An Analysis of Shoreline Change at Little Lagoon, Alabama

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(ABSTRACT)

In Alabama, the term “coastal shoreline” applies to the Gulf shoreline and the shorelines of estuaries, bays, and sounds connected to the Gulf of Mexico and subject to its tides. However, Alabama shoreline studies have yet to include Little Lagoon, which has been connected to the Gulf of Mexico for most of the last 200 years, according to historical charts. This study used historical nautical charts, aerial photographs, and LIDAR derived shorelines from 1917 to 2004 to analyze shoreline change on Little Lagoon and its adjacent Gulf shoreline. The high water line was used as the common reference feature, and all shorelines were georeferenced, projected, and digitized in a Geographic Information System.

Between 1917 and 2001, the Gulf shoreline eroded an average of 40 m over 12.7 km, with some transects eroding almost 120 m while others accreted almost 60 m. The greatest changes to the Gulf shoreline were found near natural inlets, downdrift of jetties, and coincident with nourishment projects. Between 1955 and 1997, Little Lagoon shrank 0.5%, or 51.4 km^2, from 10,285.9 km^2 to 10,234.5 km^2. The greatest changes to Little Lagoon were found on its southern shoreline and near inlets, human development, and hurricane overwash fans. A correlation analysis conducted on the Gulf shoreline and Little Lagoon’s southern shoreline indicated that although weak overall correlation values exist when the entire 12.7 km study area is compared, strong correlation values are obtained in some areas when compared over one kilometer sections. The strongest correlations were found in the same locations as the greatest changes.

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INTRODUCTION

Problem Statement

The effects of coastal engineering on beach dynamics have long been recognized, but scientists have yet to develop a mathematical model that can adequately predict such effects. Some coastal researchers now believe that a focus on qualitative, rather than quantitative, approaches will improve understanding of coastal processes (Cooper and Pilkey, 2004a). An understanding of beach behavior may be gained by observing coastal morphology of the proposed engineering site or a shoreline under similar conditions. Unfortunately, many miles of coastline have not been observed scientifically until recently, or in some cases not at all. However, aerial photography from as far back as the 1940's is available for many areas. Such photos often contain valuable information about coastal morphology, particularly for engineered tidal inlets (Fitzgerald *et al.*, 2003). Further, historical maps and nautical charts dating to the 1800s are also available.

This research uses free or relatively low-cost, easily obtained, aerial photography from 1940 to 2005, digitized nautical charts from 1917 to 1981, and historical maps from 1804 to 1950 (Appendix A) to study shoreline change near Gulf Shores, Alabama (Figure 1-1). In Alabama, the term "coastal shoreline" applies to the Gulf of Mexico shoreline and estuaries, bays, and sounds connected to the Gulf of Mexico and subject to its tides (Smith, 1986). Throughout most of the last 200 years, Little Lagoon has been connected to the Gulf of Mexico through natural tidal inlets. Since 1981 an engineered tidal inlet known as Little Lagoon Pass has connected the two. However, previous studies of Alabama shoreline change (Hardin *et al.*, 1976; Smith, 1991; Douglas *et al.*, 1998) have yet to include Little Lagoon. Shoreline change studies should consider a wider range of

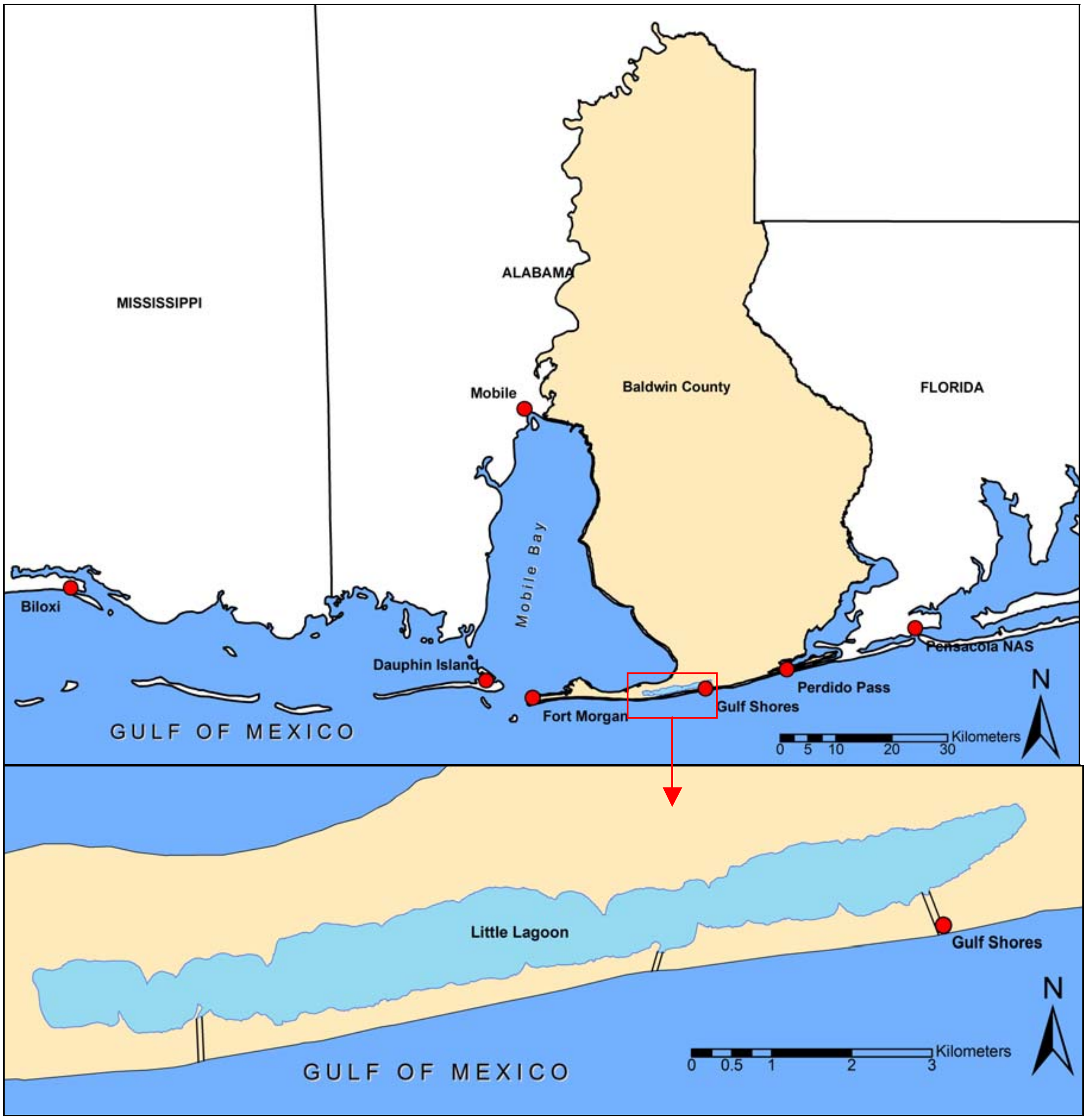


Figure 1-1 (Study Area)

beach types, like embayed beaches, including lagoons (Stephenson and Brander, 2003). The National Assessment of Shoreline Change (Morton, 2004) states that bay and lagoon shorelines show the longest stretches of erosion. This study analyzes changes to Little Lagoon's 30.5 km shoreline and the adjacent 12.7 km of Gulf shoreline, and examines their relationship.

Previous studies of Alabama shorelines have given little attention to the influence of tidal inlets, so literature describing changes along the shoreline south of Little Lagoon is absent. Also lacking is literature describing the location and nature of changes on Little Lagoon itself. As the area continues to develop (Figure 1-2) coincident with increased storm activity and relative sea level rise, the likelihood of repeated breaching of the narrow barrier between the Gulf of Mexico and Little Lagoon increases. Eventually, an alternative to the existing jettied inlet at Little Lagoon Pass may be sought, and a more astute understanding of coastal processes will be needed. By analyzing shoreline change at larger scales and shorter time periods, this study provides not only quantitative measurement, but also the qualitative analysis called for by Cooper and Pilkey (2004b).

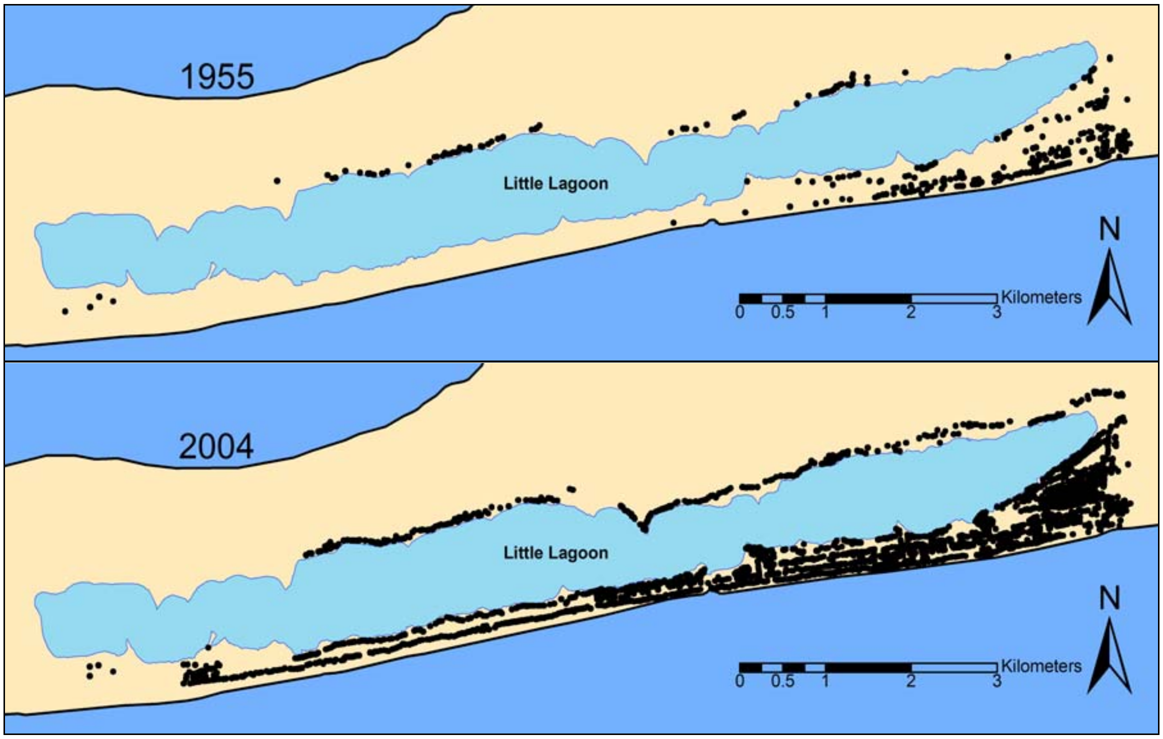
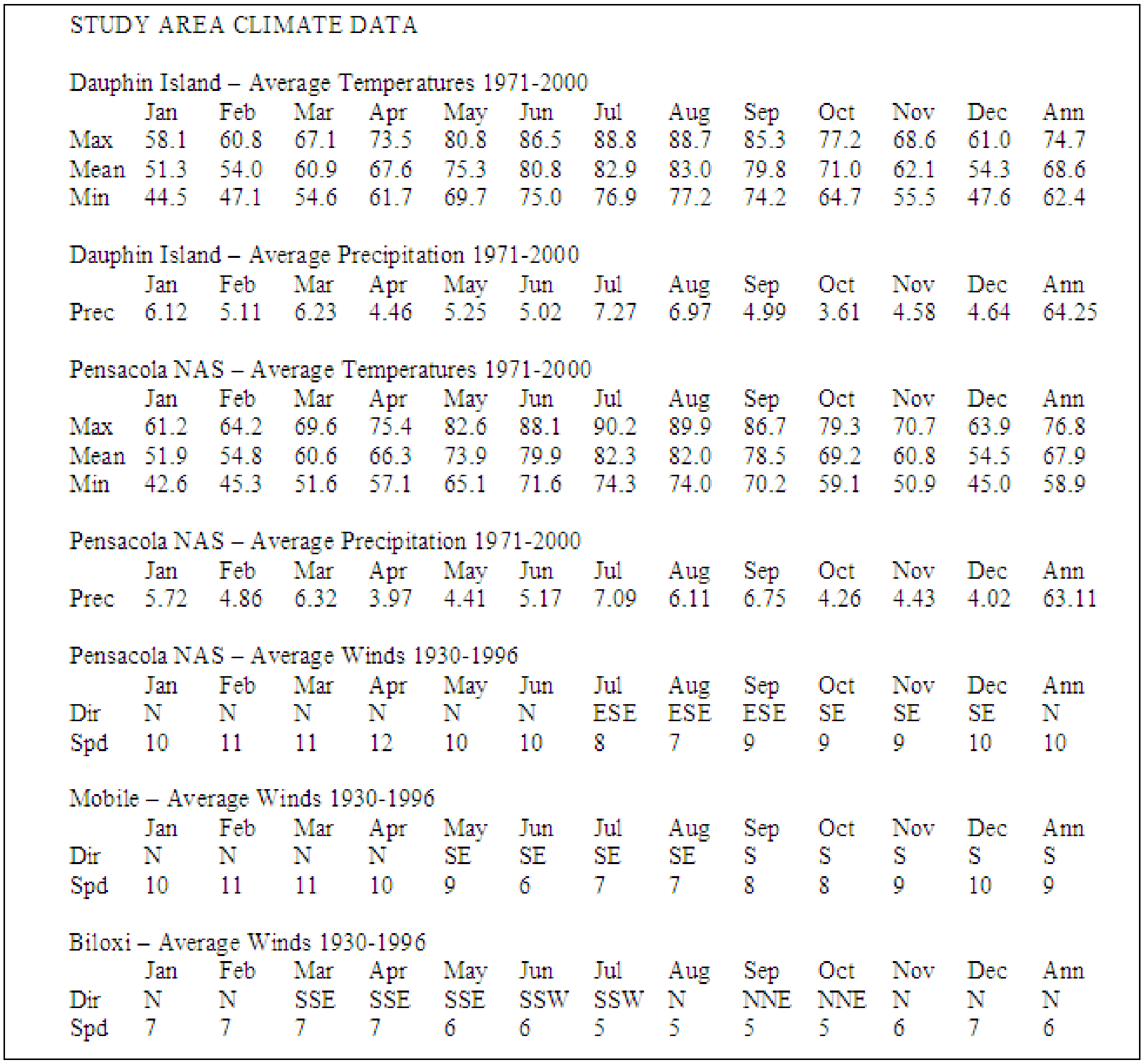


Figure 1-2 (Development 1955 and 2004)

Study Area

Alabama’s only sandy mainland shore is a stretch of beach in Baldwin County (Figure 1-1). Approximately 50 km in length, it spans from Mobile Point in the west to just east of Perdido Pass in the east. Little Lagoon (30°15’N, 87°45’W) is just west of the city of Gulf Shores. The lagoon is approximately 12.6 km in length and over 1 km wide at its widest point. The narrow strip of land between the Gulf shoreline and the lagoon’s southern shoreline is less than 180 m at its narrowest point. The study area is 12.7 km in length on the Gulf of Mexico shoreline and includes all of Little Lagoon’s shoreline.

Official precipitation totals at Pensacola Naval Air Station, one of the closest climate data recording stations, approximately 40 km east of Little Lagoon, averaged 63.11 in. annually between 1971 and 2000 (Table 1-1). There is no distinct wet or dry season, but July through September are among the rainiest months, while October through December are driest. July is the warmest month with an average high of 90.2° F, and January is coldest with an average low of 42.6° F. Based on official wind data for Pensacola NAS from 1930 to 1996, winds are predominantly from the north at 10kts per hour, but vary seasonally. During winter and spring the majority of winds are from the north at 10 to 12kts, summer winds are from the east-southeast at 7 to 9kts, and fall winds southeast at 9 to 10kts.



STUDY AREA CLIMATE DATA

Dauphin Island – Average Temperatures 1971-2000

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Max	58.1	60.8	67.1	73.5	80.8	86.5	88.8	88.7	85.3	77.2	68.6	61.0	74.7
Mean	51.3	54.0	60.9	67.6	75.3	80.8	82.9	83.0	79.8	71.0	62.1	54.3	68.6
Min	44.5	47.1	54.6	61.7	69.7	75.0	76.9	77.2	74.2	64.7	55.5	47.6	62.4

Dauphin Island – Average Precipitation 1971-2000

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Prec	6.12	5.11	6.23	4.46	5.25	5.02	7.27	6.97	4.99	3.61	4.58	4.64	64.25

Pensacola NAS – Average Temperatures 1971-2000

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Max	61.2	64.2	69.6	75.4	82.6	88.1	90.2	89.9	86.7	79.3	70.7	63.9	76.8
Mean	51.9	54.8	60.6	66.3	73.9	79.9	82.3	82.0	78.5	69.2	60.8	54.5	67.9
Min	42.6	45.3	51.6	57.1	65.1	71.6	74.3	74.0	70.2	59.1	50.9	45.0	58.9

Pensacola NAS – Average Precipitation 1971-2000

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Prec	5.72	4.86	6.32	3.97	4.41	5.17	7.09	6.11	6.75	4.26	4.43	4.02	63.11

Pensacola NAS – Average Winds 1930-1996

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Dir	N	N	N	N	N	N	ESE	ESE	ESE	SE	SE	SE	N
Spd	10	11	11	12	10	10	8	7	9	9	9	10	10

Mobile – Average Winds 1930-1996

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Dir	N	N	N	N	SE	SE	SE	SE	S	S	S	S	S
Spd	10	11	11	10	9	6	7	7	8	8	9	10	9

Biloxi – Average Winds 1930-1996

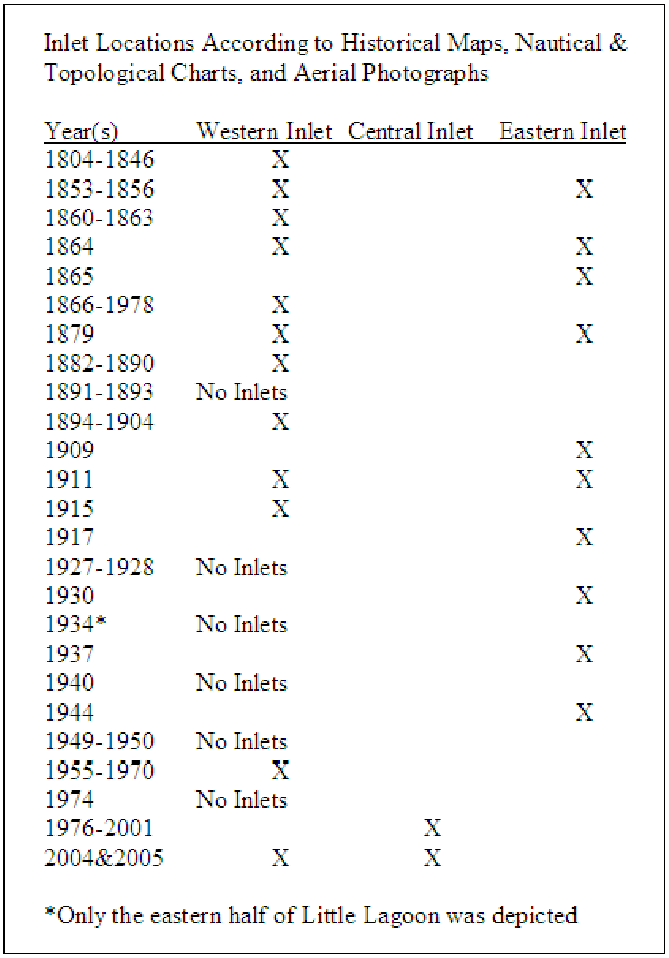
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Dir	N	N	SSE	SSE	SSE	SSW	SSW	N	NNE	NNE	N	N	N
Spd	7	7	7	7	6	6	5	5	5	5	6	7	6

Table 1-1 (Study area climate data according to National Climate Data Center reports)

According to Davies's (1980) distribution of tidal ranges, the study area is micro-tidal, with tides ranging less than 2 m. The mean wave height is 0.9 m and the average wave period is 5 seconds (http://chl.erdc.usace.army.mil). Beach face angles for Baldwin County average 6.9° (Smith and Parker 1990). Nearshore sediment is transported from east to west at about 45,000 m³ per year (Stone and Stapor 1996). The mean sea-level trend is between +2.14 mm per year at Pensacola and +2.43 mm per year at Dauphin Island (http://www.co-ops.nos.noaa.gov).

Inlets and Hurricanes

Little Lagoon has been connected to the Gulf of Mexico through natural and human-made tidal inlets for most of the last 200 years. Over the years, the inlets have opened, relocated, and closed, but even then Gulf waters probably interacted with the lagoon during the highest high tides (Hardin *et al.*, 1976). New inlets may compete with existing inlets, promoting their closure (Kraus and Wamsley, 2003). As documented on the historical maps (Appendix A), nautical charts, topological charts, and aerial photography used in this research, the study area has hosted tidal inlets at three main areas between 1804 and 2005 (Table 1-2 and Figure 1-3).



Inlet Locations According to Historical Maps, Nautical & Topological Charts, and Aerial Photographs

Year(s)	Western Inlet	Central Inlet	Eastern Inlet
1804-1846	X		
1853-1856	X		X
1860-1863	X		
1864	X		X
1865			X
1866-1978	X		
1879	X		X
1882-1890	X		
1891-1893	No Inlets		
1894-1904	X		
1909			X
1911	X		X
1915	X		
1917			X
1927-1928	No Inlets		
1930			X
1934*	No Inlets		
1937			X
1940	No Inlets		
1944			X
1949-1950	No Inlets		
1955-1970	X		
1974	No Inlets		
1976-2001		X	
2004&2005	X	X	

*Only the eastern half of Little Lagoon was depicted

Table 1-2 (Inlet Locations)

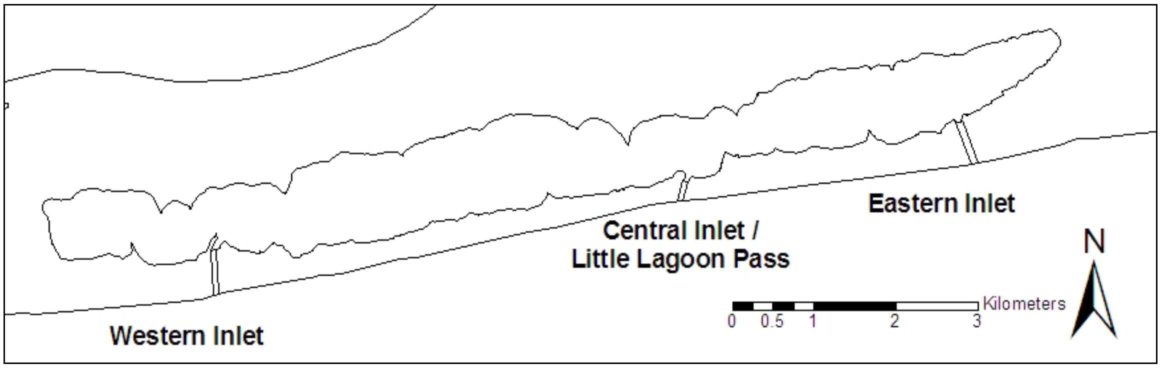
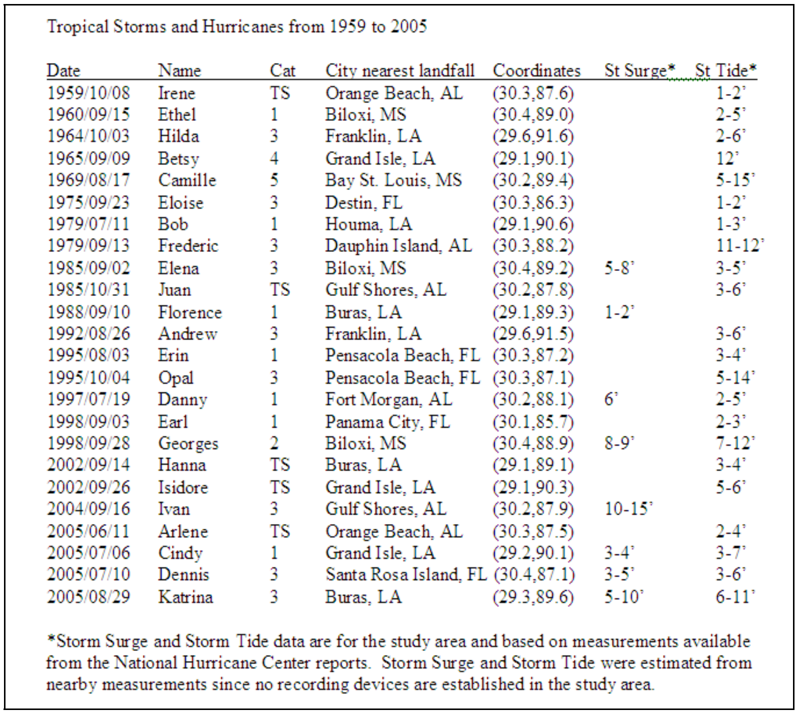


Figure 1-3 (Locations of natural inlets during last 200 years)

Since 1959, 24 hurricanes and tropical storms have affected the study area with associated storm tides or storm surges (Table 1-3). All of these storms made landfall on the Gulf Coast between June and October, but almost half (11) occurred during September. By applying the same distances of hurricane landfall from Little Lagoon as the 24 storms mentioned above, it may be reasoned that 87 storms impacted the study area between 1851 and 2005 (Tables 1-3 & 1-4 combined). Again, all of these storms made landfall between June and October, with 4 occurring in June, 9 in July, 17 in August, 41 in September, and 16 in October.

Though there is no definitive evidence that hurricanes were responsible for the opening or relocating of tidal inlets over the last 200 years, it is noteworthy that a few of the years in which inlets moved corresponded to storm years. For example, maps show that between 1846 and 1853 an additional inlet was opened, which corresponds to an 1852 category 3 hurricane landfall less than 100 km west of Little Lagoon. Similarly, the western inlet closed and one opened in the east between 1904 and 1909, coincident with a category 2 hurricane landfall approximately 100 km to the west in 1906. In 1979, Hurricane Frederic made landfall just west of the study area, and aerial photos taken over a month later still show the evidence of inlets that were opened by the storm. Also shown

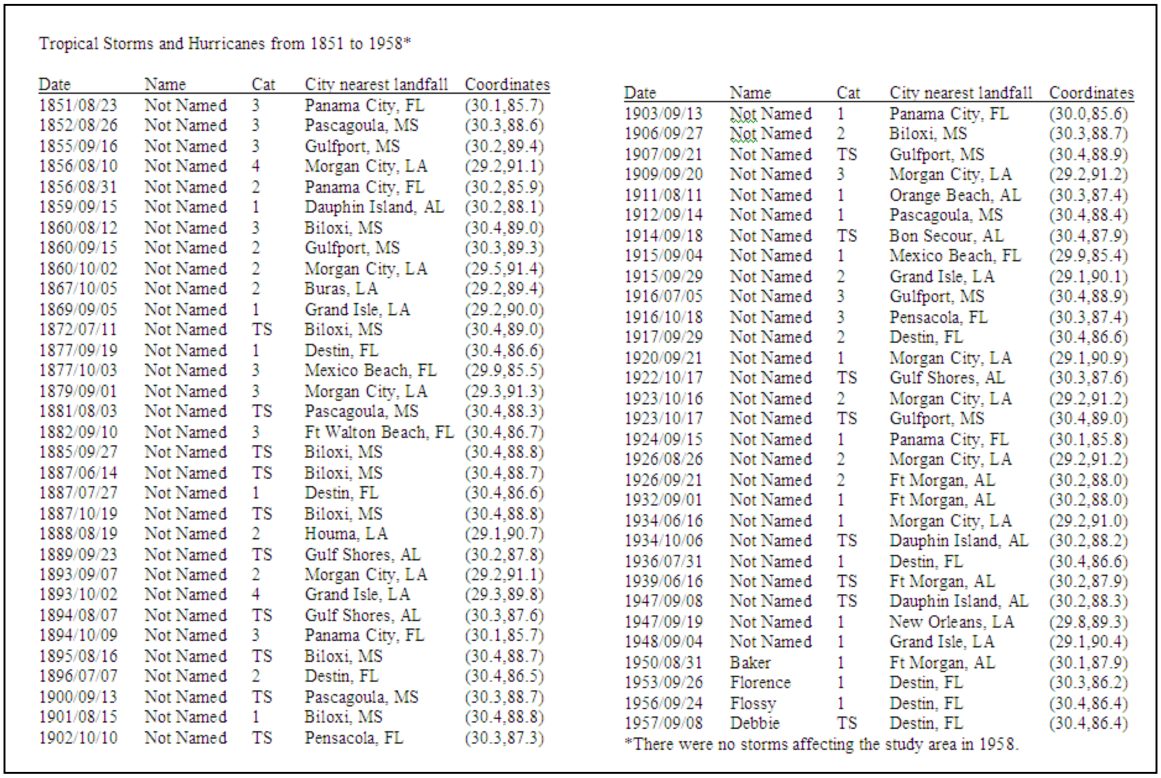


Tropical Storms and Hurricanes from 1959 to 2005

Date	Name	Cat	City nearest landfall	Coordinates	St Surge*	St Tide*
1959/10/08	Irene	TS	Orange Beach, AL	(30.3,87.6)		1-2’
1960/09/15	Ethel	1	Biloxi, MS	(30.4,89.0)		2-5’
1964/10/03	Hilda	3	Franklin, LA	(29.6,91.6)		2-6’
1965/09/09	Betsy	4	Grand Isle, LA	(29.1,90.1)		12’
1969/08/17	Camille	5	Bay St. Louis, MS	(30.2,89.4)		5-15’
1975/09/23	Eloise	3	Destin, FL	(30.3,86.3)		1-2’
1979/07/11	Bob	1	Houma, LA	(29.1,90.6)		1-3’
1979/09/13	Frederic	3	Dauphin Island, AL	(30.3,88.2)		11-12’
1985/09/02	Elena	3	Biloxi, MS	(30.4,89.2)	5-8’	3-5’
1985/10/31	Juan	TS	Gulf Shores, AL	(30.2,87.8)		3-6’
1988/09/10	Florence	1	Buras, LA	(29.1,89.3)	1-2’	
1992/08/26	Andrew	3	Franklin, LA	(29.6,91.5)		3-6’
1995/08/03	Erin	1	Pensacola Beach, FL	(30.3,87.2)		3-4’
1995/10/04	Opal	3	Pensacola Beach, FL	(30.3,87.1)		5-14’
1997/07/19	Danny	1	Fort Morgan, AL	(30.2,88.1)	6’	2-5’
1998/09/03	Earl	1	Panama City, FL	(30.1,85.7)		2-3’
1998/09/28	Georges	2	Biloxi, MS	(30.4,88.9)	8-9’	7-12’
2002/09/14	Hanna	TS	Buras, LA	(29.1,89.1)		3-4’
2002/09/26	Isidore	TS	Grand Isle, LA	(29.1,90.3)		5-6’
2004/09/16	Ivan	3	Gulf Shores, AL	(30.2,87.9)	10-15’	
2005/06/11	Arlene	TS	Orange Beach, AL	(30.3,87.5)		2-4’
2005/07/06	Cindy	1	Grand Isle, LA	(29.2,90.1)	3-4’	3-7’
2005/07/10	Dennis	3	Santa Rosa Island, FL	(30.4,87.1)	3-5’	3-6’
2005/08/29	Katrina	3	Buras, LA	(29.3,89.6)	5-10’	6-11’

*Storm Surge and Storm Tide data are for the study area and based on measurements available from the National Hurricane Center reports. Storm Surge and Storm Tide were estimated from nearby measurements since no recording devices are established in the study area.

Table 1-3 (Storm data from 1959 to 2005)



Tropical Storms and Hurricanes from 1851 to 1958*

Date	Name	Cat	City nearest landfall	Coordinates
1851/08/23	Not Named	3	Panama City, FL	(30.1,85.7)
1852/08/26	Not Named	3	Pascagoula, MS	(30.3,88.6)
1855/09/16	Not Named	3	Gulfport, MS	(30.2,89.4)
1856/08/10	Not Named	4	Morgan City, LA	(29.2,91.1)
1856/08/31	Not Named	2	Panama City, FL	(30.2,85.9)
1859/09/15	Not Named	1	Dauphin Island, AL	(30.2,88.1)
1860/08/12	Not Named	3	Biloxi, MS	(30.4,89.0)
1860/09/15	Not Named	2	Gulfport, MS	(30.3,89.3)
1860/10/02	Not Named	2	Morgan City, LA	(29.5,91.4)
1867/10/05	Not Named	2	Buras, LA	(29.2,89.4)
1869/09/05	Not Named	1	Grand Isle, LA	(29.2,90.0)
1872/07/11	Not Named	TS	Biloxi, MS	(30.4,89.0)
1877/09/19	Not Named	1	Destin, FL	(30.4,86.6)
1877/10/03	Not Named	3	Mexico Beach, FL	(29.9,85.5)
1879/09/01	Not Named	3	Morgan City, LA	(29.3,91.3)
1881/08/03	Not Named	TS	Pascagoula, MS	(30.4,88.3)
1882/09/10	Not Named	3	Ft Walton Beach, FL	(30.4,86.7)
1885/09/27	Not Named	TS	Biloxi, MS	(30.4,88.8)
1887/06/14	Not Named	TS	Biloxi, MS	(30.4,88.7)
1887/07/27	Not Named	1	Destin, FL	(30.4,86.6)
1887/10/19	Not Named	TS	Biloxi, MS	(30.4,88.8)
1888/08/19	Not Named	2	Houma, LA	(29.1,90.7)
1889/09/23	Not Named	TS	Gulf Shores, AL	(30.2,87.8)
1893/09/07	Not Named	2	Morgan City, LA	(29.2,91.1)
1893/10/02	Not Named	4	Grand Isle, LA	(29.3,89.8)
1894/08/07	Not Named	TS	Gulf Shores, AL	(30.3,87.6)
1894/10/09	Not Named	3	Panama City, FL	(30.1,85.7)
1895/08/16	Not Named	TS	Biloxi, MS	(30.4,88.7)
1896/07/07	Not Named	2	Destin, FL	(30.4,86.5)
1900/09/13	Not Named	TS	Pascagoula, MS	(30.3,88.7)
1901/08/15	Not Named	1	Biloxi, MS	(30.4,88.8)
1902/10/10	Not Named	TS	Pensacola, FL	(30.3,87.3)
1903/09/13	Not Named	1	Panama City, FL	(30.0,85.6)
1906/09/27	Not Named	2	Biloxi, MS	(30.3,88.7)
1907/09/21	Not Named	TS	Gulfport, MS	(30.4,88.9)
1909/09/20	Not Named	3	Morgan City, LA	(29.2,91.2)
1911/08/11	Not Named	1	Orange Beach, AL	(30.3,87.4)
1912/09/14	Not Named	1	Pascagoula, MS	(30.4,88.4)
1914/09/18	Not Named	TS	Bon Secour, AL	(30.4,87.9)
1915/09/04	Not Named	1	Mexico Beach, FL	(29.9,85.4)
1915/09/29	Not Named	2	Grand Isle, LA	(29.1,90.1)
1916/07/05	Not Named	3	Gulfport, MS	(30.4,88.9)
1916/10/18	Not Named	3	Pensacola, FL	(30.3,87.4)
1917/09/29	Not Named	2	Destin, FL	(30.4,86.6)
1920/09/21	Not Named	1	Morgan City, LA	(29.1,90.9)
1922/10/17	Not Named	TS	Gulf Shores, AL	(30.3,87.6)
1923/10/16	Not Named	2	Morgan City, LA	(29.2,91.2)
1923/10/17	Not Named	TS	Gulfport, MS	(30.4,89.0)
1924/09/15	Not Named	1	Panama City, FL	(30.1,85.8)
1926/08/26	Not Named	2	Morgan City, LA	(29.2,91.2)
1926/09/21	Not Named	2	Ft Morgan, AL	(30.2,88.0)
1932/09/01	Not Named	1	Ft Morgan, AL	(30.2,88.0)
1934/06/16	Not Named	1	Morgan City, LA	(29.2,91.0)
1934/10/06	Not Named	TS	Dauphin Island, AL	(30.2,88.2)
1936/07/31	Not Named	1	Destin, FL	(30.4,86.6)
1939/06/16	Not Named	TS	Ft Morgan, AL	(30.2,87.9)
1947/09/08	Not Named	TS	Dauphin Island, AL	(30.2,88.3)
1947/09/19	Not Named	1	New Orleans, LA	(29.8,89.3)
1948/09/04	Not Named	1	Grand Isle, LA	(29.1,90.4)
1950/08/31	Baker	1	Ft Morgan, AL	(30.1,87.9)
1953/09/26	Florence	1	Destin, FL	(30.3,86.2)
1956/09/24	Flossy	1	Destin, FL	(30.4,86.4)
1957/09/08	Debbie	TS	Destin, FL	(30.4,86.4)

*There were no storms affecting the study area in 1958.

Table 1-4 (Storm data from 1851 to 1958) in those photos are large overwash fans, areas where Gulf of Mexico sediment was carried over the barrier and deposited on Little Lagoon's southern shoreline as a typical alluvial fan. Hurricanes Ivan and Katrina opened additional inlets in 2004 and 2005 respectively (Figure 1-4). Possibly there are other instances, but without knowing exactly when the historical maps were penned it is impossible to draw any further conclusions.

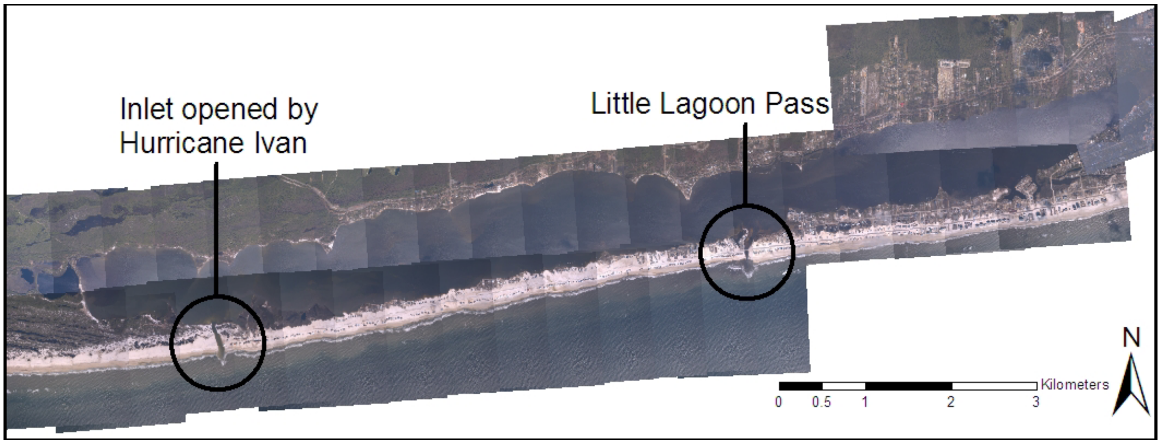


Figure 1-4 (Post-Hurricane Ivan Inlets, courtesy of NOAA)

Spatial and Temporal Scale

The previously mentioned studies of Alabama's shoreline were broader in scope than this research, covering over 800 km of total shoreline and about 70 km of Gulf beachfront, which may explain their lack of great detail for any one particular area. However, when studies conducted by Stone and Stapor (1996) and Cipriani and Stone (2001) are combined, they identify 23 separate sediment transport cells between Apalachicola Bay, Florida, and the Mississippi Barrier Islands, which in itself demands that shorelines be studied on a larger scale (smaller area). To further illustrate the need for larger scale, this paper will later show that the average change of the Gulf shoreline within the study area from 1917 to 2001 is –40 m, but even on the relatively short 12.7

km strip of beach measurements range from almost –120 m to over +60 m. It is important to understand why the changes occurred where they did and when they did.

Gibeaut (2000) defined long-term change as occurring over tens to thousands of years, short-term change occurring over several seasons to 10 years, and episodic change occurring in response to a single storm. Cowell and Thom (1994) defined times scales as either 1) *instantaneous,* for seconds to days, 2) *event,* for days to years, 3) *engineering,* for years to centuries, or 4) *geological,* spanning decades to millennia. Shoreline studies often focus on long-term change or engineering time scales. However, coarse temporal resolution can conceal important, dramatic changes that occur over shorter intervals. For example, as mentioned before, this study area's Gulf shoreline eroded an average of 40 m between 1917 and 2001. Oddly enough, the average change for the same area between 1917 and 1955 is –40 m. So does that mean all of the change between 1917 and 2001 actually occurred prior to 1955? In fact, it is known that some of the most dramatic changes happened after 1955. For this study, change will be analyzed for periods ranging from 4 to 15 years, with the exception being the 1917 to 1955 time period.

By studying shoreline change on larger spatial scales, I expect to find that rates of change vary significantly over short distances. By using shorter temporal scales, I expect to find that rates of change will also vary greatly for the same places at different times. The areas of greatest change should occur near tidal inlets, hurricane overwash fans, and human impacts like coastal construction and beach nourishment projects. By comparing change on adjacent shorelines, I will also show that statistically significant relationships exist near tidal inlets.

COASTAL PROCESSES

Beach Morphology

The beach acts as the seaward protection for the coast. It extends from the low tide line landward to the next geomorphologic feature. As shown in Figure 2-1, the beach can be further divided into the foreshore and the backshore. The foreshore, or beachface, includes the intertidal portion of the beach and extends landward to the berm. It includes the swash zone, where waves uprush and backwash as they meet the shore. The backshore extends from the berm landward to the next feature, which in the case of this study area would be human development. The backshore will not be discussed in this study, except to say that overwash may occur during storms. Because their adjacent waters directly influence coastal landscapes, I will also discuss the nearshore environment. The nearshore includes the shallow marine waters extending from the low tide line seaward to include sand bars.

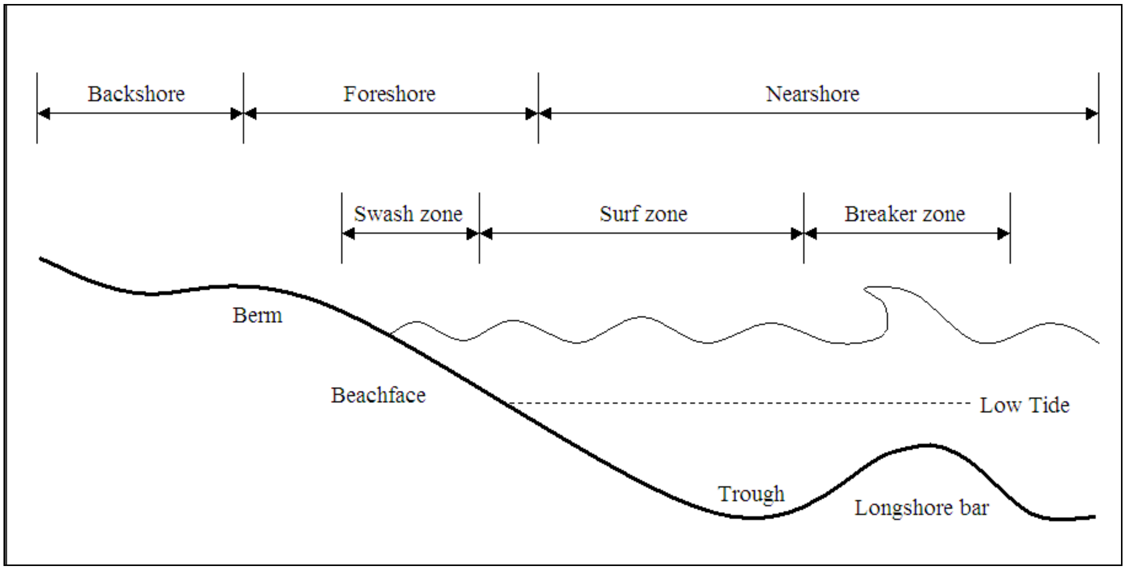


Figure 2-1 (Beach profile)

The planform shape of a beach is related to the direction of wave approach (Woodroffe, 2003). Breaking waves produce obvious interaction with the beach, placing sediments into temporary suspension. Nearshore currents then move the suspended sediment. If waves approach parallel to the shore they do not move sediment alongshore, and the beach tends to be curved, or swash-aligned (Stapor, 1971; Davies, 1980). However, waves approaching the shore at approximately 30-45° produce the greatest rates of sediment transport resulting in long, straight, or drift-aligned, beaches. Rhythmic crescentic features formed by swash action, called beach cusps, can accentuate the overall shape of a beach (Figure 2-2). They occur in a series with varying distances, like swash cusps spaced 8–25 m, storms cusps spaced 70–120 m, and giant cusps spaced 700–1500 m (Dolan, 1971). Beach cusps may be self-organized features that develop by positive feedback between swash flow and morphology, accentuating random morphological irregularities (Werner and Fink, 1993; Coco *et al*., 1999). The beach moulds to adjust to changes in wave energy by the movement of sediment (Reeve *et al*., 2001). Process adjustments may be instantaneous, but morphology will lag because of the time required to move sediments. The beach will continue to change in an attempt to reach equilibrium.

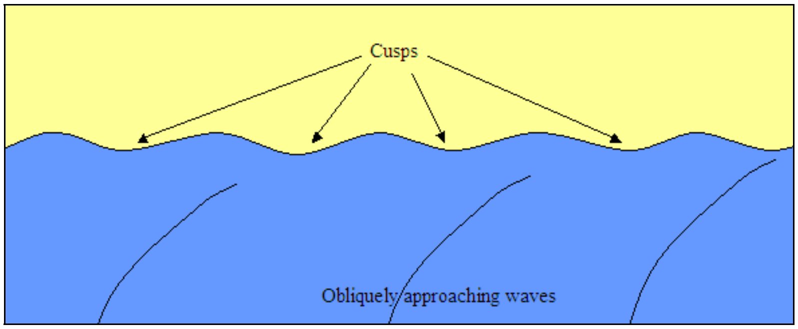


Figure 2-2 (Beach cusps on a drift-aligned beach)

The relationship between beach profile and wave conditions promotes negative feedback cycles. Under calm conditions, or "summer profile," sand is transported onshore resulting in beach accretion. As it builds up, the slope of the beach steepens until it is sufficiently altered to stop onshore transport. During storm conditions, or "winter profile," sand is transported offshore resulting in the development of an offshore bar. Wave energy is reduced by waves breaking on the bar before reaching the shore, limiting further erosion.

Longshore Currents

Currents produced by waves are among the most important agents of change on the beach (Davis and Fitzgerald, 2004). They include longshore currents, rip currents, and the onshore-offshore currents, and are responsible for the transport of sediment (Figure 2-3). Longshore currents dominate and travel parallel to the coast

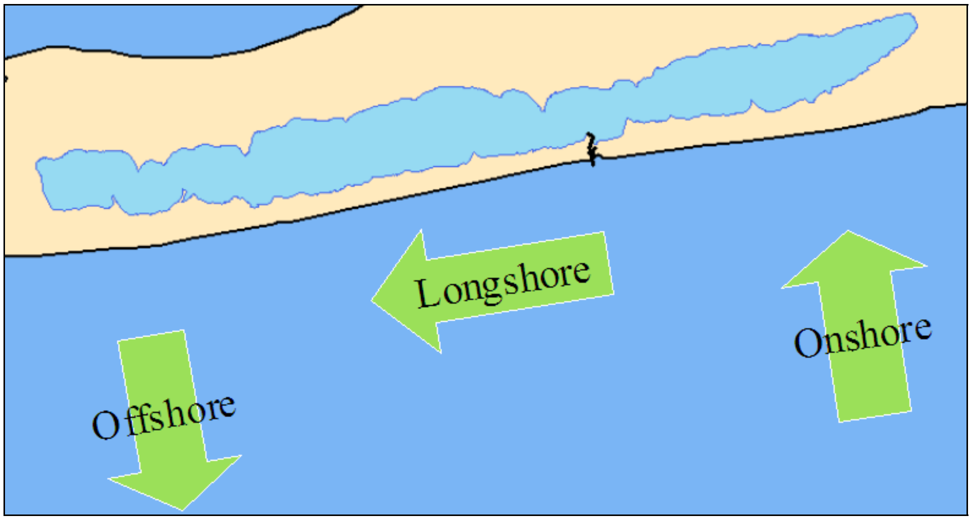


Figure 2-3 (Nearshore currents)

(Huggett, 2003). They are the currents generated by obliquely approaching waves that run up the shore in the direction of wave propagation but move down the steepest slope, perpendicular to the shoreline. This parabolic path creates an overall movement along the shore. Longshore currents are confined to the surf zone, with a seaward boundary at the breaker line and a landward boundary at the shoreline. The greatest velocities occur near the middle of the surf zone: normally a few centimeters per second, but reaching speeds of more than a meter per second in storm conditions. The net removal of material from a stretch of coast by longshore currents may result in coastal erosion, while the net influx of sediment by longshore currents may cause coastal accretion (Masselink and Hughes, 2003). These morphological changes will continue until the beach is shaped in a way that waves only approach parallel to the shore and longshore transport ceases.

Tidal Inlets

The influence of currents created by rising and falling tides is subtler, except near the mouth of tidal inlets. A tidal inlet is a restricted, relatively narrow channel developed across a barrier where tidal currents are accelerated (Isla, 1995). They maintain a passageway between open waters, like oceans and gulfs, to confined waters like bays, lagoons, and estuaries. Tidal currents increase at the inlet mouth during flood tides when the water level of the ocean rises faster than that inside the inlet, creating a water surface slope that forces water into the inlet. Similarly, during ebb tides the water level of the ocean falls faster than that inside the inlet, creating currents that exit the tidal inlet in a jet-like fashion. The volume of water moving through a tidal inlet is termed the tidal prism and is closely related to the cross-sectional area. If the inlet size decreases, flow velocity increases and sediments within the inlet will be removed. If inlet size increases, flow velocity decreases and sediments will be deposited in the inlet. If the inlet shoals to the point of instability it will close. The flood tides carry sediment that was entrained primarily by wave currents, and they settle inside the inlet and embayed waters during slack high tide, called "settling lag." Without the wave action in the embayment, the high current velocities required to entrain sediments are not present during ebb tides, resulting in a net landward flux (Woodroffe, 2003). The sediments deposited landward of the inlet form a flood-tidal delta and those deposited on the seaward side form an ebb-tidal delta.

Tidal inlets are not only responsible for the temporary loss of sediments during a tidal cycle, but also for longer-term interruption of longshore transport along the coast, affecting the position and mechanisms of sediment transfer along the shoreline (Nordstrom, 1987). Tidal inlets migrate when longshore transport adds sediment predominantly to the updrift side of the inlet and erodes it from the other. The migration is usually in the direction of transport. If the inlet is stable over the long term, then the beach and inlet have reached a form of equilibrium that allows for sediment bypassing (Davis and Fitzgerald, 2004).

The relationship between the cross-sectional area of tidal inlets and their tidal prism possesses considerable variability, largely because many inlets are controlled by physical structures like jetties. Jetties are walls built to line the banks of tidal inlets to stabilize the waterway for navigation. The jetties extend into the sea, interrupting longshore transport, and promoting deposition on the updrift side and erosion on the downdrift side (Figure 2-4). Also, jettied inlets continue to shoal and require dredging to maintain adequate depths. The dredged sediments are often deposited on the downdrift side of the inlet as nourishment projects to mitigate erosion.

Figure 2-4 (Direction of longshore transport, Little Lagoon Pass, 1989)

Nourishment Projects

Nourished beaches are built into a short-term state of disequilibrium that is smoothed out by surf-zone processes and longshore currents in the months after emplacement (Walton, 1994; Larson *et al.*, 1999). Therefore, the deposited sediments are often rapidly eroded and need regular replenishing; often sourced by dredging coastal waters (Masselink and Hughes, 2003). Typically, the size of the sand used for nourishment must be equal to or somewhat coarser than that of local sediments to create a steeper profile and minimize rapid sediment loss offshore (Dean and Yoo, 1992; Stive *et al.*, 1991). Like other forms of coastal protection, nourishment projects only treat the symptoms of coastal erosion, and are not a long-term solution. However, it is often the preferred method because it is relatively cost efficient and appears more natural than physical structures like groins designed to capture sediments by blocking longshore transport.

Coastal Lagoons

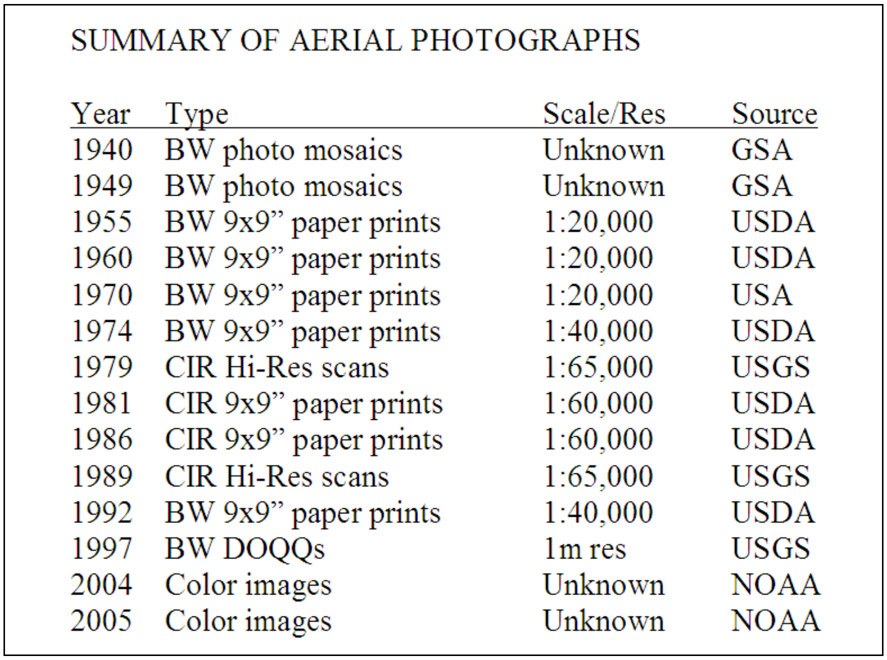
Not only do tidal inlets accommodate navigation, but they are also conduits through which nutrients are exchanged between confined and open waters. In many lagoons, tidal inlets maintain salinities, temperatures, and nutrient levels. Coastal lagoons are impounded water bodies that represent an extreme form of barrier estuary (Cooper, 1994; Isla, 1995). Typical coastal processes such as tides and waves are not prevalent in lagoons, except near tidal inlets (Davis and Fitzgerald, 2004). They are often shallow and elongated, parallel to the coast, and seldom more than a kilometer wide. Because of their shape and confinement, often the only circulation within a lagoon is generated by wind waves formed over a limited fetch. On a geological time scale, lagoons are short-lived features controlled by sea level and climate (Woodroffe, 2003). Many coastal lagoons are not in equilibrium because they are subject to barrier transgression, relative sea-level change, and input of sediment from seaward and landward sources (Nichols, 1989).

DATA & METHODS

Data

Three types of data were used in this study. First, digital vector shorelines (DVS) were downloaded from the National Ocean Service (NOS) Data Explorer website (http://www.ngs.noaa.gov/newsys_ims/shoreline/index.cfm) for 1917, 1934, 1958, and 1981. However, the 1934 and 1958 digital vector shorelines only covered approximately half of the study area and therefore were used only for reference, not measuring change. The 1917 vector shoreline did not include Little Lagoon and could only be used for measuring change along the Gulf shoreline. The 1981 vector shoreline completely covered the study area.

I collected the aerial photography from a variety of sources (Table 3-1). Digital Orthophoto Quarter Quadrangles (DOQQs) were from the United States Geological



SUMMARY OF AERIAL PHOTOGRAPHS

Year	Type	Scale/Res	Source
1940	BW photo mosaics	Unknown	GSA
1949	BW photo mosaics	Unknown	GSA
1955	BW 9x9" paper prints	1:20,000	USDA
1960	BW 9x9" paper prints	1:20,000	USDA
1970	BW 9x9" paper prints	1:20,000	USA
1974	BW 9x9" paper prints	1:40,000	USDA
1979	CIR Hi-Res scans	1:65,000	USGS
1981	CIR 9x9" paper prints	1:60,000	USDA
1986	CIR 9x9" paper prints	1:60,000	USDA
1989	CIR Hi-Res scans	1:65,000	USGS
1992	BW 9x9" paper prints	1:40,000	USDA
1997	BW DOQQs	1m res	USGS
2004	Color images	Unknown	NOAA
2005	Color images	Unknown	NOAA

Table 3-1

Survey (USGS) Earth Explorer website (http://edcsns17.cr.usgs.gov/EarthExplorer), and received on disk along with high resolution (21-micron) scans of 1979 and 1989 color infrared photography (CIR).

Paper photographs were from the United States Department of Agriculture's (USDA) Aerial Photography Field Office. The 1955, 1960,1974, and 1992 photos were black and white 9x9" prints, while the 1981 and 1986 were CIR.

I downloaded post-Hurricane Ivan photos from the National Oceanographic and Atmospheric Administration (NOAA) website (http://alt.ngs.noaa.gov/ivan). The photos were taken the day after Hurricane Ivan made landfall on the study area on September 16, 2004, but they were not usable in this study for measuring change because of the significant impacts major storms have on coastal geomorphology. However, because Little Lagoon does not have strong currents or circulation, sediments deposited after major storms in the form of overwash fans tend to remain. Therefore the 2004 post-Ivan photos were suitable for measurement of change on Little Lagoon's shoreline. Post-Hurricane Katrina photos (NOAA) did not completely cover the study area and were only used for reference.

I scanned black and white aerial photos at the University of South Alabama's (USA) Engineering Department for 1970 and used them to measure change. USA's Engineering Department also archives aerial photos taken by the Alabama Department of Environmental Management (ADEM) every September since 1992, but because they did not cover Little Lagoon they were not used in this study. Photomosaics were scanned at the Geological Survey of Alabama for 1940 and 1949, but were used only for reference.

Finally, a LIDAR-derived vector shoreline from 2001 was downloaded from the USGS's Coastal and Marine Geology Program (http://pubs.usgs.gov/of/2004/1089/gis-data.html) along with transects, a baseline, and a vector representing nourishment projects created by Miller *et al*. (2004).

Methods

Data were analyzed using ArcMap 9.1. The use of Geographic Information Systems (GIS) should provide more accurate estimates of shoreline change than previous research studies because of the limitations in methods and equipment used in older studies (Langley *et al*., 2003). The DOQQs were loaded first. Because they were already spatially referenced to Universal Transmercator (UTM) North American Datum (NAD) 83, Zone 16, I used that projection for all other data.

Paper prints were scanned and saved as a tagged image file formats (TIFF). All TIFFs, including the Hi-Res scans obtained from the USGS, were added to ArcMap and georeferenced to the DOQQs using the Georeferencing Tools. I applied sixteen ground control points (GCPs) to all but the 2004 post-Ivan photos. For those, only three GCPs were needed to ensure a good fit because of their large scale. With a first order polynomial transformation for the post-Ivan photos and a third order for all others, the total root mean square (rms) error was less than 1.5 m for every photo, well within the 0.5 to 3.0 m rms error typical of shoreline change studies (Fletcher *et al*., 2003).

The next step was to determine a shoreline reference feature upon which to base measurements. This study used the high-water line (HWL) because it was easily distinguishable on all photos as a wet/dry line (Figure 3-1). Also, the HWL is the legal shoreline of the United States, represented in NOAA nautical charts, and is considered the most consistent reference feature (Parker, 2003).

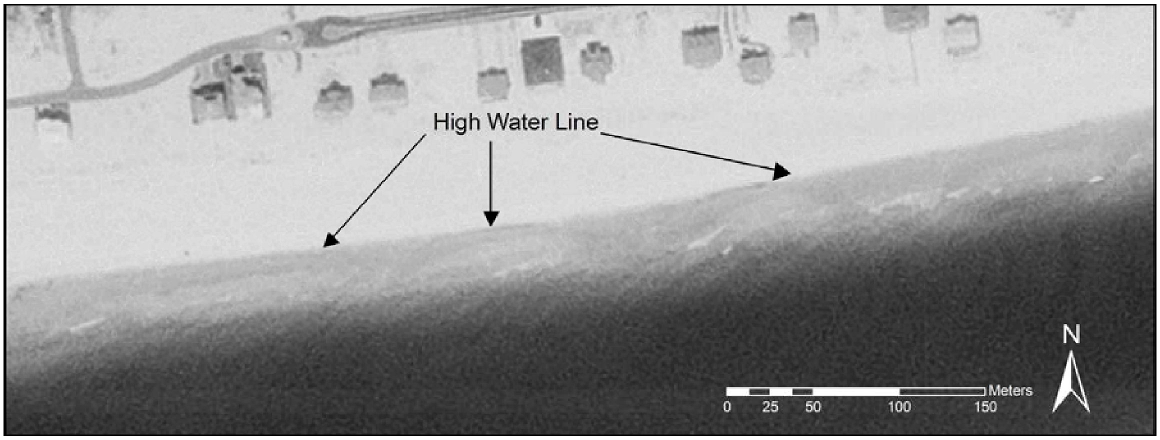


Figure 3-1 (Example of distinguishable HWL)

I digitized the HWL manually by creating a new line feature in ArcMap. By zooming to a 1:1,000 scale, I was able to follow contours along the wet/dry line by adding vertices at each change in direction. The contrast between wet and dry sand varied over distance so more automated methods like assigning unique colors to each of the 256 values in the black and white photos failed because no single spectral value appeared to follow the HWL consistently. A supervised classification of the CIR images also failed to follow the HWL consistently.

In ArcMap, I added the baseline downloaded from the USGS upon which to base all Gulf shoreline measurements. The baseline is positioned over water, parallel with the general shape of the beach. Next I added the transects downloaded from USGS. The transects are spaced 50 m apart perpendicular to the baseline, covering about 12.7 km of shoreline south of Little Lagoon. The transects are numbered 1–254 from east to west, following the direction of longshore transport (Figure 3-2).

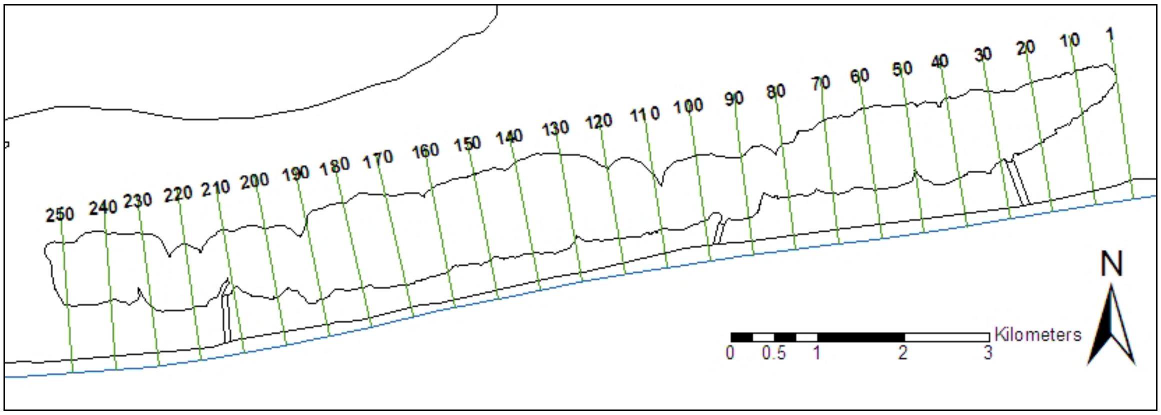


Figure 3-2 (Transect numbering)

I used the Intersection Tool in ArcMap to create a point where transects and digitized shorelines intersected. However, the utility of the Intersection Tool was somewhat limited because it would create more than one point on a transect when the shoreline crossed the transect more than once, as was often the case near tidal inlets. Also, no point was created where the shoreline did not cross a transect, a situation that occurred when the transect happened to lie within a tidal inlet. Some manipulation was required to ensure that only one point existed along each transect, and that the points were in the same order as the numbered transects. The points were then spatially joined to the baseline (Figure 3-3) to create a field that calculated the shortest perpendicular distance from each point to the baseline. The process was repeated for Little Lagoon's southern shoreline, but only to facilitate a correlation analysis.

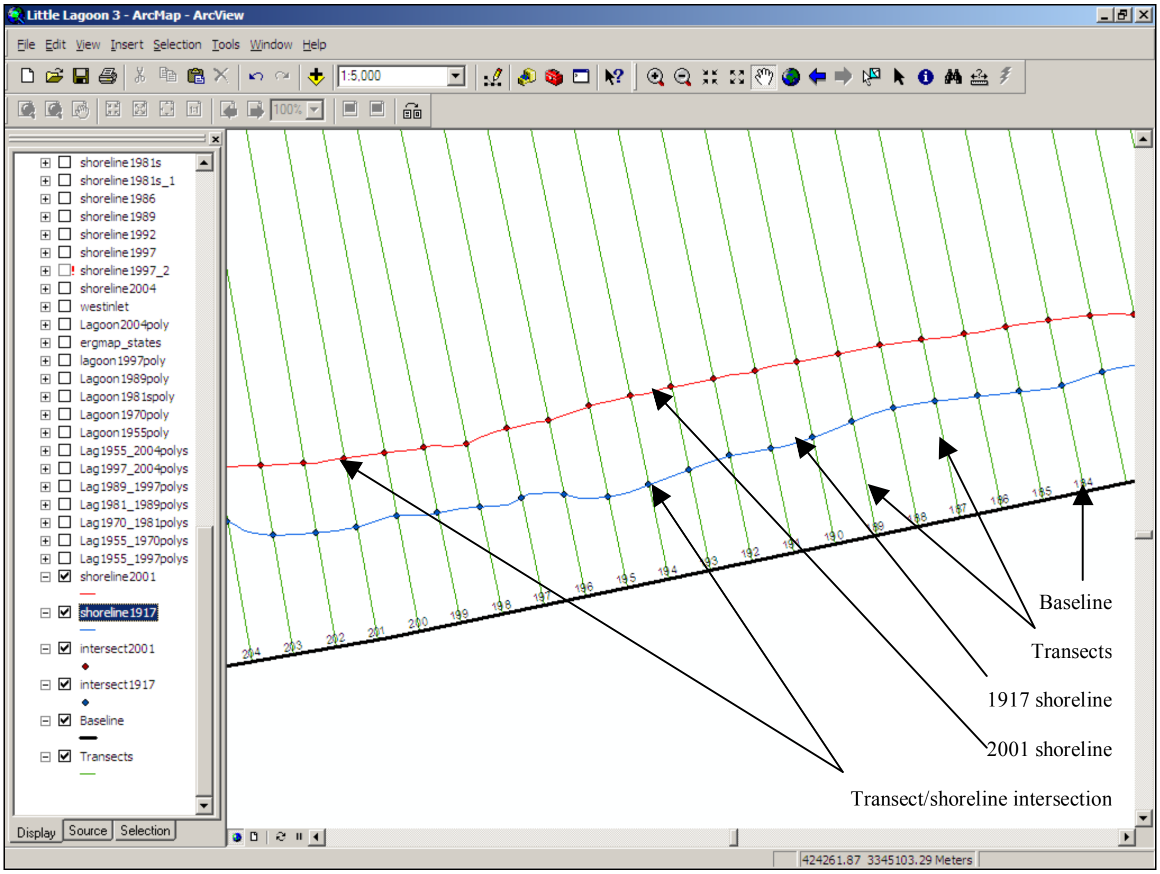


Figure 3-3 (Digitized shorelines in ArcMap)

The distance field for each year group was then copied into an Excel spreadsheet. I calculated the amount of change along each transect between years by subtracting the distances of one year group from the distances of another year group. Then graphs like the one in Figure 3-4 were created with exaggerated scales to highlight areas of significant change.

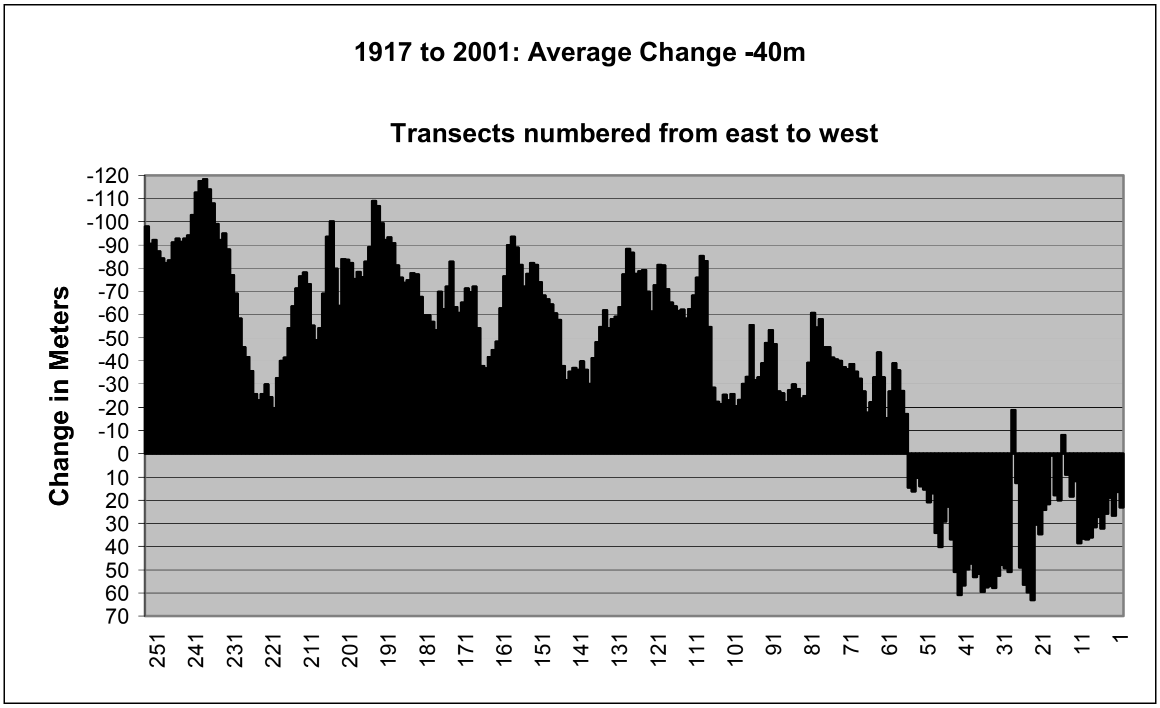
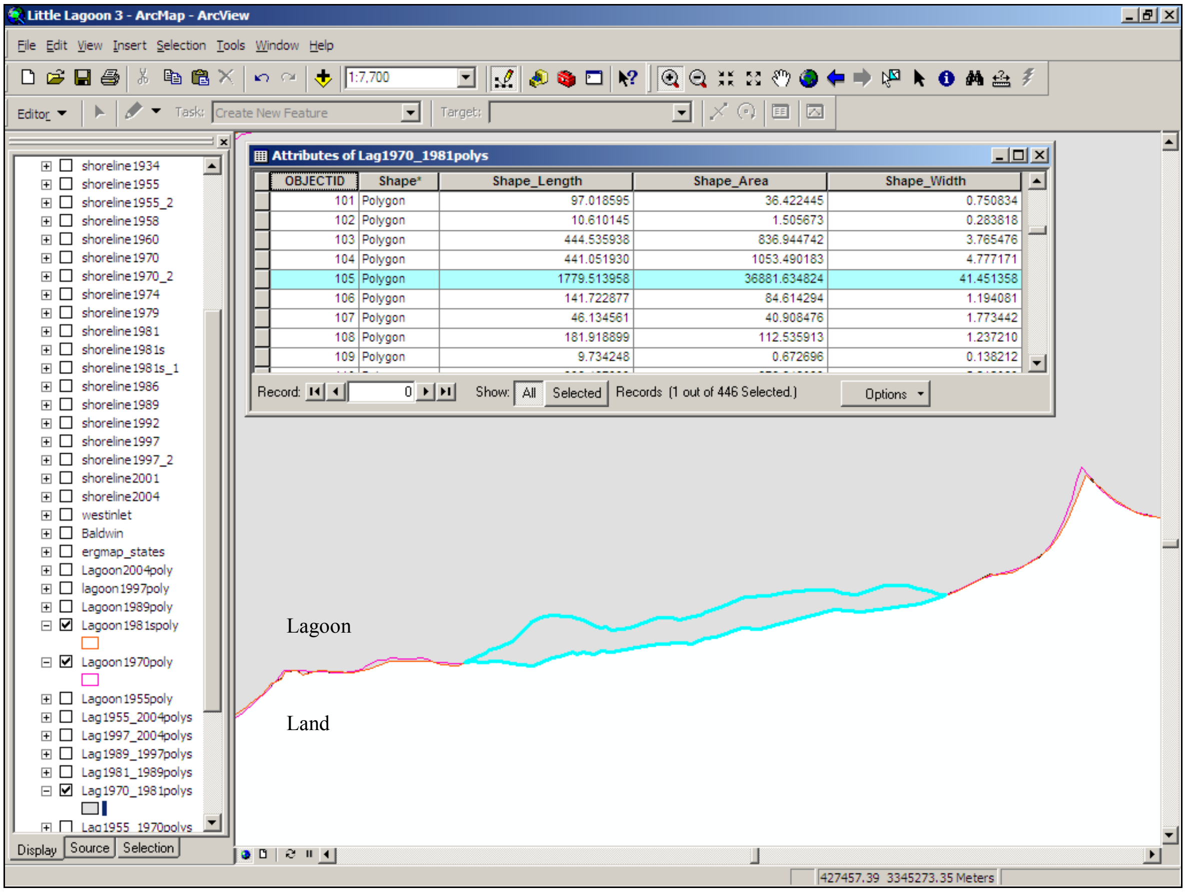


Figure 3-4 (Example shoreline change chart)

The change on Little Lagoon's shoreline was calculated differently. Because the lagoon shoreline has steep curves in many places, linear transects will exaggerate the amount of change significantly even with the slightest error associated with the georeferencing process. Therefore the lagoon shoreline was digitized into a polygon shapefile. By combining two polygons from different years using the Construct Features tool in ArcMap, I was able to create polygons representing the areas of change between years (Figure 3-5). This tool also provides a shape area for the new polygons, as well as a shape length. By dividing the shape area by half the shape length, the average accretion or erosion can be calculated along linear stretches of Little Lagoon's shoreline.



Attributes of Lag1970_1981polys

OBJECTID	Shape*	Shape_Length	Shape_Area	Shape_Width
101	Polygon	97.018595	36.422445	0.750834
102	Polygon	10.610145	1.505673	0.283818
103	Polygon	444.535938	836.944742	3.765476
104	Polygon	441.051930	1053.490183	4.777171
105	Polygon	1779.513958	36881.634824	41.451358
106	Polygon	141.722877	84.614294	1.194081
107	Polygon	46.134561	40.908476	1.773442
108	Polygon	181.918899	112.535913	1.237210
109	Polygon	9.734248	0.672696	0.138212

Record: 0 Show: All Selected Records (1 out of 446 Selected.) Options

Figure 3-5 (Lagoon polygons in ArcMap with area of greatest change highlighted)

A correlation analysis was conducted to determine if and where relationships existed between areas of change on the Gulf shoreline and Little Lagoon's southern shoreline. I conducted the correlation analysis for all 254 transects to represent the overall relationship. Then I conducted an analysis for 1 km lengths to locate isolated areas of correlation to better understand larger-scale patterns. For example, I ran correlations for transects 1 through 21, then 2 through 22, 3 through 23, and so on. I used a two-tailed test (α 0.01). Coefficients of 0.549 (or –0.549) or greater are critical values of Pearson's *r* for testing the significance (Kachigan, 1986). Knowing areas of correlation may help identify areas of future change.

Sources of Error

The resolution of the aerial photos used can cause error when attempting to delineate the shoreline. While there is no absolute value for the resolution of the photographs used in this study, it should be pointed out that the resolution needed depends on the application. For example, the low-altitude aerial photos taken by ADEM are of greater resolution than the higher-altitude aerial photos used in this study, but they did not include Little Lagoon and therefore were of no use in this research. Also, the georeferencing process may have been completed with an rms error of less than 1.5 m, but that doesn't ensure that any one feature is actually within 1.5 m of where it is depicted (Fletcher *et al*., 2003).

The use of the HWL to delineate the shoreline also creates some error. The HWL has been proven to have shortcomings because of the effects of numerous influences like winds, wave action, temperature, and salinity to name only a few (Parker, 2003). Plus, the HWL only approximates the Mean HWL (MHWL) used by the National Ocean Service and many other agencies to define the land/sea boundary (Graham *et al*., 2003). The strength of the MHWL is that it is an average of 19 years of HWLs in order to mitigate the influence of tides. The photos used in this study were not tide-coordinated, so the stage of the tide creates another source of error (Hess, 2003). However, many studies have concluded that the difference between the HWL and the MHWL is either insignificant or acceptable error (McBeth, 1956; Dolan *et al*., 1980; Crowell *et al*., 1991). The location of the HWL in aerial photographs can also be influenced by the time of year the photos were taken, i.e. winter profile or summer profile. Despite its shortcomings, the HWL is still the most consistent way to represent shorelines (Parker, 2003).

The sampling technique used may include error. Much of this study is based on transects spaced 50-m apart, perpendicular to the general shape of the shoreline and mostly parallel to one another. The correlation analysis conducted in this study was tested on three separate areas of shoreline for five different year groups using 10-, 25-, and 50-meter spacing. The values obtained were almost identical, proving that 50-meter spacing captures as much signal, and noise, as smaller spacing, and is therefore acceptable.

Errors considered, the results are still accurate enough to determine where erosional or accretional trends existed between year groups and to estimate average change.

RESULTS & DISCUSSION

Organization

Shoreline change depends on many factors, such as wave and current regime, sea-level change, storm frequency, sediment supply, and human activities like large-scale civil engineering projects (Gonzalez *et al.*, 1997). Between 1917 and 2001, the study area's Gulf shoreline had an average change of –40 m over the 254 transects. That is almost half of a meter of erosion per year for the entire 12.7 km Gulf shoreline study area. While this may seem like a small amount of change when compared to similar studies, an examination of the graphic representation (Figure 6) shows that some portions of beach eroded almost 120 m while other portions accreted more than 60 m. Also, distinct spikes or reverses in trends exist near transects 27, 97, and 213. The spikes are where inlets have closed and opened during the study period, but the areas of accretion and erosion are harder to explain at this temporal scale. For example, the average change for the years 1917 to 1955 is –40 m, coincidentally the same as the average for 1917 to 2001, but that does not mean no change has occurred since 1955. On the contrary, some of the most dramatic changes have occurred in the last 50 years. To better understand shoreline dynamics over the entire period of study (1917-2004), I have broken the analysis down into shorter time periods, based on available data.

The results are presented in six groups. The years 1917 through 1955 represent the first group and the longest time period analyzed. This was a period of transition when the natural inlet moved from the eastern end of the lagoon to the western end. Because the 1917 DVS did not include Little Lagoon, correlation and lagoon shoreline change for the period 1917 to 1955 will not be discussed. The second group spans the years 1955 through 1970; the natural tidal inlet was located near the western end of the lagoon throughout this time period. The years between 1970 and 1981 mark another period of transition when the natural inlet in the west closed and a natural inlet opened near the center of the lagoon. The HWL represented in the 1981 shoreline is prior to the construction of jetties to stabilize the natural tidal inlet that same year, an engineering project known as Little Lagoon Pass. The fourth group spans from 1981 to 1989 and shows clearly the change associated with Little Lagoon Pass, and ends at a time described by Smith (1991) as near equilibrium. The years between 1989 and 1997 represent the fifth group and include changes to the Pass, such as the shortening of the jetties and beach nourishment projects. Because the LIDAR data taken in 2001 did not include Little Lagoon, the period from 1997 to 2001 will only focus on Gulf shoreline change. However, the 2004 photos taken immediately after Hurricane Ivan reveal some significant changes to the lagoon shoreline that will be discussed separately in a 1997 to 2004 group.

1917 to 1955

Gulf Shoreline

The 1917 DVS shows only one inlet to Little Lagoon, approximately 1.5 km from the eastern end of the lagoon near transect 27. In the 1934 DVS the inlet is no longer there, but because the data are incomplete it is impossible to determine if an inlet was open in the western half of the lagoon at that time. Also, the 1940 and 1949 photo mosaics show no clear-cut inlet in the study area. In the 1955 aerial photos a natural inlet is clearly distinguishable approximately 2 km from the western end of the lagoon near transect 213, which is where the inlet was depicted in most historical maps dating back to 1804 (Appendix A).

The average change to the Gulf shoreline over all 254 transects during this time period was –40 m, or –1.05 m per year (Figures 4-1 and 4-2). However there are two areas that depart from this erosional trend. One is immediately downdrift of the 1917 eastern inlet at transect 27, and the other is downdrift of the 1955 western inlet at transect 213. The accretion downdrift of the eastern inlet at transect 27 occurred because sediments were no longer being lost to the lagoon during flood tides. The area resistant to erosion downdrift of the western inlet at transect 213 is an area of equilibrium, described by Masselink and Hughes (2003), where the morphology is able to dissipate incoming energy and resist morphological change.

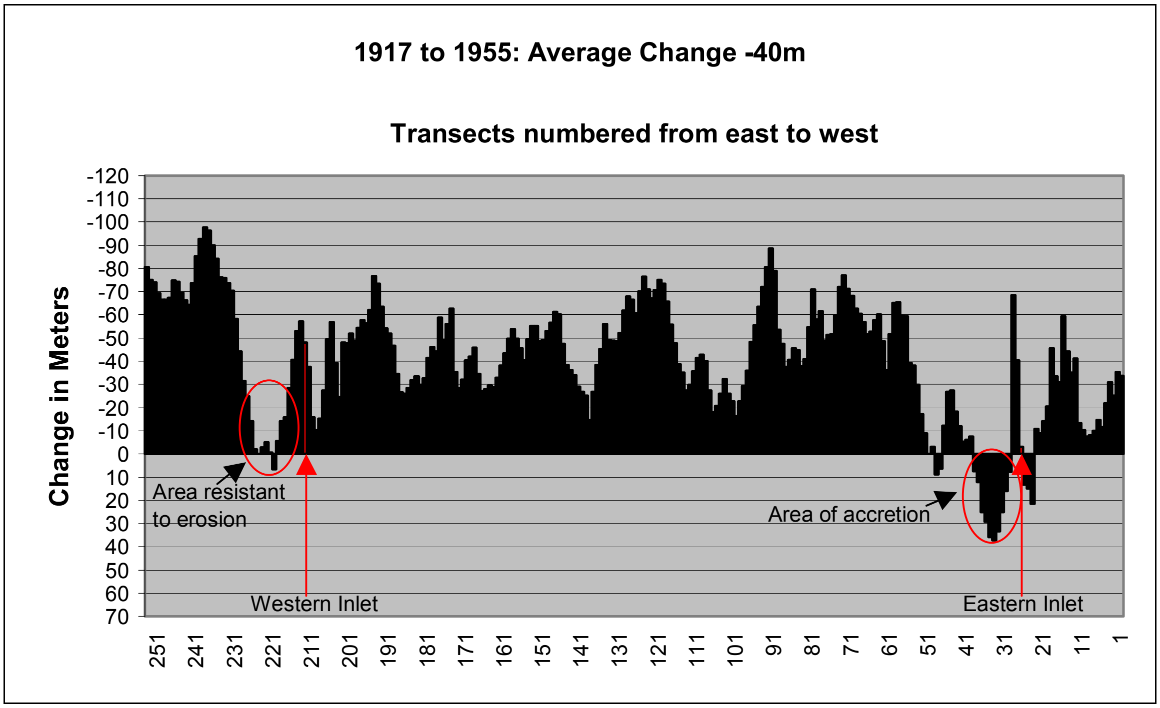


Figure 4-1 (Gulf shoreline change from 1917 to 1955)

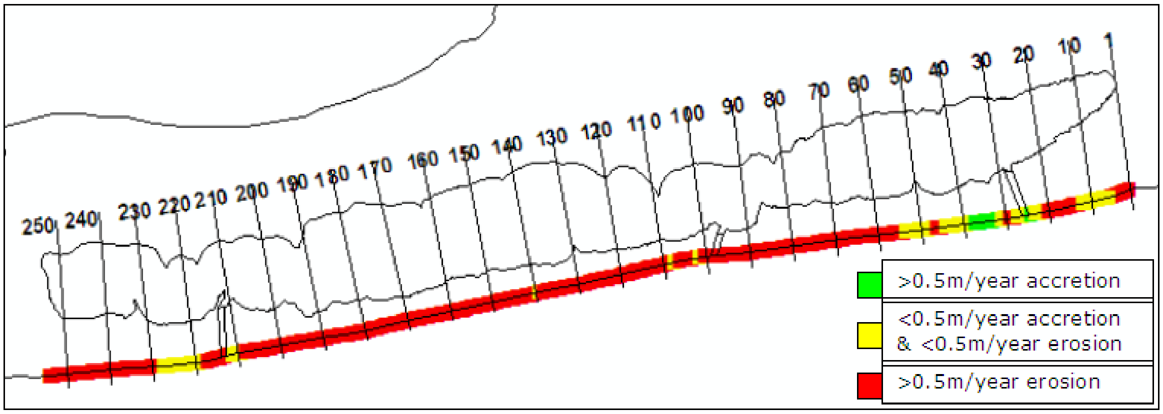


Figure 4-2 (Gulf shoreline change per year from 1917 to 1955)

1955 to 1970

Gulf Shoreline

The western natural inlet remained open throughout this period, though its shape did change over time. The average change of all 254 transects was –10 m on the Gulf shoreline, approximately -0.67 m per year (Figures 4-3 and 4-4).

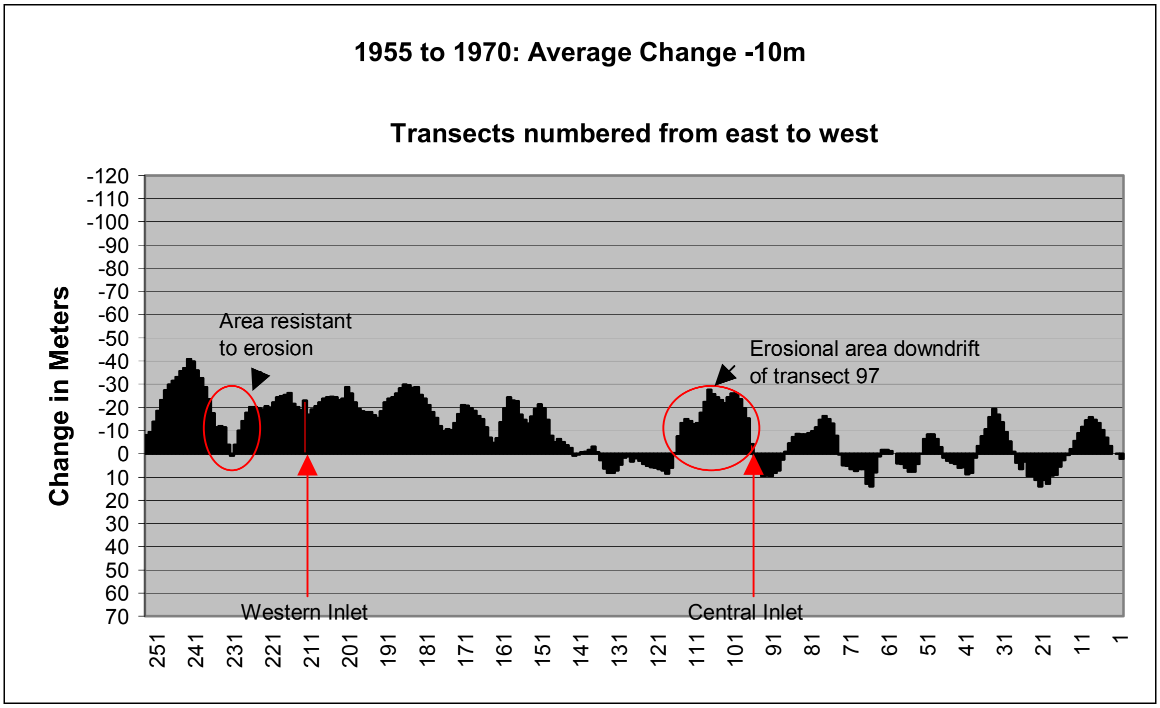


Figure 4-3 (Gulf shoreline change from 1955 to 1970)

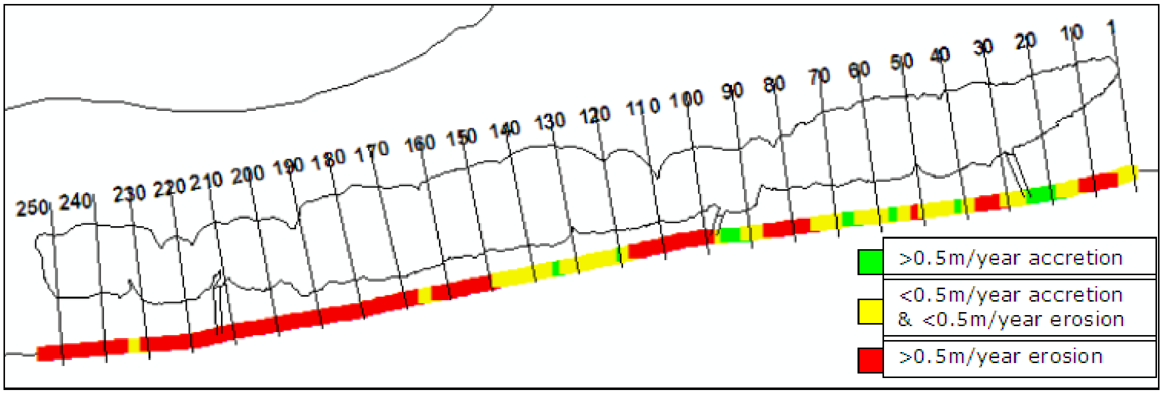


Figure 4-4 (Gulf shoreline change per year from 1955 to 1970)

A noticeable erosional trend exists downdrift of transect 97 for about 1 km. Transect 97 is the location of the central inlet in Figure 1-3. In the aerial photographs of this period, the area does appear to accommodate interaction between the Gulf of Mexico and Little Lagoon, probably during higher high tides and storm tides (Figure 4-5). Sediment

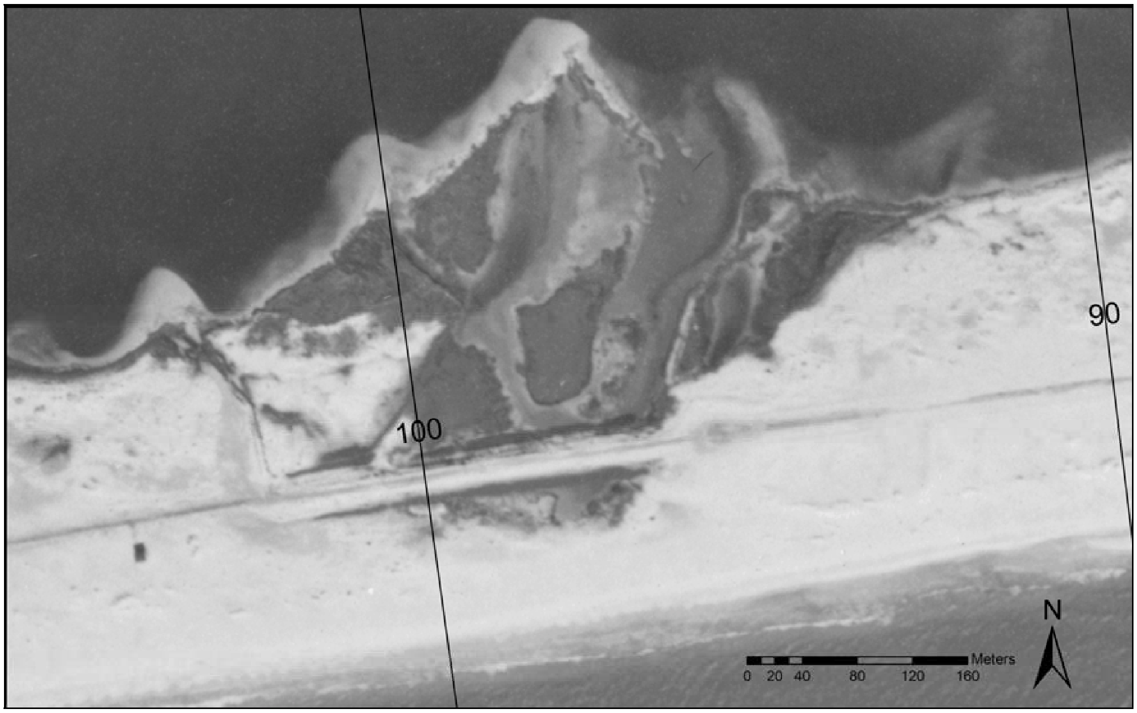


Figure 4-5 (Central inlet in 1955. Though there is no clear-cut inlet,

it does appear to allow interaction between the Gulf and lagoon.)

was lost to the lagoon during flood tides or storms, but not returned to the Gulf during ebb tides. Further downdrift exists an erosional trend that stretches from about transect 144 through most of the remainder of the study area, spanning almost 5 km. Again, sediment was probably being lost to the lagoon during higher high tides. Figure 4-6 is centered on transect 144. The dark (wet) sand leading to the lagoon in the center of the barrier is evidence of Gulf and lagoon interaction. An area near transect 232 seems resistant to the erosional trend. It is about 1 km downdrift of the inlet at transect 213 and is an area of equilibrium (Masselink and Hughes, 2003).

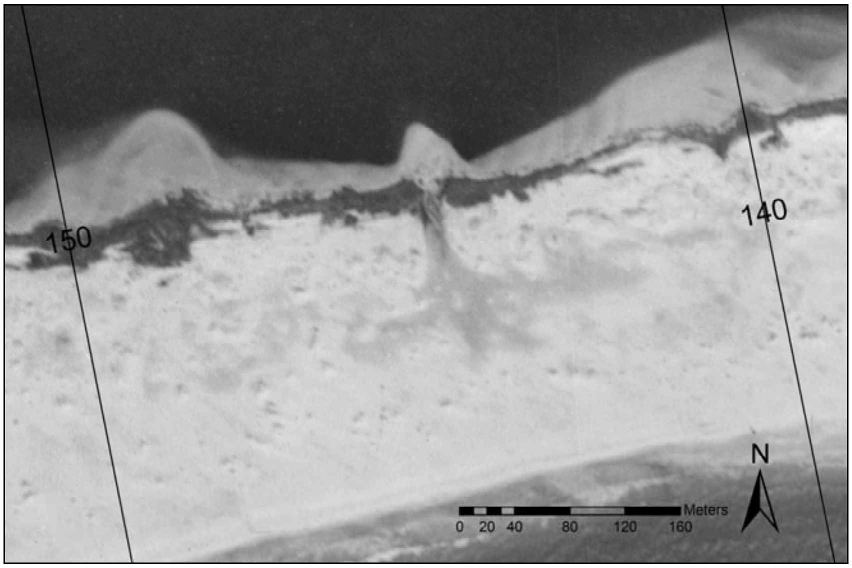


Figure 4-6 (An intermittent inlet in 1955. The dark, wet sand in the center of the barrier may indicate some interaction between the Gulf and lagoon.)

Little Lagoon

Between 1955 and 1970, Little Lagoon shrank (i.e., the shoreline accreted) 7.7 km^2, from 10,285.9 to 10,278.2 km^2, or 513 m^2 per year. Two areas showed substantial change (Figure 4-7).

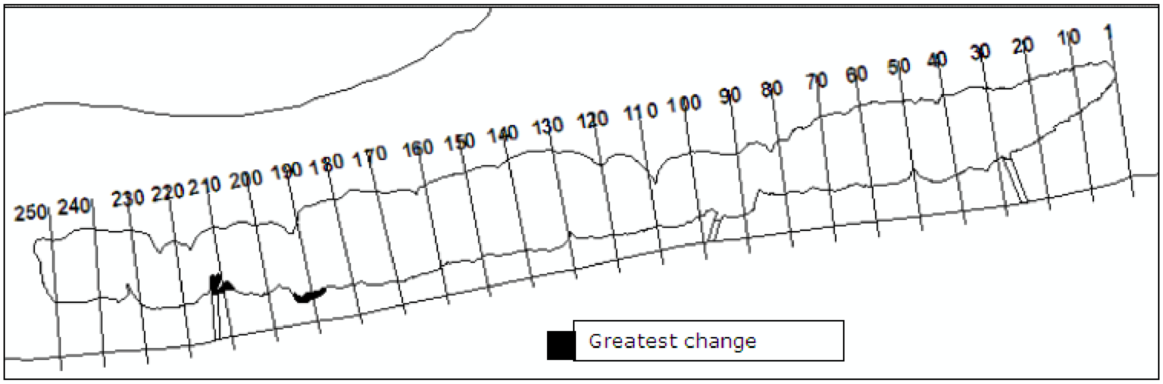


Figure 4-7 (Lagoon shoreline change 1955 to 1970)

First, the area near the natural inlet that existed between 1955 and 1970 accreted 11 km² (Figure 4-8), or 733 m² per year. When a new inlet is cut, the lagoon that it connects will experience change (Kraus, 2005). The accretion at the western inlet was in the form of a flood delta, as floodtides carried sediments into the lagoon that were deposited as the rate of discharge was reduced. Little change has occurred in the area since the 1970 photos, indicating that little to no tidal waters have interacted there since the inlet's closure sometime between 1970 and 1974.

The second area of significant change existed on Little Lagoon's southern shoreline between transects 187 and 194 (Figure 4-9). During this time, 9.3 km² of shoreline were eroded – 620 m² per year. By dividing the polygon shape area by half the shape length, I calculated an average erosion of almost 24 m linearly. While there is no readily apparent cause of the erosion, it is possible that as homes were developed the marshy area was deliberately removed to make the property more aesthetically appealing.

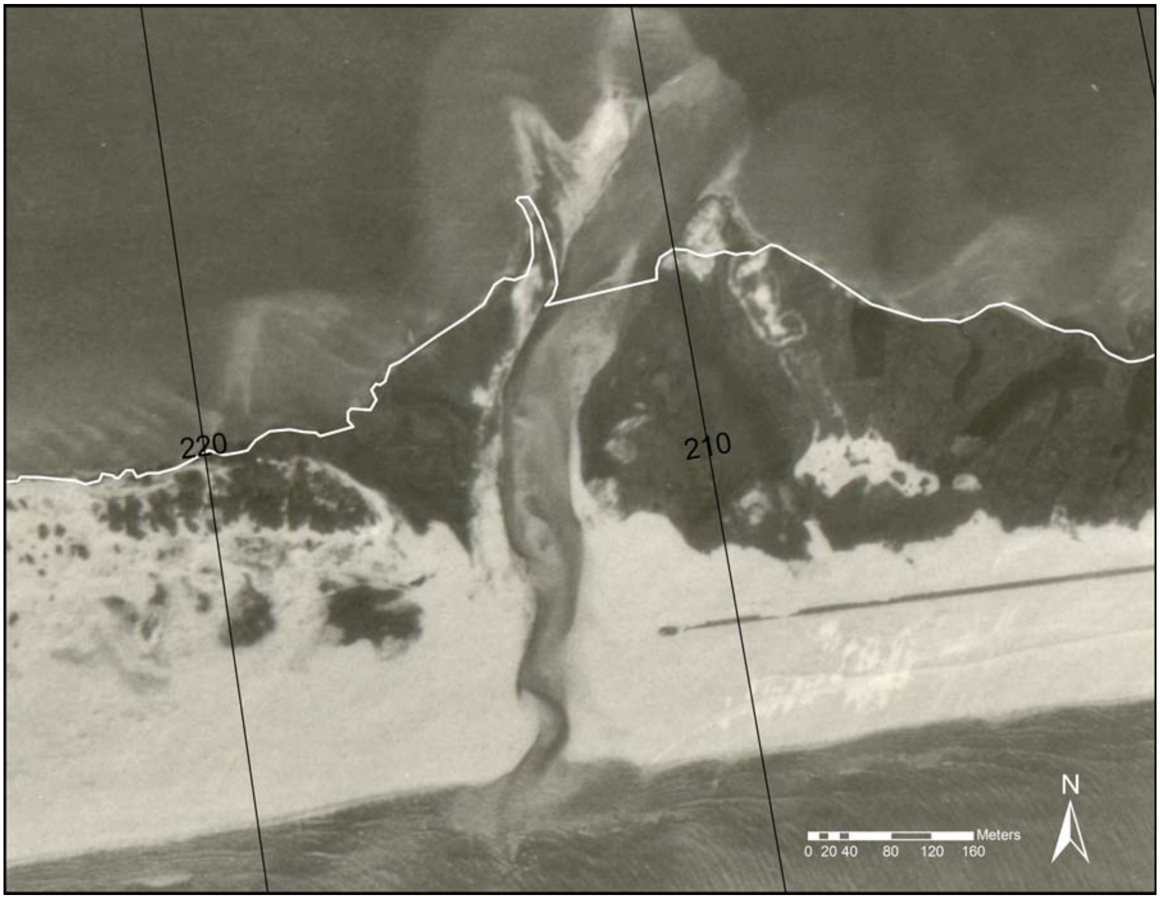


Figure 4-8 (Western inlet in 1970, 1955 shoreline in white.)

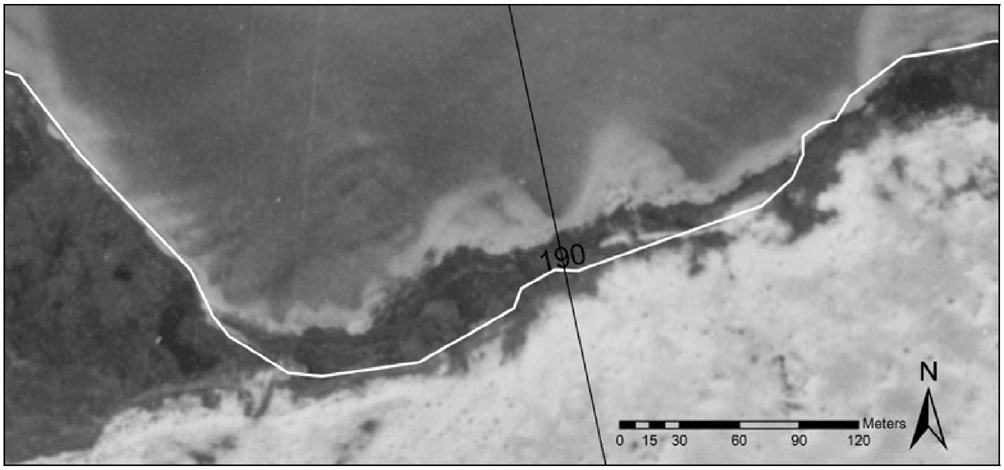


Figure 4-9 (1955 photo of area that later eroded, 1970 shoreline in white)

Correlation

I found no significant correlations when the analysis was conducted for the entire study area. Between 1955 and 1970, the Gulf shoreline eroded an average of –10 m over the 254 transects, while the lagoon accreted an average of +2 m. Examining the data on a larger scale, I found three areas exhibiting significant correlation (Figure 4-10), probably because the inlets permit transfer of sediments.

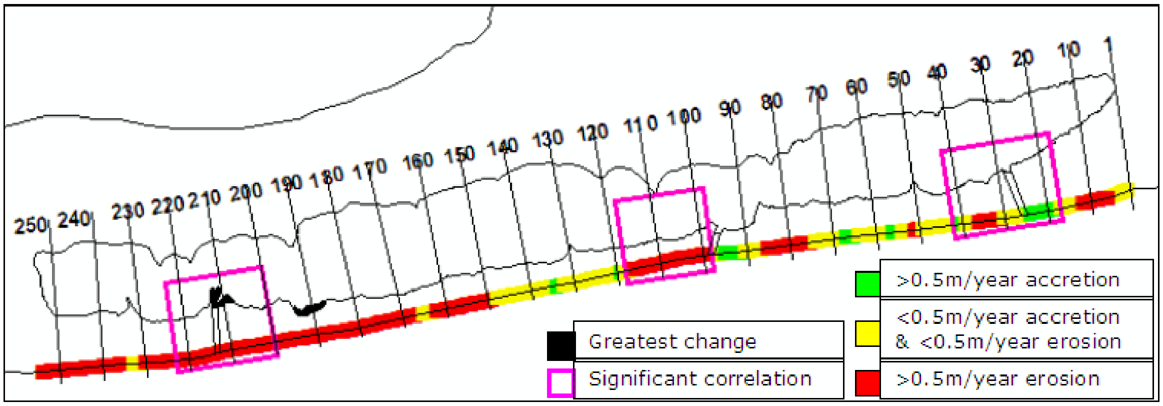


Figure 4-10 (Correlation areas, 1955 - 1970)

Between transects 17 and 42, over a distance of 1.2 km, one-kilometer correlation coefficients range from –0.559 to –0.633, $p<0.01$. This area corresponds with the location of a natural tidal inlet near transect 27 that was open in 1917, but closed some time before 1950. While the Gulf shoreline accreted an average of 1 m over the 25 transects, the lagoon shoreline showed no change. However those numbers do not tell the entire story. Updrift of the inlet, the Gulf shoreline accreted over all 11 transects with values ranging from +3 m to +14 m for an average of 9 m, but the lagoon shoreline eroded on 8 out of the 11 transects with values ranging from +4 m to –32 m for an average of –8 m. Conversely, downdrift of the inlet, the Gulf shoreline eroded on 10 of

15 transects with values ranging from +9 m to –19 m for an average of –5 m, but the lagoon shoreline accreted on 11 of 15 transects with values ranging from –1 m to +26 m for an average of +6 m. The negative correlation reflects the inverse relationship between the Gulf and lagoon shorelines: where the Gulf side accreted, the lagoon side eroded, and vice versa (Figure 4-11a).

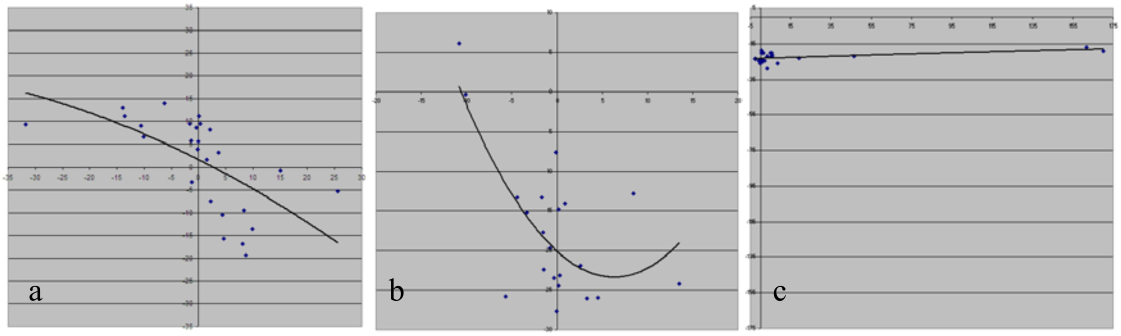


Figure 4-11 (Correlation scatter plots, 1955 - 1970)

Another area of significant correlation occurred downdrift of transect 97 for 1 km, between transects 98 and 118. This is interesting because a natural inlet opens at transect 97 sometime between 1974 and 1976, but obviously some interaction between the Gulf of Mexico and Little Lagoon was occurring prior to that. Over the 1 km, the Gulf shoreline eroded –18 m, and the lagoon shoreline eroded less than –1 m ($r=-0.562$, $p<0.01$). The Gulf shoreline eroded on all but one of the 21 transects with values ranging from +6 m to –28 m, while the lagoon shoreline eroded on 12 of 21 transects with values ranging from –11 m to +14 m. Figure 4-11b shows the relationship is non-monotonic, concave upward, meaning that the two variables are positively related within a certain range of values, and negatively related in another range (Kachigan, 1986).

The third area to be discussed for this time period exists between transects 200 and 223, total 1,150 m. Correlation coefficients range from –0.566 to –0.598. The Gulf shoreline eroded over all 24 transects with values ranging from –17 m to –29 m for an average of –23 m, but the lagoon shoreline accreted over 20 of the 24 transects with values ranging from –3 m to +170 m for an average of +18 m. This area is almost centered about the natural inlet that was open between 1955 and 1970 near transect 213. The negative correlation again reflects the inverse relationship between the Gulf and lagoon shorelines: where the Gulf eroded, the lagoon accreted. Figure 4-11c shows a positive linear relationship, but is exaggerated because two values are outliers.

1970 to 1981

Gulf Shoreline

The period from 1970 to 1981 is another transitional period during which natural inlets moved. Sometime before 1974, the western inlet closed leaving no clear-cut inlet to Little Lagoon, though the area around transect 97 does appear to have an ebb delta present in the 1974 aerial photographs (Figure 4-12). Most likely, the Gulf and lagoon did interact during higher high tides and storm tides. In 1976 USGS topographic quadrangles of the study area, a natural inlet does exist near transect 97. The 1979 and 1981 aerial photos, and the 1981 DVS show a natural inlet at that location.

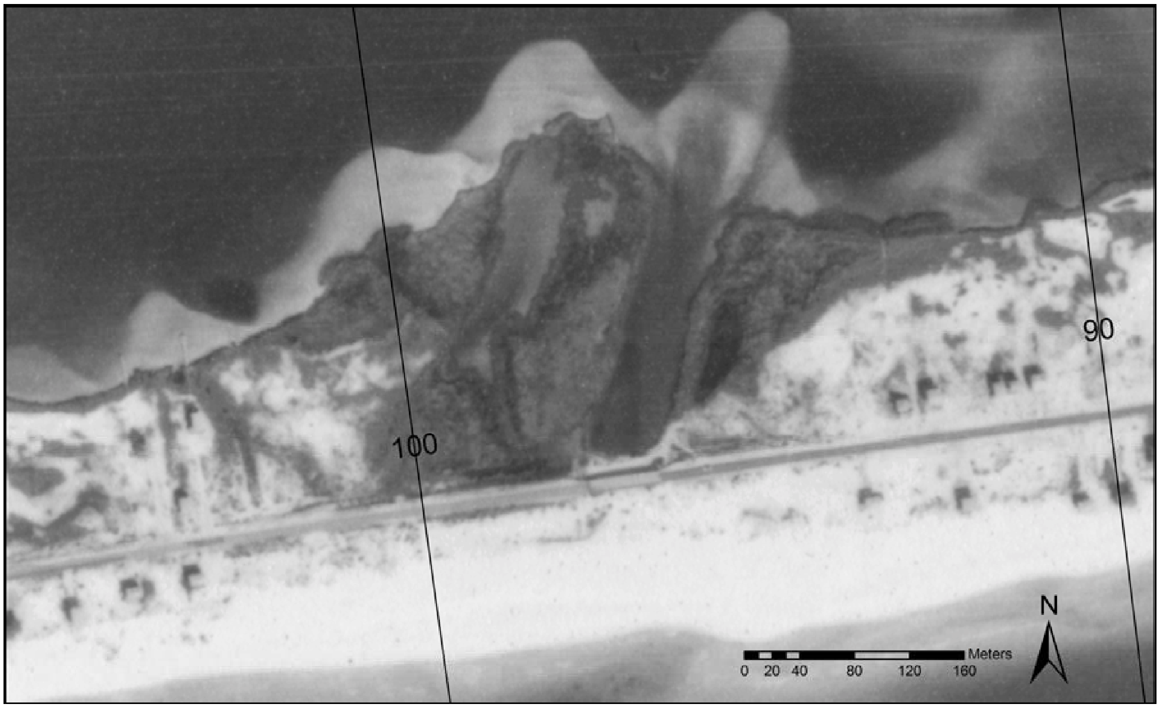


Figure 4-12 (Central inlet in 1974)

When all 254 transects are averaged, less than 1 m of change occurred on the Gulf shoreline during this time period. But Figures 4-13 and 4-14 show an erosional trend for the first 3 km, from east to west. This time period coincides with significant coastal construction taking place in the city of Gulf Shores, including the construction of piers that may have forced some littoral drift sediments to be diverted offshore, causing erosion for a few kilometers. These sediments later returned with onshore flow, explaining the spotty accretional trend spanning much of the remaining transects. Also, a major hurricane impacted the area in 1979 and probably significantly altered the shoreline morphology to an extent that two years of normal conditions could not return the shore to its previous state.