MATERIALS AND METHODS

The commonly used methods of measuring erosion rates can be grouped into two main classes, on-site data collection and measurement from compiled historical sources. The main advantage of on-site data collection is that change rates can be measured precisely, and change over short time periods can be quantified accurately; however, this method requires significant field work and, therefore, is not well suited to research involving time constraints or large study areas. Measurement from historical sources is a process which allows the intrusion of considerable error; however, this method allows for the relatively rapid assessment of change over large areas and time spans and does not require field work other than ground truthing. Due to time and budgetary constraints and the desire to study as large an area as possible, this study used methods involving measurement from compiled historical sources.

Analysis of aerial photography, a method routinely used to analyze coastal geomorphic trends (see Cox, Wadsworth and Thomson, 2003, for a recent example), was used to measure the extent of erosion along the AICW in the southern section of the GTMNERR over the past thirty-one years. The Florida Department of Transportation (FDOT) Survey and Mapping Office provided digital versions of 1:24,000 scale, black and white aerial photography of the Flagler County portion of the study area taken in November and December of 1970 and in February of 2002. FDOT also provided 1:24,000 scale, black and white photography of the St. Johns County portion of the study area taken in April of 1971. Photography of the St. Johns County portion of the study area taken in 2002 was purchased from St. Johns County. Both sets of 2002 photography were received as digital orthophotos pre-rectified to geographic coordinate systems. All photo sets were scanned using a resolution of 2000 dots per inch to yield digital photo sets with a 0.3-meter pixel resolution. Environmental Systems Research Institute (ESRI) Arc Geographic Information System (GIS) software was used to georectify the 1970 and 1971 photos using the pre-rectified 2002 images. A minimum of 9 links was used in the rectification of each image and the mean root-mean-square (RMS) error for all rectified images was 3.3 meters. RMS error is the measure of uncertainty in geographic data promoted by the Federal Geographic Data Committee (FGDC, 2004). It is the square root of the mean squared differences in location between the data set being rectified (1970 and 1971 photography) and the established data set used as a base for rectification (2002 photography). The FGDC does not establish a specific threshold by which to judge RMS error; it instead suggest that users develop a standard threshold sufficient for the purposes of assessment related to how the data will be used.

Once photos were rectified, the channel margin in both the 2002 and the 1970/1971 photo sets were digitized to yield a digital line file. The channel margin was defined as the border of the major tidal channels of the GTMNERR. The margin should be distinguished from the edge of the navigation channel and from the channel shoreline. While the channel margin and the shoreline are often in the same location, there are also many locations in the study area where practically all of the energy generated in the channel dissipates on intertidal bars which can be over a hundred meters from dry land. When the shoreline and the channel margin were in the same place, the vegetation line was used to locate the channel margin. In unvegetated areas, margin definition was less precise. When tributary mouths or openings between dredge spoil islands intersected the channel margin, the shoreline was followed away from the main channel until the end of the white, sandy erosive zone (Fig. 4).

The methods used by Kastler and Wiberg (1996) were used to ascertain the uncertainty involved in this digitization process. Three randomly selected, vegetated, one-kilometer margin reaches were digitized three times each and the mean distance between each successive digitization was calculated. This calculation yielded a mean digitization error of 3.9 meters. This number was combined with the 3.3 meter RMS error as the square root of the two squared numbers following the methods of Gaeuman, Schmidt, and Wilcock (2003), to yield a total estimated error of 5.1 meters (Fig. 5).

While this error makes precise location of individual points difficult, it is essentially randomly distributed, so widespread changes in a single general direction are likely to be real. Additionally, this error only applies to vegetated margin types, including marsh, most dredge spoil disposal areas, and uplands. As exposure of intertidal bars varies with the tide, the degree to which they are distinguishable in aerial photographs varies depending on when the photos were taken. It was found that dead shell bars, which were significantly more common in the 2002 photographs, were much easier to discern than live oyster bars. Water margins, found in the mouths of tributaries along the channel, are also imprecise. These differences make estimation of a reliable error rate in the delineation of intertidal bar and water margins is difficult.

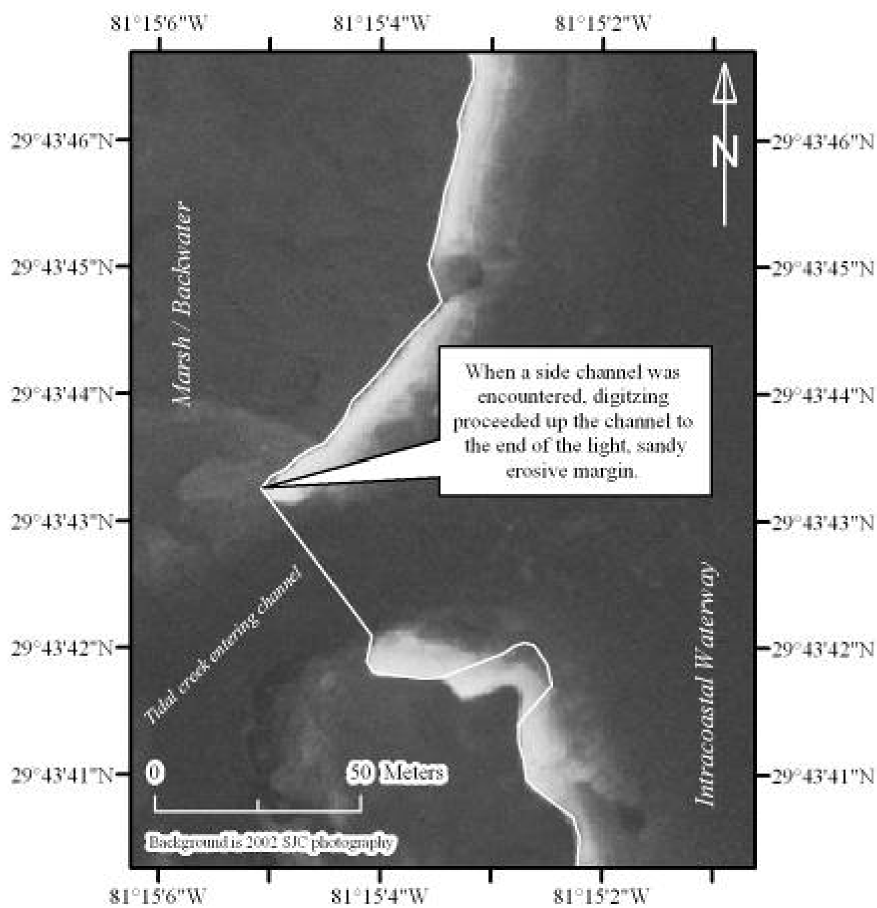

Fig. 4: Digitizing the channel margin in the vicinity of a side channel

$$\sqrt{(digitizing\_error)^2 + (RMS\_error)^2} = Total\_estimated\_error$$

$$\sqrt{(3.9)^2 + (3.3)^2} = 5.1m$$

Figure 5: Estimation of error

The channel margin lines were manually attributed as water, intertidal bars, marsh, spoil or upland by referencing the 1970/1971 photo set, as displayed in Figure 6. Where margin type was uncertain, on-site ground truthing inspections were conducted. The margin classes are subjective; however, they are good indicators of predominant sediment type and level of biological stabilization.

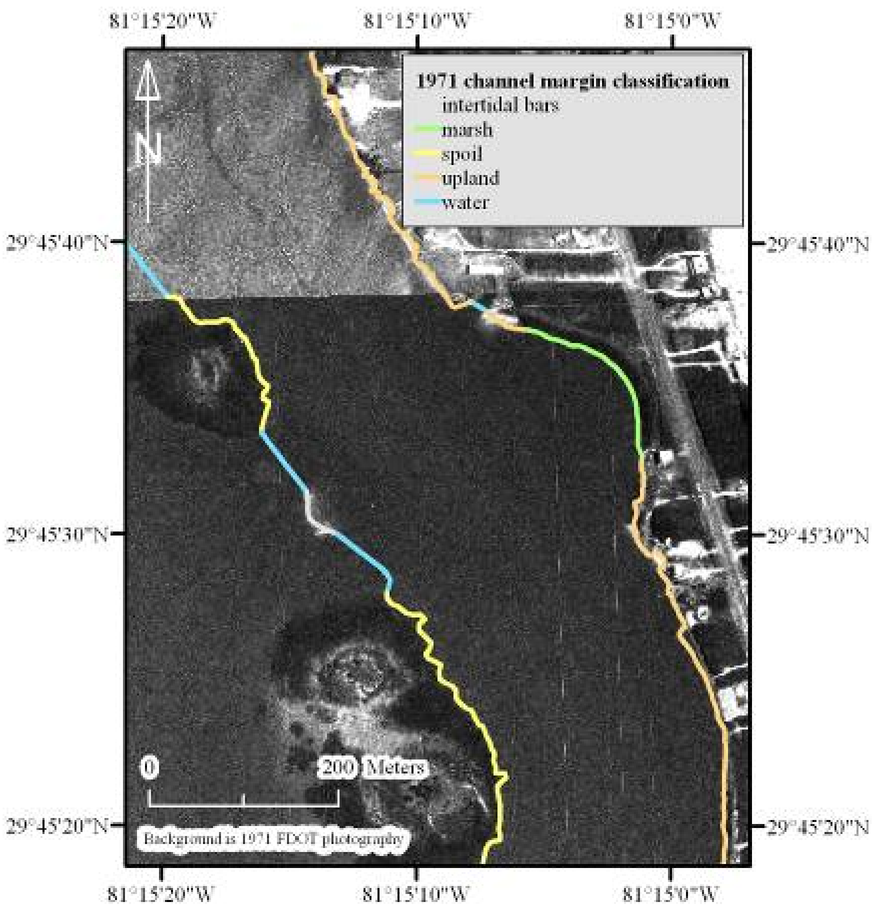

Fig. 6: Classification of channel margin types

Once digitization and margin classification were complete, change in margin location was assessed using two separate methods: a polygon-based analysis of change in area, and a point-based analysis of lateral margin movement.

Polygon-based analysis

The polygon-based analysis was used to determine the total change in area of each margin classification as a result of erosion or accretion. Following the classification of the channel margin, the channel margin lines were used to create two polygons representing the major tidal channels in 1970/1971 and 2002. Using the methods of Gaueman et al. (2003), these polygons were clipped to create two new polygon files. One file contained all areas which were not part of the channel in 1970/1971 but were part of the channel in 2002, and thus represented erosion. The second file contained areas which were part of the channel in 1970/1971 but were not in 2002 and thus represented accretion. Examples of erosion and accretion polygons are displayed in Figure 7. Using GIS software, erosion polygons were manually categorized as one of the five margin types by spatially joining them to the file containing channel margin classification types. Accretion polygons, which were much less numerous, were categorized manually while referencing the 2002 photos (Figs. 18-33). The total area of erosion and accretion of each margin classification was calculated.

Point-based analysis

The point-based method of analysis was structured to determine the rate of lateral erosion or accretion along the channel and to allow examination of rates of change in relation to a suite of indicator variables developed to ascertain the role of the various causal factors in erosion or accretion. Point files were constructed through an automated process which located points every 10 meters along the 64.8 kilometers of digitized channel margin in the study area for both the 1970/1971 and 2002 channel margin line files. This created two point files of approximately 6,480 points each (examples of which are displayed in Fig. 7). If the points were found to lie on the margins of the previously created erosion polygons, the distance from each 1970/1971 point to the nearest point in the 2002 layer was recorded as a negative number. If the points were found to lie on the margins of the accretion polygons this distance was recorded as a positive number.

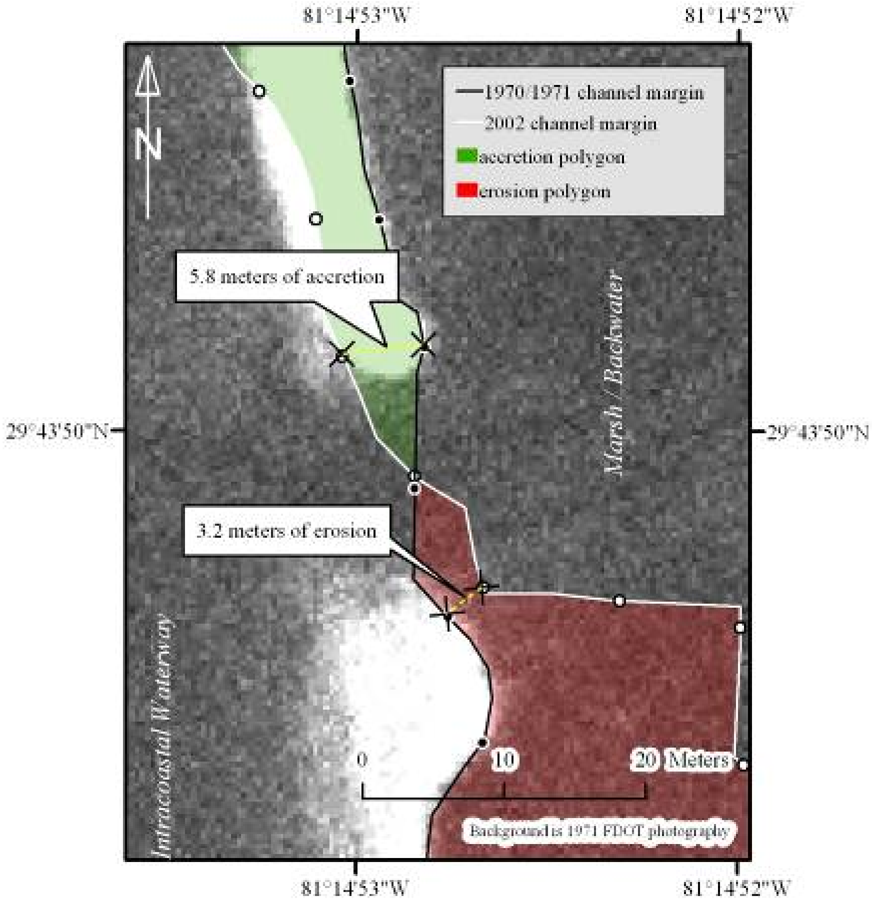

Fig. 7: Measurement of erosion and accretion

The points, at which lateral movement of the channel margin was measured, were classified according to their characteristics which have the potential to influence erosion and accretion using automated geoprocessing techniques. Each point in the 1970/1971 file was dichotomously classified according to its exposure to wind waves formed by prevailing winds, its exposure to boat wakes generated by vessels in the AICW channel, its exposure to tidal currents likely to cause erosion, and its location north or south of the State Road 206 Bridge (as an indicator of dredging activity). Points were also classified according to channel margin type. In addition, the width of the entire 1970/1971 channel, as well as the distance between the 2002 channel margin and the edge of the AICW in 1999, were calculated. These indicator variables are summarized in Table 2.

Table 2: Indicators of factors affecting erosion and accretion

Variable	Continuous value mean ± stdev (min, max)	Category	Intended to quantify erosion due
channel margin classification	N/A	0 (water) 1 (intertidal bars) 2 (marsh) 3 (dredge spoil) 4 (upland)	sediment type and biological stabilization
exposure to wind waves	N/A	1 (margin facing predominant wind direction) 0 (margin not facing predominant wind direction)	wind waves
exposure to AICW channel	N/A	1 (exposed to boat wakes generated in AICW) 0 (unexposed to boat wakes generated in AICW)	boat wakes
entire 1970/1971 channel width (m)	426.2 ± 687.9 (91.1, 1290.5)	N/A	boat wakes
distance from 1999 AICW channel (m)	272.4 ± 711.1 (7.8, 773.0)	N/A	boat wakes
exposure to tidal currents	N/A	1 (likely to be effected by tidal currents) 0 (unlikely to be effected by tidal currents)	currents
radius of curvature (m) of the nine identifiable bends	789.1 ± 268.6 (439.3, 1195.1)	N/A	currents
location relative to SR206 bridge	N/A	1 (south of bridge - along dredged channel) 0 (north of bridge - along undredged channel)	dredging

Points were coded 1, as exposed to wind waves formed by the prevailing winds, if the margin faced any direction from 300 to 90 degrees. Unexposed points, where the margin faced from 90 to 300 degrees, were coded as 0. Figure 8 displays an example of wind exposure coding and presents a conceptual diagram used to estimate margin angle and subsequent exposure. Exposure was determined based on photographs at a scale of approximately 1:5,000 so minor variations, on the scale of several meters, are not reflected in this variable. Such precision would be prohibitively time consuming and would likely exceed the precision of the digitized channel margins.

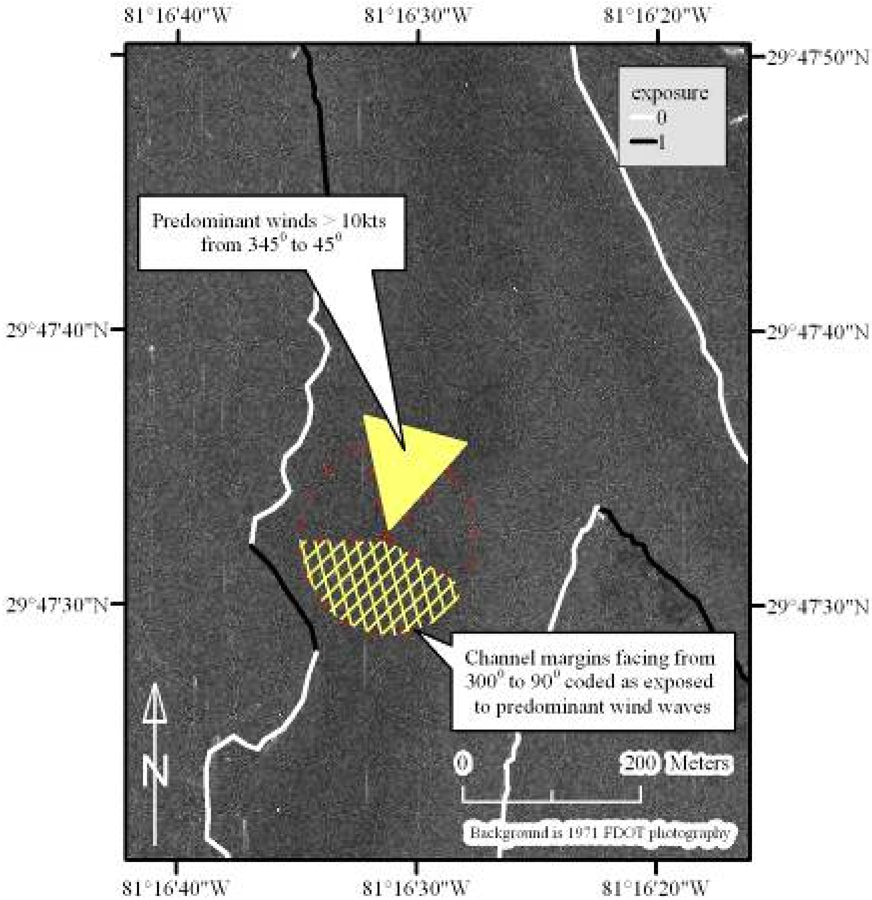

Fig. 8: Coding of exposure to waves caused by predominant winds

Points were coded 1, as exposed to boat wakes, if a line drawn perpendicular to the centerline of the AICW navigation channel could pass through them without crossing a second channel margin (Fig. 9). If points did not meet this condition they were coded 0 for this attribute. The same lines used in this test were used to measure the width of the 1970/1971 channel. Channel width was measured perpendicular to the centerline of the AICW at 10 meter intervals. Since the width measurement lines usually did not intersect the points where change was measured, channel margin points were assigned the width measurement which intersected the channel margin closest to their location. Points unexposed to boat wakes were excluded from the analyses involving channel width. Because boat wakes decay with distance from the sailing line of the boats which produce them, wake-caused erosion can be expected to be most severe when the entire tidal channel is narrower and wakes have less distance over which to dissipate before they impact the channel margin.

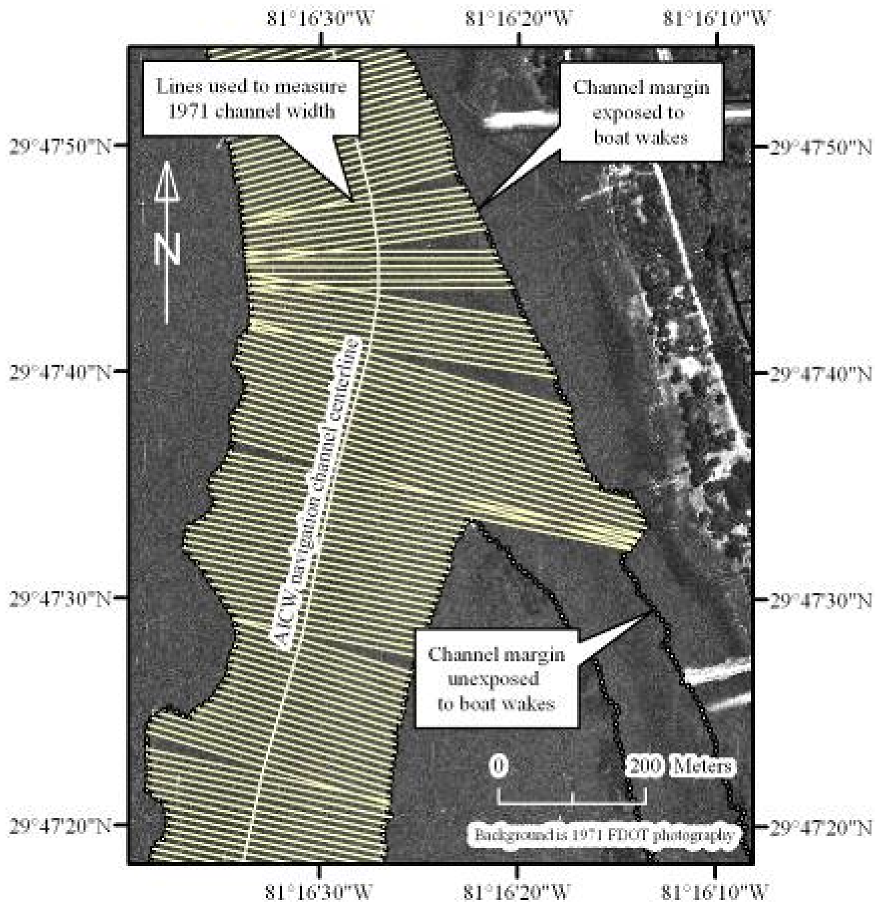

Fig. 9: Determination of exposure to navigation channel boat wakes and measurement of 1970/1971 channel width

The distance from the edge of the navigation channel, as defined by the location of United States Coast Guard navigation markers in 1999, to the channel margin was measured as displayed in Figure 10. This measurement serves as a third indicator of the influence of boat wakes on erosion rates. As with the channel width variable, points were assigned the measurement which intersected the channel margin closest to their location and points coded as unexposed to boat wakes were excluded. Erosion rates influenced by boat wakes can be expected to be highest where the navigation channel runs closest to the channel margin and wakes have the least time to dissipate.

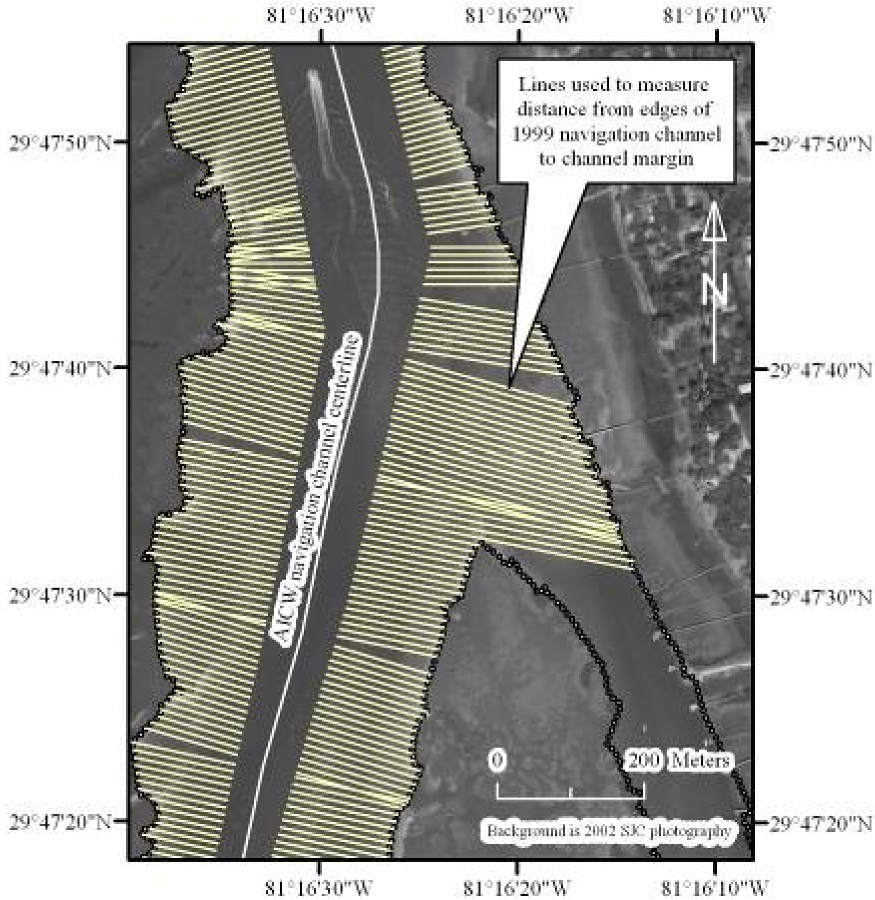

Fig. 10: Measurement of distance from edge of 1999 navigation channel to channel margin

Points were coded 1, as exposed to tidal currents, if they were on the outside of one of the nine identifiable bends in the AICW channel in the study area. Points on the inside of bends or on straight reaches of margin were coded as 0. The radius of curvature, of all identifiable bends, was also recorded to serve as a secondary measure of erosion caused by tidal currents. The radius of curvature of a bend can be interpreted as the radius of the largest circle which fits the curve of a bend smoothly. In this study, Arc GIS software was used to fit an arc to each curve and determine its radius. In addition to these two indicators of tidal current-caused erosion, the bathymetric cross sections of the nine bends (taken from data provided by the St. Johns Water Management District) were examined for signs of active outer bank erosion, mainly a significant increase in depth towards the outside of the bend. Such erosion can be expected to be most severe in the tightest bends. Figure 11 shows an example of coding of the tidal current exposure variable and measurement of radius of curvature.

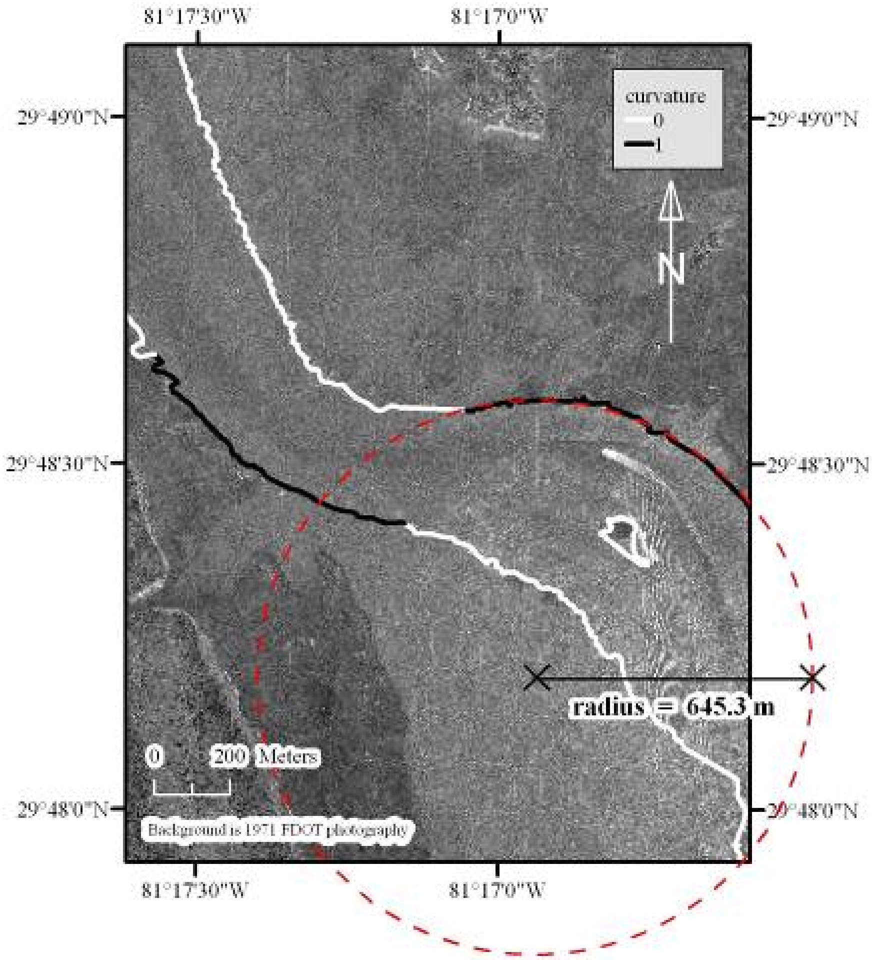

Fig. 11: Coding of curvature variable and determination of radii of curvature

In addition to the variables discussed previously, the location of each point relative to the State Road 206 Bridge was also recorded as a binary variable to indicate presence or absence of dredging (south of bridge = 1, north = 0).

The 1970/1971 points, where lateral margin movement was measured, were analyzed to detect and examine relationships between accretion or erosion rate and each of the potential contributing factors in Table 2. Linear regression was used to examine the correlation between margin movement rates and causal factors measured on a continuous scale. The non-parametric Kruskal-Wallis test, Tukey's studentized range test, and the Wilcoxon rank sum test were used to examine differences in rates of channel margin movement for independent variables measured on a categorical scale. All significant variables were entered into a multiple linear regression model to allow estimation of channel margin movement rates given different site characteristics. Kendall's Tau-b was calculated to overcome the weaknesses of least-squares regression as a measure of correlation between binary independent variables and a continuous response.