CAUSES OF EROSION, EROSIONAL RATES, AND THE IMPACT IN SOUTHEAST COASTAL MISSISSIPPI

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Introduction

Coastal erosion is responsible for substantial losses of natural resources in the extreme southeast corner of Jackson County, Mississippi. This area of bays, bayous, and marshes (Figure 1) is comprised of Point aux Chenes Bay, Bang's Lake, Middle Bay, Bayou Cumbest, Heron Bayou, west Grand Bay, and the contiguous marshes and uplands. For convenience, this coastal marine system will herein henceforth, be referred to as "Point aux Chenes." This is Mississippi's only remaining pristine estuarine subsystem and has considerable economic and social value. Essential for prudent planning to reduce or prevent further coastal erosion at Point aux Chenes requires identifying the erosive forces and understanding their contributions to the erosive processes.

Background

The area supports limited recreational and subsistence commercial fisheries. Besides marine species, wildlife in the area includes a large number of reptiles, mammals, and birds [1]. This marsh-bay-bayou complex is crucial to migratory waterfowl and is therefore a vital component of the North American Waterfowl Management Plan [2].

Of the four general types of marshes in Mississippi, i.e. saline, brackish, intermediate, and fresh water, almost all of the marshes are of the saline, i.e. salt marsh, type [3]. In addition, scattered throughout the area in special niches in the salt marsh and uplands are a number of rare plants [4].

North of where the Grand Batture Islands once lay and around the west margin of Point aux Chenes Bay, Eleuterius [5] found extensive beds of shoal grass. This rich and diverse flora at Point aux Chenes is attributable, in part, to its geology.

The geological evolution of Point aux Chenes involves a long, complex sequence of events and processes. Studies of its geology which served as sources for much of the geological information synthesized here are those of Priddy and others [6], Otvos [7,8], Minshew and others [9], and Waller and Malbrough (10). Oldest of the surface deposits found in the area today were deposited during the mid-Pliocine epoch when an apron of fluvial-deltaic deposits blanketed the region and coalesced to form the Citronelle Formation. Subsequently, during the Pleistocene, regional uplift and erosion resulted in elevating and partially removing this deposit. Early Pleistocene fluvial sediments were deposited here and beneath the present adjacent Mississippi Sound. Erosion, following this period of deposition, removed much of the early Pleistocene sediments.

With the melting of glaciers and frozen polar seas near the end of the Pleistocene Epoch, sea level rose inundating the area. During this period of encroachment by the sea, a nearshore geological formation consisting of marine sediments developed as did the Prairie Formation which was formed from fluvial sediments. As Earth entered a new ice age, withdrawal of the sea was accompanied by fluvial deposition along the southwardly retreating seaward margin. Coastal streams subsequently cut valleys through the Prairie and other underlying formations.

With the return of the sea near the end of the Pleistocene and during early Holocene times, sediments filling the excavated fluvial valleys were initially freshwater sediments, followed by brackish, and then later by marine deposits. Subsequently, marshes and swamps developed behind the mainland shores adjacent to relatively quiescent waters.

The Escatawpa River, rather than following its present course, i.e. connecting with the Pascagoula River as a contributary, instead flowed south-southeast and emptied into the Point aux Chenes Bay-Grand Bay area. During this period, the Escatawpa River built a sizable delta which encompassed all of the study area. Deterioration of this delta began when the Escatawpa switched course and became a tributary of the Pascagoula River as it is today.

With the change in the course of the Escatawpa River, the seaward transport and deposit of fluvial sediments that had formerly offset that lost to erosion ceased. Today, bayous Cumbest and Heron, remnants of the former main Escatawpa River channels, provide little fluvial sediment to Point aux Chenes. After the switch in the course of the river, the attack by waves under normal conditions, by greater waves that accompany ordinary storms, and by waves and surges of tropical hurricanes eroded the abandoned delta of the Escatawpa. The marshy delta-remnant shores were eroded and retreated northwestward. Winnowing, sorting, and transport of sediments by waves and currents produced sandy barrier islands along the seaward limit of the deteriorating and retreating delta.

The marsh substrate is rich in wood/peat organic material and mud, but, due to the sandy sources of the material that formed this now abandoned delta, the substrate contains a larger-than-average proportion of sand. Sediments comprising the marsh substrate are unconsolidated, highly compactible, and contain a large proportion of water. The substrate is the poorest of engineering soil types.

In Mississippi Sound, remnants of the Grand Batture Islands and adjacent seaward shoal area consists of sandy-bottom sediments. The greatest clay-mud concentrations are located in the deeper parts of the Sound where they are least affected by wave motion and currents. Zones of mixed sandy-muddy bottom deposits exist between the predominantly sandy-bottom and the predominantly muddy-bottom areas. Among the areas where these sandy-muddy zones occur is along the margin of the sandy belt skirting the mainland shore.

Weather contributes directly and indirectly to erosion at Point aux Chenes. Wind speeds of spring and summer are normally considerably less than those of fall and winter. Generally, the source of the winds during the period October-March lies from northwest through north around to northeast while, for the period April-September, it lies from southwest to south around to southeast [11]. The predominant source for all winds during the year lies within the eastern quadrants.

While the principal season for hurricanes in the North Atlantic region is from June through November, the preponderance of hurricanes occurs during August-September. One-half of all hurricanes that have affected Point-aux Chenes occurred in September [11]. The large wind-driven waves associated with storms and hurricanes, forerunners, are responsible for most of the hurricane enduced erosion. Storm surges, as they move into shallower waters, put into suspension and carry away large amounts of sediments.

Astronomical tides of the area are those of the adjacent Gulf of Mexico, but modified by the bathymetry and geometry of Mississippi Sound. The tides are primarily diurnal with a mean diurnal range of 1.5 feet and an annual range of 3.4 feet [12]. Large excursions from the astronomical tide elevations at Point aux Chenes occur during strong, sustained winds. Winds, when in conjunction on the flood, further increase water levels and, when in opposition, prevent water levels from reaching the levels prescribed by astronomical forces. Winds, when in conjunction on the ebb, drive the low waters even lower, and, when in opposition, prevent water levels from attaining the lows prescribed by astronomical forces. Because of the wind influence, the overall range in water elevations during a year exceeds that due to the astronomical forces alone.

Associated tidal currents are guided by the geometry of the coastline and the local bathymetry. At Point aux Chenes, tidal currents outside the bays are generally directed westerly through Mississippi Sound. Maximum tidal current speed calculated for, and later observed at the mouth of bays and passes, is approximately 0.5 m/s [13].

Reliable wave climate information for Mississippi Sound does not exist. Monthly distributions of wave heights as a percentage of time for the location 28°52.5'N, 88°30'W were calculated by Eleuterius [1] using the hind-cast method. While this site lies 25 miles south where the heights of waves are generally larger, the wave statistics serve as a reliable relative indicator of the severity of the wave climate at Point-aux Chenes. The wave climate during October-April is more severe than that of May-September. Winds, which are predominantly southerly from May-September, generate northerly-directed waves.

Methodology

Developing a pertinent aggregate of information on coastal erosion at Point aux Chenes required synthesizing data and information from disparate sources, i.e. reports, journal articles, maps, charts, and aerial photographs. Because of fiscal constraints, only a limited number of maps, charts, and aerial photographs were obtained. A set of line drawings delineating the land masses were constructed by tracing the shorelines from back-lit photographs, charts, and maps. The land masses depicted on each drawing were blacked-in, producing silhouette images. These silhouette images were then digitized via an image scanner, imported into a computer, and, by use of computer software, transformed to a common scale for comparative analyses. Shoreline changes at select sites were measured along transects through the chronological sequence of charts and then averaged to determine a yearly rate of land-loss. A number of visits to the area during the past five years helped in assessing erosion over the short term and two aerial surveys resulted in the detection of topographic features and aspects of erosion that otherwise would have gone undetected.

RESULTS

Comparison of the area in 1848 with that for 1860 (Figures 2 and 3) revealed that appreciable changes in the area occurred during the interim 12 years. Most noticeable is the southwesterly extension and broadening of the Grand Batture Island. This growth toward the southwest is explained by the westerly alongshore current. Storm surges and waves associated with the hurricanes of 1852, 1856, and probably 1860 would have reduced the island's elevation while simultaneously broadening the island via overwash. Islets within Point aux Chenes Bay, north of and in close proximity to Grand Batture Island, and those islets within Middle Bay and Grand Bay disappeared. The marsh area north of and connecting with the middle of Grand Batture Island developed twin, eastwardly-oriented peninsulas.

Erosive processes during the period 1860-1896 (Figures 3 and 4) resulted in further elongation of the Grand Batture Island while reducing its width and recurving its southwest end. In addition, the tongue-like extensions of the marshes in Point aux Chenes Bay, Grand Bay, the south shore of Middle Bay, and near the north shore, center of Grand Batture Island, were greatly reduced in size. Formation of some islets, widening of others, and the development of shoals by 1896 were probably the result of overwash. The seaward shore of the Grand Batture Islands retreated roughly 100 meters to the northwest. The scalloped seaward shoreline in the southwest part of the area in 1860 had by 1896 become rather smooth. Sixteen hurricanes and tropical storms during this intervening period contributed to the erosion. Hurricanes and storms, which crossed the coastline close enough to have caused erosion, occurred in: 1870, 1872, 1875, 1877, 1879, 1880, 1881, 1882, 1885 (2), 1887 (2), 1889, 1893, 1894, and 1895. The storm of 1895 and the hurricanes of 1887 and 1893, made landfall at Pascagoula, Mississippi.

From 1896-1921 (Figures 4 and 5), the erosive forces of 5 tropical storms and 7 hurricanes contributed substantially to the erosion. Two of these hurricanes, 1904 and 1906, made landfall at Pascagoula, Mississippi. Erosion produced dramatic changes. By 1921, Grand Batture Island was no longer a single island, but had been transformed into a string of islands. Figure 5 shows that the islands and peninsulas within Grand Bay had eroded substantially. The remnant of Grand Batture Island lying seaward of Grand Bay had also been greatly reduced. The width of the long, narrow, northeast-southeast island on the east side of Point aux Chenes Bay was narrower. Erosion of South Rigolets Island left it with a very irregular shoreline. The seaward shoreline, once the approximate center of Grand Batture Island, had retreated toward the northwest approximately one-fourth mile. The breaching of Grand Batture Island southeast of Point aux Chenes Bay allowed the entry of waves into Point aux Chenes from a southerly direction. The subsequent accelerated erosion of the north shore by waves is evident in Figure 5.

During the interim 1921-1940 (Figures 5 and 6), four tropical storms struck the area in 1922, 1923, 1934, and 1939 while hurricanes hit in 1926 and 1932. The 1932 hurricane made landfall between Pascagoula, Mississippi and Mobile, Alabama. The magnitude of the coastal erosion that occurred is striking. The entire string of remnant islands that were formed by the multiple breaching of Grand Batture Island had, by 1940, been reduced to half their 1921 width. The islands and peninsulas within west Grand Bay were either reduced by half or had disappeared entirely. The island situated on the east side of Point aux Chenes Bay had been similarly reduced to half its 1921 width. Continuous wave action transformed the irregular seaward shore of South Rigolets Island into a nearly straight, southwest-northeast oriented, shoreline. A similar irregular-to-linear transformation had taken place along the north shore of Point aux Chenes Bay. Crescent-shaped, flood-tidal deltas (dotted lines), located between the islands south of Point aux Chenes Bay, were probably the result of a combination of wave and current action.

Two tropical storms made landfall in the vicinity during the period 1940-1952 (Figures 6 and 7); the first in 1944 and the second in 1947. The island on the east side of Point aux Chenes Bay was bisected. By 1952, the Grand Batture Islands were reduced to approximately two-thirds their 1940 dimensions. The islets northeast of South Rigolets Island had disappeared. The seaward shore of South Rigolets Island, with the other Grand Batture Islands, had migrated northwest. Flood tidal deltas between the islands south of Point aux Chenes Bay grew in size as the width of the passages increased. The length of the embayment on the northeast side of South Rigolets Island grew in length.

During the relatively short period, 1952-1957 (Figures 7 and 8), waves associated with two tropical storms, both of which occurred in 1955, would have contributed to further erosion. Among the most noticeable changes that took place was the narrowing of the peninusula that lies just outside the south, seaward perimeter of Middle Bay. Other changes were the narrowing of the northeast end of South Rigolets Island, the recurving of the west end of South Rigolets Island, and the disappearance of the flood tidal deltas between the islets south of Point aux Chenes Bay. A large part of the mainland marsh in northwest Grand Bay was eroded, leaving a highly irregular shoreline and many new marsh islands.

During the period 1957-1975 interval (Figures 8 and 9), two tropical storms occurred. One struck at Pensacola, Florida, and the other hit Pascagoula. Several hurricanes also contributed to the erosion during this period. Hurricane Betsy, which struck the Louisiana coast in 1965, caused relatively little damage to buildings and other structures in Mississippi; however, it caused appreciable coastal erosion. In 1969, the center of the most powerful hurricane to strike the North American continent in recorded history, Camille, crossed the Mississippi Coast in 1969 causing tremendous changes along the entire mainland coast and barrier islands. Height of the storm surge at Point aux Chenes was approximately 10 feet above mean sea level.

Although the area is not included in Figure 9, the islands that lay south of Point aux Chenes in 1957 were reduced to shoals by 1975. Islets that were in the north part of Point aux Chenes Bay in 1957 were greatly reduced and the formerly almost linear shoreline of the north shore became very irregular with many small embayments. The two islets north of the west tip of South Rigolets Island were substantially diminished. The west portion of South Rigolets Island was bisected, thereby forming a small island. The islet northeast of South Rigolets Island, a remnant of the Grand Batture Islands, was reduced to roughly one-half its 1957 size. The northeast tip of South Rigolets Island disappeared during this interim.

Because of the questionable accuracy of the small craft navigation charts produced in 1978, it is difficult to determine exactly what changes occurred during the 1975-1978 period. Charts produced from a 1975 aerial photograph (Figure 9) and from the 1978 edition of the small craft navigation chart (Figure 10) show few changes in the land masses. The island that formed as the result of the bisection of the west tip of South Rigolets Island during 1957-1975 period had reconnected. The northward oriented point on the northeast tip of South Rigolets Island which appears on the 1978 chart, according to the 1975 aerial photograph, had disappeared before 1975. Another error in the 1978 chart is the depiction of islands which, according to same early photograph, had either disappeared or had been greatly reduced before 1975. No tropical storms or hurricanes made landfall near the area during this period.

Comparisons of charts made for 1978 (Figure 10) and for 1979 (Figure 11) support the previous statements regarding the topography of the area in 1978. Figure 11 shows that no islands existed southwest of South Rigolets Island on November 15, 1979. Other than South Rigolets Island, most of what was once Grand Batture Island appeared only as shoals.

Comparisons of the area of November 15, 1979, (Figure 11) with that of April 9, 1988, (Figure 12) reveal that an extraordinary degree of erosion took place over a period of less than five months. The diminished size of islands, islets, and peninsulas and the changes in both the leeward and seaward shores of South Rigolets Island and the north shore of Point aux Chenes Bay reflect magnitude of the erosive forces. Hurricane Bob, which made landfall near Grand Isle, Louisiana, which caused a rise in sea level of about 3.5 feet at Point aux Chenes, was accompanied by considerable wave action. Hurricane Frederic which made land fall at Dauphin Island, Alabama, on September 14, 1979, had sustained winds of 115 kn and peak winds of 126 kn as the hurricane made landfall. Frederic was the most intense hurricane of this century to affect the Mobile, Alabama - Pascagoula, Mississippi, area. The storm surge, recorded at Dauphin Island at a height of 11 feet above MSL, washed over the island carrying with it much sediment which it deposited as overwash fans on the island's north shore. The evidence clearly shows that Frederic had a substantial erosive impact on Point aux Chenes.

Despite the effects of Hurricane Elena which moved onshore at Biloxi, Mississippi, on September 2, 1985, with average maximum winds of 91 kn and gusts to

117 kn recorded at Dauphin Island, erosion during the period 1980-1986 (Figures 12 and 13) were not dramatic. Shoreline changes in Point aux Chenes Bay were largely manifested in the loss of islets and the reworking of the seaward shore of South Rigolets Island. On September 2, 1985, The center of Hurricane Elena moved onshore at Biloxi, Mississippi. Maximum reported coastal winds of 91 kn with gusts 117 kn were recorded at Dauphin Island, Alabama.

Unlike the previous period, during the period 1986-1988 (Figures 13 and 14) erosion took a heavy toll. Comparison of the size and configuration of South Rigolets Island at the beginning and end of this period shows that the island was reduced to about two-thirds its 1986 size. The shoreline of Point aux Chenes Bay from north around to southeast had eroded extensively. Similarly, the land masses contiguous to Middle Bay and west Grand Bay had also eroded extensively. Florence, a minimal hurricane that made land fall in southeast Louisiana on September 9, 1988, caused a 4 ft rise in sea level and generated large waves that struck Point aux Chenes shores.

Changes in the location of the shoreline along transects perpendicular to the local shoreline were measured at seven sites on Figures 3-13 of Point aux Chenes for the period 1940-1988. Estimated average annual land loss due to coastal erosion using these measurements is approximately 20 acres per year.

Observed during an aerial survey were a series of five offshore bars that paralleled the south coast of South Rigolets Island. The bars extended roughly three-fourths of a mile beyond the island in both directions. Although the direction and size of offshore bars normally change with the seasons, these appeared to be more permanent features of the bathymetry.

Discussion

Two episodic events brought about the conditions responsible for the accelerated erosion at Point aux Chenes. The first event occurred prior to written history. This first episodic event was the change in the course of the Escatawpa River which virtually eliminated the supply of fluvial sediments necessary to offset losses due to erosion. In the area behind the then longer offshore barrier island, Dauphin, Point aux Chenes was protected from the larger waves of the Gulf of Mexico and storm surges. Erosion was limited to that caused by the smaller waves and weaker currents.

The second event, a hurricane between 1740-1760, bisected the protective barrier, Dauphin Island, creating a new island from the island's west end, now known as Petit Bois, and creating a new passage also named Petit Bois. This breach, which has since grown in width, allowed the greater waves generated in the Gulf of Mexico to enter Mississippi Sound and attack the mainland shores of Point aux Chenes.

The reworking of the delta by waves and currents from the time of the change in the course of the Escatawpa River (Figure 2) resulted in the development of the Grand Batture Islands. The major axis of the island in 1848 was oriented roughly northeast-southwest (40°-220°). This elongated barrier island protected Point aux Chenes from attack by northerly-directed waves generated in the Gulf of Mexico. Sparse information indicates that the island was of low vertical relief and vegetated only by brush and grass.

Currents with speeds attaining 1 knot have been calculated for and observed in the shallow coastal waters, in the passages, e.g. South Rigolets Bayou, and at the mouth of the bays. Currents of this magnitude are able to efficiently transport most sediments found in the area.

Waves large enough to erode and transport sediments occur year-round. However, it is normally during winter when waves generated by strong northerly winds and during late summer when strong southeasterly winds produce larger waves that the greatest erosion occurs.

From 1848 through 1988, thirty-eight tropical storms and hurricanes either made landfall at Point aux Chenes or passed in such close proximity to the areas as to cause erosion. The erosive force of large waves and surges accompanying hurricanes and tropical storms were responsible for dramatic changes in the land.

Based on the changes in land masses as determined from charts and aerial photographs for the period 1848-1988, the estimated rate of erosion is approximately 20 acres per year.

The orientation of the series of offshore bars that parallel the south shoreline of South Rigolets Island indicates that the predominant wave direction is 310° for the year.

Insight gained from observing coastal erosion at Point aux Chenes for several years combined with the knowledge accruing from this study has enabled the authors to develop two scenarios of coastal erosion processes at Point aux Chenes. The scenarios are a function of two variables: tidal (astronomical and wind tides) water elevation and short-period waves.

In the first scenario, the water elevation is low on the tidal plane, i.e. where the water elevation is near the base of the beach scarp. Waves traveling shoreward, upon "feeling" bottom, peak, plunge, and break against the face of the scarp. Over a period of time, this process results in undermining the overlying marsh. When the concavity reaches the depth where the weight of the overlying marsh and substrate can no longer be supported, it falls away in large clumps. Surging breakers have the same effect.

The second scenario occurs when the water elevation is high on the tidal plane which may be due to either spring tides or to strong winds directed toward the coast. In this case, when the water level lies at or near the top of the marsh substrate, waves directed shoreward "feel" bottom abruptly as they near the scarp and plunge forward, breaking on top of the marsh substrate. If the scarp has been undermined by prior erosion, the undermined portion may be broken away in large clumps by the impact of the waves.

In this latter scenario, sediment laden waters driven inland after impacting the base of the marsh, may literally cut away the marsh vegetation - leaving only stubble for 10-15 feet inland from the shoreline. Beyond this sheared area, fans of sediment are layed down burying more salt marsh. The first few inches of the surface of the marsh substrate may be removed in this case. Narrow channels may also be cut well into the marsh by the waves.

The rapid erosion that has and continues to occur along the marshy shores at Point aux Chenes is, in part, due to the nature of the sediments forming the marsh substrate. The substrate, which consists of unconsolidated sediments rich in decaying plant material, contains a large amount of interstitial water and is weakened further by the burrows of fiddler crabs and the voids left by decaying roots and other organic deposits. These make the substrate particularly susceptible to erosion.

The destinations of the different sediments eroded from Point aux Chenes are only partly identified by the sediment distribution chart (Figure 3). The large clumps of marsh substrate that break away from the marshy shoreline are rapidly reduced by wave action. Winnowing and sorting by wave action separates the sediments into its various components. The fate of the sediments depends upon the length of time the sediments remain in suspension relative to the period of the prevailing waves. If the time the sediment remains in suspension is less than the period of the wave, the sediment remains near shore. If, on the other hand, the time the sediment remains in suspension is greater than the wave period then the sediment is removed from the area and, in some cases, may be deposited a considerable distance from the point of erosion.

The coarse sands generally remain in the area, probably moving offshore and onshore with the seasonal changes in the wave climate. This material is often found forming narrow strips of beach near the base of the marsh scarp. Finer sands may be carried along shore by longshore and tidal currents or offshore by tide and density driven currents. Both coarse and fine sands are found within the embayments, carried there by flood-tide currents or by waves entering the bays. The fine silts and clays which remain in suspension longer may be carried farther into the bays before they are deposited, but are more likely to be carried seaward by ebb-tidal currents.

Based on the information presented here, the future of Point aux Chenes is rather dismal. By 2041, another 1,000 acres will have vanished. Accompanying this great loss of wetlands will be associated losses of marine "fishes", mammals, reptiles, herptiles, and birds. The present economic and social value of the area will be greatly reduced.

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Figure 1. STUDY AREA (from C. & G. S. Chart No. 1267, 16th Edition, January 16, 1971).

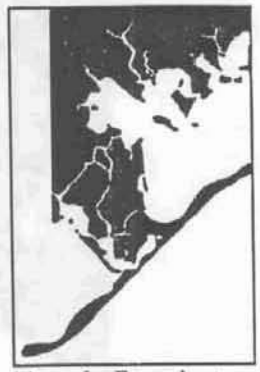

Figure 2. From chart circa 1848.

Figure 3. From chart circa 1860.

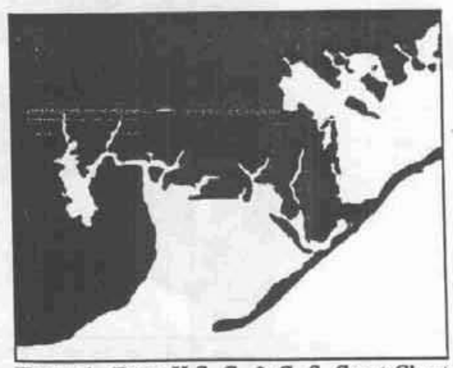

Figure 4. From U.S. C. & G. S. Coast Chart No. 189, 1896.

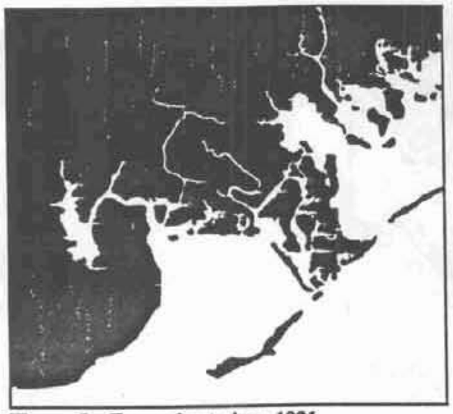

Figure 5. From chart circa 1921.

Figure 6. From aerial photograph of October 27, 1940.

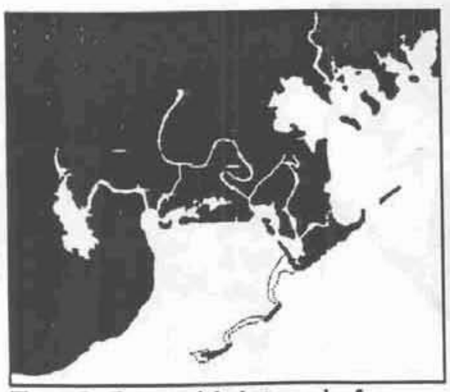

Figure 7. From aerial photograph of April 30, 1952.

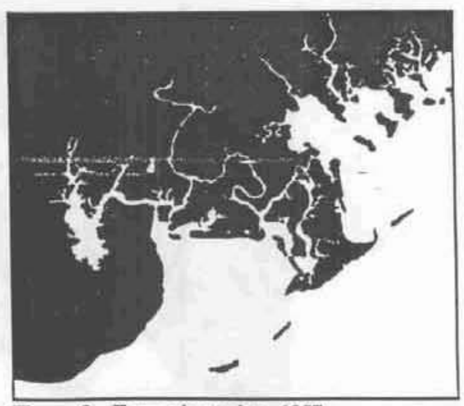

Figure 8. From chart circa 1957.

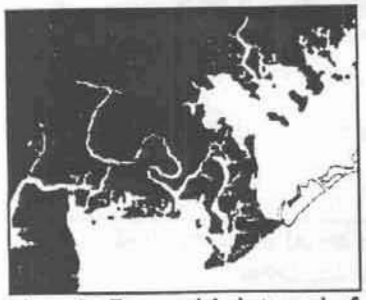

Figure 9. From aerial photograph of October 20, 1975.

Figure 10. From chart circa 1978.

Figure 11. From aerial photograph of November 15, 1979.

Figure 12. From aerial photograph of April 9, 1980.

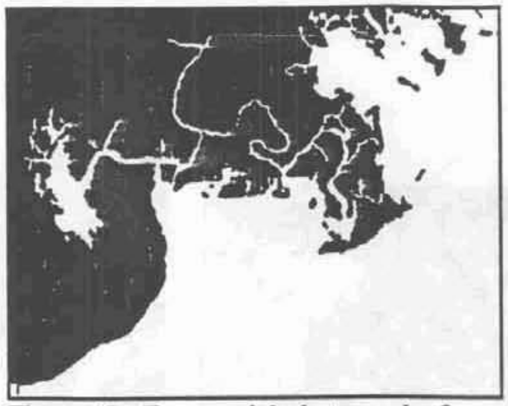

Figure 13. From aerial photograph of April 23, 1986.

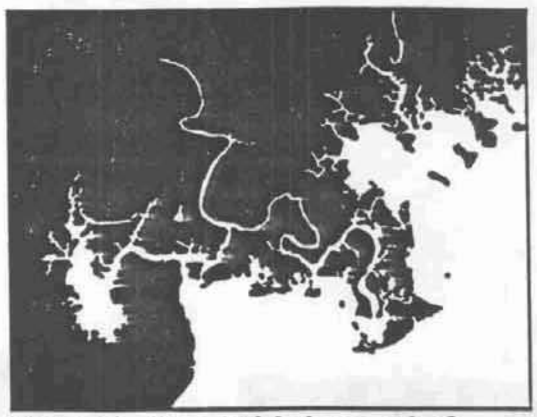

Figure 14. From aerial photograph of November 21, 1988.