MONITORING NEAR AND OFF SHORE SEDIMENT FORMATIONS BY SATELLITE

Charles C. Watson, Jr
GIS Administrator, Town of Hilton Head Island
1 Town Center Court, Hilton Head Island, SC 29928 USA
(803) 842-8900

ABSTRACT

In 1990, a portion the Atlantic Ocean beach of Hilton Head Island was renourished using sand taken from nearshore borrow sites. The Town's Geographic Information Systems (GIS) staff has been studying the effects of the renourishment project on offshore areas through the use of satellite images and data. The study consisted of acquiring SPOT images and historical photography of the Hilton Head area from various times before and after the renourishment project. The images were processed and specific features converted to GIS coverages for analysis. Bathymetric data from nautical charts was updated using bathymetry derived from the satellite data. Results of the study consist of data showing the geometry and motion of shoals both before and after the renourishment. In addition, the configuration and extent of a large area of underwater 'sand waves', located from the shore to 5 kilometers offshore, were described and monitored. The full extent and configuration of this area were previously unknown. The use of the satellite derived data in various computer models is also discussed. This study revealed several points in the process of coastal planning where satellite derived data could be profitably used, such as borrow site selection and ongoing monitoring.

KEY WORDS: GIS, MAPPING, CHANGE-DETECTION, COASTAL-APPLICATIONS

INTRODUCTION

Hilton Head Island is a resort community located on the southern end of the Atlantic coast of the state of South Carolina. Affluent part-time residents and tourists are the driving force of the local economy, visiting the Island primarily for its sandy beaches and controlled development. As with many barrier islands along the United States' southeastern coastline, Hilton Head is slightly to moderately erosional along most of its shoreline. Unfortunately, developers have chosen to build on the primary dune line in many areas, and have left very little buffer between their buildings and the ocean. Since the economics involved would not permit allowing these multi-million dollar investments to fall in to the sea, the municipal government has made a major commitment to returning the beach to its configuration of the early 1980's and maintaining it in that state. The technique chosen by the Town's consulting engineer was to 'renourish' the beach by pumping sand from offshore borrow sites on to the eroding beach (**Figure 1**). After nearly 5 years of planning, primarily focused on funding the 7.92 million dollar (US) project, the renourishment was undertaken in the summer of 1990. Soon after the completion of the project several groups of citizens complained that the project had resulted in erosion in their areas of the beach. At the request of the Town Manager, the Geographic Information System (GIS) administrator began an independent study of possible adverse effects of the renouishment project. This paper describes how the GIS, aerial photography, and images from the SPOT satellite were used to create a data base to analyze the possible effects of the renourishment project.

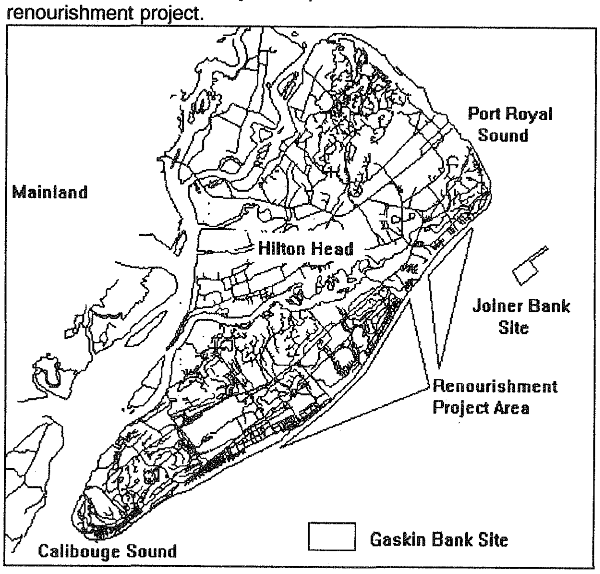

Figure 1: Study Area

DESCRIPTION OF THE STUDY

The study of the renourishment project centered on mapping the offshore areas. The three major tasks undertaken during this study are shoal location and migration monitoring, updating bathymetric data, and monitoring underwater features. Also noted are actual wave refraction patterns seen on some SPOT images.

Shoal Location and Migration Monitoring

Fill material for the beach nourishment project was obtained from two borrow sites. The first site was located near a hooked spit adjacent to the north end of Hilton Head Island. Joiner bank is part of the dynamic shoal system that borders Port Royal sound. As originally designed, part of the spit was to be excavated to provide the fill material. The project design was finalized in 1986, using National Ocean Survey (NOS) nautical charts. These charts were based on data obtained in the 1970's. Between that time and the time the project was designed, the part of the spit which was proposed to be excavated had become submerged, and the hooked end of the spit had migrated over 700 meters. By the time work began on the project, the spit had moved an additional 220 meters. Despite the changes to the location, work proceeded and nearly 900,000 cubic meters of material was removed from the site, increasing the water depth by 3.3 meters. Soon after project completion, severe erosion was noted along the shoreline directly landward of Joiner bank, prompting citizen complaints.

The first stage of the GIS study of the renourishment project was to determine the location and movement of Joiner bank before and after the project. The Town of Hilton Head GIS is implemented using ESRI's ARC/INFO package on Sun Microsystems workstations. Much additional work was done on IBM PC compatible systems using Clark University's IDRISI package and software developed by the GIS Administrator. Several sources of material were used to create five coverages ranging in time from 1974 to 1991. NOS charts, created from 1974/75 field data, were digitized manually using a Calcomp 9100 digitizer. These were the same charts used by the Town's consultant for the project design. An aerial photograph from January 1984 was scanned and stored as a raster file. Three SPOT satellite images were obtained: multispectral images from February 86 and May 89, and a panchromatic image from March 1991. For comparison purposes, aerial photography from January 1986 was compared with the February 86 satellite image. Most of the analysis was concentrated on the three satellite images.

The basic method for creating a line coverage from the raster image data was quite simple. A 'radiance contour' map was created for each image near a cutoff value. This cutoff value represented the 'low tide line' for sand in the image, and was selected based on the radiance of sand on the island beach front at pixels known from surveys to be near the low tide mark. For the multispectral images, band 3 (0.79 to 0.89 micrometers) was used, as this band has the steepest water absorption. As a check, the

March 91 satellite image and the January 86 aerial photograph were manually digitized. The January 86 aerial was taken at low tide, whereas the February 86 SPOT image was acquired at nearly high tide. The only substantial difference between the hand digitized and computer created vector coverages was that the computer converted a small boat in the March 91 image in to a shoal. Inspection of the other computer created coverages showed that this was an intermittent problem, depending on the speed of the boat. (Faster boats left larger, brighter wakes.) The boat wakes, of which 4 were converted to "shoals", were eliminated by hand from the remaining images. None of the boat wakes occurred in the primary study areas. **Figure 2** shows several results for the Joiner Bank Area. The distance of the tip of the hook to the low tide line was measured for each of the five data sets. One surprising result of this study is that Joiner bank appeared to move fairly consistently over the period from 1974 to 1989, averaging just over 70 meters per year of landward migration. For SPOT multispectral data at 20 meters/pixel, this would be 3.5 pixels of movement per year, an easily detectable amount. From comparisons between the 1986 aerial photograph and SPOT image, it appears that the position of the low tide line on a shoal can be determined to approximately 1/3 pixel, or about +/- 3 meters. Panchromatic data, at 10 meters/pixel, lends greater accuracy to the movement rates and positions. However, it should be noted that this increase in apparent accuracy may not be entirely relevant, as these shoals can move several meters during a single mild storm event, and due to the variation in low tide levels. The movement rates and estimated positional accuracy's for Joiner Bank are summarized in **Table 1**. From this data it would appear that the rate of movement of the shoal has increased since the end of the renourishment project. Although only additional study over time will verify this, there are other indications of increased wave energy in the Joiner bank area which will be described later. The same process was performed on the Barrett and Grenadier shoals at the south end of the island. Very little migration was detected in that area. Conversations with local boaters seem to indicate that the south end is not nearly as dynamic as the northern areas of the island.

Date	Source of Data	Distance to Tip of Spit	Estimate Accuracy of Dist.	Ave Rate of motion
Mid 74	NOS Chrt	2195 m	+/- 10 m	------------
Jan. 84	Aerial	1524 m	+/- 01 m	67 m/yr
Feb. 86	SPOT XS	1373 m	+/- 03 m	72 m/yr
May 89	SPOT XS	1148 m	+/- 03 m	70 m/yr
Mar. 91	SPOT Pan	948 m	+/- 02 m	109 m/yr

Table 1: Movements of the End of Joiner Bank.

To summarize, analysis of the satellite data resulted in reasonably accurate positions and geometry of emergent shoals. The tide level at the time of image acquisition is an important factor in the analysis, and must be corrected for. There was very little positional difference in manual versus automated raster to vector conversion. As with any image classification, inspection for spurious data (such as boat wakes) was important. Overall, this method was considered to be very successful for ongoing shoal location and geometry monitoring.

Updating and Using Derived Bathymetric Data

The waters off the Atlantic shoreline of Hilton Head are quite shallow. Waves coming in from the deep ocean are refracted significantly before striking the shoreline, either concentrating or scattering wave energy. Since wave energy is the primary driving force of near shore sediment movement, determining wave refraction patterns is a key to understanding shoreline erosion. Given the dynamic nature of the shoals around Hilton Head, traditional nautical charts should probably not be used as the only source of bathymetric data for use in computer models of wave refraction. The most significant refraction effects occur when the wave enters water shallower than 1/25 the wavelength. For the highest energy waves striking Hilton Head, this corresponds to a depth of around 5 meters. (US Army COE, 1973) The following assumptions and methods were used in developing a bathymetric data set for use in the wave refraction model:

- Given the sandy characteristics of the area, a bottom reflection based model would be accurate to a depth of 3 meters. Band 1 was used to calculate depth, with band 2 being used as a check.
- Reflective characteristics of the sand across the area are fairly uniform.
- Changes between 3 and 5 meters were less likely to occur than those above 3 meters, and NOS data could be used in these areas if sediment loads precluded the use of the satellite model.

The 1989 multispectral image was used to derive the bathymetric data for this study. Throughout the study area, comparisons were made between the satellite derived model, NOS charts, and soundings used for the design of the renourishment project. The correlation between known sites and the satellite derived depths was generally good, with the average error less than .3 meters. The composite bathymetric model was used as the basis for a wave refraction study, which was compared to the wave refraction study submitted by the Town's consulting engineer. (Olsen Assoc, 1987) The model used by the consultant was based on a 366 meter grid, while the model derived for this study used the 20 meter grid size of the original satellite image. This point is important, since the grid size for the consultant's model was 3 times larger than the wavelength of the waves under consideration, while the GIS grid was about 1/5 wavelength. While the results of the two models generally agreed, there were some significant differences. The finer grid model predicted somewhat higher wave energies impacting the Port Royal shoreline opposite Joiner Bank due to the dredging. Also, the finer grid indicated other possible disruptions to that area, such as changes to the tidal currents from Port Royal sound. (The consultant study did not consider tidal effects.) The finer grid was very sensitive to wave input conditions, with variations resulting in more changes to the impact on the beach than coarser grids. Work is still progressing on the integration of the high resolution refraction model and the results of beach profiles taken during and after the project.

Detection of Refraction Patterns

A variety of image processing algorithms were tried to enhance features which may be visible on the satellite images. One feature visible in certain areas was the actual wave refraction patterns. Simple edge enhancement of a contrast stretched image was sufficient to bring out these patterns. Ocean waves at the time of the 1991 image were from the south east, 0.6 to 1.0 meter in height, with a wavelength of approximately 120 meters. These parameters were used as input to the wave refraction model. Refraction patterns were output as a GIS vector coverage. On a digital overlay of the computer model patterns on the enhanced image the patterns matched quite closely. Although aerial photography would show shorter wavelength waves not resolved by satellite, with further work this method may be useful for the verification of wave refraction models over large areas.

Monitoring Underwater Features

The original reason for attempting to derive an updated bathymetric model was to update NOS charts for areas near the dynamic shoal systems. Study of the images revealed a number of entirely submerged features. Mapping underwater formations was the third task undertaken during this study. Most significant among these was imaging the actual borrow sites used for the beach renourishment project. The March 1991 panchromatic image clearly showed both sites. It was, however, apparent that the two sites were recovering in different ways. The Gaskin Bank site appeared to be infilling with material of the same type as the surrounding sandy sediment. The reflectance values were consistent with those of the surrounding areas after correction for the attenuation due to being 2 meters deeper. There was some suspended sediment apparent. The Joiner Bank area, however, showed a great deal of suspended sediment in the area of the site. The site itself was darker than could be accounted for by attenuation due to depth. Patterns in the sediment plume appeared to originate from Port Royal sound. These interpretations were confirmed by a study of the site by the South

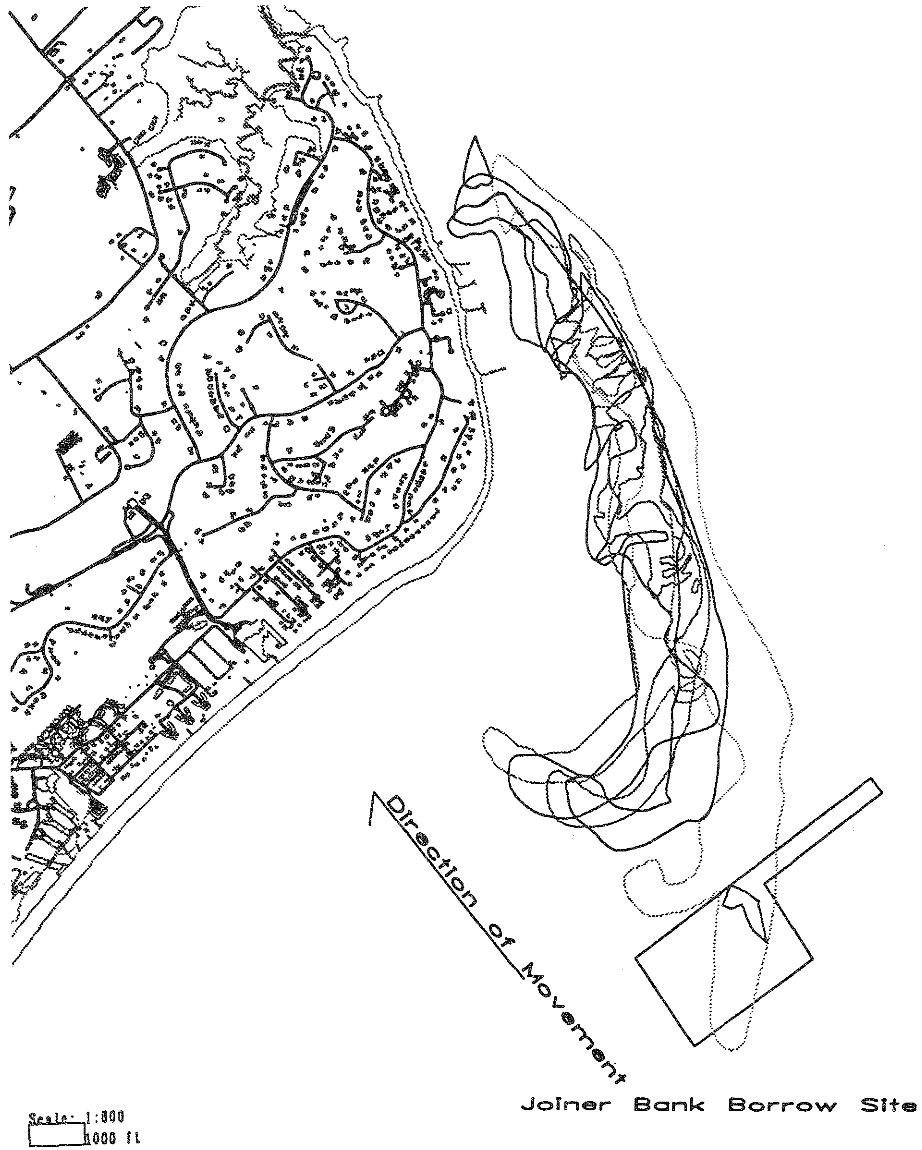

Figure 2: Movements of Joiner Bank

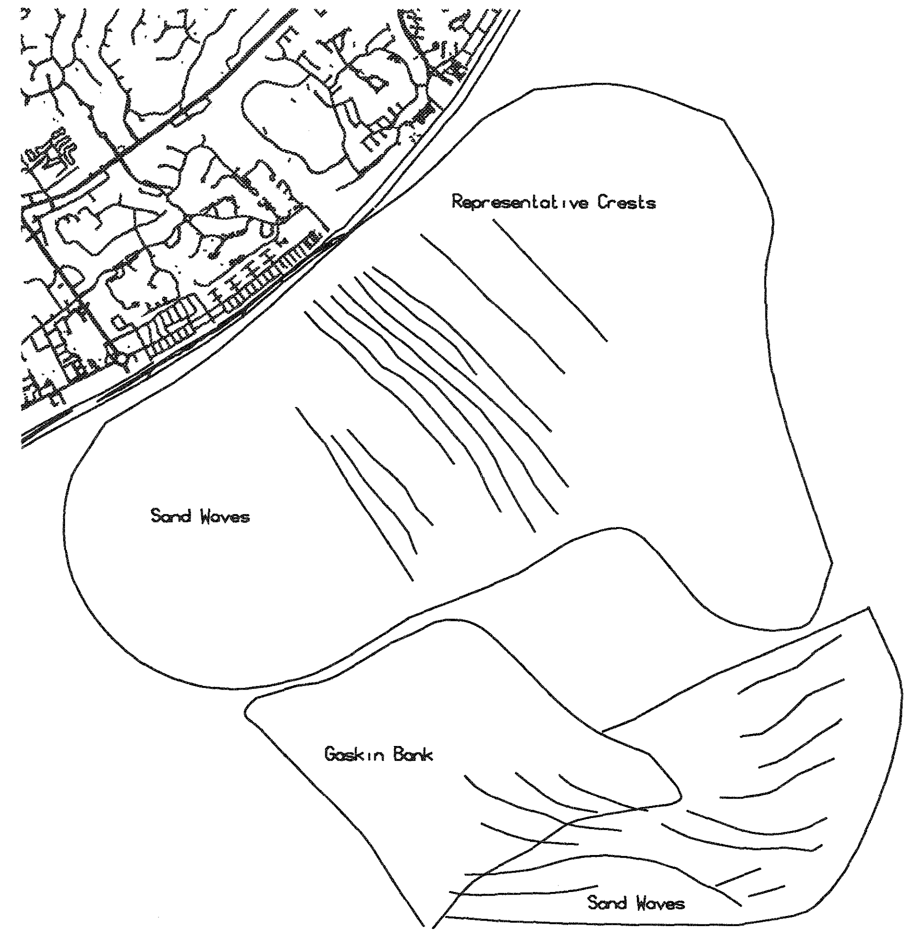

Figure 3: Dune Fields near Gaskin Bank

Carolina Marine Resources Center. The SCMRC divers noted "a layer of loosely consolidated mud that varied from less than one foot to an unknown depth beyond the divers' reach" during a dive conducted approximately two weeks before the satellite image acquisition. (Van Dolah, et al, 1992) Samples obtained at the borrow site showed a significant increase in silt and organic material (from 5% pre-project to 36% after). This change in composition is probably the source of the change in reflectance of the material in the borrow site.

One unexpected benefit of this study was the ability to map a complex system of underwater sand dunes located from 1 to 5 kilometers offshore. Although the presence of these dunes has been known for some time, the full extent and configuration of these fields were not well established. Previous studies (such as Henry and Harding, 1985) were based on data derived from soundings, and did not provide a complete picture of these features. **Figure 3** shows the location and geometry of the largest of these dune fields. The bathymetric GIS coverage was classified in order to find crests and troughs. The crest/valley vector coverage was superimposed over the satellite image for visual inspection. Spacing was determined by measuring the distances from crest to crests both visually and using GIS functions. The waves range up to 2 meters in height, and in some cases are over two kilometers in length. The waves are relatively evenly spaced, ranging from 140 to 150 meters apart. The dune fields appear relatively stable, with very little change detected between the 1986 and 1989 images. A slight migration to the SW, on the order of 40 meters, was possible, perhaps in response to the slow landward migration of Gaskin Bank. In several instances, the waves appear to extend from Gaskin Bank nearly to the shoreline. Further study of the dunes and their relation to indicent waves and shoreline changes are underway.

RESULTS AND EVALUATION OF THE STUDY

Summary of Results of the Study

Excavation of the Joiner bank site definitely resulted in changes to the environment. This conclusion is backed up by on site studies by SCMRC. Direct changes as a result of the dredging of Gaskin bank, other than the actual excavation of the site itself, were not detected. The wave refraction study indicated some energy dispersal as a result of the deeper site. The Barret and Grenadier shoals at the south end of the island were relatively stable. The system of sand waves was accurately mapped, and a baseline established for their continued monitoring.

Implications for Coastal Planning

The study of effects of the beach renourishment project on Hilton Head Island was completed in less than four months using mainly "off the shelf" hardware and software. Most of this study was conducted on an IBM PC compatible system (Intel 386 processor with math coprocessor, Trident SVGA graphics, 150MB Hard Drive, Laser Printer) using IDRISI, a grid based GIS available at low cost from Clark University. IMDISP, a public domain program available from NASA's Jet Propulsion Laboratory, was used for some image manipulation and processing functions. The wave refraction models were originally written in C on a Sun SPARCstation, but were refined and rewritten in C++ on the PC. Presentation maps were generated using UNIX workstation based ARC/INFO, but could have been done equally well on the PC. If the object were to update NOS charts for pre-project planning, the study could have been performed for about $14,000 (US), including software, hardware, and the SPOT image. This would have amounted to 0.18% of the project cost. Because the original project design used older NOS charts, changes to the geometry of Joiner Bank detected by either aerial photography or a satellite image analysis may have resulted in a different configuration for the borrow site for the northern section of the project. In addition, the political benefits of having used the best available information should not be underestimated.

SUMMARY

Engineering projects that alter the natural environment should be planned carefully, using the most current data possible. The availability of satellite imagery in the 20m/pixel or better range presents an excellent opportunity for current maps and models to be used in planning these projects at the local level. In the coastal environment, this data can be effectively used for updating the geometry and movements of shoals and underwater sediment formations. Although suspended sediment loads may interfere with accurate determination of bathymetry, with care remotely sensed data may be used for updating water depths for use in a variety of models. The costs involved are minimal compared to the overall costs of coastal engineering projects.

REFERENCES:

Henry, V., and Harding, J., 1985. Results of A Study to Locate Suitable Beach Nourishment Material in the Nearshore Area Off North Forest Beach and Palmetto Dunes Resort, Hilton Head Island, SC. Report for the Town of Hilton Head Island.

Olsen Associates, Inc., 1987. Wave Refraction Analysis of the Existing Bathymetry and Potential Impact of Offshore Borrowing at Hilton Head Island, SC. Report for the Town of Hilton Head Island.

Olsen Associates, Inc. 1992. Hilton Head Island Beach Restoration Project Monitoring Report, Year 1. Report for the Town of Hilton Head Island.

US Army Corps of Engineers, 1973. Shore Protection Manual.

Van Dolah, R., Wendt, P. Martore, R. Levisen, M, and Roumillat, W. 1992. Final Report for A Physical and Biological Monitoring Study of the Hilton Head Beach Nourishment Project.