Annex B:

Additional Environmental and Engineering Information

1. Summary Information from MMS (2006), Studies Conducted by VERSAR, Inc. of Offshore Shoals off Maryland/Delaware, 2002-2004.

2. Great Gull Bank Dredging and Impacts: 1998 and 2002

3. MGS Monitoring Report of Borrow Areas 2 and 3

4. Projected Dredging Impact Area as Function of Total Volume and Thickness of Material Removed

5. LTSM Project Dredging Record

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Summary Information from MMS (2006). Studies Conducted by VERSAR, Inc. of Offshore Shoals and Seafloor Flats off Maryland/Delaware, 2002-2004.

Full report available (November 2007) at:

http://www.mms.gov/sandandgravel/PDF/MMS2005-042/MMS2005-042Non-TechnicalSummary.pdf

and

http://www.mms.gov/sandandgravel/PDF/MMS2005-042/MMS2005-042TechnicalSummary.pdf

Table. List of fish species with management plans collected by VERSAR at four shoals and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004.

Taxonomic Name Common Name Juvenile Adult

Scientific Name	**Common Name**	**Juvenile**	**Adult**
Alosa pseudoharengus	Alewife		X
Alosa sapidissima	American shad		X
Squatina dumeril	Atlantic angel shark		X
Gadus morhua	Atlantic cod		X
Micropogonias undulatus	Atlantic croaker	X	X
Clupea harengus harengus	Atlantic herring		X
Scomber scombrus	Atlantic mackerel	X	
Brevoortia tyrannus	Atlantic menhaden		X
Rhizoprionodon terraenovae	Atlantic sharpnose shark		X
Raja laevis	Barndoor skate	X	
Centropristis striata	Black sea bass	X	X
Alosa aestivalis	Blueback herring		X
Pomatomus saltatrix	Bluefish		X
Peprilus triacanthus	Butterfish	X	X
Raja eglanteria	Clearnose skate	X	
Rachycentron canadum	Cobia		X
Carcharhinus obscurus	Dusky shark	X	
Lophius americanus	Monkfish		X
Alosa mediocris	Hickory shad	X	
Limulus polyphemus	Horseshoe crab	X	
Raja erinacea	Little skate	X	
Urophycis chuss	Red hake	X	
Carcharhinus plumbeus	Sandbar shark	X	
Stenotomus chrysops	Scup	X	X
Merluccius bilinearis	Silver hake	X	
Scomberomorus maculatus	Spanish mackerel		X
Squalus acanthias	Spiny dogfish		X
Leiostomus xanthurus	Spot		X
Cephalopoda	Squids	X	X
Morone saxatilis	Striped bass		X
Paralichthys dentatus	Summer flounder		X
Alopias vulpinus	Thresher shark	X	X
Cynoscion regalis	Weakfish	X	X
Scophthalmus aquosus	Windowpane		X
Pleuronectes americanus	Winter flounder		X
Raja ocellata	Winter skate		X

Table. Taxa Collected Only on Shoals or Only on Non-Shoal Reference Sites (MMS, 2006). VERSAR sampling 2002-2004.

Small Trawls, Commercial Trawls, and Gillnets Results Presented

		Small Trawls		Commercial Trawls		Gillnets	
Taxa/Species		**Non-Shoal Reference**	**Shoals**	**Non-Shoal Reference**	**Shoals**	**Non-Shoal Reference**	**Shoals**
INVERTEBRATES							
Callinectes sapidus	Blue crab		X		X		
Octopus vulgaris	Common octopus			X			
Nudibranchia	Nudibranch snail	X					
VERTEBRATES							
Alosa sapidissima	American shad						X
Squatina dumeril	Atlantic angel shark			X			
Sarda sarda	Atlantic bonito						X
Gadus morhua	Atlantic cod			X			
Scomber scombrus	Atlantic mackerel						X
Anchoa mitchilli	Bay anchovy	X		X			
Rhinoptera bonasus	Cownose ray						X
Lophius americanus	Goosefish			X			
Peprilus alepidotus	Harvestfish				X		
Alosa mediocris	Hickory shad			X			
Synodus foetens	Inshore lizardfish		X				
Hippocamus erectus	Lined seahorse	X					
Urophycis chuss	Red hake	X		X			
Carcharhinus plumbeus	Sandbar shark						X
Leiostomus xanthurus	Spot			X		X	
Anchoa hepsetus	Striped anchovy	X					
Ophidion marginatum	Striped cusk eel	X					
Alopias vulpinus	Thresher shark			X			X
Cynoscion regalis	Weakfish	X		X		X	

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Great Gull Bank: Short-Term Restoration Impacts - Bathymetric Monitoring

In October and November of 2002, up to approximately 1,800,000 cubic yards of sand were authorized to be dredged from the southeastern side of Great Gull Bank to supply sand for the Short-Term Restoration of Assateague project. The delineated borrow area was roughly rectangular in shape, with a length of approximately 11,000 ft (length axis oriented generally NE/SW) and average width of 1,200 ft (width axis oriented NW/SE). The total borrow area size is approximately 320 acres.

It was necessary to conduct a comparison of pre- and post-project bathymetric conditions on the shoal to determine whether borrow actions met the guidelines and constraints stipulated in the July 2001 Environmental Assessment prepared for this proposed dredging work. It was necessary to 1) identify the area where dredging was conducted to verify whether it was within the delineated borrow area, and 2) determine the thickness of material removed/dredged to verify that no more than 6 feet of material were removed. In addition, it was necessary to 3) identify/quantify bathymetric changes on the shoal outside of the borrow area to characterize changes on the shoal that occurred as a result of natural processes or as an indirect consequence of the project (assuming that the borrow area can be readily identified and distinguished from other non-borrow areas of the shoal). Three hydrographic data sets were available to evaluate bathymetric changes at Great Gull Bank immediately prior to and following implementation of the Short-Term Restoration project (Table 1). These surveys each covered the entire length and width of the borrow area, but differed in their coverage of portions of the shoal outside of the borrow area. In each survey, bathymetric data was collected along profiles perpendicular to the long axis (SW/NE) of the borrow area at 500 foot intervals. Profiles were numbered using engineering surveying convention as 0+00 through 110+00. The surveys did not provide any data on vertical or horizontal accuracy limitations, however since each was performed professionally (surveys were contracted by Baltimore District Engineering Division), it is assumed that the data accurately recorded field conditions.

Table 1: Hydrographic data.

Survey Date	Distance Surveyed NW of Borrow Area (ft)	Distance Surveyed SE of Borrow Area (ft)	NW/SE Survey Width (ft)
Dec-1999	4200	1600	7000
Dec-2002	500	500	2200
Feb-2003	7000	4200	12400

Overlaid graphs from each of three surveys for each 500-foot interval profile were visually compared to address the three points identified above. No pre-project survey data from immediately before the dredging work was available. Therefore, to evaluate direct impacts of the dredging, the December 1999 graphs were compared to those of December 2002. Comparison of the December 2002 graphs to those of February 2003 provided a means to evaluate changes in the borrow area that occurred as a consequence of natural processes over that time period.

The December 2002 surveys depict a general lowering of the shoal surface elevation by about 5 feet within the borrow area compared to the December 1999 survey. This lowering did not extend beyond the borrow area. Proceeding outward towards the outer limit of the borrow area, this reduction in elevation tapered to zero in the vicinity of the boundary. At several points along profiles 85+00, 90+00, and 100+00 the shoal was reduced in elevation by more than 6 feet. During the three years that elapsed between completion of the December 1999 survey and December 2002 survey it is possible that substantial natural movement of material could have occurred. However, based on the close relationship between the position of the area of lowered elevation with the designated borrow area, and passage of only a couple of months between dredging and completion of the December 2002 survey, it is believed that borrow activities were intensively focused within the designated borrow area. (From this data it is not possible to state that no dredging occurred outside of the borrow area, however if it did, only a much thinner thickness of material was removed, or natural processes have obscured the impact). Although there were several points where shoal elevation was reduced by more than 6 feet between December 1999 and December 2002, it is believed that the stipulation limiting dredging to no more than 6 foot thickness was met in the majority of the borrow area. It is possible that the shoal surface in areas where greater than 6 feet of surface elevation reduction occurred was actually lower just immediately prior to dredging than depicted in the December 1999 survey. In that event, dredging at those few points where more than 6 feet of elevation reduction occurred between December 1999 and December 2002 may not have exceeded the 6 foot limit.

A substantial portion of the borrow area (majority of profiles between 5+00 and 65+00) actually gained elevation between December 2002 and February 2003. This gain of material was most pronounced along profiles 10+00, 15+00, and 20+00 where up to 10 feet of elevation gain occurred along the northwestern edge of the borrow area. The southwesternmost portion of the borrow area possessed the steepest slopes in all years of surveying. Profiles 25+00 through 65+00 showed gains in elevation within the borrow area of up to several feet. Along profiles 10+00 through 20+00 the December 2002 survey shows the shoal having gained in elevation by up to a couple of feet along its northwestern boundary since the December 1999 survey. It is possible that elevation gain here between these two periods of time was actually substantially more, but that much of this was removed in fall 2002 dredging.

The December 2002 survey was focused on the borrow area and didn't cover all of the area surveyed in December 1999. However, the February 2003 survey extends substantially beyond the designated borrow area to well beyond the limit of the area surveyed in 1999. It is thus useful in determining changes that occurred outside of the designated borrow area.

Changes were observed between the December 1999 survey and February 2003 survey in areas outside of the designated borrow area. The most dynamic conditions were in the southwestwardmost part of the shoal. The southwestern end of the shoal crest shifted towards the southeast by about 200 feet along profile 5+00. This area of the crest shifting southeastward was adjacent to portions of the borrow area that showed gains in elevation of up to 10 feet as described above. Stations along profiles 5+00 through 65+00 on the northwest of the borrow area showed a reduction in elevation by 1 to 2 feet out to about –2800 feet horizontally. The shoal surface also lowered by about 1 ft on the southeast side of the borrow area at stations 5+00, 40+00, and 100+00 – but not between these stations.

Swift and Field (1981) stated that offshore shoals of this region exhibit a net seaward (southeastward) migration. Based on the observations of shoal crest movement towards the southeast, and general accretion in the borrow area in the southeast between 5+00 and 65+00 with general loss of material immediately to the northwest, it appears that net movement of material at Great Gull Bank is towards the southeast.

Great Gull Bank Previous Dredging – Assateague Emergency Project

In January and February of 1998 approximately 134,000 cubic yards of sand were dredged from a borrow area located immediately northwest of the crest in the southern portion of Great Gull Bank. Comparison of hydrographic surveys from 1995 and 1999 indicated that bathymetric changes that occurred on Great Gull Bank within the emergency borrow area appear to be a loss of up to 3 feet in elevation. These losses are about 1 foot greater than any changes that occurred elsewhere on the shoal outside of the area dredged for the emergency project, where loss in elevation of up to about 2 feet occurred. Large-size depressions in the borrow area that could be attributable to the emergency project are absent. However, it is unclear at this time whether large holes were never created, or whether the period of time that elapsed between dredging and the survey was sufficient enough time for natural processes to have refilled holes excavated by the dredge.

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Bathymetry, Side-scan, and Seabed Classification Surveys of Borrow Shoals 2 and 3 off Ocean City, Maryland

by

Darlene Wells, Robert Conkwright, Katie Offerman and Stephen VanRyswick

INFORMATIVE ABSTRACT

In 2004 and 2005, the Maryland Geological Survey (MGS*), in cooperation with the University of Maryland Eastern Shore's Earth Mapping Laboratory (EML),* conducted geophysical surveys on two borrow sites which were dredged for sand for a beach nourishment project. The two sites, referred to as Borrow Areas 2 and 3, were dredged between 1988 and 1992. During this period, 7 million cubic meters of sand were removed and placed on12 kilometers of beach along Ocean City, Maryland. Post-dredging bathymetric surveys were conducted on the borrow areas in 1991 and 1992, respectively. Since that time, no additional surveys or further monitoring has been conducted on the borrow areas.

In order to document the current condition of the borrow areas and surrounding seafloor, and determine how these features have evolved since dredging, MGS conducted hydrographic, side-scan and seabed classification surveys on each site over a two-day period in September of 2004. Due to the limited time available for surveying, the bathymetric data were collected simultaneously with the side-scan and seabed classification data. Survey track lines for Borrow Area 2 were spaced at 160 ft (50 m) apart and ran parallel to the long axis of the shoal. The area surveyed was approximately 2,400 ft by 8,800 ft, and covered adjacent areas 400 to700 feet outside the designated dredged boundaries. Approximately 24 miles (38.5 km) of surveys were collected on Borrow Area 2. Borrow Area 3 was surveyed at 325-ft (100-meter) line spacing. Track lines ran NNE - SSW, parallel to the long axis of the shoal. Total area surveyed was approximately 1.5 square miles and extended 400 to 800 feet beyond the borrow area boundaries. Approximately 50 miles of surveys were collected on Borrow Area 3. In June, 2005, additional side-scan surveys were collected on the northern end of Borrow Area 3, with track lines running in an E – W direction.

Historical National Oceanic and Atmospheric Administration (NOAA) (1978) data were used to create the bathymetric surface representing pre-dredging conditions for each borrow area. Post-dredging hydrographic surveys of the borrow areas conducted during the various phases of dredging were used to create post-dredging bathymetry.

Borrow Area 2

Borrow Area 2 is located on the western half of semi-detached shoal (Shoal 2), about 2.3 miles (3.7 kilometers) offshore of south Ocean City (Figure 1). Prior to dredging, the shoal's axis trended NNE to SSW (azimuth of approximately 30º), and the shoal was approximately 2.36 miles (3.8 Km) long and 0.7 mile across at it's maximum width. The crest had four distinct crest knolls, or second-order ridges, defined by the 30-ft (10-meter) isobath (Figure 2). Approximately 3.76 million yd^3 of medium to fine sand, essentially one-third of the shoal's volume, were extracted from this borrow area for beach fill during dredging. The post-dredging bathymetry, a composite of several surveys collected between 1986 and 1991 (henceforth, referred to as the 1991 bathymetry), clearly shows the extent of the dredged area, the boundaries of which were very linear and steep, with slopes between 11 and 17% along the eastern edge (Figure 3). Most of the western flank and a portion of the crest were removed, reducing the shoal width by half. Some areas were excavated below the project limit of -50-ft, NGVD, resulting in an irregular seafloor. In one area, dredging resulted in a 400-ft wide hole with a depth of -59 feet (~10 below surrounding area). Pleistocene sediments consisting of poorly sorted, fine to coarse sand with gravel, shells and mud were exposed on the bottom within the dredged area. Changes in bathymetry indicate that portions of the shoal have migrated to the southwest approximately 500 feet since 1978 (Figure 4a).

The 2004 bathymetry of Borrow Area 2 revealed that, while remaining shoal features maintained their general shape, several changes have taken place since 1991 (Figure 5). The remnant shoal crest and eastern flank remained intact over the 13 years, but lost 2 to 4 feet in height in some areas. It is presumed that sand from the crest was redistributed along the steep dredge cut on the landward flank of the shoal, which has become less steep since 1991. The second order ridges, or crest knolls, grew more distinct. The northern-most crest appears more detached from the main shoal and the adjacent inter-crest trough to the southeast grew wider (Figure 5, a and b, respectively). The deep dredged holes filled in partially and the dredged area had become more level, continuous with the adjacent (northwestern) intershoal area with depths between -45 and -50 feet. The low ridge marking the northwestern edge of the dredged area disappeared completely. Changes in bathymetry suggest that portions of the shoal continued to migrate to the south-southwest (parallel to the shoreline), but at a slower rate than prior to dredging (Figure 4b).

The 2004 sidescan surveys of Shoal 2 revealed an array of bedforms superimposed on each other, reflecting the episodic nature of current conditions and sediment transport (Figure 6). Small ripples (~ 1 foot in length) were the most abundant bedform observed, accounting for the higher backscatter (darker or shaded areas) in sidescan imagery of both borrow areas. Large portions of the dredged area of Shoal 2 and the adjacent intershoal seafloor were covered with ripples, ranging from 8 inches to 30 inches (20 to 80 cm) in length. The ripples were superimposed on larger bedforms including sand waves and inter-knoll troughs and generally were restricted to depths greater than 35 ft (11.5 m). Orientation of the ripples indicated the predominant bottom current flow was to the south-southwest, reflecting the wave conditions at the time the surveys were collected. Ripples were not observed on the shallower shoal crests. Well-developed sand waves, with orientations of north-northwest to south-southeast direction, oblique to the smaller ripples, formed along the shoreward side of the remaining shoal. Less defined sand waves were visible in the northern end of the dredged area. These sand waves are thought to reflect longer-term bottom current conditions, and form where sand is relatively thick. The sand waves indicate a significant southwesterly current flow along the landward flank of the remaining shoal. Sidescan imagery also revealed a patch work of various backscatter intensities within the dredged area, primarily in the southern end, and in the intershoal areas. The patch-work pattern is interpreted to reflect a range of sediment textures, from mud to sand and mixtures in between, with some areas covered with benthic organisms.

Four classes of bottom types were derived from the QTC seabed classification surveys for Borrow Area 2 (Figure 7). The seabed classes were related to the bathymetry, sidescan imagery, and historical textural data for preliminary interpretation. The four classes are:

1) S<u>hoal crest</u> - generally is restricted to the undisturbed shoal crest at depths less than 35 ft (11.2 m) and, has no discernable bedforms;

2) Flank - bottom class associated with the shoal crest; primarily found along the shoal flanks between -35 ft and -40 ft, representing transitional bottom, from shoal crest to intershoal bottom type; sand, the texture of which may or may not be significantly different than that of the shoal crest; occasional ripples;
3) Ripples - associated with the deeper seabottom (> 40 feet), both disturbed (dredged) and undisturbed intershoal areas or troughs; sandy bottom dominated by small ripples (< 0.40 meter widths); and
4) Patch – occurring in the deeper sea bottom (> 40 feet) in trough or intershoal areas; large patches, ~100 ft in diameter, associated with rippled bottom within the dredged area; interpreted to be soft, finer-grained sediment based on low backscatter intensity return.

The changes observed in and around Borrow Area 2 since 1991 reflect several processes: those related to adjustments of the altered topography to local hydrodynamic regime; and longer term natural evolution and maintenance of the shoal itself. The degree to which dredging has affected the natural processes can not be determined without additional monitoring. Hayes and Narin (2004) suggested that reducing the height or width of the shoal could disrupt the processes that maintain the integrity of the shoal. In the case with Borrow Area 2, although the width of the shoal was reduced to half (resulting in a loss of crest height over the last 14 years), the overall shoal feature remains distinct, at least along the southern end. However, wave and current dynamics across the crest have been altered as evidenced by the changes in the shape of the second order ridges and troughs.

The apparent southerly migration of shoal features agrees with similar observations reported for mid Atlantic shoals. A conceptual model for shoal dynamics proposed by Hayes and Nairn (2004) predicts a net shoreward transport of sand (Figure 8). Shoal 2 is smaller, closer to the shore, and differs in morphology compared to Fenwick Shoal, on which the model is based. Presence of the second order ridges on Shoal 2, as opposed to the single, well-define ridge crest of Fenwick Shoal, suggests that Shoal 2 is still in the 'coalescing stage' and, thus, may be less prone to permanent impact from the dredging.

Borrow area 3

Borrow area 3 is located on the Maryland portion (approximately the southern third) of an irregularly-shaped nearshore shoal, 2.75 miles offshore of northern Ocean City (Figure 1). Prior to dredging, the shoal had four distinct crests or second-order ridges, orientations of which were oblique to the main shoal. The shoal was approximately 3.5 miles (5.56 km) long and 0.8 miles (1.27 km) wide (Figure 9). Sand contained in this shoal was significantly coarser than that found in Shoal 2. Sand ranged from moderately well to poorly sorted, medium to very coarse sand with gravel. Between 1988 and 1992, over 5 million yd^3 of sand were removed from the borrow area during Phase I and II of the Ocean City Beach Replenishment Project and Post-91 Storm Restoration Project. Most of the sand, as much as 20 to 22 feet thick sections, was taken from the central portion of the borrow area, essentially removing the southern 'tail' of the shoal (Figure 10). Within this area post dredging depths were at the project limit of -50 ft NGVD with some areas slightly deeper (-50 to -55 ft), resulting in a 'pockmark' topography. Several 'islands' of undisturbed sand were left. A thin layer of sand, less than 4 feet thick, was extracted from the southern sub-area of the borrow site, resulting in little change in relief or steepness (Figure 11a).

Figure 12 shows the 2004 bathymetry of Borrow Area 3. Since 1992, the dredged area has flattened out, although not to the extent observed at Borrow Area 2. While the well-defined dredge cuts seen in the 1992 bathymetry are no longer visible, the ‘pockmark’ signature from dredging activities was still evident throughout most of the borrow area. Overall depths in much of the area have changed very little, less than +/- 2 feet (Figure 11b). The greatest changes were limited to the perimeter of the dredge cuts and undisturbed islands due to sediment redistribution. Based on the overall pattern of bathymetric changes between 1992 and 2004, the net transport of sediment appears to be to the south at a rate between 15 and 25 ft per year.

The 2004 sidescan imagery for Borrow Area 3 revealed a highly irregular seabed surface within and around the dredged areas (Figure 13). High backscatter return, corresponding to rougher sea bottoms predominately covered with ripples, were observed on the shoal crest, adjacent intershoal areas, and the deeper dredged areas. While the orientation of the ripples were the same as those observed on Borrow Area 2, the ripple lengths were generally larger, the size of which most likely reflect the coarser texture of the Borrow Area 3 sand. Several sets of sand waves, with lengths ranging between 100 and 200 feet were also visible in the sidescan imagery. Sand waves with east-west orientation were visible primarily in the southern end of the study area. A less prominent second set of waves with NW-SE orientations were visible in the northern end of the study area, south of the shoal crest, and in deeper areas. The different depths and orientations of the sand wave set and ripples suggest a complex hierarchy of current conditions within the study area. Deeper sand waves are reactivated during the more intense storm events whereas ripples are formed during less intense wave conditions.

Smaller patches of low backscatter return, interpreted to represent fine-grained sediment, were visible primarily in the deeper intershoal areas outside of the dredging limits, but also in shallow depressions and sand wave troughs within the disturbed areas.

Four classes of bottom types were derived from the QTC seabed classification surveys for Borrow Area 3 (Figure14). The distribution of the classes are similar to that of Borrow Area 2. However, with the exception of the Patch class, descriptions based on sidescan imagery of the borrow area 3 classes are slightly different. The four classes found on Borrow Area 3 include:

1) <u>Shoal crest</u> – found on crest tops above 36 ft, and, on borrow area 3; characterized by 1.5 ft to 3 ft sand ripples;
2) <u>Transitional</u> - bottom class associated with the shoal crest; primarily found along the shoal flanks between -39 ft and -43 ft, but also scattered throughout dredged area; represents transitional bottom; sandy, the texture of which may or may not be significantly different than that of the shoal crest; occasional ripple;
3) <u>Small ripple</u> - associated with the deeper seabottom (> 40 feet), both disturbed (dredged) and undisturbed intershoal areas or troughs; sandy bottom dominate by small ripples < 1.5 ft lengths); and
4) <u>Patch</u> – occurring mostly in the deeper seabottom (> 40 feet) in troughs or intershoal areas; occur as patches, ~60 to 100 ft in diameter associated with rippled bottom within the dredged area; interpreted to be soft, finer-grained sediment based on low backscatter intensity return.

Conclusions

The 2004 and 2005 survey data yield information about existing conditions of two borrow shoals and provide a basis for future monitoring. Comparisons with historical data provide some insight as to how the borrow shoals have changed in response to natural processes and dredging activities. The differences in seafloor character and degree of changes observed for the two borrow shoals are related to the differences in their geomorphology and the different dredging activities they underwent. The shoals are significantly different in size and shape, and in sediment texture. The areas dredged on each shoal are distinctly different in terms of morphological function of the shoal. The landward flank of Shoal 2 was removed as opposed to the landward tail of Shoal 3.

Bathymetric data combined with side-scan imagery proved to be useful in identifying both small and large scale bedforms (Table 1). These bedforms provide some information on hydrodynamic processes operating within the study areas, and localized morphodynamic impacts from dredging. These bedforms also play an important role in assessing potentially important habitats of benthic organisms and finfish populations.

The QTC classification scheme for the borrow areas does not discern subtle textural differences in the sandy areas. Spatial distributions of the four QTC seabed classes for both borrow areas are very similar despite the known textural differences in the two shoals. The distribution pattern of the seabed classes suggests that the dredged areas have taken on bottom characteristics similar to the intershoal areas.

Comparisons of 1978 and 1991-92 bathymetry with 2004 bathymetry reveal that Borrow Shoal 2 has migrated to the SSW at a rate of 25 to 30 ft/yr. While the direction of movement is similar to that before dredging, the rate after dredging is slower, suggesting that dredging may have impacted the migration process. The Maryland portion of Borrow Shoal 3 appears to have migrated to the south at rate of 15 to 25 ft/yr.

Even though dredging resulted in a significant reduction in width and crest height, Shoal 2 remains a defined bathymetric feature, and thus has maintained its "geomorphologic integrity" in that respect. On the other hand, bathymetric changes suggest that the northern-most second-order ridge or crest knoll may be separating from the rest of the shoal as the inter-knoll trough becomes more pronounced. This change may be related to the proximity of the original dredge cut to the second order features, and thus may have some implications as to the location of dredging with respect to certain shoal features such as second order ridges and troughs in the future.

Less overall changes are observed in and around Borrow Area 3 compared to Borrow Area 2. This may be due to the coarser texture of the sediments which require more energy to transport than the sand found on Shoal 2. The Borrow Area 3 site occupies the shoreward tail of the shoal as opposed to the flank. The southerly shift in some of the shoal features appears to follow the Hayes and Nairn model for shoal dynamics. In addition, the Borrow Area 3 site occupies an area of deposition, and thus is expected to show accumulation over time. If this is the case, dredging will not have a long-term impact on the shoal.

While the severe topography as a result of dredging have ‘softened’ over the last 11 to 14 years on both borrow shoals, the dredged areas remains distinct compared to the surrounding undisturbed seafloor. This distinction may represent a unique assemblage of bedforms and micro- topography that may be attractive habitat to fish. Both side-scan imagery and fathometer records revealed fish congregating within dredged areas, particularly in the dredged pits.

Table 1. Bedforms and features observed on the borrow shoals.					
Bedform/ Feature	**Length (size)**	**Height**	**Orientation***	**Processes**	**Possible Dredging Impact**
Shoal	1-3 Km	10-20 m	SSW - NNE	Sea level rise; regional hydrodynamic regime	Reduction in shape, volume, and crest height (depth)
Crest knoll/2nd-order ridge	150-500 m (500-1000 ft)	1-2 m (3 -6 ft)	WSW - ENE	Near shore wave hydrodynamics; asymmetrical wave convergence on shoal crest	Change in orientation, and shape
2nd order ridge tough	Width-variable	2-3 m	WSW - ENE	Near shore wave hydrodynamics; wave convergence on shoal crest	Increase in depth, width
Sand wave	10-50 m (30-150 ft)	0.5-2 m	Variable over time	Long-term, dominant storm wave direction/	Change in orientation, location
Ripple	0.2-1 m (0.5–3.0 ft)	2-3 cm	Variable over time	Short term current/wave direction/	Change in size, location in response to sediment textural changes, depths
Patch-work	30 m (100 ft)	0.1 m		Textural dependent/ bioturbation	
Bedforms absent	-	-		Depth limiting (within wave base; bioturbation	
*Orientation (Azimuth) of crest of ripples or sand wave; or long axis of knoll and trough					

Recommendations

Due to limited funding and time, surveying was restricted to the borrow areas and near vicinity and did not include the entire borrow shoals. This is particularly significant with Shoal 3, two-thirds of which lies in Delaware State water and was not surveyed for this project. Any changes or impacts from dredging to that portion of the shoal were not documented. Future monitoring should include a broader area around the borrow areas and include the entire borrow shoals. As a control site, an undisturbed shoal that is similar in size and shape and in proximity to borrow shoals should be included in any future monitoring. Other recommendations include:

- Ground truthing to confirm the side scan image interpretation and QTC seabed classes. Ground truthing should include visual inspection of seabottom, either with photography by drivers, or video sled;
- Biological assessment, including fish and benthic surveys, of the dredged area ; and

- Re-assessment of the borrow areas in 10 years to confirm any trends in the continued adjustment of the shoals.

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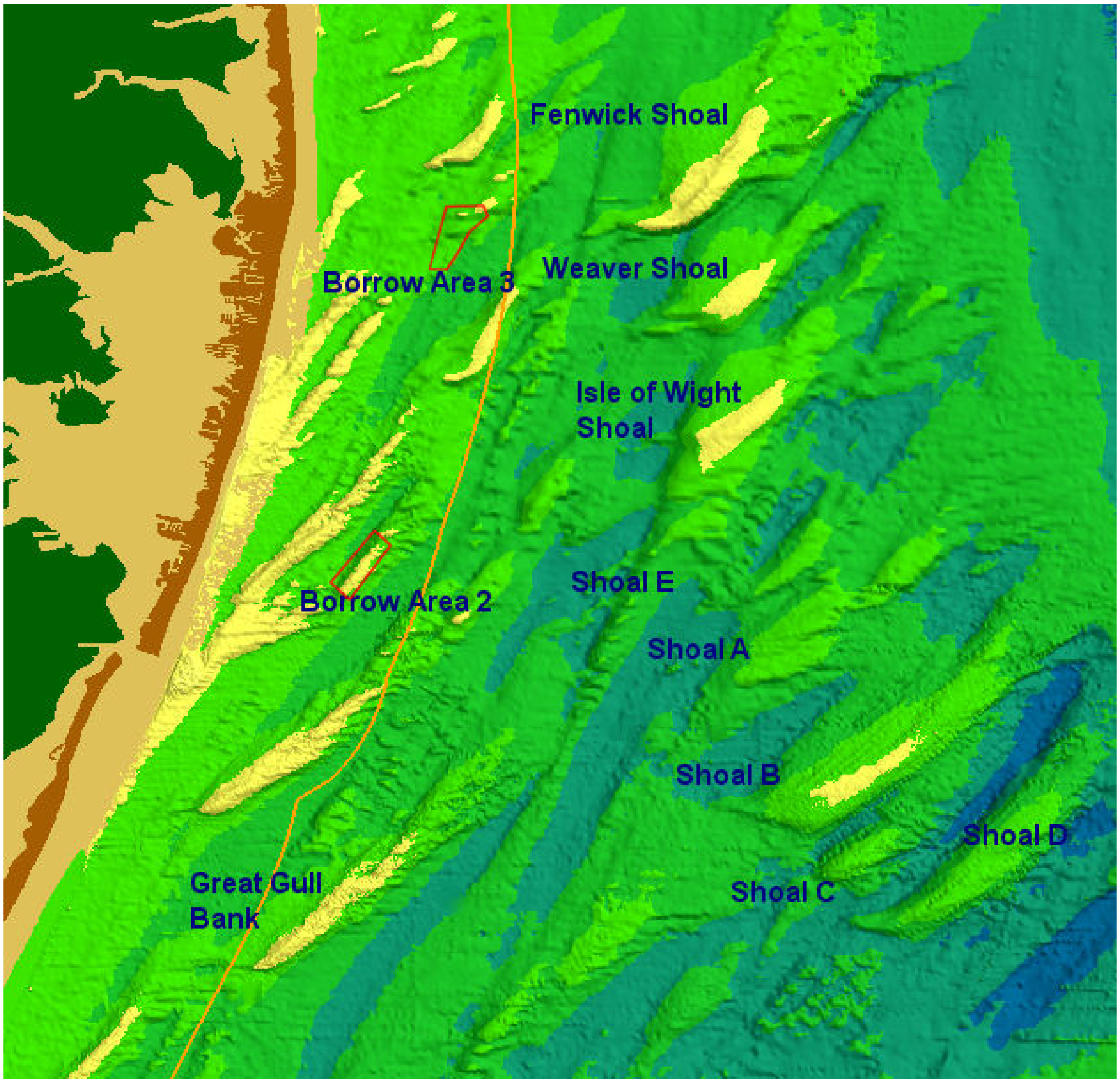


Figure 1. Shoal field off Ocean City, Maryland with shoals of interest named. Dredging boundaries for Borrow areas 2 and 3 are indicated in red. Both borrow areas are within the State's 3-mile limit, shown as orange line.

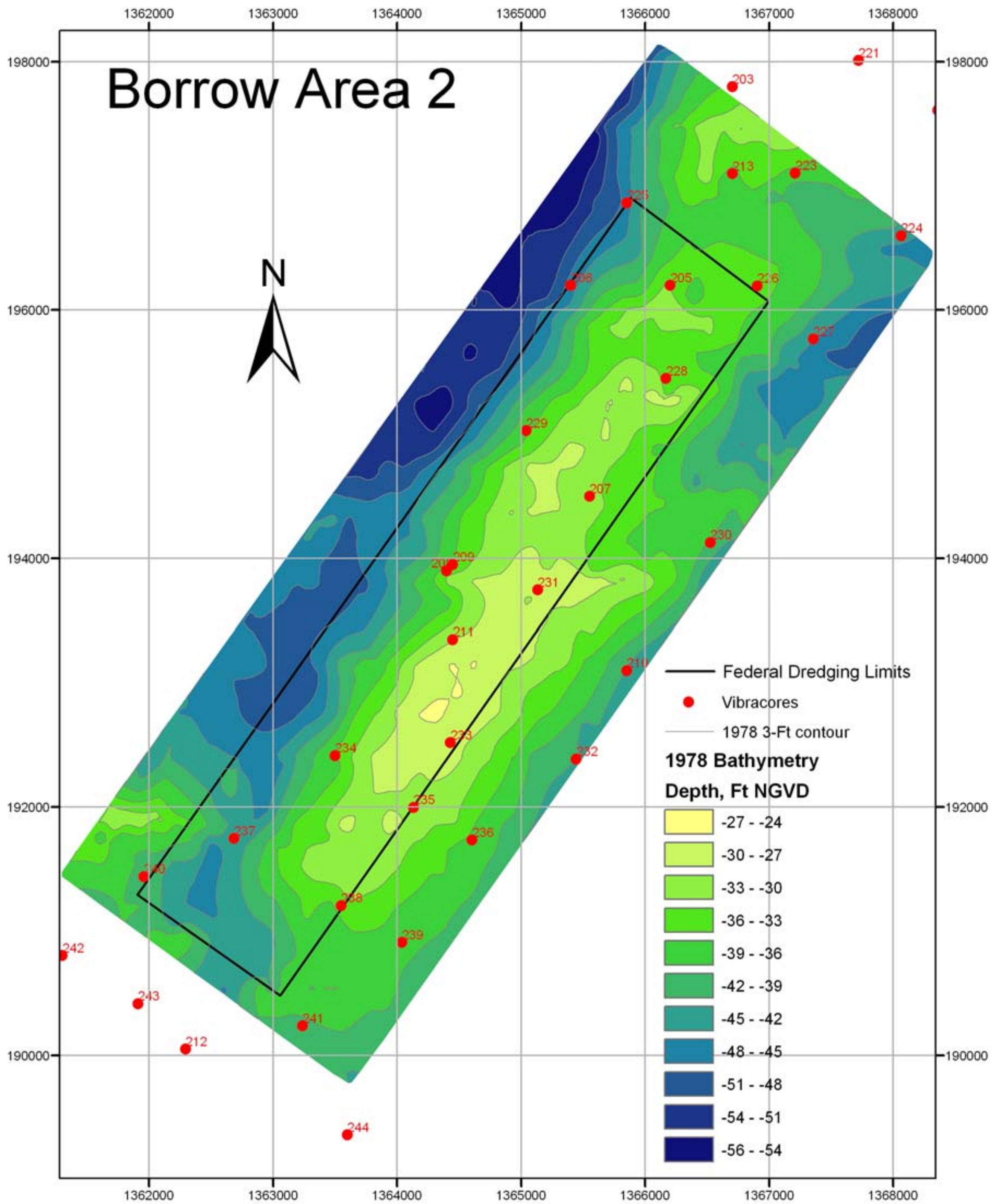
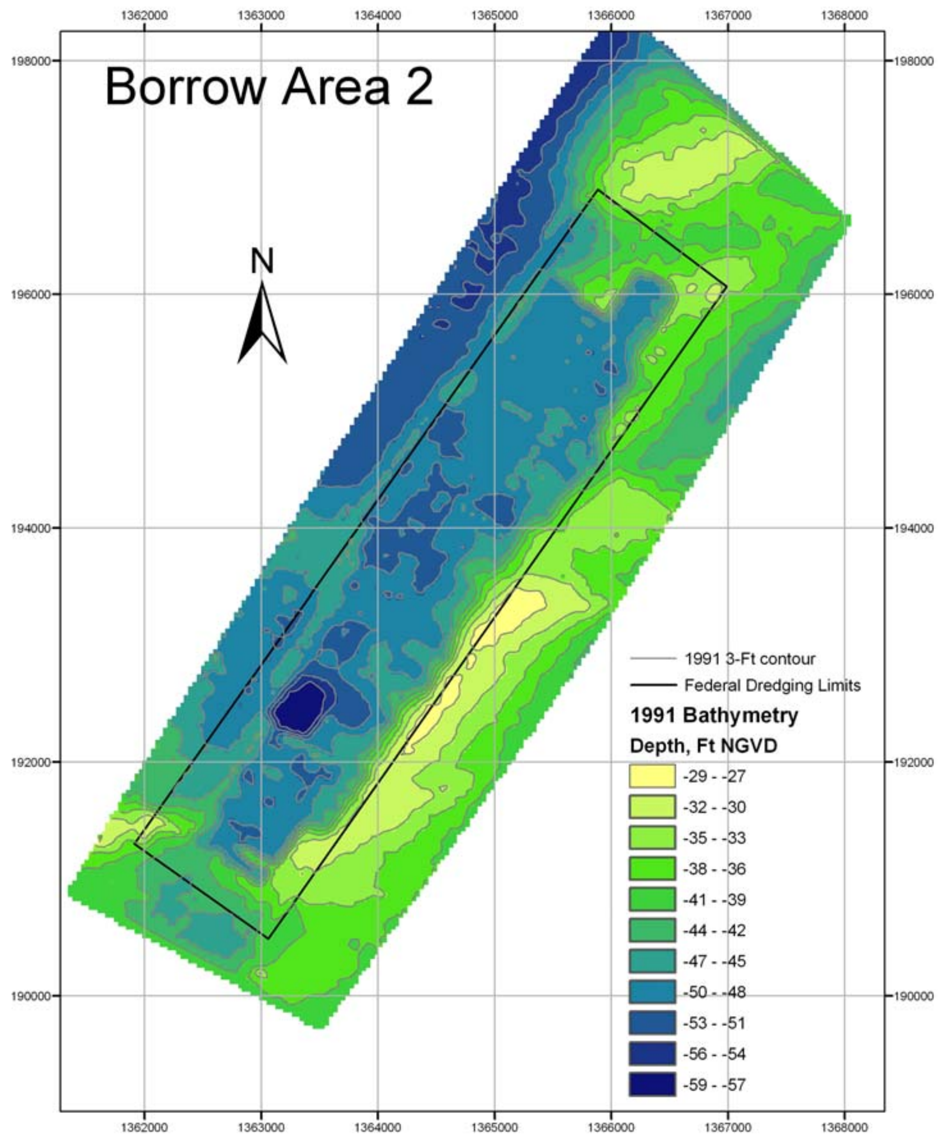


Figure 2. Shoal 2 showing dredging limits for borrow area. Bathymetry is based on NOAA data collected in1978. Locations of sediment vibracores collected for sand quality assessment are shown.



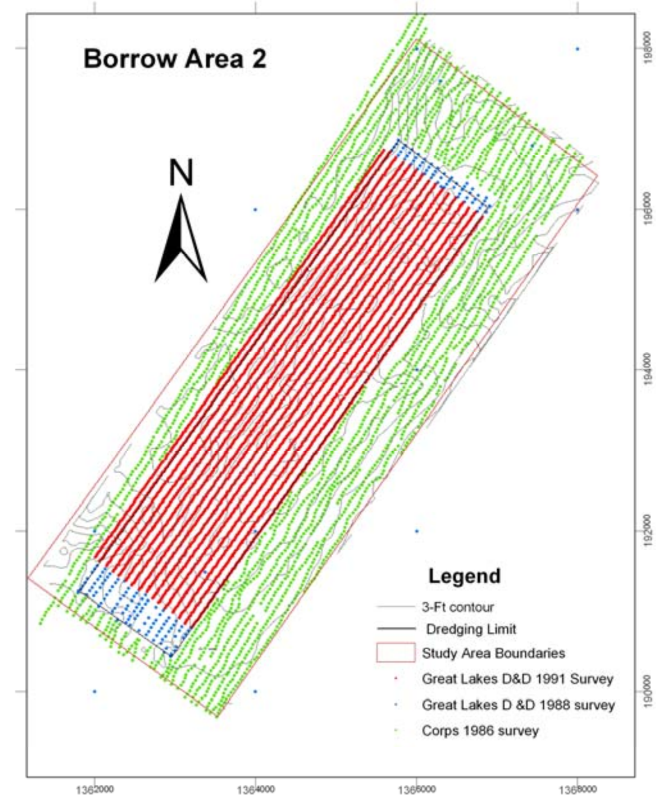


Figure 3. Shoal 2 showing post-dredging bathymetry. Historical hydrographic surveys collected in 1986 (green), 1988 (blue), and 1991 (red) were compiled to create post-dredging bathymetry (see inset above).

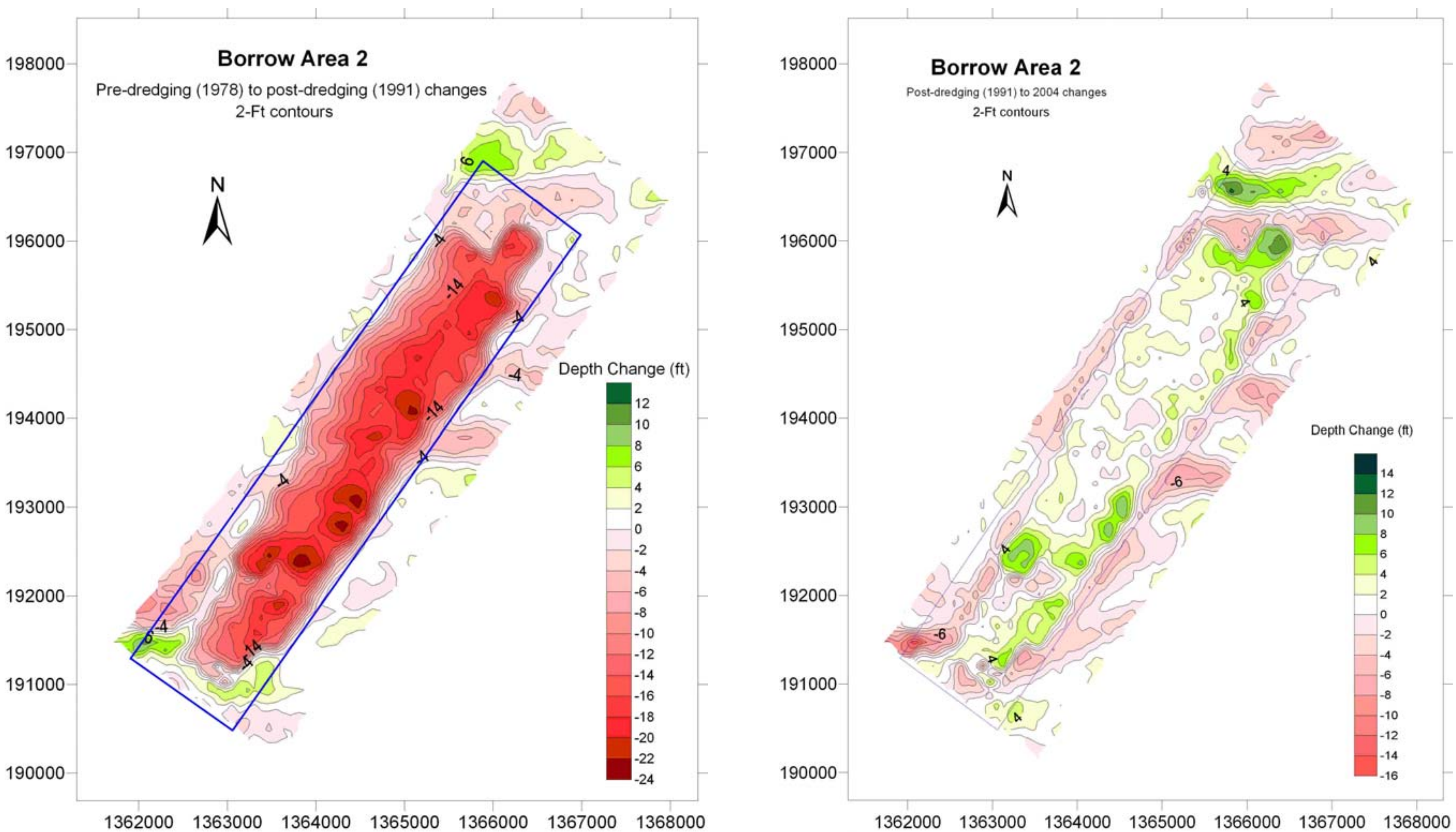


Figure 4. Shoal 2 bathymetric changes between a) 1978 and 1991; and b) 1991 and 2004

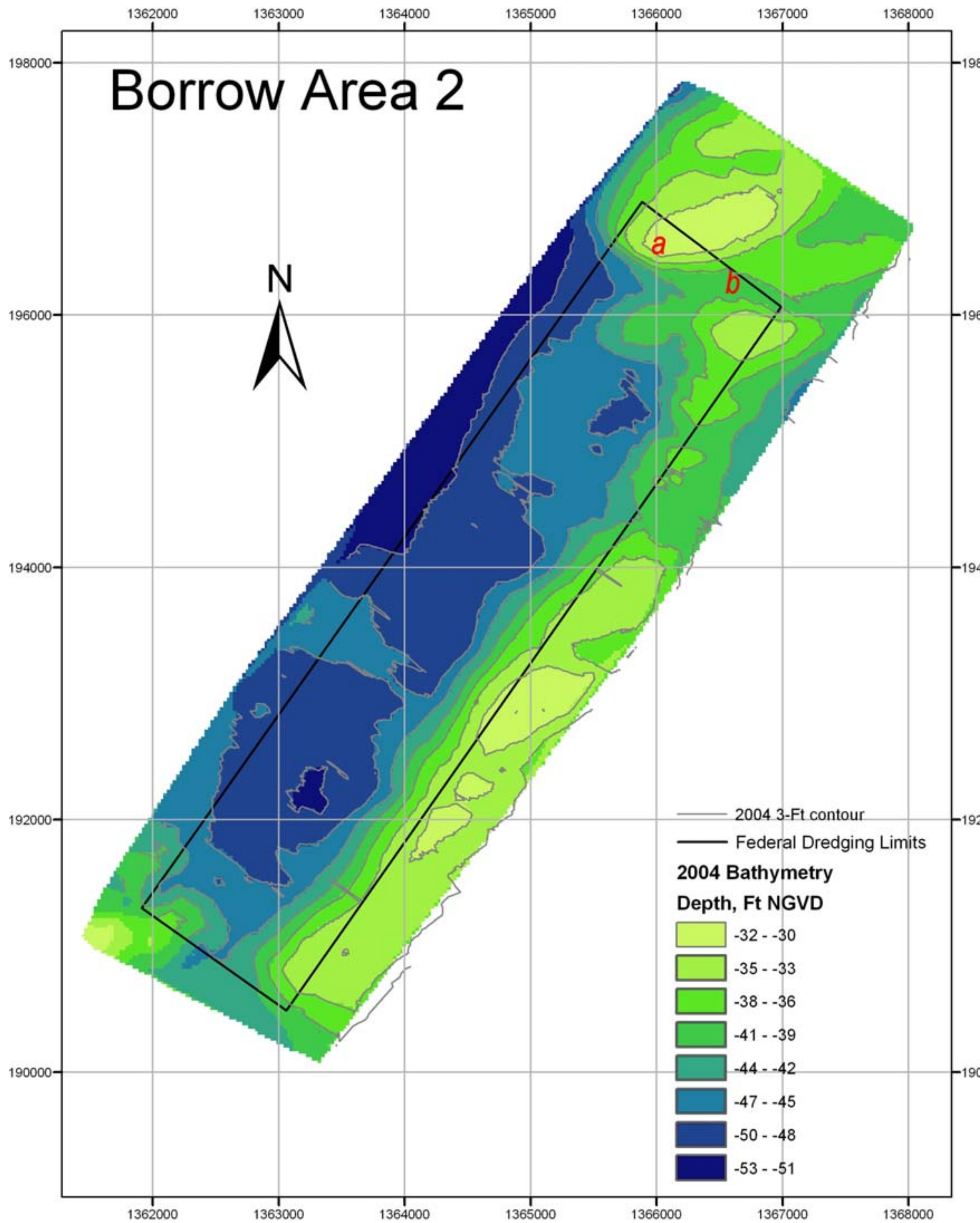


Figure 5. Shoal 2 showing 2004 bathymetry.

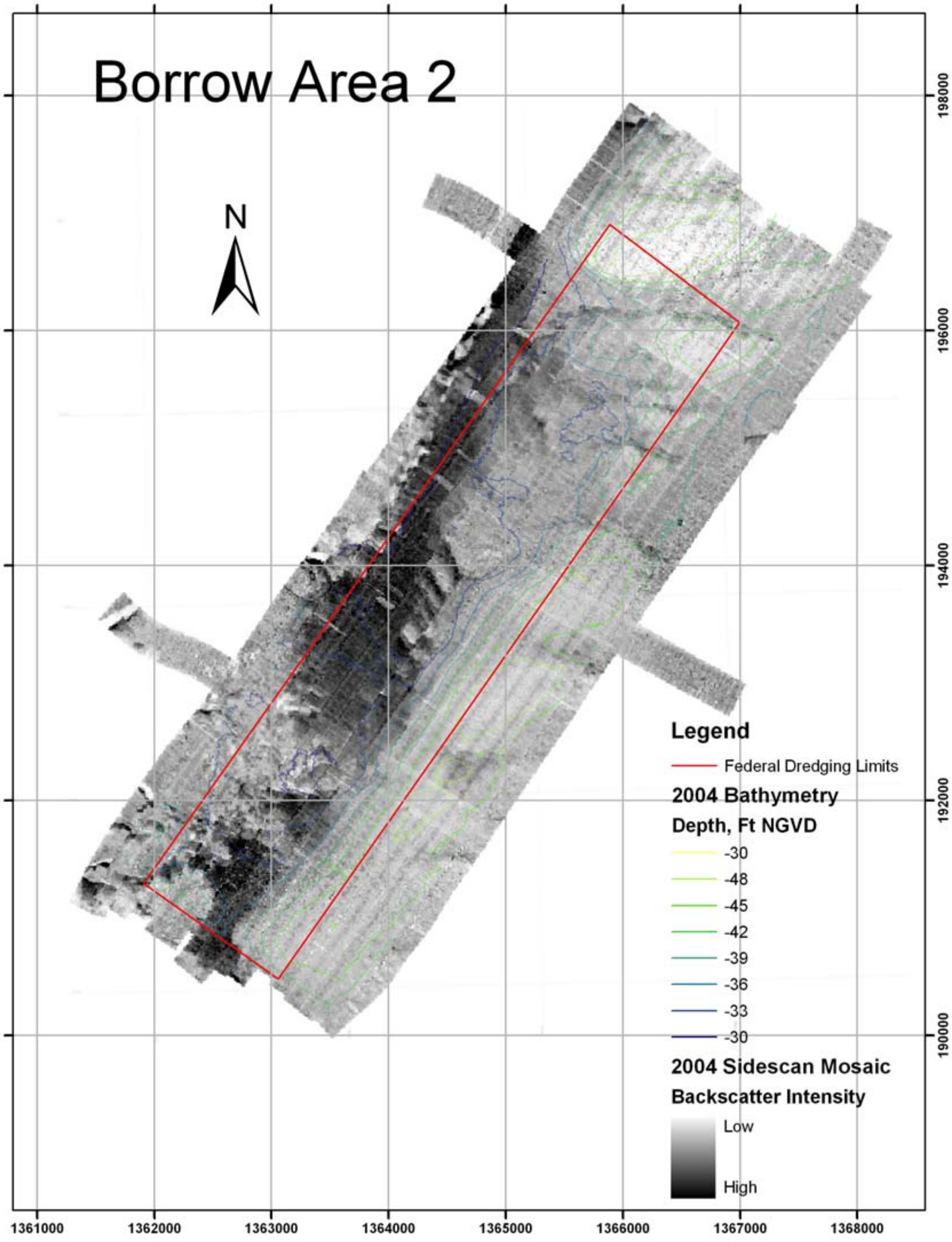


Figure 6. Side-scan mosaic for Shoal 2.

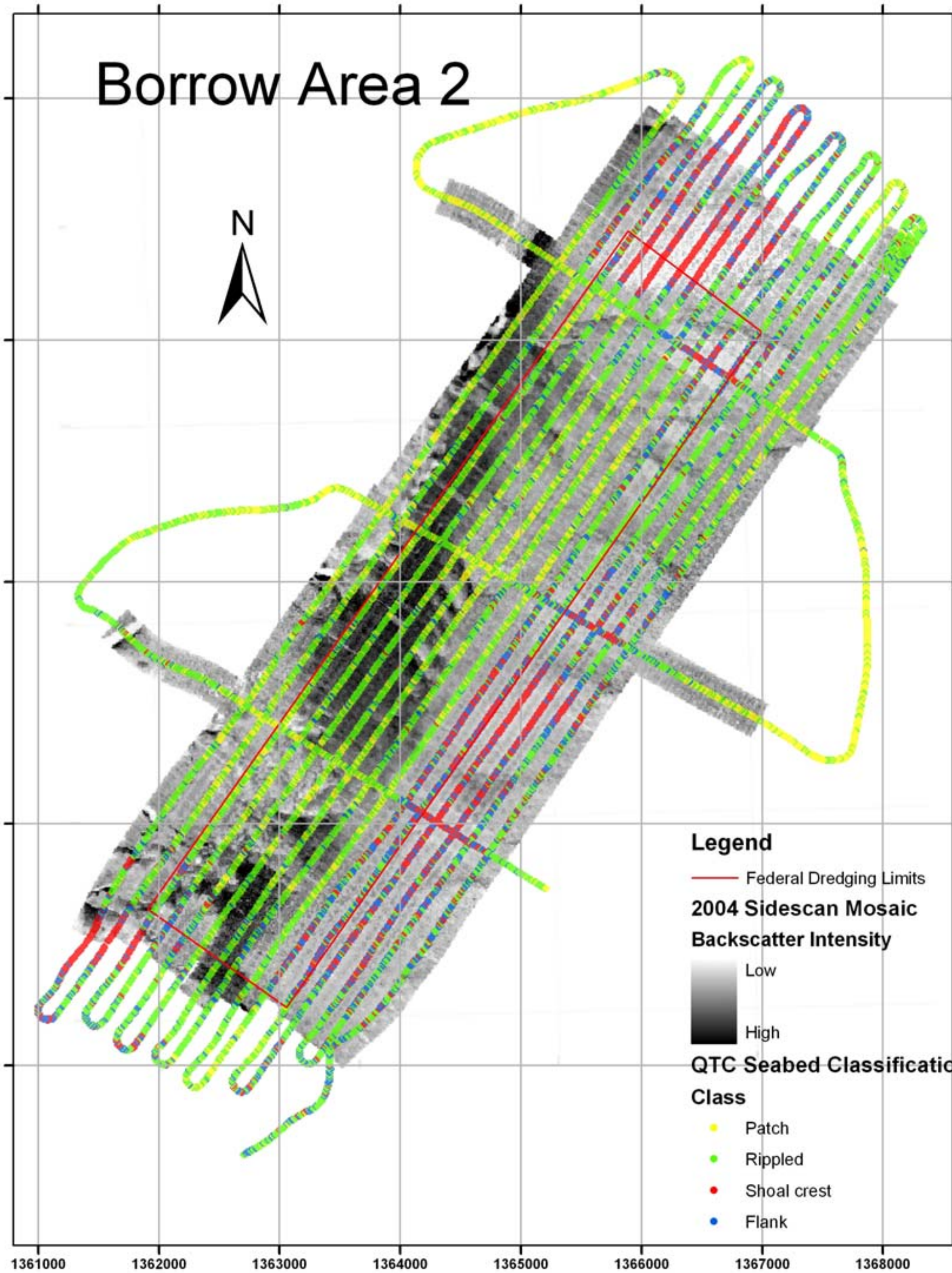


Figure 7. QTC seabed classes distribution for Shoal 2.

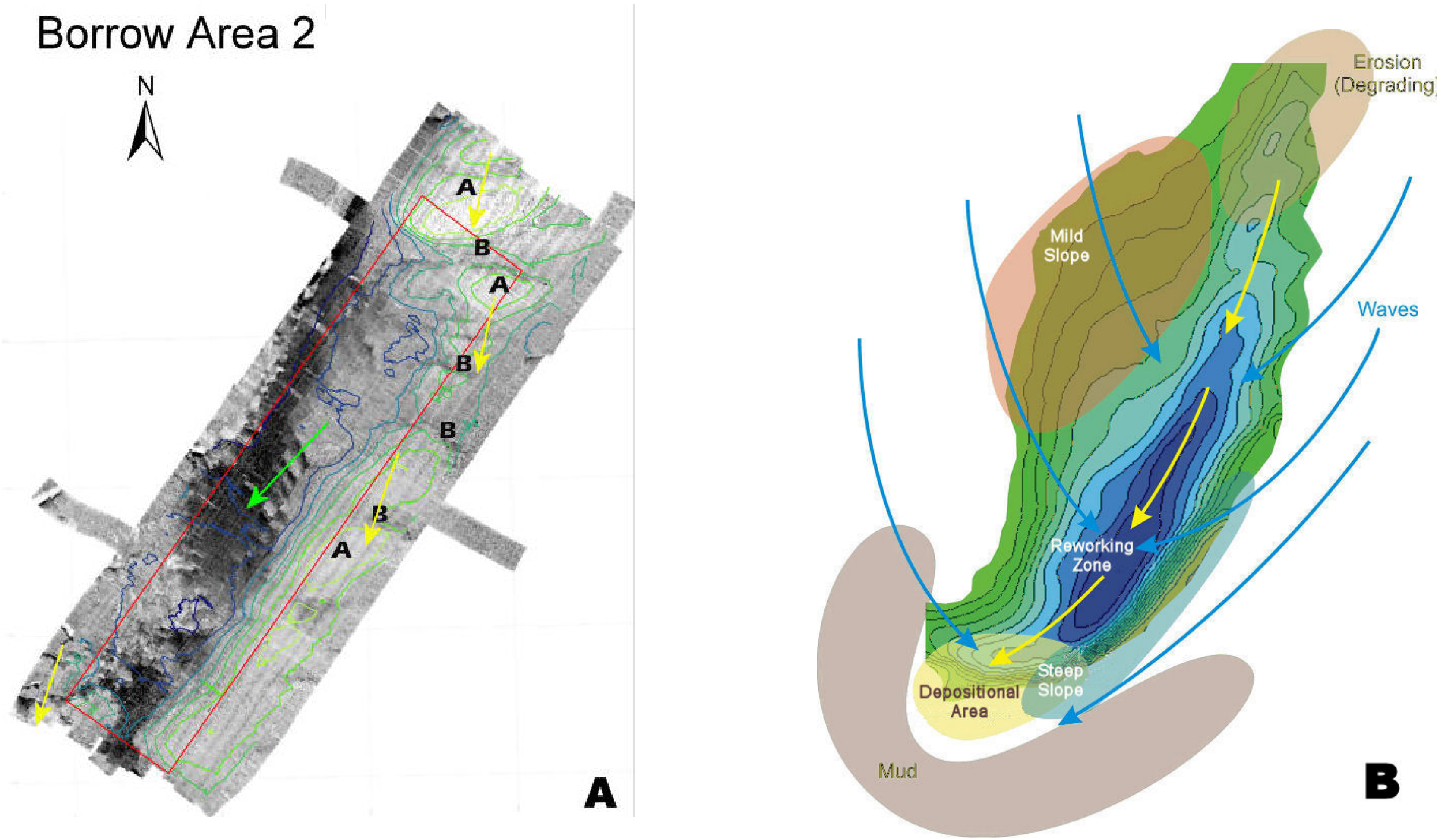


Figure 8. Comparison of Shoal 2 to a "conceptual model" for shoal dynamics. **A)** Shoal 2 with 2004 bathymetry overlain on sidescan mosaic. Green lines (shoal 2) are direction of flow interpreted from sand waves; yellow lines indicate direction of migration of features. Second-order ridges (crest knolls) and troughs are labeled 'A' and 'B', respectively. **B)** Conceptual model was developed by Hayes and Nairn (2004) based on their work on Fenwick Shoal (see Figure 1 for location). Blue lines are waves and wave-induced transport, yellow lines are direction of dominant transport and migration of the feature (modified from original model figure from Nairn).

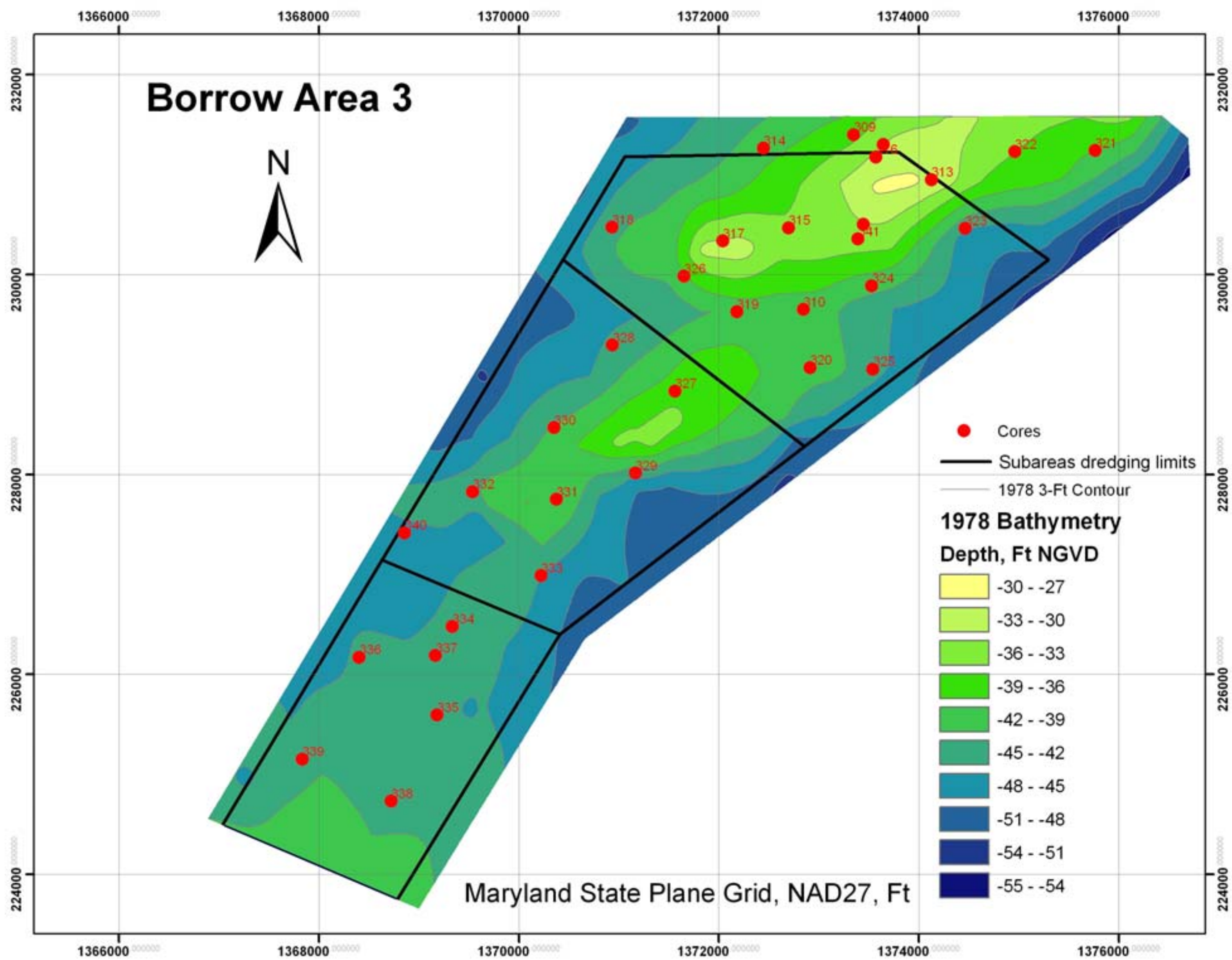


Figure 9. Borrow Area 3 showing 1978 bathymetry based on NOAA data. Locations of sediment vibracores collected for sand quality assessment are shown. Black lines show the dredging limit, which was divided into sub-areas designated for different phases of the beach restoration at Ocean City, Maryland.

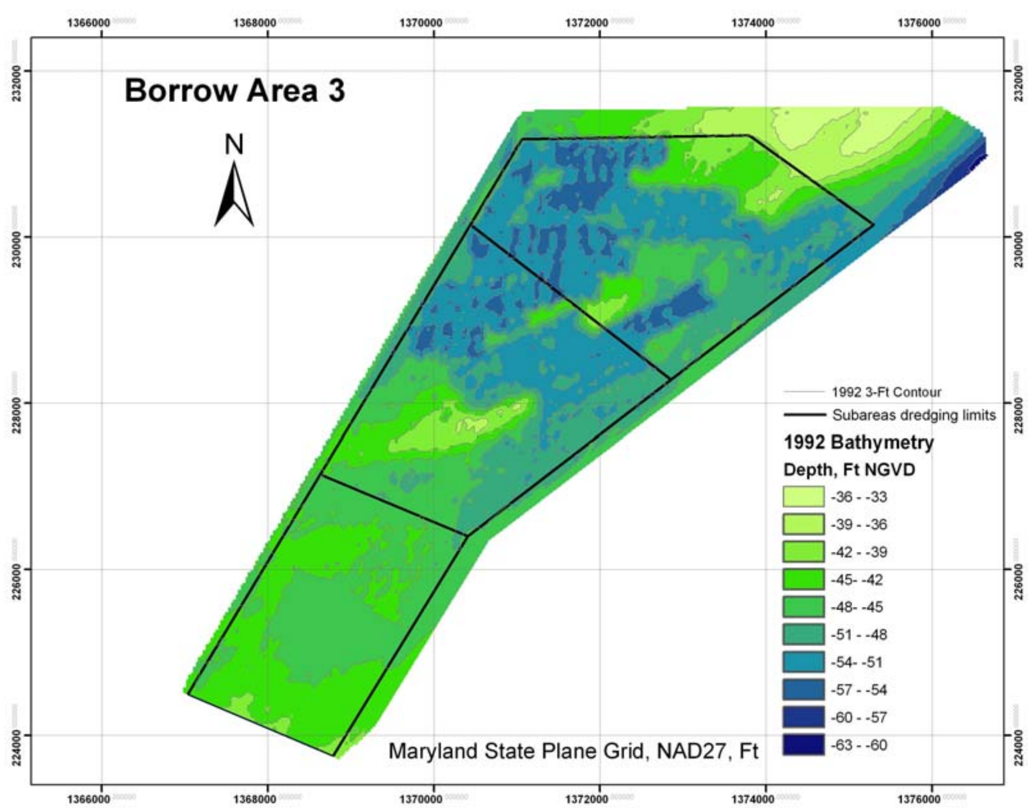
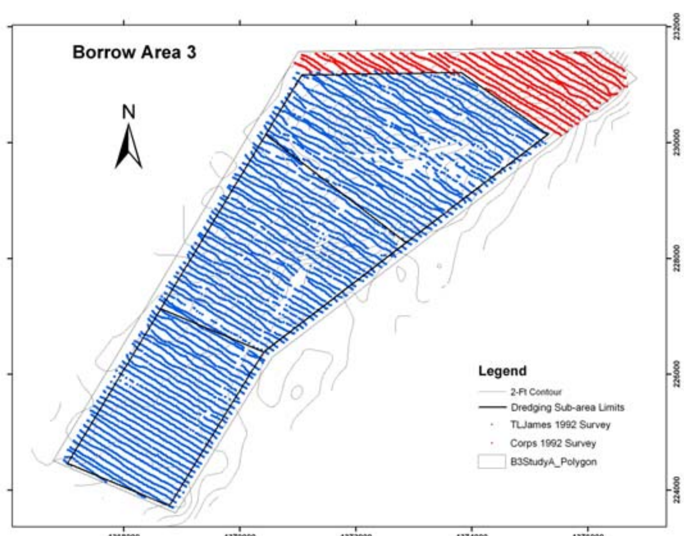


Figure 10. Borrow Area 3 showing post-dredging bathymetry. Historical hydrographic surveys collected in 1992 by the Corps (red) and by Great Lakes Dredging and Dock Co. (blue) were compiled to create the post-dredging bathymetry (see inset right).



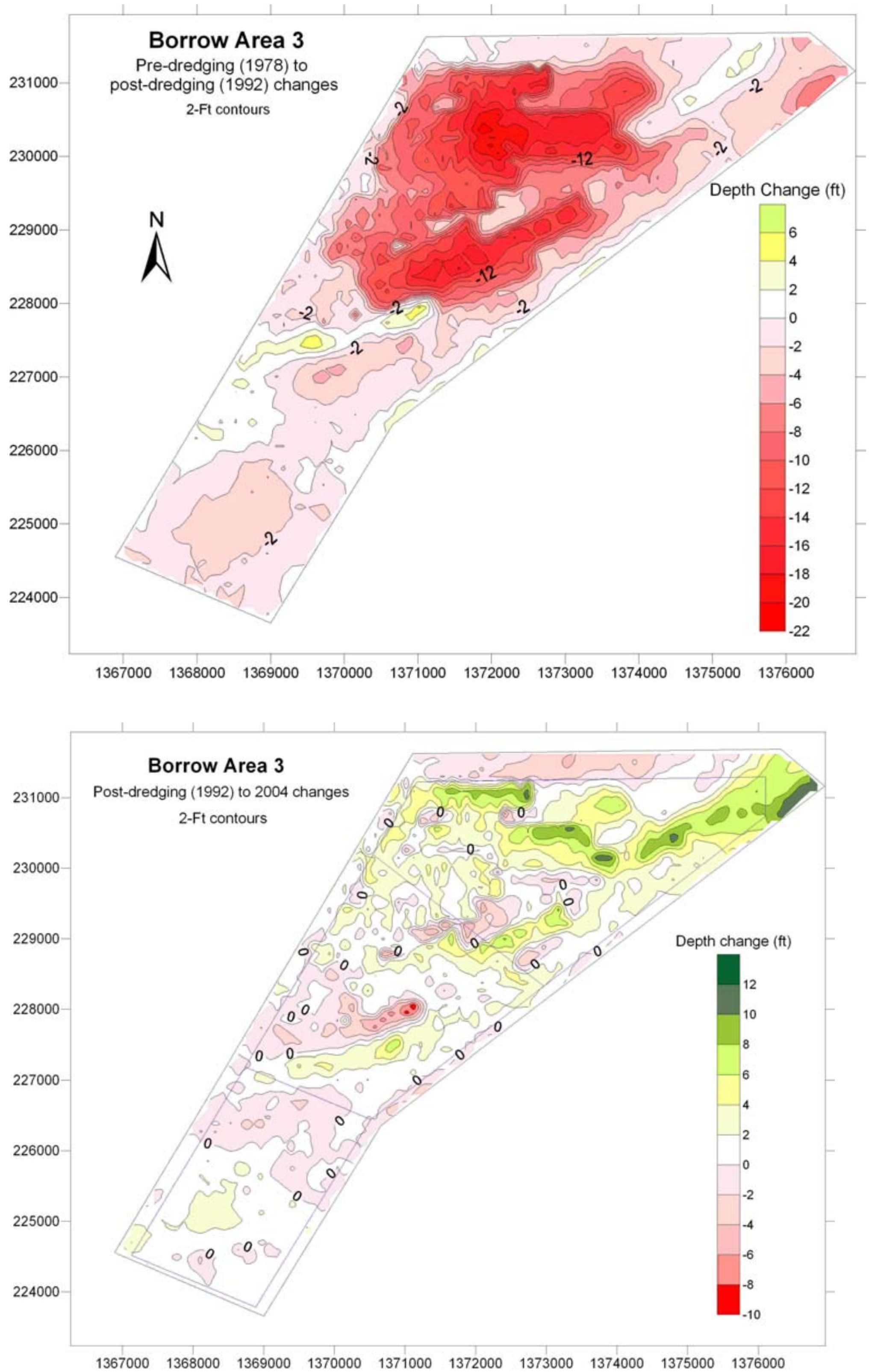


Figure 11. Shoal 3 bathymetric changes between a) 1978 and 1992; and b) 1992 and 2004.

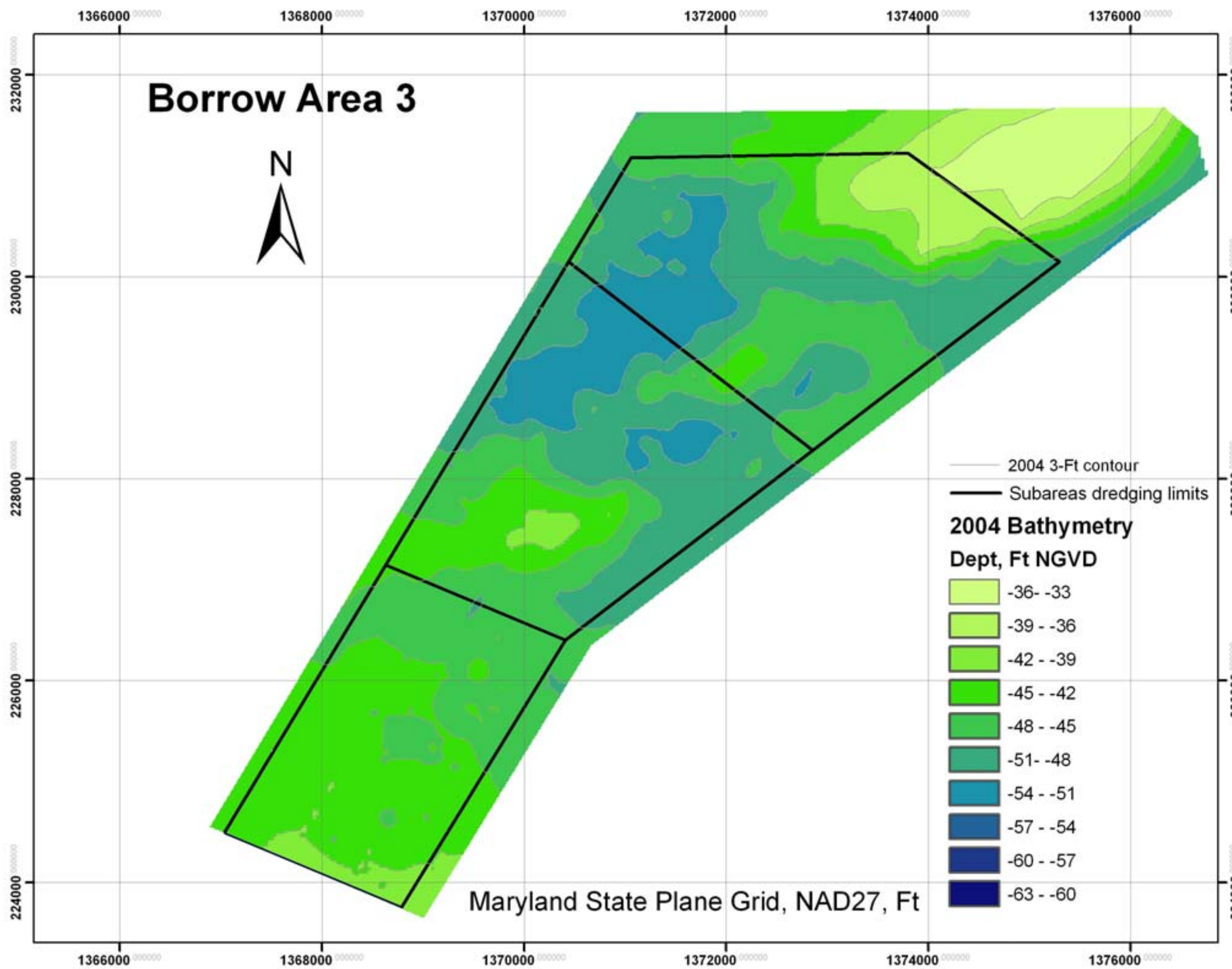


Figure 12. Shoal 3 showing 2004 bathymetry.

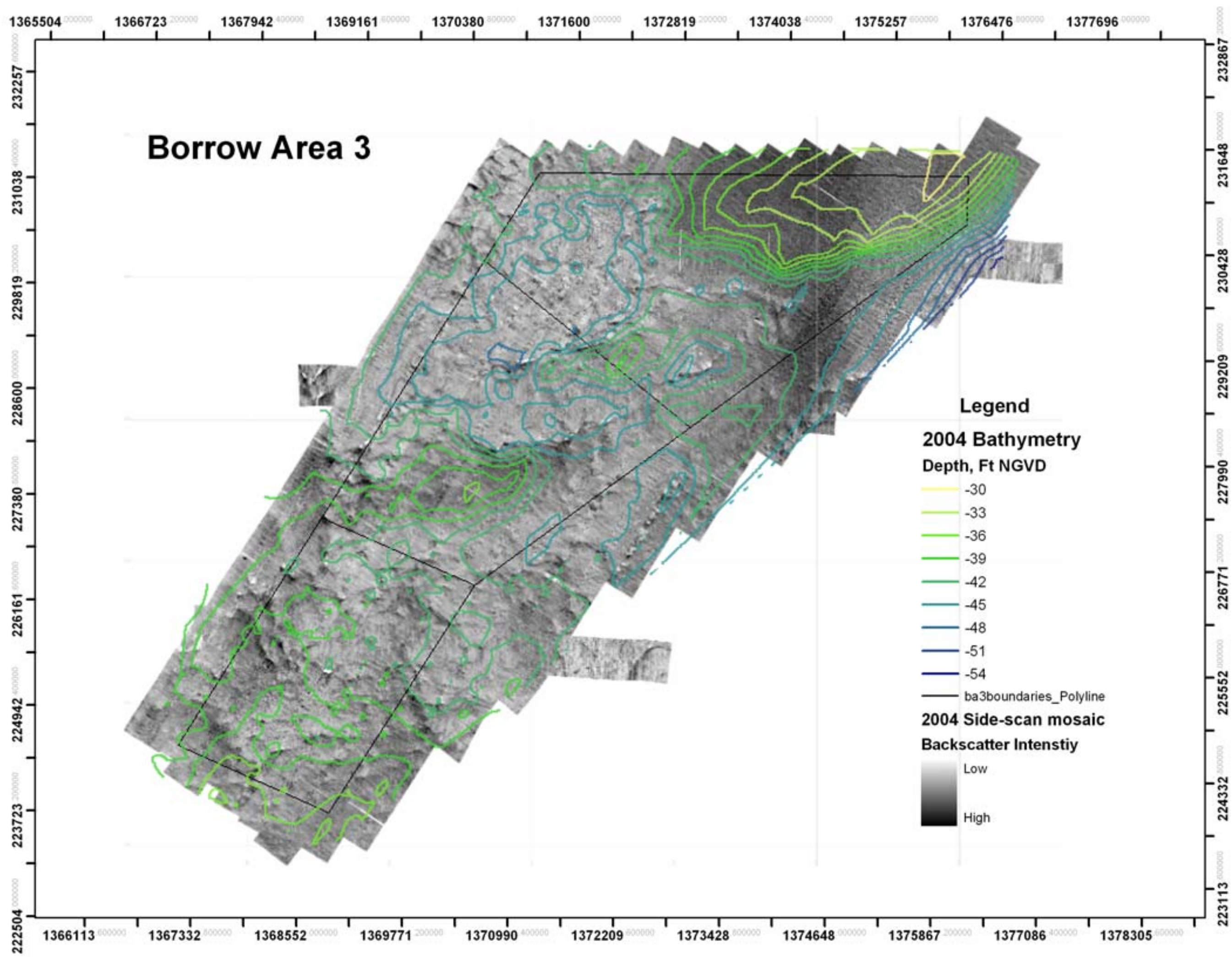


Figure 13. Side-scan mosaic for Shoal 3.

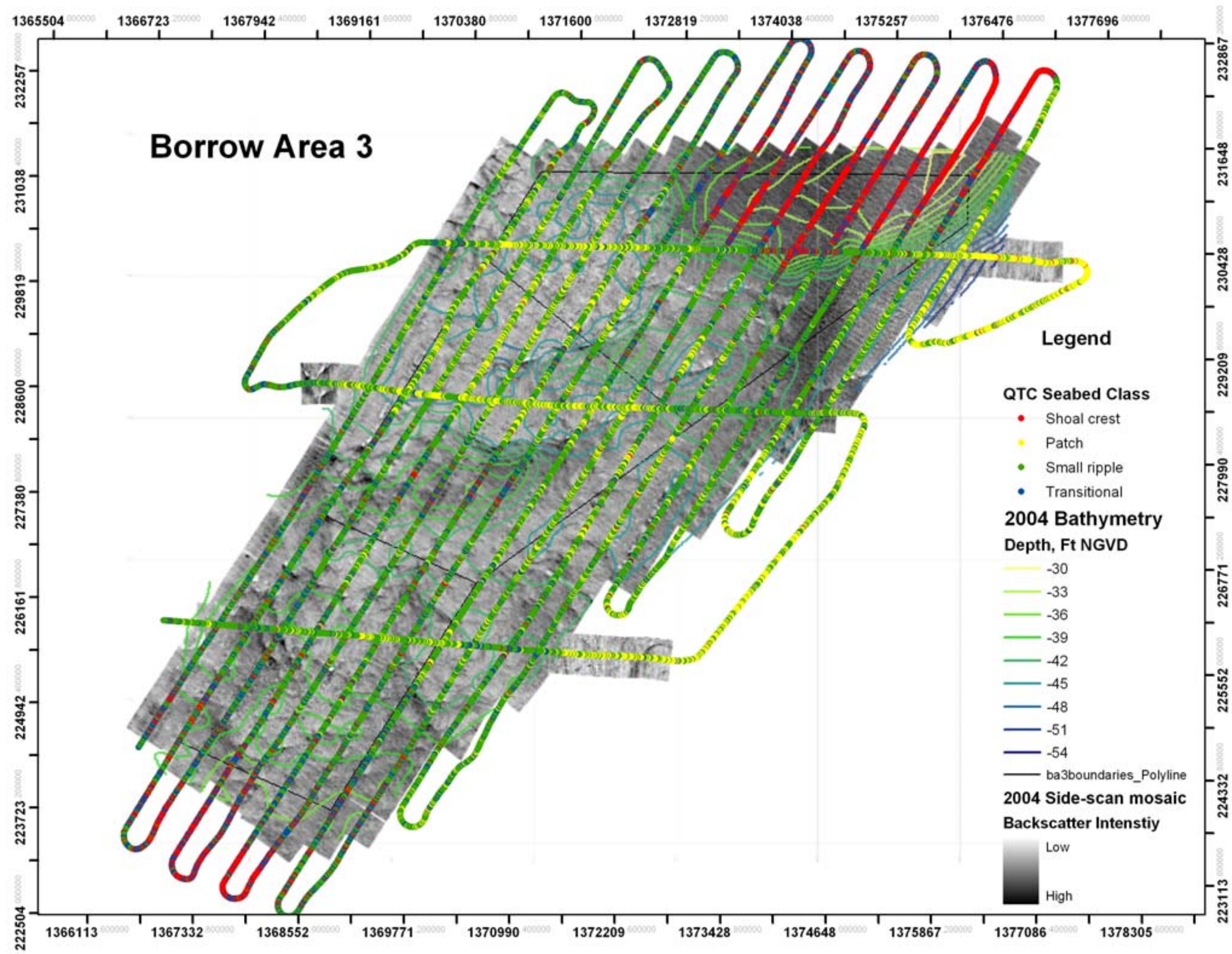


Figure 14. QTC seabed classes distribution for Shoal 3.

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Table: Surface area impacted as function of total volume and thickness of material dredged.

Volume to be dredged (yd3)*	Surface area impacted (acres) at maximum thickness dredged of						
	0.5 ft (6 in)	1 ft	1.5 ft	2.5 ft	5 ft	7.5 ft	10 ft
600,000	744	372	248	149	74	50	37
800,000	992	496	331	198	99	66	50
1,000,000	1,240	620	413	248	124	83	62
1,200,000	1,488	744	496	298	149	99	74
1,400,000	1,736	868	579	347	174	116	87
1,600,000	1,983	992	661	397	198	132	99
1,800,000	2,231	1,116	744	446	223	149	112
2,000,000	2,479	1,240	826	496	248	165	124
2,200,000	2,727	1,364	909	545	273	182	136
2,400,000	2,975	1,488	992	595	298	198	149

*Encompasses historic range of total volumes dredged per dredging event +/- 150,0000 cubic yards. Note that volume placed would be somewhat less if any loss of material occurred during dredging.

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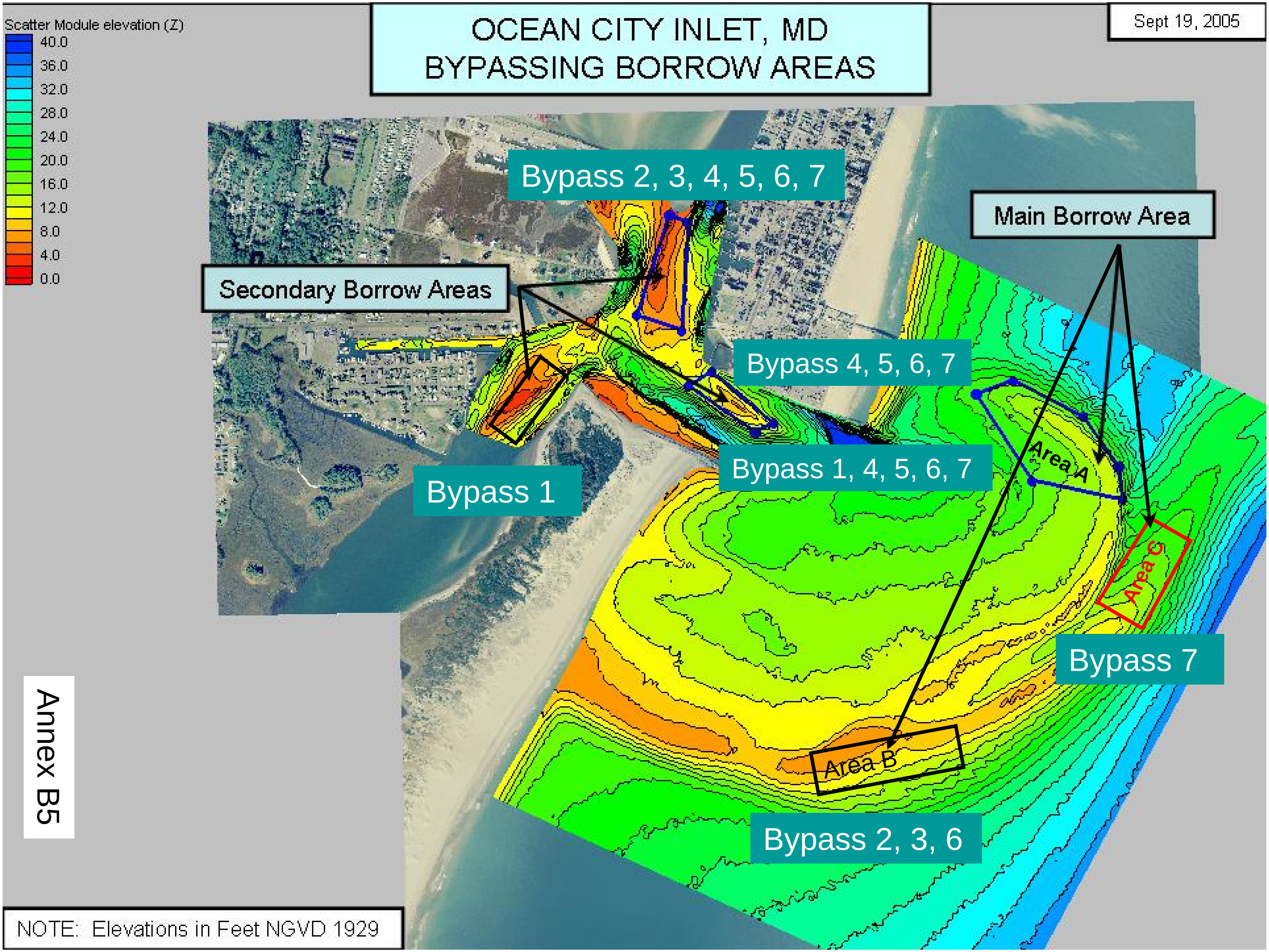
Long-Term Sand Management Project: Volumes Dredged and Placed by Site (yd3)

	Dredging Sites						Placement Sites	
	Ebb Shoal			Flood Shoal				
Dredging Dates	**Area A, Tongue**	**Area B, Outer Bar**	**Area C**	**Sinepuxent Bay**	**Isle of Wight**	**Inlet Throat**	**Assateague Island**	**Ocean City**
Jan. to Apr. 2004	64,785			17,790			73,705	5,810
Oct. to Nov. 2004		87,890			7,630		91,680	3,340
Mar. to Apr. 2005		31,825			1,565		32,840	550
Sep. to Nov. 2005	64,595					16,185	69,505	11,275
Apr. to May 2006	38,450					9,145	45,750	1,845
Aug. to Oct. 2006	92,985					19,795	103,980	8,800
Apr. to Jun. 2007	7,040		59,800			7,305	73,875	270
Totals	267,855	119,715	59,800	17,790	9,195	52,430	491,335	31,890


OCEAN CITY INLET, MD
BYPASSING BORROW AREAS
Sept 19, 2005
Scatter Module elevation (Z)
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
Bypass 2, 3, 4, 5, 6, 7
Main Borrow Area
Secondary Borrow Areas
Bypass 4, 5, 6, 7
Bypass 1, 4, 5, 6, 7
Bypass 1
Area A
Area C
Bypass 7
Area B
Bypass 2, 3, 6
Annex B5
NOTE: Elevations in Feet NGVD 1929