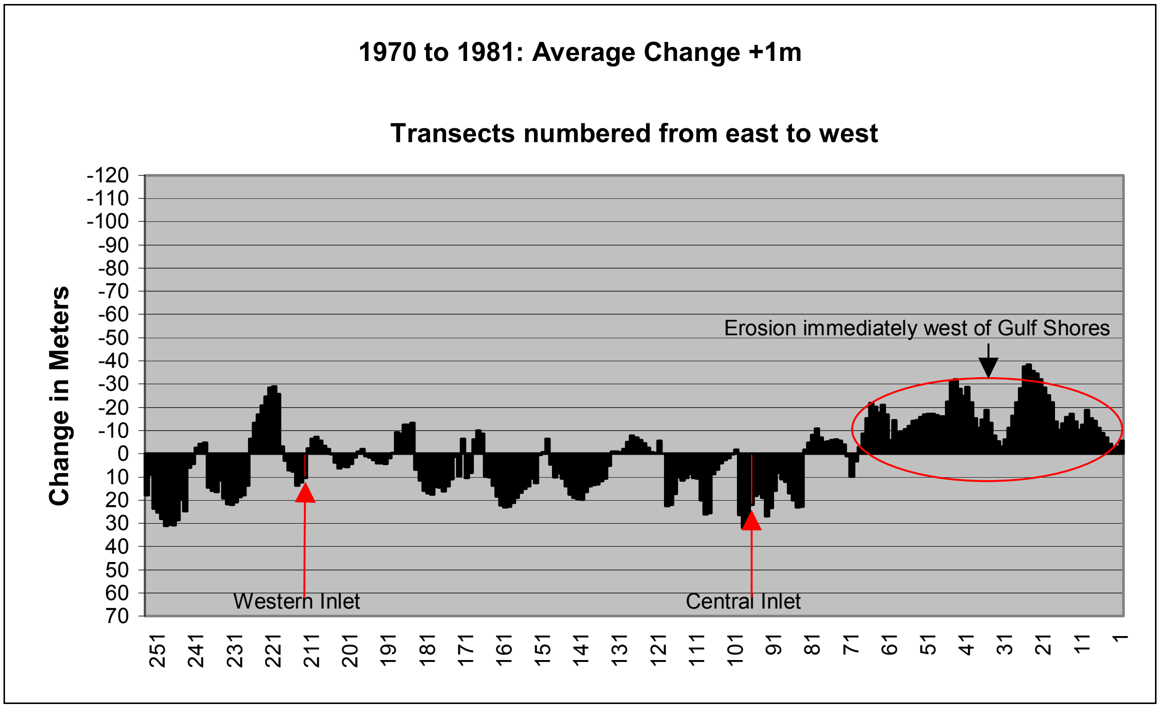

Figure 4-13 (Gulf shoreline change from 1970 to 1981)

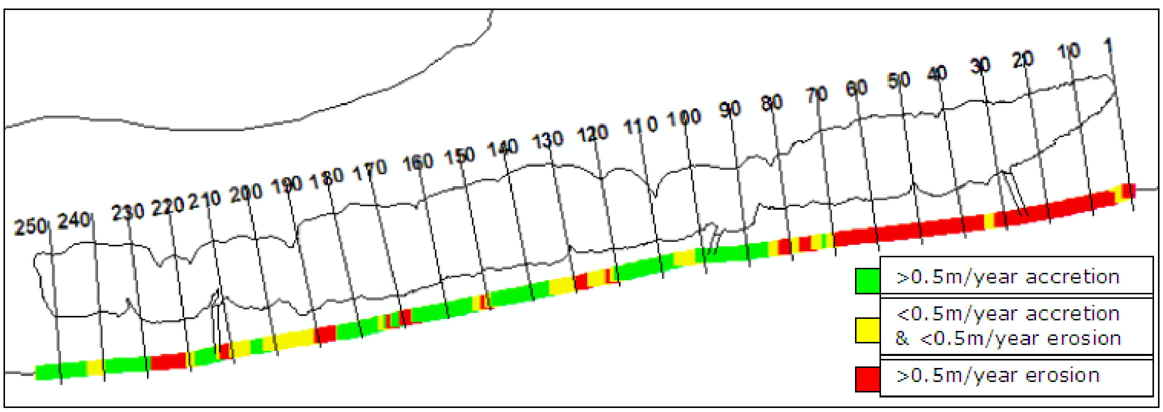

Figure 4-14 (Gulf shoreline change per year from 1970 to 1981)

Little Lagoon

Between 1970 and 1981, Little Lagoon lost another 41.6 km² to reach a total area of 10,236.6 km². That loss equates to 3,783 m² per year. The greatest change occurred along a linear stretch of beach between transects 135 and 152 that accreted an average of over 41 m (Figure 4-15). Careful inspection of the aerial photos revealed that this wasn't

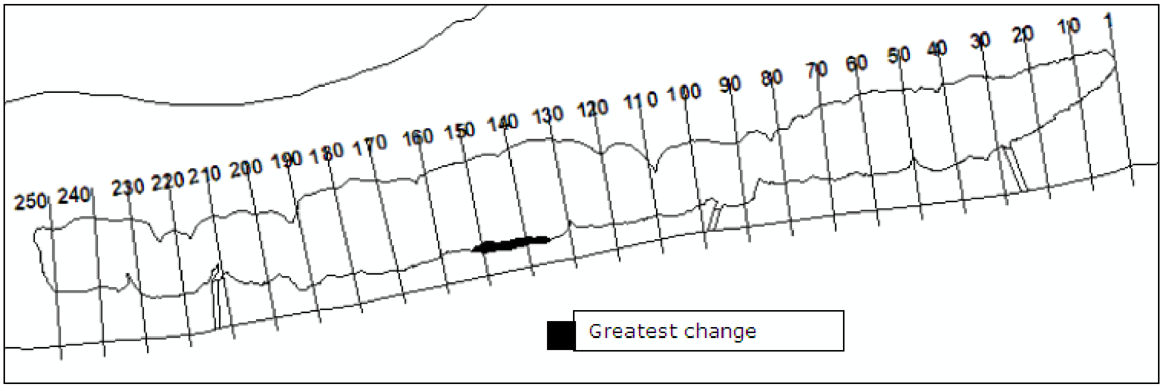

Figure 4-15 (Lagoon shoreline change from 1970 to 1981)

a slow process spanning 11 years, but a rapid accretion that occurred between 1974 and 1979 (Figure 4-16). Most likely the accretion represents the resulting overwash fan from Hurricane Frederic in 1979, one of the most powerful storms ever to affect the study area, with storm surges between 10 ft and 12 ft. That single overwash fan comprises almost 37 km^2 of sediment deposition onto Little Lagoon's southern shoreline. The 1979 photos were taken only a few weeks after Frederic made landfall, but the evidence of overwash is still apparent today. Stallins and Parker (2003) observed that overwash disturbances affect feedbacks among vegetation, landforms, and sediment mobility, meaning that such a single event can have long-lasting effects.

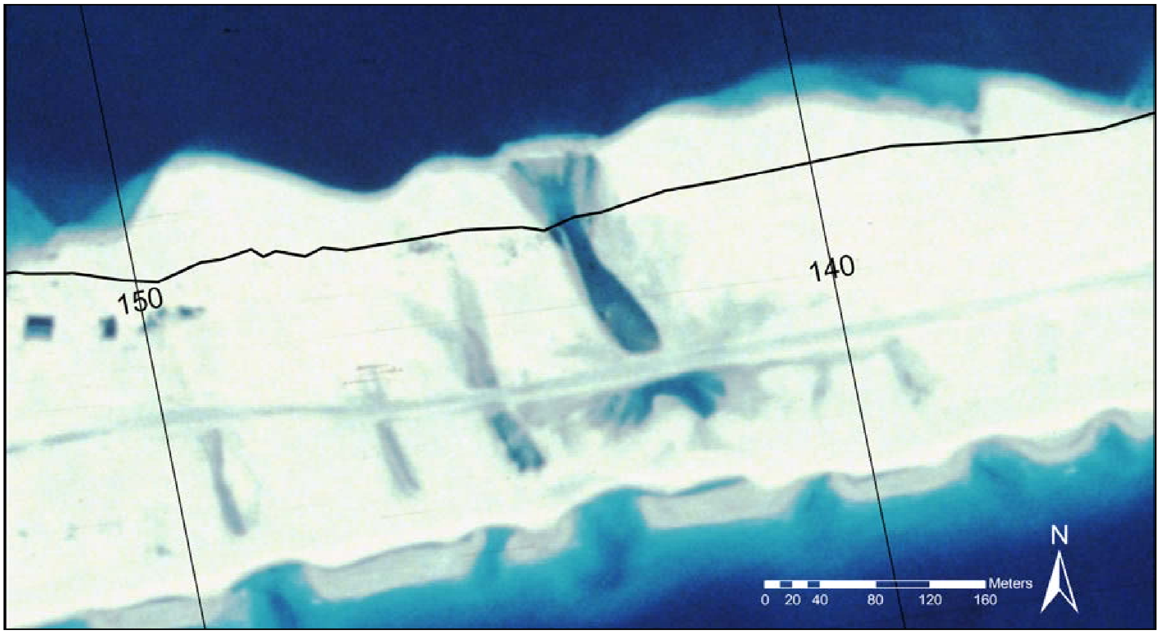

Figure 4-16 (Hurricane Frederic overwash fan in 1979, 1970 lagoon shoreline in black)

Correlation

During this eleven-year period, the Gulf and lagoon shorelines showed little overall change when averaged across the 254 transects, +1 m and +3 m respectively. The overall correlation was weak, however, two areas exhibiting significant correlation are worth mentioning (Figure 4-17).

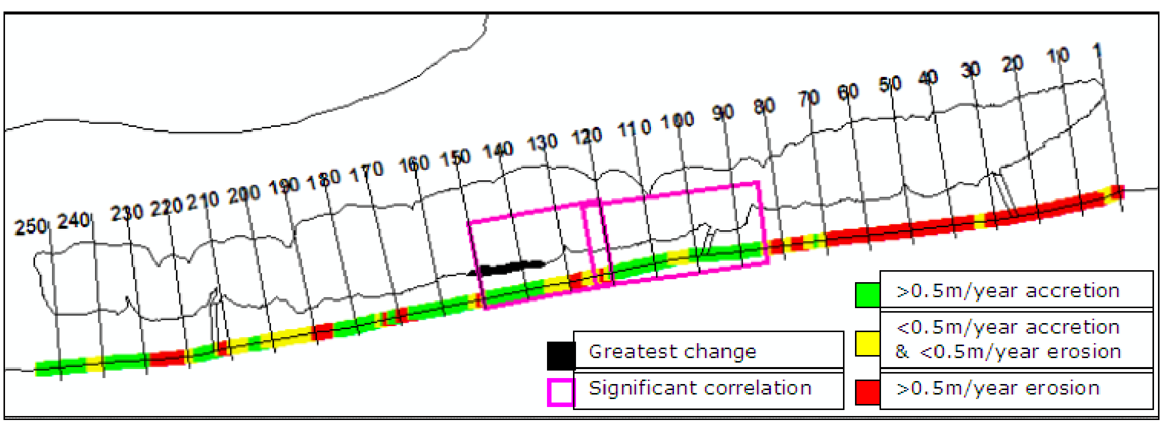

Figure 4-17 (Correlation areas, 1970 - 1981)

Significant negative correlations (–0.549 to –0.732, $p<0.01$) occurred between transects 84 and 124. This area represents the central inlet and the shoreline about 1 km downdrift of it. Over the 2 km, the Gulf shoreline accreted on 35 of 41 transects with values ranging from –6 m to +32 m for an average of +13 m, and the lagoon shoreline eroded on 35 of the 41 transects with values ranging from –12 m to +18 m for an average of –2 m. The negative correlation reflects the inverse relationship between the Gulf and lagoon shorelines (Figure 4-18a).

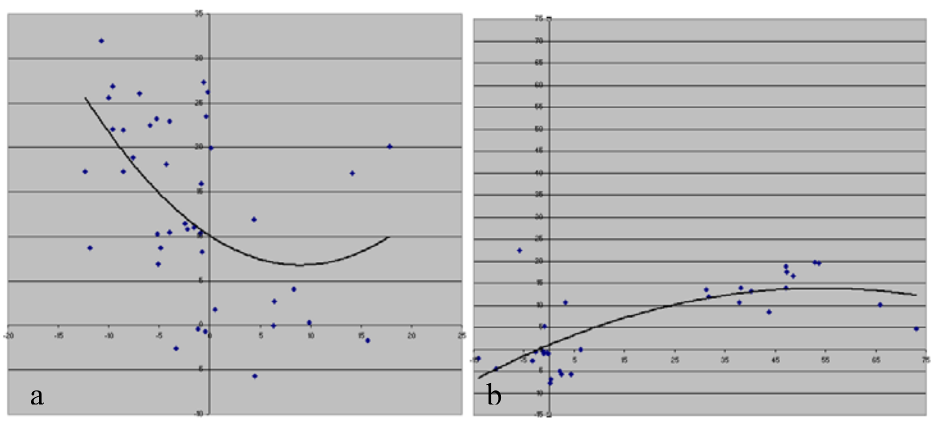

Figure 4-18 (Correlation scatter plots, 1970 - 1981)

Significant correlations also exist between transects 120 and 150, ranging from +0.573 to +0.917. This area somewhat overlaps the other area of substantial correlation (Figure 4-17), and coincidently occurs around a large overwash fan created by Hurricane Frederic in 1979. Here the Gulf shoreline accreted on 16 of the 31 transects with values ranging from –8 m to +23 m for an average of +6 m, and the lagoon shoreline accreted on 21 of the 31 transects with values ranging from –14 m to +73 m for an average of +21 m. The positive correlation (Figure 4-18b) reflects the direct relationship between the Gulf and lagoon shorelines, both seemingly growing from the amount of sediment moved by Hurricane Frederic.

1981 to 1989

Gulf Shoreline

The fourth time period in this study is from 1981 to 1989. In 1981, the Alabama Highway Department constructed Little Lagoon Pass, two jetties to stabilize the natural inlet near transect 97. Coastal construction is usually established with an expectation for permanency, but the land-sea buffer is in dynamic equilibrium with natural forces and therefore susceptible to change (Smith, 1981). An obstruction to longshore drift, like a jetty, often triggers erosion downdrift of the obstruction (Orford, 1988). The initial erosional depression moves downdrift because the transport potential downdrift is always greater (Inman, 2003), which is why the erosion cut may be defined as "infinite" (Bruun, 1995). Subsequent deepening and steepening of the seafloor reduces the ability of beaches to accumulate sand by allowing for larger waves, creating greater erosion (Buijsman, 2003). Coastal engineers predicted that significant erosion would take place downdrift of the jetties (Douglas, 2002), but the project was carried out without a sand bypassing system. This study period ends in 1989, close to the time that Smith (1991) states that the area was approaching equilibrium. Although the average change over the 12.7 km study area during this short eight-year time period is a significant –12 m, or –1.5 m per year, some areas eroded much more than others (Figures 4-19 and 4-20). From transect 1 to transect 96, just prior to the eastern jetty, the average change was zero. From transect 98, just after the western jetty, to the end of the study area the average change was –20 m, or –2.5 m per year. However, the most significant erosion occurred within the first 2.5 km following the western jetty: –31 m, almost 4 m per year.

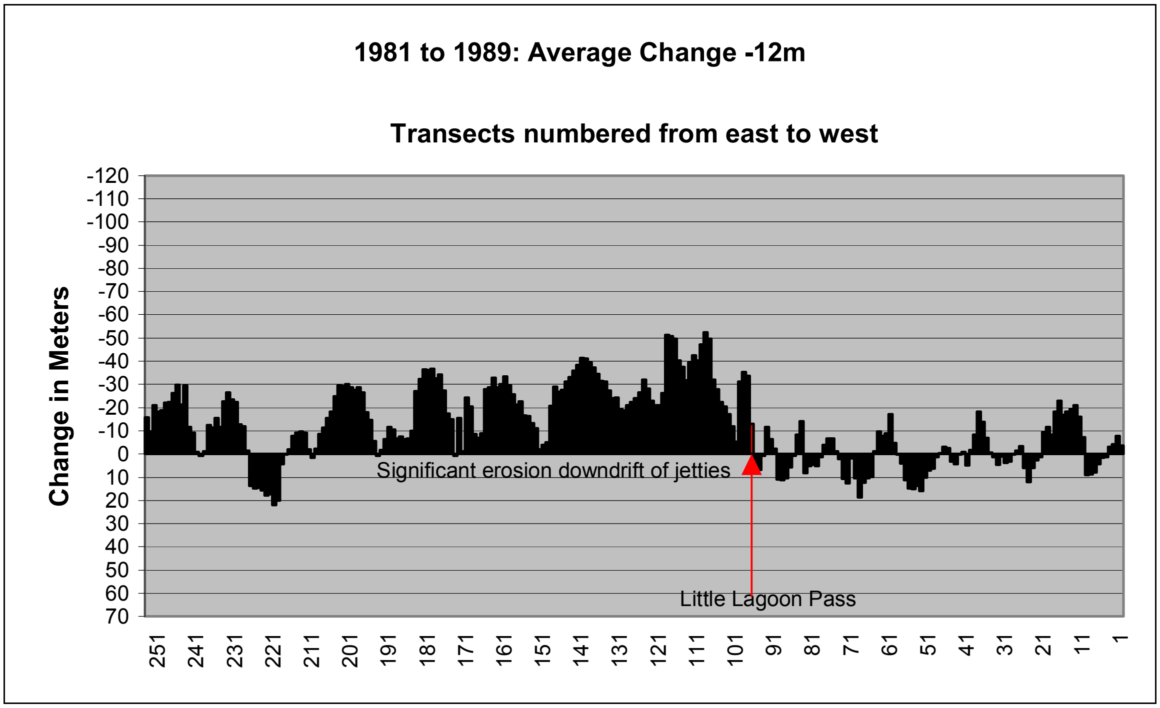

Figure 4-19 (Gulf shoreline change from 1981 to 1989)

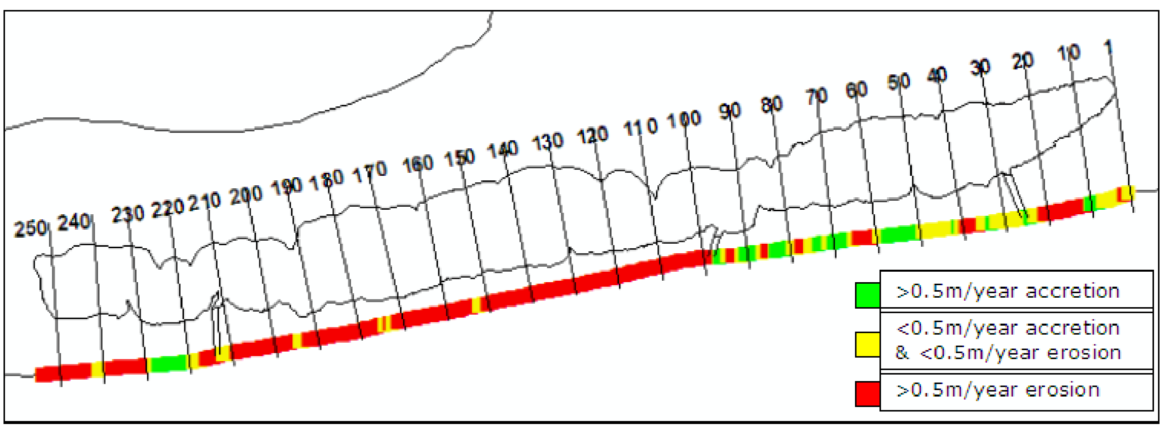

Figure 4-20 (Gulf shoreline change per year from 1981 to 1989)

Little Lagoon

Between 1981 and 1989, Little Lagoon continued to lose area from 10,236.6 to 10,227.9 km², a total of 8.7 km², or 1089 m² per year. However, the most significant change was the accretion that occurred near Little Lagoon Pass (Figures 4-21 and 4-22). East of the Pass, the lagoon shoreline accreted 3,576 m². When the shape area is divided by half the shape length, the area grew an average of over 8 m linearly. The lagoon's southern shoreline east of the pass was not stabilized with seawalls, as was the west, and suffered from jet-like flows common with engineered tidal inlets (Hughes, 2000) that carried and deposited large amount of sediments. Immediately west of the Pass, the lagoon shoreline accreted 460 m², or an average of 4 m. However, accretion may not be the best description of what happened because the change simply reflects the placement of a seawall on the western side of the Pass. Another area of substantial change occurred near the overwash fan deposited by Hurricane Frederic. Between transects 141 and 150, the lagoon shoreline eroded 2,716 m², about –6 m linearly.

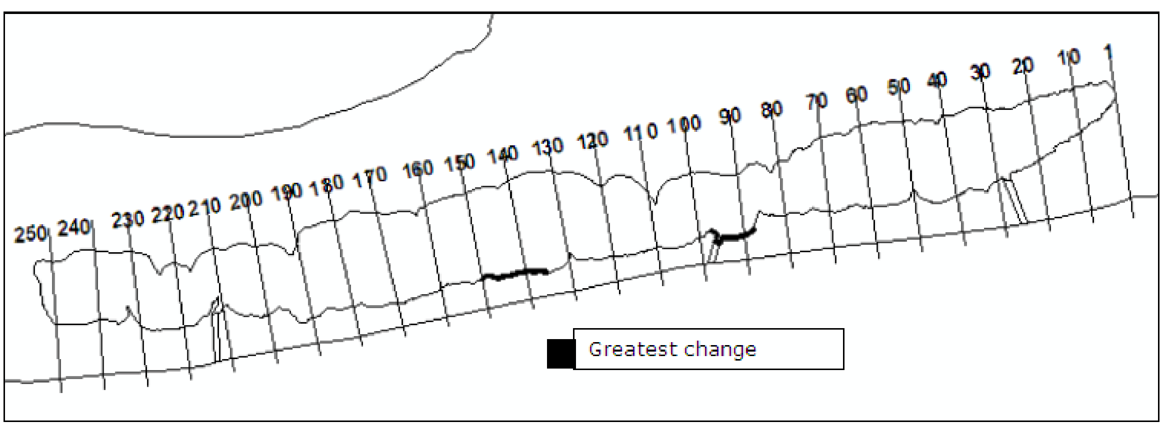

Figure 4-21 (Lagoon shoreline change from 1981 to 1989)

Figure 4-22 (Little Lagoon Pass in 1989, 1981 lagoon shoreline in white)

Correlation

The correlation of the Gulf and lagoon shorelines between 1981 and 1989 is a weak –0.030, with the Gulf shoreline eroding –12 m and the lagoon's southern shoreline accreting just over +1 m along the 254 transects.

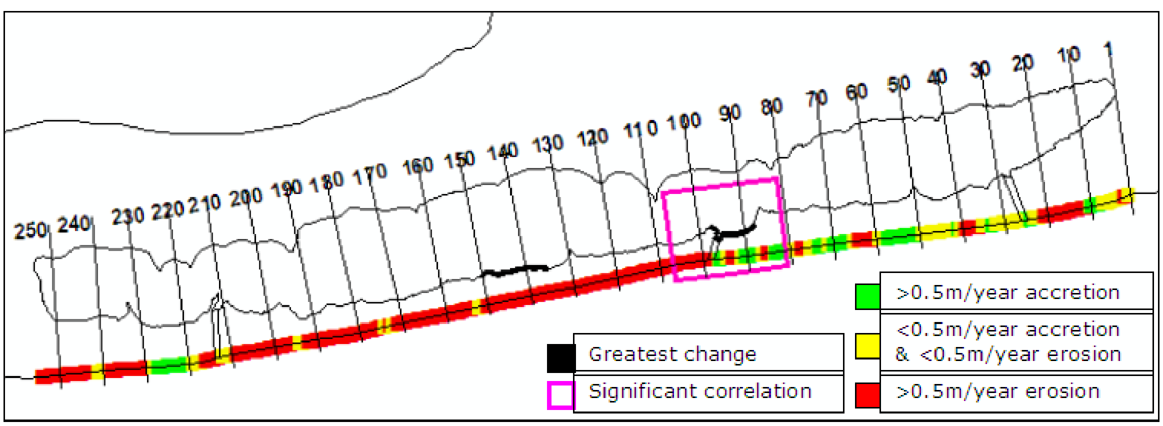

Figure 4-23 (Correlation areas, 1981 - 1989)

Not surprisingly, the one area of significant correlation during this period is at Little Lagoon Pass. Between transects 81 and 107 the correlation ranges from +0.560 to +0.668. Over the 1.3 km area, the Gulf shoreline eroded on 16 of the 27 transects with values ranging from –35 m to +11 m for an average of –8 m, while the lagoon shoreline accreted on 19 of the 27 transects with values between –7 m and +16 m for an average of +4 m. However, updrift of the Pass, the Gulf shoreline accreted on 11 of the 16 transects with values ranging from –14 m to +11 m for an average of +2 m, while the lagoon shoreline accreted on all but two transects with values from –2 m to +16 m for an average of +6 m. Downdrift of the Pass, the Gulf shoreline eroded on all of the 11 transects with values ranging from –5 m to –35 m for an average of –23 m, while the lagoon shoreline eroded on 6 of the 11 transects with values between –7 m and +7 m for an average of less than –1 m of erosion. The positive correlation reflects the direct relationship between the Gulf and lagoon shoreline at the engineered inlet: where the Gulf shoreline accretes, so does the lagoon shoreline, and vice versa (Figure 4-24).

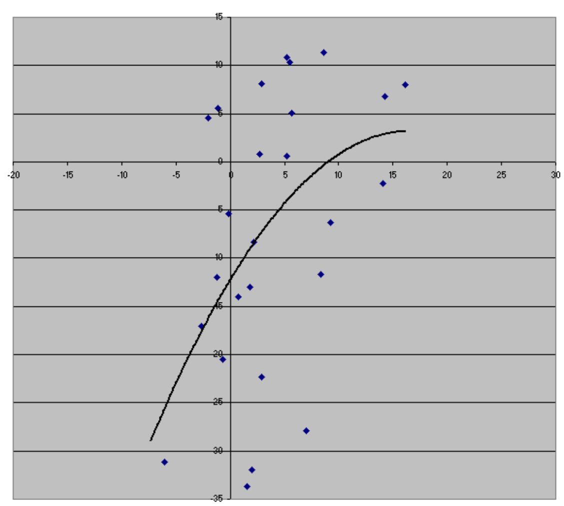

Figure 4-24 (Correlation scatter plot, 1981 - 1989)

1989 to 1997

Gulf Shoreline

Between 1989 and 1997, the average change along the gulf shoreline was +10 m, about +1.25 m per year (Figures 4-25 and 4-26). Beach nourishment projects are

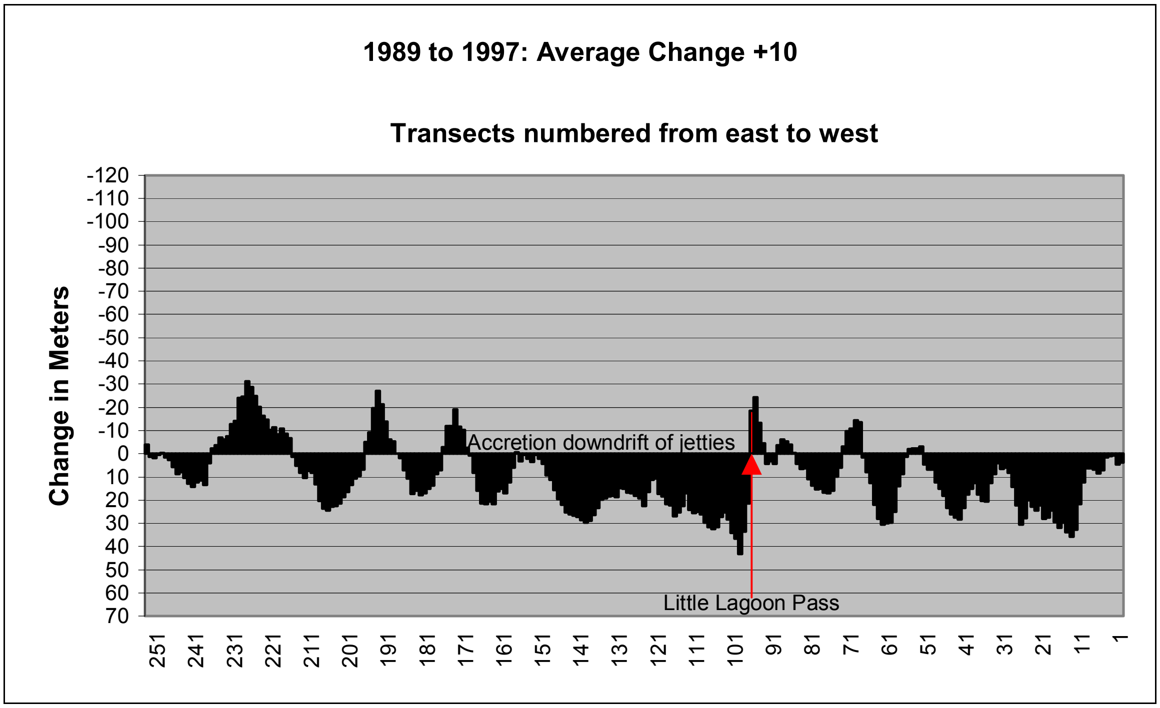

Figure 4-25 (Gulf shoreline change from 1989 to 1997)

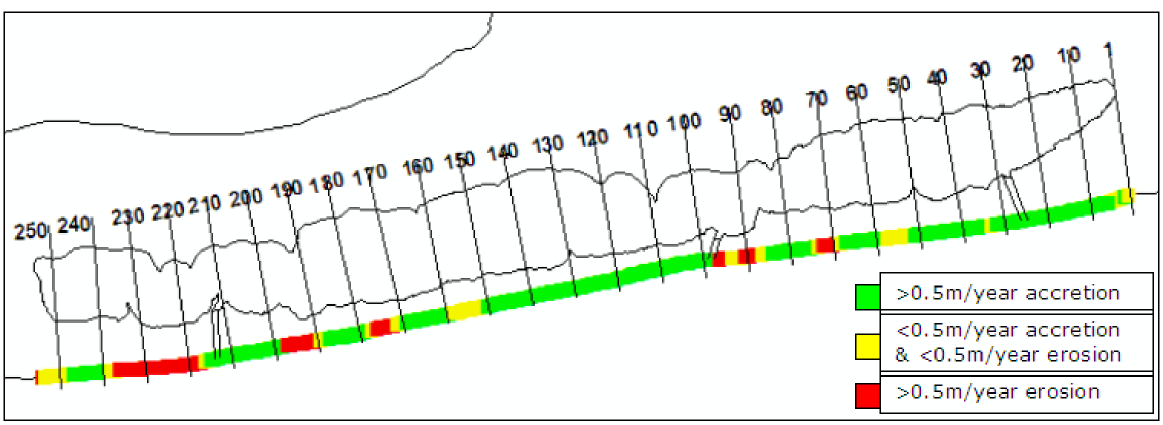

Figure 4-26 (Gulf shoreline change per year from 1989 to 1997)

responsible for the overall accretion. Specific morphological response depends on the amount of dredging associated with coastal inlets and the location of dredged material placement (Kraus, 2005). In 1992, landowners downdrift of Little Lagoon Pass filed a lawsuit against the Alabama Department of Transportation (ALDOT), formerly the Alabama Highway Department, claiming that they had lost property due to the jetties (Parsons v. Hand *et al.*, 1992). ALDOT was ordered to shorten the jetties and to conduct nourishment projects to maintain beach widths downdrift of the western jetty. ALDOT's method was to dredge 150,000 m³ of sediment from Little Lagoon, visible in Figure 4-27 as the dark lines in the center of the lagoon, and deposit it within the first 1,000 ft downdrift of the western jetty.

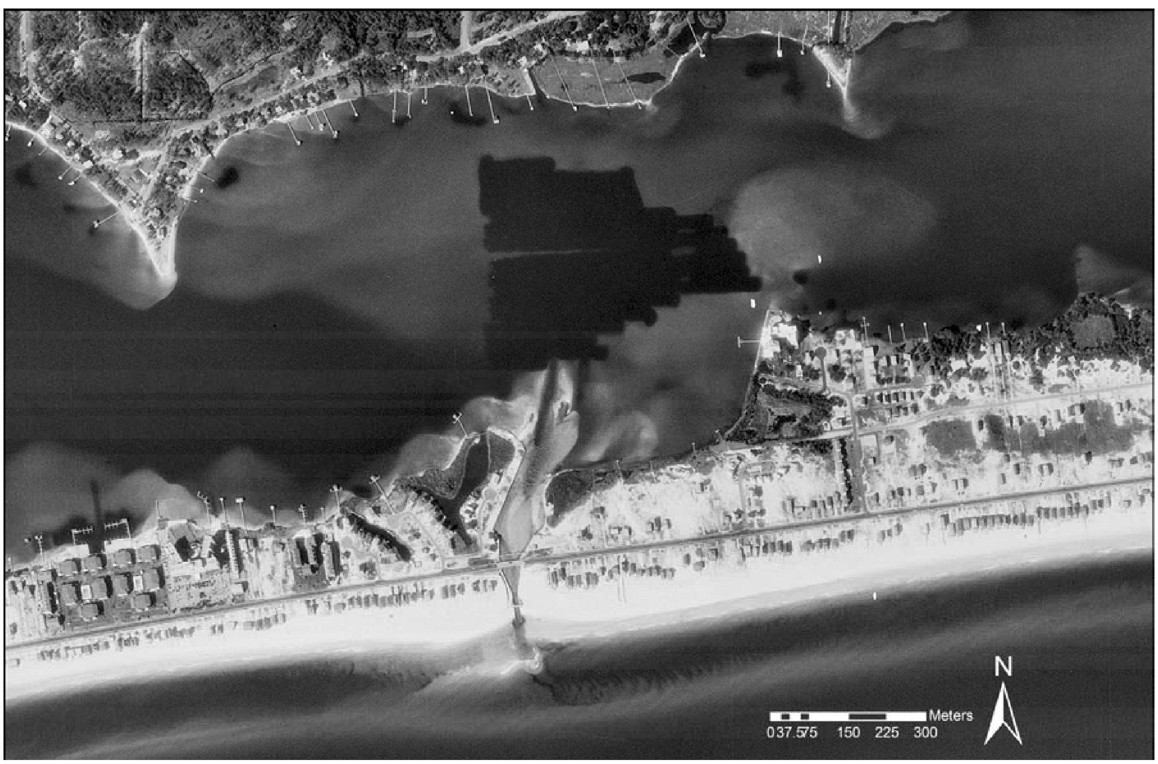

Figure 4-27 (Little Lagoon Pass in 1997, and associated dredging)

Since 1992, nourishment projects have been conducted almost continuously (Appendix B). Wang (2003) noted that some beach fill projects erode much faster than the average erosion rate, creating the need for additional fill. However, these projects appear to be working – the average change downdrift of the Pass was +9 m, or +1.13 m per year, with the most significant change occurring immediately west of the Pass and little change thereafter. For the first 2.5 km downdrift of the western jetty, the Gulf shoreline accreted an average of 24 m; after that the shoreline accretes an average of only 2 m. Unfortunately, the availability of sediment for future nourishment projects in the long-term is uncertain (Nordstrom *et al*., 2004).

Little Lagoon

Over the eight-year period, Little Lagoon grew from 10,227.9 km² to 10,234.5 km², a total of 6.6 km², or 825 m² per year. The area of greatest change occurred between transects 130 and 151 (Figures 4-28 and 4-29), which is the location of the large overwash fan created by Hurricane Frederic in 1979. The area eroded 7,614 m² during the time period, meaning that Little Lagoon grew by 7.6 km² in that one place. When the shape area is divided by half the shape length, the area eroded an average of 6 m linearly.

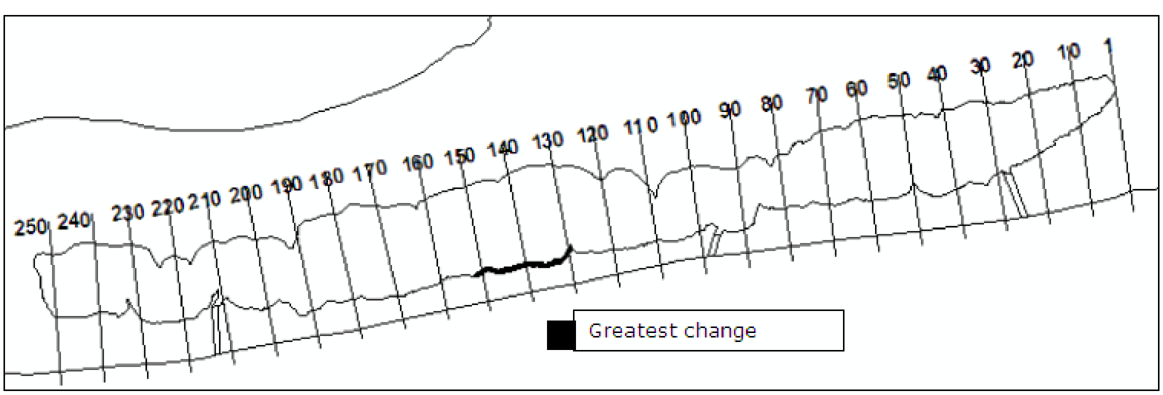

Figure 4-28 (Lagoon shoreline change from 1989 to 1997)

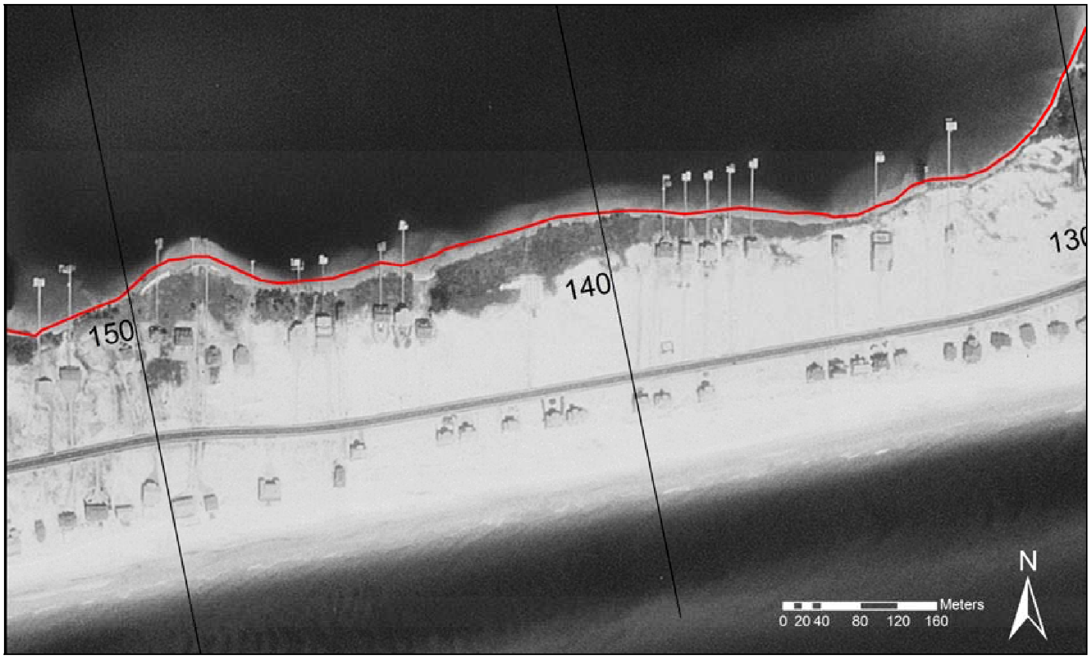

Figure 4-29 (Hurricane Frederic overwash fan in 1997, 1989 lagoon shoreline in red)

Correlation

For the time period covering 1989 to 1997, the Gulf shoreline accreted +10 m and the lagoon's southern shoreline eroded over –1 m. There were two overlapping areas showing significant correlation (Figure 4-30).

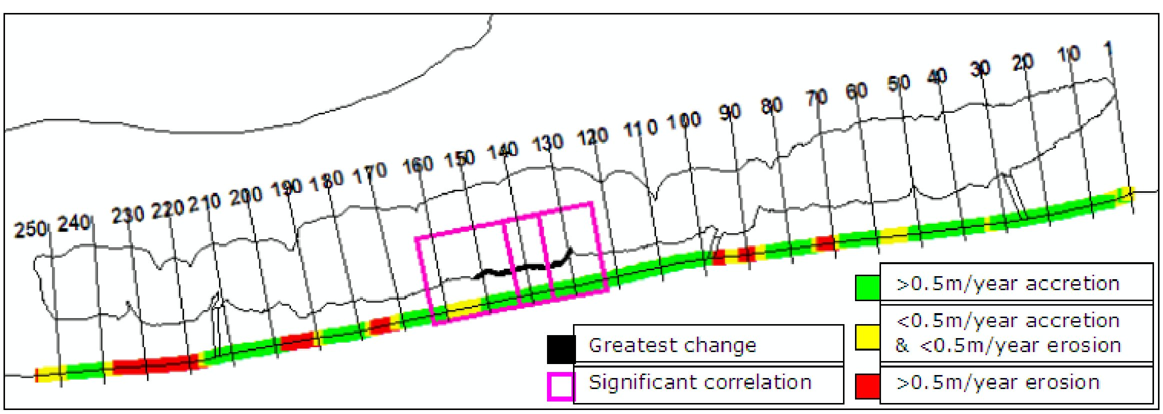

Figure 4-30 (Correlation areas, 1989 - 1997)

The first area (r = -0.565, p < 0.01) exists between transects 123 and 143, which is coincident with the location of, and mostly updrift of, the overwash fan from 1979. Over that kilometer, the Gulf shoreline accreted on all 21 transects with values ranging from +11 m to +30 m from an average of +20 m, while the lagoon shoreline eroded on all but three of the 21 transects with values ranging between –10 m to +6 m for an average of –4 m. However, the accretion on the Gulf shoreline was part of a larger nourishment project, and probably exaggerates the correlation (Figure 4-31a).

For the second area, correlation coefficients range from –0.555 to –0.679 between transects 135 and 163, the location of the overwash fan created by Hurricane Frederic. Over the 1.4 km, the Gulf shoreline accreted on all but one of the 29 transects with values ranging from –1 m to +30 m for an average of +15 m, and the lagoon shoreline eroded on all of the 29 transects with values ranging from less than –1 m to –16 m for an average of –6 m. The negative correlations reflect the inverse relationship between the Gulf and lagoon shorelines (Figure 4-31b).

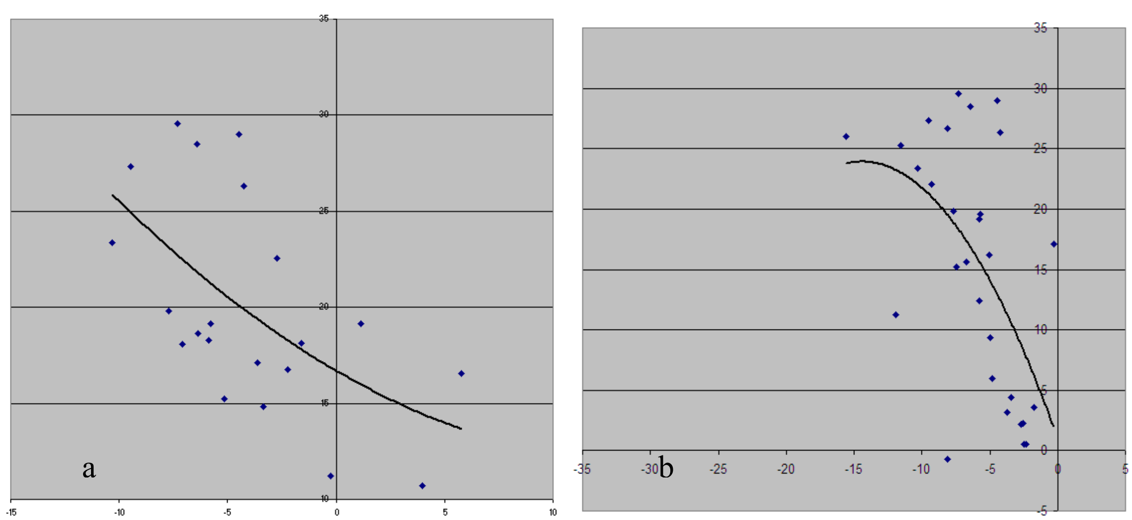

Figure 4-31 (Correlation scatter plots, 1989 - 1997)

1997 to 2001

<u>Gulf Shoreline</u>

Between 1997 and 2001, the Gulf shoreline accreted an impressive 12 m, or +3 m per year. Beach nourishment projects are responsible for the accretion. In 2000 and 2001 the city of Gulf Shores conducted numerous nourishment projects, reflected in Figures 4-32 and 4-33 as the large area of accretion within the first 3.5 km of the study area. There, the average change was +43 m. Downdrift of that, the average change is zero, reinforcing the idea that the nourishment projects related to Little Lagoon Pass continued to be effective.

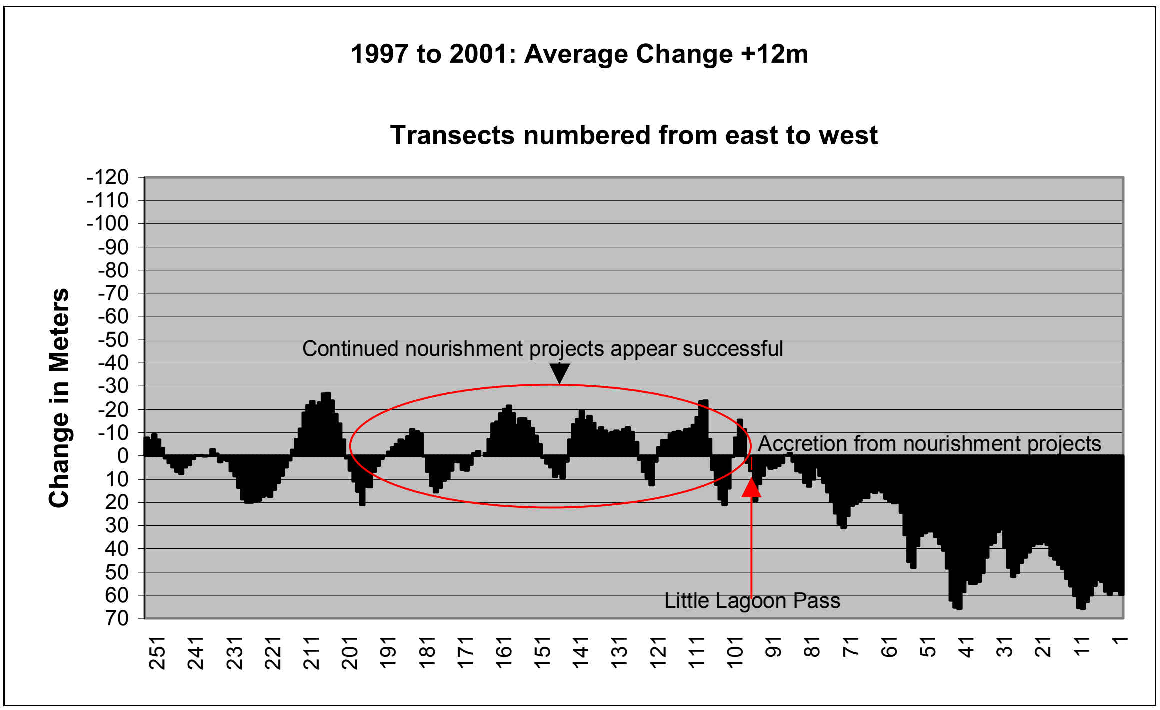

Figure 4-32 (Gulf shoreline change from 1997 to 2001)

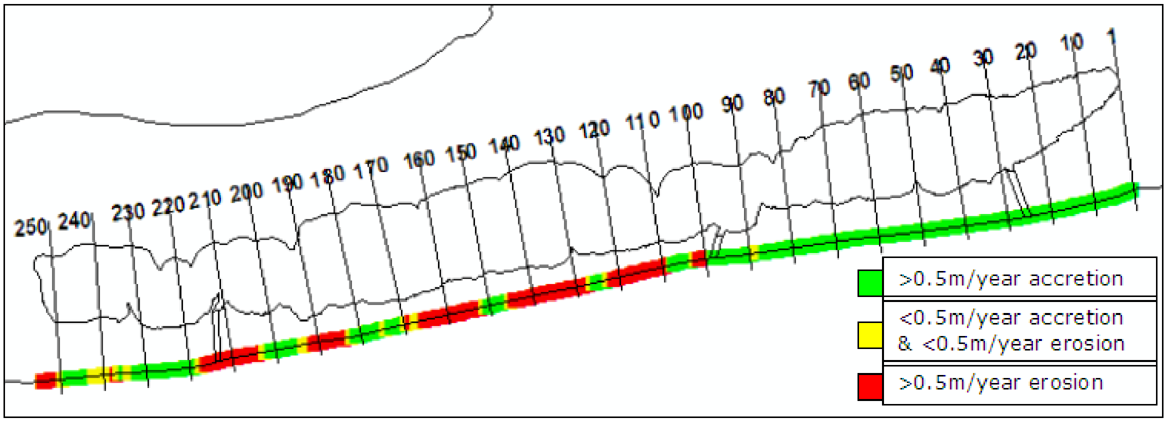

Figure 4-33 (Gulf shoreline change per year from 1997 to 2001)

1997 to 2004

Little Lagoon

On September 16, 2004, Hurricane Ivan made landfall on Little Lagoon with storm surges ranging between 10 ft and 15 ft. Because the aerial photographs of Little Lagoon were taken the day after Hurricane Ivan, they are not useful in actually measuring overall change from 1997 to 2004. However, one change is worth mentioning. Just as Hurricane Frederic deposited an overwash fan of 37 km² between transects 135 and 152, Hurricane Ivan deposited over 33 km² of sediment on many overwash fans between transect 130 and 182 (Figures 4-34 and 4-35). The average accretion was over 11 m.

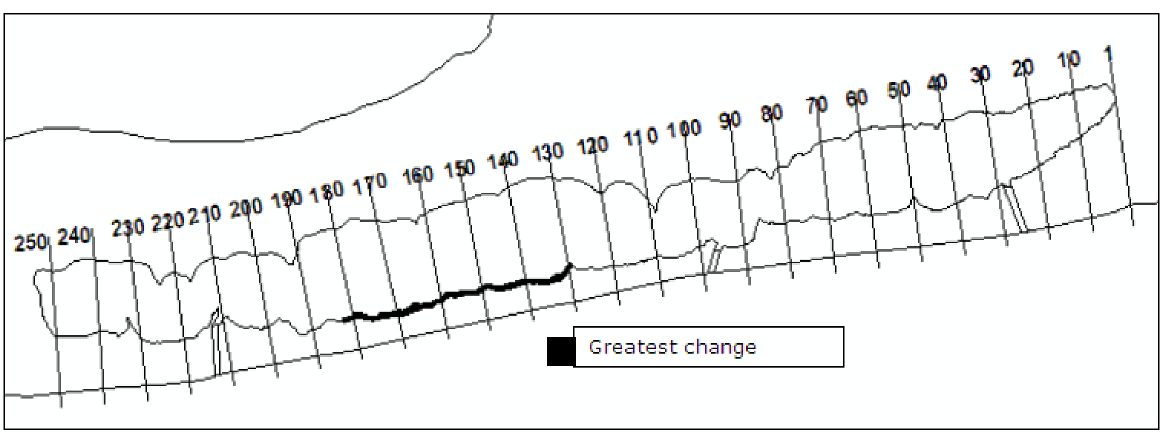

Figure 4-34 (Lagoon shoreline change from 1997 to 2004)

Figure 4-35 (Hurricane Ivan overwash fans in 2004, 1997 lagoon shoreline in black. Hurricane Ivan produced numerous overwash fans like those in this photo.)

Some significant changes occurred at the Pass as well (Figure 4-36), such as crenulate-shaped innerbank erosion as described by Seabergh (2001).

Figure 4-36 (Little Lagoon Pass in 2004, damaged by Hurricane Ivan)

It should be noted that many changes on Little Lagoon occurred gradually. However, when comparing the 1955 lagoon polygon to the 1997 or 2004 polygon, the greatest changes were still in the locations of tidal inlets or overwash fans.

CONCLUSION

Little Lagoon and the adjacent Gulf shoreline represent a unique area to observe changes associated with natural inlets, major storms, coastal engineering, and nourishment projects. The area continues to develop despite the devastation caused by double-digit storm surges from major hurricanes in 2004 and 2005. An understanding of beach behavior in response to future engineering can be gained by observing coastal morphology of the proposed engineering site, and this study of historical changes in shoreline morphology at Little Lagoon over the past century can contribute to local shoreline management.

Between 1917 and 2001, the Gulf shoreline had an average change of –40 m over the 254 transects. However, some areas of beach eroded almost 120 m while other portions accreted more than 60 m. By analyzing the changes in six groups, I was able to show that the greatest changes to occur on the Gulf shoreline were related to either the location of natural inlets, human construction, or beach nourishment projects. The single greatest change appears to be the nourishment projects conducted by the City of Gulf Shores in 2000 and 2001.

Little Lagoon experienced little change between 1955 and 1997. In 1955 the total area of Little Lagoon covered 10,285.9 km^2. By 1997 the total area was reduced to 10,234.5 km^2. That equals a change of –51.4 km^2, meaning that the land is encroaching upon Little Lagoon's estuarine waters at a rate of over 1.2 km^2 per year. The total change was about 0.5%. As seen on the Gulf shoreline, the changes vary from place to place and from year to year. Of course, it is impossible to account for every change, but the greatest changes occurred at the western and central (later Little Lagoon Pass) tidal inlets, the hurricane overwash fans deposited in 1979 and 2004, and one area of significant erosion that I assume to be the result of human impacts between 1960 and 1970.

Weak correlations between the Gulf shoreline and the lagoon's southern shoreline exist for each time period when all 254 transects are used, but much stronger correlations are seen when measured over 1 km sections, some reaching +0.917. The most statistically significant correlations exist at the same places that we find the greatest changes to both the Gulf and lagoon shorelines: near tidal inlets and hurricane overwash fans, where sediments are transported from one shoreline to another.

I recommend that the Alabama Department of Environmental Management include Little Lagoon and other embayed waters when taking aerial photographs of Alabama shorelines. By doing so, their low-altitude, high-resolution photos taken annually in September will provide more accurate measurements of shoreline change to Little Lagoon than the photos that were available for this study. I also recommend that future studies include more historical nautical charts, or T-sheets, to compliment the aerial photographs. NOS continues to digitize such charts, and they are easily imported to a GIS.

Coastal regions are growing faster than many other areas. With the threats of sea-level rise and increased hurricane activity combined with a dynamic landscape, shoreline studies provide critical knowledge to developers, city planners, and emergency responders. By analyzing shoreline change at larger-scales and over shorter-terms, this study provided the type of qualitative analysis called for by Cooper and Pilkey (2004b), and the methodology can be applied to almost any area with available data. Further, the findings may be applicable for shorelines under similar conditions.

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Appendix A

Maps and Charts

1. **Historical Maps** (downloaded from University of Alabama's Historical Map Archive at http://alabamamaps.ua.edu/historicalmaps/index.html).

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3. Topological Charts

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Appendix B

Little Lagoon Pass Dredging Projects

Project Number	Begin Date	End Date
Beach Restoration	04/18/1992	06/25/1992
99-709-022-182-340	01/25/1993	02/07/1993
	02/23/1993	03/03/1993
	03/24/1993	03/31/1993
	04/29/1993	05/05/1993
	06/03/1993	06/07/1993
	07/08/1993	07/14/1993
99-709-022-182-344	09/10/1993	09/18/1993
	10/14/1993	10/24/1993
99-509-022-182-348	12/03/1993	01/06/1994
	02/04/1994	03/06/1994
	06/21/1994	06/27/1994
	09/22/1994	09/30/1994
	10/17/1994	10/21/1994
	12/16/1994	12/22/1994
	01/25/1995	02/20/1995
	04/03/1995	04/14/1995
	06/15/1995	06/23/1995
	08/07/1995	08/19/1995
	09/08/1995	09/16/1995
	11/05/1995	11/10/1995
	04/05/1996	04/26/1996
99-509-022-182-648	06/17/1996	06/25/1996
	08/11/1996	08/21/1996
	10/09/1996	10/18/1996
	12/03/1996	01/23/1997
	02/25/1997	03/06/1997
	04/19/1997	05/02/1997
	06/23/1997	07/04/1997
	09/08/1997	09/12/1997
	10/27/1997	12/19/1997
	03/03/1998	04/24/1998
	06/29/1998	07/25/1998
	08/31/1998	11/17/1998

Project Number	Begin Date	End Date
99-509-022-182-848	11/18/1998	12/16/1998
	03/22/1999	04/28/1999
	06/19/1999	07/19/1999
	10/22/1999	12/20/1999
	02/16/2000	03/11/2000
	05/02/2000	05/11/2000
	07/06/2000	07/19/2000
	09/06/2000	12/13/2000
	04/11/2001	05/13/2001
99-509-022-182-148	07/13/2001	08/21/2001
	09/27/2001	11/02/2001
	12/03/2001	01/31/2002
	04/18/2002	05/15/2002
	09/16/2002	11/20/2002
99-509-022-182-348	11/17/2003	11/27/2003
	12/20/2003	12/23/2003
	08/31/2004	09/13/2004

VITA

Glen Gibson grew up in Foley, Alabama, and joined the military in 1989. While on active duty, he graduated from Embry-Riddle Aeronautical University with a Bachelor of Science in Aeronautics in 1998. He has served as an Air Traffic Controller, Weapons Director Technician, B-1 Weapons System Officer, and Air Liaison Officer. During his military career, Captain Gibson began to appreciate the influence of geography on the mission planning process. This interest, coupled with his impeccable service record, led the United States Air Force Academy to sponsor him for a Masters of Science in Geography at Virginia Tech. Captain Gibson will begin teaching at the Academy in Fall 2006.