Modeling transport of disposed dredged material
from placement sites in Grays Harbor, WA

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Abstract

The US Army Corps of Engineers Seattle District (NWS) is addressing short- to mid-term dredge material management strategies for the Federal Navigation Project at Grays Harbor, Washington. This includes evaluating navigation channel realignment in the Point Chehalis/Entrance reach. It is hypothesized that relocating the channel to align with natural channel migration will reduce future annual dredging quantities. However, the most heavily used dredged material placement sites lie in proximity to the Federal navigation channel. Thus, the goal of this numerical modeling study was to assess the impact of the three dispersive dredged material placement sites on future channel maintenance dredging.

The modeling study simulated tidal and wave-induced sediment transport in the Grays Harbor estuary using a surface water modeling system EFDC under four different hydrodynamic and wave forcings that corresponded to 0.5-, 2-, and 5-year events and the most extreme event from a 38-year wave hindcast record. A coastal wave model CMS-Wave was used to simulate wave conditions in the model domain, and a regional circulation model ADCIRC was used to provide the clamped tidal boundary conditions along the ocean boundaries of the EFDC model domain. Model results using both the existing and realigned channel configurations were analyzed to estimate residence times of dredged placed sediment at the three placement sites and channel infilling rates from sediment eroded from the placement sites for the existing and realigned channel configurations. The findings from the analysis indicated that there were significant differences in the erosion rates of the dredged material between the existing and realigned channel simulations at one of the three placement sites, and that there were no significant differences in the fate of the eroded sediment between the existing conditions and realigned channel configuration.

Background

The Grays Harbor (GH) estuary that is nearly 24-km wide at its broadest point is located along the southwestern coast of the State of Washington about 81-km north of the Columbia River mouth (see Figure 1). The navigation channel starts seaward of the entrance and ends near the mouth of the Chehalis River. The middle section of estuary, where the channel passes through, is deeper than the areas north and south of channel. There are three dredged material placement (DMP) sites in the inlet region: Point Chehalis, South Jetty, and Half Moon Bay Disposal Sites (see Figure 2).

Maintenance dredging requirements for the Point Chehalis and Cow Point reaches have been the most excessive. Past field studies in 1999 and 2003 involved collection of wave and current data, and evaluation of alternate channel orientations to determine the optimal channel design for minimizing maintenance dredging requirements (Hericks and Simpson, 2000). The NWS wanted to evaluate a proposed channel realignment in the Point Chehalis and Entrance reaches that was hypothesized to reduce annual dredging quantities. The present navigation channel is shown in Figure 3. The realigned channel (see Figure 4) would utilize the new thalweg developing north of the present channel.

The two goals of this modeling study were to 1) evaluate the proposed navigation channel realignment in the Point Chehalis and Entrance reaches, and 2) assess the impact of sediment eroded from the three DMP sites on channel maintenance with both existing and realigned channel reaches. This paper describes the following: a) modeling approach; b) selection of seasonal storm events; c) application of the numerical models to simulate waves, hydrodynamics, and sediment transport; d) simulation of sediment transport for four different hydrodynamic and wave events using both existing and realigned channel reaches; and e) analyses performed of the modeling results (Demirbilek et al., 2010).

Modeling Approach

The modeling study was comprised of the following six main tasks.

1. Review and analysis of 1999 and 2003 field data: Bathymetry, current and wave data collected by the NWS in 1999 and 2003 were used to calibrate and validate, respectively, the wave and hydrodynamic models used in this study.
2. Analysis of a 38-yr (1970-2007) GROW hindcast data set (Oceanweather, 2007): Seasonal and inter-annual variability in storm conditions, caused by the El Nino Southern Oscillation (ENSO) climatic patterns that influence sedimentation processes in the GH estuary, were considered in the selection of return periods for defining input conditions for wave and hydrodynamic modeling. A 38-yr hindcast data set that spanned the years 1970-2007, called the Global Reanalysis of Ocean Waves (GROW) by Oceanweather (2007), was used to develop short- and long-term statistics that were defined in terms of “return periods” varying from 0.5 to 5 yrs. The specific time periods used to model the response of the navigation channel system to the chosen environmental forcings with 0.5 to 5 yr return periods were seasonal, defined as Q1 (January – March), Q2 (April – June), Q3

(July – September), and Q4 (October – December). In addition, the role of an individual extreme storm on the navigation channel was simulated using the most severe event that occurred during the 38-year record.

3. Numerical modeling of regional and local scale waves and hydrodynamics due to winds and tides: Offshore tidal and wave conditions were transformed to local conditions at GH estuary. This was accomplished using the ADCIRC hydrodynamic model (Luettich et al., 1992) and the CMS-Wave spectral wave models (Lin et al., 2008). The offshore wave conditions were obtained from the GROW hindcast data. The offshore tidal constituents used as boundary conditions for ADCIRC were obtained from the Le Provost tidal constituents (Le Provost et al., 1994). The sediment transport modeling was performed with the Environmental Fluid Dynamics Code (EFDC) model (Hamrick 2007a,b,c). The regional ADCIRC model provided the tidal boundary conditions for EFDC. These models were calibrated with the 1999 field data and validated using the 2003 data.

4. Analysis of sediment samples: SEDFLUME tests were performed on the dredged material from Cow Point Reach. SEDFLUME is a field- or laboratory-deployable flume for quantifying cohesive sediment erosion (McNeil et al., 1996; McNeil and Lick, 2004). The erosion rates and critical shear stresses for initiation for erosion determined from these tests were used in both the near-field and far-field sediment transport modeling performed in this study. The settling speeds of cohesive aggregates that were eroded during the SEDFLUME tests were measured using the Particle Imaging Camera Sysem (PICS) that was designed to measure the *in-situ* floc sizes and settling velocities (Smith and Friedrichs, 2010).

5. Near-field modeling of local scale sediment transport affecting the DMP sites: Modeling was performed using the Lagrangian model MPFATE that represents dredged material descent from the placement vessel, collapse of the dredged material on the sediment bed, and passive transport of dredged material in suspension (Demirbilek et al., 2010). MPFATE was used to simulate the accumulated sedimentation resulting from multiple placements of dredged material from hoppers and scows dredges. MPFATE was used to estimate the initial sediment bed conditions at the three DMP sites following a season of dredged material placement of sediment dredged from the navigation channel.

6. Numerical modeling of sediment transport: Following the calibration and validation of CMS-Wave and EFDC, current- and wave-induced sediment transport was simulated for the Existing and Realigned Channel cases with the chosen return period events and the extreme event. The model results were analyzed to evaluate the proposed channel realignment in the Point Chehalis and Entrance reaches, and to assess the impact of sediment eroded from the three DMP sites on channel maintenance with both existing and realigned channels.

Selection of Seasonal Storm Events

The target return intervals of interest for dredging quantities are relatively short compared to storm damage analyses of structures such as breakwaters, jetties, or

levees. The 38-year GROW hindcast defines the statistical period of analysis, and sediment mobility was selected as the parameter defining the relevant response of sediments at the DMP sites to environmental forcing. Sediment mobility is defined as the ratio of the current- and wave-induced bed shear stress to critical bed shear stress. Six analysis points were selected within the three DMP sites. These points were selected to obtain representative sampling for sediment transport potential within each of the three sites. Environmental conditions and the resulting sediment transport response were computed at each of these locations.

The target return periods for this study were selected as 0.5, 2, and 5 years. Demirbilek et al. (2010) describes the analysis performed that ranked the return periods of quarterly events as 1993Q2 (0.5 year), 2006Q4 (2 year), and 1998Q4 (5 year). The extreme storm event from the 38-year record was found to occur during the period 20 January - 18 February 1990. The winter season of 1990 represents a 20-40 year return interval at the Half Moon Bay and Point Chehalis placement sites and approximately a 5-year return interval at the South Jetty site. These were the four periods for which sediment transport modeling was performed for both the existing and realigned navigation channels.

Application of Numerical Models

The application of the ADCIRC, CMS-Wave, MPFATE and EFDC models to the GH estuary is described in this section.

ADCIRC: The two-dimensional, depth-integrated implementation of the ADvanced CIRCulation (ADCIRC) model was used in this study. ADCIRC solves time dependent, varying free surface, circulation and transport problems in two horizontal dimensions using the finite element method in space and therefore can be run using unstructured meshes. Model simulations performed included forcing with tidal constituents and wind.

The ADCIRC model domain (Figure 5) includes all of GH and has a 2,000 km open ocean boundary. Its ocean boundary, which extends to depths of thousands of meters, lies outside the resonant basins and is not located near the tidal amphidromes. The domain's boundaries were selected to ensure the correct development, propagation, and attenuation of tides and storms without necessitating nested solutions. The tidal response at the open boundary is dominated by astronomical constituents (the M2, S2, N2, K2, O1, K1, P1, Q1, M4, M6 and STEADY tidal constituents were used), and nonlinear energy is limited due to the depth. This boundary allows the model to accurately capture basin-to-shelf physics.

The ADCIRC finite element mesh contained approximately 77,000 elements, with mesh resolution varying from 50 km in the Pacific Ocean to about 10 m in the GH estuary complex. The calibration and validation of the regional ADCIRC model using the 1999 and 2003 data sets is described in detail by Demirbilek et al. (2010).

CMS-Wave

CMS-Wave is a two-dimension, steady-state spectral wave model that calculates wave refraction, shoaling, diffraction, reflection, breaking, and dissipation based on the wave action balance equation (Mase et al., 2005a; 2005b).

The non-uniform Cartesian wave grid used in this study is shown in Figure 6. The model domain covers approximately 860 km^2, and its offshore boundary is at the 40 m depth contour. The finite difference grid has 68,000 computational cells, with the largest and smallest cell sizes of 2,000 m and 30 m, respectively. The smallest cells were used in the areas from the entrance channel to Point Chehalis. The calibration and validation of the CMS-Wave model using the 1999 and 2003 data sets is described in detail by Demirbilek et al. (2010).

MPFATE

MPFATE represents the dominant physical processes describing DMP site morphology throughout a dredging cycle (timescales of weeks to years) (Demirbilek et al., 2010). Functions of the model include: description of the placement sequence, description of dredging equipment and sediment properties, physical processes during and immediately following placement (descent, collapse, passive transport), and physical processes at longer timescales following placement, i.e., consolidation.

The objective of the MPFATE modeling was to provide initial bathymetric conditions for sediment transport simulations following dredged material placement at the three DMP sites. The MPFATE placement sequence was developed to reproduce the dredge placements conducted in 2008 and 2009 as indicated in dredging records. A bathymetric grid was developed from the ADCIRC model bathymetry with 25 by 25 m spacing for each DMP site. Hydrodynamic forcing was provided from ADCIRC simulations for the placement locations and times obtained from the dredge track logs. Each of the four dredges used at GH was assumed to place material at a speed ranging from 0.5 to 1.5 m/s, with 10 degree variability in vessel bearing. Transport of the deposited dredged material was not simulated during the placement simulation. As a result the mounds from the MPFATE simulations were more peaked than indicated by post-placement surveys. Figure 7 shows the final mound configuration at the Point Chehalis placement site.

EFDC

The sediment transport modeling component of this study was performed with the Environmental Fluid Dynamics Code (EFDC) surface water modeling system (Hamrick 2007a,b,c). EFDC is a three-dimensional (3D) finite difference modeling system that contains dynamically linked hydrodynamic and sediment transport modules. EFDC can simulate barotropic and baroclinic flow in a water body due to astronomical tides, wind, density gradients, and river inflow by solving the 3D, vertically hydrostatic, free surface, turbulence averaged equations of motion. The turbulence parameterization in EFDC is based on the Mellor and Yamada (1982) level 2.5 turbulence closure scheme that relates turbulent correlation terms to the mean state variables. EFDC also solves transport equations for dissolved and suspended constituents, and is capable of simulating wetting and drying of flood plains, mud flats, and tidal marshes.

The sediment transport model used in this study is the SEDZLJ sediment transport model (Jones and Lick, 2001). SEDZLJ is an advanced sediment bed model that represents the dynamic processes of erosion, bedload transport, bed sorting, armoring,

consolidation of fine-grain sediment dominated sediment beds, settling, and deposition. Multiple size classes of both cohesive and noncohesive sediments can be represented in the sediment bed. The sediment bed in SEDZLJ can be divided into multiple layers to represent the existing sediment bed as well as new bed layers that form due to deposition during model simulations. SEDFLUME was used to measure erosion rates of sediment cores formed using slurried dredge materials collected in Cow Point Reach as a function of the bed shear stress and consolidation time.

A curvilinear-orthogonal grid with 5,406 horizontal grid cells was used to represent the same model domain as that used for CMS-Wave. The model domain and model bathymetry are shown in Figure 8. Notice that the model domain extends 15 km up the Chehalis River to the location of Tide #5 station (see Figure 9). Astronomical tides are the dominant forcing mechanism within GH, with riverine flows in the Chehalis and Humptulips Rivers secondary in importance. EFDC was forced using tidal boundary conditions that were constructed using the ADCIRC interpolated water surface elevation time series for each grid cell composing the ocean boundaries. The river inflows from the Chehalis and Humptulips Rivers were simulated in the model. Because of the dominance of tide-induced advection at this estuary,

With the meso-tidal conditions in Grays Harbor, the water column is not completely vertically well-mixed for most of the tidal cycle, though measurements by Landerman et al. (2004) showed that the maximum difference between surface and bottom salinities at several nearshore stations was approximately 3 psu. No measurements of vertical salinity profiles inside the harbor were found. With such a relatively small salinity gradient, baroclinic flow in Grays Harbor would be minimal. As such, the EFDC model was run in the depth-averaged mode. However, to represent the longitudinal salinity profile that was apparent from the salinity measurements by Hericks and Simpson (2000) at the five tidal stations shown in Figure 9, the salinity transport module in EFDC was used. A salinity of 31 psu was assumed at the ocean boundaries, and salinities of 0 psu were used for the river inflows.

The selected model calibration time period (14 October to 12 November 1999) was simulated using EFDC for the purposes of adjusting the effective bottom roughness height used in EFDC to achieve an acceptable agreement with measured tides and current velocities. The tides measured at tide stations 1 - 5 and currents measured at stations 2 - 6 (see Figures 9 and 10) were compared to EFDC simulated tides and currents at the grid cells where the measurements were made. It was found that the EFDC simulated tides and currents at these cells were less than the measured tidal ranges and maximum current speeds. The ADCIRC simulated water surface elevation time series used for the ocean tidal boundaries had to be increased by 10 percent (i.e., ADCIRC calculated water surface elevation was multiplied by 1.1) to achieve satisfactory agreement with the measured tides and currents. The effective bottom roughness that gave the best agreement was 0.1 mm. A complete description of EFDC calibration and validation using the 1999 and 2003 data sets, respectively, is described in detail by Demirbilek et al., (2010). Only a few sample comparisons are included in this manuscript. Figure 11 shows a comparison between the measured and simulated tides for the calibration period at Tide Station #1, which was the closest station to the three DMP sites. Similar results were obtained at the other four tide

stations. While not acceptable at all phases of the spring-neap cycle, and poorer during neap tides for unknown reasons, the overall agreement between tidal ranges and phases is acceptable considering a larger scale coastal sea model (ADCIRC), as opposed to measured tides, was used to drive EFDC. The root-mean-square (RMS) error between the measured and simulated water surface elevations at Tide Station #1 was 0.16 m, and ranged between 0.12 m and 0.19 m for all stations. Figure 12 shows the comparison between the measured and simulated currents for the calibration period at Current Station #5. The comparison at this station is shown since it was the closest to the three DMP sites. While not acceptable at all phases of the spring-neap cycle, the overall agreement between measured and simulated current speeds is considered acceptable. Similar levels of agreements were obtained at the other current stations. The RMS error between the measured and simulated currents at Current Station #5 was 0.29 m/s, and ranged between 0.24 m/s and 0.35 m/s for all stations.

The selected model validation time period (21 days in December 2003) was simulated using EFDC for the purposes of checking the calibrated hydrodynamic model. The bottom friction coefficient was not adjusted for this simulation. Figure 13 shows the comparison between the measured and simulated tide at Tide Station #1. The RMS error between the measured and simulated water surface elevations at Tide Station #1 was 0.17 m, and ranged between 0.13 m and 0.21 m for all stations. Figure 14 shows the comparison between the measured and simulated currents at Current Station #5for the validation period. The comparison of the tides show a similar degree of agreement with that achieved during model calibration. There was fair agreement between the measured and simulated tidal phases, whereas the agreement between the measured and simulated tidal ranges, while not acceptable at all portions of the spring-neap cycle, was overall considered acceptable. The RMS error between the measured and simulated currents at Current Station #5 was 0.34 m/s, and ranged between 0.28 m/s and 0.40 m/s for all stations. Differences in bathymetry between that incorporated into the model grid and that at the site where the ADCPs were installed is one possible cause for the observed differences in current speeds.

Sediment transport modeling

The SEDZLJ sediment bed model was setup to investigate sediment transport processes using the following information and procedures:

- As determined using PICS, a mean settling velocities for flocs of 0.35 mm/s, and mean settling velocities of bed aggregates of 1.1 mm/s.
- The SEDFLUME determined erosion rate versus bed shear stress given by:

  $$E = 301\,\tau^{2.5} \quad (\tau > \tau_{cr})$$
  $$E = 0 \quad (\tau \le \tau_{cr})$$

  where E = erosion rate ($\mathrm{cm \cdot s^{-1}}$); τ is the bed shear stress, and τ_{cr} is the critical shear stress for measurable sediment erosion. The critical shear stress for erosion versus bed density relationship was determined from the SEDFLUME analysis for the representative dredged sediment sample for Cow Point Reach.
- MPFATE simulated initial mound configurations at the three placement sites.

- The regions inside Grays Harbor where marine, river, and mixed marine and river sediments have deposited as reported by Scheidegger and Phipps (1976).
- Grain size distributions at multiple locations inside and at the mouth of Grays Harbor, the lower Chehalis River, and offshore locations reported by SAIC (2007) and SAIC (2009). These distributions were used to determine the initial composition of the marine, river, mixed marine and river sediments.
- The time series of wave heights, periods and directions predicted by CMS-Wave were spatially interpreted onto the EFDC grid and used to calculate the combined current- and wave-induced bed shear stress in each EFDC grid cell during each time step. These bed shear stresses were used in the SEDZLJ bed model to predict the rates of erosion and deposition as well as bedload transport rates.

Based on an analysis of available data it was decided that six sediment grain sizes were needed to adequately represent the wide range of sediment within the model domain. The diameters of the six classes were 10, 22, 222 μm (fine sand), 375 μm (medium sand), 750 μm (coarse sand), and 4,000 μm (fine to very fine gravel). The 10 μm cohesive class was used to represent the flocs whose settling speeds were measured in the PICs experiment, whereas the 22 μm cohesive class was used to represent the bed aggregates eroded in the SEDFLUME experiments. These two size classes are used to represent the erosion, transport and settling of the fine-grain sediment placed at the DMP sites. The gravel size sediment was needed to represent the range of noncohesive sediment found by SAIC (2009) in the Chehalis River.

Based on the size distributions for the slurried GH dredged material, three sediment size classes (22, 222 and 375 μm) were used to represent the placement material in the mounds at the three DMP sites. To be able to determine the fate of the sediment eroded from each placement site, nine additional sediment size classes were used – three for each DMP site. So a total of 15 sediment classes were used in the modeling.

Using the available grain size distribution data, eight different sediment compositions (and therefore eight SEDFLUME cores) were used to represent the spatially varying sediment composition in the model domain. One of the sediment compositions is assigned to each grid cell. The eight sediment compositions are: Offshore, Marine, Mixed marine and river, Riverine, Chehalis River, Half Moon Bay placement site, South Jetty placement site, and Point Chehalis placement site. The grain size distributions for these eight sediment types are given by Demirbilek et al. (2010).

Seven bed layers were used for each SEDFLUME core. The top layer is the active layer through which depositing and eroding sediment passes. The second layer is the layer in which new sediment deposits are placed. The third through seventh bed layer are used to represent the existing sediment bed in each cell at the start of the model simulation. A different procedure was used for the SEDFLUME cores that represented the Point Chehalis, South Jetty and Half Moon Bay DMP sites. Bed layers 3 through 5 were used to represent the placement material at these sites, whereas bed layers 6 and 7 were composed of marine sediments that occupied the inlet mouth and outer bay regions of GH.

Because EFDC was run in a depth-averaged mode, a Rouse profile (Rouse, 1937) was assumed for the vertical suspended sediment concentration (SSC) profiles for all

noncohesive sediment size classes. The deposition rate for each noncohesive size class was calculated as the product of the nearbed concentration and settling velocity.

No measurements of SSC have been made at the USGS gages in the Chehalis and Humptulips Rivers that were used in developing their discharge time series. As such, it was assumed that these rivers transported a constant 100 mg/L concentration of the two cohesive sediment size classes and the finest noncohesive sediment size class.

Modeling Results

EFDC was applied o simulate the four selected hydrodynamic events using the existing navigation channel and the realigned navigation channel. EFDC was run in the morphologic mode, which means that simulated changes in the bed elevation due to erosion or deposition in each grid cell was used to update the flow field during the next time step. The output from each of these eight simulations was processed to determine the percentage of the initial total mass of dredged placement sediment that erodes (see Table 1). The results were also used to calculate the percentage of sediment that eroded from the DMP sites and deposited in one of the following four reaches of the Grays Harbor navigation channel: Entrance channel, Pt. Chehalis reach, South reach, and Crossover reach.

Figure 15 shows bar graphs of simulation results for the Pt Chehalis placement site for the existing condition for the 0.5-yr event (1993 2nd quarter) in the top panel, for the 2-yr event (2006 4th quarter) in the second panel, for the 5-yr event (1998 4th quarter) in the third panel, and for the extreme event (Jan-Feb 1990) in the bottom panel, respectively. The ordinate shows the ratio (percentage) of sediment mass of each of the three sediment size classes that eroded from this placement site that subsequently deposited in the navigation channel reach specified along the abscissa to the total sediment mass that eroded from the placement site. The total bar to the right of the 375 µm bar represents the sum of the three percentages for each channel reach. The fifth column (Total) represents the sum of eroded material deposited in the four channel reaches. Figures 16 and 17 present the same results for the South Jetty and Half Moon Bay placement sites, respectively. The results for the realigned channel are given by Demirbilek et al. (2010).

Discussion of Results

The EFDC-SEDZLJ modeling of GH sediment transport at three existing DMP sites showed the following general results:

- During the simulation periods, 6 to 53 percent of the placed mass eroded from the Pt Chehalis site with the existing channel configuration, whereas less than 7 percent of the placed sediment eroded with the realigned channel. At the South Jetty Site, 90 to 100 percent of the placed sediment eroded for both channel configurations. For the Half Moon Bay site, 80 to 100 percent eroded with the existing channel, whereas 60 to 97 percent eroded with the realigned channel. The conclusion is that significant variation in the eroded sediment mass with offshore wave conditions only occurred at the Pt Chehalis site for the existing channel configuration, and at the Half Moon Bay site for the realigned channel.

- There are no significant differences in the fate of the eroded sediment between the existing and realigned channel simulations. Of the mass eroded from the Pt Chehalis placement site, approximately 20 percent deposits within the navigation channel during the simulation period, with the Pt Chehalis reach receiving the vast majority of the sediment that erodes from this site. Mass eroded from the South Jetty site does not vary significantly with offshore wave conditions.
- Eroded fractions for the existing and realigned channel configurations are essentially identical. The largest fractions of dredged material eroded from the South Jetty Site deposit at the Pt Chehalis and South Channel reaches, although the total amount deposited is very low (2-3 percent). Insignificant fractions deposited in the Entrance and Crossover reaches. Since the percentage of eroded sediment was essentially the same for the simulated events, the vast majority of the sediment that eroded during the simulations for both channel configurations deposited elsewhere, i.e., not in these four navigation channel reaches. Like the South Jetty site, the Half Moon Bay site is mostly insensitive to incident wave climate. The milder 1993-Q2 period eroded 80 and 60 percent of the dredged material for the existing and realigned configurations, respectively, while the more energetic 2006-Q4, 1998-Q4, and 1990-Q1 periods eroded between 95 to 100 percent of the dredged material. Differences between existing and realigned channel configurations are insignificant at the Half Moon Bay site. About the same percentage of sediment that eroded from this site during the 1993-Q2 simulation deposited in the Entrance Channel, Pt Chehalis Channel and South Channel reaches, while insignificant fractions deposited in the Entrance and Crossover reaches for the three more energetic simulation events. Very little (less than 1.5 percent) of the sediment that erodes from the Half Moon Bay site deposits in any of these four navigation channel reaches.

Conclusion

This hydrodynamic, wave, and sediment transport modeling study was performed for the purpose of addressing short- and mid-term dredge material management issues for the Federal Navigation Project at Grays Harbor, Washington. The modeling methodology used in this study involved the use of multiple numerical models that enabled investigation of the following issues: 1) possible realignment of the navigation channel in the Point Chehalis and Entrance reaches; and 2) the impact of the dredged material placement sites on channel maintenance. This methodology was employed successfully in this study and enabled investigation of a) changes in waves, hydrodynamics and sediment transport in the navigation channel over time scales of 0.5 to 5 years, b) consequences of channel realignment on waves, hydrodynamics and sedimentation in the navigation channel, and c) channel infilling estimates from frequently occurring, low energy storms and less frequent, but more energetic storms for both the existing and realigned channel configurations.

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Table 1 Percentage of Dredged Placement Sediment that Eroded from Placement Sites

Placement Site / **Event**	**Existing Conditions**	**Realigned Channel**
	% Eroded Mass	**% Eroded Mass**
Pt Chehalis		
1993-Q2	6	2
2006-Q4	18	7
1998-Q4	53	7
1990-Extreme	13	4
South Jetty		
1993-Q2	94	90
2006-Q4	100	100
1998-Q4	100	100
1990-Extreme	97	97
Half Moon Bay		
1993-Q2	80	60
2006-Q4	97	97
1998-Q4	100	97
1990-Extreme	95	95

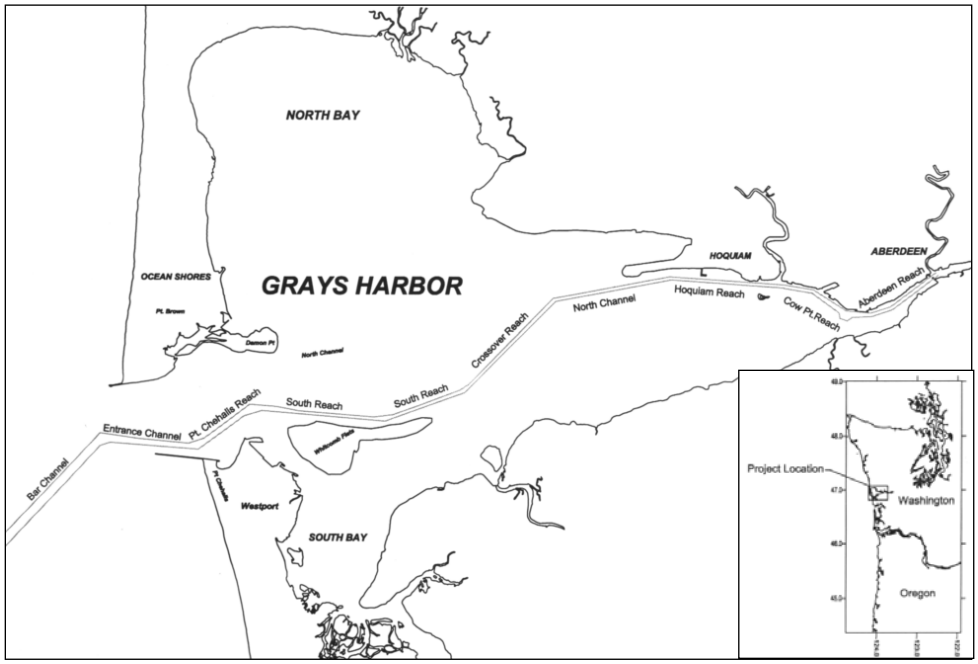

Figure 1. Grays Harbor Navigation Project and channel reaches.

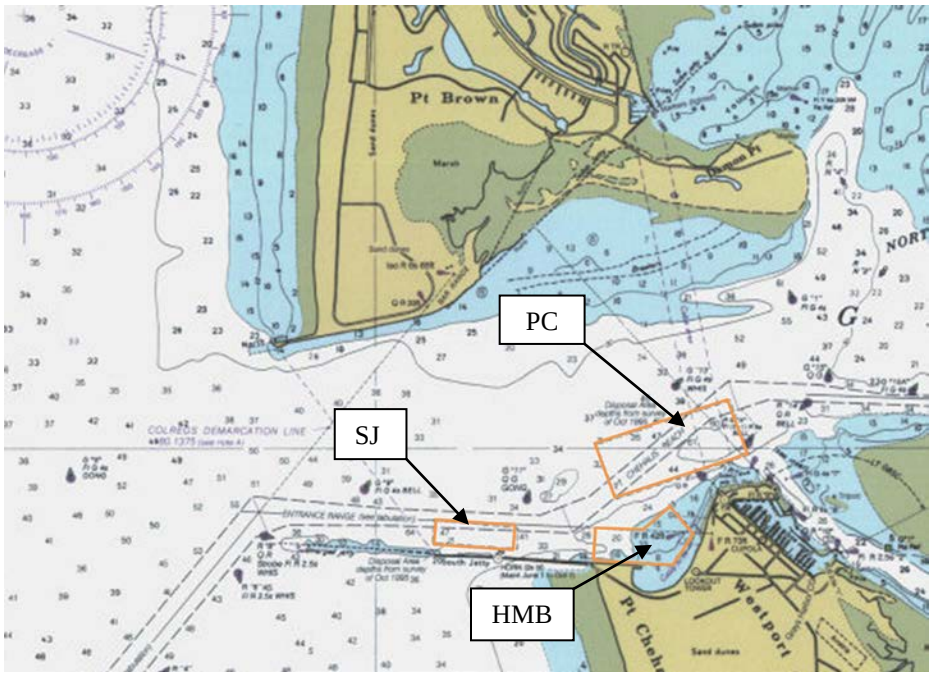

Figure 2. Dredged Material Placement Sites (orange lines are the boundaries of the sites). HMB – Half Moon Bay. PC – Point Chehalis. SJ – South Jetty.

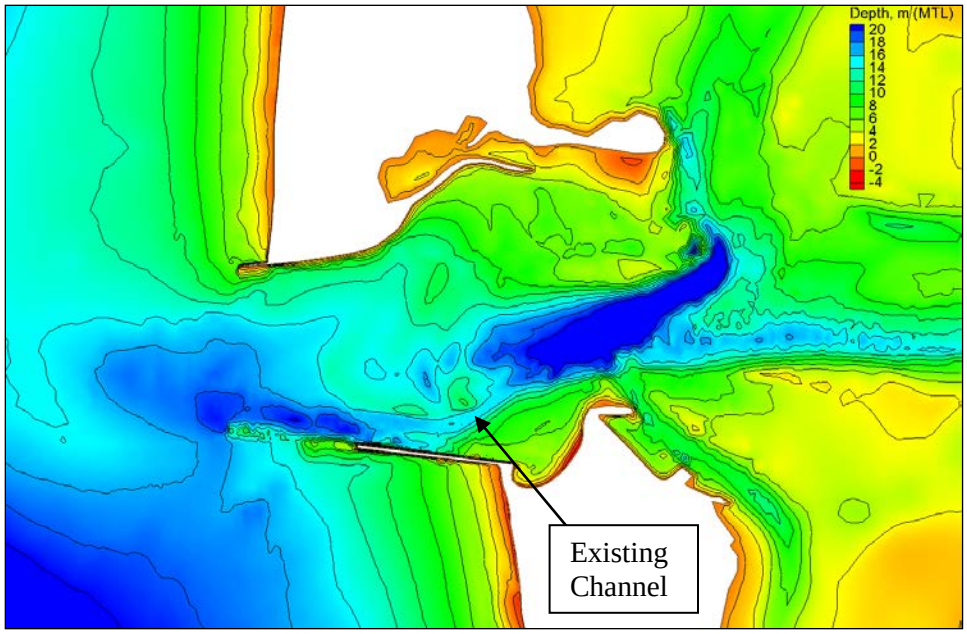

Figure 3. Bathymetry of existing navigation channel.

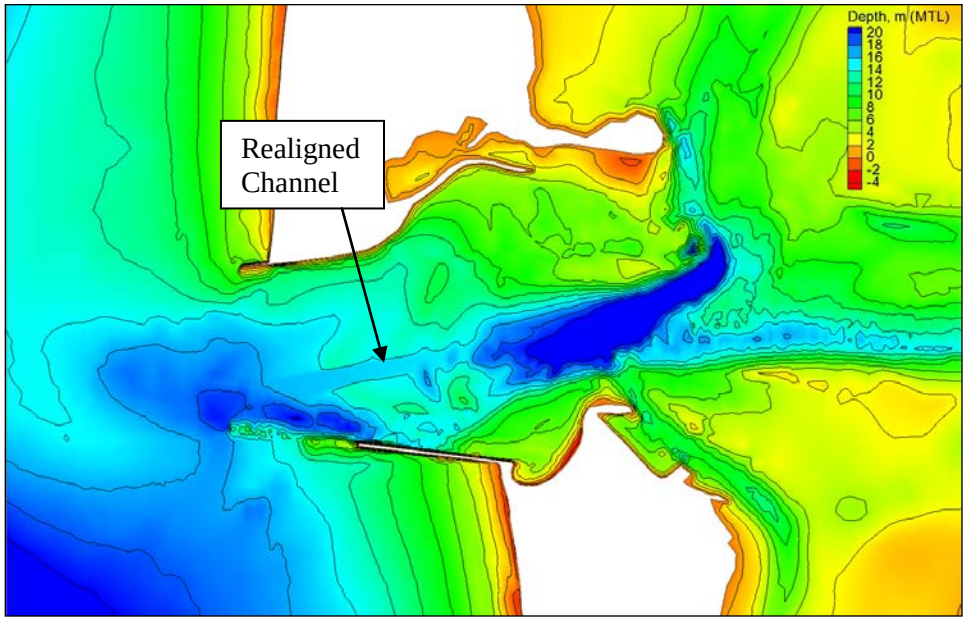

Figure 4. Bathymetry of realigned navigation channel.

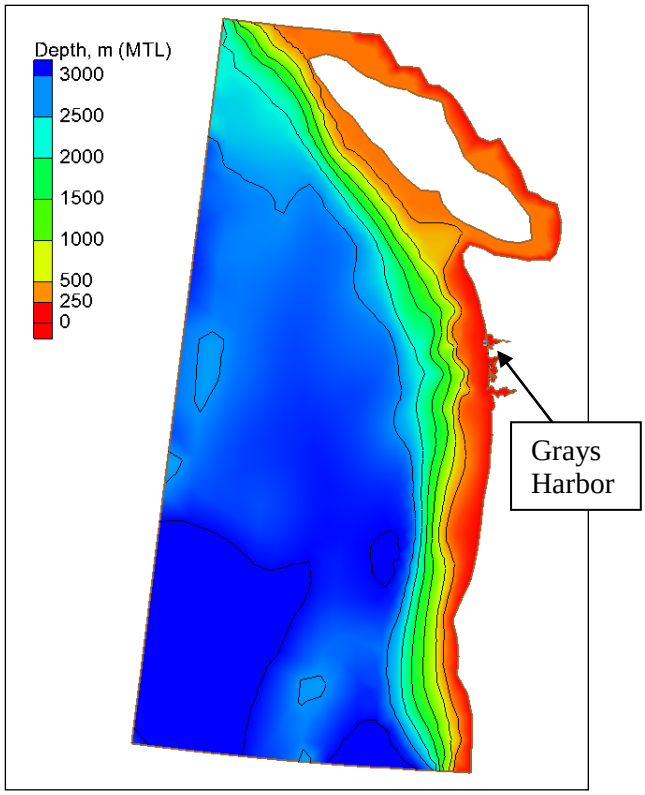

Figure 5. Regional ADCIRC model domain.

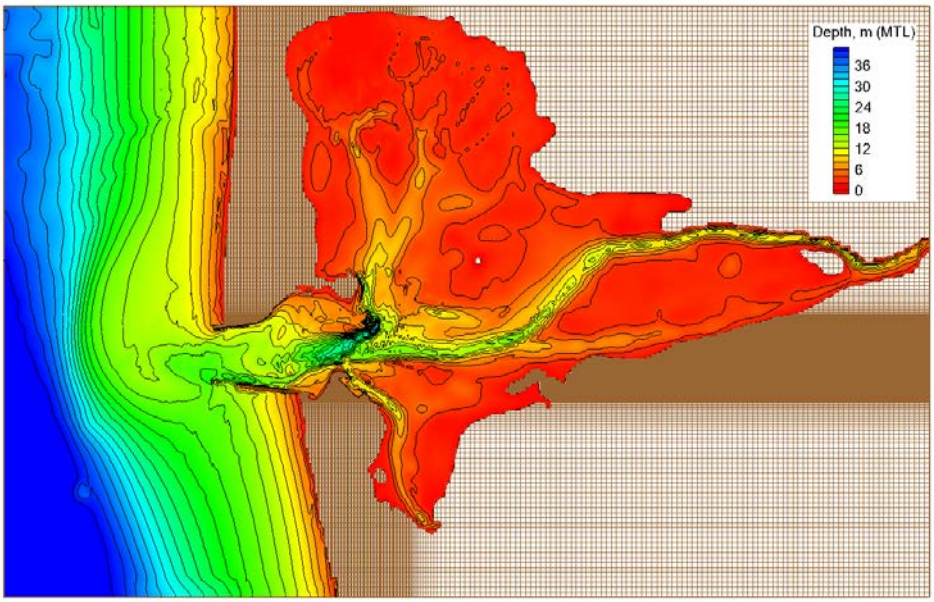

Figure 6. CMS-Wave model domain and non-uniform Cartesian grid.

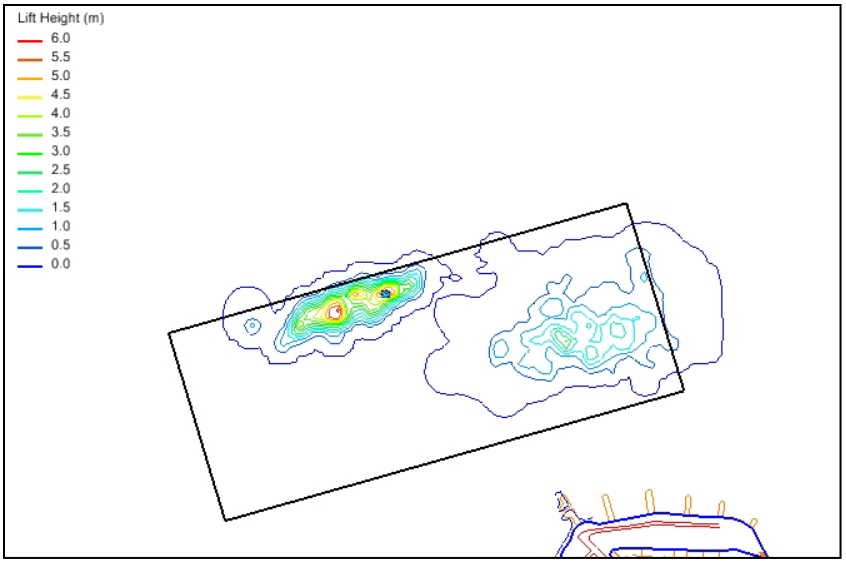

Figure 7. MPFATE simulated mound configuration at the Point Chehalis (PC) placement site shown in Figure 2.

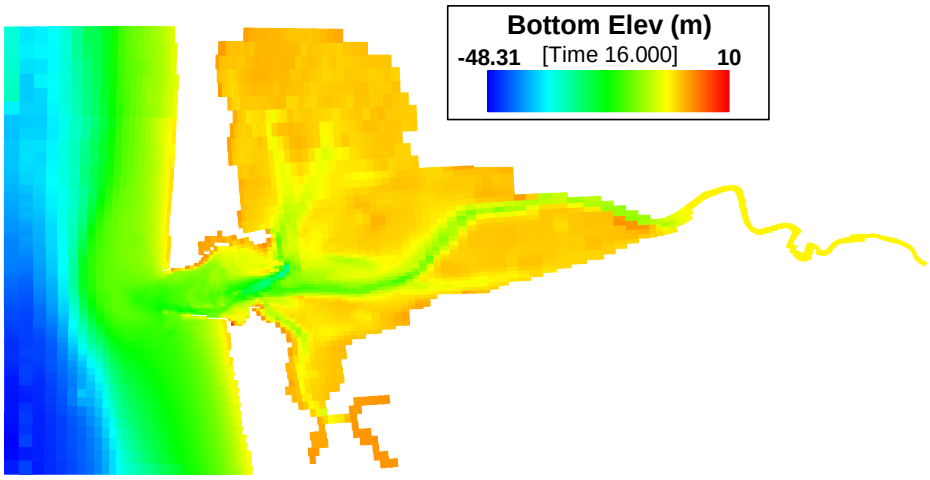

Figure 8 EFDC model domain for Grays Harbor.

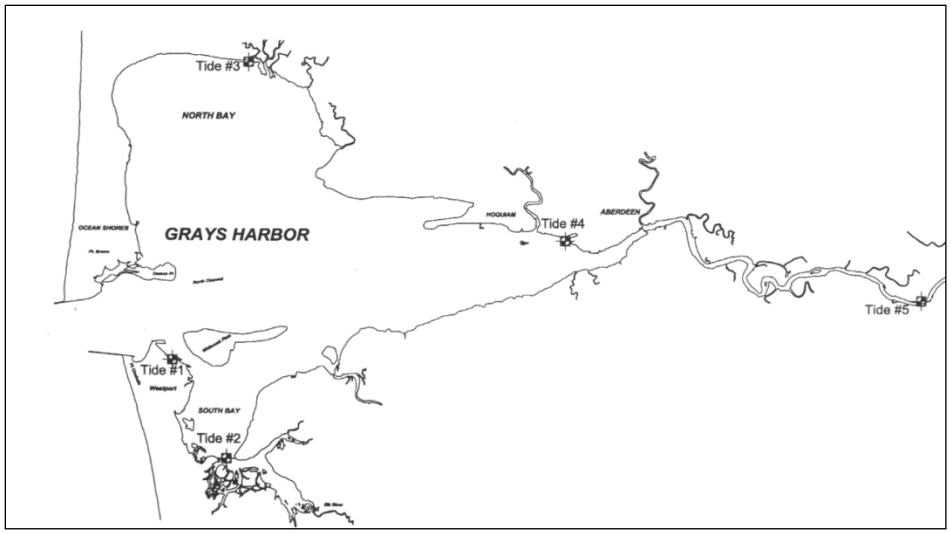

Figure 9 Location of tide stations in 1999 field measurement program.

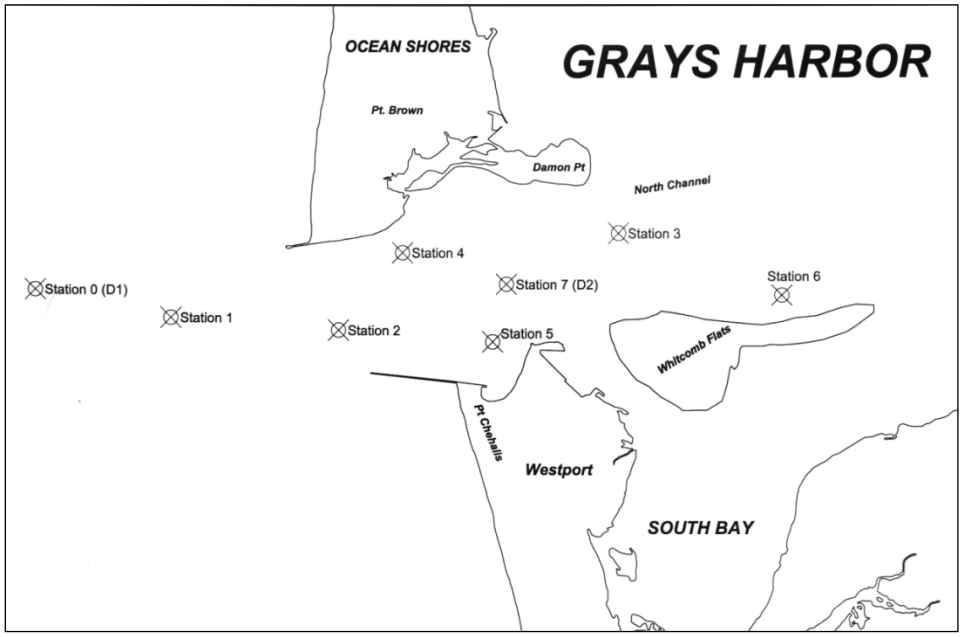

Figure 10 Location of wave and current stations in 1999 field measurement program.

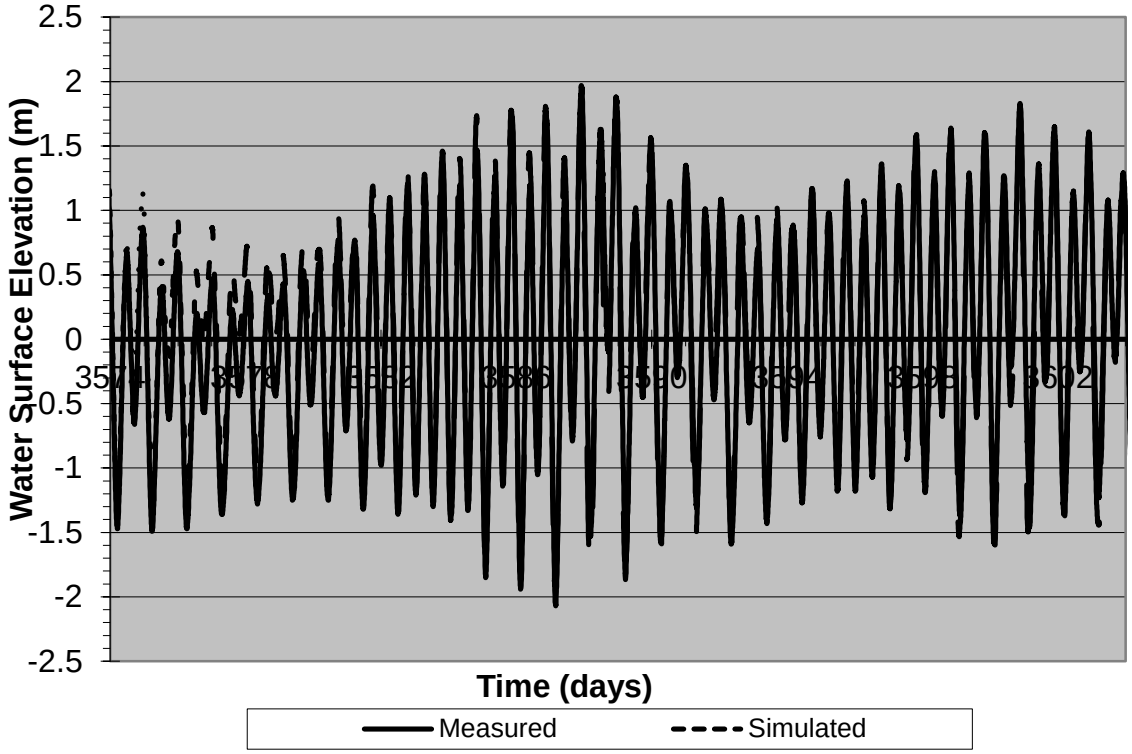

Figure 11 Comparison of measured and EFDC simulated tides at Tide Station #1 during calibration period. Day 0 corresponds to 01 Jan 1990.

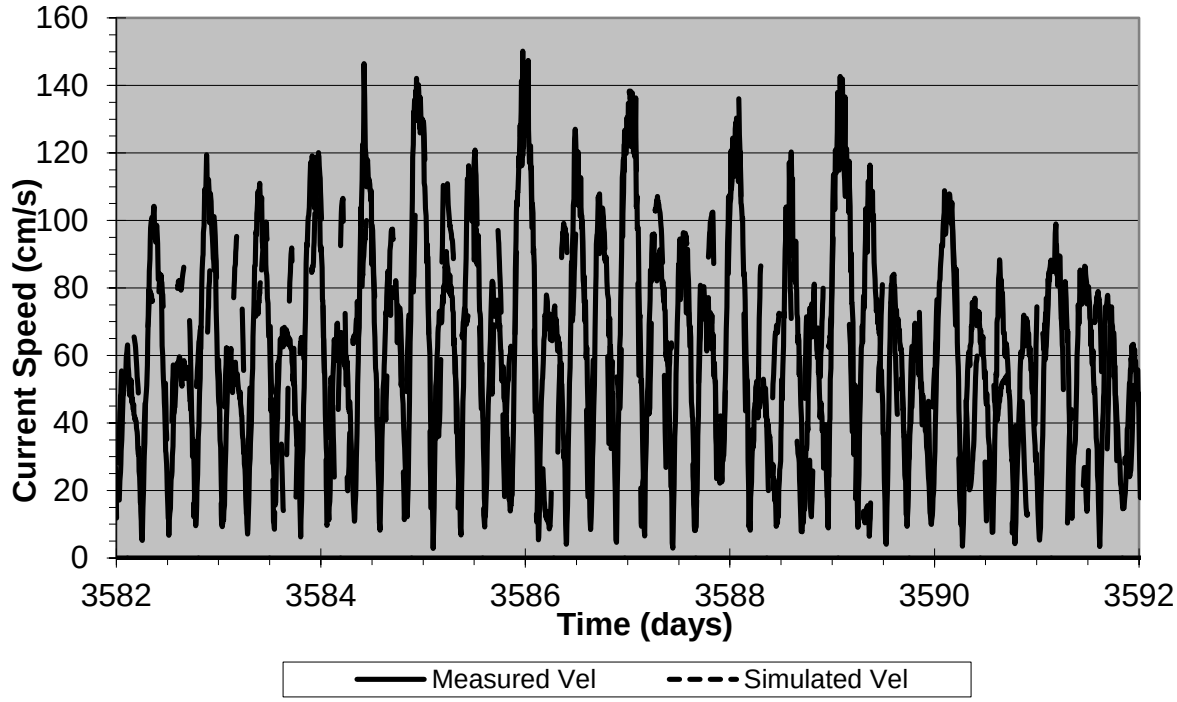

Figure 12 Comparison of measured and EFDC simulated currents at Current Station #5 during calibration period. Day 0 corresponds to 01 Jan 1990. Solid curve is measured current speed.

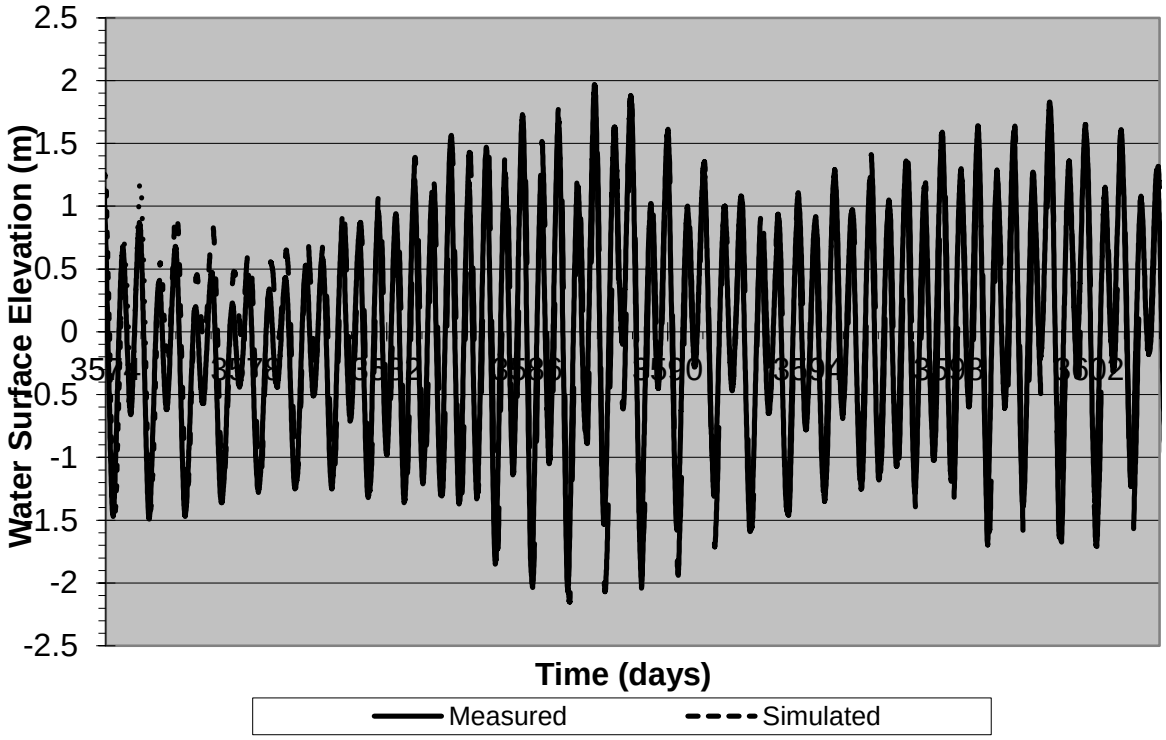

Figure 13 Comparison of measured and EFDC simulated tides at Tide Station #1 during validation period. Day 0 corresponds to 01 Jan 1990.

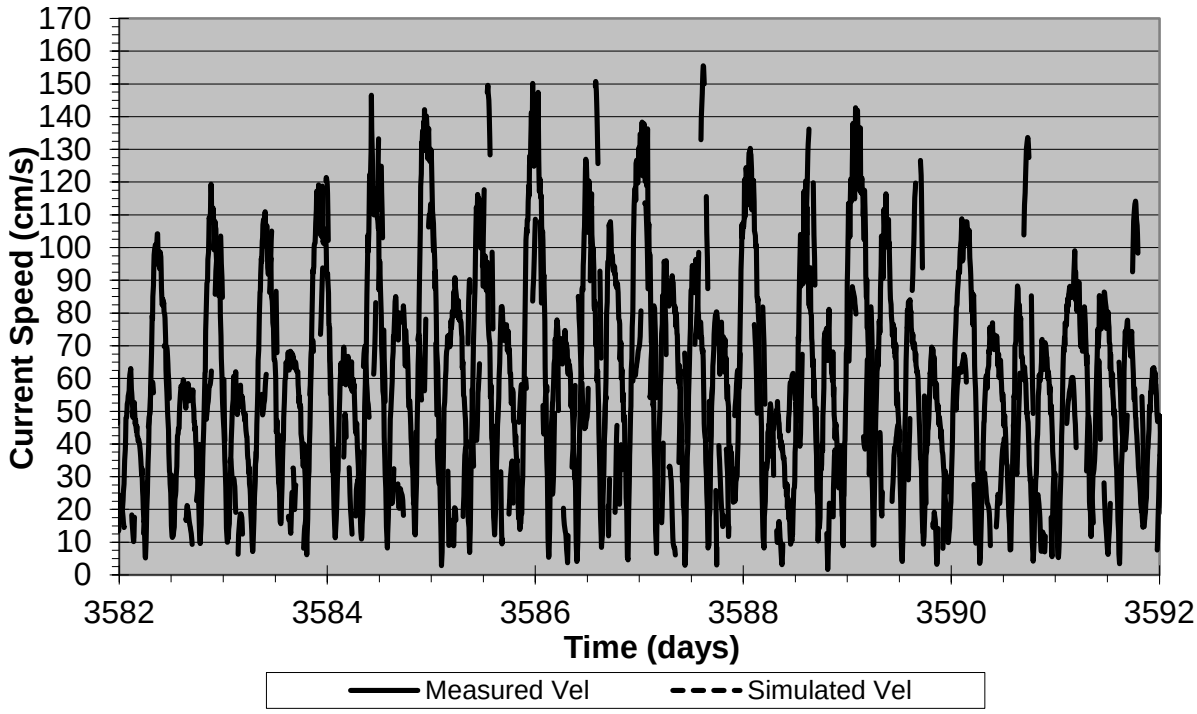

Figure 14 Comparison of measured and EFDC simulated currents at Current Station #5 during validation period. Day 0 corresponds to 01 Jan 1990. Solid curve is measured current speed.

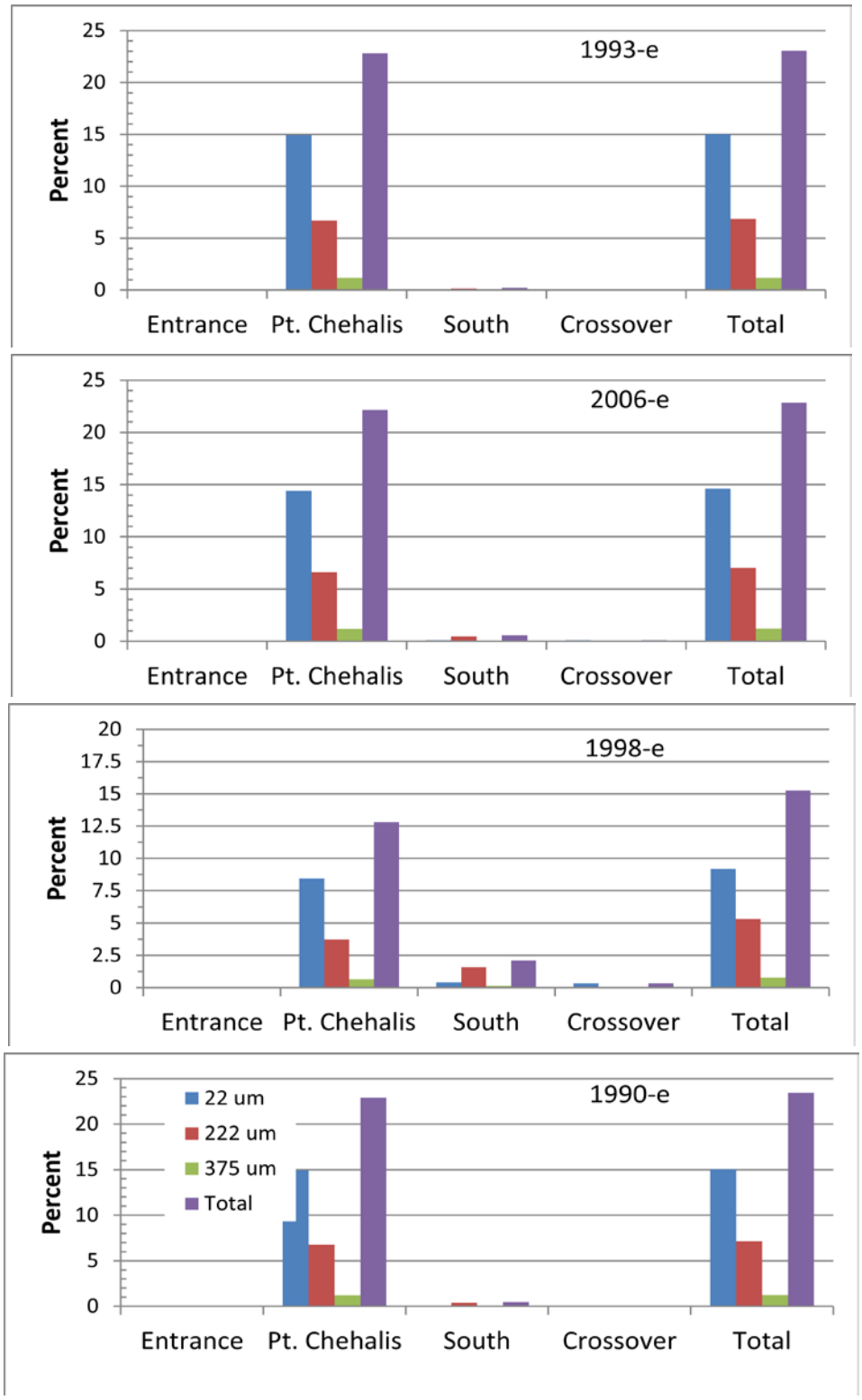

Figure 15 Percentage of sediment eroded from Pt Chehalis placement site with existing conditions (dash "e") that deposits in selected channel reaches for: a) 1993 event, b) 2006 event, c) 1998 event, and d) 1990 event.

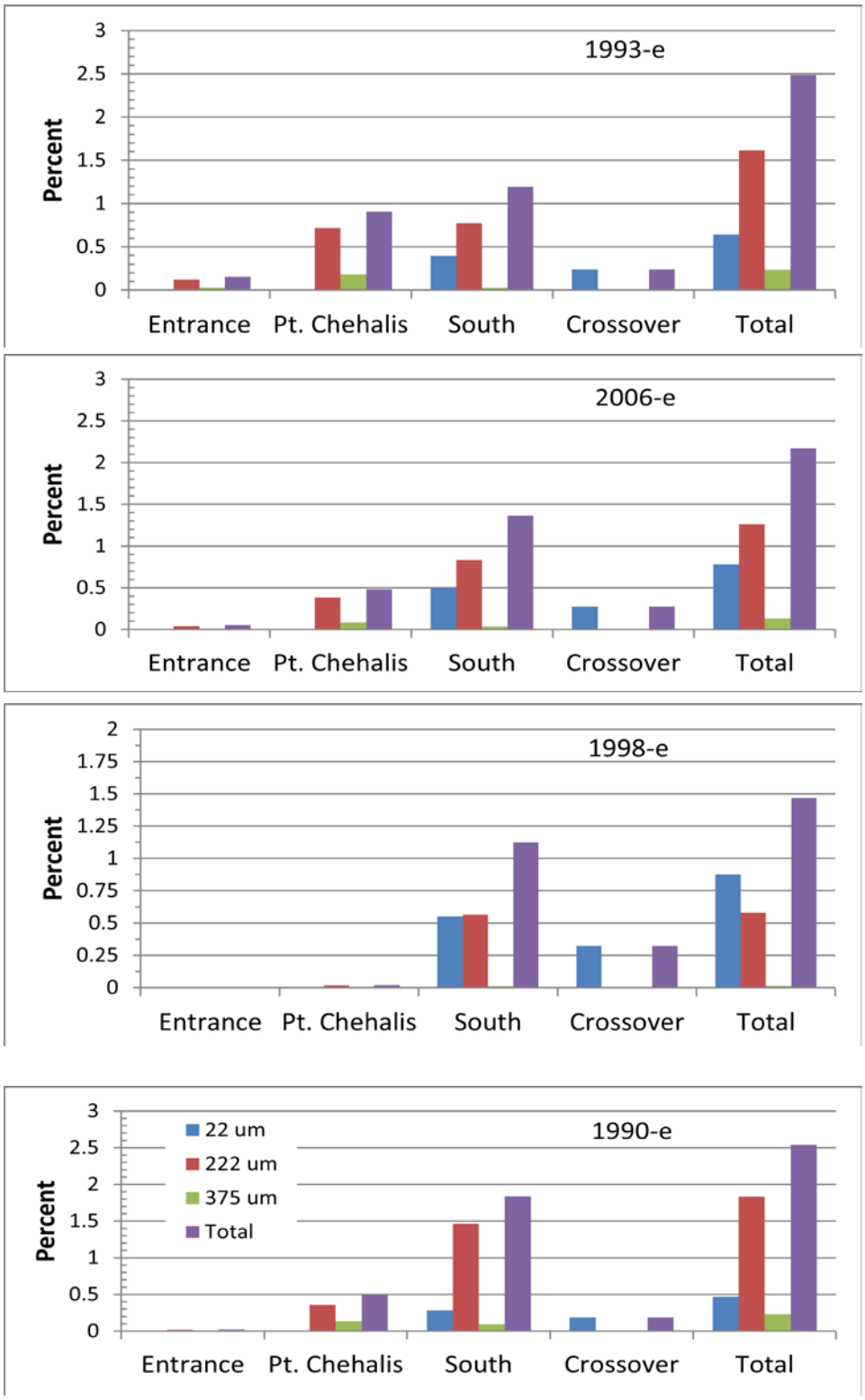

Figure 16 Percentage of sediment eroded from South Jetty placement site with existing conditions that deposits in selected channel reaches for: a) 1993 event, b) 2006 event, c) 1998 event, and d) 1990 event.

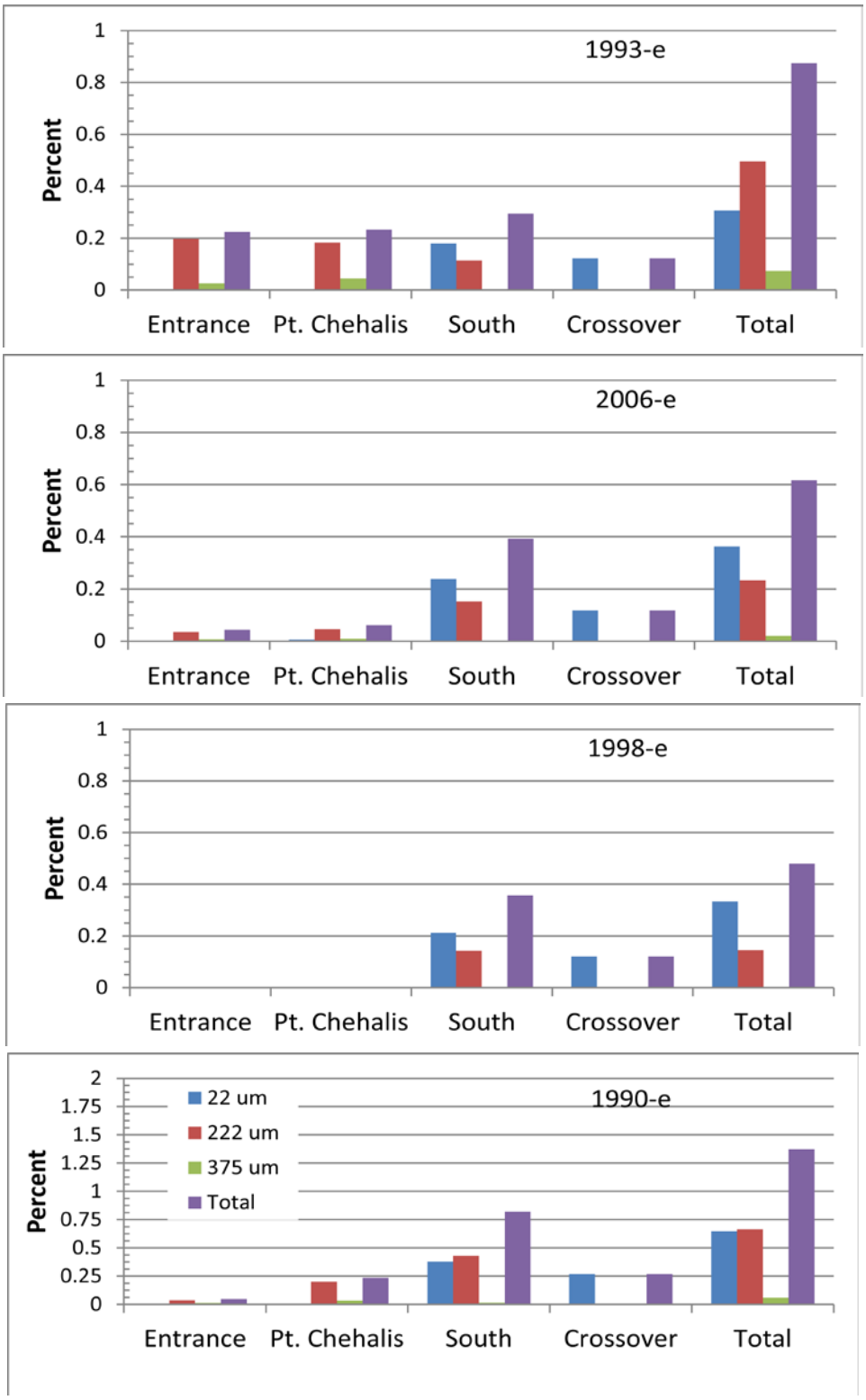

Figure 17 Percentage of sediment eroded from Half Moon Bay placement site with existing conditions that deposits in selected channel reaches for: a) 1993 event, b) 2006 event, c) 1998 event, and d) 1990 event.