132	1987-present
Tides	NOAA-9439040	Astoria, Columbia River, OR	---	1925-present
Tides	NOAA-9440910	Toke Point, Willapa Bay, WA	---	1979-present

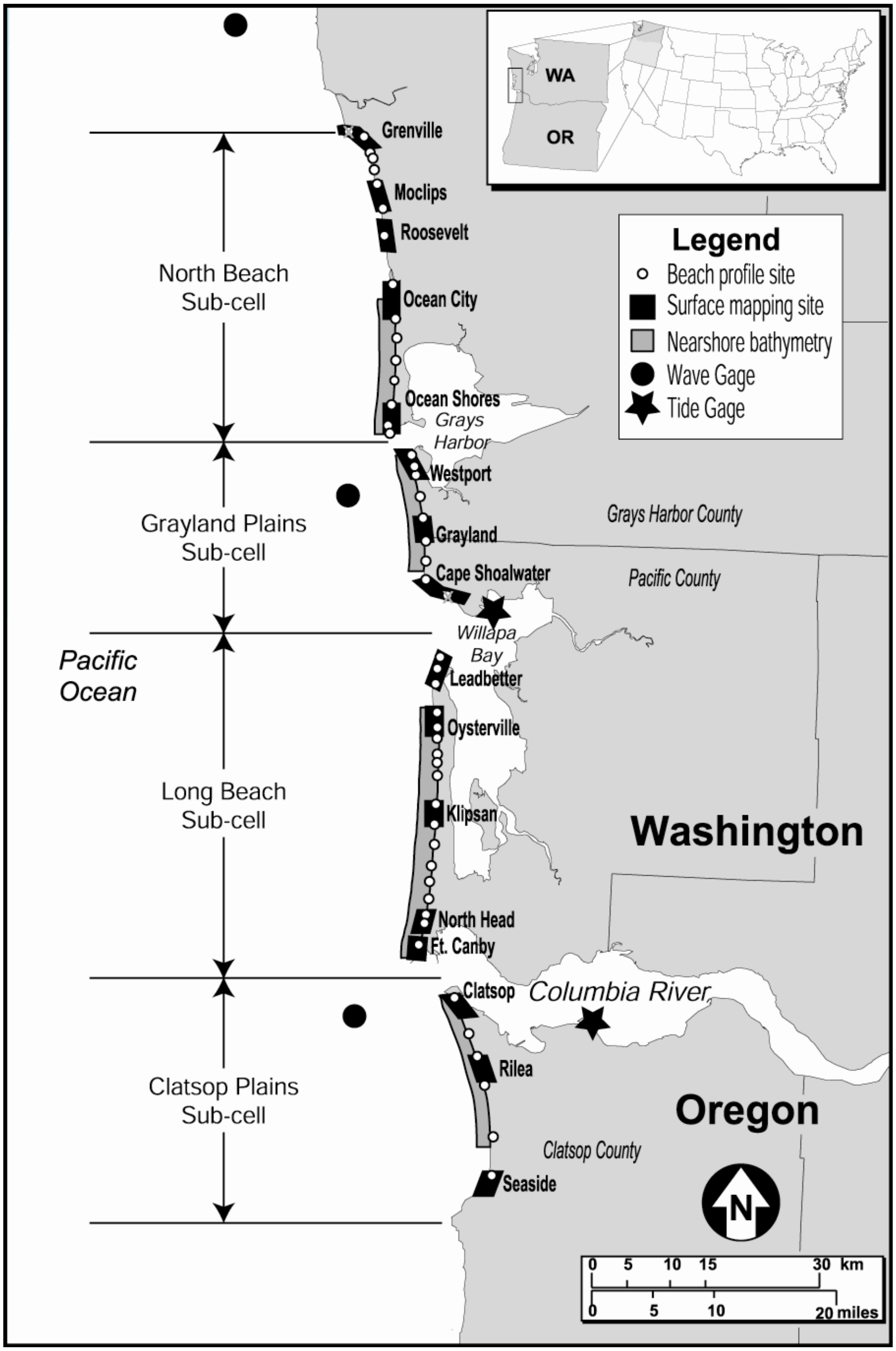

Figure 2. Beach profiles are monitored at 47 sites throughout the littoral cell. Three-dimensional surface maps are collected at 16 sites. Nearshore bathymetry is collected annually along more than half of the littoral cell, nominally at kilometer-spaced transects and in more detail at selected surface map sites. The locations of long-term tide and wave gages are also shown.

2.2 Geodetic Control

In order to reference all beach monitoring data to consistent horizontal and vertical datums, a network of 76 geodetic control monuments was established during the summer of 1997. Monuments are spaced approximately 3-4 km apart throughout the littoral cell. The network has been referenced to the Washington State Plane (South) North American Datum of 1983 (NAD 83) and the land-based North American Vertical Datum of 1988 (NAVD 88). The results of the 1997 survey were published in Daniels et al. (1999). Since that time additional monuments have been added as needed in a continuing effort to maintain the Washington Coastal Geodetic Control Network and to support the planning and land use activities of coastal communities.

2.3 Topographic Beach Profiles

Cross-shore topographic beach profiles are collected at 49 locations throughout the littoral cell (Figure 2) to quantify the regional variability of seasonal to inter-annual morphologic change. Profile locations (Table 2) are typically coincident with the location of a control network monument. Table 2 lists the beginning and ending coordinates of each of the beach profiles in the monitoring program. A description of and driving directions to the individual profile locations can be found in Appendix A.

Table 2. Name and location for each of the 49 beach profiles.

Profile	Name	Northing 1 (m)	Easting 1 (m)	Northing 2 (m)	Easting 2 (m)
1	E2	225794.36	214700.11	225734.16	214801.01
2	SOUTH	224784.28	216647.64	224952.33	216898.35
3	L443	222775.12	217379.61	222873.62	217739.28
4	B1	221821.27	217568.46	221946.13	217978.11
5	A1.5	220351.73	217949.63	220446.90	218272.15
6	PIER RM1	218426.05	218214.73	218500.53	218652.01
7	GKAM	214935.43	219043.27	214973.51	219436.26
8	BHUX	211223.23	219636.35	211270.35	219975.43
9	GP-14109	204544.51	220355.02	204515.41	220786.75
10	DIANA	199493.91	220670.82	199539.70	220967.07
11	DAMONS	193770.05	220647.67	193748.67	220993.84
12	ET	191097.81	220436.54	191031.88	220838.53
13	BUTTER	187681.80	220256.29	187628.41	220570.37
14	X1 NORTH	184272.54	220163.19	184243.89	220375.48
15	X1 SOUTH	183978.55	220157.48	183954.17	220363.43
16	HD-1	180591.97	223133.14	180644.63	223459.37

17	WORM	179022.99	223529.84	179076.78	223817.57
18	SPICE	177785.08	223798.72	177783.81	224065.67
19	RDAN	174825.48	224415.63	174837.17	224708.98
20	PRUG	171925.70	224794.66	171897.18	225140.21
21	PC068	168644.85	225072.47	168607.78	225460.14
22	PC064	165807.43	224645.36	165743.83	225501.50
23	GELF	163407.50	224819.88	163317.12	225399.85
24	CSW	161117.44	228466.28	161117.44	228466.28
25	LB1	152826.59	226927.59	152511.56	227435.75
26	PC055	151125.25	226216.35	150936.59	226851.71
27	PC051	148673.63	226307.28	148627.79	226882.66
28	PC044	144566.00	226544.10	144587.97	226960.05
29	PC057	142558.87	226592.94	142637.80	227064.88
30	OYSTER3	141082.47	226656.67	141024.08	227100.06
31	PC037	138882.05	226811.82	138872.38	227028.63
32	PC035	137709.00	226743.17	137673.09	227018.17
33	PC032	135799.28	226713.18	135788.76	226967.19
34	KLIPSAN2	131914.81	226566.37	131890.83	226936.94
35	PC021	129081.57	226384.48	129004.65	226658.39
36	RICH	126273.37	226114.67	126276.59	226424.39
37	PC014	123174.70	225883.58	123155.23	226195.58
38	PC008	118704.24	225457.33	118610.52	225779.31
39	PC025	116481.76	225188.73	116434.64	225473.27
40	PC004	115252.14	224990.61	115181.85	225209.80
41	CANBY	112244.40	224293.31	112237.25	224520.23
42	EASTJETTY2	104587.22	229089.38	104710.93	229436.92
43	IREDALE	99785.88	231088.98	99900.93	231426.35
44	KIM	96508.79	232147.97	96603.58	232520.89
45	RILEA	92440.71	233258.77	92546.38	233651.59
46	DELRAY	85420.49	234322.18	85376.47	234631.56
47	SEASIDERM2	80311.88	234060.17	80087.63	234615.29
48	CASINO	196607.68	220723.02	196564.21	221000.06
49	JACKSON	120901.04	225694.13	120844.05	226027.70

2.3.1 Field Equipment

Field equipment for topographic beach profiles consists of an RTK DGPS base station and an RTK DGPS rover. The base station consists of a Trimble 4000 series receiver, a Trimble non-micro centered T1/T2 GPS antenna with a ground plane, a Pacific Crest UHF radio modem, radio antenna, two tripods, and various cables. The rover consists of a Trimble 4000 series GPS receiver, a Trimble micro centered T1/T2 GPS antenna, Pacific Crest radio modem, radio antenna, a Trimble TDC1 or TSC1 data logger, and various cables mounted to a backpack. For surveys completed during and after the summer of 2005, one rover consists of a Trimble R8 GPS System, a TSCE data logger, and various cables mounted to a backpack.

2.3.2 Field Procedures

An RTK DGPS base station is setup on or near a control monument of the Washington Coastal Geodetic Control Network (Daniels et al., 1999). The GPS antenna is mounted onto a tripod that is leveled over a known monument or a random location. Once leveled, the tripod is secured with sand bags and the antenna is connected to the GPS receiver via a data cable. The radio modem and antenna are attached to the second tripod and connected to the GPS receiver via a data cable (Figure 3). After all connections have been made, the Trimble 4000 series receiver is started using a handheld data logger and the radio modem is turned on.

Figure 3. Example setup of GPS equipment. The disc antenna on the tripod (left) receives data from satellites while the antenna on the right transmits this information to a rover receiver collecting data on the beach.

Beach profiles are measured by walking with the rover unit from the landward edge of the primary dune, over the dune crest, to wading depth at spring low tide (Figure 4a). Between 2 and 8 beach profiles are collected during any one low tide and stored in the same file on the data logger. Two or more calibration points per survey are collected for subsequent field calibration, ensuring consistency with the Washington Coastal Geodetic Control Network.

Figure 4. Real Time Kinematic Differential Global Positioning System surveying techniques used in the beach morphology monitoring program. a) Cross-shore topographic beach profiles are collected with a rover receiver, an antenna attached to a backpack, and a hand-held data logger, b) three-dimensional topographic surface maps are collected with the Coastal All-terrain Morphology Monitoring and Erosion Research Vehicle (CLAMMER), and c) nearshore bathymetry is collected with a Coastal Profiling System.

2.3.3 Horizontal and Vertical Accuracy

Two types of survey-grade GPS equipment are used in the monitoring program.

The Trimble 4000 series receivers have manufacturer reported root mean square (RMS) accuracies of approximately ±3 cm + 2ppm (parts per million) of baseline length (typically 10 km or less) in the horizontal and approximately ±5 cm + 2ppm in the vertical while operating in Real Time Kinematic surveying mode (Trimble Navigation Limited, 1998). The manufacturer reported RMS accuracies for the Trimble R8 GPS Sytem are approximately ±1 cm + 1ppm of baseline length (typically 10 km or less) in the horizontal and approximately ±2 cm + 1ppm in the vertical while operating in Real Time Kinematic surveying mode (Trimble Navigation Limited, 2004). Baselines are typically less than five kilometers, suggesting a vertical uncertainty of ±6 cm. These reported accuracies are, however, additionally subject to multi-path, satellite obstructions, satellite geometry, and atmospheric conditions that can combine to cause a vertical GPS drift that can be as much as 10 cm (Sallenger et al., 2003). To minimize these uncertainties a local site calibration is performed during each survey, where between two and five geodetic control monuments are occupied that are known to have a horizontal and vertical accuracy of approximately 2 cm (Daniels et al., 1999). A three-parameter least squares fit is applied to fix all data points in the current survey to the Washington Coastal Geodetic Control System, within an RMS error typically less than 4 cm in the vertical, regardless of the phase of the GPS drift. Uncertainties in GPS position estimates also arise from collecting beach profiles by walking with a GPS antenna mounted on a backpack. Prior to fall 2000, GPS operators determined the horizontal location of the beach profiles in the field by locating permanent markers set in the dunes. The horizontal variability from the dune toe to the waters edge between subsequent surveys could be as much as tens of meters. Since fall 2000, a Trimble model TSC1 or TSCE data logger has been used that allows for simultaneous navigation and data collection, reducing the horizontal variability between subsequent surveys to typically less than 1 m. These horizontal deviations typically result in negligible vertical uncertainties due to the wide gently sloping beaches of the CRLC. However in highly three-dimensional dune fields, vertical uncertainties associated with horizontal deviations between subsequent profiles could be significant.

To test the vertical repeatability of our beach profile methodology, three different GPS operators collected the same profile data in a single day (Ruggiero and Voigt, 2000). This test resulted in mean vertical offsets between the three surveys of approximately 2 cm, and RMS deviations of approximately 4 cm (Figure 5). Assuming that the vertical uncertainties are statistically independent, we combine the GPS error (~6 cm), the calibration error (~4 cm), and the repeatability error (~4 cm) in quadrature by taking the square root of the sum of the squares. Therefore, the methodology used in the monitoring program can only reliably detect beach elevation change greater than approximately 8 cm. While not as accurate as standard terrestrial surveying using a rod and level, walking the profiles with a GPS backpack is justified by both the reduction in survey time and the large seasonal changes observed on the high-energy beaches of the CRLC.

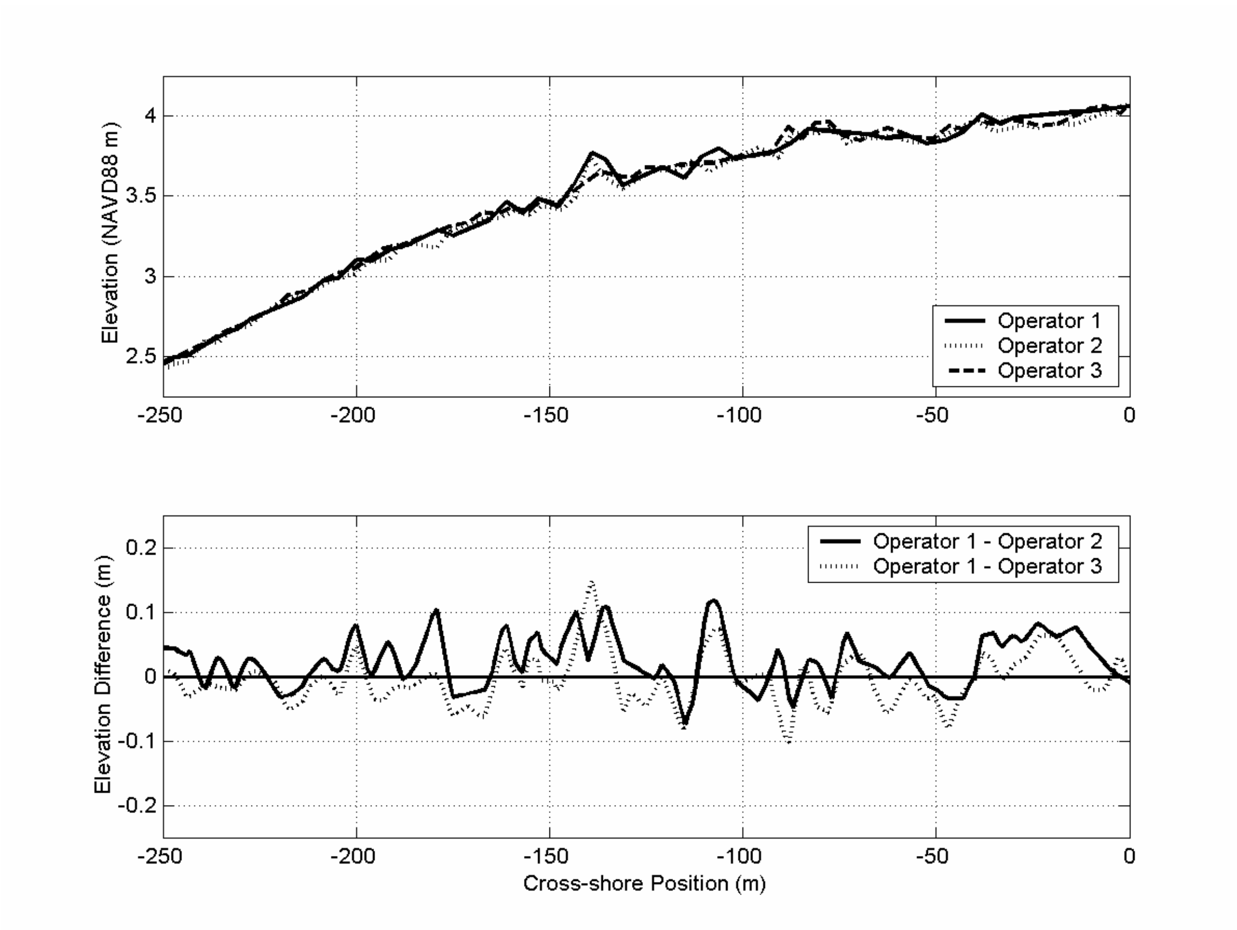

Figure 5. Repeatability of the cross-shore beach profile methodology. The top panel shows a section of a beach profile as measured by three GPS operators. The bottom panel features the elevation difference between the subsequent profiles indicating the resolution of the beach profile data collection technique.

2.3.4 Data Processing

Data calibrations (also referred to as horizontal and vertical adjustments) reduce discrepancies between local control and GPS-derived coordinates. Typically a field calibration is performed, and if not, the calibration is performed in the office to constrain the horizontal and vertical coordinates with the Washington Coastal Geodetic Control Network (Daniels et al., 1999). A calibration is accomplished by obtaining two to five calibration points at monuments of known vertical and horizontal position in the vicinity of the survey area. Calibration points are measured by centering the GPS antenna over a known monument at a set height and recording data for approximately 30 seconds. If the precisions are satisfactory (<5 cm error), the point is stored and applied to the survey. The Trimble Survey Controller software automatically performs a spatial correction on all survey points collected and matches the grid points to the known values.

Field data stored in the data logger is downloaded to one of Trimble's proprietary office software programs (Trimmap, TSOffice, and TGOffice have all been used). The office software allows for further quality assurance and quality control (QA/QC) through visualization, calibration and archiving. The data is then exported from the office software to an ASCII text file that is imported into Matlab (The Mathworks, Inc.).

Matlab scripts are used to visualize individual beach profiles and compare them to previously collected data for final QA/QC. Following final QA/QC, the entire data file is split into individual cross-shore topographic profiles and exported as individual ASCII text files (e.g., prof_21_su00.out). Data are reported as x, y, z triplets (Easting, Northing, Elevation) with the horizontal datum Washington State Plane South NAD 83 m, and the vertical datum NAVD 88 m. Finally, a Matlab script is used to export all of the data collected during one survey campaign into another ASCII text file. This file is then imported into Excel and saved as a DBF file (e.g., profiles_summer_2000.dbf) in order to facilitate the use of these data with a wide variety of software packages (e.g. GIS platforms).

2.4 Sediment Size Distributions

Surface sediment samples are collected at each beach profile location during each summer surveying campaign.

2.4.1 Field Procedures

Surface sediment samples are collected by hand (typically several hundred grams) within the dune, at the dune toe, at mid-beach and within the swash zone at low tide along a corresponding topographic beach profile. Due to a limited amount of processing time, the mid beach sediment samples are the only samples collected from summer 2002 on and processed consistently.

2.4.2 Data Processing

Sediment samples are taken to a sediment lab where sand grain size distributions are determined using American Society for Testing and Materials (ASTM) approved dry sieves at quarter-phi intervals following current EPA protocols for sediment analysis in the state of Washington (Tetra Tech Inc., 1986). Sediment samples are emptied into Gilson Model No. SC-152 9 by 9 inch metal drying trays and placed into a Quincy Lab Inc. Model 40 GC lab oven set at a temperature of 90ºC (200ºF). Samples are allowed to dry for 24 hours and are then placed into labeled plastic bags and stored until sorting. Before sorting, sample sizes are reduced to a target weight between 50 and 100 grams. Sediment samples are passed through a Sepor Inc. sediment splitter in order to reduce sample weight without adding bias to the process. The split samples are weighed to ensure target weight and recorded into a spreadsheet that allows for quick statistical analysis of sand grain size distributions. Split samples of target weight are poured into a stack of ASTM E-11 Specification USA Standard Testing Sieves and placed into a W.S. Tyler Model R x 29 Ro-Tap for 15 minutes. The Ro-Tap agitates the samples, sorting the sediment into its respective sieve size. Once sorting is complete, the sieve stack is dismantled and sediment on each sieve is collected, weighed and entered into the spreadsheet column corresponding with sieve size. Although this process is relatively error free, some error is generated when sediment is caught within the sieves. In order to reduce error caused by lost sediment, sample weights are compared before and after they are sorted. Sorted samples that weigh below 99.0% or above 100.99% of the original sample weight are discarded and not recorded. A fresh sediment sample is taken from the original sample bag and the process is restarted.

2.5 Topographic 3-D Beach Surface Maps

Whereas analyses of beach profiles can reveal the cross-shore variability in beach change, little information about the alongshore component of beach change can be extracted from this data. In lieu of multiple closely spaced cross-shore transects, three-dimensional topographic beach surface maps are generated by mapping the sub-aerial beach surface. To determine both the alongshore and cross-shore morphologic variability of the beach, surface maps are collected biannually at 16 sites (Figure 2, Table 3), totaling more than 60 km of alongshore distance.

Survey frequency is increased in areas that are highly dynamic (*e.g.*, Ocean Shores, WA) in an attempt to determine shorter-scale temporal changes of the beach planform.

Table 3. Name and bounding coordinates for each of the 16 beach surface maps.

Surface Map #	Name	Northing 1 (m)	Easting 1 (m)	Northing 2 (m)	Easting 2 (m)
1	GRENVILLE	225862.00	214789.00	223412.00	217536.00
2	MOCLIPS	218742.00	218510.00	214823.00	219353.00
3	ROOSEVELT	213117.00	219522.00	209027.00	220035.00
4	OCEAN CITY	204655.00	220215.00	199608.00	220537.00
5	OCEAN SHORES	187583.00	220249.00	183657.00	220105.00
6	WESTPORT	181088.00	223121.00	177084.90	224031.00
7	GRAYLAND	171987.00	224993.00	168613.00	225290.00
8	NORTH COVE	163419.00	225016.00	160868.00	228528.00
9	LEADBETTER POINT	153229.00	227210.00	148562.00	226659.00
10	OYSTERVILLE	142715.00	226833.00	138783.00	226928.00
11	KLIPSAN	131964.00	226670.00	128609.00	226486.00
12	NORTH HEAD	117127.00	225326.00	113948.00	224672.00
13	FORT CANBY	113280.00	224460.00	110154.00	224188.00
14	CLATSOP	105159.00	229197.00	101866.00	230547.00
15	RILEA	96593.00	232392.00	93003.00	233370.00
16	SEASIDE	80395.00	234166.00	77238.90	233556.00

2.5.1 Field Equipment: The CLAMMER

Field equipment for surface maps consists of an RTK DGPS base station, an RTK DGPS rover, and an amphibious all-terrain vehicle. The base station setup is identical to that used for the beach profiles. The rover consists of a Trimble 4700 GPS receiver, a Trimble micro centered T1/T2 GPS antenna, Pacific Crest radio modem, radio antenna, a Trimble TDC1 or TSC1 data logger, and various cables mounted to a six-wheel drive amphibious all-terrain vehicle called the CLAMMER (CoastaL All-terrain Morphology Monitoring and Erosion Research Vehicle). The CLAMMER is a model MAX IV vehicle made by Recreatives Industries INC (pre Fall 2002). It was chosen as the surface map survey vehicle because of its all-terrain and amphibious capabilities as well as the low weight to tire size ratio (Figure 4). The weight distribution is important because while surveying at low tide the CLAMMER is often driven over Razor clam beds that are sensitive to pressure. The MAX IV manufacturer reports that the vehicle applies less pressure on the ground than a human footprint, causing minimal damage to invertebrate populations. In October of 2002, the CLAMMER was replaced with a similar vehicle called the KD-V. The KD-V is an ARGO Vanguard 2 6-wheel drive amphibious off road vehicle. For surface maps completed after the summer of 2005, the rover consists of a Trimble R8 GPS System, TSCE data logger, and various cables mounted to the KD-V.

2.4.2 Field Procedures

The RTK DGPS base station is setup in a similar fashion as for collecting beach profiles. Surface map data is stored onboard the CLAMMER using either Aspen RTK (Trimble) software on a ruggedized personal computer (pre-summer 2000) or using a Trimble TDC1, TSC1, or TSCE data logger (post-summer 2000). Individual sites are each approximately 4 km in length and hundreds of meters in width, spanning the area between the toe of the primary dune and the swash zone. The CLAMMER, traveling along the beach at approximately 6 m/s, collects individual point measurements every 5 - 10 m. Individual point measurements are densely spaced in the alongshore direction to resolve relatively small-scale features such as beach cusps, and are over long enough distances to resolve larger scale, potentially migrating features such as mega-cusps, rip-current embayments, and sand waves. The cross-shore distance between alongshore transects is typically 20 - 30 m but is determined in the field based on cross-shore breaks in beach slope, such as at crests and troughs of swash bars and sand berms.

2.4.3 Horizontal and Vertical Accuracy

The survey-grade GPS equipment and site calibration process are discussed in section *2.3.3*. The non-uniformly spaced raw data, typically 5,000 to 10,000 points per surface map, feature accuracies better than approximately 0.05 m in the horizontal.

Uncertainties in vertical GPS position estimates also arise from collecting surface map data while on a moving platform, including vehicle bounce and tires sinking into the sand. While these additional errors are not readily measurable, comparisons with beach profile surveys suggest that they are small (~5 cm). Assuming that the vertical uncertainties are statistically independent, we combine the GPS error (~6 cm), the calibration error (~4 cm), and the vehicle error (~5 cm) in quadrature by taking the square root of the sum of the squares. Therefore, the methodology used in collecting topographic beach surface maps can only reliably detect vertical beach elevation change greater than approximately 10 cm.

2.4.4 Data Processing

Data calibrations (also referred to as horizontal and vertical adjustments) are performed in a similar manner as for beach profiles. Field data stored in the ruggedized laptop or data logger is downloaded to a Trimble proprietary software program. Pathfinder Office (pre-summer 2000), Trimmap, TSOffice or TGOffice have all been used. The Trimble software allows for further quality assurance and quality control (QA/QC) through visualization, calibration and archiving. The data is then exported from the office software to an ASCII text file that is imported into Matlab for final QA/QC. The non-uniformly spaced raw data (typically 5,000 to 10,000 points) are typically mapped onto a uniform 2-dimensional gridded surface via triangle-based, weighted linear interpolation, allowing for comparison with subsequent data sets. The surface maps are compared to earlier data and visualized in a variety of ways. Following final QA/QC the raw data points are exported to individual ASCII text files. Data are reported as x, y, z triplets (Easting, Northing, Elevation) with the horizontal datum Washington State Plane South NAD 83 m, and the vertical datum NAVD 88 m (e.g., sm_Seaside_su97.out).

2.6 Shoreline Reference Feature Mapping

Erosion reference features, such as scarps or drift lines, are being mapped on rapidly eroding beaches by walking the feature in the alongshore direction with an RTK DGPS backpack. These data are used to complement the historical shoreline change analyses being conducted by digitizing historical NOS topographic sheets and aerial photography (Kaminsky et al., 1999). Shoreline change reference features also serve to expand the regional coverage between cross-shore profiles and define a landward boundary to the beach surface maps.

2.6.1 Field Equipment

Field equipment for shoreline reference feature surveying consists of an RTK DGPS base station and an RTK DGPS rover on a backpack.

2.6.2 Field Procedures

The RTK DGPS base station is setup in a similar fashion as for collecting beach profiles. The surveyor walks with the RTK rover unit along the base of the erosional scarp, toe of dune, or landward extent of the vegetation line.

2.6.3 Horizontal and Vertical Accuracy

The survey-grade GPS equipment and site calibration process are discussed in section *2.3.3*. Uncertainties in horizontal positions also occur when there is no clear toe of an erosion scarp or dune, when debris (i.e., driftwood) prevents the GPS operator from following the scarp toe, or when satellite visibility is diminished due to overhead trees and debris. These additional uncertainties are not readily measurable but combine to limit the horizontal uncertainty of this technique to be approximately 1-3 m. Additional uncertainties in vertical GPS position estimates also arise from the GPS operator being prevented from walking exactly at the scarp toe. Therefore, a conservative estimate of the total vertical uncertainty is approximately 1 m.

2.6.4 Data Processing

Data calibrations (also referred to as horizontal and vertical adjustments) are performed in a similar manner as for beach profiles.

Field data stored in the data logger is downloaded to a Trimble proprietary office software program (Trimmap, TSOffice or TGOffice have all been used). The office software allows for further quality assurance and quality control (QA/QC) through visualization, calibration and archiving. The data is then exported from the office software to an ASCII text file that is imported into Matlab. Matlab scripts are used to visualize individual reference feature surveys and compare them to data collected earlier for final QA/QC. Following final QA/QC, the entire data file is reported as x, y, z triplets (Easting, Northing, Elevation) with the horizontal datum Washington State Plane South NAD 83 m, and the vertical datum NAVD 88 m (e.g., Ocean_Shores_030597.out).

2.7 Nearshore Bathymetry

The sub-aerial, or visible beach comprises only a portion of the active coastal zone. Variability in sub-aqueous morphology can influence the amount of energy from waves that is available to impact the shoreline and cause beach change. It has historically been very difficult and expensive to collect data in this highly dynamic region and only a few coastlines in the world have sufficient nearshore data to quantify this variability. The Coastal Profiling System (CPS), a hydrographic surveying system mounted on a Personal Watercraft (PWC) originally designed by Oregon State University (Beach et al., 1996; Côté, 1999; MacMahan, 2001) to collect data in energetic nearshore environments, is now being used in the CRLC to collect regional scale nearshore bathymetric data (Figure 4).

The CPS was designed to improve at least three of the limitations of existing nearshore surveying platforms (Côté, 1999).

1. Increase our ability to survey in shallow water and overlap with sub-aerial beach profiles, closing the existing data gap within the surf zone.
2. Improve the efficiency and accuracy of echo sounder surveys to approximately 10 cm, while decreasing the limitations imposed by environmental conditions in the surf zone.
3. Increase the mobility of the survey system such that it can be easily transported to a variety of field locations.

This section describes the bathymetric and co-located topographic beach profile data collected in the CRLC, beginning with a pilot effort in 1998 and eventually becoming a full component of the beach monitoring program in 1999.

2.7.1 Summer 1998 Pilot Study

In 1998, a pilot effort was initiated to determine whether the CPS could be used as a regional monitoring tool in the Pacific Northwest. A 2-3 kilometer representative section of each of the four sub-cells of the CRLC (Figure 2) was surveyed in late July and early August 1998.

2.7.1.1 Field Equipment

Combining the high accuracy positioning of DGPS, the efficiency of an acoustic echo sounder, and the mobility of a personal watercraft, the CPS provides a fast and accurate method to obtain sub-aqueous bathymetric profiles. The original CPS (CPSI) was configured on a Yamaha Waverunner III 2 cycle, 62 horsepower PWC that is 3 m long and 1.1 m wide (Figure 6). A Meridata MD 100 fan beam echo sounder is used with the transducer (12.5 ° beam width) mounted in the hull at the stern of the PWC. The MD 100 operates at 200 kHz, samples at 1 Hz, and is capable of measuring in water depths ranging from 1 – 180 m, with a resolution of approximately 10.0-cm. The CPSI incorporates a Trimble (4000 series) RTK-DGPS operating at 5 Hz with a land-based antenna mounted over a known reference station. The rover antenna is mounted approximately in the center line of the boat, directly over the echo sounder transducer, on an A-frame at the stern of the PWC. A daylight-readable Liquid Crystal Display (LCD) provides the PWC operator with GPS status, speed of vessel, and depth information. Data from the CPS are collected in an onboard computer system and stored on a 32 MB PCMCIA card.

Figure 6. Original Coastal Profiling System (CPSI) being launched.

2.7.1.2 Field Procedures

During the original ground-truthing of the CPSI at the SandyDuck '97 field experiment, operation procedures were dependent on the infrastructure of Field Research Facility (FRF) in Duck, North Carolina. For application to a regional beach morphology monitoring in the CRLC, new controls on surveying, additional personnel, and safety procedures had to be developed to complete nearshore bathymetric data collection.

At each survey site, the GPS base station was located over a known geodetic control monument (Daniels et al., 1999). Prior to launching the CPSI, discrepancies between local control and GPS-derived coordinates were reduced by conducting a field calibration (also referred to as horizontal and vertical adjustments). This calibration was accomplished by obtaining between two and three calibration points at markers of known vertical and horizontal position in the vicinity of the survey area. Calibration points were measured by initializing the CPSI system, centering the GPS antenna over a known marker at a set height and recording data for several minutes. If precisions were satisfactory, the calibration points were used to perform a least squared fit spatial correction on all survey points collected to constrain the horizontal and vertical coordinates to the Washington Coastal Geodetic Control Network (Daniels et al., 1999). The CPSI was completely initialized on land and then recorded data continuously until the PWC was retrieved from the water and powered down. While data was collected continuously, the CPSI operator only concentrated on maintaining data quality while moving along cross-shore transects, beginning in deep water, approximately 10-12 m below NAVD88, and ending within the surf zone. Three range poles were used on the beach to align the individual shore perpendicular transects. This cross-shore operation of the CPSI minimized the effect of roll and pitch on depth estimates. The alongshore spacing between cross-shore profiles was typically around 200 m. The CPS surveys were conducted near high tide to maximize the landward limit of the profile measurements. In some cases, beach topography (sub-aerial) measurements were made at low tide within approximately 24 hours of the bathymetry measurements using the CLAMMER.

2.7.1.3 Horizontal and Vertical Accuracy

The CPSI was first tested in the nearshore during February 1996 at Agate Beach, Oregon as part of the High Energy Beach Experiment (Beach et al., 1996). Following these initial field trials the primary test of the system took place in October 1997 at the SandyDuck '97 field experiment at the USACE Field Research Facility (FRF) in Duck, North Carolina where the bathymetric data collected by the CPS were compared against the data collected by the CRAB (Birkemeir et al., 1984). Error analyses from these tests indicate that the system typically maintains sub-decimeter vertical accuracy (Cote, 1999). Horizontal uncertainties for individual points are approximately 0.05 m, based solely on GPS accuracies and coordinate system calibrations. However, the CPSI could at times be up to approximately 100 m off of a true shore perpendicular transect due to the methodology of sighting range poles on the beach.

2.7.1.4 Data Processing

The GPS and echo sounder were sampled at different rates and recorded separately. However the need to estimate the tidal elevation of the water surface is eliminated by the co-collection of depth data and an accurate GPS vertical position. The GPS data, sampled at 5 Hz, was recorded in the WGS84 datum. The program Corpscon (US Army Corps of Engineers) was used to convert to the Washington State Plane (South) NAD83 horizontal datum and the NAVD88 land-based vertical datum. A cubic spline interpolation using a piece-wise polynomial fit obtains the GPS coordinates for the echo sounder depth at a specified location and time. The elevation of both data streams are then subtracted to obtain the depth of the seafloor, h, in NAVD88

$$h = z_{gps} - \Delta z + h_{sonar} \tag{1}$$

where z_{gps} is the elevation of the GPS antenna phase center in NAVD88, the correction factor Δz is a fixed vertical distance between the echo sounder transducer and the GPS antenna phase center, and h_{sonar} is the depth to the seafloor below the transducer (Figure 7). Although the CPSI collects data continuously, beach profiles are only derived from measurements taken while driving onshore in order to minimize the influence of waves on the measurements. Individual data points below the echo sounders blanking interval (0.0 – 0.6 m) and points 1.75 m above a linear regression through the data were removed as outliers. A second pass through the data removed points 0.5 m vertically different from nearest neighbor data points. These two steps typically reduce data density by approximately 15%. Next a ten point median filter is used to smooth the remaining high frequency noise.

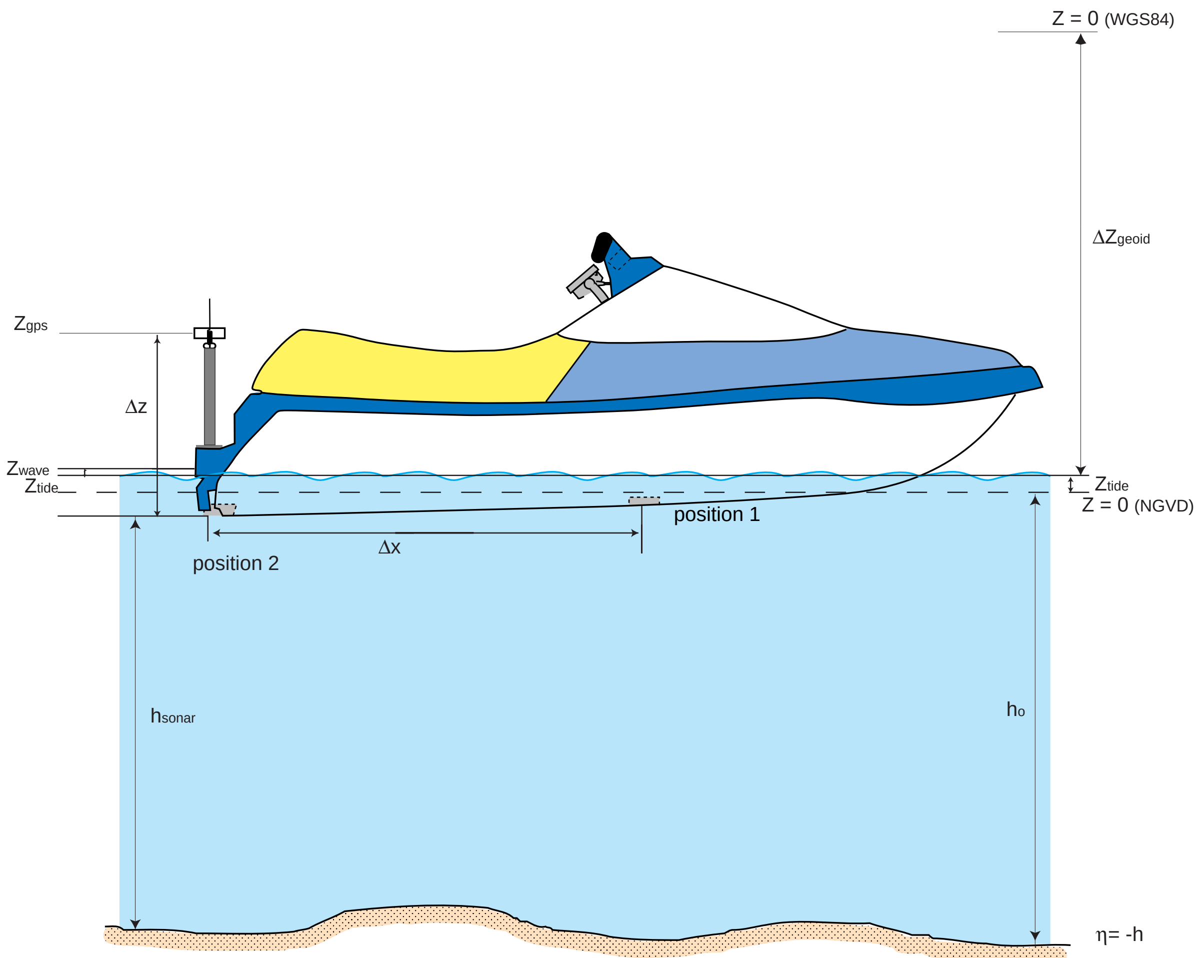

Figure 7. The Coastal Profiling System records vertical elevations relative to a land based vertical datum in meters. The vertical component of bathymetry combines several variables as indicated here.

The final data processing step used on the 1998 data set is an elevation correction resulting from differences between the actual speed of sound in water and the preset speed of sound that was typically set equal to 1450 m/sec. The speed of sound calibration uses the UNESCO (1982) algorithm (2) for the computation of the speed of sound in seawater, *U*, as a function of salinity, temperature, and pressure

$$U(S,T,p) = C_w(T,p) + A(T,p)S + B(T,p)S^{3/2} + D(T,p)S^2 \quad (2)$$

where S is salinity in psu, T is temperature in degrees Celsius, p is pressure in decibels, and C_w, A, B, and D are constants.

The corrected depth measurement, h_c, is obtained by multiplying the depth, h, from (1), by the ratio of the calculated speed of sound, U, to the assumed constant value.

$$h_c = \left(U/1450 \right) * h \quad (3)$$

Data from each day of collection in 1998 have been processed in the above manner and stored as Easting, Northing, Elevation triplets in an ASCII file in the following directory: *nearshore_bathymetry\data_98\NorthBeach\bathy\output_raw*.

Profiles in the subsequent years of this surveying campaign were collected along preset track lines. In order to compare the 1998 data to these subsequent profiles a further processing step is necessary. Both the bathymetry data and the topography data are mapped onto a uniform 2-dimensional gridded surface from which beach profiles falling along the subsequent track lines are extracted. These profiles are considered the final output for the 1998 data set and are located in *nearshore_bathymetry\data_98\NorthBeach\bathy\output_fin.*

2.7.2 Regional nearshore monitoring, 1999-2003

Between summer 1998 and summer 2003, cross-shore profiles were collected using a second generation Coastal Profiling System (hereinafter referred to as CPSII, Figure 8). Each of the five sections surveyed in 1998 were surveyed again in 1999, 2000, 2001, 2002, and 2003. Additionally, tens of profiles (approximately 1.0-km spacing) covering most of the rest of the CRLC have also been collected.

Figure 8. Second generation Coastal Profiling System (CPSII) in dry dock.

2.7.2.1 Field Equipment: Second Generation Coastal Profiling System

The CPSII, cooperatively designed with the University of Florida (MacMahan, 2001), also consists of a personal watercraft equipped with a GPS receiver and antenna, an echo sounder, and computer running hydrographic survey software. Modifications to the original system include: 1) a monitor for visual aid, 2) an echo sounder with a higher sampling frequency, 3) a keypad for operator control, and 4) surveying software for navigation, data collection, and data analysis (MacMahan, 2001).

The CPSII PWC used was a 1998 3-person Yamaha Venture 700 Wave Runner. This model was chosen because of its stability, compartment space, and relatively low price. The 3-person PWC measures 3.15 m in length, 1.25 m in width, and 1.05 m in height. During 1999 and 2000 only 1 of the 2 boats (Jose) was used to collect data while the second boat (Josb) served as water-based support for safety. During normal surveying operation, the wave runner travels at approximately 3 m/s (5 knots) and can operate for approximately 3-5 hours on one 50 L fuel tank. The instruments are placed in the compartment space located under the back seat, on a bracket at the stern on the vessel, and on brackets in the forward part of the vessel in front of the handlebars. In the storage space under the rear seat of the PWC, a platform (false bottom) was mounted with a watertight case located on the underside containing a DC-DC converter and an in-line fuse. On top of the platform are two watertight cases, which house the GPS, computer, and echo sounder electronics. The computer case contains the echo sounder and the laptop computer. This case has six external watertight connectors: one is for serial communication with the GPS, one for the echo sounder transducer, one for the external screen, one for the external 17 button keypad, one for power, and one spare. The complete system is powered by two gel cell 12-volt marine batteries, configured in series and housed in a Pelican box mounted on the bracket at the stern of the PWC. The system draws approximately 24 volts at approximately 2.8 amps (MacMahan, 2001).

Horizontal and vertical positioning of the CPSII is obtained using a Trimble 4700 GPS receiver, which is enclosed in a waterproof Pelican box stowed in the storage compartment underneath the seat. The GPS case also includes the GPS radio modem (Pacific Crest) that is used to communicate with the base station. A small bracket is attached on top of the stern of the vessel for mounting the GPS antenna and the radio antenna. The GPS antenna is mounted approximately 90 cm directly above the echo sounder transducer.

A Bathy-500 single-frequency echo sounder (manufactured by Ocean Data Equipment Corporation) with a 208 kHz transducer was used. This echo sounder has adjustable gains, offset, serial outputs, and speed of sound control. The sampling rate is a function of water depth with the highest sampling rate of 8 Hz applied in shallow water (0-10 m). The resolution of the echo sounder is approximately 3 cm. The transducer has a 10 degree conical beam width and generates a pulse at 208 kHz. The echo sounder transducer is mounted on a removable plate on the underside of the vessel at the stern just below the engine jet. It is located 29.2 cm below the waterline of the unmanned wave runner. The electronics of the echo sounder were reconfigured and along with the laptop computer (Toshiba Libretto 100 CT until 2000 and replaced by a Palmax Pen Computer following 2000), placed in a watertight Pelican Case. The CPSII collects data at 5 Hz and while traveling at 3 m/s generates a depth sounding every 0.6 meters along the sea floor.

HYPACK (Coastal Oceanographics Inc.) hydrographic surveying software is used as the data synchronization software and navigation system. Hypack allows visual observation of the transect, distance offline, depth, latitude, longitude, easting, northing, corrected depth, filename, line number, satellite quality, number of satellites, collection mode, and recording mode. All of this information is useful to the operator when collecting hydrographic data.

Navigation and surveying are aided by the use of a monitor (a 25.4 cm) Computer Dynamics VAMP 1000 day light readable screen with 900 NIT reading) which is mounted in a watertight case on a bracket forward of the handlebars. A retractable bellows is mounted onto the screen case, sheltering the screen from direct sunlight to allow better viewing of the external monitor. A 17-button programmable Logic Controls keypad (24 cm X 8.9 cm X 3.2 cm) is placed in a waterproof radio bag mounted on the handlebars to allow the user to start and stop data collection and modify the screen view.

In the spring of 2001, the second PWC (Josb) was outfitted to collect data concurrently with boat 1 (Jose). The second boat was outfitted in a similar manner to boat 1 with a few key differences, including: 1) the echo sounder is a Bathy-500 MF (multiple frequency) from ODEC using an 8 degree conical beam width transducer, and 2) the onboard computer is a Palmax Pen Computer (266MHz, Pentium, Windows 98).

2.7.2.2 Field Procedures

As HYPACK allows for surveying within a user-defined coordinate system, in this case NAD83 Washington State Plane (South) and NAVD88, collecting land based control points is no longer necessary with the CPSII. The GPS base station is set up over a known survey monument within the Coastal Geodetic Control Network (Daniels et al., 1999) and survey accuracy data is stored by the HYPACK software in the appropriate datum.

Another significant improvement with the CPSII is the ability to survey preset track lines, eliminating the need for range poles on the beach. The preset track lines for each of the sub-cells are included in *\nearshore_bathymetry\Hypack_Line_Files*. Data is now collected only when the PWC operator selects a transect. The PWC operator maneuvers the vessel offshore to either a target depth (typically around 12 m) or a target easting along a preset track line. Each profile extends a deep-water limit ranging between 10 and 16 m (MSL) toward the shoreline where the operator ends the line when turning the vessel around in a water depth of approximately 1 m.

When possible the bathymetry data are combined with topographic surveys, extending the cross-shore profiles landward to the dune fields. Topographic cross-shore beach profiles are collected by walking with an RTK DGPS receiver and antenna mounted to a backpack or by extracting the profiles from topographic beach surface maps surveyed with the CLAMMER.

2.7.2.3 Horizontal and Vertical Accuracy

The survey-grade GPS equipment accuracy is discussed in section *2.3.3*. While the horizontal uncertainty of individual data points is approximately 0.05 m, the CPSII operators cannot stay "on line," in waves and currents, to this level of accuracy. Typically, mean offsets are less than 2.0 m from the preprogrammed track lines and maximum offsets along the approximately 2 km long transects are typically less than 10.0 m. While repeatability tests and merges with topographic data collected with the CLAMMER or a backpack suggest sub-decimeter vertical accuracy (Figures 9 and 10), significant variability in seawater temperature (~10 degrees Celsius) can affect depth estimates by as much as 20 cm in 12 m of water. However, water temperatures within the CRLC usually remain within a few degrees of the temperature associated with the present sound velocity. Therefore, a conservative estimate of the total vertical uncertainty for these nearshore bathymetry measurements is approximately 15 cm.

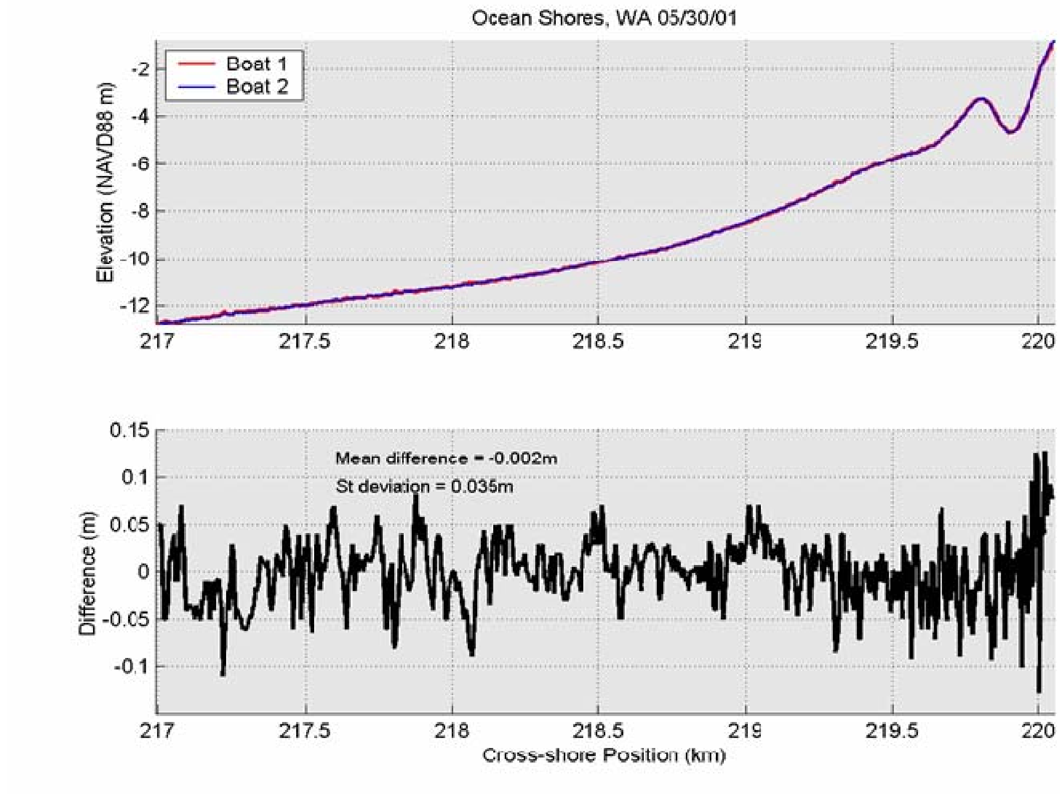

Figure 9. Repeatability comparison between a (smoothed) cross-shore profile surveyed with two different boats.

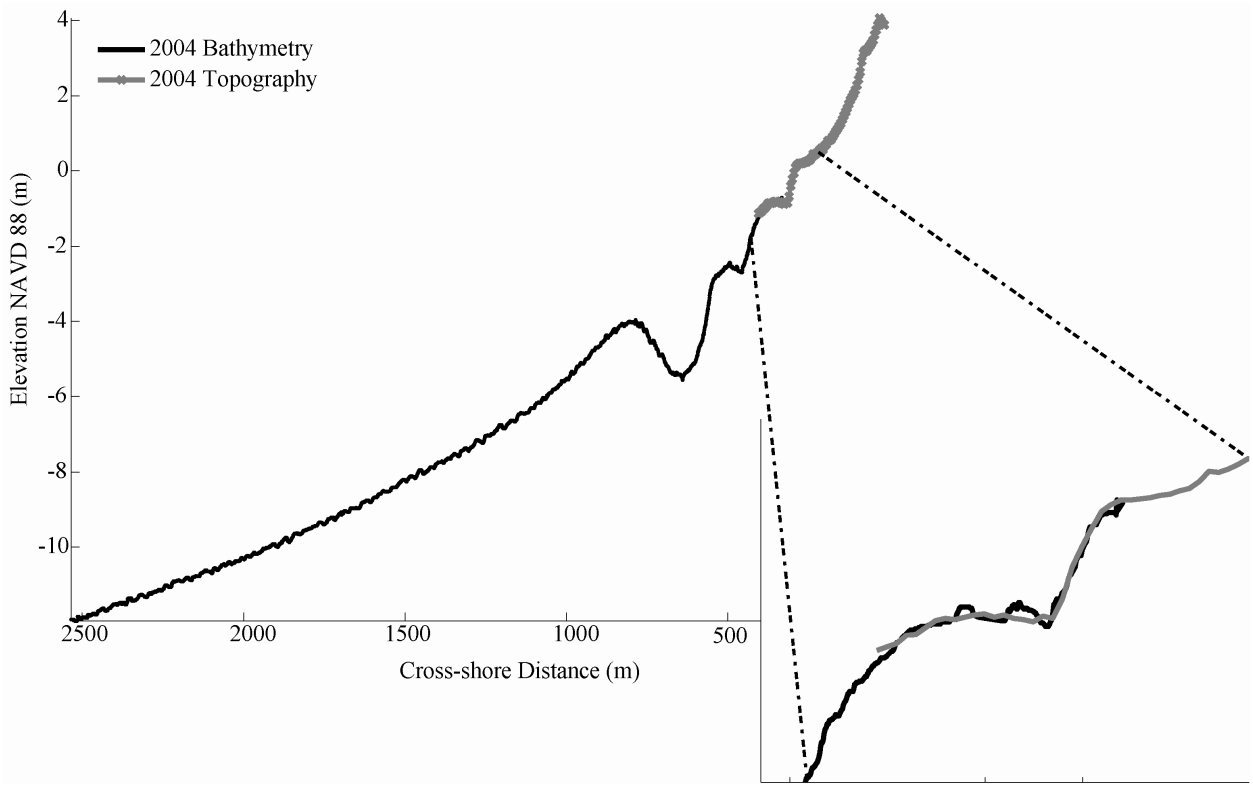

Figure 10. Merge between bathymetric and topographic data collected along a profile.

2.7.2.4 Data Processing

The following data processing steps are performed on each individual data file:

1. **Outlier/Bad GPS Elimination:** Each profile is examined, typically using a Perl script, to detect and remove any data points collected when the GPS receiver is not initialized in kinematic mode. Earlier versions of HYPACK store data regardless of GPS quality and therefore the raw data files may contain non-precise data. However, HYPACK does record a GPS data quality string so the Perl script eliminates any data without the appropriate string value. This script also eliminates any obvious outliers from the raw files that are either shallower than the echo sounder blanking interval or deeper than a user defined cutoff value.

2. **HYPACK editing:** Each profile is viewed using HYPACK's editor. Outliers that were not eliminated in the first step are removed by highlighting the point and deleting it from the record.

3. **Export:** Individual files (representing a single profile) are exported from Hypack as Easting, Northing, Elevation triplets in ASCII format.

4. **Offset Corrections:** Detailed laboratory and field tests (bar check) comparing the two echo sounders from Jose and Josb revealed a constant offset of approximately 15 cm. The echo sounder on Josb was accurate to approximately 2 cm and the echo sounder on Jose consistently measured 15 cm deeper. Throughout the 2001 field campaign the two boats' instruments were compared by having each boat collect at least one duplicate profile per data collection session. This check also consistently showed the 15 cm offset between the two boats. To compensate for this offset, a 15 cm correction was added to the vertical coordinate of all the data collected using the echo sounder of Jose (1999, 2000, 2001, 2002 and 2003 profiles). These files, which have been run through Perl script, the HYPACK editor, and corrected for offsets, are considered the 'raw' data files. They are included in directories such as: *\nearshore_bathymetry\data_00\NorthBeach\output_raw*.

5. **Speed of Sound/Salinity Corrections:** Since the echo sounders did not directly measure water temperature and therefore did not correct the speed of sound in water in real time, all data have been corrected to adjust the vertical coordinate for the actual speed of sound based on water temperatures measured by local wave buoys. Further, no measurements of salinity were made or were available from local buoys. A sensitivity analysis was performed to investigate the effect of salinity and temperature on depth measurements through speed of sound adjustment on a profile. The results show that a normal range of water temperature can have a measurable effect on depth readings. The worst possible inducement of error, when the water temperature estimate is approximately 10 º C different from the actual water temperature, results in approximately 0.20 m of vertical change at a water depth of 11 m. Therefore, the temperature chosen to correct the

bathymetric measurements for each profile is taken as the average of the surface water temperatures recorded at the wave buoy closest to the data collection site during the corresponding survey period (Tables 7 – 14). Two standard deviations of all water temperature estimates (over 90 samples in four years) is less than three degrees Celsius. Therefore, the majority of nearshore bathymetric profiles have been vertically adjusted for temperature by less than 10 cm.

The salinity is fixed at 31 psu for all lines as its small variations in the sampling region (Gelfenbaum et al., 2000) had a negligible effect when performing a speed of sound correction to the data.

6. **Smoothing:** A smoothing operation was performed using a median filter on the z coordinate in the x-direction to reduce high frequency fluctuations. Varying window sizes were used to obtain a smooth profile while maintaining the integrity of the actual data points. These files, which have been run through a customized Perl script, the HYPACK editor, corrected for offsets, speed of sound and salinity, and smoothed are considered as the 'processed' data files. They are located in the *\nearshore_bathymetry\data_00\NorthBeach\output_fin* folder.

2.7.3 Regional nearshore monitoring, 2004-present

During the summer of 2004, a third generation Coastal Profiling System (hereinafter referred to as CPSIII, Figure 11) was designed, built, and implemented for sampling in the CRLC. This new system continued with the sampling scheme described in Section 2.7.2.

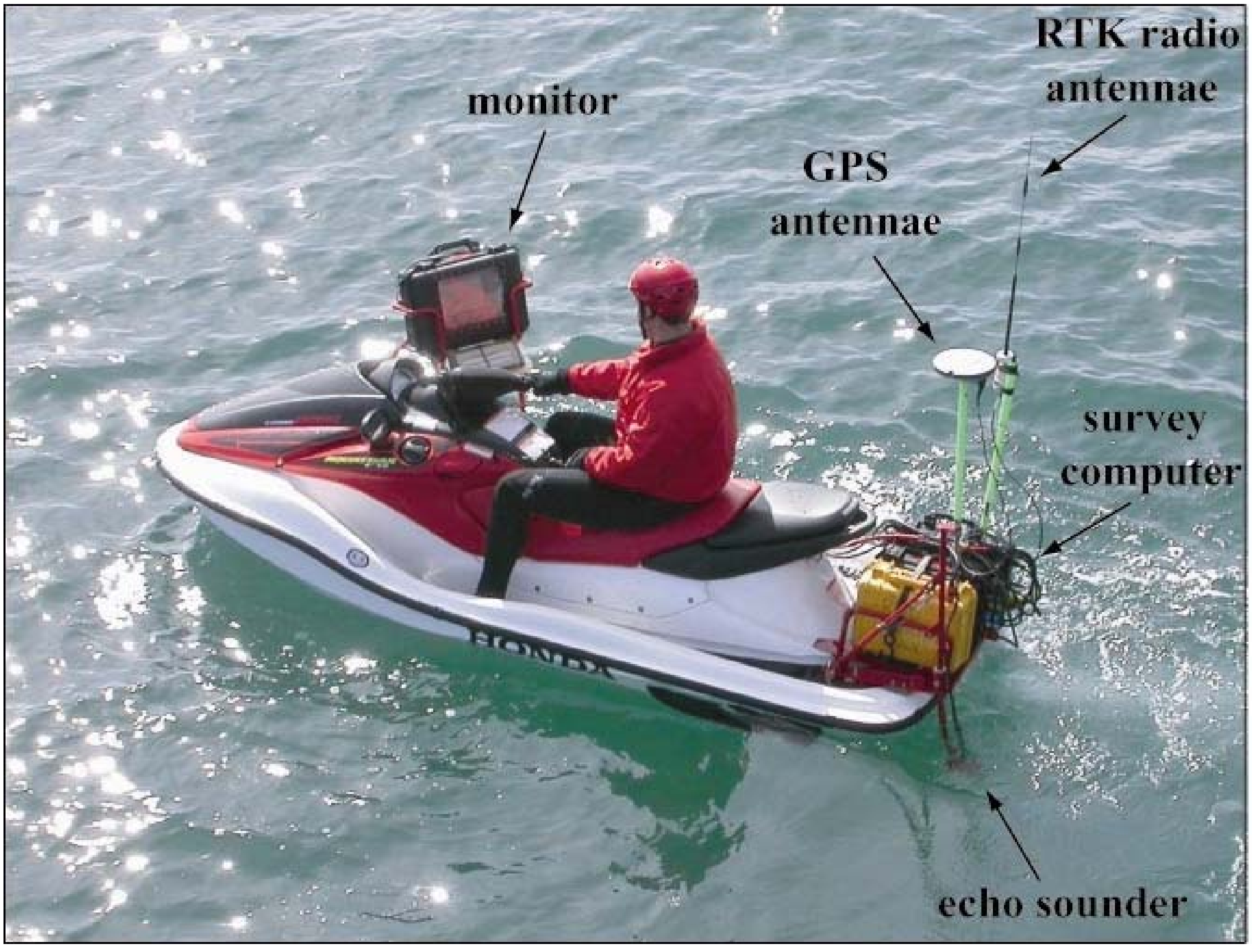

Figure 11. Third generation Coastal Profiling System (CPSIII) in action.

2.7.3.1 Field Equipment: Third Generation Coastal Profiling System

The CPSIII has a similar physical setup as the CPSII, but is mounted on a newer PWC model and includes updated hardware.

The modifications for the third generation system are discussed below. The PWC used for the CPSIII is a 2003 Honda Aquatrax F-12, which was chosen because it has a four-stroke engine and improved stability over the CPSII. This 3-person PWC measures 3.20 m in length, 1.25 m in width, and 1.06 m in height. The CPSII no longer contains a DC-DC converter and inline fuse in the storage space under the rear seat of the PWC. The GPS receiver setup has been incorporated into the water tight Pelican cases mounted on the stern of the vessel. The CPSIII system draws approximately 24 volts at approximately 2.8 amps. The GPS antenna is located approximately 120 cm directly above the echo sounder transducer.

The echo sounder is an ESE-50 single frequency echo sounder with a 200 kHz transducer manufactured by Flash Fire Technology, Inc. This echo sounder has adjustable gains, offset, and serial outputs. One limitation of the new system is that the speed of sound is set at 1500 m/s and cannot be adjusted to compensate for varying conditions. The echo sounder transducer is mounted on a removable and adjustable arm at the stern of the vessel. This adjustable arm allows the PWC operator to raise the echo sounder during vessel deployment and recovery and helps to avoid potential damage to the echo sounder in very shallow water. The Palmax Pen Computer from the CPSII system was replaced by a Big Bay Technologies P3 mini PC. The monitor was replaced with a 12 inch Big Bay Technologies outdoor high bright display monitor, which eliminates the need for the retractable bellows.

2.7.3.2 Field Procedures

These have not changed from the CPSII (see section 2.7.2.2 Field Procedures).

2.7.3.3 Horizontal and Vertical Accuracy

These have not changed from the CPSII (see section 2.7.2.3 Field Procedures).

2.7.3.4 Data Processing

Modifications to Data Processing for the CPSIII system are discussed below.

1. **Outlier/Bad GPS Elimination:** The updated version of HYPACK software (Hypack Max) can be set to store only data collected when the GPS receiver is initialized in real time kinematic mode, so the PERL script is not needed to eliminate data that does not meet this specification. However, the PERL script is still used to eliminate any obvious outliers from the raw files that are either shallower than the echo sounder blanking interval or deeper than a user defined cutoff value.

2. **Offset Corrections:** There is no longer a consistent offset recorded between the echo sounder of Boat 1 and Boat 2, therefore no offset correction is applied.

3. DATA COLLECTED

Many components of the monitoring program are collected at different sampling frequencies. Table 4 provides a description of the seasonal variability in sampling for several components.

Table 4. GPS data collected.

Field Campaign	Geodetic Control	Topographic Beach Profiles	Topographic Surface Maps	Nearshore Bathymetric Profiles	Sediment Samples
Summer 1997	x	x	x	---	x
Fall 1997	---	---	---	---	---
Winter 1998	---	x	x	---	x
Spring 1998	---	---	---	---	---
Summer 1998	---	x	x	x	x
Fall 1998	---	x	---	---	---
Winter 1999	---	x	x	---	---
Spring 1999	---	x	---	---	---
Summer 1999	x	x	x	x	x
Fall 1999	---	x	---	---	---
Winter 2000	---	x	x	---	---
Spring 2000	---	x	---	---	---
Summer 2000	---	x	x	x	x
Fall 2000	---	x	---	---	---
Winter 2001	---	x	x	---	---
Spring 2001	---	x	---	---	---
Summer 2001	---	x	x	x	x
Fall 2001	---	x	---	---	---
Winter 2002	---	x	x	---	---
Spring 2002	---	x	---	---	---
Summer 2002	---	x	x	x	x
Fall 2002	---	x	---	---	---
Winter 2003	---	x	x	---	---
Spring 2003	---	x	---	---	---
Summer 2003	---	x	x	x	x
Fall 2003	---	x	---	---	---
Winter 2004	---	x	x	---	---
Spring 2004	---	x	---	---	---
Summer 2004	---	x	x	x	x
Fall 2004	---	x	---	---	---
Winter 2005	---	x	x	---	---
Spring 2005	---	x	---	---	---
Summer 2005	---	x	x	x	x
Fall 2005	---	x	---	---	---

3.1 Waves and Water Levels

The CRLC is well known for the severity of its wave climate (Tillotsen and Komar, 1997; Allan and Komar, 2000; Allan and Komar, 2002) with deep-water significant wave heights and periods having annual averages of 2.2 m and 10.4 s respectively, but with winter storms generating significant wave heights of up to 14 m. High long-period waves (averaging approximately 3 m in height and 12 – 13 s periods), high water levels, and a west-southwest direction of wave approach characterize the winter months (November through February) along the CRLC, while smaller waves and shorter periods (1.2 m and 8 s), lower water levels, and wind and waves from the west-northwest are the typical summer (May through August) conditions (Figure 12). The seasonal cycle in waves and water levels along the CRLC (Figure 12) results in a seasonal morphodynamic cycle. Offshore and northerly sediment transport results in beach erosion during the winter and onshore and southerly sediment transport dominates beach recovery in the summer months. Tides throughout the CRLC are mixed semi-diurnal with a 2 - 4 m tide range. Water levels also have a distinct seasonal cycle measuring approximately 15 cm higher in the winter than during summer months (Figure 12) (NOAA Station # 9440910, CDIP Station # 036).

In the Pacific Northwest, strong El Niños feature increased frequency of storm tracks from the south-southwest and higher than normal sea levels (Komar, 1986; Kaminsky *et al*., 1998; Komar et al., 2000). Interannual climatic variability also affects waves and water levels, which in turn can influence beach responses. During the strong El Niño of 1982/1983, large wave heights and acute southerly wave angles forced an increased magnitude of northerly offshore sand transport in Oregon during the winter, causing severe beach erosion and changes in shoreline orientation that persisted for several years (Peterson *et al.*, 1990). Unfortunately, the magnitude of beach change during that El Niño was not recorded by detailed surveys. The winter of 1997/1998, the first winter of the monitoring program, coincided with one of the strongest El Niño events on record for the Pacific Northwest (Komar *et al*., 2000). During that El Niño the CRLC experienced monthly mean water levels up to 0.4 m higher than typical (Figure 12), mean winter wave heights up to 1.0 m higher than usual, and wave directions having a more SW approach (Kaminsky *et al*., 1998). These changes in environmental conditions had a distinct effect on CRLC beaches.

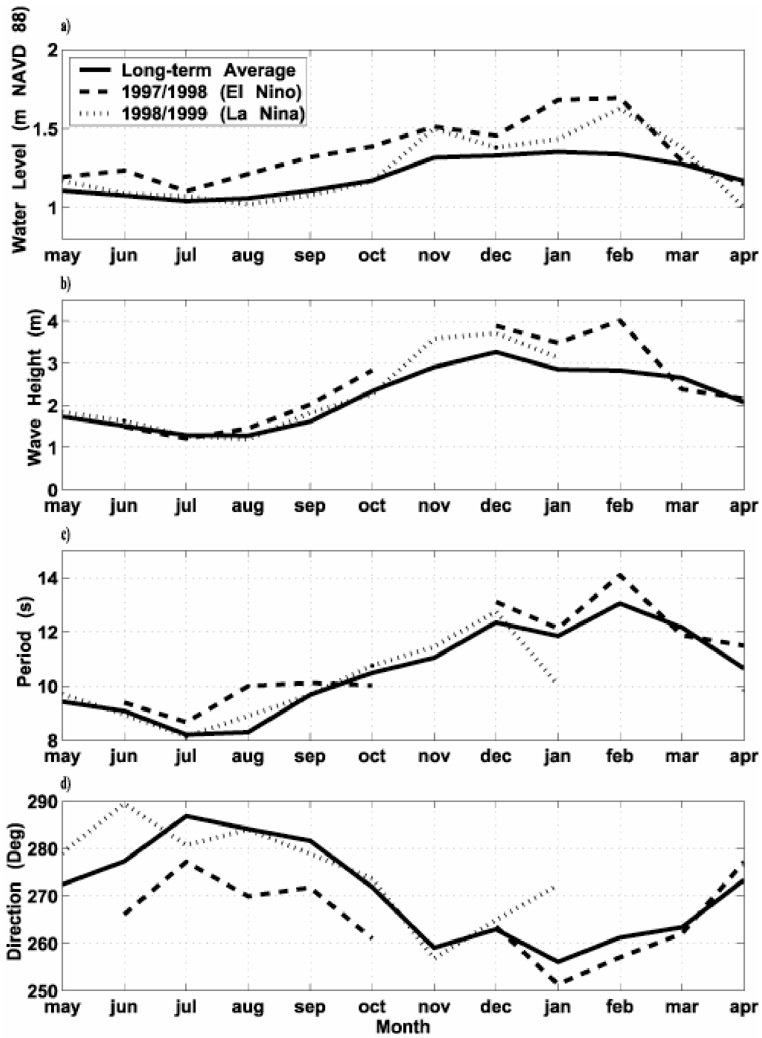

Figure 12. Monthly means a) water levels measured at the NOS Toke Point tide gage in Willapa Bay, b) significant wave height, c) period, and d) direction from the Grays Harbor CDIP buoy. The solid line represents long-term means beginning in 1980 for water levels, 1981 for wave heights and periods and 1993 for wave direction. The 1997/1998 El Niño (dash line) and the 1998/1999 La Niña (short dashed) are also shown.

3.2 Geodetic Control

The Washington Coastal Geodetic Control Network consists of 96 stations, the locations of which are described in Table 5. Thirteen of these stations were created by the Coastal Monitoring Program while others already existed and were included in the network. In the summers of 1997 and 1999, geodetic control surveying campaigns were conducted to create new stations and ensure the accuracy of existing stations.

3.2.1 Data Coverage

Table 5. Coordinates for the stations contained within the Washington Coastal Geodetic Control Network in the Washington State Plane, South, meters, NAD 83 and NAVD 88 coordinate systems.

Station Number	County	NGS PID	Station Designation	Station	NAD 83 (1991)		NAVD 88 Elevation
				Type	Easting (m)	Northing (m)	(m)
01	Grays Harbor	SD0794	GRENVILLE	Local	214355.081	225915.358	37.63
02	Grays Harbor	SD0132	SOUTH	Secondary	216603.847	225290.033	4.643
03	Grays Harbor	SD0129	L 443	Local	217632.452	223555.901	6.86
04	Grays Harbor	SD0780	PIER RM 1 AZ MK	Local	218706.174	218480.556	7.13
05	Grays Harbor	SY5644	HATCHERY	Primary	236150.840	216822.073	36.537
06	Grays Harbor	AH6996	GKAM	Local	219509.529	214862.915	7.16
07	Grays Harbor	SD0117	R 443	Secondary	225227.546	212765.386	32.988
08	Grays Harbor	AH6997	BHUX	Local	220002.033	211327.432	5.96
09	Grays Harbor	AH6998	GP 14109-31	Local	220961.222	204470.295	7.34
10	Grays Harbor	AH6999	DIANA	Local	221227.901	199520.997	6.01
11	Grays Harbor	SD0720	MOTULIPS	Secondary	232060.108	198880.826	15.49
12	Grays Harbor	AH7000	DAMONS	Local	221436.304	193625.612	5.55
13	Grays Harbor	AH7001	ET	Local	221016.816	191040.669	8.55
14	Grays Harbor	AH7002	BUTTER	Local	220765.202	187608.277	5.50
15	Grays Harbor	SC2824	CENTRAL	Primary	256336.103	187168.504	38.31
16	Grays Harbor	AH6993	OMEN	Secondary	225495.170	185461.276	4.59
17	Grays Harbor	AH7003	NERR NERR (Destroyed)	Local	221682.225	184240.742	7.42
18	Grays Harbor	AH7004	X 1	Local	220427.159	183793.925	7.10
19	Grays Harbor	SD0042	944 1102 TIDAL 2	Local	224937.418	181306.423	4.652
20	Grays Harbor	AH7005	HD 1	Local	223445.898	180809.016	8.04
21	Grays Harbor	SD0394	GRAYS HARBOR E BASE 2	Secondary	225837.656	180705.800	5.06
22	Grays Harbor	AH7006	WORM	Local	223748.246	179169.649	9.90
23	Grays Harbor	AH7007	SPICE	Local	224091.455	177805.208	10.93
24	Grays Harbor	SD0020	GUNVILLE	Secondary	227653.074	176052.922	4.934
25	Grays Harbor	AH7008	RDAN	Local	224751.964	174824.006	6.05
26	Grays Harbor	AH7009	PRUG	Local	225147.769	171889.637	8.33
27	Pacific	AH7010	PC 068	Local	225461.984	168616.114	7.80
28	Pacific	SD0453	PC 064	Local	225502.985	165743.021	8.14
30	Pacific	AH7011	GELF	Local	225512.109	163324.692	5.74
31	Pacific	AH7012	CSW 2	Local	228200.073	161801.350	91.40
29	Pacific	AH6994	CSW 1	Secondary	228207.248	161750.215	96.91
32	Pacific	AH7013	GP 25105-13	Local	229654.821	161131.872	4.33
33	Pacific	SC0916	FLAG	Local	234674.370	158293.909	4.095
34	Pacific	SC2806	SOUTH BEND	Primary	246765.528	153108.439	25.193
35	Pacific	AH7014	LB 1	Local	227437.439	152509.793	3.88
36	Pacific	AH7015	PC 055 RM2	Local	227077.024	150868.728	4.58
37	Pacific	SD0533	PC 051	Local	226884.585	148626.156	8.69
38	Pacific	AH6995	BONE	Secondary	237206.298	148161.257	3.76
39	Pacific	SD0358	MESS	Local	229982.397	144909.939	4.209
40	Pacific	AH7016	PC 044	Local	227016.756	144587.456	7.26
41	Pacific	AH7017	PC 057	Local	227065.847	142639.147	7.76
42	Pacific	AH7018	GOULTER 3	Local	229766.295	141522.662	4.63
43	Pacific	SD0531	OYSTER 3	Local	227103.068	141090.565	8.29
44	Pacific	AH7019	PC 037	Local	227115.905	138871.463	9.79

45	Pacific	AH7020	PC 035	Local	227095.614	137662.732	9.76
46	Pacific	SD0323	X 537	Secondary	227176.554	137586.974	5.763
47	Pacific	AH7021	PC 032	Local	227056.809	135788.931	9.67
48	Pacific	SD0554	COTTA	Local	228989.637	135555.140	2.80
49	Pacific	SD0560	KLIPSAN 2	Local	226941.030	131888.571	8.85
50	Pacific	AH7022	PC 021	Local	226778.994	128970.830	8.69
51	Pacific	SD0538	SNAKE 2	Local	229550.786	128681.474	3.03
52	Pacific	SC1020	M 536	Secondary	238304.176	127434.240	7.789
53	Pacific	SD0563	RICH	Local	226581.743	126285.947	7.48
54	Pacific	SD0536	LIME 2	Local	229630.549	125706.828	3.32
55	Pacific	AH7023	PC 014	Local	226345.349	123150.053	7.40
56	Pacific	AH7024	PC 008	Local	225822.964	118601.072	7.42
57	Pacific	AH7025	PC 025	Local	225473.758	116431.952	6.32
58	Pacific	SD0287	TURN RM 4	Local	226897.696	116248.932	5.376
59	Wahkiakum	SC2756	GP 35004-3	Primary	257618.624	116055.406	27.89
60	Pacific	AH7026	PC 004	Local	225210.806	115181.161	7.23
61	Pacific	SD0854	NORTH HEAD RM 4	Secondary	224613.617	113727.382	77.69
62	Pacific	SD0090	MCKENZIE HEAD	n/a	Bad GPS Visibility		
77	Pacific	AH7027	MCKENZIE HEAD RM 3	Local	225330.915	111871.682	58.99
63	Pacific	SD0640	BETTY M	Local	227089.549	110920.242	6.55
64	Pacific	SD0299	944 0574 A TIDAL	Local	224638.597	110670.308	4.872
65	Clatsop	SD0651	EAST JETTY 2	Local	229432.797	105168.514	9.8
66	Clatsop	AB2106	SMUR*	Secondary	233158.444	102901.091	7.6
67	Clatsop	SC2198	MIT	Local	232150.030	100432.955	28.7
68	Clatsop	AH7028	IREDALE (Destroyed)	Local	231520.392	99783.876	8.3
78	Clatsop	AH8187	IREDALE RESET	Local	231520.396	99783.896	8.6
69	Clatsop	AH7029	KIM	Local	233109.080	96639.806	28.3
70	Clatsop	SC0554	UU 282*	Secondary	239326.392	95561.858	4.4
71	Clatsop	AH7030	RILEA	Local	233676.170	92569.623	13.0
72	Clatsop	SC1033	X 711*	Local	235757.129	88256.226	9.6
73	Clatsop	AH7031	DELRAY	Local	234763.667	85204.106	11.5
74	Clatsop	SC0617	MEADOW RESET*	Secondary	235240.572	82967.391	11.7
75	Clatsop	RD1141	SEASIDE RM 2*	Local	234404.488	79328.263	7.2
76	Clatsop	RD4216	CANN	Primary	231371.929	64617.918	30.5
79	Pacific	SD0297	944 0574 C TIDAL	Local	225226.997	111061.382	4.678
80	Grays Harbor		X 1 RM 1	Local	220440.491	183959.508	5.66
81	Grays Harbor		NERR 2	Local	222313.201	185939.810	4.29
90	Clatsop		ASTOR (a.k.a. ASTO)	Local	238953.073	97089.346	3.02
91	Pacific		BC TIDAL	Local	236074.214	149158.719	4.23
92	Pacific		NC TIDAL	Local	229622.823	135895.987	6.01
93	Pacific		NR TIDAL	Local	238296.162	127535.464	2.96
94	Pacific		SB TIDAL	Local	246578.968	153728.636	4.33
95	Pacific	SC0980	T 540	Local	240118.114	138893.909	31.47
96	Lacey		PARK	Special	324710.351	192957.682	49.78

3.3 Beach Profiles

The Coastal Monitoring Program has collected over fifteen hundred beach profiles since the field program began in 1997. The following sections discuss the breadth of data coverage, and issues concerning data quality.

3.3.1 Data Coverage

Starting in summer 1997, profiles were collected bi-annually, but since fall 1998 they have been collected quarterly. Summer surveys are conducted in late August and September, fall surveys in November and December, winter surveys in February and March, and spring surveys are performed in June. It typically takes 10 spring low tides (approximately five full days) to complete the 49 profiles, however, there can be several weeks separating profile collection dates within a single surveying campaign. Shoreline armoring and a beach nourishment project significantly changed the beach environment at CSW and poor GPS satellite visibility at the E2 led to elimination of these two profiles from the survey program in 1999. Two new sites (CASINO and JACKSON), in areas where increased monitoring was warranted, replaced these locations. Table 2 lists the locations of each of the 49 profiles that have been surveyed from 1997 to 2005.

While not as accurate as standard terrestrial surveying using a rod and level, walking the profiles with a GPS backpack is justified by both the reduction in survey time and the large seasonal changes observed on the high-energy beaches of the CRLC (Figure 13a). Datum-based shorelines are extracted from the beach profiles to investigate seasonal to interannual beach change (Figure 13b). Along the CRLC the 3.0-m (NAVD88) contour position has been shown to most closely approximate proxy-based shorelines as derived from aerial photography and historical surveys such as the National Ocean Service T-sheets (Ruggiero *et al.*, 2003a). Error bars on the position of the 3.0 m contour are calculated using the methodology described by Stockdon et al., 2002 for datum-based shorelines (Figure 13b).

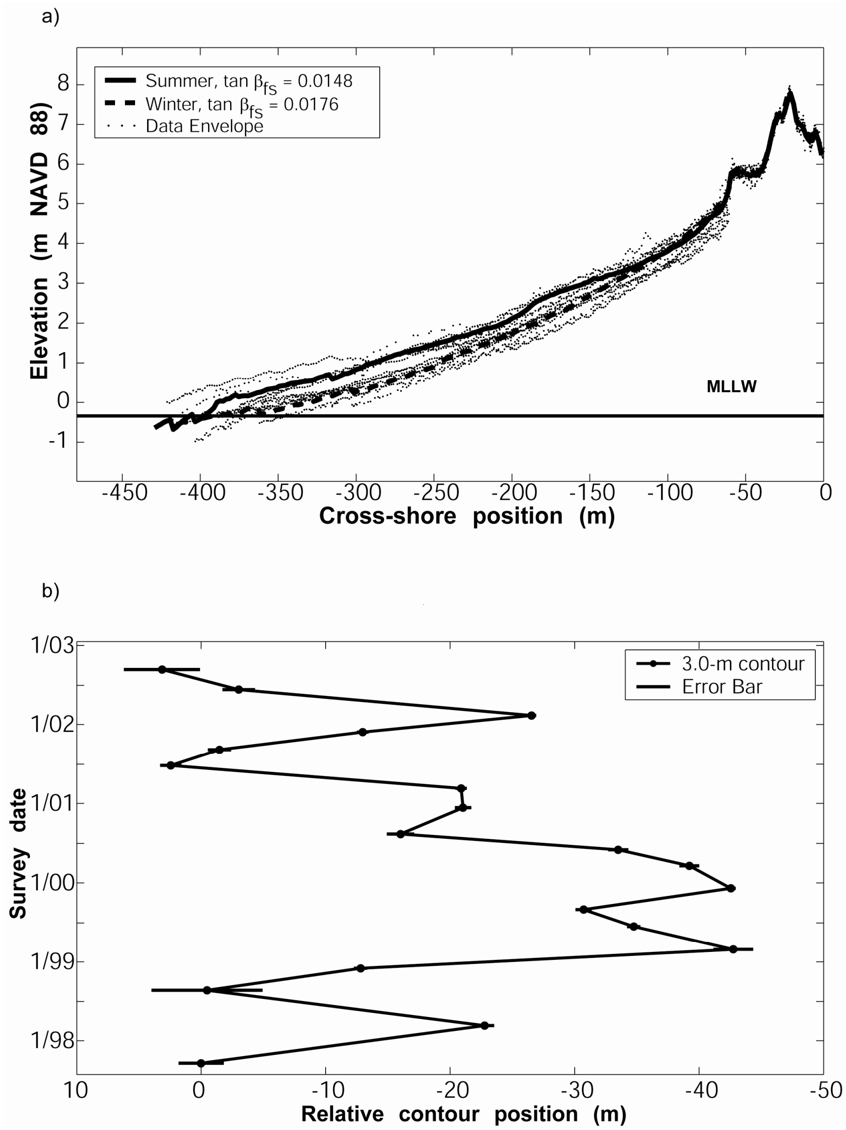

Figure 13. Seasonal changes a) observed along a cross-shore beach profile and, b) in a datum-based extracted shoreline in the CRLC.

3.4 Sediment Size Distributions

The Coastal Monitoring Program has collected and processed over 280 mid-beach surface sediment samples from 1997 to 2005.

3.4.1 Data Coverage

Due to a limited amount of processing time, the mid beach sediment samples are the only samples collected and processed consistently since the summer of 2002. Table 6 presents the coordinates for the mid-beach sample locations on each profile.

Table 6. Coordinates for sediments surface sample locations.

PROFILE NUMBER	PROFILE NAME	BEACH LOCATION	NORTHING (m)	EASTING (m)	LATITUDE (N)	LONGITUDE (W)
1	E2	Mid-Beach	225784.50	214697.70	47.30318	124.2740727
2	SOUTH	Mid-Beach	224955.20	216904.50	47.296675	124.244404
3	L443	Mid-Beach	222877.80	217749.20	47.27837	124.2319491
4	B1	Mid-Beach	221946.08	217981.20	47.270097	124.2283043
5	A1.5	Mid-Beach	220447.06	218278.70	47.256755	124.2234424
6	PIER RM1	Mid-Beach	218502.04	218664.01	47.239443	124.2171468
7	GKAM	Mid-Beach	214972.65	219443.45	47.208061	124.2046751
8	BHUX	Mid-Beach	211269.68	219982.67	47.175016	124.1952762
9	GP-14109	Mid-Beach	204506.90	220896.84	47.114634	124.1790701
10	DIANA	Mid-Beach	199581.77	221214.77	47.070511	124.1718652
11	DAMONS	Mid-Beach	193729.54	221181.36	47.01791	124.1687221
12	ET	Mid-Beach	191000.72	221042.10	46.993331	124.1688829
13	BUTTER	Mid-Beach	187598.47	220754.82	46.962638	124.170575
14	X1 NORTH	Mid-Beach	184242.38	220380.98	46.932323	124.1734288
15	X1 SOUTH	Mid-Beach	183946.08	220430.55	46.929682	124.1725975
16	HD-1	Mid-Beach	180648.70	223503.94	46.90133	124.1302886
17	WORM	Mid-Beach	179096.15	223914.21	46.887548	124.1239736
18	SPICE	Mid-Beach	177788.03	224098.37	46.875868	124.120772
19	RDAN	Mid-Beach	174837.29	224737.73	46.849615	124.1106218
20	PRUG	Mid-Beach	171888.75	225155.84	46.823289	124.1033795
21	PC068	Mid-Beach	168607.71	225461.75	46.793929	124.0974138
22	PC064	Mid-Beach	165742.80	225503.35	46.768199	124.0951596
23	GELF	Mid-Beach	163299.62	225501.38	46.746242	124.0937284
24	CSW	Mid-Beach	161117.44	228466.29	46.727838	124.0536785
25	LB1	Mid-Beach	152507.99	227436.34	46.650045	124.0620546
26	PC055	Mid-Beach	150869.71	227077.21	46.635175	124.0657744
27	PC051	Mid-Beach	148630.85	226894.65	46.61498	124.0668345
28	PC044	Mid-Beach	144588.01	227016.82	46.578695	124.0628577
29	PC057	Mid-Beach	142638.33	227066.07	46.561192	124.0610677
30	OYSTER3	Mid-Beach	141023.13	227101.57	46.54669	124.0596547
31	PC037	Mid-Beach	138870.83	227114.62	46.527352	124.0582191
32	PC035	Mid-Beach	137661.13	227094.63	46.516471	124.0577685
33	PC032	Mid-Beach	135789.31	227056.95	46.499633	124.0571593
34	KLIPSAN2	Mid-Beach	131890.57	226940.21	46.464545	124.0563892
35	PC021	Mid-Beach	128970.91	226777.85	46.438239	124.0567874
36	RICH	Mid-Beach	126284.98	226594.30	46.414024	124.0575977
37	PC014	Mid-Beach	123150.18	226345.83	46.385749	124.0589871
38	PC008	Mid-Beach	118598.87	225819.85	46.344629	124.0631464
39	PC025	Mid-Beach	116433.47	225474.97	46.325027	124.0663507
40	PC004	Mid-Beach	115182.56	225211.80	46.313677	124.0690301
41	CANBY	Mid-Beach	112242.20	224488.27	46.286955	124.0766841
42	EASTJETTY2	Mid-Beach	104717.31	229459.65	46.22133	124.0078901
43	IREDALE	Mid-Beach	99886.90	231467.36	46.178714	123.9791308
44	KIM	Mid-Beach	96632.44	232633.04	46.149923	123.962198
45	RILEA	Mid-Beach	92557.89	233693.27	46.113717	123.9461826
46	DELRAY	Mid-Beach	85352.77	234803.45	46.049389	123.9277849
47	SEASIDERM2	Mid-Beach	80086.18	234619.88	46.001978	123.9271987
48	CASINO	Mid-Beach	196607.68	220723.02	47.043581	124.176508
49	JACKSON	Mid-Beach	120901.04	225694.13	46.365269	124.066130

3.5 Three Dimensional Beach Surface Maps

The Coastal Monitoring Program has collected over 300 three-dimensional beach surface maps between 1997 and 2005. The following section describes the data collected.

3.5.1 Data Coverage

The non-uniformly spaced raw data (typically 5,000 to 10,000 points per survey) are mapped onto a uniform 2-dimensional gridded surface (10 m X 20 m), permitting comparisons with subsequent surveys (Figure 14c). Once the CLAMMER data are gridded onto a surface (Figure 14d), datum-based shorelines (contour lines) can be extracted (Figure 14b).

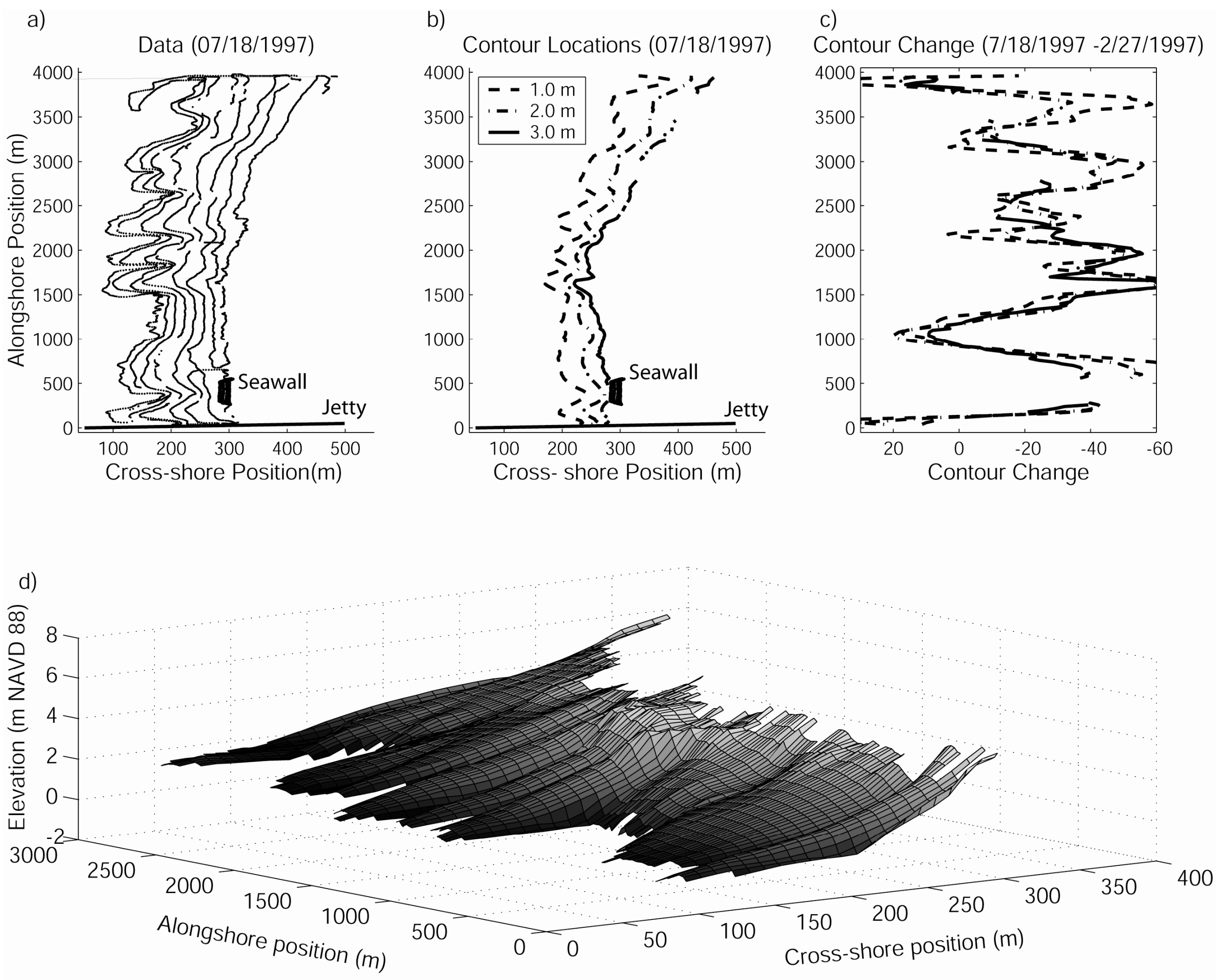

Figure 14. Surface map data is used to a) generate contour maps, b) extract contour locations, c) and compare contour change over time, d) by creating a 2-dimensional gridded surface from raw data points.

3.6 Shoreline Reference Feature Mapping

The Coastal Monitoring Program has surveyed approximately 30 shoreline reference features from 1997-2005.

3.6.1 Data Coverage

Shoreline reference feature mapping has been performed in the following five sites: Ocean Shores, Westport, Cape Shoalwater, Fort Canby, WA and Clatsop, OR. Table 7 shows the extreme northern and southern extent of these surveys. Since shoreline reference feature positions change rapidly these bounding coordinates are not strictly adhered to during these surveys. Figures 15-19 present plan views of the shoreline reference features that have been mapped at each site.

Table 7. Shoreline Reference Feature Positions

Site	Extreme Northern Extent Northing (m)	Extreme Southern Extent Northing (m)
Ocean Shores	187622.36	183742.34
Westport	181426.49	177781.09
Cape Shoalwater	163307.70	161116.17
Fort Canby	113344.66	110353.21
Clatsop	105108.52	102584.71

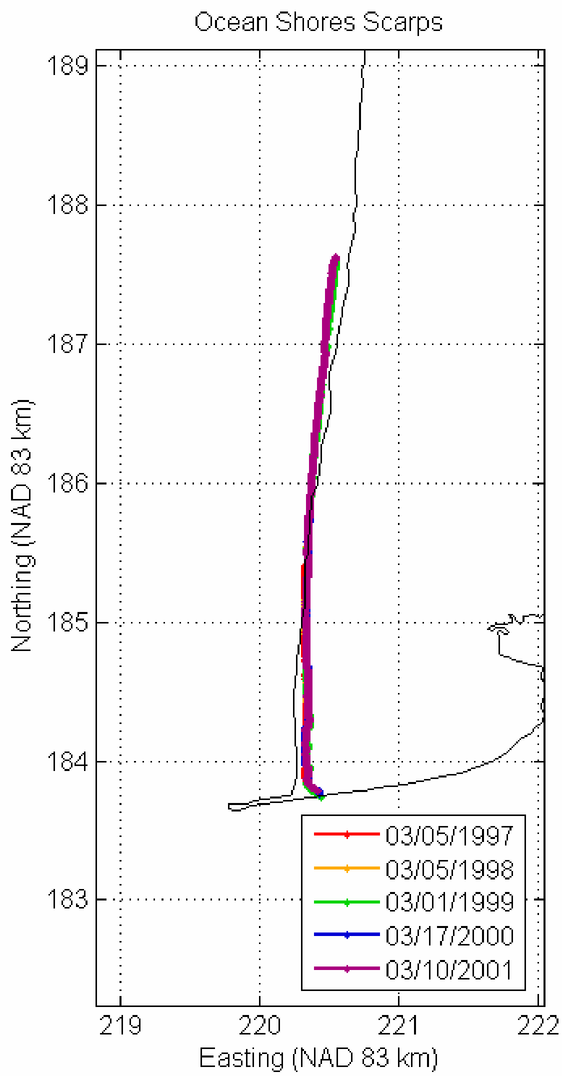

Figure 15. Shoreline reference features mapped at Ocean Shores, WA from 1997-2001.

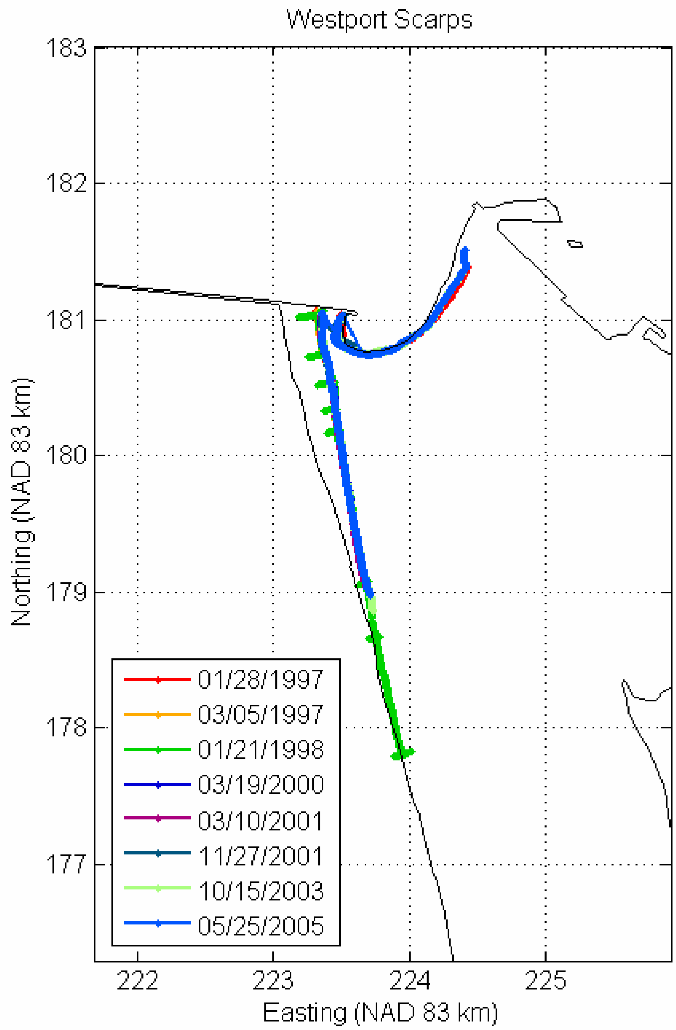

Figure 16. Shoreline reference features mapped at Westport, WA from 1997-2003.

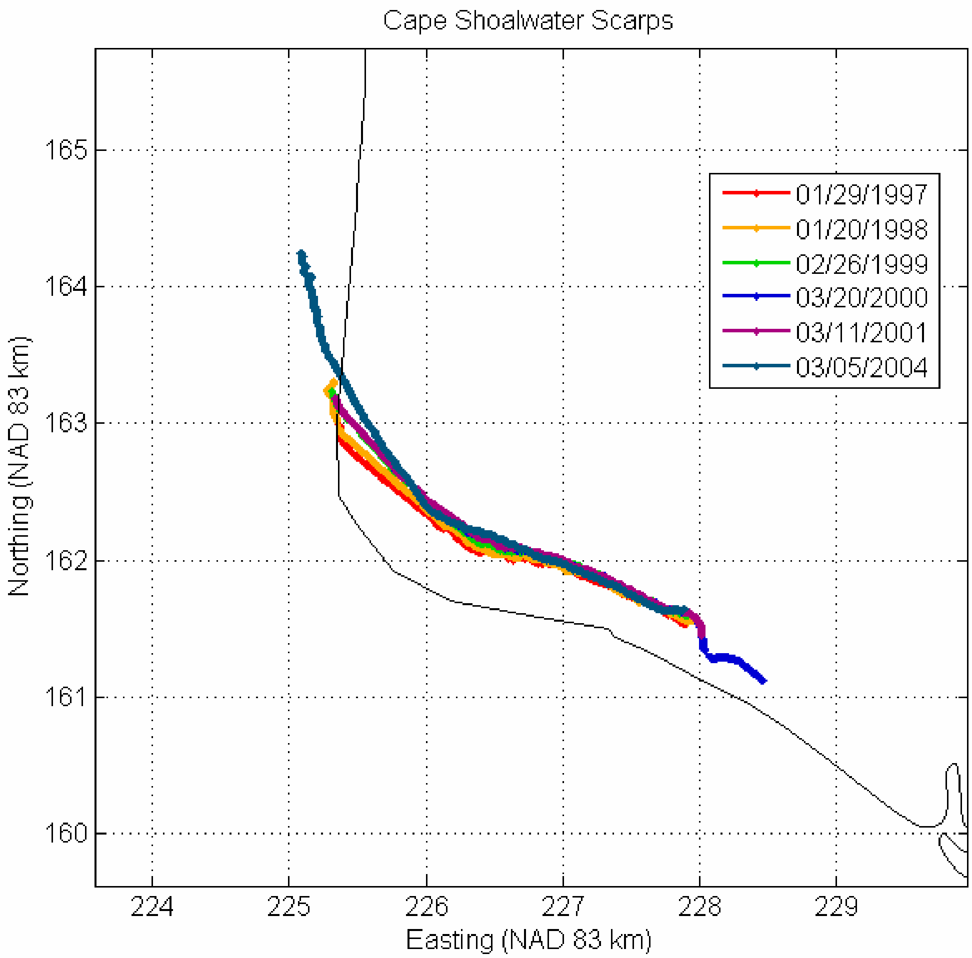

Figure 17. Shoreline reference features mapped at Cape Shoalwater, WA from 1997-2001.

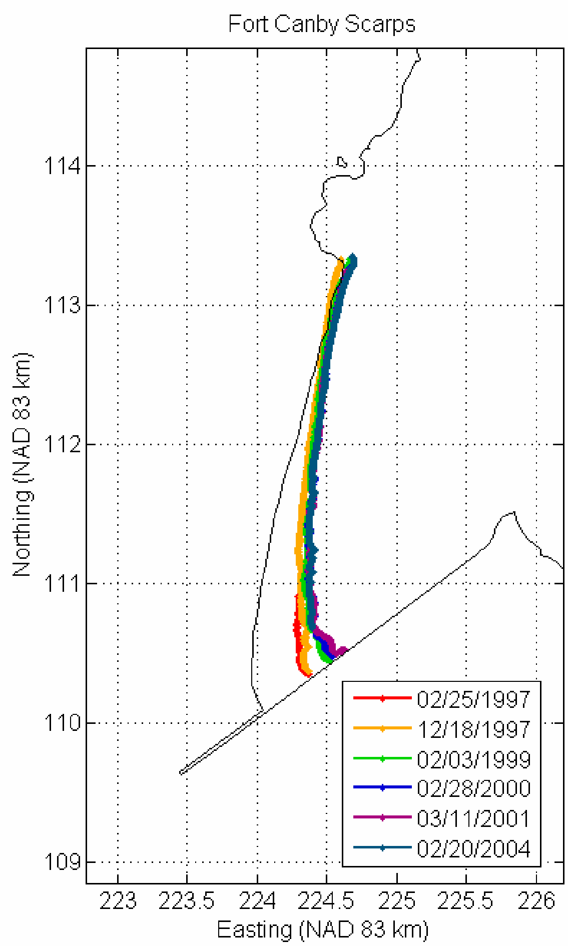

Figure 18. Shoreline reference features mapped at Ft Canby, WA from 1997-2004.

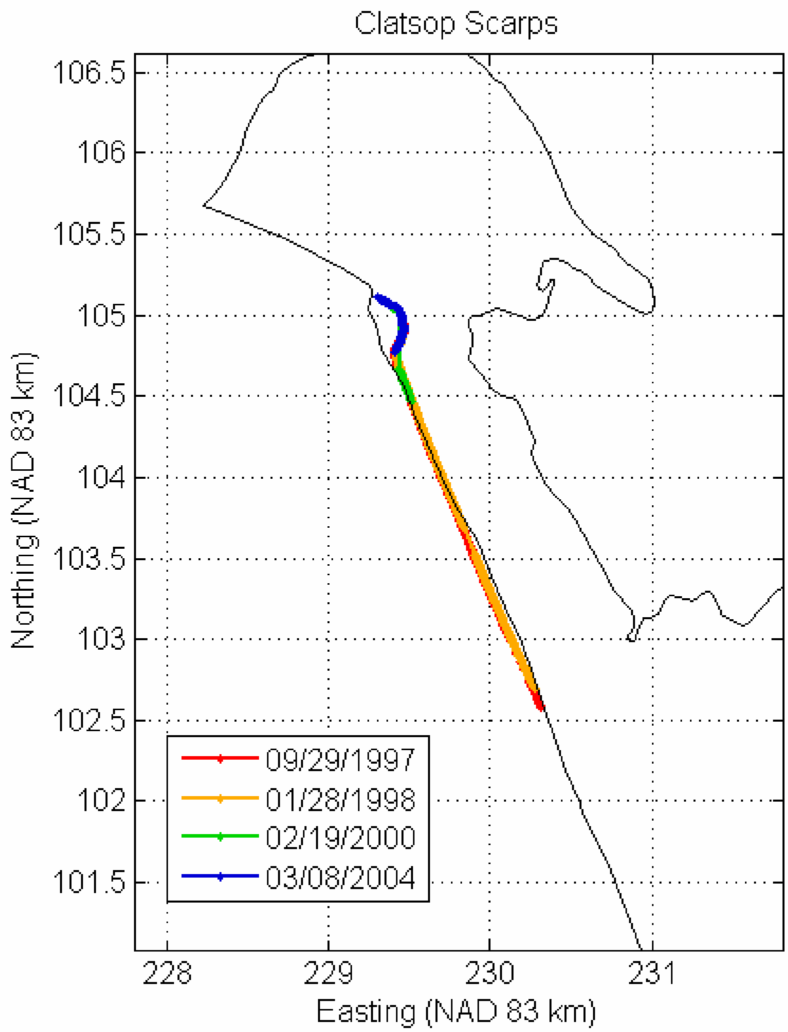

Figure 19. Shoreline reference features mapped at Clatsop, OR from 1997-2000.

3.7 Nearshore Bathymetry

We have collected over one thousand bathymetric profiles with the CPS since the field program began in 1998. Due to the impact of water temperature on echosounder data, the following sections discuss the environmental conditions during the surveys and the breadth of data coverage.

3.7.1 Environmental Conditions

Tables 8- 15 indicate the broad range of environmental conditions in which the CPS made bathymetric surveys from 1998-2005. The environmental condition data is from the closest wave buoy to the survey site (Table 1). The GH and the CRB on the right hand side of each table stand for the CDIP 036 Grays Harbor Buoy and the NDBC 46029 Columbia River Buoy, respectively. The tables have data gaps where buoy data was unavailable for that time period. Wave heights ranged from 0.6 m to 2.8 m, wave periods ranged from 4.5 seconds to 14.7 seconds, and wind speed ranged from 1.1 m/s to 9.0 m/s. When wave heights were greater than 3 m conditions were determined to be too dangerous to collect data with the CPS. In Table 14, both buoys are referenced for Long Beach because measured water temperature values at the NDBC Columbia River buoy were unrealistically low, therefore water temperature measurements from the CDIP Grays Harbor buoy (those included in Table 14) were used for sound velocity corrections. All other environmental condition data for Long Beach listed in Table 14 is from the NDBC Columbia River buoy.

Table 8. List of bathymetric profiles collected by subcell and environmental conditions in 1998

			Waves			**Wind**		**Temp**			**Buoy**	
Site / Date	**Raw Data File**	**Profiles Collected**	**Hs m**	**Tp sec**	**Dir deg**	**Speed m/sec**	**Dir deg**	**Air °C**	**Water °C**	**P mb**	**GH**	**CRB**
Ocean City												
7/21/1998	nb_072198_b.xyz	80,81,82,83,84	1.36	7.50	283	8.5	324		14.8		x	
7/22/1998	nb_072298_b.xyz	85,86,87,88,89	1.50	8.40	282	6.8	332		14.0		x	
7/23/1998	nb_072398_b.xyz	90,91,92,93,94,95	1.62	7.70	294	4.8	316		13.3		x	
Grayland Plains												
7/15/1998	gp_071598_b.xyz	33,34,35,36,37,38	1.71	7.60	236	4.5	164		15.0		x	
7/16/1998	gp_071698_b.xyz	39,40,41,42	1.20	7.40	243	2.4	242		15.2		x	
Long Beach												
8/3/1998	lb_080398_b.xyz	60,61,62,63,64,65,66	0.96	5.20	311	4.8	346		16.6			x
8/4/1998	lb_080498_b.xyz	67,68,69,70,71	1.29	4.50	346	9.2	340		16.7			x
8/5/1998	lb_080598_b.xyz	72,73,74,75,76	0.90	6.20	205	2.1	192		17.9			x
8/6/1998	lb_080698_b.xyz	220,219,218,217,216	1.56	5.50	264	6.3	336		16.0			x
8/7/1998	lb_080798_b.xyz	215,214,213	1.54	5.40	318	1.3	243		16.7			x
Clatsop Plains												

7/28/1998	cp_072898_b.xyz	83,84,85,86,87	1.21	7.00	310	1.1	244	17.5	x
7/30/1998	cp_073098_b.xyz	89,90	1.72	6.20	304	5.7	298	16.5	x

Table 9. List of bathymetric profiles collected by subcell and environmental conditions in 1999

		Waves			**Wind**		**Temp**			**Buoy**	
Site / Date	**Profiles Collected**	**Hs**	**Tp**	**Dir**	**Speed**	**Dir**	**Air**	**Water**	**P**	**GH**	**CRB**
		m	**sec**	**deg**	**m/sec**	**deg**	**°C**	**°C**	**mb**		
<u>North Beach</u>											
7/15/1999	1,1_b,2,3,5,7,9,11,13,15,16_b	1.46	9.72	303				11.6		x	
7/16/1999	18_b,20,22,24	1.04	8.18	299				11.2		x	
7/20/1999	42,43,44,16,18,26,28, 30,32,34,36,38,40	1.25	7.53	306				12.2		x	
7/21/1999 a.m.	20,15,10,5,1,2,3,4,25,30,35	0.75	6.55	301				12.5		x	
7/21/1999 p.m.	40,45,50,55,60,65	0.80	7.55	302				13.5		x	
7/22/1999	15_b,19,18,17,16,14,13,12,11,12_ls	0.90	8.35	296				13.1		x	
<u>Grayland Plains</u>											
8/23/1999	32,33,34,35,36,37	1.02	5.88	301				14.7		x	
8/24/1999	38,39,40,41,42,43,44,45, 46,47,48,49,50,51	0.75	8.13	288				15.2		x	
8/25/1999	52,53,54,55,56,57,58,59,60,61	2.01	8.90	273				15.0		x	
8/26/1999	62,63,64,65,66,67,68,69,70,71,72,73	1.27	8.48	266				15.1		x	
8/27/1999	31,30,29,28,27,26,25,24,23	1.18	8.28	275				13.6		x	
8/30/1999	73_b,74,75,76,77,78,79,80,81,82	1.69	7.97	287				12.6		x	
8/31/1999	23_b,22,21,20,19,18,17	1.48	8.35	284				14.4		x	
9/1/1999	99,98,97,96,95,94,93, 92,91,90,88,86,84	1.01	7.78	277				13.5		x	
9/2/1999	17,16	1.53	10.18	284				12.9		x	
<u>Long Beach</u>											
7/27/1999	67,68,69,70,71,72,73,74,75,76, 77,77_ls1,77_ls266,65,64	1.06	7.70	303	5.59	335	12.8	14.8	1014.6		x
7/28/1999	199,190,200,198,197,196, 195,185,180,175,170,165	1.02	7.69	293	1.73	229	13.2	14.5	1017.9		x
7/29/1999	110,115,120,125,130,135,140, 145,150,155,160,105,100	1.11	8.48	300	2.98	307	14.1	15.1	1020.8		x
8/3/1999	221_b,220,219,218,217, 216,215,214,213	0.71	14.29	247	4.13	322	16.5	17.0	1021.0		x
8/5/1999	212,211,210,209,208,207,206,221	0.95	9.70	277	5.30	333	15.3	15.9	1011.7		x
8/6/1999	95,90,85,80,64_b,63	1.08	6.25	316	2.03	233	14.7	15.4	1010.7		x
<u>Clatsop Plains</u>											
8/10/1999	82,83,84,85,86,87,88,89,90,91,92	1.41	6.68	292	5.54	328	14.6	14.8	1011.6		x
8/11/1999	93,94,95,96,97,98,99,100,101	1.99	8.33	308	3.30	189	15.5	14.9	1016.5		x

8/12/1999	66,71,76,61,56_b	1.16	10.74	295	2.20	290	14.8	14.7	1020.0		x
8/17/1999	56,51,46,41,40,39,38,37,42,43_ls	0.93	8.81	261	5.30	300	15.3	16.5	1018.7		x
8/18/1999	199,194,189,184,179,174,169,164,159	1.00	12.50	265	3.00	217	15.9	16.9	1016.1		x
8/10/1999	82,83,84,85,86,87,88,89,90,91,92	1.41	6.68	292	5.54	328	14.6	14.8	1011.6		x

Table 10. List of bathymetric profiles collected by subcell and environmental conditions in 2000

		Waves			**Wind**		**Temp**			**Buoy**	
Site / Date	**Profiles Collected**	**Hs m**	**Tp sec**	**Dir deg**	**Speed m/sec**	**Dir deg**	**Air °C**	**Water °C**	**P mb**	**GH**	**CRB**
North Beach											
7/19/2000	79,80,81,82,83,84,85	0.60	9.09	286				14.1		x	
7/20/2000	86,87,88,89,90	0.92	8.00	287				13.5		x	
7/25/2000	90_b,90_ls1,90_ls2,91, 92,93,94,95,96,97,98	1.10	7.12	269				13.3		x	
7/26/2000	16,15,14,13,12,25	1.05	7.47	280				13.8		x	
8/7/2000	60,65,69,74,55,50,45,40	1.40	8.97	290				16.0		x	
8/8/2000	35,30,20,19,18,17,16_b	1.74	8.12	298				14.0		x	
8/9/2000	11,10,9,8,7,6,5,4,3,2,1,20_ls	1.86	7.93	304				13.7		x	
Grayland Plains											
8/10/2000	32	2.05	8.71	305				13.6		x	
8/11/2000	33,34,35,36,37,38,39,40,41, 42,43,44,45,46,47,48,53	1.21	7.58	298				15.1		x	
8/12/2000	99,98,97,96,95,94,93,92,91,90, 89,88,87,86,83,78,73,68,63	0.83	7.89	293				14.5		x	
Long Beach											
8/24/2000	60,61,62,63,64,65,66,67_b	1.25	13.54	261	4.1	164	16.1	16.1	1021.0		x
8/28/2000	67,68,69,70,71,72,73,74	1.75	7.87	309	8.5	336	15.0	15.1	1018.2		x
9/5/2000	211,212,213,214,215,216, 217,204_ls,218,219,220, 221,210,209,208,207,206	1.03	14.67	217	1.8	202	14.6	15.2	1025.1		x
9/6/2000	200,199,198,197,196,195, 190,185,180,175,170,165, 160,155,150,145,140	1.60	9.61	305	3.6	297	15.4	16.7	1025.3		x
9/7/2000	110,105,100,95,90,85,80,77, 76,75,115,135,130,125,120	1.23	12.25	282	5.6	178	14.8	15.7	1014.8		x
Clatsop Plains											
9/19/2000	66,61,56,51,46,42_b	1.94	10.37	287	7.8	350	14.3	15.6	1021.6		x
9/21/2000	42,41,40,39,38,37,71, 76,82,83,84,85,86,87	2.57	9.74	297	7.5	292	14.4	15.5	1008.1		x
9/22/2000	88,89,90,91,92,93,94,95,96,97, 98,99,100,101,199,194,189,184	1.54	8.89	310	4.8	49	14.1	15.0	1014.9		x

Table 11. List of bathymetric profiles collected by subcell and environmental conditions in 2001

		Waves			Wind		Temp			Buoy	
Site / Date	**Profiles Collected**	**Hs**	**Tp**	**Dir**	**Speed**	**Dir**	**Air**	**Water**	**P**	**GH**	**CRB**
		m	**sec**	**deg**	**m/sec**	**deg**	**°C**	**°C**	**mb**		
North Beach											
8/6/2001	20,20_b,19,17,16,15,13	1.74	10.04	274				15.8		x	
8/8/2001	18,14,12,11,10	1.57	8.35	289				15.1		x	
8/9/2001	79,79_b,80,81,82,83,84,85, 86,87,88,89,90,91,92,93, 94,95,96,97,98,99,74,65	1.28	8.13	301				14.6		x	
8/10/2001	9,9_b,8,7,6,5,4,3,2,1, 25,30,35,40,45,50,55	1.14	7.51	297				15.2		x	
Grayland Plains											
7/17/2001	32,32_b,33,34,35,36,37,38,39,40, 41,42,43,44,45,46,47,48,53,58,63	1.18	7.09	296				11.8		x	
7/18/2001	99,98,97,96,95,94,93,92,91,90,89,88 87,86,83,78_b,73,68,78,84,85	0.78	7.28	278				12.7		x	
7/19/2001	32_c,32_d,gl_ls1,gl_ls2, gl_ls3,30,25,20,18,16,15	1.11	8.17	292				13.2		x	
Long Beach											
7/23/2001	60,60_b,61,62,63,64,65,66,67,68,69 70,71,72,73,74,75,76,77,80	0.97	14.29	221	4.6	324	14.1	14.1	1019.9		x
7/24/2001	211,212,212_b,213,214,215,216, 217,218,219,220,221,210,209, 208,207,206,ftcan_ls1,ftcan_ls2	2.33	9.09	315	6.1	325	14.6	14.7	1020.4		x
7/25/2001	200,200_b,199,198,197,196,195, 190185,180,175,170,165,160,155	1.96	8.22	316	7.0	322	14.0	13.6	1019.9		x
7/26/2001	150,145,140,135,130,125,120,115, 110105,100,95,90,85,85_b,85_c	1.29	7.87	315	6.0	327	13.8	13.8	1020.5		x
Clatsop Plains											
7/30/2001	101,100,100_b,99,98,97, 96,95,94,93,92,91,90,89	1.74	10.00	288	4.8	316	13.8	13.3	1018.7		x
7/31/2001	88,88_b,87,86,85,84,83,82,76,71, 66,61,56,51,46,42,41,40,39,38,37	1.40	8.73	293	0.5	226	15.1	13.9	1019.9		x
8/1/2001	106,111,116,121,126, 131,136,141,146	0.93	7.25	279	5.3	168	14.4	13.4	1017.8		x

Table 12. List of bathymetric profiles collected by subcell and environmental conditions in 2002

		Waves			Wind		Temp			Buoy	
Site / Date	**Profiles Collected**	**Hs**	**Tp**	**Dir**	**Speed**	**Dir**	**Air**	**Water**	**P**	**GH**	**CRB**
		m	**sec**	**deg**	**m/sec**	**deg**	**°C**	**°C**	**mb**		
North Beach											
8/10/2002	20,19,18,16,15,14,13,12,11,10,9,8,7	1.4	7.53	289				12.2		X	
8/12/2002	17,6,5,4,3,2,1,25,30,35,40,45,50	1.4	8.24	306				12.1		X	

8/13/2002	79,80,81,82,83,84,85,86,87, 88,89,9091,92,93,94,95	1.0	7.97	300				12.5		X	
8/14/2002	96,97,98,99,99,74,69, 69,65,65,60,60,55,55	2.8	9.74	297				12.6		X	
Grayland Plains											
7/24/2002	32,33,34,35,36,37,38,39,40, 41,42,43,44,45,46,47,48	1.1	7.97	284				13.0		X	
7/25/2002	99,97,98,95,96,93,94,92	1.3	7.32	288				14.0		X	
8/9/2002	91,90,89,88,63,58,53,68,73,78,83,87	1.1	8.65	279				14.8		X	
Long Beach											
7/15/2002	211_b,211,212,213,214,215, 216,217,218,219,220,221,223	0.9	5.74	306	6.1	331	14.4	14.1	1016.6		X
7/16/2002	210,209,208,208,207,206,bb30, bb32,bb34,222,bb36,bb38	1.3	8.33	281	1.9	247	16.2	16.6	1015.5		X
7/17/2002	200,200,199,198,197, 196,195,190,185,180, 175,170,165,160,155,150	1.5	8.20	278	4.2	200	15.5	15.4	1017.2		X
7/18/2002	115,120,125,135,140, 145,130,110,105,100,95	1.4	9.09	281	2.0	197	15.9	15.9	1018.0		X
7/19/2002	66,65,64,63,62,61,60,67,68,69,70	1.2	8.71	274	4.7	337	17.0	16.7	1020.5		X
7/22/2002	72,71,73,74,75,76, 77,80,85,90,95,73	2.2	8.94	309	1.9	267	15.8	14.6	1011.6		X
Clatsop Plains											
8/19/2002	38,39,40,41,42,46,51,56,61,66,71,76	1.6	7.27	317	3.9	349	13.7	14.2	1015.9		X
8/20/2002	81,82,83,84,85,86,87,88,89,90,91,92, 93,94,95,96,97,98,99,100,101	0.7	14.89	226	3.4	262	14.6	15.6	1018.3		X

Table 13. List of bathymetric profiles collected by subcell and environmental conditions in 2003

		Waves			Wind		Temp			Buoy	
Site / Date	**Profiles Collected**	**Hs**	**Tp**	**Dir**	**Speed**	**Dir**	**Air**	**Water**	**P**	**GH**	**CRB**
		m	**sec**	**deg**	**m/sec**	**deg**	**°C**	**°C**	**mb**		
North Beach											
8/10/2003	20,18,17,16,15,14,13,12,11, 10,9,8,7,6,20,19,18,17,16, 15,14,13,12,11,10,9,8,6	0.7	5.32	219				15.1		X	
8/11/2003	13,5,4,3,2,1,25,30,35,40,45,50,55, 60,13,5,4,3,2,1,30,35,40,45,50,55	1.2	5.65	211				15.4		X	
8/12/2002	79,80,81,82,83,84,85,86,88,79, 80,81,82,83,84,85,86,87,88	0.8	8.96	275				17.1		X	
8/13/2002	89,90,91,92,93,94,95,96,97, 98,99,74,69,65,89,90,91,92,93, 94,95,96,97,98,99,74,69,65	1.3	7.30	305				16.9		X	
Grayland Plains											
8/5/2003	30,31,32,33,34,35,36,37,38,39, 40,41,42,43,44,45,46,30,31,32, 33,34,35,36,37,40,41,42,43,44	0.9	7.20	301				13.1		X	

Site / Date	Profiles Collected	Hs	Tp	Dir	Speed	Dir	Air	Water	P	GH	CRB
8/6/2003	99,98,96,95,94,93,92,91,90,89,88,87, 86,85,84,83,78,73,99,97,95,94,92,91, 90,89,88,87,86,85,84,83,78,73	1.0	7.04	303				12.0		X	
8/7/2003	46,47,48,53,58,63,68,25,20,15, 46,47,48,53,58,63,68,25,20,15	0.7	9.95	260				12.1		X	
Long Beach											
7/28/2003	199,200,199,198,197,196,195	1.7	8.17	320	5.6	318	15.43	14.9	1017.7		X
7/29/2003	190,185,175,165,155,145,130,190, 180,170,160,150,140,135,125	1.5	8.33	322	3.6	320	15.82	15.9	1016.8		X
7/30/2003	66,65,63,60,50,68,70,72,73,66, 64,62,61,55,45,67,69,71	2.1	9.09	316	7.6	334	15.78	15.9	1017.0		X
7/31/2003	125,135,105,95,90,85,76,115,120, 130,135,110,100,95,80,77,75,74	1.8	8.79	322	5.0	348	14.90	14.8	1019.6		X
8/1/2003	211,212,214,215,217,219,220,221, 222,210,209,208,207,206,203, 211,213,216,218,220,221,222, 223,224,210,209,208,207	0.9	10.00	285	5.3	289	15.02	15.1	1019.8		X
Clatsop Plains											
9/15/2003	5,5,6,7,8,9	2.1	9.55	309	2.4	224	15.00	15.0	1015.9		X
9/16/2003	10,11,16,19,24,25,26,29,10, 11,12,13,14,15,17,18,20, 20_cross,21,22,22_cross,23,27,28,30	1.6	8.30	298	6.3	295	14.35	14.5	1015.0		X
9/17/2003	31,33,36,56,61,31,32,34,37,38, 39,40,41,42,46,51,56,66,71	1.4	7.71	307	3.8	196	14.43	14.4	1022.8		X
9/18/2003	66,76,85,87,89,91,93,66,82,83, 84,86,88,90,92,94,96,97	1.9	7.90	282	9.0	182	14.20	13.7	1016.8		X

Table 14. List of bathymetric profiles collected by subcell and environmental conditions in 2004

		Waves			Wind		Temp			Buoy	
Site / Date	**Profiles Collected**	**Hs**	**Tp**	**Dir**	**Speed**	**Dir**	**Air**	**Water**	**P**	**GH**	**CRB**
		m	**sec**	**deg**	**m/sec**	**deg**	**°C**	**°C**	**mb**		
North Beach											
8/17/2004	25,20,19,18,16,14,12,10,8,17,15,13,11	0.6	8.19	244				17.7		X	
8/18/2004	35,9,6,4,2,40,50,30,7,5,3,1,45,55,65,60	1.2	12.7	270				15.4		X	
8/19/2004	98,96,94,92,90,88,86,84,82,80,99,97,95, 93,91,89,87,85,83,81,79,69	1.3	6.41	303				15.5		X	
Grayland Plains											
8/15/2004	99,97,95,93,91,89,87,85,83,73,63,109, 107,105,103,101,98,96,94,92,90,88,86, 84,78,67,68,108,106,104,102,100	0.7	7.77	274				16.4		X	
8/16/2004	53,48,47,46,45,44,43,42,41,40,39,38,37, 36,35,34,33,32,31,25,20,15	0.6	8.19	244				17.7		X	
Long Beach											
7/28/2004	210,211,213,215,217,219,31,33,35,37, 39,266,204,202,212,214,216,218,30,32, 34,36,38,268,264	2.1	8.84	313	3.7	323	15.68	16.1	1017.2	X	X
7/29/2004	206,207,209,203,205,208	2.2	8.33	310	5.3	334	15.42	16.3	1017.2	X	X

7/30/2004	201,200,198,195,185,175,165,155,145, 199,198,197,196,190,180,170,160,150, 140	1.4	7.28	302	1.6	266	16.00	15.3	1016.6	X	X
7/31/2004	115,120,125,130,135,115,110,105	2.0	8.12	305	4.4	308	14.77	17.5	1014.3	X	X
8/1/2004	100,95,90,85,80,77,76,75,74,73,72,71	2.1	8.71	309	3.4	315	14.80	16.9	1014.1	X	X
8/2/2004	69,70,68,66,65,64,63,62,61,60	1.2	7.42	315	1.4	171	14.90	15.3	1015.8	X	X
Clatsop Plains											
8/20/2004	66,56,42,40,71,61,51,46,41,39,38,37, 40,76	1.2	6.46	319	4.7	330	16.8	13.6	1017.9		X

Table 15. List of bathymetric profiles collected by subcell and environmental conditions in 2005

		Waves			Wind		Temp			Buoy	
Site / Date	**Profiles Collected**	**Hs m**	**Tp sec**	**Dir deg**	**Speed m/sec**	**Dir deg**	**Air °C**	**Water °C**	**P mb**	**GH**	**CRB**
North Beach											
9/17/2005	25,19,17,15,13,11,9,4,25,20,18,16,14, 12,10,8,7,6,5,3,2,1,30,35	1.0	18.18	230				13.7		X	
9/18/2005	81,82,85,86,89,90,93,94,97,98,74,45, 79,80,83,84,87,88,91,92,95,96,99,69, 65,60,55,50,40	0.8	16.67	229				14.5		X	
Grayland Plains											
8/20/2005	35,37,39,41,43,45,47,58,68, 30,32,31, 33,34,36,38,40,42,44,46,48,53,63	0.6	14.29	223				11.2		X	
8/21/2005	98,96,94,92,90,88,86,84,78,97,99,97, 95,93,91,92,89,87,85,83,73,99	1.1	7.20	304				12.7		X	
Long Beach											
8/23/2005	214,215,216,217,218,219,30,220,32,221, 34,222,36,223,38,224,213,212,211,210, 209,208,207,206	1.6	7.32	317	2.0	295	15.55	13.5	1017.5		X
8/24/2005	200,201,199,198,202,203,204,205,197, 196,195,190,185,180,175,170,165,160, 155,150	1.3	7.42	314	8.2	333	14.42	12.9	1013.5		X
9/21/2005	61,63,65,67,69,71,73,75,85,95,105,115, 60,62,64,66,68,70,72,74,76,77,80,90, 100,110	1.9	11.1	297	7.9	334	13.47	12.1	1022.7		X
Clatsop Plains											
9/22/2005	89,87,85,83,81,71,39,41,66,61,56,51,46, 42,40,38,37,76,82,84,86,88	1.8	9.3	301	3.3	337	13.2	12.4	1019.9		X

3.7.2 Data Coverage

Figures 20-21 show the locations, in plan view, of each of the bathymetric profiles collected between 1998 and 2005.

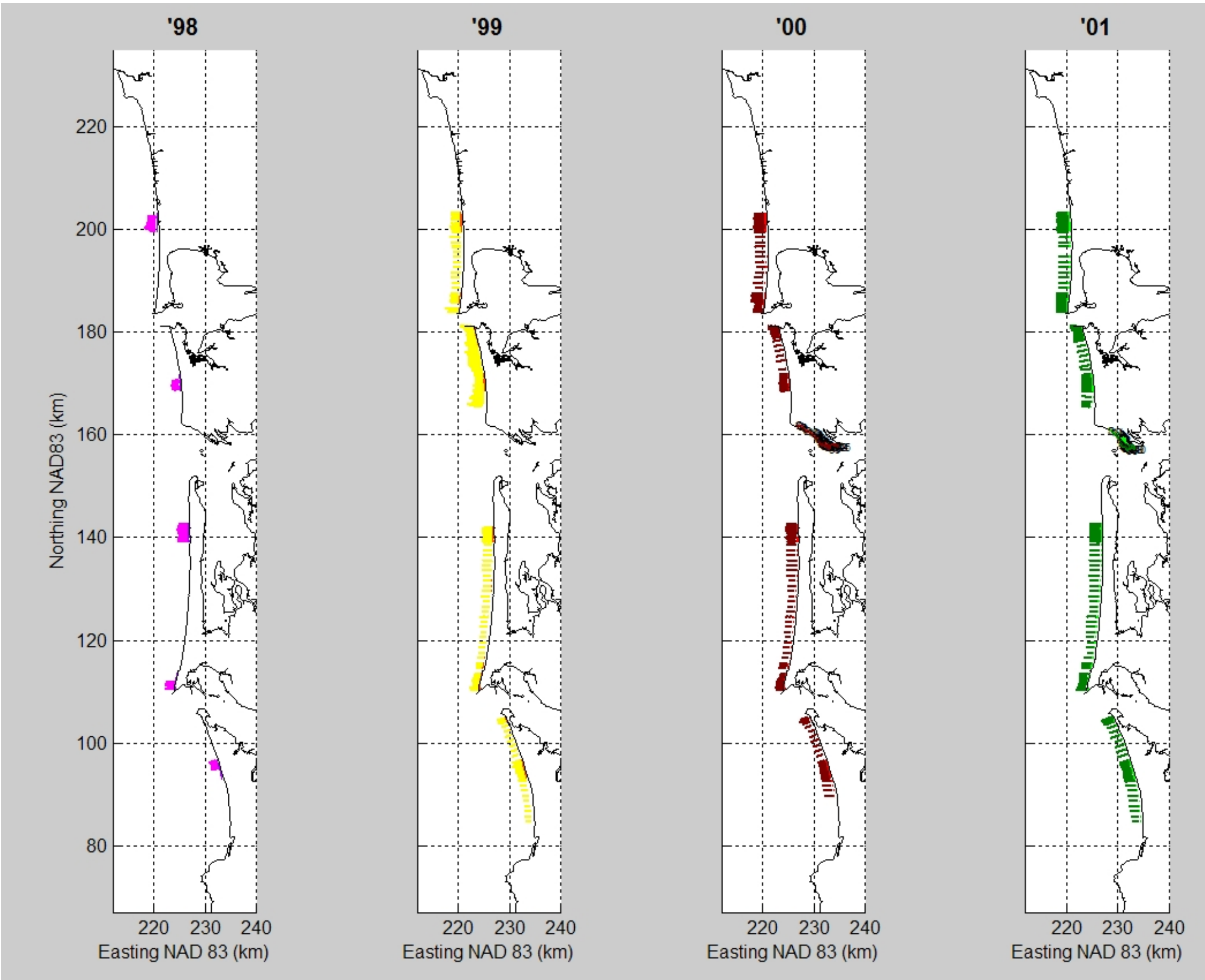

Figure 20. Nearshore bathymetry profiles collected from 1998-2001 in each of the four sub cells.

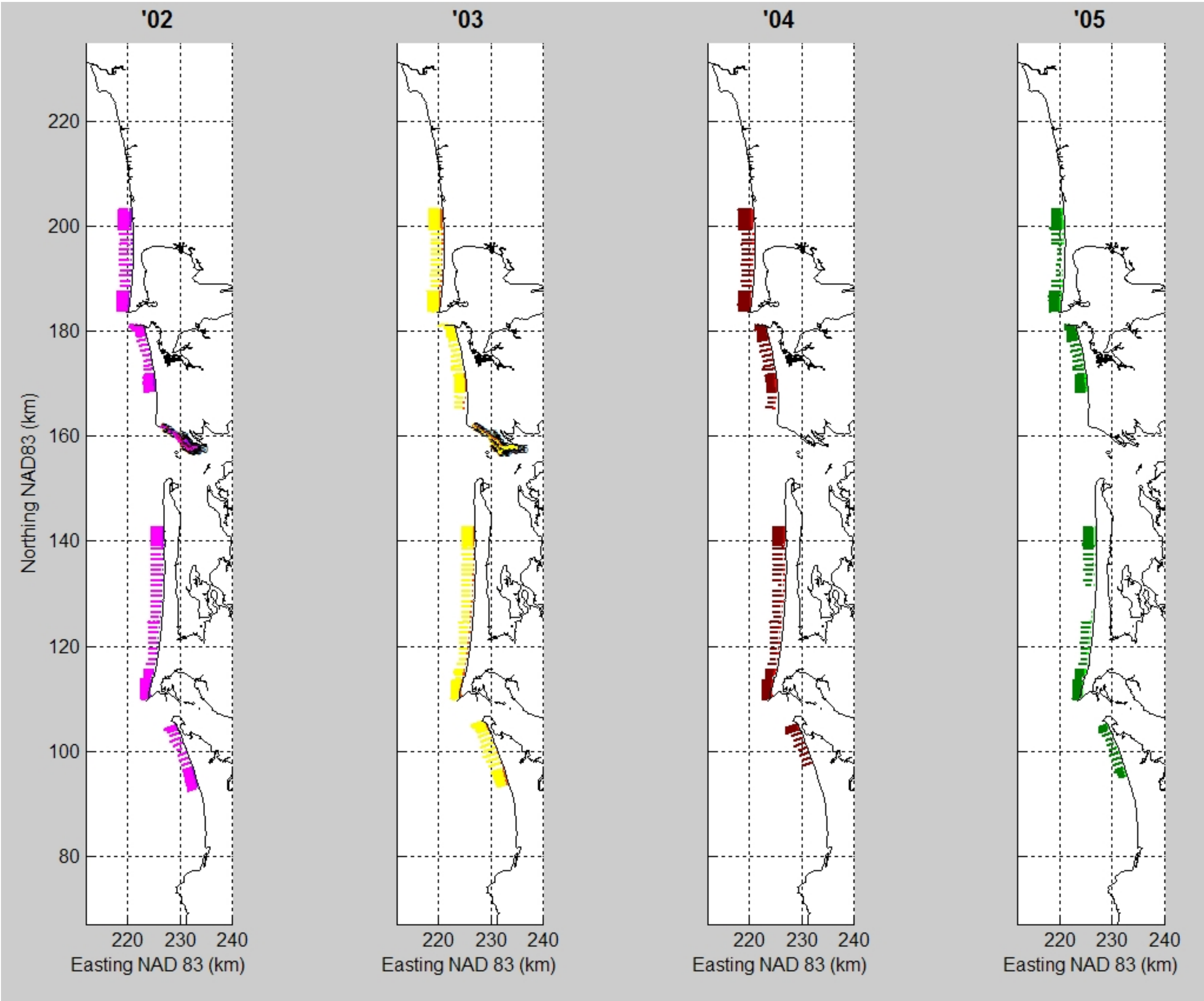

Figure 21. Nearshore bathymetry profiles collected from 2002-2005 in each of the four sub cells.

4. PRELIMINARY OBSERVATIONS

We have employed a nested sampling scheme to quantify the alongshore variability of a variety of beach state parameters as well as the short- to medium-term (seasonal to interannual) beach change rates along the CRLC. The following sections discuss the morphodynamic variability along the CRLC found during the first 8 years of the monitoring program.

4.1 Beach State Parameters

Data from the monitoring program provide a regional inventory of physical parameters that help define the morphological 'state' of the beach. The beaches of the CRLC are comprised primarily of well-sorted medium to fine sand with a temporal and alongshore-averaged median mid-beach grain size of approximately 0.20 mm (ranging from 0.12 to 0.71 mm within the littoral cell with a standard deviation of 0.11 mm). Extensive black-sand placer deposits exist on the beaches adjacent to the mouth of the Columbia River accounting for up to 70% of most samples (Li and Komar, 1991). While there is a coarsening of sediments with increasing distance from the source within approximately the first 10 km north of the Columbia River, the general trend suggests grain sizes decrease with increasing distance from the Columbia River (Figure 22, Table 16). This trend of alongshore sorting is interrupted near the mouth of Grays Harbor, where coarse sediment lag deposits (derived from glacial outwash and eroded from the shoreface) exist on the beach. Eliminating the two sites (Worm and Spice) that contain this coarse sediment lag reduces the median mid-beach (~MHW) grain size to approximately 0.18 mm.

The sediment size trend is well correlated to a gradient in foreshore beach slope, with slopes decreasing with distance from the Columbia River. The slope of the sub-aerial beach, β_{fs}, is defined as the gradient between the 1.0 and 3.0 m elevation contours on the beach profiles, and here we have taken the temporal mean of several summer values at each site, typically 6 observations from 1997 – 2002. The mean foreshore beach slope in the CRLC is approximately 0.021 (1V:48H), ranging from 0.01 (1V:100H) to 0.055 (1V:18H) with a standard deviation of 0.008 (Table 3). The northern portion of the North Beach sub-cell exhibits the finest grain sizes and the lowest sloping beaches within the CRLC.

Large-scale coastal behavior varies along the CRLC as evidenced by variability in foredune ridge morphology, nearshore beach slopes, and morphometric bar parameters (Ruggiero et al., 2005). The highest primary foredune ridges, as measured in summer 1997, are in the Clatsop Plains sub-cell, with dunes elevations measuring as high as 15 m (NAVD 88). North of the Columbia River foredune ridges are distinctly lower, with the lowest primary dune elevations in the northern section of the North Beach sub-cell, where small incipient dunes less than 5 m (NAVD 88) have formed in front of the backing sea cliffs and bluffs (Figure 22). The cause for this variability in foredune height is probably most closely linked to variability in decadal scale shoreline change rates along the CRLC. While the shoreline along Clatsop Plains has remained relatively stable since the 1950s (Kaminsky *et al*., 1999), the beaches along much of Long Beach and North Beach sub-cells prograded at several meters per year during this time period. Following the conceptual model of foredune morphology described by Hesp (2002), stable beaches tend to build dunes vertically while prograding beaches build a series of foredune ridges over time.

Sandbars are also prominent morphological features within the CRLC and the spatial and temporal variability of bar properties is striking. The CRLC nearshore exhibits between 0 and 4 distinct sandbars, ranging in height from approximately 0.1 m (measurement limit) to a remarkable 6.0 m as measured from the seaward crest to landward trough. Sandbar crest position varies from approximately 100 m from the shoreline (approximated here by the 3.0 m contour position) for intertidal slip face ridges to over 1000 m from the shoreline for subtidal outer bars. The water depth at the crest of the outer bar ranges from -3.0 to -8.5 m (NAVD88) while crest depths are typically -1.5 to -3.0 m (NAVD88) for middle bars and +2.0 to -1.5 m (NAVD88) for intertidal bars.

Nearshore slopes and morphometric bar parameters are summarized in Figure 23 for data collected during summer 2002. The water depths 1500 m from the shoreline (3.0 m contour), a proxy for nearshore slope, are relatively shallow where profiles intersect the lobes of ebb-tidal deltas near the mouth of the Columbia River, Willapa Bay, and Grays Harbor. Away from estuary entrances, the nearshore slope decreases with distance from the Columbia River. Bar behavior along Long Beach is different than along the other sub-cells because the outer bar is further from the shoreline and in deeper water. The 2002 Long Beach middle bar is larger in amplitude than any other bars within the CRLC. Along the southern 10 km of the Long Beach sub-cell, there is a correlation between nearshore beach slope and outer bar position with steeper beaches (deeper water at 1500 m) having outer bars further from the shoreline (Figure 23).

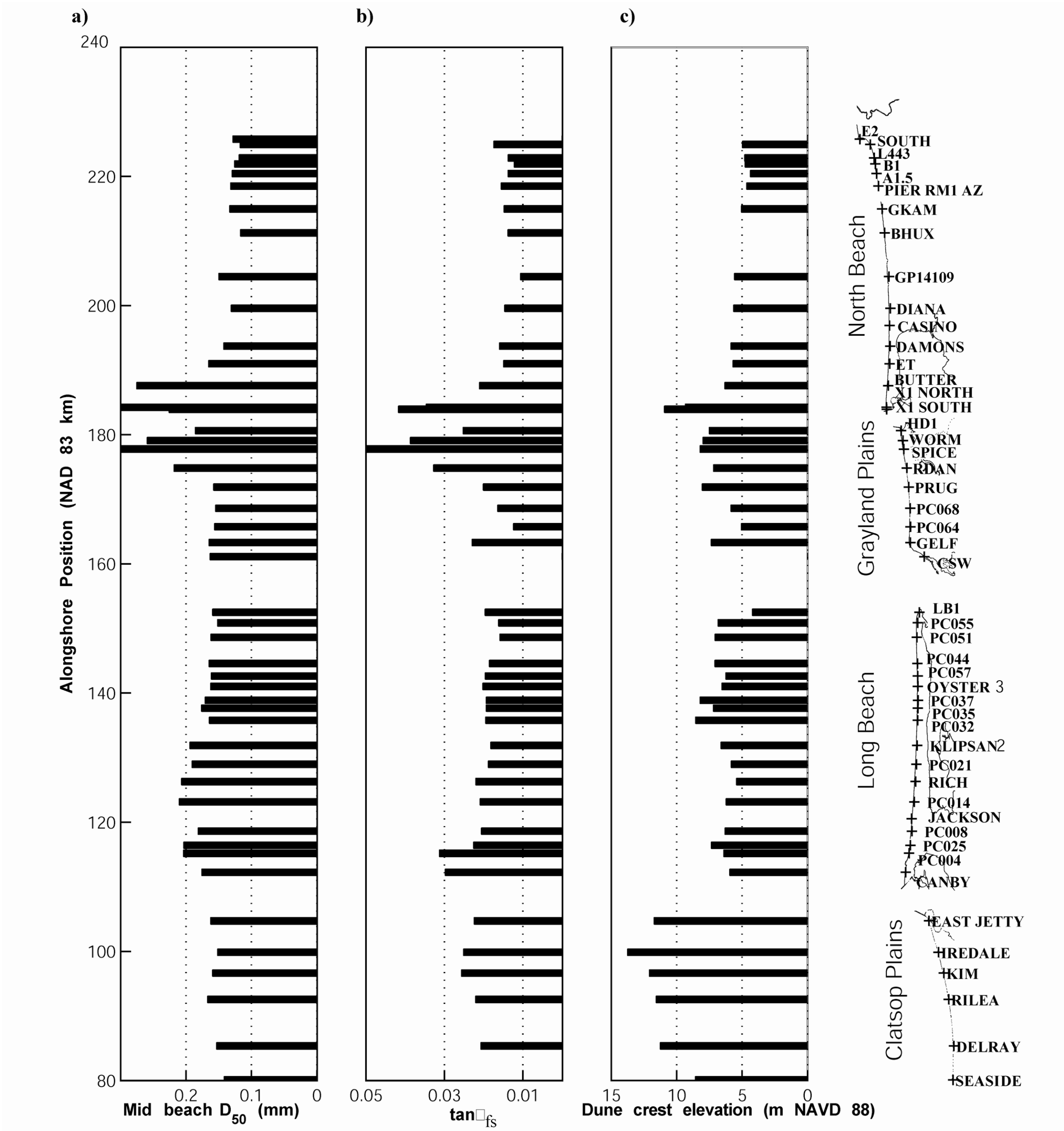

Figure 22. Beach state parameters along the CRLC. a) The average median grain size from samples collected at approximately MHW during both the summer 1998 and summer 1999 survey are shown. b) The slope of the sub-aerial beach as defined as the gradient between the 1.0 and 3.0 m elevation contours on the profile. Slope values have been averaged for 6 summer surveys collected between 1997 and 2002 at each of the 47 beach profile locations. c) The primary dune crest elevation, as measured in summer 1997, is given relative to NAVD 88.

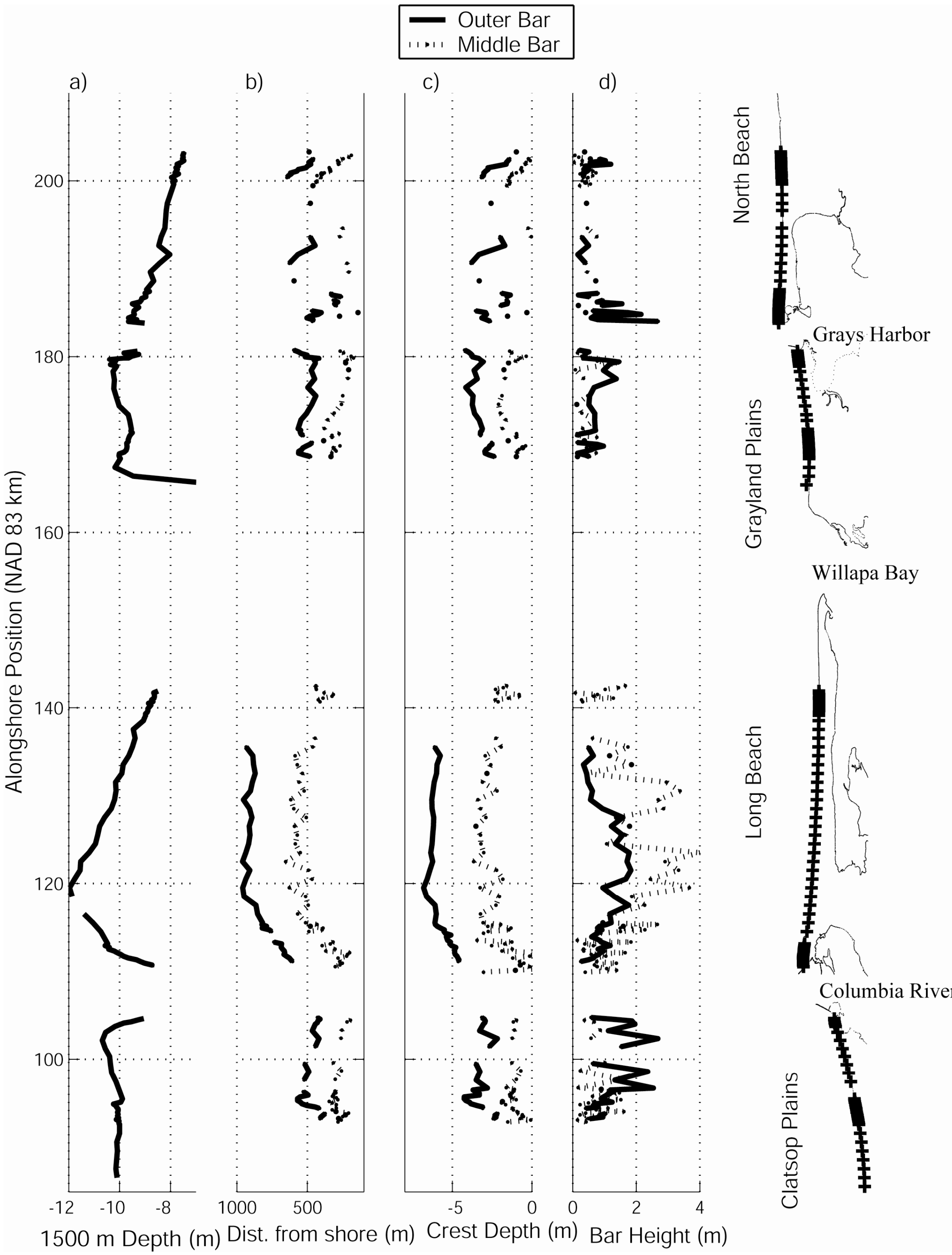

Figure 23. Bathymetric beach state parameters (summer 2002). a) A regional inventory of nearshore beach slope represented by the water depth 1500 m from the 3.0 m contour, b) the position of sandbar (outer and inner) crests, c) sandbar crest depths, and d) sandbar heights. The plusses on the map of the littoral cell indicate where nearshore beach profiles are collected.

4.2 Seasonal to Interannual Beach Change

The sub-aerial topographic beach profiles and surface maps are used to quantify the seasonal cycles in the sub-aerial beach of the CRLC. The average horizontal retreat of the shoreline (3.0 m contour) for each of the profiles and surface maps during each winter season as well as the average horizontal recovery during each summer season is listed in Table 16 and 17 respectively. As a result of the seasonal reversals in cross-shore and alongshore sand transport directions, the net change of the shoreline position over the full annual cycle is often small relative to the seasonal variability (Figure 24). However, the interannual change rates can be significant, particularly near estuary entrances (Figure 25, Table 16, Table 17). The average net shoreline change rate as determined from the beach profiles over eight years of survey data is 5.37 meters per year of progradation. The average net shoreline change rate as determined from the surface maps over eight years of survey data is 2.5 meters per year of progradation. This discrepancy can be explained by several beach profiles with high progradation rates near estuary entrances.

4.3 Future Directions

The beach morphology monitoring program of the SWCES has for the first time comprehensively and systematically quantified the short- to medium-term morphodynamic variability of the 165 km-long Columbia River littoral cell. The sampling scheme, nested both in time and space, is successfully resolving the seasonal cycles of beach loss and recovery. Variations in upper shoreface slopes, foredune ridge morphologies, and sandbar dimensions document the extent of alongshore variability in large-scale coastal behavior not previously known to exist in U.S. Pacific Northwest littoral cells or on high-energy dissipative beaches in general. Continued research on the variability in beach behavior across multiple scales is important for both an improved understanding of large-scale coastal behavior and coastal management decision-making. While important alongshore differences in sub-regional coastal behavior have been found, future work aims to examine the primary causative processes, e.g., sediment supply, shoreface morphology, and wave climate, responsible for these differences.

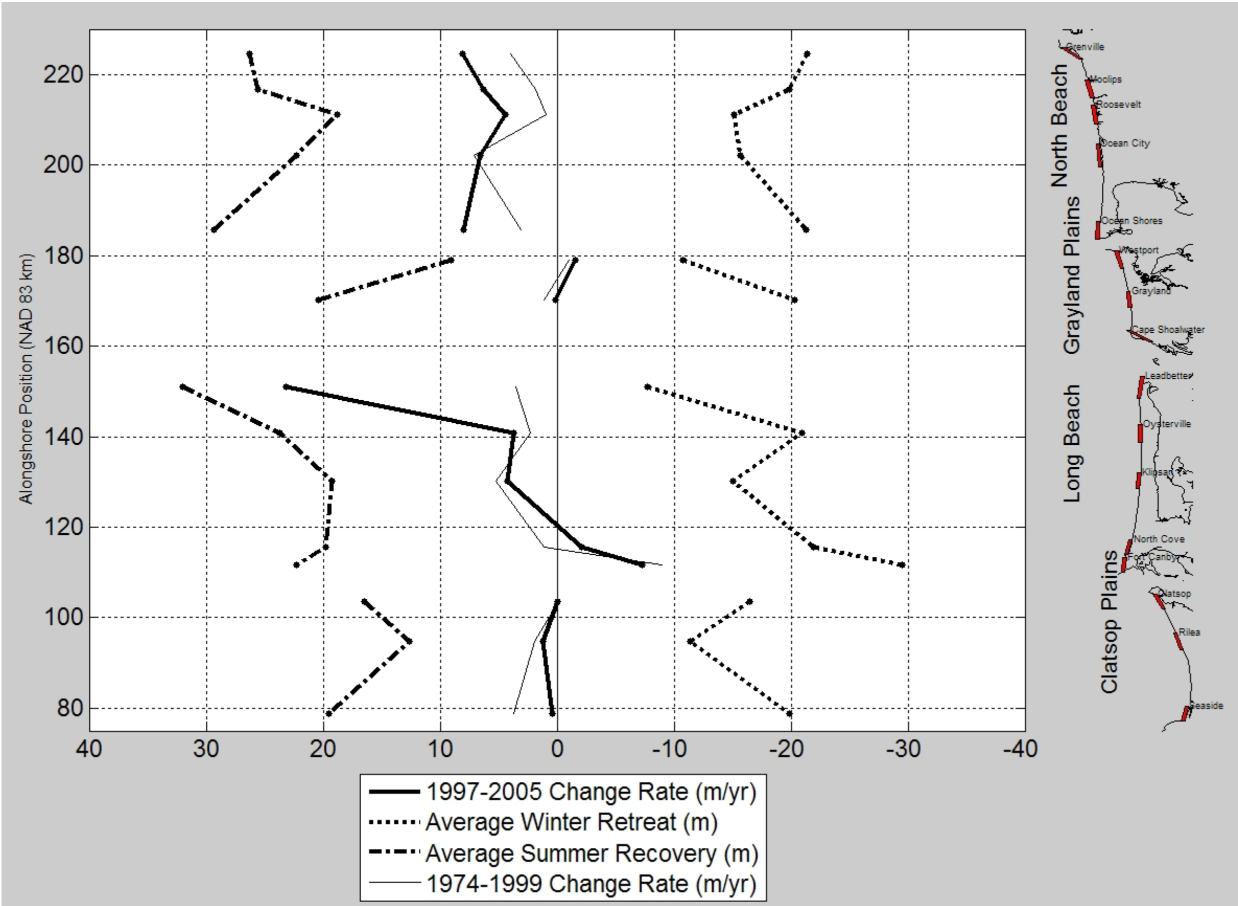

Figure 24. Seasonal- interannual shoreline (contour) variability. The average winter erosion and average summer progradation of the 3.0 m contour line derived from 15 of the 16 beach surface maps between 1997 and 2005. These large seasonal fluctuations produce low net annual shoreline change rates. Recent interannual shoreline change rates are similar to decadal-scale shoreline change observed between 1974 and 1999 (Kaminsky et al., 1999).

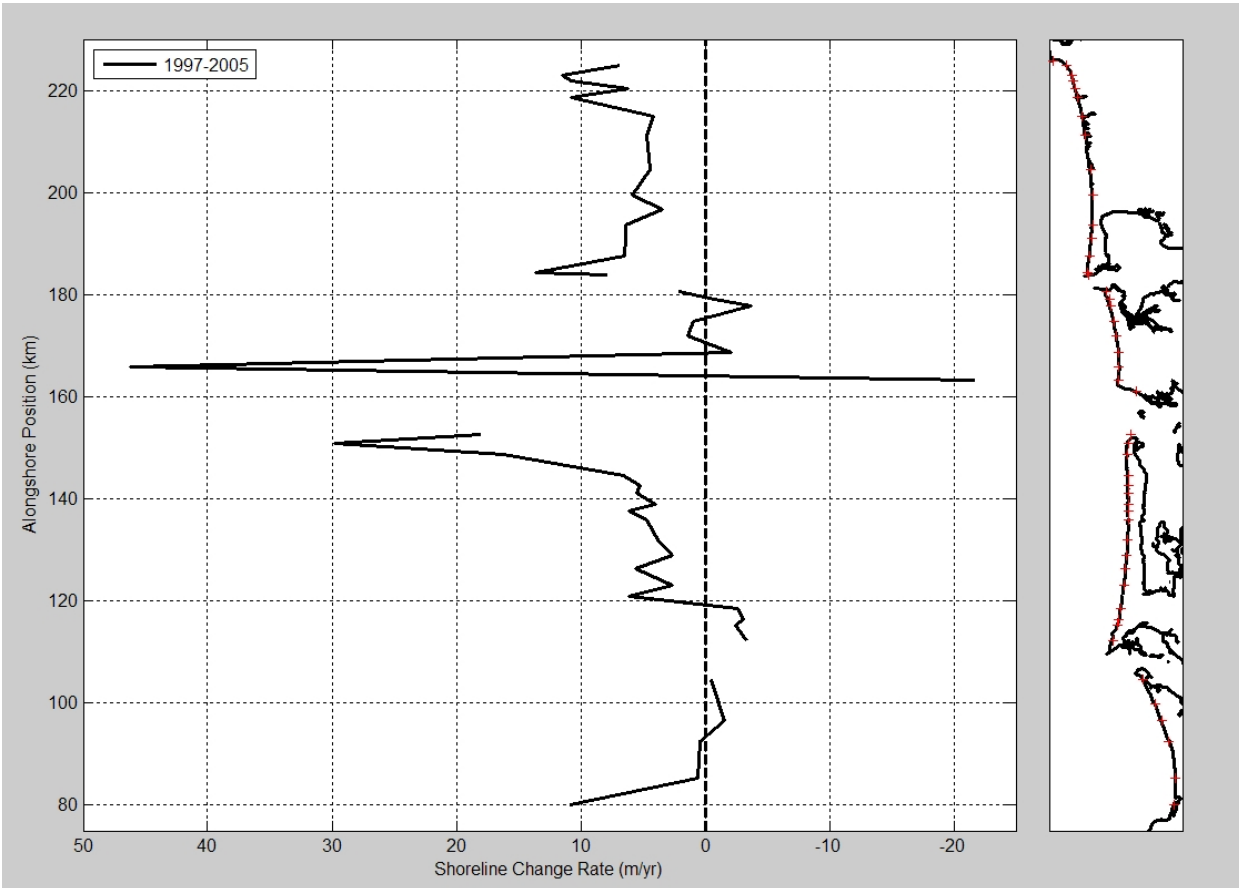

Figure 25. Interannual shoreline change rate determined from sub-aerial topographic beach profiles collected from 1997-2005.

Table 16. Beach profile name, location, 3.0-m contour change rate, beach slope and sediment size.

Profile #	Profile Name	Northing (m NAD 83)	Winter Retreat (m)	Summer Recovery (m)	Net Change (1997-2005) (m)	Change Rate (m/yr)	Foreshore Beach Slope	D_{50} (mm)
[1,4]1	E2	225785	---	---	---	---	---	---
2	SOUTH	224955	-5.82	13.64	54.63	6.83	0.014	0.125
3	L443	222878	-17.47	34.33	91.74	11.47	0.013	0.119
4	B1	221946	-13.54	25.43	86.14	10.77	0.012	0.126
5	A1.5	220447	-2.39	23.50	49.46	6.18	0.014	0.129
6	PIER RM1 AZ	218502	-17.01	21.93	86.14	10.77	0.015	0.137
7	GKAM	214973	-14.55	18.19	32.92	4.11	0.014	0.139
8	BHUX	211270	-5.91	6.46	37.69	4.71	0.014	0.126
[2,4]9	GP-14109	204507	---	26.04	35.42	4.43	0.010	0.156
10	DIANA	199582	-10.32	17.92	46.67	5.83	0.015	0.139
11	DAMONS	193730	-7.18	15.89	51.02	6.38	0.016	0.151
12	ET	191001	-8.51	15.96	51.10	6.39	0.014	0.176

13	BUTTER	187598	-12.84	27.67	51.76	6.47	0.020	0.249
14	X1 NORTH	184256	-19.91	36.60	108.80	13.60	0.033	0.300
15	X1 SOUTH	183946	-21.41	27.28	62.70	7.84	0.040	0.226
16	HD-1	180649	-4.33	11.39	16.48	2.06	0.025	0.179
17	WORM	179096	-11.05	11.50	-5.97	-0.75	0.039	0.599
18	SPICE	177788	-4.51	0.54	-29.35	-3.67	0.055	0.714
19	RDAN	174837	-4.41	8.81	7.43	0.93	0.033	0.209
20	PRUG	171889	-10.38	11.35	11.13	1.39	0.020	0.169
21	PC068	168608	-19.24	17.67	-16.97	-2.12	0.016	0.161
[4]22	PC064	165743	29.81	24.29	369.94	46.24	0.013	0.165
[4]23	GELF	163300	-38.52	14.58	-173.93	-21.74	0.023	0.188
[1,4]24	CSW	161117	---	---	---	---	---	---
[4]25	LB1	152508	-5.87	21.39	143.94	17.99	0.016	0.169
[4]26	PC055	150870	-0.72	27.79	238.13	29.77	0.015	0.162
27	PC051	148631	-14.12	29.48	129.60	16.20	0.016	0.169
28	PC044	144588	-13.49	19.88	52.17	6.52	0.019	0.171
29	PC057	142638	-15.93	22.23	41.63	5.20	0.020	0.168
30	OYSTER 3	141023	-11.82	20.30	43.67	5.46	0.020	0.173
31	PC037	138871	-11.47	13.77	32.08	4.01	0.019	0.180
32	PC035	137661	-6.56	15.94	48.70	6.09	0.019	0.185
33	PC032	135789	-13.49	18.95	37.56	4.70	0.019	0.178
34	KLIPSAN 2	131891	-16.61	21.59	30.58	3.82	0.018	0.196
35	PC021	128971	-13.81	22.39	21.12	2.64	0.018	0.197
36	RICH	126285	-15.91	21.96	44.79	5.60	0.022	0.214
37	PC014	123150	-15.50	19.09	20.99	2.62	0.021	0.216
38	PC008	118599	-20.83	18.10	-21.07	-2.63	0.020	0.187
39	PC025	116433	-14.97	13.22	-24.42	-3.05	0.022	0.206
40	PC004	115183	-13.36	12.10	-19.52	-2.44	0.030	0.206
41	CANBY	112242	-14.42	16.75	-27.07	-3.38	0.030	0.187
42	EAST JETTY 2	104717	-1.85	12.15	-3.73	-0.47	0.022	0.165
43	IREDALE	99862	-14.03	14.69	-8.66	-1.08	0.024	0.163
44	KIM	96632	-13.37	13.81	-12.40	-1.55	0.025	0.167
45	RILEA	92558	-10.16	11.83	3.14	0.39	0.022	0.174
46	DELRAY	85353	-11.18	12.56	4.92	0.61	0.021	0.163
47	SEASIDE RM2	80086	-16.89	35.76	87.12	10.89	0.015	0.151
[3,4]48	CASINO	196608	2.87	13.29	54.53	10.91	---	---
[3,4]49	JACKSON	120901	-11.91	21.53	28.34	5.67	---	---
		Average	**-11.19**	**18.76**	**41.94**	**5.37**	**0.021**	**0.196**
		Std	**9.18**	**7.43**	**76.24**	**9.56**	**0.008**	**0.107**
		Max	**29.81**	**36.60**	**369.94**	**46.24**	**0.055**	**0.714**
		Min	**-38.52**	**0.54**	**-173.93**	**-21.74**	**0.010**	**0.119**

[1] Profiles 2 and 24 were discontinued in spring 2000, due to bad GPS satellite visibility, and winter 2000, due to a beach fill, respectively.
[2] Profile 9 was impacted by the northerly migration of a coastal stream in 1999.
[3] Profiles 48 and 49 were begun in fall 1999 and winter 2000 respectively.
[4] Profiles 2, 9, 22, 23, 24, 25, 26, 48, and 49 have not been included in the 5-year averages.

Table 17. Alongshore averaged change rates of the 3.0 m contour calculated for each of the 16 topographic beach surface maps.

Surface Map #	Surface Map Name	Northing (m NAD 83)	Winter Retreat (m)	Summer Recovery (m)	Net Change Rate 1997-2005 (m/yr)	Shoreline Change 1974-1999[2] (m/yr)
1	Grenville	225862	-21.4	26.3	8.1	4.0
2	Moclips	218742	-19.9	25.6	6.3	1.8
3	Roosevelt	213117	-15.1	18.8	4.4	0.9
4	Ocean City	204655	-15.7	22.3	6.6	7.1
5	Ocean Shores	187583	-21.3	29.3	8.0	3.1
6	Westport	181088	-10.8	9.1	-1.6	-1.0
7	Grayland	171987	-20.3	20.4	0.1	1.1
8	[1]Cape Shoalwater	163419	-52.8	23.4	-9.4	---
9	Leadbetter	153229	-7.7	32.0	23.2	3.5
10	Oysterville	142715	-20.9	23.7	3.7	2.3
11	Klipsan	131964	-15.0	19.2	4.2	5.2
12	North Head	117127	-21.9	19.8	-2.1	1.1
13	Ft. Canby	113280	-29.5	22.3	-7.3	-9.0
14	Clatsop Spit	105159	-16.5	16.5	0.0	-0.1
15	Rilea	96593	-11.4	12.6	1.2	1.9
16	Seaside	80395	-19.9	19.5	0.4	3.7
		Average	**-19.9**	**21.0**	**2.5**	**1.7**
		STD	**10.6**	**5.8**	**7.5**	**3.6**
		MAX	**-7.7**	**32.0**	**23.2**	**7.1**
		MIN	**-52.8**	**9.1**	**-9.4**	**-9.0**

[1]Cape Shoalwater surface map data is not included in the calculations of regional statistics due to the influence of inlet processes at Willapa Bay.
[2]Shorelines presented in Kaminsky et al., 1999.

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APPENDIX A.

The following section provides directions to each of the 49 beach profiles in the monitoring program. The majority of the beach profiles originate well landward of the primary dune. A 4x4 inch wooden post with a metal name-plate that indicates the profile name typically marks the profile origins. The first (most landward) point of each profile is given in Table 2. Northings and Eastings are presented in NAD 83 (m), Washington State Plane South. Many of the profiles are co-located with geodetic control monuments that are well marked with witness posts. All of the profiles extend from the starting point across the dunes at an angle roughly perpendicular to the shoreline. Many of the profiles have 1 or 2 witness posts in the dunes to assist with the profile orientation.

A.1 North Beach Sub-cell

E2

This site is located in the vicinity of Moclips, Washington, south of Point Grenville on Quinalt Indian Tribal property. This beach is closed to the general public, and access to this site is limited to those with permission to be on tribal land. To reach the site, proceed north on SR109 from Moclips. Take the last beach access road off of SR109 before Point Grenville. The profile location is approximately 500 m (1640 ft) north of the beach access road. The monument associated with this profile is located on Point Grenville.

SOUTH

This site is located in the vicinity of Moclips, Washington, south of Point Grenville on Quinalt Indian Tribal property. This beach is closed to the general public, and access to this site is limited to those with permission to be on tribal land. To reach the site, proceed north on SR109 from Moclips. Take the last beach access road off of SR109 before Point Grenville. The profile location is approximately 200 m (656 ft) south of the beach access road. The monument corresponding with this profile is on the beach approximately 100 m north of the access road on a large rock.

L443

This site is located in the vicinity of Moclips, Washington, south of Point Grenville on Quinalt Indian Tribal property. This beach is closed to the general public, and access to this site is limited to those with permission to be on tribal land. To reach the site, proceed north on SR109 from Moclips. Take the last beach access road off of SR109 before Point Grenville. The profile location is approximately 2 km (1.24 miles) south of the beach access road. The monument associated with this profile is located on the southwest corner of a bridge just north of the profile on SR109.

B1

This site is located in the vicinity of Moclips, Washington, south of Point Grenville on Quinalt Indian Tribal property. This beach is closed to the general public, and access to this site is limited to those with permission to be on tribal land. To reach the site, proceed north on SR109 from Moclips. Take the last beach access road off of SR109 before Point Grenville. The profile location is approximately 3 km (1.86 miles) south of the beach access road. There is no monument in the immediate vicinity of this profile.

A 1.5

This site is located in the vicinity of Moclips, Washington, south of Point Grenville on Quinalt Indian Tribal property. This beach is closed to the general public, and access to this site is limited to those with permission to be on tribal land. To reach the site, proceed north on SR109 from Moclips. Take the last beach access road off of SR109 before Point Grenville. The profile location is approximately 4.5 km (2.8 miles) south of the beach access road. There is no monument in the immediate vicinity of this profile.

PIER RM1 AZ

This site is located in the vicinity of Moclips, Washington. To reach the site from the post office in Moclips, follow SR 109 north 0.64 km (0.4 miles) to 2nd Street (intersection is on the north side of the Moclips River). Continue west on the 2nd Street beach access road. The monument can be found in the southwest corner of a yard just north of 2nd Street and east of a side street. The beach profile is located approximately 50 m (164 ft) north of the 2nd Street beach access and approximately 50 m (164 ft) west of the monument.

GKAM

This site is located in the City of Pacific Beach, Washington, within Pacific Beach State Park. To reach the site from SR109 in Pacific Beach, at the intersection of Ocean Beach Road/Main Street and SR109 proceed west to 2nd Street. Continue south on 2nd Street into Pacific Beach State Park. Travel west inside the State Park, past the restroom, to the beach access parking area. The monument is located at the center of a small traffic circle. The profile begins approximately 110 m (361 ft) north of the monument in front of the bluff.

BHUX

This site is located in the vicinity of Roosevelt Beach, south of Pacific Beach, Washington. To reach the site from SR109 in Pacific Beach, follow SR109 south 5.47 km (3.4 miles) to the intersection with the beach access road at Roosevelt Beach. Continue on the access road to the beach access parking area. The monument is approximately 3 m (9.5 ft) west of the northwest corner of the small restroom in the parking area. The profile is located approximately 70 m (230 ft) to the south of the monument, fronting the large sea cliff.

GP-14109

This site is located in the vicinity of Copalis, Washington in the Griffith-Priday State Park. To reach the site from Ocean City, follow Highway 109 north to Benner Road. Continue west on Benner Road 0.40 km (0.25 miles) to the monument that is just north of Benner Road located on a small grassy mound in the southern end of the beach access parking lot. The profile begins approximately 50 m (164 ft) northwest of the monument.

DIANA

This site is located in Ocean City, Washington within Ocean City State Park. To reach the site from the intersection of SR109 and Route 115, follow SR109 north to 2nd Street in Ocean City. Travel west on 2nd Street into Ocean City State Park. Follow 2nd street west to the beach access parking area on the left. The monument is located 12 m (39 ft) south of the southwest corner of the parking area and the profile begins approximately 100m (328 ft) west of the monument.

CASINO

This site is located north of Oyhut State Park in front of the Quinalt Indian Nation Casino. To reach the site from the intersection of Route 115 (Damon Road) and Point Brown Boulevard in Ocean Shores, follow the Damon Road beach access west approximately 745 m (2444 ft) to the beach. Travel north approximately 2.8 km (1.74 miles) to the front of the casino. The profile is located 20 m (394 ft) east in the dune in front of the Casino. There is no monument in the immediate vicinity of this profile.

DAMONS

This site is located within Oyhut, Washington in Oyhut State Park. To reach the site from the intersection of Route 115 (Damon Road) and Point Brown Boulevard in Ocean Shores, follow the Damon Road beach access west to the parking area on the left. The monument is located at the east end of the traffic island in the parking area. The profile is located approximately 250 m (820 ft) northwest of the monument in the dunes across the street from the Best Western Hotel.

ET

This site is located within the City of Ocean Shores, Washington. To reach the site from the intersection of Route 115 and Point Brown Avenue, follow Point Brown Avenue south to Chance-A-La-Mer Road. Travel west on Chance-A-La-Mer Road to Ocean Shores Boulevard. Follow Ocean Shores Boulevard south to the Pacific Boulevard beach access road. Travel west on Pacific Boulevard to the end of the road. The monument is located approximately 21 m (69 ft) south of the centerline of Pacific Boulevard next to a telephone pole in the dune. The profile begins approximately 50 m (164 ft) southwest of the monument.

BUTTER

This site is located in the City of Ocean Shores, Washington. To reach the site from Ocean Shores, follow Ocean Shores Boulevard south to the Butter Clam Road beach access. Continue west on Butter Clam Road to the beach access parking area. The monument is located 1 m (3.28 ft) west of the northwest corner of the parking area. The profile begins approximately 20 m (65.6 ft) southwest of the monument.

X1 NORTH

This site is located in the City of Ocean Shores, Washington. To reach the site from Ocean Shores, follow Ocean Shores Boulevard south to the Grays Harbor North Jetty. The profile begins approximately 450 m (1476 ft) north of the jetty and 10 m (33 ft) north of the north end of the “wave bumper” rock revetment. This profile intersects the geotubes that were installed in December 1998. The landward edge of the profile is on Ocean Shores Boulevard. The monument associated with this profile is located approximately 200 m (656 ft) east of the profile in the grass just beyond Ocean Shores Boulevard.

X1 SOUTH

This site is located in the City of Ocean Shores, Washington. To reach the site from Ocean Shores, follow Ocean Shores Boulevard south to the Grays Harbor North Jetty. The profile begins approximately 150 m (492 ft) north of the jetty and 10 m (33 ft) south of the south end of the “wave bumper” rock revetment. The landward edge of the profile is on Ocean Shores Boulevard. The monument associated with this profile can be found approximately 50 m (165 ft) north of the jetty and approximately 50 m (164 ft) west of Ocean Shores Boulevard.

A.2 Grayland Plains Sub-cell

HD-1

This site is located in the City of Westport, Washington in Westhaven State Park. To reach the site from the intersection of SR105 and SR105 Spur, follow SR105 Spur north to the Ocean Avenue beach access road. Continue east on Ocean Avenue to Montesano Avenue. Head north on Montesano Avenue to the Westhaven State Park beach access road. Follow the beach access road 1.61 km (1.0 miles) to the beach access parking area. On the west side of the parking area is a wood-frame restroom. The monument is located 28 m (92 ft) west of the northwest corner of the restroom and 262 m (860 ft) south of the Grays Harbor South Jetty. The profile begins approximately 160 m (525 ft) south of the monument.

WORM

This site is located in the City of Westport, Washington 0.72 km (0.45 miles) southwest of the Westport Lighthouse. To reach the site from the intersection of SR105 and SR105 Spur, follow SR105 Spur north to the Ocean Avenue beach access road. Continue west on Ocean Avenue to the beach access parking area on the north side of the road. Follow the concrete walkway to the monument west of the first wooden platform. The profile begins approximately 70 m (230 ft) to the south of the monument.

SPICE
This site is located in the City of Westport, Washington. To reach the site from the intersection of SR105 and SR105 Spur, follow SR105 north to Newell Avenue. Follow Newell Avenue west to Surf Street. Follow Surf Street north to Dunehaven Road. Travel west on Dunehaven Road to Dune Crest Drive, and follow Dune Crest Drive south. The monument is located at the end of the road. The profile begins approximately 20 m (66 ft) to the south of the monument.

RDAN
This site is located in the vicinity of Westport, Washington at the southern boundary of Twin Harbors State Park. To reach the site from the intersection of SR105 and SR105 Spur, travel south on SR105 2.25 km (1.4 miles) to Bonge Avenue. Follow Bonge Avenue west to the beach access parking area. On the west side of the parking lot is a wood-framed restroom. The monument is located 34 m (112 ft) southwest of the southwest corner of the restroom. The profile begins approximately 20 m (66 ft) to the west and 13 m (43 ft) to the north of the monument.

PRUG
This site is located north of Grayland, Washington. To reach the site from Grayland, go north 0.48 km (0.30 miles) on SR105 to the intersection of SR105 and Marine Drive. Go west on Marine Drive to the intersection of Marine Drive and Salt Air Boulevard. The monument is approximately 4 m (13ft) north of the centerline of Marine Drive and 71 m (232 ft) west of the centerline of Salt Air Boulevard. The profile originates 5 m (16.4 ft) northeast of the monument.

PC068
This site is located in the vicinity of Grayland, Washington. To reach the site from the intersection of SR105 and the County Line Road, go west on the County Line Road beach access 0.60 km (0.37 miles). The monument is located approximately 5m (16.4 ft) south of the center line of the access road. The profile begins 3 m (9.84ft) south of the monument.

PC064
This site is located in the vicinity of Grayland, Washington. To reach the site from the intersection of SR105 and Midway Beach Road, travel west on the Midway Beach Access Road 1 km (0.62 km) to the beach. Proceed 80 m (264 ft) south along the crest of the primary dune to the monument. The profile originates 1 m (3.28 ft) north of the monument.

GELF
This site is located in the vicinity of North Cove, Washington. To reach the site from the intersection of SR105 and Cranberry Lane / Grayland Beach Road, follow SR105 south 9.17 km (5.7 miles) to Warrenton Cannery Road. Travel west on Warrenton Cannery Road to the beach access parking area. On the north side of the road is a wood frame restroom. The monument is located approximately 100 m (328 ft) west of the northwest corner of the restroom. The profile begins across the beach access road approximately 30m (98.4 ft) south of the monument.

CSW
This site is located approximately 100 m (328 ft) southeast of the SR105 groin that was completed during summer 1998. To reach the site from the intersection of SR105 and Warrenton Cannery Road, follow SR105 south toward Tokeland. The profile is accessible from a path that begins at the turnout located at the southern end of the SR105 revetment. The profile is located approximately 200 m (656 ft) northwest of the path/beach intersection.

A.3 Long Beach Sub-cell

LB-1
This site is located in the vicinity of Oysterville, Washington. This profile is within the Willapa Bay National Wildlife Refuge at the northern end of Leadbetter Point, and driving motor vehicles on the beach is not permitted. To reach the site from Oysterville, travel west on the Oysterville Road beach access. Continue north on the beach 11.90 km (7.40 miles). The monument is located approximately 300m (984 ft) to the east. The profile begins 1 m (3.28 ft) southwest of the monument.

PC055
This site is located in the vicinity of Oysterville, Washington. This profile is within the Willapa Bay National Wildlife Refuge, and driving motor vehicles on the beach is not permitted. To reach the site from Oysterville, head west on the Oysterville Road beach access. Continue north on the beach 9.83 km (6.10 miles) and then east approximately 300 m (984 ft) to the monument. The profile originates near the monument.

PC051
This site is located in the vicinity of Oysterville, Washington. This profile is within the Willapa Bay National Wildlife Refuge, and driving motor vehicles on the beach is not permitted. To reach the site from Oysterville, proceed west on the Oysterville Road beach access. Continue north on the beach 7.85 km (4.88 miles) then east approximately 110 m (370 ft) to the monument. The profile originates near the monument.

PC044
This site is located in the vicinity of Oysterville, Washington. To reach the site from Oysterville, travel west on Oysterville Road to G Street. Continue west on the beach access road to the beach. Proceed north on the beach 3.5 km (2.17 miles). The monument is located approximately 100 m (328 ft) to the east. The profile originates near the monument.

PC057
This site is located in the vicinity of Surfside Estates, northwest of Oysterville, Washington. To reach the site from Oysterville, travel west on Oysterville Road to G Street. Continue west on the beach access road to the beach. Proceed north on the beach 1.43 km (0.89 miles). The monument is located approximately 70 m (230 ft) to the east. The profile originates near the monument.

OYSTER 3
This site is located in the vicinity of Oysterville, Washington. To reach the site from Oysterville, travel west on Oysterville Road to G Street. Continue west on the beach access road to the beach. Proceed south on the beach approximately 120 m (400 ft). The monument is located approximately 50 m (164 ft) to the east. The profile originates approximately 70 m south of the monument.

PC037

This site is located in the vicinity of Ocean Park, Washington. To reach the site from the intersection of SR103 and Bay Avenue, travel west on the Bay Avenue beach access 0.58 km (0.36 miles) to the beach. Continue north on the beach 3.96 km (2.46 miles). The monument is located approximately 90 m (300 ft) to the east. The profile originates near the monument.

PC035
This site is located in the vicinity of Ocean Park, Washington. To reach the site from the intersection of SR103 and Bay Avenue, travel west on the Bay Avenue beach access 0.58 km (0.36 miles) to the beach. Continue north on the beach 2.75 km (1.71 miles). The monument is located approximately 90 m (300 ft) to the east. The profile originates near the monument.

PC032
This site is located in the vicinity of Ocean Park, Washington. To reach the site from the intersection of SR103 and Bay Avenue, travel west on the Bay Avenue beach access 0.58 km (0.36 miles) to the beach. Continue north on the beach 0.89 km (0.55 miles). The monument is located approximately 90 m (300 ft) to the east. The profile originates near the monument.

KLIPSAN 2
This site is located in the vicinity of Ocean Park at Klipsan Beach. To reach the site from the intersection of SR103 and Bay Avenue, travel south on SR 103 for 2.98 km (1.85 miles). Continue west along the Klipsan Beach access road. The monument is located approximately 100 m (328 ft) south of the small restroom on the access road. The profile originates near the monument.

PC021
This site is located in the vicinity of Klipsan Beach, Washington. To reach the site from the intersection of SR103 and Klipsan Road, travel west along the Klipsan Road beach access 0.37 km (0.23 miles) to the beach. Continue south on the beach 2.98 km (1.85 miles). The monument is located approximately 100 m (330 ft) to the east on the top of the highest dune. The profile originates near the monument.

RICH
This site is located in the vicinity of Klipsan Beach, Washington. To reach the site from the intersection of SR103 and Klipsan Road, travel west along the Klipsan Road beach access 0.37 km (0.23 miles) to the beach. Continue south on the beach 5.67 km (3.52 miles). Proceed east approximately 175 m (575 ft) to the monument. The profile originates near the monument.

PC014
This site is located in the vicinity of Long Beach, Washington. To reach the site from the intersection of SR103 and Cranberry Road, follow Cranberry Road beach access west 0.48 km (0.3 miles) to the beach. Travel south on the beach 1.06 km (0.66 miles). The monument is located approximately 190 m (620 ft) to the east. The profile originates near the monument.

JACKSON
This site is located in the vicinity of Long Beach, Washington. To reach the site from the intersection of SR103 and Bolstad, travel 730 m (2400 ft) west on Bolstad St. to the beach. Continue north on the beach 1.5 km (0.9 miles). The profile begins 120 m (394 ft) east in the dune. No monument is in the immediate vicinity of this profile site.

PC008
This site is located in the vicinity of Long Beach, Washington. To reach the site from the intersection of SR103 and 10th Street South in Long Beach, continue west on the 10th Street South beach access road to

the beach. Travel south on the beach 140 m (460 ft). The monument is located approximately 90 m (300 ft) to the east. The profile originates near the monument.

PC025

This site is located in the vicinity of Seaview, Washington. To reach the site from the intersection of SR101 and D Street in Seaview, follow D Street west for 0.89 km (0.55 miles) to the beach. Travel south on the beach for 0.58 km (0.36 miles). The monument is located approximately 90 m (300 ft) to the east. The profile originates near the monument.

PC004

This site is located in the vicinity of Seaview, Washington. To reach the site from the intersection of US101 and D Street in Seaview, follow D Street west for 0.89 km (0.55 miles) to the beach. Travel south on the beach for 1.87 km (1.16 miles). The monument is located approximately 90 m (300 ft) to the east on the top of the highest dune. The profile originates near the monument.

CANBY

This profile is located within Fort Canby State Park southwest of Ilwaco. To reach the site from the junction of first street south and US101, travel 0.16 km (0.1 miles) along Spruce Street. Proceed south along 2nd Avenue for 3.6 km (2.2 miles) to the entrance of Fort Canby State Park. Enter the main park entrance and turn right into the camping area. Stay to the left and follow the road through the camping area to the intersection with a park staff access road. The profile is located approximately 0.40 km (0.25 miles) west on the access road. No monument is in the immediate vicinity of this profile site.

A.4 Clatsop Plains Sub-cell

EAST JETTY 2

This site is located 4.83 km (3.0 miles) northwest of Hammond and is within the Fort Stevens State Park. To reach the site from Hammond, follow signs to the State Park, and once within the State Park, follow signs to the south jetty. On the final access road to the south jetty, travel south on a sand road for 0.16 km (0.1 miles) (access of which is prohibited to motor vehicles). The monument is 2.59 m (8.5 ft) southwest of a 2.44 m (8.0 ft) high iron cross set in a concrete base. The profile begins approximately 450 m (0.28 miles) south of the monument.

IREDALE

This site is located in the vicinity of Warrenton, Oregon, in Fort Stevens State Park. To reach the site from Warrenton, follow US101 Spur to 18th Street SW. Follow 18th Street north to the southern entrance to the State Park. Travel west through the entrance to a flashing red light. Continue west through the camping area to Peter Iredale Road. Follow signs to the Peter Iredale parking areas. Proceed to the southern-most parking area with a wood frame restroom on the north side of the lot. The monument is 28.5 m (93.5 ft) east of the southeast corner of the cement slab foundation of the restroom. The profile originates approximately 80 m (262.5 ft) north of the monument and passes the north side of the Peter Iredale shipwreck.

KIM

This site is located in the vicinity of Warrenton, Oregon, at the northern boundary of Camp Rilea National Guard Base. To reach the site from Warrenton High School, travel west on South Main Street / US101 Spur to 18th Street. Continue north on 18th Street 2.81 km (1.75 miles) to a “Y” intersection. Proceed west across Ridge Road to Delaura Beach Road SW. The profile begins just south of the intersection of the gravel portion of Delaura Beach Road SW and the beach. There is no monument in the immediate vicinity of this profile.

RILEA
This site is located in the vicinity of Gearhart, Oregon at the southern end of the Camp Rilea National Guard Base. To reach the site from US101/26, proceed west on Sunset Beach Road to the beach. Continue north on the beach 1.75 km (1.09 miles). Travel east to the top of the dune and the lone telephone pole. The monument is approximately 20 m (66 ft) southeast of the pole. The profile begins near the monument.

DELRAY
This site is located in the vicinity of Gearhart, Oregon. To reach the site from the intersection of US101/26 and Pacific Way in Gearhart, travel north 2.82 km (1.75 miles) on US101/26 to Highlands Road. Continue west on Highlands Road to the Delray Beach Access parking area. The monument associated with this site is located 68 m (223 ft) southwest of the southern corner of a park information sign. The sign is located at the "Y" intersection of the beach access road and the parking lot road. The profile originates approximately 150 m (490 ft) north of the monument in the dunes north of the beach access road.

SEASIDE RM 2
This site is located in the City of Seaside, Oregon. To reach the site from the western end of 12th Avenue in Seaside, travel approximately 100 meters (330 ft) north of the public restroom. The seaward end of the profile is south of the mouth of the Necanicum River. There is no monument in the immediate vicinity of this profile.