GIS and 3D Analysis Applied to Sea Turtle Mortalities and Navigation Channel Dredging

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ABSTRACT

Between 2000 and 2003 there were an increased number of documented sea turtle mortalities related to hopper dredging in the channels of the Chesapeake Bay. A pilot study was undertaken to create a bathymetric surface and three-dimensional model of the Cape Henry Channel using Geographic Information Systems (GIS) as a visualization tool to examine sea turtle mortalities in relation to the dredging. In Fall 2003, the US Army Corps of Engineers dredged the Thimble Shoals Federal Navigation Channel, and a more refined model was developed using this data. This project examines the growing concerns over sea turtle mortality rates and dredging operations, as well as a description of the usage of GIS analysis, interpolation, and visualization methods as tools for examining turtle habitat and mortality issues. Future directions for incorporating GIS into attempts to reduce sea turtle mortality in dredging operations are then outlined.

INTRODUCTION AND BACKGROUND

The section of the Chesapeake Bay off the Virginia coast contains a series of Federal Navigation Channels that are periodically dredged by self-propelled hopper dredges. These dredges are suitable for all but hard materials and are, by far, the best suited dredges for offshore work (Herbich 2000). There are four main navigation channels in the lower Chesapeake Bay: York Spit, York River Entrance, Cape Henry Channel, and Thimble Shoals Channel. Cape Henry Channel and Thimble Shoals Channel mark the entrance to the Bay from the Atlantic Ocean. The Thimble Shoals and Cape Henry channels are congressionally authorized Federal projects located in the mouth of the Chesapeake Bay between Hampton Roads and the Atlantic Ocean. Thimble Shoals Channel is approximately 18288 meters long, 304.8 meters wide, with an original depth of 13.7 meters at mean low water (CENAO 1973). The channel was constructed in 1914 and requires maintenance dredging once every 2-3 years. Cape Henry Channel is approximately 328 meters wide and 3.7 kilometers long, with an original depth of 12.8 meters at mean low water (CENAO 1980). Figure 1 shows the locations of the Thimble Shoals channel and a portion of the Cape Henry channel as they relate to the Chesapeake Bay coastline region.

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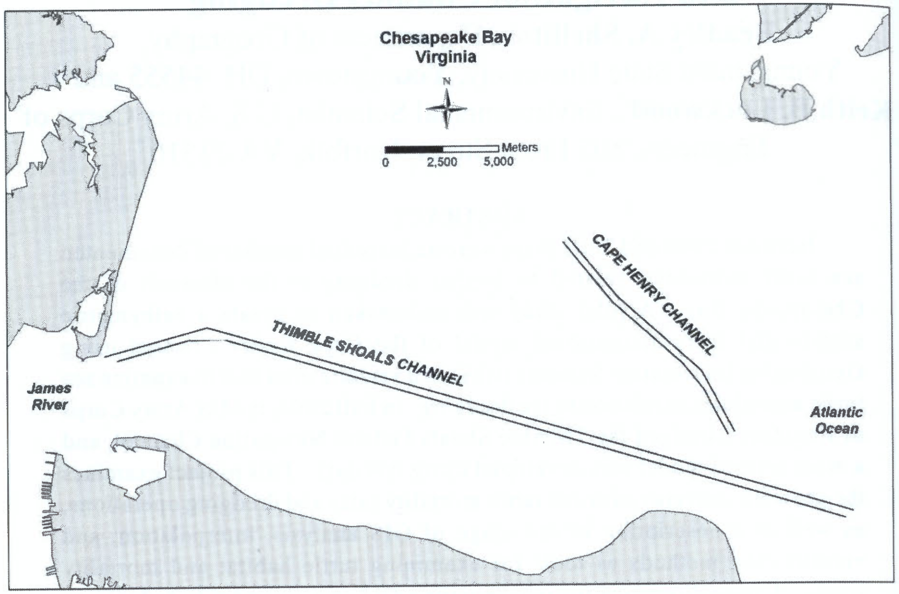

FIGURE 1. A plan view map of the Cape Henry and Thimble Shoals Channels

The Chesapeake Bay is also home to sea turtles, which live in the Bay during the warmer months when the water temperatures remain above approximately 18˚C (Keinath *et al.* 1987). Historical aerial surveys conducted in the 1980s estimated that 6,500 to 9,700 sea turtles were found in the lower Chesapeake Bay annually (Byles 1988; Musick 1988; Keinath 1993; Mansfield 2005). Aerial surveys during the period 2001-2004 found a 65-75% reduction in the population estimate, or a range of 2,500 to 5,500 turtles (Mansfield 2005). The majority of turtles that frequent the Bay and come in contact with hopper dredges are loggerhead turtles (*Caretta caretta*) and Kemp's ridley sea turtles (*Lepidochelys kempii*). Hopper dredging can adversely affect sea turtles, either directly by encounters with dredging equipment (which can result in sea turtle mortality) or indirectly by alteration of nesting habitat (Coston-Clements and Hoss 1983).

In response, several studies have been conducted in coordination with new regulations to protect the threatened and endangered sea turtles. The National Marine Fisheries Service (NMFS) has set guidelines to require relocation trawling if a certain amount of incidents were documented in an allotted time period or within dredging projects. Sea turtle relocation trawling uses shrimp trawlers to move ahead of the hopper dredge collecting sea turtles and depositing them elsewhere (Lincoln 2001). For the Cape Henry and Thimble Shoals Federal Navigation channels of the Chesapeake Bay, relocation trawling must be started if a dredge entrains two sea turtles of any species in a twenty-four hour period or if four sea turtles are caught during a two- month time period (Kurku, 2002).

The Cape Henry and Thimble Shoals channels were chosen for the area of study for several reasons. First, the Army Corps of Engineers dredged the Thimble Shoals channel in Fall 2003 and the Cape Henry channel one year earlier. The threshold on sea turtle mortalities was reached (Mansfield and Musick 2004), and trawlers began working in front of the dredges. Also, the channels mark the entrance to the Chesapeake Bay, which may act as funnels for turtles migrating in and out of the Bay during the spring and fall. Therefore, the Cape Henry and Thimble Shoals channels are ideal for studies of the relationship between sea turtles and dredging. In this project, the Cape Henry channel operation is presented as a pilot study, while gaps or discrepancies in the data were corrected for the relevant information collected for the Thimble Shoals channel. Data recorded on the observer reports on both the dredges and trawlers were heavily scrutinized for discrepancies, and thus data accuracy was greatly improved from the previous Cape Henry project.

Several projects have examined turtle mortalities and catches from trawling and fishing gear. Casale *et al.* (2004) examined turtle catches from trawling in the Adriatic Sea, while Robins (1995) provides estimations for the turtle catches off the shore of Australia. Cheng and Chen (1997) examine sea turtle catches from fisheries in coastal areas of Taiwan. Robins- Troeger *et al.* (1995) discuss the success of a TED (Turtle Excluder Device) used in Australia to reduce and prevent turtles being caught by trawlers. The TED acts as an escape hatch for sea turtles caught in a trawler's net and when used on a dredge acts as a plow pushing sea turtles out of the way of the drag head as it moves along the bottom.

Other studies have spawned from the increases in sea turtle mortalities. The Virginia Institute of Marine Science (VIMS) began tagging sea turtles to trace their surfacing and traveling patterns (Mansfield and Musick 2002). Results from this study provides researchers information on turtle migration patterns, surfacing behaviors, and the maximum number of individual turtles (per species) that may be taken incidentally by anthropogenic activities, such as hopper dredging, while still allowing for the recovery of the species (TEWG 2000; Mansfield 2005). The U.S. Army Corps of Engineers (USACE) Norfolk District maintains a database of turtle catches by both dredges and relocation trawlers in the Chesapeake Bay Federal Navigation Channels. From the period when monitoring began in 1994 to 2003, 55 sea turtle were incidentally taken by hopper dredging activities in the Chesapeake Bay. An additional 61 sea turtles were caught by a trawler working in one of the four navigation channels, and relocated approximately 8.05 kilometers away from the respective channel. The USACE maintains a Microsoft Access database that includes fields representing the location of catches in various coordinate systems, the date and time, type of vessel, water and air temperature, condition of specimen, tide, and several other attributes while the coordinates of a turtle take are recorded when the event occurs. The database has a live link with Geographic Information Systems (GIS) software in order to portray a point shapefile of turtle takes in the Chesapeake Bay. Figure 2 shows a map of the Chesapeake Bay with the channels, as well as the historic turtle takes attributed to water temperature for 2002. Another map portrays the same points, but attributed to type of vessel, whether dredge or trawler (Figure 3).

Team members on the project are concentrating on the technical aspects of the dredge equipment to identify any changes that can be made to prevent turtle mortalities.

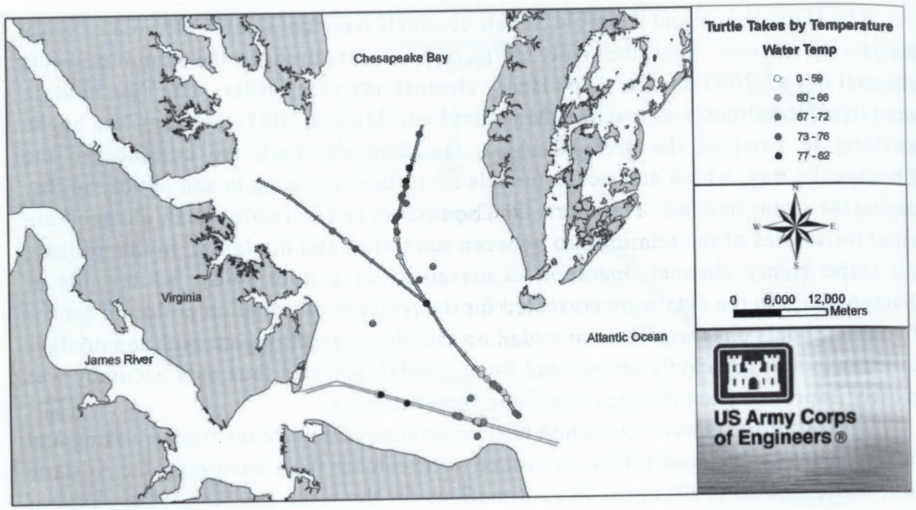

FIGURE 2. The channels of the Chesapeake Bay and turtles takes attributed to water temperature for 2002.

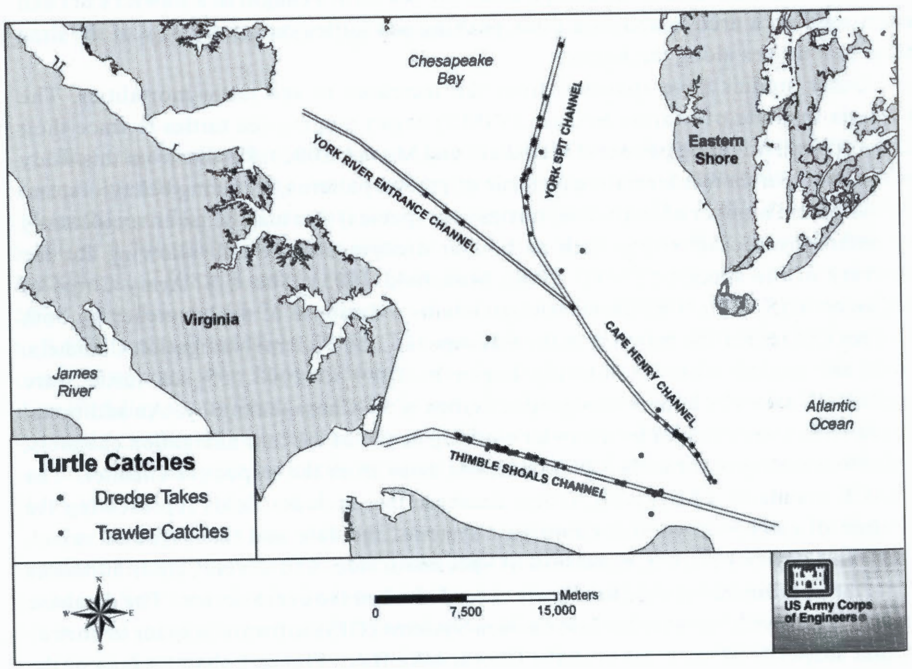

FIGURE 3. Turtle takes attributed to type of vessel (dredge or trawler)

Even though hopper dredges can entrain sea turtles, this type of vessel is used as it is the most efficient type of equipment for dredging unprotected offshore channels (Kurkul 2002). A hopper dredge has a drag head that acts like a vacuum on the bottom sucking up sediments, and turtles can get entrained or crushed by the suction capacity of the drag head. One major modification was a turtle deflector, located on the drag head of the dredge. It acts as a plow that digs into the bottom approximately six inches, and pushes anything on the surface of the bottom out of the way (Fonferek 2001). The rigid deflector, properly installed and operated, blocked 95 percent of mock turtles in a field test experiment performed by the Army Corps of Engineers (USACE 1997). Also, dredging specifications have altered because of the turtle conflict; now dredging operators shall not have the pumps running if the drag head is not in contact with the bottom. GIS has been incorporated with dredging operations to model dredged material mounds and sediment concentrations, such as the SSFATE model (Howlett 2003; Swanson *et al.* 2004), although these models are focused on the physical dredging and disposal operations and have not been connected to marine life interactions.

GIS and related technologies have been integrated with sea turtle analysis and studies of the turtles in various ways. Many projects have used satellites to track the movement of sea turtles based on tags the turtles have been outfitted with. Satellites are then used to track the signals from the transmitting units on the turtles (Godley *et al.* 2002; Echols 2003; Mansfield and Musick 2004) for locating their position. Using this information, the movements of turtles can be tracked to determine where turtles are going and when they are going there. Broderick and Godley (1999) also identify potential negative impacts on the turtles from these tracking efforts, but note that tagging did not interfere with sea turtle nesting behaviors. Beyond tracking and analysis, GIS has been used for modeling of turtle habitats. McDaniel *et al.* (2000) use GIS for models of predicting turtle abundance and density. Chaloupka (2002) provides a model for examining population dynamics of turtles in the Great Barrier Reef, however this does not take spatial features into account. This paper seeks to provide additional applications of the technology beyond these efforts.

This paper also provides an examination of the relationship between sea turtles in the region and the dredging operations. In order to aid in exploration of this process, GIS techniques are used to construct bathymetric surfaces and three-dimensional visualizations of the dredged areas to examine sea turtle mortalities in relation to the bathymetry of the channels. The surfaces provide a measure of the bathymetry associated with the available turtle take data which remains unrecorded during surveys. These new visualizations can potentially aid in the attempt to curb sea turtle mortalities with examination of locations of sea turtles with respect to the bottom surface. These tools can also be extended to uses beyond turtle mortalities and can prove adaptable to many types of habitat-based scientific research.

MATERIALS AND METHODS

To create a surface representing a section of a channel where sea turtles were entrained or captured, base heights for the bottom of the channel must be established. Several studies have incorporated geospatial techniques into working with bathymetric

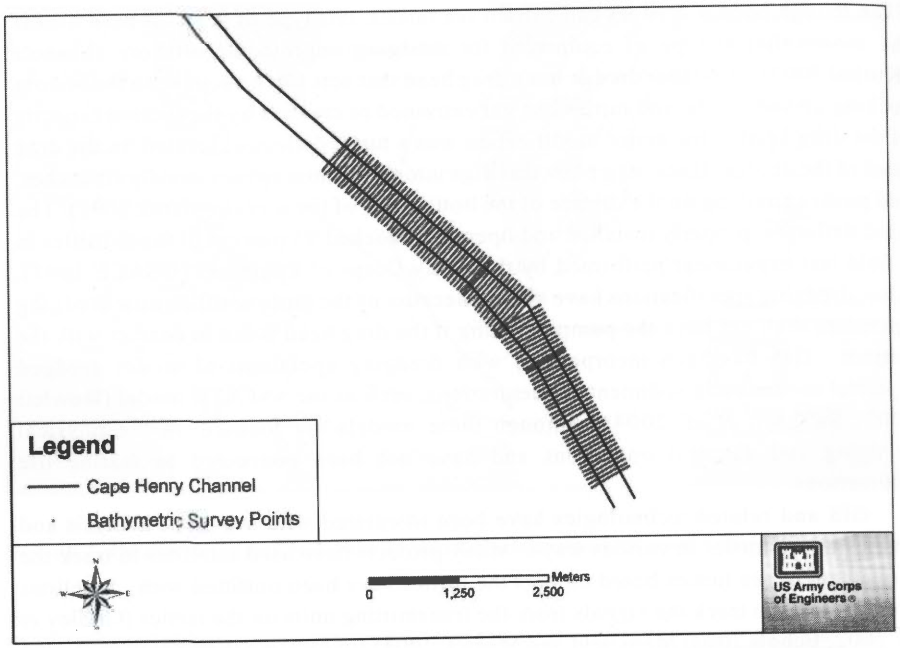

FIGURE 4. The locations of the survey depth sample points for Cape Henry Channel

surfaces to aid in analysis including Pang *et al.*'s (2003) use of a linear interpolation method to create a bathymetric surface, Guitton and Claerbont's (2004) methods for reducing noise in bathymetric data, and Kozlenko and Jeffries (2000) utilization of remotely sensed SAR (synthetic aperture radar) images to produce bathymetric surfaces. Gesch and Wilson (2002) and Parker *et al.* (2001) discuss the use of blending gridded datasets of different elevation surfaces from both bathymetry and topography together.

The project described in this study utilized a series of bathymetric measurements gathered by regular Army Corps of Engineers surveys performed on all navigation channels at various times throughout the year, which record the depth of sections of the channel. The location and depth data for sea turtle incidental takes was gathered at continuous time intervals by Silent Inspector software onboard the dredges, which were in turn supplemented by observer reports for the trawlers. This point data was transferred to CAD (Computer Aided Design) drawings that were merged together creating into a single GIS shapefile for the sections of the channels being studied (Figure 4), while other shapefiles were created to show the best available spatial data representing the turtles that were captured by both dredges and trawlers.

A notable element unrecorded by the surveys is the bathymetric depth for the turtle take reading. To aid in accounting for this, ArcGIS interpolation methods were used to create the bathymetric surface of the channels (which were then fashioned into 3D representations). These processes use points with known values (i.e. the readings of bottom elevation from the surveys) to estimate values at other points (for which survey

information was not collected), and to create a surface that shows a visual representation of what a channel looks like underwater. Interpolation methods are commonly utilized to create bathymetric surfaces for use in GIS analysis and several are available for use in ArcGIS with its 3D Analyst extension. These methods calculate values for the unknown locations based upon known values, thus creating an elevation surface from a sampling of points (Bratt and Booth 2004). The goal of this paper is to demonstrate the usefulness of the interpolation methods of ArcGIS for visualization purposes, not to provide a methodological examination of the methods, nor to delve into the mathematics behind them (see Isaaks and Srivastava 1989 for an excellent reference on geostatistical methods).

ArcGIS allows the creation of surfaces as TINs (Triangulated Irregular Networks), a surface generation method which takes the points as the source of elevation / depth values and interpolates the faces that make up the surface between the points (Bratt and Booth 2004). TINs have been utilized in bathymetric surface generation (Zhang and Yang 2006; Johnston 2003; Byrnes *et al.* 2002), especially when depth values are unevenly distributed across the area (Byrnes *et al.* 2002).

ArcGIS gives the user several other interpolation options for use in creating a surface from a series of points. The first of these is Inverse Distance Weighting (IDW) a process that assumes that those known values closer in distance to the unknown point are weighted heavier in determining the unknown value than those points further away (Bratt and Booth 2004). A second method is Kriging (Isaaks and Srivastava 1989; Johnston 2003), a process used to fit a model to the data based not only the distance between the points but also the spatial arrangement among the known points (McCoy and Johnston 2001). This modeling of spatial dependence comes in the form of a semivariogram (Johnston *et al.* 2001). With Kriging, a semivariogram is used to examine the fit of the points to the model, and three values used to fit this semivariogram: range (limit of spatial dependence), sill (the value at which the range is reached), and the nugget (the value for the semivariance when the distance is zero). Using these variables, the semivariogram can be fit to the data and the weights for each unknown point can be calculated (Isaaks and Srivastava 1989; Chang 2004). The form of Kriging known as Universal Kriging accounts for overriding trends (or drift) in the data by first removing the trend and then performing Kriging on the residuals.

Splines are another interpolation method suggested for use in determining elevation surfaces (Bratt and Booth 2004). The surface created through Spline methods can be conceived as bending and stretching a rubber sheet to pass through all points on the surface while trying to minimize the curvature and thus be as smooth as possible (Mitasova *et al.* 1995; Bratt and Booth 2004). Splines can take one of two forms: tensioned (where the elasticity of the surface can be controlled) and regularized (where the smoothness of the surface can be controlled) (Bratt and Booth 2004). Hargrove *et al.* (1995) successfully utilized Splines in the interpolation of a bathymetric surface, while Mitasova *et al.* (1995) used Splines to create bathymetric surfaces in conjunction with other studies of the Chesapeake Bay region.

The generated surfaces can be rendered in pseudo-3D through the use of the ArcScene tool in ArcGIS' 3D Analyst. In 3D analysis, the z-values of the surface (in this case, representing bathymetric depths) are utilized as base heights, and those base heights applied to the surface itself to create a 3D rendering of the surface (Bratt and

TABLE 1. Sample of 2002 Turtle Catches (by dredge and trawler) from Cape Henry (source: US Army Corps of Engineers, Norfolk District)

ID	Date	Time	Water Temp	Air Temp	Dredge Name	Turtle Species
37	04/24/2002	1114	57°F		Bayport	Loggerhead
38	05/13/2002	1000	66°F		Bayport	Loggerhead
39	05/18/2002	1946	65°F		Bayport	Loggerhead
40	05/23/2002	0555	61°F		Bayport	Loggerhead
41	06/01/2002	2112	71°F		Bayport	Green
42	06/04/2002	2227	70°F		Bayport	Loggerhead
61	10/26/2002	1437	65°F	64°F	Relocation Trawler	Green
62	10/26/2002	2256	65°F	64°F	Relocation Trawler	Kemp's Ridley
63	10/31/2002	1512	60°F	48°F	Relocation Trawler	Loggerhead
64	10/31/2002	1600	60°F	48°F	Relocation Trawler	Loggerhead

Booth 2004). The survey values were multiplied by a value of -1 to create negative numbers to that the vertical depth of the channel areas could be properly viewed in 3D.

RESULTS

A sample of the turtle take information from the 2002 dredging and trawling operations in Cape Henry Channel is presented in Table 1. Note that the information in these tables provides basic information as to the time, temperature, and species of turtle (where this information is available). The ten turtle catches listed in the table are represented in the bathymetry model of the Cape Henry Channel.

Unfortunately, the exact locations of the actual turtle take cannot be determined as the turtles are discovered at the end of a dredge or trawl transect. To maintain consistency, the locations of turtle takes are recorded at the end of the transect where the turtle was observed entrained by a dredge, or caught in a trawler. While this does not provide the exact location of the turtle capture, it provides the best available approximation of the location.

Six versions of the bathymetry of Cape Henry Channel were created using a variety of different methods from the ArcGIS 3D Analyst: IDW, Ordinary Kriging, Universal Kriging, Tensioned Splines, Regularized Splines, and a TIN (Figure 5). In order to validate which surfaces best fit the bathymetry, a source for comparison was needed. Unfortunately USACE survey contours are based on 50' contours, creating generalized maps, and thus would not provide a proper comparison. For general visual comparison purposes, USGS Digital Raster Graphics (DRGs) showing the bathymetry of the areas were used in comparing sections of the generated surfaces to available sections of the bathymetric contours shown on the DRGs. While no surface was a match for the generalized contour profile represented by the DRGs, the Ordinary Kriging, Tensioned Splines, IDW, and TIN surfaces better approximated selected sections of the contours

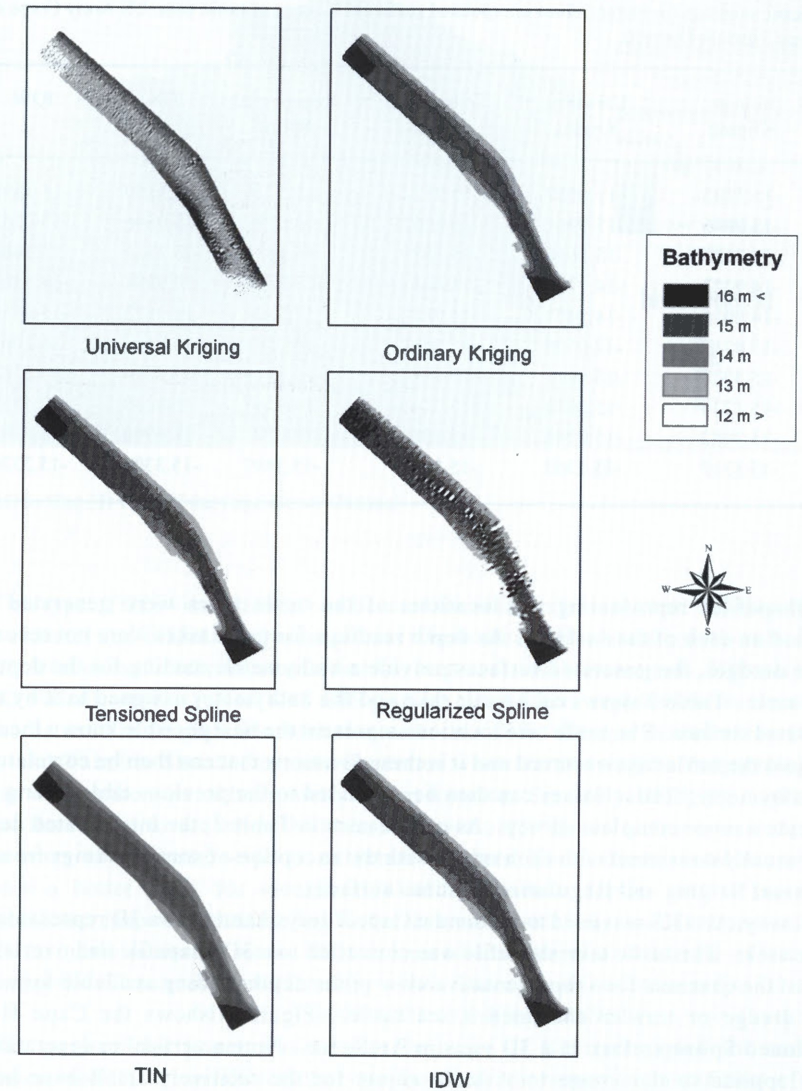

FIGURE 5. The Cape Henry Channel bathymetry created through several GIS methods

than the other surfaces. Possibly due to the spatial arrangement and distribution of the survey points, the Universal Kriging and Regularized Splines generated surfaces inconsistent with the others that did not provide an approximation of the DRG contours. However, as Table 2 shows, all surfaces generated similar values for bathymetry in relation to the turtle take locations, with few deviations.

TABLE 2. Sample of 2002 Turtle Catches (by dredge and trawler) from Cape Henry matched against bathymetric readings (in meters) from interpolated surfaces (source of turtle data: US Army Corps of Engineers, Norfolk District)

ID	Ordinary Kriging	Universal Kriging	Tensioned Spline	Regularized Spline	TIN	IDW
37	-15.3293	-15.6929	-15.3522	-15.5716	-15.3180	-15.3397
38	-15.0846	-15.0961	-15.0251	-15.0199	-15.0346	-15.0562
39	-15.3125	-15.2656	-15.2525	-15.1086	-15.2714	-15.3461
40	-14.9227	-14.9794	-14.8813	-13.9836	-14.9398	-14.8361
41	-14.8916	-14.9401	-14.9812	-14.9824	-14.9873	-15.0468
42	-15.0711	-12.0506	-15.0687	-15.2741	-15.0763	-15.1007
61	-15.3028	-15.3473	-15.3580	-15.1568	-15.3714	-15.3363
62	-15.1236	-15.2613	-15.0745	-14.9547	-15.1239	-15.3385
63	-15.7182	-15.8246	-15.7082	-16.0291	-15.6740	-15.8191
64	-15.3317	-15.3363	-15.3452	-15.3497	-15.3305	-15.3330

Shapefiles representing the locations of the turtle takes were generated and overlaid on each of the surfaces. As depth readings for turtle takes were not recorded by the dredges, the generated surfaces provide a bathymetric reading for the depth of each turtle. Table 2 shows each turtle take and the bathymetry assigned to it by each generated surface. The turtle take locations represent the best possible known location of where the turtle take occurred and it is these locations that can then be correlated to the bathymetry. These values can then be appended to the previous tables using GIS to create a more complete survey. As can be seen in Table 2, the interpolated depths were usually consistent with each other, with the exception of some readings from the Universal Kriging and Regularized Splines surfaces.

Lastly, ArcGIS was used to render the Cape Henry channel for a 3D representation of the area. The turtle take shapefile was converted to a 3D shapefile and overlaid in each of the channels for a representative view of the depth reading available for where each dredge or trawler entrained a sea turtle. Figure 6 shows the Cape Henry Tensioned Spline surface in a 3D view in ArcScene. Note a vertical exaggeration of 75 is applied to the image to visually adjust for the relatively small base height differences in the channels.

The same processes were applied to construct an interpolated surface and 3D visualization of the Thimble Shoals area to demonstrate the usefulness of the data and methods. Although no turtle takes occurred in this particular section of the Thimble Shoals channel during the 2003 survey, turtles have historically been entrained in the area as well as other portions of the channel. Figure 7 shows the locations of the survey points for Thimble Shoals Channel, while Figure 8 shows a section of the 3D view of Thimble Shoals (generated from the Tensioned Spline surface).

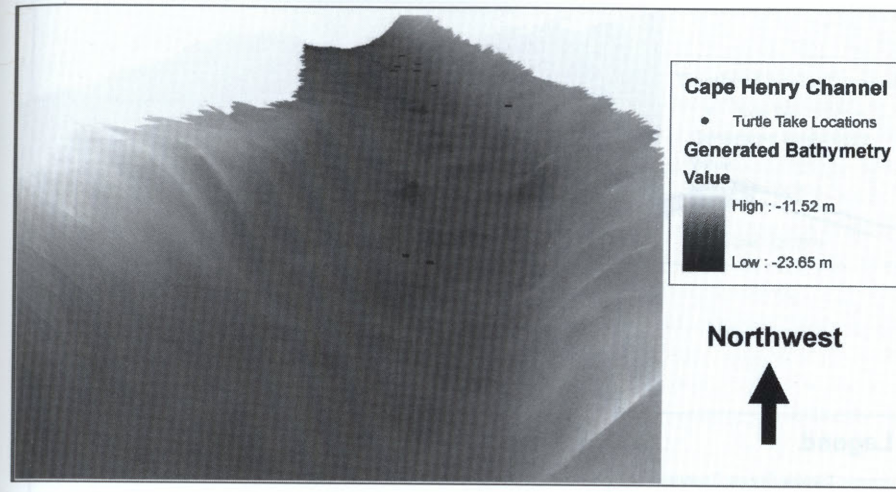

FIGURE 6. The 3D view of the Cape Henry Channel

This type of GIS visualization can be used for creation of real-time "fly-throughs" of the channel and is ideal for presentations where areas of a channel, such as bottom irregularities or turtle take locations, need to be more closely examined. The surfaces and 3D visualizations created with GIS provide researchers supplementary data and tools to be used in conjunction with the turtle take data. First, a model of the Cape Henry and Thimble Shoals channels illustrates where turtles may be frequenting an area, as well as the type of bathymetry at that location. Secondly, dredging engineers can use the results to see where historical interactions with sea turtles occurred, and design ways to minimize impacts on future projects. The 3-dimensional modeling provides a better basis for visualization of the bottom depths than a standard 2-dimensional map would, enabling better examination of the surface bottom with relation to turtle mortality sites. This enhanced visualization would be of use for examining the format of the bathymetry rather than a regular contour map.

DISCUSSION AND CONCLUSIONS

The goal of this paper was to provide a set of GIS techniques for surface generation and 3D visualization that can be used for better understanding of the relationship between turtles and dredging, as well as to act as a basis for future projects. GIS can be used as a way to store, manipulate, analyze, and visualize information related to coastal issues, and its importance is realized in this project. GIS has been used to incorporate transcribing the information from reports into a database and further analysis of the relationship between sea turtles and hopper- dredging operations results from these uses of GIS. For example, prior to Fall 2002, observer and trawling reports documenting sea turtle incidents in the Chesapeake Bay navigation channels were bound in hard copy reports. These reports were often tedious to analyze and use, and therefore filed away. Storing the data in a GIS database allows engineers and

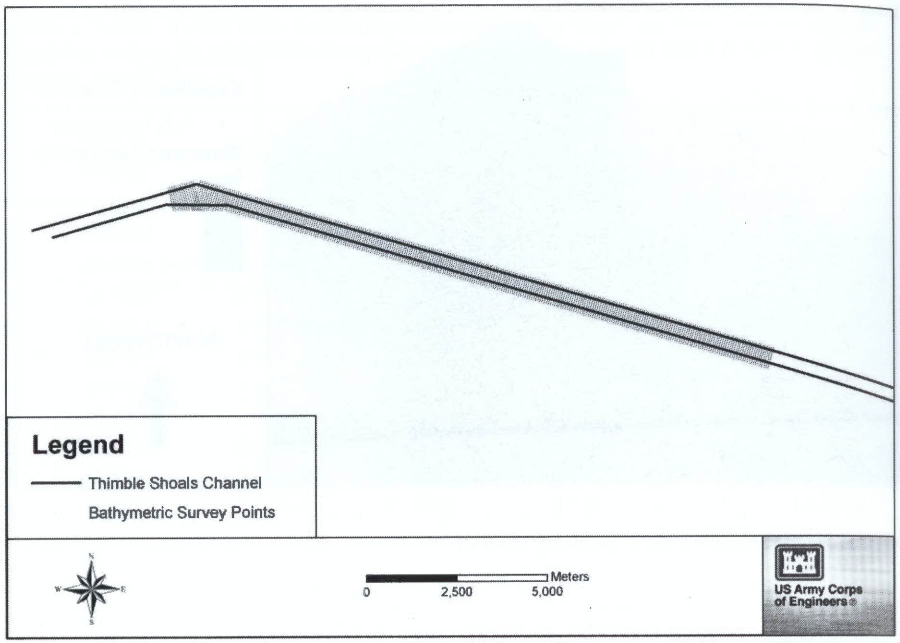

FIGURE 7. The locations of the survey depth sample points for Thimble Shoals Channel

scientists to use the information to discover trends and make better decisions. Once all the information representing important factors has been recorded, GIS can be used to manipulate the data in a multitude of ways.

For the Cape Henry / Thimble Shoals project, the main objective was to use GIS to create a visualization of the channels with the sea turtle incidents overlaid. The Thimble Shoals project provides a better realization than the Cape Henry project due to the increase in data accuracy. For the Cape Henry project, data used was collected before the project began, while for the Thimble Shoals project, data was collected in an ongoing fashion; thus data quality could be immediately checked and any errors could be corrected.

The project performed for the Cape Henry channel in 2002, and refined for the Thimble Shoals channel in 2003, can be used as a template for future projects that looks at certain trends that the model may suggest. A visualization model provides opportunities to present valuable information that cannot be depicted through hard-copy reports. Other modeling efforts examining benthic habitats (Bjorgo *et al.* 2001) note that the 3-dimensional imagery serves as a useful tool for management and analysis. All the necessary information for each sea turtle incident is stored in a database with a direct feed to the GIS project. In addition, steps can be taken to narrow down areas in the models that should be given a closer look. For instance, if a shoal forms in the Thimble Shoals channel, then that section of the channel needs dredging. In order to understand the history of sea turtle incidents in that area, with complementing factors such as water temperature, location, date, and tide, the GIS can

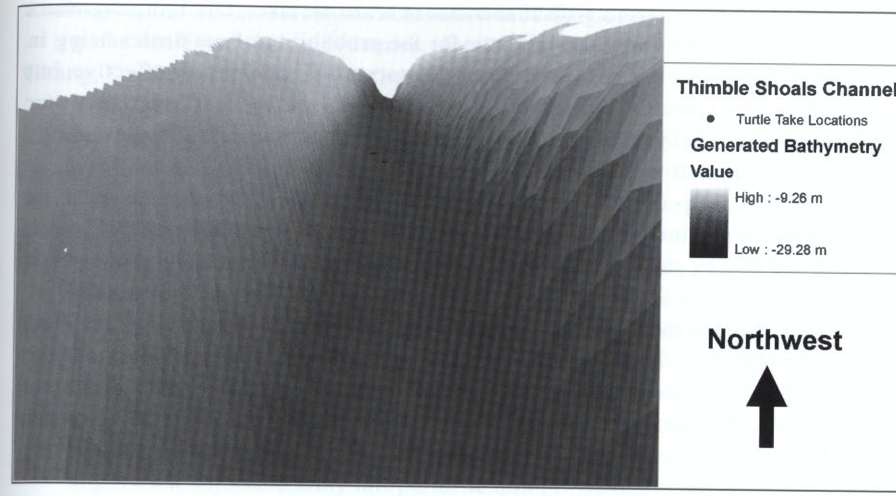

FIGURE 8. A 3D view of the Thimble Shoals Channel.

be used to focus on the shoaled section of the channel. This will increase the efficiency of discovering useful trends, and provide for more effective decision-making. However, since neither relocation trawling nor dredging occurred continuously throughout the project, gaps remain in the data. Therefore, certain trends or assumptions based on why, where, or when sea turtles were captured cannot be conclusive, instead they should act as red flags for more intensive study.

The interpolated surfaces and 3D models created in this project can be used as a platform for future studies in applications of GIS to the sea turtle mortality problem. For example, Mansfield *et al.* (2001) identified that water temperature and time of year are important independent factors that can be used to predict the probability of sea turtles using certain areas. Future applications of the techniques presented in this project can move further forward by manipulating the water temperatures recorded for the sea turtle incidents. A more specific temperature range or trend could be established in conjunction with bathymetry, and used when scheduling dredging projects.

Also, a factor that has been recorded, but not yet studied with intensity, is the forage base, or food source, for sea turtles. In the Thimble Shoals study, prioritizing the criteria recorded, such as putting more focus on bycatch (the biological material or organisms that are caught during the trawling haul or dredging cycle) numbers, would allow for more factors to be analyzed in connection with sea turtle takes. On each trawling and dredging report, observers record the amount and type of bycatch. Sea turtles may be using an area due to food availability, such as blue crabs (Calinectes sapidus) and horseshoe crabs (Limulus polyphemus). Recording the numbers of crabs caught could end up having a positive relationship with the number of sea turtle incidents in the area. It is known that sea turtles forage on blue crabs, horseshoe crabs, and channel and knobbed whelk (Busycon canaliculatum; Busycon caricas) (Seney 2003; Seney and Musick 2005). Therefore, creating a surface of sea turtle food source bycatch could potentially produce a positive trend. This trend may prove that increases in food source bycatch correlate with an increase in sea turtle takes. Dredging engineers could then use bycatch as another indicator for the probability of sea turtles being in the area. The use of just one of the various indicators would not be very effective, but by combining the various indicators, such as food source, bathymetry, water temperature, and time of year in a GIS, a solid probability portraying sea turtle use may be extremely useful and valid.

Ultimately, this project is an example of the type of work that must be accomplished in order for us to utilize our natural resources without adversely affecting them. The use of GIS and the related interpolation and visualization techniques have numerous applications far beyond modeling turtle habitats and mortalities and are certainly not limited to them. These types of tools have a broad scope and applicability to a host of problems. This project incorporates many methods together under the umbrella of GIS (database management, surface modeling, and 3D visualization) and through combining these methods in GIS, their functionality becomes greatly increased.

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