ERDC/CHL TR-17-16

Coastal and Hydraulics Laboratory

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PTM Modeling of Dredged Suspended Sediment at Proposed Polaris Point and Ship Repair Facility CVN Berthing Sites – Apra Harbor, Guam

Joseph Z. Gailani, Sun-Chan Kim, David B. King Jr.,
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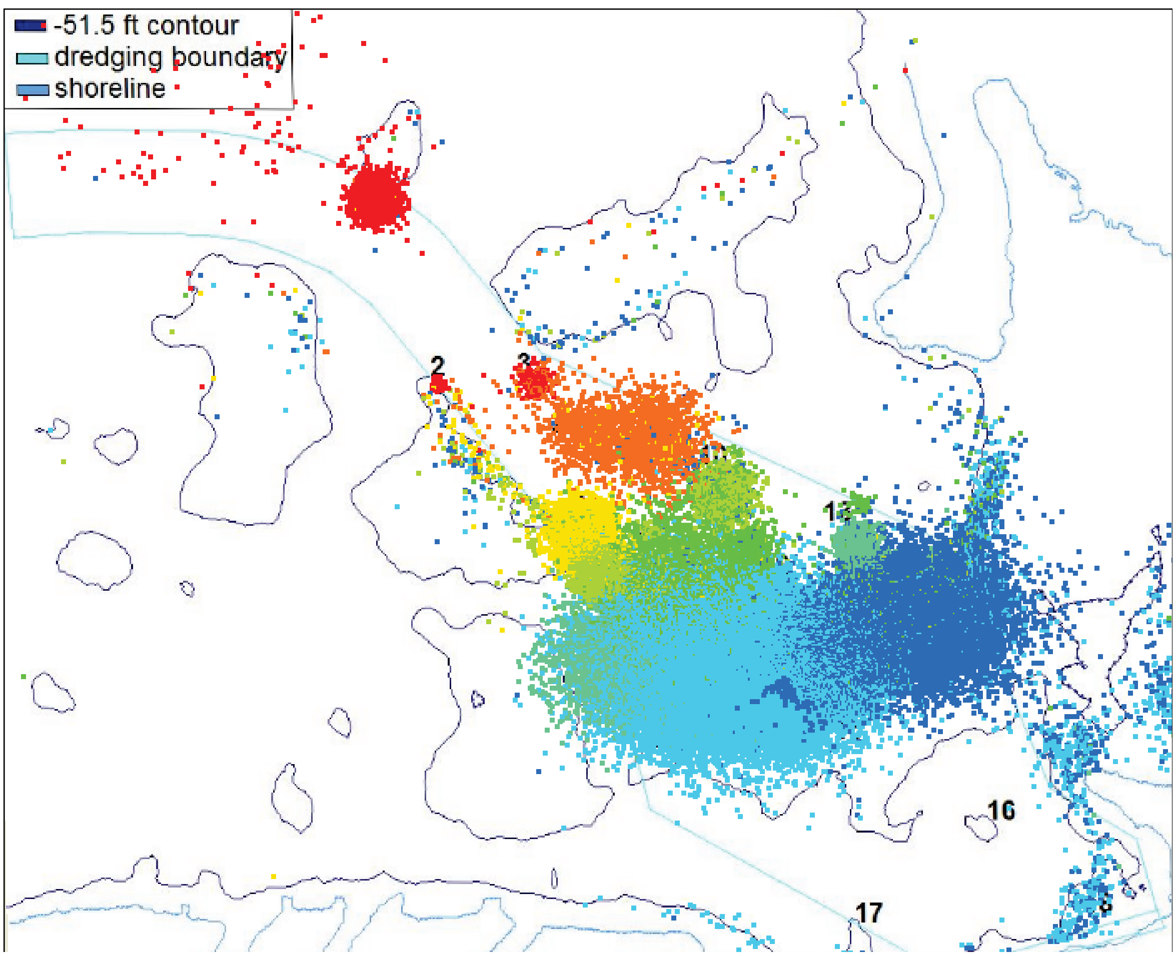
September 2017



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Coastal and Hydraulics Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Rd.
Vicksburg, MS 39180-6199

Final report

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258 Makalapa Drive, Suite 100
Pearl Harbor, HI 96860-3134

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Abstract

The U.S. Navy is studying alternatives for the construction of a new, deep-water wharf at Apra Harbor, Guam, to provide a berthing site for transient nuclear-powered aircraft carriers. The U.S. Army Corps of Engineers, Engineer Research and Development Center, was tasked with predicting the fate of resuspended dredged sediment during dredging operations for this port development. One byproduct of dredging is release of suspended material into the water column. This material temporarily increases turbidity during and after the dredging operation. Another byproduct is the deposition of suspended solids on surrounding coral. The Particle Tracking Model was applied to evaluate exposure of coral to suspended sediment for various dredging alternatives.

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Preface

The research presented in this paper was conducted with funding provided by U.S. Naval Facilities Engineering Command Pacific. The U.S. Army Corps of Engineers Dredging Operations Environmental Research Program funded model development and report writing.

Dr. Jarrell Smith, U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), provided an internal technical review of the project. Dr. Deborah J. Shafer of ERDC Environmental Laboratory was the Project Manager.

At CHL, the work was performed under the general supervision of Ms. Ashley E. Frey, Chief, Coastal Processes Branch (CEERD-HFC), and Dr. Cary Talbot, Chief, Flood and Storm Protection Division (CEERD-HF).

Mr. Jeffrey Eckstein was Deputy Directory, CHL, and Mr. José E. Sánchez was Director.

At the time of publication of this report, COL Bryan S. Green was Commander of ERDC, and Dr. David W. Pittman was Director of ERDC.

Unit Conversion Factors

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
inches	0.0254	meters
microns	1.0 E-06	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
square feet	0.09290304	square meters
square yards	0.8361274	square meters
yards	0.9144	meters

1 Introduction

Background

The U.S. Navy is studying alternatives for the construction of a new, deep-water wharf at Apra Harbor, Guam, to provide a berthing site for transient nuclear powered aircraft carriers (CVN) (In Navy-speak, C = aircraft carrier, V = Vice rotating wings [helicopter], and N = Nuclear powered).

Development of a site would involve dredging at the wharf location and additional dredging to provide a turning basin and access fairway. This report discusses two sites that are under consideration, Polaris Point and Ship Repair Facility. These sites are adjacent to large diverse coral reefs, and there are concerns about the impacts of dredging upon the biological community within Apra Harbor.

The U.S. Naval Facilities Engineering Command Pacific (NAVFAC PAC) requested U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC) assistance with determining the fate of resuspended dredged sediment during dredging operations for this Apra Harbor port development. One byproduct of dredging is release of suspended material into the water column. This material temporarily increases turbidity during and after the dredging operation. In addition, this suspended material is transported by currents and will eventually deposit. Suspended solids-induced turbidity and sedimentation have the potential to adversely impact the diverse coral formations in Apra Harbor.

Objective

The objective of this report is to develop a framework for quantifying turbidity and sedimentation exposure mechanisms for corals in Apra Harbor, Guam. The framework must be flexible and computationally efficient so that multiple scenarios can be evaluated in a cost-effective manner.

Approach

ERDC applied the Particle Tracking Model (PTM) to quantify the fate of dredged material released during the harbor expansion project to accommodate CVNs. The results of this modeling effort quantified exposure of the nearby coral reefs to turbidity and sedimentation. These exposure assessments are a critical component in risk analysis.

Key features of PTM are the ability to simulate dredge sources and dredge controls. These features support risk evaluation for dredging operations and risk reduction introduced through controls. The exposure estimates are then transferred to risk assessment and risk reduction introduced by each control measure. Control measures simulated using PTM include silt curtains and dredging rates. Results discussed in this report will form the basis for more informed decision support. In addition, results discussed in this report will lead to refined scenarios and additional simulations, if necessary.

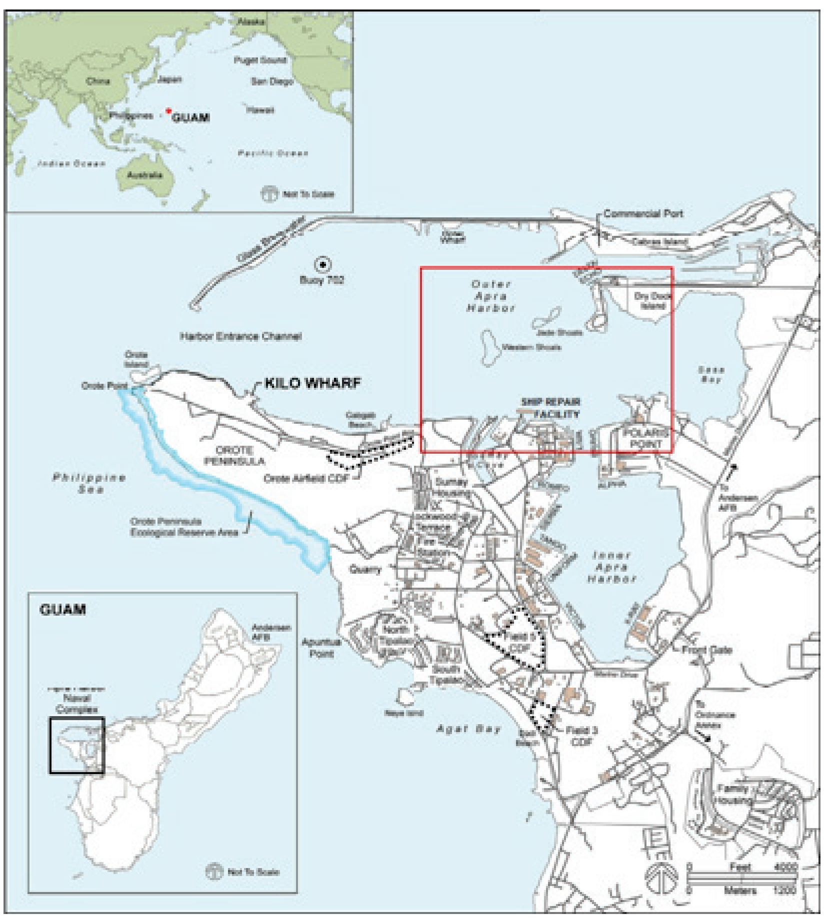
This report addresses the effects of dredging at the proposed Polaris Point and Ship Repair Facility sites. The report is divided into seven sections:

- Chapter 1–Introduction
- Chapter 2–Site Description
- Chapter 3–Particle Tracking Model (PTM)
- Chapter 4–Bathymetry and Hydrodynamics
- Chapter 5–PTM Suspended Sediment Sources and Dredging Scenarios
- Chapter 6–Results
- Chapter 7–Summary and Conclusions

2 Site Description

Apra Harbor is on the western coast of the island of Guam, as shown in Figure 2-1 (modified from Smith 2007). The harbor includes a large U.S. Navy facility. The Navy is considering expansion of existing facilities. The water in Apra Harbor generally has low turbidity, but it does increase during wind events. The harbor is also periodically exposed to increased turbidity from vessel movement but is protected from most major wave influences that can resuspend bottom sediments. Currents in the harbor are dominated by the tide, which is described in detail later in the text. Trade winds affect the surface currents, but this effect does not generally propagate to deep water. Typical bottom tidal currents are less than 5 centimeters per second (cm/s) and do not generate significant suspension. Despite their proximity to ship traffic, large diverse coral reefs have existed adjacent to the ship channel for decades.

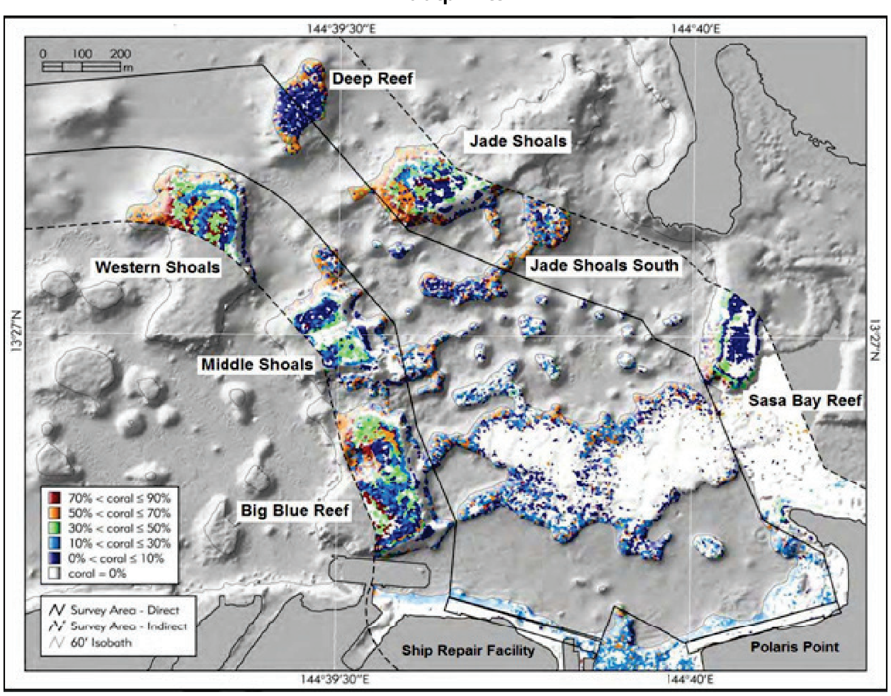
Figure 2-1. Site Location map, Apra Harbor, Guam.



The red rectangle in Figure 2-1 shows the study area for this project. Two potential berthing areas are analyzed in this study. The potential Polaris Point and Ship Repair Facility berthing sites are located along the southern Outer Apra Harbor shoreline on either side of the entrance to Inner Apra Harbor.

In addition to dredge removal of material in the berthing areas, this project includes deepening of the existing channel to 51.5 feet (ft) Mean Lower Low Water (MLLW) water depth to accommodate a CVN turning basin. Therefore, some dredging will occur north of the two berthing alternatives currently being evaluated. Figure 2-2 (modified from Dollar et al. 2009) shows coral density for areas above the 60 ft contour in the vicinity of the proposed dredging operations. The solid black line indicates the combined dredging boundary for the two sites. The dashed lines are 200 meters (m) from the channel boundary. Seven coral reefs are named in this figure. Western Shoals, Middle Shoals, Big Blue Reef, and Jade Shoals are names commonly used to refer to those reefs. However, the other three names were created for this study to rapidly identify those areas of interest. Deep Reef was named because its crest does not approach the water surface as do the other reefs. Jade Shoals South refers to a series of patch reefs extending to the south from Jade Shoals. Sasa Bay Reef refers to a broad shallow area near the entrance to Sasa Bay that is to the east of the dredging footprint.

Figure 2-2. Percent coral cover map in the vicinity of the combined dredging footprints.



Figures 2-3 and 2-4 show the individual dredging footprints for the Polaris Point and Ship Repair Facility alternatives, respectively. These figures also give numbered locations of all sites that require dredging for each alternative. Note that in these figures the -51.5 ft MLLW contour (depth of dredging) is similar, but not identical, to the 60 ft contour shown in Figure 2-2. Much of the areas that would be dredged in each alternative are currently within the existing navigation channel to Inner Apra Harbor. Therefore, most of the sites numbered in Figures 2-3 and 2-4 already have minimum depths of approximately -46 ft MLLW. Most of the numbered locations are isolated coral outcrops that will require between a few hours and a few days to dredge. However, site 15 (both figures) is a large flat platform that was probably originally a large reef that was removed decades ago. It is expected to take several months to deepen this portion of the channel from -45 ft to -51.5 ft MLLW. The majority of the material to be removed for each alternative is at the shoreside locations, which will be used as new berths (area 18, both figures).

Figure 2-3. Polaris Point dredging footprint boundary and numbered dredging sites.

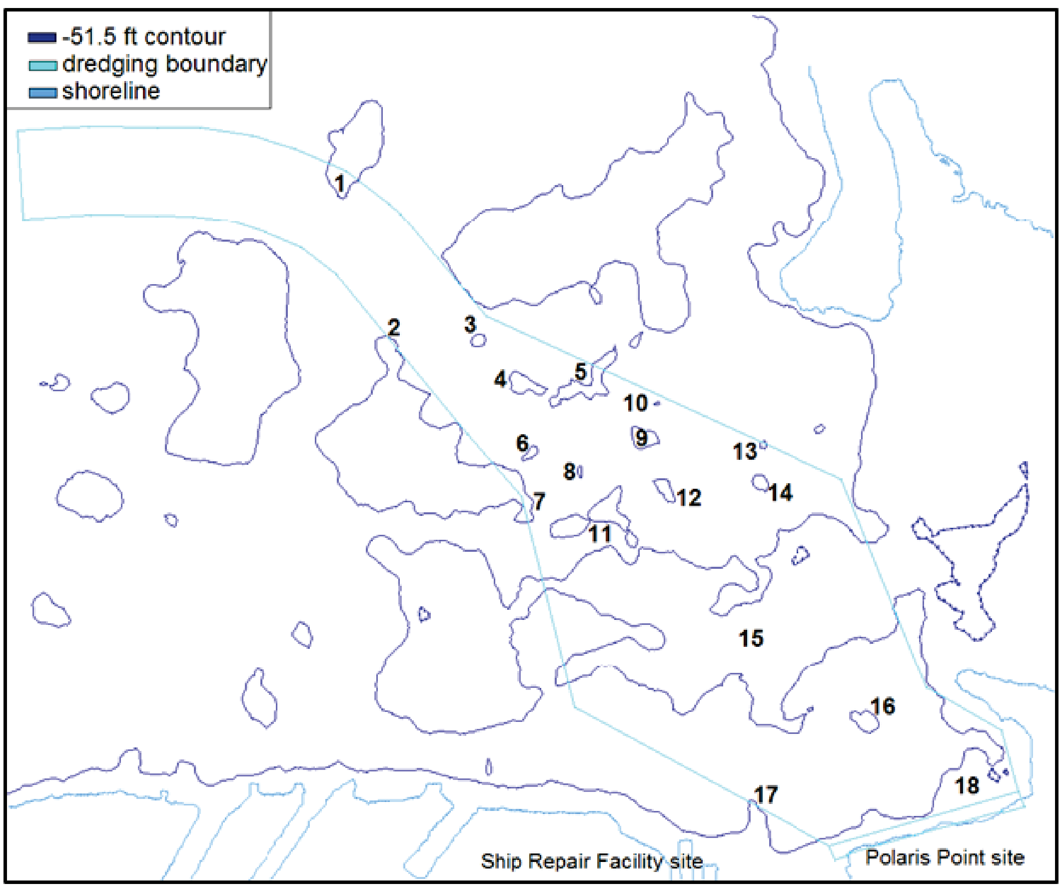
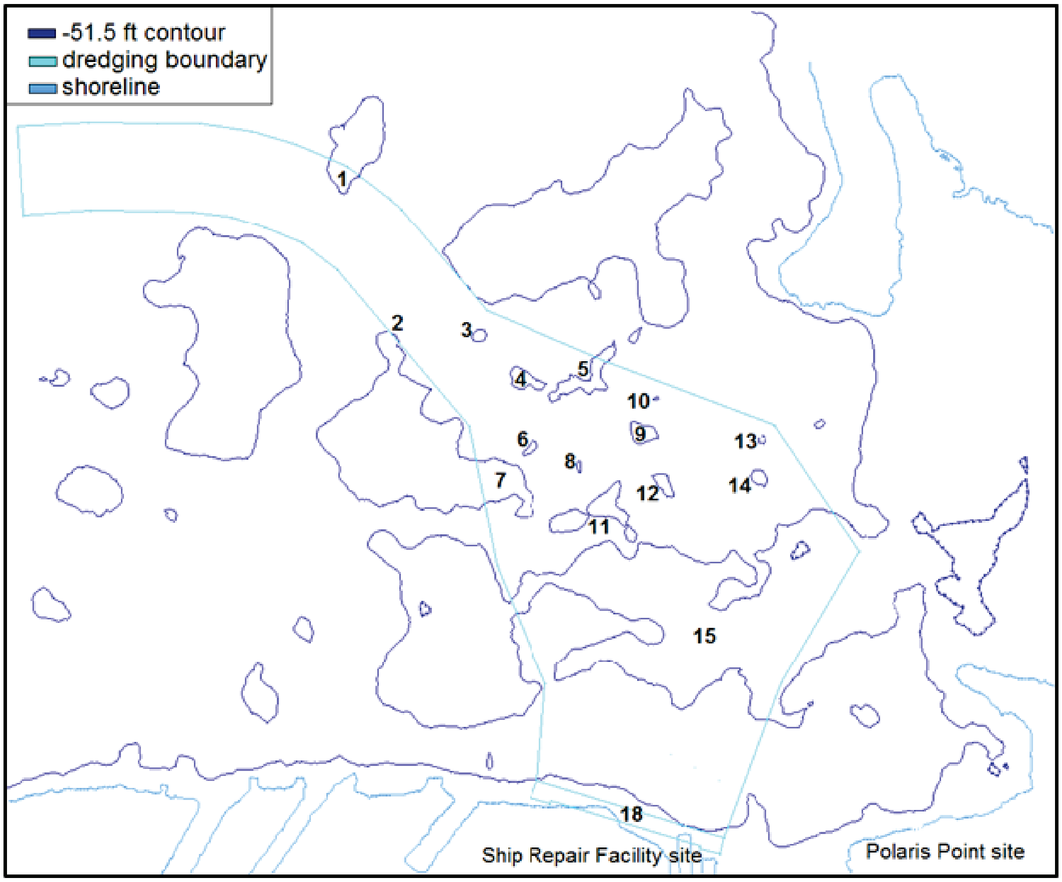


Figure 2-4. Ship Repair Facility dredging footprint boundary and numbered dredging sites.

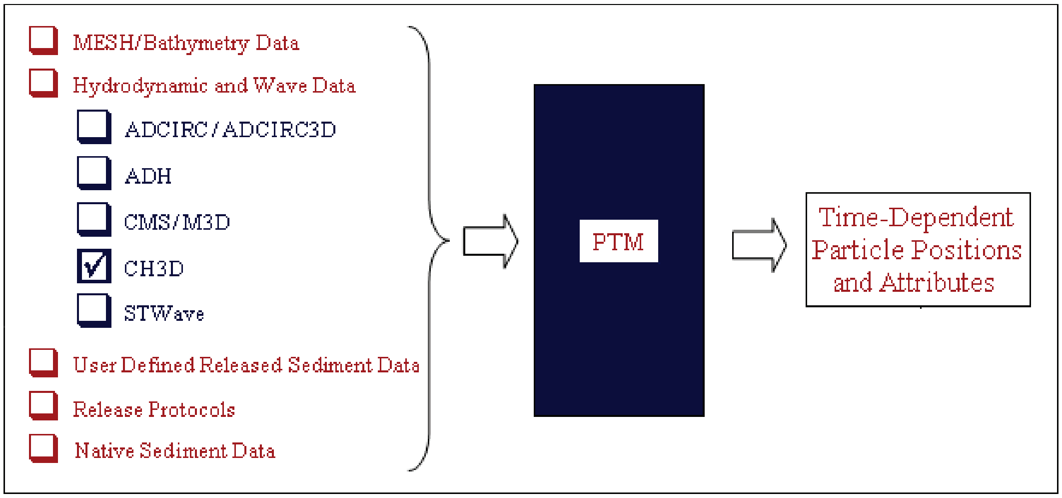


3 Particle Tracking Model (PTM)

Accurate prediction of the fate of sediments and other water-borne particulates is a key element in coastal engineering and dredged material management. These predictions are used to assess the impact of dredging and placement operations on contaminant transport, sensitive habitat, endangered species, rehandling, and beneficial use activity. The PTM, a Lagrangian particle tracker, addresses these needs by simulating sediment movement of multiple sediment types in a flow field (Davies et al. 2005; Lackey et al. 2007). Although a versatile model currently utilized in various coastal, estuarine, and riverine applications, PTM is specifically designed to predict the fate of material suspended during dredging and placement operations and to address the stability and fate of in-place sediment including dredged material mounds, sediment caps, and contaminated sediment deposits. PTM combines accurate and efficient transport computations with effective visualization tools, making it useful for assessment of dredging practices and proposed dredging operations. The interface for PTM is the Surface-water Modeling System (SMS) (Demirbilek et al. 2005a,b).

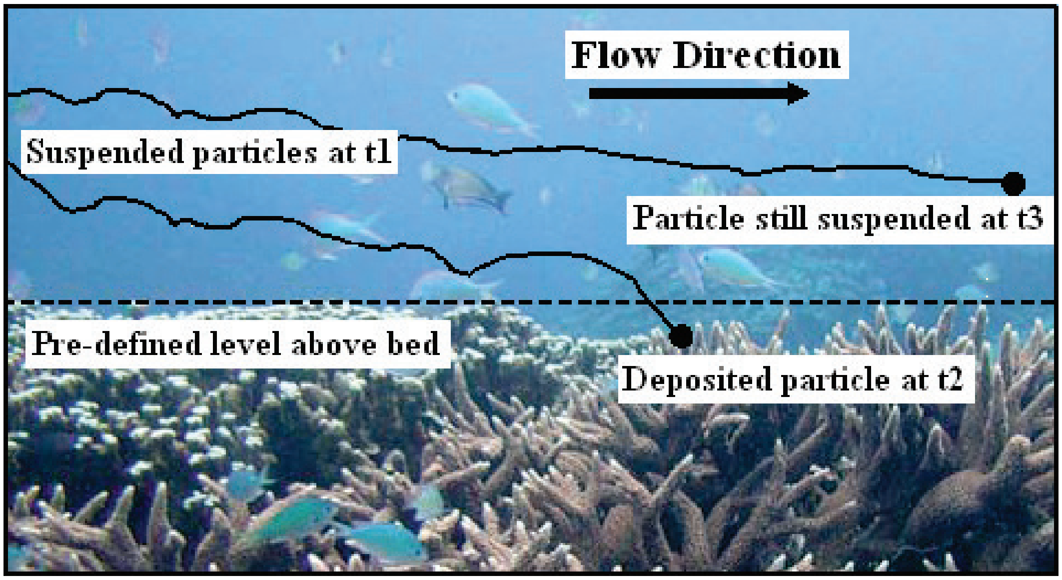
PTM models such processes as settling, deposition, resuspension, and particle-bed interactions to simulate the transport of both fine and coarse sediment. PTM requires the water surface elevation and velocity input of a hydrodynamic model, the mesh and bathymetry information of the model, and sediment characterization of both the native or bed sediment and the sediment sources (Figure 3-1). These sources may initiate from sediment resuspended during dredging and/or placement. Instead of undertaking the impossible task of modeling every grain of sand, silt, and clay, sediment is discretized into *parcels*. Each parcel is representative of a specific mass of sediment. These parcels preserve the overall size distribution and total mass of the sediment source. The model then steps through time tracking the position of each parcel. PTM output includes time-accurate horizontal and vertical positions of sediment parcels. Various other attributes such as mass, density, and suspension status are also assigned to each of the output parcels.

Figure 3-1. PTM model input and output schematic.



Particle settling speeds may be user-defined or determined by algorithms based on verified theoretical and empirical relationships. For this application, particle size and density are used to define settling. PTM also includes particle interaction with native sediments and the potential for resuspension. Resuspension potential is based on known parcel sediment characteristics, native bed sediment characteristics, and water column processes (McDonald et al. 2006). PTM includes probabilistic methods to account for burial, hiding, etc. Resuspension of sediment deposited on complex coral reefs is poorly understood. Coral reefs include craggy surfaces with numerous crevices to trap sediment. For this reason and because of the low current velocities at this site (see Chapter 4), the model applied here assumes that all particles which fall below a predefined level (2 cm away from the bed) are deposited and are not allowed to resuspend (Figure 3-2). This provides a conservative estimate of sedimentation in the vicinity of the dredging operation. Specific parameter settings for this study are listed in Appendix C.

Figure 3-2. Modeling technique for deposition on coral reefs. For this application, the model assumes no resuspension once deposition occurs.



4 Bathymetry and Hydrodynamics

Bathymetry grid

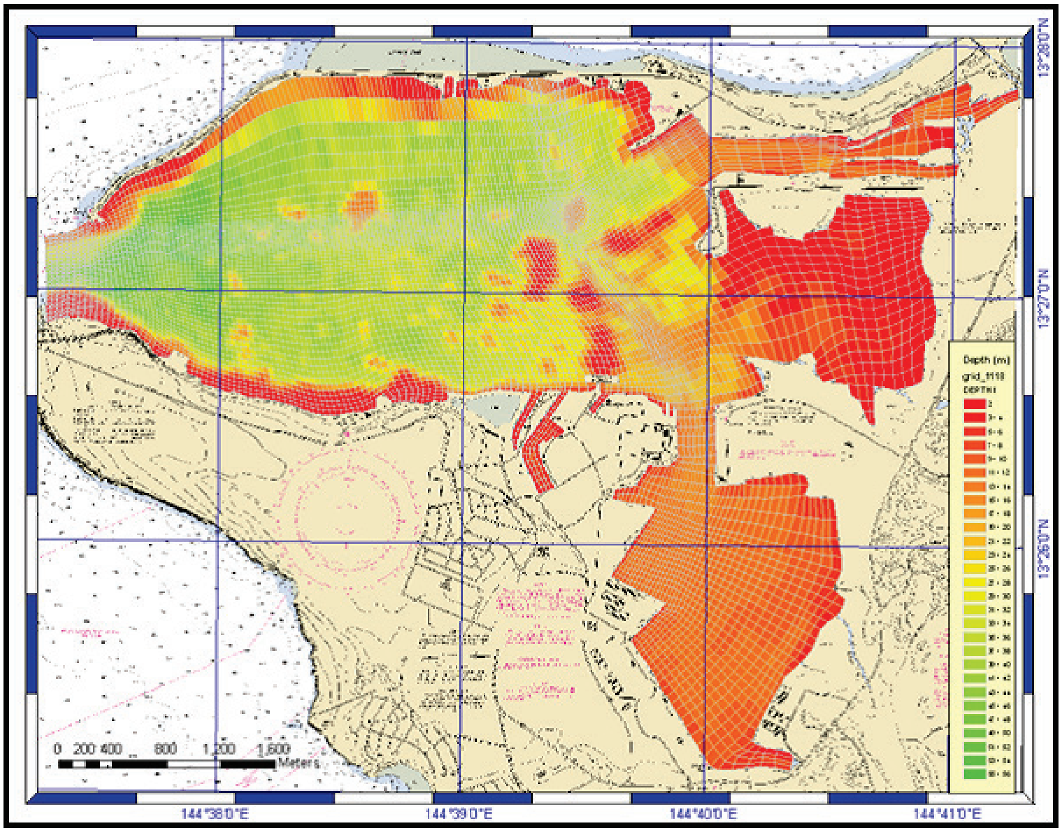
CH3D-Z (Curvilinear Hydrodynamic in Three Dimension—Z-plane version) is a general-purpose, three-dimensional (3D) hydrodynamic model for simulating flows in rivers, lakes, and coastal areas (Johnson et al. 1993). The model solves primitive equations and is based upon the Boussinesq approximation and the hydrostatic assumption. 3D internal mode and depth-integrated external mode use the same time step. For turbulence closure, a k-ε model is invoked. The numerical grid is boundary fitted in the horizontal dimension with the vertical dimension being Cartesian (z-plane). For this study, a curvilinear grid in the horizontal plane was generated for the CH3D-Z model. In the horizontal domain, 167 by 97 quadrilateral grid cells were generated. The resolution varies between approximately 30 m in the vicinity of the navigation channel (including the coral reefs defined in Figure 2-2) and 200 m west of the area of interest. The vertical grid is in the z-plane and has increments of 2 m. The maximum depth was set as 56 m, corresponding to 28 layers. Figure 4-1 shows the extent of the grid. The colors represent depths. Bathymetric data from various sources were gridded at 2 , 10, and 20 m resolutions to compile a final comprehensive bathymetry for the site. In addition, National Oceanic and Atmospheric Administration Electronic Navigational Charts (NOAA ENC) (electronic nautical chart) digital sounding data were utilized. The available data for each grid cell were averaged. The elevation values were then rounded to the nearest 2 m (resolution of the z-grid). The distribution of corals was also considered (Figure 2-2).

Hydrodynamic simulation period and input forcing parameters

The simulation covers a 3-month period between 1 November 2007 and 31 January 2008. This 3-month period coincides with the acoustic doppler current profiler (ADCP) deployment period by TEC, Inc. (Sea Engineering 2009) when field data could be used for model calibration. The major driving forces are the water surface elevations at the entrance of the harbor and surface wind. The source of the water level information was the NOAA tide gage at Apra Harbor (ID 1630000) (Latitude: 13° 26.3' N Longitude: 144° 39.2' E). The tide has both diurnal and semidiurnal constituents. For wind forcing, the first 2 months between 1 November 2007 and 31

December 2007 is from Apra Harbor, and the third month of January 2008 is from the Guam Airport. The dominant wind direction is westerly (180°). The model time step was 10 s.

Figure 4-1. Model grid shown with water depths.



Hydrodynamic simulation calibration and results

For analyses, the hourly water levels and currents were extracted from seven ADCP locations (Figure 4-2). Calculated water levels were compared favorably to the observations. Figure 4-3 shows a portion of time series of water levels at the CM2 location. Direct comparison of currents is difficult because ADCP signal tends to contain high frequency variations. Instead, the profiles of mean current speeds were compared. Figure 4-4 shows that the model reasonably represents current profile at the CM7 location.

Figure 4-2. ADCP locations used for model calibration.

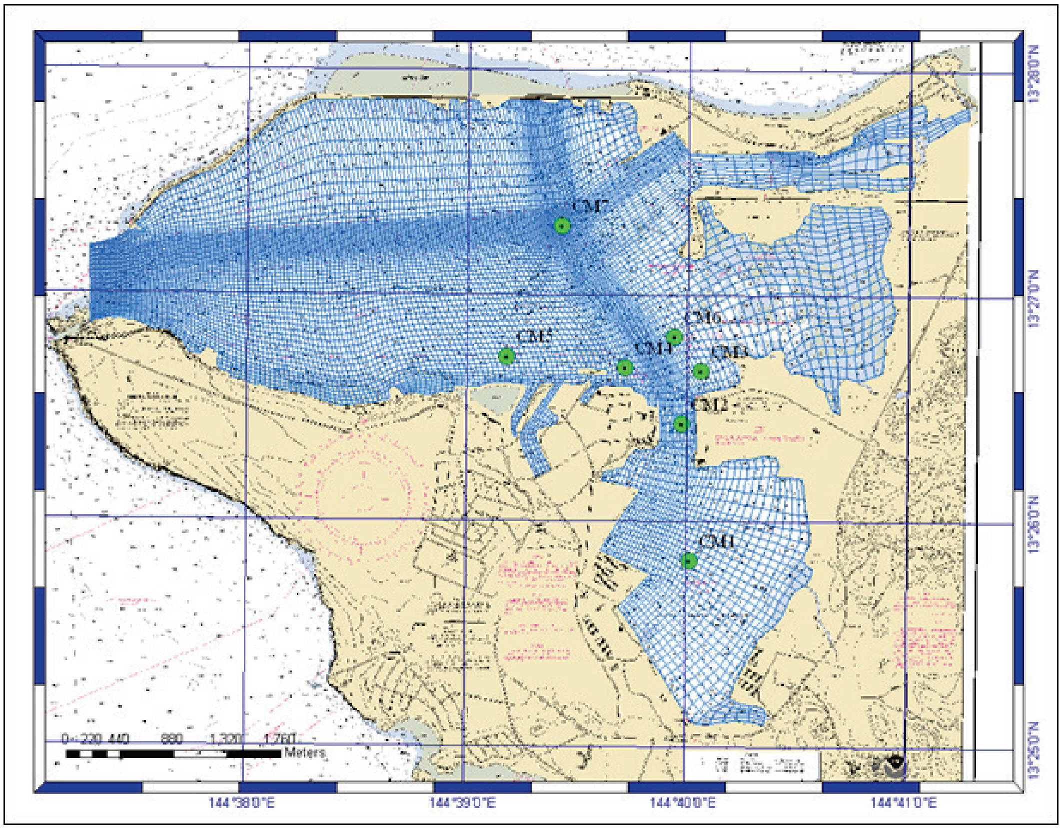


Figure 4-3. Sample water level time series at CM2.

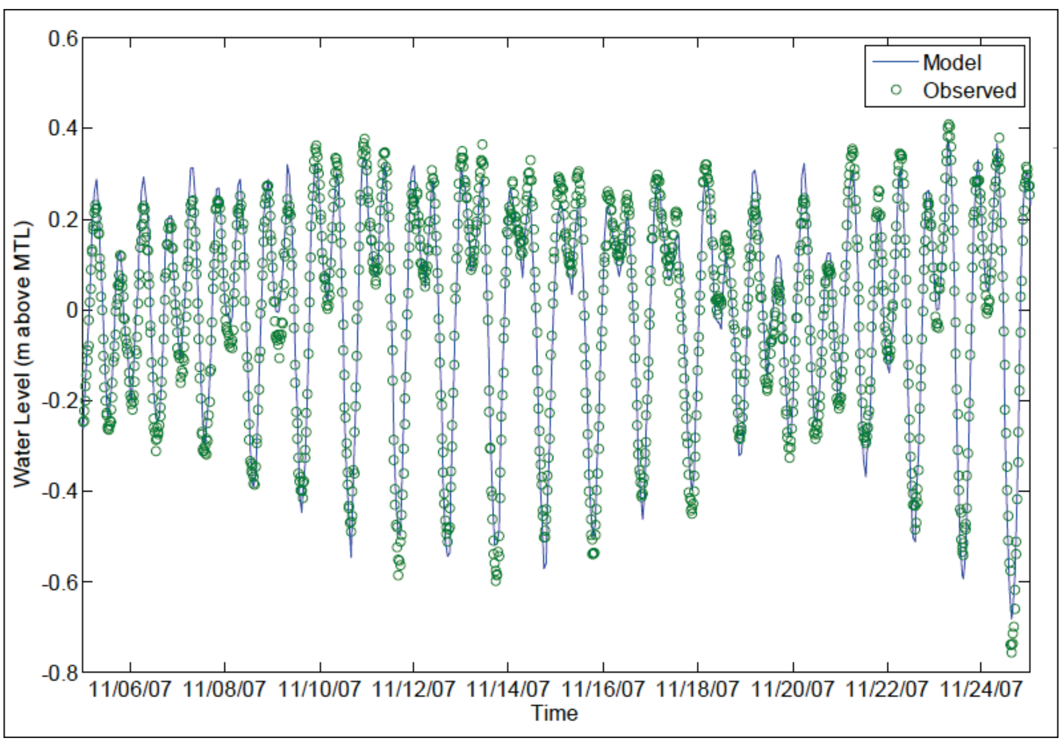
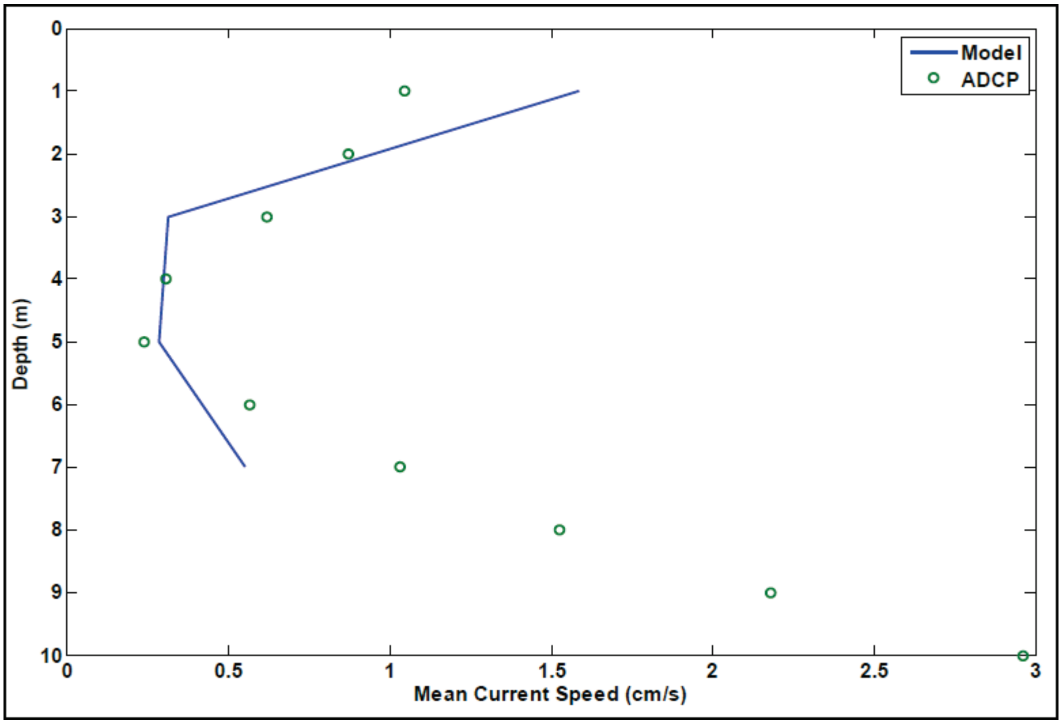


Figure 4-4. Mean current speed at CM7.



Figures 4-5 to 4-11 show the water levels and speed direction of currents at surface (red) and bottom (blue) layers, respectively. There was little variation in water levels among observing locations. Shear between surface and bottom layers was apparent. Inner harbor (CM1) shows small currents at maxima of approximately 1.5 cm/s. In the navigation channel (CM3, CM6, CM7), the maxima for surface currents reached 4 cm/s. Also shown are veering of currents over depths except shallow shoals (CM2 and CM5). For example, CM6 showed bottom currents were under 1 cm/s most of times, but surface currents reached over 2 cm/s. The directions of surface and bottom currents were opposite (180° difference). The small bottom current of less than 1 cm/s implies resuspension of deposited sediments was unlikely.

Figure 4-5. Extracted water level and currents at CM1.

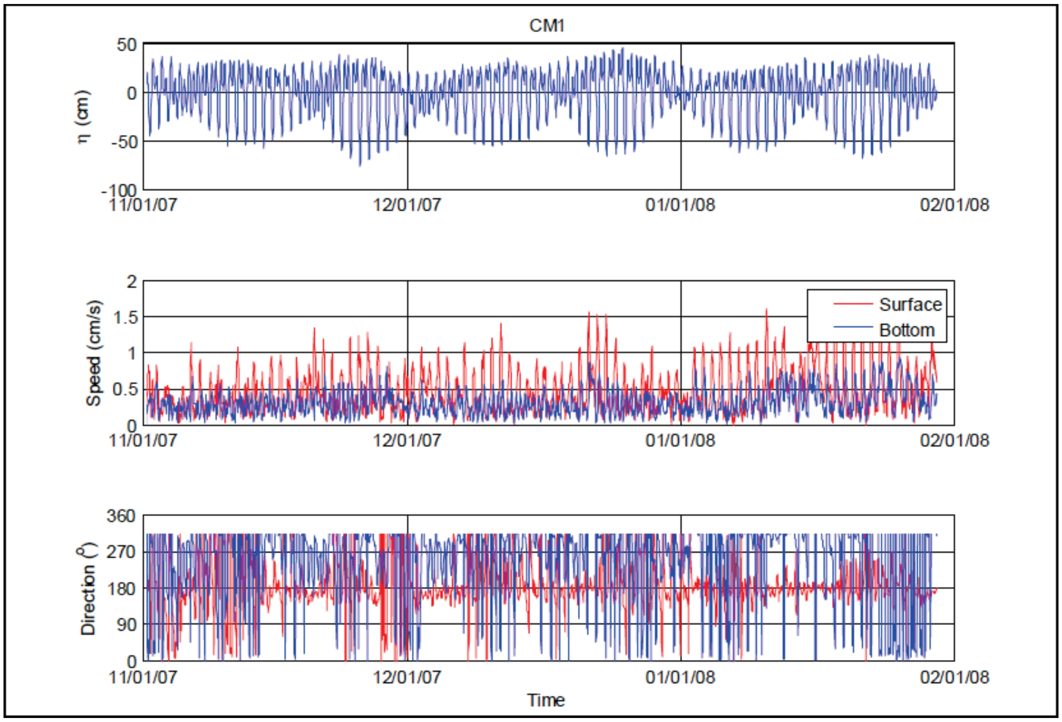


Figure 4-6. Extracted water level and currents at CM2.

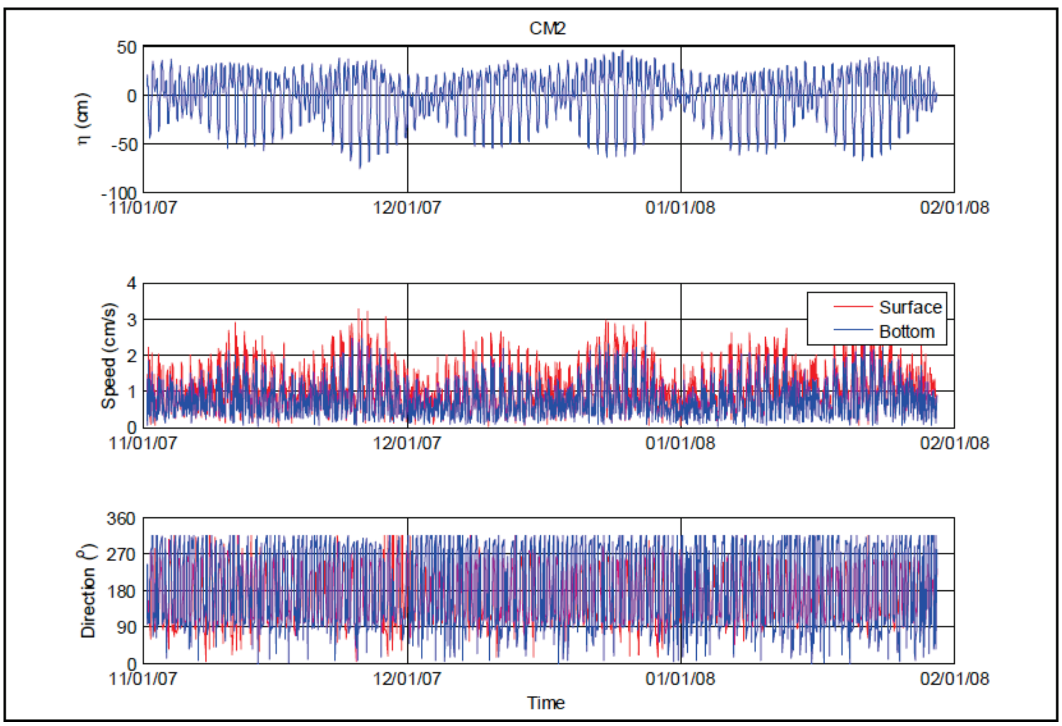


Figure 4-7. Extracted water level and currents at CM3.

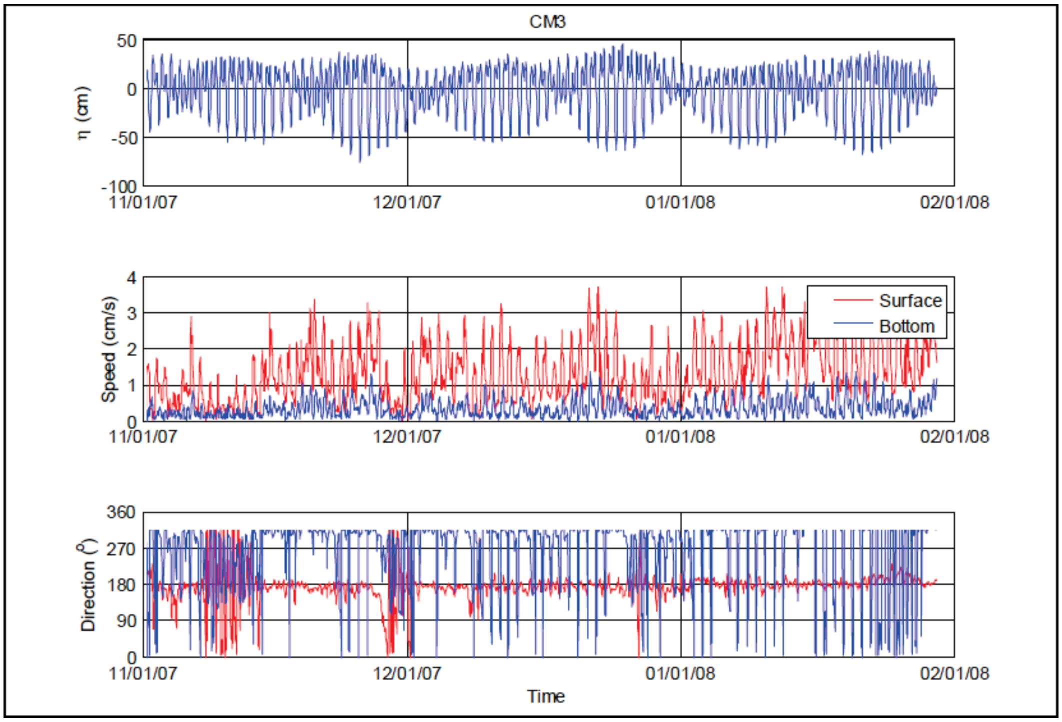


Figure 4-8. Extracted water level and currents at CM4.

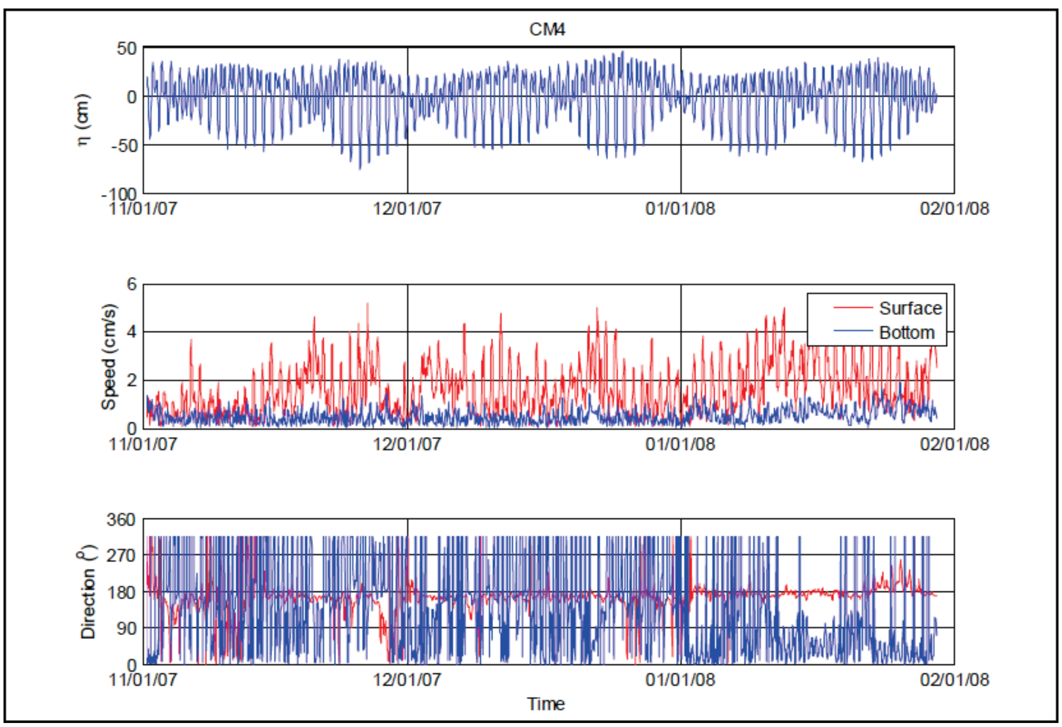


Figure 4-9. Extracted water level and currents at CM5.

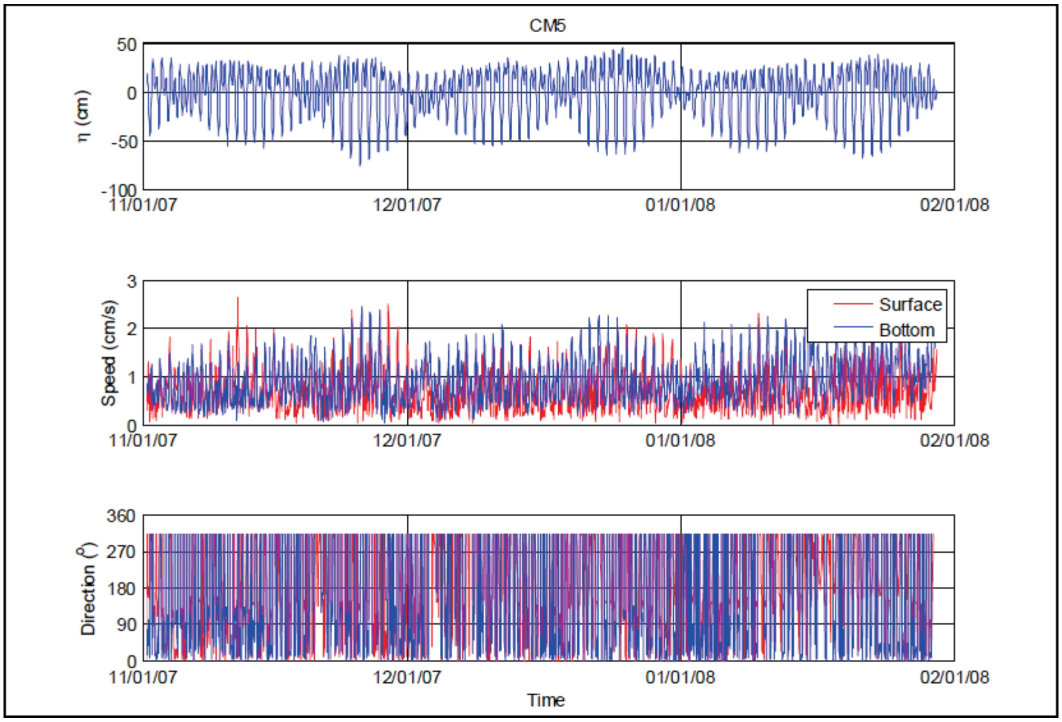


Figure 4-10. Extracted water level and currents at CM6.

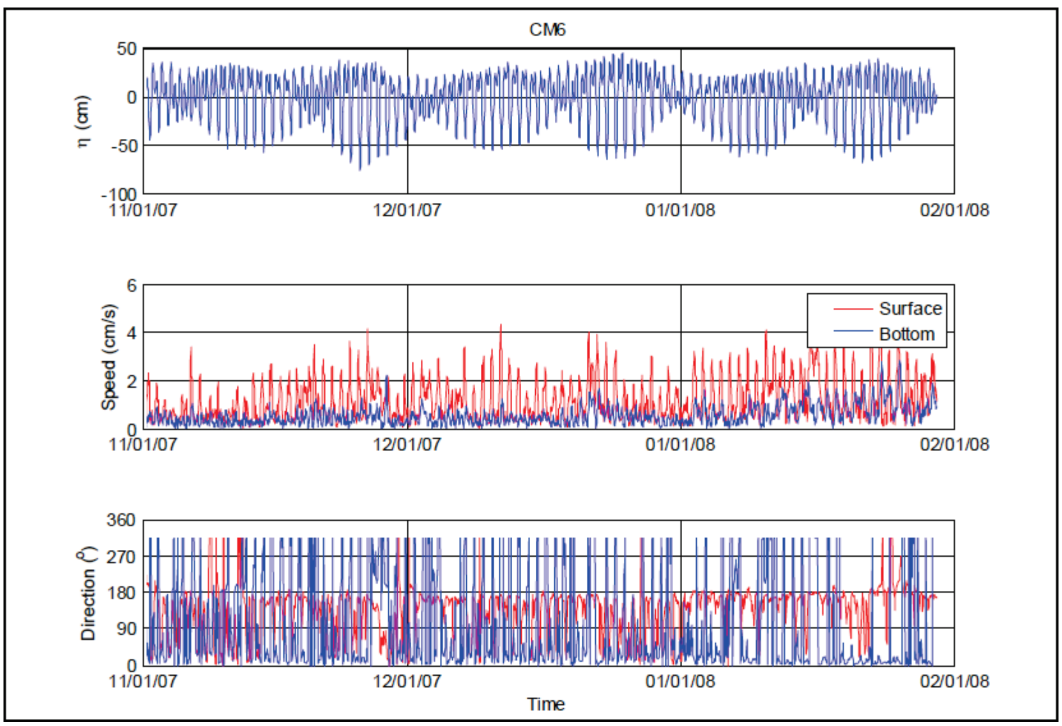
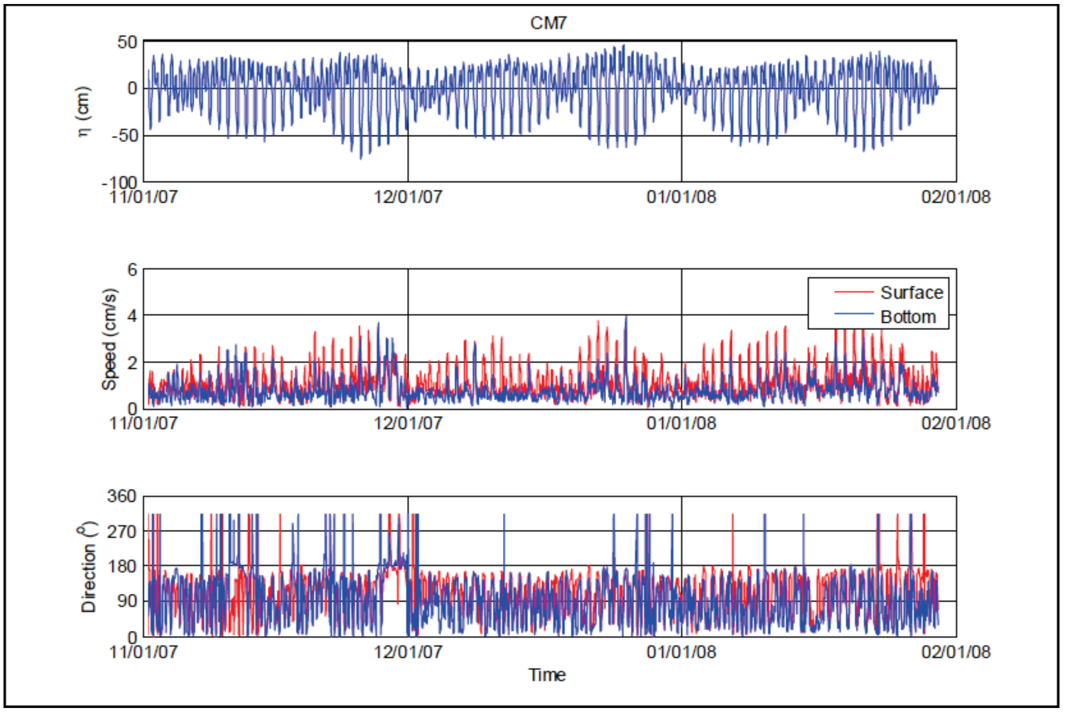


Figure 4-11. Extracted water level and currents at CM7.



5 PTM Suspended Sediment Sources and Dredging Scenarios

Install the template file

Dredging introduces sediment into the water column, which PTM is designed to track. To simulate the sources of dredging-derived suspended material, PTM requires the following information: size distribution of suspended sediment, sediment density, rate of sediment introduction, position (x,y,z) of sediment introduced into the water column, and start and stop time of dredging operations. The derivation of these input parameters is discussed below.

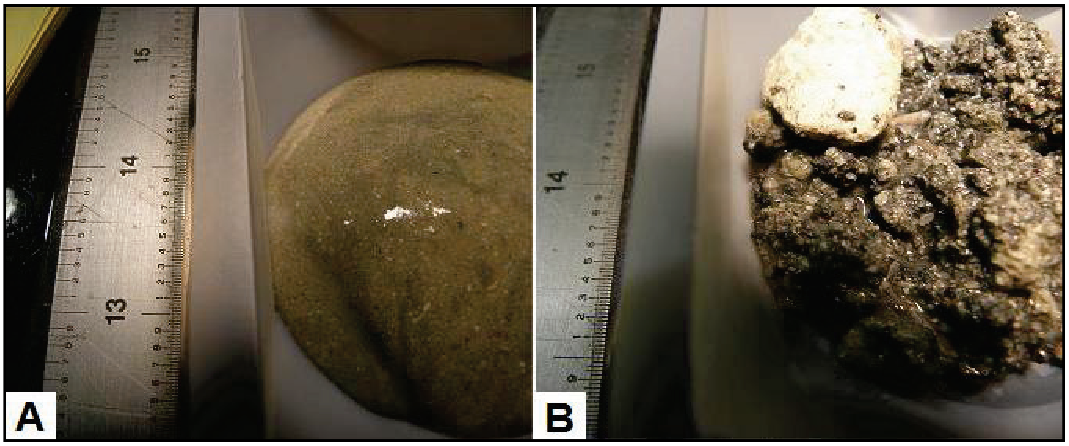
Sediment analysis

Four sets of sediment samples were collected in the vicinity of the project area and analyzed to determine their sediment size distributions. These sets include the following:

a. May 2006–a set of sediment cores as discussed in Weston Solutions and Belt Collins Hawaii (2006)
b. November 2007– a set of grab samples as discussed in Sea Engineering (2009)
c. December 2009–a set of sediment cores as discussed in Weston Solutions and Element Environmental (2010)
d. November 2010–a set of grab samples that were analyzed at ERDC for this project.

Some of the samples contained mostly fine material (silts and clays) while others contained mostly coarse sands as shown in Figure 5-1. However, these were extremes; most of the samples were fairly similar and intermediate in distribution. A review of the samples failed to show a consistent gradation of distributions across the study area. Therefore, it was deemed appropriate to only segregate the samples into three groups: (1) those taken adjacent to the Polaris Point shoreline, (2) those taken adjacent to the Ship Repair Facility shoreline, and (3) those taken inside the Turning Basin (approximately defined as the area inside the black line in Figure 2-2, excluding the two shorelines). Some of the sets contained additional samples that were taken from outside the study area (e.g., from Inner Apra Harbor). These were excluded from this analysis.

Figure 5-1. (A) Example of fine sediment sample [Set d, Sample B30]. (B) Example of coarse sediment sample [Set d, sample B05].



The distribution of the 75 total samples is listed in Table 5-1. The table shows that there were many more samples taken from the Turning Basin, but these samples cover an area over 50 times larger than either of the two shoreline locations.

Table 5-1. Number of sediment samples.

Data Set	Turning Basin	Polaris Point	Ship Repair	Total
a	6	5	3	14
b	8	0	0	8
c	6	8	4	18
d	33	1	1	35
Total	53	14	8	75

Though the samples were taken in different years using different methodologies (cores and grab samples) and analyzed in different labs, there was little systematic difference in the different data sets. An example of this is shown in Figure 5-2. This figure shows average Turning Basin sediment distributions for the four data sets, along with an overall average.

Figure 5-2 illustrates one analysis artifact. Different coarse and fine analysis endpoints were used for the size distribution analyses carried out in different laboratories. To obtain smooth average curves for the three sites, a slight amount of curve smoothing was done to produce the average curves shown in Figure 5-3 for the three locations. Table 5-2 lists the percentage of sands, silts, and clays for these three curves. In this analysis, the boundary between silts and clays is 8 phi (0.0039 millimeters [mm]) and between sands and silts is 4 phi (0.0625 mm). These boundaries are shown by the heavy vertical dashed lines in the sediment size distribution plots.

Figure 5-2. Turning Basin average sediment distributions obtained from different data sets.

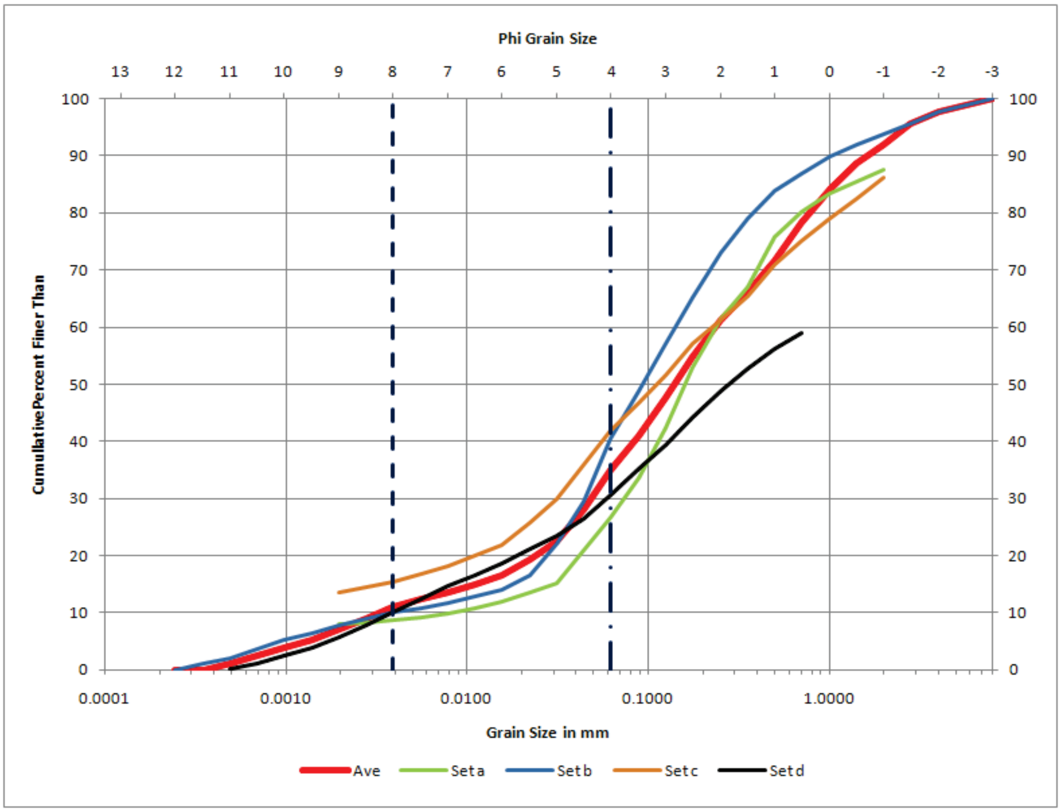


Figure 5-3. Average sediment distribution curves for the three locations.

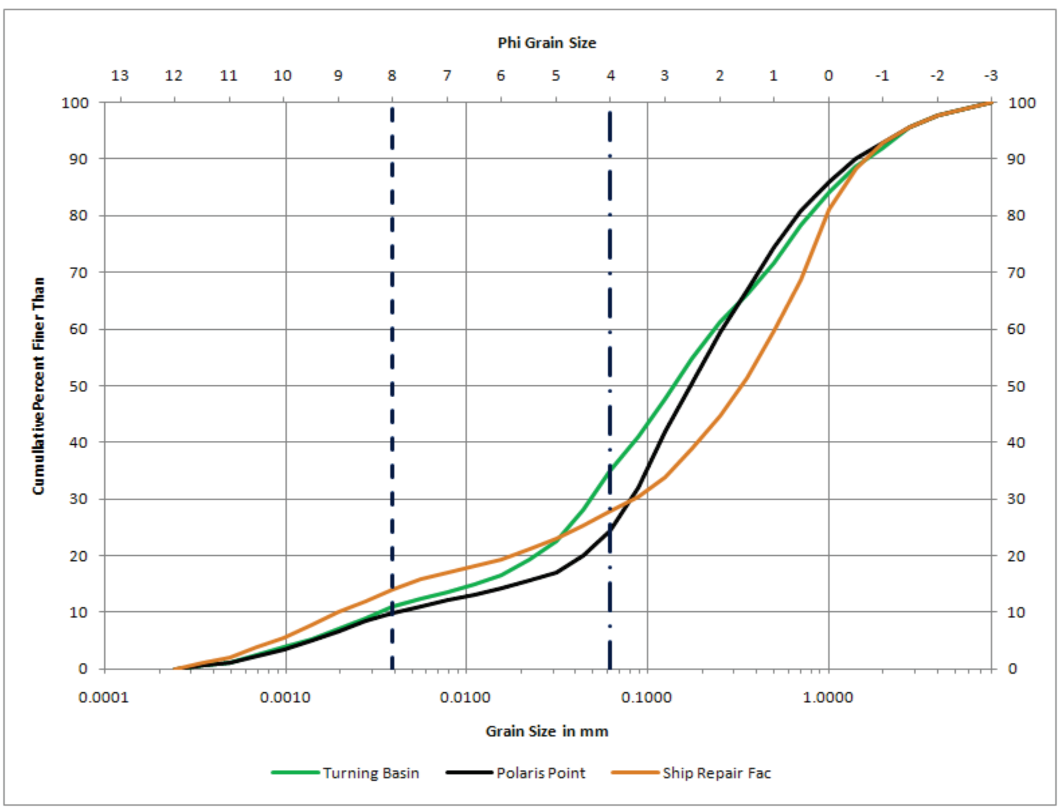


Table 5-2. Percent sediment size fractions.

Sediment	Turning Basin	Polaris Point	Ship Repair
% sand	65.1	75.6	72.3
% silt	23.8	14.5	13.7
% clay	11.1	9.9	14.1
% fines	34.9	24.4	27.7

To appropriately model the behavior of the fine material, the average curves were then separated into sand, silt, and clay fractions. An example of this for the Turning Basin is shown in Figures 5-4 through 5-7. The median and standard deviation values shown in Table 5-3 were then calculated for these three subsets. These values were used as inputs to the PTM model. Grain sizes for the silt and clay fractions closely bracket the measured suspended sediment grain size values observed during the recent dredging at Kilo Wharf (Sea Engineering 2010).

Figure 5-4. Turning Basin average sediment size distribution curve.

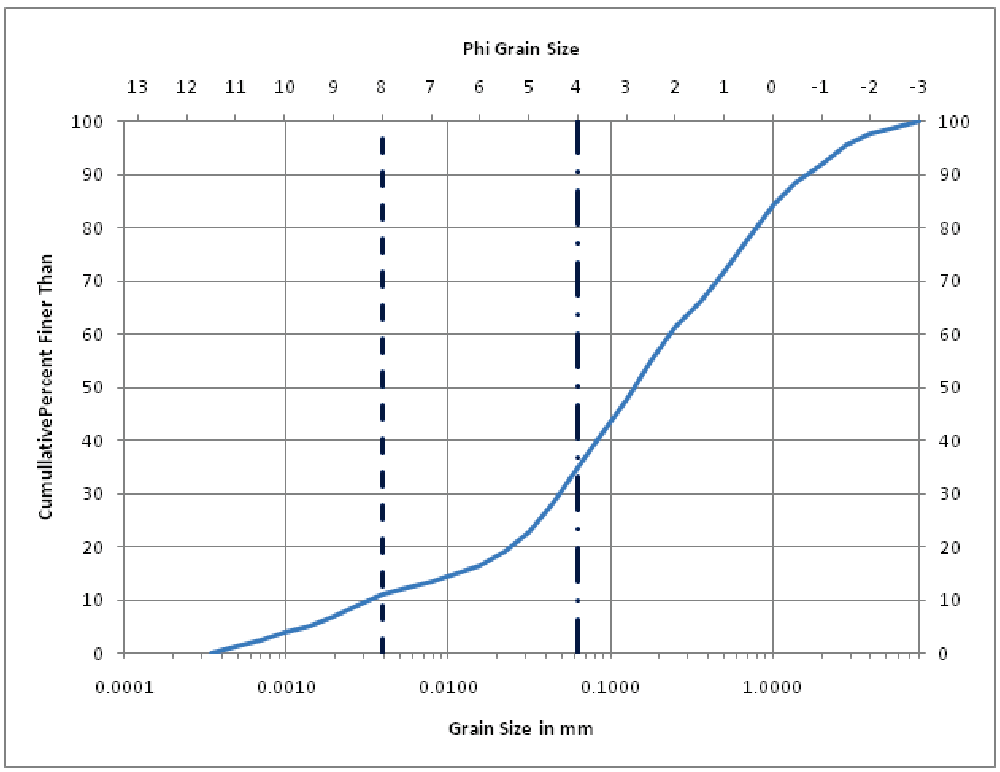


Figure 5-5. Turning Basin average size distribution curve for sand size sediments.

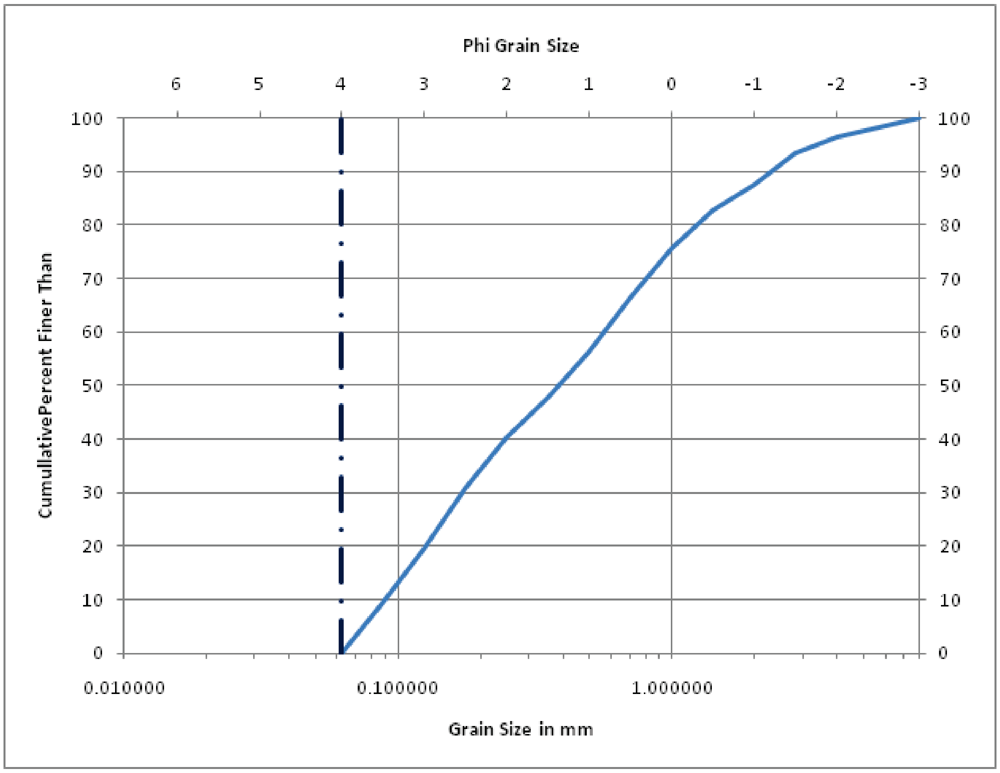


Figure 5-6. Turning Basin average size distribution curve for silt size sediments.

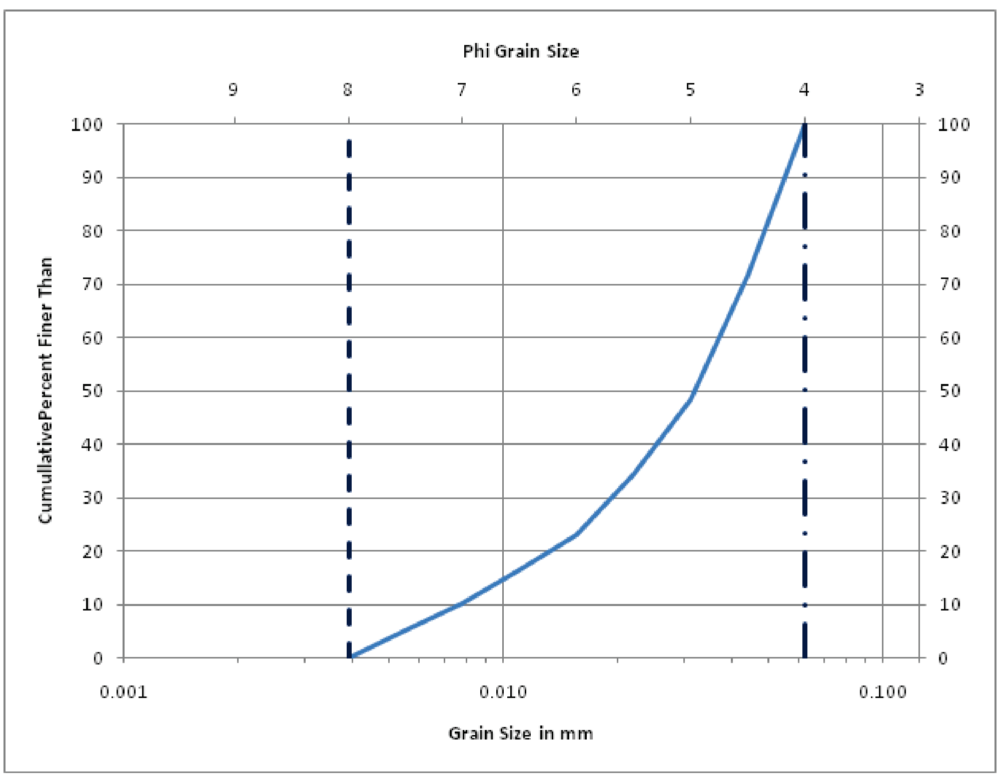


Figure 5-7. Turning Basin average size distribution curve for clay size sediments.

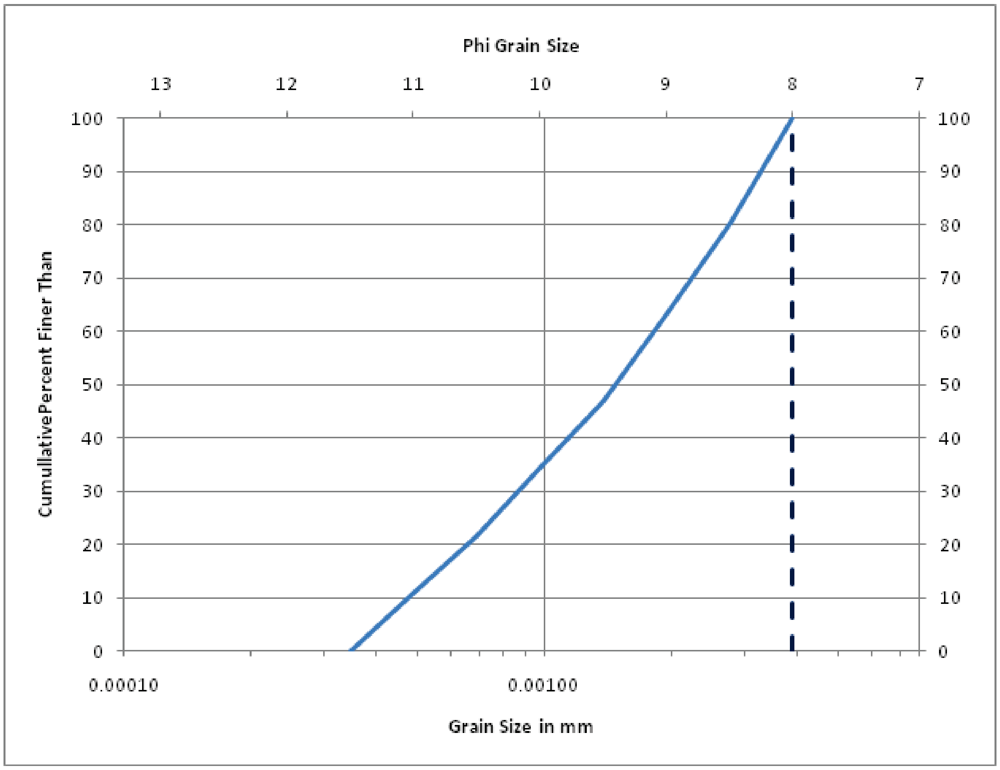


Table 5-3. Grain size statistics.

Location	Size	Median Grain Size (mm)	Phi Standard Deviation
Turning Basin	Overall	0.13986	3.086
	Sand	0.38596	1.907
	Silt	0.03207	1.126
	Clay	0.00147	1.175
Polaris Point	Overall	0.17388	2.590
	Sand	0.28350	1.749
	Silt	0.03137	1.362
	Clay	0.00134	1.141
Ship Repair Facility	Overall	0.33064	3.819
	Sand	0.58872	1.496
	Silt	0.02088	1.440
	Clay	0.00121	1.215

The majority of sediment in Apra Harbor is biologically derived carbonate material. These sands exhibit a wide range of densities, depending on conditions. For this study, a typical value found in the literature (King and

Galvin 2002) of 2,800 kilograms per cubic meter (kg/m^3) was used for all simulations.

The rate at which dredge-induced suspended material will be introduced into the water column at Apra Harbor is a function of many parameters, several of which are still being studied. To model this quantity, reasonable estimates had to be made for the dredging production rate, the suspended sediment loss rate, the distribution of the losses within the water column, and the effects of a silt curtain. Based upon recent dredging activities within Apra Harbor, it was assumed that a clamshell dredge would be employed, and two dredging production rates, 1,800 cubic yards per day (yd^3/day) and 1,110 yd^3/day (assuming 24 hours [hr] of dredging per day) were chosen. The higher value was based upon typical maximum production rates from dredging events in the vicinity of Alpha and Bravo wharfs[1], at Kilo Wharf (Sea Engineering 2010), and from previously modeled values (Sea Engineering 2009). While dredging logs show that this production value can be frequently reached on some days, entire dredging operation production rates are typically much lower, due to *down-time* events. However, using this production rate for the entire simulation was expected to produce the maximum sediment loadings to sensitive areas. For a production rate of 1,800 yd^3/day, the Lockwood project could be dredged in approximately a month. The project would take 1.5 months to complete using a production rate of 1,110 yd^3/day. The lower production rate is a more likely achievable, long-term production rate.

The percent of the dredge material lost or released during the clamshell dredging process was also required. Loss rates typically average less than 1% (Hayes and Wu 2001; Hayes et al. 2007; Bridges et al. 2008). A 2% loss rate was chosen as a maximum loss rate value, and a 1% rate was also modeled to conservatively represent a more average value.

This material is introduced into the water column at the bottom as the clamshell bucket picks up a load, while the bucket is ascending to the surface, and at the surface while the material is being transferred to a barge or other holding facility. A conservative estimate is that 40% is introduced near the bottom, 30% within the water column, and 30% near the surface[2].

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[1] Donald Murata, U.S. Navy, personal communication, 2010.

[2] Paul Schroeder, U.S. Army Engineer Research and Development Center, personal communication, 2010.

A silt curtain is expected to be used during dredging operations to reduce the suspended sediment load. Silt curtains are typically porous and deployed with a gap at the bottom to reduce the current drag. Therefore, the curtain permits some water and possibly a small portion of the finest sediments to pass through. A 3 m bottom gap was conservatively chosen for modeling purposes. Two silt curtain conditions were modeled, one that was 90% effective in stopping the finest material from passing (along with all of the coarser material) and a curtain that was 100% effective at stopping sediment passage (USACE 2005). Figure 5-8 shows how the vertical distribution of each kilogram of suspended sediment was modeled by PTM in the Turning Basin, assuming a 90% effective silt curtain. The curtain was assumed to stop all of the sand and silt-size material. Each kilogram of released material was assumed to contain 65.1% sand, 23.8% silt, and 11.1% clay (Table 5-2). Therefore, for each kilogram of material released into the water column during the dredging process, 3.3 grams (g) of clay were released within the top 3 m (1,000 g × 11% clay × 30% released near the surface × 10% curtain ineffectiveness). An additional 3.3 g of clay were released through the silt curtain in the middle of the water column. All other material released during the dredging operation was released in the lowest 3 m of the water column. For the condition with a 100% effective curtain, all material was released within 3 m of the bottom. At Polaris Point and Ship Repair Facility, the vertical distribution of the clay release was slightly different based upon the information in Table 5-2.

As shown in Figures 2-3 and 2-4, the volume of material to be dredged at each of the numbered sites was obtained by calculating the amount of material above the 51.5 ft contour. Tables 5-4 and 5-5 list the dredging time in days at each site for Polaris Point and Ship Repair Facility, respectively, assuming a production rate of 1,800 yd^3/day.

The anticipated total dredge volume is approximately 608,000 yd^3 for the Polaris Point alternative, and the anticipated total dredge volume is approximately 479,000 yds^3 for the Ship Repair Facility alternative. At a rate of 1,800 yd^3/day, Polaris Point would require over 11 months to dredge the entire entrance channel and wharf. Under the same conditions, the Ship Repair Facility would take just under 10 months. For computational efficiency, the modeling for each scenario was divided into a series of simulations, each lasting less than 3 months (5 for Polaris Point and 4 for Ship Repair Facility). When dredging was completed at a site (Figure 2-3 and 2-4), it began immediately at the next site. Dredge-site modeling proceeded from north to south (sensitivity analysis included alternative sequencing which had little effect on exposure estimates). The timing of the various model runs is listed in Table 5-6. Some of the larger dredge sites were divided further into subsites for modeling purposes.

Figure 5-8. Vertical distribution of sediment released, assuming a 90% effective silt curtain as modeled for the Turning Basin.

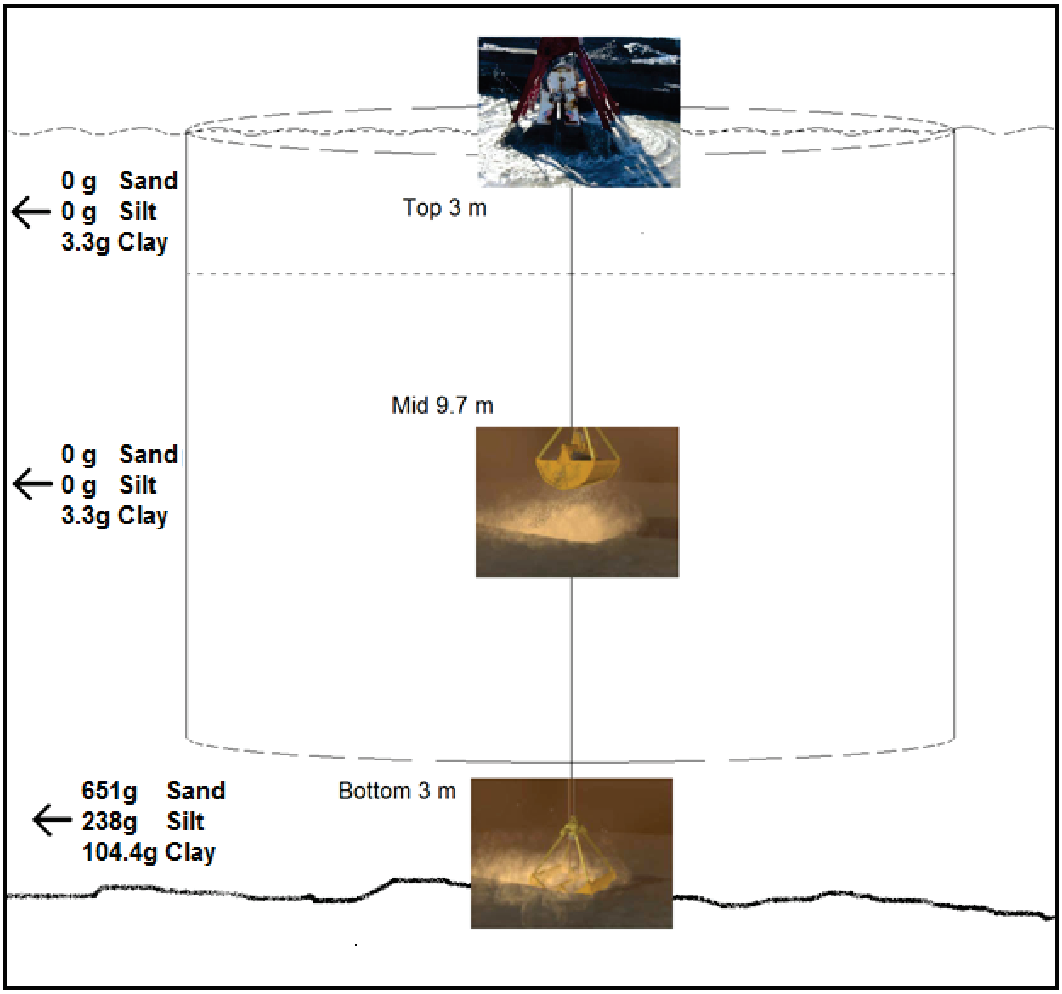


Table 5-4. Polaris Point dredging-site data.

Site Designation	Easting	Northing	Area (m^2)	Vol (m^3)	Dredging Time (days)
PPT01	246346	1488662	2,431	1,727	1.25
PPT02	246456	1488329	138	52	0.04
PPT03	246629	1488330	564	266	0.19
PPT04	246722	1488240	2,044	807	0.59
PPT05	246843	1488229	3,545	1,610	1.17
PPT06	246735	1488097	483	211	0.15

Site Designation	Easting	Northing	Area (m^2)	Vol (m^3)	Dredging Time (days)
PPT07	246726	1488027	2,480	6,755	4.91
PPT08	246838	1488060	159	47	0.03
PPT09	246969	1488129	1,754	1,444	1.05
PPT10	246997	1488201	46	11	0.01
PPT11	246878	1487962	6,769	4,211	3.06
PPT12	247014	1488024	1,110	719	0.52
PPT13	247215	1488114	176	75	0.05
PPT14	247209	1488037	773	1,247	0.91
PPT15	247158	1487753	196,941	161,952	117.68
PPT16	247430	1487546	1,736	1,233	0.90
PPT17	247195	1487380	101	71	0.05
PPT18	247565	1487443	24,400	282,413	205.21
TOTAL			245650	464849	338

Table 5-5. Ship Repair Facility dredging-site data.

Site Designation	Easting	Northing	Area (m^2)	Vol (m^3)	Dredging Time (days)
SRF01	246346	1488662	2,431	1,727	1.25
SRF02	246456	1488329	138	52	0.04
SRF03	246629	1488330	564	266	0.19
SRF04	246722	1488240	2,044	807	0.59
SRF05	246841	1488231	3,755	1,756	1.28
SRF06	246735	1488097	483	211	0.15
SRF07	246682	1488025	8,168	24,314	17.67
SRF08	246838	1488060	159	47	0.03
SRF09	246969	1488129	1,754	1,444	1.05
SRF10	246997	1488201	46	11	0.01
SRF11	246878	1487962	6,769	4,211	3.06
SRF12	247014	1488024	1,110	719	0.52
SRF13	247215	1488114	176	75	0.05
SRF14	247209	1488037	773	1,247	0.91
SRF15	247104	1487763	139,945	142,365	103.45
SRF18	246965	1487355	7,261	186,971	135.86
TOTAL			175577	366222	266

Table 5-6. Model runs to complete a scenario.

Run Name	First Parcel Release	Last Parcel Release	Run Ends	Run Days	Total Parcels	# of Dredge Sites
PPT-A	1/1/2010 0:00	2/26/2010 22:08	3/8/2010 22:08	66.9	65,753	22
PPT-B	2/26/2010 22:08	4/25/2010 6:04	5/5/2010 6:04	67.3	66,246	10
PPT-C	4/25/2010 6:04	7/9/2010 6:04	7/19/2010 6:04	85.0	86,683	7
PPT-D	7/9/2010 6:04	9/22/2010 6:04	10/2/2010 6:04	85.0	86,697	1
PPT-E	9/22/2010 6:04	12/5/2010 15:11	12/15/2010 15:11	84.4	85,978	2
SRF-A	1/1/2010 0:00	2/26/2010 22:08	3/8/2010 22:08	66.9	65,753	22
SRF-B	2/26/2010 22:08	4/25/2010 6:04	5/5/2010 6:04	67.3	66,246	10
SRF-C	4/25/2010 6:04	7/10/2010 3:40	7/20/2010 3:40	85.9	87,731	4
SRF-D	7/10/2010 3:40	9/24/2010 0:07	10/4/2010 0:07	85.9	87,678	3

Eight dredging scenarios were modeled in this exercise for each of the two sites (Polaris Point and Ship Repair Facility) (Table 5-7). The results for Case 1 to 4, which encompass the worst-case to best-case scenarios, will be described within Section 7. Cases 5 through 8 results are displayed in Appendices A-C. Parameters not listed in Table 5-7 were not changed between model scenarios.

Table 5-7. Case descriptions.

Case	Production Rate (yd^3/day)	Dredge Time (months)	% Loss	Silt Curtain Efficiency
1	1,800	12	2	90%
2	1,110	18	2	90%
3	1,800	12	1	100%
4	1,110	18	1	100%
5	1,800	12	1	90%
6	1,800	12	2	100%
7	1,110	18	1	90%
8	1,110	18	2	100%

6 Results

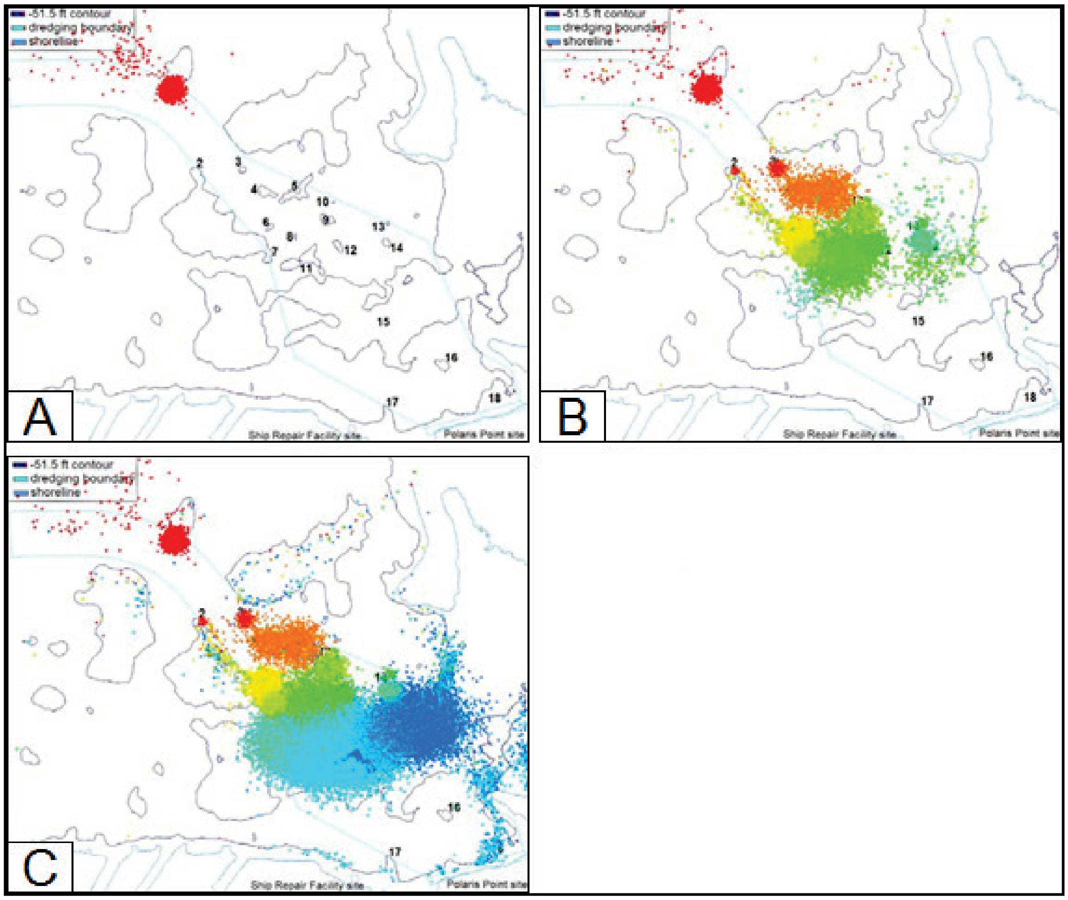
Four types of data analysis techniques were utilized in this project. The PTM provides time-dependent particle positions as output. These data were used to determine particle pathways and study general sediment movement. In addition, three types of maps (Concentration Map, Accumulation Map, and Rate of Deposition Map) were developed using the SMS Data Analysis options and utilized to provide useful information to help determine exposure. Data analysis tables were created to summarize results from the maps.

Particle pathways

Particle positions produced by PTM help to establish general sediment transport pathways. Figure 6-1 shows the particle positions at various times within the first two months of the Polaris Point operation for Case 1 (1,800 yd^3/day with 2% loss from the clamshell and 90% silt curtain efficiency) simulation. The particles are color coded based on their initial source locations. The order in which sites were dredged in the simulation follow the sequential numbering shown in Figure 2-3. Particle colors are contoured between red and blue for sites 1–15. Particle colors range from red, which represents sediment dredged at the Deep Reef area designated as site 1, and particles in blue, which were dredged from site 15 (Figure 2-3). After 1 day, only the area adjacent to Deep Reef has been dredged (Figure 6-1A). By Day 15, the majority of the upper portion of the dredging footprint has been dredged (Figure 6-1B). By day 30, dredging begins within site 15 and continues for another 30 days as shown in Figure 2-3. Day 61 until the completion of the approximately 12-month scenario in which dredging continues into site 16 through site 18 is not visualized in this figure.

Several observations can be determined by these snap shots of particle positions. First, it can be seen that generally sedimentation remains largely confined to the dredging footprint (Figure 2-2). The majority of the sediment is confined within the outer dashed line, which represents the distance of 200 m away from the footprint shown in Figure 2-2. In addition, it is evident that sediment dredged at each site generally stays near the dredge site. Therefore, it can be concluded that lateral transport is nominal because of the small velocities within Apra Harbor. The model also indicates that sediment tends to deposit shortly after initial suspension.

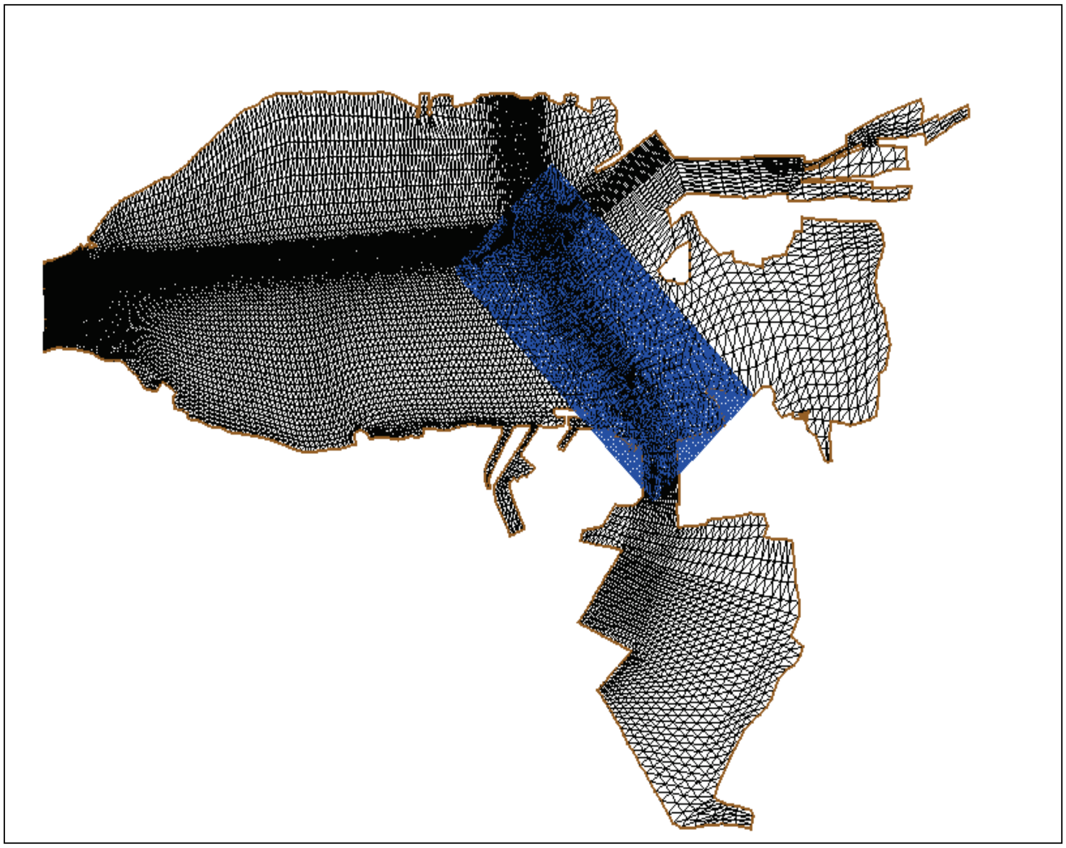
Figure 6-1. Particles at (A) 1 day , (B) 15 days, and (C) 60 days. Particles are colored based on source.



Cartesian grid mapping technique

The grid mapping technique for the accumulation, concentration, and rate of deposition maps was performed using SMS. As stated previously, PTM utilizes a finite element mesh (Figure 6-2, black) for particle tracking of the sediment. Output includes time-dependent particle positions. Each particle is representative of a designated mass of sediment. The particles retain relevant data, including grain size, mass, density, etc. The data is post-processed to create contour maps of relevant data, such as concentration. A Cartesian grid (Figure 6-2, shown in blue) is placed within the area of interest. At each time-step, particles located within a grid cell are used to calculate deposition, concentration, and accumulation for that cell. The resulting values can be used to create contoured maps of the properties. For this work, each grid cell is 60 m × 60 m, and the total area of the grid is approximately 2.5 million m^2.

Figure 6-2. PTM finite element mesh (black) with data analysis Cartesian grid (blue).



Total accumulation

Figure 6-3 shows the total accumulation from the Polaris Point and Ship Repair Facility dredge footprints for the Case 1 conditions. These maps represent the total accumulation of sediment within an area due to deposition of resuspended dredged material at the end of the dredging project. In Case 1, this means the accumulation is over an approximately 1 yr period. The values shown on the map range from 5 g/cm^2 (red) to 0.05 g/cm^2 (blue). The greatest sedimentation is found close to Polaris Point and the Ship Repair Facility, respectively. This is expected because the largest amount of material is dredged in those areas. Also, the majority of the sediment accumulates within the navigation channel footprint, which is consistent with the results from the particle position snapshots seen in Figure 6-1. There are a few regions such as the south-western portion of the footprint where sediment deposits outside of the footprint (solid black line). Values there generally remain less than 0.6 g/cm^2. Within the ship repair facility map there is one small region in which the contour values present outside of the footprint area range from 0.60 to 1.15 g/ cm^2. A time-series of accumulation from a point within that region is shown in Figure 6-4. In the graph, accumulation is represented by the vertical axis, and time (in days) is on the horizontal axis. The specific point from which this data were extracted is denoted by a red star on the map beside the graph. The graph shows a maximum value of accumulation of 1.08 g/cm². Also seen in the graph is that sedimentation occurs over time. Initially values increase very little. Then, at approximately 120 days, there is an increase from 0.01 g/cm² to 1.1 g/cm². This time period corresponds to dredging near the starred location. Note that dredging controls can be used to reduce sedimentation outside of the channel footprint. For example, dredging near the edge of the footprint can be confined to time periods when tidal currents would move the material back toward the channel. This type of dredging control will reduce volumes deposited outside the channel footprint. Dredge control measures were not used in these simulations.

Figure 6-3. Case 1 accumulation contours for Polaris Point and Ship Repair Facility.

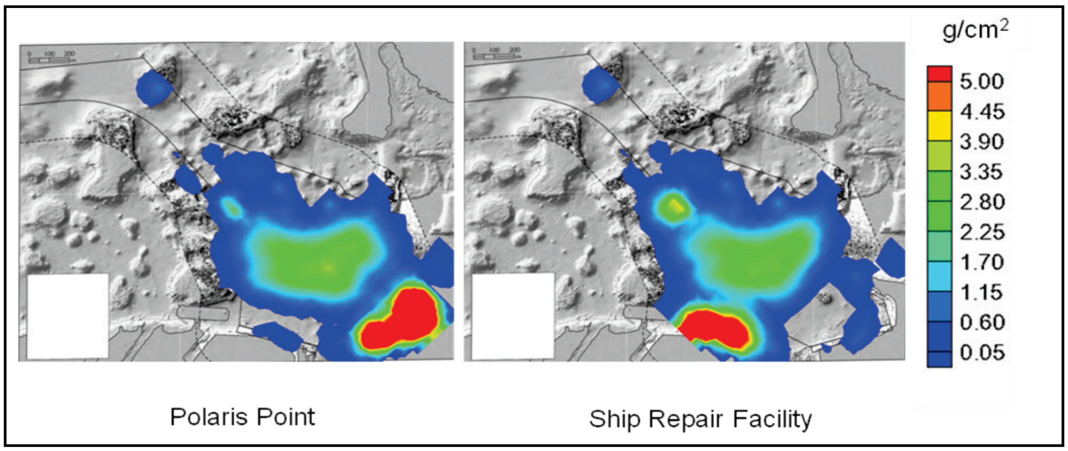
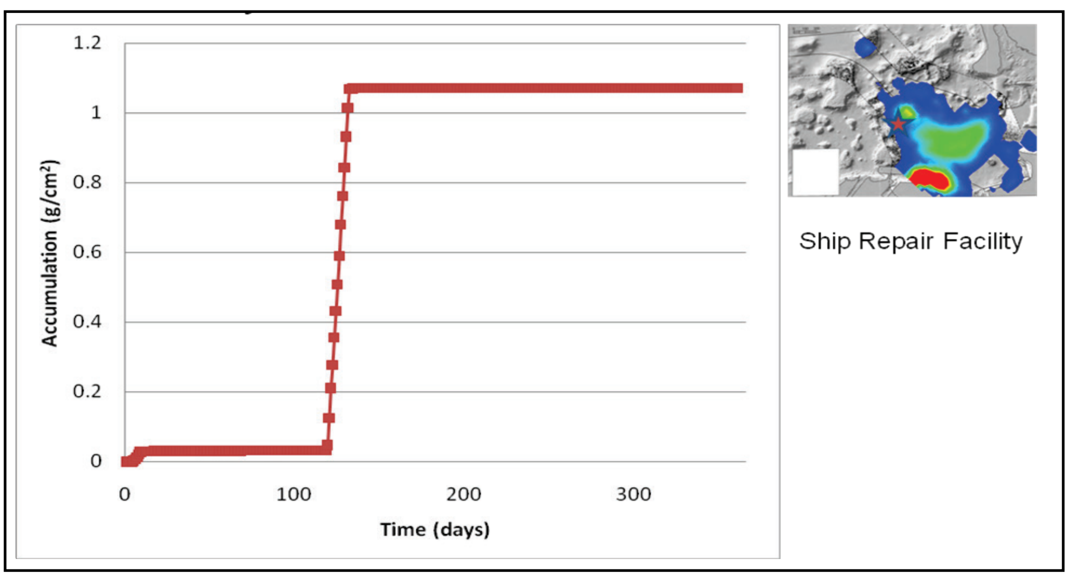


Figure 6-4. Ship Repair Facility, Case 1 accumulation time-series at specified point (denoted by red star).



Figures 6-5, 6-6, and 6-7 show results for Cases 2, 3, and 4, respectively. Case 2, which differs from Case 1 only by a lower dredging rate, produces results of total accumulation similar to that of the Case 1 scenario. This is to be expected because the total loss during the dredging operation remains the same. However, it can be seen that Case 3 and Case 4 have lower values of accumulation. In both these cases, the loss is reduced from 2% to 1%, and the silt curtain is assumed to be 100% effective. Therefore, there is less sediment introduced into the water column, and the sediment that is released occurs lower in the water column.

Figure 6-5. Case 2 accumulation contours.

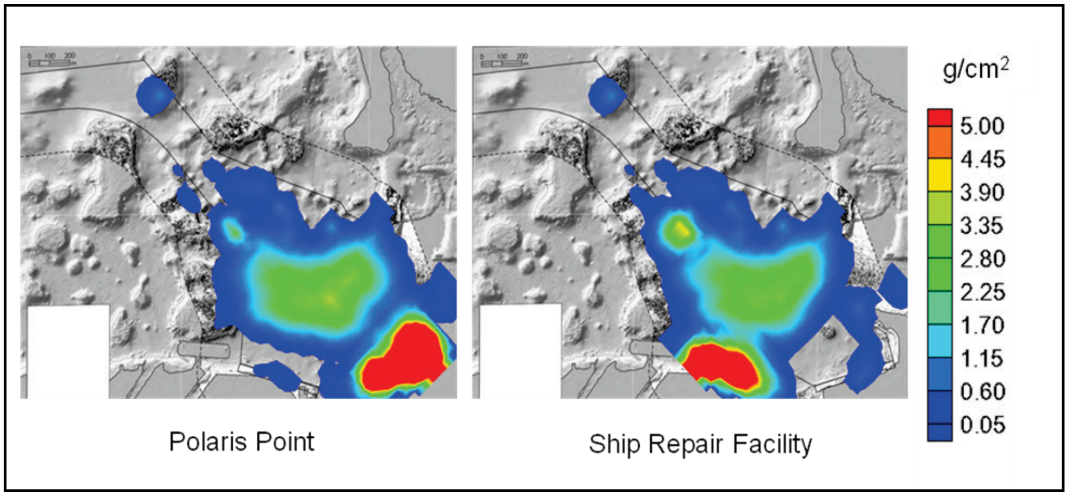


Figure 6-6. Case 3 accumulation contours.

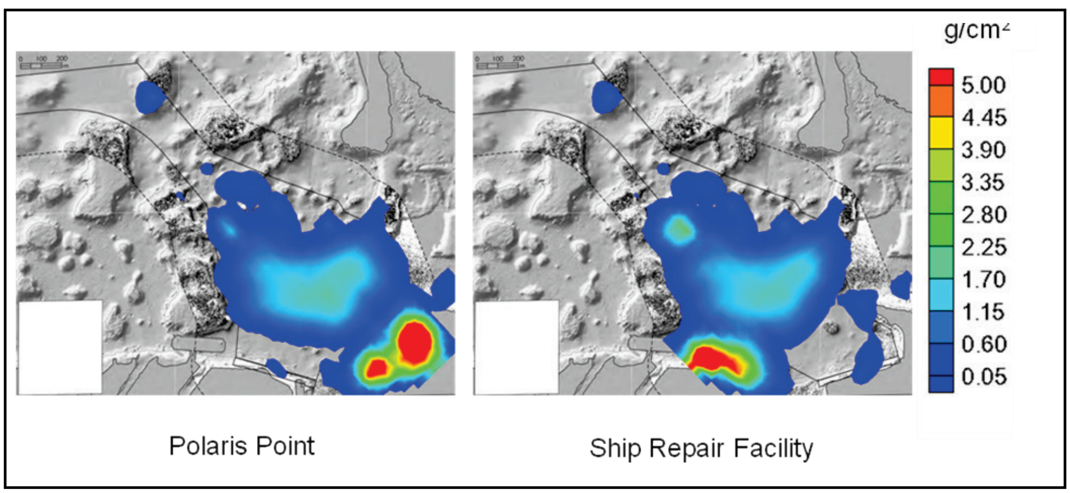
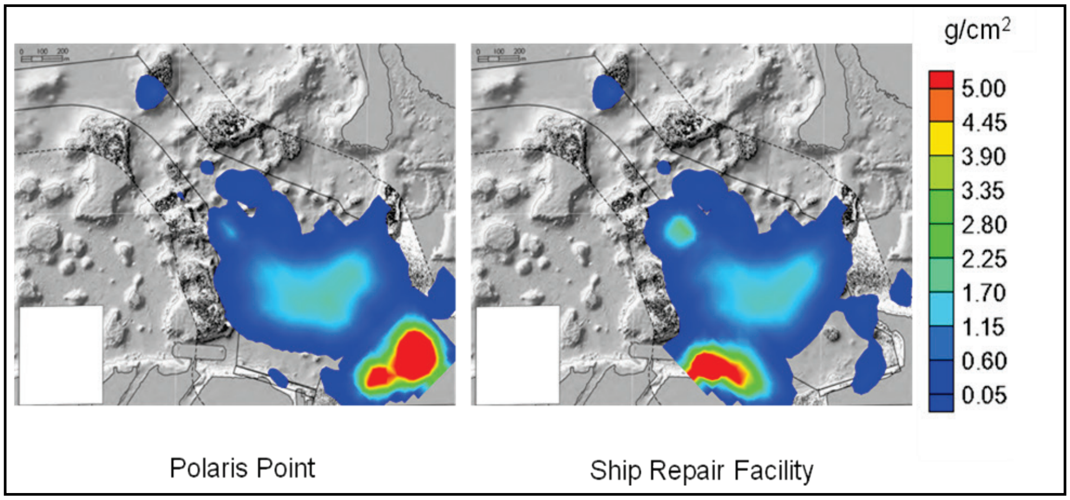


Figure 6-7. Case 4 accumulation contours.



Maximum deposition rate

Maximum deposition rate is defined as the greatest daily rate of sedimentation that occurs at each grid cell during any time in the simulation. Therefore, the resulting plots are not indicative of any snapshot in time but rather are a compilation over time of the maximum sedimentation rate value in the time-series at each individual grid cell. Figures 6-8, 6-9, 6-10, and 6-11 show the maximum deposition rate for Cases 1, 2, 3, and 4, respectively. The values are given in g/cm²/day. The time at which the maximum deposition occurs at each grid cell generally corresponds to the time at which dredging occurs in a nearby location. In the figures, maximum deposition rate is primarily less than 0.70 g/cm²/day. For Case 1, which is the most conservative case, the values outside the footprint (but within the 200 m line) remain less than 0.25 g/cm²/day. For Case 2, the values decrease slightly due to the lower dredging rate. In Case 2, dredging takes 18 months, and in Case 1, dredging takes 12 months. Case 2 maximum values are approximately 0.45 g/cm²/day. Case 3 indicates lower sedimentation rates than either Cases 1 or 2 due to the lower loss rate. Sedimentation rates outside the channel prism are further reduced because all sediment is introduced in the lowest 3 m of the water column. The lowest sedimentation rates are estimated for Case 4 which has not only the 18-month dredge period but also the lower dredging rate and the 100% effective silt curtains. Maximum values in this case are 0.25 g/cm²/day within the dredging footprint and 0.10 g/cm²/day within the 200 m line.

Figure 6-8. Case 1 maximum deposition rate contours.

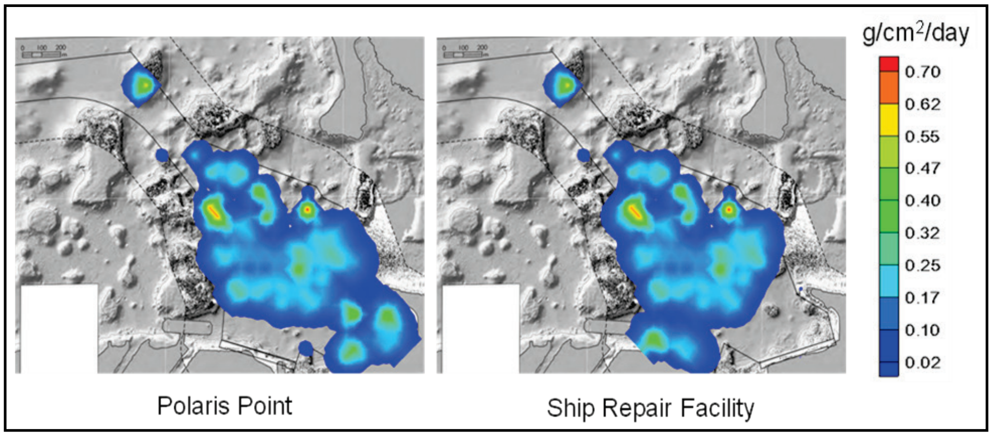


Figure 6-9. Case 2 maximum deposition rate contours.

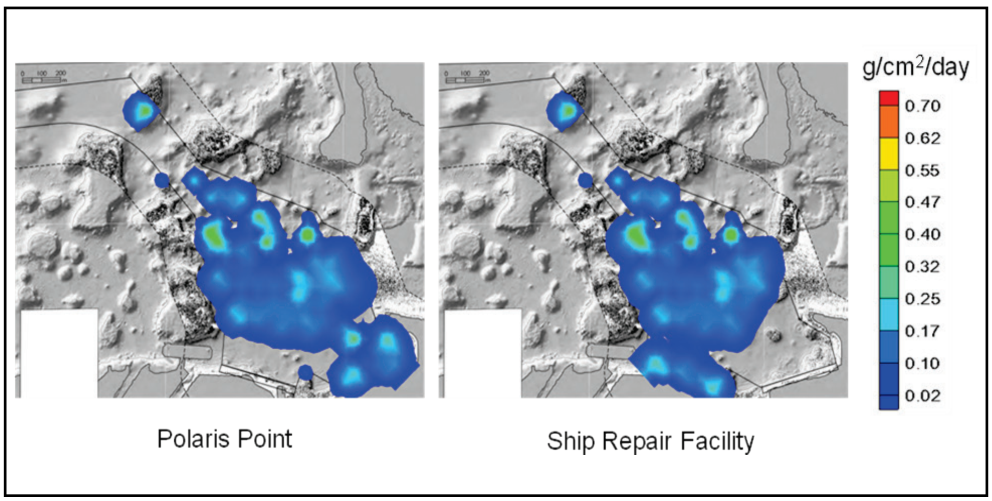


Figure 6-10. Case 3 maximum deposition rate contours.

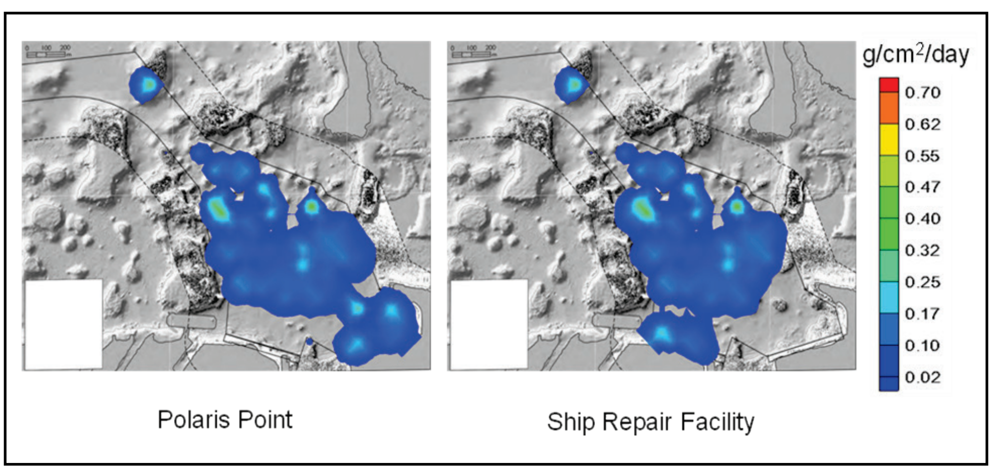
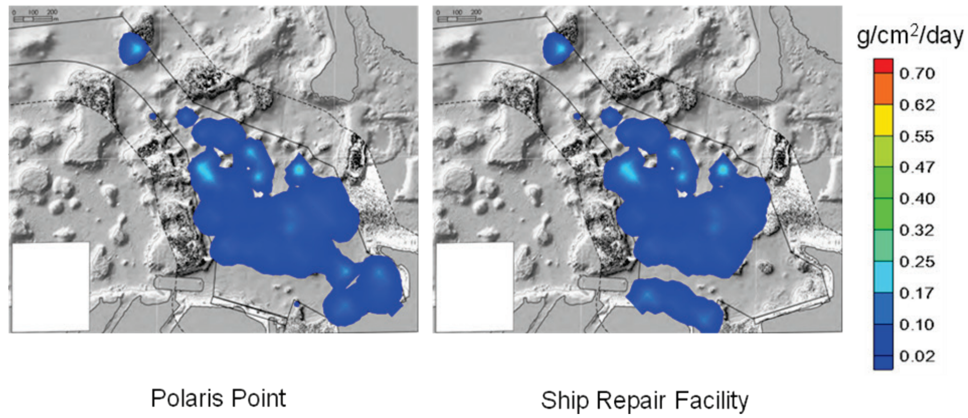


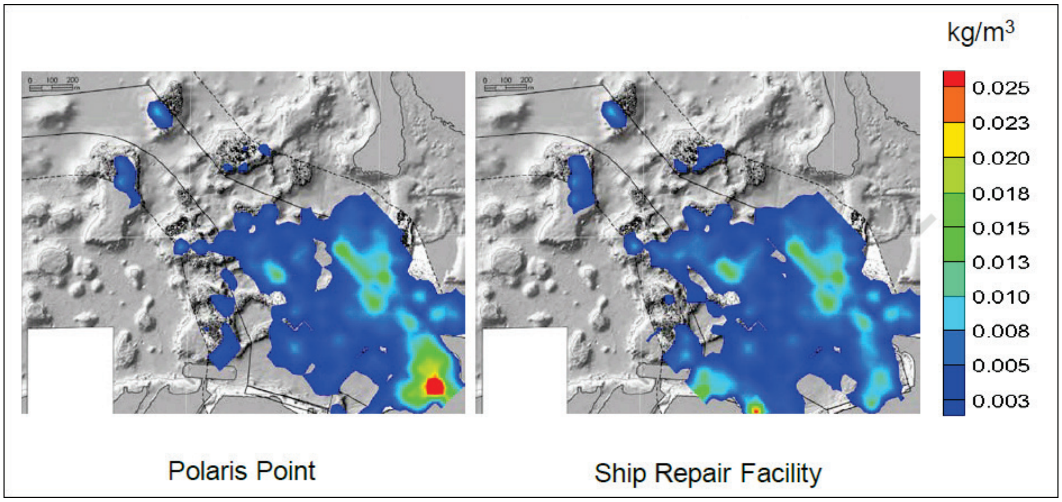
Figure 6-11. Case 4 maximum deposition rate contours.



Suspended solids concentration

The concentration of sediment within the water column is important when determining light attenuation and ultimately the effect of lack of light on the coral. Background total suspended solids (TSS) is not part of this study. Therefore, only additional TSS introduced by dredging operations is quantified in this study. TSS is not the same as turbidity. However, as part of the ongoing effects study being performed in coordination with the University of Hawaii, dredged sediment TSS will be correlated with turbidity based on multiple samples provided by the Navy. Similar to sedimentation rates, TSS values provided in subsequent figures are maximum values at each grid cell for any time during the simulation. They therefore do not represent a snapshot in time but rather a compilation of the greatest values over time. TSS values vertically averaged over the water column and units are kg/m^3 ($1\ kg/m^3 = 1$ g/liter [L] = 1,000 mg/L). Figure 6-12 shows the maximum concentration for Case 1. Maximum concentration is highest near Polaris Point and the Ship Repair Facility where most dredging occurs. The maximum value for Polaris Point is approximately $0.1\ kg/m^3$. For the Ship Repair Facility, values are lower. This is most likely due to the specifics of the bathymetry at the Ship Repair Facility and reduced volume of dredging compared to Polaris Point.

Figure 6-12. Case 1 maximum concentration contours.



A time-series of concentration has been extracted within the area near Polaris Point (Figure 6-13). At this particular point, maximum concentration is 0.03kg/m3. As can be seen in the time-series concentration values change with time, increasing and decreasing as sediment passes through the area due to the tidal currents of the system. The greatest concentration values occur between July and December, which is the time frame during which dredging occurs in that area.

Figures 6-14, 6-15, and 6-16 show the maximum concentration contour maps for Cases 2, 3, and 4, respectively. The maximum concentration values are less than Case 1, which is the worst-case scenario. In Case 2, maximum values decrease due to the decrease in the dredging rate. In Case 3, the decrease in the loss term and increase in the silt curtain effectiveness reduces the concentration to less than 0.01 kg/m3 for the Ship Repair Facility results. This trend continues for Case 4.

Note that minimum values indicated on Figures 6-12 through 6-16 are approximately 3 milligrams (mg)/L. Values of less than 10 mg/L may exist outside the shaded areas in each figure. These data are stored in PTM and can be further analyzed, if required.

Figure 6-13. Case 1 concentration time series at a specified point (denoted by red star).

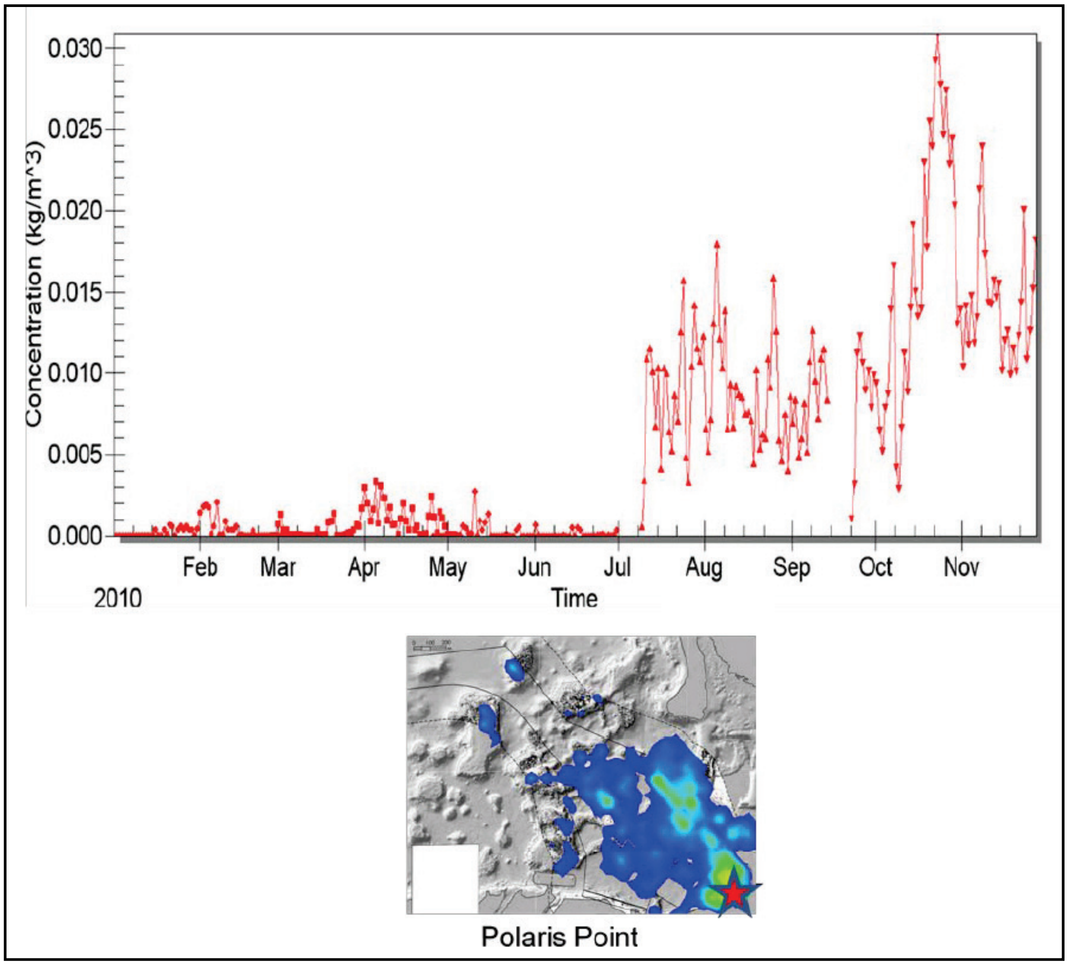


Figure 6-14. Case 2 maximum concentration contours.

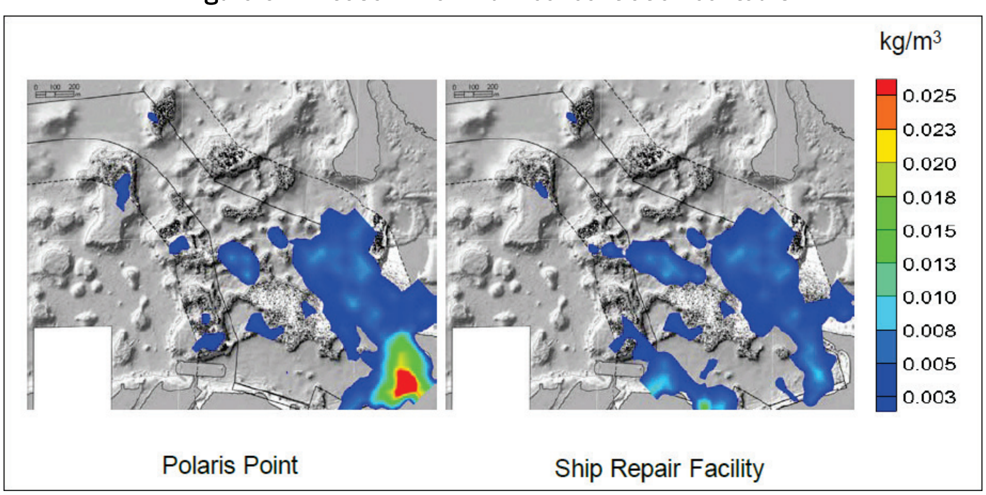


Figure 6-15. Case 3 maximum concentration contours.

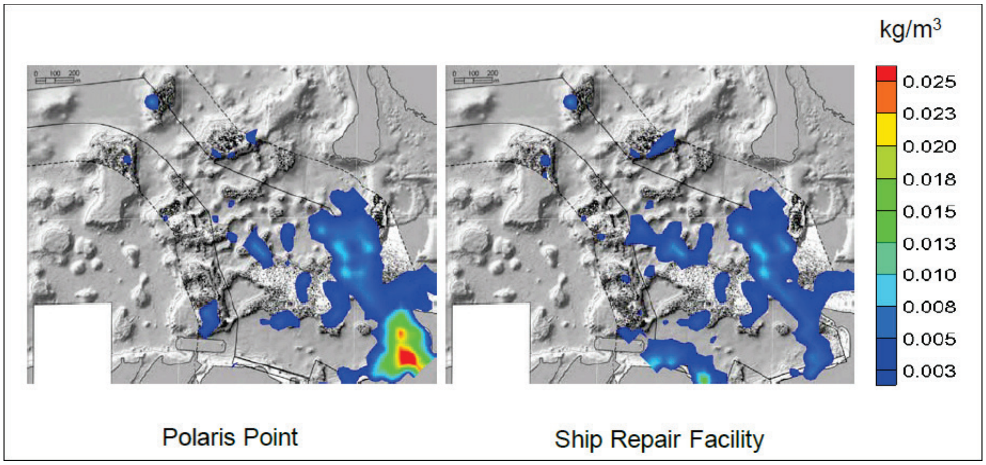
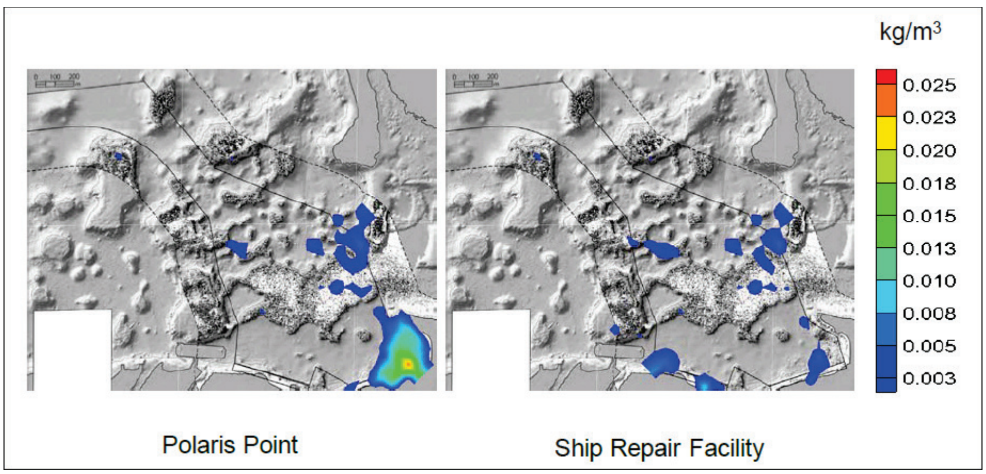


Figure 6-16. Case 4 maximum concentration contours.



Data analysis tables

Tables 6-1 through 6-6 list the results from the previous maximum concentration, maximum deposition rate, and total accumulation maps in table format. The tables list the results for the maximum and minimum exposure cases (Cases 1 and 4, respectively). Each table lists the quantity of area (in meters squared) that has a contour value greater than a specified level. For example, Table 6-1 indicates that for the Polaris Point Case 1 dredging scenario, 830,400 m^2 of the study area will have sediment accumulation levels of greater than 0.1 gm/cm^2. Half the tables (those labeled “Entire Area” [i.e., Tables 6-1, 6-3, 6-5]) list values for the entire study area as defined by the gridded area shown in blue in Figure 6-2. The other half of the tables (those labeled “Outside Area” [i.e., Tables 6-2, 6-4, 6-6]) list study area values that are outside the two dredging footprints shown in Figures 2-3 and 2-4, for Polaris Point and Ship Repair Facility, respectively.

Table 6-1. Entire area accumulation.

Case	Total Accumulation					
	Area (m^2) greater than 0.1 g/cm^2		Area (m^2) greater than 0.5 g/cm^2		Area (m^2) greater than 1.0 g/cm^2	
	Polaris Point	Ship Repair Facility	Polaris Point	Ship Repair Facility	Polaris Point	Ship Repair Facility
1	830,400	833,600	524,800	512,000	400,000	390,400
4	742,400	729,600	451,200	451,200	342,400	331,200

Table 6-2. Outside area accumulation.

Case	Total Accumulation					
	Area (m^2) greater than 0.1 g/cm^2		Area (m^2) greater than 0.5 g/cm^2		Area (m^2) greater than 1.0 g/cm^2	
	Polaris Point	Ship Repair Facility	Polaris Point	Ship Repair Facility	Polaris Point	Ship Repair Facility
1	252,800	305,600	78,400	96,000	41,600	41,600
4	195,200	230,400	56,000	70,400	28,800	28,800

Table 6-3. Entire area maximum deposition rate.

Case	Maximum Deposition Rate					
	Area (m^2) greater than 0.001 $g/cm^2/day$		Area (m^2) greater than 0.01 $g/cm^2/day$		Area (m^2) greater than 0.1 $g/cm^2/day$	
	Polaris Point	Ship Repair Facility	Polaris Point	Ship Repair Facility	Polaris Point	Ship Repair Facility
1	1,961,600	1,945,600	880,000	868,800	473,600	446,400
4	1,800,000	1,736,000	737,600	718,400	206,400	211,200

Table 6-4. Outside area maximum deposition rate.

Case	Maximum Deposition Rate					
	Area (m^2) greater than 0.001 $g/cm^2/day$		Area (m^2) greater than 0.01 $g/cm^2/day$		Area (m^2) greater than 0.1 $g/cm^2/day$	
	Polaris Point	Ship Repair Facility	Polaris Point	Ship Repair Facility	Polaris Point	Ship Repair Facility
1	1,232,000	1,297,600	252,800	313,600	48,000	52,800
4	1,086,400	1,107,200	148,800	187,200	16,000	14,400

Table 6-5. Entire area maximum concentration.

Case	Maximum Concentration					
	Area (m^2) greater than 0.0005 kg/m^3		Area (m^2) greater than 0.001 kg/m^3		Area (m^2) greater than 0.002 kg/m^3	
	Polaris Point	Ship Repair Facility	Polaris Point	Ship Repair Facility	Polaris Point	Ship Repair Facility
1	3,819,200	3,427,200	2,190,400	2,056,000	1,600,000	1,534,400
4	1,990,400	1,892,800	1,443,200	1,409,600	608,000	585,600

Table 6-6. Outside area maximum concentration.

Case	Maximum Concentration					
	Area (m^2) greater than 0.0005 kg/m^3		Area (m^2) greater than 0.001 kg/m^3		Area (m^2) greater than 0.002 kg/m^3	
	Polaris Point	Ship Repair Facility	Polaris Point	Ship Repair Facility	Polaris Point	Ship Repair Facility
1	2,980,800	2,700,800	1,478,400	1,448,000	976,000	996,800
4	1,299,200	1,292,800	852,800	886,400	337,600	363,200

Tables 6-1 and 6-2 present total accumulation values for the entire study area and outside the dredge footprints, respectively, for both the Ship Repair Facility and Polaris Point. These values reflect the total amount of accumulation that is expected to occur during an entire dredging scenario. Values are calculated from the total number of parcels deposited in each cell throughout the study area. Tables 6-3 and 6-4 present maximum deposition rate values for the entire study area and outside the dredge footprints, respectively. These values reflect the greatest daily rate of parcel deposition (sedimentation) that occurs in each grid cell on any date during the dredging scenario. Tables 6-5 and 6-6 present maximum suspended solids concentration values for the entire study area and outside the dredge footprints, respectively. These values reflect the maximum number of parcels within the water column at each grid cell on any date during the dredging scenario.

7 Summary and Conclusions

Simulations were performed to model the transport of sediment suspended during dredging operations at Apra Harbor, Guam. The primary concern is the exposure of coral reefs in the area to the resuspended sediment. Sediment source terms were developed for clamshell dredging utilizing silt curtains within two dredging areas at Polaris Point and the Ship Repair Facility. The z-grid version of the Ch3D hydrodynamic model was employed to model 3D velocities and water surface elevation for a 3-month period. For sediment transport simulations longer than 3 months, hydrodynamic results were cycled. Cycling the hydrodynamic solution is acceptable at Apra Harbor because hydrodynamic conditions during which dredging would occur (nonstorm conditions) do not vary significantly with season. Eight scenarios were defined and modeled based on the dredging sources. Clamshell loss terms, silt curtain effectiveness, and the dredging rate were varied between 2% and 1%, 90% and 100%, and 1,800 yd^3/day and 1,110 yd^3/day, respectively.

Data analysis was performed to produce maximum suspended sediment concentration maps, total accumulation maps, and maximum deposition rate maps. In addition, particle pathways were investigated. Results show that maximum values within the worst case scenario (Case 1) for total accumulation maps occurred within the dredging footprint. Outside of the dredging footprint, values remained below 2 g/cm^2 for the Polaris Point alternative and 4 g/cm^2 for the Ship Repair Facility alternative. Maximum concentration values were below 0.1 kg/m^3. Deposition rate values remained below 0.7 g/cm^2/day. When silt curtain effectiveness was increased to 100% and the clamshell loss terms reduced to 1%, maximum total accumulation decreased to 0.5 g/cm^2 outside of the dredging footprint. In the same case, the maximum values for the suspended sediment concentration were below 0.02 kg/m^3 for the Ship Repair Facility. Deposition rates were reduced to 0.10 g/cm^2/day outside the dredge footprint but within the 200 m line.

This report documents what has been done using PTM. Results discussed in this report will be used within decision support and risk assessment frameworks. In addition, the results will lead to additional analysis, refined scenarios, or additional simulations, if necessary. These data will then be used in quantifying effects on coral species. This report does not include the extent of analysis that can and will be performed on the data developed in this study. The scope and methods of analysis performed will be assessed during ongoing effects studies. In addition, this text provides specific examples of visualization of data only (e.g., contour levels displayed, analysis grid dimensions).

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Appendix A: Cases 5 through 8 Maps

Total Accumulation, Cases 5 through 8

Figure A-1. Case 5 - Total accumulation: PPT on left, SRF on right.

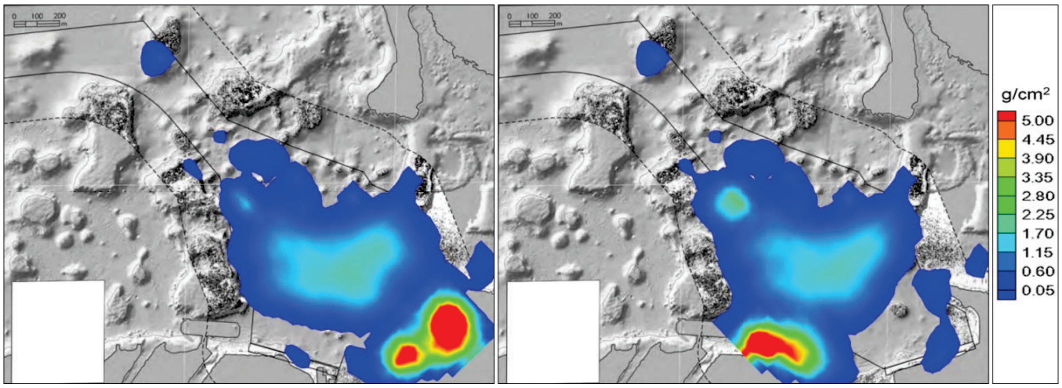


Figure A-2. Case 6 - Total accumulation: PPT on left, SRF on right.

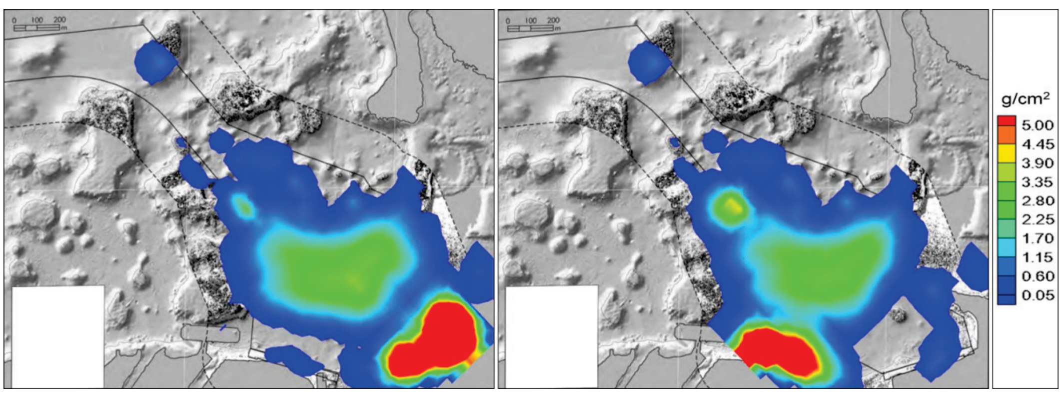


Figure A-3. Case 7 - Total accumulation: PPT on left, SRF on right.

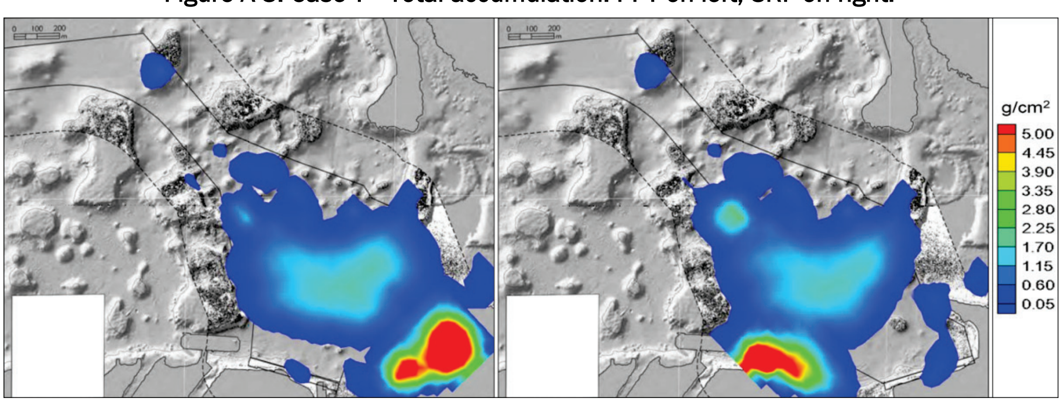
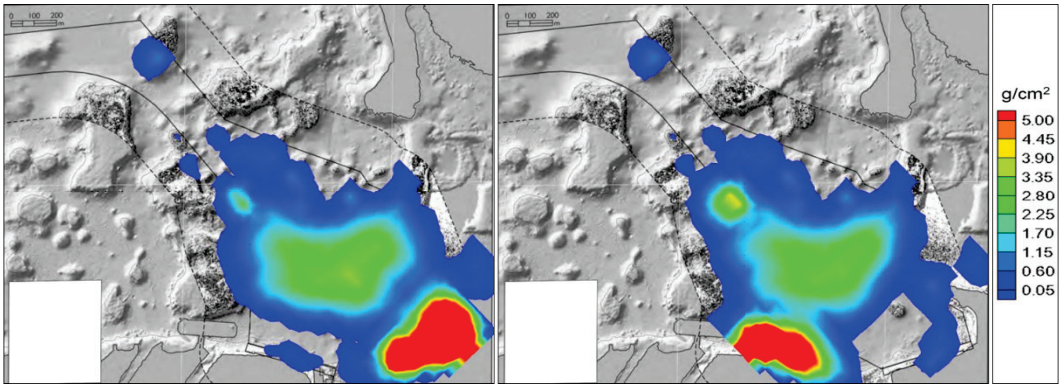


Figure A-4. Case 8 - Total accumulation: PPT on left, SRF on right.



Maximum Deposition Rate, Cases 5 through 8

Figure A-5. Case 5 - Maximum deposition rate: PPT on left, SRF on right.

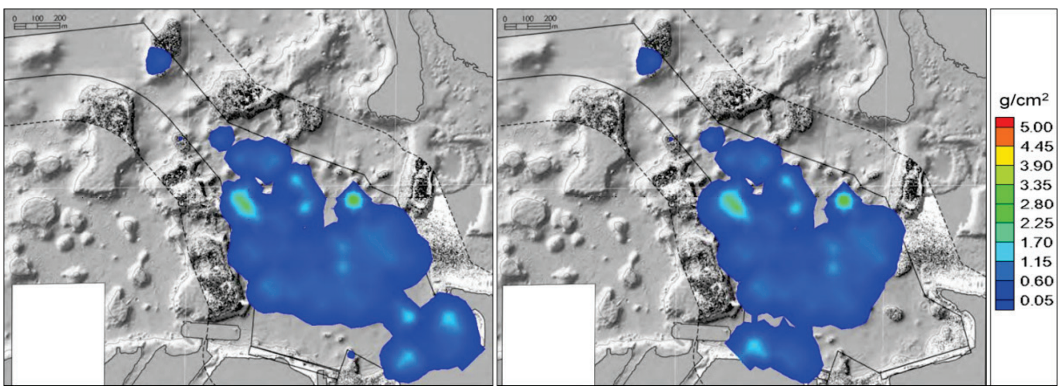


Figure A-6. Case 6 - Maximum deposition rate: PPT on left, SRF on right.

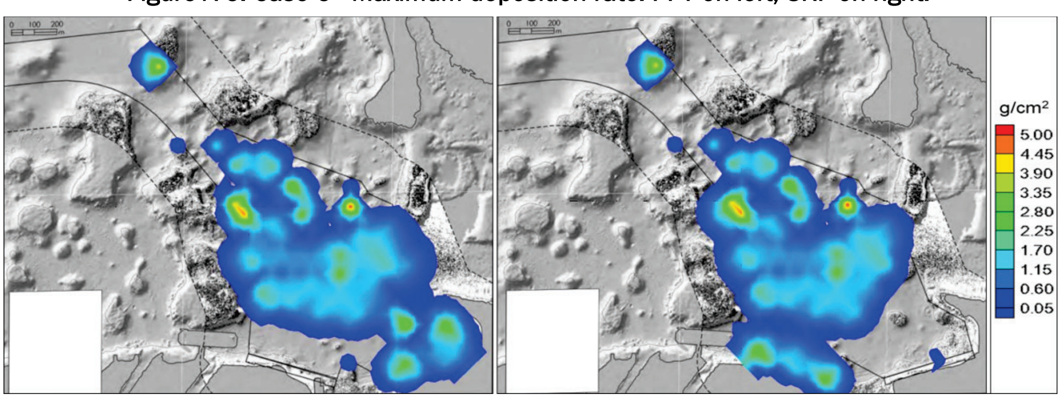


Figure A-7. Case 7 - Maximum deposition rate: PPT on left, SRF on right.

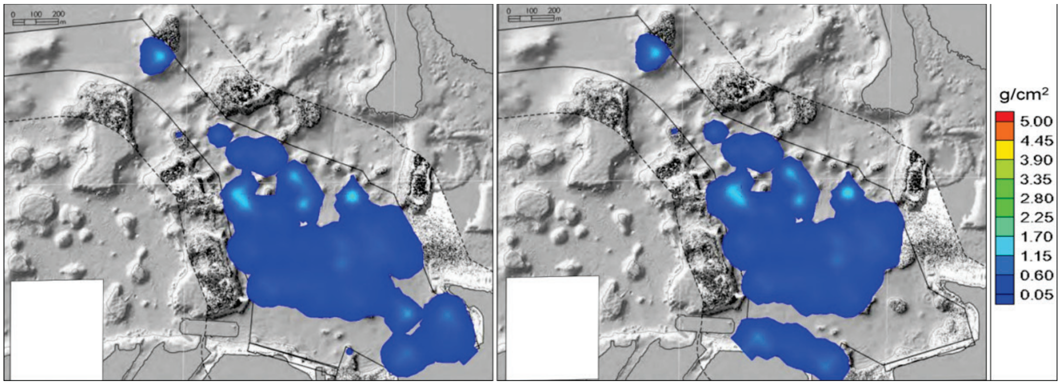
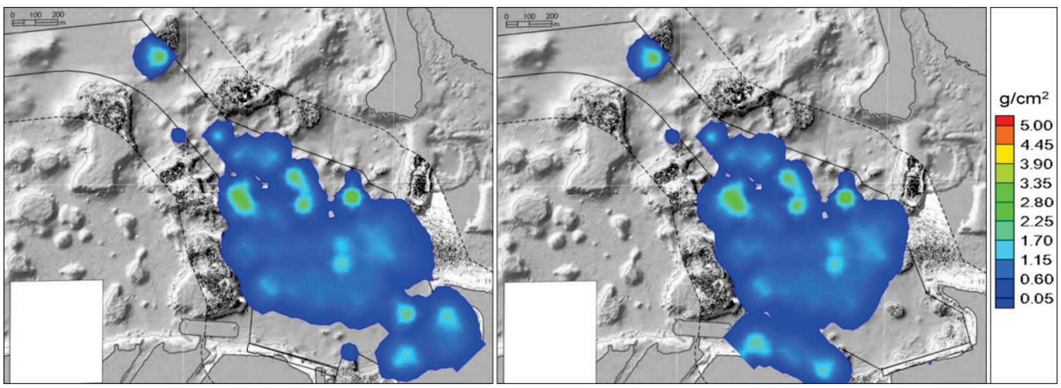


Figure A-8. Case 8 - Maximum deposition rate: PPT on left, SRF on right.



Maximum Concentration, Cases 5 through 8

Figure A-9. Case 5 - Maximum concentration: PPT on left, SRF on right.

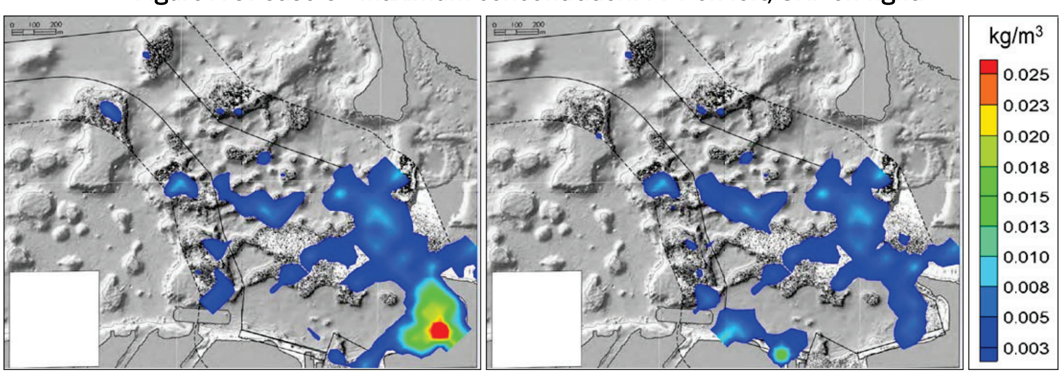


Figure A-10. Case 6 - Maximum concentration: PPT on left, SRF on right.

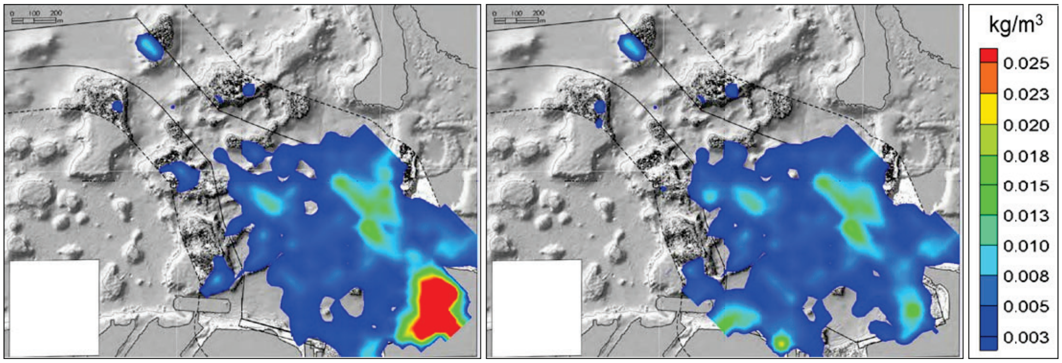


Figure A-11. Case 7 - Maximum concentration: PPT on left, SRF on right.

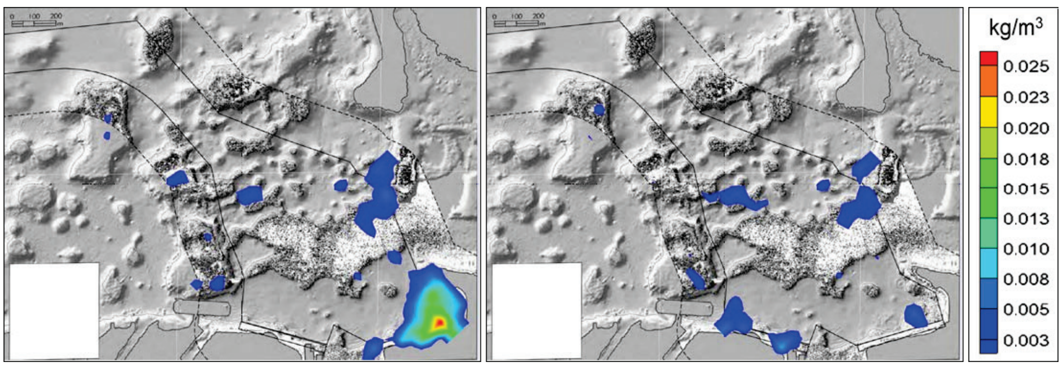
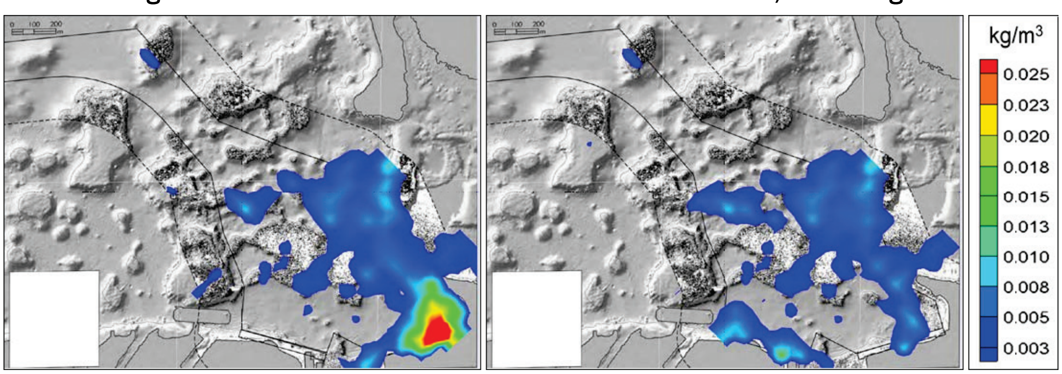


Figure A-12. Case 8 - Maximum concentration: PPT on left, SRF on right.



Appendix B: Flocculation

Flocculation is a complex process by which suspended solids in the water column loosely bind to each other, causing them to settle at a speed that is a function of the composite particle's size, density, and shape. For particles that are small enough (silts and especially clays), electrostatic charges (attractive forces) on the surface of the particles become of first-order importance to particle attraction. Due to this attraction, particles tend to loosely stick together, and the clumps behave as larger particles. The settling velocity of these flocculated particles is greater than for individual particles. Particle chemical composition, water salinity, and other dissolved ions in the water have major impacts on this process, as does the presence of additional electrostatically charged particulate matter in the water column (*sticky stuff*), such as marine snow. Other than in the deep ocean, the process of flocculation is usually not only highly site specific but also time variable.

For this application, flocculation is primarily important because it affects the settling velocity of particles. A particle's fall velocity is the speed at which the downward force of gravitational attraction is just balanced by the retarding (upward) drag force of the fluid on the particle. Unflocculated particle fall speed is generally represented as proportional to the diameter squared. The smallest particles can take very long times to settle (months or longer, depending upon diameters and water depths). Sand particles are large enough that they tend to fall as individual particles and do not flocculate. Specifically, the gravitational forces working on a sand particle are much greater than the forces attracting two particles, and these larger particles therefore do not flocculate. Silts and clays normally are susceptible to flocculation. Flocculation changes the relationship between their volume and surface area, which means they fall faster until a larger drag force balances the larger gravitational force.

To assist the biologists in their analysis of the impacts of dredging in the biota in Apra Harbor, additional modeling scenarios were run to address the effect of flocculation. Since appropriate data were not available to define the process of flocculation at Apra Harbor, the approach was to bracket this effect, which meant to run the model twice using minimum and maximum values for the sediment fall velocity. The two values modeled are no-flocculation where all particles fall at a speed based upon their grain size and flocculation where all silt and clay particles fall at a speed of 3.0 mm/s. The parameter choice of no-flocculation as one modeling extreme is the obvious conservative (greatest impact) case for far-field turbidity and sedimentation. It will cause particles to travel farther before settling to the bed. The no-flocculation condition is the one presented in the body of this report.

The 3 mm/s fall speed for all silts and clays will cause all particles to settle out relatively quickly and thus is the optimistic extreme. The 3 mm/s fall speed was chosen after extensive internal discussion. It was based upon the work of Asaeda and Wolanski (2002), a paper which addresses the settling velocity of flocculated marine snow produced at coral reefs. Figure 3 in Asaeda and Wolanski is a log-log plot of settling speed vs. marine snow (floc) diameter, for several types of particles. While a few data points approach fall speeds of 10 mm/s, most of the data points for marine snow with sediment have fall speeds below 5 mm/s. Since this was a laboratory experiment, it was assumed that the test tank (dimensions 10 cm × 10 cm × 1 m high) held essentially quiescent fluid. Any natural, large water body, particularly one regularly subjected to tides, waves, and wind, would have substantially higher ambient turbulence levels, which would tend to break up the larger pieces of marine snow. Therefore, 3 mm/s was chosen as an appropriate maximum settling velocity for modeling purposes. If a faster fall speed had been chosen, the result would have been even less dispersion of the particles from each dredge site.

The modeling results using this fall velocity were consistent with the monitoring results of the Kilo Wharf dredging project (Sea Engineering 2010). The Sea Engineering study found that dredge plume material was typically confined to an area within 125 m from the dredge site, which was in qualitative agreement with the modeling results where a 3 mm/s settling velocity was applied to fine-grained sediment. To simulate this condition, the model with flocculation was run for all eight cases listed in Table 5-7.

Figure B-1 shows a typical example comparison of the effects of flocculation on sediment accumulation. The example is for Polaris Point, Case 1, on day 53. By this date, several of the small northerly sites have been dredged, but dredging has not yet begun along the shoreline. Note that the differences in sedimentation pattern are not dramatic. With flocculation, the sediment is slightly less dispersed (more concentrated near the dredge locations).

Figure B-1. Appendix B, Example sediment accumulation. Left panel, no flocculation; right panel, 3 mm/s flocculation.

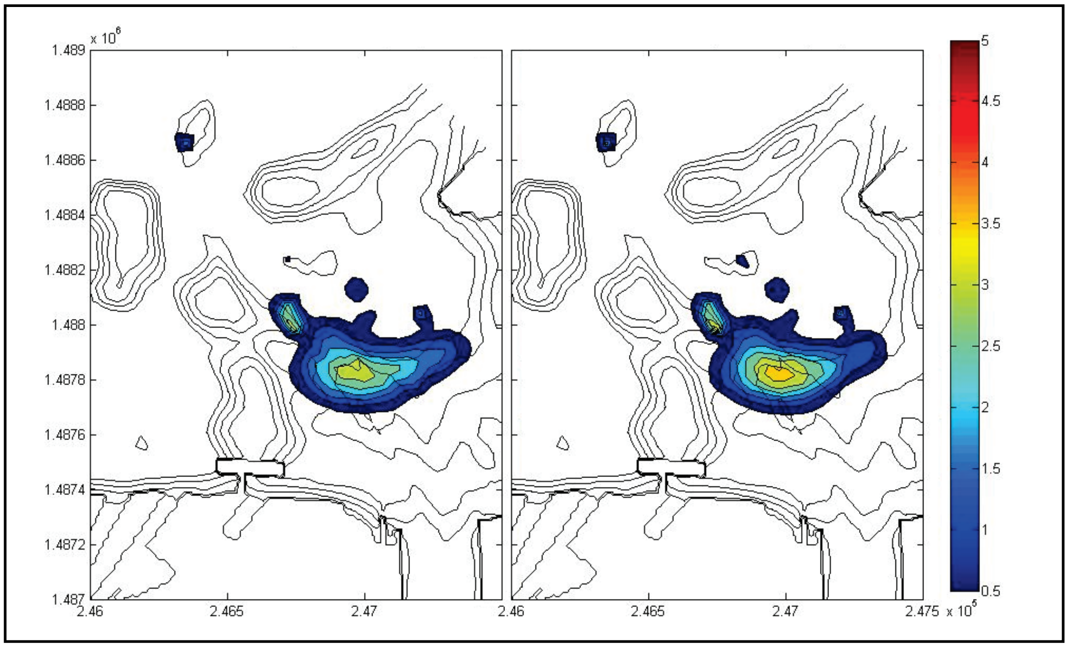
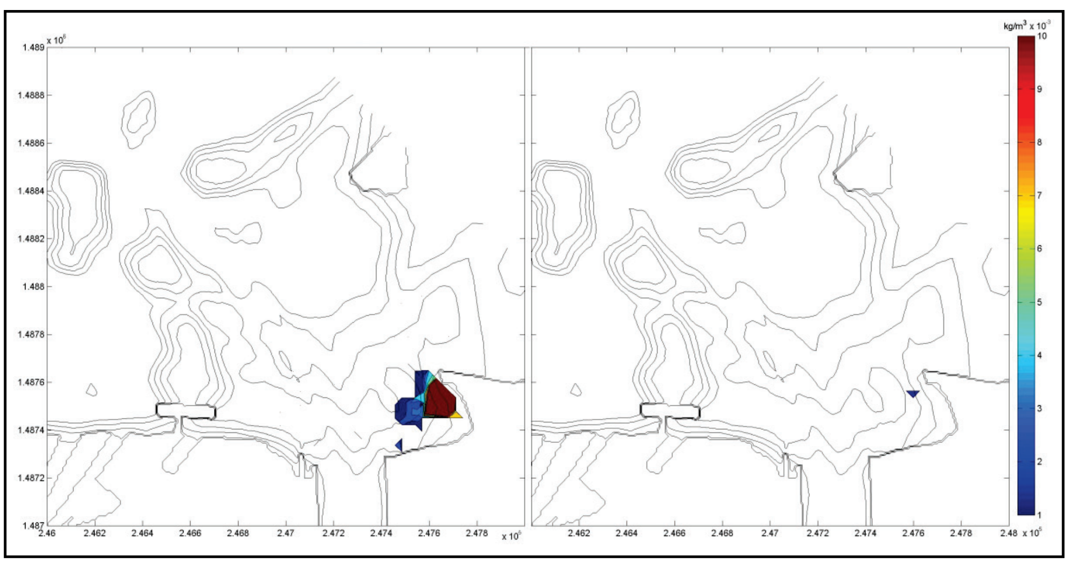


Figure B-2 shows a typical example comparison of the effects of flocculation on sediment concentrations within the water column. The example is for Polaris Point, Case 1, day 290. On this date, dredging is occurring at the berthing site. Because the flocculated particles settle faster, the concentration is much lower within the water column.

Figure B-2. Appendix B, Example suspended sediment concentration. Left panel, no flocculation; right panel, 3 mm/s flocculation.



Appendix C: Model Configuration Parameters

The following parameter settings, taken from the particle control file, were used in the Apra Harbor PTM model runs. These parameters are discussed in MacDonald et al. (2006).

Table C-1. Model Control File Parameter Settings

Time	
:START_RUN	Variable
:STOP_RUN	Variable
:TIME_STEP	30
:GRID_UPDATE	99999
:FLOW_UPDATE	60
Files	
:START_FLOW	72 hours prior to first parcel release to allow for hydro model spinup
Computation Methods	
:ADVECTION_METHOD	3D
:CENTROID_METHOD	ROUSE
:EULERIAN_METHOD	PTM
:VELOCITY_METHOD	3DZ
:EULERIAN_SED_TRANS	SOULSBY-VAN_RIJN
:NUMERICAL_SCHEME	2
Computation Parameters	
:BED_POROSITY	0.4
:RHOS	2800
:MIN_DEPTH	0.01
:TEMPERATURE	21
:KET	0.25
:SALINITY	34
:KEW	5
:KEV	0.00859
:ETMIN	0
:EVMIN	0
:CURRENTS	
:NO_WAVE_MASS_TRANSPORT	

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14. ABSTRACT :
The U.S. Navy is studying alternatives for the construction of a new, deep-water wharf at Apra Harbor, Guam, to provide a berthing site for transient nuclear powered aircraft carriers. The U.S. Army Corps of Engineers, Engineer Research and Development Center was tasked with predicting the fate of resuspended dredged sediment during dredging operations for this port development. One byproduct of dredging is release of suspended material into the water column. This material temporarily increases turbidity during and after the dredging operation. Another byproduct is the deposition of suspended solids on surrounding coral. The Particle Tracking Model (PTM) was applied to evaluate exposure to coral for various dredging alternatives.

15. SUBJECT TERMS
Apra Harbor, Coral, Dredging, Exposure, Modeling, PTM, Sediment Deposition, Sediment Transport, Total Suspended Solids

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