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Evaluating Opportunities to Reduce Shoaling within the Federal Navigation Channel at Port Orford: A Relative Comparison of Breakwater Repair Alternatives

Port Orford, Oregon

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Supplemental Project Report

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Abstract

This report describes a qualitative evaluation of sediment transport at Port Orford, Oregon. Conclusions are based on application of the ERDC Particle Tracking Model (PTM), driven by the ERDC Coastal Modeling System (CMS). The models were not calibrated or validated for use at Port Orford due to scope limitations. Based on the extent for which these models had been previously developed, tested, and applied at numerous other project locations, the model output for Port Orford was deemed to be qualitatively accurate.

The PTM and CMS models were used to evaluate the timing and source of coarse sand deposited by waves and currents within the Port's 750-ft-long navigation channel with a depth of -16 ft mllw. A 550-ft-long breakwater that is severely damaged currently protects the Port from severe wave action. The breakwater has induced shoaling at the Port since construction in 1969.

The report evaluated three differing alternative configurations for the breakwater (Modified Breakwater Repair, Notched Breakwater, and Breakwater Removal), to determine if breakwater modification could alleviate channel shoaling. The evaluation approach documented within this report is based on a relative comparison framework. Model results for each alternative for breakwater (repair and associated effect on channel shoaling) were compared to each other, to evaluate alternatives on a relative and qualitative basis.

Based on the results of this report, there appears to be no viable solution for alleviating the Port's shoaling problem through breakwater modification while at the same time maintaining the intended function of the breakwater which is to protect the Port from damaging wave action. The prudent course of action would be to repair the damaged breakwater (Modified Breakwater Repair alternative) and operate the Port to make best use of favorable tides for launching and mooring vessels, and leverage resources to perform targeted dredging to sustain Port function.

Contents

Figures and Tables

Figures

Tables

Preface

This study was conducted for Headquarters, U.S. Army Corps of Engineers (HQUSACE), Washington, D.C. under the USACE Regional Sediment Management (RSM) Program; Project 454632, "Sediment Transport Analysis; Port Orford, Oregon" Project. The USACE RSM Program Manager was Linda S. Lillycrop, CEERD-HN-C. Jeffrey A. McKee was the HQUSACE Navigation Business Line Manager overseeing the RSM Program.

The work described within this report was performed by the U.S. Army Engineer District, Portland (NWP) and the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL). This report features integrated use of ERDC physics-based models. Although these models were not calibrated or validated for use at Port Orford, output was deemed to be qualitatively accurate based on accurate portrayal of model boundary conditions. Synthesis of model results is based on a relative comparison of various alternatives.

The approach and methods featured in this report serve as an example of how to conduct qualitative and rational modeling activities within the scope of USACE SMART Planning Guidelines. Publication of this work is intended to provide relevant tech-transfer to help others in USACE apply a similar integrated modelling framework within a stream-lined budget and schedule. The report conclusions identify lessons learned and need for further model enhancement, showing the strengths and limits of these models.

Cover photo by City of Port Orford, Oregon.

Unit Conversion Factors

Multiply	By	To Obtain
Acres	0.4046856	Hectares
Cubic yards	0.76455	Cubic meters
Feet	0,3048	Meters
Miles (Statute)	1.609344	Kilometers
Pounds	0.3732417	Kilograms
Tons	907.18473	Kilograms

Tidal Datums for Port Orford, Oregon

MEAN HIGHER HIGH WATER, MHHW = 7.28 ft (2.22m) MLLW

MEAN HIGH WATER, MHW = 6.57 ft (2.00m) MLLW

MEAN TIDE LEVEL, MTL = 3.97 ft (1.21m) MLLW

MEAN SEA LEVEL, MSL = 3.93 ft (1.20m) MLLW

MEAN LOW WATER, MLW = 1.30 ft (0.40m) MLLW

MEAN LOWER LOW WATER, MLLW = 0.0 MLLW

North American Vertical Datum, 0 NAVD88 = 0.49 ft (0.15m) MLLW

Based on tidal epoch of 1983-2001 (source = NOAA-COOPS tide station 9431647

1 Introduction

Regional Sediment Management Program

The goal of the U.S. Army Corps of Engineers (USACE) Regional Sediment Management (RSM) Program is to optimize the use of sediments and management of projects through a systems-based approach. RSM supports sustainable navigation and dredging, flood and storm damage reduction, and environmental restoration practices to increase overall benefits and reduce lifecycle costs. The RSM Program strives to enhance the planning, construction, and operation and maintenance (O&M) of projects where the exchange of sediments would occur naturally. RSM is also a means to identify needs and opportunities, and develop solutions to improve the utilization and management of sediments. The main focus is to better understand the regional sediment transport processes through integration of regional data and application of tools that improve knowledge of the regional processes, understand and share demands for sediment, and identify and implement adaptive management strategies to optimize use of sediments and streamline projects. Benefits of this approach are improved partnerships with stakeholders, improved sediment utilization and project management on a regional scale, improved environmental stewardship, and reduced overall lifecycle costs.

The study summarized in this report was supported by the USACE Regional Sediment Management (RSM) program, and extends work previously completed by the U.S. Army Engineer District, Portland (NWP). Team members contributing to this study included personnel from the USACE Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL), Vicksburg, Mississippi; USACE NWP, Portland, Oregon; and the City of Port Orford, Oregon.

Background

Port Orford, Oregon, is located on U.S. Highway 101 between the Pacific Ocean and the Siskiyou National Forest, 28 miles north of Gold Beach and 27 miles south of Bandon (Figure 1). It is the westernmost city in the contiguous United States although there are three unincorporated communities that are farther west than Port Orford. Port Orford lies within a natural cove and supports a vibrant and unique small boat harbor that has been in operation since 1930. The Port is a critical harbor of refuge.

Figure 1. Port of Port Orford, location along the Pacific coast of Oregon, dock, and protective breakwater. (photo by Google Earth.)

The winter sea state offshore of Port Orford is characterized by large swell approaching from the northwest (NW) to southwest (SW), combined with locally generated wind waves approaching from the south (S) to southwest (SW). Individual storm events can be energetic and complex, persisting for 3-12 hours as they make landfall producing S-SW offshore waves having height greater than 7 meters (m) and wave period ranging from 8-17 seconds (sec). During the summer, high pressure systems dominate the coast of the U.S. Pacific Northwest (PAC-NW), producing sustained seasonal NW winds of 10-20 knots, with attendant NW wave height typically less than 2 m and modal wave period ranging from 5-10 sec (USACE 2012). Summer swell can occur, having wave height of 1 m or less and periods of 14-22 sec (Moffatt and Nichol 2011). The result is a bi-modal wave environment being affected by the winter SW and summer NW seasonal wind forcing. Approximately 65 percent (%) of observed storm wave events are characterized by a modal wave direction from the NW, as compared to 35% of events having a SW modal direction. The most severe storm wave conditions tend to have an S-SW onshore wave direction (Moritz et al. 2013). Diurnal tide range at Port Orford is 0 to 7.28 ft mean lower low water (mllw).

The Port of Port Orford Federal Breakwater and dredged Federal Navigation Channel (Figure 2) are critical assets enabling Port function. The navigation channel is adversely impacted by significant shoaling that can severely limit Port operations.

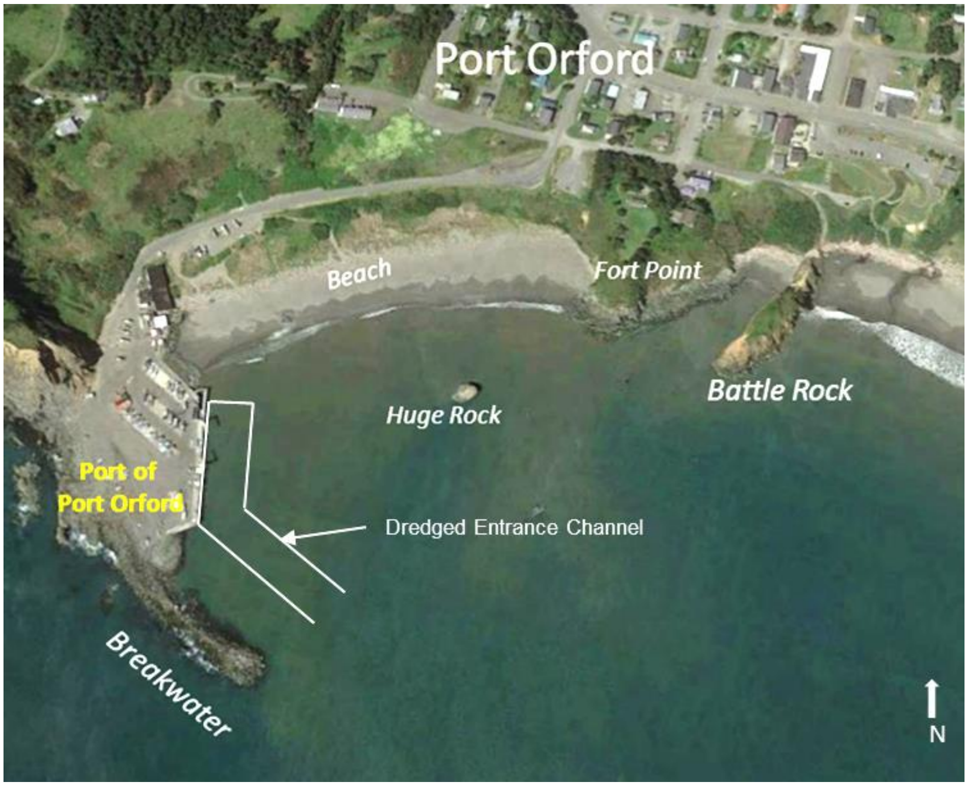

Figure 2. Port of Port Orford, Oregon, existing breakwater and dock, and dredged entrance channel adjacent to the dock and parallel with the breakwater. (photo by Google Earth.)

Commercial and recreational fishing are the main economic drivers for the Port, representing nearly 90 percent (%) of the Port's activity. Port Orford does not provide vessel moorage because it is unprotected to the southeast and, on occasion, experiences extreme wave impact during severe weather conditions. The Port is unique, being one of only two "dolly docks" in the United States, and one of only six in the world. Giant hoists lift all vessels out of the water each day using two boat launching cranes adjacent to the wharf (Figure 3). The harbor area is too shallow for safe mooring and, when not in the ocean, the boats are parked in rows on the dock for dry storage or are hauled to an offsite location (Figure 4). The boats are cradled in custom-made dollies that are easily pulled around by pickup trucks. The dollies can accommodate up to 40 dry storage slips. The Port is used throughout the year by vessels 20 to 42 feet (ft) long drafting 1 to 4 ft.

Figure 3. Hoist lifting fishing boats out of water each day at Port Orford, Oregon. (photo by City of Port Orford, Oregon.)

The fishery at Port Orford includes cabezon, Dungeness crab, black cod, ling cod, rock fish, tuna, salmon, and sea urchin. Fish processing is co-located at the Port, and includes a live-catch facility catering to international markets. Commercial fishing directly employs approximately 120 community members in Port Orford, over 25% of the local job market. An additional two-thirds of the local community is indirectly influenced by commercial fishing at the Port. Port Orford holds over 50% of the available nearshore fishing permits in Oregon. Per capita, the economic contribution of Port Orford commercial fishing is the third highest in Oregon. The annual local catch is about 2 million pounds (lb), and the value of the local fisheries is about $3 million/year. Dungeness crab (mainly a wintertime fishery) accounts from a third to a half of the total catch value. Port Orford fishing depends on continuing dock access and port operations through the year.

Figure 4. Fishing boats on trailers for dry storage at Port Orford, Oregon. (photo by City of Port Orford, Oregon.)

Port operations have been severely perturbed by trends in harbor shoaling, breakwater degradation, and lack of Federal funding to sustain consistent O&M dredging of the Federal Navigation Channel.

One solution to keeping this access channel maintained is dredging. The dredging technique used at Port Orford is a clam shell bucket dredge suspended from any onboard crane that deposits the dredged material into a scow for transport to a disposal site (Figure 5). This process is repeated every 1 to 2 years to keep the channel deep enough for vessels. Annual O&M dredging has been performed since 1971.

The dredged sediment is classified as medium to coarse sand having mean diameter of 0.3 to 0.6 millimeters (mm) and 4-7% fines content (USACE 2007). Since 2003, the dredged sand has been placed at an in-water site located 500 feet (ft) offshore of the breakwater. Prior to 2003 the dredged sand was either placed on the beach, or dredging was performed using an enhanced agitation method by which the sediment was flushed beyond the breakwater (Moffatt and Nichol 2011).

Although providing enhanced wave protection, the breakwater extension also had the unintended effect of modifying littoral sediment transport patterns within the Port's harbor and embayment. In addition to the elevated cost of O&M dredging, the harbor shoaling also has a direct negative impact on navigation and port operations due to increased wave steepness and wave breaking along the pier.

Figure 5. Clam shell bucket dredge and scow dredging entrance channel behind breakwater at Port Orford, Oregon. (photo by City of Port Orford, Oregon.)

In 1974, the USACE performed a physical model study to evaluate corrective measures for the shoaling problem at Port Orford. Results indicated that removal of portions of the existing breakwater would slightly reduce sediment shoaling within the Federal Navigation Channel, but would worsen the wave climate at the dock. Although the 1974 USACE physical model was state-of-the-art at the time and rigorously executed, the model had several limitations that hindered insight to the processes influencing present day sediment movement at the Port, including: (a) The physical model utilized a material (coal dust) that did not correspond well with the prototype sediment (medium-to-coarse sand) at Port Orford, when accounting for model-scaling functions; (b) The physical model accounted for wave forcing but did not include the coastal current that is normally present and becomes enhanced during storm events; and (c) The bathymetry condition employed within the 1974 physical model no longer corresponds with the present bathymetry condition at Port Orford due to cumulative shoaling within the embayment. These limitations do not invalidate the 1974 physical model results, but do indicate that the results were qualitative and have inherent uncertainty with respect to the present condition.

In 1992, the Federal Navigation Channel at Port Orford was re-authorized to be 750 ft long and 90 ft wide, with a bottom elevation of -16 ft mllw, and extended to the dock face. In 1999, Port Orford replaced the timber pile-supported dock with a steel sheet-pile wharf located alongside the breakwater structure. The vertical sheet-pile wharf face was anticipated to provide a self-scouring effect that would reduce shoaling immediately adjacent to the dock face. Unfortunately that effect was not produced as a result of the new dock construction. O&M dredging of the channel actually increased. After the 1999 dock modification, seabed contours pro-graded along the face of the new Port dock, resulting in a wider beach and re-positioning the beach slope within the navigation channel. The net change in the harbor embayment bathymetry from 1971 to 2013 is estimated to be 5 to 10 ft of deposition, depending on location within the harbor embayment.

Objective

The objective of this study by the USACE Portland District (NWP) and ERDC Coastal and Hydraulics Laboratory (CHL) was to conduct an evaluation of sediment transport at Port Orford, Oregon. Results are based on application of a USACE ERDC Coastal Modeling System (CMS) and Particle Tracking Model (PTM). These computer models were used to evaluate the timing and source of sediment deposited by waves and currents within the Port's 750-ft-long Federal Navigation Channel having an authorized depth of 16 ft under mllw. A 550-ft-long Federal Breakwater that is severely damaged currently protects the Port from severe wave action. The breakwater has induced shoaling at the Port since breakwater construction in 1969. The PTM and CMS evaluations were performed for three differing alternative configurations of the breakwater, to evaluate if breakwater modification could alleviate channel shoaling.

The Port originally consisted of a timber pile-supported pier protected by a short rubble-mound breakwater. In 1969, the USACE constructed a 550-ft-long rubble-mound breakwater extension (using 8- to 15-ton armor stone), to provide improved protection from destructive southwesterly storm waves.

Soon after the breakwater extension was completed, excessive shoaling began in the harbor, reducing water depths by 6 to 10 ft along the dock (Figure 6). In 1970, the need for periodic maintenance dredging prompted Federal authorization for maintenance of an access channel to the Port dock (Figure 7). By 1971, the net change in the harbor embayment bathymetry from 1961 was 6 to 20 ft of deposition. It was unknown what proportion of the total change could be associated with the breakwater, which had been in service from 1969 to 1971.

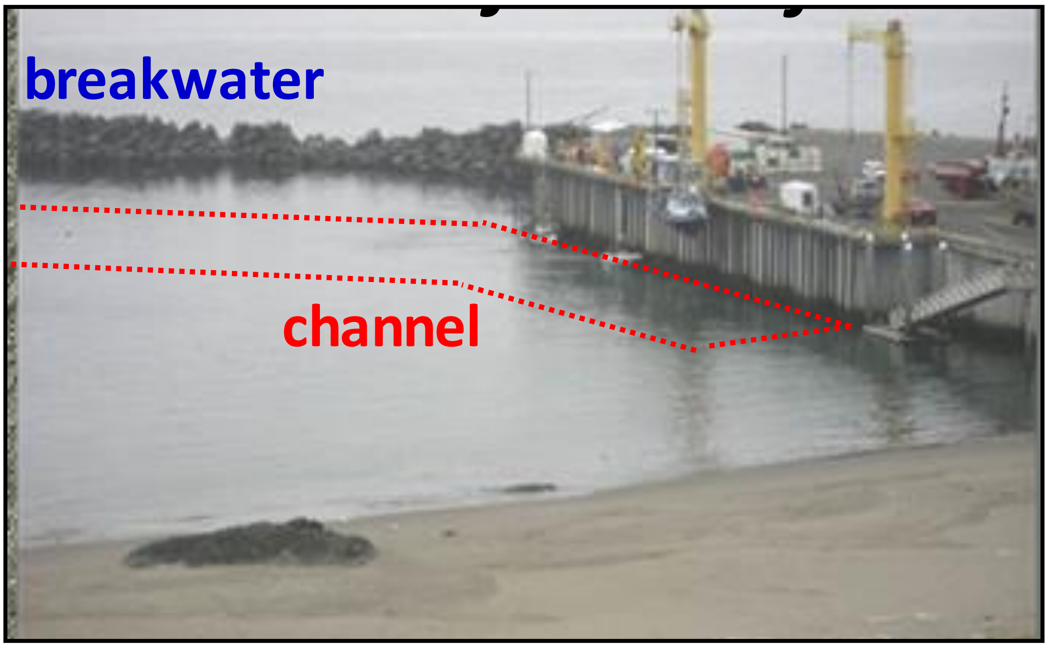

Figure 6. Harbor channel near dock at Port Orford, Oregon, which must be maintained by dredging. Photo shows vessel haul-out along dock face and damaged breakwater (2014).

Approach

The USACE ERDC Particle Tracking Model (PTM) was selected for this evaluation because it can be used to investigate the relative importance for transport pathways of sediment particles from multiple sources that could contribute to the navigation channel shoaling at Port Orford. The USACE ERDC models (CMS-Flow and CMS-Wave) were used to provide current and wave forcing for the PTM. Coastline and bathymetry data for configuring the CMS were extracted from existing model results previously developed for the MMR by using a flexible mesh spectral wave module

(MIKE 21) of the Danish Hydraulic Institute series of models. Water level data were obtained from the National Oceanic and Atmospheric Administration (NOAA) coastal station (9431647) at Port Orford, Oregon. Wind and incident wave conditions were specified based on the measurements at the National Data Buoy Center (NDBC) Buoy 46015 located approximately 16.8 miles west of Port Orford.

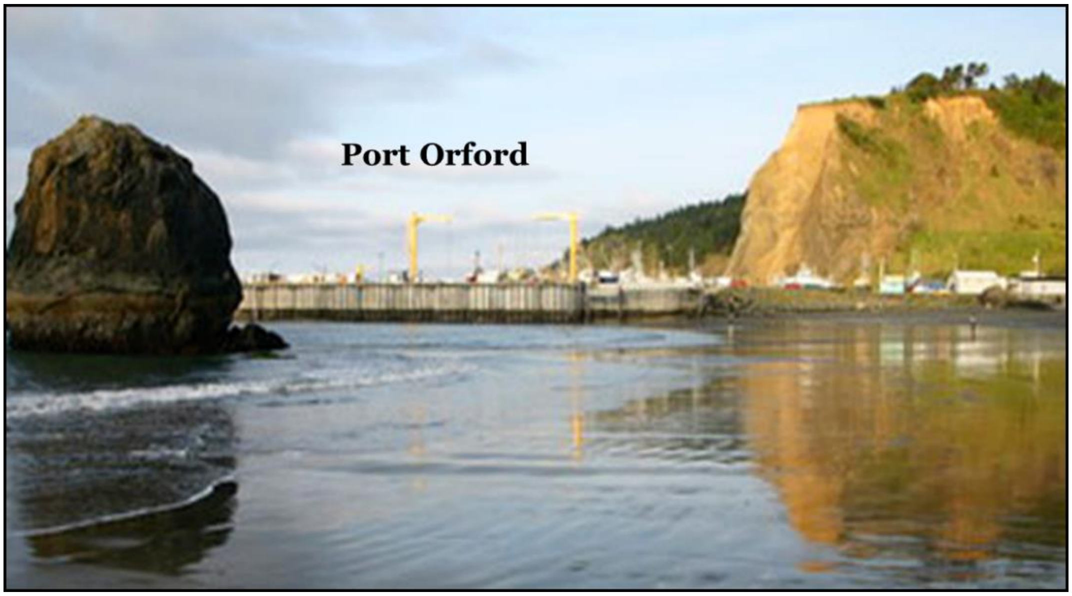

Figure 7. Port Orford, Oregon, viewed from the south during low tide, with entrance channel extending along the dock west (left) to the ocean. Entrance channel requires dredging every 1-2 years. (photo by City of Port Orford, Oregon.)

The application of the USACE Engineer Research and Development Center (ERDC) Coastal Modeling System (CMS) (Sanchez et al. 2011a), and Particle Tracking Model (PTM) (Demirbilek and Connell 2008), applied during this study provided enhanced insight regarding present sediment movement at Port Orford beyond the results portrayed by the 1974 physical model. A comparison between the physical model results (1974) and the application of CMS with PTM numerical model results of this present study is discussed later in this document.

All sediment referred to in this document is sand-sized, and the two terms are used interchangeably throughout.

2 Shoaling of Port Orford Channel and Harbor

Problematic Project Feature

The present 750-ft-long Federal Navigation Channel (original breakwater crest elevation +20 ft mllw) was intended to facilitate access from the open coast, around the breakwater, and to the Port's dock. However, the navigation channel frequently experiences significant shoaling which can severely limit Port operations. The frequency at which the Corps is able to maintain the channel is 1 to 3 years, and the annualized O&M channel dredging volume is about 17,000 cubic yards/year (cy/year). When shoaling along the dock becomes severe enough such that neither of the two crane-hoists can be operated (not enough water depth for vessel access), Port operations are suspended until emergency dredging is performed.

Possible abatement of an essential contributing factor

Although the breakwater extension is altering shoaling within the Port's Federal Navigation Channel, the breakwater is an essential project feature for the Port, protecting its dock-face from ocean waves. In addition to protecting the Port from storm waves, the 550-ft-long breakwater extension also functions to reduce wave action along the dock face during nominal wave conditions. This secondary breakwater function enables vessel launching and retrieval operations during "workable conditions", when offshore wave height may approach 9 to 12 ft. The breakwater extension is currently in a severely degraded condition, with 300 ft of breakwater sustaining more than 50% damage to the structure's cross-section along the mid-span (due to severe wave loading). Without repair, the damaged structure will continue to deteriorate, compromising its intended function. To reduce the shoaling effect that the breakwater is currently having on the Port, it may be possible to alter the breakwater's present configuration (rather than just repair it), if such an alternative can be ascertained.

In 2011, the USACE Portland District (NWP) completed a Major Maintenance Report (MMR) addressing a breach in the breakwater structure and evaluating measures to reduce channel shoaling at the Port

(Moffatt and Nichol Engineers 2011). The MMR developed six alternatives that were intended to maintain the federally-authorized function of the breakwater (to protect the Port from wave action by reducing severe storm waves at least 50%), while potentially alleviating (or at least not increasing) the Port's shoaling problem. The least cost alternative, the "Mid-Section Notch" (Notched Breakwater) (Figure 8), would implement a 250-ft-long notch in the breakwater. This alternative was ranked #1 for least life-cycle cost because, as indicated by the MMR model studies, the Notched Breakwater alternative had potential for reducing shoaling in front of the dock which would reduce maintenance dredging costs. Recurring costs associated with dredging overwhelm the costs of the breakwater repair when factored into the 50-year life-cycle costs. Given the potential for the Notched Breakwater alternative to reduce these costs, it would have been desirable to conduct further evaluations to verify the sediment dredging reduction and, in essence, buy down the risk.

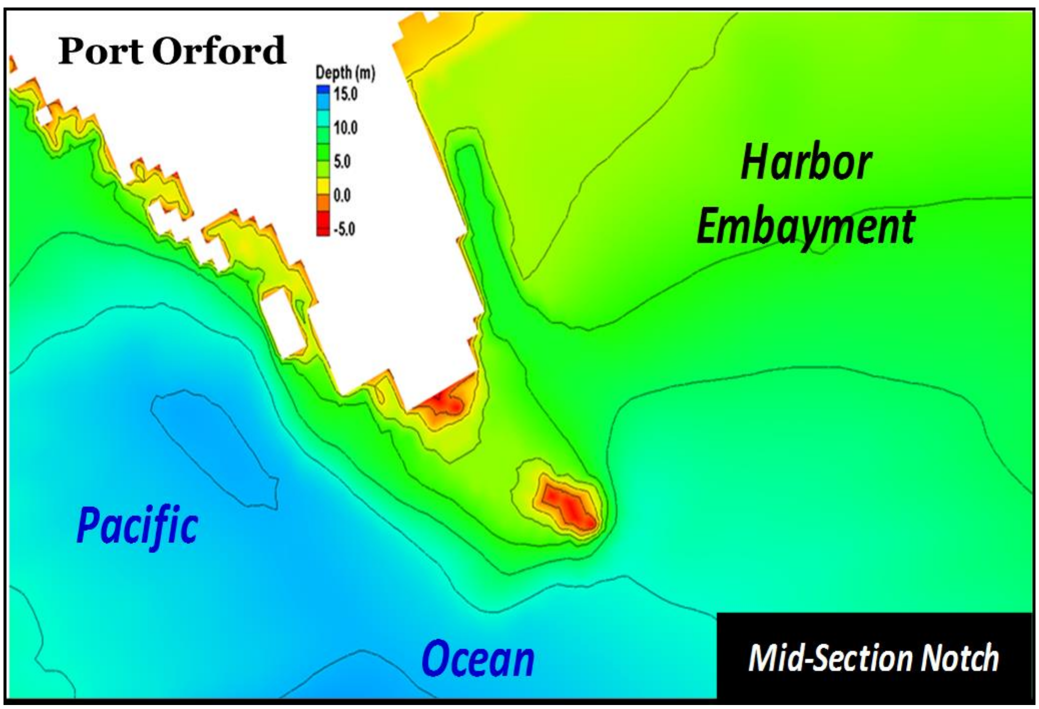

Figure 8. Notched Breakwater alternative to reduce shoaling within Port Orford Federal Navigation Channel. This #1 life-cycle cost option would remove the middle 200 ft of the 550-ft-long breakwater extension to a pre-project elevation of -5.5 ft mllw.

Such studies were beyond the MMR scope. Without additional studies to reduce uncertainty associated with implementing the Notched Breakwater alternative, a more conventional (less uncertain) alternative was chosen as the preferred alternative for the MMR, that being a full repair to a crest elevation of +20 ft mllw with cross-section improvements. This "Modified Breakwater Repair" alternative had a life-cycle cost rank #2 (Figure 9). The "Breakwater Removal" alternative (Figure 10) was ranked #3 for life-cycle cost.

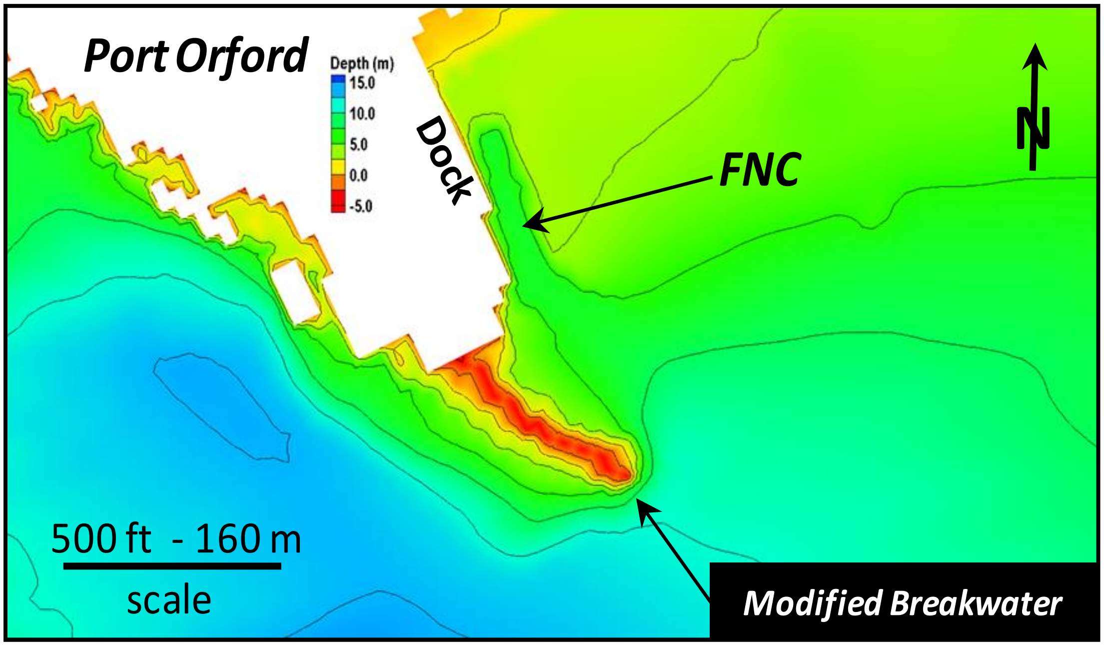

Figure 9. Modified Breakwater Repair alternative to reduce shoaling within Port Orford Federal Navigation Channel. This #2 life-cycle cost option would re-establish the breakwater to its fully authorized foot-print, with an improved cross-section at elevation +20 ft mllw. This is the present recommended plan, and serves as the default future condition for the breakwater.

Specific issues

The 550-ft-long Federal Breakwater extension has been in service at Port Orford since 1969 to protect the Port from wave action, yet the breakwater is causing problematic shoaling for the Port. The breakwater extension is currently severely degraded in its mid-section, limiting Port operations during "workable conditions" and adversely impacting the Port during severe storms (Figure 11).

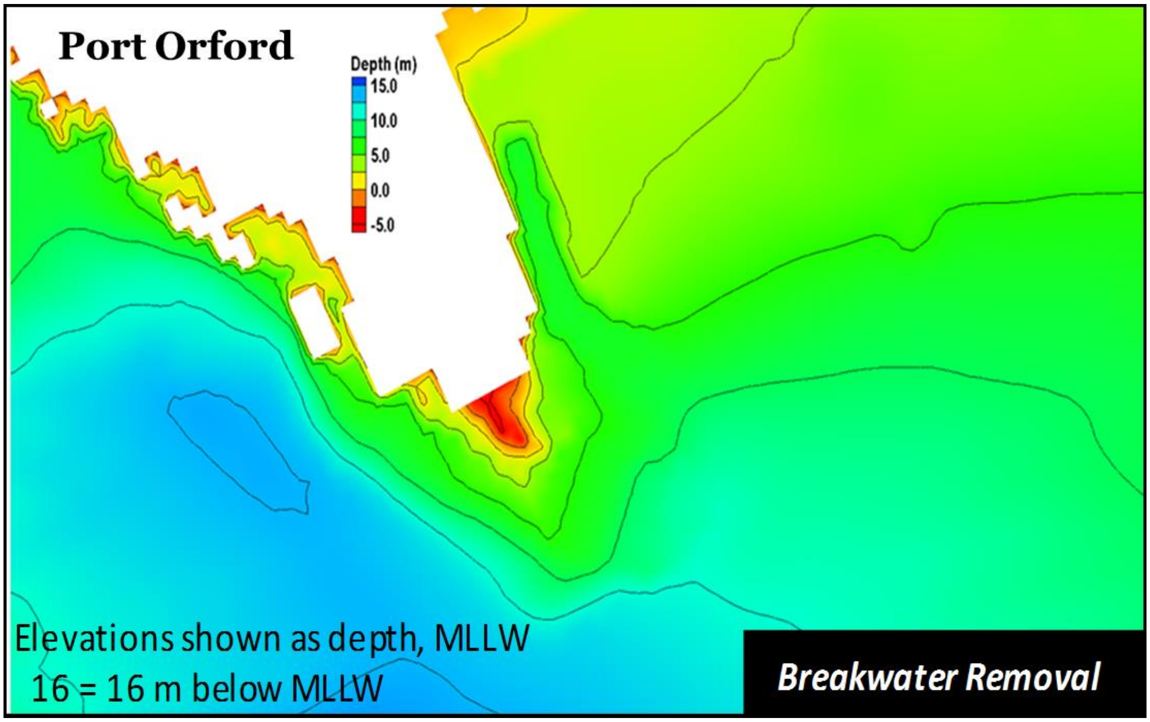

Figure 10. Breakwater Removal alternative to reduce shoaling within Port Orford Federal Navigation Channel. This #3 life-cycle cost option would remove the eastern 450 ft of the 550-ft-long breakwater extension to a pre-project elevation of -5.5 ft to -20 ft mllw.

Without periodic maintenance dredging, vessel access to the Port dock can be restricted to the upper half of the tidal cycle when sufficient water depth is available within the Port's channel. This limits Port operations by 50% workable time. Timely boat launching and retrieval operations at the Port are critical for safe and successful Port operations, as the Port is used throughout the year's fishing seasons. Despite its importance to the local and regional economy of the southern Oregon coast, Port Orford is classified as a low-use port (less than 1 million tons/year of shipping) which lowers its priority for receiving federal funding for channel maintenance dredging. Yet, the Federal Navigation Channel requires O&M dredging every 1-to-3 years to provide access to the Port dock.

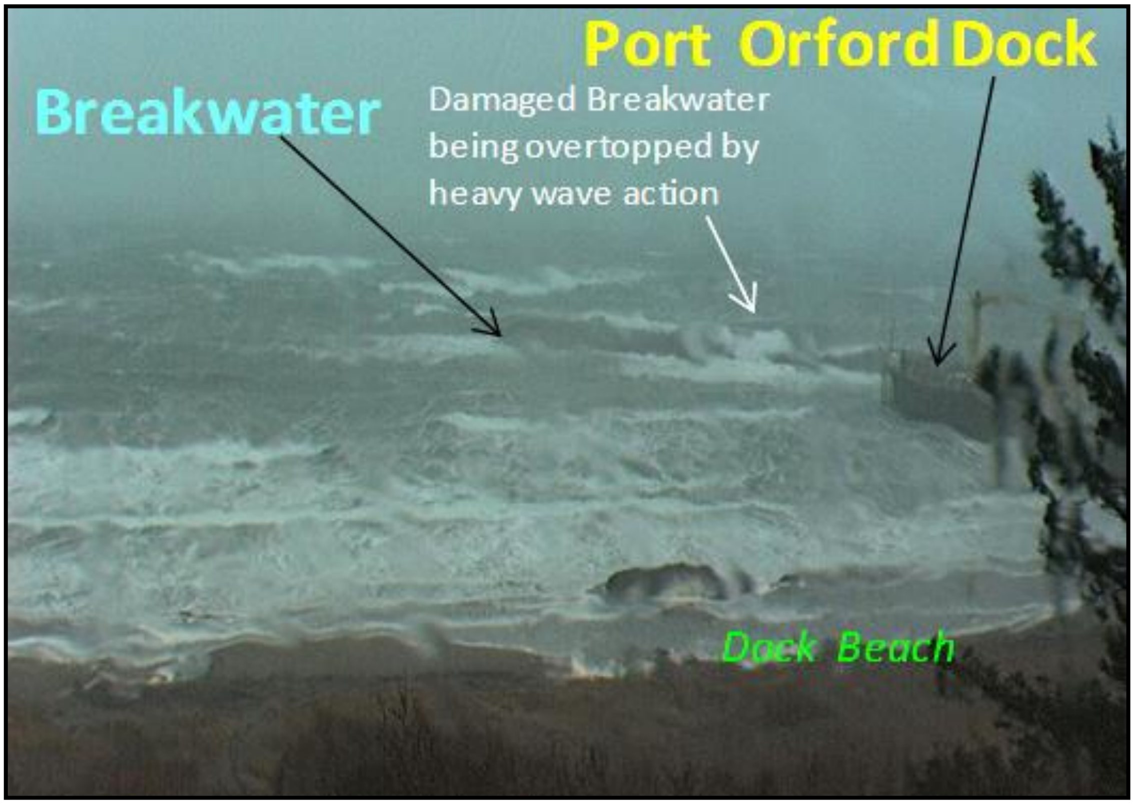

Figure 11. Dock at Port Orford, Oregon, 19 November 2012, 10:00 a.m. during winter storm wave activity. Offshore waves were from the south 20-to-25 ft high. View is to the southwest. The damaged breakwater allows increased wave overtopping transmission that can adversely impact the Port.

The navigation issue at Port Orford is the problematic shoaling within the Port's Federal Navigation Channel. The motivating question for addressing this issue is: Can the shoaling be alleviated by altering the configuration of the Federal Breakwater? The breakwater is now severely damaged after 45 years of service. The opportunity exists that, since the breakwater requires repair, perhaps the breakwater could instead be modified to reduce channel shoaling. This question was partially answered by the 2011 MMR (Moffatt and Nichol Engineers 2011), but more work was still needed to reduce risk of implementing an unconventional breakwater modification.

The Modified Breakwater Repair alternative (Figure 9) is the present recommended plan and serves as the default future condition for the breakwater, if funding were provided for repairs. This configuration re-establishes the breakwater to its fully authorized foot-print, with an improved cross-section, but will not provide any improvement for the Port's channel shoaling condition.

In August 2012, NWP submitted a proposal to the USACE RSM program for supplemental evaluation of breakwater modification alternatives developed in the 2011 MMR. The proposal was accepted by the RSM program and funded in FY2013. This report is the synthesis of that RSM-sponsored supplement to the 2011 MMR for Port Orford. The RSM mission was to further evaluate the MMR alternative configurations to reduce channel shoaling within the Port's navigation channel. Those alternatives for altering the breakwater configuration are shown in Figures 8 through 10.

Channel shoaling within the Federal Navigation Channel at Port Orford is both operationally problematic for the Port and challenging for USACE to maintain and evaluate. Based on trends in local and regional shoreline change, dredged material placement practices, and long-term harbor bathymetry change, there may be multiple contributing sediment sources that are affecting shoaling within the Federal Navigation Channel at Port Orford. Analysis of channel shoaling at Port Orford included these potential sediment sources within the RSM evaluation framework.

Considerable investment was made by NWP to produce the 2011 MMR. Products developed by the authors of that report (Moffatt and Nichol Engineers 2011) reflected a high degree of technical competence. To maximize progress, the supplemental evaluation featured in this report used many of the numerical modeling products previously developed for the 2011 MMR as the foundation to apply improved (more focused) analysis methods.

Numerical models for sediment transport analysis

Particle Tracking Model (PTM)

The Particle Tracking Model (PTM) is based upon the Lagrangian technique which is a modeling framework that moves with the flow (MacDonald et al. 2006). In the PTM, the sediment being modeled is discretized into a finite number of particles that are followed as they are transported by the flow (Demirbilek and Connell 2008; Demirbilek et al. 2012a, 2012b; Li 2011). Lagrangian modeling is especially appropriate for modeling transport from specified sources. Each particle (or parcel) in a Lagrangian transport model represents a given mass of sediment (not an individual sediment particle or grain), and each parcel has its own unique set of characteristics. As a minimum, a parcel must be defined with certain physical properties (e.g., grain size and specific gravity) and an initial position. Parcels being modeled (as opposed to the local, or native bed sediment) are introduced (released) into the domain from specified source locations. A sufficient number of parcels are modeled such that transport patterns are representative of all parcel movement from the sources. Additionally, sediment pathways can be identified within the modeling framework. PTM uses waves and currents as forcing functions to suspend and transport sediment. Forcing functions for waves and currents are developed through hydrodynamic and wave models (such as CMS) and input directly into the PTM.

The basic structure of the PTM is (a) a region (geometry) defined with bathymetric and sediment data, (b) currents (flow field) and, if applicable, wave fields supplied to the PTM, and (c) parcels released into the model domain. The computations then proceed through time, modeling the behavior (entrainment, advection, diffusion, settling, deposition, burial, etc.) of the released parcels. There are two types of calculations performed at each time-step of PTM. Eulerian (mesh-based) calculations are required to determine the local characteristics of the environment, and Lagrangian (particle-based) calculations are required to determine the behavior of each sediment parcel (MacDonald et al. 2006).

The hydrodynamic and wave modeling for Port Orford was conducted using the ERDC Coastal Modeling System (CMS). The CMS is an integrated suite of numerical models consisting of a hydrodynamic and sediment transport model (CMS-Flow), and a spectral wave model (CMS-Wave), and can be coupled with a Particle Tracking Model. The coupled modeling system calculates time-dependent water elevation, current speed and direction, waves, sediment transport, and morphology change in coastal and inlet applications. All pre- and post-processing for these models is performed within the ERDC Surface-water Modeling System (SMS) interface (Aquaveo 2013). The framework of CMS is shown in Figure 12.

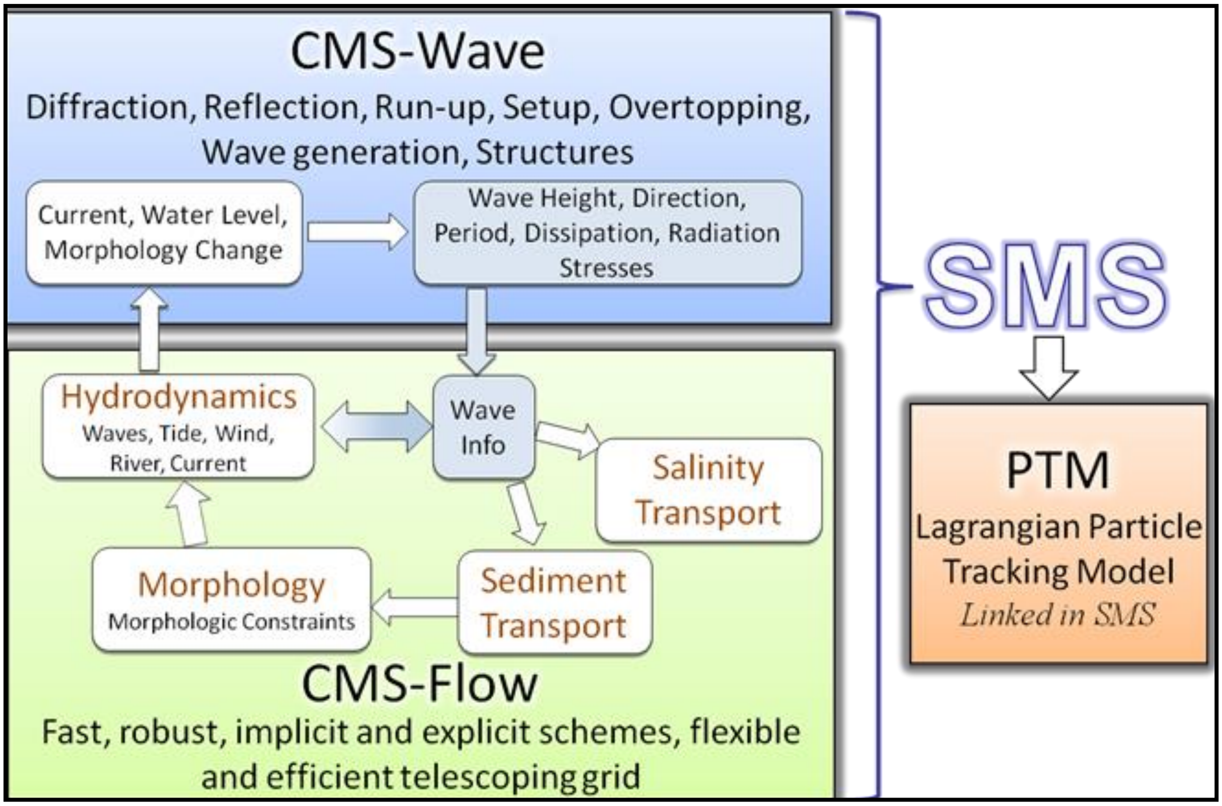

Figure 12. The ERDC Coastal Modeling System (CMS) framework and its components.

CMS-Flow

CMS-Flow is a two-dimensional depth-integrated (2-D) finite-volume model that solves the mass conservation and shallow-water momentum equations of water motion on a non-uniform Cartesian grid (Buttolph 2006, Sanchez et al. 2011a, b). Wave radiation stresses and other wave hydrodynamic and sediment transport calculations. For the Port Orford application, CMS-Flow was run to evaluate water-level and current at 3-hour intervals.

CMS-Wave

CMS-Wave is a 2-D spectral wave transformation model that solves the steady-state wave-action balance equation on a non-uniform Cartesian grid (Lin et al. 2008, 2011). The model is designed to simulate wave processes that are important in coastal inlets, in the nearshore zone, in the vicinity of jetties and breakwaters, and in ports and harbors. These processes include wave shoaling, refraction, diffraction, reflection, wave breaking and dissipation, wave-structure and wave-current interactions, and wave generation and growth mechanisms.

For the Port Orford application, the CMS-Flow was driven by tides, winds, and waves. The coupling between CMS-Wave and CMS-Flow was run at a 3-hr interval to evaluate water-level, current, and wave parameters (wave height, wave period, and wave direction) at the project. Hourly CMS output time series data were used within the PTM to simulate sediment transport and fate within the Port Orford model domain. The PTM was set-up and run with the visualization of model output being performed within the SMS.

3 Sediment Transport Evaluation

The objective of this RSM evaluation was to apply the USACE ERDC PTM to fully supplement the qualitative sediment transport modeling work previously performed with MIKE 21 for the MMR (Moffatt and Nichol Engineers 2011). The objective was realized by completing several tasks:

- Conform MIKE 21 data to the CMS model framework.
- Apply the CMS at Port Orford for winter and summer conditions.
- Set up the PTM for Port Orford using CMS generated forcing.
- Apply the PTM to evaluate shoaling pathways at Port Orford, present condition.
- Apply the PTM to evaluate shoaling pathways at Port Orford, alternative configurations.

Coastline, harbor details, and topography/bathymetry data were extracted from a suite of MIKE 21 models previously developed as part of the 2011 MMR for Port Orford (Moffatt and Nichol Engineers 2011). The MIKE 21 model data were extracted and pre-processed by USACE Seattle District (NWS) and then used by ERDC to configure the CMS model that was used for this supplemental RSM evaluation.

CMS set-up

The CMS-Flow domain was discretized using a telescoping variable-resolution grid. The areal extent for the modeling domain is 12.8 miles (in the along-shore direction) by 10.2 miles (in the cross-shore direction). The CMS-Flow grid has about 140,000 ocean cells (Figure 13). The fine resolution cells with 32.8-ft spacing are specified around the Port, with coarsening resolution expanding to 1,050-ft spacing in the offshore area. The average water depth is 9.8 to 13.1 ft near the Port and increases to 525 ft at the CMS offshore boundary. The navigation channel leading to the Port was defined as having a fully maintained depth of 16 ft mllw. A numerical grid with similar spatial resolution was used to configure the CMS-Wave domain (Figure 14).

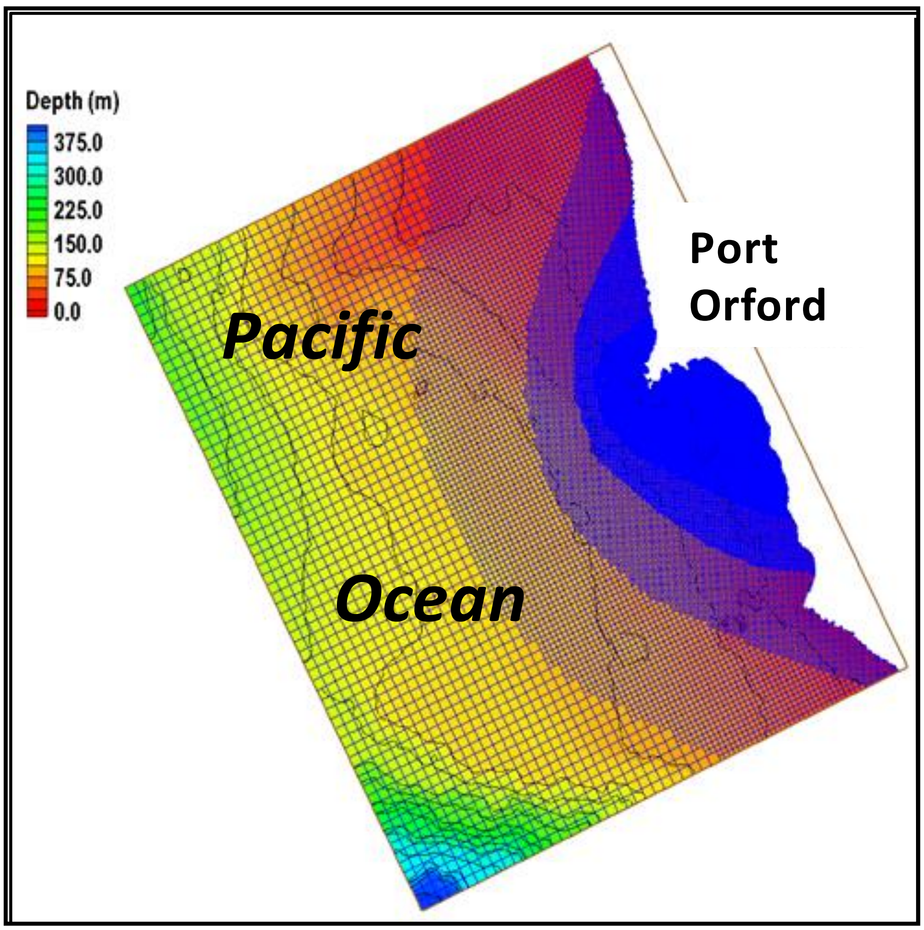

Figure 13. ERDC Coastal Modeling System (CMS) numerical model domain, Port Orford, Oregon. CMS was used to calculate currents and waves for the Producl Tracking Model (PTM). Areal extent is 12.8 miles in the along-shore direction and 10.2 miles in the cross-shore direction. Elevations in meters, mean sea level (msl).

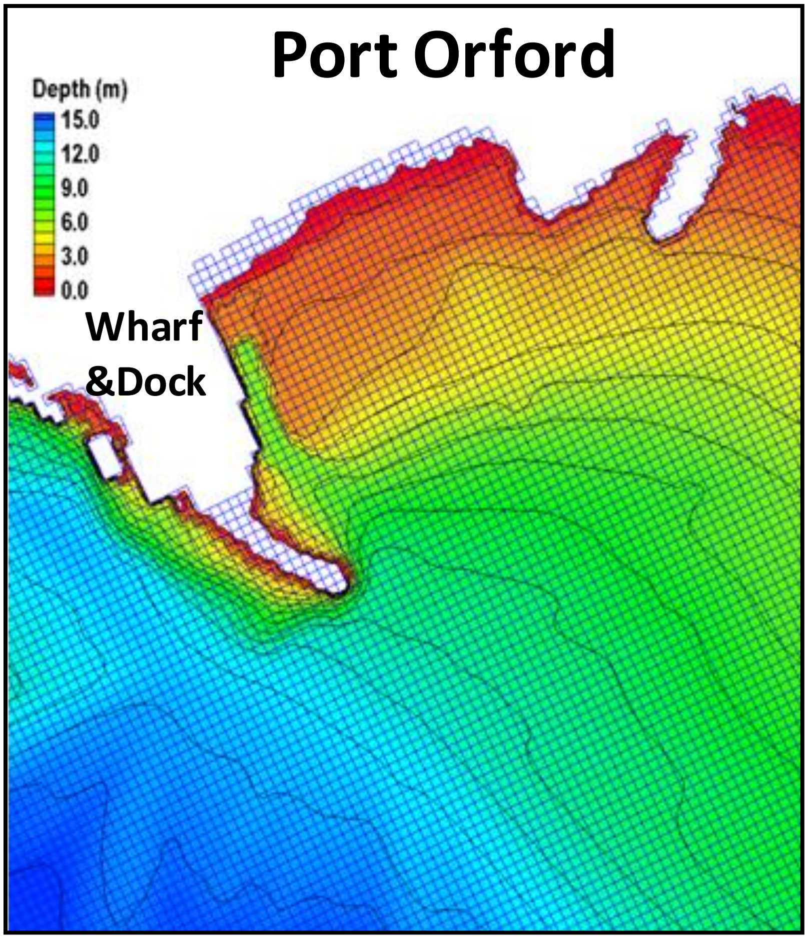

Figure 14. Spatial resolution of the CMS-Wave model at Port Orford, Oregon, was 26.2 to 32.8 ft. Note definition of the existing breakwater and Federal Navigation Channel leading to the wharf and dock. Elevations in meters, msl.

Simulation time frame

Simulations were conducted for a fall (6 November – 15 December 2007, 40-day) and a summer (June 2010, 30-day) period. These periods were selected to represent typical sediment transport and shoaling conditions during the seasons of summer and winter. Figures 15 through 17 show the hourly wind, tide, and offshore wave conditions, respectively, that were used as CMS input boundary conditions for the November-December 2007 and the June 2010 time periods.

Wind data were obtained from the National Data Buoy Center (NDBC, http://www.ndbc.noaa.gov) Buoy 46015, located approximately 27 km west of Port Orford. Figure 15 shows the distinct seasonal wind patterns. During the late fall-early winter time period, there were several storm sequences indicative of fall-winter conditions with lulls between storms. The winter storm is characterized by S-SW winds. The first winter storm in the area appeared on 12 November 2007, and an extreme storm with a maximum speed of 23.3 m/s occurred between 1-3 December 2007. The summer period is relatively calm at this offshore buoy site. The mean wind speed is less than 10 m/s and the dominant wind direction is from the north.

During these winter storm sequences, the wind field was characterized by gale force winds from the S (180 deg) producing offshore waves that were from the S-SW. The directionality of the wave field for these storms can be seen in Figures 15 through 17, and is typical for intense maritime extra-tropical low pressure systems making landfall along the PAC-NW coast of the U.S. (USACE 2012). Note the occurrence in peak wind speed events and associated wind direction (S 180 deg), and compare to the timing of peak wave height and associated wave direction (also from S 180deg). During these winter storm conditions, the coastal current becomes aligned with the wind stress direction and exhibits sheet flow at 0.5-0.8 m/sec magnitude through the water column to depths of 25 m (Moritz et al. 2000).

Water surface elevation at the gauge (Figure 16) indicates a mixed, predominately semi-diurnal tidal regime surrounding the study area. The mean tidal range (mean high water – mean low water) is 5.21 ft, and the great diurnal tidal range (mean higher high water – mean lower low water) is 7.28 ft.

Incident wave conditions were based on directional wave data collected by NDBC Buoy 46015. The buoy wave data were transformed to the seaward boundary of the CMS-Wave grid using a simplified wave transformation for shore-parallel depth contours. Wave parameters are shown in Figure 17. The maximum wave height is 10.6 m during the extreme winter storm. The average wave height is 1.9 m during the summer month. The same wind data described above were also used as atmospheric input to wave modeling for wind and wave interactions.

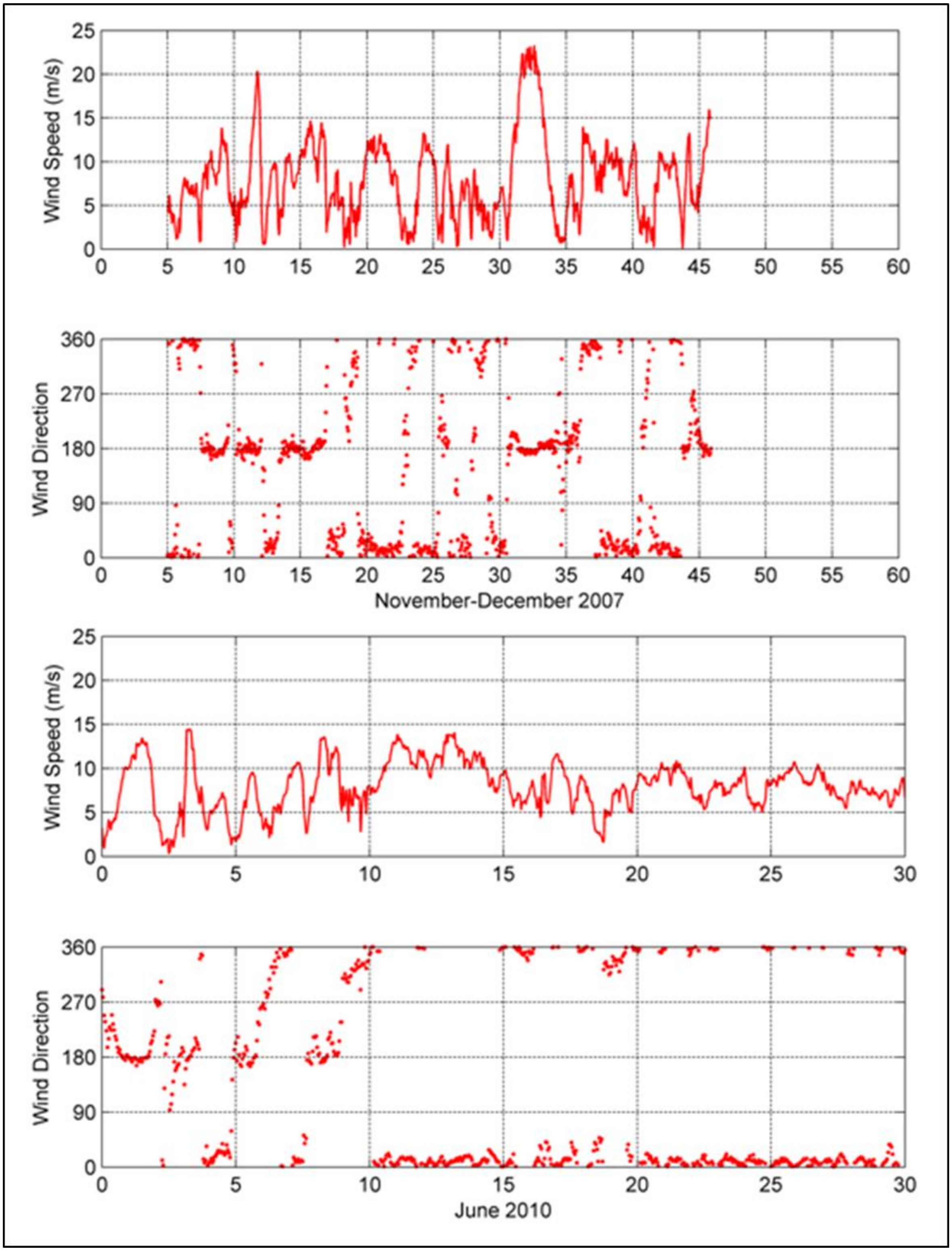

Figure 15. Wind speed and direction used within CMS to simulate currents and waves at Port Orford, Oregon, during 6 November–15 December 2007 and June 2010. Observed offshore data from NDBC Buoy 46015. (Time = 0 corresponds to beginning of Day 1.)

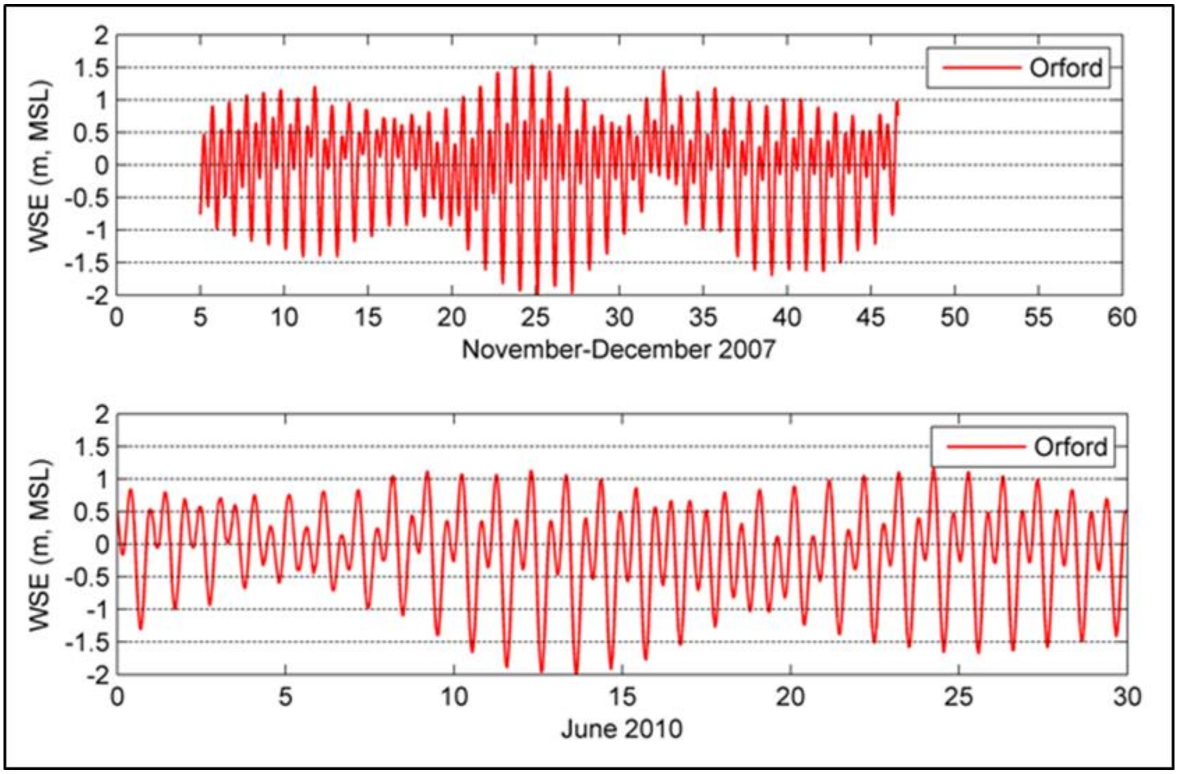

Figure 16. Water surface elevation used within CMS to simulate currents and waves at Port Orford, Oregon, during 6 November–15 December 2007 and June 2010. Observed data from NOAA Station 9431647. (Time = 0 corresponds to beginning of Day 1.)

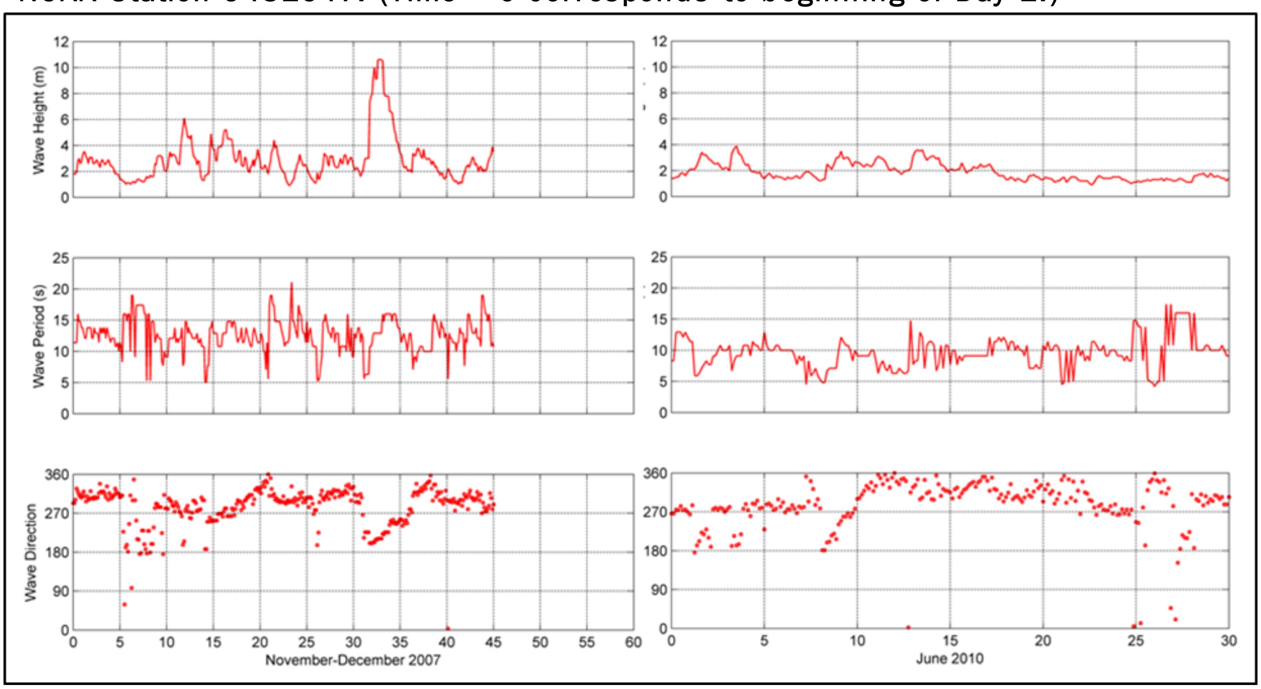

Figure 17. Wave height, period, and direction used within CMS to simulate currents and waves at Port Orford, Oregon, during 6 November–15 December 2007 and June 2010. Observed offshore data from NDBC Buoy 46015. (Time = 0 corresponds to beginning of Day 1.)

The entire 40-day winter and 30-day summer sequences were modeled within CMS to produce wave height and current velocity time series for the domain shown in Figures 13 and 14. The resulting CMS time series output for wave height and current velocity are shown in Figures 18 and 19, respectively, for November-December 2007 and June 2010. Output results are for a given point location approximately 985 ft south of the Port Orford breakwater within the outer half of the Clean Water Act-404 (CWA-404) Dredged Material Placement Site (DMPS) in water depth of approximately 50 ft.

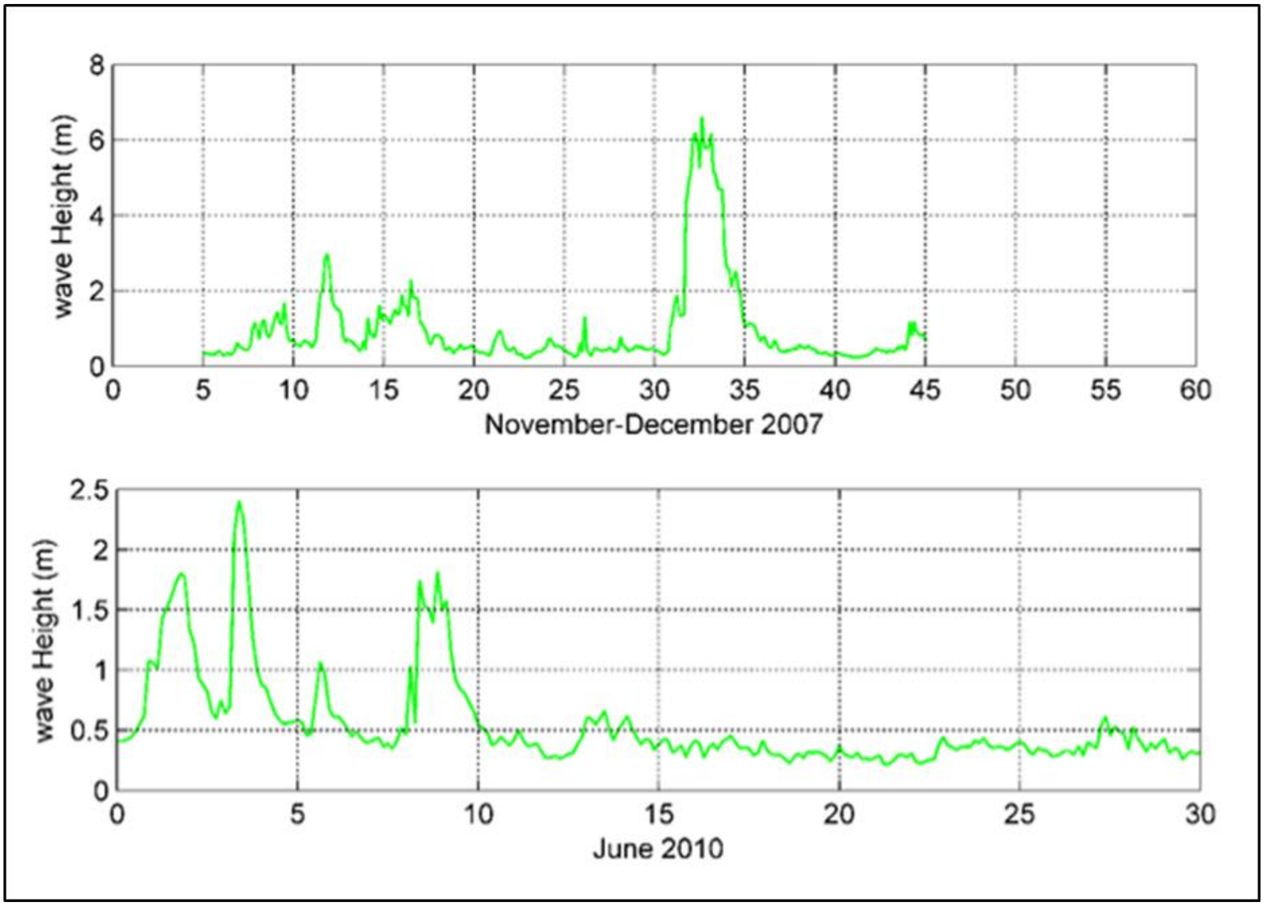

Figure 18. Wave height generated by CMS at a location 300 m south of the Port Orford, Oregon, breakwater during 6 November–15 December 2007 and June 2010. (Time = 0 corresponds to beginning of Day 1.)

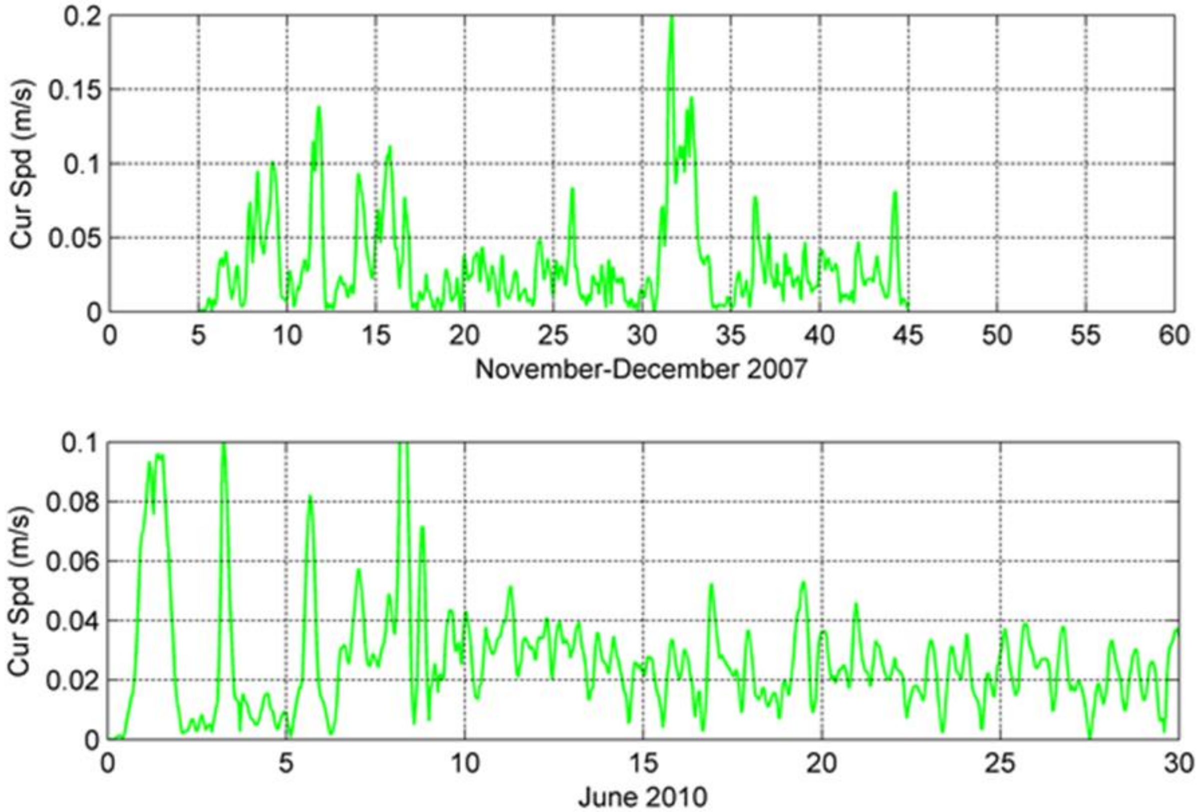

Figure 19. Depth-averaged current speed generated by CMS at a location 300 m south of the Port Orford, Oregon, breakwater during 6 November–15 December 2007 and June 2010. (Time = 0 corresponds to beginning of Day 1.)

Currents

The Port Orford breakwater protects the harbor from the northwest and southeast waves. However, severe winter storms (southerly waves and wind) can have direct impact on the harbor and result in significant long-shore sediment movement into the harbor channel. The vertical black line in Figure 20 at Day 12 shows the wind speed and direction on 12 November 2007 during the first winter storm of 2007. Figures 21 through 23 show snapshots of calculated current fields during the first winter storm of 2007 (12 November 2007) for the Modified Breakwater Repair, Breakwater Removal, and Notched Breakwater, respectively.

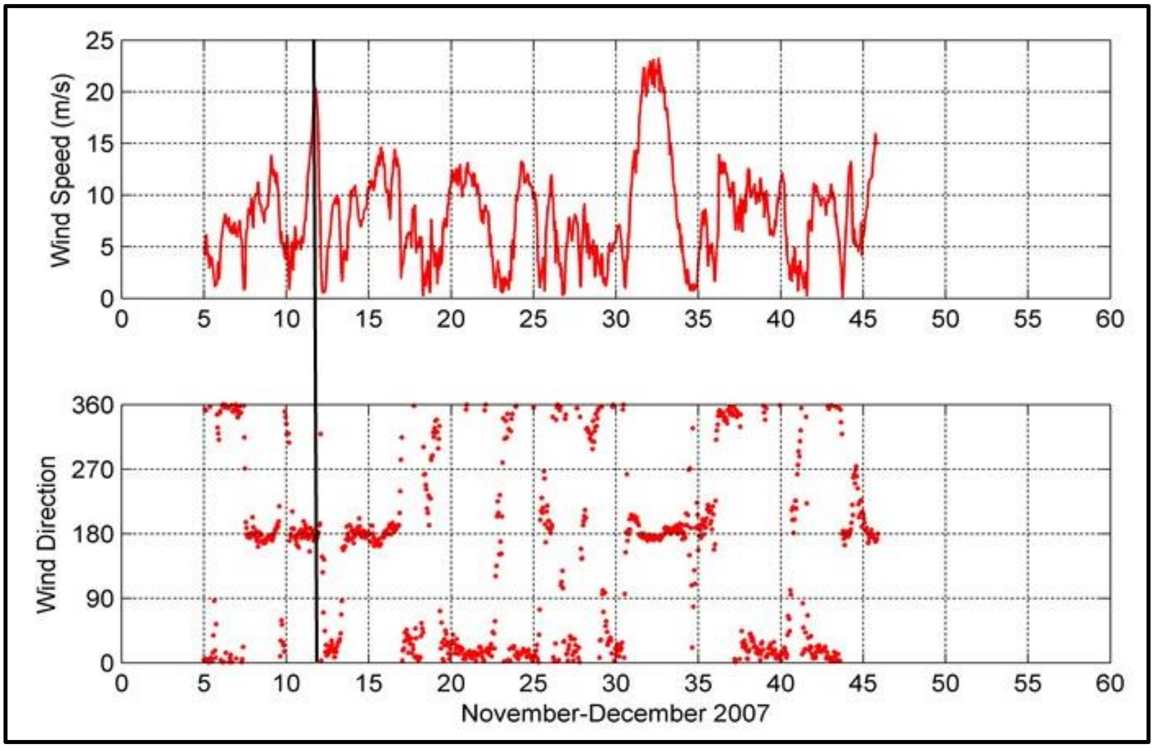

Figure 20. Wind speed and direction used within CMS to simulate currents and waves at Port Orford, Oregon, during first winter storm of 12 November 2007 (vertical black line at Day 12). (Time = 0 corresponds to beginning of 1 November 2007)

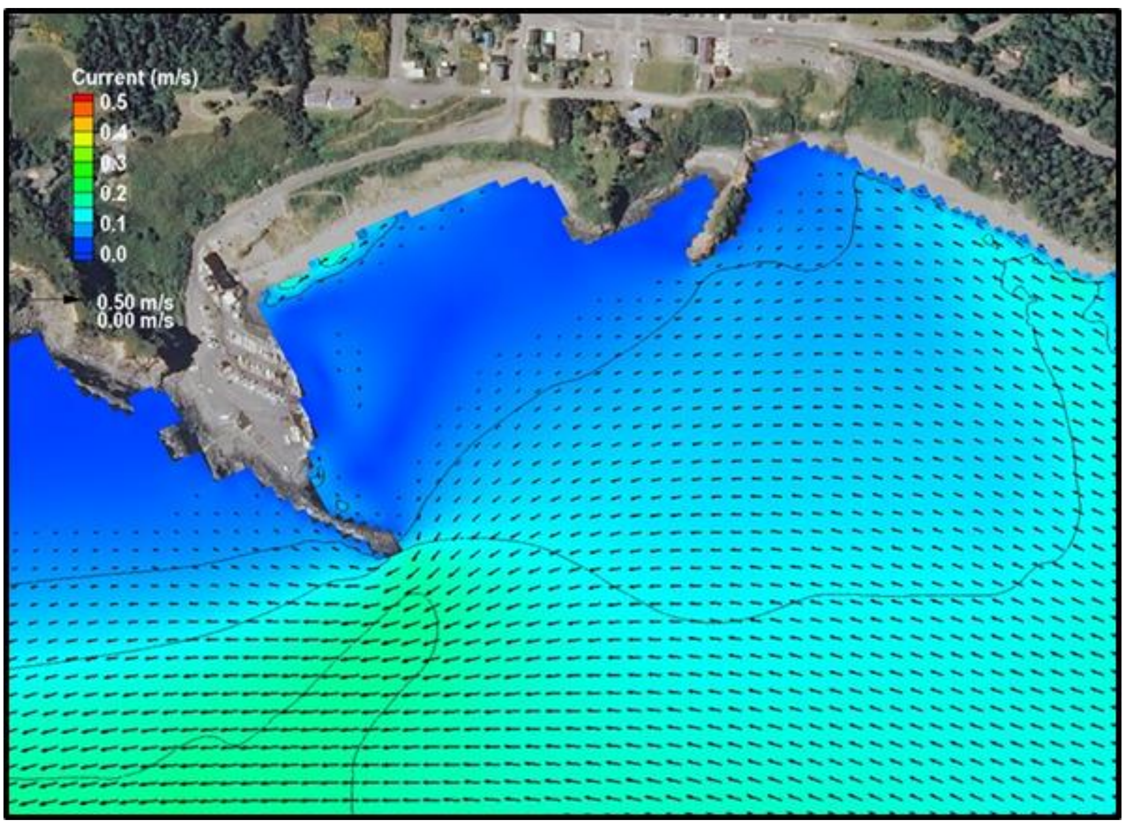

Figure 21. Calculated current field for the Modified Breakwater Repair alternative for the first winter storm on 12 November 2007, 18:00 GMT.

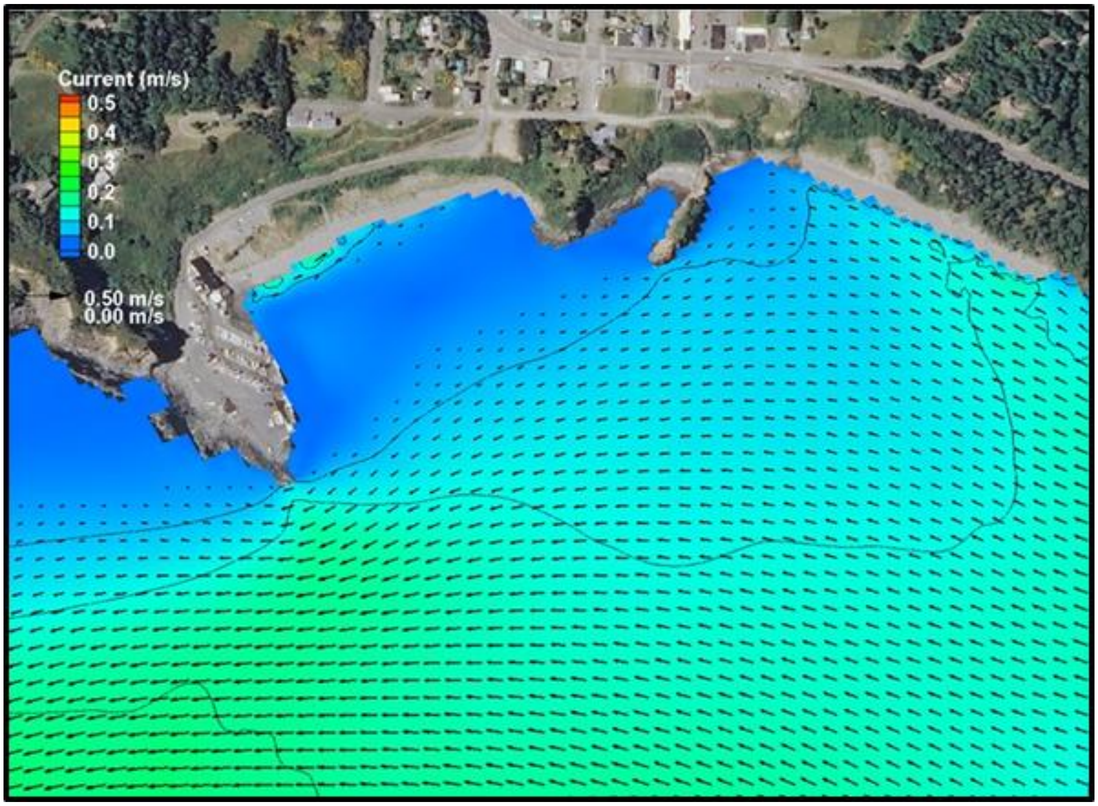

Figure 22. Calculated current field for the Breakwater Removal alternative for the first winter storm on 12 November 2007, 18:00 GMT.

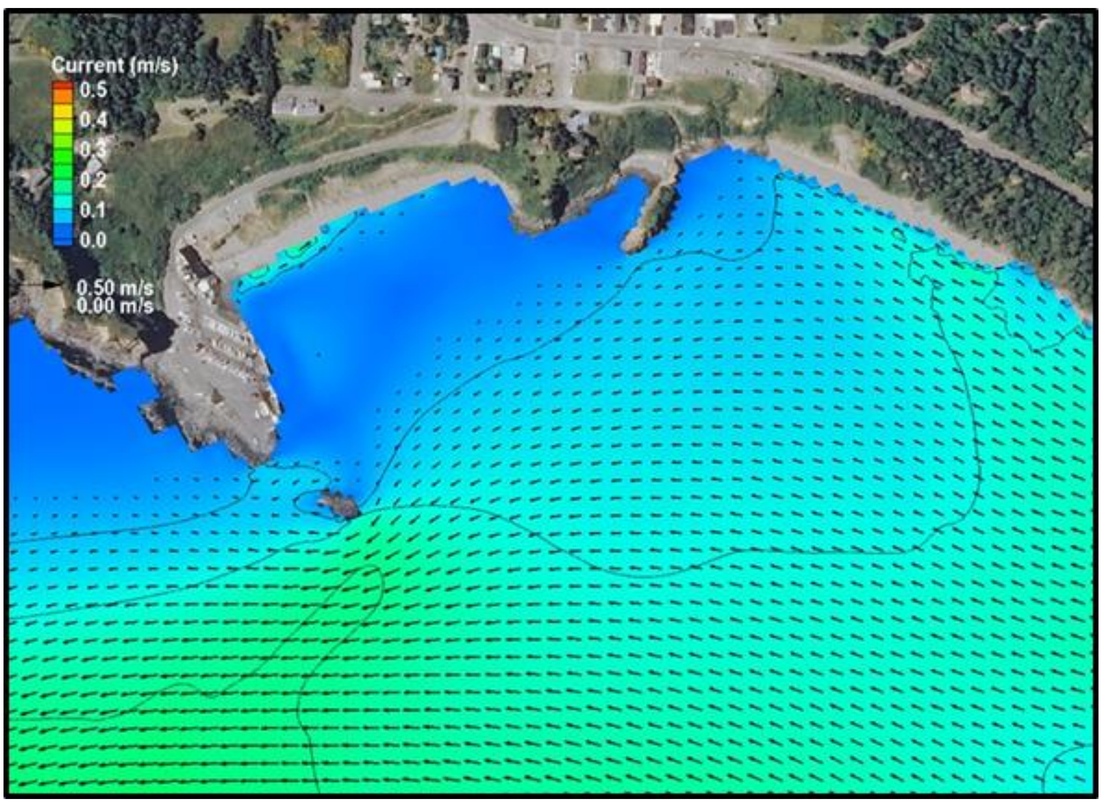

Figure 23. Calculated current field for the Notched Breakwater alternative for the first winter storm on 12 November 2007, 18:00 GMT.

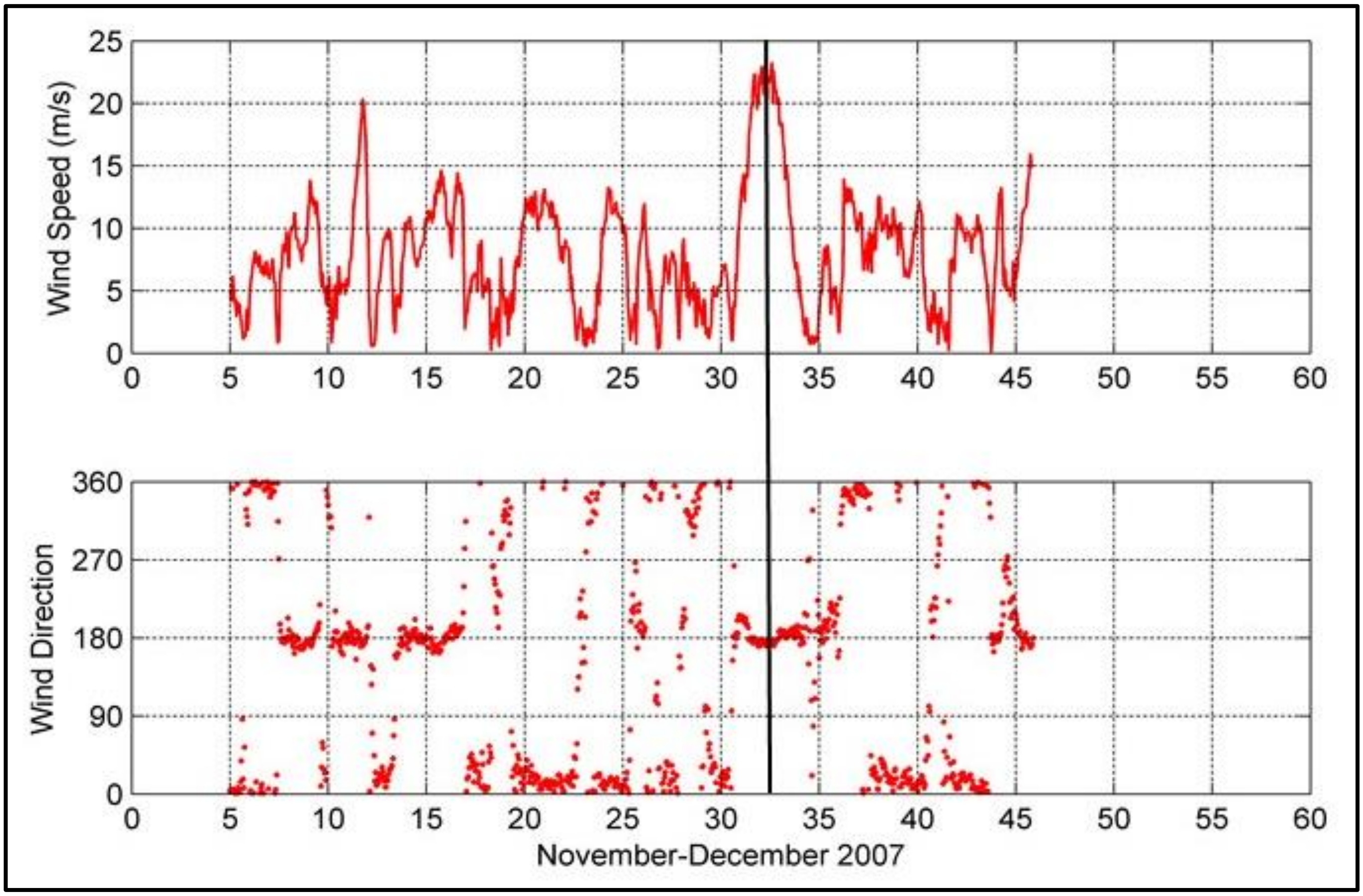

Figure 24. Wind speed and direction used within CMS to simulate currents and waves at Port Orford, Oregon, during extreme winter storm of 3 December 2007 (vertical black line at Day 32). (Time = 0 corresponds to beginning of 1 November 2007)

The vertical black line in Figure 24 at Day 32 shows the wind speed and direction on 3 December 2007 during an extreme winter storm of 2007. Figures 25 through 27 show snapshots of calculated current fields during this extreme winter storm (3 December 2007) for the Modified Breakwater Repair, Breakwater Removal, and Notched Breakwater, respectively.

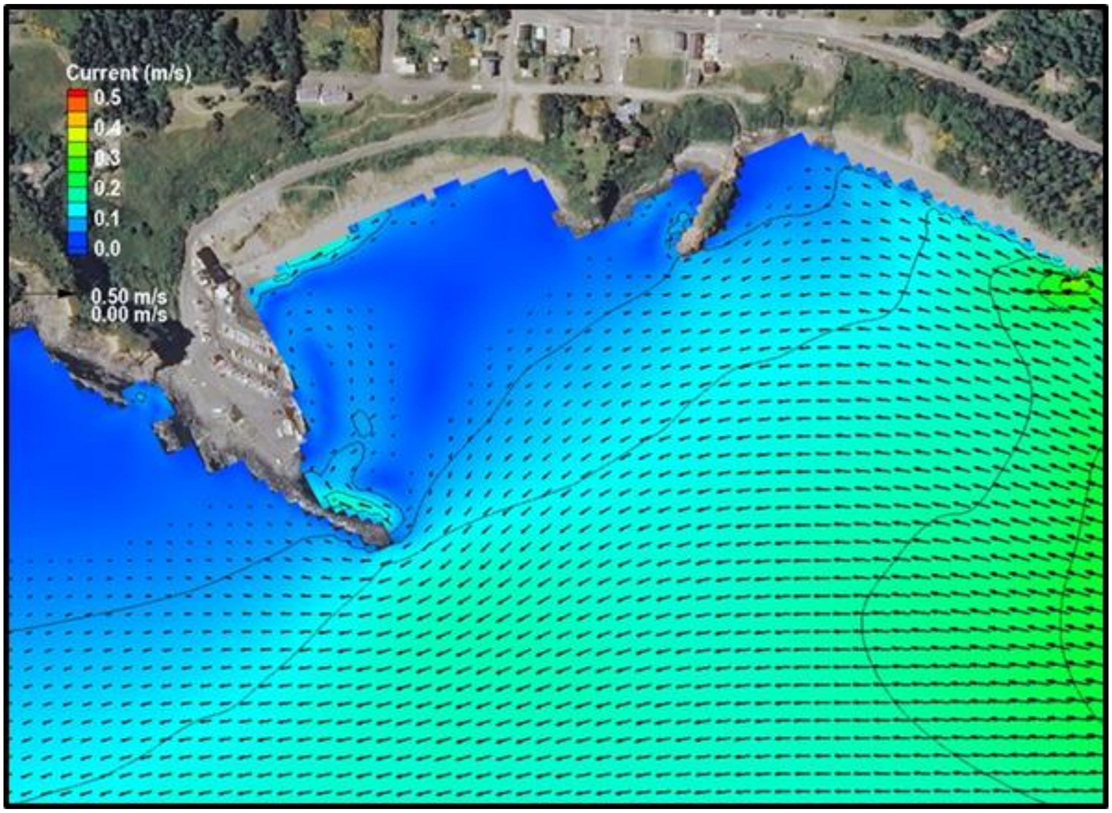

Figure 25. Calculated current field for the Modified Breakwater Repair alternative for an extreme winter storm on 3 December 2007, 13:00 GMT.

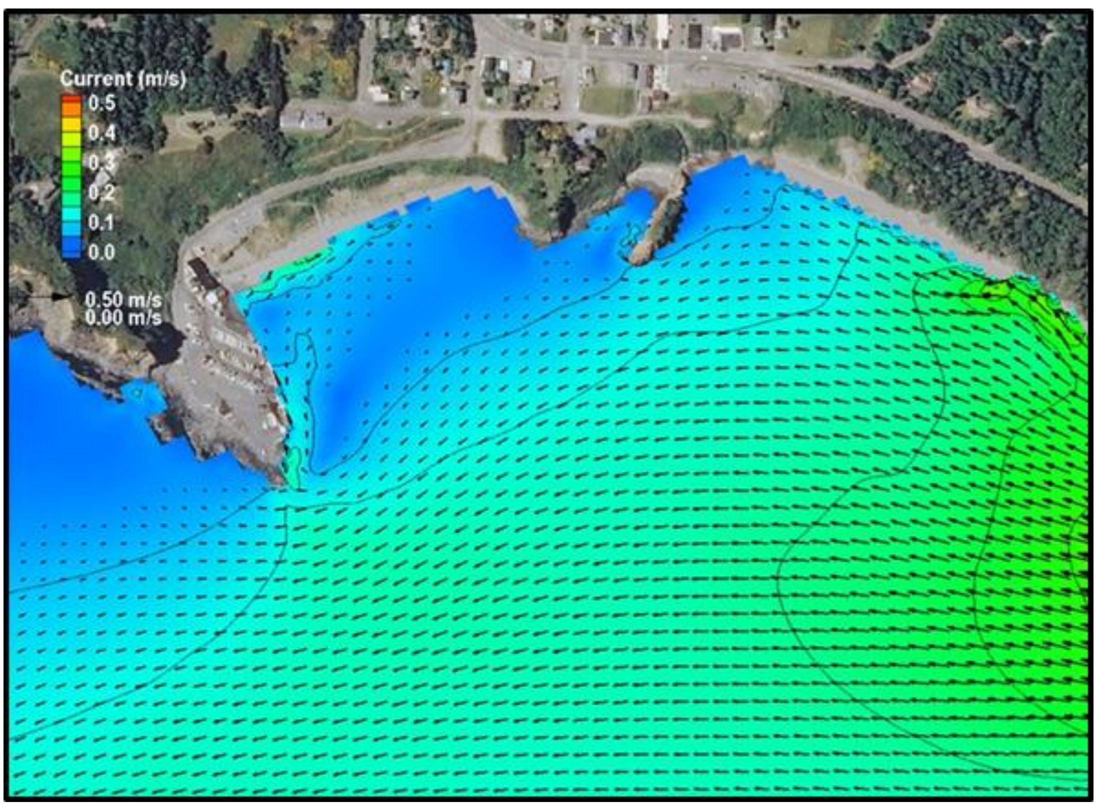

Figure 26. Calculated current field for the Breakwater Removal alternative for an extreme winter storm on 3 December 2007, 13:00 GMT.

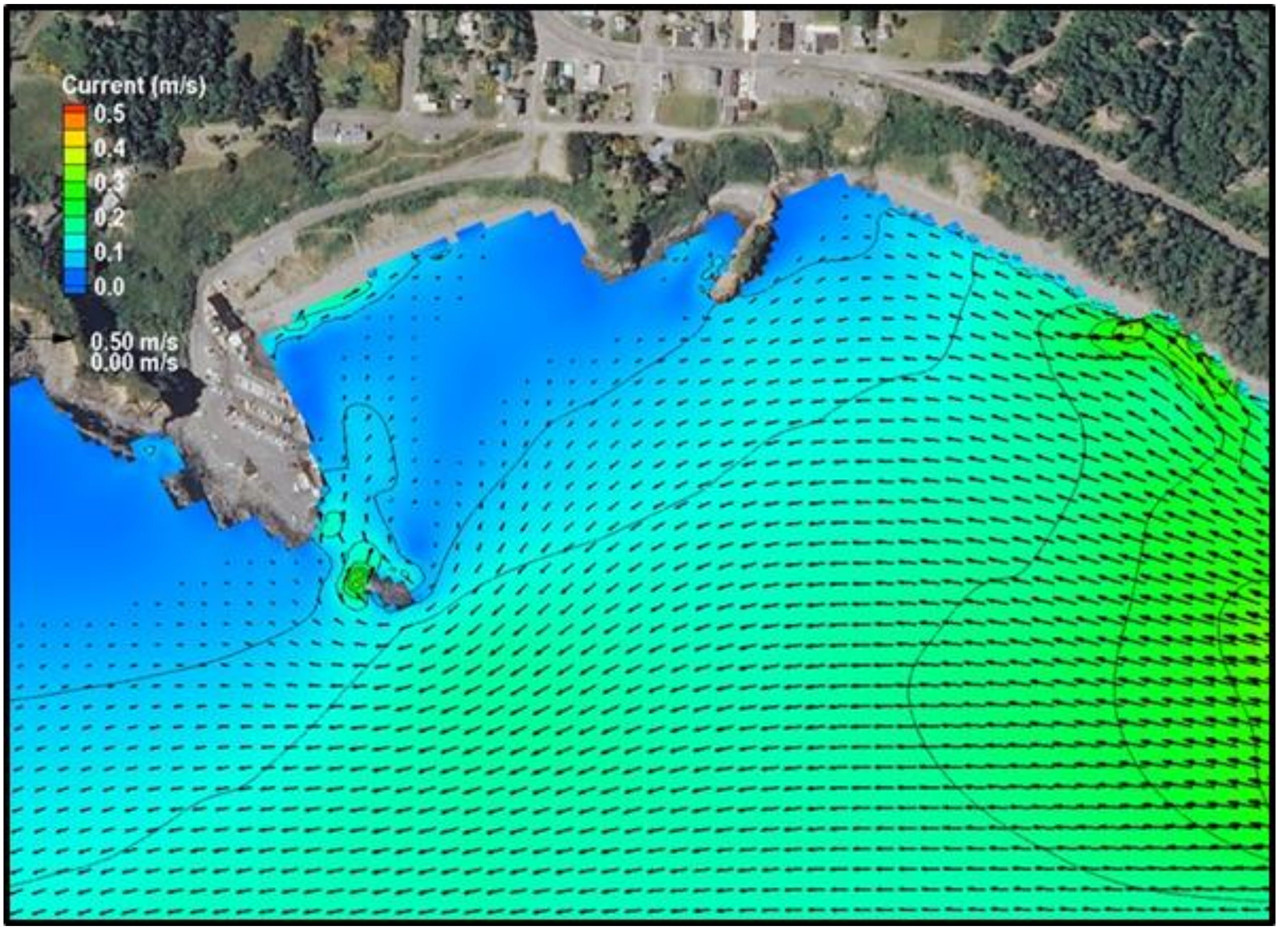

Figure 27. Calculated current field for the Notched Breakwater alternative for an extreme winter storm on 3 December 2007, 13:00 GMT.

For all three breakwater alternative configurations, the nearshore flow pattern is clearly wind driven (Figures 21 through 23, and Figures 25 through 27), with the longshore current being from south to north and turning west in front of the port for both the first winter storm of 2007 and for the extreme winter storm.

Due to the relatively short duration of the first winter storm, lasting about 20 hours, the maximum current speed in Figures 21 through 23 is approximately 0.3 to 0.5 ft/sec around the breakwater and in the nearshore surf zone. The extreme winter storm lasted about 3 days with a peak wind speed of approximately 75 ft/sec (50 miles/hour), which induced stronger current alongshore and near the harbor (Figures 25 through 27).

It should be noted that under the extreme storm conditions, the current pattern around the breakwater structure changes more significantly. For the Modified Breakwater Repair alternative, a small current branch was separated from the primary westward current, flowing parallel to the breakwater and into the harbor channel. For the Notched Breakwater alternative, the flow separation occurred as the primary current passed the head of the breakwater and the secondary flow entered the harbor area through the opened section on the breakwater.

Compared to the winter storms, the summer months are relative calm. The selected summer storm had a peak southerly wind period on 4 June 2010 (Figure 28). The summer flow patterns (Figures 29 through 30) look very similar to the winter flow patterns in the offshore area (Figures 25 through 27), but the peak current speed during the summer time is generally small, around 0.3 ft/sec.

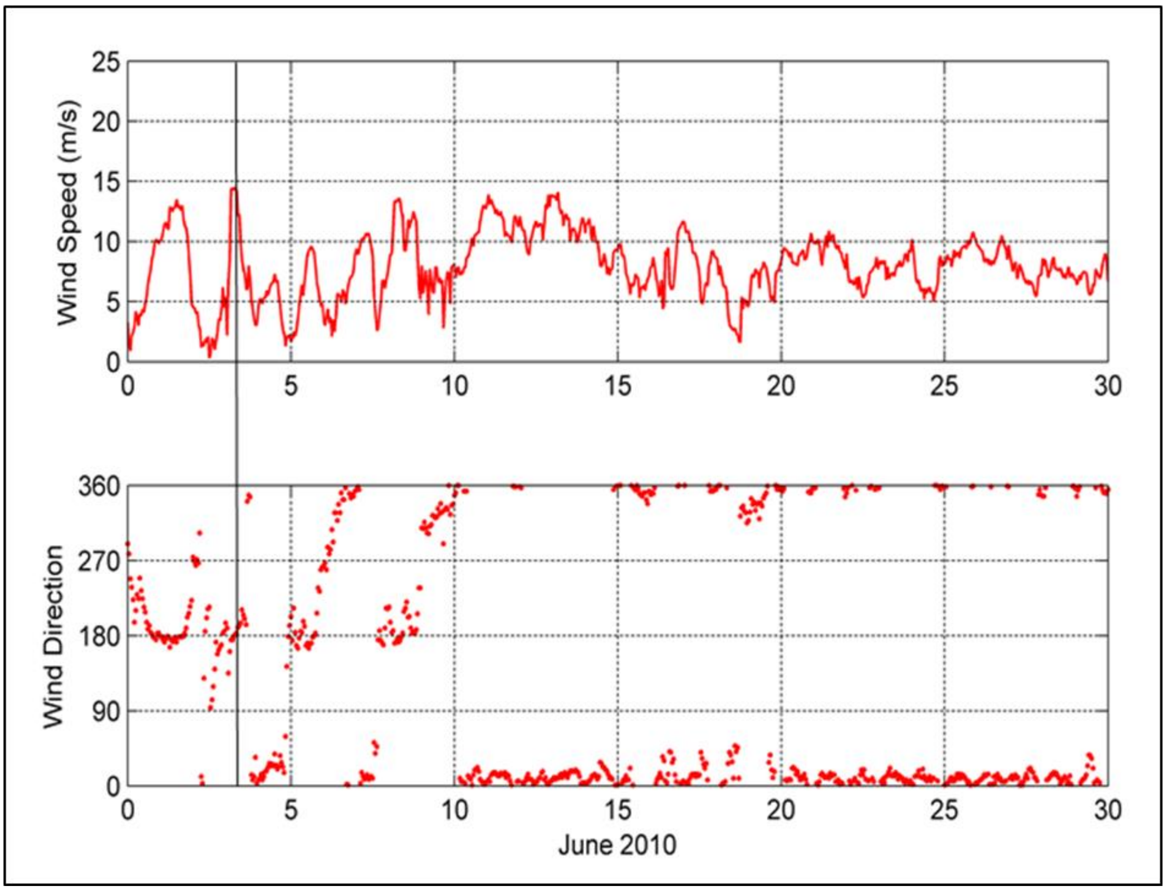

Figure 28. Wind speed and direction used within CMS to simulate currents and waves at Port Orford, Oregon, during June 2010 (vertical black line at Day 4).

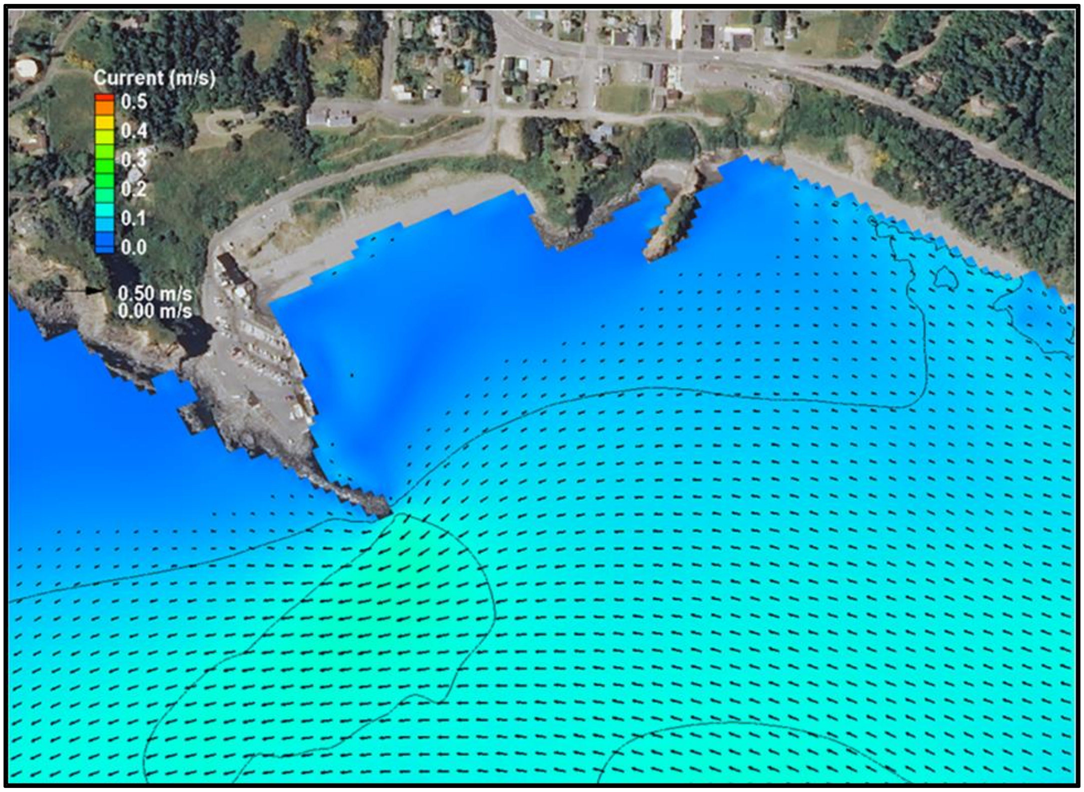

Figure 29. Calculated current field for the Modified Breakwater Repair alternative for a summer storm on 4 June 2010, 06:00 GMT.

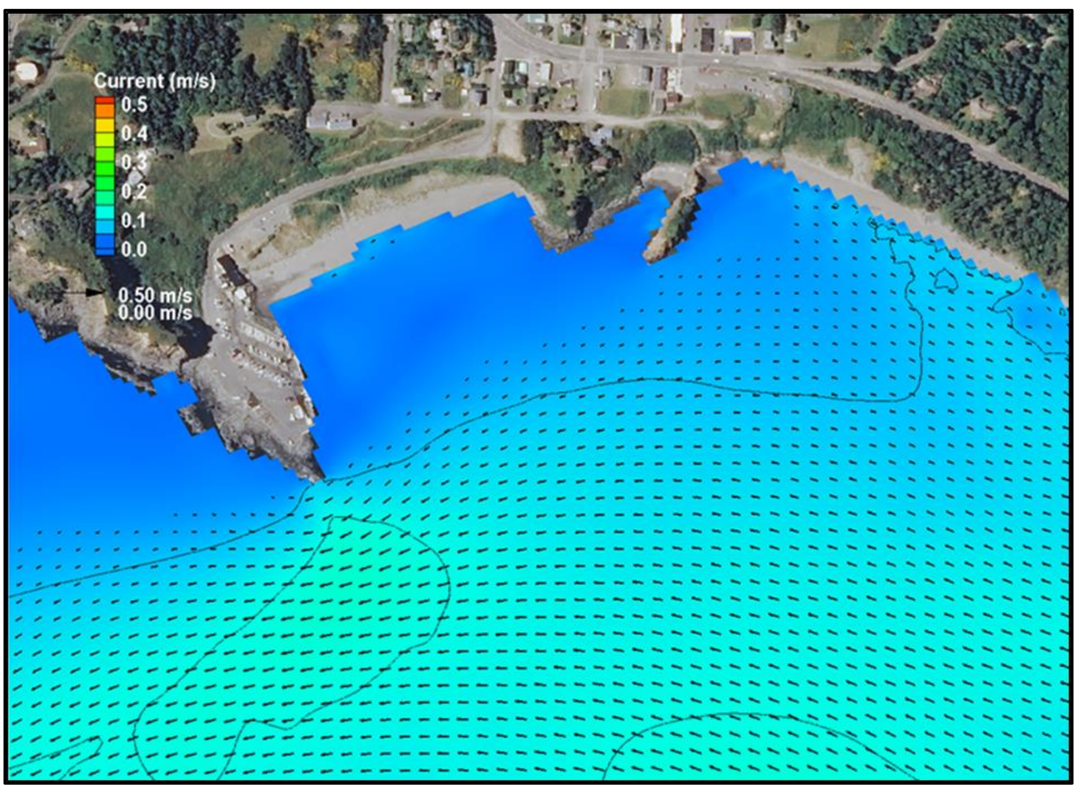

Figure 30. Calculated current field for the Breakwater Removal alternative for a summer storm on 4 June 2010, 06:00 GMT.

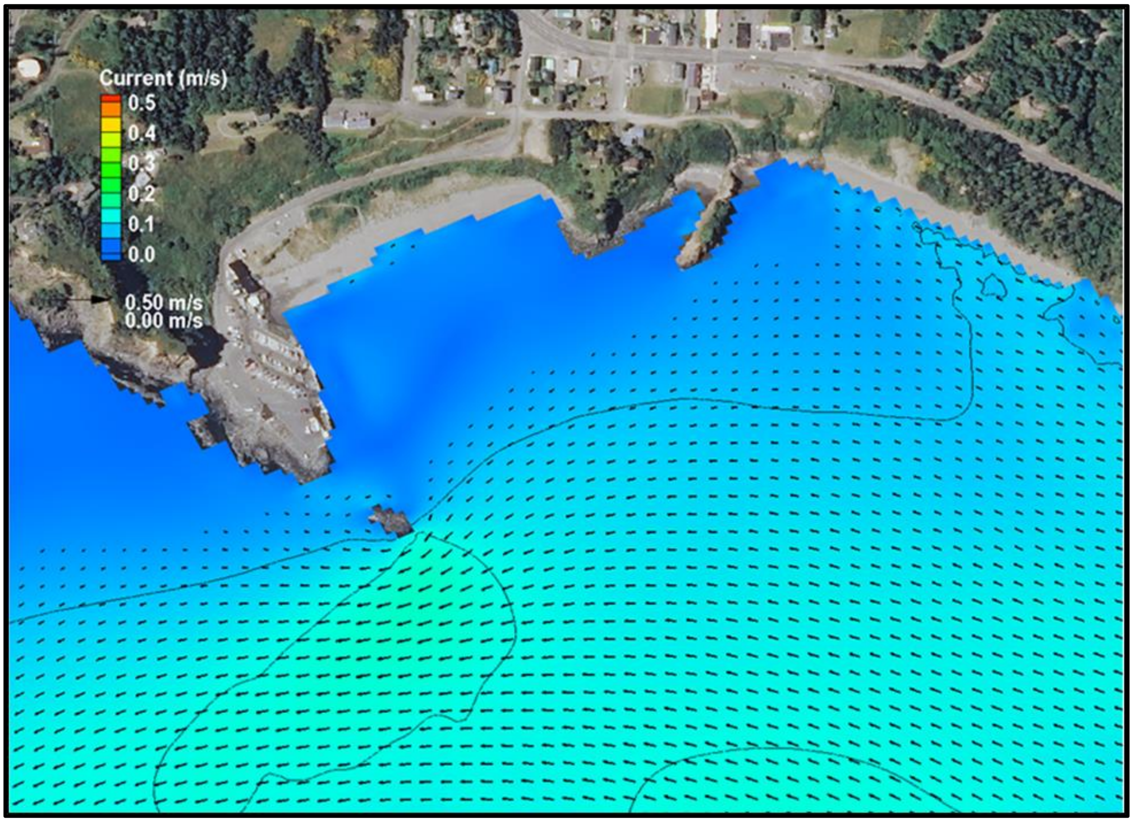

Figure 31. Calculated current field for the Notched Breakwater alternative for a summer storm on 4 June 2010, 06:00 GMT.

Transport thresholds and wave action

In the absence of wave action, the threshold current speed that can mobilize sand along the seabed can vary from 0.5 to 0.8 ft/sec, but when sufficient wave action is present to agitate sand on the seabed and temporarily suspend sediment into the water column, sandy sediment can be transported at a current threshold as low as 0.16 ft/sec (USACE 2002 [revised 2008]). This is an important consideration (accounted for within the PTM) at coastal areas like Port Orford where currents and waves are frequently interacting to enhance the transport of sediment within the littoral zone. All sediment referred to in this document is sand-sized, and the two terms are used interchangeable.

In the PAC-NW, the active littoral zone can be limited to inshore areas of water depth less than 33 ft during summer when wave action and coastal currents are relatively small. During winter, the active littoral zone can extend further offshore to water depths of 65 ft due to storm-enhanced coastal currents and large waves (Moritz et al. 2000). Given that all of the harbor-embayment at Port Orford is now inshore of the 33-ft depth contour (Figure 14), it is likely that some nearshore sediment transport occurs throughout the year based on the Pacific Northwest wave environment where the mean wave height and period are 6.5 ft and 11 sec, respectively.

During the summer few storms occur, and bottom sediment tends to be mobilized intermittently by relatively weak tidal currents when sufficient wave action is present to suspend bottom sands. Sediment movement will tend to be short-lived and irregular (random). In winter, bottom sediment will likely be mobilized often and vigorously due to frequent storms, and sediment movement will tend to be sustained and regular (orderly).

During initial PTM application at Port Orford, preliminary evaluations found that the PTM model was over-estimating sediment mobility when wave action was accompanying currents. Storm wave activity in the Pacific Northwest has higher and longer-period waves than most other coastal areas. ERDC found that the PTM analytics were suspending bottom sediment off the seabed for every wave when wave height and period exceeded specific thresholds based on sediment type. In reality, sediment mobilization due to wave action is a naturally chaotic process. Not every threshold-exceeding wave will mobilize sediment (Moritz et al. 2000). A method for bounding the probability of sediment mobility (due to wave action) was implemented within PTM to improve simulation of the stochastic processes that motivate wave-induced sediment transport.

PTM sediment sources

Within the PTM, sediment parcels were “sourced” at eight locations within the immediate project area of Port Orford. Multiple sources were implemented to address the uncertainty regarding where the sediment affecting the Port is coming from. Sources represent locations where sediment is available for erosion from the seabed and introduced into the PTM model domain. Many insightful viewpoints were embraced to increase the likelihood of correctly capturing sediment sources that may contribute to shoaling within the Federal Navigation Channel. Port stakeholders, NWP, and ERDC collaborated on developing sediment sources for PTM evaluation.

Figure 32 shows the areal distribution of sediment sources defined for the Port Orford PTM. Sources include nearby beaches, updrift littoral zone, the harbor embayment, the nearshore zone immediately offshore of the harbor, and the CWA-404 dredged material placement site (which has been regularly used since 2003). Within the Port Orford PTM, sediment sources were represented as 3.3-ft radius "lines" on the seabed, where sediment parcels were released at pre-specified rates, with each sediment parcel representing a specific mass of sediment (22 lb). If the wave and current environment was not capable of transporting the released sediment parcels, they would stay on the seabed at the release point until environmental conditions (as forced by CMS input) were capable of moving the released parcels.

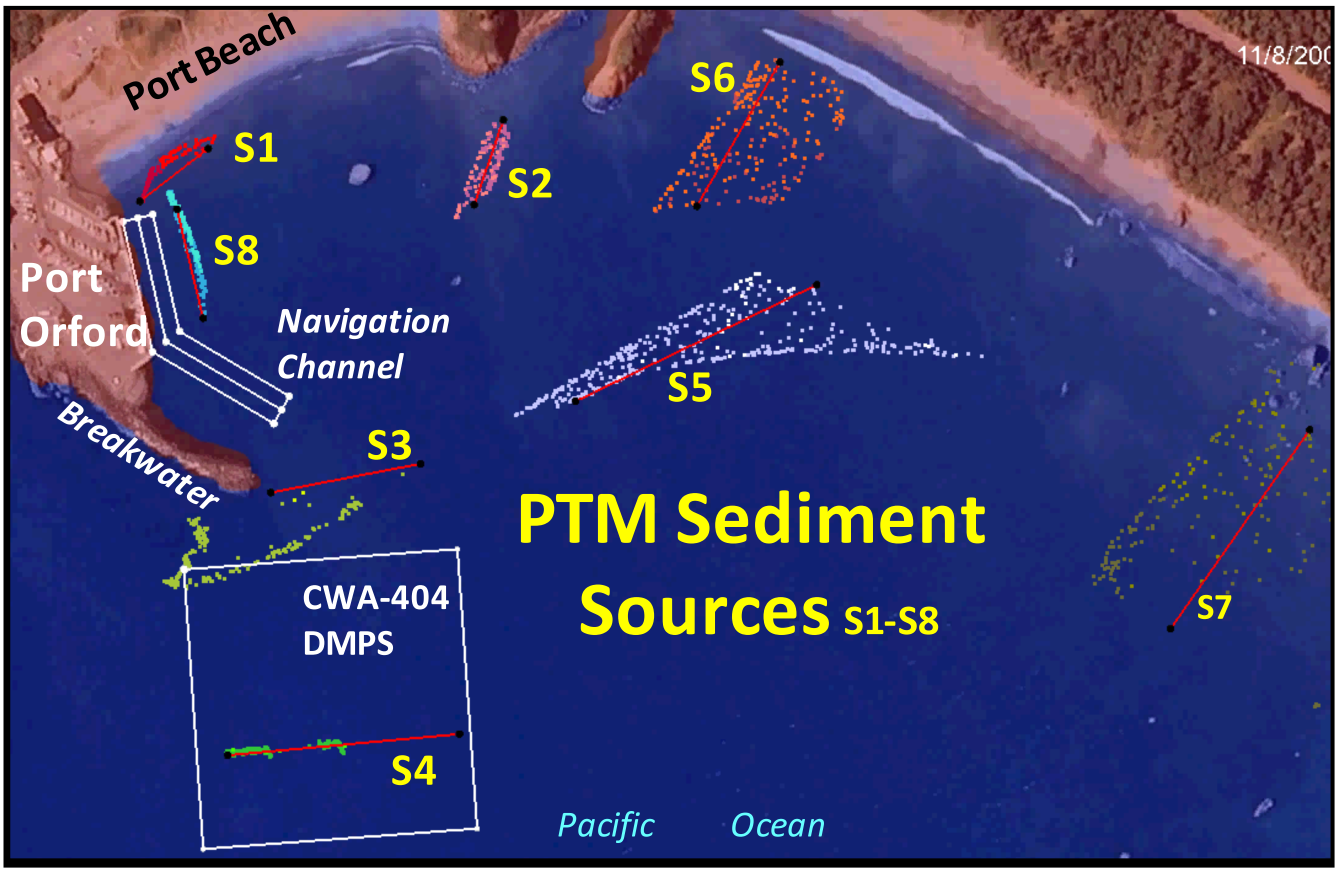

Figure 32. Sediment sources specified for Port Orford, Oregon, PTM for evaluation of shoaling within the Federal Navigation Channel. S1 = local beach source; S2 and S8 = harbor-embayment sources; S3 and S5 = nearshore sources; S4 = CWA-404 DMPS source; S6 and S7 = updrift littoral sources. This image shows distribution of sediment parcels 48 hours into the PTM simulation for 7 November – 16 December 2007.

Table 1 summarizes the physical aspects of the sediment sources implemented within the PTM, which correspond with the source locations (names and colors) shown in Figure 32. The sediment sources were defined based on analysis of sediment samples taken from within the Federal Navigation Channel. The lack of sediment sampling beyond the channel limited ability to fully define the physical parameters.

Table 1. Physical properties of eight sediment sources defined for the Port Orford PTM model.

Sediment Source Location-Color	Parcel Mass kg	Mass Relase Rate mass, kg/m/sec	Source Type	Source Size meters, Seabed	Sediment Release bulk vol, CY/sec	Sediment Type	Grain Size D50, mm	Variation Phi-units
S1 - Local Beach	10	0.00001	Line	80 X 1	0.16	coarse sand	0.45	0
S2 - Harbor-Embayment	10	0.00001	Line	80 X 1	0.16	coarse sand	0.45	0
S3 - Nearshore	10	0.00001	Line	140 X 1	0.29	coarse sand	0.45	0
S4 - CWA-404-DMPS	10	0.00001	Line	210 X 1	0.43	course sand	0.45	0
S5 - Nearshore	10	0.00001	Line	240 X 1	0.49	course sand	0.45	0
S6 - Updrift Littoral	10	0.00001	Line	150 X 1	0.31	course sand	0.45	0
S7 - Updrift Littoral	10	0.00001	Line	215 X 1	0.44	course sand	0.45	0
S8 - Harbor-Embayment	10	0.00001	Line	100 X 1	0.21	course sand	0.45	0

note: sediment porosity (n) = 0.4, sediment mass desity = 2650 kg/m3, bulk density = 1590 kg/m3, Sediment Release = Mass rate*(1-0.4)*2650*source size
sediment is sourced at the seabed (z=0)

Mean grain size of Federal Navigation Channel sediment samples was observed to be 0.02 inches (in.) (0.51 mm) with material classified as a poorly-sorted coarse sand. Sediment grain size variation about the mean grain size (standard deviation) was not reported, and was specified as 0 for the PTM. Based on the total rate of sediment release from all eight sediment sources, approximately 850 22-lb parcels/day were introduced into the PTM model domain. This is equivalent to 215,000 cy of sediment applied over a collective release area of approximately 240 acres.

Sediment sinks (traps)

The Federal Navigation Channel was divided into six different "sediment trap" zones (T1 through T8) to evaluate which areas of the channel would most likely experience shoaling based on the PTM results (Figure 33).

The CMS and PTM were applied with the channel in a fully maintained depth condition (project depth 18 ft mllw). The bottom half of the water column within the channel (channel bottom to 8 ft above the bed) was specified as a series of *closed* sediment traps, to allow only one-way deposition. When a PTM sediment parcel enters a *closed* trap, one-way deposition occurs. The parcel becomes inactive, and the parcel's deposition and source is associated with the sediment trap that it entered.

After entering a closed sediment trap, the sediment parcels are no longer shown within the simulation (as they are assumed to be inactive). The one-way deposition may or may not be occurring at the Port Orford field site channel. However, the *closed* trap accounting allows for direct assessment of parcel transport pathways, and channel deposition for bed-load sediment transport that is assumed to remain within the channel after initial deposition.

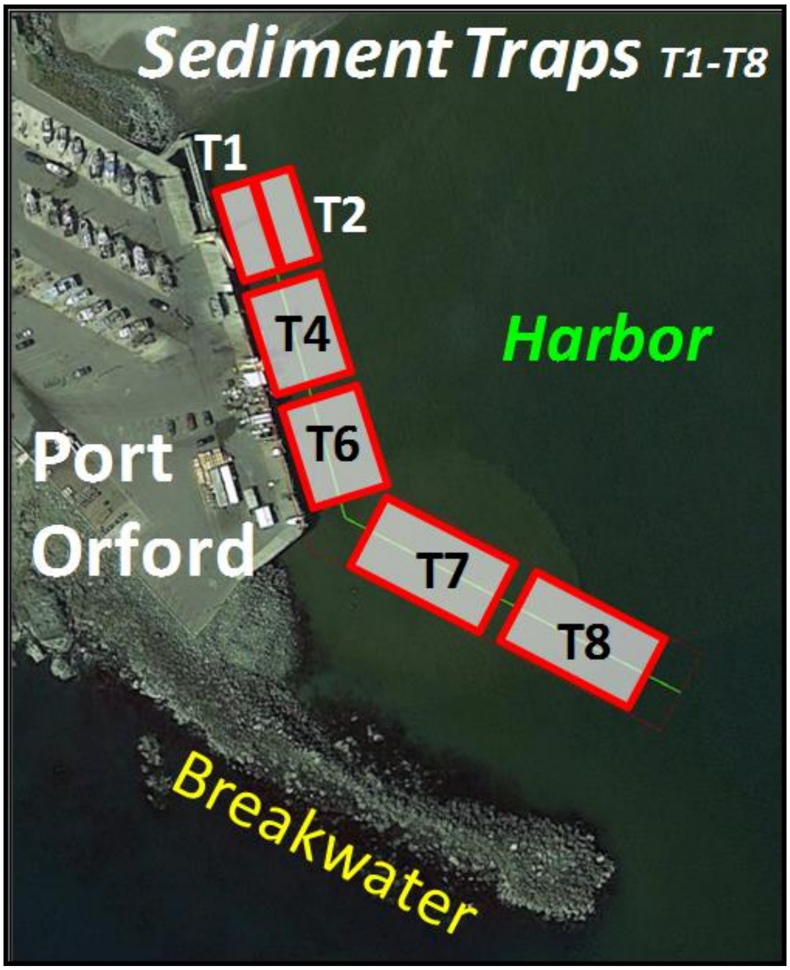

Figure 33. Sediment trap zones along the Port Orford, Oregon, Federal Navigation Channel to determine which areas would most like experience shoaling based on PTM analysis.

The top half of the water column within the channel (between 8 ft depth and the water surface) was specified as a series of open sediment traps. In open traps, sediment parcels can enter and leave the trap, and remain active. This type of parcel accounting applies to sediment that is suspended within the upper water column and would likely not deposit within the channel. Parcels are attributed to an *open* trap as they enter the trap, for one-time accounting within this application.

If no sediment parcels appear to enter the channel, then the PTM results indicate that sediment transport into the Federal Navigation Channel is dominated by processes within the lower half of the water column associated with bed-load effects. In that case, parcels are being deposited within the Federal Navigation Channel and are then inactivated within PTM, as in Figure 32 (the parcels are not shown).

4 Sediment Transport Results

Winter storms

The overall synthesis of Figures 21 through 23, and Figures 25 through 27, illustrates how the breakwater at Port Orford acts to deflect coastal circulation away from the harbor and embayment during winter storms when the coastal current is moving northward.

Figures 34 through 36 show PTM results obtained for the three different breakwater alternative configurations for the Fall 2007 model run. Each of these figures is a snapshot at 0000 hours on 3 December 2007 (time-series index 209) when a severe winter storm brought high southerly winds and waves to the Oregon coast. During this storm, offshore winds exceeded 65 ft/sec (45 miles/hour), offshore waves exceeded 33 ft, and depth-averaged current exceeded 0.7 ft/sec. Sandy sediment can be mobilized at a threshold current of 0.16 ft/sec with the enhanced agitation of wave action (USACE 2002 [revised 2008]). Eight sediment sources were implemented into the Port Orford PTM model to evaluate the shoaling components from all possible sources in the project area. Sediment sources S1, S2, S3, and S8 are directly feeding sediment into the harbor-embayment area shown in Figure 36, the Notched Breakwater alternative. The different colored dots indicate sediment parcels (22 lb each) that have been transported from a specific sediment source. See Figure 20 and Table 1 for sediment source identification (color). The yellow vectors were interpreted renderings imposed on the model results, based on the time-series sequence of the PTM during the model run.

Figure 34 defines the Modified Breakwater Repair alternative which re-establishes the breakwater to its fully authorized foot-print. During the southerly storm event of 3 December 2007, sediment from S2, S5, and S6 was transported southwest (toward lower left) past the outer end of the breakwater and offshore of the harbor embayment, along a convergence zone of flow. Most of the sediment that entered the Federal Navigation Channel for the Modified Breakwater Repair alternative during this time originated from S1, S2, and S8.

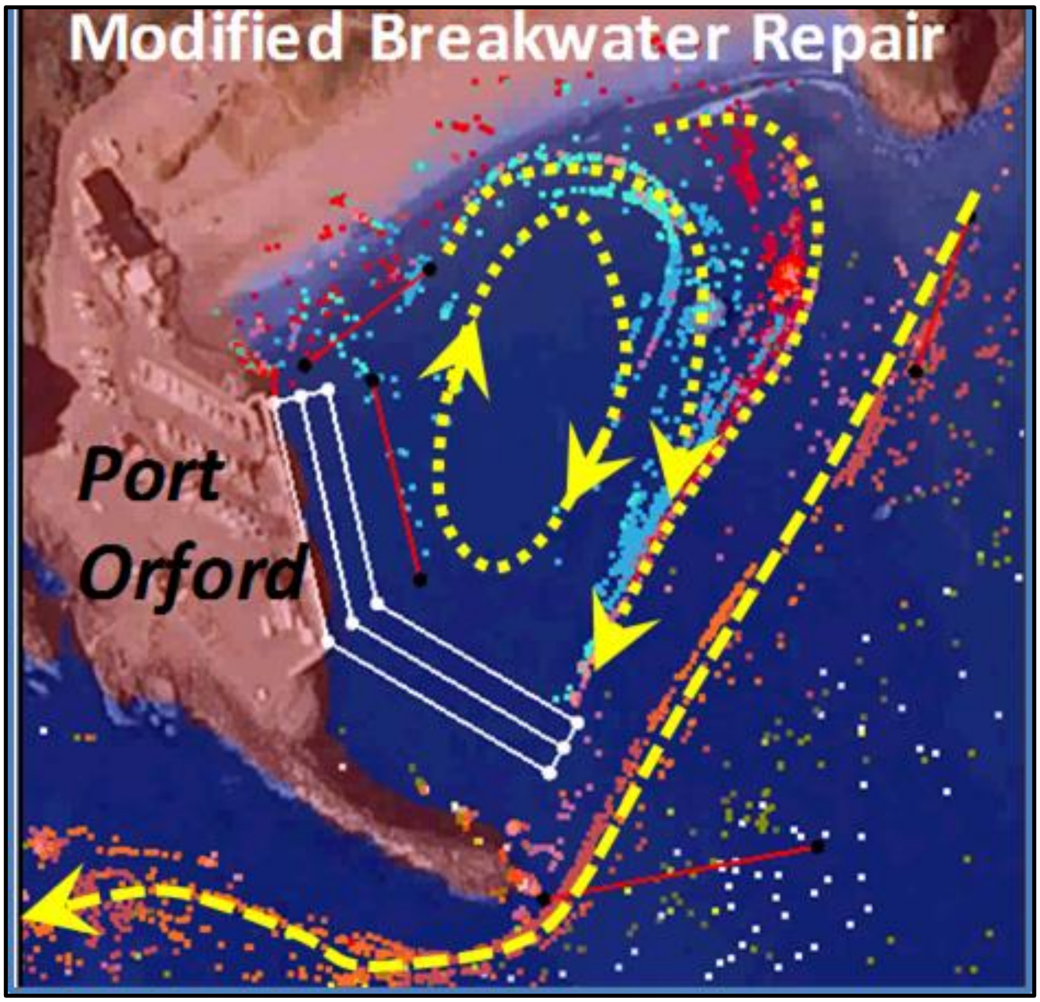

Figure 34. PTM results for sediment transport at 0000 hours, 3 December 2007, during an extreme winter storm, for the Modified Breakwater Repair alternative, Port Orford, Oregon.

The region of closed circulation acts to deflect flow and sediment parcels away from the channel, even for the near-field sediment sources S1 and S8. Maintaining the full breakwater extension (Figure 34) forces open coast flow to move offshore and around the breakwater, and limits the flow from entering the harbor embayment area (Figures 21 and 25, Modified Breakwater Repair alternative). The 550-ft-long breakwater extension enhances eddy formation within the harbor area of Port Orford during severe southerly wind and wave conditions, consistent with results from the 1974 physical model (see details in section "Comparison to 1974 Physical Model Study" of this present document). The absence of parcel appearance within the channel indicates that parcel transport into the channel is by bed-load movement.

Figure 35 defines the Breakwater Removal alternative which would remove the eastern 450 ft of the 550-ft-long breakwater extension to a pre-project elevation of -5.5 to -20 ft mllw. With most of the breakwater removed, currents would flow unimpeded from the harbor to the ocean, allowing open coast current to move much closer to shore than the present condition (Figures 22 and 26, Breakwater Removal alternative). This change in circulation would eliminate most of the eddy within the harbor embayment. Significantly more storm-driven flow and associated sediment transport would enter the Federal Navigation Channel, resulting in increased channel shoaling.

Increased transport of sediment from sources S1, S2, and S8 appears to occur for the Breakwater Removal alternative as compared to the Modified Breakwater Repair alternative. This effect can be seen by comparing the trajectory of the sediment parcels highlighted by the yellow vectors in Figure 35 (Breakwater Removal alternative) with Figure 34 (Modified Breakwater Repair alternative). The yellow dashed trajectory lines are an interpretation of sediment parcel transport based on the time-series results of PTM**.**

Figure 36 defines the Notched Breakwater alternative which would remove the middle 150 to 250 ft of the 550-ft-long breakwater extension to a pre-project elevation of -5.5 ft mllw. With the middle of the breakwater removed, currents (and sediment parcels) are shown to flow through the breakwater from the harbor to the ocean, allowing open coast circulation to move closer toward shore (Figures 23 and 27, Notched Breakwater alternative). This change in circulation associated with the breakwater notch acts to interrupt and reduce the areal extent of the eddy within the harbor embayment.

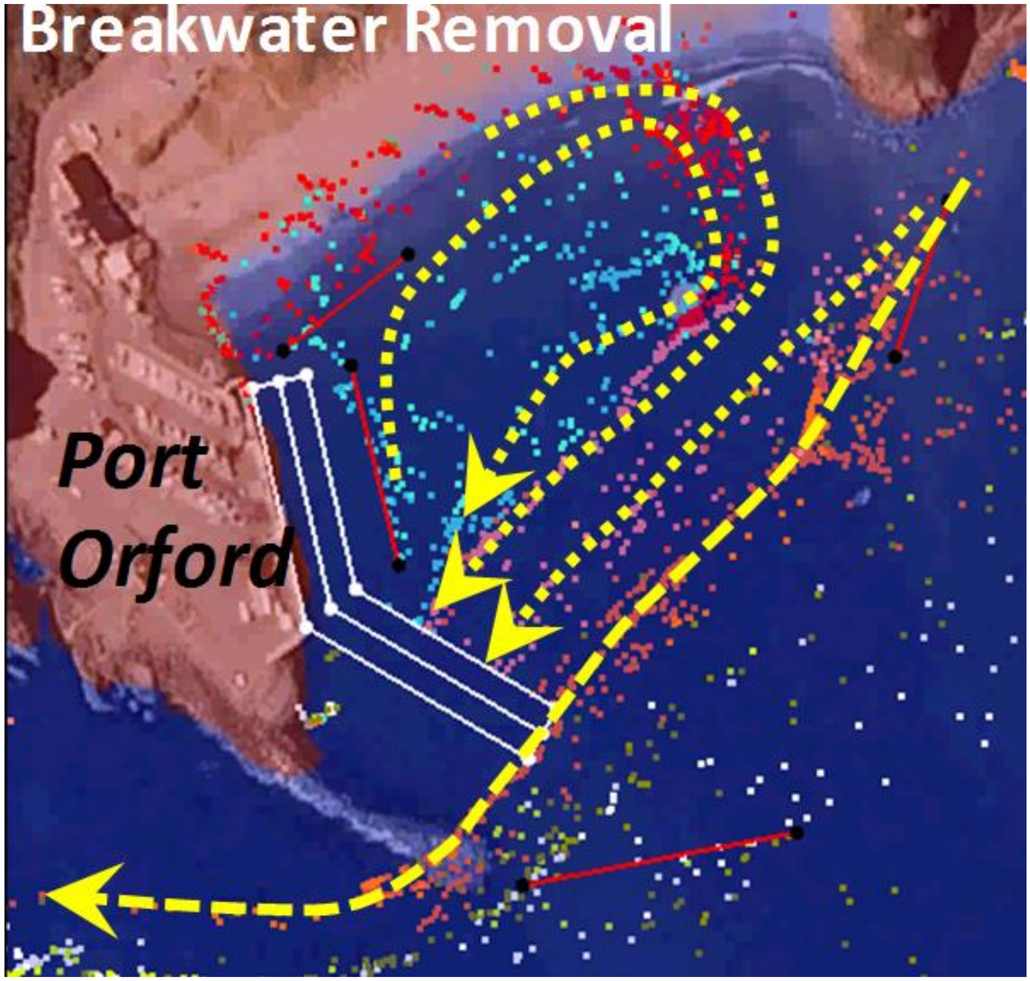

Figure 35. PTM results for sediment transport at 0000 hours, 3 December 2007, during an extreme winter storm, for the Breakwater Removal alternative, Port Orford, Oregon.

With the Notched Breakwater alternative, less storm-driven flow and sediment transport appear to deposit in the inner channel, reducing channel shoaling along the dock (traps T1 through T6). However, increased transport of sediment from sources S1 and S2 appears to occur along the outer extent of the channel (traps T7 and T8) for the Notched Breakwater alternative as compared to the Modified Breakwater Repair alternative. This effect can be seen by comparing the trajectory of the sediment parcels highlighted by the yellow vectors of Figure 36 (Notched Breakwater alternative) with Figure 34 (Modified Breakwater Repair alternative). Based on PTM results for November-December 2007, the total cumulative amount of sediment that enters the overall Federal Navigation Channel for both the Modified Breakwater Repair alternative and the Notched Breakwater alternative is equivalent for this simulated scenario.

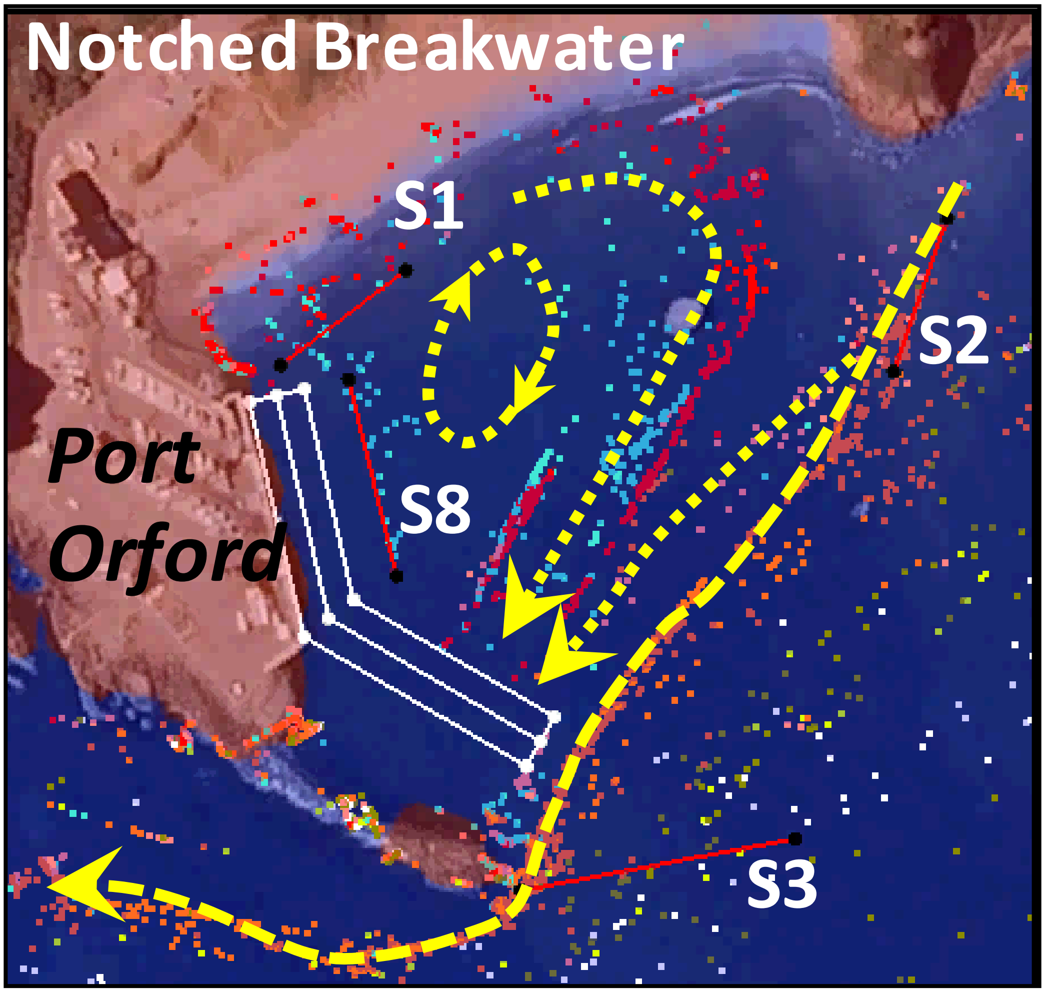

Figure 36. PTM results for sediment transport at 0000 hours, 3 December 2007, during an extreme winter storm, for the Notched Breakwater alternative, Port Orford, Oregon.

Figures 37 and 38 document the sourcing, timing, and location of cumulative deposition for PTM sediment parcels that contributed to shoaling within the Port Orford Federal Navigation Channel during November-December 2007. Figure 33 illustrates how the timing for deposition within the outer area of the Federal Navigation Channel (trap 7 and 8) for all breakwater alternatives was dominated by the 3 December storm event. Figure 34 indicates that the Federal Navigation Channel was impacted by sediment sources from “harbor-embayment, S2 and S8”, “local beach, S1”, and “updrift littoral, S6” locations.

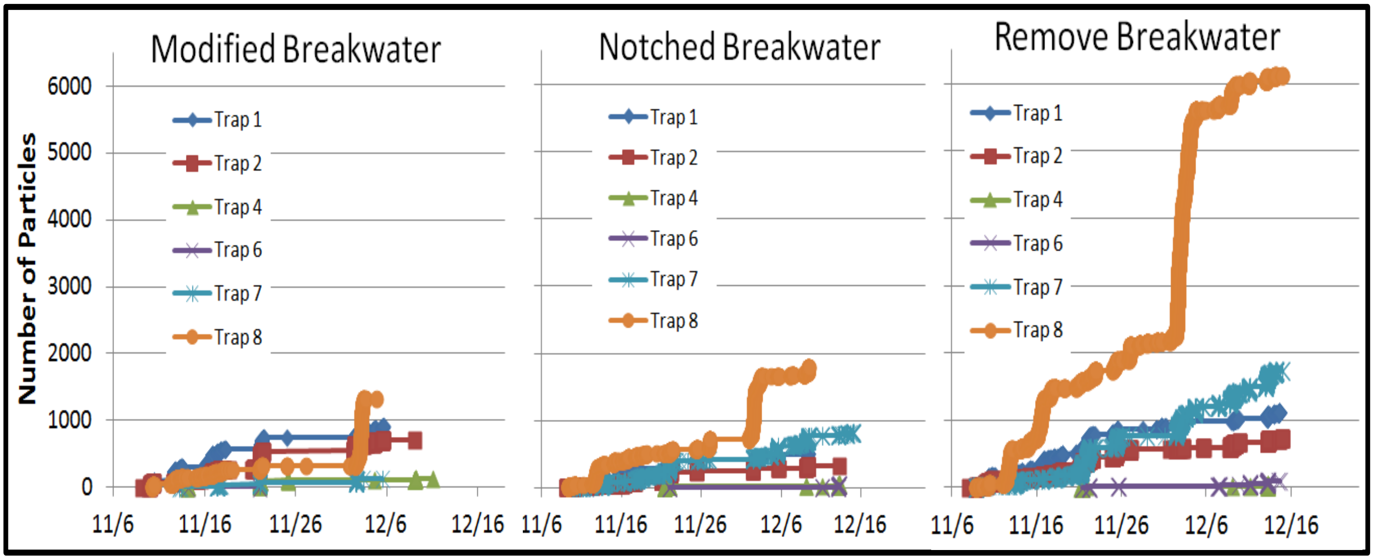

Figure 37. PTM results at Port Orford, Oregon, documenting the timing and location of cumulative sediment deposition within the Federal Navigation Channel during November-December 2007. Each parcel has 10 kilograms (Kg) mass of sediment.

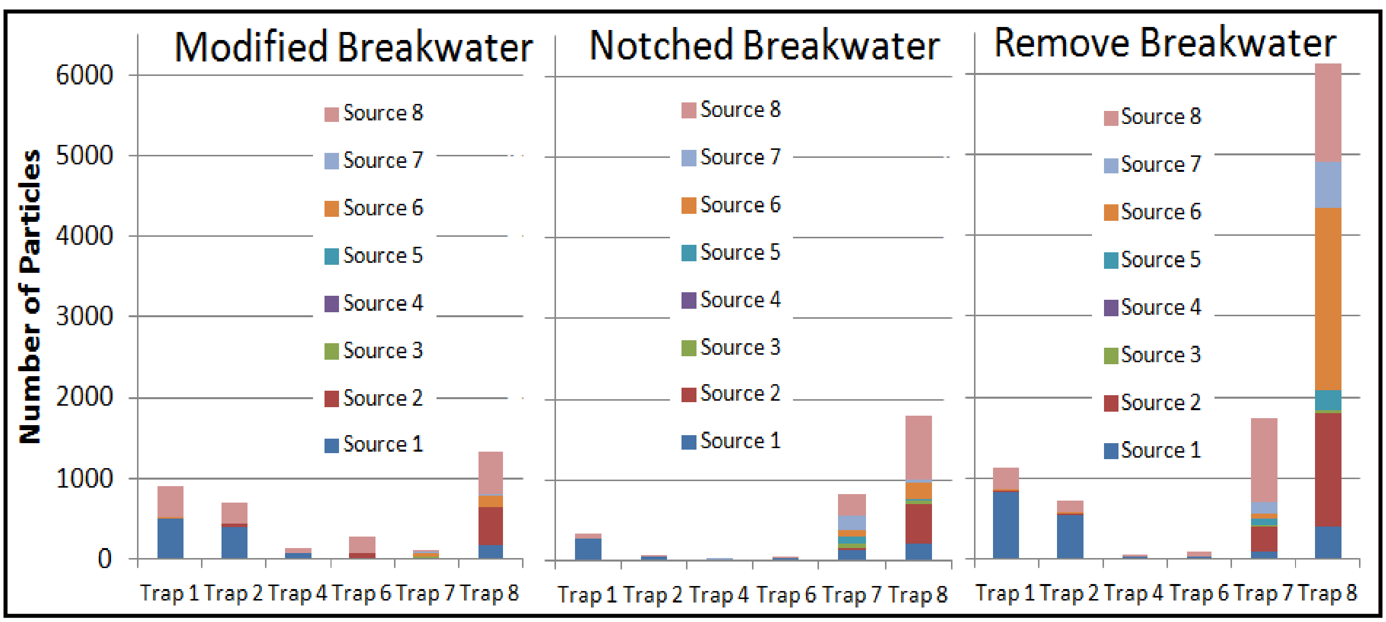

Figure 38. PTM results at Port Orford, Oregon, documenting the contributing sediment sources and associated deposition location within the Federal Navigation Channel during November-December 2007. Each parcel has 10 kilograms (Kg) mass of sediment.

Summer storms

The overall synthesis of Figures 39 through 41 illustrates how the summer currents within the breakwater at Port Orford act to re-deflect much of the tidal flow through the removed area of the breakwater from the harbor and embayment when a coastal current is flowing southward.

Figures 39 through 41 show PTM results of summer waves obtained for the three different breakwater alternatives that were previously considered for winter waves. The PTM results for the three different breakwater alternatives were obtained at the same time period for the summer model runs. Each of the three simulations occurred at 1530 hours on 8 June 2010 (time-series index 54). During this time, wind was from the NNW at about 13 to 20 ft/sec (10 to 15 miles/hour), waves were from the West at 6.6 to 9.8 ft high, and the open coast current was southward at 0.07 to 0.26 ft/sec, according to the CMS model results. That is typical of a summer high atmospheric pressure condition that produces onshore winds and weak southward coastal currents that are locally altered by nearshore tidal circulation.

Eight sediment sources were implemented into the Port Orford PTM model to evaluate the shoaling contribution from all possible sources in the project area. Sediment sources (S1, S2, S3, and S8) are directly feeding sediment into the harbor embayment area shown in Figure 39. The different colored dots indicate sediment parcels (22 lb each) that have been transported from a specific sediment source. (See Figure 32 and Table 1 for sediment source identification [color]).

Figure 39 illustrates the results of the summer conditions for the Modified Breakwater Repair alternative which re-establishes the breakwater to its fully authorized foot-print. During the NW high pressure conditions of 8 June 2010, sediment from S1 and S8 was transported shoreward and then southward along shore. The breakwater acts to deflect the southward coastal flow offshore from the harbor embayment along a convergence zone of flow. Almost all of the sediment that entered the Federal Navigation Channel for the Modified Breakwater Repair alternative originated from S1 and S8. The region of closed circulation acts to deflect flow and sediment parcels away from the channel for sources other than S1 and S8.

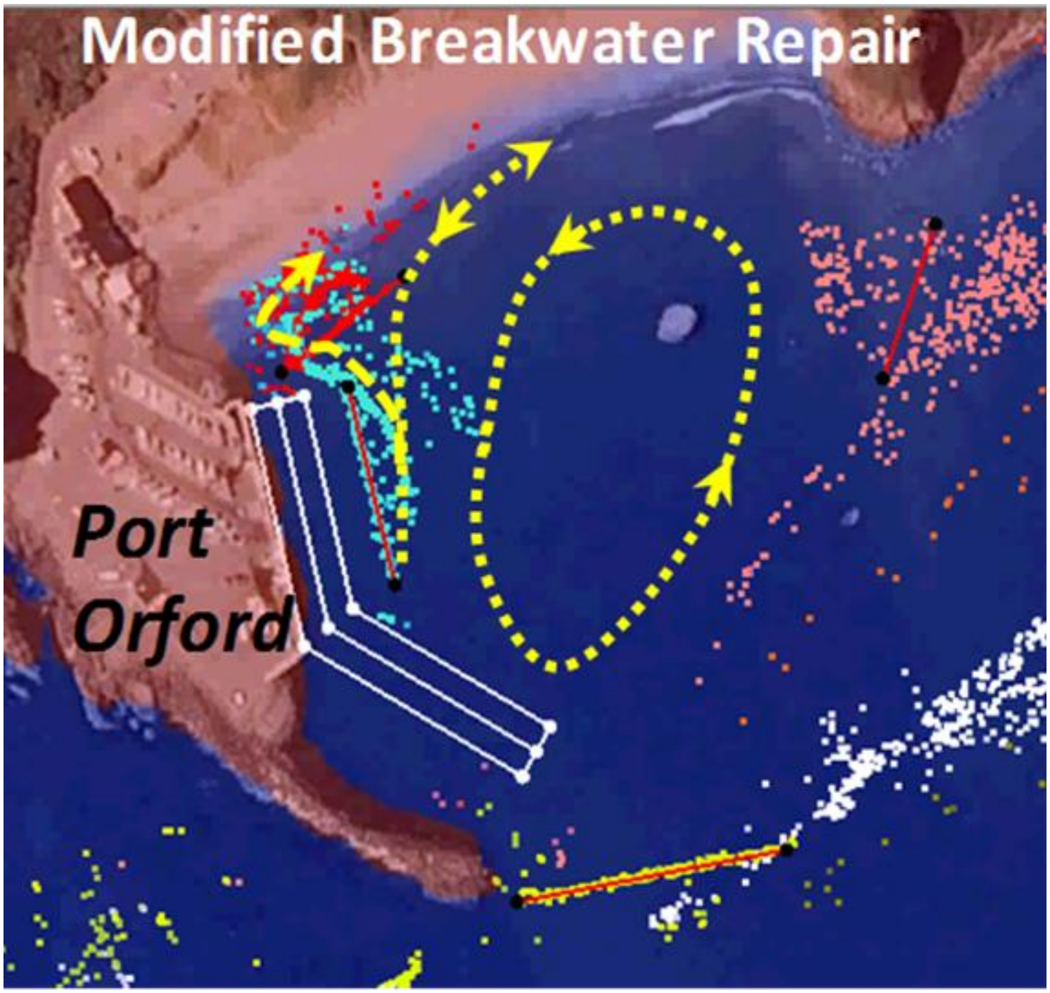

Figure 39. PTM results for sediment transport at 1530 hours, 8 June 2010 summer storm, for the Modified Breakwater Repair alternative, Port Orford, Oregon.

Maintaining the full breakwater extension acts to limit open coast flow from entering the harbor embayment by forcing open coast currents to move offshore and around the breakwater. The 550-ft-long breakwater extension enhances eddy formation within the harbor area of Port Orford during summer conditions when weak southern coastal currents are interacting with nearshore tidal circulation.

Figure 40 illustrates the results of the summer conditions for the Breakwater Removal alternative which would remove the eastern 450 ft of the 550-ft-long breakwater extension to a pre-project elevation of -5.5 to -20 ft mllw. The Breakwater Removal alternative allows open coast currents to move much closer toward shore.

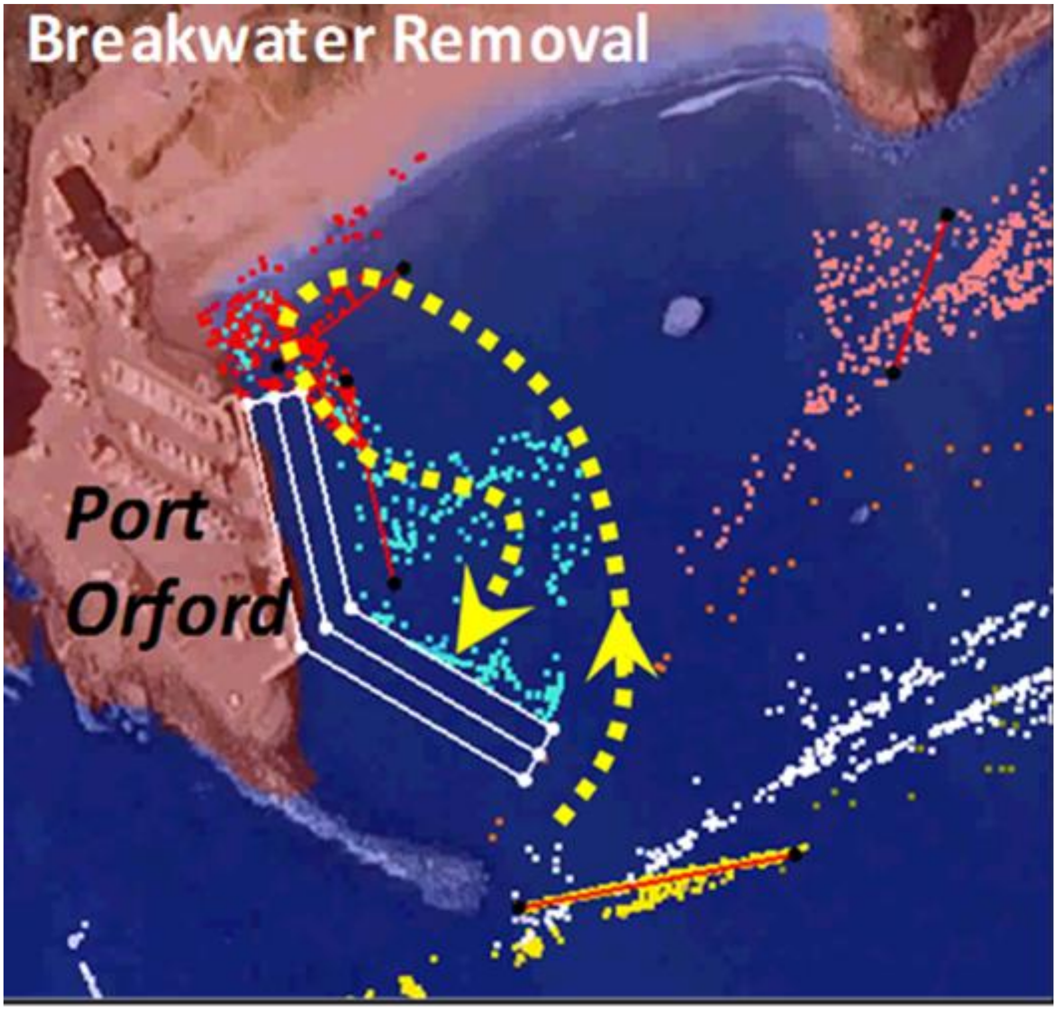

Figure 40. PTM results for sediment transport at 1530 hours, 8 June 2010 summer storm, for the Breakwater Removal alternative, Port Orford, Oregon.

With most of the breakwater removed, the size of the circulation eddy within the harbor embayment would be reduced, allowing nearshore flow within the harbor embayment to reverse unimpeded toward the Federal Navigation Channel. Significantly more sediment transport would enter the channel, resulting in increased channel shoaling.

Increased transport of sediment from sources S1, S2, and S8 occurs for the Breakwater Removal alternative as compared to the Modified Breakwater Repair alternative. This effect can be seen by comparing the trajectory of the sediment parcels highlighted by the yellow vectors in Figure 40 (Breakwater Removal alternative) with Figure 39 (Modified Breakwater Repair alternative).

Figure 41 illustrates the results of the summer conditions for the Notched Breakwater alternative which would remove the middle 150 to 250 ft of the 550-ft-long breakwater extension to a pre-project elevation of -5.5 ft mllw. With the middle of the breakwater removed, currents and sediment parcels flow toward the Federal Navigation Channel from the harbor. As the nearshore circulation changes with the tide, sediment from the harbor is transported into the channel.

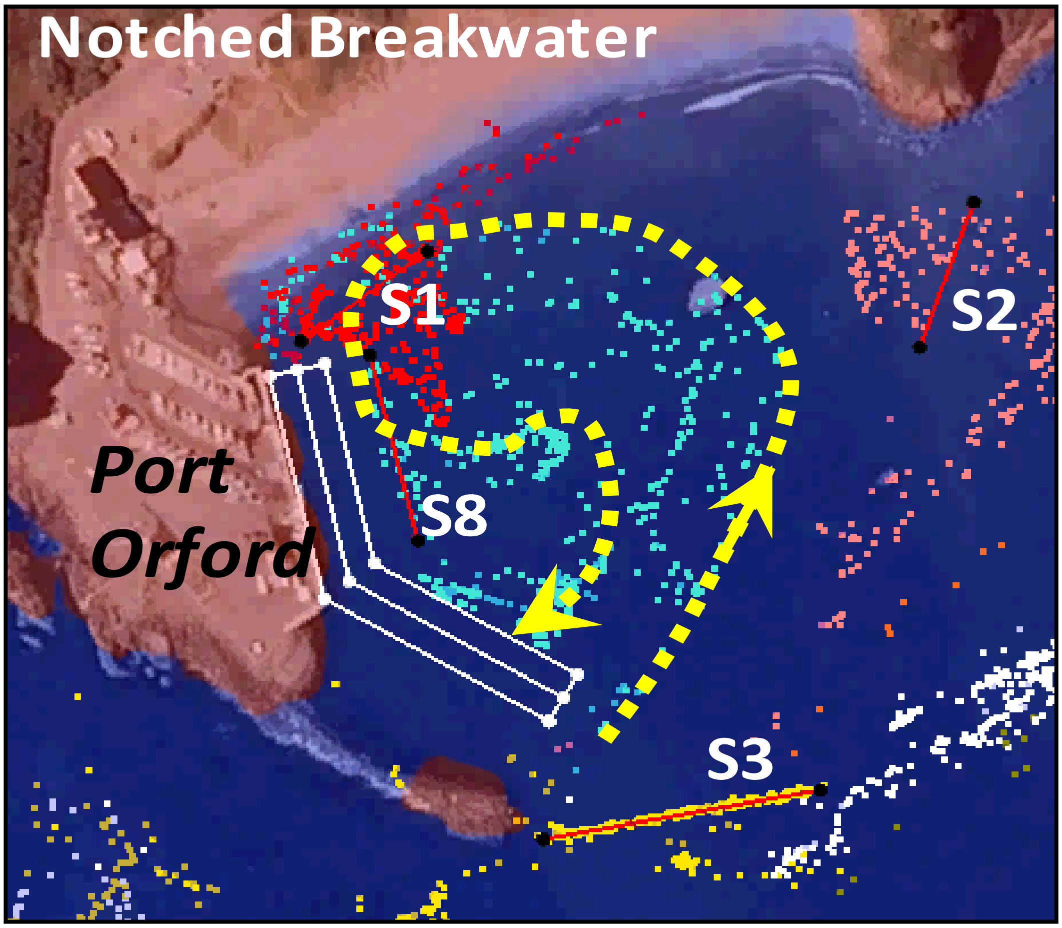

Figure 41. PTM results for sediment transport at 1530 hours, 8 June 2010 summer storm, for the Notched Breakwater alternative, Port Orford, Oregon.

The Notched Breakwater alternative allows open coast currents to move closer toward shore. This change in circulation associated with the breakwater notch also acts to reduce the areal extent of the closed circulation eddy within the harbor embayment. With the Notched Breakwater alternative, more sediment from source S2 enters the channel due to the reduced eddy size, resulting in increased channel shoaling.

Increased transport of sediment from source S8, occurs for the Notched Breakwater alternative as compared to the Modified Breakwater Repair alternative. This effect can be seen by comparing the trajectory of the sediment parcels highlighted by the yellow vectors in Figure 41 (Notched Breakwater alternative) with Figure 39 (Modified Breakwater Repair alternative).

Figures 42 and 43 document the sourcing, timing, and location of cumulative deposition for PTM sediment parcels that contributed to shoaling within the Port Orford Federal Navigation Channel during the June 2010 simulation. Figure 38 illustrates how the timing for deposition within the outer area (trap 7 and 8) and inner area (trap 2) for all breakwater alternatives was altered by moderate wave events during 10-13 June. Federal Navigation Channel shoaling for the Breakwater Removal alternative increased during late June. Figure 39 indicates that the Federal Navigation Channel was impacted by sediment sources from “harbor-embayment, S2 an S8)” and “local beach, S1”.

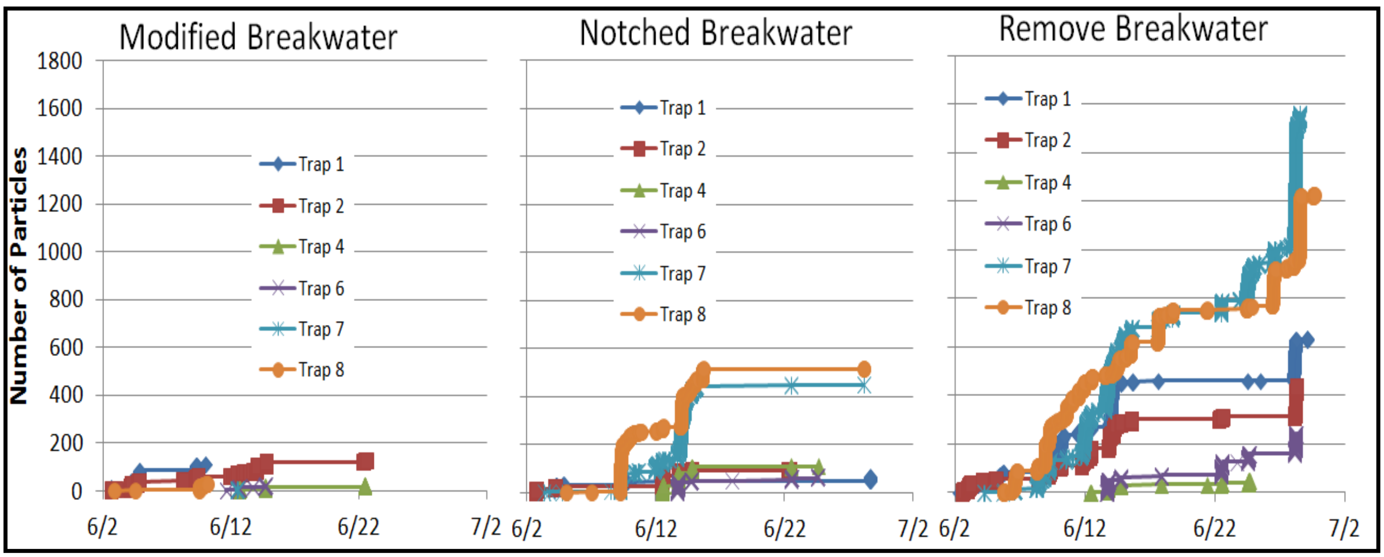

Figure 42. PTM results at Port Orford, Oregon, documenting the timing and location of cumulative sediment deposition within the Federal Navigation Channel during June 2010. Each parcel has 10 kilograms (Kg) mass of sediment.

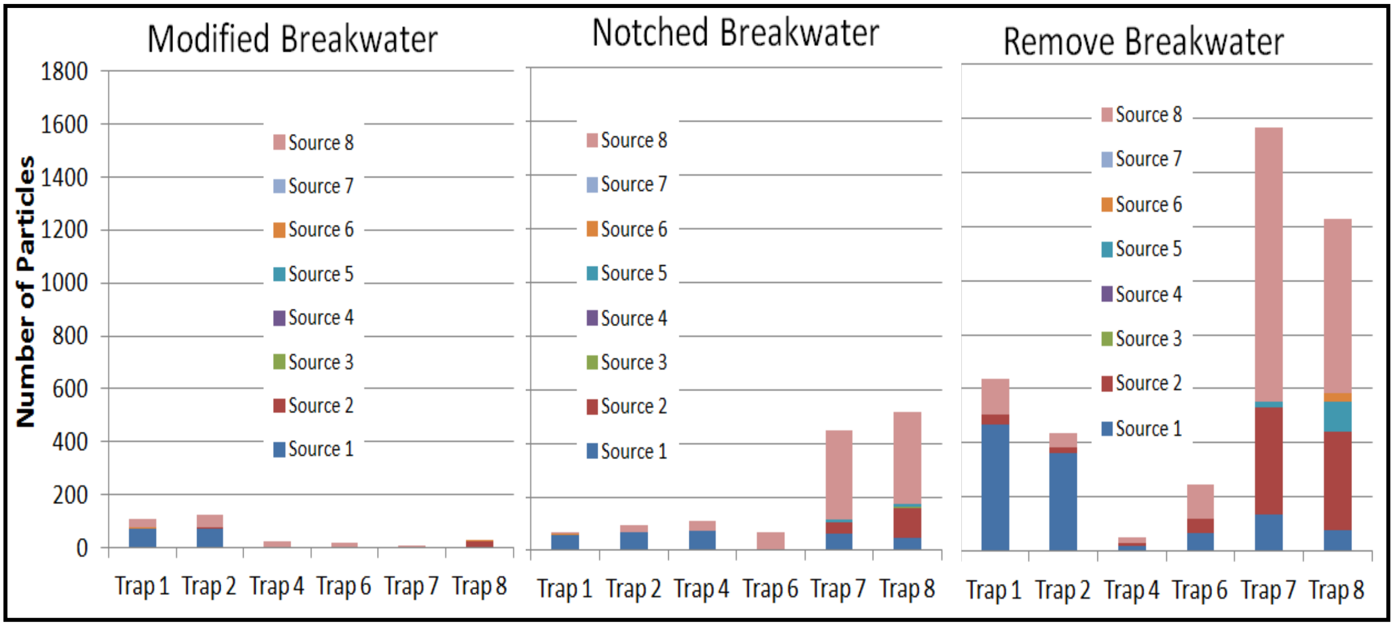

Figure 43. PTM results at Port Orford, Oregon, documenting the contributing sediment sources and associated deposition location within the Federal Navigation Channel during June 2010. Each parcel has 10 kilograms (Kg) mass of sediment.

Comparison to 1974 physical model study

Current patterns produced by the CMS-Flow model (Figures 21 through 23, and Figures 25 through 27) indicate the strong longshore current during southerly winter storms, which appears to change circulation in the Port Orford embayment. The deposition of sediment parcels shown in Figures 34 through 36, and Figures 39 through 41 (based on PTM) resemble the eddy-like deposition patterns shown within a 1974 Port Orford physical model study (USACE 1974). Figures 44 and 45 show wave, current, and sediment deposition patterns as emulated within the 1974 physical model study.

The physical model was scaled at 1:100 based on an undistorted fixed-bed. Sediment was emulated using a coal dust tracer, scaled to a prototype median diameter of 0.01 inches. Tracer movement was modified by wave-induced circulation only; external current attributable to wind or regional circulation was not imposed within the physical model. The white arrows shown in Figure 41 indicate current direction inferred by a dye tracer and coal tracer movement. The coal dust tracer was released within the physical model directly offshore of Fort Point and east of Battle Rock (Figure 45), inshore of the -16.4 ft mllw seabed contour.

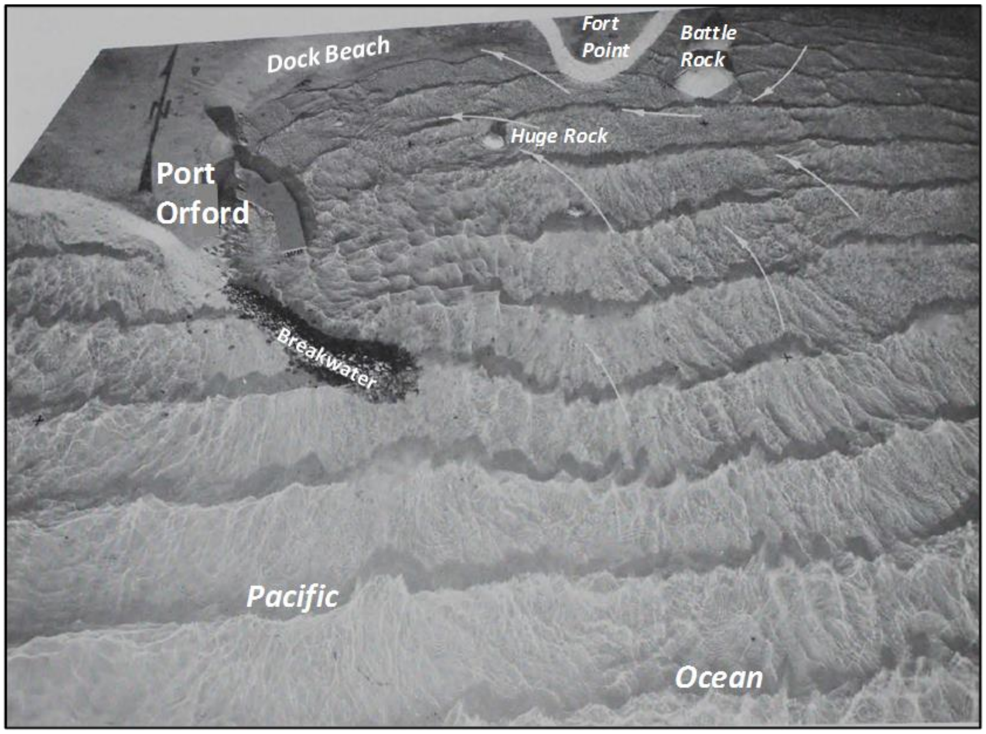

Figure 44. Wave pattern observed within the 1974 USACE model study of Port Orford. Winter waves from the south (T = 13 sec, H = 17 ft). Currents within the model were produced by wave-induced circulation only; no external current field was imposed. (after Giles and Chatham 1974).

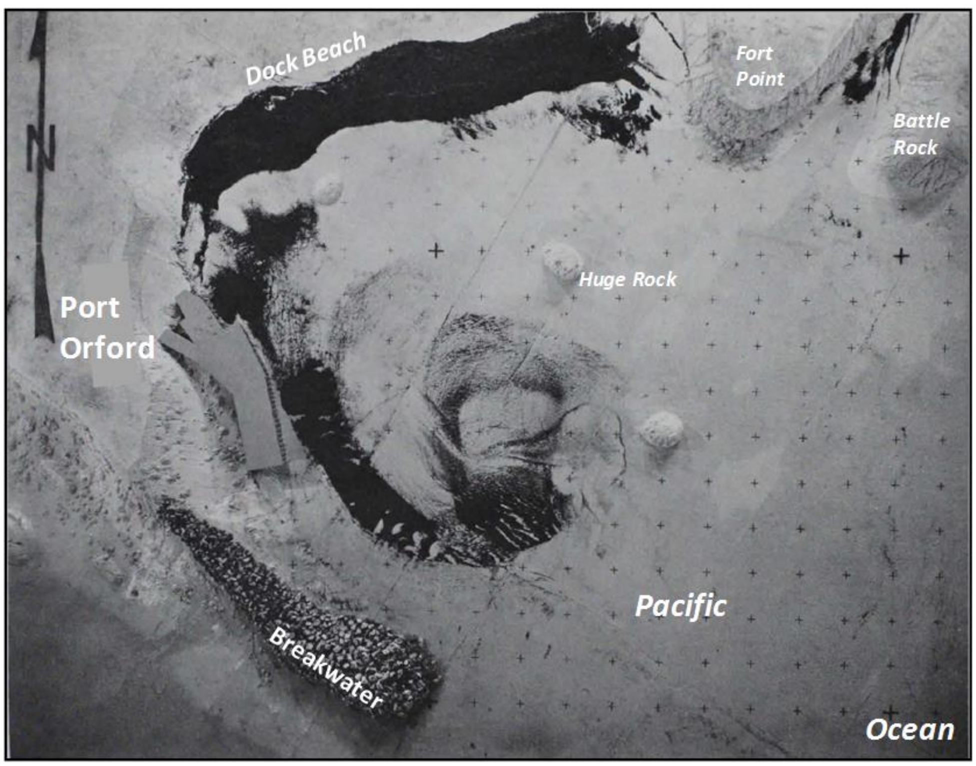

Figure 45. Deposition pattern of sediment tracer (coal dust) from 1974 USACE physical model study of Port Orford. Wave action from the south (T = 13 sec, H = 17 ft). Tracer movement was changed by wave-induced circulation only; no external current was imposed within the physical model. (after Giles and Chatham 1974.

Giles and Chatham (1974) found that “The existing breakwater altered general movement of tracer and current patterns in such a manner as to form a large eddy which carried tracer material into the harbor area from all directions”. The report also found that wave heights at the Port dock were reduced drastically by installation of the existing breakwater. The 1974 report found that the existing breakwater did not significantly reduce the current magnitude (as compared to pre-project condition), but it did alter current direction near the Port by forming a large eddy, transporting sediment toward the Port dock for most wave conditions. The altered wave-induced current patterns (via the breakwater) cause material from the area seaward and east of Battle Rock to enter the harbor between Fort Point and Huge Rock. Wave action carries material (westward) along the beach toward the harbor. Larger storm waves deposit material adjacent to the Port dock.

As previously discussed in this document, most winter storms off Port Orford, OR, generate dominant waves from the S-SW which produce the results described in this present numerical study, and in the previous Giles and Chatham (1974) physical model study. Results from this present CMS-PTM numerical simulation model study are consistent with the Giles and Chatham (1974) physical model study. Both models indicate: (1) Circulation induced by winter storms can form an eddy within the harbor of Port Orford; and (2) The Port experiences westward transport of sediment into the harbor area from beaches and nearshore areas east of the Port. The eddy that forms in response to winter storms acts to deflect sediment sources offshore of nearby littoral areas (sources S3, S4, and S5), and littoral areas located further east (source S7). However, the eddy also acts to confine and enhance westward transport of sediment from nearby littoral sources (S2 and S6) into the harbor area, eventually increasing deposition along the Port dock.

Under winter storm waves, the CMS/PTM numerical model and the 1974 physical model both present similar circulation and sediment transport patterns. However, the numerical results show finer current features around the harbor area resulting from wind-driven and tidal-driven flows.

5 Summary and Conclusions

Summary

The objective of this study was to compare the potential for sediment deposition within the Federal Navigation Channel for three breakwater alternatives (Modified Breakwater Repair, Notched Breakwater, and Breakwater Removal) for two seasonal forcing events (3 December 2007 winter storm, and 8 June 2010 summer storm). This would identify if either one of the three breakwater alternatives reduces sediment shoaling within the Federal Navigation Channel. Alternative breakwater configurations will change the formation of eddy-like flow in the harbor, alter sediment deposition within the Federal Navigation Channel, and influence wave action along the Port dock. Re-mobilization of sediment deposited within the channel was not considered to be a controlling (relevant) factor for evaluating the effectiveness of different breakwater alternative configurations in reducing channel shoaling.

Figures 37 and 38 (November-December 2007, winter season) and Figures 42 and 43 (June 2010, summer season) document the sources, timing, and locations of the trapped sediment parcels that could contribute to shoaling within the channel. Although the winter season was simulated for 45 days while the summer season was simulated for only 30 days, the scale of results for Figures 37 and 38 (winter season) is three times greater than for Figures 42 and 43 (summer season). For this PTM application, sediment shoaling within the channel was evaluated using "closed" sediment traps within the lower half of the water column. Once a sediment parcel entered a closed sediment trap, the sediment was assumed to remain deposited, even if waves and currents are capable of re-mobilizing the sediment. Closed traps were used in this study to focus the analysis on quantifying the potential sedimentation, or shoaling, as a result of bed-load processes.

The results shown in Figures 37 and 38 (winter season), and Figures 42 and 43 (summer season) are a function of the assumption that once sediment is deposited within the channel it does not move out of the channel ("closed" sediment trap). This is a reasonable assumption to use in PTM simulations for qualitative estimates of deposition as the model does not include burial processes. If desired, additional PTM simulations could be performed using open sediment traps for a lower water column elevation within the channel to include the process of sediment re-mobilization. The actual volume of deposited and stationary (or buried) sediments is somewhere in between the extreme estimates from closed and open traps.

Significant effort was invested by the PDT to apply proper boundary conditions for the CMS models, to compensate for these models not being calibrated or validated at Port Orford. Boundary conditions (forcing environmental factors) were based observed data such as wind, waves, tide elevation). Detailed observed bathymetry data was used to define model terrain. Proper imposition of model boundary conditions was necessary to achieve qualitatively realistic results. It is stressed that the results portrayed in this report are qualitative, not quantitative.

Winter time frame (November-December 2007)

Both the Modified Breakwater Repair and the Notched Breakwater alternatives produce about the same amount of total shoaling within the Federal Navigation Channel, based on the PTM results of the simulated winter time frame. The sediment contributing to most of the channel shoaling for the Modified Breakwater Repair alternative originates from sources S1, S2, S6, and S8. The Notched Breakwater alternative includes additional sediment from sources S7 and S8. The Notched Breakwater alternative reduces shoaling within the inner channel along the dock (traps T1 through T6) and increases shoaling within the outer channel (traps T7 and T8), when compared to the Modified Breakwater Repair alternative. The Breakwater Removal alternative produces more than twice the shoaling of either of the other alternatives throughout the channel due to larger contributions from sources S1, S2, S5, S6, S7, and S8.

During winter, a frequently stormy environment produces moderate to strong coastal currents that are often flowing south to north. Therefore, winter coastal currents are often storm-dominated and greater than 0.5 ft/sec. Large waves are often present in the winter, due to both local and distant storms. The Port Orford CMS and PTM results indicate that southerly waves in the winter transport regime can motivate rapid infilling of the Port's channel due to establishment of sustained coherent sediment transport pathways during storms that can persist for 1 to 3 days. This is demonstrated in Figure 35 by the rapid shoaling within the Federal

Navigation Channel during 2-3 December, when two-thirds of the total 40-day deposition occurred.

Summer time frame (June 2010)

The Notched Breakwater and Breakwater Removal alternatives both produce significantly more total shoaling within the Federal Navigation Channel than the Modified Breakwater Repair (restored) alternative, based on the PTM results. The sediment contributing to most of the channel shoaling for the Modified Breakwater Repair alternative originates from sources S1, S2, and S8. The Notched Breakwater alternative includes additional sediment from sources S3 and S7. Similar to the winter season results, the Notched Breakwater alternative slightly reduces shoaling within the innermost channel along the dock (traps T1 and T2). However, the Notched Breakwater alternative significantly increases shoaling within the outer channel (traps T7 and T8), compared to the Modified Breakwater Repair alternative. The overall amount of shoaling within the entire channel for the Notched Breakwater alternative is two times greater than the Modified Breakwater Repair alternative. Based on the PTM, the Breakwater Removal alternative produces five times more shoaling than the other two alternatives throughout the channel due to larger contributions from sources S1, S2, and S8.

During summer, there are few wave events capable of mobilizing nearshore sediment with 0.02 inches grain size. Summer currents are altered by northwest winds (Northwest Pacific High) and tidal circulation which collectively does not increase sustained nearshore flow. Consequently, bottom sediments at Port Orford are mobilized much less often in summer, experience reduced transport distances, and have less coherent transport trajectories than sediments mobilized by winter conditions. This can be seen by comparing the dispersal of sediment from nearshore sources S3, S4, S5, and S7. Summer dispersal is much less than winter dispersal.

Sediment parcels released from the dredged material placement site (source S4 at CWA-404 Site located 984 ft offshore of the Port in 49 ft depth) did not enter the channel for either the winter or summer PTM simulations. PTM results show that sediment parcels released at S4 are transported east and west along the bathymetry contours (parallel to shore), and do not move onshore toward the Port Orford embayment or channel. Implications of these results are that use of the CWA-404 site for dredged material placement can continue without increasing the channel shoaling at Port Orford.

Based on results of this investigation, neither the Notched Breakwater nor Breakwater Removal alternatives offer any meaningful reduction in the sediment shoaling presently entering the Federal Navigation Channel at Port Orford. Although the Notched Breakwater alternative reduces shoaling at localized areas adjacent to the dock during winter storms by 40%, the localized reduction is undone by an increase in shoaling at other areas of the channel. A similar trend also applies to the PTM results obtained for the summer model simulations. The Breakwater Removal alternative significantly increases channel shoaling when compared to the breakwater condition represented by the Modified Breakwater Repair alternative.

Realizing a potential reduction in shoaling along the dock by implementing the Notched Breakwater alternative would be at the expense of increased wave action along the dock by allowing waves to pass through a Notched Breakwater, and increasing shoaling at other areas within the channel. These trade-offs would end up reducing accessibility to the Port's dock. In October 2014, the Port was damaged by heavy wave action during an intense fall storm (offshore wave height of 28 ft), with greater than $500,000 in damages. The breakwater was further damaged, with approximately 60 ft of the structure sustaining additional damage. A Notched Breakwater or Breakwater Removal alternative would increase the exposure of the Port to incident storm waves. There appears to be no viable solution for alleviating the Port's shoaling problem through breakwater modification while at the same time maintaining the intended function of the breakwater which is to protect the Port from damaging wave action. The prudent course of action would be to repair the damaged breakwater (Modified Breakwater Repair) and operate the Port to make best use of favorable tides for launching and mooring vessels, and leverage resources to perform targeted dredging to sustain Port function.

Several aspects of this PTM activity may be potentially improved through better sediment characterization within the harbor embayment, using open sediment traps (instead of closed traps), and performing longer model run-times for entire seasons. If additional PTM work is conducted, it is recommended that focus be given to confirming the initial results regarding sediment fate at the CWA-404 site (to reevaluate the conclusion that sediment placed there does not increase Federal Navigation Channel shoaling).

Conclusions

The results from this work advocate for a conventional repair alternative for the breakwater over more unconventional repair alternatives, and indicate that there is no workable solution to abating the present shoaling problem, in terms of breakwater modification. As such, the results of this work introduce no additional risk for USACE or stakeholders.

RSM products and benefits

The ERDC Coastal Modeling System (CMS) and Particle Tracking Model (PTM) are PC-based and easy-to-use models with a user-friendly Graphical User Interface (GUI) (the ERDC Surface-water Modeling System [SMS]) for data entry, model creation, and model data post-processing. These models were developed to account for complex interactions of coastal physical processes. The CMS and PTM models were developed at ERDC by the USACE Coastal Inlets Research Program (CIRP), and the Dredging Operations and Environmental Research (DOER) Program. These numerical models have been sustained and improved at ERDC by the USACE Regional Sediment Management (RSM) Program through targeted utilization at problem area locations and documented as case examples. Sediment mobilization due to wave action is a naturally chaotic process. Not every threshold-exceeding wave will mobilize sediment. As a result of the PTM application at Port Orford, Oregon, a method for bounding the probability of sediment mobility due to wave action was implemented within the PTM to improve simulation of the stochastic processes that motivate wave-induced sediment transport.

The ERDC CMS and PTM models are highly relevant to in-water sediment management projects administered by USACE Districts and other Federal agencies. Scientists and engineers in public (government) and commercial (private) sectors, and academic institutions find these models highly useful for evaluating waves, currents, and fate of particulate material such as sediment or larvae within the coastal, estuarine, riverine, and lake environments.

Lessons learned

- Sediment characterization is important for PTM to properly simulate sediment pathways and fate. The sediment sampling data base at Port Orford beyond the immediate Federal Navigation Channel boundary was non-existent, making specifications of PTM sources problematic. Sources were specified as having the same sediment properties as sediment found within the channel.
- Validation of PTM results should be performed, if data are available. Validation data types could include semi-continuous bottom sediment gradation throughout the project evaluation area, and bathymetry change data identifying areas of deposition.
- PTM results can guide field data collection and other prototype evaluations.
- Short PTM simulations are useful for model testing to prepare for long-term simulations.
- Good hydrodynamic modeling is a necessity for PTM applications.
- Acknowledge model limitations at the beginning of a modeling evaluation. Models often require more input data than is feasibly available. Embrace the limitations and compensate for them as the evaluation proceeds.
- Bounding the probability of sediment entrainment to emulate the stochastic processes of wave action has improved validity of the PTM model at wave-dominated environments.
- A collaborative environment between USACE Districts (Seattle and Portland), ERDC, and Port Orford, Oregon, was an essential team element that facilitated a significant amount of relevant work being completed within a 6 month time period.
- Consider use of open sediment traps as compared to closed sediment traps to document sediment exchange and deposition within the Port Orford navigation channel, rather than assuming that all sediment that enters the channel results in fixed shoaling. Sediment could be moving into and out of the Federal Navigation Channel.

- Utilize as much existing information as possible. Research and review previous work for projects of interest. Work performed before the digital age often portrays a great deal of insight to the physical processes pertaining to a given water resource project and associated responses. If sufficient models or model output already exists for a given project region, then use it. Do not re-create work already created.

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