Nearshore Placed Mound Physical Model Experiment

PURPOSE: This technical note describes the migration and dispersion of a nearshore mound subjected to waves in a physical model. The summary includes recommendations for nearshore placement of dredged material. This technical note is the first in a series discussing the physical model experiment and guidance for nearshore mound placement. Subsequent technical notes will discuss the migration of tracer material in a physical model and mound migration of dredged material at Brunswick Harbor, GA.

BACKGROUND: The U.S. Army Corps of Engineers continues to seek opportunities for the beneficial use of dredged material. Frequently, Corps dredged material management plans include offshore placement of dredged material from channel entrances and ebb shoals. This often removes material with a high sand percent from the littoral or regional system. Maintenance dredged material from these areas is generally not considered beach quality (>88 percent sand), but often includes approximately 60-80 percent sand. Placement of dredged material in the nearshore permits natural winnowing/separation of the fine and sand particles. Nearshore mound locations, material, and configurations must be chosen judiciously to assure that the mound does not negatively impact the surrounding environment and that material remains in the littoral system and nourishes the beach. The DOER program has supported a series of physical model and field experiments intended to assess consequences of nearshore placement of the dredged material. This technical note discusses physical model experiments on local migration of a mound at the edge of the surf zone. Although nearshore mounds are generally placed outside the surf zone, these same locations are within or at the edge of the surf zone during storms. Storm events are the predominant transport interval for nearshore mounds.

PHYSICAL MODEL FACILITY: Experiments were conducted in the Large-scale Sediment Transport Facility (LSTF) of the U.S. Army Engineer Research and Development Center’s Coastal and Hydraulics Laboratory (Figure 1). The capabilities of the LSTF are discussed in detail in Hamilton et al. (2001). The purpose of the LSTF is to provide engineers with a near-field scale tool to assess sediment behavior in the surf zone. The LSTF is 30 m wide, 50 m long, and 1.4 m deep. The basin contains a sand beach and simulates conditions comparable to low-energy coasts. Long-crested and unidirectional irregular waves are produced in the LSTF by four synchronized wave generators oriented at a 10-deg angle to the shoreline. The beach is composed of approximately 150 m^3 of very well-sorted fine quartz sand with a median grain size of 0.15 mm. The sand beach is approximately 25 cm thick over a planar concrete base and extends 27 m alongshore and 18 m cross-shore. An external recirculation system minimizes adverse physical model effects at the beach boundaries. The recirculation system consists of 20 turbine pumps, each fronted by a flow channel, that are distributed through the cross-shore and located at the downdrift end of the beach. Twenty 0.75-m-wide and 6-m-long bottom traps were used to measure the total longshore sediment flux. The traps are shown in the foreground of

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Figure 1. Previous LSTF research efforts include bar migration (Wang et al. 2002, 2003), impact of headland breakwaters and tombolo formation (Gravens and Wang 2004).

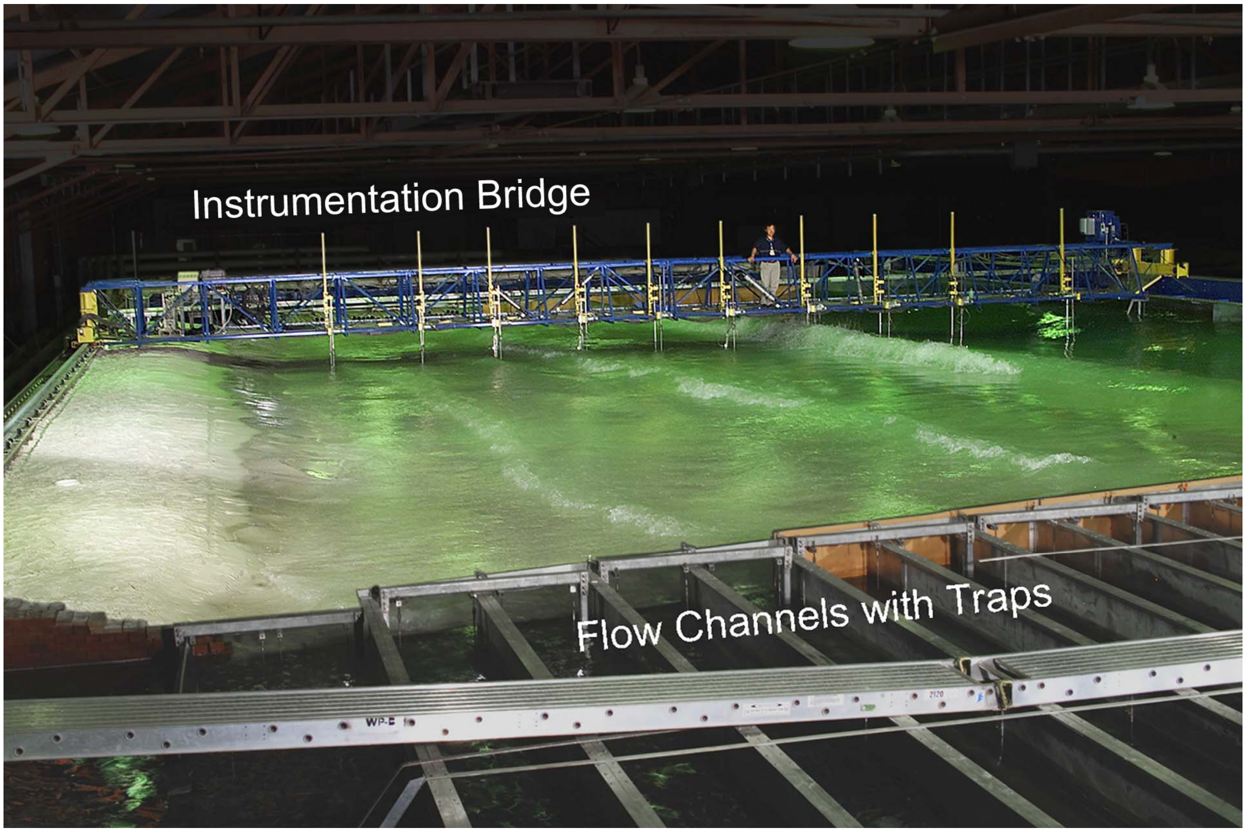

Figure 1. Photograph of the LSTF

Time series of water surface elevations are measured using 10 single-wire capacitance-type wave gauges mounted on the instrumentation bridge, shown in Figure 1. Additionally, a gauge is placed in front of each wave generator to collect data with which to develop offshore wave characteristics. Ten acoustic Doppler velocimeters (ADVs) are used to measure the velocity time series including wave orbital velocities and steady longshore currents. The gauges and ADVs are synchronized and sample at 20 Hz. An Acoustic Doppler Current Profiler measured the vertical velocity profile, the results of which will be published in subsequent technical notes. The beach was surveyed with an acoustic profiler.

HYDRODYNAMIC CONDITIONS: The wave condition selected for the experiment was an irregular wave having a peak period *Tp* of 1.5 sec, zero-moment wave height *Hmo* of 0.16 m, and water depth *d* of 0.9 m at the wave generators. A TMA shallow-water wave spectrum (Bouws et al. 1985) was used to define the spectral shape. Figure 2 shows the power spectrum of the wave condition at the toe of the LSTF beach at $x = 18.6$ m. The condition produced spilling breakers. Prior to the experiment with the nearshore mound installed, waves were run to establish a quasi-equilibrium beach and determine the cross-shore distribution of wave-driven longshore currents. The wave height distribution and quasi-equilibrium profile are shown in Figure 3.

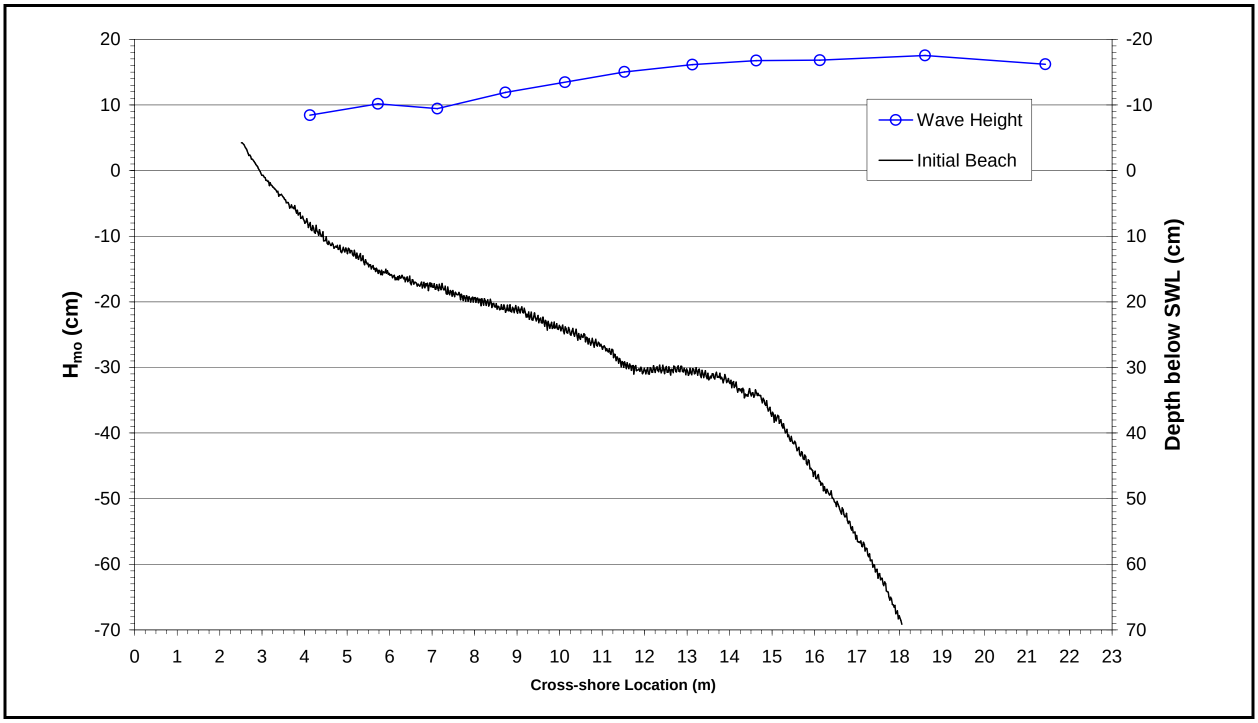

Figure 2. Wave height distribution and beach profile without mound

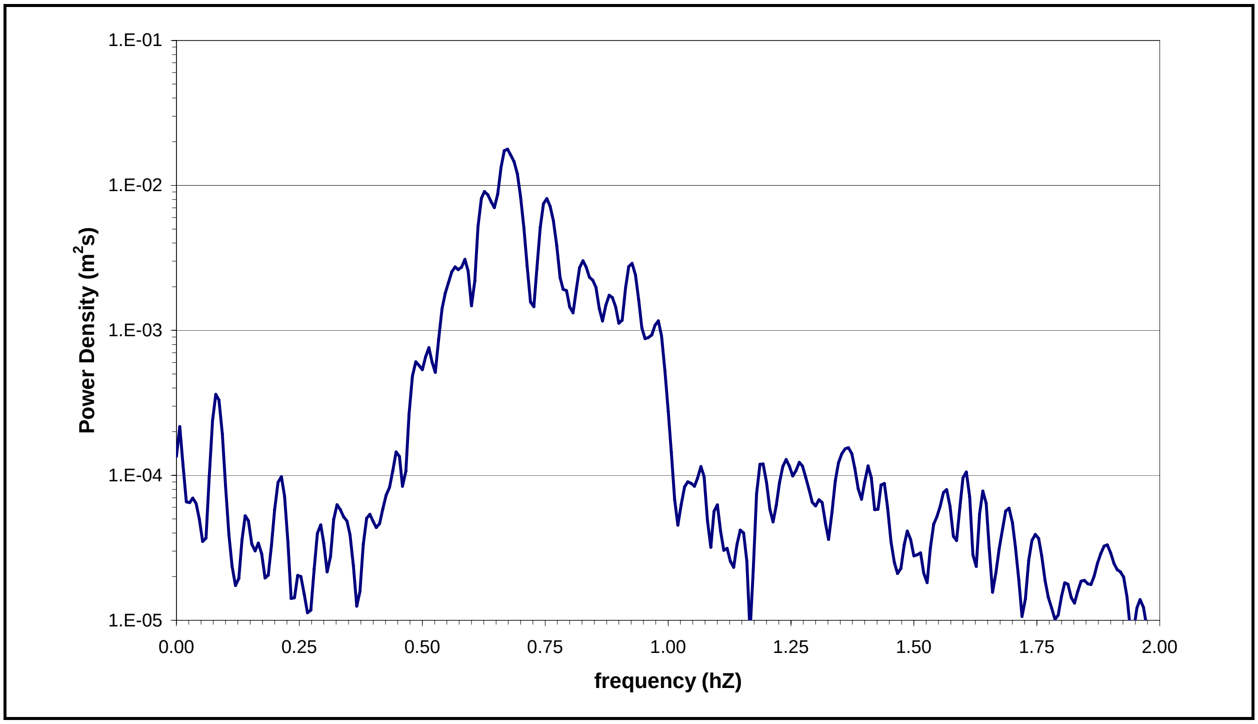

Figure 3. Power spectrum of wave condition

Figure 3 shows that wave height increases between the wave generators and cross-shore location 18.6 m, but decreases as the irregular waves break and dissipate energy.

NEARSHORE MOUND: The mound was constructed to be representative of nearshore dredged material placement. The mound had a parabolic shape with a 3-m diameter and 10-cm height.

Predominant transport of nearshore mounds occurs during storms in which the mound is within or at the edge of the surf zone. The mound was placed at the cross-shore location where a significant loss of wave energy occurs. Wave height decrease is gradual shoreward of x = 18.6 m (Figure 3). Dissipation increases slightly between 14.6 m and 13.1 m and increases further between 13.1 m and 11.5 m. The target cross-shore location for the mound center was x = 12.7 m, which placed the mound within the incipient breaking region and on the flat portion of the beach.

The longshore location of the mound was determined by placing it in a region where waves and currents remain uniform near and downstream (migration direction) of the mound. Based on previous LSTF experiments, alongshore uniformity was maintained between locations y = 18 m and y = 30 m. The selected mound center was placed at y = 28, which placed the mound near the upstream side of the uniform wave/current region.

Following construction of the mound, the basin was filled with water and the beach was surveyed. The profiler sampled at every 0.02 m in the cross-shore. The sampling density was varied in the longshore direction. In the vicinity of the mound (between y = 26 and y = 30), transects were taken every 0.25 m. The remainder of the beach was surveyed at 1- or 2-m intervals. Figure 4 shows a contour map of the constructed beach. The colorbar indicates depth below still-water level (SWL) in centimeters.

RESULTS: The mound was subjected to 10 hours of waves with breaks to survey the nearshore beach. Surveys were taken at approximately 1, 3, 5, 7.5, and 10 hours. The volume of material measured above the original mound footprint after each survey is listed in Table 1. During the first hour, 12 percent (0.039 m^3) of the sand placed in the mound was transported out of the footprint. Erosion of the initial mound slowed as testing progressed. A total of 46 percent (0.146 m^3) of the sand was transported off the mound at the end of the experiment.

The profile at y = 28 m (the longshore location of the initial mound center) is shown in Figure 5 for each survey. The initial survey (t = 0 min) was taken prior to wave action on the beach and the profile line is relatively smooth. Subsequent surveys show ripples formed as a result of waves. Elevation of the mound decreased rapidly during the first hour, losing 17 percent of its original height. Elevation continued to decrease as the test progressed, but the rate of change was smaller. After 5 hours of testing, the crest elevation was reduced by 50 percent and features of the initial mound were non-existent. At the end of the experiment, the initial mound elevation at y = 28 had decreased by 73 percent. A significant amount of this material spread within the original footprint of the mound. Therefore the percent change in elevation was much greater than the percent change in volume. The large difference between volume loss (46 percent) and elevation loss (73 percent) is not uncommon for nearshore mounds where the mound peak often moves as bedload and deposits at the base, resulting in a broader, flatter mound.

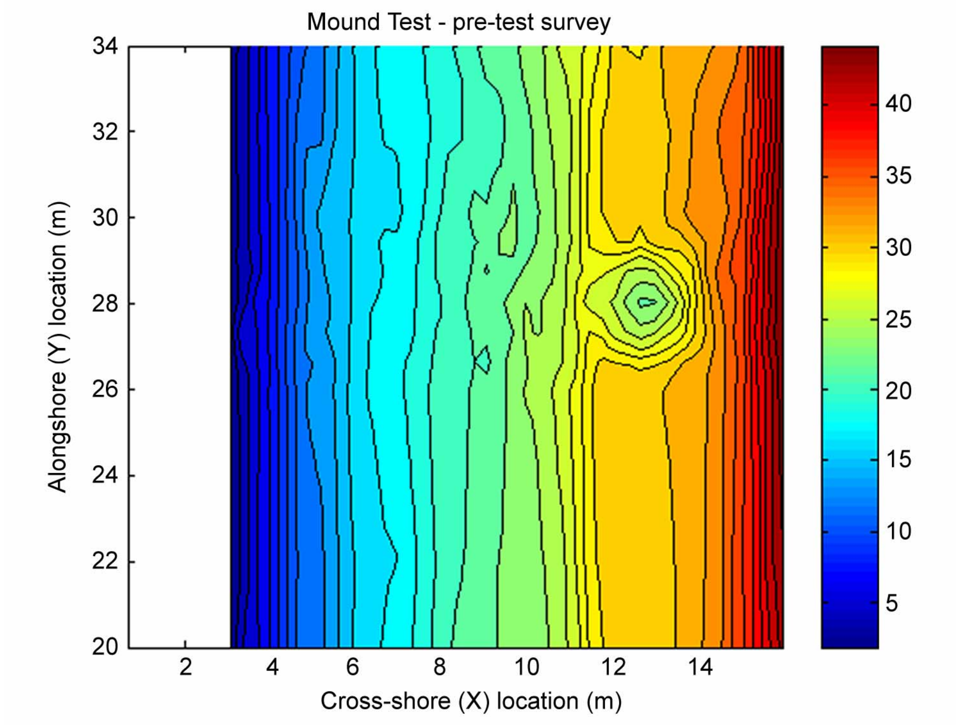

Figure 4. Contour map of initial beach

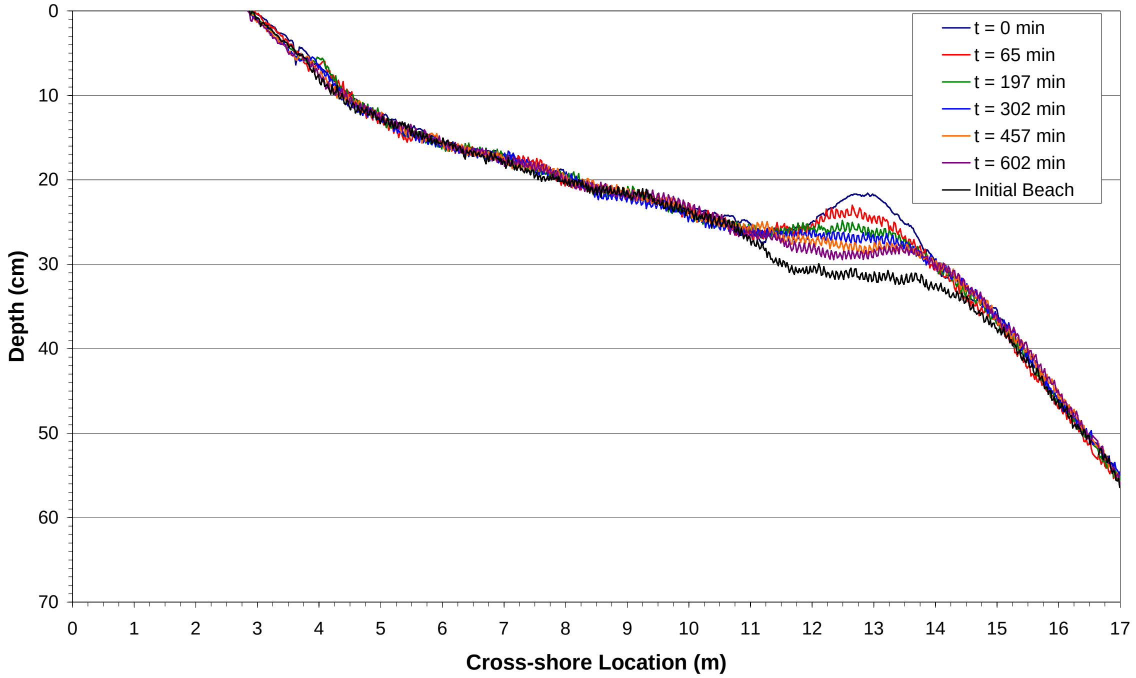

Figure 5. Evolution of mound at *y* = 28 m

Figures 6 through 10 show the difference in depth between several surveys and the initial bathymetry. The bottom ripples apparent in Figure 5 were removed by filtering for these comparisons, and only changes greater than 0.5 cm are shown (the colorbar indicates changes in cm). The rectangular box shown in the figures is the control area used to calculate center of mass, which is discussed later. Figure 6 shows bathymetric change near the mound after 65 min of waves and currents. Erosion of the mound crest at $y = 28$ m and $x = 13$ m is evident. Deposition at the base of the mound is not evident in this plot, indicating that the change is less than 0.5 cm. It should be noted that the figure indicates several other areas in which minor erosion and accretion occur. This is not uncommon in the LSTF, where the artificially constructed beach must adjust to hydrodynamic forcing at the start of the experiment.

Figure 7 shows a larger erosional area of the initial mound after 197 min of waves. Accumulation is evident downdrift and onshore of the initial mound location, with most of the accretion concentrated at the 12-m cross-shore location and 26.5-m longshore location. Figure 7 also shows erosion occurring on the beach onshore of the mound at $x = 10.5$, 7.0, and 3.5 m, with areas of accretion slightly updrift and downdrift of the eroded portions. These features may indicate effects from waves refracting around the mound, focusing, and the increasing wave energy in the region directly behind the mound.

Figures 8 through 10 show bathymetric change after approximately 5, 7.5, and 10 hours of wave and current forcing. Erosion of the original mound continues, as does accretion downdrift and onshore. Smaller amounts of accretion occur offshore of the initial migratory location. Figure 10 also shows accumulation offshore of the mound, which is probably due to the steep seaward-facing slope and a seaward-directed bedload.

Table 1 lists the volume of sand accreted after each survey. After 65 min of waves, the volume of sand transported from the initial mound (0.04 m^3) is greater than the sand deposited in the accreted mound (0.01 m^3). With further wave action, the accreted volume increased at a rate equal to or exceeding the volume eroded from the initial mound. It should be noted that the sum of the accreted volume and the volume above the initial mound footprint after 302 min exceed the initial mound volume. This indicates that sand was deposited from different sources than the initial mound.

Table 1
Results of Nearshore Mound Experiment

Survey	Time (min)	Volume Above Initial Mound Footprint (m^3)	Accreted Volume (m^3)	Accretion Area (m^2)	Control Area Center of Mass		Accreted Mound Center of Mass	
					x_o (m)	y_o (m)	x_o (m)	y_o (m)
1	0	0.320	0	7.1	12.65	28.04	-	-
2	65	0.281	0.010	9.0	12.61	27.98	11.95	27.15
3	197	0.249	0.066	12.0	12.56	27.68	12.25	26.65
4	302	0.227	0.106	12.9	12.56	27.46	12.25	26.40
5	457	0.202	0.140	16.6	12.56	27.14	12.25	26.15
6	602	0.174	0.168	21.7	12.56	26.82	12.35	26.15

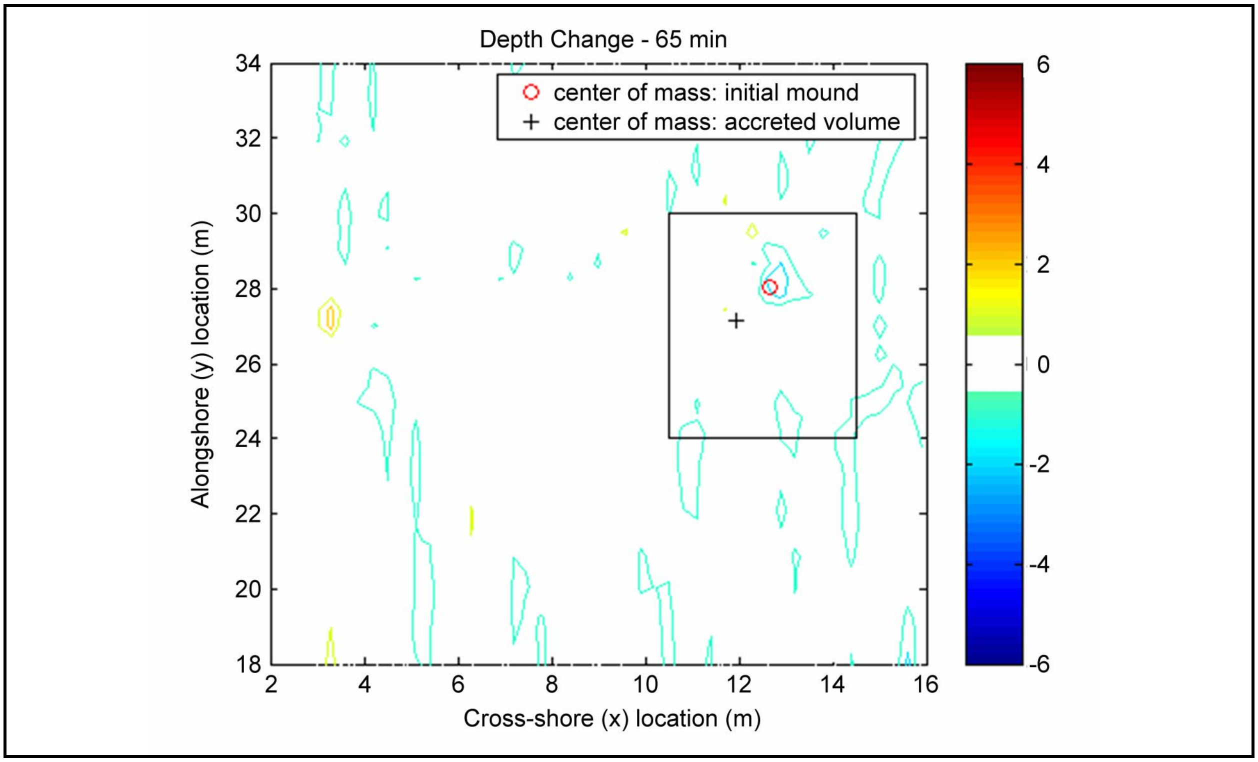

Figure 6. Depth change after 65 min of waves

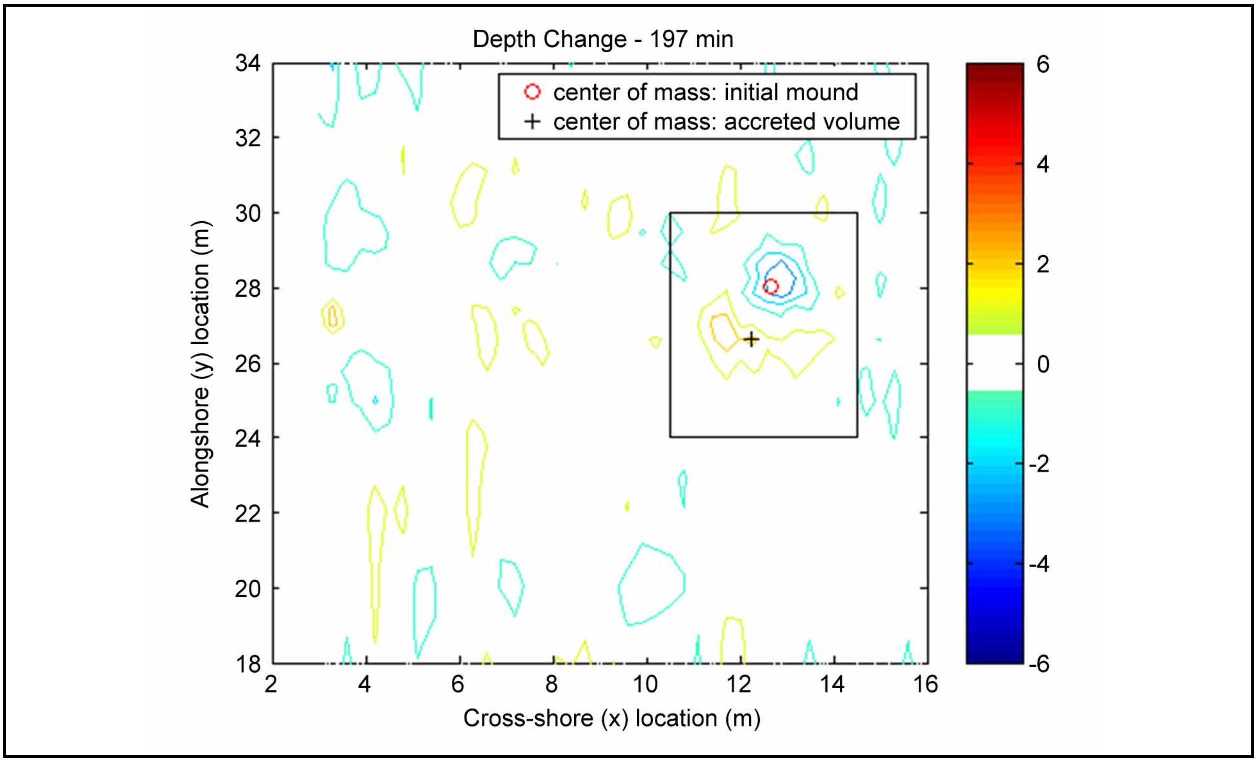

Figure 7. Depth change after 197 min of waves

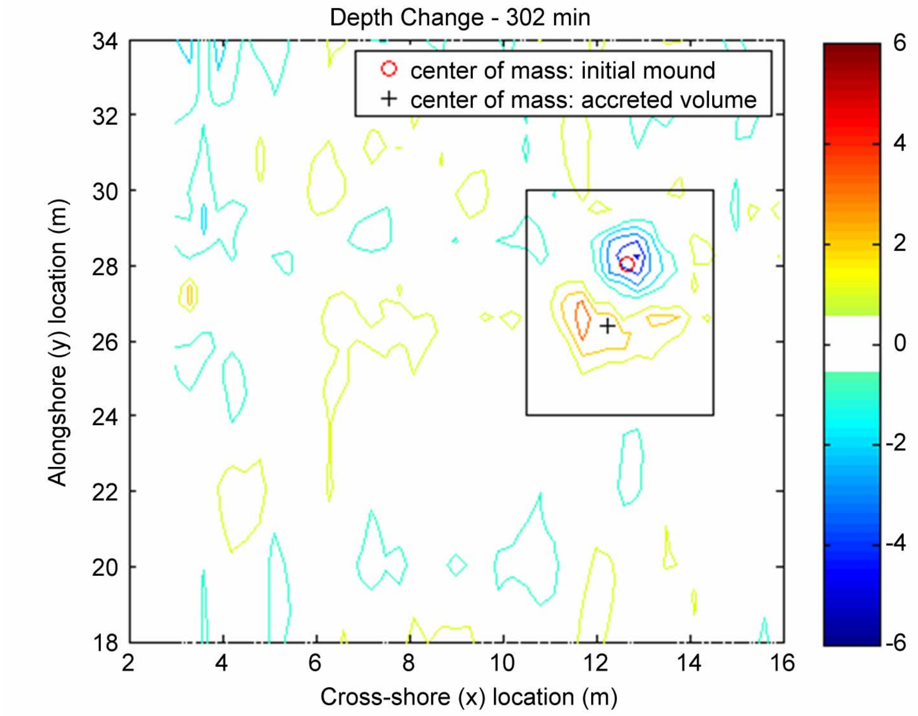

Figure 8. Depth change after 302 min

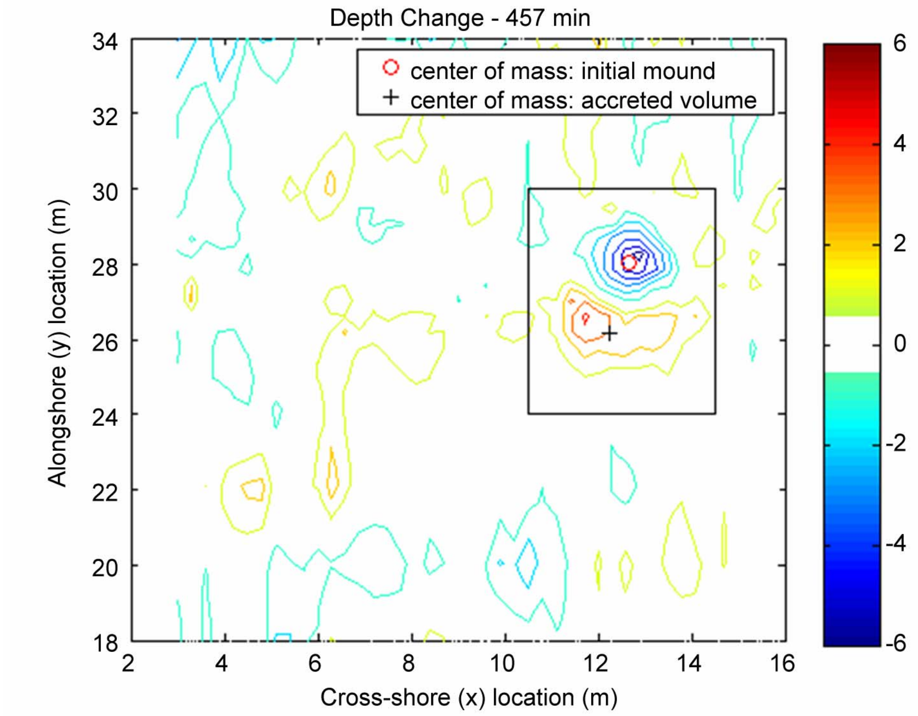

Figure 9. Depth change after 457 min

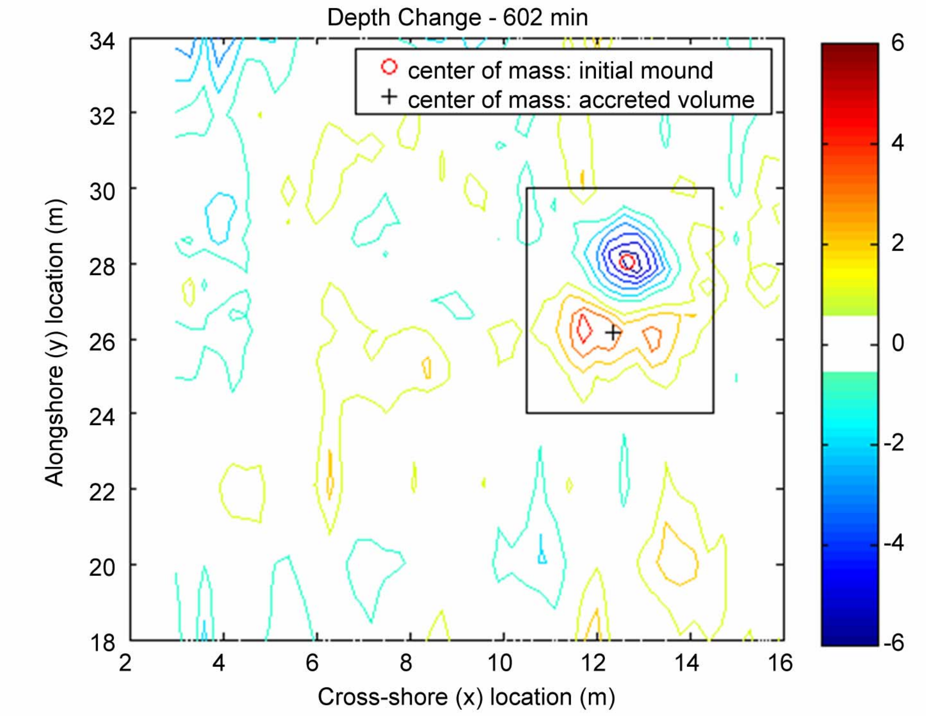

Figure 10. Depth change after 602 min of waves

The center of mass was calculated to quantify migration of the mound. Two approaches were used to determine migration. The first involved calculating the difference in elevation between the initial nearshore beach without the mound and the nearshore beach after each survey. The area in which changes were observed in the vicinity of the mound was used as a control area for the calculation. The control area for this method was defined as the rectangle bounded by x = 10.5 m, x = 14.5 m, y = 24 m, and y = 30 m, and is shown in Figures 6 through 10. The second approach calculated center of mass on only the portion of the nearshore beach that accreted sand within the control area. The first method indicates where the center of placed mound material resides and the second identifies the center of sediment migration.

The center of mass was calculated after each survey for both approaches and the results are shown in Table 1, in which x_o and y_o are the cross-shore and longshore coordinates for the center of mass, respectively. Both methods indicate that material moved downdrift and slightly onshore of the original location. The first approach shows that the mound moves 0.09 m onshore in the first 197 min, but does not move further onshore for the remainder of the experiment. Longshore movement was slow in the first 65 min, increased between 65 min and 197 min, and then decreased for the remainder of the experiment. At the end of the experiment the mound center of mass was located 0.09 m onshore and 1.22 m downdrift of the initial mound center of mass.

Initial movement of the accretion volume was 0.70 m onshore and 0.89 m downdrift of the original mound center. However, Figure 6 shows no accretion greater than 0.5 cm after the first hour, and Table 1 indicates the accreted volume consisted of little sand. As the experiment progressed, the center moved offshore and further downdrift, however migration slowed. At the end of the experiment the accretion volume center of mass was located 0.30 m onshore and 1.89 m downdrift of the initial mound center of mass. A contour map of the beach after conclusion of the experiment is shown in Figure 11.

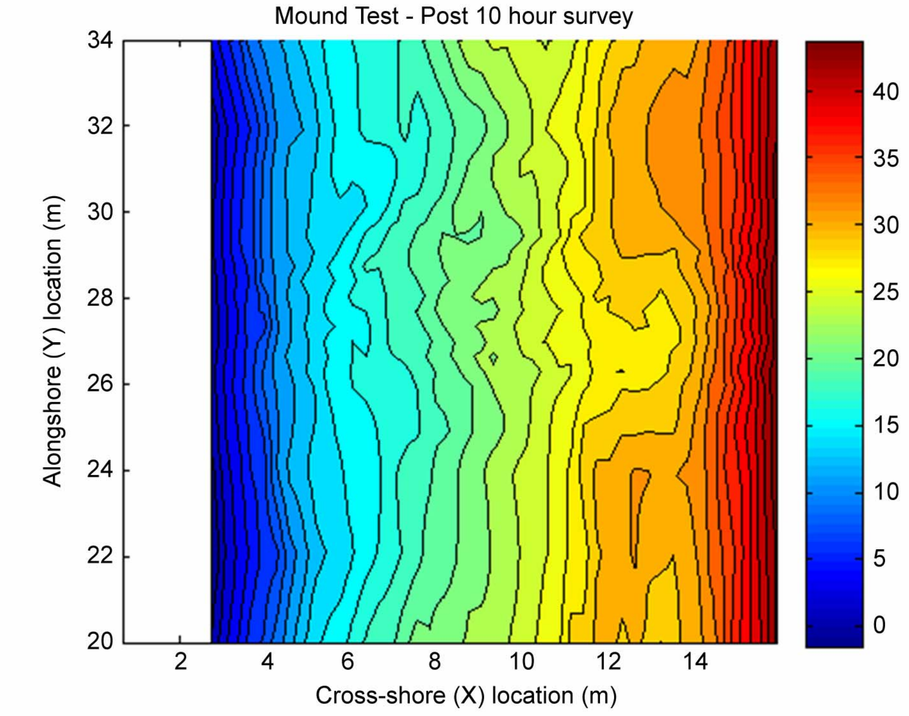

Figure 11. Contour map after 602 min of waves

Spread of the mound was calculated as the area in which migrating mound material accretion was greater than 0.5 cm. Table 1 lists the area of accretion after each survey. As expected, the area increases as the experiment progressed. It is well-documented that nearshore mounds spread as they migrate.

CONCLUSIONS: Nearshore placement is sometimes proposed as a method of keeping dredged material in the regional sediment system or as a method of littoral zone and thus beach nourishment. These experiments demonstrate the potential efficacy of dredged material dispersion in the nearshore/surf zone for littoral zone nourishment. The sand placed in the nearshore mound remained in the littoral zone and migrated downdrift and slightly onshore. Wave action is a significant contributor to 1) the amount of material available for transport, and 2) the direction of transport. Material placement near the breaker region permits wave asymmetry to induce a net onshore direction of mound migration and dispersion. The impact of wave asymmetry is reduced significantly outside this zone. Transport is initially rapid from the mound crest, and slows significantly as the mound elevation relative to the native bed is reduced. Placement in the relatively narrow, calm-weather surf zone is often not an option, but the surf zone becomes much wider during storms. Therefore, defining the storm surf zone for possible placement locations is important and can contribute significantly to the success of using nearshore placement to feed the littoral system.

POINTS OF CONTACT: For additional Information, contact the authors, Mr. Ernest R. Smith (601-634-4030, Ernest.R.Smith@erdc.usace.army.mil), or Dr. Joseph Gailani (601-634-4851, Joe.Z.Gailani@erdc.usace.army.mil), or the Manager of the Dredging Operations and Environmental Research Program, Dr. Robert M. Engler (601-524-3624, Robert.M.Engler@erdc.usace.army.mil). This technical note should be cited as follows:

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