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PRELIMINARY INVESTIGATION OF THE CHARACTERISTICS OF COASTAL LAKE OUTLETS IN THE FLORIDA PANHANDLE

Hurricane Opal Beach Recovery Study: Task C

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by

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Submitted to:

Florida Department of Environmental Protection
Bureau of Beaches & Coastal Systems

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Preliminary Investigation of the Characteristics of Coastal Lake Outlets in the Florida Panhandle

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1.0 INTRODUCTION

This report discusses the characteristics and conditions of several small outlets associated with coastal lakes in the Panhandle region of Florida. Specifically, the small lakes in Walton, Bay, Gulf, and Franklin Counties that have intermittent communication with the Gulf of Mexico are considered. These lake/Gulf connections are of interest for several reasons. The first involves flood level control in the areas surrounding the lakes; the opening to the Gulf provides a means of relieving high water/flood conditions around the lakes. The second reason entails the stability and migration of the small outlet. In some areas, coastal development has encroached upon the historic "sweep path" of the migrating outlets. The question arises of how far the outlet may migrate in the future, and if and when human intervention is appropriate.

Figure 1 shows the general locations of the coastal lake sites of interest in this study. Twenty-six sites were identified as having potential impacts from the migration of the small channels. Twelve sites lie in Walton County, all of which have an undeveloped connection to the Gulf. Nine sites are in Bay County, many of which are stabilized by culverts underneath the coastal road. In these cases the sweep path, and occasionally the lake area, are somewhat limited in extent or are difficult to delineate. In some of the more developed areas, the lake has been replaced by development and the source of the intermittent outlet is

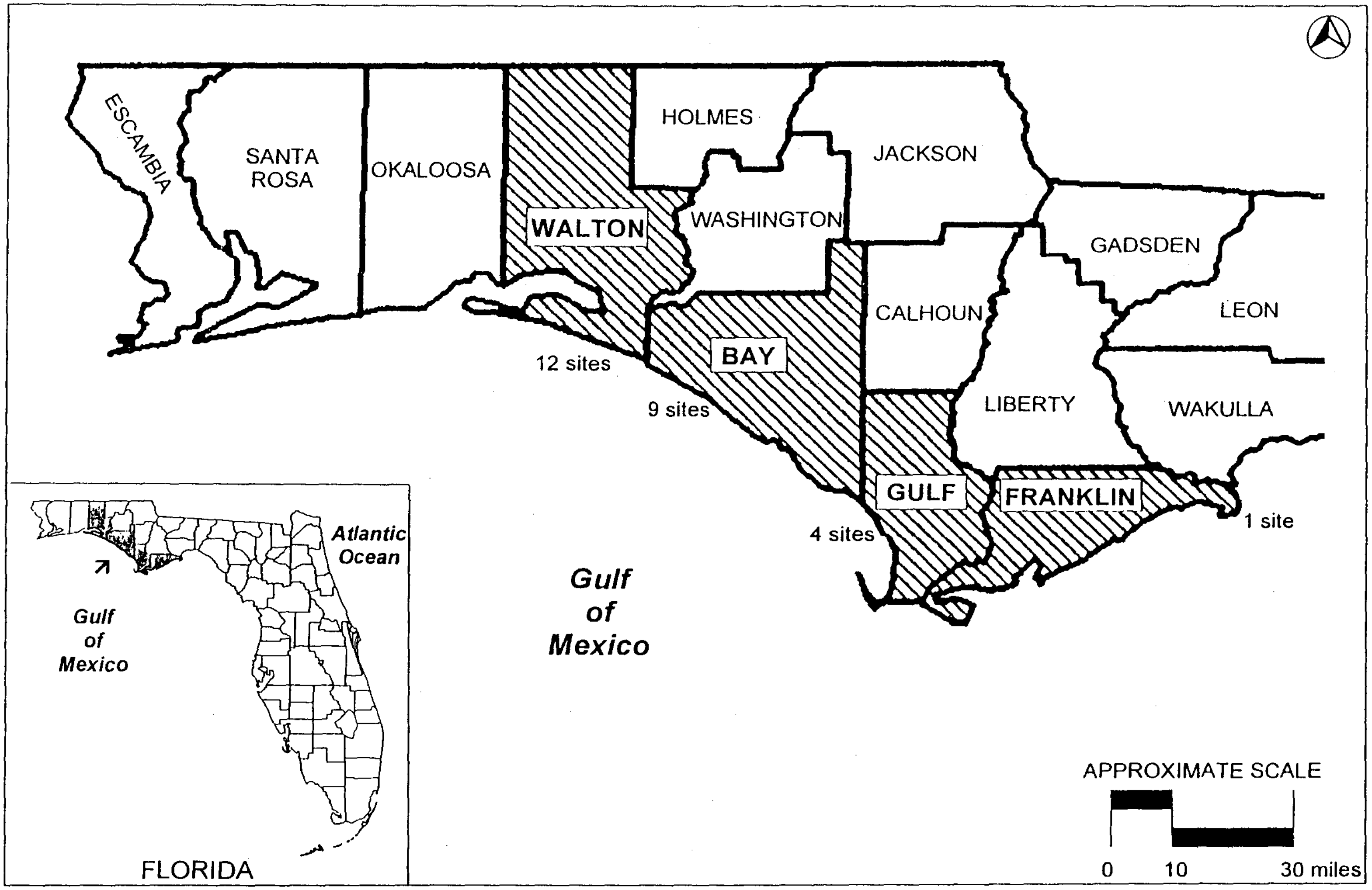


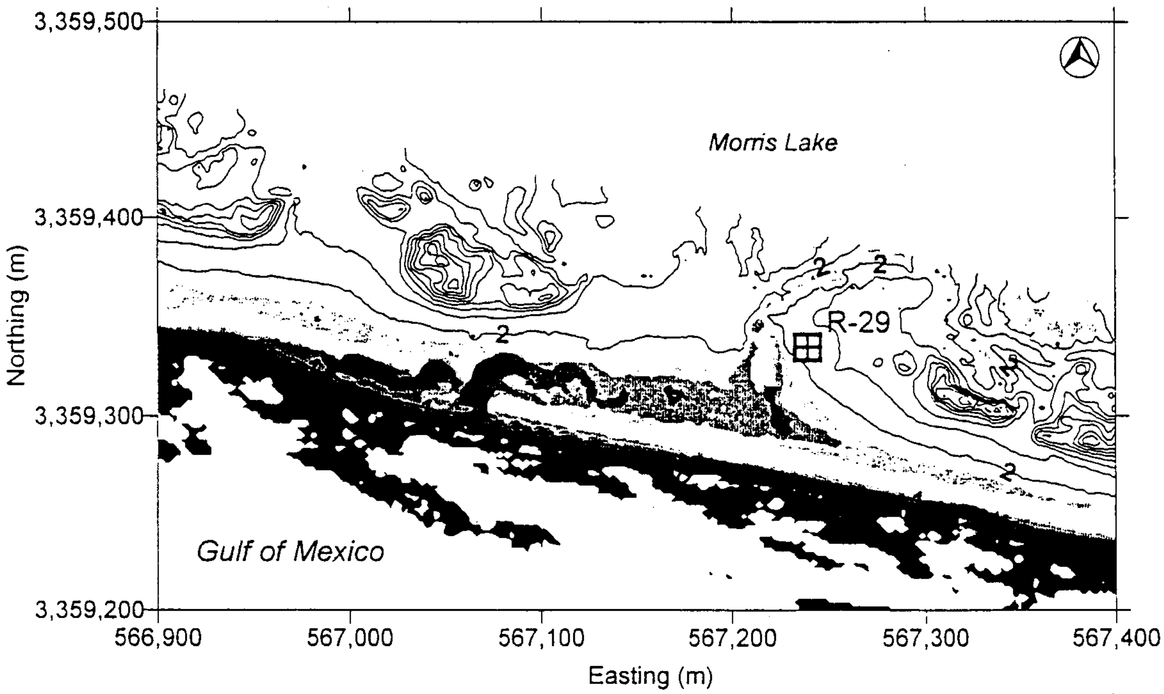
Figure 1 Location map of Walton, Bay, Gulf, and Franklin Counties in the Florida Panhandle. Walton County has 12 of the 26 sites, Bay County has nine, Gulf County has four, and Franklin County has one site in the study.

the direct runoff into the channel. The sites in this study were identified primarily from Coastal Construction Control Line (CCCL) maps for the four counties. The CCCL maps are produced by the Florida Department of Environmental Protection (FDEP). These maps identify the location of the CCCL, which delineates the State's jurisdiction in coastal matters. Construction seaward of these lines requires special permitting from FDEP. It is noted that the CCCL in the vicinity of these coastal lake outlets has generally been diverted landward of the historic sweep areas, reducing (but not eliminating) the threat of structural damage due to migration of the outlets. However, development seaward of the CCCL does exist in many of these areas, and the potential for damage still exists.

This report is divided into three sections. The first section describes the physical characteristics of the sites. Important parameters include the size of the lakes, the distance between the lake and the existing shoreline, the historic "sweep area" (the area affected by all previous identifiable locations of the channels), and local rainfall amounts, among others. The second section attempts to describe the mechanisms by which the connection between the lakes and the Gulf of Mexico is established. The third section discusses the migration of the outlet channel due to the littoral forces along the shoreline. The third section also describes the changes to several sites in Walton County resulting directly from the passage of Hurricane Opal in October, 1995.

In this report, the term outlet is used to describe the majority of the lake/Gulf connections since the flow is generally from the lake out to the Gulf of Mexico, and only occasionally is there tidal exchange between the two bodies. Few if any of these sites are navigable, even by small boat. The terms inlet and outlet are occasionally used interchangeably, and in some instances the connections have historically been labeled inlets, such as Phillip's Inlet.

This investigation was performed for the Florida Department of Environmental Protection (FDEP) Bureau of Beaches and Coastal Systems as a subtask of the ongoing monitoring and evaluation of the impacts from Hurricane Opal.



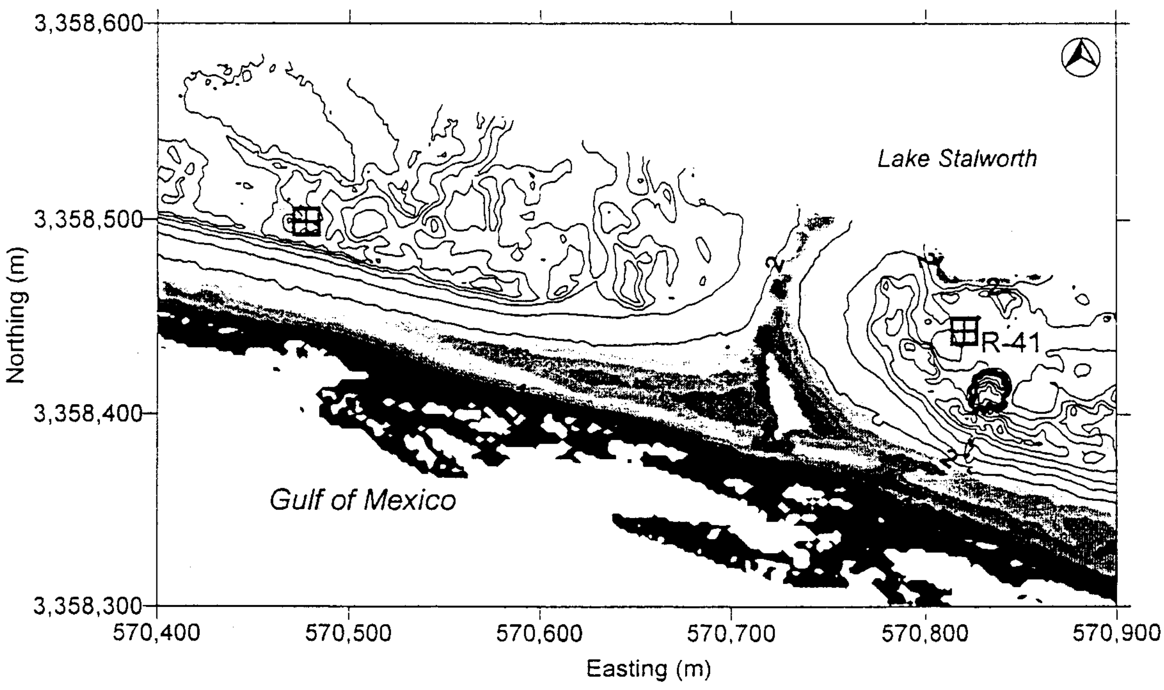


Figure A-1 Laser swath survey contour maps of Morris Lake and Lake Stalworth in Walton Co., FL. Elevations in meters above National Geodetic Vertical Datum. Survey Date - October 16-17, 1996.

2.0 PHYSICAL CHARACTERISTICS

Figure 2 presents a schematic photograph of the problem of concern. In this figure, the lake is connected to the tidally-influenced ocean (or Gulf in this case) via one potential outlet. This distinguishes the present problem from barrier island breach problems in that the lake does not experience tidal fluctuations of any kind when the one outlet is closed, thus excluding barrier island breaches (such as Navarre Pass in Escambia County), where the lagoon behind the barrier island is tidally influenced and has the potential for other outlets for high water. In the present problem, the lake/Gulf outlet represents the only escape of high water.

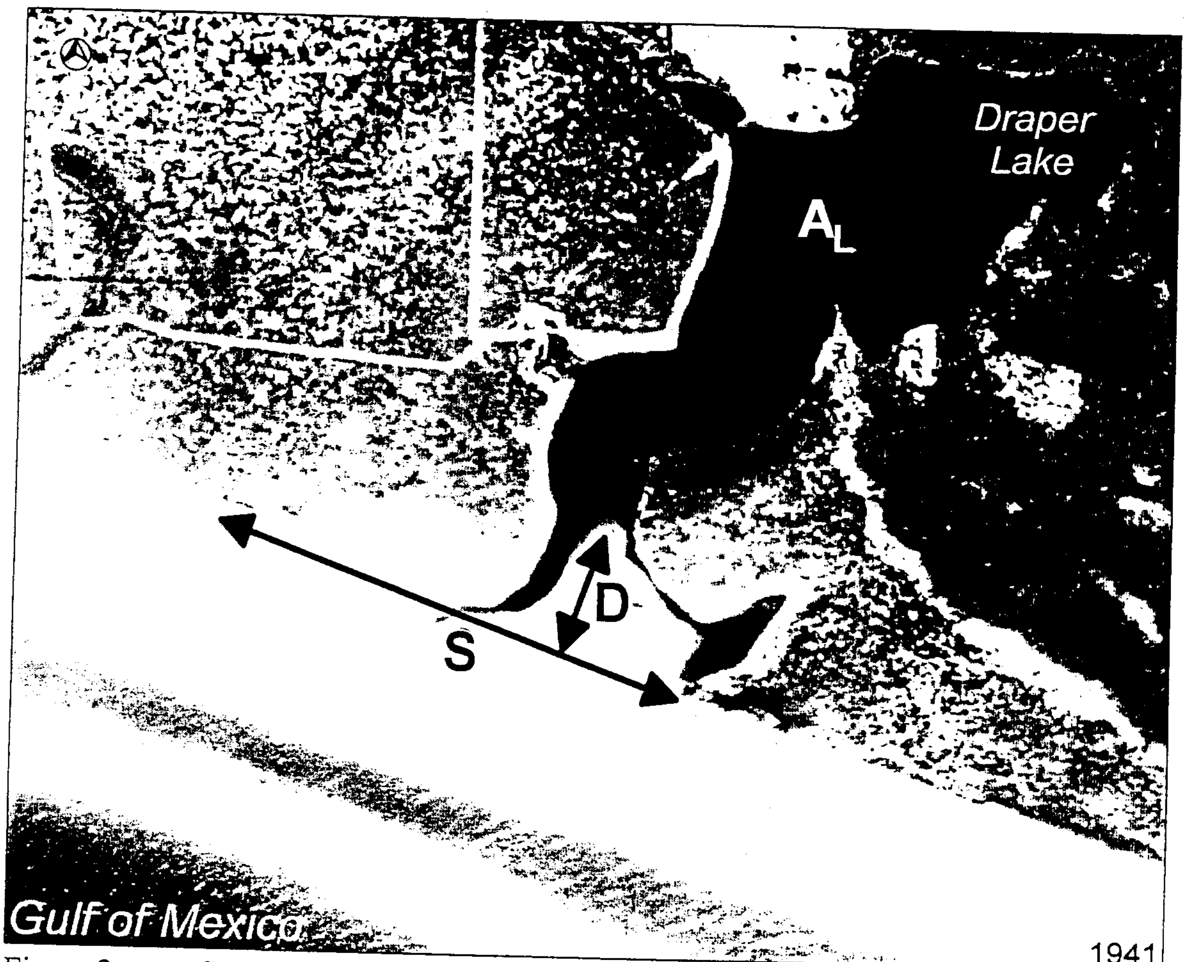


Figure 2 Schematic of coastal lake outlet.

Figure 2 also illustrates the basic physical parameters of interest in this problem. The separation distance, D, represents the shortest distance from the main body of the lake to the existing dune line on the shoreline. This value was determined from aerial photography, considering the dune line as a consistent smooth curve between the dunelines to either side of the affected area. Given the ephemeral nature of these sites, this estimation was deemed sufficient for this discussion.

Similarly, the sweep distance, S, is defined from aerial photography and survey data as the length of shoreline which can be identified as being influenced by all previous locations of the channel. This distance is determined from the extreme limits of the interrupted dune or vegetation line. The area of the lake, A_L, was digitized from recent aerial photography of the area. In addition to the actual lake area, the area of runoff corresponding to each site is certainly a relevant parameter, as is groundwater inflow. Given the nature and scope of this preliminary investigation, however, these additional areas were not determined.

One source of data for this study comes from Project LASER, conducted by the Civil Engineering Department of the University of Florida (Carter et al., 1997). This project entailed the collection of high resolution laser swath survey data along the Panhandle shoreline of Florida in October, 1996. This data set provides valuable information on the condition of the Panhandle shoreline. The data set was used in the present study to determine many of the physical characteristics mentioned above, and to obtain elevation data unavailable from aerial photography.

Figure 3 presents an example from this dataset. This figure depicts the beach area in the vicinity of Phillips Inlet on Lake Powell in Bay County is shown. The figure clearly indicates the location of the channel at the time of the survey.[1] Also evident in the figure are the remnants of two previous channels to the gulf, both located east of the flowing channel in October, 1996. From this figure it is evident that approximately 3,000 feet of shoreline are impacted by the connection between Lake Powell and the Gulf of Mexico. Figure 3 clearly highlights the issue of channel migration. At the time of the laser swath survey, the channel was nearly in its westernmost location. The location of the relict channels, and the low, unvegetated nature of the beach to the east suggest that the channel may have once been nearly 3,000 feet to the east, very close to where structures have since been built (near R-1 in Bay County). Appendix A contains plots of each of the lake-channel sites in Walton and Bay Counties and from the laser swath survey.

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The laser swath system employed does not provide sufficient survey information of smooth water surfaces.

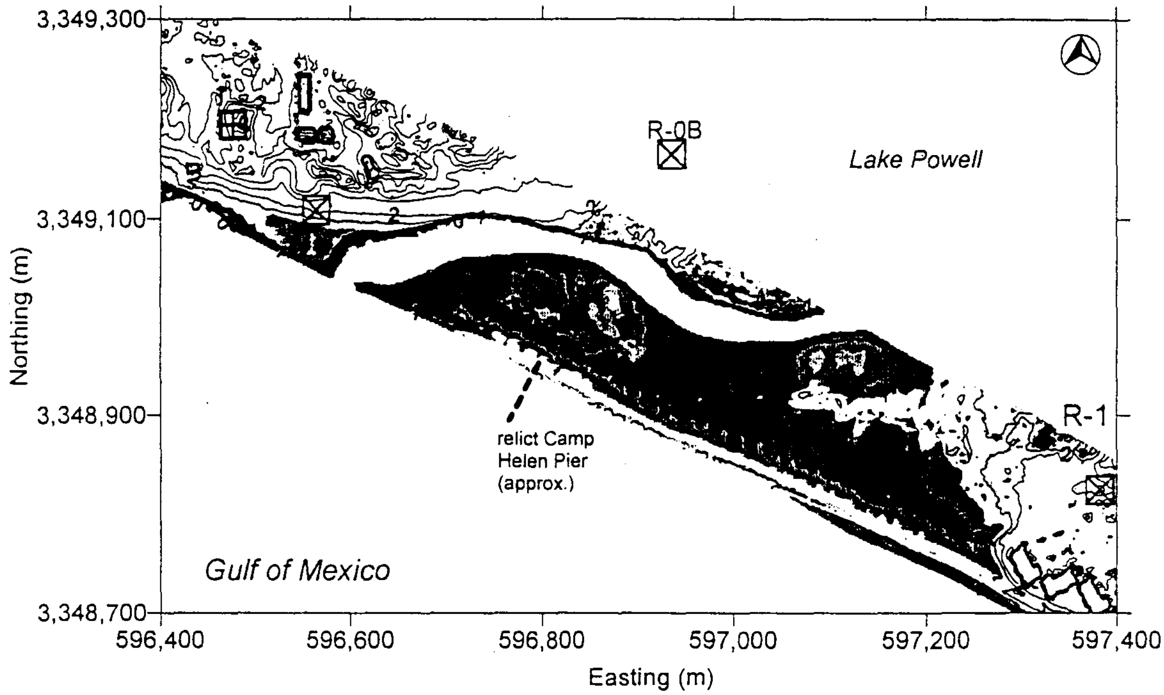

Figure 3 Example of laser swath survey data showing contour plot of Phillips Inlet in western Bay County, FL. Survey date October 16-17, 1996. Elevations in meters above National Geodetic Vertical Datum, 1929.

Table 1 presents the physical dimensions for all the sites in the study, as outlined in Figure 2. As mentioned previously, many of the sites have been stabilized by culverts and other coastal development, particularly in Bay County, where development has encroached upon some of the lakes, leaving only a drainage ditch for runoff. Most of the unrestricted coastal lakes lie in Walton County.

From Table 1, the average sweep distance, *S*, is roughly 770 feet alongshore, and the average separation distance, *D*, between the lake and the dune line is 430 feet. In those areas where pipe outfalls have been installed, older aerial photography was used to determine the separation distances. Many sites in Bay County consist of pipe outfalls issuing directly onto the sandy beach seaward of buildings or dune/vegetation lines; these areas were assigned a sweep distance of zero. In Walton County (including Phillips Inlet), where most of the unrestricted outlets are found, the average sweep distance is roughly 1,250 ft.

The lake areas associated with these outlets varies significantly. The largest, Lake Powell at Phillips Inlet, is over 650 acres in area. Some of the other outlets have no discernable open lake area, these outlets drain marsh areas. For the uncontrolled outlets, a typical lake area is of the order of 10 to 150 acres.

Table 1 Physical Characteristics of Coastal Lake Outlets.

Outlet #	County	R-Mon.	Associated Name	A_I (acres)	S (ft)	D (ft)
1	Walton	R-29	Morris Lake	75	600	1,050
2	Walton	R-41	Lake Stalworth	15	400	300
3	Walton	R-46	Oyster Lake	20	400	200
4	Walton	R-52	Dune Allen Beach	---	150	100
5	Walton	R-55	Draper Lake	35	1,200	300
6	Walton	R-64	Big Redfish Lake	25	1,500	400
7	Walton	R-65	Little Redfish Lake	10	800	250
8	Walton	R-69	Alligator Lake	15	1,200	700
9	Walton	R-73	Western Lake	150	1,900	900
10	Walton	R-95	Eastern Lake	65	1,000	500
11	Walton	R-99	Deer Lake	30	1,500	650
12	Walton	R-104	Camp Creek Lake	65	2,600	500
13	Bay	R-1	Phillips Inlet	650	3,000	800
14	Bay	R-14	Hollywood Beach	5	650	250
15	Bay	R-24	Laguna Beach	1	150	450
16	Bay	R-26	Laguna Beach	---	50	400
17	Bay	R-33	Gulf Beach	4	50	300
18	Bay	R-37	Gulf Beach	30	0	200
19	Bay	R-42	Gulf Beach	2	0	400
20	Bay	R-45	Gulf Beach	---	0	200
21	Bay	R-58	P. City Beach Pier	---	300	400
22	Gulf	R-13	Yon's Subdiv. outfall	---	100	200
23	Gulf	R-18	outfall- St. Joe's Bay	---	350	500
24	Gulf	R-20	outfall-St. Joe's Bay	---	800	300
25	Gulf	R-141	Money Bayou	---	1,000	600
26	Franklin	R-232	Mullet/Double Ponds	---	350	350

A field visit was conducted as a part of this preliminary investigation in order to provide a more up-to-date condition of the lake outlets, collect photo-documentation and limited survey data, and to identify potential sites for additional study. The field visit, conducted by UF personnel on April 16-17, 1998, included the majority of the sites listed in

Table 1[2]. At the time of the visit, conditions at several of the outlets were significantly different than in the October, 1996, laser survey dataset. Figure 4 illustrates the change in location of the thalweg of the outlet channel for Draper Lake, located near FDEP monument R-55 in Walton County. At the time of the laser survey, the thalweg was located closer to the center of the historic sweep area. By April, 1998, the channel had migrated westward approximately 150 ft and was encroaching upon the steep dune embankment and its sand fencing to the west. Several other sites were observed to be in a similar condition, such as Oyster Lake (Walton Co. R-46), Alligator Lake (Walton Co. R-69), and Eastern Lake (Walton Co. R-95). Many other sites were observed to be in a noticeably westward location (relative to previous aerials), but were not in the vicinity of structures.

The overall low elevation of the sweep areas was quite noticeable. Overwash deposits, presumably from Hurricane Opal, were evident in many areas. Previous channel locations were also identified at many sites. Figure 5 presents an alongshore cross-section taken from the laser data for Western Lake at Grayton Beach State Park, looking onshore (elevation view). The cross-sectional profile indicates the present location of the channel, roughly 440 ft west of monument R-73, and a relict channel less than 100 ft to the east. The historic sweep path of this channel extends well beyond the longshore limits of this graph, covering a distance of 1,900 ft alongshore.

Along many areas in Bay County, the lake outlets appeared to be outfalls incorporated under the coastal road (U.S. Rte. 98-Alt) and buildings. These lake outlets do not appear to be of the same concern as the unrestricted outlets in Walton County. One concern, however, would be the maintenance of the outflow drain in the event the shoreline is nourished. In many instances these outlets are directly fed by several drainage ditches from both sides of the coastal road (e.g., R-14), or were recently mechanically opened to maintain drainage requirements (e.g., R-26).

The four sites in Gulf County and the one site in Franklin County were documented. In Gulf County, the site at R-13 in Yon's subdivision was open and flowing to the east-southeast, although the longshore current at the time of observation was directed west-northwest. The two adjacent sites, R-18 and R-20, are not in developed areas, and were both closed, although wave overwash over the accretion berm was witnessed. The outlet at Money Bayou (Figure 6), east of Cape San Blas, was open and flowing. This site appears

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Some of the sites were difficult to access, requiring either 4WD vehicles or permission to enter gated communities, neither of which was available at the time of the visit.

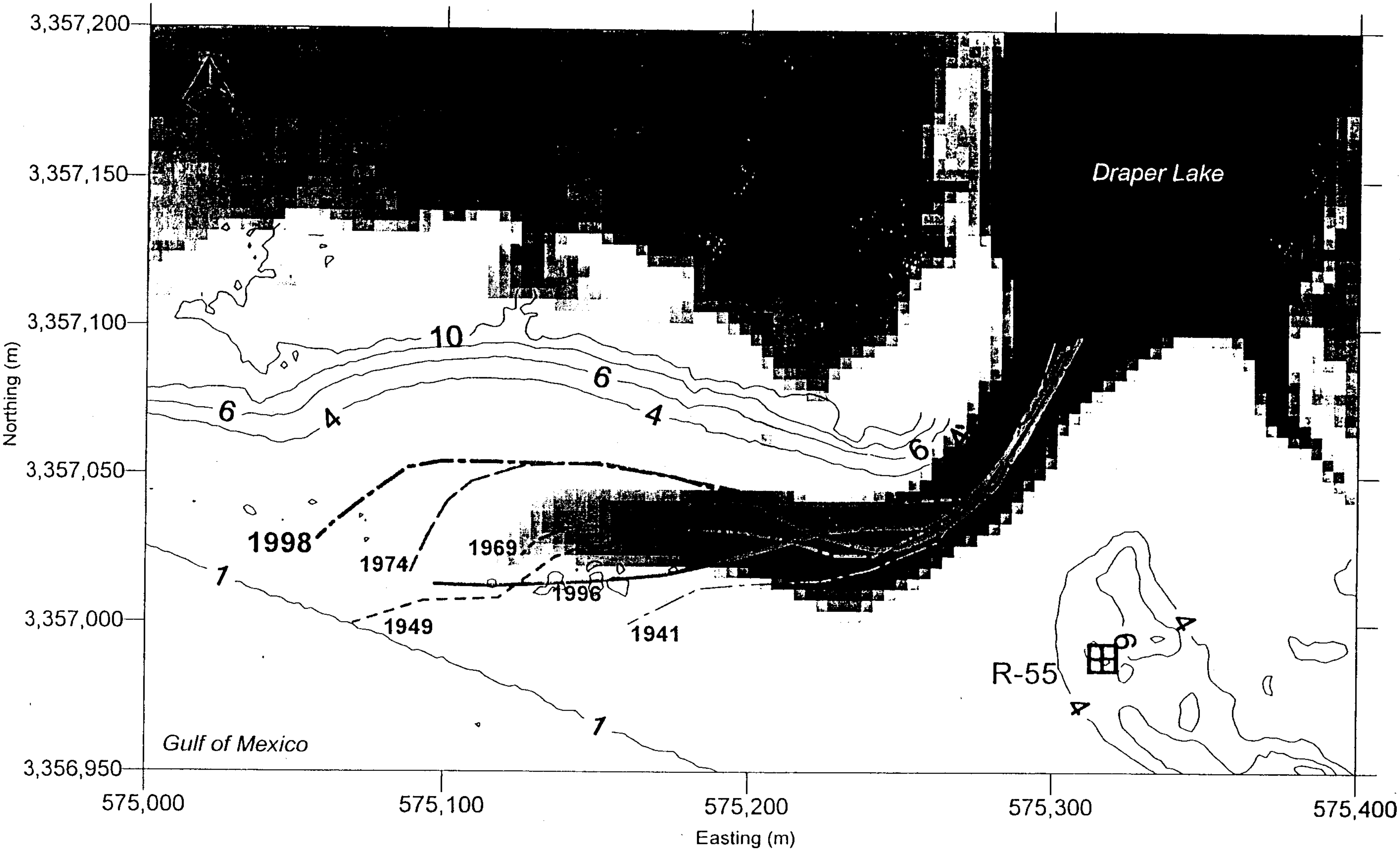

Figure 4 Variation in the location of the thalweg of the outlet channel for Draper lake in Walton County, FL. Contour elevations dated October, 1996, and are referenced to NGVD (1929). Photograph dated February, 1969.

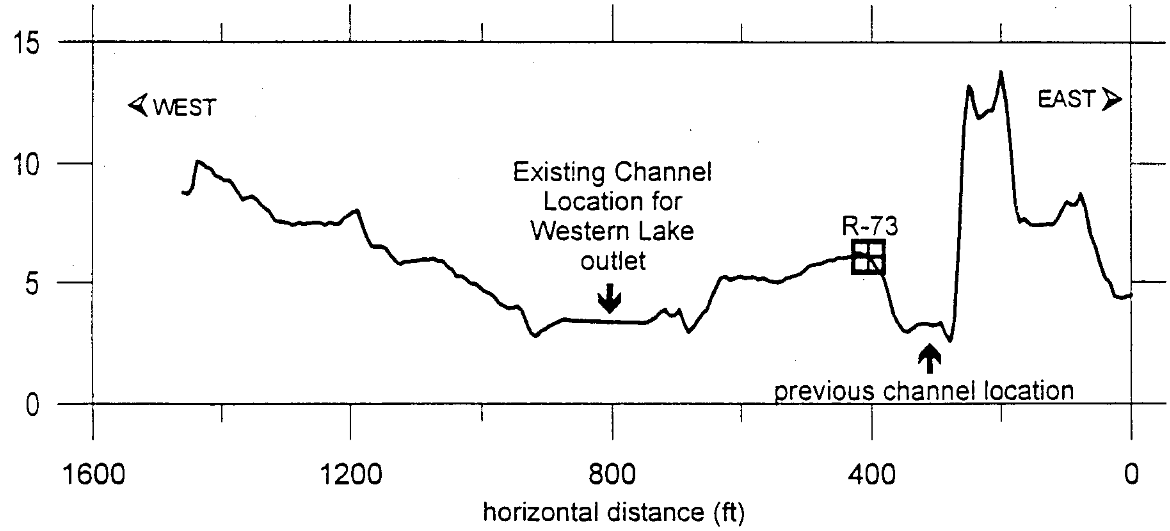

Figure 5 Alongshore elevation view of the channel outlet at Western Lake (Grayton Beach St. Park). The profile indicates the location of a relict channel.

to be much larger than most of the other sites in this study, and is likely open for a greater length of time. The one site in Franklin County is located on Bald Point adjacent to Ochlockonee Bay. This channel had recently closed after migrating slightly to the north. The channel did not appear to be a significant threat to the adjacent house to the south.

One observation made at many of the sites relates to the seemingly sudden changes in direction of the outlet channels as they progress toward the Gulf. In several areas, particularly in Walton County, a substantial accretion berm had formed. In areas where the berm crest elevation was slightly lower, overwash occurred. It appeared that this point of overwash served to redirect the flow of the channel.

Figure 6 Ground view of Money Bayou (Gulf County R-141). At the time of field inspection(April 16, 1998, roughly mid-tide), the channel was open and flowing. The channel throat dimensions were approximately 30 to 40 feet in width, and roughly 4 feet in depth at the deepest point.

3.0 MECHANISMS FOR OUTLET OPENING

This section discusses the natural mechanisms by which the connections between the coastal lakes and the Gulf of Mexico may form by natural processes. There are three principal mechanisms: 1) the water level in the lake rises to an elevation higher than the beach dune and simply overflows onto the beach, following the path of least resistance and forming a distinct channel via scour, 2) the water level rises sufficiently to saturate the sand between the lake and the Gulf, thus causing a condition in which the water can flow through the sand, destabilizing the sand and eventually creating a channel, and 3) erosion from the beach side erodes the berm between the lake and the Gulf, and the berm breaches. Of the three natural mechanisms listed, No.s 1 and 3 are fairly obvious means for water from the lake to reach the gulf, and vice-versa. In all likelihood, some combination of all three contribute to the natural opening of the channels[3]. At some of the sites, the channels are opened by mechanical means to alleviate flood conditions around the lakes.

Several investigators have studied the effects of tidal fluctuations, wave runup, and wave setup on the local watertable at the shoreline. In one of the first published works on the subject, Grant (1948), described how the effect of watertable level influenced the erosion or accretion of the beachface. He noted that water from the ocean side can percolate into the beachface more easily than it can exit. Nielsen (1990a & b) presented a mathematical description of the propagation of tidal waves into the watertable and presented field measurements from beaches near Sydney, Australia. Nielsen's results indicated that the watertable follows the tide level at higher levels of the tide, but that the watertable does not fall as low as the tide level near low tide. Hence the mean watertable near the coast is elevated above the still water condition. This also indicates that the watertable becomes discontinuous at the beach face during lower stages of the tide, creating a seepage face on the beach.

The location of the seepage face/discontinuity and its handling in models is still subject to much research. Baird and Horn (1996) presented a numerical model of the elevation of the watertable in sandy beaches. Turner et al. (1997) conducted field measurements in Australia near a coastal lake with an array of piezometers installed between the lake and the shoreline to measure fluctuations in the watertable level. Turner's group documented the effects of rainfall, tides, and waves on the local watertable. In Turner's study, however, there was no open connection between the lake and the ocean.

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[3] Inspection of aerial photography since the 1940's shows no evidence of shoreline erosion leading directly to a breach at the sites in this investigation.

Figure 7 presents a simple profile schematic of the watertable between a coastal lake and a tidally-influenced body of water (the Gulf), with waves. Here it is assumed that the level in the lake is higher than the still water level of the Gulf. The picture illustrates the hydraulic gradient that can exist across the berm between the lake and the Gulf. The gradient creates a flow of water through the sand in the direction of the gradient (Gulfward in Figure 7). The flow of water then exerts a force on the sand particles, changing the equilibrium of the particles, particularly on the beachface (see inset, Figure 7). The seepage force exerted on the particle can be determined from the hydraulic gradient via Darcy's Law (e.g. Cedergren (1989), or Nielsen (1992)).

Of interest here is the balance between the effects of tides, waves, and increased water levels, both in the lake and in the Gulf. The effects of tides and wave setup and runup are to raise the local mean water surface (and watertable) near the beachface, actually reducing the hydraulic gradient between the lake and the Gulf. At the same time, however, the waves are exerting forces on the individual sand grains at the beachface. This creates a situation in which the waves are both destabilizing the beach face and bringing in sand from updrift. At some point, the hydraulic gradient that exists across the berm may sufficiently reduce the downward force of the submerged weight of the sand grains, allowing the wave action to more easily dislodge the sand particles, leading to increased flow Gulfward, and ultimately the establishment of a channel between the two water bodies. Again, it is likely that a combination of mechanisms contributes to the opening of the channels between these coastal lakes and the Gulf of Mexico.

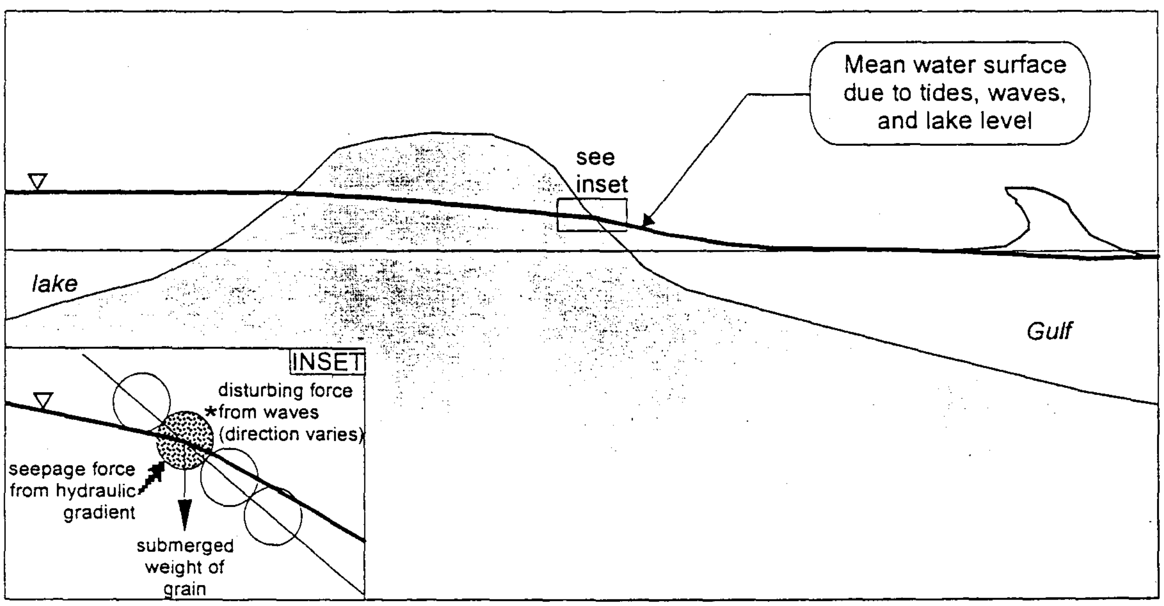

Figure 7 Schematic of watertable elevation across a sand berm between a coastal lake and a tidally-influenced body of water.

Visser (1990) describes the process of breach growth through sand dikes. In a field experiment, Visser's group investigated the behavior of a small, artificially-breached sand berm. This experiment was conducted on the southwest coast of The Netherlands, where the investigators temporarily blocked a small tidal inlet to study breaching inward (the sea level was higher than the lake level). Visser's group measured current velocities within the breach and water levels of both bodies, and developed a simple mathematical model to describe the sediment transport in the breach and the discharge rate through the breach. Wave action was not a factor in the experiment. Visser (1995) further developed the application of various sediment transport formulae to the problem of sand-dike breach erosion.

One of the most obvious factors, of course, is rainfall. The accumulation of rainfall in the lakes increases the water levels and hence the watertable around the lake. Table 2 presents the average monthly rainfall for the area, taken from the National Weather Service rainfall data for Defuniak Springs in Walton County and Panama City in Bay County. The area averages 65 to 66 inches of rain per year, with July and August being the rainiest months. In 1997 and 1998, the State of Florida has been impacted by El Niño, which has altered the rainfall patterns in the area. Detailed rainfall amounts were obtained from the Bay County Public Utilities Department for 1997 and 1998. These records do not indicate a higher total rainfall for 1997, but the records do indicate higher rainfall levels in January, February, and March of 1998. Prolonged rainfall contributes to increased lake levels and keeps the channels open and flowing longer than usual. For example, since being opened for flood control in July, 1997, Phillips Inlet has remained open as of the date of this writing.

Table 2 Average monthly rainfall in Bay and Walton Counties, FL.

Month	Avg. Rainfall (in.)	Month	Avg. Rainfall (in.)
January	5.5	July	8.9
February	5.0	August	7.7
March	6.2	September	5.7
April	4.4	October	3.5
May	4.4	November	4.0
June	6.4	December	4.3

* Compiled from rainfall data spanning 49 years from Defuniak Springs, FL, and 25 years from Panama City, FL, National Weather Service.

4.0 BEHAVIOR OF THE OPEN OUTLET CHANNEL

Once the connection between the coastal lake and the Gulf is established, the question then turns to stability and migration of a tidal or semi-tidal outlet. Of interest here is the rate and limits of migration and the time before closure once the channel is opened. At many of these sites, particularly in Walton County, the channels are unrestricted by structures (training walls, culverts, etc.). The channels are thus subject to the littoral forces on the beach face, which serve to displace the channel location along the shoreline in the direction of the littoral drift. The littoral drift will carry sand into the channel on the updrift side, shoaling the channel. In order to maintain the same cross-sectional area in the channel to maintain the flow rate, the channel will scour out the downdrift side of the channel. Hence the channel will migrate downdrift.

Along Walton and Bay County shorelines, the net annual littoral drift is generally to the west. An outlet that is able to stay open long enough in this area will generally migrate to the west. Figure 3 presents the condition of Phillips Inlet in October, 1996. From this picture it is evident that the channel has migrated from east to west, as the channel appears to be in its westernmost position at that time. In July, 1997, the State Parks Department, under permit from FDEP, opened a new channel for Phillips Inlet roughly 150 ft east of the Camp Helen Pier (see Figure 3). The western channel was closed mechanically. By April, 1998, the new channel had migrated to the pier, a 150 ft migration in nine months.

This is not to imply that all these channels migrate to the west. Beginning along the southeastern portion of the Bay County shoreline (in the vicinity of Mexico Beach), the net drift direction reverses to the southeast directed toward St. Joseph Bay, hence the outlets in Gulf County would have a tendency to migrate to the southeast (which is verified by aerial photography). Additionally, at various times of the year the littoral drift is directed opposite to the net drift direction, and any outlet that is open and flowing during this time will experience pressure from the opposite direction due to the incoming waves.

For example, Figure 8 depicts the topography on the beach near Alligator Lake in Walton County. At the time of this survey, the channel appears to be shifted to the east. This may indicate that there was a strong relict channel directed that way, or that the channel was open primarily during easterly-directed littoral drift. It is also important to note that any hard features (such as trees or structures) may redirect the flow and cause a tendency to flow in a certain direction, regardless of the prevalent littoral drift. Figure 9 provides another example. The photo shows Navarre Pass in Escambia County. This photo indicates that while the pass was open in 1965, the channel has meandered first to the east then to the west before closing just prior to the taking of the photo in September, 1965.

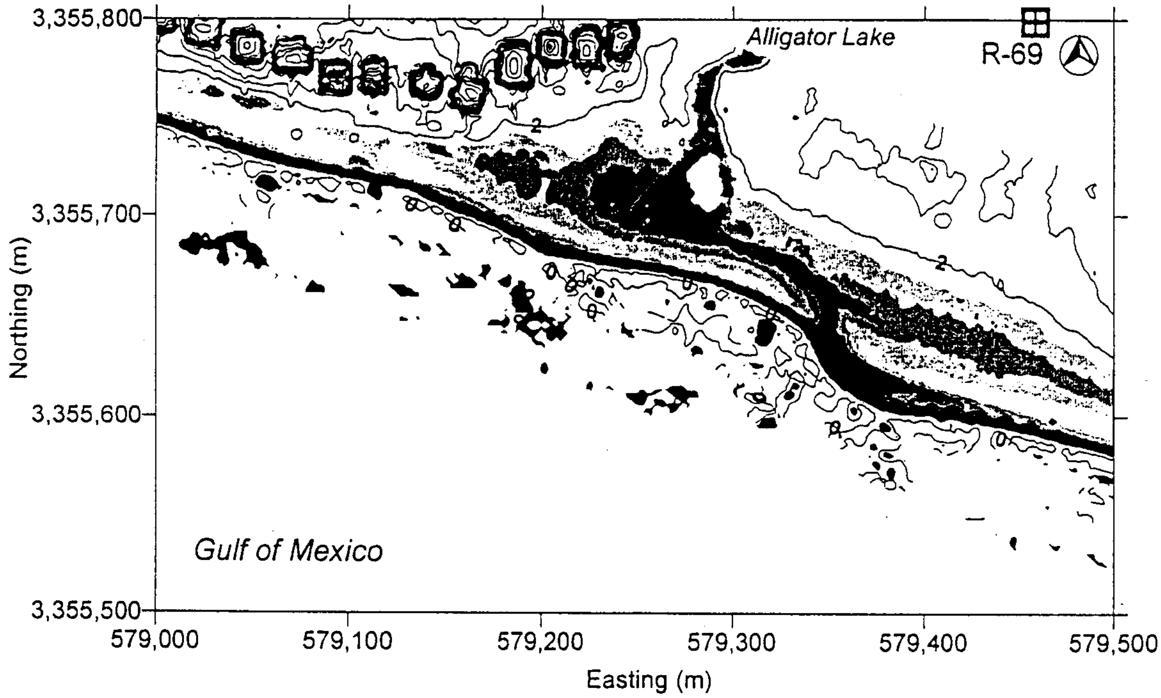

Figure 8 Contour plot of the beach topography in the vicinity of Alligator Lake in Walton County, FL. At the time of the survey, October, 1996, the channel was directed to the east, and a small ebb delta had formed.

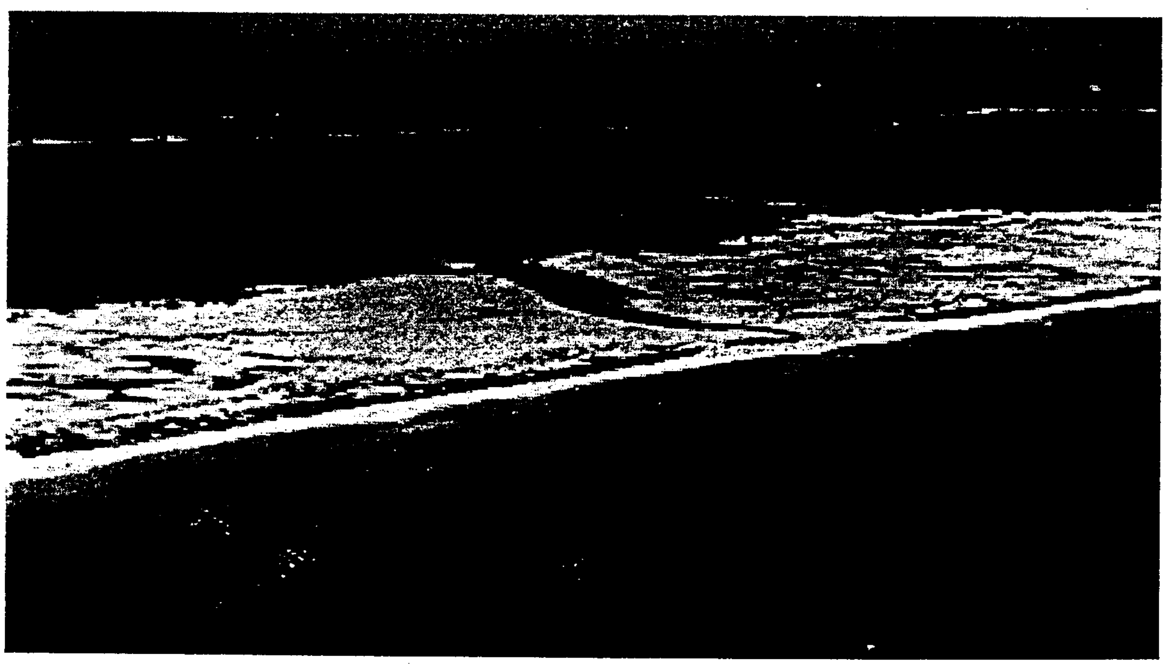

Figure 9 Oblique aerial photo of Navarre Pass in Escambia County, FL. The photo indicates that the channel has migrated both east and west during the channel's lifetime. Photo data: September, 1965.

Another short term mechanism affecting the migration direction of these channels is the accretion or erosion of the shoreline in general. During a field visit to the area on April 16-17, 1998, it was observed that a low accretion berm had formed along the shoreline fronting many of the outlets. The uprush from the waves overtopped this berm and flowed into the lake outlet channels. At some sites this flow appeared to dictate the new position of the channel. Hence, any area of low elevation along the beach berm may serve to create the new outlet location for the lake. This idea is supported by the laser data (Figure 8 and Appendix A) and aerial photography, where many outlets take sudden turns in direction, snaking their way to the Gulf.

The migration of the channel due to littoral forces also contributes to meandering of the channel, similar to river meanders. This occurs when a river channel deposits sediment on the inside of a bend in the river due to secondary flows across the channel. Eventually the river will meander sufficiently to create an oxbow lake, breaching across the severe meander. As applied to this investigation, the result would be the breaching of a new channel with a more direct line to the Gulf.

At some point, the efficiency of the channel flow diminishes to the level where the channel can no longer stay open, and the mouth of the channel is filled in with beach sand, which may occur due to a strong "pulse" of longshore sediment transport which bridges the channel and/or a period of drought. The relict channel that remains may become the site of the next opening, or, if a berm overwash channel forms or the time between openings is long enough or the rainfall is great enough, a new channel with a shorter distance between the Gulf and the lake may form. The new channel will then be subject to the littoral drift and will begin to migrate accordingly. Mehta (1985) documented this cycle for Phillips Inlet over the course of 11 years. He concluded that shoaling of the channel at the mouth causes the closure of the channel once it reaches a certain length. Mehta also documented the relationship between the cross-sectional area of the channel and the monthly rainfall.

Bodge (1998), in the new Coastal Engineering Manual, describes the process of inlet migration followed by breaching at a new updrift location. Bodge writes that this process at larger inlets may occur on time scales of 3 to 50 years. In the case of the small lake outlets of interest here, the time scales may be on the order of months to a few years. FitzGerald (1988) in describing erosional-depositional processes associated with tidal inlets, discusses the process of inlet migration and breaching as well. Fitzgerald's work mentions the role of the geologic makeup of the sediment in controlling the migration rate. Oertel (1988) also discusses the dynamics of tidal-inlet migration, highlighting the changes in channel geometry and orientation that lead to the formation of spits from the updrift side of the channel. In each of these cases, however, the focus is on deeper, tidal inlets that are always open during the period of migration. In the present case, it is apparent that overwash plays a large role in the fate of these small outlet channels. Very little literature exists that describe the specific problem of interest here.

Table 1 lists the general dimensions of each of the sites, including the sweep distance alongshore. One concern is that these channels may someday swing to an extreme location either east or west, and threaten nearby structures. These structures are evident in Figures 3 and 8 as the rectangular areas of densely packed contour lines. While for the most part these structures have been built on the margins of the sweep path, there is the possibility of extreme migration and consequent structural damage. Extreme migration could be caused by increased levels of rainfall over extended periods of time in combination with strong and persistent longshore sediment transport, allowing the channel to stay open long enough to migrate to a threatening position.

The hydraulic stability of a lake inlet/outlet is affected by several parameters. Some of the parameters relevant to this discussion include, but are not limited to:

- Difference in elevation between water bodies. Obviously this is the driving force of the flow through the channel.
- Length and cross-sectional area of the channel. The longer the channel, the greater the friction involved, hence the channel is less hydraulically efficient and more prone to closure. The cross sectional area is governed by the flow rate between the two bodies, which is a time-dependent process.
- Wave induced sediment transport characteristics in the area. The amount of sand transported alongshore affects the migration rate of the outlet and ultimately its potential for closure.
- Tidal range. In some instances there may be exchange of tidal waters between the bodies, carrying sand into the lake and potentially shoaling the channel.

The first parameter mentioned, the elevation difference between water bodies, is related to the area of the lake (and its runoff area around it) and the amount of rainfall. The flowrate through the these outlets is thus a time-dependent problem, governed predominantly by rainfall, in which the channel may begin as a small trickle, slowly grow as the channel scours in response to the driving head difference, and then ultimately close as the driving head is diminished and the shoaling sand from the gulf side can no longer be cleared.

The length of the channel is a function of the physical separation distance between the two bodies and the degree to which the channel has migrated under pressure from littoral forces. Here again the time-dependence of the problem plays a significant role. The combination of increased and prolonged rainfall with increased and prolonged littoral pressure can extend the length of the channel. Table 1 presented the sweep distances and separation distance for each of the 26 sites involved in this study. The actual channel length in most cases lies somewhere between the sweep and separation distances. In the case of Morris Lake, the channel length is actually longer than either of these, as the channel meanders back and forth through heavy brush as it traverses the 1,050 ft distance between the lake and the Gulf.

The cross-sectional area is related to the length of the channel and the driving head difference between the two water bodies. To briefly characterize the determination of the cross-sectional area, the problem is viewed from two distinct methods. The first method treats the channel as a tidal inlet that has to convey a certain tidal prism. Using the concepts developed by O'Brien (1969) and refined by Jarrett (1976), a rough estimate of typical cross sections can be determined. Jarrett suggested that the equilibrium cross-section of an unjettied, natural tidal inlet can be found from the following empirical relationship:

$$A_c = 1.04x10^{-5}\ \Omega^{1.03} \tag{1}$$

where A_c is the mean cross-sectional area (in ft^2) of the channel and Ω is the tidal prism (in ft^3). If a simple example is applied to this equation, say A_L = 100 acres and the lake level rises 6 inches, the resulting equilibrium cross-sectional area is 23 ft^2. In comparison, a channel 20 ft in width and 3 ft deep at its deepest point has a cross sectional area of approximately 51 ft^2 (for a trapezoidal channel). Many of the channels surveyed during the April, 1998, field visit had dimensions on the order of 10 to 50 feet in width and depths ranging from 6 inches to over 3 feet. Mehta (1976) reports that small beach inlets (outlets in this case) have widths and depths in the range of 10 to 160 feet and 0.3 to 3.3 ft, respectively. The appropriateness of applying this empirical relationship to the present problem may be somewhat suspect, but it does provide a good description of the relative magnitude of the cross-sectional areas of the sites in this study as compared with some of the navigable inlets around the state of Florida.

Alternatively, the flow problem could be viewed from an extremely simplified representation of steady flow in a channel. Given typical values of channel cross-sections (measured in the field) it may be possible to determine the necessary head difference (i.e. rainfall amount) needed to keep that channel open and flowing. The additional pressure of littoral material transported into the channel would increase the required head difference. Again, it is recognized that the behavior of these outlet channels is time-dependent, however simple anaylses such as this one may provide information on the *limits* of behavior of the outlets.

The wave-induced sediment transport is a function of the wave-climate in the area. Estimates of the net annual sediment transport in the Walton County area range from 17,000 m^3/yr westerly (Balsillie, 1975) to 80,000 m^3/yr (Stone et al.,1992). The tidal range has an effect on channel stability as well. If the tidal range is large enough to force flow into the lake, this flow may assist in scouring the channel, or it may simply bring more sand into the channel, hastening its closure. In the event there is no flow into the lake, the increased tide level may still result in more sand being transported into the mouth of the channel. In this area the tides are predominantly diurnal with a mean range of approximately 1.3 ft.

CCCL maps were compared to assess the impact of Hurricane Opal on these outlets[4]. New CCCL photographs were collected by FDEP immediately following the hurricane's passage. In Walton County, CCCL maps exist for February, 1995, as well. In reference primarily to the outlets in Walton County, the effect of the hurricane was to transport substantial amounts of sand as overwash into the channels, in some cases closing the channel altogether (e.g. Morris Lake). In general, however, most of the outlets reopened in a more efficient (i.e., shorter channel length) position in response to the channel flooding with sand and the increased rainfall. Some of the outlets were in their westernmost locations prior to the hurricane's landfall, and reopened in positions well over 1,000 ft east of the pre-hurricane location (Camp Creek Lake and Deer Lake).

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[4] Hurricane Opal made landfall in the vicinity of the Okaloosa/Santa Rosa Co. border on the evening of October 4, 1995.

5.0 CONCLUSIONS & RECOMMENDATIONS

A preliminary investigation of the characteristics of coastal lake outlets adjacent to the Gulf of Mexico in the Florida Panhandle has been conducted. These outlets, located in Walton, Bay, Gulf, and Franklin Counties, open intermittently, primarily in response to increased rainfall. Once open, the channels migrate in response to the wave-induced littoral drift in the area. The concern with these sites is that the water levels in the lakes may reach such elevations as to pose a flooding hazard, and that once open and flowing the outlets may migrate far enough to pose a threat to developed areas adjacent to the channel. This report has identified 26 sites in the aforementioned counties that could potentially have an impact on the adjacent properties. The physical dimensions of each site have been documented. The mechanisms involved in the opening of the connection between the lakes and the Gulf are discussed. Parameters affecting outlet migration and stability have been presented.

Under conditions where flooding around the coastal lakes poses a problem, a connection between the lake and the Gulf can be excavated, thus draining off the lake water until the level reaches an acceptable value. This is in fact what is done at Western Lake in Grayton Beach State Park and at Camp Helen at Phillips Inlet. The State of Florida and the U.S. Army Corps of Engineers have issued temporary permits for the State Park System to open the channels to control the lake levels. Once opened, the migration of the channel may become an issue. In the event that the migration of one of these channels poses a threat to upland development, there are several options. These include the relocation of the channel away from development or the closure of the channel altogether (assuming this results in an acceptable lake level). The frequency of necessary channel opening or relocation at a particular site is a function of many variables, as discussed herein.

The passage of Hurricane Opal resulted in the relocation of many of the unrestricted outlets (primarily in Walton County). Inspection of CCCL maps before and after the hurricane suggests that the hurricane caused a significant volume of sand to be transported into the mouths of the outlets, closing the pre-hurricane channels in many cases and reopening outlet channels in more efficient locations (i.e., shorter routes to the Gulf of Mexico); the accompanying rainfall appears to have kept many of the outlets open or nearly open. It is noted that many of these outlets do not continuously communicate with the Gulf of Mexico, flowing only when significant rainfall or high wave conditions exist.

Further investigation into the mechanisms of natural channel opening and migration is recommended in order to develop a probabilistic tool to predict the ultimate migration and longevity of these lake/Gulf channels based on the combination of rainfall, longshore transport characteristics, and site geometry. Such a tool would provide guidance as to the necessity of future monitoring of these as well as other sites around the State, and would provide guidance on the necessity of channel relocation or closure. Monitoring of the behavior of these outlets would provide data necessary to develop such a tool. Detailed measurements during an outlet opening (either natural or mechanical) would contribute significantly to the existing body of knowledge regarding breach or channel openings. Given the existence of permits to open some of the channels, the opportunity to obtain such data is excellent. Measurements taken before and during the opening might include groundwater level, lake and Gulf levels, current velocities in the channel, and cross-sectional area of the channel over time. Monitoring of several sites over the period of a year would provide the opportunity to track the migration and maintenance of such channels, about which there is little existing data.

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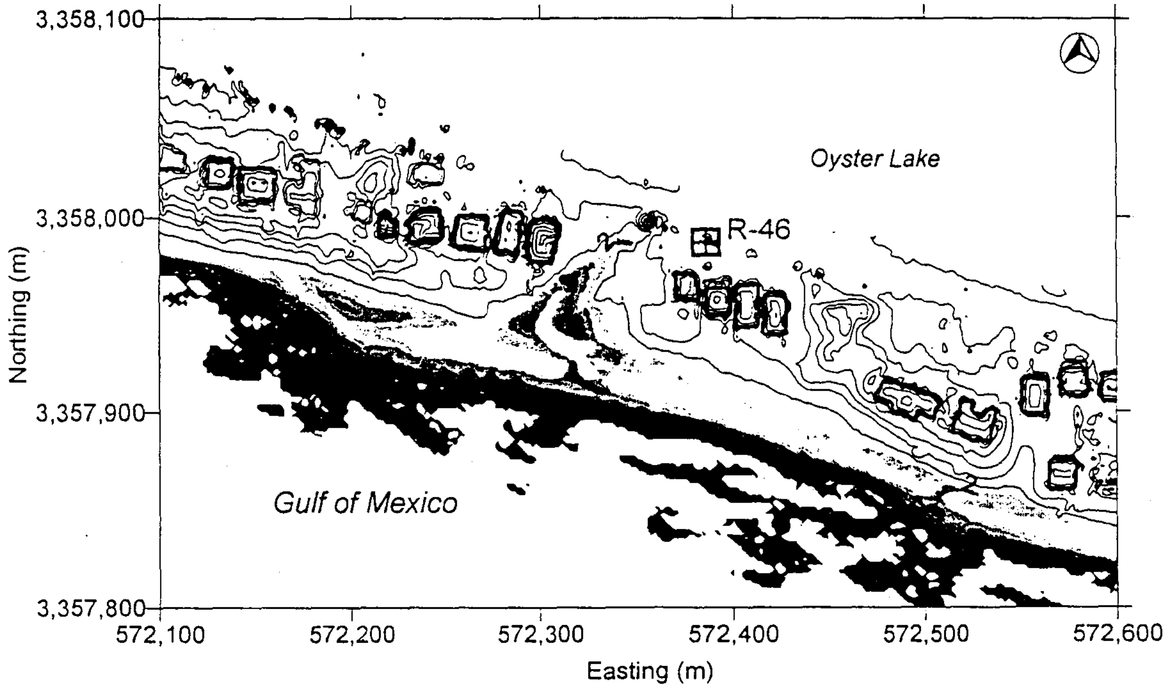
APPENDIX A

Contour Plots of Beach Elevation in the Vicinity of Coastal Lake Outlets in Bay and Walton Counties, FL

Data Source: Project LASER
Laser swath survey data
UF Civil Engineering Department



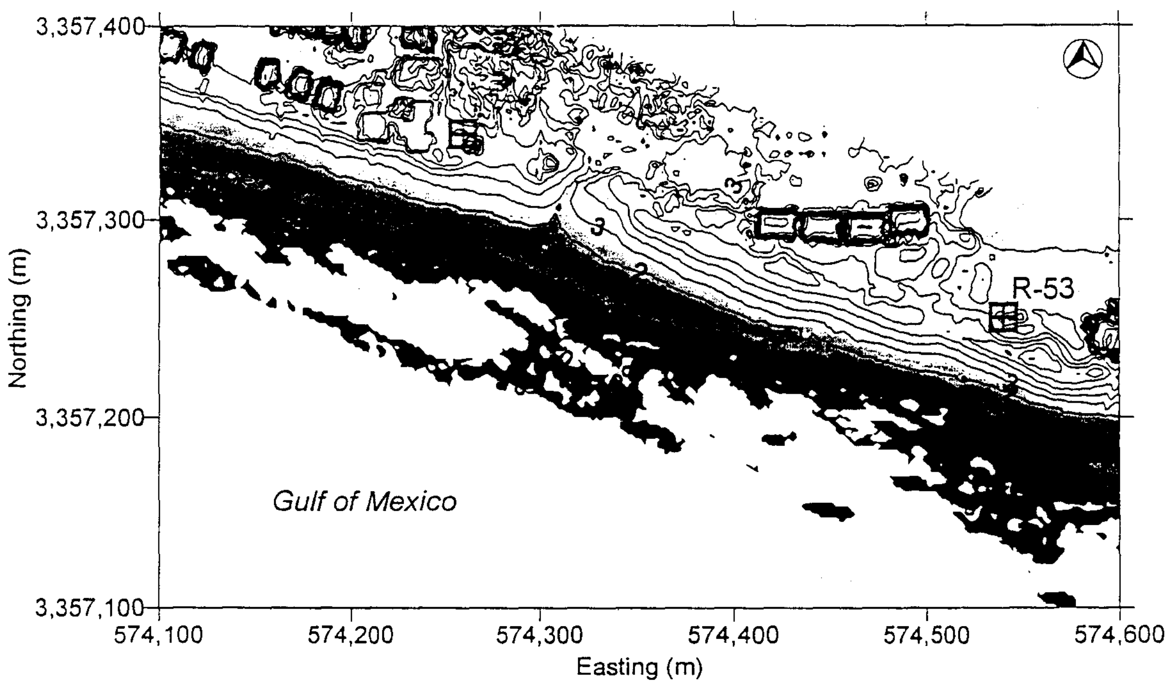
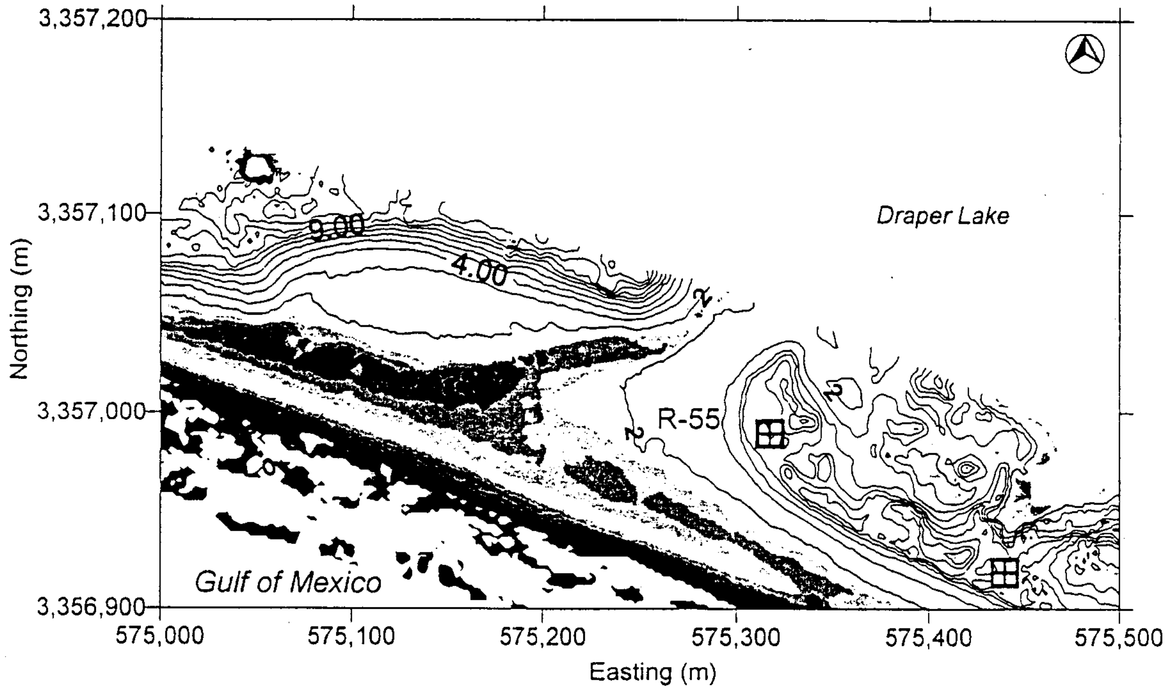


Figure A-2 Laser swath survey contour maps of Oyster Lake and Dune Allen Beach in Walton Co., FL. Elevations in meters above National Geodetic Vertical Datum. Survey Date - October 16-17, 1996.

A-2



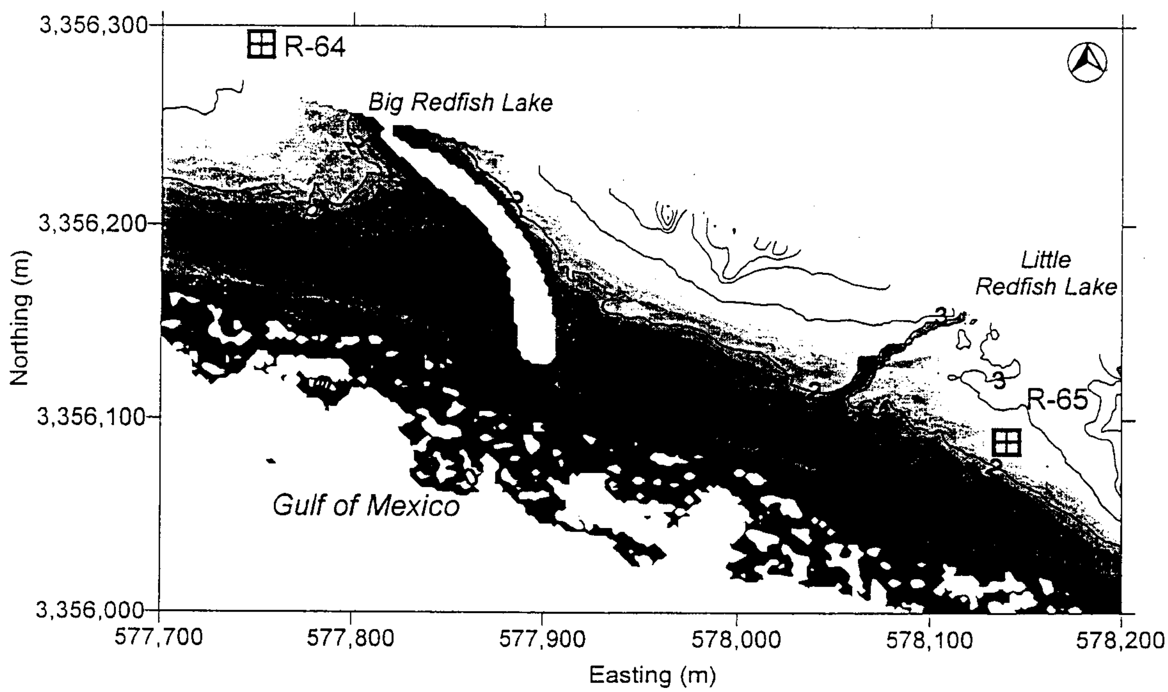


Figure A-3 Laser swath survey contour maps of Draper Lake and Big & Little Redfish Lakes in Walton Co., FL. Elevations in meters above National Geodetic Vertical Datum. Survey Date - October 16-17, 1996.

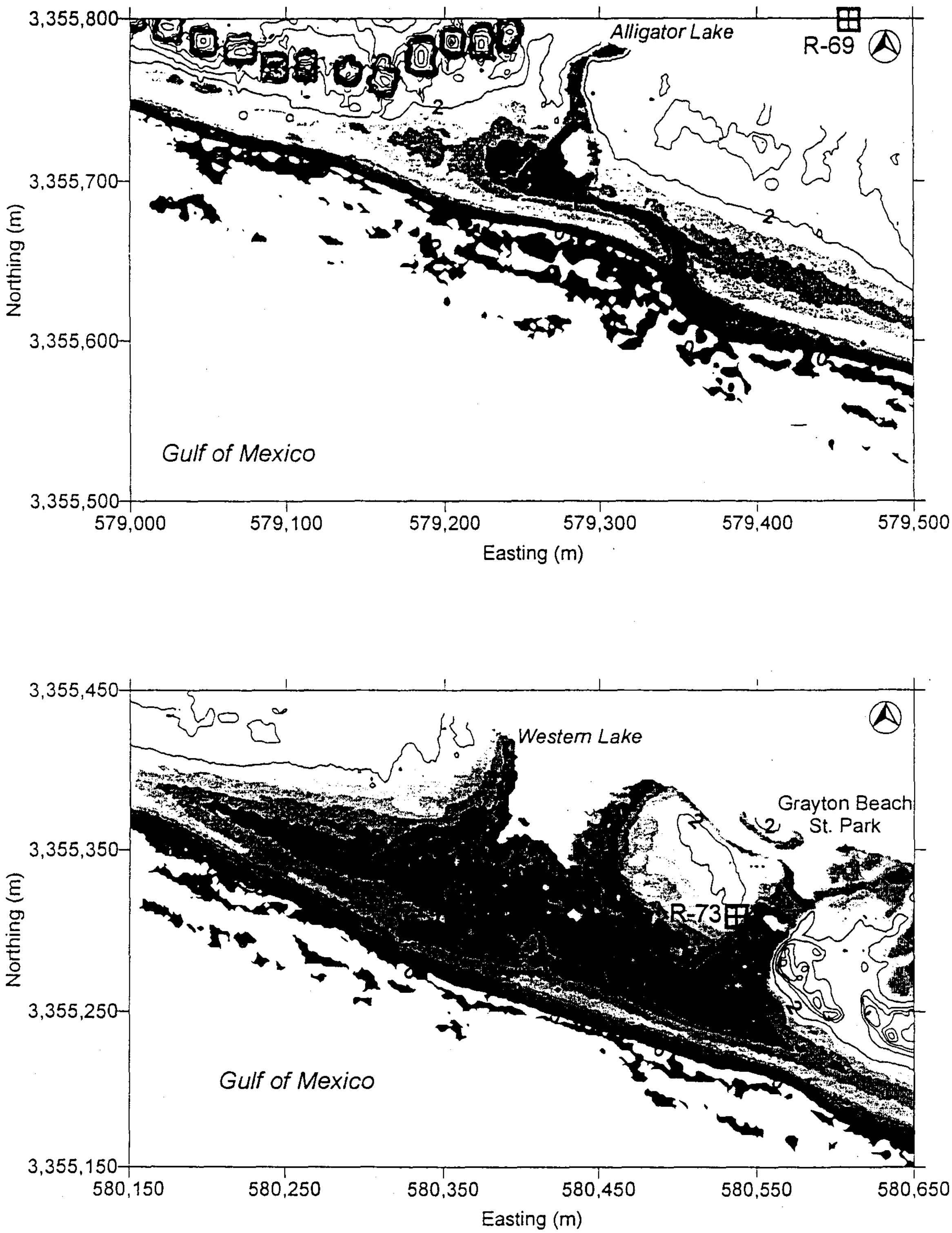
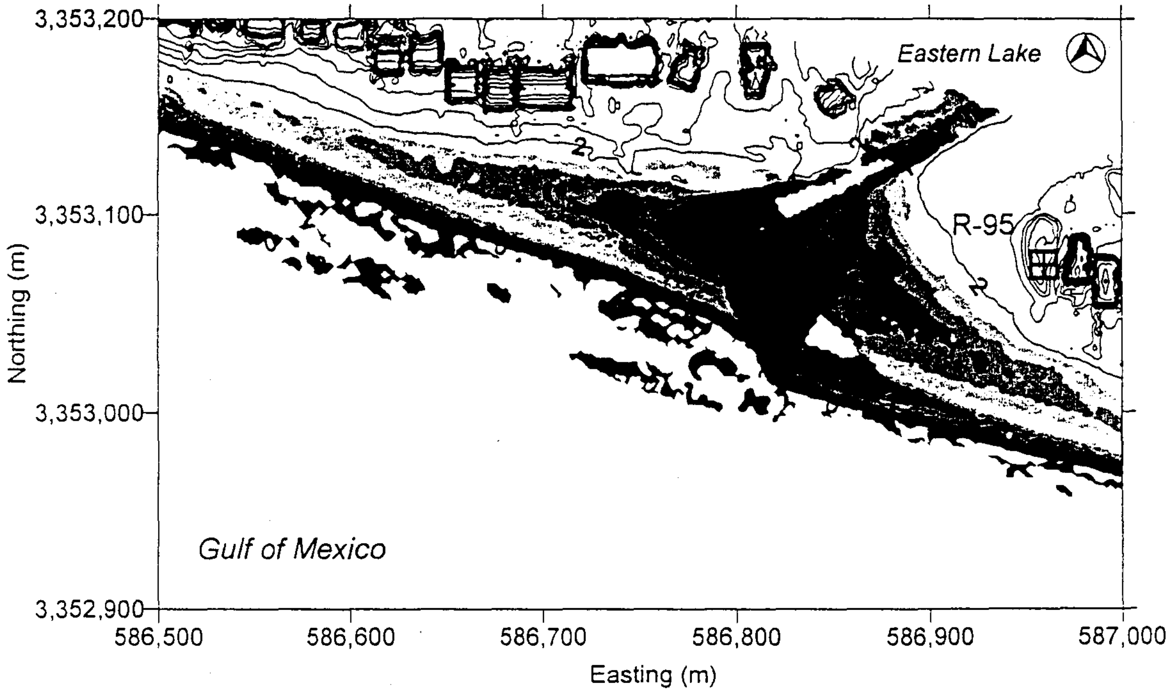


Figure A-4 Laser swath survey contour maps of Alligator Lake and Western Lake in Walton Co., FL. Elevations in meters above National Geodetic Vertical Datum. Survey Date - October 16-17, 1996.

A-4



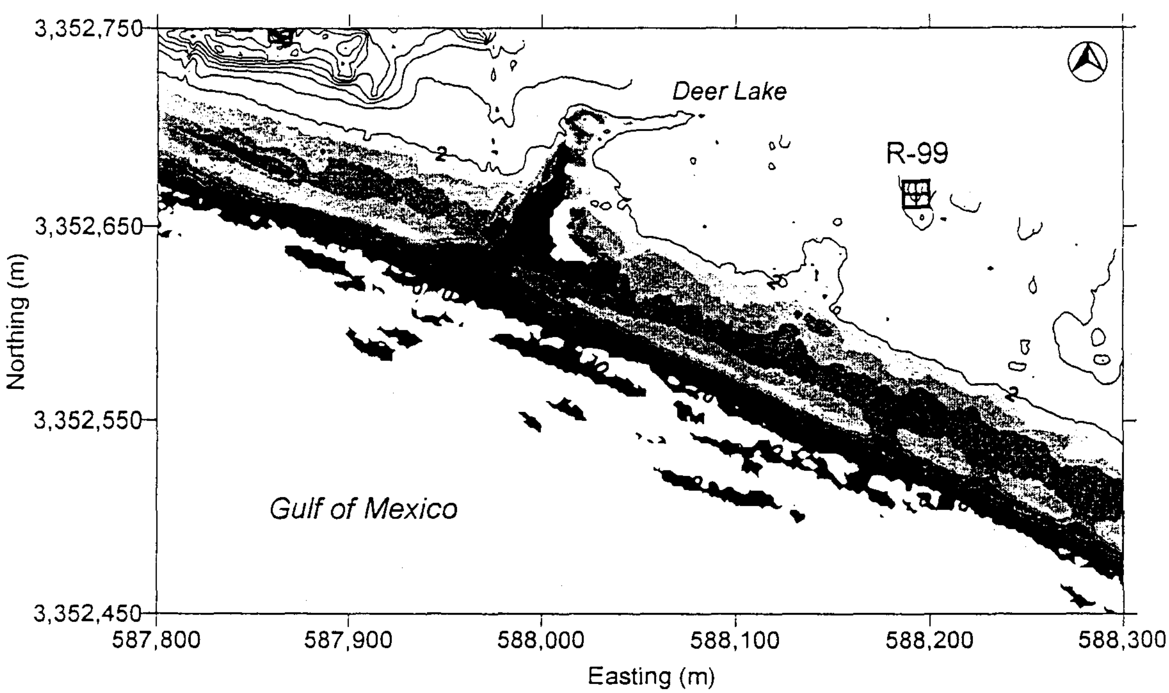
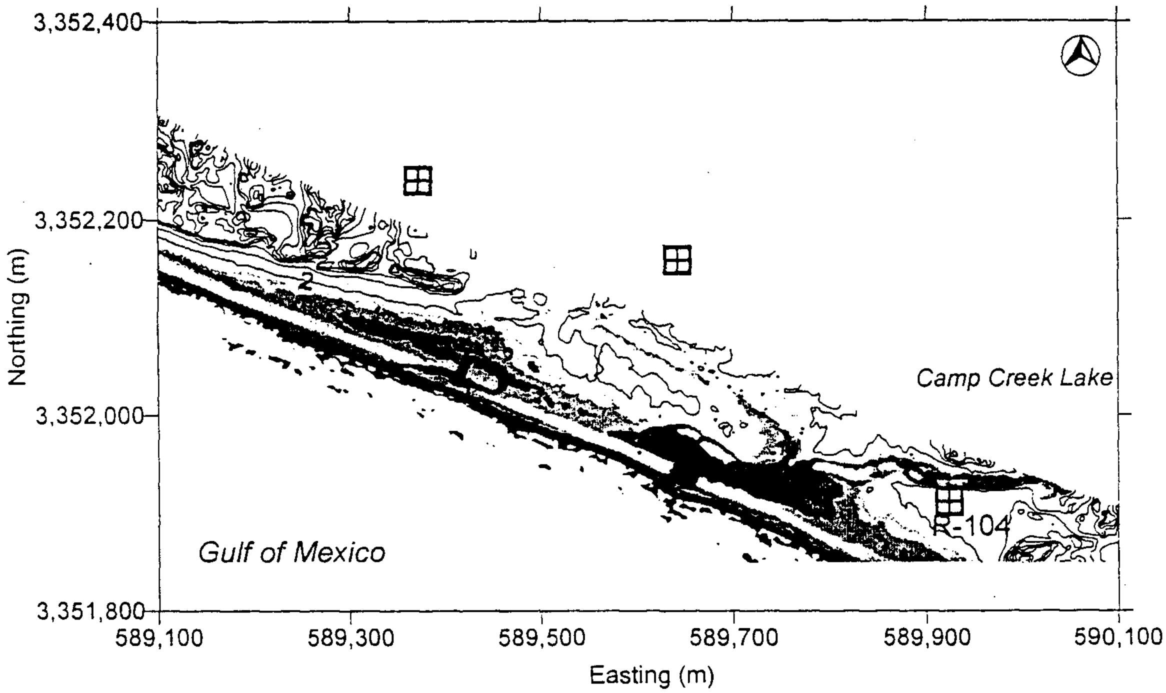


Figure A-5 Laser swath survey contour maps of Eastern Lake and Deer Lake in Walton Co., FL. Elevations in meters above National Geodetic Vertical Datum. Survey Date - October 16-17, 1996.



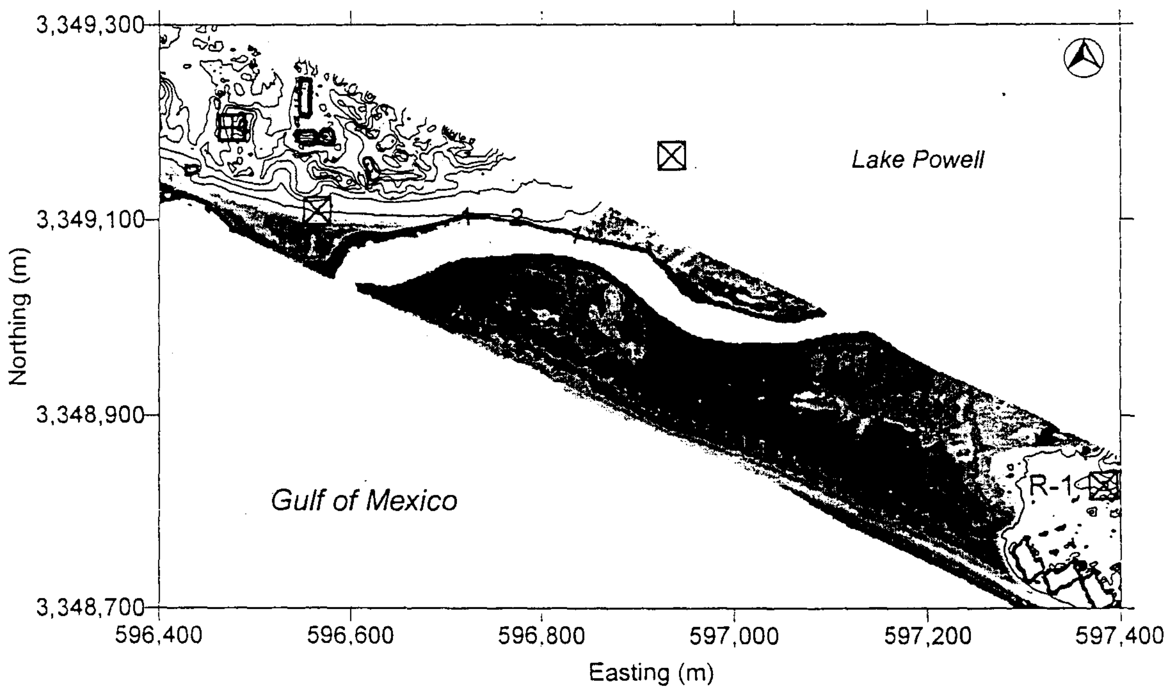
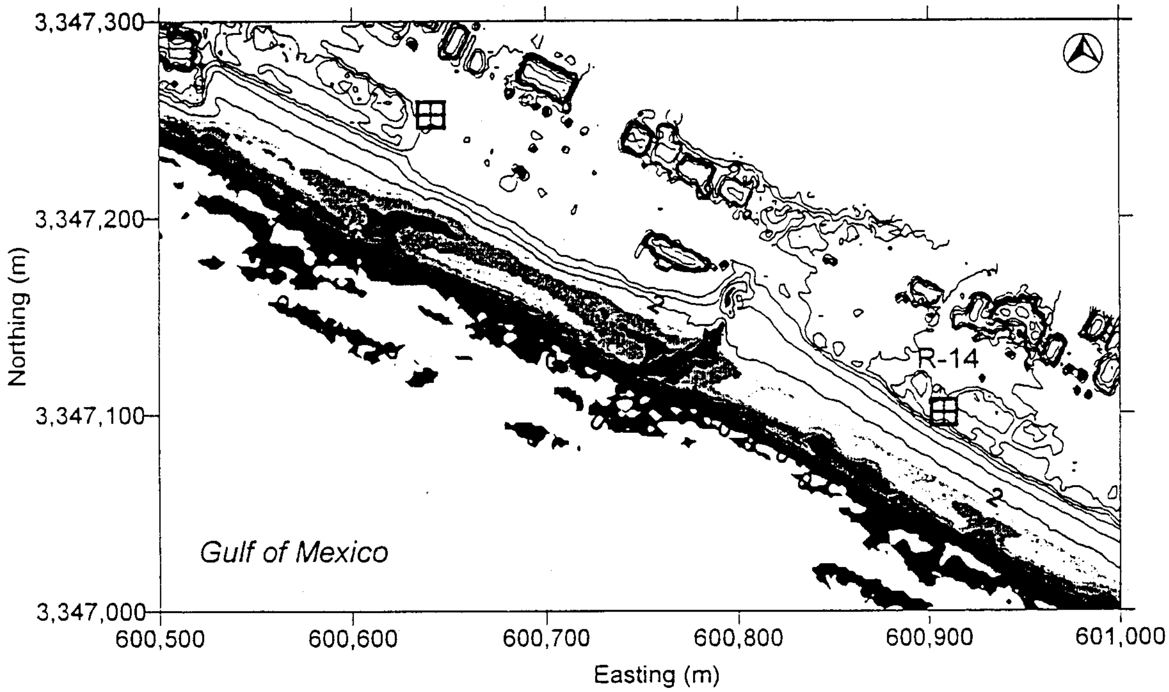


Figure A-6 Laser swath survey contour maps of Camp Creek Lake in Walton Co. and Lake Powell (Phillips Inlet) in Bay Co., FL. Elevations in meters above National Geodetic Vertical Datum.
Survey Date - October 16-17, 1996.



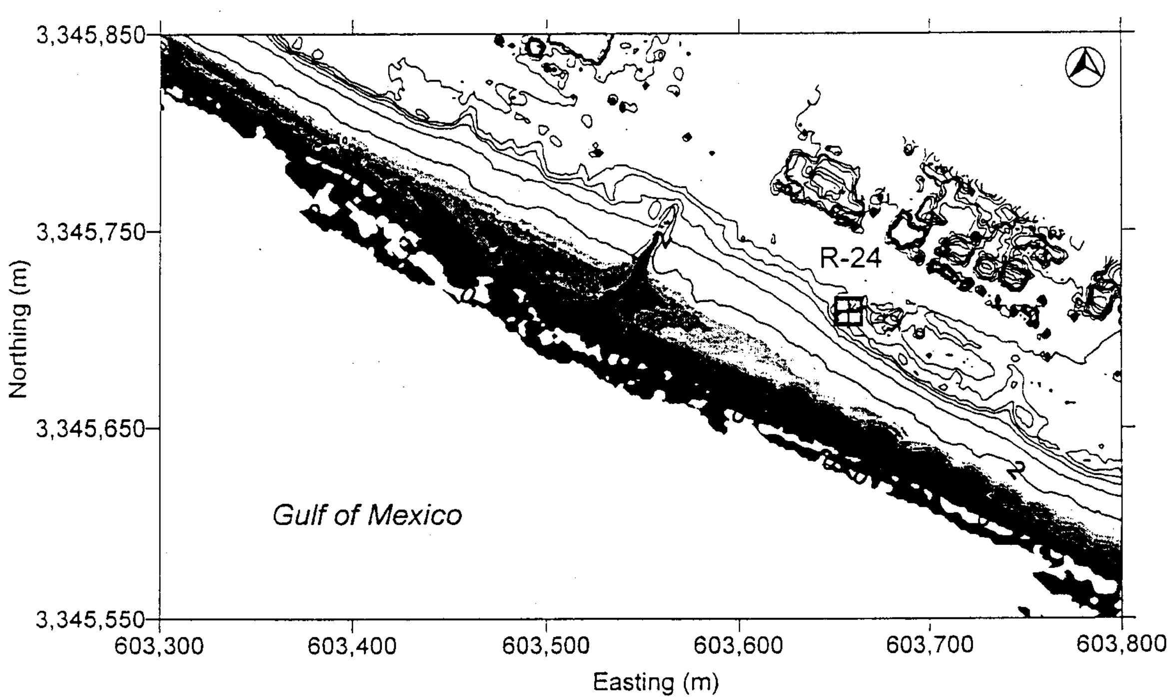
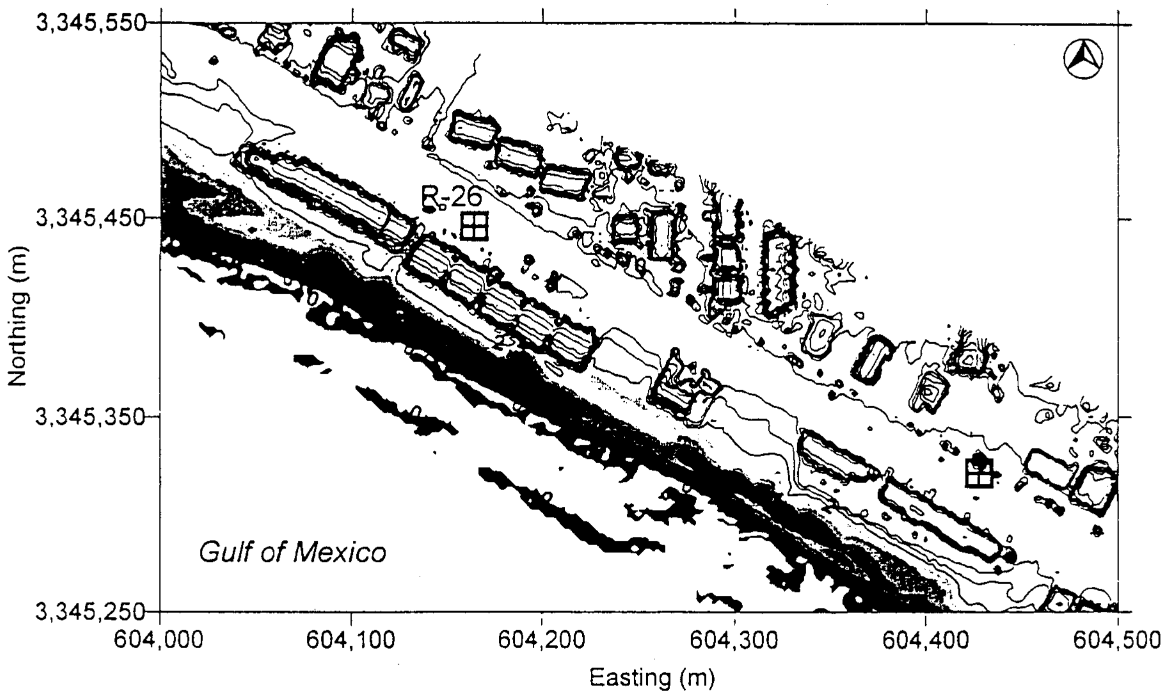


Figure A-7 Laser swath survey contour maps of the shoreline near R-14 and R-24 in Bay Co., FL. Elevations in meters above National Geodetic Vertical Datum. Survey Date - October 16-17, 1996.



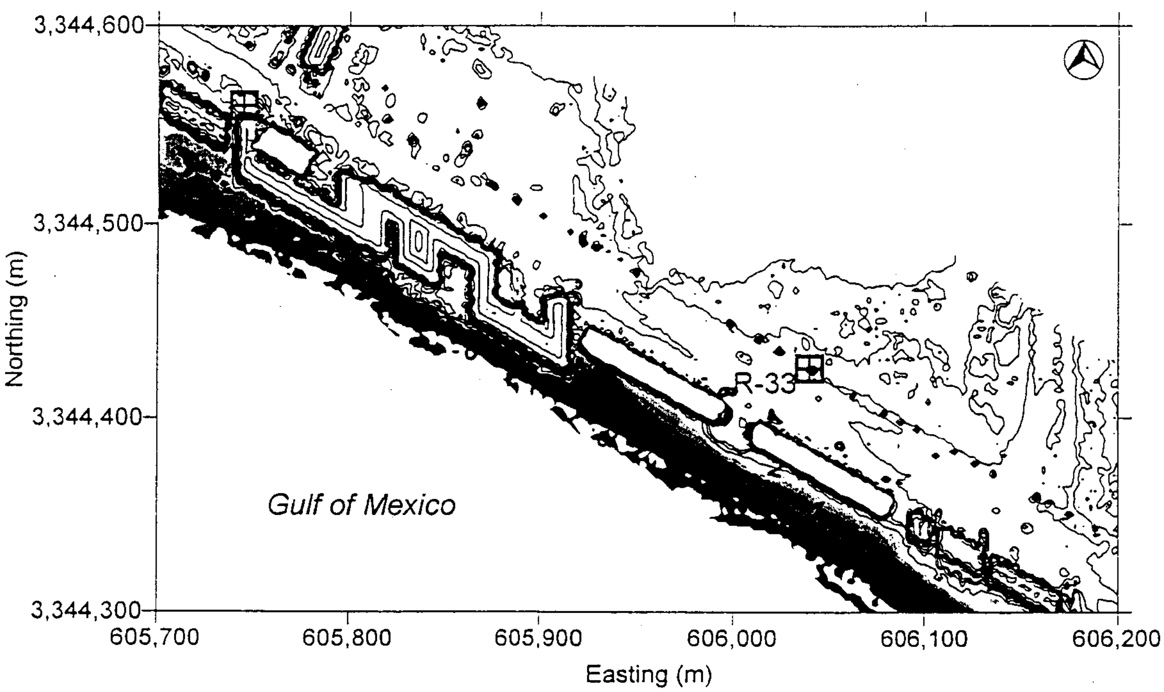
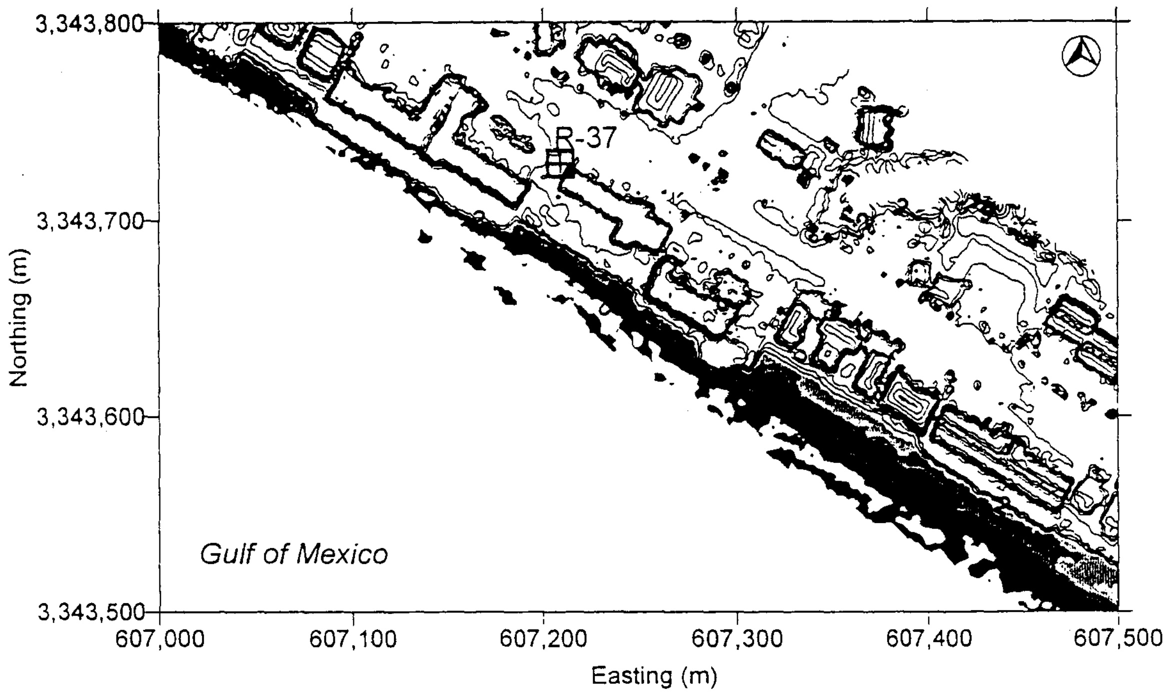


Figure A-8 Laser swath survey contour maps of the shoreline near R-26 and R-33 in Bay Co., FL. Elevations in meters above National Geodetic Vertical Datum. Survey Date - October 16-17, 1996.



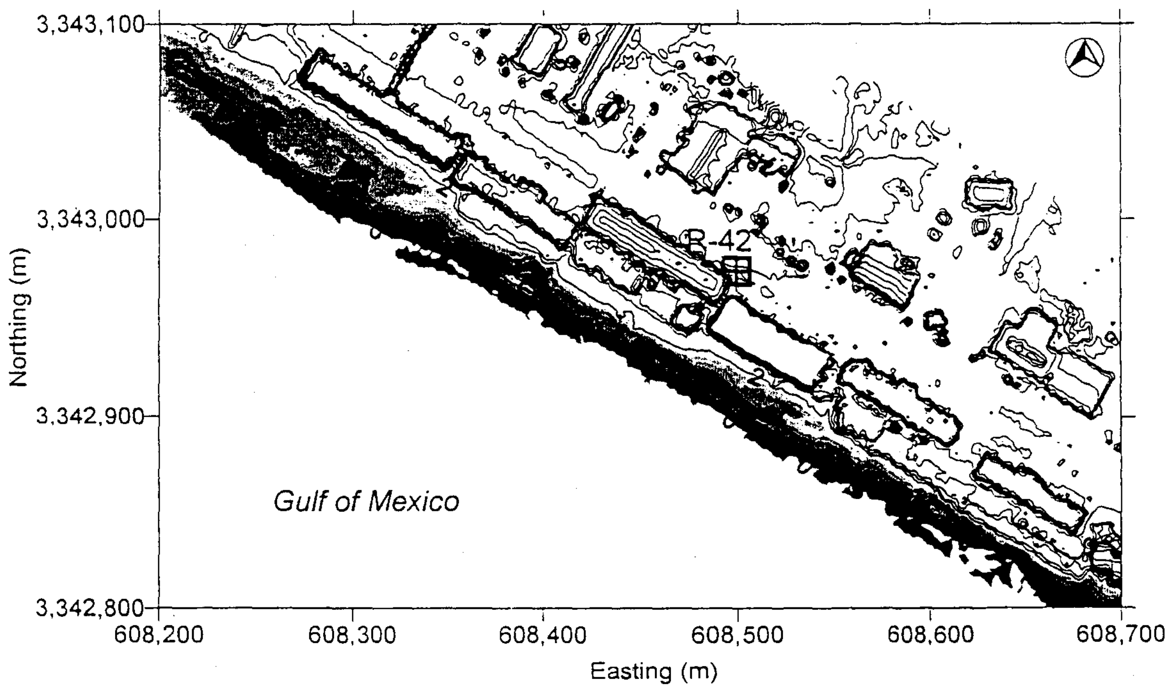
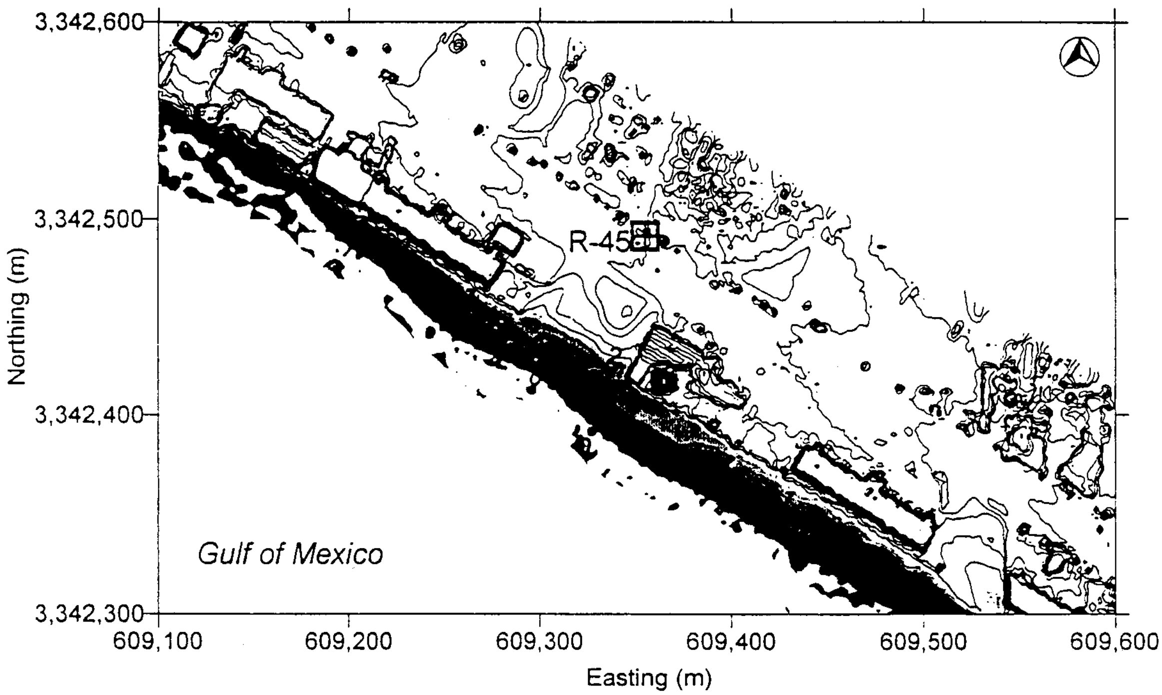


Figure A-9 Laser swath survey contour maps of the shoreline near R-37 and R-42 in Bay Co., FL. Elevations in meters above National Geodetic Vertical Datum. Survey Date - October 16-17, 1996.



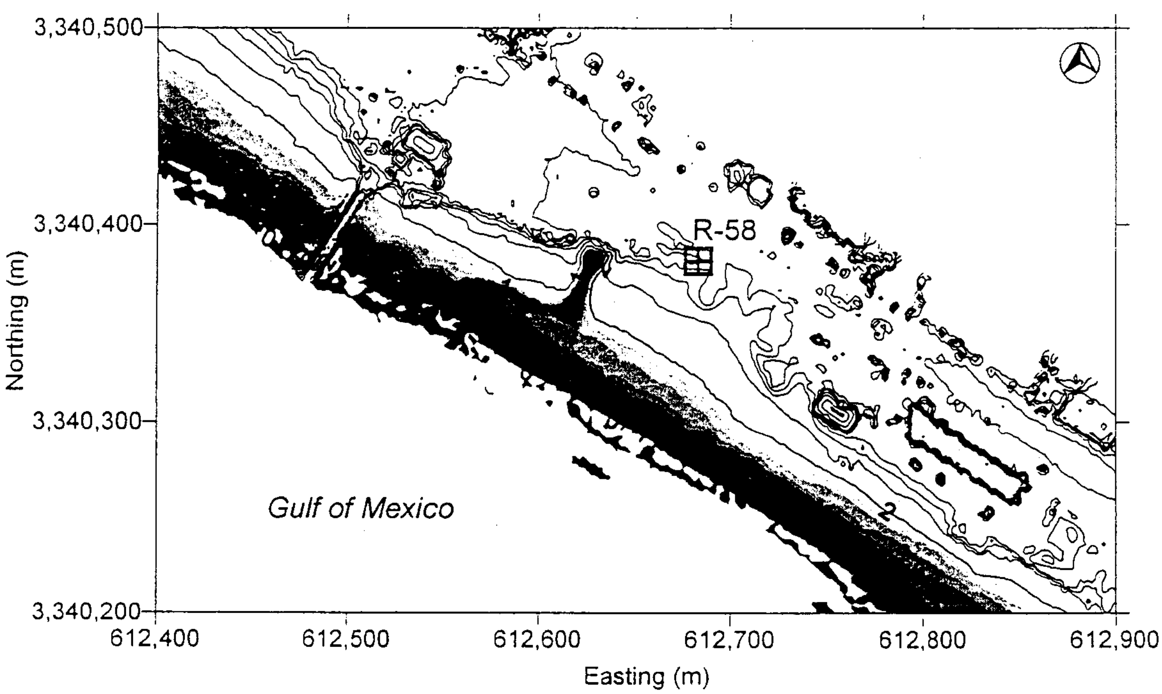


Figure A-10 Laser swath survey contour maps of the shoreline near R-45 and R-58 in Bay Co., FL. Elevations in meters above National Geodetic Vertical Datum. Survey Date - October 16-17, 1996.

A-10