An ERTS-1 Study of Coastal Features on the North Carolina Coast

by
George H. Miller and Dennis W. Berg

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

Unenhanced imagery recorded by the multispectral scanner (MSS) of the NASA Earth Resources Technology Satellite (ERTS-1) was analyzed to determine how satellite imagery may be applied to specific coastal engineering problems. The study area is a segment of the North Carolina coast comprising Wrightsville Beach, Masonboro Inlet, Masonboro Beach, Carolina Beach Inlet, and Carolina Beach, which are areas of ongoing research by CERC. Analysis was supplemented by underflight imagery supplied by NASA and ground-truth data.

20. Abstract.—Continued

Several significant coastal features are visible in the ERTS-1 imagery. Among those are plumes of suspended sediment emerging from inlets, changes in water coloration possibly due to effects of temperature change, inlet bars, and cape bars. In addition, morphological changes in selected coastal land features were determined by comparing ERTS-1 films obtained about 1 year apart.

Limited water depth penetration is afforded by examining the lower MSS spectral bands. Maximum penetration can be expected to measure in tens of feet, depending on the physical characteristics of ocean water. Although inadequate for deeper penetration, this capability is adequate for exposure of backshore and nearshore underwater features.

Image resolution capability is sufficient for observation of gross coastal features and processes but may not be adequate for viewing smaller features such as wave patterns, morphological features on beaches, and many engineering structures.

PREFACE

This report is published to provide an analysis of the application of satellite imagery to specific coastal engineering problems. The work was carried out under the coastal processes program of the U.S. Army Coastal Engineering Research Center (CERC).

The report was prepared by George H. Miller, formerly of CERC, and Dennis W. Berg, Chief, Evaluation Branch, Engineering Development Division, CERC. The satellite photography and the original report were provided by the National Aeronautics and Space Administration (NASA) under Contract No. S-70260-AG, submitted 30 October 1973.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

JAMES L. TRAYERS
Colonel, Corps of Engineers
Commander and Director

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AN ERTS-1 STUDY OF COASTAL FEATURES ON THE NORTH CAROLINA COAST

by

George H. Miller and *Dennis W. Berg*

I. INTRODUCTION

Imagery obtained by the Earth Resources Technology Satellite (ERTS-1) has proven highly useful in various scientific and engineering applications. Evidence of this has been demonstrated by the numerous technical conferences and symposiums sponsored specifically to exploit ERTS-1 imagery, and the increasing amount of published research.

Most of the research on the usefulness of satellite imagery has depended on the use of highly sophisticated, expensive equipment, and complex computer analysis to derive the significant results published. One of the intentions of the original Coastal Engineering Research Center (CERC) proposal to the National Aeronautics and Space Administration (NASA) was to determine the possible use of satellite imagery in coastal engineering applications with only the aid of conventional photographic processes and equipment. The results of this report should be beneficial to individuals and small organizations lacking the expertise or financial capability to utilize sophisticated equipment and analysis techniques to derive useful information from ERTS-1 imagery.

The results described in this report have been documented through the use of ordinary photographic processes, access to libraries, and information available to the general public. The ERTS-1 imagery was furnished by the NASA Goddard Space Flight Center, Greenbelt, Maryland, and supplemented by underflight imagery furnished by the NASA Ames Research Center, Mountain View, California, and the NASA facility at Wallops Island, Virginia.

The primary objective of this study was to determine if the status of the littoral regime for a part of a coastline could be established through the use of remote sensing imagery, and if the variations of the coastal features, i.e., barrier islands and tidal inlets, could be detected and measured by this use. The exchange of waters between the ocean and tidal areas and its contribution to the littoral budget were also investigated.

II. STUDY AREA

For an accurate analysis of the imagery, it was decided to choose a study area with plentiful ground-truth data, preferably a coastal segment with sites of active CERC research projects. Accordingly, a segment of the North Carolina coast which included the following sites was chosen (Fig. 1):

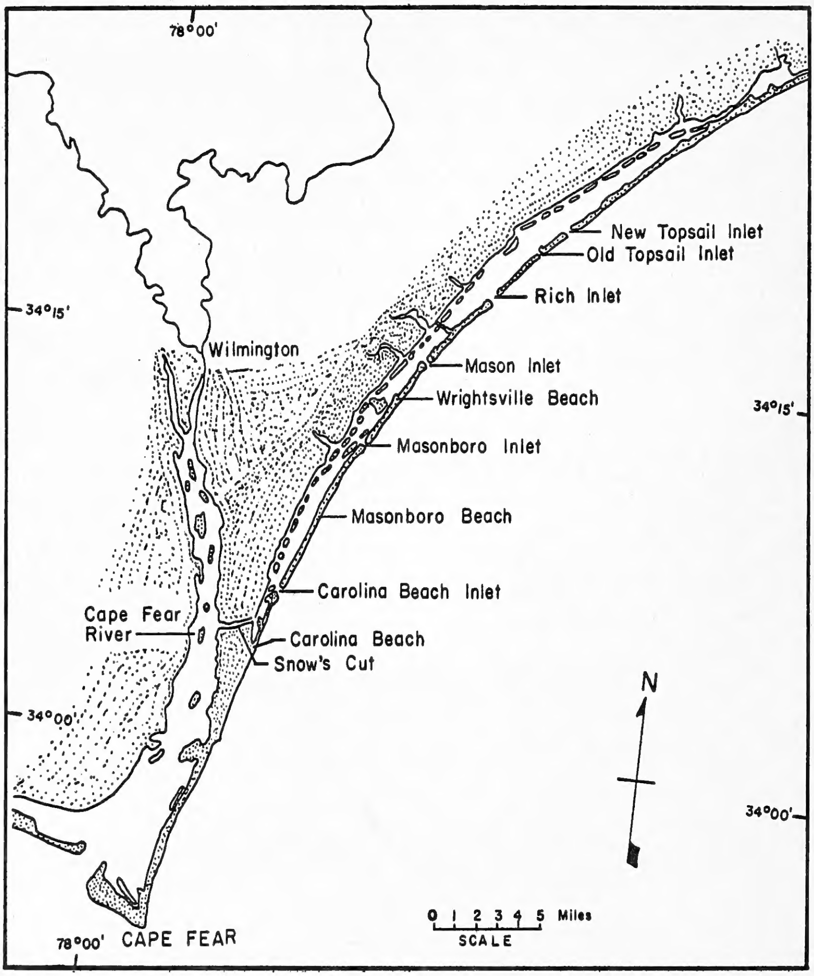


Figure 1. Location map of study area. Traced from ERTS 1314-15210.

Site	Location
1	Wrightsville Beach
2	Masonboro Inlet
3	Masonboro Beach
4	Carolina Beach Inlet
5	Carolina Beach

In addition to being sites of active research projects of CERC, sites 1, 2, and 5 are either Federally sponsored beach erosion control and hurricane protection projects or Federally maintained navigation projects.

The Carolina Beach Inlet studies are being pursued to establish the feasibility of controlling a navigation channel through an inlet by dredging a deposition basin in the throat of the inlet without constructing permanent navigation structures such as breakwaters or jetties. The Masonboro Inlet study seeks to substantiate the feasibility of a new concept in jetty design, the weir jetty, which involves the provision of a deposition area in the lee of the jetty for the storage of naturally moved littoral materials, and periodic bypassing of these materials by ordinary dredging equipment while providing navigation protection. Both Wrightsville and Carolina Beaches are Federally sponsored hurricane and shore protection projects constructed by the U.S. Army, Corps of Engineers. Data collected on these beaches are being analyzed to determine the budget of the littoral materials and to monitor the condition of the projects built by the Corps of Engineers. Masonboro Beach, at present an undeveloped barrier island between the two inlets, is being studied because of its integral relationship to the barrier island-tidal inlet complex and its contribution to the littoral budget.

The results of this report will provide additional information for CERC's larger effort in applying remote sensing techniques to understanding coastal engineering problems. Moreover, it is anticipated that the results presented here will provide a significant input to the concurrent CERC projects listed above.

III. CHARACTERISTICS OF IMAGERY

The imagery used in this study was ERTS-1 multispectral scanner (MSS) imagery in four discrete spectral bands, ranging in wavelength from 0.5 micrometer (green) to 1.1 micrometers (infrared), and conventional aerial photography taken on black and white, color, and infrared color film.

Specific information concerning the ERTS-1 satellite and details of collection, processing, and dissemination of imagery are contained in the Data Users Handbook (National Aeronautics and Space Administration, 1971); however, for this study it is important to list the radiation wavelengths to understand what is actually portrayed in the imagery of the MSS and the conventional photography. Wavelength ranges for each MSS spectral band

(band numbers fixed by NASA) and for the conventional photography used in this study are presented in Table 1. Optical filters were used in the conventional photography to match the spectral bands of the MSS. Of particular importance in this study is the water penetration capability of MSS imagery. Because light attenuation by water is related to light wavelength, each spectral band provides a different degree of water penetration. Table 2 shows total light attenuation coefficients in clear water for wavelength of peak sensitivity of each MSS spectral band (Polcyn and Rollin, 1969). Thus for clear water, penetration increases as band numbers decrease.

Table 1. ERTS-1 multispectral scanner and aerial photography spectral relationships.

Sensor	Wavelength range (micrometers)
ERTS Band	
4	0.5 to 0.6
5	0.6 to 0.7
6	0.7 to 0.8
7	0.8 to 1.1
NASA Ames Research Center Camera	
1	0.475 to 0.575
2	0.58 to 0.68
3	0.69 to 0.76
4	0.51 to 0.70
5	0.51 to 0.90[1]

1. Color infrared film roughly comparable to a composite photo of MSS bands 4, 5, and 7.

Table 2. Light attenuation coefficients in clear water.

MSS Band	Wavelength of peak sensitivity (micrometers)	Attenuation coefficient (per meter)
4	0.54	0.04
5	0.64	0.20
6	0.73	1.00
7	0.82	2.00

By using this data, underwater features can be detected and properly identified on examination of imagery. Magoon, Berg, and Hallermeier (1973) pointed out the utility of examining all four MSS bands, simultaneously and individually, and in conjunction with other existing data.

IV. IMAGERY AVAILABLE FOR STUDY

Table 3 presents imagery identification, dates, and times of obtention for both ERTS-1 and underflight coverage.

Table 3. Dates and times of ERTS and underflight observations.

Frame number	Date	Time (e.s.t.) (hours)
ERTS-1		
E-1007-15142	30 July 1972	1014
E-1080-15203	11 October 1972	1021
E-1115-15152	15 November 1972	1015
E-1134-15211	4 December 1972	1021
E-1170-15205	9 January 1973	1021
E-1188-15210	27 January 1973	1021
E-1205-15153	13 February 1973	1016
E-1242-15213	22 March 1973	1022
E-1314-15210	2 June 1973	1021
Underflights		
Flight number	Date	Time (e.s.t.) (approximate) (hours)
72-116	19 July 1972	0842
72-144	19 August 1972	1044
72-167	22 September 1972	1226
W-179-FLT1	2 November 1972	1025
73-013A	30 January 1973	0945
W-187-FLT1	13 February 1973	1025
73-062	28 April 1973	1200
W-195	11 May 1973	1140
W-222	15 June 1973	1220

V. GENERAL COMMENTS CONCERNING IMAGERY

The basic observations made and conclusions reached are referenced to the images in Table 3. However, the broad range of conditions encountered are representative of ERTS-1 imagery in general, and the statements have applicability to other studies and investigations using this imagery.

Nominal resolving power of the multispectral scanner is approximately 250 feet on the ground (National Aeronautics and Space Administration, 1971).

As a result, smaller manmade structures such as roads and buildings are not visible. However, this resolving capability is suitable for observation of gross coastal features and processes.

In selected cases, distortion of the shoreline was apparent where image scan lines intersected at nearly right angles to the shoreline, imparting a serrated appearance to the shore. This appearance could be interpreted erroneously as a natural cuspate shore by those unfamiliar with the detailed procedure used to obtain and record the imagery.

Band 7 shows the greatest tonal contrast between land and water because the water penetration is least in this band (comparable to black and white infrared photography). Contrast, in general, decreases in moving from band 7 to band 4. In some band 4 images, it was difficult to distinguish land from water in backshore areas. Although the water depth penetration is greatest in band 4, it is difficult to distinguish shoal areas from land masses because of poor contrast. Shoal areas were most apparent in band 5.

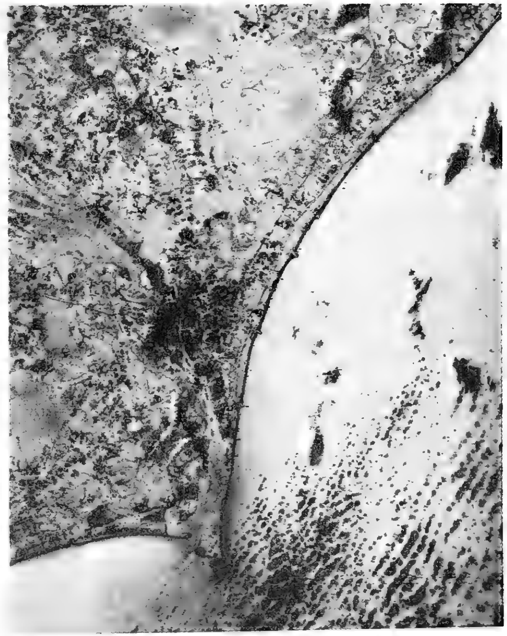
Clouds caused problems in distinguishing features on the ground and in the water. In most of the images, cloud cover was light; only one filmset was so heavily covered that analysis was impossible (27 January 1973, ERTS 1188-15210). In a few isolated cases, care had to be exercised in distinguishing between shoals and cloud shadows.

The ERTS-1 images are either contact or enlargement photographs of positive imagery (negative prints). As a result, land areas appear dark and water areas lighter. Contact prints of the four spectral bands showing the study area (11 October 1972, ERTS 1080-15203) are presented in Figure 2. The prominent cape is Cape Fear. Photographic coverage of the shoreline extends from just south of Little River Inlet, South Carolina, north to Bear Inlet, North Carolina. Spectral bands 6 and 7 clearly show the Cape Fear River and its tributaries; one tributary extends all the way to the northwest corner of the photo. The barrier islands extending north and south of Cape Fear and the inlets separating the barrier islands are also clearly delineated. Scan-line distortion along the barrier islands is apparent in all four spectral bands, e.g., Masonboro Beach.

In bands 4 and 5, contrast between land and water decreases and shoaling areas at the mouths of inlets become more apparent. These two bands illustrate the problem of contrast versus depth penetration. The result was that shoals were studied primarily by using band 5. Sediment plumes, visible in bands 4 and 5, are seen at the mouth of the Cape Fear River and migrating along the seaward edges of the barrier islands, both north and south of Cape Fear.

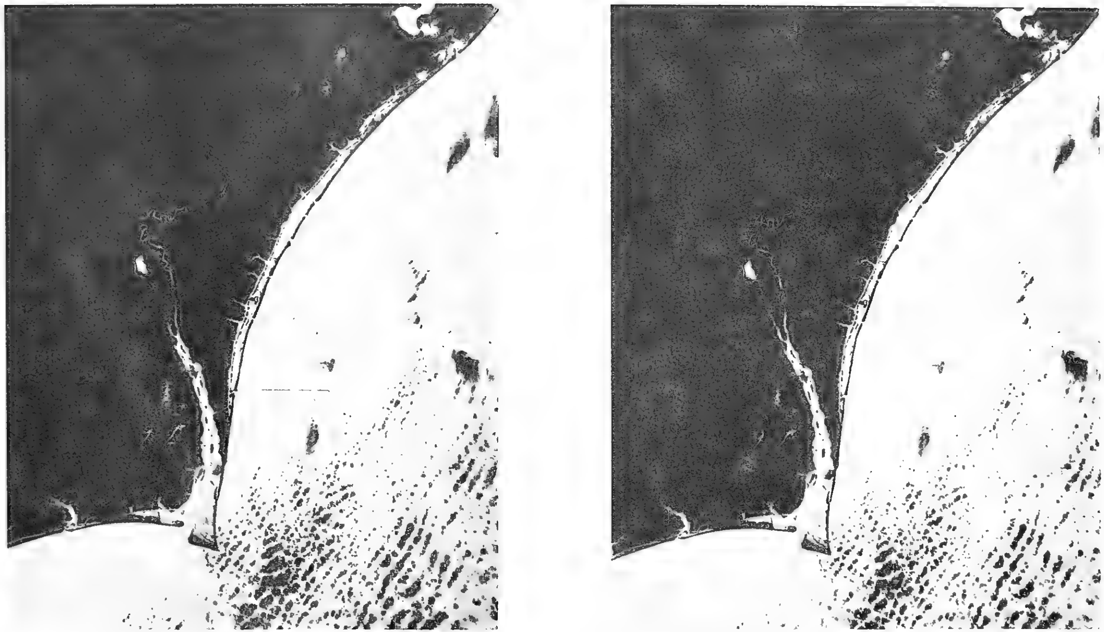
Figure 2 illustrates the problem of cloud cover. Cape Fear has a southeast-trending shoal off its tip visible in the lower spectral bands (discussed later). Cloud cover in the southeast corner of Figure 2 obscures any evidence of shoaling off Cape Fear.

Band 4



Band 5

Figure 2. Study area (ERTS 1080-15203).



Band 6 Band 7

Figure 2. Study area (ERTS 1080-15203). —Continued

VI. COASTAL FEATURES

A number of selected coastal features in the study area were noted during analysis of the ERTS-1 images. Interpretation of these features is important to coastal engineering because it provides vital clues to the littoral budget and behavior of shorelines and inlets. This section treats each feature separately with accompanying ERTS-1 photos and pertinent ground-truth data.

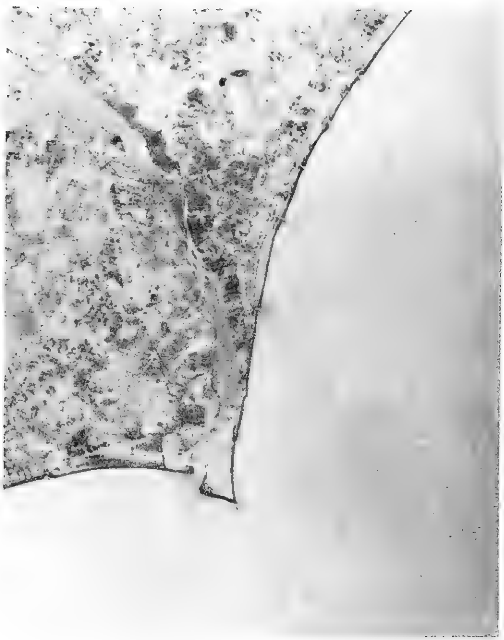
1. Sediment Plumes.

Because sediment plumes act as tracers, bodies of suspended sediment shown in aerial and space photos have long been used by coastal engineers in interpreting current structures and estuarine flushing patterns. With ERTS-1 imagery, it is possible to observe sediment plumes of areal extent measuring in thousands of square miles. These sediment bodies (plumes) are seen in spectral bands 4 and 5.

Figure 3 shows bands 5, 6, and 7 of the study area observed on 4 December 1972 (ERTS 1134-15211) (band 4 was not reproducible). Band 5 reveals sediment plumes at the mouths of Carolina Beach and Masonboro Inlets. The visible part of the plume at Carolina Beach Inlet is almost semicircular with its longest diameter against the shoreline, measuring about 2.8 nautical miles. Maximum seaward extent of the plume is about 2.1 nautical miles. Masonboro Inlet has a smaller, more linear plume extending seaward about 1.5 nautical miles and trending southeast.

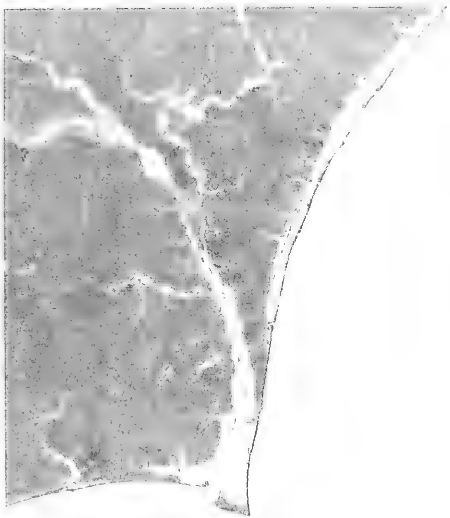
Tide data (Table 4) obtained from a station at Masonboro Inlet indicate an ebbtide occurrence during the ERTS-1 observation (National Oceanic and Atmospheric Administration, 1972b, 1973b). Tide level was 1.9 feet above mean low water (MLW) (slack waters were 4.3 and 0.3 feet above MLW, respectively). Daily weather data obtained from the National Weather Service Office, Wilmington, North Carolina (National Oceanic and Atmospheric Administration, 1972a, 1973a), for 4 December 1972 and the preceding 3 days showed zero precipitation. Hence, the sediment plumes do not reflect abnormal quantities of runoff due to heavy precipitation; they are more likely normal discharges associated with ebbtide.

The sediment plume off Carolina Beach Inlet is displaced slightly toward the south, indicating the presence of a southbound current. The near-semicircular configuration suggests that this current was relatively weak near the inlet. There is no ground-truth data available to substantiate the existence of a predominant southward littoral drift during the observation that may be a contributing factor to this movement. Wave gage data (Table 5) obtained at Wrightsville Beach for 0100, 0700, 1300, and 1900 hours (e.s.t.) on 4 December 1972 show lower significant wave heights and longer wave periods than the average for the month of December 1972. Therefore, wave energy was lower than average. Wave observation data obtained by volunteer observers at Wrightsville Beach under the Beach Evaluation Program (Galvin and DeWall, 1971) managed by CERC showed

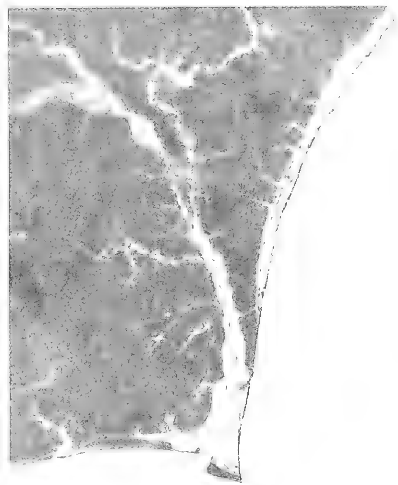


Band 5

Figure 3. Sediment plumes and Cape Fear bar (ERTS 1134-15211).



Band 6



Band 7

Figure 3. Sediment plumes and Cape Fear bar (ERTS 1134-15211). —Continued

Table 4. Tide data - Masonboro Inlet[1].

Date	Time (e.s.t.) (hours)	Tide (feet)	Range[2] (feet)	Cycle
ERTS-1				
1972				
30 July	1014	4.1	-0.4 to 4.1	Floodtide
11 October	1021	4.1	4.2 to 1.0	Ebbtide
15 November	1015	1.5	0.9 to 3.7	Floodtide
4 December	1021	1.9	4.3 to 0.3	Ebbtide
1973				
9 January	1021	3.6	-0.1 to 3.6	Floodtide
27 January	1021	1.1	0.7 to 2.4	Floodtide
13 February	1016	0.0	4.0 to 0.0	Ebbtide
22 March	1022	3.1	3.2 to -0.1	Ebbtide
2 June	1021	2.7	3.6 to -1.0	Ebbtide
Underflights				
1972				
19 July	0842	0.6	0.5 to 3.4	Floodtide
19 August	1044	1.2	0.8 to 3.7	Floodtide
22 September	1226	0.0	4.7 to -0.1	Ebbtide
2 November	1025	0.7	4.3 to 0.5	Ebbtide
1973				
30 January	0945	0.8	3.4 to 0.4	Ebbtide
13 February	1025	0.0	4.0 to 0.0	Ebbtide
28 April	1200	1.1	0.2 to 3.6	Floodtide
11 May	1140	1.1	0.0 to 3.9	Floodtide
15 June	1220	0.1	2.9 to -0.1	Ebbtide

1. From National Oceanic and Atmospheric Administration, 1972a, 1973a.

2. Ranges denote maximum or minimum tidal height preceding and following tide levels.

Table 5. Significant wave heights and periods[1].

Date of Flight	0100 Hours		0700 Hours		1300 Hours		1900 Hours	
	H (feet)	T (seconds)	H (feet)	T (seconds)	H (feet)	T (seconds)	H (feet)	T (seconds)
1972								
17 July[2]	2.3	9.7	2.0	8.8	2.2	8.0	2.1	8.0
18 July	2.0	9.7	1.7	8.8	2.1	8.8	2.0	8.8
19 July	2.0	7.4	2.1	8.8	2.2	8.8	2.1	8.0
July Average[3]	2.4	7.3	2.2	7.8	2.3	7.8	2.3	7.6
17 August[2]	2.4	5.0	1.9	5.0	2.0	10.8	2.0	9.7
18 August	2.1	9.7	---	---	1.8	8.8	1.7	8.0
19 August	1.5	7.4	1.4	8.0	1.7	8.8	1.4	7.4
August Average[3]	2.4	7.3	2.6	6.1	2.6	7.4	2.7	6.8
31 October[2]	3.0	5.0	2.8	4.0	3.4	4.8	2.6	5.3
1 November	2.9	4.0	2.2	4.3	2.2	8.8	1.9	8.8
2 November	1.8	7.4	1.8	10.8	1.8	8.8	1.7	10.8
October Average[3]	2.5	6.4	2.6	5.2	3.2	5.8	2.6	5.9
13 November[2]	3.4	4.0	3.0	5.0	3.0	4.8	2.5	4.3
14 November	3.3	5.0	5.6	6.9	---	---	---	---
15 November	2.9	8.0	1.9	9.7	2.4	8.8	2.5	8.8
November Average[3]	3.2	7.8	3.1	7.7	3.0	7.4	3.1	8.5
2 December[2]	1.9	6.9	1.7	9.7	1.6	9.7	2.0	3.0
3 December	1.4	8.8	1.5	8.8	1.6	8.8	1.7	8.0
4 December	1.2	8.8	1.2	8.8	1.4	8.0	1.7	8.8
December Average[3]	2.7	7.8	2.8	7.6	2.8	7.7	3.0	7.1
1973								
7 January[2]	2.0	4.1	3.5	5.6	3.3	5.6	3.8	5.3
8 January	4.6	5.0	6.8	7.4	5.3	8.0	4.6	8.0
9 January	3.1	8.0	2.7	8.8	---	---	2.0	9.7
January Average[3]	2.8	7.6	3.2	7.5	3.0	7.8	2.8	8.1

1. Obtained from Wave Gage Data, CERC.

2. Recorded values for date and time.

3. Average values for entire month.

wave crests for the most part approaching parallel to shore. Wave gage data and observers supported the view that the longshore current generated off Wrightsville Beach or nearby vicinity must have been relatively weak.

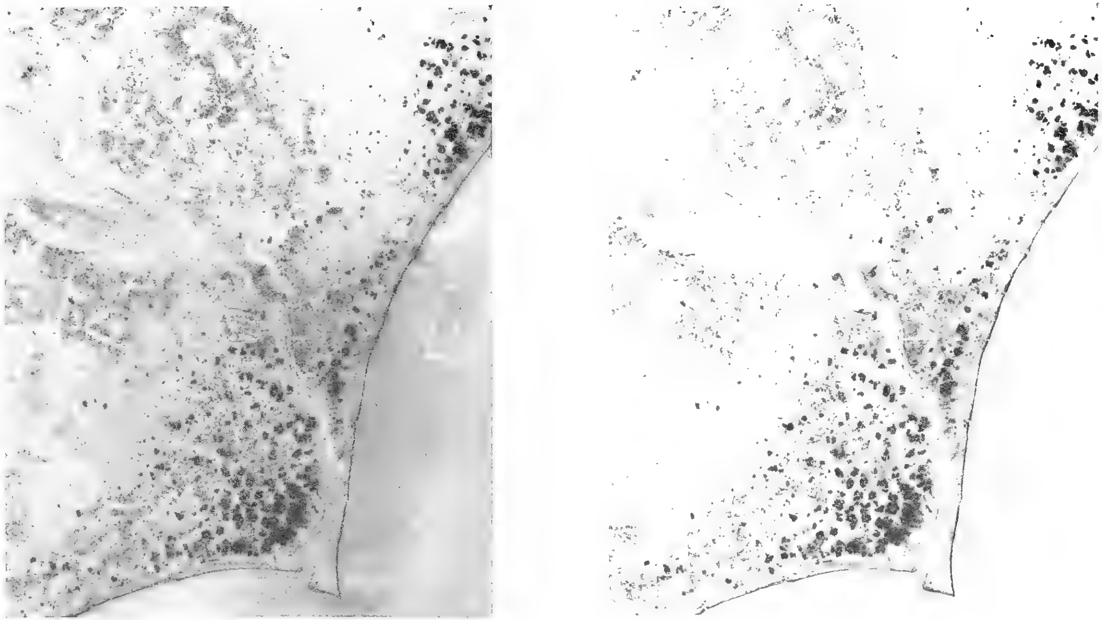
The sediment plume off Carolina Beach Inlet is much larger in areal extent than the plume off Masonboro Inlet. This phenomenon can be explained by the tidal hydraulics of the area. A detailed analysis of the tidal flow through Carolina Beach Inlet was during a study investigating erosion at Carolina Beach (U.S. Army Engineer District, Wilmington, 1970). This analysis revealed that tidal flow through the inlet is controlled not only by the ocean tide fluctuations but by the fluctuations of the Cape Fear River through Snow's Cut. High water in the ocean occurs about 1 hour before high water in the river; low water occurs about 1.5 hours before low water in the river. The result of this combined tidal action is that slack water before ebbtide at the inlet occurs 1 hour after low water in the ocean and slack water before floodtide occurs 1.5 hours after ocean high water. On 4 December 1972, slack water times (e.s.t.) for the ocean, Carolina Beach Inlet, and the Cape Fear River were as follows:

Ocean (hours)	River (hours)	Inlet (hours)
0829 (high water)	0929	0959 (slack water before floodtide)
1551 (low water)	1721	1651 (slack water before ebbtide)

Based on this information, at the time of the ERTS-1 image shown in Figure 3 (1021 hours e.s.t.), Carolina Beach Inlet was at the beginning of the floodtide cycle and not ebbtide as indicated by Table 4 which gives tidal data from Masonboro Inlet. Therefore, what is observed in the ERTS-1 photo is the plume at Carolina Beach Inlet that resulted from the preceding ebbtide cycle; what is seen at Masonboro Inlet is a partially developed plume about 2 hours after the beginning of the ebbtide cycle.

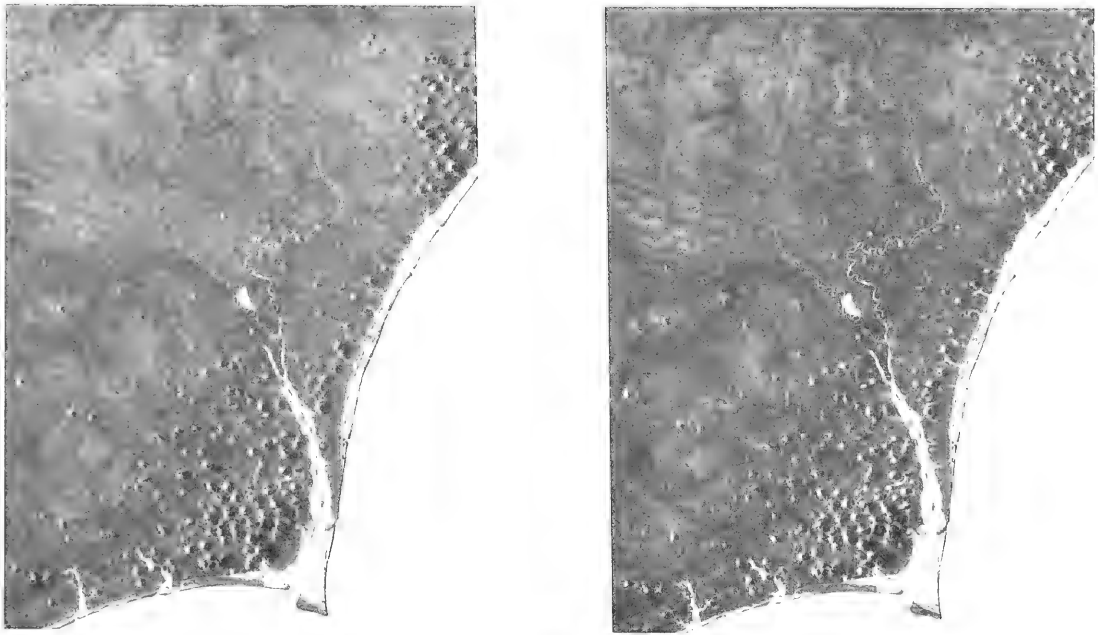
2. Density Mass.

A definable color (or gray tone) change in the ocean water off the North Carolina coast is visible in the four bands of the ERTS-1 imagery recorded on 2 June 1973 (ERTS 1314-15210, Fig. 4). The water adjacent to the coast is a lighter color (darker in the negative print) and appears to be a linear mass, irregular in outline and running roughly parallel to shore. The mass extends from the southern frame border north to Rich Inlet, fades out, and picks up again at Old Topsail Inlet. Approximate width of the mass is 7 miles from shore seaward. Examination of the adjacent frame to the south (ERTS 1314-15213, not shown) reveals that the mass is bordered on the south by the shoals off Cape Fear (discussed later). The mass does not contain visible patterns suggesting a tidal outflow. Its irregular outline suggests that mixing with adjacent ocean water is in progress. The visibility of the mass in all four MSS bands indicates the feature has some depth.



Band 4 Band 5

Figure 4. Gray tone change in ocean water (ERTS 1314-15210).



Band 6 Band 7

Figure 4. Gray tone change in ocean water (ERTS 1314-15210).—Continued

Climatological data for Wilmington (National Oceanic and Atmospheric Administration, 1972a, 1973b) revealed zero precipitation for the day of the ERTS-1 observation and the preceding 2 days. Weather observations made at 3-hour intervals on 2 June 1973, starting at 0100 hours (e.s.t.), showed that air temperature rose from 59° Fahrenheit at 0400 hours (e.s.t.), the lowest recorded temperature for that month, to 82° Fahrenheit at 1000 hours, the highest recorded temperature for the day. In a 6-hour interval, air temperature rose 23° Fahrenheit. Recorded windspeeds for 0100, 0400, and 0700 hours (e.s.t.) were zero, but the wind picked up to 8 knots by 1000 hours.

The color change is probably caused by a difference in density which may result from changes in salinity, quantity, and type of suspended matter (e.g., sediment plumes), concentrations of marine life and nutrients, or a combination of these. These changes are often observed between water masses of different temperatures. A map of the coast of the Carolinas showing sea surface isotherms recorded by an airborne radiation thermometer on 24 and 25 June 1973, the closest days to the ERTS-1 observation is presented in Figure 5 (U.S. Coast Guard, 1973). Dotted lines along some of the isotherms represent extrapolations made by the investigators. A trough of cooler water originates off the coast north of Cape Lookout and extends south as far as Cape Fear, as evidenced by the linearity of the 25° Celsius isotherm and a small entrapped 24° Celsius isotherm. A small 27° Celsius isotherm is just off Cape Fear. A body of warmer water may also be trapped by the 25° Celsius isotherm between Capes Lookout and Fear. As previously noted, the change in water temperature may be a factor in causing a tonal change in the photos. The darker tone representing warmer water was borne out by examination of the next ERTS-1 frame to the south (ERTS 1314-15213, not shown). The same tonal variation is apparent toward the southeast roughly coinciding with the Gulf Stream. Figure 4 shows that the outline of a probable density mass roughly coincides with the isothermal pattern. Although the temperature recordings were made on different days than the ERTS-1 recording, it is assumed that isothermal variations on the sea surface tend to follow predictable patterns during a given season along a particular coastal segment.

3. Inlet Bars.

Bars are generally found at the landward and seaward ends of inlet channels. These bars usually appear as lobate or delta-shaped sand bodies originating at the channel ends. The bars are formed by deposition of sediment transported alongshore to the inlet and carried through the inlet by tidal flow. During floodtide the materials are carried through the inlet and deposited on the inner bar. During ebbtide, some of the materials deposited in the inner complex are transported back through the inlet to the ocean bar. Ebbtide and floodtide channels form in both the ocean and inner bar formations; both the bars and channels generally migrate. Geometry and migration of these features are related to the rate of littoral material movement to and within the inlet, and the prevailing tidal currents.

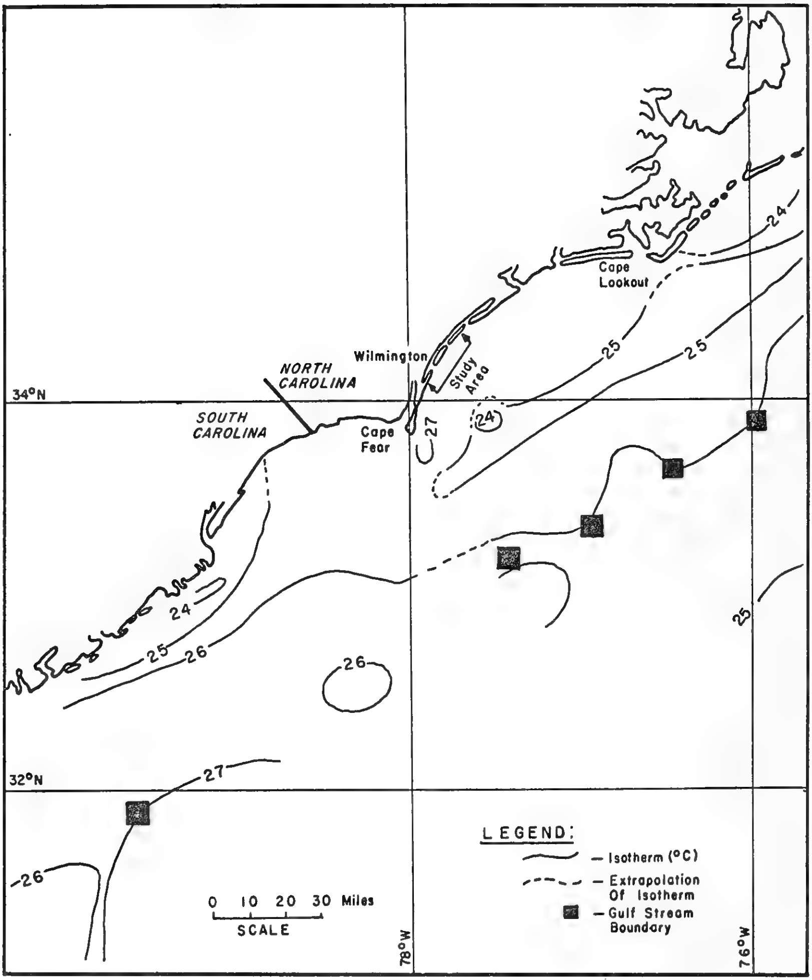


Figure 5. Sea surface isotherms recorded on 24 June (southern part) and 25 June (northern part) 1973 (U.S. Coast Guard, 1973).

Inlets are important coastal features for private and commercial water traffic because they are often the only means of access from mainland areas to the ocean. Consequently, bar migrations and shoaling rates must be closely monitored by coastal engineers so that appropriate maintenance dredging measures can be planned to maintain the inlet channels in navigable condition.

Inlet bars are visible around Carolina Beach and Masonboro Inlets (ERTS 1007-15142, Fig. 6). These bars are most striking in bands 4 and 5, and barely visible in band 6. Southbound littoral drift at Masonboro Inlet is controlled by a weir jetty at the mouth of the inlet on the north side which results in the ocean bar being a different geometry and position from the one at Carolina Beach Inlet. The ocean bar at Masonboro Inlet is roughly linear in form and displaced toward the south of the inlet channel which is bordered on the north side by the jetty. The bar trends southeast, approximately parallel to the channel and jetty, and is separated from Masonboro Beach by what is apparently a secondary tidal channel.

4. Capes.

Capes Fear and Lookout each have a southeast-trending bar extending from their tips. These bars are seen best in spectral bands 4 and 5. The bar off Cape Lookout is the longer of the two, measuring about 4 miles (Fig. 7). The bar off Cape Fear measures 1 mile (Fig. 3).

Historical records have shown these two capes as sites of shifting current directions (Shepard and Wanless, 1971). Sediment transported toward the tip of each cape by longshore currents is deposited in the shoaling areas as the sediment-laden waters reach the tip. Diffraction around the tip causes waves to lose energy which reduces the sediment carrying capacity of those waves. Shifts in longshore current direction probably prevent these shoals from approaching a direction parallel to the current. The shoals visible in the ERTS-1 imagery are oriented in a direction that reflects net deposition by shifting currents.

Bumpus (1955) points to converging currents as the mechanism for bar formation off the capes of North Carolina. The prevailing southwesterly wind blows parallel to the direction of the coast south of Cape Hatteras. This wind piles up water on the south side of the capes which results in a hydraulic current flowing out over the projecting bars. The current deflects offshore any southward current approaching the cape from the north side. The resulting decrease in current velocity also causes deposition of the sediment load, thus providing a source of sediment for the bars.

VII. MORPHOLOGICAL CHANGES

Coastal land features continually undergo erosion and accretion due to the constant action of wind, waves, and currents. As a result, the morphology of the land is constantly subject to change. Some of these

Band 4

Band 5

Figure 6. Inlet bars (ERTS 1007-15142).

Band 6

Band 7

Figure 6. Inlet bars (ERTS 1007-15142).—Continued

Band 4 Band 5

Figure 7. Bar off Cape Lookout (ERTS 1007-15142).

Band 6

Band 7

Figure 7. Bar off Cape Lookout (ERTS 1007-15142).—Continued

changes occur over very short-time periods, e.g., inlets through barrier islands have opened up in a matter of hours during storms. These same inlets were observed closing in a matter of weeks or months. Complete beaches have eroded away within a few years due either to natural processes or the influence of man; other beaches have formed in as much time. In addition to one-time changes, there are changes such as seasonal variations in beach width, steady growth of spits and hooks, and migrations of capes and inlets.

Because changes to coastal landforms are continuous and often rapid, maps of these areas become obsolete very quickly. With repeated coverage by satellite imagery, the problem of obsolescence inherent in current methods of mapping can be eliminated. Photos obtained from satellite imagery can provide an up-to-date supplement to existing maps, and with repeated coverage over relatively short-time intervals, a means of monitoring changes that are occurring in landforms, as long as those changes are large enough to be resolved by satellite sensors.

This section discusses the morphological changes that have occurred in each of the five sites along the coast of North Carolina: Carolina Beach, Carolina Beach Inlet, Masonboro Beach, Masonboro Inlet, and Wrightsville Beach. Emphasis has been placed on the comparison of what was observed in the ERTS-1 imagery to low altitude aerial photography and ground-truth data.

Blowups of the study area obtained from the first and last ERTS-1 films analyzed (30 July 1972 and 2 June 1973) are shown in Figures 8 and 9. Band 7 in Figure 8 has an overlay of the land-water interface traced directly from band 7 in Figure 9, allowing direct comparison of shoreline change between the two dates. Comparison of the two ERTS-1 films was made with a Zoom Transfer Scope (Ambrose and McHail, 1972). Figure 10 shows mosaics of underflight infrared color photos of the study area on 19 July 1972 and 15 June 1973. The following discussion relates directly to Figures 8 to 11. The location map in Figure 1 should be used to pinpoint locations of the various features.

1. Carolina Beach.

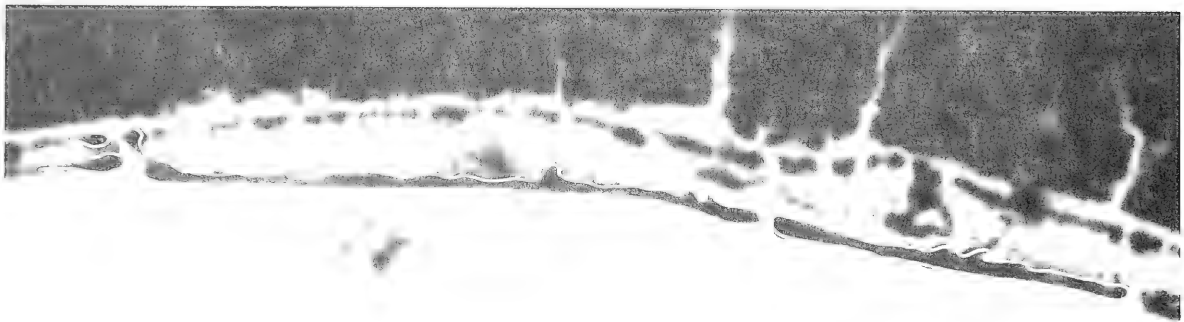
Comparison of the two underflight mosaics (Figs. 10 and 11) shows that significant erosion occurred along the arched part of Carolina Beach, immediately south of Carolina Beach Inlet. This shoreline recession was more apparent in the ERTS-1 photos than in the underflight mosaics because of the lower image resolution and scan-line distortion in ERTS-1 imagery. No erosion was apparent along the beach south of the arched part. A report by the U.S. Army Engineer District, Wilmington (1970) stated that before the opening of Carolina Beach Inlet in 1952, the now-curved part of Carolina Beach was continuous with the shoreline to the south and Masonboro Beach to the north. Subsequent erosion of the segment immediately south of the inlet has been in progress since the opening of the inlet. This erosion was a natural development resulting from a deficit of littoral drift from the north, caused by material entrapment in the inlet.

Band 4

Band 5

Figure 8. Enlargement of study area (ERTS 1007-15142, 30 July 1972).

Band 6



Band 7

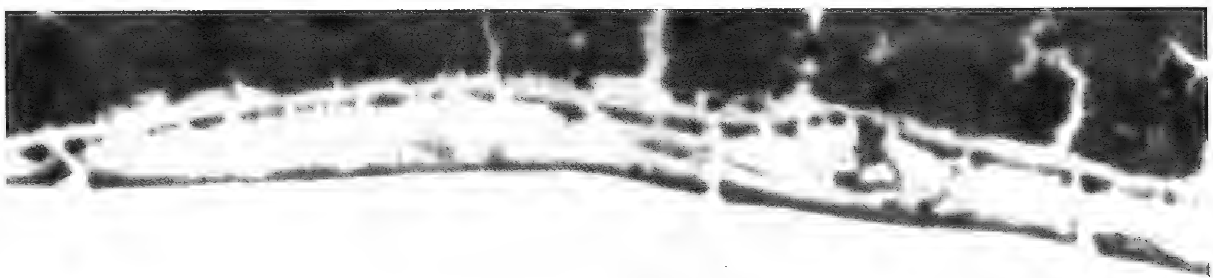
Figure 8. Enlargement of study area (ERTS 1007-15142, 30 July 1972).—Continued

Band 4

Band 5

Figure 9. Enlargement of study area (ERTS 1314-15210, 2 June 1973).

Band 6



Band 7

Figure 9. Enlargement of study area (ERTS 1314-15210, 2 June 1973).—Continued

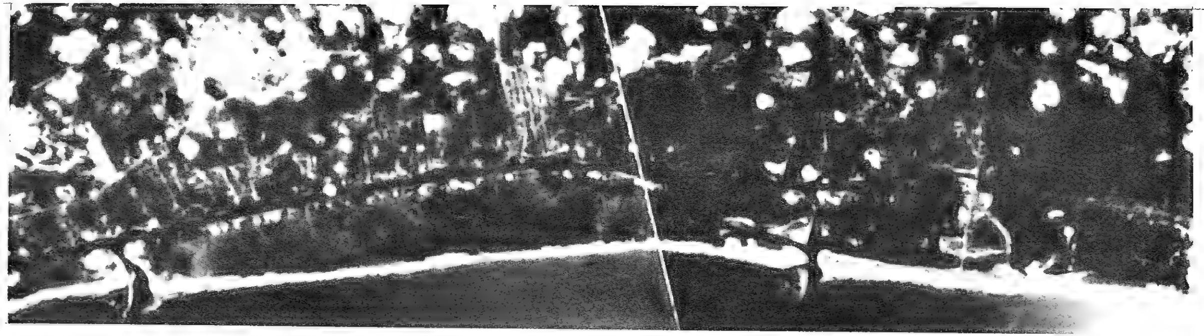


Figure 10. Underflight mosaic of study area (NASA/ARC Flight 72-116, 19 July 1972). Altitude: 65,000 feet MSL.

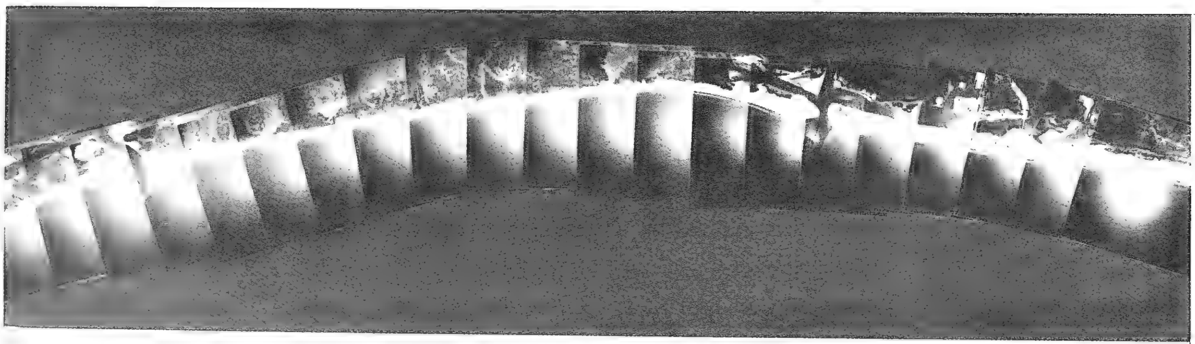


Figure 11. Underflight mosaic of study area (NASA Wallops Flight W-222, 15 June 1973). Altitude: 9,500 feet MSL.

2. Carolina Beach Inlet.

Because of the erosion at Carolina Beach, Carolina Beach Inlet has a well-defined offset, the southern ocean edge displaced landward of the projected ocean edge of Masonboro Beach. The part of the inlet channel between the barrier islands is arched northward. These features can be seen clearly in the ERTS-1 photos. Comparison with the overlay reveals that the inlet is migrating northward with a concomitant increase in the bending of the channel. There does not appear to be a significant shift in position of the mouth of the channel. However, close examination of the inlet in the underflight mosaic (19 July 1972) shows a long, (about 1,000 feet) narrow bar normal to the shore, detached from land, positioned on the south side of the inlet, and extending seaward from well within the inlet. This bar is faintly visible in Figure 8. Examination of underflight imagery subsequent to 19 July 1972 shows that the northern tip of the Carolina Beach extension accreted and filled in the gap between it and the linear bar, the latter forming a sort of cap to the barrier island's growth. This accretion was accompanied by erosion on the north side of the channel. The combination of accretion and erosion accounted for the increase in the channel arching.

3. Masonboro Beach.

No significant change in the shoreline position of Masonboro Beach was observed in either the ERTS-1 or underflight imagery. Evidently, the sand budget along this coastal segment was relatively stable for the time period under consideration. Most of the sand replenishing the southern part of Masonboro Beach was probably derived from the outer bar of Carolina Beach Inlet during littoral drift toward the north. Some littoral drift at the north end probably moved south from the shoal on the south side of Masonboro Inlet.

4. Masonboro Inlet.

A narrowing of the channel through Masonboro Inlet occurred between the two ERTS-1 observations shown in Figures 8 and 9. The narrowing resulted from accretion of the northern tip of Masonboro Beach; the northern edge of the inlet channel remained stationary. An increase in size of the shoal on the south side also narrowed the channel along the above-water part of the jetty. Recent survey data have revealed a steady northward migration of the channel thalweg since the installation of the weir jetty (Fig. 12). Thus, the ERTS-1 photography probably reflects a part of this general trend.

Accretion of the northern tip of Masonboro Beach and the increase in shoaling along the south side of Masonboro Inlet may be due to any combination of several factors in addition to normal shoaling associated with inlet tidal flow. One of these factors is northbound littoral drift. During the fall and winter months, waves approach the area around Masonboro Inlet more frequently from the northeast and east, producing southbound littoral currents. During the spring a transition period is

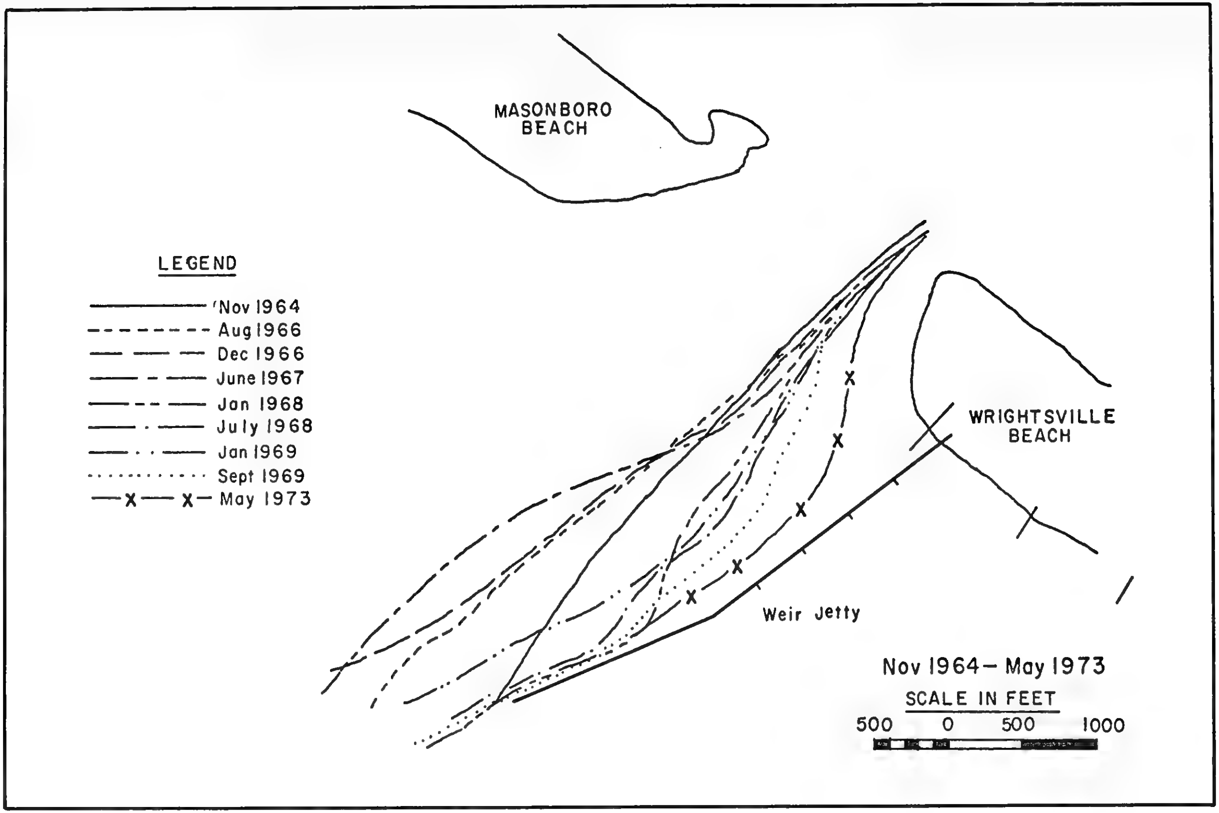


Figure 12. Channel thalwegs of Masonboro Inlet.

observed during which waves strike the beach with almost equal frequency from all directions, resulting in frequent reversals in the direction of littoral transport. During the summer, waves are more likely to come from the southeast and south and produce northward drift (U.S. Army Engineer District, Wilmington, 1969). Although on an annual basis the predominant direction of wave attack is from the northeast and east, shoaling and accretion on the south side continue because of the occasional contribution made by currents moving northward. Moreover, when the waves are coming from the northeast and east, the shoal is protected by the weir jetty.

Wave diffraction is another factor that may contribute to the shoaling. Waves approaching the end of the jetty are diffracted, and the resulting loss in wave energy causes the sediment load to be deposited in the shoaled area. This phenomenon of wave diffraction around the end of the jetty is visible in Figure 11.

5. Wrightsville Beach.

No discernible change was noted in the ERTS-1 imagery on Wrightsville Beach. Like Masonboro Beach, the amount of sand lost approximately equaled the amount gained during the time interval under consideration. Some accretion was visible on the north side of the Masonboro jetty, but like the rest of the beach, it remained stable during the time interval between ERTS-1 observations.

VIII. SUMMARY AND CONCLUSIONS

This study was undertaken to determine how satellite imagery may be applied to specific coastal engineering problems. The study analyzed unenhanced imagery recorded by the four spectral channels of the ERTS-1 multispectral scanner. Problems encountered with analysis of the ERTS-1 imagery and the advantages offered by examination of each spectral band separately were discussed. A number of coastal features seen in ERTS-1 films, including sediment plumes discharged from inlets, a change in water coloration, inlet bars, and cape bars were also examined and discussed. These features were correlated with ground-truth data. Morphological changes in selected coastal land features were determined by comparing ERTS-1 films obtained about 1 year apart. The observations presented in this report should provide a significant input to other coastal studies being conducted along the study area.

Two characteristics of satellite imagery are considered essential attributes when applied to coastal engineering problems. The first characteristic is adequate water depth penetration; depth of water penetration by light increases as wavelength decreases. This property of light allows an examination of certain underwater features in the lower MSS bands of the ERTS-1 imagery. As inferred from the imagery presented in this report, specifically in reference to the shoals and bars, depth penetration in MSS channel 4 is estimated to be tens of feet. Actual depth penetration by light of a given wavelength can vary greatly, depending on the physical characteristics of seawater. Although this penetration capability may be inadequate for deeper areas, it has proven useful for making qualitative observations of estuarine and nearshore underwater features.

The other important characteristic is the image resolution capable of discerning small-scale features normally required in coastal studies, i.e., wave patterns, nearshore current patterns, morphological features on beaches, and engineering structures such as groins, seawalls, jetties, and breakwaters. At present, such features must be sufficiently large to fall within the limits of the ERTS-1 sensor's resolving capability. Examination of the ERTS-1 imagery has shown that, although some smaller scale features of interest in coastal engineering are not visible in the imagery, many important observations of gross features can be made. Most notable were the temporal changes in morphology of tidal inlets and barrier islands observed by comparing the ERTS-1 images. In addition, the current resolving capability of the multispectral scanner appears to be adequate for mapping land-water interfaces with a degree of accuracy that compares favorably with current methods of mapping.

IX. RECOMMENDATIONS

For coastal engineering, improvements in depth penetration capability and resolving power would probably lead to wider application of satellite imagery in coastal studies. While the ERTS-1 imagery has proven useful in analyzing gross surface and nearshore features, much of what needs to be examined in the solution of coastal engineering problems is found below water level and at scales too small for or bordering on the present resolving capability of the multispectral scanner. A resolving power of 50 feet or better would adequately cover most structures and features of interest in coastal engineering. It is anticipated that improvements in optical technology to be incorporated in future satellites will include increased resolving capability. Greater water penetration capability may be afforded by the addition of a blue-band channel in future satellite-borne sensors.

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