M-13

AUTOMATIC INTERFACE MEASUREMENT AND ANALYSIS

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ABSTRACT

A technique for detecting and measuring the interface between two categories in classified scanner data is described together with two application demonstrations. Measurements were found to be accurate to 1.5% RMS error on features of known length while comparison of measurements made using the technique on LANDSAT data to opisometer measurements on 1:24,000 scale maps shows excellent agreement. Application of the technique to two frames of LANDSAT data classified using a two channel, two class classifier resulted in a computation of 64 km annual decrease in shoreline length. The tidal shoreline of a portion of Alabama was measured using LANDSAT data. Based on the measurement of this portion, the total tidal shoreline length of Alabama is estimated to be 1313 kilometers.

INTRODUCTION

Interfaces play a very important role in the physics, chemistry, biology, sociology, and politics of the world around us. Thermal energy is transferred across the boundary between a power plant cooling water discharge and ambient water; erosion takes place at the shoreline; it is across the land/water interface in the marsh that nutrients flow, as the inorganics for primary producers and the organic materials for higher marine life; at the interface between the farmlands and the small creeks and streams fertilizers and insecticides applied to farmlands become agricultural runoff; it is at the boundary of the highway construction project with the swamp, wilderness, or tundra that the environmental impact of the highway is first felt; it is at the interface with industrial development that residential neighborhood quality frequently declines; it is at the flood plain boundary that the hazard to development suddenly changes; limits of ownership of land and mineral rights are determined by particular land/water boundaries.

Given an understanding of the mechanisms involved in the environmental dynamics, definition of the interfaces involved becomes integral to a quantitative analysis of the natural and human-induced processes. Such an analysis can provide information required for effective, properly directed management. One of the first requirements of the analysis would be to monitor the interface involved, detecting and measuring it.

Many of the boundaries we find in nature are very extensive, and are also readily detectable in remotely acquired data, making automatic analysis of aircraft or satellite data very attractive. There are numerous techniques which allow one to automatically translate remotely acquired data into readily interpretable information by classifying the data into various categories. This paper discusses a technique which allows one to delineate and measure the interface between any two such categories or groups of categories while simultaneously computing the area of each. While the technique is not restricted to the analysis of the land/water interface, it is presented here in the context of a shoreline analysis tool. It may be applied to any sampled data, but the discussion here is in terms of scanner data, such as that provided by the LANDSAT Multispectral Scanner (MSS).

In a dynamic geographical area such as a marsh or river delta, it is desirable to know what changes are taking place and to be able to estimate the rate of change. For example, the delta of the Mississippi River is, overall, losing land at a rapid rate, while land is building in the Atchafalaya River Basin. A long term study[1] indicates that the Louisiana coastal area is losing more than 16 square miles per year of land. Consequently, Gagliano, Kwon, and van Beek[2] have proposed that controlled diversions of Mississippi River flow would reduce salinity intrusion and extend the delta to reverse the trend of land loss, to increase the buffer zone for reduction of hurricane-generated storm surges, and to enhance productivity of fisheries and wildlife.

Mobile Bay is another dynamic area. Current studies[3] indicate that sediment carried into the Bay is filling the northern portion of the Bay while some areas within the Bay are experiencing land loss.

The repetitive coverage by LANDSAT provides the opportunity to observe areas experiencing land loss or gain over a period of time, under varying tide and vegetation conditions, and allows measurements of land gain or loss to be continually made and evaluated quickly. This capability is particularly important to monitor an active management plan such as that mentioned above for the Louisiana delta.

The interface between land and water is an important factor in determining marshland productivity. Using data collected in a salt marsh of southern Louisiana, Day[4] has compared streamside productivity to inland productivity (See Table I) and found that the area within 50 meters of the edge of streams, ponds, and so forth has a net productivity (in terms of grasses) approximately twice that of the inland areas. Higher marine productivity is believed to be typical of areas with highly convoluted shorelines. The length of the shoreline per unit area of water is one of the factors which might be considered in estimating shrimp production for estuary systems, but because of the difficulty of obtaining measurements of shoreline length, it has not been extensively utilized. Automatic processing of remotely acquired multispectral data makes the measurement and utilization feasible.

PROCESSING STEPS

There are ten basic elements required to derive a display showing land, water, and shoreline and a measurement of the shoreline length from multispectral scanner data, such as that obtained by the primary LANDSAT sensor. These steps are outlined in Figure 1.

The data must first be examined to determine the suitability of the data set for analysis, e.g., to verify that the entire area to be studied is completely included, that cloud cover will not interfere with the analysis, and so on. Normally, this step is accomplished by inspecting film images of the scene, while all subsequent work makes use of computer compatible magnetic tapes containing the data.

A technique for converting the LANDSAT multispectral data into a land/water thematic has been developed at Johnson Space Center and is known as the Water Search Technique.[5] It utilizes the intensity measurements in the green (0.5 - 0.6 μm) band and one of the infrared bands (0.8 - 1.1 μm). This infrared band alone provides a very good definition of land and water because water strongly absorbs radiation in that spectral region while typical land features strongly reflect this radiation. The spectral signature of water is defined as all intensity values in the infrared band less than a particular value which is a function of the intensity in the green band. The intensity of green light reflected from the area being classified serves to adjust this value, the decision point, for varying turbidity levels of the water, a factor which can cause recognition problems in areas typified by muddy river discharges or marshes. The second step in the processing is the development of the spectral signature for water which will allow the computer to generate a land/water thematic from the multispectral data. Areas known to be land and areas known to be water are located in the data. Values of radiation intensity in the green and infrared spectral bands are then extracted for each picture element in these land and water areas. These areas are known as training samples because data from them is used to "train" the computer to recognize the two categories. A graph with axes representing the green band intensity and the infrared band intensity is developed, with data points corresponding to land features differentiated from those which correspond to water features (See Figure 2). A line is then drawn through the data which best separates the two sets of points. This line defines the land/water discriminator which will then classify each picture element in the scene being analyzed on the basis of the intensity of green and infrared light measured by the sensor.

The third step in the procedure is to examine each data point in the frame and compare the light intensity measured in the green and infrared bands to the land/water decision curve. The computer tests this data and determines whether it matches the spectral signature of water, and if it does, classifies the point as water. If it does not match, i.e., if the point falls to the right of the decision curve in Figure 2, it is classified as land. From this classification process, a new magnetic tape is generated which portrays each picture element with a code corresponding to either land or water.

After the image is classified, it is closely examined and compared to aerial photography of the area that was acquired within a reasonable time period of the scanner data acquisition. The acceptable time period is determined by the rate of change of the geography and the problems expected in the classification. Marsh areas generally are the most difficult to classify and also the most dynamic, so when marsh areas are to be classified there should be aerial photography for comparison which is not more than a year or two before or after the date of the satellite image. If the comparison shows that there are serious discrepancies between the classification and the visual interpretation of the photography, the land/water discriminator must be modified. The most common cause for such discrepancies is that the training samples are not representative of all features portrayed by the data. After modifying the discriminator, the classification process is repeated and results are compared again to the photography. These steps are repeated until a satisfactory land/water thematic has been generated.

The classification into land and water classes may be performed by any valid classification technique, and the classes do not have to be water and land per se. Instead, one of the many available classifiers may be used to generate a classification showing several types of vegetation and different types of water (e.g., lakes and rivers), or different types of ice and snow, or any other identifiable categories, provided only that the categories can be grouped into land and water superclasses. This is useful when fresh water marshes are to be analyzed, as floating vegetation which obscures the water may be grouped with the water categories for an accurate land/water discrimination. The computer program which performs the final shoreline analysis will accept as many as sixty-four classes for the land superclass and eight as the water superclass.

The data to be analyzed will frequently cover a greater area than the desired study area. For example, a typical problem is to measure the land/water interface in a coastal region using LANDSAT data, while a LANDSAT image will typically include not only the coastal area, but the inland region containing small ponds, lakes, creeks, and rivers. The region of interest must be isolated. This is accomplished by displaying the image and determining the limits of the area to be analyzed, and then changing the code for each picture element outside the area of consideration from either land or water to a third code which will be recognized by subsequent computer analysis and ignored. The image is then ready for the detection and measurement of the shoreline.

The scanner data must be scaled accurately for the shoreline measurement to be meaningful. This may be accomplished by computing the picture element size from the scanner characteristics and operating parameters together with the altitude of the platform, or from the data itself. The latter has been found to be a better approach. To determine the factors for cross track scaling (along the scan line, referred to below as the horizontal direction), and along track scaling (along the platform ground track, perpendicular to the scan direction, referred to below as vertical direction), geographic points identifiable in the scanner data are located on accurate maps. The distances between these points are measured on the maps, and the number of picture elements separating them in the scanner data along the scan line and perpendicular to it are determined. The scale factors are then computed by a least squares error analysis. In addition to the scale factors, a correction for rotation of the earth is required when the platform carrying the sensor is a satellite. This correction term is computed in the same analysis as the scale factors.

For the latitudes at which all of our work has been performed, correction for rotation of the earth beneath LANDSAT is consistently equivalent to approximately one element every eleven scan lines. However, the LANDSAT MSS scans six contiguous lines simultaneously, so that there is in fact no correction to be made within the six line units. The LANDSAT data is processed to remove the skew caused by earth rotation by shifting every twelfth scan line one picture element to the west, starting with the first scan line of a six line unit. An additional single picture element shift is introduced every 132 lines. Considering the data as a whole, the correction is therefore equivalent to one shift every eleven scan lines, and preserves the geographic integrity of the six line unit. This is particularly important for the shoreline measurement analysis, because a shift introduced between scan lines where it does not belong results in a change in the length of the linear features being measured.

With the data corrected for the rotation of the earth (if necessary) and the scale factors determined, the shoreline may be detected and measured. The grouping of classes into land and water superclasses is performed at this point, the areas of the two superclasses being computed simultaneously by counting the picture elements being placed into each one. An interface element is defined as the edge of an element of water which is adjacent to an element of land. A two picture element wide and two picture element high "window" is scanned over the classified image, and each element of shoreline is noted. There are four basic types of interface elements: horizontal (i.e., two water elements in one scan line, two land in the other); vertical (e.g., the first element of each scan line within the window is land and the second is water); diagonal (see Figure 3a); and corner (see Figure 3b). Each of these types has a different length, so the number of each type of interface element is accumulated for the entire image. After scanning the entire image, the number of each type of interface element is multiplied by its respective length and these products are then summed to give the total interface length.

The scale factor analysis determines the length of each interface element type. The horizontal and vertical elements contribute one picture element width and height, respectively. The diagonal contribution is the square root of the sum of the squares of the width and height, and corresponds exactly to the diagonal measure of the picture element. Because sharp corners are not typical of natural scenes, the contribution of such apparent features is that of a rounded corner, the length being one-half the width plus one-half the height of the picture element, plus one-quarter of the average of the perimeters of the ellipses which can be inscribed and circumscribed on the picture element.

The final step in the processing, which is performed simultaneously with the interface detection and measurement, is the generation of a new image of the scene being analyzed. This image is a modification of the isolated land/water image which shows the interface as a fourth category, in addition to the land, water, and excluded area. This is accomplished by changing the code on the magnetic tape for every picture element of water which was found to be adjacent to an element of land. This final image is normally recorded on film, examples of which may be seen in Figures 4 and 5.

EVALUATION OF MEASUREMENTS

The interface measurement technique was first tested on figures constructed of string of known length. Various shapes were studied, with figures at different orientations to the sampling grid which was applied to simulate scanner data. Different size grids were also employed. In order to provide a meaningful evaluation, the string figures were of such complexity that all major figure details could be resolved in the sampled data. This study showed that the measurement was very accurate, giving a root mean square error of 1.5% for the figures analyzed. There was also little sensitivity to rotation of the sampling grid.

The technique was then applied to a group of geographic features which could be clearly defined in LANDSAT imagery. These consisted of islands, lakes, and canals which were also accurately portrayed on USGS maps. The shoreline analysis technique was applied to the LANDSAT data while the features were measured on 1:250,000 and 1:24,000 scale maps using an opisometer. Table II presents the results of the analysis. The comparison with the small scale map at first appears disconcerting until the opisometer measurements on the two different scale maps are themselves compared. The LANDSAT-based measurements compare very favorably with the large scale map measurements, with a root mean square deviation of only 7%. Because the interface lengths as computed from the satellite data exceeded the small scale map measurements consistently, and this excess was reduced when the large scale maps were used, it appears that the LANDSAT data contains more detailed information about the features analyzed than the small scale maps, either because of greater fidelity in the detail or higher spatial resolution. Alternatively, the deficiency in the map analysis could be in the opisometry. However, the good agreement indicates that the interface measurement technique may be applied to LANDSAT data with results that will be comparable to measurements made on 1:24,000 scale maps by traditional methods.

One feature which was analyzed but not included in the evaluation deserves special mention. A bridge which crosses Lake Pontchartrain, Louisiana, is 38.41 kilometers long. It was identified in a LANDSAT image which was analyzed using Water Search to define the bridge, which was then isolated from the adjoining lakeshore. Application of the interface detection and measurement technique resulted in a calculated length in error by approximately 55 meters--a deviation less than 0.2%.

The problem of resolution deserves further attention. An area of the marsh in Louisiana near Grand Isle has been analyzed using data with two different resolutions: LANDSAT data, with 79 meter resolution, and aircraft scanner data, with a resolution of approximately 4 meters. The two analyses did not cover exactly the same area, with the LANDSAT data extending slightly beyond the coverage of the aircraft data. However, the aircraft data indicated a shoreline length 54% greater than that measured in the satellite data. Carried to its extreme, resolution may be increased to the point at which the perimeter of every blade of grass is being included in the measurement, at which point the measurement becomes of little practical value. It is clear, however, that the resolution of the data upon which the interface analysis is performed must be associated with the resulting measurement. This is also true with traditional methods, as increasing map detail yields increasing shoreline length.

APPLICATION DEMONSTRATIONS

Two projects demonstrating the application of the automatic shoreline measurement technique have been completed. The first was an analysis of the Mississippi River delta and was designed to detect changes between two frames of LANDSAT data acquired approximately one year apart; the second was to measure the shoreline of Alabama.

Mississippi River Delta Study.- The Mississippi River delta is an area of particularly rapid change, with a very rapid rate of land loss. According to one study[2] the 50% land/water isopleth retreated over 16 kilometers in that region between 1930 and 1970 and is projected to retreat an additional 50 kilometers by 2000.

The Garden Island Bay subdelta is a typical area. In 1935, several small ponds and minor distributaries broke up what was otherwise continuous land (see Figure 6a). By 1958 (Figure 6b), the ponds had expanded considerably, resulting in a substantial loss of land area. At the same time, however, it appears that the length of shoreline in the subdelta increased.

The satellite data indicates that the trend of land loss is continuing both in the Garden Island Bay subdelta and the lower delta in general. An area was isolated downriver from Boothville, Louisiana in two frames of LANDSAT data, acquired on January 16, 1973 and December 5, 1973. The data was processed using the Water Search Classifier and the Interface Detection and Measurement computer program. The January data gave a land area measurement of 428 square kilometers and a shoreline length of 4039 kilometers. Comparison of the classified data to the quadrangle maps showed that the trend of land loss was continuing in the Garden Island Bay subdelta while land building was continuing along Pass a Loutre.

The second frame (December 5, 1973) was processed identically. Scale factors and parameters in the classification were different because of different altitude of the satellite, different lighting conditions, and change in the calibration of the sensor. The analysis indicated that the land area was then 411 square kilometers and the shoreline length was 3980 kilometers. A decrease of 58 kilometers in shoreline length and 17 square kilometers is therefore indicated by the analysis. There are several striking examples of land loss: in the vicinity of Grande Pass, near Baptiste Collette Bayou, and at the mouth of Main Pass (circled areas 1, 2, and 3 in Figure 4). However, land has built up between Main Pass and Baptiste Collette Bayou.

This change detected must be considered in its proper context. The two measurements represent two instants in time, and do not in any way represent mean conditions. Two significant variables which were not controlled were tide stage and vegetation growth. One point where tide stage difference is evident is the island in the mouth of Main Pass. According to the navigation charts (C&GS 1272, dated 1972) the island appears as depicted in the December frame. However, a mud flat is indicated surrounding the island, the boundary of which corresponds to the shape of the island as it appears in the January frame. Accurate and meaningful stage data is not available; there are, however, indications that the tide was in fact slightly lower for the January satellite pass, which would explain some of the decrease in exposed land for the December frame.

The vegetation problem is more subtle. Floating vegetation and vegetation growing in the intertidal regions causes areas that should be classified as water to be recognized as land, because the water surface is hidden by the vegetation. The problem is minimized in this case because the data was taken in the winter months when the plants had died back to their minimum extent. A non-seasonal change in the plant life did take place during that eleven-month period. The vigor of vegetation along the west bank of the river to Southwest Pass seems to have been reduced considerably from the appearance of the area in satellite and aircraft imagery. The change in vegetation state began during the eleven month interval and is continuing. Why this has taken place is not known, but the effect on the land/water consistency of the area is significant. Much of the land loss detected took place in this area of altered vegetation state.

Another measurement of approximately the same area has been made by the Coastal Resources Unit of the Center for Wetland Resources at Louisiana State University.[6] The measurements of streams and bayous, canals and dredge cuts, and major rivers were made using an opisometer on the quadrangle maps which were available for the area while a tracing technique was used to determine the length of lake, bay, and marsh shorelines. This tracing technique involved drawing an ink line over the shoreline shown on the quadrangle map and detecting the change in weight of the sheet as a result of this inking. The ink weight was then calibrated to line length. This technique was found to have what Becker calls good "agreement between replications" on repetitive measurements, and agreement within 20% of true values. The shoreline lengths are listed by both quadrangle sheet and what is referred to as hydrologic unit. The quadrangle maps which cover slightly more than the area included in the LANDSAT study yielded a shoreline length of 5483 kilometers by Becker's composite technique. Hydrologic Unit II of the Becker Study corresponds closely to the slightly larger area included in the LANDSAT study and was determined to have a shoreline length of 4796 kilometers. If this value corresponds to the measurement made in the satellite analysis, a decrease of 54 kilometers of shoreline per year has been occurring since the 1958-1960 date of the quadrangle maps. Considering the fact that short term and periodic effects are included in the change measured in the satellite study, the 64 kilometer loss per year computed in that study is not unreasonable.

Alabama Shoreline Study.- The measurement of the shoreline of Alabama was undertaken at the suggestion of the Remote Sensing Section of the Geological Survey of Alabama. Previously published values of the shoreline length for the state varied from the U.S. Army Corps of Engineers' measurement of 491 kilometers to a

NOAA measurement of 977 kilometers. The Geological Survey of Alabama, in what they considered to be a conservative estimate, determined the land/water interface length in the tidal region to be 811.3 kilometers, using 1:24,000 and 1:62,500 scale maps.

As in the case of the Mississippi River Delta study, two frames of LANDSAT data were analyzed. The entire coastal region of Alabama was not included because of the limited resources allocated to this project, with the area of consideration being restricted to the region bounded on the west by the Alabama-Mississippi state line and on the east by longitude 87° 42'W. This excludes the Perdido Bay area and requires only two computer compatible tapes for each date.

Data from December 28, 1972 and from December 5, 1973 were analyzed. Winter dates were chosen again to minimize the effects of vegetation. Aerial photography acquired in February 1973 (NASA Earth Resources Aircraft Project, Flight Number 73-023) was compared with the computer land/water category classification. There was some difficulty in detecting the narrow water courses in the marsh areas north and west of Mobile Bay, which demonstrates the effect of sensor resolution on the portrayal of the scene. The detection of small streams was more complete in the 1972 data and may be the result of any of a number of factors including atmospheric conditions, vegetation state, and sensor performance. It is also likely that the streams were swollen at the time the 1972 data were collected. Discharge data for the Mobile River indicated a flow approximately one-third greater in December of 1972 than in December 1973. While the drainage areas for some of the streams in question are different from the Mobile River Basin, the Mobile River conditions were representative of the entire area. Differences in the final shoreline measurement are due primarily to the ability to resolve the small streams and marsh land/water features. This is seen in figures 5 and 7, the shoreline images from the analysis.

The 1972 data yielded a land/water interface length in coastal area studied equal to 1122 kilometers, while the 1973 imagery was found to have a shoreline length of 879 kilometers. The latter measurement is comparable to the 977 kilometer measurement published by NOAA, although the area included in the satellite study is somewhat smaller. It represents a measurement under what might be considered normal conditions, while the higher value is the shoreline length during a flood. The Geological Survey extrapolated the LANDSAT-based shoreline measurement to include the entire coastal area of the state (adding the Perdido Bay region) and estimated that the mean shoreline length was 1313 kilometers, considerably more than both the NOAA and Survey estimates.

CONCLUSIONS

A technique for the automatic extraction of interface length from remotely acquired data has been developed. While designed for use with scanner data, any form of sampled data may be used. The technique for measuring the interface is very accurate, but the overall accuracy of the remote measurement system must be compared to a surface truth standard. The closest thing available to a surface truth standard is the USGS quadrangle maps, although these have admitted shortcomings, not the least of which is the fact that they tend to be out of date. The classification of the scanner data and geometric distortion are factors in the automatic analysis which contribute to error. Even considering these, the agreement with map-based measurements is very good.

Two demonstration projects were undertaken to apply the technique to actual problems. The active delta of the Mississippi River was studied using LANDSAT data acquired at an interval of nearly a year. The land area and shoreline length were both found to decrease during that period at annual rates of 18.5 km^2 and 64 km, respectively. Two frames of LANDSAT data covering most of coastal Alabama were analyzed. One represented normal conditions while the other was acquired during a period of flooding. The Geological Survey of Alabama has accepted this data and extrapolated it to cover the remaining portion of the coastal area to give a tidal shoreline length for the state 34% greater than the largest previous estimate. While the LANDSAT analysis is still being evaluated, it appears to be the most accurate.

ACKNOWLEDGMENTS

The original suggestion to develop a technique for automatically detecting and measuring shoreline was made by Dr. G. C. Thomann of the Earth Resources Laboratory. The algorithm for carrying out this task was implemented on the computer by J. G. Glydewell of Lockheed Electronics. Glydewell was also responsible for performing the computer work necessary for the geometric corrections and analyses upon which the evaluation of the technique is based. His dedication to the work is greatly appreciated, as well as the efforts of Marjorie Smith and Helen Isbell in typing this paper.

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TABLE I

PRIMARY PRODUCTION IN THE BARATARIA BAY AREA[1] OF LOUISIANA IN g DRY WT/M^2/ YEAR

MARSH		PRODUCTION GROSS	NET*
GRASS:	STREAMSIDE	14000	2960
	INLAND (50m)	9750	1484
	AVERAGE OVER MARSH	8418**	1518**
EPIPHYTES:	STREAMSIDE	103.9	60
	INLAND (2 m)	27.3	- 18.4▲
	AVERAGE (to 2 m)	32.2	25.8▲
WATER			
PHYTOPLANKTON		598	418
BENTHOS		698	488

* Net production is less respiration of plants
** Takes into consideration bare areas on marsh
▲ Community net production for epiphytes

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[1] Day, John W., Jr; Smith, William G; Wagner, Paul R; Stowe, Wilmer C: Community Structure and Carbon Budget of a Salt Marsh and Shallow Bay Estuarine System in Louisiana, LSU-SG-72-04, Louisiana State Univ., 1973, p 13.

TABLE II

AUTOMATIC SHORELINE MEASUREMENT EVALUATION USING LANDSAT DATA

TEST AREA	COMPUTER MEASUREMENT (km)	PER CENT DEVIATION OF MAP MEASUREMENT *	
		1:250,000	1:24,000
1. Gulfport to Broadwater	12.57	4.1	4.5
2. Deer Island	15.62	3.3	5.4
3. Big Creek Lake	58.48	35.6	-7.4
4. Petit Bois Island	18.48	12.7	*
5. Dauphin Island	79.89	15.7	2.9
6. Inner Harbor Navigation Canal	13.13	*	12.3
7. Anchor Lake	4.79	-0.8	*
8. Pass Christian to Gulfport	23.54	21.8	*
9. Long Beach to Gulfport	5.45	27.7	0.7
10. Grand Island	12.68	36.9	3.6
11. Calumet Island	5.79	18.8	-10.9
12. Island north of Grand Isle	4.12	4.8	*
Root Mean Square Deviation		20.6	7.0

*Excluded because of discrepancy between the appearance of the feature on the map and in the LANDSAT image.

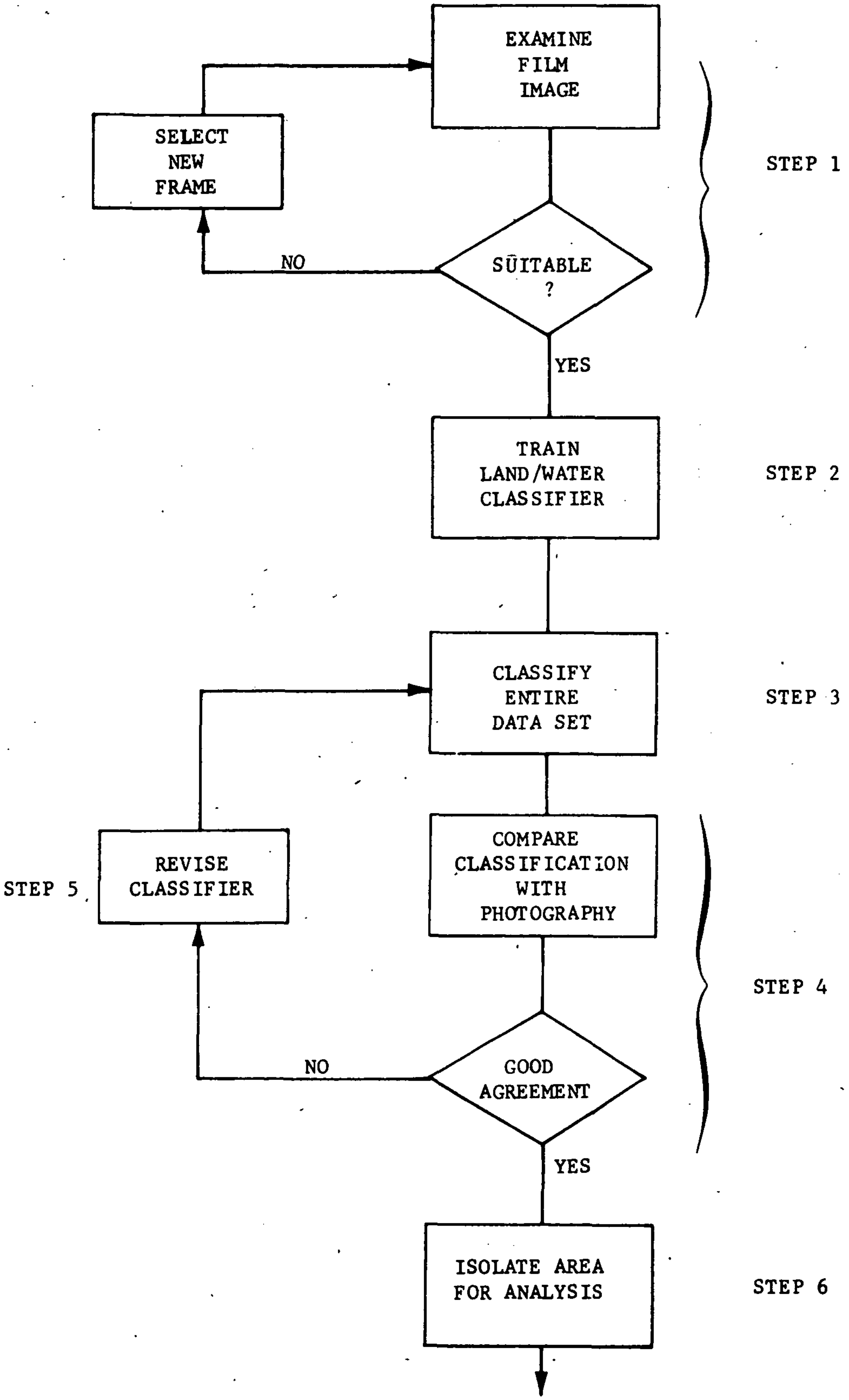

Figure 1. Processing steps to translate multispectral scanner data into land/water/shoreline image and measure shoreline length.

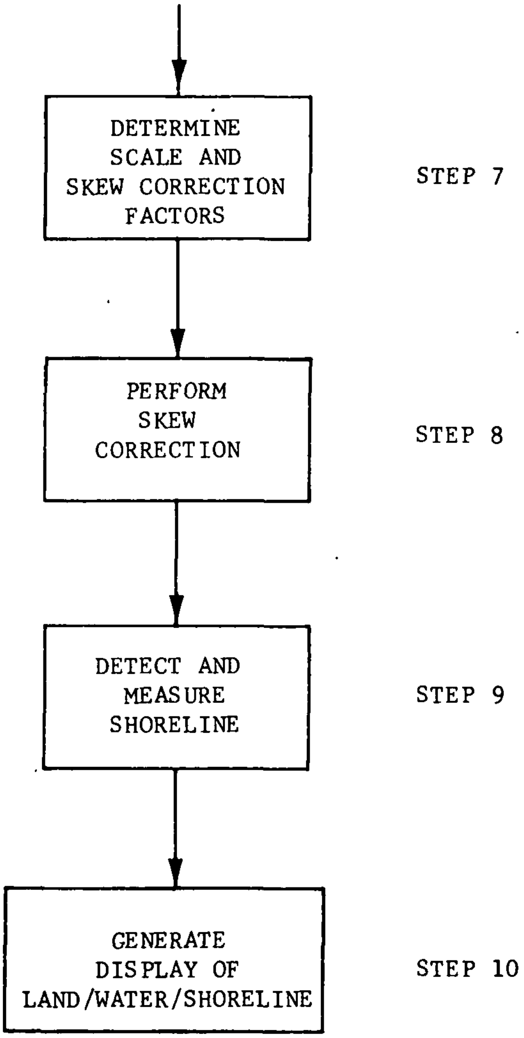

Figure 1. (continued).

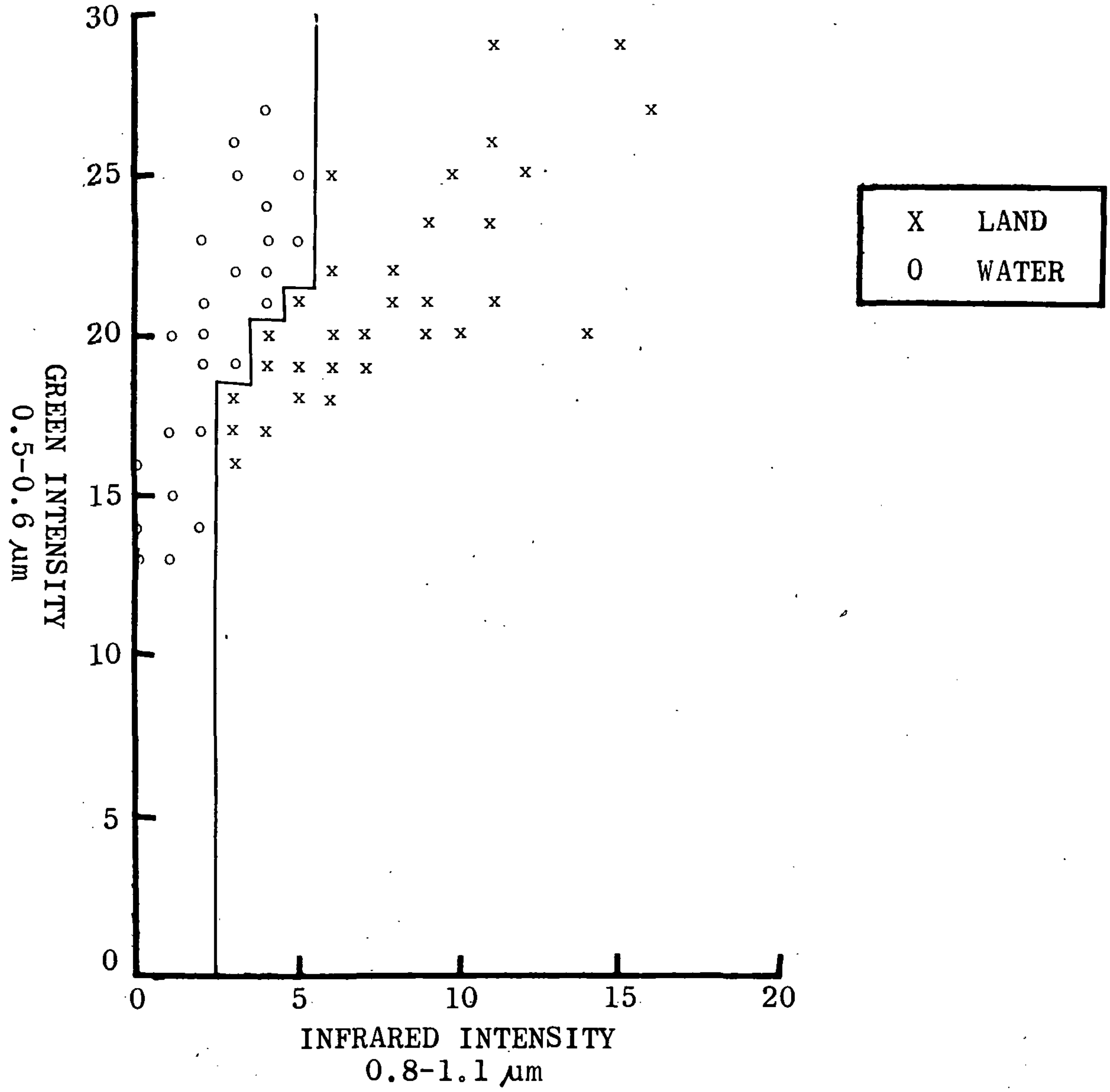

Figure 2. Development of decision curve for LANDSAT MSS Land/Water discriminator.

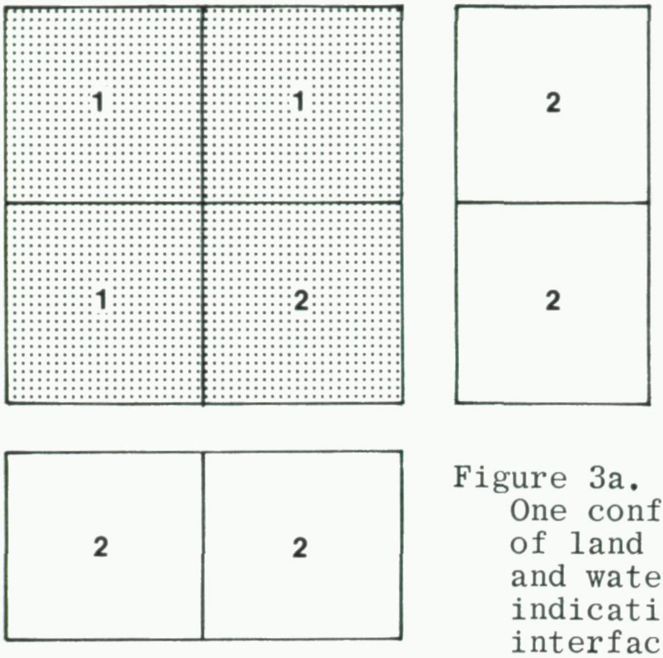

Figure 3a.
One configuration of land (class 1) and water (class 2) indicating a diagonal interface feature.

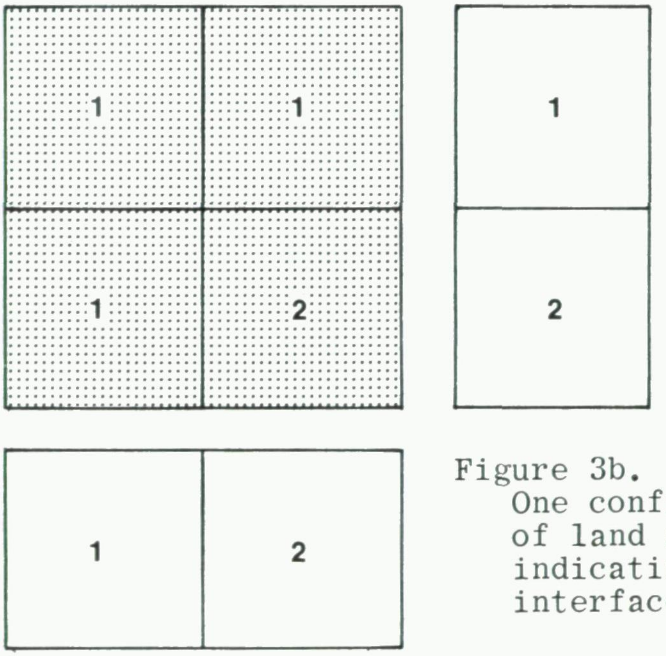

Figure 3b.
One configuration of land and water indicating a corner interface feature.

LAND / WATER INTERFACE ANALYSIS

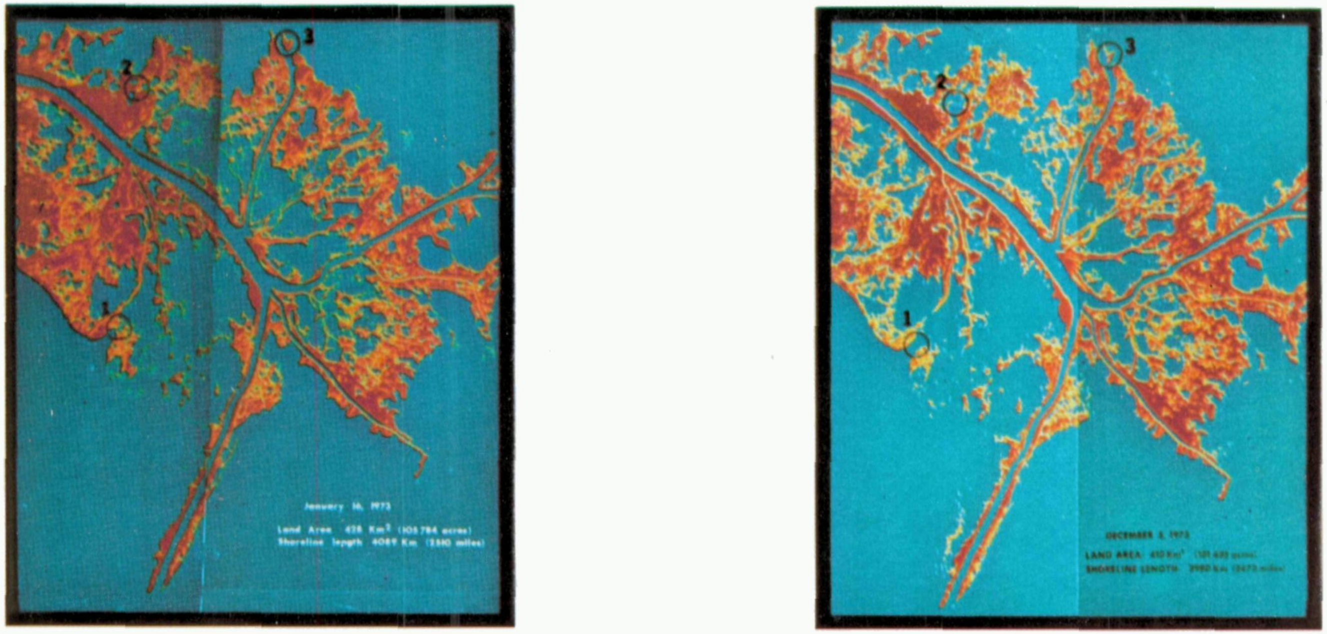

Figure 4.- LANDSAT MSS data, processed by water search and shoreline analysis programs, indicates a 17 km^2 land area decrease and 58 km loss of shoreline at mouth of Mississippi River, between January and December of 1973.

Figure 5. Tidal shoreline measurement using LANDSAT data from 1972 was 1122 km.

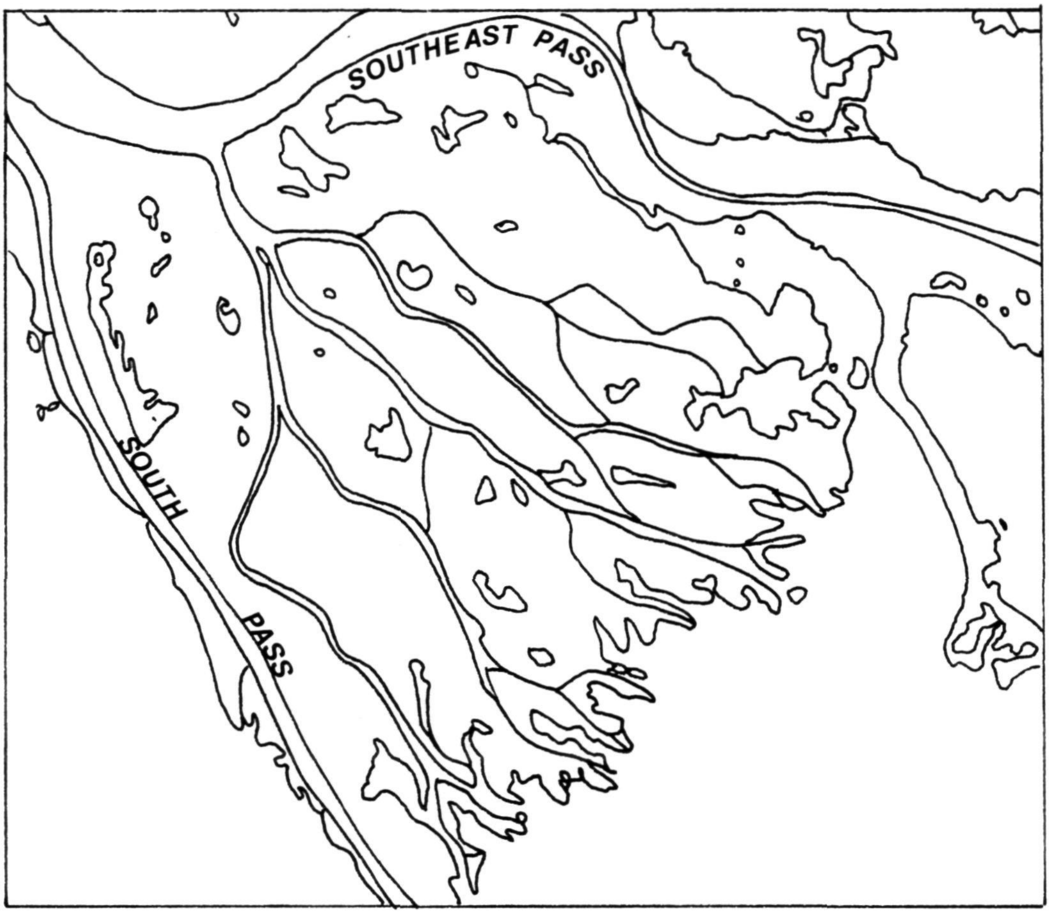

Figure 6a. Garden Island Bay Subdelta of Mississippi River in 1935. Land is broken by a few small ponds and the distributaries.

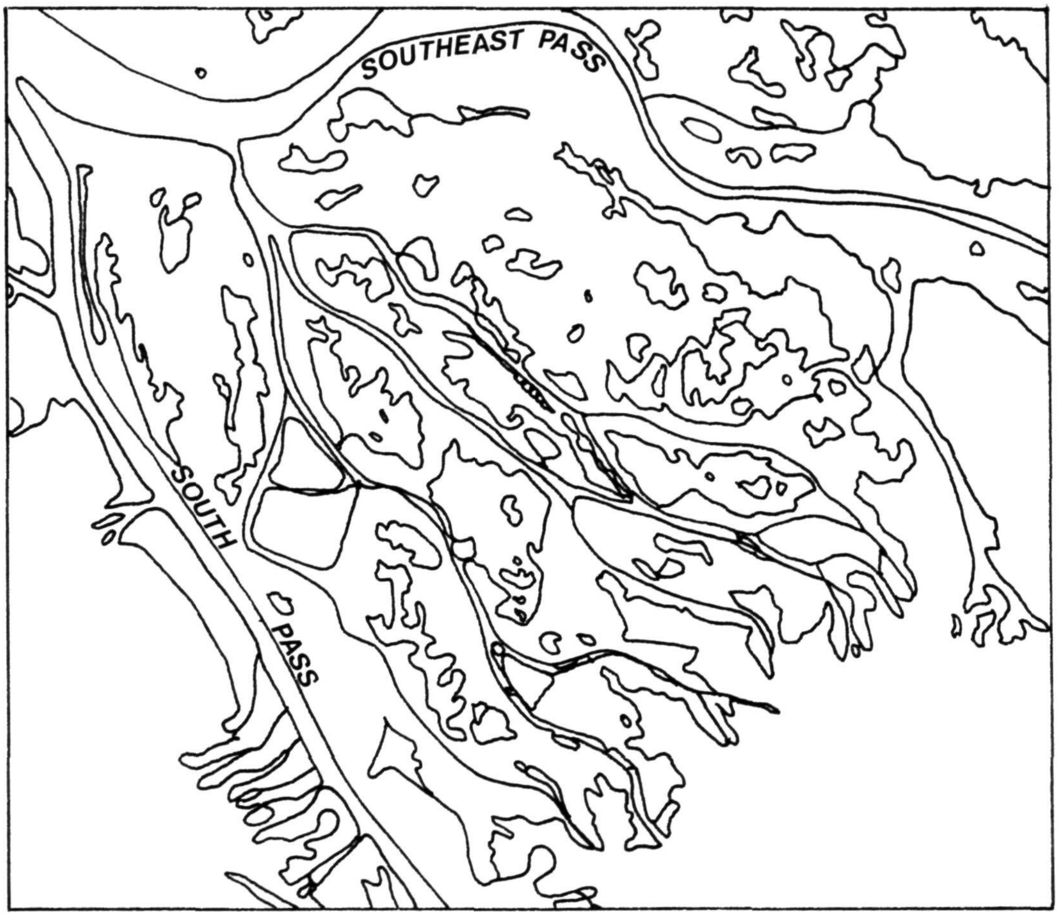

Figure 6b. Garden Island Bay Subdelta in 1958. Land area in subdelta has decreased as a result of subsidence and coastal erosion. Land building is apparent on the west side of the southwest pass.

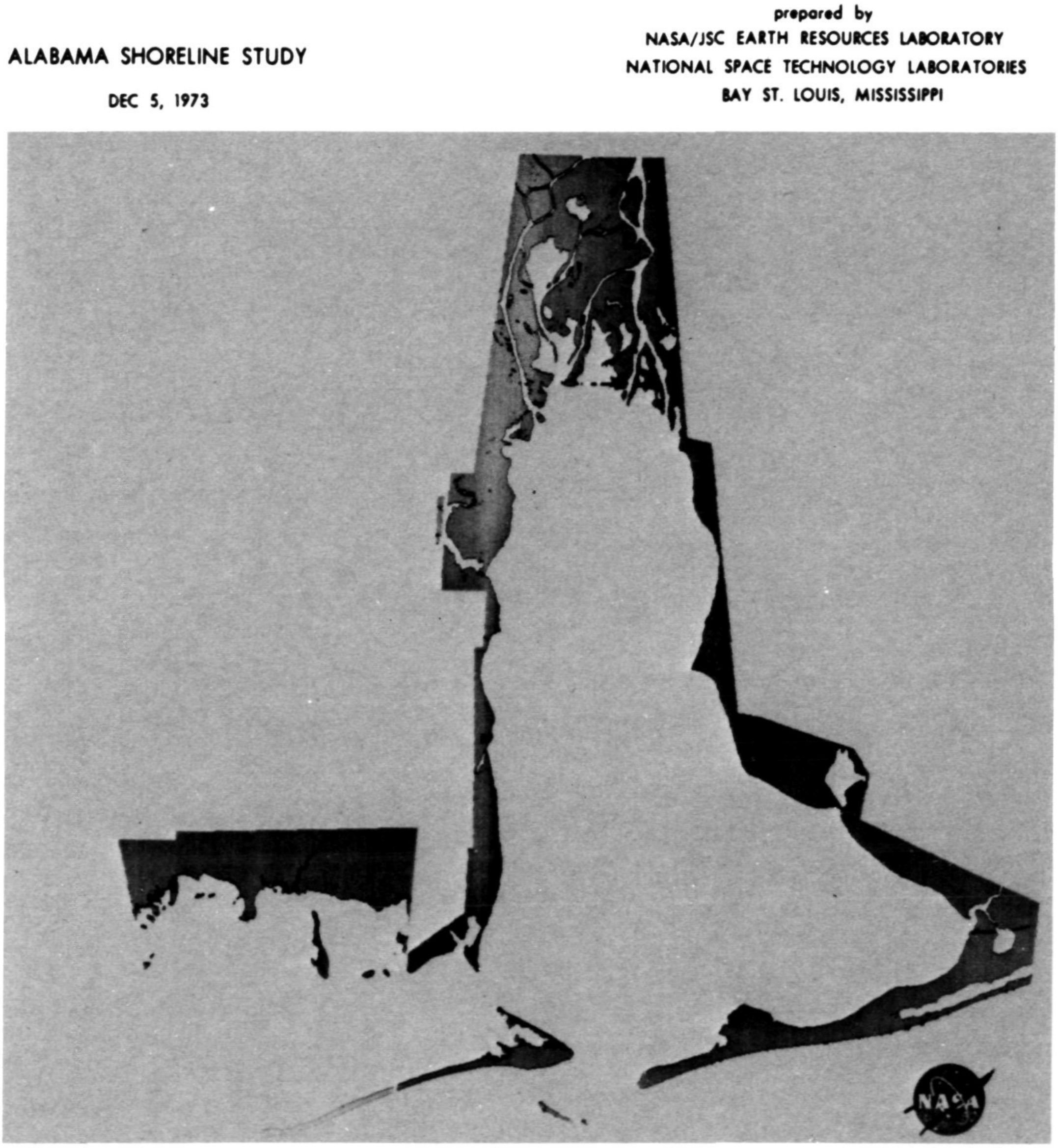

Figure 7.- Tidal shoreline measurement using LANDSAT data from 1973 was 879 km.