BEACH MORPHOLOGY CHANGE STUDY USING ARCGIS SPATIAL ANALYST

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ABSTRACT: *Even though beach nourishment has been a preferred method in recent years for mitigating the effects of coastal erosion and reducing the damage from coastal storms, it has been a topic of controversy. This paper examines a beach nourishment project that was finished in July 2005 in Rehoboth and Dewey Beaches, Delaware. The purpose of the study was to conduct a geomorphologic assessment of beach changes using a Geographic Information System (GIS) to show if the project was successful. The study evaluates the morphologic success of the beach nourishment project measured in terms of the physical changes that occur. Elevation x,y,z survey data for the research years 1999, 2000, 2001, 2002, 2003, and 2006 were supplied by the Shoreline and Waterway Management team that performs the regular surveys of the beaches. A GIS was used to analyze and compute area elevation changes and volume of gained or lost sand. First, in order to carry out analysis of the survey data points, the points were interpolated to create rasters of the study area using Ordinary Kriging. Second, the movement of the 0 elevation contour line was examined for the pre- and post-nourishment years to show the changes throughout the years. Third, area elevation changes for the different years were computed as well, along with a sand volume loss or gain computation, in order to show how much sand the beach gained after the nourishment. The geomorphic assessment shows that the 2006 beach nourishment was successful.*

Keywords: *Beach nourishment, GIS, Beach volume change, Coastal, Delaware*

OVERVIEW

Beaches are an important dynamic environment that is constantly changing due to the effects of waves, wind, tides and currents. This paper discusses beach nourishment as a coastal management process that involves adding sand to the eroding beach in order to maintain or restore its width. Beach nourishment is the only management option that directly addresses the problem of sand loss by adding additional amounts of sand. Even though beach nourishment has been a preferred method for mitigating the effects of coastal erosion and coastal storms, it has been a topic of controversy simply because a large amount of funding is necessary to facilitate a nourishment project. Some people question whether spending this kind of money is justified – after all, renourishment will almost always be needed to maintain the beach. This paper examines a beach nourishment project that was undertaken in July 2005 in Rehoboth and Dewey Beaches, Delaware. The project was named the Rehoboth/Dewey Beach Storm Damage Reduction Project and it was designed to provide coastal storm damage reduction and shoreline protection along the 2.5 miles of ocean front from the northern end of Rehoboth Beach to the southern end of Dewey Beach. The geomorphologic success of this project is measured in terms of the amount of sand that is deposited on the beach.

DATA AND METHODOLOGY

The Delaware Natural Resources and Environmental Control (DNREC) survey team supplied the data for this paper - points of winter beach profiles for Rehoboth and Dewey beaches from 1999 through 2003, and 2006. Years 2004 and 2005 were surveyed by the US Army Core of Engineers (USACE) and the survey team did not have them available at the time of this study. Since the nourishment took place in 2005, the only post-nourishment year was 2006. The data for year 2001 could not be used at the time because of some erroneous values in the data.

The study covered a length of beach that was approximately 2.5 miles. There were a total of 28 monuments along the beach spaced approximately 500 feet apart. The elevation of the area where the points were collected along the monument ranged from approximately 20 feet (dry beach) to approximately -38 feet (into the water). See Figure 1 below. The purpose of the project is to look at the different years from 1999 to 2003 (with the exception of 2001) and 2006, analyze changes of volume of sand lost or gained, changes in overall elevation of the beach, and draw some conclusions and predictions about the success of the beach nourishment project.

Figure 1. Rehoboth/Dewey survey points.

GIS General Observations

ArcGIS 9.2 with the Geostatistical Analyst and Spatial Analyst extensions was used to study the change of the beach between the different years. A File Geodatabase was created in ArcCatalog. Then the ASCII x, y, z files for each year were properly delimited and converted to point feature classes to be useable in ArcGIS.

In order to carry the analysis of the survey data points, the points had to be interpolated to create a raster (continuous surface) of the study area. Interpolation is the process where values of cells in a raster are predicted based on the limited number of sample data points that are available. The Geostatistical Analyst extension was used to interpolate the data into rasters using Ordinary Kriging.

Contour Analysis

Tebbens et al. (2002) measured shoreline change by determining the horizontal change in position of the 0.8 m contour lines from shore-perpendicular profiles spaced at 20-m apart. In this analysis, in order to visualize where the 0 elevation line was for different years, and thus show displacement of the beach, contours of the 0 elevation were created for the different years using the Spatial Analyst extension. The displacement of the 0 contour line can be seen and a general trend between years 1999 and 2003 can be observed. Then, for post-nourishment 2006 year, it can be visualized how the 0 contour line shifted in relation to the rest of the years.

Using the Measure Tool in ArcGIS, it can be measured how sea level changed at the 0 elevation contour line, and then deduced whether sand was gained or lost. The change in 0 elevation (sea level) was computed for the different years between all 28 monuments and then the average 0 elevation shift in feet for all 0 contour lines was estimated to see if sand was gained or lost at the 0 elevation.

Area Elevation Change

To examine what most likely happened to the beach area between two different years, it is helpful to examine a difference raster (Meredith et al., 1999). A difference raster can be created by subtracting two grids, presenting two different years, from one another. This can be accomplished with the Minus Tool in ArcGIS Spatial Analyst. The Minus tool subtracts the value of the second input raster from the value of the first input raster on a cell by cell basis (ESRI ArcGIS Desktop Help, 2007). A new output raster is created which represents the elevation change from one year to the next. A total of four difference rasters were created: 1) between years 2000 and 1999, 2) between years 2002 and 2000, 3) between years 2003 and 2002, and 4) between years 2006 and 2003.

Volumetric Measures

A volumetric measure of the sand gained or lost in different years can be done with the Cut/Fill tool in ArcGIS Spatial Analyst. Two input surfaces are used from two different periods (before and after) to show the volume of surface material that has been changed by addition or removal of surface material. The Cut/Fill tool produces a raster of regions where material was removed, added or where the surface did not change (ESRI ArcGIS Desktop Help, 2007). In studying beach volume changes, the Cut/Fill tool is an ideal measure for making computations and visually interpreting areas that gained or lost sand. Further, in the attribute table of the raster, the total volumetric measure of material gained or lost, in cubic feet, can be computed.

Prediction Model

In ArcGIS Spatial Analyst, there are a number of raster Math tools that provide capacity to build a prediction model to see how the beach would look 5 years after year 2006, granted that there are no significant storm events and that other nourishment projects are not carried out in these 5 years. The goal was to see if the beach does lose a significant amount of sand and deduce if it is worth nourishing it.

This prediction model can be built first by computing the average yearly change of elevation for the pre-nourishment years. This can be done by adding the area elevation change rasters for years “2000 Minus 1999”, “2002 Minus 2000” and “2003 Minus 2002”, and dividing that by the total number of rasters. The output raster would represent the average yearly change. In order to do this, a geoprocessing model was built in ArcGIS. Once this average yearly change of elevation is determined, it can be multiplied by 5 to represent the change that would happen from 2006 to 2011. Once this “Times 5” raster is obtained, it can be added to the 2006 raster.

After the Beach 2011 raster was computed, it was determined where the 0 elevation contour line would be, and it was compared to the preceding. The area elevation change between 2006 and 2011 can also be shown, to see what areas lost or gained elevation. Cut/Fill between 2011 and 2006 can also be computed, to estimate the total volume of sand that will be lost.

RESULTS AND DISCUSSION

Contour Analysis

Figure 2 represents the 0 elevation contours for the study years. Every year is symbolized with a different color. The 0 elevation contour for 2006 is symbolized with red. We can see that the 0 elevation is much further in the ocean for 2006 compared to any of the rest of the years, showing that the elevation of the beach after the nourishment increased significantly. The general trend of how the beach eroded in this particular section of the beach can be seen. The year 1999 symbolized in purple eroded inland to its 2000 location (green) and then to its 2002 location (yellow). The 2003 contour (cyan) was furthest inland of all pre-nourishment years, which is logical considering the fact that this is a highly erosional environment.

Using the Measure Tool procedure described in Data and Methodology, measurements of the displacement of the 0 elevation contour line were done between different years. The results are summarized in Table 1. Negative values indicate that the 0 elevation line shifted inland, the beach lost sand and eroded from a given year to the next year. It should be noted that these measurements are estimates.

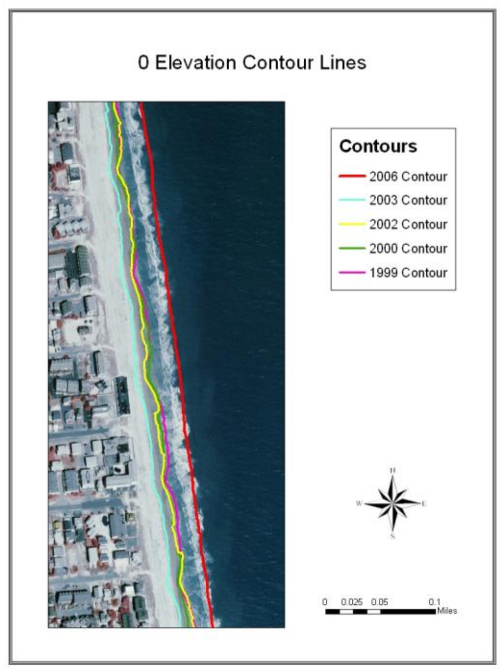

Figure 2. Sea level (0 Elevation) contour lines.

It can be seen that this sea level 0 elevation line shifts inland from year to year, therefore, the beach is eroding. However, there is an interesting exception to this from years 2000 to 2002. The 0 elevation line actually shifted out toward the ocean, meaning that there was more sand at this 0 elevation in 2002 compared to 2000. This most likely shows a

Table 1. Displacement of 0 Elevation Contour Lines (in feet)

0 Elevation Shift	**1999 – 2000**	**2000 - 2002**	**2002 - 2003**	**2003 – 2006**
Average per year	**-16**	**+21**	**-56**	**+153**

development or presence of an offshore bar (before the nourishment project took place). It needs to be kept in mind that this is only at this particular 0 elevation. Overall the beach lost sand at other elevations, if the study area is taken as a whole, which will be shown in the methods used in the next two sections. The importance of the contour analysis method is that it shows that the beach gained a large amount of sand at the 0 elevation line after the nourishment. If we look at the shift at this 0 contour from 2003 (cyan) to 2006 (red), we see that on average the 0 elevation shifted +153 feet into the ocean. This means that the beach at this elevation gained a lot of sand, which was due to the beach nourishment project. This gain would appear to validate the project.

Area Elevation Change

By subtracting two grids, a difference raster for two different years can be created using the Minus Tool in ArcGIS Spatial Analyst. The area elevation change was determined for the different years. See Figure 3. The green color indicates where significant gain of sand occurred – anywhere between 1 and 10 feet or above. The yellow color indicates where none or little positive change occurred (sand was gained) – from 0 to 0.5 feet. The orange colors indicate where little negative change occurred (sand was lost) – from -0.5 to -1 feet. The bright red colors indicate where more significant erosion occurred – between -1 and -5 feet loss of elevation.

In the first two years rasters between 2000-1999 and 2002-2000, we can see that most of the areas lost sand but the loss was not significant – colors range from orange to red. The majority of the area lost between -0.5 to -2 feet of elevation. Some areas did gain sand anywhere between 0 – 0.5 feet. It should be noted that the bright green and bright red areas out in the ocean are areas that most likely have not been interpolated correctly, perhaps due to erroneous data at the edge of the study area.

The interesting observation that was examined in the 0 contour elevation shift for 2000 – 2002 could be seen again in the 2003 – 2002 difference raster. In the contour analysis it was observed that the 0 elevation line shifted out toward the ocean in the later year (2002). It can be seen that the beach close to the 0 elevation line actually gained sand anywhere between 1 – 3 feet in elevation (the green line). Right in front of it, closer to the land into the positive elevation, the beach actually lost sand between -1 and -5 feet (darker red line). This is again most likely caused by an offshore bar formation in the winter season.

The last difference raster between 2006 and 2003 shows the elevation change after the beach nourishment. It can be seen that since the nourishment took place, a large amount of the sand was deposited on the front face of the beach closer to the shoreline – where the green color is. There is positive elevation between 1 – 10 feet where the sand was deposited, i.e. the beach's elevation grew significantly. The beach nourishment was effective in adding a significant amount of sand to the beach, which is easily visualized with GIS tools.

Volumetric Measurements

Below in Figure 4 are rasters that visually represent gained and lost sand. The blue color represents areas that gained material, and the Red color represents areas that lost material.

The first raster is between winter of 1999 and winter of 2000 and shows a predominantly red color. Table 2 shows the Summary Statistics from the attribute table of the raster. In the Sum box for 1999 - 2000 it is shown that there were approximately 1,723,742 cubic feet of sand that were lost in this one-year time period. The value is positive because it symbolizes volume that was cut (the smaller value of year 2000 is subtracted from the larger value of year 1999).

There is also a predominantly red color in the Cut/Fill raster between winter of 2000 and winter of 2002. Approximately 10,593,319 cubic feet of sand was lost in this two year time period. This value is much larger than the year above because it symbolizes the amount of sand lost in a two-year time period versus one. The Cut/Fill raster between 2002 and 2003 and the volume statistics table demonstrate that between winter of 2002 and winter of 2003, approximately 1,812,185 cubic feet of sand that was lost. Evidence for the probable formation of an offshore bar can also be seen.

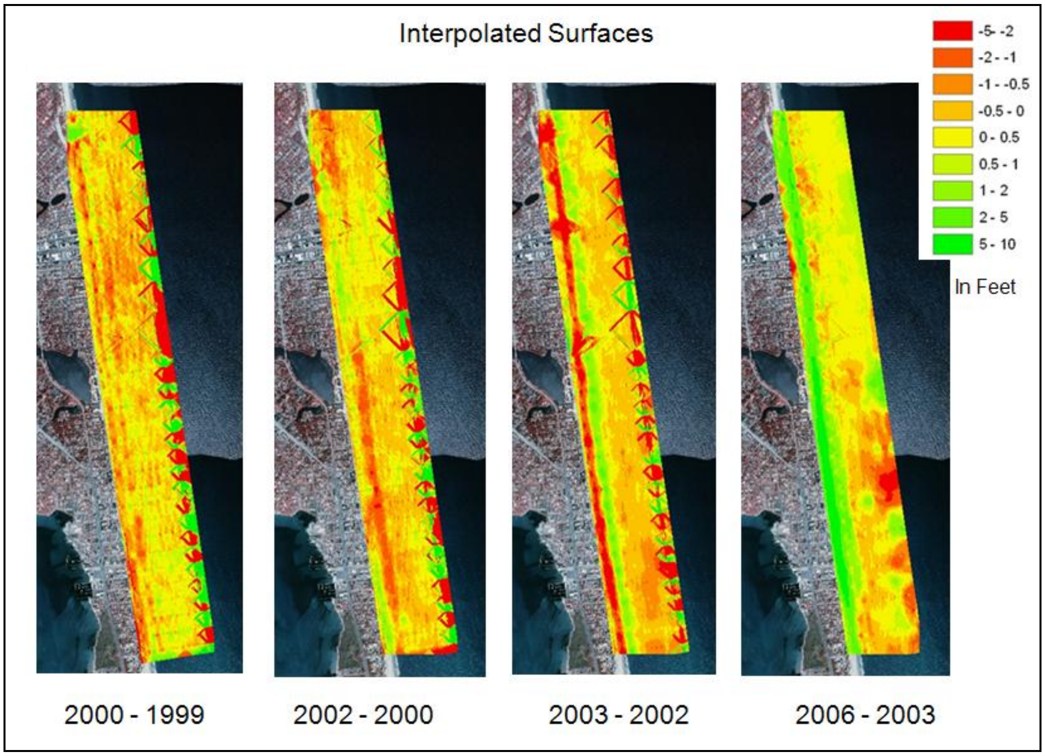

Figure 3. Area elevation change rasters.

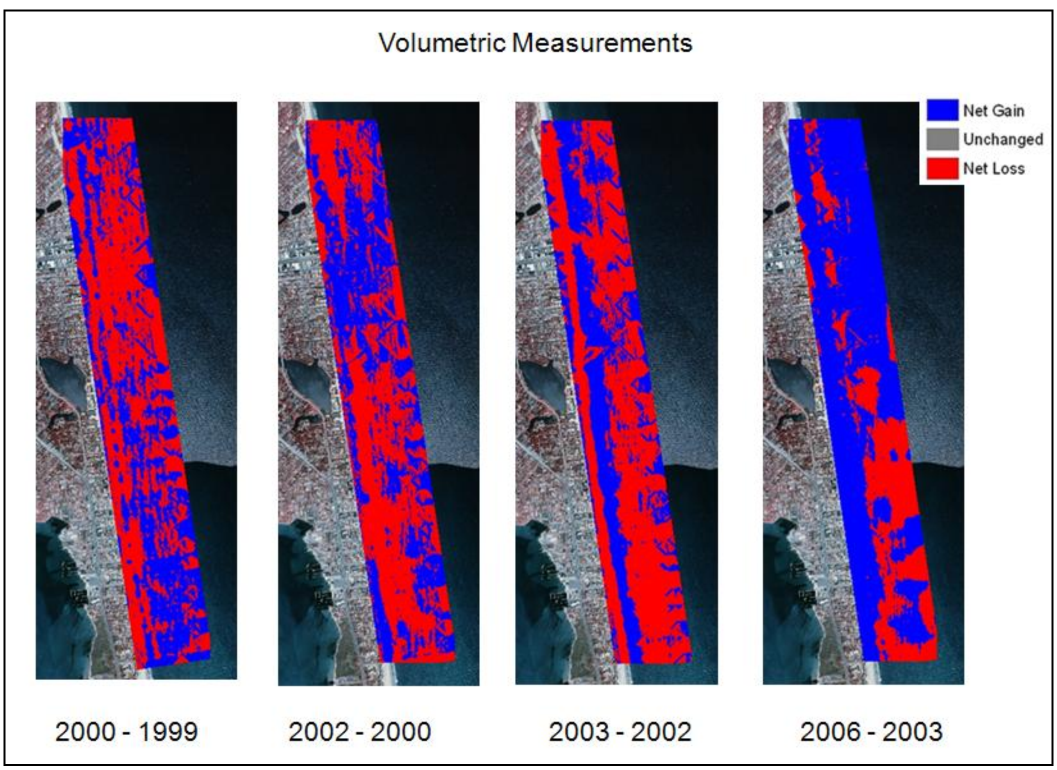

Figure 4. Cut/Fill rasters

Table 2. Volume Statistics (in cubic feet)

Year	2000 – 1999	2002 – 2000	2003 – 2002	2006 - 2003
Sum	1,723,742.42	10,596,310.49	1,812,185.52	- 5,466,192.56

The 2003 and 2006 Cut/Fill raster has a predominantly blue color which means that more sand was gained, as we would expect to see after the beach nourishment took place. There were approximately -5,466,192 cubic feet of sand gained after the beach was nourished. The sum value is negative because it symbolizes the amount of sand that was gained (the larger year of 2006 was subtracted from the smaller year of 2003). Again it can be seen that GIS provides useful functionality to analyze beach areas before and after a nourishment project takes place. In this case it again illustrates that the beach did, indeed, gain sand after the 2005 nourishment.

Prediction Model

After the two prediction geoprocessing models were run, the 0 elevation contour line for 2011 was added to the rest of the 0 elevation contour lines. The 2011 contour line was symbolized in black. In Figure 5, we can see that the 0 elevation contour line has shifted significantly inland for these 5 years signifying loss of sand. This means that the beach should be nourished periodically in order to maintain its elevation and volume.

The average area elevation change between 2011 and 2006 was determined as well. The middle raster in Figure 5 shows mostly dark orange to red colors which means that the beach will lose height. The majority of the beach lost anywhere between -0.5 to -2 feet. There are only a few light green areas where it seems that the beach gained elevation. The bright red line on the dry beach portion shows a considerable loss in elevation between -2 to -5 feet. This again shows us that the beach should be nourished periodically to sustain its height.

The Cut/Fill tool from ArcGIS Spatial Analyst was used as well to determine the beach volume change from 2006 to 2011. See the third raster in Figure 5. We see the predominantly red color which signifies loss of sand. In the Volume statistics box in Table 3 below, it is shown that the beach will lose approximately 18,578,762 cubic feet of sand, which is a considerable amount. That means that the beach should be nourished periodically to maintain its volume of sand.

Table 3. Volume Statistics 2006-2011

Year	2006 – 2011
Sum	18,578,762.56

CONCLUSION

The staff at the Shoreline and Waterway Management section shared their x,y,z survey data used in this paper. GIS was utilized to display the changes that occurred to the beach throughout the study years. From the methods employed, it was determined that that this is an erosional environment and the process of beach nourishment does add a significant amount of sand to the beach. Judging from the physical changes that occur to the beach, the project was a success. It was concluded that the beach should be nourished in order to sustain its current level of sand volume and elevation, and in order to keep attracting visitors. In this project, GIS proved to be a useful tool for projecting some of the future changes that might occur. GIS showed us what we probably knew already – that the beach would have gained sand after the nourishment – but the technology gave us yet another way to visualize and compute some of these changes.

Something that could have helped tremendously in this research, and could be done at a later point in time, is doing this analysis over a greater period of time. The available data was only 5 years pre-nourishment, one of which was not useful (2001). Then there was a lapse in 2004 and 2005 data, and the only post-nourishment year was 2006. It would have been a better study if there were more years pre-nourishment and more years post-nourishment that would have helped the analysis and achieved better and more accurate results. The importance of this research is that it at least laid down the groundwork for further studying of these beaches using GIS.

Something that was not touched upon in this study was the environmental effects that beach nourishment has on the local site (where sand is deposited) and on the borrow site (where sand is taken from), such as disturbance of species' feeding and breeding patterns, elevated turbidity levels, changes in near shore bathymetry, etc. This paper

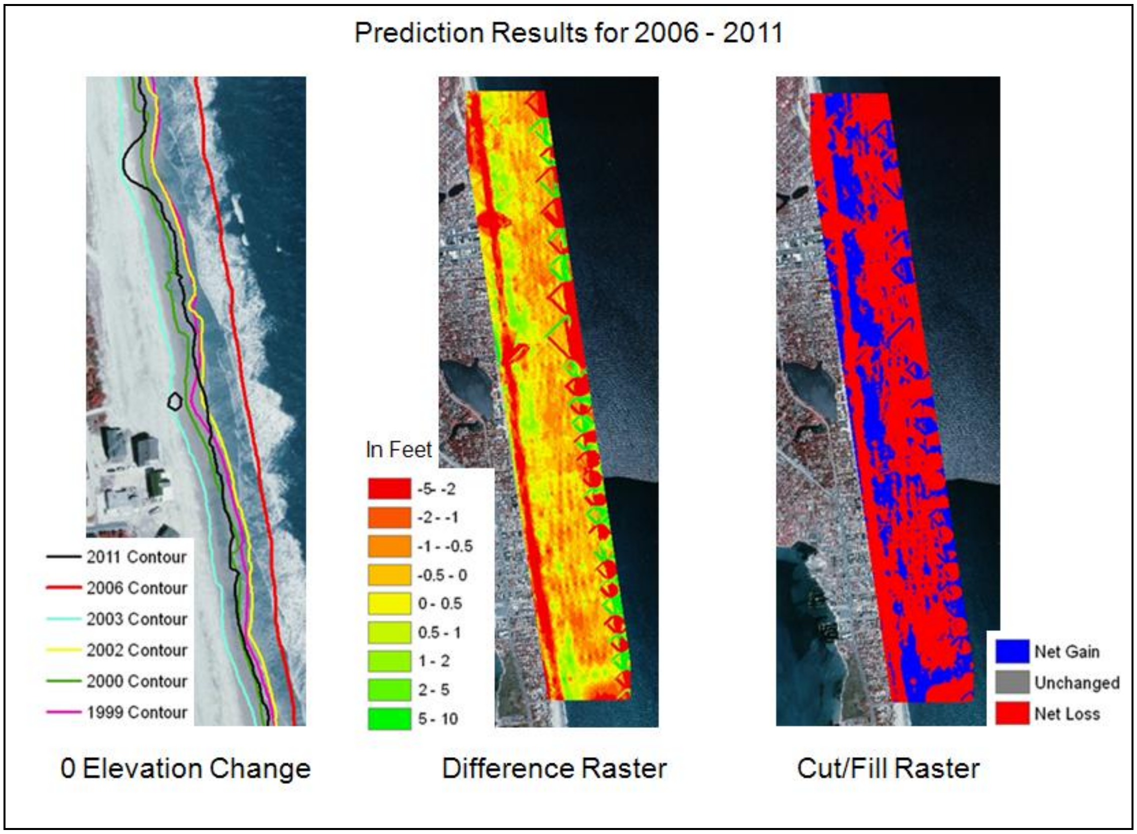

Figure 5. Prediction results.

examined the geomorphologic changes of the beach pre- and after-beach nourishment, but it did not cover any of these environmental effects. This would be something that could be examined in future research as well.

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