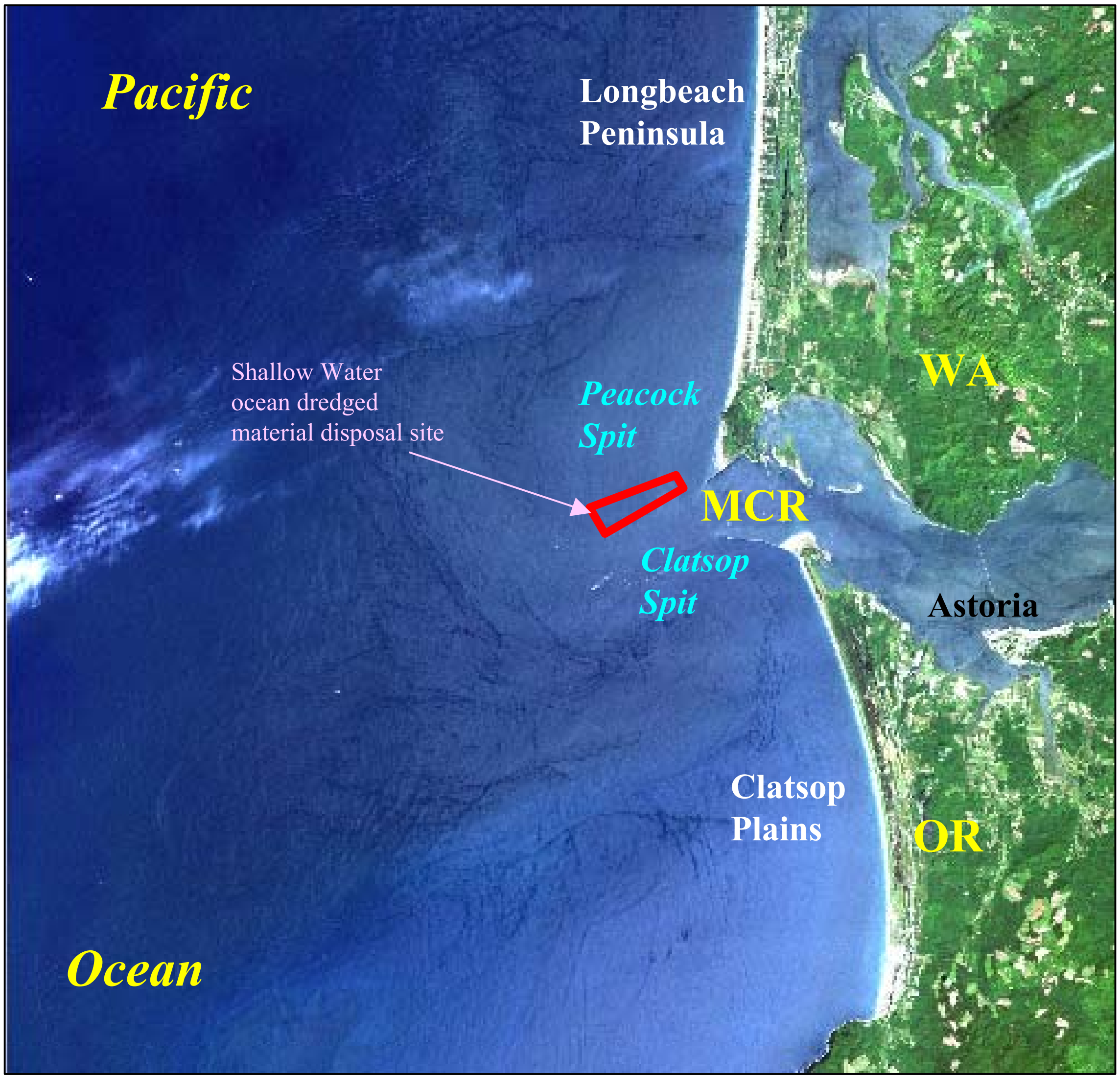
Mouth of the Columbia River
Shallow Water Ocean Dredged Material Disposal Site

Supplemental Evaluation of Optimized Site Utilization and Assessment of Potential Wave-Related Impacts



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EXECUTIVE SUMMARY

The U.S. Army, Corps of Engineers, Portland District, (Corps) is responsible for maintaining the deep draft channel at the Mouth of the Columbia River (MCR), where 3-5 million cubic yards of sand is dredged per year from the 6-mile long entrance channel. Since 1977, the Corps has relied upon the existence of U.S. Environmental Protection Agency (EPA)-designated ocean dredged material disposal sites, and since 1992, has worked closely with EPA's Region 10 to develop a long-term disposal plan for the MCR project and lower Columbia River estuary, which could include formal designation of new ocean dredged material disposal sites. Ocean disposal has occurred in this location for many years, under different names and configurations, i.e., Site E and "Expanded Site E" since 1977. EPA intends to propose a Shallow Water ocean dredged material disposal site (SWS) for formal designation, but that action had not occurred when this report was initiated. Throughout this report the term, SWS, is used consistently to represent the area that has become the primary location for dredged material disposal at MCR, as well as the specific configuration to be proposed for designation. The SWS is located on the ebb tidal delta of the Columbia River. Waves and currents disperse most of the dredged material placed at the site. Continued use of the SWS is of strategic importance to the MCR project for maintaining the federal entrance channel and deferring repair on the north jetty at a reduced cost to the federal government. There are two competing objectives for use and management of the SWS: Maximize use the site to retain as much sand (dredged material) as possible in the nearshore littoral system, and minimize any exacerbation of the already hazardous wave climate at MCR. To assist EPA in developing the designation proposal and a Site Management and Monitoring Plan (SMMP) for any new sites, the need to evaluate how to optimally meet both management objectives was recognized and undertaken by the Corps. This report is composed of three sections:

Part I of this report describes the MCR environment, past utilization of the SWS, and shows that the SWS is highly dispersive. Therefore, the SWS can receive a given volume of dredged material indefinitely, provided that dredged material is dispersed throughout the entire site both in terms of time and space during the entire dredge season. A rational is proposed to improve use of the SWS by achieving uniform placement of dredged material throughout the entire site, thereby minimizing the occurrence of dredged material mounding and undesirable impacts to the local wave environment. Achieving uniform deposition of placed dredged material throughout the entire SWS will minimize the mounding of placed dredged material, maximize the dispersive capability of the SWS (by increasing the surface area over which waves and currents can transport the material out of the SWS), and potentially allow more dredged material to be placed within the site per year.

Part II of this report examines the potential change in the wind-wave environment at MCR, as it relates to recent changes in seabed conditions on or near the ebb tidal shoal. Of particular interest, is the potential change in the local wave environment at MCR due to bathymetry (seabed topography) change at the SWS. Wave modeling results, presented in Section II, indicate that utilizing the SWS during 1997-2002 have had a minimal effect on the MCR wave environment to date. The wave-related effects of regional bathymetry change at MCR during 1997-2002 far exceed the wave-related effects of using the SWS for dredged material disposal.

Part III of this report investigates the wave-related impacts associated with three levels of the Shallow Water Site utilization: 2, 4, and 6 mcy of sand placed (per year). The three SWS utilization scenarios were based on the rational developed in Part I. Estimates of the vertical accumulation of dredged material that would result from the three levels of SWS utilization ranged between 2-8 ft. Estimates of the effect of dredged material accumulation upon the MCR wave environment indicate: A) Wave height in vicinity of the SWS might be increased by 1-15% (or 0.3 – 2 ft); and B), The creation of "breaking" wave conditions as a result of SWS use would occur only during the most intense storm wave conditions and would be limited to isolated areas away from the entrance channel. On a relative comparison basis, the presence of current (interacting with waves) does not increase the effect that dredged material accumulation (i.e. bathymetry change) has upon the wave environment within or near the SWS.

Based on the above modeling analysis and conclusions, the U.S. Army Corps of Engineers, Portland District, recommends 102 site designation of Expanded Site E (proposed Shallow Water Site (SWS)).

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PART I: INTRODUCTION

Study Approach

Estimates of wind-wave behavior, associated with a specific nearshore bathymetry condition, were derived using a numerical wave model (computer simulation). The results of various computer simulations were compared to assess the potential changes in the wave environment due to bathymetry change. Relevant bathymetry change is assumed to be inshore of the 150 ft depth contour. The specific objective of the report is two-fold:

A) Estimate, using computer simulations, the extent of wind-wave modification that has occurred in/near the Shallow Water ODMDS due to dredged material disposal during 1997-2002 and qualify the results in context of regional bathymetry change at MCR.
B) Formulate dredged material placement scenarios and estimate, using computer simulations, the related impacts to the wind-wave environment in vicinity of the Shallow Water ODMDS.

The report is composed of three parts. Each part deals with a distinctly different aspect of the SWS. Conclusions are presented at the end of each part of the report. The progression of analyses presented in this report follow the ordering of Parts I-III. The figures are grouped based on functional analysis.

Part I of this report introduces the MCR navigation project in terms of the general physical environment, sediment dynamics, and recent Shallow Water ODMDS (SWS) management practices. The SWS is dispersive: Dredged material placed at the site is transported by waves and currents to adjacent nearshore areas, abating the erosion trend of Peacock Spit. Monitoring results summarizing the recent utilization of the SWS show the desirability of continued use of the SWS and opportunities for improved site use. A strategy is formulated to optimize use of the SWS, by achieving uniform deposition of dredged material placement within the site.

Part II of this report discusses the concepts of wind-waves, spectra, and wind-wave transformation as they relate to wave modeling. The wave environment offshore of MCR is described in terms of 10 representative wave fields, ranging from summer calm to winter storm. The 11 representative wave fields were used as input (boundary conditions) for simulating wind-wave behavior for two MCR bathymetry conditions, as described by surveys for 1997 and 2002. Wind-wave simulations were conducted using the STWAVE model [Smith et al 2001]. Adaptation of survey data necessary to describe the bathymetry at MCR sufficient for modeling wave conditions for 1997 and 2002 is summarized. Bathymetry change that has occurred at MCR between 1997 and 2002 is presented, as is the STWAVE modeling results that were generated for each of the two bathymetry conditions. The objective of Part II is to evaluate the potential change in wave conditions that may have occurred at the SWS during 1997-2002 (associated with dredged material disposal), in context of the larger-scale changes in the nearshore wave environment that occurred at MCR (due to regional bathymetry change).

Part III of this report investigated potential impacts to the wind-wave environment, in vicinity of the SWS, based on future (improved) utilization scenarios for the SWS. Part III used a two-step procedure. First, bathymetry change within the SWS was predicted for three scenarios where dredged material was placed uniformly throughout the site. Second, wave transformation over the modified SWS bathymetry was predicted using 11 representative wave fields. The three scenarios for placing dredged material with the SWS were based on the site use strategy formulated in Part I of the report and included annual disposal volumes of; 2, 4, and 6 mcy per year. For each scenario, dredged material placement was simulated using the MDFATE model [Moritz and Randall 1992 and Herbich 2000a] to estimate post-disposal bathymetry at the SWS. The simulated post-disposal bathymetry conditions of the SWS were assessed using STWAVE to evaluate the potential changes in the wave environment, as related to the potential change in bathymetry at the SWS. The effect of current was included. All pertinent findings are shown and discussed. The objective of Part III was to evaluate if the SWS could be used as a primary site for MCR dredged material disposal while minimizing wave-related impacts.

Background

The Mouth of the Columbia River (MCR) is the ocean gateway for maritime navigation to/from the Columbia – Snake River navigation system (**figure 1**). The ocean entrance at MCR is characterized by large waves and strong currents and has been considered one of the world's most dangerous coastal inlets. The sea state at the river entrance during storm conditions is characterized by high swell approaching from the northwest to southwest combined with locally generated wind waves from the south to southwest. During October-April average wave height and period is 9 ft (2.7 m) and 12 seconds, respectively. During intense winter storms, waves can exceed 30 ft (9 m). During May-September, average wave height and period is 5 ft (1.5 m) and 9 seconds, respectively. Astronomical tides at MCR are mixed semi-diurnal with a diurnal range of 8.5 (2.6m) feet. The instantaneous flow rate of estuarine water through the MCR during ebb tide can reach 1.8 million cfs (51,000 m3/sec). Tidally dominated currents at the MCR and near the SWS can exceed 2 meter/sec (4 knots or 7 ft/sec). The nearshore wave and tidal environment at MCR is greatly affected by Peacock Spit, due to the spit's significant offshore extent (figure 2). The combination of large waves and strong tidal currents can transport large volumes of sediment on Peacock Spit and within the SWS. During the course of several tidal cycles (1-2 days), the seabed of Peacock Spit can vary by 1-3 ft. The transition from coastal regime to oceanic is abrupt. Excluding Astoria Canyon, which is about 11 miles offshore, the continental shelf lies approximately 18 miles offshore from the MCR.

Dredging the MCR Navigation Channel

To secure reliable and safe navigation through the MCR, the U.S. Army Corps of Engineers constructed several jetties during 1885-1939 to provide a stable deep-draft channel.

The Corps presently dredges 3-5 mcy of sand per year to maintain the 6-mile long deep-draft navigation channel at MCR. The MCR channel is 2,640 ft wide and nominally 55 ft deep (below MLLW). **Figure 2** shows the relevant project features at MCR.

Due to the exposed ocean conditions at MCR, only ocean-going hopper dredges can perform dredging and disposal at MCR; dredging is limited to summer when wave conditions are favorable for working on the bar. A hydraulic hopper dredge is a self-propelled seagoing ship with sections of its hull compartmented into one or more hoppers. It is normally configured with two drag arms, one on each side of the dredge. During dredging, the drag arms are lowered to the bottom; bottom sediment is sucked into the drag arm by hydraulic pumps and deposited into the dredge's hoppers. The dredged material enters the hoppers in slurry form and settles to the bottom as excess water flows over the top of the hoppers. Once the hoppers are full, the drag arms are lifted, and the dredge transits to the disposal area where the dredged material is usually dumped thru doors located on the bottom of the ship (hoppers). Two hopper dredges are used to perform maintenance dredging at MCR: A government operated dredge and a contractor operated dredge, each with different capacities. The dredged material (fine-medium sand) is placed in specified open water disposal sites.

Ocean Dredged Material Disposal Sites (ODMDSs)

Although the navigation channel is considered "the" project feature at MCR by the Corps, open water dredged material disposal sites are legitimate project features and require a rationale for design, utilization, and designation. Management of an ODMDS is predicated on the need to efficiently utilize the site while minimizing impacts to navigation and environment outside the ODMDS. The capacity of an ODMDS is the volume (or height and area) of dredged material that can accumulate within a site's boundaries without adversely affecting navigation or the environment.

In general, the potential for dredged material to accumulate within an ODMDS is a concern for site management. However, excessive vertical accumulation of dredged material placed within a relatively shallow, nearshore, ODMDS can potentially affect the wind-waves that pass through the site, via mound-induced wave shoaling. This was borne out by previous use of ODMDS A and B [USACE 1999]. Figure 2 and 4 show the general location of ODMDS A and B. Dredge material placed at non-dispersive ODMDSs typically remains within the site. If the ODMDS is small with respect to the volume of dredged material placed at the site, the placed dredged material can accumulate vertically on the seabed of the site, resulting in a distinct mound. This type of mounding condition occurred at ODMDS A and B during 1980-93. Such an effect on the wave environment can degrade the navigability in or near an ODMDS. Consequently, use of ODMDSs A and B was restricted in 1994 and 1997 by EPA. Present procedures and constraints for utilizing MCR open water dredged material disposal sites are described in USACE 2002aandb.

History of the Shallow Water ODMDS (ODMDS E)

The area in vicinity of SWS (formally ODMDS E) has been used as a dredged material disposal site since 1973. In 1977, the area was formally designated an *interim* dredged material disposal site (site E) by EPA rule. In August 1986, the MCR *Interim* disposal site E received final EPA designation under section 102 of the MPRSA (figure 3, smaller site described by dashed line). The EPA-designated ODMDS E has nominal dimensions of 1,000 ft x 4,000 ft. During 1973-1997, approximately 50 mcy of dredged sand had been placed at or near ODMDS E. Material placed at ODMDS E each year was transported by waves and currents out of the site and onto Peacock Spit before the following year (see figure 4). On a cumulative basis, very little (if any) of the volume placed during 1973-1997 resided within the site as of 1997. This indicated that ODMDS E was a highly dispersive site. A complete description of ODMDS E and the site's utilization prior to 1998 is contained in USACE [1999].

1997 Expansion of ODMDS E

ODMDS E has become a highly desirable site to use for the placement of MCR dredge material due to the high dispersion rate observed at ODMDS E, its close proximity to the MCR entrance channel (short haul distance from dredging sites), potential to prevent foundation-related failure of the north jetty, and the potential for dredged material placed at ODMDS E to be re-introduced into the littoral environment of the Washington coast. In light of the site's positive attributes, ODMDS E was temporarily expanded in 1997 [USACE 1997, figure 3], and is proposed to be formally designated by EPA (as the SWS). A site utilization plan for the 1997-expanded ODMDS E was developed to minimize navigation impacts [USACE 1998a]. In 1998, the *dispersive* capability of ODMDS E, during the dredging/disposal season (June –September), was estimated to be 40-60% of the volume placed within the site [USACE 1998b]. This meant that if 3.5 mcy of dredged sand was to be placed within the site during a given summer, approximately 1.4-2.1 mcy could be expected to be transported out of the site by the end of the dredging season. At present, the SW ODMDS has the same boundary configuration as the 1997-expanded ODMDS E and is managed with respect to the 1997 baseline bathymetry condition.

Recent Use of the Shallow Water ODMDS (SWS)

The SWS has become the principal disposal site for MCR project maintenance dredged material. Since 1997, 72% of all MCR dredged material (sand) has been placed in the SWS. The bathymetry of the SWS was more intensively monitored prior to, during, and after the dredging/disposal season to determine the extent of dredged material dispersion and accumulation on the seabed [USACE 1998b and 2002a]. During this time frame, different placement strategies were used to learn how material dispersed or accumulated in order to improve site management. The dredged material accumulation within the SWS is evaluated with respect to the 1997 baseline bathymetry condition. If necessary, utilization adjustments are made during the disposal operations to avoid exceeding management targets [USACE 2002b]. Results of monitoring the SWS, since 1997, are shown in figures D1-D6 and summarized in Table 1. As the SWS was used for the placement of dredged material during 1997-2002, the bathymetry variation within the site has typically been 3-7 ft, with respect to the site's baseline (1997) condition.

Observed Sediment Dispersion at the SWS

As of September 2002, 87% of the dredged material volume placed within the site since May 1997 had been dispersed by waves and currents in a north-northwesterly direction onto Peacock Spit. Figure 4 shows the northerly trends of sediment transport at the SWS and on Peacock Spit. Less than 5% of the dredged material placed at the site has been transported southward into the MCR navigation channel [USACE 2002a]. The lack of southeastward transport at the SWS is due to the prevailing tidal currents that affect the site. The eastern half of the SWS has experienced net erosion since 1997. Figure 5 shows the general trend for tidal currents at MCR. The SWS is affected much more by offshore flowing ebb currents than by inshore flowing flood currents (see Part III). The eastern half of the site is located just offshore of the flood current regime. Tidal ebb currents at the SWS regularly exceed 1 meter/sec (2 knots or 6 ft/sec). Based on monitoring conducted during 1997-2002 (see table 1), about 45% of the dredged material placed at the SWS was dispersed during the dredging/disposal season (June-October). The dispersion rate within the site during the ensuing winter (November-May) was about 45% of the volume placed at the SWS. The site's average annual dispersive rate was about 90% of the volume of dredged material placed each year during 1997-2002. It is noted that since 2000, the western half of the SWS has been accumulating about 200,000 cy/yr of sediment; not all of the placed dredged material is transported out of the site on an annual basis.

Figures D1-D6 show the distribution of dredged material placement within the SWS and the resulting accumulation for each year during 1997-2002. Typically, only 50-80% of the site was used in any given year. The presence of a navigation buoy (#7) within the middle of the SWS contributed to the lack of complete site area utilization. In some cases, dredged material placement within the SWS (and deposition on the seabed) was concentrated to small areas. When localized mounding occurred within the SWS, less than 10% of the dredged material placed during the dredging/disposal season contributed to an accumulation that was greater than the management target [USACE 2001 and 2002a-c]. If the same "10%" of dredged material had been placed in the area of the SWS that was *not* used (20-50% of the site), the potential for mounding would have been greatly reduced. In short, using 100% of the site for the placement of dredged material would reduce the occurrence of localized mounding.

Depositional Surface Area vs. Sediment Dispersion

In a highly dispersive area such as the SWS, increasing the area over which dredged material is placed (deposited) can increase the transportability of placed dredged material. For example, the dispersion rate for a fixed volume of dredged material that is deposited in a confined area (and forms a discrete feature 3-5 ft thick) is less than for the same volume deposited in a large area (and forms a low-relief lift of less than 1-2 ft thick). This is based on two factors: A) Compaction, and B) Surface Area. Compacted sand is harder to erode than loose (recently deposited) sand. Although sand does not consolidate in a classical soil mechanics mode, loose submerged sand can self-compact under the influence of oscillatory vibration or pressure (i.e. waves). Such is the case for recently deposited dredged material placed at the SWS; the thicker the "recent deposit", the more rapid the compaction. This deposition-compaction-erosion trend has been observed at the SWS [USACE 2002a-c]. An underwater depositional feature (at the SWS) having a large surface area, will experience more sediment dispersion than a compact feature (e.g., discrete mound) having the same volume. To enhance the dispersion for a given volume of dredged material to be placed at the SWS, the material should be placed (deposited) over the largest area possible. This surface area vs. erosion trend has been observed at the SWS [USACE 2002a-c].

Additional Considerations – The Regional Littoral Budget and MCR Jetties

During 1885-1939, construction of the MCR jetties facilitated the discharge of 500-800 mcy of sand from the Columbia River estuary to the ocean. Since 1926, the surplus of sand on the ocean side of MCR has been dispersed by waves/currents onshore, offshore, and to points north and south. Figure 6 shows the north-south dispersal of sand from the Columbia River during 1926-1995. This process resulted in rapid shoal and landform accretion north and south of MCR. Much of the present-day Peacock Spit and Clatsop Spit were formed by sand discharged from MCR during/after jetty construction. Figure 7 shows the degree of bathymetry change that has occurred at MCR since 1885. Note how the large ebb tidal shoals offshore MCR (Peacock Spit and Clatsop Spit) have shifted over time. The MCR rubblemound jetties were built on these flood/ebb tidal shoals, which had protected the jetties from excessive waves and currents. To a large degree, the stability of the MCR channel is related to both the jetties and the morphology of Peacock Spit. If Peacock Spit were to change radically, the stability of the jetties and the navigation channel would be jeopardized.

The surplus of sand at MCR is turning to deficit (see figure 6). Gelfenbaum et. al. (2001) have estimated that 2-5 mcy per year of sand is being eroded from Peacock Spit. The eroded sand is transported to the north. The present erosion trend of Peacock Spit is problematic; for the long-term stability of the MCR north jetty, the MCR navigation channel, and shoreland areas north of MCR. As Peacock Spit is diminished in size, so is the volume rate of sediment supplied to the littoral areas north of MCR: The shoreline has begun to recede. As the ebb tidal shoals offshore MCR change shape, the nearshore wave and current regime will change; adding to the shoreline re-adjustment (recession). As Peacock Spit recedes shoreward, the water depth along the north jetty gets deeper and the jetty fails due to increased wave action and foundation scour [USACE 1881-1948]. It is extremely costly to rebuild Pacific NW jetties [Moritz et. al. 2003].

Part I Conclusions

At the MCR, the interaction of the bathymetry and oceanographic processes of the Pacific Northwest coast with processes of the Columbia River system and estuary produce a complex dynamic system. Within this system, an efficient method to maintain both the MCR deep-draft navigation channel and the littoral budget of MCR must be found. If 2-5 mcy per year of dredged sand were placed at the SWS, the present erosion trend of Peacock Spit would be reduced, thereby protecting the integrity of the MCR north jetty, navigation channel, and shorelands to the north.

The SWS is highly dispersive and therefore can receive a given volume of dredged material indefinitely. During 1997-2002, an average of 3 mcy per year of dredged material was placed at the SWS and the average annual dispersion rate was observed to be 90%. During this time, an average of 70% of the SWS area was used during a given year. Improvement of SWS utilization could be achieved by promoting even deposition of dredged material throughout the *entire SWS* boundary. This means that the dredged material would be placed though out the entire site, both in space and time, using a regimented procedure to produce a uniform continuous layer on the seabed, avoiding the formation of any localized mounding.

Achieving uniform deposition of placed dredged material throughout the entire SWS will minimize the mounding of placed dredged material, increase the dispersiveness of the SWS (by increasing the surface area over which waves and currents can transport the material out of the SWS), and potentially allow more dredged material to be placed within the site per year. In an annualized sense, the actual volume of dredged material to be placed within the SWS will depend on the how much is to be placed, the method of placement, and residence time for the material in the site.

Using MCR dredged material (placed at the Shallow Water ODMDS) to feed the littoral supply of sand to Peacock Spit will reduce the rate of shoreline recession north of MCR and prevent accelerated deterioration of the north jetty. This could avoid or at least reduce the need and cost of rebuilding the jetty in the near-term. The cost of rebuilding Pacific NW jetties has ranged from $20,000-60,000 per foot length. If only 20% of the MCR north jetty had to be rebuilt, it would cost $40-60 million [Moritz et al 2003]. To address a specter of issues dealing with the diminishing littoral sediment budget of MCR (coastal sand-a non-renewable resource), it is now necessary to use the SWS at an optimal level.

Based on the results described above, several improvements for immediately optimizing use of the SWS are proposed: A) Remove/relocate Buoy #7 out of the SWS during the dredging disposal season, B) Manage disposal operations to distribute dredged material uniformly through out the entire SWS both in terms of time and space during the entire dredged season, and C) Continue to use assigned grid cells to promote the uniform distribution the release point for each disposal event within the SWS.

As experience is gained by future disposal operations, two additional management actions should be evaluated. Measures could be explored to promote enhanced dispersal of dredged material during the release of each load at the SWS, by decreasing the rate at which dredged material is deposited on the seabed during placement. This can be accomplished by increasing the speed of the hopper dredge during placement, restricting the rate of dredged material release, or both. Also, future monitoring will likely show that dredge material placed within the one area of the site is dispersed more rapidly than material placed in another part of the site. If this result is shown by future monitoring, placement activities should be fine-tuned to match the volume of dredged material placed within a given region of the SWS with the site's variable dispersive capability.

PART II: RECENT BATHYMETRY CHANGE and RELATED WAVE EFFECTS

The nearshore wave environment at MCR is a function of the bathymetry. If the bathymetry changes, the nearshore wave environment changes. From year to year, the bathymetry at MCR can experience significant change due to environmental forcing. Additionally, the bathymetry near the MCR is continually re-adjusting to the influence of jetties constructed at the estuary mouth and the present deficit in the littoral sediment budget.

The objective of Part II was to evaluate the potential change in wave conditions that may have occurred at the SWS during 1997-2002 (associated with dredged material disposal), in context of the larger-scale changes in the nearshore wave environment that occurred at MCR (due to regional bathymetry change). The two timeframes of focus in Part II are 1997 and 2002. The year 1997 is the established baseline condition for assessing impacts at the SWS. The year 2002 is the latest point in time available that shows the cumulative effect of dredged material placement with the SWS and natural bathymetry change at MCR Much of the wave modeling approach developed in Part II was used in Part III to assess future conditions within the SWS.

Characteristics of Wind-Generated Waves

Wind generated waves are defined by their height, length, period (frequency), and direction. Wave *height* is the vertical distance from the top of the wave crest to the bottom of the wave trough. Wave *length* is the horizontal distance between successive wave crests. Wave *period* is the time between successive wave crests passing a given point. Wave length is proportional to wave period. Often the term wave *frequency* is used to describe waves in place of wave period; frequency is 1/period. Wave *direction* is the direction that the waves are traveling from; the same convention as used to define wind (direction).

If winds of a local storm blow toward shore, the waves generated by the wind will reach the coast in nearly the same waveform in which they were generated. Under these conditions the waves are steep (wavelength is 10-20 times the wave height) and are commonly called *seas*. If waves are generated by a distant storm they may travel through 10s-1,000s of miles of relatively calm wind areas before reaching the shore. Under these conditions, waves decay (short steep waves area transformed into long low waves) and have wave lengths that are 30-500 times the wave height; these waves are called *swell* [USACE 1984]. In some cases, slow moving storms that are vary large (cover a large area over the ocean), can generate a wave field that contains both seas and "local" swell.

Irregularity of the Coastal Wave Environment

In the coastal environment, rarely is the case that a wave field is composed of uniform waves (waves having equal wave height and period) approaching shore from only one direction; even during the course of a short observation. This rare case would be similar to observing waves along the edge of a pond that were generated by dropping uniform sized rocks into the center of the pond (from the same height) at a constant time interval; all the waves would be the same. In a real coastal environment, the wave field is usually composed of many types of waves approaching shore from many different directions. This general case would be similar to observing waves along the edge of a pond generated by dropping different sized rocks into the pond from different heights, at varying locations, and at varying time intervals. In reality, the coastal wave environment is irregular, being composed of a combination of *seas* and *swell* approaching from various directions.

To describe a given coastal wave field in a concise manner, the individual wave components are "mapped" into a spectrum. A spectrum is similar to a statistical "distribution", i.e. a bell-curve showing the distribution of test scores. A one-dimensional wave spectrum describes the wave field in terms of wave energy versus wave period (frequency), or wave energy versus wave direction. Wave energy is related to wave height. A two-dimensional wave spectrum describes the distribution of the wave field components in terms of wave energy versus wave direction <u>and</u> wave frequency. A two-dimensional spectrum can be used to identify: The waves that have the most energy (typically swell) within a wave field; the direction of the biggest waves (typically seas); the different directions from which seas and swell are approaching; and other wave field properties that can be used to address specific assessments. An example of a one- and two-dimensional wave spectrum is shown in figure S1. Often (and for ease of description), a wave field is summarized in terms of "mean" values for wave height, period, and direction.

<u>Wave Transformation in the Nearshore Region</u>

As wind-generated waves approach the coast, as indicated by increasingly shallower depths, the waves are transformed based on the rate (and direction) of seabed contour change. In other words, as waves propagate into shallow water, the waves are refracted and shoal as the waves "feel" the bottom. As a wave passes over a progressively shallower seabed, the wave height increases. At a nearshore location, the height of the wave can be larger than in deep water-offshore, due to shoaling. As the wave continues to propagate shoreward, the wave eventually becomes so steep (unstable) that it breaks.

Wave breaking is a process by which wind waves transfer energy when the wave becomes unstable; some of the energy is transmitted to more stable wave frequencies, some is dissipated into turbulence. A breaking wave can be energetic and unpredictable. Breaking waves are of particular concern to the mariner, since surface vessels are susceptible to capsizing, flooding, cork-screwing, or pitch-poling when overtaken by a breaking wave.

The degree to which individual waves shoal, refract, and ultimately break is a function of the wave properties (wave period, wave height, and wave direction). For a given nearshore water depth, larger waves (large period and/or large height) are affected more by a change in water depth than smaller waves (small period and/or small height). An example follows. Given two wave conditions (*A* and *B*) where the offshore wave height and direction is equal, but condition *A* has a longer wave period than condition *B*; the shoaling and eventual breaking of wave condition *A* would occur further offshore than for condition *B*. This is because the depth at which wave condition *A* (long period wave) begins to shoal and eventually break is deeper than for wave condition *B* (shorter period wave). During an offshore wave condition dominated by short period waves, the nearshore transformation of these waves results in a visually consistent-looking environment: The waves appear to be predictable by shoaling and eventually breaking in roughly the same location. However, the occurrence of an infrequent long period wave during a time when short period waves are dominate can result in a "sneaker wave"; the solitary long period wave shoals unexpectedly and breaks out of "nowhere".

To fully account for the shoreward transformation of a coastal wave field, the complete offshore two-dimensional wave spectrum must be known in addition to the three-dimensional coastal bathymetry.

Wave-Current Interaction

The presence of current in the coastal environment is a common occurrence, especially at estuary entrances like the MCR. On encountering a current, the characteristics of a wave change. In the presence of current, the wave height and wave length are modified. If the waves are travelling obliquely to the current, the wave direction can be modified. If the current is in the direction of the wave propagation (i.e. the waves are propagating in the same direction as the current), the wave height (H) decreases and the wave length (L) increases making the wave less steep (H/L) and less prone to breaking. At MCR, this would be the case during flood tide (the tidal current is flowing from the ocean into the estuary). On the other hand, if the current opposes a wave, the wave height increases and the wave length decreases making the wave more steep and more prone to breaking. At MCR, this would be the case during ebb tide (tidal current if flowing from the estuary out of into the ocean). If the opposing (ebb) current is strong enough and wave period is small, an opposing current can "block" the propagation of waves: The waves stop propagating and the wave energy is dissipated by turbulence and wave breaking. At areas of MCR where the water depth is less than 50 ft deep, wave blocking can occur during ebb tide (when the current exceeds 1.5 m/sec) for wave periods smaller than 5 sec.

Navigation Restrictions at MCR

Breaking wave conditions, due to steep waves, are the principal reason that the U.S. Coast Guard will sometimes "close the bar" at MCR to navigation. Determination of "bar closure" condition at MCR is made in the following manner: The Coast Guard performs a visual check of the wave conditions at MCR (morning and evening, first and last light) and a judgement call is made by the surf coxswain on duty (he/she has 2 years of training for this job). The wave height, period, and whether the wave is breaking or sloughing (not quite breaking) are all used to determined whether the bar is closed. For example, if average wave height is are around 8-12 ft and the waves have long period, the bar would likely be open. But if the waves are 8-12 ft and the wave period is short; or if breaking waves are present, the bar might be closed.

Sometimes a "small craft" advisory is issued to inform mariners of wind-wind conditions that may be unfavorable for coastal navigation. A small craft advisory is issued when wind speed reaches 25 knots (12 m/s). The average wind-wave conditions that may be encountered during a small craft advisory would be in the range of wave height=1.5-2.5 m; and wave period = 5-8 seconds. Vessels are classified as *Small craft* if they are either: A) un-inspected commercial vessel [determined by usage or number of paying passengers per boat, limit is 6], or B) recreational vessels smaller than 30' length.

For the Pacific Northwest, there are 2 levels of warnings above the "small craft advisory". A Gale Warning is issued when wind speed is 25 - 48 knots (13-25 m/s); waves may have average height = 3-5 m and period = 7-10 seconds. A Storm Warning is issued when wind speed is 49 - 74 knots (25-38 m/s); waves may have average height = 4-8 m and period = 8-12 seconds). Small-craft are advised to seek refuge during gale and storm warnings.

Bathymetric Change at MCR and Effects on Wave Environment

The nearshore wave environment at MCR is a function of the bathymetry. If the bathymetry changes, the nearshore wave environment changes. From year to year, the bathymetry at MCR can experience significant change (5-10 ft or more) due to environmental forcing caused by episodic events such as high river flow , El Nino, and La Nina. Additionally, the bathymetry near the MCR is continually re-adjusting to the influence of jetties constructed at the estuary mouth and the present deficit in the littoral sediment budget. Figures 4 and 7 show the bathymetry re-adjustment that has occurred at MCR during 1958-1998 and 1885-2000 in response to jetty construction. Note that the MCR bathymetry is still attaining equilibrium. The leading edge of Peacock Spit (as defined by the 40-ft depth contour) has receded landward since it's maximum offshore extent in 1919. The rate of change (landward recession of the 40-ft depth contour) on Peacock Spit during 1997-2000 was 7 times the rate during 1930-1997.

During 1997 and 2002, the seabed at various MCR locations had changed by 5-10 ft. Although increased depth (due to natural erosion) in and around the MCR entrance channel is desirable from a maintenance dredging perspective, this change in seabed elevation allows the propagation of potentially larger waves through MCR entrance channel and may degrade navigation and adversely affect the structural integrity of the north and south jetties. Assessing bathymetry change at a given MCR ODMDS (i.e., the SWS) and attendant change in wave conditions must be taken in context with the larger scale changes that are naturally occurring at MCR.

Simulation of Nearshore Wind-Wave Transformation

STWAVE (STeady-State spectral WAVE) is a computer model used to predict the two-dimensional behavior of a wave field as it travels through winds and current, and encounters variable bathymetry. STWAVE simulates depth-induced wave refraction and shoaling, current-induced refraction and shoaling, depth-and steepness-induced wave breaking, wind-wave growth, wave-wave interaction, and white capping that redistribute and dissipate energy in a growing wave field [Smith et al 2001]. STWAVE is a phase-averaged spectral model. This means that STWAVE is based on the assumption that the relative phases (or time-varying positions) of the individual waves within a wave field are random; wave phase information is not tracked. Thus, the phases of all wave components are averaged within any given location of the model domain to obtain an aggregate estimate of wave height, at each point within the model domain.

STWAVE accounts for nonlinear transfer of energy as waves of different period and direction interact when passing over shallow and irregular bathymetry. The STWAVE model is the present industry standard for steady-state two-dimensional phase-averaged wave models and has been recommended by an independent federal review team [USACE 2001] for evaluating the wave climate at MCR. STWAVE has been applied at numerous locations accounting for diverse environments. In this regard, STWAVE has evolved to a high degree of robustness and reliability. Descriptions of several STWAVE applications can be found in Smith et al [1998, 2000, and 2001], Kelley et al [2001], Krause et al [2002], Rhee and Corson [1998], Smith and Smith [2001], Smith and Ebersole [2000], Smith [2000], and USACE [2001]. As described in several of the above references, the STWAVE model has been successfully used to describe the wave environment at Willapa Bay, WA and Grays Harbor, WA. STWAVE results for Willapa Bay and Grays Harbor were in close agreement with wave gauge (measured) data, differing by 2-15% for areas located on or seaward of the ebb tidal delta. Wave gauge data error is typically 1-5% of "true values". Since the coastal inlets at Willapa Bay and Grays Harbor are very similar to the MCR entrance (in terms of offshore wave conditions, local tidal effects, and spatially variable bathymetry), the STWAVE model is considered to be calibrated and verified for MCR.

Within this wave analysis, STWAVE was used to assess the potential changes in nearshore wave environment near MCR due to bathymetry change. Effects due to wave-current interaction was not included in Part II. Specifically, STWAVE was used to estimate the change in wave height and change in wave breaking location for areas near the MCR due to: A) The change in bathymetry that occurred at MCR during 1997 to 2002; and B) Various utilization scenarios for the placement of dredged material within the Shallow Water ODMDS.

Set-Up of STWAVE Model for MCR

Applying STWAVE requires several steps: A) Create the model's computational "domain" by adapting the bathymetry of interest to form a numerical grid. B) Obtain offshore wave data to "force" the offshore boundary of the STWAVE model. C) Run the STWAVE model; the offshore wave data is transformed through the model domain to estimate the nearshore wave conditions of interest. D) Post-process the STWAVE output.

For this part of the analysis, STWAVE was set-up to simulate nearshore wave transformation for two MCR bathymetry conditions: Summer 1997 and Fall 2002. Each bathymetry condition was described by compiling different sets of survey data; based on the most detailed surveys available for each year. Each bathymetry survey composite (for 1997 and 2002), was adapted to an STWAVE grid to form a computational domain of 20 km x 60 km (offshore distance x alongshore distance). The cell size used to generate the STWAVE grid domain was 61 meters (making the grid dimensions = 317 cells x 563 cells).

To simulate waves that approach the MCR from a wide range of directions, two STWAVE grids needed to be generated for each bathymetry condition. To model waves approaching MCR from the south to west; a "southwest-facing" (SW) grid was developed. To model waves approaching MCR from the west to northwest; a "west-facing" (W) grid was developed. Figure B1 and B3 show the orientation of the two STWAVE domains that were used to assess waves for 1997 and 2002.

Figure B2 illustrates the bathymetry change that had occurred at MCR during 1997 to 2002. Note the degree of change that has occurred on Peacock Spit and Clatsop Spit; 3-6 ft of erosion on Peacock Spit and 10 ft of erosion on part of Clatsop Spit). Refer to figure 2 and 5 for the location of Peacock and Clatsop Spits. The SWS and vicinity is the only area of Peacock Spit that has not experienced NET erosion during 1997-2002. This is because the SWS is an active placement site for millions of cubic yards of dredged material. The disposal sites offshore of Peacock Spit (site A, B and F) have experienced varies levels of deposition and erosion. Figure B4 shows a close up view of MCR bathymetry (for 1997 and 2002) as described in STWAVE. The grid orientation shown was used for modeling waves approaching from the south to west. Note the change in depth contour orientation between 1997 and 2002 (see figures B3 and B4). It is this type of bathymetry change that can create significant modifications in the nearshore wave environment at MCR.

Offshore Wave Conditions at MCR

Eleven (11) wave fields were selected to represent the range of the typical wave conditions offshore of MCR. The offshore wave data was obtained from NDBC Buoy #46029, located approximately 18 miles offshore from the MCR (figure B1). A FORTRAN program was written to convert the NDBC data into two-dimensional spectra suitable for use in STWAVE. The summary statistics of each wave field are shown in Table 2. The range of storm intensity that affects the MCR was included in the candidate wave fields (for summer and winter storms). However, these seasonally varying storms can be further categorized by the specific characteristics of wave energy and direction that they exhibit. Also represented are the relative calm wave conditions that exist both during summer and winter, with the attendant swell.

Each selected wave condition represents a distinctive type of wave field as seen by examining its wave spectrum (figures S1-S11). Some of the candidate wave fields describe waves that have been generated primarily by large storms far offshore, creating “swells” that come from a specific direction with high energy and low frequency. Others wave fields shown in figure S1-S11 represent conditions that are dominated by locally generated “seas”, waves with a larger range of frequency and direction. Most are a combination of these two sources, with varying degrees of influence from each. This diversity of storm characteristics in the different wave scenarios ensures that all wave events likely to occur at MCR have been considered. In the aggregate, the 11 selected wave conditions (Table 2 and figures S1-S11) describe 79% of all summer wave occurrences and 84% of all winter wave occurrences, for the area offshore of MCR.

The 11 candidate wave fields were used to “force” the offshore boundary condition for the STWAVE model. Five (5) of the wave conditions were used as offshore boundary condition data for the Southwest-facing grid (figures S1-S5), and six of the wave conditions were used as offshore boundary condition data for the West-facing grid (figures S6-S11).

STWAVE transformed the offshore wave field (boundary condition) through the model domain, to generate the wave conditions in the nearshore based on the bathymetry that is described within the model domain. The nearshore wave environment (as simulated by the STWAVE model) is a function of the offshore wave boundary condition and bathymetry within the model domain. It must be noted that the wave conditions inshore (say at water 60 ft depth) are not the same as offshore (200 ft) due to wave shoaling, wave-wave interaction, wind and wave interaction, and wave breaking: This is the case in reality and it is also simulated by STWAVE.

The difference between offshore waves and waves nearshore MCR must be kept in mind when viewing many of the results in this report: Assessment wave height change at the SWS and vicinity was based on the comparison of nearshore wave conditions.

STWAVE Modeling Results: 1997 vs. 2002 Bathymetry at MCR

The STWAVE model was run for two bathymetry conditions (1997 and 2002). A total of 20 model runs were conducted for this part of the investigation. Results are shown in figures B5-B44. Results are shown only for the part of STWAVE grid that covers the MCR region; which is the "area of interest". Each bathymetry condition (1997 and 2002) was represented by two STWAVE grids: A "southwestern grid" and a "western grid" (see figures B1 and B3). Five to six different offshore wave (boundary) conditions were applied on each grid. Results are shown first for the southwest-facing (SW) grid (figures B5-B23), and then for the western-facing (W) grid (figures B24-B44).

There are 3-4 different types of STWAVE output shown, for each series of model runs: 1) A comparison of wave height within the model domain for each bathymetry condition; 2) A "map" showing the relative change in wave height that occurred between 1997 and 2002 through the model domain; 3) A "map" showing areas of wave amplification that occurred between 2002 and 1997 through the model domain; and if the process occurs, 4) a "map" showing areas of potential wave braking for each bathymetry condition; this data is an indication that waves have the potential to break where indicated. Table 3 summarizes STWAVE results for all 11 wave scenarios, in terms of the change in wave conditions at or near the SWS during 1997 and 2002.

Assessment of Southwest Waves - 1997 vs. 2002

In the Pacific northwest, wind fields associated regional cyclonic storms (maritime low pressure systems) typically produce large waves that approach the coast from the south-southwest. These conditions are most prevalent during winter months, but they can also occur during summer. The following STWAVE results were obtained by applying south-southwest offshore wave conditions on the MCR bathymetry for 1997 and 2002 (see figures S1-S5 and "wave cases" #1- #5 in Table 2). Wave conditions #1 - #5 cover a range in offshore (average) wave height of 3.5 – 8.3 m and a range in average wave period of 7.7-16.7 seconds. Overall, wave conditions #1 - #5 can be expected to occur during 8% of the time during any given year (or 12% of the time during November-April). Although this would seem to be infrequent, one must keep in mind that these are storm conditions; occurrences which by their nature happen infrequently

Figures B5-B8 show the estimated changes in nearshore wave environment that occurred at MCR during 1997 and 2002, based on an offshore wave condition as specified in **figure S1**. The offshore wave condition corresponds to a winter storm with average wave height = 6.48 m (wave period = 12.5 sec, wave direction = SW), and it is composed of locally generated swell and seas. Figure B5 compares nearshore wave height at MCR for 1997 and 2002. Note the increased wave height near ODMDS A and B, for both 1997 and 2002: Due to wave focusing caused by the remnant accumulation of dredged material placed at ODMDS A and B. There was a change in wave height (in 2002) on Peacock Spit, Clatsop Spit, and the SWS due to changes in seabed elevation at these locations. Figure B6 shows the relative change in wave height that occurred between 1997 and 2002 for areas near MCR, for the offshore wave condition as specified in **figure S1**. Results shown in figure B6 were obtained by dividing the data shown in figure B5; bottom graphic (2002) divided by the top graphic (1997). In 2002, there were areas at MCR that have experienced an increase in wave height (Peacock Spit, Clatsop Spit, the navigation channel, areas within or near ODMDS A and B, and the SWS site). There are also areas at MCR that experienced a decrease in wave height. The change in wave height at ODMDS A and B is due to the re-distribution of dredged material previously placed at these sites, caused by waves-currents. The change in wave height at the SWS is due to dredged material accumulation within the site during 1997-2002. The change in wave height on Peacock Spit and Clatsop Spit is due to the erosion of the seabed that has occurred at these locations, and changes in wave refraction that has occurred at ODMDS A and B (due to seabed change at these sites). Estimated wave amplification is shown in figure B7 and highlights the potential for increased wave activity at Peacock Spit due to seabed erosion; larger waves now get closer to shore before breaking. The maximum increase in wave height *within the SWS* was estimated to be 6% (or 6.8 m in 2002 vs. 6.4 m in 1997), for the offshore wave condition show in figure S1. Figure B8 shows estimated wave breaking locations for both MCR bathymetry conditions (1997 and 2002). Note the reduction in wave breaking for 2002 as compared to 1997; waves now break closer to shore due to deeper water. This is due to the regional bathymetry change that occurred at MCR during this timeframe. A small area of wave breaking (for 2002, shown in red) immediately north of buoy #7 is likely the result of accumulated dredged material placed within the SWS during 1997-2002. It must be noted that to attain this level of wave breaking north of the SWS and on Peacock Spit; the offshore wave conditions are at a "storm warning" level of severity. It is highly unlikely that any vessel would be transiting MCR, outside of the navigation channel, during such a storm wave condition.

Figures B9-B12 show the estimated changes in nearshore wave environment that occurred at MCR during 1997 and 2002, based on an offshore wave condition as specified in **figure S2**. This offshore wave condition is most severe case examined in this report (in terms of wave height), and corresponds to a winter storm with average wave height = 8.34 m (wave period = 16.7 sec, wave direction = W). Wave condition #2 is composed of swell and seas from two separate storms. Note that the wave period for case #2 is larger than for case #1 and the waves are almost due west. One would expect that the effect of wave shoaling and breaking due to offshore wave case #2 would be more pronounced than #1. Figure B9 shows that the nearshore wave height on Peacock Spit and Clatsop Spit has changed from 1997 to 2002, for the same reasons as noted for wave case #1. Note how larger waves are able to propagate further onto Peacock and Clatsop Spit and into the entrance channel; because of deeper water depth at those areas. Figure B10 highlights wave height change in vicinity of Peacock and Clatsop Spits. Along the northern edge of Clatsop Spit and in the navigation channel, wave height had increased from 1997 to 2002. In 2002 the bathymetry is deeper on Clatsop Spit and waves no longer break where they did in 1997; allowing larger waves to propagate further inshore. The change in wave height at the SWS is due to a combination of dredged material accumulation within the site during 1997-2002 and bathymetry change on Peacock Spit. During offshore wave conditions as specified in **figure S2**, complex interaction of waves converging on Peacock Spit has lead to a shadow zone effect along the northern boundary of the SWS; in 2002, average wave height at this location is equal to or less than waves during 1997. This effect is due to the spatially varying bathymetry changes that have occurred on Peacock Spit and within the SWS. Estimated wave amplification is shown in figure B11 and highlights the potential for increased wave activity at Peacock Spit due to seabed erosion; larger waves now get closer to shore before breaking. The maximum increase in wave height *within the SWS* was estimated to be 7% (or 8.7 m in 2002 vs. 8..0 m in 1997), for the offshore wave condition shown in figure S2. Figure B12 shows estimated wave breaking locations for both MCR bathymetry conditions (1997 and 2002). In some locations, waves (in 2002) now break closer to shore due to deeper water than was the case in 1997. This is due to the regional bathymetry change that occurred at MCR during this timeframe. An area of wave breaking (for 2002, shown in red) north and west of buoy #7 is likely is due to a combination of dredged material accumulation within the site during 1997-2002 and bathymetry change on Peacock Spit. It must be noted that to attain this level of wave breaking north of the SWS and on Peacock Spit; the offshore wave conditions are at a "storm warning" level of severity. It is highly unlikely that any vessel would be transiting MCR, outside of the navigation channel, during such a storm wave condition.

Figures B13-B16 show the estimated changes in nearshore wave environment that occurred at MCR during 1997 and 2002, based on an offshore wave condition as specified in **figure S3**. This offshore wave condition corresponds to a winter storm with average wave height = 6.78 m (wave period = 10.5 sec, wave direction = SW), and is composed of locally generated seas and some swell. Note that the wave period for case #3 is smaller than for case #1 or #2. One would expect that the effect of wave shoaling and breaking due to offshore wave case #3 would be less pronounced than #1 or #2, because the waves in #3 do not "feel" the bottom as much. Figure B13 shows that the nearshore wave height on Peacock Spit and Clatsop Spit has changed from 1997 to 2002, for the same reasons as noted for wave cases #1-2. Note how larger waves are able to propagate further onto Peacock and into the entrance channel; because of deeper water depth at those areas. Figure B14 highlights relative wave height change in vicinity of Peacock. Along the inshore area of Peacock Spit and in the navigation channel, wave height is greater in 2002 than in 1997. On Clatsop, wave height has decreased in 2002 as compared to 1997, due to the increase in water depth on the spit (during offshore **condition #3** condition no longer shoal where they did in 1997). The change in wave height at the SWS is due to a combination of dredged material accumulation within the site during 1997-2002 and bathymetry change on Peacock Spit. Estimated wave amplification is shown in figure B15 and highlights the potential for increased wave activity at Peacock Spit due to seabed erosion; larger waves now get closer to shore before breaking. The maximum increase in wave height *within the SWS* was estimated to be 3% (or 5.4 m in 2002 vs. 5.2 m in 1997), for the offshore wave condition show in figure S3. Figure B16 shows estimated wave breaking locations for both MCR bathymetry conditions (1997 and 2002). In some locations, waves (in 2002) now break closer to shore due to deeper water than was the case in 1997. This is due to the regional bathymetry change that occurred at MCR during this timeframe. An area of wave breaking on Peacock Spit (for 2002, shown in red) north and east of buoy #7 is likely is due to a combination of dredged material accumulation within the site during 1997-2002 and bathymetry change on Peacock Spit. It must be noted that to attain this level of wave breaking north of the SWS and on

Peacock Spit; the offshore wave conditions are at a "storm warning" level of severity. It is highly unlikely that any vessel would be transiting MCR, outside of the navigation channel, during such a storm wave condition.

Figures B17-B19 show the estimated changes in nearshore wave environment that occurred at MCR during 1997 and 2002, based on an offshore wave condition as specified in **figure S4**. This offshore wave condition corresponds to a summer storm with average wave height = 3.56 m (wave period = 7.7 sec, wave direction = SSW), and is composed of locally developed seas. Note that the wave height and period for case #4 is smaller than for case #1-3. One would expect that the effect of wave shoaling and breaking due to offshore wave case #4 would be much less pronounced than wave cases #1-3, because the waves in #4 do not "feel" the bottom as much. Figure B17 shows that the nearshore wave height on Peacock Spit and Clatsop Spit has changed very little from 1997 to 2002, for the above offshore wave condition. For both 1997 and 2002, the presence of Peacock Spit causes waves to shoal as they approach the shore (the same effect can be seen near ODMDS A). Figure B18 highlights relative wave height change in vicinity of Peacock. Except for areas along the inshore area of Peacock Spit and in the navigation channel, there is very little change in wave height between 1997 and 2002. The change in wave height at the SWS is due to a combination of dredged material accumulation within the site during 1997-2002 and bathymetry change on Peacock Spit. Estimated wave amplification is shown in figure B19. The potential for increased wave activity at MCR, due to bathymetry change during 1997-2002 is limited to the inshore area of Peacock Spit. The maximum increase in wave height *within the SWS* was estimated to be 4% (or 2.9 m in 2002 vs. 2.8 m in 1997). For the offshore wave condition show in figure S4, there is no wave breaking expected to occur within the area of interest for either the 1997 or 2002 bathymetry. The offshore wave condition shown in figure S4 would invoke a "small craft advisory".

Figures B21-B23 show the estimated changes in nearshore wave environment that occurred at MCR during 1997 and 2002, based on an offshore wave condition as specified in **figure S5**. This offshore wave condition corresponds to a summer storm with average wave height = 3.51 m (wave period = 10.5 sec, wave direction = S), and is composed of locally developed seas. The offshore wave condition #4 and #5 are similar, except that #5 has an average wave period that is larger than wave condition #4. One would expect that the effect of wave shoaling and breaking due to offshore wave case #5 would be more pronounced than wave cases #4, because the waves in #5 would "feel" the bottom more. Figure B21 shows that the nearshore wave height on Peacock Spit and Clatsop Spit has changed very from 1997 to 2002, for the above offshore wave condition. For both 1997 and 2002, the presence of Peacock Spit causes waves to shoal as they approach the shore (the same effect can be seen near ODMDS A). Now (in 2002) that the water depth over Peacock Spit is greater than in 1997, waves shoal less; the wave height over much of Peacock Spit is less in 2002 than it was in 1997. Figure B22 highlights relative wave height change in vicinity of Peacock. Except for areas along the inshore area (and northern side) of Peacock Spit and in the navigation channel, there is very little change in wave height between 1997 and 2002. The change in wave height at the SWS is due to a combination of dredged material accumulation within the site during 1997-2002 and bathymetry change on Peacock Spit. The change in wave height along the northern side of Peacock Spit is due to bathymetry change at that location. The change in wave height within the entrance channel is due to bathymetry changes on Clatsop Spit. Estimated wave amplification is shown in figure B23. The potential for increased wave activity at MCR, due to bathymetry change during 1997-2002 is expected to occur along the northern side of Peacock Spit, inshore area of Peacock Spit, and entrance channel. The maximum increase in wave height *within the SWS* was estimated to be 5% (or 2.9 m in 2002 vs. 2.8 m in 1997). For the offshore wave condition show in figure S5, there is no wave breaking expected to occur within the area of interest for either the 1997 or 2002 bathymetry. The offshore wave condition shown in figure S4 would invoke a "small craft advisory".

Assessment of Northwest Waves - 1997 vs. 2002

In the Pacific Northwest, wind fields associated with fair weather (regional high pressure systems) or distant storms (greater than 1,000 miles away) typically produce waves that approach the coast from the west-northwest. The waves associated with these conditions are usually composed of swell and local seas (chop). These conditions are most prevalent during summer months, but they can also occur during winter. The following STWAVE results were obtained by applying west-northwest offshore wave conditions on the MCR bathymetry for 1997 and 2002 (see figures S6-S10 and "wave cases" #6- #10 in Table 2). Wave conditions #6 - #11 cover a range in offshore (average) wave height of 1.3 – 6.5 m and a range in average wave period of 11-16.7 seconds. Overall, wave conditions #6 - #11 can be expected to occur during 73% of the time during any given year (or 77% of the time during May-October and 66% of the time during November-April).

Figures B25-B27 show the estimated changes in nearshore wave environment that occurred at MCR during 1997 and 2002, based on an offshore wave condition as specified in **figure S6**. The offshore wave condition corresponds to a summer swell with average wave height = 1.79 m (wave period = 11 sec, wave direction = W), and is composed of local seas (chop) and some swell. Figure B25 compares nearshore wave height at MCR for 1997 and 2002. Note the decreased wave height on Peacock Spit due to the increase in water depth. Figure B26 shows the relative change in wave height that occurred between 1997 and 2002 for areas near MCR, for the offshore wave condition as specified in **figure S6**. Results shown in figure B26 were obtained by dividing the data shown in figure B25; bottom graphic (2002) divided by the top graphic (1997). In 2002, there were areas at MCR that had experienced a change in wave height (inshore area and center of Peacock Spit, areas within or near ODMDS A and B, the SWS site, and the northern edge of Peacock Spit). The change in wave height at ODMDS A and B is due to the re-distribution of dredged material previously placed at these sites, caused by waves-currents. The change in wave height in and near the SWS is due to dredged material accumulation within the site during 1997-2002 and bathymetry changes on Peacock Spit. The change in wave height on Peacock Spit is due to the erosion and deposition of the seabed that has occurred at these locations, due to evolution of the Spit. Estimated wave amplification is shown in figure B27 and highlights the potential for increased wave activity at Peacock Spit due to seabed change. The maximum increase in wave height *within the SWS* was estimated to be 7% (or 2.1 m in 2002 vs. 2.0 m in 1997). For the offshore wave condition show in figure S6, there is no wave breaking expected to occur within the area of interest for either the 1997 or 2002 bathymetry.

Figures B29-B32 show the estimated changes in nearshore wave environment that occurred at MCR during 1997 and 2002, based on an offshore wave condition as specified in **figure S7**. This offshore wave condition corresponds to a winter swell with average wave height = 2.85 m (wave period = 16.7 sec, wave direction = W), and is composed of swell and seas. The average wave height for conditions #6 and #7 are similar, but the average wave period for #7 is larger than wave condition #6. One would expect that the effect of wave shoaling and breaking due to offshore wave case #7 would be more pronounced than wave cases #6, because the waves in #6 would "feel" the bottom more. Figure B29 shows that the nearshore wave height on Peacock Spit and Clatsop Spit has changed from 1997 to 2002, for the same reasons as noted for wave case #6. In 2002 larger waves are estimated to be present within the SWS, as compared to 1997. Figure B30 highlights wave height change in vicinity of Peacock Spit, ODMDS A and B, and the SWS. The change in wave height at the SWS is due to dredged material accumulation within the site during 1997-2002. Changes in wave conditions at Peacock Spit, and ODMDS A and B are due to the spatially varying bathymetry changes that have occurred at these locations. Estimated wave amplification is shown in figure B31 and highlights the potential for increased wave activity at the inshore area of Peacock Spit. The maximum increase in wave height *within the SWS* was estimated to be 11% (or 3.2 m in 2002 vs. 2.9 m in 1997), for the offshore wave condition shown in figure S7. Figure B32 shows estimated wave breaking locations for both MCR bathymetry conditions (1997 and 2002). In some locations, waves (in 2002) now break closer to shore due to deeper water than was the case in 1997. This is due to the regional bathymetry change that occurred at MCR during this timeframe. An area of wave breaking on Peacock Spit (for 2002, shown in red) north and west of buoy #9 is likely is due to a combination of dredged material accumulation within the site during 1997-2002 and bathymetry change on Peacock Spit.

Figures B33-B35 show the estimated changes in nearshore wave environment that occurred at MCR during 1997 and 2002, based on an offshore wave condition as specified in **figure S8**. The offshore wave condition corresponds to a summer swell with average wave height = 1.29 m (wave period = 16.7 sec, wave direction = SW), and is a bi-modal combination of swell (distant source) and seas (local source). Figure B33 compares nearshore wave height at MCR for 1997 and 2002. Note the decreased wave height on Peacock Spit due to the increase in water depth. There is an increase of wave height within the SWS. Figure B34 shows the relative change in wave height that occurred between 1997 and 2002 for areas near MCR, for the offshore wave condition as specified in **figure S8**. The change in wave height at ODMDS A and B is due to the re-distribution of dredged material previously placed at these sites, caused by waves-currents. The change in wave height in and near the SWS is due to dredged material accumulation within the site during 1997-2002 and bathymetry changes on Peacock Spit. The change in wave height on Peacock Spit is due to the erosion and deposition of the seabed that has occurred at these locations, due to evolution of the Spit. Estimated wave amplification is shown in figure B35 and highlights the potential for increased wave activity at Peacock Spit due to seabed change. The maximum increase in wave height *within the SWS* was estimated to be 7% (or 1.5 m in 2002 vs. 1.4 m in 1997). For the offshore wave condition show in figure S8, there is no wave breaking expected to occur within the area of interest for either the 1997 or 2002 bathymetry.

Figures B37-B40 show the estimated changes in nearshore wave environment that occurred at MCR during 1997 and 2002, based on an offshore wave condition as specified in **figure S9**. The offshore wave condition corresponds to a winter swell with average wave height = 3.75 m (wave period = 16.7 sec, wave direction = W), and is a bi-modal combination of swell (distant source) and seas (local source). Figure B37 compares nearshore wave height at MCR for 1997 and 2002. Note the decreased wave height on Peacock Spit and ODMDS B due to the increase in water depth, and change in wave height within the SWS. Figure B38 shows the relative change in wave height that occurred between 1997 and 2002 for areas near MCR, based on the offshore wave condition specified in **figure S9**. In 2002, there were areas at MCR that had experienced a change in wave height (inshore area and center of Peacock Spit, areas within or near ODMDS A and B, the SWS site, and the northern edge of Peacock Spit). The change in wave height at ODMDS A and B is due to the re-distribution of dredged material previously placed at these sites, caused by waves-currents. The change in wave height in and near the SWS is due to dredged material accumulation within the site during 1997-2002 and bathymetry changes on Peacock Spit. The change in wave height on Peacock Spit is due to the erosion and deposition of the seabed that has occurred at these locations, due to evolution of the Spit. Estimated wave amplification is shown in figure B39 and highlights the potential for increased wave activity at nearshore areas on Peacock Spit, due to seabed change. The maximum increase in wave height *within the SWS* was estimated to be 12% (or 4.3 m in 2002 vs. 3.9 m in 1997). This is the maximum relative change in wave height within the *SWS* observed for any of the offshore wave cases assessed. Figure B40 shows estimated wave breaking locations for both MCR bathymetry conditions (1997 and 2002). In some locations, waves (in 2002) now break closer to shore due to deeper water than was the case in 1997. This is due to the regional bathymetry change that occurred at MCR during this timeframe. An area of wave breaking on Peacock Spit (for 2002, shown in red) north and west of buoy #9 is likely due to a combination of dredged material accumulation within the site during 1997-2002 and bathymetry change on Peacock Spit.

Figures B41-B44 show the estimated changes in nearshore wave environment that occurred at MCR during 1997 and 2002, based on an offshore wave condition as specified in **figure S10**. The offshore wave condition corresponds to a winter storm with average wave height = 6.55 m (wave period = 14.0 sec, wave direction = NW), and is a mix of locally generated swell and seas. Figure B41 compares nearshore wave height at MCR for 1997 and 2002. Note the increased wave height on Peacock Spit and decreased wave height near ODMDS B due to the increase in water depth, and change in wave height within the SWS. Figure B42 shows the relative change in wave height that occurred between 1997 and 2002 for areas near MCR, based on the offshore wave condition specified in **figure S10**. In 2002, there were areas at MCR that had experienced a change in wave height (inshore area and center of Peacock Spit, areas within or near ODMDS A and B, the SWS site, and the northern edge of Peacock Spit). The change in wave height at ODMDS A and B is due to the re-distribution of dredged material previously placed at these sites, caused by waves-currents. The change in wave height in and near the SWS is due to dredged material accumulation within the site during 1997-2002 and bathymetry changes on Peacock Spit. The change in wave height on Peacock Spit is due to the erosion and deposition of the seabed that has occurred at these locations, due to evolution of the Spit. Estimated wave amplification is shown in figure B43 and highlights the potential for increased wave activity at nearshore areas on Peacock Spit, due to seabed change. The maximum increase in wave height *within the SWS* was estimated to be 8% (or 7.1 m in 2002 vs. 6.6 m in 1997). Figure B44 shows estimated wave breaking locations for both MCR bathymetry conditions (1997 and 2002). In some locations, waves (in 2002) now break closer to shore due to deeper water than was the case in 1997. This is due to the regional bathymetry change that occurred at MCR during this timeframe. An area of wave breaking on Peacock Spit (for 2002, shown in red) north of buoy #9 is due to bathymetry change on Peacock Spit. It must be noted that to attain this level of wave breaking north of the SWS and on Peacock Spit; the offshore wave conditions are at a "storm warning" level of severity. It is highly unlikely that any vessel would be transiting MCR, outside of the navigation channel, during such a storm wave condition.

Conclusions

Since the time of jetty construction at MCR (1885-1917), the nearshore bathymetry has been in a constant state of flux. At present, the nearshore bathymetry of MCR is continuing to evolve. One manifestation of this nearshore evolution is that ephemeral features like Peacock Spit and Clatsop Spit are being eroded by the natural forces of waves and currents (figure 4). As the bathymetry across Peacock Spit and Clatsop Spit progressively changes, the nearshore wave environment will change accordingly. During 1997 to 2002, these "natural" bathymetry changes have been greater in magnitude and scale than the bathymetry changes that have occurred at the SWS due to dredged material disposal (figures D1-D6). STWAVE results indicate that the wave-related effects of "natural" bathymetry change at MCR during 1997-2002 far exceed the wave-related effects of using the SWS for dredged material disposal. During 1997 to 2002, the "natural" processes of erosion and deposition at MCR have potentially changed wave height on Peacock Spit and Clatsop Spit by 10-20%. The larger changes associated with erosion of Peacock Spit and Clatsop Spit overshadow the small change in wave conditions at the SWS. Care must be taken not to ascribe a bathymetry-related wave impact to the SWS, when the effect is in fact due to evolution of Peacock Spit.

When waves approach the MCR form the South-Southwest (S-SW), waves first encounter the bathymetry along the southern side of Peacock Spit (including the SWS) before sweeping northward and eastward across the highest areas of the spit. This means that for southerly waves, bathymetry change within the SWS will have more potential to effect the local wave environment within the SWS and northward on Peacock Spit, than areas south of the SWS. Comparing conditions in 1997 to 2002, use of the SWS for dredged material disposal had potentially increased nearshore wave height (within the site or at nearby locations) by 3-7% or 0.1 – 0.6 m, for S-SW waves (cases #1-#5). Effects of SWS use upon wave breaking occurred only for the most severe wave conditions, and were limited to localized areas which did not affect the MCR entrance channel. Results are summarized in table 3.

When waves approach the MCR from the West-Northwest (W-NW), waves first encounter the shallowing bathymetry along the western or northern side of Peacock Spit then sweep southward and eastward across the highest areas of the spit, before the waves encounter the SWS. This means that for W-NW waves, there is complex interaction of waves with Peacock Spit first and then the SWS. Bathymetry change within the SWS will have more potential to effect the local wave environment within the SWS and areas southward, than for areas north of the SWS. Comparing conditions in 1997 to 2002, use of the SWS for dredged material disposal had potentially increased nearshore wave height (within the site or at nearby locations) by 7-12% or 0.1 – 0.5 m, for W-NW waves (cases #6-#10). Effects of SWS use upon wave breaking occurred only for the most severe wave conditions, and were limited to localized areas which did not affect the MCR entrance channel. Results are summarized in table 3.

Based on the results described above, offshore waves approaching MCR from the W-NW are effected to a greater extent than offshore waves approaching from the S-SW because of the complex shoaling/refraction of waves when they pass over Peacock Spit before they reach the SWS. This shoaling/refraction of waves form the W-NW tends to cause instability and increase wave height and direction within the SWS. Waves from the S-SW do not encounter such obstacles and are therefore not affected. The STWAVE results presented herein indicate that the effects of the SWS on the MCR wave environment to date (during 1997-2002) have been minimal.

PART III: OPTIMIZED USE OF SWS and RELATED WAVE EFFECTS

Part III of this report investigated potential impacts to the wind-wave environment, in vicinity of the SWS, based on future (optimized) utilization scenarios for the SWS. A two-step procedure was used. First, bathymetry change within the SWS was predicted for three scenarios where dredged material was placed uniformly throughout the site. Second, wave transformation over the modified SWS bathymetry was predicted. The three scenarios for placing dredged material with the SWS were based on the site use strategy formulated in Part I of the report and included annual disposal volumes of; 2, 4, and 6 mcy per year. The objective of Part III was to evaluate if the SWS could be used as a primary site for MCR dredged material disposal while minimizing wave-related impacts.

Simulating the Behavior of Sediment Placed at the SW ODMDS

Rather than expend the effort to simulate behavior of dredged material during placement at the SWS, a simpler approach could have been applied: Add a uniform "lift" to the SWS bathymetry based on volume to be placed, and the area over which deposition is to occur. While simple to apply, this expedient method would not have verified the feasibility of actually achieving uniform deposition based on a given dredged material placement strategy.

A major focus of this analysis was to evaluate if dredged material could be placed such that uniform deposition could be achieved with the SWS. Therefore, a disposal sequence and sediment fate model (MDFATE) was used to simulate dredged material disposal operations within the SWS, based on 3 disposal scenarios. The objective of using MDFATE was to estimate the bathymetric condition within the SWS, resulting from each disposal scenario. The STWAVE model was then used to assess the modified bathymetry (as simulated by MDFATE) for potential effects on the wave environment at MCR.

The MDFATE Model

MDFATE defines an open water disposal site in terms of a numerical grid and simulates 2-dimensional bathymetry change resulting from a series of disposal events [Herbich 2000a and 200b]. The model accounts for all physical, environmental, and operational parameters that affect dredged material when it is placed in an open water site. The MDFATE model simulates short-term and long-term processes that affect the fate of dredged material placed in open water. Short-term processes are those which influence placed dredged material up to the point at which all momentum imparted to the material from the placement activity (dump) is expended through convection, diffusion, and bottom friction. At this point the placed dredged material has come to rest on the seabed. Long-term processes deal with the ambient environment and occur after the dredged material has been deposited on the seabed. Long-term processes include self-weight consolidation, sediment transport by waves-currents, and mound slumping.

MDFATE has been successfully applied at numerous locations accounting for diverse dredged material properties and operating environments. Descriptions of several MDFATE applications can be found in Lillycrop and Clausner [1997], Moritz and Randall [1995], Clausner [1998a and 1998b], Moritz et al [1999], USACE [1995, 1997, 1999], and Johnson et al [1999].

As described in Moritz et al [1999], the MDFATE model has been at MCR to hindcast the placement (and deposition) of dredged material within the SWS during 1998. MDFATE results for the 1998 dredged material placement event at the SWS were in close agreement with hydrographic survey results, differing by 5-10% . Hydrographic survey data error is typically 1-3% of "true values". The aerial footprint and the centroids of the depositional areas for the MDFATE results matched the survey results. Given the prior application of MDFATE at the SWS of MCR, the model is considered to be calibrated and verified for MCR.

Set-Up of MDFATE Model for MCR

As a first step in simulating a disposal operation, MDFATE is used to produce a discretized representation (rectangular digital elevation model) of the disposal site and surrounding area of interest. Bathymetry survey data are fitted to the MDFATE digital elevation model (DEM) by a multi-point interpolant scheme. For this application, MDFATE was used to produce a DEM that bounded the SWS within a computational domain of 9,700 ft (N-S distance) x 15,700 ft (E-W distance), using a grid interval of 100 ft. A composite of 1997 surveys used to describe the "pre-disposal" condition for the MDFTAE domain. All simulations were conducted with respect to the 1997 "pre-disposal" condition. MDFATE results were then boundary fitted to the STWAVE domain, to allow wave modeling on the post-disposal bathymetry.

The accuracy of MDFATE results is highly dependent upon the parameters input to the model. Controlling parameters are physical characteristics of the dredged material, disposal operation sequencing, and forcing environment. The time-varying oceanographic data that was used in the MDFATE model included wind wave height and period, tide, and depth-averaged current velocity measured at the SWS during the summer of 1997 and 1998. The data used in this report was obtained from a 3 year monitoring program co-sponsored by the EPA and USACE {Moritz et al 1999, 2000, 2001]. Oceanographic data were acquired at four MCR locations, with a suite of six instruments in flow regimes ranging from current-dominated to wave-dominated. The instruments were installed on 2-m tall aluminum-frame platforms that were deployed on the seabed. The location of measurement and time series description of the oceanographic data used in the MDFATE model for this SWS assessment is shown in figures F1-F3. The physical properties of the dredged material placed at the SWS are given in table 4. A detailed description of previous MDFATE calibration, oceanographic data collection (and assimilation), and application at MCR ODMDS E can be found in Moritz et al [1999].

Table 4. Characteristics of MCR dredged material.

Material Type	Specific Gravity	Solids Concentration	Grain Diameter (mm)	Depositional Void Ratio	Crit. Shear Stress lb/ft*ft
Sand-fine	2.7	0.215	0.15	1.05	0.015
Sand-med	2.7	0.215	0.20	1.05	0.030
Sand-course	2.7	0.050	0.27	1.05	0.200

Density of water profile at dredging and disposal site = 1.020 g/ml.

θs = subaqueous shearing angle = 2.0°, θps = sub aqueous post-shearing angle = 1.9°

Candidate Disposal Scenarios

Proposed disposal scenarios simulated 2, 4, and 6 mcy per year to be placed within the SWS over a single disposal season (4-month period) with hundreds of “dumps” occurring during each season. A “dump” is defined as an individual load of dredged material released into open water from a hopper dredge.

Two hopper dredges were assumed to use the SWS during each scenario; a split-hull contract hopper dredge and a multi-bottom door government hopper dredge. Each hopper dredge was assumed to place an equal volume of dredged material within the SWS over the course of the dredging season. MDFATE was used to simulate dredged material disposal for each dredge separately. This required that two sequential model runs (conducted in a cumulative manner) be made for each placement scenario. Operating parameters for each dredged modeled are shown in table 5.

Table 5. Operating parameters for hopper dredges commonly used at MCR.

DREDGE	OVERALL DIMENSIONS length (ft)	beam (ft)	draft(ft) loaded/empty	CAPACITY average (cy)	VESSEL SPEED during disposal (knots)	DISPOSAL vessel type (# of doors/size of each)	DURATION placement of each load (minutes)
Newport (contract)	300	55	20/10	2,800	2 to 4	split-hull/ 200x30 ft	4 to 8
Essayons (govt.)	350	68	27/15	5,400	2 to 6	bottom doors(12)/ 8x8 ft	6 to 15

For the hopper dredges that commonly work in the Columbia River or MCR, the Corps’ multiple bottom-door hopper dredge ESSAYONS would produce a thinner deposit than the split-hull contract hopper dredges at any given water depth (per load). As an example, in 50 feet of water with a one-foot per second (fps) current, a single load for the ESSAYONS would produce a disposal mound that would have a maximum height of less than 8 inches and an area of about 20 acres. A single load placed by the contract dredge NEWPORT would produce a mound with a maximum height of over 10 inches and an area of around 10 acres. The above results were obtained with the MDFATE model, assuming a relatively straight disposal run. During an actual hopper dredge disposal operation, the environment and operating conditions at a disposal site are constantly changing. The depositional footprint of each dump would be different, in reality and as simulated by the MDFATE model.

Cell-Based Assignment for Disposal Locations

An integral part of this investigation was the development of a cell-based placement plan to achieve optimal utilization of available site capacity (minimize the vertical accumulation of placed dredged material) within the SWS. The method used to “control” the placement of dredged material within the SWS was based on a random distribution of dumps about pre-determined master coordinates (Figure F5). Note that the entire boundary of the SWS (as expanded in 1997) was used as a “drop zone” for dredged material placement. A drop zone is the area at the water surface within which dredged material discharge can occur. In general, dredged material deposition on the seabed occurs over a “placement area” that is beyond the drop zone. The “placement area” of an ODMDS is the area of the sea bottom that will be immediately occupied by disposed dredged material released at the drop zone (or water surface).

The master coordinates were based on the centroid of 83 cells sized at 500 ft x 500 ft (figure F5). The radial distance for which the release point of each dump was "randomized" from a given master coordinate was 300 ft. The randomized radial distance was weighted based on the southeasterly direction from which hopper dredges approach the SWS. The ending point of each dump was determined as the distance traveled from the release point by the hopper dredge during disposal and assigned about a random direction. The randomized release and ending dump coordinates and number of dumps per master coordinate varied for each dredge and for disposal scenario. A FORTRAN program was written to generate coordinates for the release and end point locations, based on the cell layout shown in figure F5, and hopper dredge operating parameters shown in table 5. An example of assigning beginning and ending points for each dump for the 2 mcy placement scenario is shown in figures F6 (government dredge) and F8 (contract dredge). This method of simulating individual disposal locations achieves a realistic distribution of disposal points, provided that the goal is to use the entire SWS; see figures D1-D6 for comparison.

MDFATE Results

Three scenarios for optimally placing dredged material at the SWS, on an annual basis, were simulated using MDFATE: 2 mcy per year, 4 mcy per year, and 6 mcy per year. The distribution of individual dump locations within the SWS and the resultant bathymetry (accumulation of dredged material placed in site) for all scenarios are shown in figures F6-F17. It must be noted that the pre-disposal bathymetry on which the MDFATE model was applied corresponded to the 1997 (baseline) condition. The only bathymetry change that was allowed to occur within the MDFATE model was associated with the placement of dredged material within the SWS. The placed dredged material was allowed to be deposited, eroded, and re-deposited on the 1997 bathymetry; but no "erosion" was allowed to occur to the 1997 bathymetry itself.

Figures F9 (2 mcy scenario), F13 (4 mcy scenario), and F17 (6 mcy scenario) show the resultant accumulation within the SWS for each placement scenario. These are the bathymetry conditions that were assessed using STWAVE to evaluate the effect of dredged material accumulation upon the MCR wave environment; based on optimal dispersal scenarios. Refer to section "*STWAVE Modeling Results – SWS Optimized Use*" to review potential wave-related effects due to the three scenarios for optimized use of the SWS.

It is noted that the cell-based placement schemes used to guide the above dredged material disposal simulations achieved a much improved distribution of dredged material through out the SWS than what was observed at the SWS during 1997-2002: Compare figures F9, F13, and F17 to figures D1-D6. Hence the term "optimal." Figure F18 shows the accumulation of placed dredged material on the seabed of the SWS as compared to the baseline condition (1997) via a cross-sectional view.

The "pink dashed line" shown in figures F9, F13, F17, and F18 describes a proposed "placement zone" boundary for the SWS; it extends 500 ft beyond the existing southern boundary and 1,500 ft beyond the existing western and northern boundary. The proposed "placement zone" is intended to contain all dredged material accumulation during active disposal. Dredged material would be placed within the inner (existing) boundary and would be contained inside the outer boundary after depositing on the seabed during disposal. Over time, the deposited dredged material will be transported out of the "outer boundary" of the SWS.

Figures F19-F21 describe the loss of placed dredged material within the water column; that occurred during simulated disposal at the SWS, on a per dump basis (when loss does occur) for each placement scenario. The volume of dredged material loss during disposal is shown in terms of transport direction (material leaving the SWS). For each placement scenario, the volume of placed dredged material lost to the water column (during the disposal process) was 22% of the total volume placed. Note that very little dredged material was carried (south-southeast) toward the channel during disposal at the SWS.

Figure F22 shows the cumulative transport volume of dredged material during the dredging/disposal season, after it has been deposited on the seabed within the SWS. For each placement scenario, the volume of placed dredged material transported on the seabed (by waves and currents) after the disposal process, averaged 33% of the total volume placed. The simulated values of sediment loss and transport shown in figures F19-21 and F22 (22% + 33%) agree with observations shown in Table 1 (45%).

STWAVE Modeling Results: 1997 Condition vs. Optimized Use of SWS

This part of the study assessed the impact to the MCR nearshore wave environment caused by potential bathymetry change within or near the SWS. This wave assessment was conducted with respect to the 1997 (baseline) bathymetric conditions at MCR. Since the bathymetry (1997 condition) far outside the SWS was held constant, impacts to waves due to bathymetry change within or near the SWS are limited to the general vicinity of the SWS.

The MDFATE model was used to simulate the post-disposal bathymetry within the SWS resulting from three scenarios of dredged material placement within the SWS. The STWAVE model was then run for four (4) bathymetry conditions; the 1997 (or baseline condition) and three scenarios of utilizing the SWS (generated using MDFATE). STWAVE results from each of the three SWS utilization scenarios were compared to the 1997 (baseline) configuration. A total of 40 STWAVE simulations were conducted for this part of the investigation. Results are shown in figures M1-M78. Results are shown only for the part of STWAVE grid that covers the MCR region; which is the "area of interest". Each bathymetric condition (1997 and 3-SWS use scenarios) was represented by two STWAVE grids: A "southwestern grid" and a "western grid". Five different offshore wave (boundary) conditions were applied on each grid. Results are shown first for the southwest-facing (SW) grid, and then for the western-facing (W) grid; for each SWS use scenario, beginning with the simulated 2 mcy placement.

There are 2-3 different types of STWAVE output shown, for each series of model runs: 1) A comparison of <u>wave height</u> within the model domain for the 1997 bathymetry vs. a SWS "utilization" scenario; 2) A "map" showing areas of <u>wave amplification</u> associated with the SWS "utilization" scenario; and if the process occurs, 4) a "map" showing areas of potential <u>wave breaking</u> for each bathymetry condition. The wave breaking data is an indication that waves have the potential to break where indicated. Table 6 (last four columns) summarizes STWAVE results of applying all 10 offshore wave conditions, in terms of the change in wave conditions at or near the SWS due to the three SWS utilization scenarios.

Assessment of Southwest Waves - 2 mcy Placed in SWS

Figures M1-M13 show the STWAVE results obtained by applying south-southwest offshore wave conditions on two MCR bathymetry conditions: the 1997 baseline and the simulated 2 mcy SWS placement scenario. For a description of the MCR offshore wave climate associated with wave-fields originating from the south-southwest, refer to the section "*STWAVE Modeling Results: 1997 vs. 2002 Bathymetry at MCR*" , figures S1-S5, and "wave cases" #1- #5 in Table 2.

Figures M1-M3 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 2 mcy placement scenario, based on an offshore wave condition as specified in **figure S1**. The offshore wave condition corresponds to a winter storm with average wave height = 6.48 m (wave period = 12.5 sec, wave direction = SW), and it is composed of locally generated swell and seas. Figure M1 compares nearshore estimated wave height at MCR for 1997 and the 2 mcy placement scenario: Changes in the wave height at MCR are difficult to discern. Estimated wave amplification is shown in figure M3 and demonstrates the wave-related effect of placing 2 mcy of dredged material "uniformly" within the SWS. Waves are potentially effected within the SWS and at areas within 1,000 ft north of the site. The maximum increase in wave height *due to the 2 mcy scenario* was estimated to be 3% (or 6.6 m for the 2 mcy scenario vs. 6.4 m in 1997) and occurs near the middle of the SWS. Figure M3 shows estimated wave breaking locations for the 1997 conditions and the 2 mcy placement scenario. A very small area of wave breaking (for the 2 mcy scenario, shown in red) immediately north of buoy #7 is the result dredged material placement within the SWS. Immediately west of that point, there is an area of wave breaking reduction associated with the 2 mcy placement scenario. It must be noted that to attain this level of wave breaking north of the SWS and on Peacock Spit; the offshore wave conditions are at a "storm warning" level of severity. It is highly unlikely that any vessel would be transiting MCR, outside of the navigation channel, during such a storm wave condition.

Figures M4-M6 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 2 mcy placement scenario, based on an offshore wave condition as specified in **figure S2**. The offshore wave condition corresponds to a winter storm with average wave height = 8.34 m (wave period = 16.7 sec, wave direction = W), and is composed of swell and seas from two separate storms. Figure M4 compares nearshore estimated wave height at MCR for 1997 and the 2 mcy placement scenario: Changes in the wave height at MCR are difficult to discern. Estimated wave amplification is shown in figure M5. Waves are potentially affected within the SWS; but there is little effect outside the site. The maximum increase in wave height *due to the 2 mcy scenario* was estimated to be 4% (or 8.4 m for the 2 mcy scenario vs. 8.1 m in 1997) and occurs near the middle of the SWS. Figure M6 shows estimated wave breaking locations for the 1997 conditions and the 2 mcy placement scenario. An area of wave breaking (for the 2 mcy scenario, shown in red) along the northern boundary of the SWS is the result dredged material placement within the SWS. Northwest of the SWS, there is an area of wave breaking reduction associated with the 2 mcy placement scenario. It must be noted that to attain this level of wave breaking north of the SWS and on Peacock Spit; the offshore wave conditions are at a “storm warning” level of severity. It is highly unlikely that any vessel would be transiting MCR, outside of the navigation channel, during such a storm wave condition.

Figures M7-M9 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 2 mcy placement scenario, based on an offshore wave condition as specified in **figure S3**. The offshore wave condition corresponds to a winter storm with average wave height = 6.78 m (wave period = 10.5 sec, wave direction = SW), and is composed of locally generated seas and some swell. Figure M7 compares nearshore estimated wave height at MCR for 1997 and the 2 mcy placement scenario: Small changes in the wave height can be seen along the northern side of the SWS. Estimated wave amplification is shown in figure M8. The maximum increase in wave height *due to the 2 mcy scenario* was estimated to be 2% (or 5.3 m for the 2 mcy scenario vs. 5.2 m in 1997) and occurs in the northern half of the SWS. For a distance of 1,500 ft north of the SWS, there is a minor effect on wave height. Figure M9 shows estimated wave breaking locations for the 1997 conditions and the 2 mcy placement scenario. There are several “cells” where wave breaking has changed due to the subtle effects of the 2 mcy scenario within the SWS, but no continuous effect is discernable. It must be noted that to attain this level of wave breaking north of the SWS and on Peacock Spit; the offshore wave conditions are at a “storm warning” level of severity. It is highly unlikely that any vessel would be transiting MCR, outside of the navigation channel, during such a storm wave condition.

Figures M10-M11 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 2 mcy placement scenario, based on an offshore wave condition as specified in **figure S4**. The offshore wave condition corresponds to a winter storm with average wave height = 3.56 m (wave period = 7.7 sec, wave direction = SSW), and is composed of locally developed seas. Figure M10 compares nearshore estimated wave height at MCR for 1997 and the 2 mcy placement scenario: Small changes in the wave height can be seen along the middle of the SWS. Estimated wave amplification is shown in figure M11. The maximum increase in wave height *due to the 2 mcy scenario* was estimated to be 1% (or 2.8 m for the 2 mcy scenario vs. 2.8 m in 1997) and occurs in the northern half of the SWS. There is little or no effect on wave height outside of the SWS.

Figures M12-M13 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 2 mcy placement scenario, based on an offshore wave condition as specified in **figure S5**. The offshore wave condition corresponds to a summer storm with average wave height = 3.51 m (wave period = 10.5 sec, wave direction = S), and is composed of locally developed seas. Figure M12 compares nearshore estimated wave height at MCR for 1997 and the 2 mcy placement scenario: Changes in the wave height are not discernable. Estimated wave amplification is shown in figure M13. The maximum increase in wave height *due to the 2 mcy scenario* was estimated to be 3% (or 2.9 m for the 2 mcy scenario vs. 2.8 m in 1997) and occurs in the northwestern quarter of the SWS. There is a minor effect on wave height, for a distance of 1,500 ft north of the SWS.

Assessment of Northwest Waves - 2 mcy Placed in SWS

Figures M14-M28 show the STWAVE results obtained by applying west-northwest offshore wave conditions on two MCR bathymetry conditions: the 1997 baseline and the simulated 2 mcy SWS placement scenario. For a description of the MCR offshore wave climate associated with wave-fields originating from the north-northwest, refer to the section "*STWAVE Modeling Results: 1997 vs. 2002 Bathymetry at MCR*" , figures S6-S11, and "wave cases" #6-#11 in Table 2.

Figures M14-M15 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 2 mcy placement scenario, based on an offshore wave condition as specified in **figure S6**. The offshore wave condition corresponds to a summer swell with average wave height = 1.79 m (wave period = 11.0 sec, wave direction = W), and is composed of local seas (chop) and some swell. Figure M14 compares nearshore estimated wave height at MCR for 1997 and the 2 mcy placement scenario: Changes in the wave height at MCR are difficult to discern. Estimated wave amplification is shown in figure M15. The maximum increase in wave height *due to the 2 mcy scenario* was estimated to be 4% (or 2.1 m for the 2 mcy scenario vs. 2.0 m in 1997) and occurs near the middle of the SWS. There is little or no effect on wave height outside of the SWS.

Figures M16-M18 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 2 mcy placement scenario, based on an offshore wave condition as specified in **figure S7**. The offshore wave condition corresponds to a winter swell with average wave height = 2.85 m (wave period = 16.7 sec, wave direction = W), and is composed of swell and seas. Figure M16 compares nearshore estimated wave height at MCR for 1997 and the 2 mcy placement scenario: Small changes in the wave height can be seen within the middle of the SWS. Estimated wave amplification is shown in figure M17. The maximum increase in wave height *due to the 2 mcy scenario* was estimated to be 5% (or 3.0 m for the 2 mcy scenario vs. 2.9 m in 1997) and occurs in the eastern half of the SWS. There is a minor effect on wave height outside of the SWS, east of the SWS toward the navigation channel (less than 3%). Figure M18 shows estimated wave breaking locations for the 1997 conditions and the 2 mcy placement scenario. There are no discernable areas where wave breaking has changed due to the 2 mcy placement scenario.

Figures M19-M20 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 2 mcy placement scenario, based on an offshore wave condition as specified in **figure S8**. The offshore wave condition corresponds to a summer swell with average wave height = 1.29 m (wave period = 16.7 sec, wave direction = SW), and is a bi-modal combination of swell (distant source) and seas (local source). Figure M19 compares nearshore estimated wave height at MCR for 1997 and the 2 mcy placement scenario: Small changes in the wave height can be seen along the northern edge of the SWS. Estimated wave amplification is shown in figure M15. The maximum increase in wave height *due to the 2 mcy scenario* was estimated to be 3% (or 1.4 m for the 2 mcy scenario vs. 1.4 m in 1997) and occurs near the middle of the SWS. There is a minor effect on wave height outside of the SWS, north of the SWS toward the Peacock Spit (less than 3%).

Figures M21-M23 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 2 mcy placement scenario, based on an offshore wave condition as specified in **figure S9**. The offshore wave condition corresponds to a winter swell with average wave height = 3.75 m (wave period = 16.7 sec, wave direction = W), and is a bi-modal combination of swell (distant source) and seas (local source). Figure M21 compares nearshore estimated wave height at MCR for 1997 and the 2 mcy placement scenario: Small changes in the wave height can be seen within the western half of the SWS. Estimated wave amplification is shown in figure M22. The maximum increase in wave height *due to the 2 mcy scenario* was estimated to be 5% (or 4.1 m for the 2 mcy scenario vs. 3.9 m in 1997) and occurs in the middle of the SWS. There is a minor effect on wave height outside of the SWS, within 1,000 ft north of the site (less than 3%). Figure M23 shows estimated wave breaking locations for the 1997 conditions and the 2 mcy placement scenario. There are several “cells” where wave breaking has changed due to the subtle effects of the 2 mcy scenario within the SWS, but no continuous effect is discernable.

Figures M24-M26 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 2 mcy placement scenario, based on an offshore wave condition as specified in **figure S10**. The offshore wave condition corresponds to a winter storm with average wave height = 6.55 m (wave period = 16.7 sec, wave direction = NW), and is a mix of locally generated swell. Figure M24 compares nearshore estimated wave height at MCR for 1997 and the 2 mcy placement scenario: Small changes in the wave height can be seen within the western half of the SWS. Estimated wave amplification is shown in figure M25. The maximum increase in wave height *due to the 2 mcy scenario* was estimated to be 3% (or 6.8 m for the 2 mcy scenario vs. 6.6 m in 1997) and occurs in the western half of the SWS. There is a minor effect on wave height outside of the SWS, east of the SWS toward the navigation channel (less than 3%). Figure M26 shows estimated wave breaking locations for the 1997 conditions and the 2 mcy placement scenario. There are no discernable areas where wave breaking has changed due to the 2 mcy placement scenario.

Figures M27-M28 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 2 mcy placement scenario, based on an offshore wave condition as specified in **figure S11**. The offshore wave condition corresponds to summer seas with average wave height = 1.77 m (wave period = 8.3 sec, wave direction = NW), and is composed of local seas (chop) and some swell. Figure M27 compares nearshore estimated wave height at MCR for 1997 and the 2 mcy placement scenario: Changes in the wave height at MCR are difficult to discern. Estimated wave amplification is shown in figure M28. The maximum increase in wave height *due to the 2 mcy scenario* was estimated to be 2% (or 1.7 m for the 2 mcy scenario vs. 1.7 m in 1997) and occurs through the middle of the SWS. There is little or no effect on wave height outside of the SWS.

Assessment of Southwest Waves - 4 mcy Placed in SWS

Figures M29-M41 show the STWAVE results obtained by applying south-southwest offshore wave conditions on two MCR bathymetry conditions: the 1997 baseline and the simulated **4 mcy SWS placement scenario**. For a description of the MCR offshore wave climate associated with wave-fields originating from the south-southwest, refer to the section

"*STWAVE Modeling Results: 1997 vs. 2002 Bathymetry at MCR*" , figures S1-S5, and "wave cases" #1- #5 in Table 2.

Figures M29-M31 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S1**. The offshore wave condition corresponds to a winter storm with average wave height = 6.48 m (wave period = 12.5 sec, wave direction = SW), and it is composed of locally generated swell and seas. Figure M29 compares nearshore estimated wave height at MCR for 1997 and the 4 mcy placement scenario: Small changes in the wave height are visible in the western half of the SWS. Estimated wave amplification is shown in figure M30 and demonstrates the wave-related effect of placing 4 mcy of dredged material "uniformly" within the SWS. Waves are potentially effected within the SWS and at areas within 1,000 ft north of the site. The maximum increase in wave height *due to the 4 mcy scenario* was estimated to be 6% (or 6.8 m for the 4 mcy scenario vs. 6.4 m in 1997) and occurs along the northern edge of the SWS. Figure M31 shows estimated wave breaking locations for the 1997 conditions and the 4 mcy placement scenario. A very small area of wave breaking (for the 4 mcy scenario, shown in red) immediately north of buoy #7 is the result dredged material placement within the SWS. Immediately west of that point, there is an area of wave breaking reduction associated with the 4 mcy placement scenario. It must be noted that to attain this level of wave breaking north of the SWS and on Peacock Spit; the offshore wave conditions are at a "storm warning" level of severity. It is highly unlikely that any vessel would be transiting MCR, outside of the navigation channel, during such a storm wave condition.

Figures M32-M34 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S2**. The offshore wave condition corresponds to a winter storm with average wave height = 8.34 m (wave period = 16.7 sec, wave direction = W), and is composed of swell and seas from two separate storms. Figure M32 compares nearshore estimated wave height at MCR for 1997 and the 4 mcy placement scenario: Small changes in the wave height within the western half of the SWS are visible. Estimated wave amplification is shown in figure M33. Waves are potentially effected within the SWS; but there is little effect outside the site. The maximum increase in wave height *due to the 4 mcy scenario* was estimated to be 4% (or 8.4 m for the 4 mcy scenario vs. 8.1 m in 1997) and occurs near the middle of the SWS. Figure M34 shows estimated wave breaking locations for the 1997 conditions and the 4 mcy placement scenario. An area of wave breaking (for the 4 mcy scenario, shown in red) along the northern boundary of the SWS is the result dredged material placement within the SWS. Further north of the SWS, there is an area of wave breaking reduction associated with the 4 mcy placement scenario. It must be noted that to attain this level of wave breaking north of the SWS and on Peacock Spit; the offshore wave conditions are at a "storm warning" level of severity. It is highly unlikely that any vessel would be transiting MCR, outside of the navigation channel, during such a storm wave condition.

Figures M35-M37 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S3**. The offshore wave condition corresponds to a winter storm with average wave height = 6.78 m (wave period = 10.5 sec, wave direction = SW), and is composed of locally generated seas and some swell. Figure M35 compares nearshore estimated wave height at MCR for 1997 and the 4 mcy placement scenario: Small changes in the wave height can be seen along the northern side of the SWS. Estimated wave amplification is shown in figure M36. The maximum increase in wave height *due to the 4 mcy scenario* was estimated to be 5% (or 5.5 m for the 4 mcy scenario vs. 5.2 m in 1997) and occurs in the northern half of the SWS. For a distance of 1,500 ft north of the SWS, there is a minor effect on wave height (less than 2%). Figure M37 shows estimated wave breaking locations for the 1997 conditions and the 4 mcy placement scenario. There are several "cells" where wave breaking has changed due to the subtle effects of the 4 mcy scenario within the SWS, but no continuous effect is discernable. It must be noted that to attain this level of wave breaking north of the SWS and on Peacock Spit; the offshore wave conditions are at a "storm warning" level of severity. It is highly unlikely that any vessel would be transiting MCR, outside of the navigation channel, during such a storm wave condition.

Figures M38-M39 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S4**. The offshore wave condition corresponds to a winter storm with average wave height = 3.56 m (wave period = 7.7 sec, wave direction = SSW), and is composed of locally developed seas. Figure M38 compares nearshore estimated wave height at MCR for 1997 and the 4 mcy placement scenario: Small changes in the wave height can be seen along the middle of the SWS. Estimated wave amplification is shown in figure M39. The maximum increase in wave height *due to the 4 mcy scenario* was estimated to be 2% (or 2.9 m for the 4 mcy scenario vs. 2.8 m in 1997) and occurs in the northern half of the SWS. There is little effect on wave height outside of the SWS (less than 2%).

Figures M40-M41 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S5**. The offshore wave condition corresponds to a summer storm with average wave height = 3.51 m (wave period = 10.5 sec, wave direction = S), and is composed of locally developed seas. Figure M40 compares nearshore estimated wave height at MCR for 1997 and the 4 mcy placement scenario: Changes in the wave height are barely discernable in the middle of the SWS. Estimated wave amplification is shown in figure M41. The maximum increase in wave height *due to the 4 mcy scenario* was estimated to be 3% (or 2.9 m for the 4 mcy scenario vs. 2.8 m in 1997) and occurs in the northwestern quarter of the SWS. There is a minor effect on wave height (less than 2%), for a distance of 1,500 ft north of the SWS.

Assessment of Northwest Waves - 4 mcy Placed in SWS

Figures M42-M56 show the STWAVE results obtained by applying west-northwest offshore wave conditions on two MCR bathymetry conditions: the 1997 baseline and **the simulated 4 mcy SWS placement scenario**. For a description of the MCR offshore wave climate associated with wave-fields originating from the north-northwest, refer to the section "*STWAVE Modeling Results: 1997 vs. 2002 Bathymetry at MCR*", figures S6-S11, and "wave cases" #6- #11 in Table 2.

Figures M42-M43 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S6**. The offshore wave condition corresponds to a summer swell with average wave height = 1.79 m (wave period = 11.0 sec, wave direction = W), and is composed of local seas (chop) and some swell. Figure M42 compares nearshore estimated wave height at MCR for 1997 and the 4 mcy placement scenario: Changes in the wave height at MCR are difficult to discern. Estimated wave amplification is shown in figure M43. The maximum increase in wave height *due to the 4 mcy scenario* was estimated to be 6% (or 2.1 m for the 4 mcy scenario vs. 2.0 m in 1997) and occurs in the eastern half of the SWS. There is a minor effect on wave height east of the SWS (less than 3%) .

Figures M44-M46 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S7**. The offshore wave condition corresponds to a winter swell with average wave height = 2.85 m (wave period = 16.7 sec, wave direction = W), and is composed of swell and seas. Figure M44 compares nearshore estimated wave height at MCR for 1997 and the 4 mcy placement scenario: Small changes in the wave height can be seen in the western half of the SWS. Estimated wave amplification is shown in figure M45. The maximum increase in wave height *due to the 4 mcy scenario* was estimated to be 7% (or 3.1 m for the 4 mcy scenario vs. 2.9 m in 1997) and occurs in the middle of the SWS. There is a minor effect on wave height outside of the SWS, east of the SWS toward the navigation channel (less than 4%). Figure M46 shows estimated wave breaking locations for the 1997 conditions and the 4 mcy placement scenario. There are no discernable areas where wave breaking has changed due to the 4 mcy placement scenario.

Figures M47-M48 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S8**. The offshore wave condition corresponds to a summer swell with average wave height = 1.29 m (wave period = 16.7 sec, wave direction = SW), and is a bi-modal combination of swell (distant source) and seas (local source). Figure M47 compares nearshore estimated wave height at MCR for 1997 and the 4 mcy placement scenario: Small changes in the wave height can be seen along the northern edge of the SWS. Estimated wave amplification is shown in figure M48. The maximum increase in wave height *due to the 4 mcy scenario* was estimated to be 6% (or 1.5 m for the 4 mcy scenario vs. 1.4 m in 1997) and occurs near the middle of the SWS. There is a minor effect on wave height outside of the SWS, 1,000 ft north of the SWS toward the Peacock Spit (less than 4%).

Figures M49-M51 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S9**. The offshore wave condition corresponds to a winter swell with average wave height = 3.75 m (wave period = 16.7 sec, wave direction = W), and is a bi-modal combination of swell (distant source) and seas (local source). Figure M49 compares nearshore estimated wave height at MCR for 1997 and the 4 mcy placement scenario: Small changes in the wave height can be seen within the western half of the SWS. Estimated wave amplification is shown in figure M50. The maximum increase in wave height *due to the 4 mcy scenario* was estimated to be 9% (or 4.3 m for the 4 mcy scenario vs. 3.9 m in 1997) and occurs in the eastern half of the SWS. There is a minor effect on wave height outside of the SWS, within 1,000 ft north of the site (less than 3%). Figure M51 shows estimated wave breaking locations for the 1997 conditions and the 4 mcy placement scenario. There are several "cells" where wave breaking has changed due to the subtle effects of the 4 mcy scenario within the SWS, but no continuous effect is discernable.

Figures M52-M54 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S10**. The offshore wave condition corresponds to a winter storm with average wave height = 6.55 m (wave period = 16.7 sec, wave direction = NW), and is a mix of locally generated swell. Figure M52 compares nearshore estimated wave height at MCR for 1997 and the 4 mcy placement scenario: Changes in the wave height can be seen within the western half of the SWS. Estimated wave amplification is shown in figure M53. The maximum increase in wave height *due to the 4 mcy scenario* was estimated to be 6% (or 7.0 m for the 4 mcy scenario vs. 6.6 m in 1997) and occurs in the western half of the SWS. There is a minor effect on wave height outside of the SWS, east of the SWS toward the navigation channel (less than 3%). Figure M54 shows estimated wave breaking locations for the 1997 conditions and the 4 mcy placement scenario. There are no discernable areas where wave breaking has changed due to the 4 mcy placement scenario.

Figures M55-M56 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S11**. The offshore wave condition corresponds to summer seas with average wave height = 1.77 m (wave period = 8.3 sec, wave direction = NW), and is composed of local seas (chop) and some swell. Figure M57 compares nearshore estimated wave height at MCR for 1997 and the 4 mcy placement scenario: Changes in the wave height at MCR are difficult to discern. Estimated wave amplification is shown in figure M58. The maximum increase in wave height *due to the 4 mcy scenario* was estimated to be 4% (or 1.8 m for the 4 mcy scenario vs. 1.7 m in 1997) and occurs in the western half of the SWS. There is a minor effect on wave height east of the SWS (less than 2%) .

Assessment of Southwest Waves - 6 mcy Placed in SWS

Figures M57-M69 show the STWAVE results obtained by applying south-southwest offshore wave conditions on two MCR bathymetry conditions; the 1997 baseline and the simulated **6 mcy SWS placement scenario**. For a description of the MCR offshore wave climate associated with wave-fields originating from the south-southwest, refer to the section "*STWAVE Modeling Results: 1997 vs. 2002 Bathymetry at MCR*" , figures S1-S5, and "wave cases" #1- #5 in Table 2.

Figures M57-M59 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 6 mcy placement scenario, based on an offshore wave condition as specified in **figure S1**. The offshore wave condition corresponds to a winter storm with average wave height = 6.48 m (wave period = 12.5 sec, wave direction = SW), and it is composed of locally generated swell and seas. Figure M57 compares nearshore estimated wave height at MCR for 1997 and the 6 mcy placement scenario: Changes in the wave height are visible in the western half of the SWS and areas north. Estimated wave amplification is shown in figure M58 and demonstrates the wave-related effect of placing 6 mcy of dredged material “uniformly” within the SWS. The maximum increase in wave height *due to the 6 mcy scenario* was estimated to be 10% (or 7.0 m for the 6 mcy scenario vs. 6.4 m in 1997) and occurs along the northern edge of the SWS. Waves are potentially effected within the SWS and at areas within 1,000 ft north and east of the site (less than 5%). Figure M59 shows estimated wave breaking locations for the 1997 conditions and the 6 mcy placement scenario. A small area of wave breaking (for the 6 mcy scenario, shown in red) immediately north of buoy #7 (inside and outside the SWS) and on the western boundary of the SWS is the result dredged material placement within the SWS. Further north (outside of the SWS), there is an area of wave breaking reduction associated with the 6 mcy placement scenario. It must be noted that to attain this level of wave breaking north of the SWS and on Peacock Spit; the offshore wave conditions are at a “storm warning” level of severity. It is highly unlikely that any vessel would be transiting MCR, outside of the navigation channel, during such a storm wave condition.

Figures M60-M62 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 6 mcy placement scenario, based on an offshore wave condition as specified in **figure S2**. The offshore wave condition corresponds to a winter storm with average wave height = 8.34 m (wave period = 16.7 sec, wave direction = W), and is composed of swell and seas from two separate storms. Figure M60 compares nearshore estimated wave height at MCR for 1997 and the 6 mcy placement scenario: Changes in the wave height within the western half of the SWS are visible. Estimated wave amplification is shown in figure M61. Wave height is potentially effected within the SWS; but there appears to be little effect outside the site. The maximum increase in wave height *due to the 6 mcy scenario* was estimated to be 2% (or 8.2 m for the 6 mcy scenario vs. 8.1 m in 1997) and occurs near the middle of the SWS. Figure M62 shows estimated wave breaking locations for the 1997 conditions and the 6 mcy placement scenario. An area of wave breaking (for the 6 mcy scenario, shown in red) along the northern half of the SWS is the result dredged material placement within the SWS. Further north of the SWS, there is an area of wave breaking reduction associated with the 6 mcy placement scenario. It must be noted that to attain this level of wave breaking north of the SWS and on Peacock Spit; the offshore wave conditions are at a “storm warning” level of severity. It is highly unlikely that any vessel would be transiting MCR, outside of the navigation channel, during such a storm wave condition.

Figures M63-M65 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 6 mcy placement scenario, based on an offshore wave condition as specified in **figure S3**. The offshore wave condition corresponds to a winter storm with average wave height = 6.78 m (wave period = 10.5 sec, wave direction = SW), and is composed of locally generated seas and some swell. Figure M63 compares nearshore estimated wave height at MCR for 1997 and the 6 mcy placement scenario: Changes in the wave height can be seen along the northern side of the SWS. Estimated wave amplification is shown in figure M64. The maximum increase in wave height *due to the 6 mcy scenario* was estimated to be 7% (or 5.6 m for the 6 mcy scenario vs. 5.2 m in 1997) and occurs in the northern half of the SWS. For a distance of 1,500 ft north of the SWS, there is a minor effect on wave height (less than 2%). Figure M65 shows estimated wave breaking locations for the 1997 conditions and the 6 mcy placement scenario. There are several “cells” where wave breaking has changed due to the subtle effects of the 6 mcy scenario within the SWS, but no continuous effect is discernable. It must be noted that to attain this level of wave breaking north of the SWS and on Peacock Spit; the offshore wave conditions are at a "storm warning" level of severity. It is highly unlikely that any vessel would be transiting MCR, outside of the navigation channel, during such a storm wave condition.

Figures M66-M67 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 6 mcy placement scenario, based on an offshore wave condition as specified in **figure S4**. The offshore wave condition corresponds to a winter storm with average wave height = 3.56 m (wave period = 7.7 sec, wave direction = SSW), and is composed of locally developed seas. Figure M66 compares nearshore estimated wave height at MCR for 1997 and the 6 mcy placement scenario: Changes in the wave height can be seen within the middle of the SWS. Estimated wave amplification is shown in figure M67. The maximum increase in wave height *due to the 6 mcy scenario* was estimated to be 4% (or 2.9 m for the 6 mcy scenario vs. 2.8 m in 1997) and occurs in the northern half of the SWS. There is little effect on wave height outside of the SWS (less than 2%).

Figures M68-M69 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 6 mcy placement scenario, based on an offshore wave condition as specified in **figure S5**. The offshore wave condition corresponds to a summer storm with average wave height = 3.51 m (wave period = 10.5 sec, wave direction = S), and is composed of locally developed seas. Figure M68 compares nearshore estimated wave height at MCR for 1997 and the 6 mcy placement scenario: Changes in the wave height are discernable in the middle of the SWS. Estimated wave amplification is shown in figure M69. The maximum increase in wave height *due to the 6 mcy scenario* was estimated to be 6% (or 3.0 m for the 6 mcy scenario vs. 2.8 m in 1997) and occurs in the northwestern quarter of the SWS. There is an effect on wave height (less than 5%), for a distance of 1,500 ft north of the SWS.

Assessment of Northwest Waves - 6 mcy Placed in SWS

Figures M70-M84 show the STWAVE results obtained by applying west-northwest offshore wave conditions on two MCR bathymetry conditions; the 1997 baseline and **the simulated 6 mcy SWS placement scenario**. For a description of the MCR offshore wave climate associated with wave-fields originating from the north-northwest, refer to the section "*STWAVE Modeling Results: 1997 vs. 2002 Bathymetry at MCR*" , figures S6-S11, and "wave cases" #6- #11 in Table 2.

Figures M70-M71 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 6 mcy placement scenario, based on an offshore wave condition as specified in **figure S6**. The offshore wave condition corresponds to a summer swell with average wave height = 1.79 m (wave period = 11.0 sec, wave direction = W), and is composed of local seas (chop) and some swell. Figure M70 compares nearshore estimated wave height at MCR for 1997 and the 6 mcy placement scenario: Changes in the wave height at MCR are visible within the middle of the SWS. Estimated wave amplification is shown in figure M71. The maximum increase in wave height *due to the 6 mcy scenario* was estimated to be 11% (or

2.2 m for the 6 mcy scenario vs. 2.0 m in 1997) and occurs in the eastern half of the SWS. There is a minor effect on wave height east of the SWS (less than 5%).

Figures M72-M74 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 6 mcy placement scenario, based on an offshore wave condition as specified in **figure S7**. The offshore wave condition corresponds to a winter swell with average wave height = 2.85 m (wave period = 16.7 sec, wave direction = W), and is composed of swell and seas. Figure M72 compares nearshore estimated wave height at MCR for 1997 and the 6 mcy placement scenario: Changes in the wave height can be seen in the western half of the SWS. Estimated wave amplification is shown in figure M73. The maximum increase in wave height *due to the 6 mcy scenario* was estimated to be 13% (or 3.3 m for the 6 mcy scenario vs. 2.9 m in 1997) and occurs in the middle of the SWS. There is a minor effect on wave height outside of the SWS, east of the SWS toward the navigation channel (less than 5%). Figure M74 shows estimated wave breaking locations for the 1997 conditions and the 6 mcy placement scenario. There are no discernable areas where wave breaking has changed due to the 6 mcy placement scenario.

Figures M75-M76 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 6 mcy placement scenario, based on an offshore wave condition as specified in **figure S8**. The offshore wave condition corresponds to a summer swell with average wave height = 1.29 m (wave period = 16.7 sec, wave direction = SW), and is a bi-modal combination of swell (distant source) and seas (local source). Figure M75 compares nearshore estimated wave height at MCR for 1997 and the 6 mcy placement scenario: Changes in the wave height can be seen along the northern edge of the SWS. Estimated wave amplification is shown in figure M76. The maximum increase in wave height *due to the 6 mcy scenario* was estimated to be 7% (or 1.5 m for the 6 mcy scenario vs. 1.4 m in 1997) and occurs near the middle of the SWS. There is a minor effect on wave height outside of the SWS, 1,000 ft north of the SWS toward the Peacock Spit (less than 5%).

Figures M77-M79 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 6 mcy placement scenario, based on an offshore wave condition as specified in **figure S9**. The offshore wave condition corresponds to a winter swell with average wave height = 3.75 m (wave period = 16.7 sec, wave direction = W), and is a bi-modal combination of swell (distant source) and seas (local source). Figure M77 compares nearshore estimated wave height at MCR for 1997 and the 6 mcy placement scenario: Changes in the wave height can be seen in the middle of the SWS. Estimated wave amplification is shown in figure M79. The maximum increase in wave height *due to the 6 mcy scenario* was estimated to be 15% (or 4.5 m for the 6 mcy scenario vs. 3.9 m in 1997) and occurs in the eastern half of the SWS. There is an effect on wave height outside of the SWS, within 1,000 ft north and 1,500 ft east of the site (less than 8%). Figure M75 shows estimated wave breaking locations for the 1997 conditions and the 6 mcy placement scenario. There are several “cells” where wave breaking has changed due to the subtle effects of the 6 mcy scenario within the SWS, but no continuous effect on wave breaking is discernable.

Figures M80-M82 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 6 mcy placement scenario, based on an offshore wave condition as specified in **figure S10**. The offshore wave condition corresponds to a winter storm with average wave height = 6.55 m (wave period = 16.7 sec, wave direction = NW), and is a mix of locally generated swell. Figure M80 compares nearshore estimated wave height at MCR for 1997 and the 6 mcy placement scenario: Changes in the wave height can be seen within the western and eastern half of the SWS. Estimated wave amplification is shown in figure M81. The maximum increase in wave height *due to the 6 mcy scenario* was estimated to be 8% (or 7.1 m for the 6 mcy scenario vs. 6.6 m in 1997) and occurs in the western half of the SWS. There is an effect on wave height outside of the SWS, east of the SWS toward the navigation channel (less than 4%). Figure M82 shows estimated wave breaking locations for the 1997 conditions and the 6 mcy placement scenario. There are several locations (i.e. "cells") within the northern half of the SWS that experience wave breaking due to the 6 mcy placement scenario.

Figures M83-M84 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 6 mcy placement scenario, based on an offshore wave condition as specified in **figure S11**. The offshore wave condition corresponds to summer seas with average wave height = 1.77 m (wave period = 8.3 sec, wave direction = NW), and is composed of local seas (chop) and some swell. Figure M83 compares nearshore estimated wave height at MCR for 1997 and the 6 mcy placement scenario: Changes in the wave height at MCR are visible within the eastern half of the SWS. Estimated wave amplification is shown in figure M84. The maximum increase in wave height *due to the 6 mcy scenario* was estimated to be 6% (or 1.8 m for the 6 mcy scenario vs. 1.7 m in 1997) and occurs though the middle of the SWS. There is a minor effect on wave height southeast of the SWS (less than 3%).

STWAVE Modeling Results with Current: 1997 Condition vs. Optimized Use of SWS

The interaction of current with waves at MCR was investigated to determine if the presence of current would increase the effect of dredged material deposition upon waves at the SWS. A peak ebb current condition (associated with a spring tide) was used to assess wave-current interaction. This condition corresponds to a worst-case current (see Part II). Currents at the SWS were estimated using a numerical model. The ADCIRC-generated current field was used within the STWAVE model to estimate current related effects on waves at MCR. Results were obtained by applying west-northwest offshore wave conditions on two MCR bathymetry conditions; the 1997 baseline and **the MDFATE simulated 4 mcy SWS placement scenario**. For a description of the MCR offshore wave climate associated with wave-fields originating from the north-northwest, refer to the section "*STWAVE Modeling Results: 1997 vs. 2002 Bathymetry at MCR*", figures S6-S11, and "wave cases" #6- #11 in Table 2.

Ebb Current at MCR

The ADCIRC (ADvanced CIRCulation) model was used to simulate flow through the MCR [USACE 1992 and USACE 2002]. ADCIRC is a 3-dimensional finite element hydrodynamic model developed by USACE for civilian and military use. As used for this investigation, ADCIRC simulated the depth-averaged (2-D) flow conditions at MCR. ADCIRC is a finite amplitude non-linear model that simulates unsteady water surface variation and current due to tides, wind, riverine Flow, and wetting and drying of tidal flats, which is a crucial element of modeling the Columbia River estuary. ADCIRC-generated current data (for a peak ebb flow condition at the SWS) was extracted and used within the STWAVE model to wave-current interaction at the SWS. The MCR ADCIRC model has been calibrated and modeled current matched measurements at the SWS [USACE 2002].

ADCIRC was used to generate a peak ebb-flow current field for the bathymetry conditions corresponding to the 1997 baseline and the simulated 4 mcy SWS placement scenario. Results for each bathymetry condition current field are shown in figure C1. The maximum estimated current speed within the SWS was about 1.9 m/sec (6.2 ft/sec). Note the slight increase in current velocity near the center of the SWS for the 4 mcy SWS placement scenario, due to the decreased water depth from dredged material deposition. Figure C2 shows the detailed change in peak ebb current due to the 4 mcy SWS placement scenario. The largest change in current speed due to the 4 mcy SWS placement scenario was about 5% and occurs near the southwest corner of the SWS.

<u>Assessment of Northwest Waves and Ebb Current- 4 mcy Placed in SWS</u>

Figures C3-C18 show the STWAVE results obtained by applying west-northwest offshore wave conditions and an ebb current field on two MCR bathymetry conditions: the 1997 baseline and **the simulated 4 mcy SWS placement scenario**. The results are summarized in table 7. The interested reader can compare these results with those that did not include current (**figures M40-M52**). Note that by including current, the predicted wave height for areas near the SWS, is larger than conditions without current.

Figures C3-C4 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S6** and an ebb current (shown in figure C1). The offshore wave condition corresponds to a summer swell with average wave height = 1.79 m (wave period = 11.0 sec, wave direction = W), and is composed of local seas (chop) and some swell. Figure C3 compares nearshore estimated <u>wave height</u> at MCR for 1997 and the 4 mcy placement scenario: Changes in the wave height at MCR are difficult to discern. Estimated <u>wave amplification</u> is shown in figure C4. The maximum increase in wave height *due to the 4 mcy scenario* (with current) was estimated to be 5% (or 2.9 m for the 4 mcy scenario vs. 2.8 m in 1997) and occurs in the western half of the SWS. There is a minor effect on wave height southeast of the SWS (less than 2%).

Figures C5-C7 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S7** and an ebb current (shown in figure C1). The offshore wave condition corresponds to a winter swell with average wave height = 2.85 m (wave period = 16.7 sec, wave direction = W), and is composed of swell and seas. Figure C5 compares nearshore estimated <u>wave height</u> at MCR for 1997 and the 4 mcy placement scenario: Small changes in the wave height can be seen in the western half of the SWS. Estimated <u>wave amplification</u> is shown in figure C6. The maximum increase in wave height *due to the 4 mcy scenario* (with current) was estimated to be 8% (or 4.6 m for the 4 mcy scenario vs. 4.3 m in 1997) and occurs in the middle of the SWS. There is a minor effect on wave height outside of the SWS, southeast of the SWS toward the navigation channel (less than 2%). Figure C7 shows estimated <u>wave breaking</u>

locations for the 1997 conditions and the 4 mcy placement scenario. There are several "cells" where wave breaking has changed due to the subtle effects of the 6 mcy scenario within the SWS, but no continuous effect on wave breaking is discernable.

Figures C8-C10 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S8** and an ebb current (shown in figure C1). The offshore wave condition corresponds to a summer swell with average wave height = 1.29 m (wave period = 16.7 sec, wave direction = SW), and is a bi-modal combination of long period swell (distant source) and short period seas (local source). Figure C8 compares nearshore estimated <u>wave height</u> at MCR for 1997 and the 4 mcy placement scenario. Note that "wave blocking" is predicted to occur for both bathymetry conditions, due to short period waves (3-5sec period) propagating against a strong ebb current (see Part II). Wave height just outside the wave blocking area is about 1.5 m. Wave height inside of the wave blocking area is about 1 m. Changes in the wave height can be seen in the middle of the SWS. This caused by the change in ebb current (due to the 4 mcy placement scenario) changing the location of wave blocking. Estimated <u>wave amplification</u> is shown in figure C9. The maximum increase in wave height *due to the 4 mcy scenario* (with current) was estimated to be 15% for areas outside of the wave blocking (or 1.6 m for the 4 mcy scenario vs. 1.4 m in 1997) and occurs near the eastern half of the SWS. The maximum increase in wave height for areas inside of the wave blocking was estimated to be 50% (or 1.5 m for the 4 mcy scenario vs. 1.0 m in 1997) and occurs near the eastern half of the SWS. There is a minor effect on wave height outside of the SWS, 1,000 ft north and south of the SWS (less than 4%). Figure C10 shows estimated <u>wave breaking</u> locations for the 1997 conditions and the 4 mcy placement scenario. For both bathymetry conditions, wave breaking is due to ebb currents "blocking" the short period waves. The small increase in ebb current (due to the 4 mcy placement scenario) shifts the location of wave blocking and reduces the area over which wave blocking occurs, as compared to the 1997 bathymetry condition.

Figures C11-C13 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S9** and an ebb current (shown in figure C1). The offshore wave condition corresponds to a winter swell with average wave height = 3.75 m (wave period = 16.7 sec, wave direction = W), and is a bi-modal combination of swell (distant source) and seas (local source). Figure C11 compares nearshore estimated <u>wave height</u> at MCR for 1997 and the 4 mcy placement scenario: Small changes in the wave height can be seen within the western half of the SWS. Estimated <u>wave amplification</u> is shown in figure C12. The maximum increase in wave height *due to the 4 mcy scenario* (with current) was estimated to be 9% (or 5.3 m for the 4 mcy scenario vs. 4.9 m in 1997) and occurs in the eastern half of the SWS. There is a minor effect on wave height outside of the SWS, within 1,000 ft north of the site (less than 4%). Figure C13 shows estimated <u>wave breaking</u> locations for the 1997 conditions and the 4 mcy placement scenario. There are several "cells" where wave breaking has changed due to the subtle effects of the 4 mcy scenario within the SWS, but no continuous effect is discernable.

Figures C14-C16 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S10** and an ebb current (shown in figure C1). The offshore wave condition corresponds to a winter storm with average wave height = 6.55 m (wave period = 16.7 sec, wave direction = NW), and is a mix of locally generated swell. Figure C14 compares nearshore estimated wave height at MCR for 1997 and the 4 mcy placement scenario: Changes in the wave height can be seen within the middle-western half of the SWS. Estimated wave amplification is shown in figure C15. The maximum increase in wave height *due to the 4 mcy scenario* (with current) was estimated to be 5% (or 8.0 m for the 4 mcy scenario vs. 7.6 m in 1997) and occurs in the western half of the SWS. Figure C16 shows estimated wave breaking locations for the 1997 conditions and the 4 mcy placement scenario. An area of wave breaking (for the 4 mcy scenario, shown in red) along the northern half of the SWS is the result dredged material placement within the SWS. Further north of the SWS, there is an area of wave breaking reduction associated with the 4 mcy placement scenario. It must be noted that to attain this level of wave breaking north of the SWS and on Peacock Spit; the offshore wave conditions are at a "storm warning" level of severity. It is highly unlikely that any vessel would be transiting MCR, outside of the navigation channel, during such a storm wave condition.

Figures C17-C18 show the potential changes in nearshore wave environment that would be expected to occur at MCR due to the SWS 4 mcy placement scenario, based on an offshore wave condition as specified in **figure S11** and an ebb current (shown in figure C1). The offshore wave condition corresponds to summer seas with average wave height = 1.77 m (wave period = 8.3 sec, wave direction = NW), and is composed of local seas (chop) and some swell. Figure C17 compares nearshore estimated wave height at MCR for 1997 and the 4 mcy placement scenario: There is a small change in the wave height at MCR in the western half of the SWS. Estimated wave amplification is shown in figure C18. The maximum increase in wave height *due to the 4 mcy scenario* (with current) was estimated to be 5% (or 2.3 m for the 4 mcy scenario vs. 2.2 m in 1997) and occurs in the western half of the SWS. There is a minor effect on wave height west and south of the SWS (less than 2%) .

In terms of an absolute comparison (wave height with current vs. wave height without current), the presence of an opposing (ebb) current can amplify wave height at MCR and cause wave breaking (due to "blocking" effects, see Part II). The effect of an ebb current on waves within the SWS is shown in table 8.

However, the relative change in wave height at the SWS between the 1997 baseline condition vs. the simulated 4 mcy SWS placement scenario for wave-current interaction is about the same as for waves not affected by current (compare tables 6 and 7). The amplification of waves by the 4 mcy dredged material placement scenario is about the same (1-2% difference) for waves with and without current. Wave-Current interaction for wave conditions S8 and S10 did cause some additional wave breaking at the SWS and compare to waves not affected by current. These changes are either due to a shift in the wave blocking location (S8) or increased wave steepness during a large storm wave event (S10), and are not considered significant in terms of affecting small vessel navigation at the SWS.

Table 8. Change in wave height within the SWS due to Wave-Current interaction. Results are based on the SWS bathymetry post 4 mcy placement, for west-northwest waves. Current effect on wave height (% change) is calculated as "(with current – without current)/ without current."

Wave Condition	Maximum Wave Height in SWS Without Current	With Current	Current Effect % Change in Wave Height
S6	2.3 m	3.4 m	48%
S7	4.1 m	5.5 m	34%
S8	1.6 m	2.3 m	44%
S9	5.0 m	5.9 m	18%
S10	7.2 m	8.5 m	18%
S11	2.3 m	2.8 m	22%

Conclusions

Three levels of SWS utilization (for dredged material disposal) were investigated using the MDFATE computer simulation: 2 mcy, 4 mcy, and 6 mcy. Results indicate that if dredged material is placed uniformly throughout the SWS, the level of vertical accumulation of that could be expected to occur within the SWS would be: 3 ft for the 2 mcy placement, 5 ft for the 4 mcy placement, and 8 ft for the 6 mcy placement. During the "release phase" of dredged material placement, approximately 22% of the dredged material placed within the SWS would be lost to the water column and transported north-northwest onto Peacock Spit. During the course of the dredged/disposal season, approximately 33% of the material placed at the SWS would be transported by waves and currents north-northwest along the seabed onto Peacock Spit. The above MDFATE model results are within 10% of observed trends, for the SWS.

To determine if placing dredged material within the SWS (according to the 3 placement scenarios) could affect the MCR nearshore wave environment, the post-disposal geometry for each placement scenario was assessed using the STWAVE model. Results were compared to the 1997 to assess potential wave impacts.

Comparing conditions in 1997 to the three levels of SWS use, the use of the SWS for dredged material disposal has the potential to increased nearshore wave height (within the site or at nearby locations) by 1-10% or 0.1 – 0.6 m, for S-SW waves (cases #1-#5). Effects of "simulated" SWS use upon wave breaking occurred only for the most severe wave conditions, and were limited to localized areas (within the SWS or northward on Peacock Spit) which did not affect the MCR entrance channel. Results are summarized in table 6.

For North-Northwest waves (cases #1-#5), the use of the SWS for the three levels of dredged material disposal has the potential to increase nearshore wave height (within the site or at nearby locations) by 3-15% or 0.1 – 0.6 m, with respect to the 1997 condition. Effects of "simulated" SWS use upon wave breaking occurred only for the most severe wave conditions, and were limited to localized areas (within the SWS or northward on Peacock Spit) which did not affect the MCR entrance channel. Results are summarized in table 6.

For 9 of the 10 offshore wave conditions tested, the larger (higher) the accumulation of placed dredged material within the SWS, the greater the shoaling effect on local wave height. The apparent exception was Wave Case #2, which was a winter storm composed of long and short period waves. The larger the accumulation within the SWS for wave case #2, the less the nearshore waves were "amplified". Closer inspection of the STWAVE results (wave breaking) reveals that for larger SWS accumulations, there is more wave breaking. For wave case #2, the waves along the western boundary of the SWS are at the limit of breaking stability; additional shoaling causes the waves to break.

Waves from west-northwest are more sensitive to bathymetry change on Peacock Spit (and within the SWS), than waves from the south-southwest. The largest increase in wave height was associated with the longest periods waves (swell). Long period waves (swell) are more susceptible to bathymetry changes than short period waves (seas), regardless of wave direction.

On a relative comparison basis, the presence of current (interacting with waves) does not increase the effect that dredged material accumulation (i.e. bathymetry change) has upon the wave environment within or near the SWS. The location of maximum wave amplification within the SWS for conditions with wave-current interaction can be different when compared to wave conditions without current. However, the value of maximum wave amplification is about the same for both conditions (with and without current).

The STWAVE results presented herein indicate that the effect of the 3 SWS placement scenarios on the MCR wave environment would minimal. It may be possible to detect the changes in wave conditions using sophisticated measurement techniques, but it would be difficult to do so by visual comparison.

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