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Tidal Inlet Shoal and Channel Change Analysis from Aerial Imagery Using *Inlet, Nearshore, and Littoral Enhancement Tool for Geographic Information Systems* (*INLETGIS*)

by Kenneth J. Connell and Gary A. Zarillo

PURPOSE: The Coastal and Hydraulics Engineering Technical Note (CHETN) herein presents *Inlet, Nearshore, and Littoral Enhancement Tool for Geographic Information Systems* (*INLETGIS*) and describes a methodology for an objective, rapid inlet shoal and channel analysis through classification schemes using aerial photography and the *INLETGIS* extension for ArcView™ 3.x Geographic Information System (GIS).

BACKGROUND: Maintenance of tidal inlets and tidal inlet channels has always been a costly and time-consuming activity dependent upon condition surveys. Barriers to inlet maintenance include budget restrictions, weather, sea-state conditions, permit restrictions, and highly dynamic processes. These factors make planning and design of maintenance projects difficult. However, dredging and reconstruction of inlets are necessary burdens at many sites for purposes of commercial, recreational, and defense navigation, as well as shoreline and habitat preservation. Digital image analysis of aerial photography is a tool that is currently under-utilized in examining tidal inlet dynamics. Remote sensing techniques for such imagery have been developed and are applied herein to two inlets on Long Island, NY, to analyze channel and shoal dynamics. A classification scheme using spectral reflectance pattern recognition (Figure 1) is applied to the water and shoal portions of a digital historical photoset of Shinnecock and Moriches Inlets in New York to determine where channels, sub-tidal shoals, inter-tidal shoals, and super-tidal shoals spatially occur in the image. Once a classification scheme has been created, temporal pattern recognition from one photograph to the next photograph in time may also be used to analyze changes in channeling and shoaling. The *INLETGIS* extension to ArcView™ 3.x was developed to facilitate this process by providing a set of tools which automate many of the steps involved in shoal and channel change analysis using aerial imagery. The result is a tool package that provides rapid data turn-around, less subjectivity, and a gentle learning curve, thus catering to users with a broad range of scientific and engineering backgrounds in need of a rapid, objective image analysis tool.

Some possible applications for applying a classification method like the one presented in this Technical Note include:

a. Rapid assessment of conditions present at the time the aerial photograph was taken.
b. Historical change analysis.
c. Shoal movement.
d. Channel migration analysis.
e. Area calculations of shoals and channels.
f. Sediment budget analysis.
g. Determination of erosion or accretion "hot spots."

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14. ABSTRACT
This Coastal and Hydraulics Engineering Technnical Note (ERDC/CHETN) presents the Inlet, Nearshore, and Littoral Enhancement Tool for Geographic Information Systems (INLETGIS) and describes a methodology for an objective, rapid inlet shoal and channel analysis through classification schemes using aerial photography and the INLETGIS extension for ArcView 3.x Geographic Information System (GIS).

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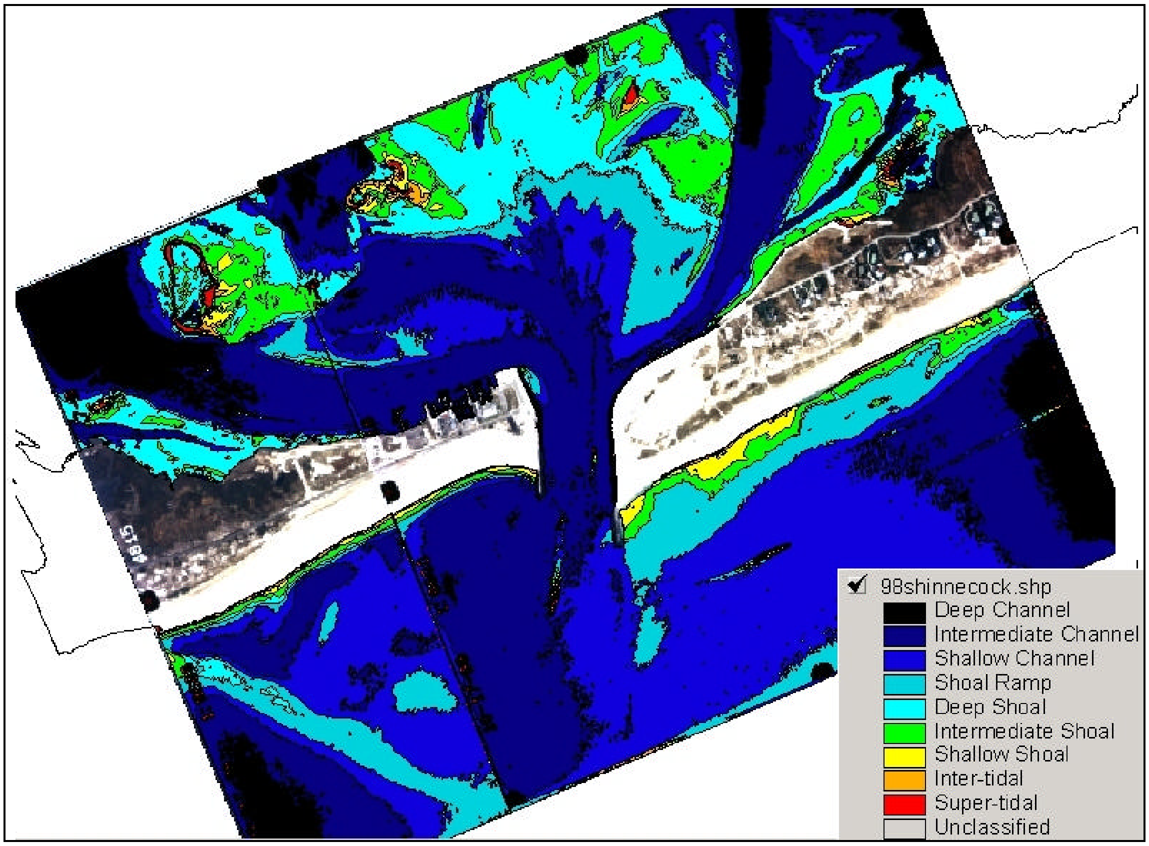


Figure 1. Classification scheme showing shoals and channels

The primary benefit from using these remote sensing techniques is after the initial set-up, these methods provide rapid analysis of inlet dynamics, while remaining much more objective than traditional channel and shoal classification by "eye". Although these methods are site specific, adjustments to the spectral response classification may be made to incorporate other tidal inlets. Implementation of these remote sensing techniques could lead to improvements in planning, design, and maintenance of tidal inlets in order to optimize channeling and shoaling for efficient sand transfer while minimizing shoreline erosion due to the scouring effects of water currents.

INSTALLING *INLETGIS*

The installation of *INLETGIS* is identical to that of most other ArcView™ 3.x extensions. The file *INLETGIS*.avx must first be placed in the ArcView™ extension directory (windows default path is: $\ESRI\AV_GIS30\ARCVIEW\EXT32). Then, under the *FILE* menu in ArcView™, select *Extensions*, check the box next to *INLETGIS*, and click the *OK* button. One important step to note in the installation process is that the ArcView™ ImageAnalysis™ extension must be installed before *INLETGIS* is installed. This is necessary because *INLETGIS* expands upon the capabilities of ImageAnalysis™ and utilizes many of ImageAnalysis'™ features. Once the *INLETGIS* extension is installed and loaded into ArcView™, the *INLET* menu and four *INLETGIS* buttons are present in all ArcView™ View documents as shown in Figure 2.

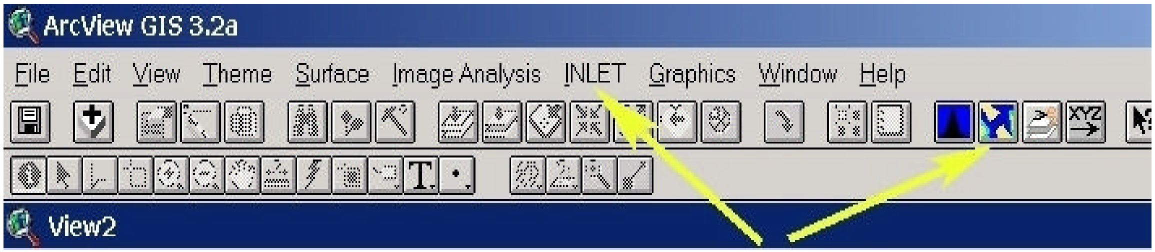


Figure 2. The menu and buttons added to the ArcView™ interface when the *INLETGIS* extension is loaded

METHODS FOR SHOAL AND CHANNEL ANALYSIS

In the following section, the methods employed in order to conduct the inlet morphology analysis are outlined in detail. The steps are organized in sequential order, although not all steps are necessary in every case. One must first determine what specific end product is desired before conducting the steps, as certain steps may be altered for different types of analyses. In all cases ArcView ImageAnalysis™ extension package must be installed along with ArcView GIS 3.x in order to conduct the following methods (Note: as of the date of this technical note publication, the *INLETGIS* extension has not been developed for ArcView 8.x, therefore it is necessary to use ArcView 3.x in order to conduct the analyses discussed herein).

Aerial Image Rectification

In order to use an aerial image for any kind of spatial analysis, one must first place the image into a known coordinate system. This is achieved by referencing pixels in the image that represent a known stationary location to known, and preferably "real-world" coordinates for that location. Pixels may be referenced to entered coordinates, control points on rectified engineering drawings, or to control pixels in other previously georeferenced images. With enough control points are spread out throughout the image, a fairly accurate image rectification may be attained using the ImageAnalysis™ align tool, which uses a process known as "digital rubber-sheeting" to place an image into a map coordinate system. If a more advanced rectification is desired, a photogrammetrist should be consulted. The following steps may be used as a guideline for using the align tool in ArcView™'s ImageAnalysis™ package. Please consult the ArcView™ ImageAnalysis™ *Align* tool help files for further information on image rectification.

1. Add a theme, making sure to select image analysis data source as the data source type.

2. If control point map coordinates are available, click the align tool button , which will change the cursor into a cross hair. Then, simply click on the pixel that needs to be referenced to the control point, right-click to bring up the *Align*

menu and select *Enter To Coordinate*. When the coordinate window opens, manually enter in the X and Y control coordinates and click the *OK* button.

3. If the control point coordinates are not available for manual data entry, add another theme containing either a referenced drawing or a referenced image.

4. Make the image analysis theme being rectified current, active, and on the top layer.

5. Click the align tool button  again, this should change the cursor into a cross hair. This will also move the un-rectified image into the same vicinity as the georeferenced image.

6. Click on a pixel in the un-rectified image to be referenced to a control point on the rectified image. Next, right-click on the view to bring up the *Align* menu and select *Image to Bottom*, which sends the current image to the bottom layer so that the georeferenced image is visible. Finally, click on the pixel or drawing point that represents the control point in the georeferenced image.

7. The control points should cover as much distance in the image as possible with as many control points as possible. A minimum of four control point pairs is necessary to generate a root mean squared (RMS) error analysis, which is displayed on the status bar at the bottom of the screen. The idea is to make the RMS error as low as possible for best possible rectification.

8. Once the image is rectified, simply go under the *Theme* menu and click on *Save Image As…*in order to save the newly rectified image as an ERDAS Imagine image (*.img), a GeoTIFF (*.tif), or an ArcView grid (*.rrd).

Image Analysis

After the aerial imagery has been rectified to a known coordinate system, the imagery may be analyzed for spectral reflectance and spatial change. The categorization routine for spectral reflectance is described below. A decision should be made as to how many categories are needed to yield the best possible results. This usually is only possible after several iterative attempts at different categorization levels. Usually between six and ten categories yields the best results. Of course, a different number could apply to a specific study.

1. Open a View document and load a rectified aerial image file as an Image Analysis Theme.

2. Under the *View* menu select *Properties* and in the properties window set the *Map Units* to match the map units of the projection used to rectify the aerial photography to. It is imperative that these units match properly. A map unit mismatch will seriously alter any calculations made from the analysis.

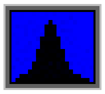


Image Histogram Stretch

1. Make the image visible by checking the box next to the file name in the table of contents and make it active by selecting the image theme in the table of contents.

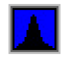
2. Click the *INLETGIS Histogram Stretch* button  to display the histogram stretch control window (Figure 3). Alternatively, this window may be opened by selecting *Image Histogram Stretch* under the *INLET* menu. This control window consists of seven buttons that represent different methods of image histogram stretches. Histogram stretching is a method of changing the contrast of an image by adjusting the number of pixel spectral intensity values in each value bin (from 0 to 255) of the image's spectral reflectance intensity histogram. The seven methods used here are described below. See the ImageAnalysis™ Help files in ArcView™ for further explanation of each method:

Figure 3. Histogram stretch control window

a. *Gaussian Stretch*: This method distributes the spectral values across the entire spectrum to form a normal curve in the data density bins and an S-shaped cumulative distribution curve. This method is one of the better methods for quickly bringing out the location of sandy shoals in an image.

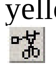
b. *Equalize Stretch*: This method is similar to the Gaussian method. It examines at the original input histogram and redistributes those values across the bin spectrum, while retaining a similar histogram shape.

c. *Gamma Stretch*: This stretch creates a parabolic curve on the cumulative distribution curve.

d. *Level Slice*: This method applies a stair-step shape to the cumulative distribution curve. *INLETGIS* selects twenty steps on the first click of this button, then decreases the number of steps by one each time the button is pressed thereafter. Once the *Level Slice* button is pressed twenty times, the very high contrast image can no longer be level sliced.

e. *Standard Deviations Stretch*: This method assumes that the image histogram starts as a normal curve and moves the pixel values to a distance away from the mean values. INLETGIS moves the values one standard deviation away from the mean producing a fairly high contrast image.

f. *NONE*: Depressing this button returns the image to its original state before any histogram stretches were applied.

g. *Custom Stretch*: This button allows more advanced users to customize the histogram stretch to their own preferences. Pressing the *Custom Stretch* button opens up the advanced histogram options window (Figure 4), where breakpoints on the cumulative curve may be moved to the desired position by using the pointer tool  and selecting breakpoints, added by clicking on the add breakpoint tool  and clicking on the yellow cumulative curve, or removed by clicking on the remove breakpoint tool  and selecting the breakpoints desired for removal.

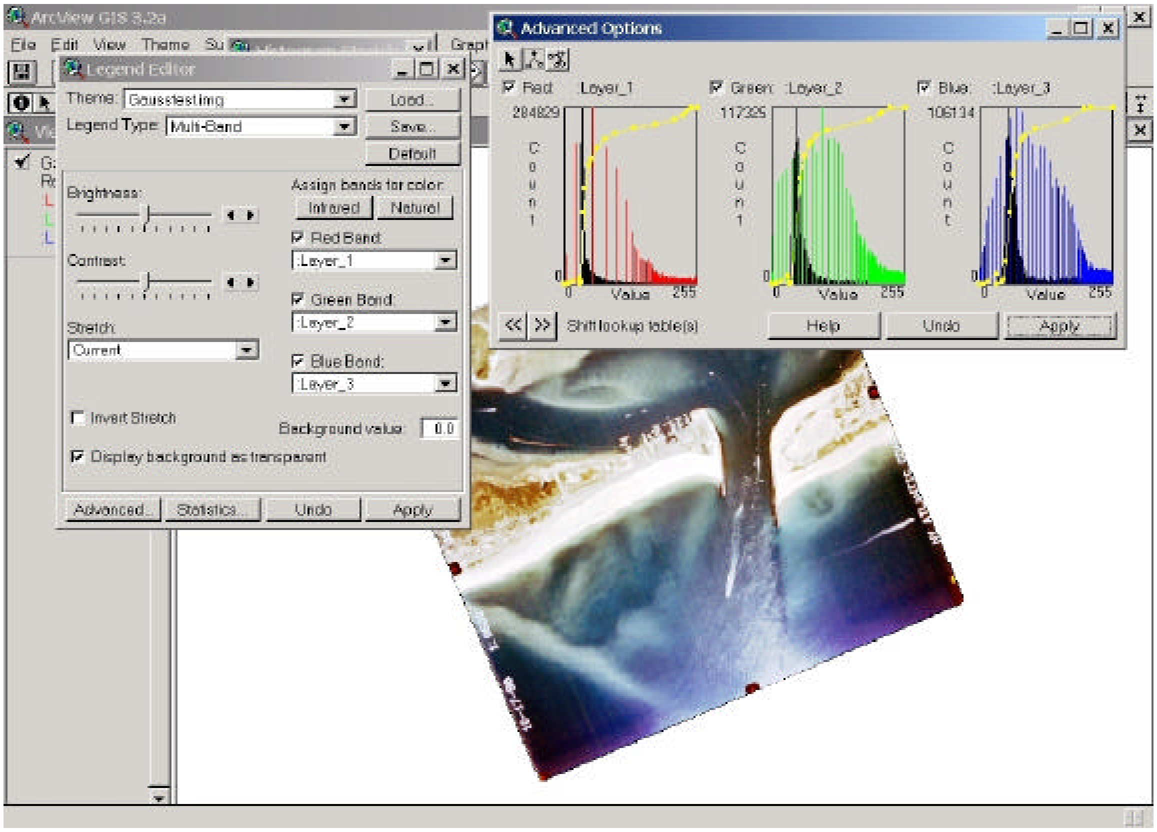


Figure 4. The custom histogram stretch window for advanced histogram stretches

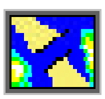


Image Classification

1. Once a sufficient histogram stretch has been achieved, click the INLETGIS *Image Classification* button  to open the *Select Classification Method* window (Figure 5). Alternatively, this window may be opened by selecting *Classify INLET* under the *INLET* menu.

2. The *Select Classification Method* window (Figure 5) controls the type of classification desired. INLETGIS supports the Unsupervised Classification method. However, the Supervised Classification method, which requires the user to select pixels of similar values to the area being classified, is supported by the BeachTools extension, which is covered in another CHETN (Hoeke et al. 2001). In order for the *Supervised Classification* button to work, BeachTools extension must be installed and loaded into ArcView™. The classification described in this CHETN will only cover the Unsupervised method. Make the image theme active, and click on the *Unsupervised Classification* button to continue with the INLETGIS image classification, which opens the *Number of Classes* window (Figure 6).

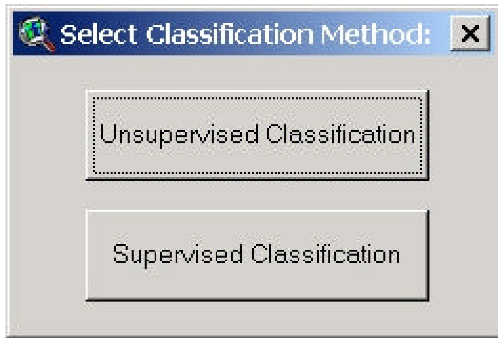


Figure 5. Classification method control window

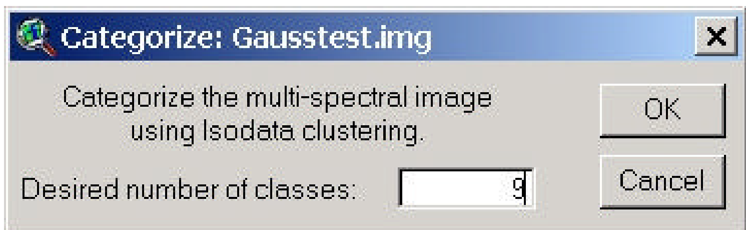


Figure 6. This window is where the user enters the desired number of classification categories

3. The *Number of Classes* window (Figure 6) is where the user inputs the number of feature classification categories desired in the image. Type a number in the box and click on the *OK* button to continue with the classification.

4. At this point INLETGIS performs the image classification, smoothes the results, and converts the resulting theme to a shapefile. Should the user prefer different classification colors or names, the legend editor will appear after this step (Figure 7). Consult ArcView™ Help on how to use the legend editor.

5. Once the image has been classified, various spatial and temporal analyses may be performed to fit the user's specific needs. Spatial calculations, such as area, may be made in the classified shapefile's theme table. Change over timescale historical photosets may be made using the *Thematic Change* option under the *Image Analysis* menu.

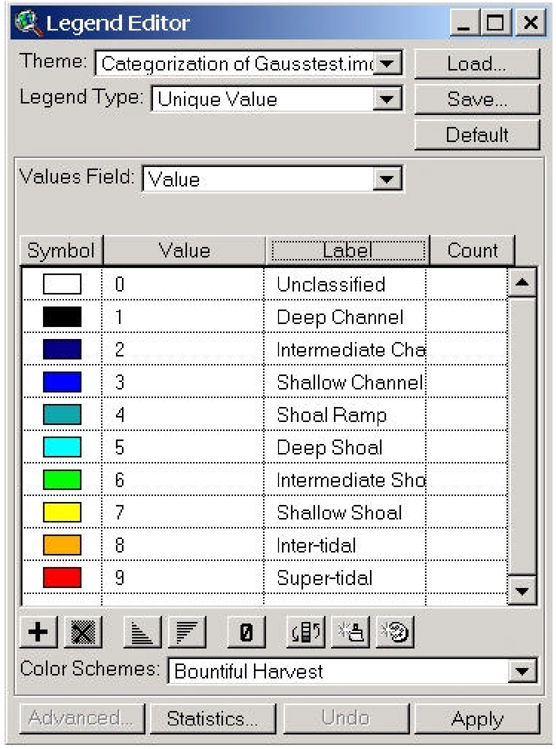
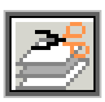


Figure 7. The Legend Editor appears after classification, which allows further customization of the shapefile



Shoreline Extraction

The spectral response from pixels representing the shoreline will be included in any quantified aerial image analysis. Therefore, if an analysis of just areas covered by water or shoals is desired, the shoreline and land classes must be extracted from the classification scheme. The simplest and most precise method of shoreline extraction would be to import a surveyed shoreline polygon and use that polygon to clip out all landward classes. A survey is not always available, and a set of methods to remove shoreline classes through spectral analysis is discussed below.

1. Under the *Image Analysis* menu select seed tool properties and select a low value for the seed tool radius (5 or less pixels) and uncheck the box in front of "Include Island Polygons".

2. Make sure the image theme is active, and click on the seed tool button . Use the seed tool to select pixels on the image that represent spectral values similar to other pixels in the shoreline or land regions. This tool will make polygons around regions of similar spectral signature. Continue creating polygons with the seed tool until the majority of the shoreline is represented.

3. Make a new theme by selecting *New Theme* under the *View* menu.

4. Copy polygons from the image theme by selecting the polygons, then selecting *Copy Graphics* under the *Edit* menu. Then, make the new theme active and select *Paste* under the *Edit* menu to paste the polygons into the new theme.

5. Use the append polygon tool  to connect all the shoreline polygons. If there are any edges that need to be extended or shortened, use the select vertices tool  to stretch the polygon.

6. Use the pointer tool  to select all polygons.

7. Under the *Edit* menu, select *Union Features* to create one large feature of landmass.

8. Save the theme as a in the desired directory by selecting *Save Edits As* under the *Theme* menu, then select *Stop Editing* under the *Theme* menu.

9. Make both the new shoreline theme and the INLETGIS classification theme active by selecting each theme in the table of contents while holding the shift key.

   To remove the shoreline data, click the INLETGIS *Clip Theme* button  and select *Keep Features Outside Shoreline*.

Category Isolation and Extraction

There are often cases where one specific category or portion of an image is to be examined in detail. For instance, perhaps a study is to be conducted on how a shoal or a channel changes shape and size over the time domain of an historical aerial photoset. In these cases it is best to isolate these categories or areas in the image from the other categories so that a more thorough analysis may be performed. The following steps may be used to generate a theme that contains only the categories that the investigator cares to study more thoroughly.

1. Use the select feature tool  to select the categories or portions of categories desired. Hold the shift key down to select multiple regions.

2. Under the *Theme* menu, select *Convert to Shapefile….*

3. Add the shapefile to the view and make it active to view the isolated regions (Figure 8).

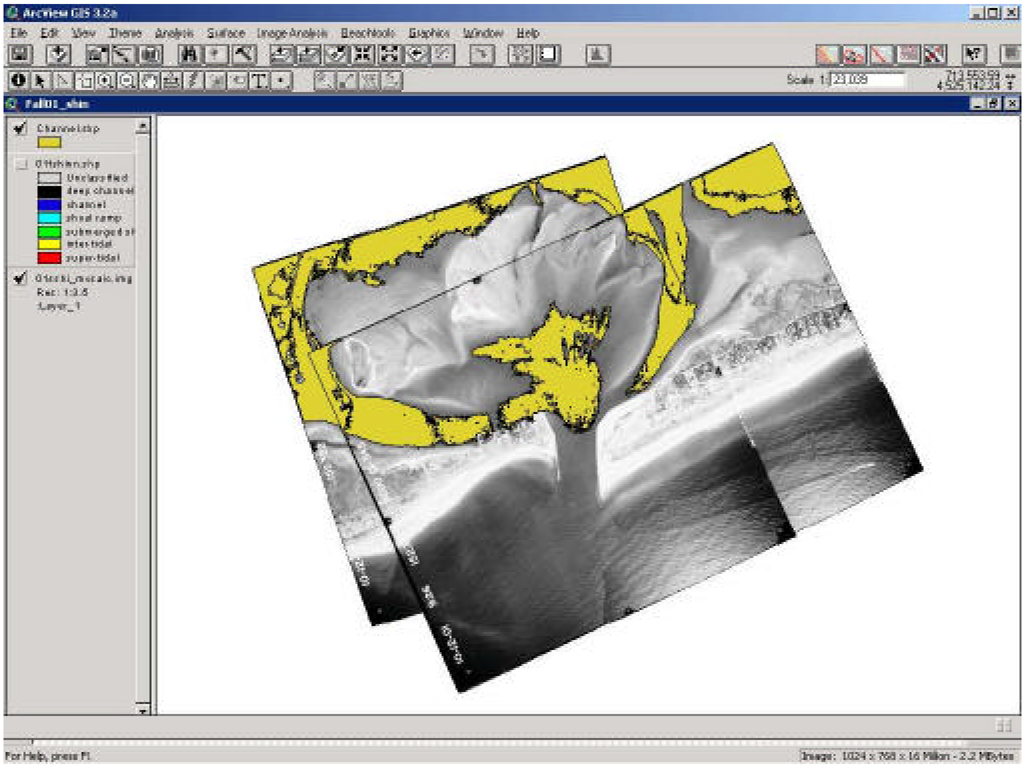
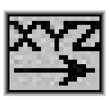


Figure 8. Example of channel isolation



Import XYZ Data

Another tool that is useful in the analysis of inlet environments are bathymetric survey data. The XYZ Import tool allows the user to easily import XYZ data from a large file for viewing and manipulation. XYZ files may be space or comma delimited.

1. Prior to selecting the *Import XYZ* button , it must be determined that the view projection matches the mapping projection of the data points. This may be accomplished by selecting *Properties* under the *View* menu and verifying by clicking the *Projection* button. If the projections do not match, change appropriately.

2. Click the INLETGIS *Import XYZ* button to select the input data file. Alternatively, this may be accessed under the *INLET* menu by selecting *Import XYZ*.

3. Select the input file and click *OK*.

4. The next window prompts the user to name an output file for the tabulated data (*.dbf). Select a directory to save the tabulated data to and select *OK*.

5. Next, the *Table Created…Continue?* window (Figure 9) pops up, prompting the user to continue to import the *.dbf file as a point event theme into the active view. This window also informs the user of the name of the newly created table (*e.g.*, Table 1). If *Yes* is selected, the import process continues and the *Table Name* window opens. If *No* is selected, the import process terminates and the user is brought to the imported table, but no new point theme will exist in the view.

6. The *Table Name* window then prompts the user to select the table he/she wishes to import to the active view. Select the desired table to import as points to the active view from the pull down list and select *OK*. This action will import a point theme representing the data points in the XYZ file into the active view (Figure 10).

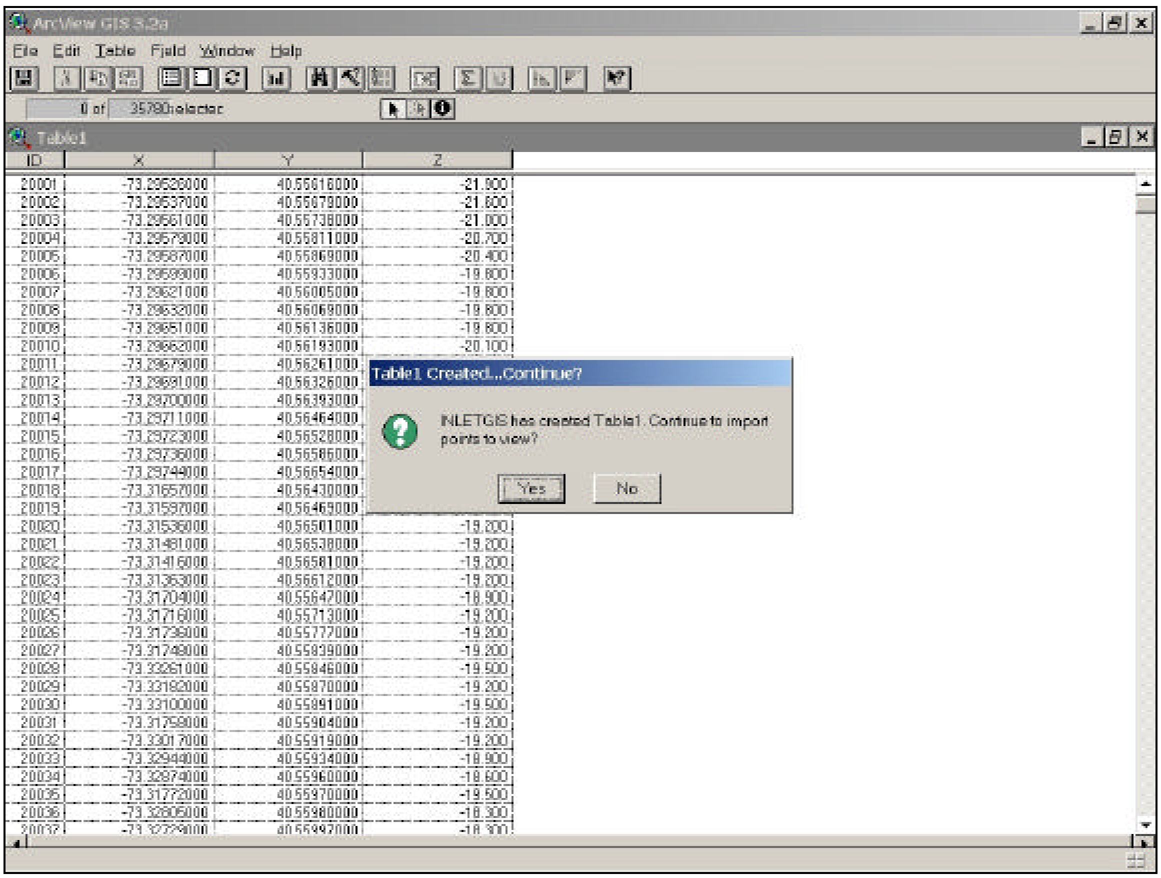


Figure 9. New table created using import XYZ data tool

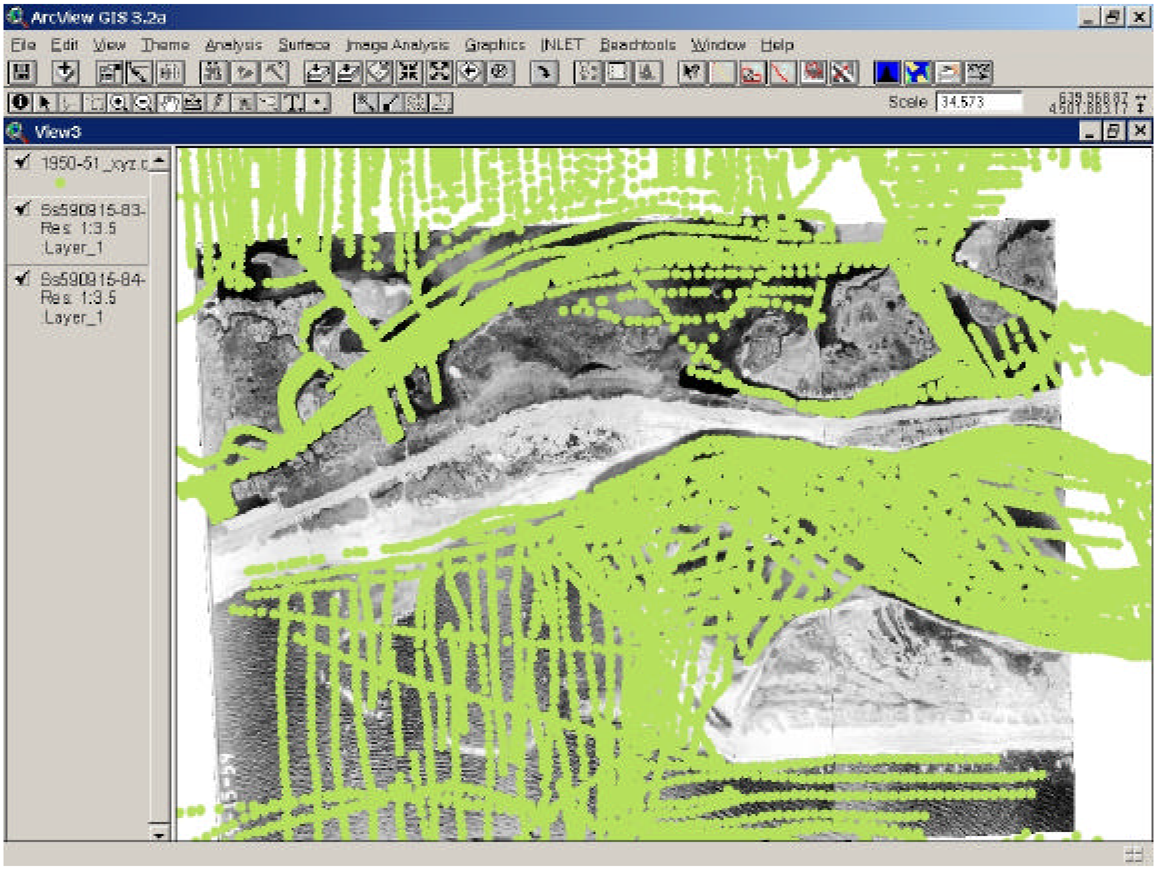


Figure 10. Example of XYZ survey data points imported into the view

Manipulation of XYZ Point Data

Many options exist for further examination of the imported XYZ data. These options were not automated due to the varied needs of custom tailoring data handling options to match site specific and project specific goals. This section of the technical note will briefly describe some common data handling practices for creating digital elevation models (DEM) in ArcView™. For more information on handling point data in ArcView™, please consult the ArcView™ manual or help files. Most of these functions are accessed under the *Surface* menu, which requires the ESRI™ 3D Analyst™ extension. The analysis extent properties and masking options are accessed under the *Analysis* menu, which requires the ESRI™ Spatial Analyst™ extension.

Interpolating a Grid

This process of data visualization involves the creation of a block of square grid cells at user-assigned cell resolution values, which represent interpolated data values generated from the point data.

1. Under the *Surface* menu, select *Interpolate Grid…*.

2. The *Output Grid Specification* window allows the user to select the output grid extent. In most cases this should be set the same as the data point theme extent. The cell resolution and block size may also be manually adjusted in this window. It is best to leave the number of columns and rows at the values given by the output grid extent. However, the output grid cell size may be adjusted to a resolution that matches the needs of the user. It is important to consider that as grid resolution is increased the computer must execute more calculations, resulting in longer processing times. After the grid specifications have been selected, click the *OK* button.

3. ArcView™ interpolates data using one of two interpolation methods: Spline and Inverse Distance Weighted (IDW). The Spline method of interpolation is best used when there are no drastic changes in elevation and when data points are somewhat evenly spaced. If drastic elevation jumps occur or if data are not evenly spaced, it is best to use the IDW method of interpolation so that excessive spline curvature errors are not introduced. The user will normally select the Z (elevation) column of data for the *Z value field.* In instances where IDW is used, the user may decide to use the *Fixed Radius* option, which limits the interpolation of the point data to within a user-defined radius of each interpolation point. This may be useful in situations where there is data on both sides of a barrier island and the user does not wish to interpolate across the barrier island. Other methods of preventing interpolation across islands are by introducing a masking theme or a break-line theme. Mask themes may be used under the *Analysis* menu under *Properties…*, and break-line themes may be used under the *Barriers* section of the IDW grid interpolation window. Further information on mask grids and break-lines may also be found in the ArcView™ help files. Finally, once all of the interpolation properties have been set, the user should select *OK* and the grid is then calculated and opened in the view as a new grid theme.

Creating a Triangulated Irregular Network (TIN)

This process of data visualization involves the creation of a surface that consists of irregular triangles linking the data points. Data is interpolated between the triangles. Mask themes may be used under the *Analysis* menu for TIN surfaces, as well as grid surfaces.

1. Next to *Surface*, select *Create TIN from Features….*

2. Next to *Height Source*, select Z (elevation) data.

3. Next to *Input as,* select Mass points.

4. Next to *Value Field,* select <none>, select *OK*.

5. The *Output TIN Name* window will appear, specify name and directory to save the output file, select *OK*.

Creating Contours

This process of data visualization involves the creation of lines of constant elevation, which may be created from the data points using methods similar to the methods used for creating a grid. Contour lines may also be rapidly computed from a grid using the following steps:

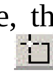
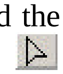
1. Select the grid theme as the current and active theme.

2. Under the *Surface* menu, select *Create Contours….*

3. Select the contour interval and base contour (i.e. starting contour).

4. Select *OK*.

5. The display properties of the contours may be altered by double-clicking on the contour theme, then selecting *Graduated Color* under *Legend Type*, and next to *Classification Field* selecting contour. Other options for changing the contour display properties exist under the *Classify* and *Color Ramps* selections in the same window.

6. To edit the contours, make the contour theme active, then select *Start Editing* under the *Theme* menu. Use the select feature tool  to select individual or multiple contour lines, and then press the delete key on the keyboard to remove selected lines. If a line is mistakenly deleted, click and hold the right mouse key and select *Undo Feature Edit*. The select vertices tool  can be used to manipulate individual vertices along the line. To save edits, select *Save Edits* or *Stop Editing* under the *Theme* menu. Select *Yes* to save edits, or *No* to reject edits. Edits can also be saved in a new file by selecting *Save Edits As*. Ensure that contour lines are not selected when ending an editing session (if selected, they will appear highlighted, or a different color than the rest of the theme).

FURTHER APPLICATIONS AND LIMITATIONS: Although this imagery analysis tool provides a rapid form of analyzing inlet dynamics, there are several limitations to the usefulness of this tool. Since this tool is based on aerial imagery, the analysis is limited to a snapshot in time and can only be correlated to the conditions present at the time represented by the image. As a result, not only the date, but also the time of the photograph must be known in order to account for changes sea level due to tides and wind. Sea level changes will, of course, affect the spectral reflectance signal due to the amount of water covering a shoal or channel. In order for a long-term geomorphologic quantification analysis to be conducted using this tool, sea level data must be known for the time of the images, and short-term changes for shoreline position between the photograph sets should be accounted for in order to significantly decrease errors (Smith and Zarillo 1990). Spectral signals are often distorted or contaminated due to the following factors: Sun glint, turbidity changes and plumes, photo exposure, and bottom composition. Breaking and refracting waves may also be another source of spectral signal contamination, although these are also good indicators of the edges of shoals (Stauble 1998). As a result, this analysis method is site specific to tidal inlets with a relatively clear and uniform water column and a relatively uniform bottom composition. Adjustments may be made to adapt the methodology to a particular site, but it is difficult to compare one site to another using this method, unless the sites are very similar with respect to water and bottom composition. Errors may also be brought into the analysis if the images are poorly georeferenced.

Despite a number of errors present in this analysis method, there are many advantages to this tool. A quick large-scale assessment of the processes in a tidal inlet may be made from these methods. These methods could potentially be used as a vital tool in the assessment of the condition of a tidal inlet shortly after a storm, as it is often easier to mobilize an aerial photo survey than it is to perform and produce a bathymetric and topographic survey in such conditions. Another advantage of this tool presents itself in the analysis of historical photosets. Shoal and channel evolution becomes very obvious when comparing photosets from the same location at different periods in time. Images may also be used from years where no bathymetric survey was conducted. These remote sensing techniques could also be used in conjunction with sediment budgets to give better insight into sand migration patterns during an existing conditions or historical conditions and may give insight into future conditions (Rosati and Kraus 1999).

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