# CREATION OF ARTIFICIAL REEF STRUCTURES USING DREDGED ROCK FROM NY/NJ HARBOR DEEPENING PROJECTS

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## ABSTRACT

Channel deepening projects associated with the Port of New York and New Jersey have generated millions of cubic meters of dredged rock. During the past six years, structures have been created at four artificial reefs permitted by the Corps of Engineers to the states of New York and New Jersey. Because natural rock is a preferred material for creation of artificial reefs, the states have eagerly accepted the rock, and have provided design parameters for creation of structures. From August, 1999 through March of 2005, ~3.8 million $m^3$ (~5 million $yd^3$) of rock were dredged and used to create structures within four reef sites. An additional ~3.8 million $m^3$ (~5 million $yd^3$) of dredged rock will be beneficially used for offshore reef construction during the next five years.

DGPS positioning systems and draft sensors incorporated on each scow used to transport loads of rock have allowed highly accurate placement of each rock load, enabling creation of discrete mounds or linear ridges, as high as 18m (60ft) above the surrounding bottom. A numerical model that simulates cumulative placement effects was developed to assist in planning and monitoring reef mound construction. The model, ROCDMP (**ROC**ky **D**redged **M**aterial **P**lacement), allows user input of initial, individual mound side slope angles, and maximum side slope angles associated with mounds constructed through cumulative placements. These input parameters are combined with scow volume, position, heading, and speed at the start of each placement event to determine the position and morphology of individual mounds. The cumulative bathymetric changes associated with model mound development provide near-real-time indications of the actual bathymetric changes associated with rock placement, prior to validation with bathymetric surveys.

**Keywords:** Beneficial use, FORTRAN, simulation, marine, construction

## INTRODUCTION

Artificial reefs created in tropical, sub-tropical, and temperate waters have utilized a wide variety of materials, including bricks, tires, concrete slabs, vehicles, vessels, tanks, rocks, and engineered structures such as reef balls. Natural rock, if available, is often favored due to its durability and rapid colonization by benthic flora and fauna. Ships and other large steel objects provide good vertical relief, but usually deteriorate due to corrosion.

The Port of New York and New Jersey is one of the most significant components of the northeastern U.S. economy. To accommodate the increased navigation depth requirements associated with modern, deep-draft cargo ships, a series of navigation improvement projects began in the 1980s and will continue through the rest of this decade. Many of the new channel areas have been, and are presently being, excavated through rock, producing millions of cubic meters of dredged rock for potential beneficial use. Creation of structures at artificial reef sites permitted to the states of New York and New Jersey (Figure 1) has been the primary beneficial use of the dredged rock during the past six years.

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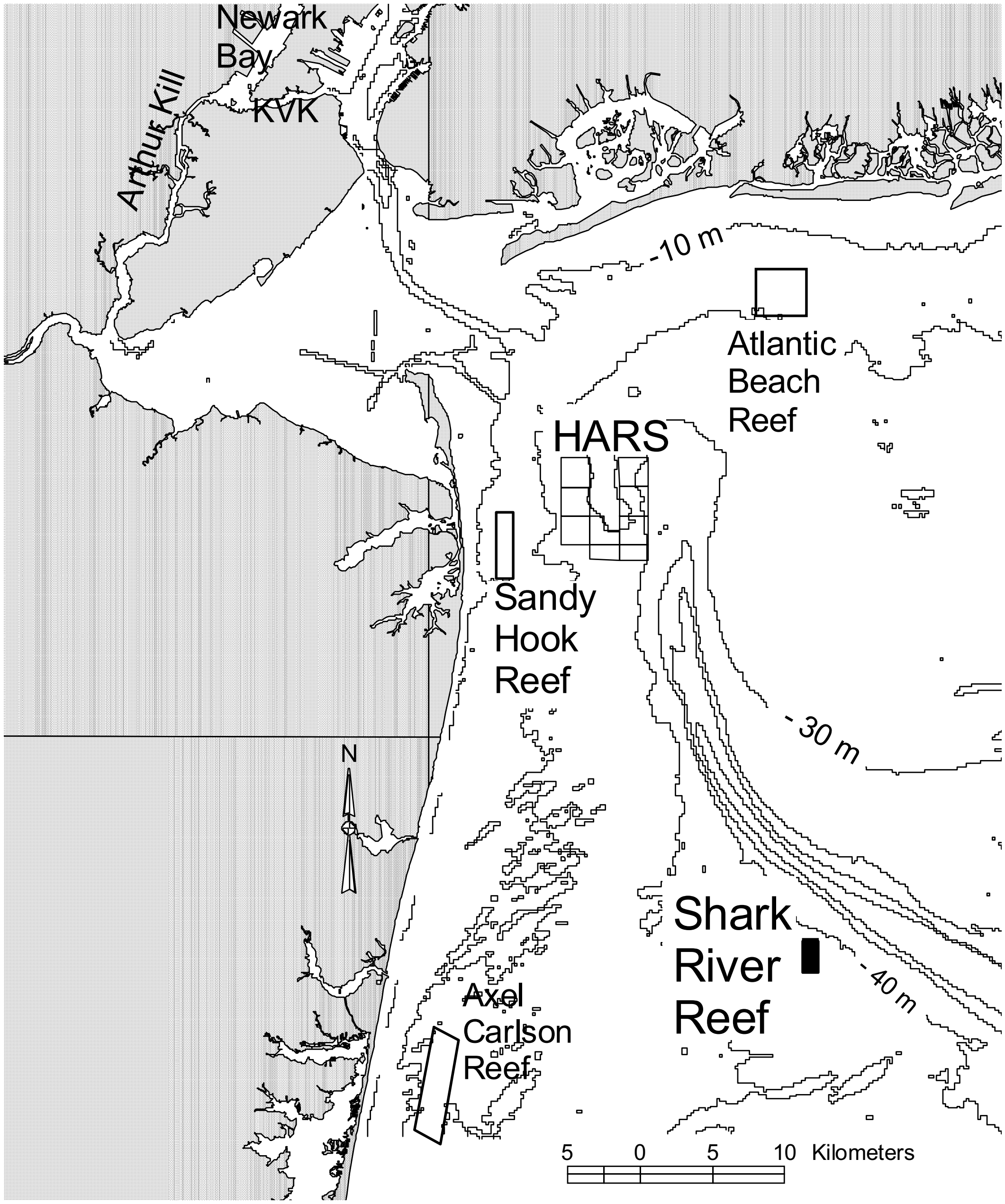


**Figure 1. New York Harbor Estuary and inner New York Bight. Note location of the waterways where rock is being dredged (Kill Van Kull (KVK), Newark Bay, and Arthur Kill), the HARS, and the four artificial reefs used for rock placement.**

Arrays of reef mounds are being constructed by using state-of-the-art scow monitoring equipment. Bathymetric and side-scan sonar surveys, and a computer program used to simulate rock placement, are used to plan and monitor reef construction. This paper discusses creation of reef structures using dredged rock from the channel deepening projects, with an emphasis on Shark River Reef, located offshore of New Jersey (Figure 1).

**Harbor Deepening Projects**

The Federal navigation channels in the New York Harbor Estuary were deepened in the 1980's to accommodate deeper draft vessels. A second phase of deepening projects began in 1999 and ended in November, 2005, during which ~3,500,000$m^3$ (4,583,000$yd^3$) of rock were dredged. The second phase involved deepening Federal navigation channels in the Kill Van Kull, Newark Bay, and Arthur Kill to -13.7m (-45ft) or -14.3m (-47 ft) MLW (Figure 1). The third phase, which began in 2005, involves deepening the channels to -15.2m (-50ft) or -15.8m (-52ft) MLW, with ~3,800,000 $m^3$ (~5 million $yd^3$) of additional rock to be dredged. Dredged material determined to be unsuitable for ocean placement (recently deposited mud) is transported to an upland treatment facility for beneficial use such as brownfield reclamation. Sand, silt, clay, and gravel that are determined to be suitable for ocean placement are placed at the Historic Area Remediation Site (HARS) (Figure 1), an area designated for remediation by the U.S. Environmental Protection Agency, due to sediment contamination associated with historical dredging activities (EPA, 1997). Dredged rock produced from the deepening projects has been placed at artificial reef sites located offshore of New York and New Jersey (Figure 1)(Table 1).

**Table 1. Volume of dredged rock placed at artificial reef sites from 1999 through March 2006.**

| Reef | Volume | |
|---|---|---|
| Atlantic Beach | 389,000 $m^3$ | (509,000 $yd^3$) |
| Sandy Hook | 73,000 $m^3$ | (96,000 $yd^3$) |
| Shark River | 3,021,000 $m^3$ | (3,952,000 $yd^3$) |
| Axel Carlson | 294,000 $m^3$ | (385,000 $yd^3$) |

## MONITORING OF ROCK TRANSPORT AND PLACEMENT

Comprehensive ocean placement guidelines and monitoring requirements have been developed during the past eight years in association with HARS remediation. These guidelines and requirements have been adopted for use during placement of rock at the reef sites, along with some additional requirements due to special considerations associated with rock placement.

The **A**utomated **DI**sposal **S**urveillance **S**ystem (**ADISS**) was developed by Science Applications International Corporation (SAIC) through contracts with NY District and U.S. Army Waterways Experiment Station (SAIC 1998). The basic system consists of a DGPS and scow draft sensor onboard each scow used to transport dredged material, and a lap top computer onboard the tugboat used to transport the scow. The laptop includes software that allows the position and draft of the scow to be monitored by NY District Certified Inspectors of Open Water Placement of Dredged Material (Inspectors), and tugboat crew members, throughout each placement trip. The position of the scow and the tugboat are viewed on the laptop screen in relation to nautical charts and maps of the placement site, allowing the Inspector and vessel crew to coordinate placement at specific latitude-longitude coordinates. Each placement trip is documented with a Transportation and Placement Log form, completed by the Inspector, that includes most of the information associated with the trip; time of departure, volume and characteristics of material, time and position of placement, weather and sea conditions, tug and scow identification, water depth at placement location, etc. A digital photograph of each loaded scow is also recorded by the Inspector. Fathometer data recorded from the tug's fathometer are stored within the laptop computer. When combined with the automated data collection of the ADISS system, the Log form, photograph, and fathometer data provide a complete record of each trip.

Bathymetric surveys of the reef sites are conducted to provide complete and more accurate depth information than possible through tug fathometer data or visual fathometer readings. Tug fathometers provide useful, but imprecise, bathymetric data; considered to be $\pm$ 0.6m (2ft) in accuracy due to limited tidal correction and uncertain vessel speed affects. Nonetheless, cumulative data records from multiple trips provide useful updates of bathymetric change caused by rock placement, allowing modification of the placement scheme prior to ground-truthing with conventional hydrographic surveys. Bathymetry at the Shark River Reef site, prior to placement of rock, is shown in Figure 2. The most recent bathymetric survey of the Shark River Reef, conducted in August, 2005, is shown in Figure 3. Three areas were used for rock placement; two rows of 7 coordinates in the north (Area A), 12 coordinates south of the eastern end of the northern two rows (Area B), and a single column of 7 coordinates extending south of the western end of the northern two rows (Area C) (Figure 3).

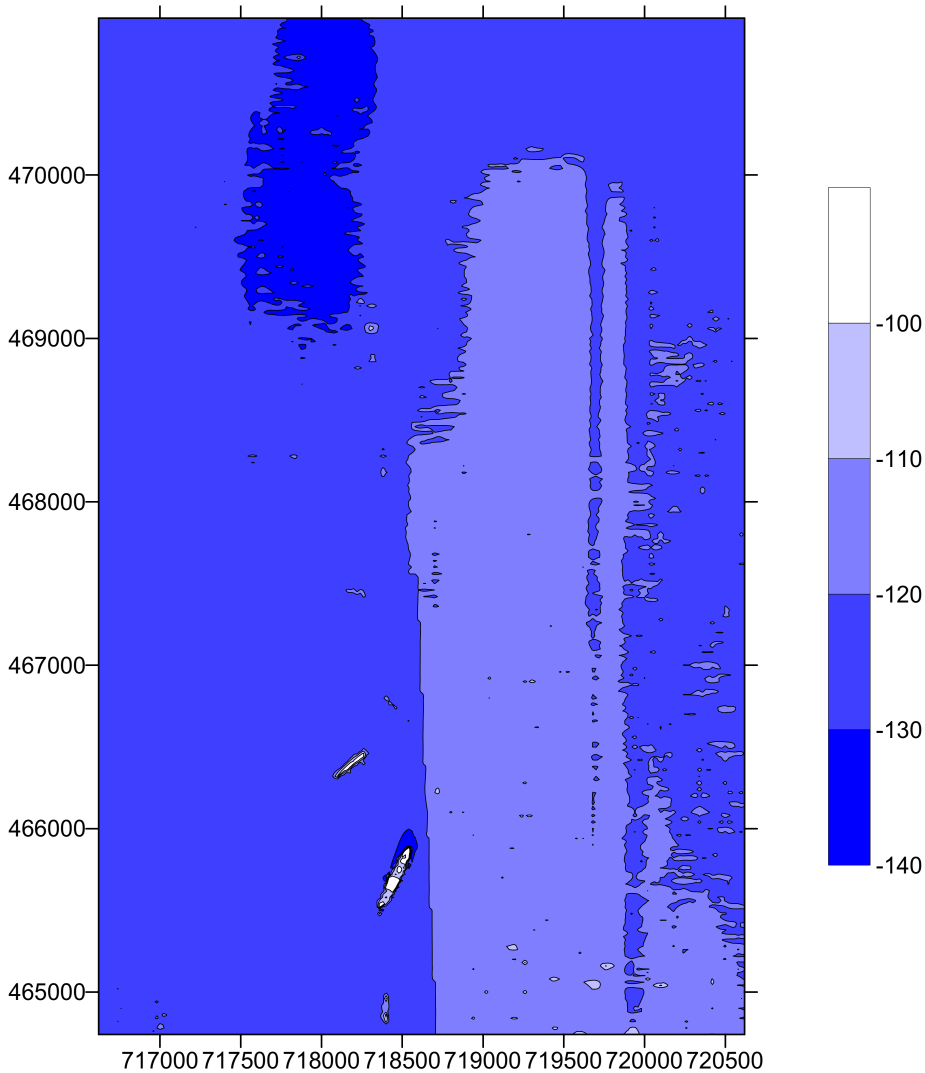


**Figure 2. Bathymetry of Shark River Reef in January 2002, prior to placement of rock. Contour interval = 3m (10 ft). State plane coordinates in feet (1000ft = 305m). The area was mostly flat and featureless. The two elongate features at the southern end of the map are shipwrecks.**

Coordinates selected by the New Jersey artificial reef program manager were incorporated within placement grids such that the desired coordinates were the centerpoints of certain grid cells. Only grid cells that represented the desired placement coordinates were "open" for placement. All other grid cells were "closed" for placement. During each placement trip, one "open" grid cell was selected as the target grid cell. Open grid cells were sequentially targeted until a desired volume, or placement trip total, for each coordinate was achieved. The grid cells associated with the coordinates comprising Areas A and B were spaced far enough apart, with two "closed" grid cells for separation, such that individual mounds were created. Seven adjacent grid cells within Area C were all used for placement, creating a somewhat continuous ridge of rock (Figure 3).

Side-scan sonar surveying is also periodically conducted, usually in conjunction with hydrographic surveys. High-quality side-scan sonar data provides an almost photographic depiction of the reef surface. However, with improvements in multi-beam bathymetric surveys, the high-resolution bathymetry data comes close to providing the kind of information that used to only be possible with side-scan surveys. Figure 4 shows high-resolution bathymetric data from the western two mounds of the northern row of reef mounds in Area A. The elongate features are New York City subway cars put on the rock mounds after rock placement in the area had been completed.

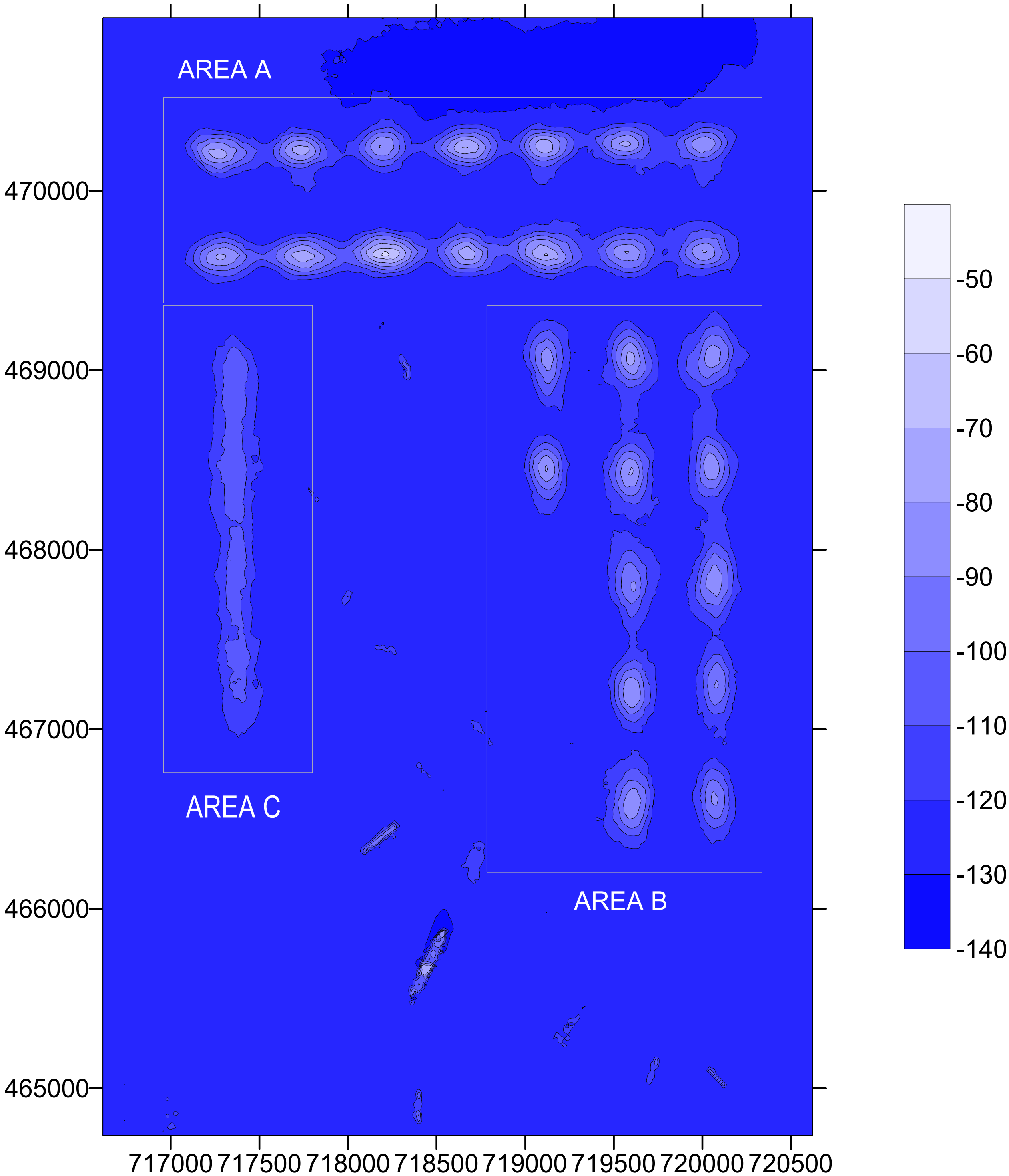


**Figure 3. Bathymetry at Shark River Reef in August, 2005, after placement of 2,956,000m$^3$ (3,866,000yd$^3$) of rock during 1237 placement trips. Contour interval is 3m (10ft). State plane coordinates in feet (1000ft = 305m). The three areas used for placement are indicated. The elongate features at the southern end of the map are shipwrecks.**

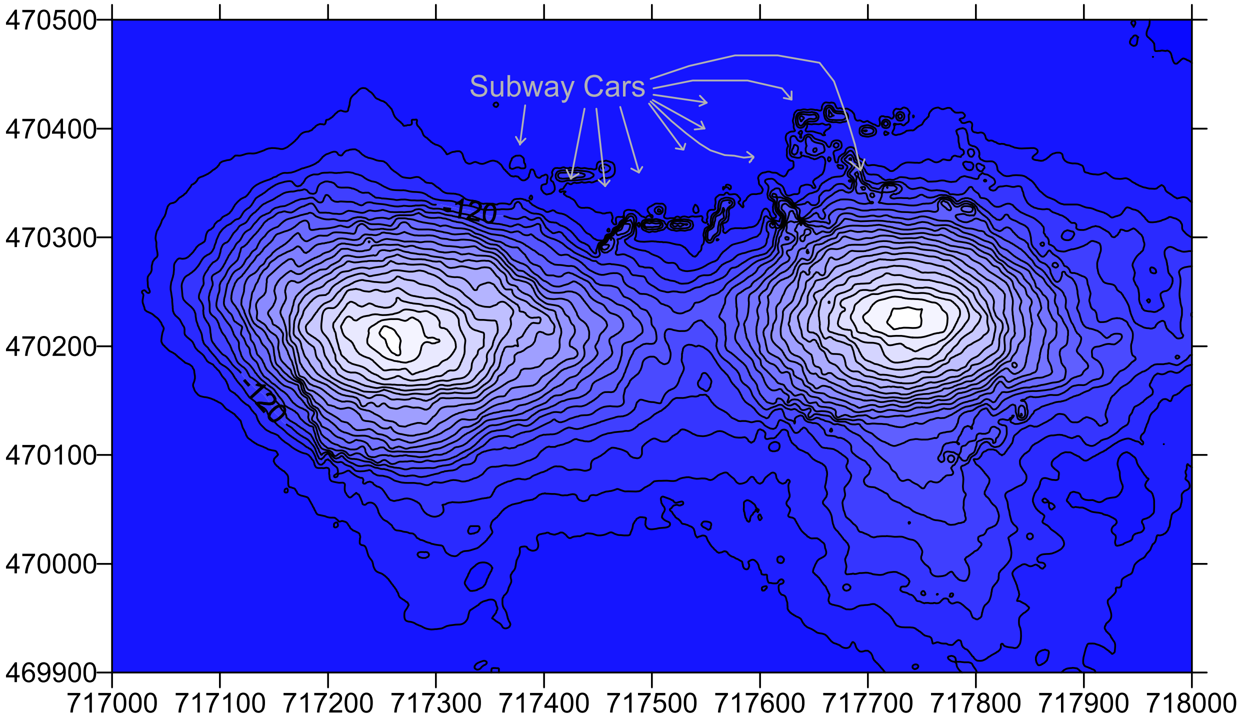


**Figure 4. High-resolution, multi-beam bathymetry of the western two mounds of the northern row of mounds in Area A. Contour interval is 0.76m (2.5ft), state plane coordinates in feet (100ft ≈30m). The elongate features are subway cars. Some over-steepened mound slopes are also depicted.**

## THE ROCDMP MODEL

Due to the need to predict capacity at reef sites, and provide advanced notice of potential shoaling problems during rock placement, a computer model was developed. The **ROC**ky **D**redged **M**aterial **P**lacement model (**ROCDMP**) was written in 2002 using the Fortran language. The model uses a simple, circular mound geometry associated with the volume placed during each trip. The center of the mound is located at a position based on the time each scow begins to release material, as recorded by the ADISS system, and incorporates the speed and heading of the scow. Initial mounds are given a user-defined side slope of from 1 to 6 degrees. Smaller initial side slopes create broader, lower-relief mounds that help to account for uncertainties in the assignment of centers of placement for each trip. Subsequent trips create individual mound morphologies that are added to the bathymetry associated with the previous trip, cumulatively changing the bathymetry until the model has cycled through all of the trips. As cumulative trip effects develop, steeper side slopes are created. A user input critical slope angle is checked during each simulated placement trip. If the critical slope angle is exceeded between any two adjacent model grid nodes (spaced 6m (20ft) apart), adjustments of the bottom elevations are made to bring the slope to the critical angle, resulting in "material" moving downslope, causing mounds to increase in area. The actual mounds created by release of rock from split-hull scows can be quite complex. If scows are being towed at relatively high speeds (>~9km/hr (>5 knots)) two parallel mounds, tapered at the ends, may be created. During very slow, or nearly stationary, placement, circular mounds with central craters may be created. Because the reef mounds are created during placement of dozens to hundreds of trips, the simplified geometry was considered to be a good approximation for assessing the cumulative effects of rock placement.

Figure 5 shows the results of a model run conducted after several months of placement of rock in Area A at the Shark River Reef site. Figure 6 is the actual bathymetry at the time. The model produced morphological characteristics similar to the actual bathymetry. The modeled mound heights were also similar to the actual mound heights; slightly underpredicting the shoaling at 4 of the mounds, and over predicting shoaling at 10 of the mounds

(Figures 7, Table 2). Overprediction is a goal of a model such as this since early warning of potential shoaling problems is the desired outcome.

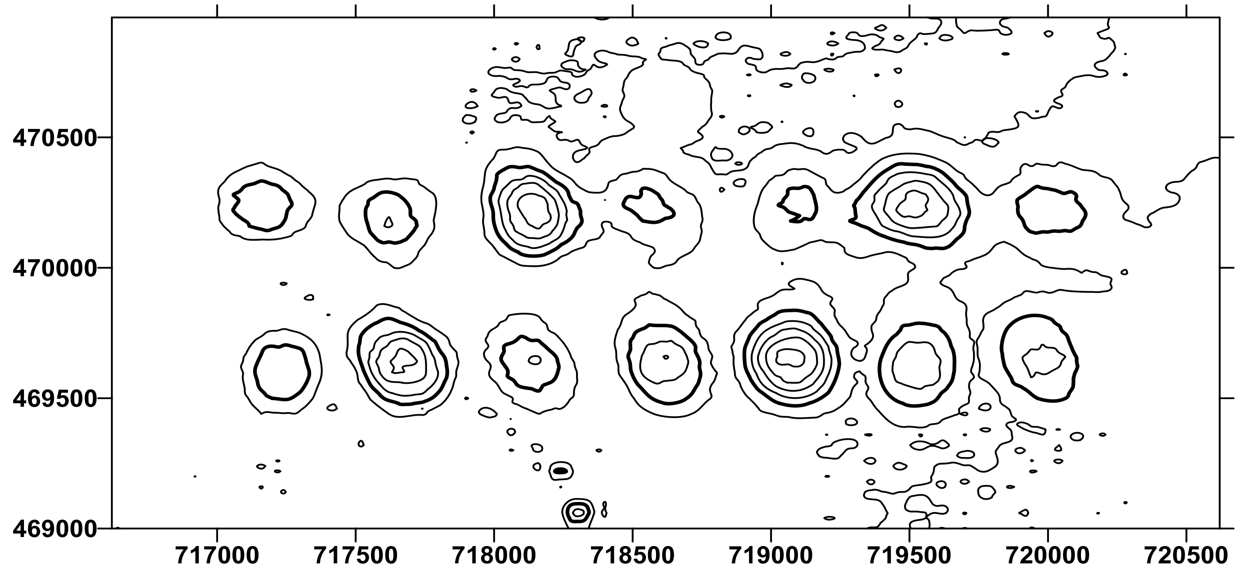


**Figure 5. ROCDMP model bathymetry at Shark River reef, Area A, simulating placement of ≈411,00m$^3$ (538,000yd$^3$) of rock during 164 trips. Contour interval = 1.5m (5ft), state plane coordinates in feet (500ft = 152m). The -36.6m (-120ft) contour is bold.**

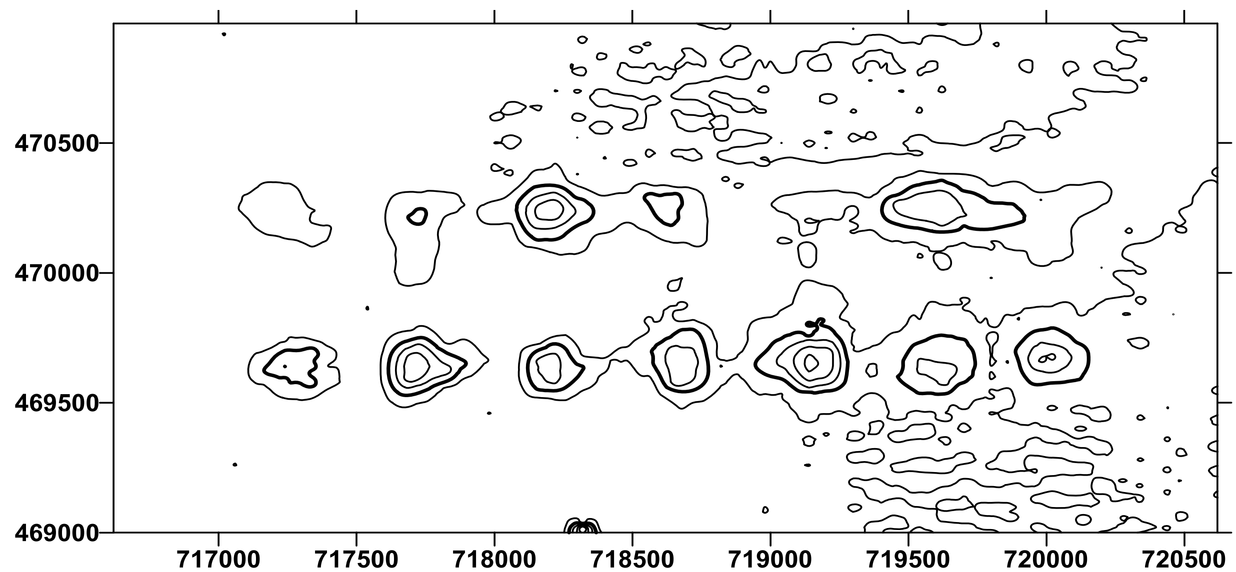


**Figure 6. September 2002 bathymetry of Shark River Reef, Area A, after placement of ≈411,000m$^3$ (538,000 yd$^3$) of rock during 164 trips. Contour interval = 1.5m (5ft), state plane coordinates in feet (500ft = 152m). The -36.6m (-120ft) contour is bold.**

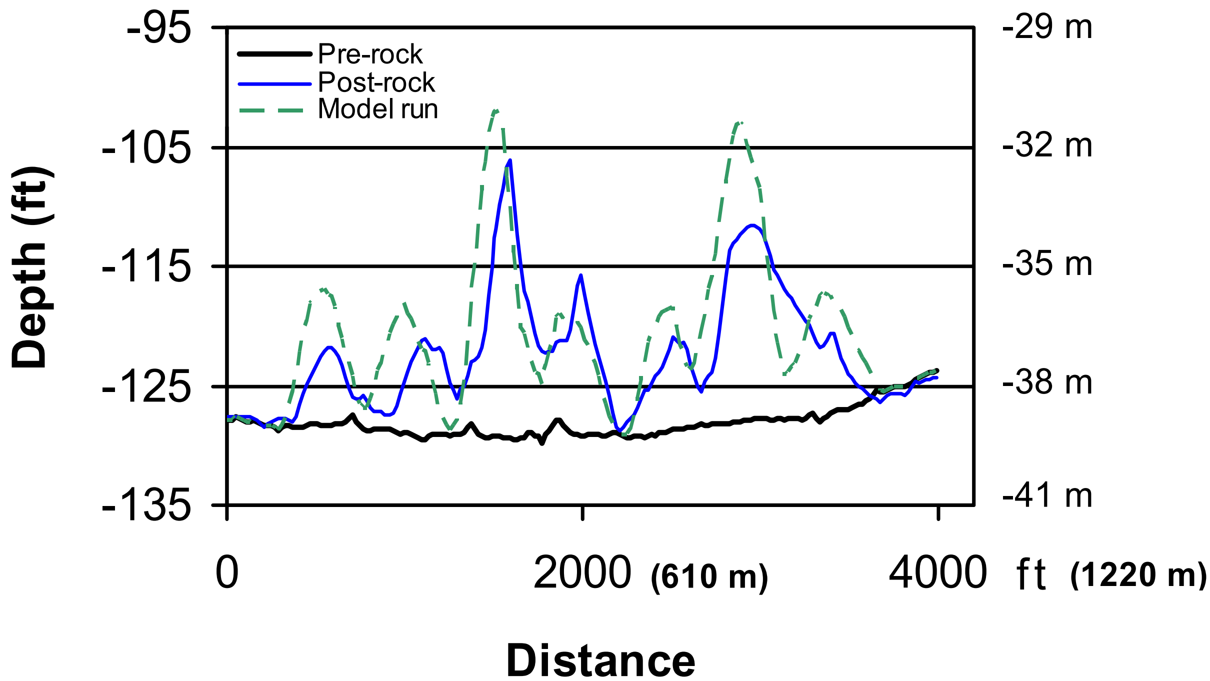


**Figure 7. Bathymetric profiles across northern row of reef placement grid cells.**

**Table 2. Comparison of ROCDMP model results with measured data. Mound heights refer to feet above the pre-disposal bottom. Model dumps occurred at a scow position equivalent to 15 seconds after the scow "door open" command was sent. One-hundred-sixty-four scow loads totaling 411,000 m$^3$ (538,000 yd$^3$) of rock were input to the model. Initial placed mounds were assigned a 1-degree side slope. Maximum cumulative mound side slope were set to 15 degrees.**

| | Mound Heights | | | | Model - | Model - |
|---|---|---|---|---|---|---|
| Mound I.D. | Measured (m) | Measured (ft) | Modeled (m) | Modeled (ft) | Measured (m) | Measured (ft) |
| North 1 | 2.4 | 7.9 | 4.1 | 13.3 | 1.6 | 5.4 |
| North 2 | 3.1 | 10.3 | 4.3 | 14.0 | 1.1 | 3.7 |
| North 3 | 7.3 | 23.8 | 8.4 | 27.5 | 1.1 | 3.7 |
| North 4 | 4.2 | 13.8 | 3.0 | 10.0 | -1.2 | -3.8 |
| North 5 | 2.4 | 7.8 | 3.2 | 10.4 | 0.8 | 2.6 |
| North 6 | 5.2 | 17.0 | 7.6 | 25.0 | 2.4 | 8.0 |
| North 7 | 2.1 | 7.0 | 3.2 | 10.6 | 1.1 | 3.6 |
| South 1 | 4.5 | 14.7 | 3.9 | 12.8 | -0.6 | -1.9 |
| South 2 | 7.1 | 23.2 | 8.4 | 27.4 | 1.3 | 4.2 |
| South 3 | 4.9 | 16.0 | 4.4 | 14.5 | -0.5 | -1.5 |
| South 4 | 4.6 | 15.2 | 5.3 | 17.3 | 0.6 | 2.1 |
| South 5 | 6.9 | 22.5 | 8.4 | 27.4 | 1.5 | 4.9 |
| South 6 | 4.1 | 13.6 | 4.3 | 14.1 | 0.2 | 0.5 |
| South 7 | 4.7 | 15.5 | 3.9 | 12.7 | -0.9 | -2.8 |
| Mean | 4.5 | 14.9 | 5.2 | 16.9 | 0.6 | 2.1 |
| Std Dev | 1.7 | 5.5 | 2.1 | 6.8 | 1.1 | 3.5 |

## CONCLUSIONS

The scow monitoring technologies and placement procedures associated with placement of conventional dredged materials at the HARS have been used to create structures at artificial reefs using dredged rock from the NY/NJ Harbor Deepening Projects. The ROCDMP computer model has been successfully used to predict the morphological characteristics of structures created with the dredged rock at reef sites, and has allowed near-real-time analysis of the cumulative effects of rock placement, prior to validation with hydrographic surveys. Additional refinements to the monitoring program may allow even more precise sub-marine construction projects in the future, such as nearshore submerged breakwaters.

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