

Numerical Modeling of Coastal Dredged Material Placement Study at Noyo Harbor, CA

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ABSTRACT

This paper describes the numerical modeling of nearshore placement of dredged material at Noyo Harbor, CA. The numerical models include the US Army Corps of Engineers (USACE) Short-Term FATE model (STFATE), Coastal Modeling System (CMS), and Particle Tracking Model (PTM). The STFATE simulates the spatial distribution of dredged material in open water after it has passed through the water column on release of the barge load. The CMS calculates wave transformation, flow circulation, water levels, sediment transport, and morphology change. The modeling provides technical information necessary to evaluate a location site that is economically feasible for the optimum sediment placement. The model simulation showed small onshore sediment transport in typical summer and winter months. The calculated fine sediment transport during the dredged material release at the placement site indicated more longshore movement as the result of strong wind driven current along the coast.

KEY WORDS: Noyo Harbor; dredged material placement; modeling.

INTRODUCTION

The US Army Engineers San Francisco District and Coastal Inlets Research Program have conducted a pilot study on the dredged material placement near Noyo Harbor in the north central California coast (see Figure 1). The Noyo Harbor and River channel was authorized by the River and Harbor Act of 1930 and construction was completed in 1961. The harbor consists of a jettied entrance at the river mouth. The navigation channel is maintained at 10-ft deep and 100-ft wide in the jettied entrance, and 10-ft deep and 150-ft wide extending upstream for 0.6 mile. Dredging of the Noyo River channel is necessary to provide access to Harbor for the US Coast Guard search/rescue vessels and recovery operations, and for mariners and fishing boats. Approximately 35,000 cy/yr of beach-quality sediment (Weston Solutions, Inc. 2009) is dredged from the entrance channel and river. The pilot study investigates potential locations for dredged material placement north of Noyo Bay. The numerical modeling includes nearshore sediment transport and suspended concentration during and after the placement of dredged material under combined wave, tides, and flow conditions.

NUMERICAL MODELS

The USACE STFATE, CMS, and PTM models were applied to determine the sediment fate and movement during and after the dredged material placement. The STFATE (Johnson 1990) simulates the areal distribution of dredged material in open water after it has passed through the water column on an individual release of the barge load. The CMS (Demirbilek and Rosati, 2011) interactively calculates wave transformation and wave-induced currents, water level change by tide, wind, and waves, interacting waves and currents, and sediment transport and morphology change.



Fig. 1: Location map of Noyo, California.

The CMS calculates sediment transport and morphology change under combined wave and current condition by coupling a flow model CMS-Flow (Demirbilek and Rosati, 2011) and a wave transformation model CMS-Wave (Lin et al. 2008, 2011) through a Steering Module operated within the Surface-water Modeling System (SMS, Zundel, 2006). The PTM (Demirbilek et al. 2008) was linked with CMS through SMS to simulate the fine sediment movement during and after the release of the dredged material by the barge at the placement site.

DATA ASSEMBLY

Coastline and Bathymetry

The coastline digital data for Noyo Bay along the north central coast of the California are available from the National Geophysical Data Center website (<http://rimmer.ngdc.noaa.gov>). Bathymetry data for nearshore surrounding Noyo Bay were obtained from the NOAA Coastal Services Center Lidar (<http://www.csc.noaa.gov/data.html>) and California Seafloor Mapping Program (<http://walrus.wr.usgs.gov/mapping/csmf>). The offshore bathymetry data were obtained from GEophysical DATA System (GEODAS), developed by the National Geophysical Data Center (<http://www.ngdc.noaa.gov/mgg/bathymetry/relief.html>). The land elevation data were downloaded from USGS Geographical Digital Elevation models (DEM, <http://edc2.usgs.gov/geodata/index.php>). Figure 2 shows the depth contours, relative to Mean Sea Level (MSL) from the combination of the above datasets for the study domain.

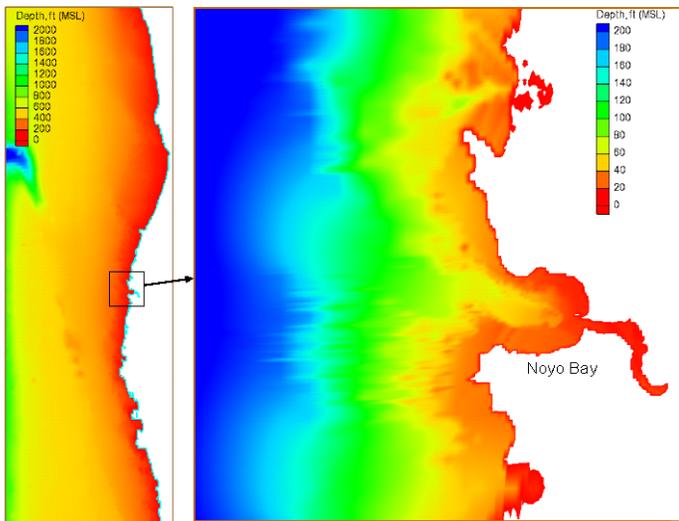


Fig. 2: Noyo Bay and bathymetry contours in ft relative to MSL.

Wind and Wave Data

Directional wave spectral data are available from the National Data Buoy Center (NDBC, <http://www.ndbc.noaa.gov>) Buoy 46022 and Coastal Data Information Program (CDIP, <http://cdip.ucsd.edu>) Buoy 46213. NDBC Buoy 46014, located offshore Noyo Bay, collects non-directional wave spectral data. Ocean surface wind data are available from NDBC Buoys 46014 and 46022. Coastal wind data are available from NOAA Stations ANVC1 (Arena Cove) and PTAC1 (Point Arena). Figures 3 and 4 show the wind and wave roses, respectively, at offshore buoys and coastal stations based on 2008 data. Figure 5 shows the monthly mean wave height at Buoys 46014, 46022, and 46213 for 2008. The monthly mean wave height offshore Noyo Harbor at Buoy 46213 can exceed 3.5 m in the winter and 2.0 m in the summer.

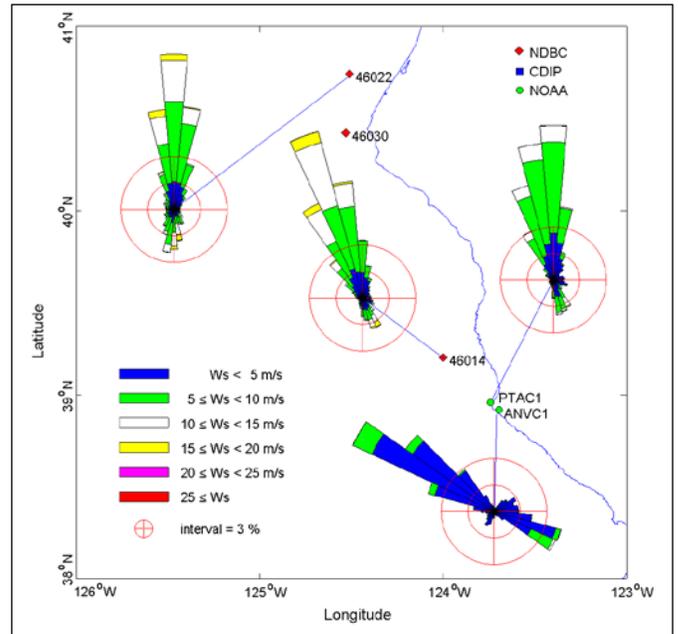


Fig. 3: Wind roses based on 2008 data.

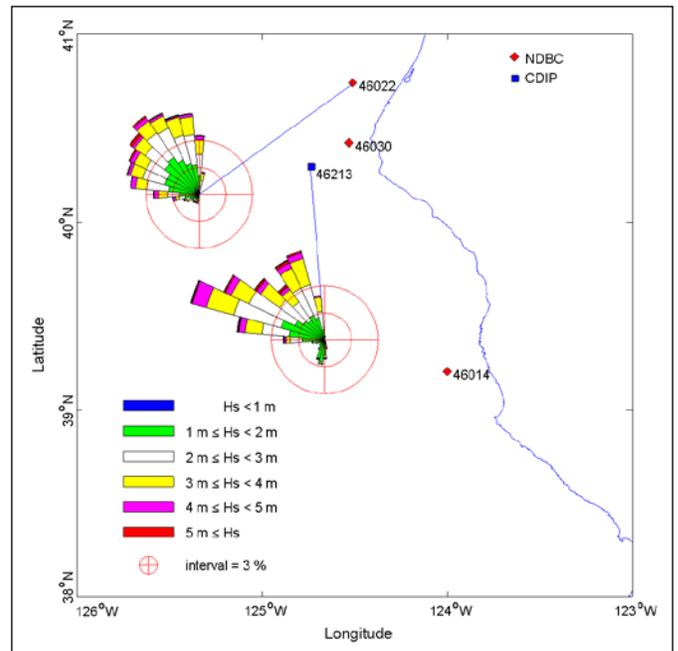


Fig. 4: Wave roses based on 2008 data.

Water Surface Elevation

Water level data are available from NOAA Station 9416841 at Arena Cove (<http://tidesandcurrents.noaa.gov>). Figure 6 shows the hourly water surface elevations for April and December 2008 from NOAA Stations 9416841 and 9418767 (North Spit, Humboldt Bay, approximately 95 miles north of Noyo Harbor). The water level data indicate a mixed semi-diurnal tidal regime surrounding northern California coast. The mean tidal range (mean high water – mean low water) is 1.2 m and the maximum tidal range (mean higher high water – mean lower low water) at Arena Cove is 1.8 m. Table 1 lists these NDBC, CDIP, and NOAA stations and their location information.

9418767 for April and December 2008.

Sediment Characteristics

A recent sediment study of the Noyo River navigational channel in 2009 conducted by Weston Solutions, Inc. indicated the dredge material was primarily sand with small percentages of mixed gravel, silt and clay (Table 2).

Table 1. NDBC, CDIP, and NOAA station locations

Station	Latitude	Longitude	Nominal depth (m)
NDBC 46014	39° 13' 12" N	123° 58' 12" W	275
NDBC 46022	40° 44' 24" N	124° 30' 36" W	610
CDIP 46213	40° 17' 33" N	124° 44' 21" W	325
NOAA PTAC1	38° 57' 36" N	123° 44' 24" W	N/A
NOAA 9416841, ANVC1	38° 54' 47" N	123° 42' 29" W	N/A
NOAA 9418767	40° 46' 01" N	124° 13' 01" W	N/A

Table 2. Grain grain sizes of sediment samples taken in Noyo Harbor channels (Weston Solutions, Inc. 2009)

Sediment	Grain Fractions (%)
Gravel	1.0
Sand	89.8
Silt	6.1
Clay	3.1

MODEL DOMAIN AND POTENTIAL PLACEMENT SITES

The CMS model domain is a rectangular area that extends approximately 35.4 miles (57 km) alongshore and 11.1 miles (18 km) offshore (see Figure 2) with the offshore boundary reaching to the 1,000-ft (300-m) isobath. The grid consists of 273 × 747 cells that permits much finer grid resolution to 65 ft x 65 ft (20 m x 20 m) in areas of high interest such as the near the harbor, and coarser resolution to 650 ft x 650 ft (200 m x 200 m) at the ocean boundary.

Because littoral drift along the Noyo coast is directed from north to south as a result of the majority of ocean wind and waves comes between the north and west directions. For a beneficial use of the clean dredge sediment from Noyo Harbor and River, the ideal locations for nearshore placement were considered north of Noyo Bay. Figure 7 shows three potential dredged material placement sites, located approximately two, five, and eight miles north of Noyo Bay.

In the present study, only Sites 1 and 2, two and five miles north of Noyo, respectively, were simulated by models as the most northern site (Site 3) at eight miles north of Noyo is geologically more sensitive to the beach and dunes in the nearby MacKerricher State Park and economically more expensive to barge the dredge material from Noyo River. Figure 8 shows the location of Sites 1 and 2, with the footprint each site of approximately 700 ft x 3,700 ft (210 m x 1,120 m), located between the 40- and 60-ft (12- and 18-m) contours.

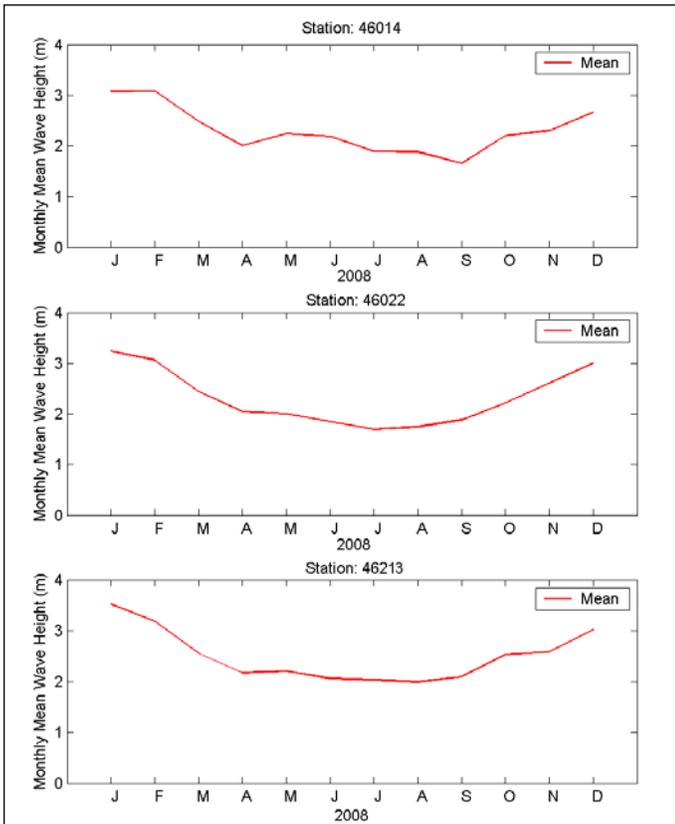


Fig. 5: Monthly mean wave height at Buoys 46014, 46022, and 46213 for 2008.

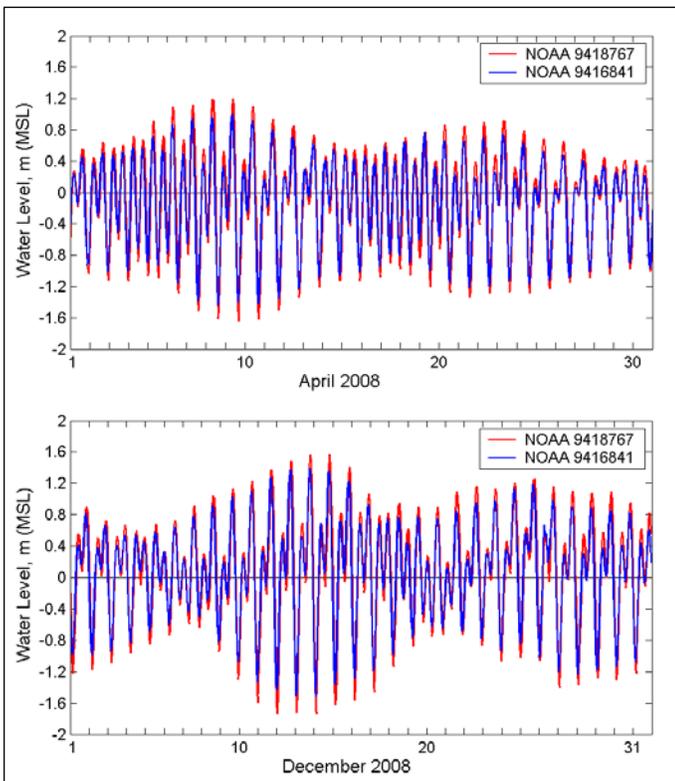


Fig. 6: Time series of water levels at NOAA Stations 9416841 and



Fig. 7: Three potential placement sites for dredge material.

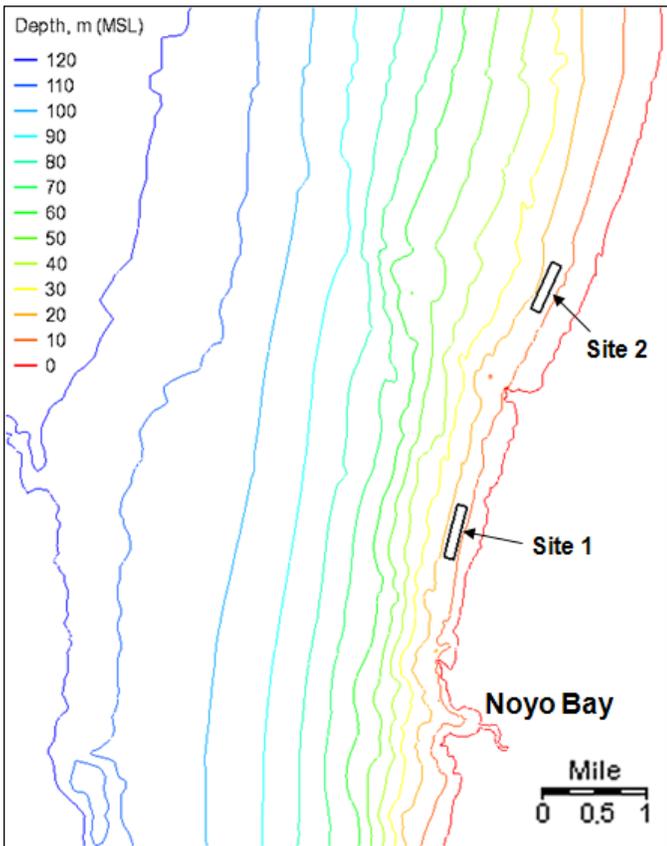


Fig. 8: Location map of placement Sites 1 and 2. SIMULATION PERIOD AND FORCING

The model simulations were conducted for August 2008 and January 2009 to represent typical summer and mild winter months, respectively. Figure 9 shows the time series of wave and wind data collected at Buoys 46014, 46022, and 46213 for August 2008. Figure 10 shows the hourly wave and wind data at Buoys 46014 and 46213 for January 2009. Table 3 presents the corresponding buoy mean and maximum significant wave heights of August 2008 and January 2009. The wave data collected at Buoy 46213, further offshore of Buoys 46014 and 46022, show largest mean and maximum significant heights among three buoys in August 2008 and January 2009.

In the present study, the directional wave spectra collected at Buoy 46213 were used as input for wave simulation. The wind data collected at Buoy 46014 were used as input for both wave and flow simulations. Wind magnitude is greater in January 2009 than in August 2008. The wind direction at Buoy 46014 is predominantly from north-northwest and is parallel to the local coastline. This predominant wind direction is consistent to the wind rose diagram in Figure 3. The local water level data from NOAA Station 9416841 were used as the boundary condition for coupled flow and wave models.

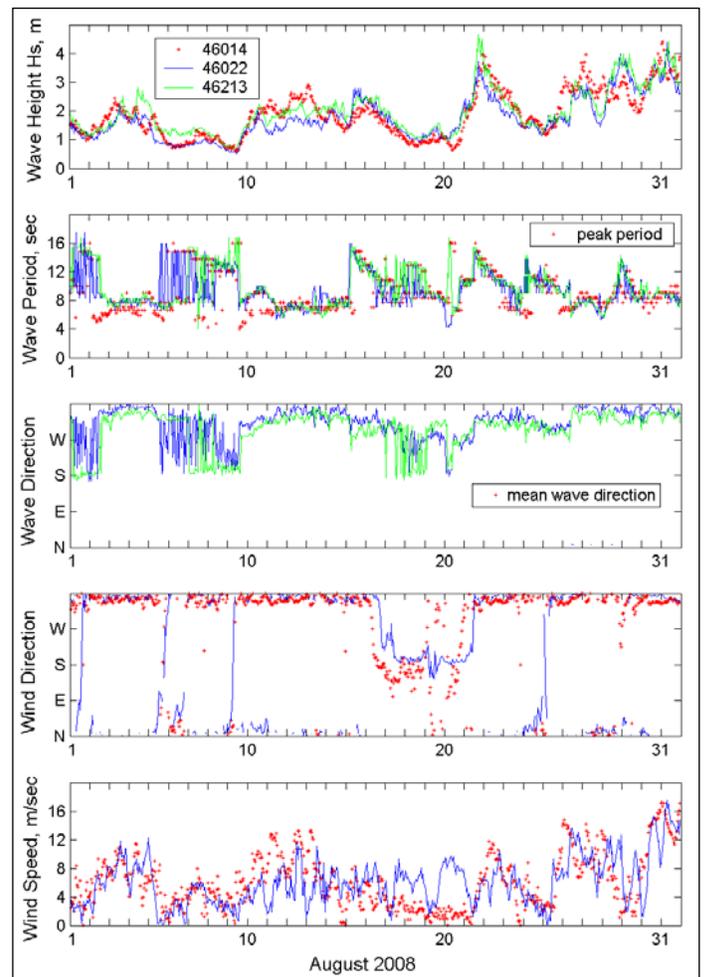


Fig. 9: Significant wave height, peak wave period, mean wave direction, wind speed, and wind direction from Buoys 46014, 46022, and 46213, August 2008.

the rectangular placement area.

Sediment Transport

Figure 11 shows the calculated sediment concentration transport field with dredged material placement at Sites 1 and 2 under combined forcing of wind, waves, tides, and currents for August 2008. The sediment concentration at Site 1 and 2 is negligibly small as compared to the more sediment movement by waves along the shoreline inside the surfzone. Figure 12 shows the calculated sediment accretion and erosion field. The wave breaking at the shoreline has caused significant sediment movement in both nearshore and offshore, and there is very little change in the placement sites, indicating that the placed sediment was mobilized in each site.

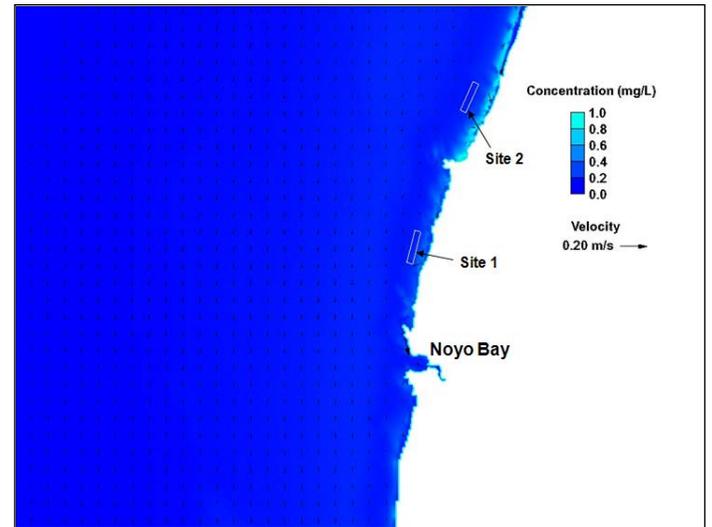


Fig. 11: Calculated sediment concentration field with wind, waves, tides, and current forcing for August 2008.

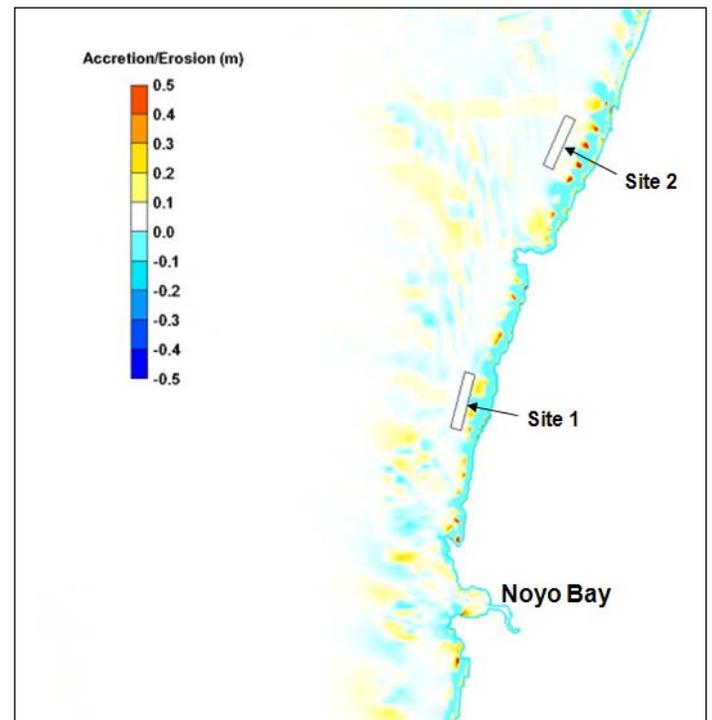


Fig. 12: Calculated sediment accretion/erosion field with wind, waves,

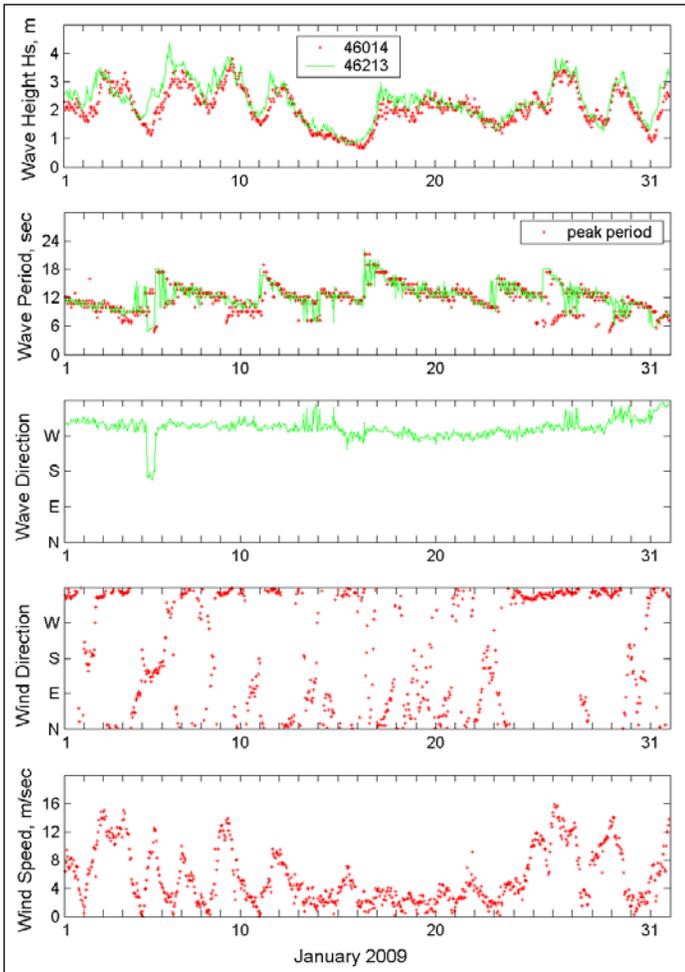


Fig. 10: Significant wave height, peak wave period, mean wave direction, wind speed, and wind direction from Buoys 46014 and 46213, January 2009.

Table 3. Mean and maximum significant wave heights from Buoys 46014, 46022, and 46213 for August 2008 and January 2009

Station	Significant height (m) August 2008		Significant height (m) January 2009	
	Mean	Maximum	Mean	Maximum
46014	1.9	4.4	2.1	3.8
46022	1.8	4.4	N/A	N/A
46213	2.0	4.7	2.3	4.4

MODEL RESULTS

The simulations were conducted to calculate the sediment transport using tide, wind, and wave forcing for August 2008 and January 2009, representing one normal summer month and one mild winter month, respectively. The simulations included the existing configuration, and two nearshore potential sites, Sites 1 and 2, for the beneficial use of clean dredge material placement. A constant sediment volume of 46,000 cu yd (35,000 cubic meters) was released to each placement site for the nearshore model simulation. This sediment volume presented a uniform 6-inch (15-cm) sediment layer above the existing seabed inside

tides, and current forcing for August 2008.

Figure 13 shows the calculated sediment concentration pattern with dredged material placement at Sites 1 and 2 under combined forcing of wind, waves, tides, and currents for January 2009. The sediment concentration in the nearshore is increased as a result of large waves breaking in the surf zone. Figure 14 shows the corresponding sediment accretion and erosion pattern. The wave breaking at the shoreline in the winter has substantially increased the sediment movement in the nearshore as compared to the offshore regions. The morphology change in the placement area of Sites 1 and 2 is negligibly small.

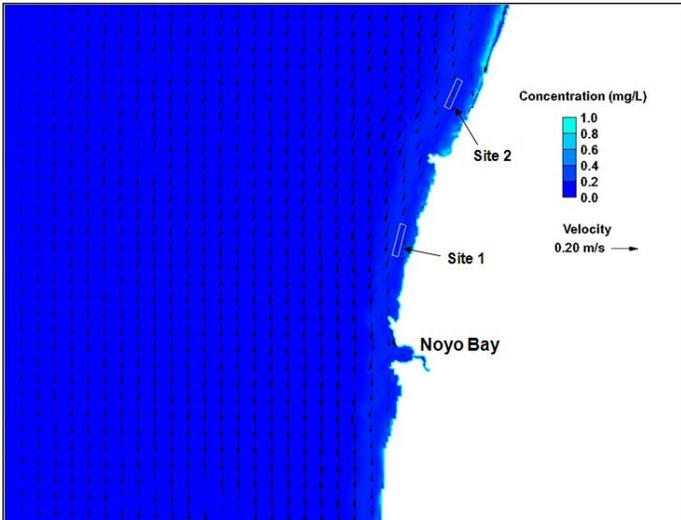


Fig. 13: Calculated sediment concentration field with wind, waves, tides, and current forcing for January 2009.

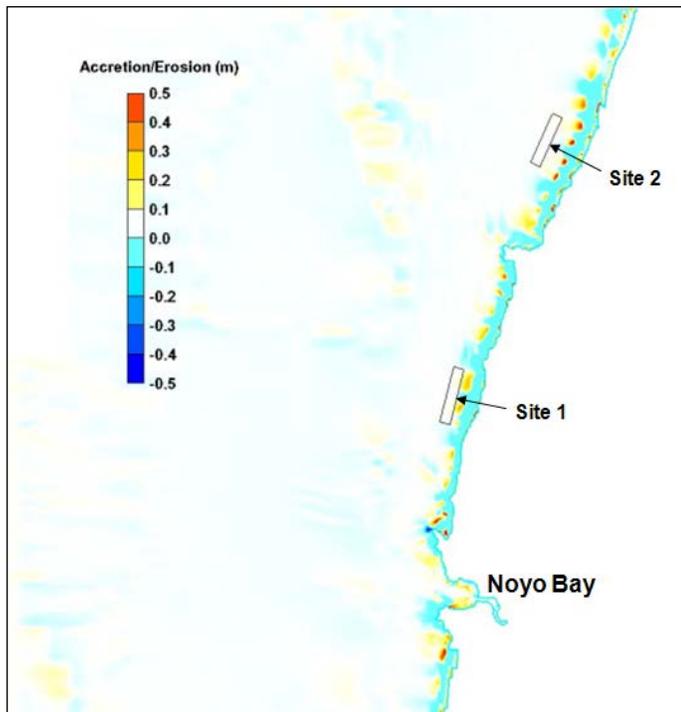


Fig. 14: Calculated sediment accretion/erosion field with wind, waves, tides, and current forcing for January 2009.

The calculated morphology change for placement in Sites 1 and 2 were compared to the existing configuration based on simulation results for

August 2008 and January 2009. Figures 15 and 16 show two areas, Areas A and B, that encompass Site 1 and Site 2, respectively, for the comparison of morphology change with the dredge material placement. Recalled 46,000 cu yd (35,000 cubic meters) of dredged material placement was designated for each of Sites 1 and 2. The background sediment accretion and erosion pattern shown in Figures 15 and 16 is from the August 2008 simulation.

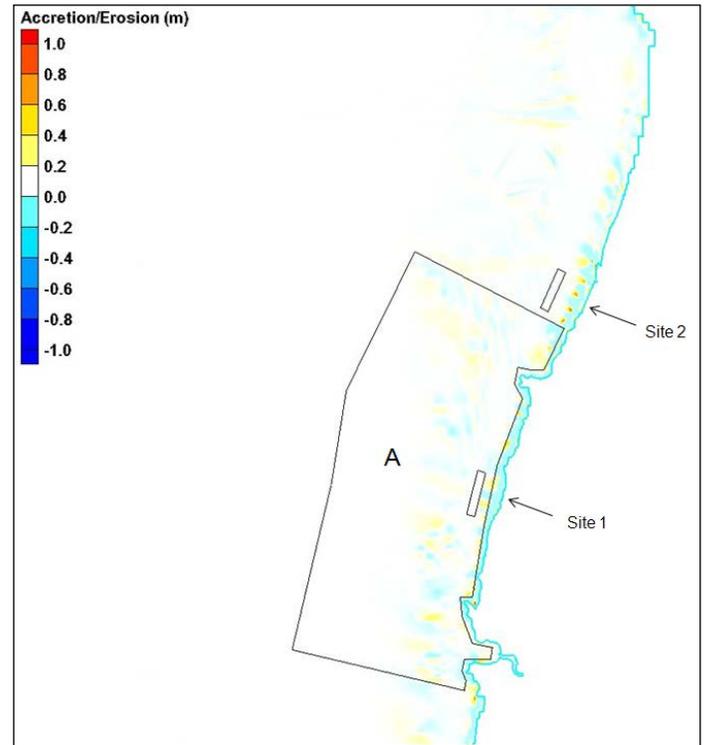


Fig. 15: Area A encompassing Site 1.

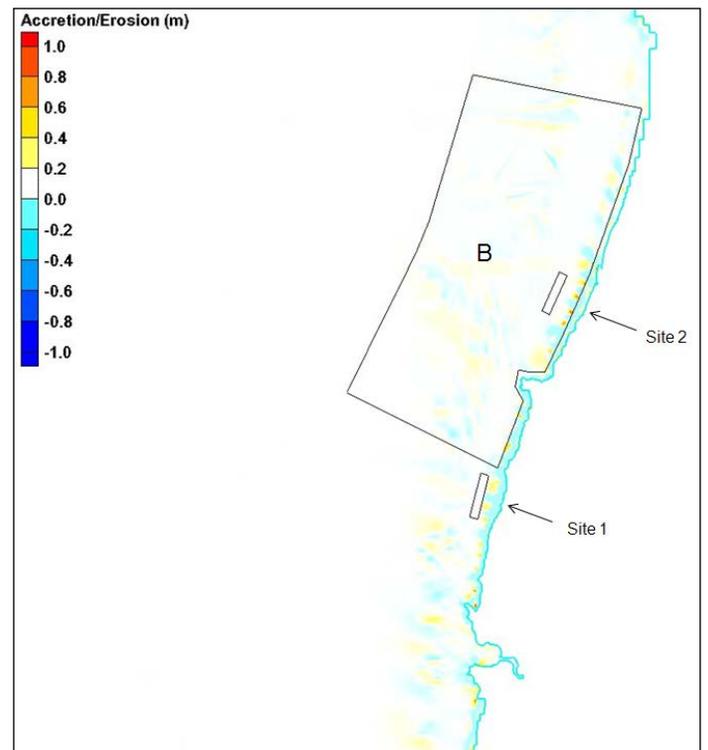


Fig. 16: Area B encompassing Site 2.

Tables 4 and 5 present respectively the calculated morphology changes and percent differences for August 2008 and January 2009. The August 2008 simulation indicates a net gain of sediment in Areas A and B, and is slightly less (two percent smaller) with Sites 1 and 2 placement as compared to the existing configuration. The January 2009 simulation, on the other hand, shows a consistent net loss of sediment in Areas A and B. The difference of morphology change in Areas A and B with Site 1 or 2 placements is similar to the existing configuration.

Table 4. Calculated morphology change and percent difference for August 2008

Placement Site	Calculated Morphology Change (cu yd)*	
	Area A	Area B
None	60,830	16,400
Site 1	59,850 (-1.6%)	16,280 (-0.7%)
Site 2	59,700 (-1.8%)	16,250 (-0.9%)

* Percent difference in parentheses is compared to the existing configuration

Table 5. Calculated morphology change and percent difference for January 2009

Placement Site	Calculated Morphology Change (cu yd)*	
	Area A	Area B
None	-186,560	-157,930
Site 1	-186,490 (-0.04%)	-157,860 (-0.05%)
Site 2	-186,620 (0.03%)	-157,980 (0.03%)

* Percent difference in parentheses is compared to the existing configuration

STFATE and PTM Simulations

The PTM was applied to simulate sediment motion during and after release of sediment at Site 1 from the barge. The CMS flow and wave results from August 2008 simulation were input to PTM to calculate the clay and silt particle movement. This simulation excludes the fine sand particles as the sand has quickly settled to the sea bed at the placement site at depths between 40 and 60 ft (12 to 28 m) as calculated by STFATE. The sediment particles were released twice a day in the first 12 days of August 2008. Total volumes of clay and silt on each release of the barge load in simulations are approximately 105 and 155 cu yd, respectively.

Figure 17 shows the volume distribution of gravel, fine sand (settled), clay, and silt (suspended) 30 minutes after the release calculated by STFATE. Note that the total percentage of clay and silt is small (less than 20 percent) as compared to the majority of sand in the dredge material.

Figures 18 and 19 show the snapshot of calculated clay particle distributions at the end of the release (day 12) and the end of simulation (day 30), respectively. Notice that by day 30 (Figure 19), clay particles have moved into the nearshore north of Noyo, although some have moved south and offshore. Figures 20 and 21 are snapshots of calculated silt particle distributions at the end of the release (day 12) and the end of simulation (day 30), respectively. These simulations show both clay and silt particles either follow the waves propagating towards shore or move southward driven by the northerly wind during this summer period. A large portion of the fine sediments can move southward past Noyo Bay, and some move permanently out of the model domain in the simulation period. Comparing to silt particles, less clay particles are left within the domain at the end of the simulation.

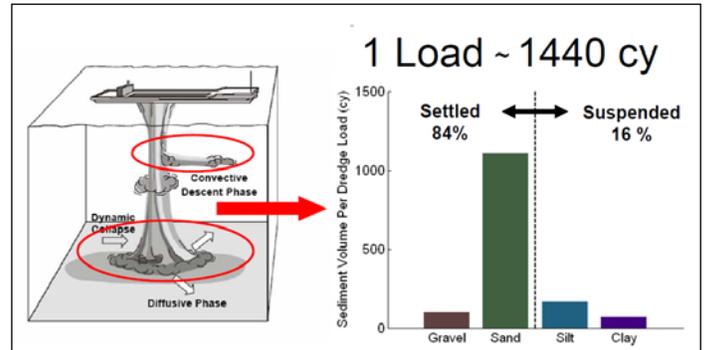


Fig. 17: STFATE result of suspended sediments, 30 min. after release.

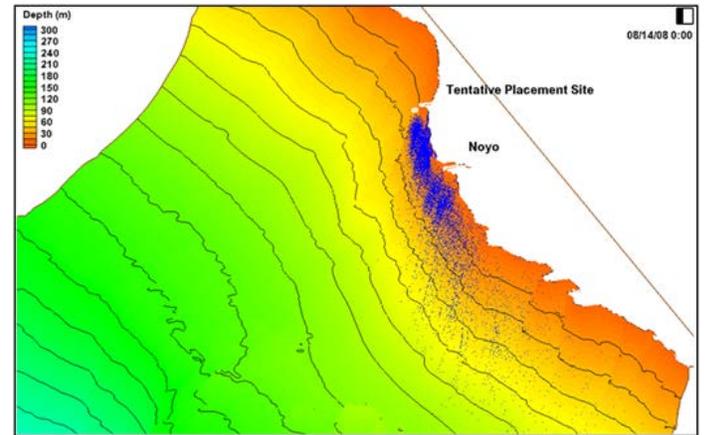


Fig. 18: Calculated clay particles at the end of the release (day 12).

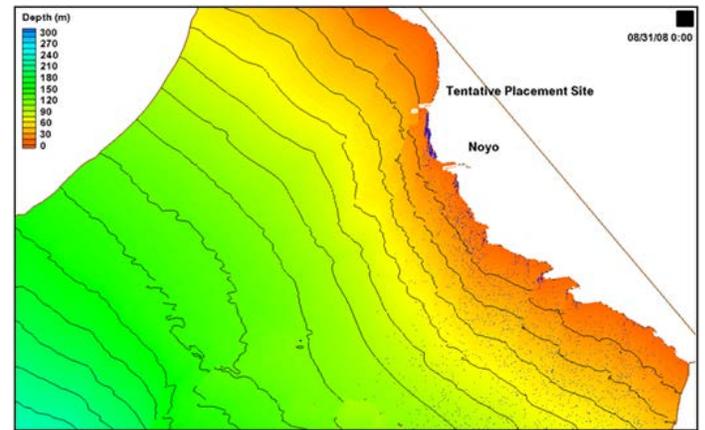


Fig. 19: Calculated clay particles at the end of the simulation (day 30).

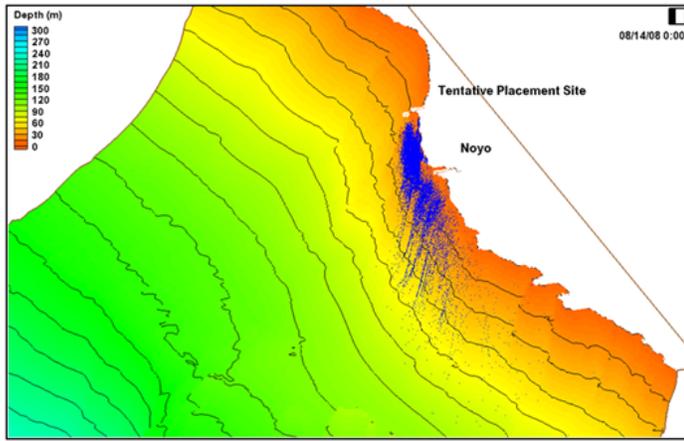


Fig. 20: Calculated silt particles at the end of the release (day 12).

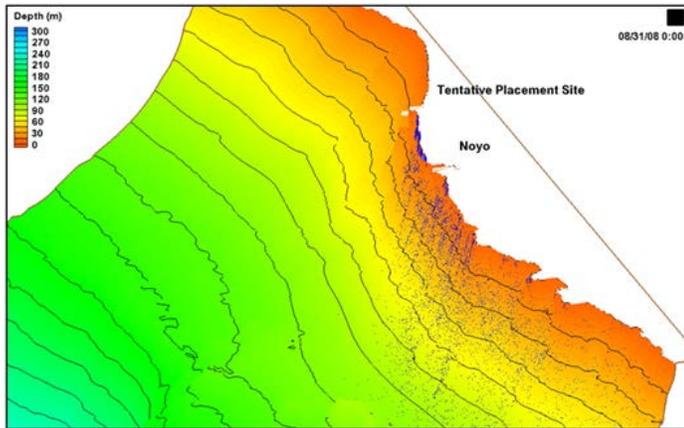


Fig. 21: Calculated silt particles at the end of the simulation (day 30).

CONCLUSIONS

The USACE STFATE, CMS, and PTM models were applied to simulate placement of dredged sediment placed in the nearshore north of Noyo Bay, CA. The simulations included two placement locations, Sites 1 and 2, approximately two and five miles north of Noyo Harbor. Each site covered a rectangular area of 700 ft x 3,700 ft (210 m x 1,120 m) at depths between 40 and 60 ft (12 and 18 m). A dredge material volume of 46,000 cu yd (35,000 cubic meters) was placed at either Site 1 or 2 in these simulations. Numerical simulations were conducted for combined tides, waves, currents and wind forcing to evaluate the sediment transport at the placement sites.

The CMS simulations were conducted for August 2008 and January 2009 representing a normal summer month and a mild winter month, respectively. The coastal processes at the Noyo coast were more dominated by large waves than tides and wind-driven currents. The calculated morphology change as result of tide, wind-driven current, and waves was more significant in the nearshore because of wave breaking than at two placement sites located at depths of 40 to 60 ft (12 and 18 m). The effect of placing dredged sediment at the two proposed sites is insignificant as compared to the existing configuration without the dredge material placement. The modeling indicated overall mild sediment accretion at the coast in August 2008 and significant erosion in January 2009 because of large long waves that occur in the winter. The calculation of clay and silt particle movement by the PTM showed that the fine sediments moved towards the shore by wave motion or southward by the wind-driven current parallel to the coastline.

Because recent bathymetry and bedrock data were unavailable to represent nearshore sea bottom characteristics accurately, results from the present numerical modeling study should be considered preliminary, and more research is needed to determine short- and long-term sediment transport and morphology change trends at these two placement sites.

ACKNOWLEDGEMENTS

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