OPEN-FILE REPORT 97-01

Holly Beach to Constance Beach Shore Protection

Preliminary Feasibility Report

A Cooperative Effort

LOUISIANA DEPARTMENT OF NATURAL RESOURCES

Jack C. Caldwell, Secretary

Coastal Restoration Division

P.O. Box 94396

Baton Rouge, La. 70804-9396

LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

Frank Denton, Secretary

P.O. Box 94245

Baton Rouge, La. 70804-9245

Coastal Restoration Division

April 1997

STATE OF LOUISIANA

M. J. "Mike" Foster, Jr., Governor

DEPARTMENT OF NATURAL RESOURCES

Jack C. Caldwell, Secretary

COASTAL RESTORATION DIVISION

Bill J. Good, Administrator

This public document was published at a total cost of $354.00. Fifty-five copies of this document were published in the first printing at a cost of $354.00. This document was published by the Department of Natural Resources, Coastal Restoration Division, P.O. Box 94396, Baton Rouge, Louisiana, 70804-9396, to aid the public in understanding of the coastal restoration efforts in Louisiana. This material was printed in accordance with standards for printing by state agencies established pursuant to R.S. 43:31.

STATE OF LOUISIANA

M. J. "Mike" Foster, Jr., Governor

DEPARTMENT OF NATURAL RESOURCES

Jack C. Caldwell, Secretary

COASTAL RESTORATION DIVISION

Bill J. Good, Administrator

This public document was published at a total cost of $354.00. Fifty-five copies of this document were published in the first printing at a cost of $354.00. This document was published by the Department of Natural Resources, Coastal Restoration Division, P.O. Box 94396, Baton Rouge, Louisiana, 70804-9396, to aid the public in understanding of the coastal restoration efforts in Louisiana. This material was printed in accordance with standards for printing by state agencies established pursuant to R.S. 43:31.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

The Louisiana Department of Natural Resources (LDNR) and the Louisiana Department of Transportation and Development (LDOTD) gratefully acknowledge the contributions of those who assisted in compilation of this report.

Steven Gammill, LDNR/Coastal Restoration Division (CRD) directed interagency coordination and report preparation. Henry Barousse, LDOTD/Design Support Division prepared the sections on the history and needs of Louisiana Highway 82 and provided valuable engineering input. Scott VanŽant, LDNR/CRD, contributed the bulk of material on the project background and all of the engineering cost information. Much of the detailed data analyses and interpretation were performed by Renjie Chen, LDNR/CRD. Steven Underwood, LDNR/CRD provided ecological and monitoring expertise in addition to assistance in data analyses and interpretation. Warren Blanchard, LDNR/CRD, is acknowledged for his engineering insight and helpful commentary. Thanks also to Stehle Harris, LDNR/CRD, for his assistance in the Wetland Value Assessments and ecological input.

Finally, the departments are grateful to Bill Good, LDNR/CRD Administrator, for conceptual development, direction and review; Marty Beasley, LDNR/Information Processing, for his assistance in generating Geographic Information System (GIS) information and graphics included in this report; and Margo Olinde, Louisiana Geological Survey, for editorial consultation.

EXECUTIVE SUMMARY

This report provides a preliminary plan to protect a segment of coastline between Holly Beach and Constance Beach where the highway is impacted by wave attack from the Gulf of Mexico. Louisiana Highway 82 (Hwy. 82) is situated on a chenier that protects more than 31,000 acres of fragile coastal marsh and prime waterfowl habitat from direct wave attack and tidal exchange with the Gulf of Mexico. The highway is an integral transportation artery to the southwestern Louisiana coast and serves as a hurricane evacuation route for the communities of Holly Beach, Constance Beach, Peveto Beach, Ocean View Beach, and Johnson's Bayou.

Representatives from the Louisiana Department of Natural Resources and the Louisiana Department of Transportation and Development developed an array of restoration options from which three alternatives were selected and analyzed in detail in terms of engineering feasibility, cost, management, maintenance and monitoring needs, implementation speed, and environmental effects. These alternatives include: (1) No-Action; (2) Existing Breakwater Enhancement and Sand Management; and (3) Construction of a Seawall on Hwy. 82. The No-Action Alternative refers to a no-project scenario and will include repairs to the state highway until such a time when the cost of preserving the road without implementing off-site protection measures are no longer deemed economically justifiable. As such, the "No-Action Alternative" is not considered viable, but is used as a base condition for comparison of restoration alternatives.

Under the No-Action Alternative, within 5 years, Hwy. 82 is projected to suffer structural failure resulting in the establishment of numerous hydrologic connections between the Gulf of Mexico and more than 31,000 acres of intermediate marsh. A loss of more than 11,000 acres of high-quality coastal marsh is predicted over 20 years, when this area is opened to tidal exchange with high-salinity gulf waters. Some of this habitat will likely shift to a more salt-tolerant vegetative species composition, but the overall quality and value to fish, wildlife, and waterfowl will be dramatically diminished. The impacts of saltwater intrusion may be noticed well beyond the confines of the study area delineated within the scope of this report.

Alternative 2 was selected over Alternative 3 primarily due to its relatively low cost of approximately $23.6 million, compared to more than $83.8 million for a seawall. Under this alternative, the beach, highway, and marsh would be protected. Environmental benefits between Alternatives 2 and 3 differ principally in that Alternative 2 preserves the beach habitat for the benefit of shorebirds and fish that utilize the nearshore zone, as well as the aesthetic and recreational value to the public. The frequency of highway overwash would be reduced and the potential for highway breaching would be significantly reduced, thereby mitigating maintenance costs.

Several potential funding sources are described. One thing is indubitable. If the highway and chenier are not stabilized and protected, there will be a catastrophic loss of thousands of acres of highly productive and valuable coastal marsh.

INTRODUCTION

The purpose of this report is to provide a preliminary plan to protect Louisiana Highway 82 (Hwy. 82) along an 8-mi reach between Holly Beach and Constance Beach, where the highway periodically suffers wave attack and overwash from the Gulf of Mexico. Hwy. 82 is situated on a chenier that protects more than 31,000 acres of fragile coastal marsh and prime waterfowl habitat from direct wave energy and tidal exchange with the Gulf of Mexico. It also serves as an integral transportation artery to the southwestern Louisiana coast and as a hurricane evacuation route for the communities of Holly Beach, Constance Beach, Peveto Beach, Ocean View Beach, and Johnson's Bayou.

The report is divided into five principle sections. Section I describes the physical and environmental settings and details historical shoreline changes that have resulted in an eroded beach and damaged highway. Section II evaluates alternatives for protection of the beach, highway, and adjacent marsh. Preliminary costs of construction, maintenance, management, and monitoring are discussed in addition to implementation speeds. Section III describes the predicted environmental benefits of the alternatives and the adverse impacts of abandoning Hwy. 82. The fourth section identifies the recommended plan and describes the rationale for the selection of that alternative. The final section describes some potential funding sources and suggests an approach to secure funding of the recommended plan.

SECTION I: PHYSICAL AND ENVIRONMENTAL SETTING

The chenier plain of southwestern Louisiana is a marginal deltaic environment that has developed over the past 3,000 to 4,000 years through a series of shoreline transgressions and regressions. Although the ontological development and source of sediment for the chenier plain are not completely understood, the general mechanism of deposition for the chenier plain is related to shifts in the position of the Mississippi River mouth (Byrnes and McBride 1995). Cheniers are the remnant stranded beaches resulting from these shifts.

The outer coast of the chenier plain between Sabine Pass and Calcasieu Pass is a microtidal environment with diurnal tides ranging from 2.0 to 2.4 ft (mean to spring). Waves in the area are generally from the south-south southeast on the averages of 16 and 28.4% of the time (Wave Information Study [WIS] station data), respectfully, with breaking heights averaging 1.6 ft and a period of 5 seconds (Byrnes and McBride 1995). Monthly significant deep-water wave heights were taken from a WIS station located roughly 16 mi due south from Constance Beach at 29.50°N 93.50°W for a period between 1956 to 1975.

The estimated net longshore sediment transport is to the west ranging from 47,000 to 97,000 yd^3/yr (U.S. Army Corps of Engineers [USACE] 1971). The processes primarily responsible for shoreline changes in the area are waves and storm surges produced by severe weather events. Hurricane Audrey, in 1957, produced the maximum recorded storm surge in the area of 13.0 ft. Average storm surge elevation between 1939 and 1986 was 6.1 ft relative to mean sea level (MSL) (Byrnes and McBride 1995).

The area between Holly Beach and Ocean View Beach has historically undergone severe erosion. Average long-term shoreline position changes from Calcasieu Pass to Sabine Pass for the period of 1947–1994 is approximately -1.8 ft/yr (Byrnes and McBride 1995). Short-term changes, 1990–1995, range from +20.0 ft/yr to -17.2 ft/yr. Hwy. 82 has been relocated inland several times to accommodate shoreline retreat and is now located on a chenier that also serves as the last barrier between the gulf and approximately 31,000 acres of marsh. Once this barrier is breached, it is likely that the destruction of marshes landward of the highway will follow, resulting in catastrophic loss of marsh habitat. In 1969 and 1970 a revetment was constructed to protect the highway from destruction. Since that time, maintenance of the highway and revetment has become a chronic and expensive problem.

Figure 1: Louisiana Hwy. 82 as it appeared prior to breakwater construction in 1991. Note the waves breaking on the revetment. *Photograph by LDNR*

Existing Breakwaters

In 1985, six experimental breakwaters were constructed to test beach response to and structural properties of two different types of breakwaters. Five of the six structures were timber (tire and pylon) construction with similar design parameters. The sixth was a rock rubble mound structure. After eight months of data collection, a decision was made in favor of a regional rock breakwater system for erosion control along Hwy. 82. In 1991, construction was started on what is now the largest breakwater system in the United States.

Construction began on 34 breakwaters from Constance Beach, eastward, 14,600 ft. The breakwaters were 150 ft long with gap widths of 300 ft and placed offshore at distances varying from 185 ft to 450 ft. In 1992, another 21 breakwaters were installed. Eight were constructed on the western end and 13 on the eastern end. Breakwater lengths and gaps remained the same, but, the distance offshore ranged from 335 ft to 520 ft. In 1993, another 21 structures were added to the eastern end. Structure length was increased to 175 ft, gap length decreased to 275 ft, and distance offshore once again varied, ranging from 444 ft to 595 ft. In 1994, the final nine breakwaters were added to the western end. "As-Built" construction plans show their lengths as 150 ft. Gap length for "as-built" breakwaters were 300 ft and distance offshore varied from 350 ft to 465 ft. This final addition brought the total number of breakwaters in the system to 85 (figures 1 and 2). While they have shown some degree of success in causing the deposition of new sand, they are not high enough to adequately protect the roadway from overtopping waves.

There was no regional beach replenishment effort accompanying construction of the breakwaters. However, a modest amount of sand (a total of 11,969 yd^3) was placed at various beach locations. This sand was mined and trucked from a nearby chenier, and met with strong local

Figure 2. Louisiana Hwy. 82 after breakwater construction. Note salient formation behind the structures. *Photograph by LDNR*

opposition to the concept of mining another chenier for beach nourishment. No sand management plan was developed.

Beach Survey Results

The beach surveys conducted in August 1990, August 1994, and October 1995 indicate that the area accreted landward of breakwaters concomitant with significant beach erosion west of the breakwaters. In the lee of the breakwaters, it

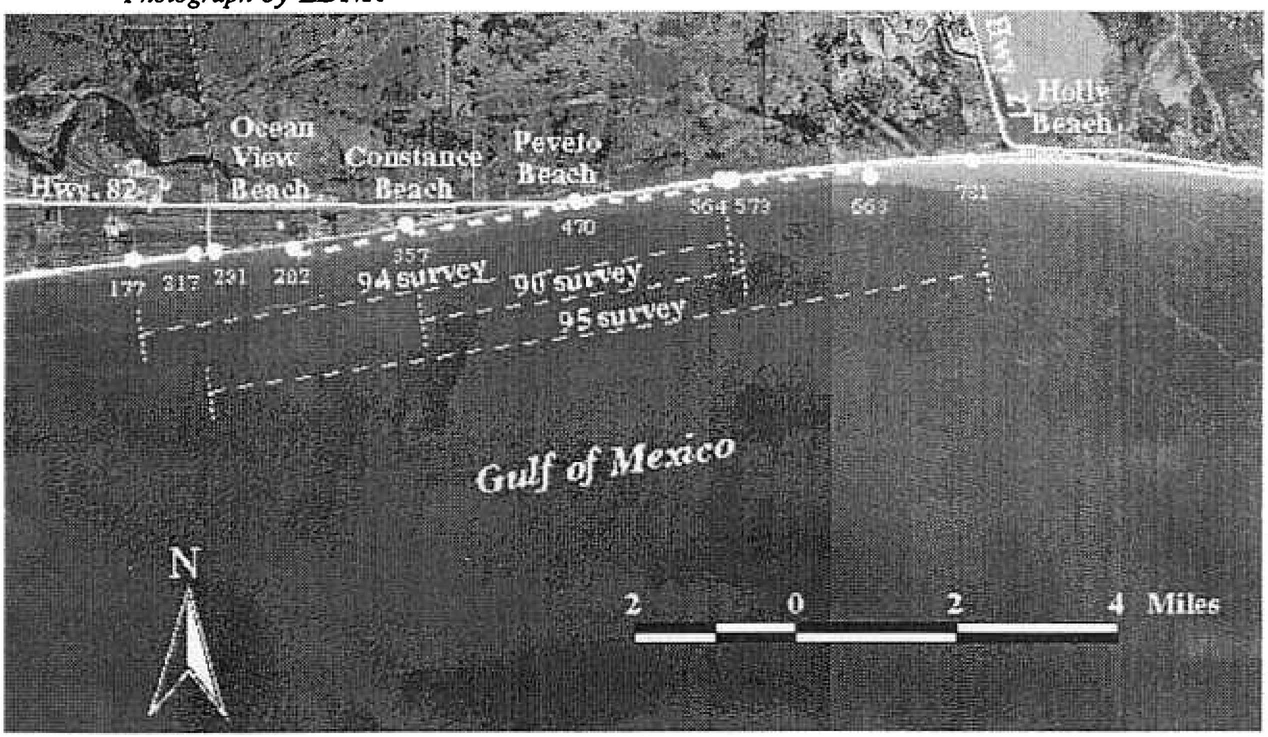


Figure 3. Available beach elevation survey data for the project area (1990–1995). Numbers represent locations of selected beach elevation profiles referenced in figures 4 and 5.

appears that both wave heights and currents are reduced, causing localized sediment deposition on the updrift side, with downdrift erosion due to sediment starvation (figures 4 and 5). There is a consistent erosional trend for the areas immediately west of the breakwaters. In lay terms, the breakwaters appear to be trapping sediment as it travels east to west, inducing salient formation in the lee of the easternmost 40–50 structures. When the salients form, they act more or less as jetties, causing reduced sediment availability such that the westernmost breakwaters become increasingly ineffective in sediment trapping because the longshore transport of sediment has been interrupted.

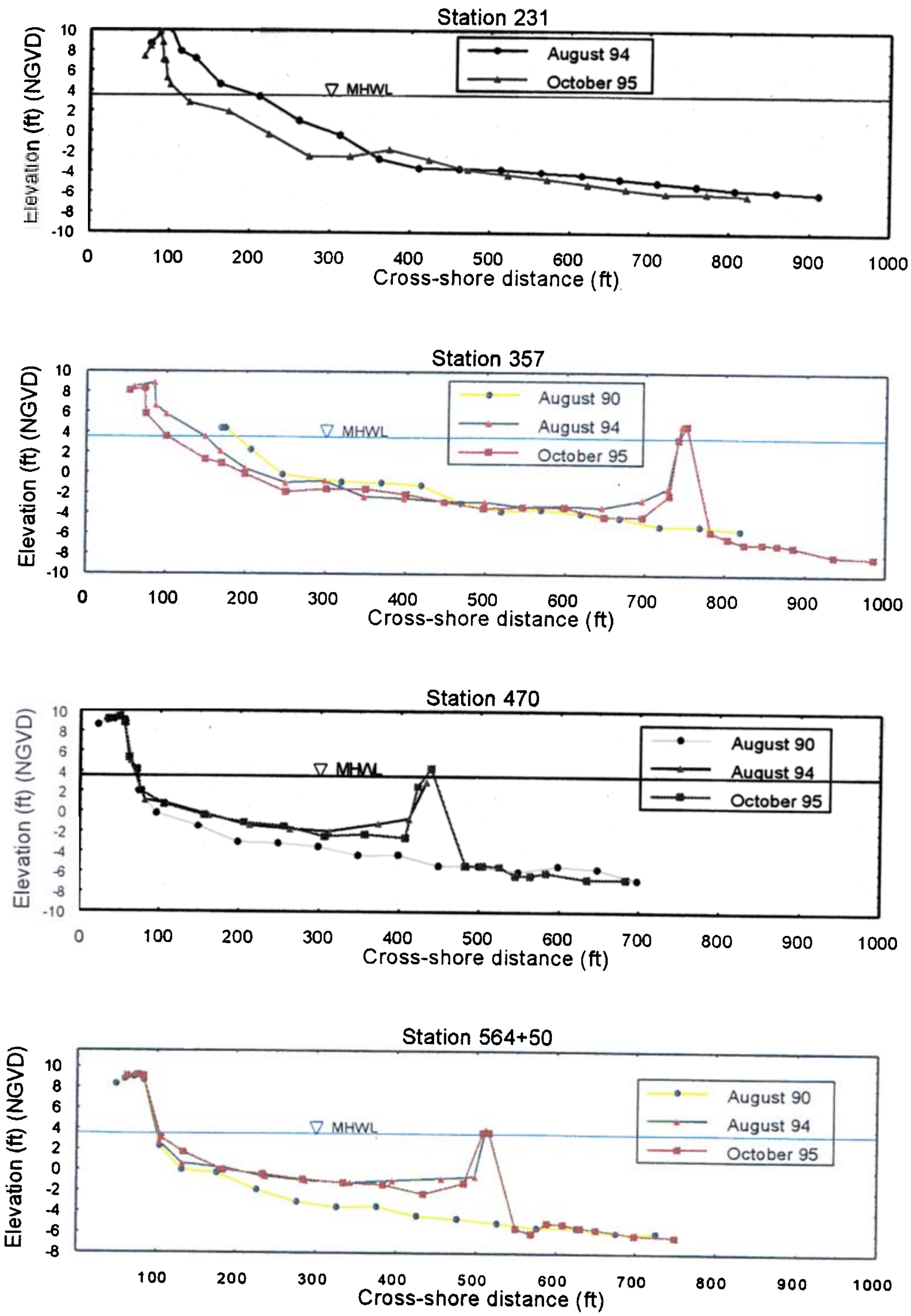


Figure 4. Selected beach elevation profiles illustrating changes in before and after breakwater construction 1990–1995. Station number locations are illustrated in figure 3.

Shoreline Changes

Since the breakwaters were constructed in different configurations, the erosion rates are not consistent throughout the system. These different rates were calculated for both above and below MHWL for the periods of `90–`94,`94–`95 and `90–`95. For the `90–`95 period, the volume changes range from +10.13 yds^3/ft/yr to -4.15 yds^3/ft/yr, with a mean of +2.4 yds^3/ft/yr for below MSL, and +0.2 to -1.0 yds^3/ft/yr, with a mean of +0.07 yds^3/ft/yr for above MHWL (figure 5). These numbers are deceptive because they only show volume changes. They also include the effects of the modest beach nourishment effort of 11,969 yd^3. Shoreline changes for this period, which are much more reflective of the real problem in the area, range from +2.36 to -17.2 ft/yr behind the breakwaters, with most areas experiencing shoreline retreat. In an area west of the breakwaters and immediately east of Sabine Pass, shoreline advancement has occurred by as much as +20 ft/yr due to sediment trapping by the jetty on Sabine Pass.

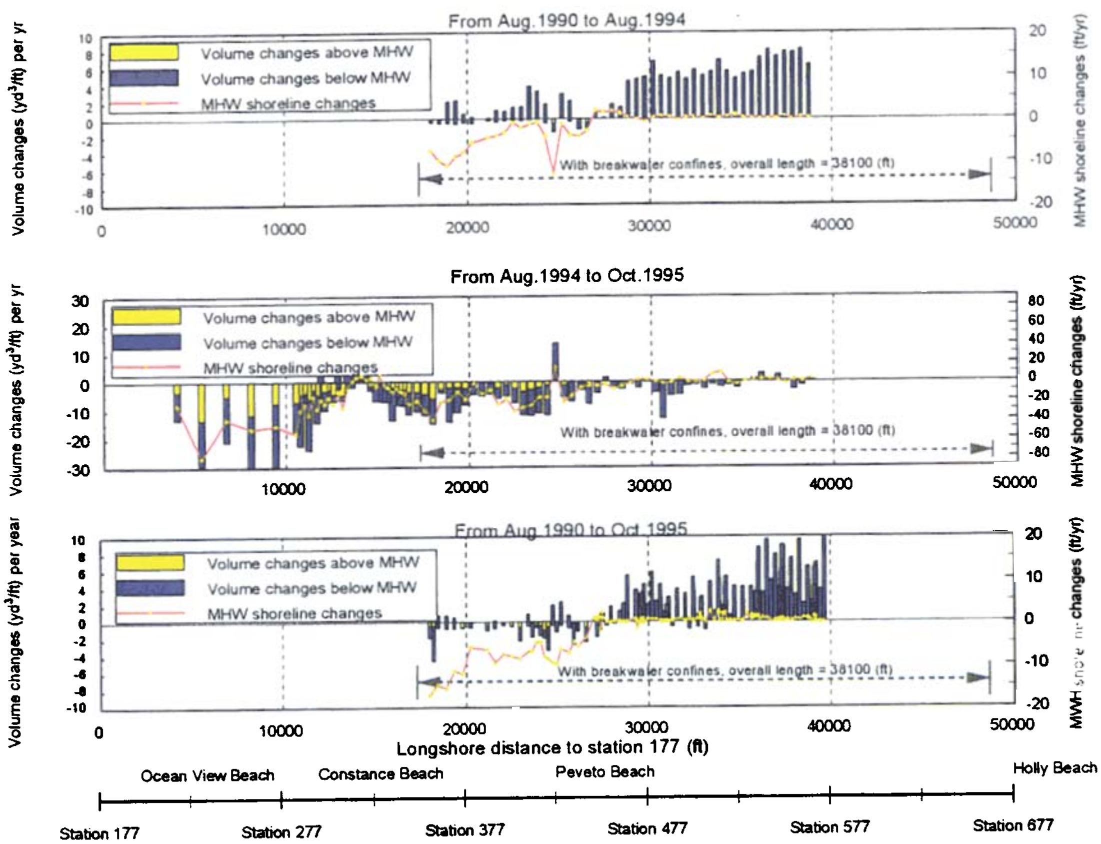


Figure 5. Sand volume changes along beach elevation profiles calculated from survey data. Survey station reference points are illustrated in figure 3.

Louisiana Highway 82

One of the few coastal areas in the state directly accessible by car is located along Louisiana Hwy. 82 in Cameron Parish. Between Constance Beach and Holly Beach, Hwy. 82 roughly parallels the Gulf of Mexico shoreline. Before 1932, the roadway between the town of Cameron and Johnson's Bayou serviced only local traffic. When a ferry was installed in 1932 at the Sabine River, the coastal roadway became an important link between the coastal communities of Texas and Louisiana. In 1936, the roadway became a state route and was resurfaced with shell.

Along this section of highway, the fore slope of the roadway embankment is under frequent wave attack, a problem that has grown steadily more frequent and severe with the progressive loss of beach in front of the highway.

History of Damage and Repair

The original highway was located on a low sand ridge that was once the back side of a chenier, well protected from the gulf by at least 300 feet of beach and dunes. The highway became increasingly exposed to wave damage as the beach diminished, and it had to be relocated several times. Eventually, further relocation of the highway to the north became unreasonable, and efforts were undertaken to protect the seaward side of the embankment with revetment. The first revetment project was done in 1970, and in the next 3 years the highway was inundated approximately 20 times, but without major damage. Damages caused in 1973 by Tropical Storm Delia resulted in raising the most critical 4-mi section of the road approximately 1.5 ft in an effort to reduce the frequency and severity of overtopping. However, from 1977 to 1983, the road was ravaged by numerous hurricanes and tropical storms, necessitating continual repair and maintenance of the revetment and the roadway.

In the 27 years between 1963 and 1990, an average of approximately $600,000 per year has been spent in repair and protection of the roadway and embankment (not including money spent on experimental segmented breakwaters). Unless the frequency and severity of the overtopping of the road by gulf waves can be reduced, the annual cost of keeping the road in use can only increase. If the roadway embankment cannot be adequately protected, it will eventually be breached by the wave action.

Current Highway Needs

Presently, approximately 40% of the seaward side revetment is in need of repair or replacement. On the landward side, overtopping waves have caused large scour holes that have destroyed the shoulder and threaten undermining the west-bound lane. The land side embankment slope must be restored and an erosion protection system installed. Also, spot repairs and general overlay of the roadway are necessary. Repairs to the road and embankment will focus on restoring the foundation and driving surface, and to provide protection for areas weakened by overtopping. However, it is not likely that the road can be made invincible to future overtopping events of the magnitude and frequency which have been experienced in recent years. Unless repairs to the road are accompanied by off-site actions to reduce the frequency and severity of overtopping, the repairs are likely to be short-lived, and similar repair projects will be necessary every few years.

As usual, design options are limited by funding constraints. The Louisiana Department of Transportation and Development (LDOTD) hopes to be able to commit approximately $5 million to roadway repairs—a modest amount for the work needed.

The financial resources required to fight the encroachments of an ocean on an eroding coastline are not reasonable justified by the transportation needs being addressed by a roadway with an average daily traffic (ADT) of only approximately 1,200 vehicles. Costs to maintain the 4-mi section of Hwy. 82 have far exceeded the norm for a two-lane rural route with such modest traffic demand. The $600,000 per year expenditure since 1963 (a figure which would be considerably larger if corrected for current economic conditions) will necessarily increase in the future unless some protection from waves and inundation can be provided. Absent any measures to protect the roadway from gulf encroachments, a conservative estimate for periodic repairs and maintenance for the next 20 years would be $750,000 per year. This translates to approximately $1.70 per vehicle use. By comparison, the same per-vehicle expenditure on a 4-mi segment of Airline Highway in Baton Rouge, with an ADT of 60,000, would be more than $37 million per year, every year. Obviously, this expenditure cannot be reasonably supported on the basis of transportation alone. Even with this maintenance, it is unlikely that overtopping of the highway will cease or even be significantly reduced unless accompanied by additional off-site improvements to the beach and existing breakwaters.

While the traffic demand on the subject section of Hwy. 82 is modest, the road serves a second and possibly greater purpose; it is the only barrier between the waters of the Gulf of Mexico and thousands of acres of valuable coastal wetland.

SECTION II: ALTERNATIVES EVALUATED

Preliminary Screening of Alternatives

Representatives from the Louisiana Department of Natural Resources (LDNR) and LDOTD conducted a field investigation at the project site and discussed a wide variety of options to protect the highway, beach, and marsh. These options included:

1 Elevating the highway to reduce the frequency of overwash;

2. Beach renourishment;

3. Strengthening the existing revetment along the highway;

4. Narrowing the gaps between the existing breakwaters;

5. Lifting the existing breakwaters and narrowing the gaps;

6. Construction of a sacrificial dune system immediately seaward of the highway;

7 Mining salients formed in the lee of the breakwaters to form a sacrificial dune;

8. Construction of a massive seawall that will prevent overwashing and breaching of the highway; and

9. Combination of options 2, 5, 6, and 7.

Options 1–7 were eliminated from further consideration based on a consensus that those options, in and of themselves, would be either ineffective and/or cost-prohibitive. It was determined that options 8 and 9 merited further analysis. A No-Action Alternative was selected to serve as the baseline for comparison of alternatives that afford protection to transportation infrastructure and environmental resources.

Alternative 1: No-Action

Under this alternative nothing would be done to provide additional protection to the beach, highway or adjacent marsh. There are no design, construction, or maintenance costs associated with this action. There are, however, monitoring activities associated with the existing breakwater project as described below.

Monitoring

The monitoring plan includes three key elements for evaluating project performance over time. The first element is near-vertical, 1:12,000-scale, color aerial photography. This was to be flown before project implementation and every subsequent fifth year. This photography will be utilized for determining changes in the permanent *berm crest* portion of the shoreline, which is recognized on the photography as the area just above the color contrast line (light-dry beach/dark-wet beach) or high water line. The line is commonly used for shoreline mapping procedures. However, due to increased shoreline position accuracy and cost-saving measures, a recommendation of using Global Positioning System (GPS) for all future shoreline mapping is preferred over interpretation of near-vertical aerial photography.

Three nearshore areas of importance were selected for subsequent survey profile lines: an updrift portion; downdrift portion; and breakwater area. Begin surveys 0.5 mi updrift of final position of eastern-most breakwater. Extend surveys 2 mi downdrift (west) of last breakwater. Each survey profile line updrift and downdrift was spaced 1,350 ft apart, extending seaward approximately 800 ft. Survey lines along center line of each breakwater, to toe of structure and seaward of breakwater (200 ft; gives idea of scour problems and of sediment movement [accretion or erosion]). The breakwater area profile line spacing is established at approximately 225 ft, extending seaward approximately 800 ft. Survey lines in between breakwaters (i.e., center line of gap between breakwaters) out to the depth of adjacent breakwater line. Maintain present interval of 50 ft per survey point.

Surveys are done preconstruction and every 5 years in September. Average cost of a full survey is $100,000.

The total length of shore monitored in the project and reference areas is 11.52 mi. The length of shore fronted by the 85 breakwaters is 7.22 mi. Evaluation of beach response to breakwater placement has been conducted annually to address the stated objectives. Temporal and spatial changes in shoreline position (retreat and/or advance) are referenced to the movement of the berm crest (estimated to be approximately 3 ft in elevation). Sequential beach profile changes are used to quantify sediment quantities among the subaerial and subaqueous portions of the beach.

The total first cost of Alternative 1 is $100,000.

Alternative 2: Enhance Breakwaters and Sand Management

The design and effectiveness of offshore segmented breakwaters is largely dependent on the combined effects of the length-to-gap ratio, length-to-distance offshore ratio and the wave energy overtopping the breakwater. Therefore, improvements to the breakwaters need to incorporate all of the above affects, (i.e., improving one deficiency without improving others may not produce the desired results).

The following is a conceptual design with appropriate cost estimates. A final design would have to be completed and costs estimated pending the acquisition of required geotechnical data that is presently unavailable (see Management Plan).

Design and Cost

Breakwater Rehabilitation

In their current configuration, the ratio of breakwater length to gap length is not ideal for salient formation, according to U.S. Army Corps of Engineers studies and design manuals (USACE 1984; 1992; 1993; Harris and Herbich 1986). The gaps between the breakwaters are too wide, allowing too much wave energy to impinge on the beach. This effect is intensified during high-energy storm events causing much of the erosion and damage to the highway.

To reduce wave energy transmitted through the gaps and help protect the shoreline, all 85 breakwaters should be lengthened 50–75 ft. This will create a length-to-gap ratio more suitable for salient formation. To help protect against frequent storm damages and wave overtopping, all breakwaters should be raised approximately 3 ft. Table 1 itemizes the costs for these modifications.

Table 1. Estimated costs to modify the existing breakwaters.

Project Component	Cost
Lengthen all 85 breakwaters	$4,384,000
Elevation lift of all 85 breakwaters	$6,930,000
Mobilization/Demobilization	$120,000
Engineering, surveys, Construction insp.	$300,000
Total Initial Costs	**$11,734,000**
Cost per breakwater	$138,100

Initial Beach Renourishment

In their current configurations, most of the breakwaters' length-to-distance offshore ratios are not within accepted ranges for effective shoreline protection and salient formation (USACE 1984, 1992, 1993, Harris and Herbich, 1986). Since different sections of the breakwaters were built at different distances offshore, this ratio varies throughout the project. To attain an acceptable ratio that is consistent throughout the system, varying quantities of sand should be placed behind the different reaches of breakwaters. Beach renourishment is a common practice with other breakwater projects and is a necessary component used in the absence of adequate longshore drift material. In order to maintain these ratios, a dedicated sand management plan including renourishment, should be incorporated into the long-term design of the project (table 2) (see Management Plan).

Feeder beaches (berms) should also be placed both updrift and downdrift of the breakwater system. Feeder berms will supply sediment to the areas affected by sand mining for artificial dune creation described in the Management Plan below. This will also reduce the downdrift sediment starvation problem associated with the existing breakwater system. One possible source of material may be the Calcasieu Ship Channel. The channel undergoes periodic maintenance dredging and some of this material may be suitable for beach renourishment.

Table 2. Estimated start-up costs in beach renourishment.

Project Component	Cost
Station 282+50 - 320+40	$54,500
Station 320+40 - 402+00	$285,600
Station 402+00 - 569+00	$240,100
Station 569+00 - 663+50	$588,000
Feeder Berm at East end	$35,000
Mobilization/Demobilization	$120,000
Engineering, surveys, Construction insp.	$200,000
Geotechnical, analysis of borrow sites	$50,000
Total Initial Costs	**$1,829,800**

Note: These estimates are based on a conceptual offshore dredge borrow site with a grain size compatible with the existing beach grain size. It is unknown at this time if sand deposits witha compatible grain size are available offshore in sufficient quantities. If sand must be trucked instead of dredged, costs for sand could possibly triple.

Artificial Dune Construction

Sacrificial dunes are the best natural protection against storms. They help to prevent excessive overwash, protect against high tides and tidal surges, and are mobilized (eroded) during these high energy events, all of which protect the shoreline and structures located behind the dunes from being damaged (USACE 1984). An artificial dune system would help protect Hwy 82, the chenier upon which it is built, approximately 31,000 acres of coastal marsh, and residential structures.

Dunes could be constructed in two ways: (1) pumped from an offshore dredge site, or (2) placed by truck onto the beach during or immediately after the initial beach nourishment. After dewatering and settling, the sand would be worked by machinery into site-specific dunes, dimensions of which would be governed by the length of beach available for dune construction. This type of dune construction would produce immediate protection for the shoreline. Table 3 is a cost estimate per reach, based on dredged sand.

Table 3. Dredging cost estimates.

Reach (see figure 3)	Cost
Behind feeder berm at west end	$197,000
Station 282+00 - 320+40	$283,000
Station 320+40 - 402+00	$609,000
Station 402+00 - 569+00	$1,247,000
Station 569+00 - 663+50	$705,600
Behind feeder berm at east end	$74,700
Mobilization/Demobilization (If done with initial beach nourishment)	$0
Engineering, surveys, construction insp.	$100,000
Total Dune Construction Costs	**$3,216,300**

Note: Same notes as for beach renourishment apply. Also, site restrictions may prohibit estimated dune size. Grain size may also affect estimates by restricting dune slope design. These restrictions will not be known until geotechnical analysis can be performed.

The second method of construction could be the mechanical mining of salient deposits that form landward of the breakwaters and stockpiling the sand into dunes. This method will not produce immediate shoreline protection and should be considered as maintenance. Costs for this method of dune construction are addressed in the Management Plan section.

Breakwater Maintenance Costs

During the expected 20-year project life, an elevation lift may be required. This lift may be necessary to repair damages caused by severe weather and structure settlement. Costs for such repairs should therefore be included in the design. Postconstruction monitoring will determine if this lift is necessary. Table 4 lists estimated costs for a 2-ft maintenance lift in 1997 dollars and average 20-year annualized cost with 4% inflation.

Table 4. Costs to elevate the existing breakwaters.

Item of work	1997 estimated cost	20-year annual cost
2' lift for 85 B.W.	$2,800,000	$206,000
Mob./Demob.	$120,000	$8,800
Construction insp.	$300,000	$22,100
Total	**$3,220,000**	**$236,900**

Management Plan

Sand Management

A sand management plan should be included into the design of offshore breakwater systems because of the dynamic environment in which breakwaters are built. Periodic beach and feeder berm renourishment, utilization of trapped salient material for beach and dune nourishment, and the periodic evaluation of the effectiveness of the system should all be included in the sand management plan.

In the development of sand management projects, shoreline erosion rates and grain size characteristics must be known before the project design phase. These variables affect the quantity of sand initially and periodically placed on the beach. They also affect the time period and cost of renourishment.

Historic erosion rates for the area are available, however, the existing breakwater system has reduced the erosion rate. Furthermore, proposed enhancement of the breakwater system should reduce erosion even more. Computer modeling may be a useful tool in predicting erosion, however, the accuracy of the modeled changes would be speculative. Also, historic erosion rates may not apply for the borrow area sediment. Once placed on the beach, the newly nourished sediment could possibly erode at a higher rate than native sediment due to differing grain sizes.

Adequate grain size analyses of the native beach and potential borrow sites are not available at this time. The only report of this type available is one that was conducted in the early 1980s (LDNR et al. n.d.) before the construction of breakwaters was started, and may be unreliable. Grain size analyses are required to calculate overfill ratios for beach nourishment, replenishment periods and stacking ability for dune slope design. Potential sand borrow sites are shown in figure 5.

The following is a conceptual design for sand management. It is based on an offshore borrow area with a grain size equivalent to the native beaches grain size, i.e., the overfill ratio is equal to

Figure 6. Potential sand borrow sites.

one. Historical erosion rates were used to determine replenishment periods. Once an adequate borrow site has been identified and analyzed, initial nourishment and renourishment quantities and costs will be recalculated to account for grain size differences.

Sand Volume Changes

For sand volume change calculations, it is more appropriate to use recent volume changes in the area instead of long-term changes because the breakwaters are a fairly recent addition to the system. Short-term changes would more accurately reflect the influence that the breakwaters have had on erosion rates than would long-term changes.

Potential Sand Borrow Areas

Several borrow sites may have potential for beach renourishment. Two potential offshore sites were referenced in the LDNR (et al. n.d.) report (figure 6). The first was an abandoned fluvial system with a 4- to17-ft overburden material layer. Sand thickness ranged from 7–27 ft and as much as 62.8 million yd^3 may be contained within the system. The second was a relatively thin layer of sand found in much of the area. It had an average overburden layer of 4.5 ft and a sand thickness layer averaging 4 ft. It is estimated that the system contains 32.4 million yd^3 of sand.

Another possible borrow site could be the beaches west of the breakwaters and east of Sabine Pass. These beaches have historically accreted and could be mechanically mined.

Periodic bypass dredging of the Calcasieu Pass Jetties should also be considered as a means of introducing additional longshore drift material into the area.

Sand could also be trucked in from a land-based site. This could be the most expensive method of beach nourishment and should only be considered as a last resort.

Phase II of the ongoing Barrier Shoreline Feasibility Study, funded under the Breaux Act, calls for identification of possible borrow sites for the chenier plain barrier shoreline. However, the Barrier Shoreline Feasibility Study will not perform the geotechnical investigations required for project design.

Sand Management Plan

The sand management plan should consist of periodic beach renourishment and the mining of salient deposits for dune building. The preliminary design for periodic replenishment of the beach is based on an average erosion rate of -8 ft/yr of shoreline change. An equivalent grain size and a replenishment period of 5 years was also used. Storms influence replenishment requirements, making changes in renourishment periods variable. Table 5 itemizes 1997 cost estimates for the preliminary design and average 20-year annualized cost with 4% inflation.

Table 5. Costs to implement a sand management plan.

Project Component	1997 cost	20-year annual cost
Sand Replenishment	$1,240,000	$91,300
Construction Inspection	$300,000	$22,100
Mobilization./Demobilization	$480,000	$35,300
Total	**$2,020,000**	**$148,700**
Average 5-year`cost	$743,500	

The mining of salients for dune creation will help protect against storm damages. The preliminary design was based on utilizing machinery to mechanically remove the salients and place them on the back beach as dunes. This procedure could possibly be done three times per year, depending on weather conditions. Monitoring will be utilized to determine required mining periods. The following are estimated costs in 1997 dollars and average 20-year annualized cost with 4% inflation:

Table 6. Estimated costs of salient mining.

1997 cost	20-year annual cost
$540,000	$39,700

Salient mining could be used for beach and dune nourishment. This would lower yearly costs for beach renourishment.

Breakwater Management

Survey Data

In order to evaluate the effectiveness of the breakwater system, periodic analysis of the postconstruction monitoring surveys should be performed approximately every 5 years and may cost $25,000 per analysis. The postconstruction monitoring surveys should be compared with pre-modification surveys in order to determine changes in erosion rates, sand volumes and shoreline positions. It is acknowledged that salient mining will affect these calculations. Future modifications to the system, if necessary, would be based on these comparisons. The following are estimated costs for this type of analysis in 1997 dollars, and average 20-year annualized costs with 4% inflation:

Table 7. Estimated costs periodic beach profile surveys.

1997 cost	20-year annual cost
$100,000	$7,400

Speed of Implementation

A phased approach to breakwater enhancement could be implemented, depending on budget constraints. Permitting, engineering, surveys, land rights and contracting could be completed in approximately 6–8 months. For a nonphased approach, breakwater modifications could be complete approximately 8–18 months after contracting. This project could be implemented in 3 years.

Initial beach and dune nourishment should be implemented only after breakwater modifications are complete. Permitting, engineering, geotechnical, surveys, land rights and contracting could be completed in approximately 8–12 months. This period may be extended if land rights become an issue. Construction of initial sand placement could be complete approximately 6–10 months after contracting. After initial placement, the sand management plan would dictate further implementation requirements.

Monitoring

Same as methods listed in Alternative 1 (No-Action). There would be no change in collection of elevations with lengthening/shortening of gaps. The center of each breakwater would not change, assuming the same amount of rock is placed on either side of existing breakwaters.

The total first cost of Alternative 2 is $23,560,100.

Alternative 3: Construction of a "Galveston-type" Seawall along Louisiana Highway 82

Seawalls generally are used to maintain the shoreline in an advanced position relative to that of adjacent shores, where there is a scant supply of littoral material or no protective beach. They are designed to resist high-energy wave action. The limitation of this type of structure is that it affords protection only to the land immediately behind them, and none to adjacent areas. When built on a receding shoreline, the recession on adjacent shorelines will continue and may be accelerated (USACE 1984). This may warrant future seawall lengthening to protect eroding adjacent shores.

Design and Cost

A "Galveston-type" seawall is a gravity-type concrete structure supported by pilings. It has a curved face and rubble mound toe protection and sheet piling to prevent scour. The following cost estimate is based on this type of structure. The design includes an elevation lift on top of existing revetment to 15 ft NGVD, which would protect against an 8-ft storm surge with 6-ft waves with some overwash due to wave runup. The seawall and new roadway elevation would both be at 15 ft. This should provide adequate protection from storms except during major hurricanes, when more overwash could be possible. Table 8 itemizes estimated costs for 4.5 mi of seawall construction, including a roadway elevation lift.

Table 8. Seawall construction costs.

Project Component	Cost
Seawall construction and roadway elev. lift	$62,322,500
Construction Inspec.	$5,000,000
Total	**$67,322,500**
Cost per mile	$14,960,500

The extremely high cost for this type of structure is due to the massive amounts of concrete required for its construction.

Costs Including 20-Year Maintenance

Maintenance costs for damages to seawalls are relatively small compared to their initial costs. The costs would depend upon the number of hurricanes it experiences during its project life (which is well over 20 years), and even then, damages should be minimal. Seawall lengthening, however, will probably be necessary due to continued shoreline erosion on its flanks. Therefore, within the 20-year project life it is estimated that an additional 1–2 mi of seawall may be needed for additional shoreline protection. Table 9 shows the estimated cost in 1997 dollars, and average 20-year annualized cost with 4% inflation.

Table 9. Seawall maintenance costs.

Project Component	1997 Costs	20-Year Annual Cost
Seawall maintenance	$1,000,000	$73,600
Lengthening seawall by 1 mile	$14,960,500	$1,101,100
Total	**$15,960,500**	**$1,174,700**

Management Plan

The management plan of a seawall consists of very little since damages occur mainly from large storms, which have a very low frequency of return. The plan could involve visual inspections after storms and periodic surveying and analysis (every 5 years) of the adjacent shorelines. Cost should be minimal and is estimated for the 20-year project life in 1997 dollars, and in 20-year annualized with 4% inflation, as follows:

Table 10. Estimated cost of periodic surveys and visual inspection of a seawall.

1997 Cost	20-Year Annual Cost
$100,000	$7,400

Speed of Implementation

A project of this magnitude would entail development of a feasibility study and environmental impact statement. This would take roughly 2–3 years. Engineering and design would take at least 1 year. Contracting and construction would take an additional 2 years. In all, 6–7 years would be required to implement this project.

Monitoring

Monitoring elements are identical to that described in Alternative 1, with the exception that the vertical elevations taken at the toe of the seawall (225 ft apart) would provide information as to what kind of scouring may potentially occur due to this continuous hard structure.

The total first cost of Alternative 3 is $83,783,000.

SECTION III: ENVIRONMENTAL EFFECTS OF ALTERNATIVES

Environmental Setting

The project encompasses 31,056 acres of intermediate marsh, shallow water, and beach habitat extending along approximately 8 mi of Gulf of Mexico shoreline from Holly Beach to Constance Beach. The project is bounded to the west by the Magnolia Vacuum Canal, to the east by Louisiana Highway 27, to the north by Starks South Canal, and to the south by the Gulf of Mexico.

Definitive studies and data collection have not been undertaken to determine the causes of wetland loss in the area. During severe weather events, high-salinity gulf waters overwash Hwy. 82 and result in marsh loss due to saltwater intrusion. It is likely that incidental impoundment by levees, shell roads and oil and gas infrastructure have disrupted the natural hydrology of the marsh, resulting in direct and indirect wetland loss.

Historically, land loss in this area has been variable. USACE land loss data indicate that the area was relatively stable during the period of 1933 to 1955. Geographic Information System data generated by the LDNR and the U.S. Geological Survey (USGS) indicated that between 1955 and 1978, the area suffered the loss of 3,573 acres (figure 7). This loss corresponds to the period when Hurricane Audrey and several other major storms made landfall in this area, resulting in dramatic land loss throughout the Calcasieu/Sabine Basin. Between 1978 and 1990, the area has remained relatively stable with site-specific losses and gains probably resulting from variable water levels in the area that can result in the recolonization of marsh in shallow water areas during periods of natural drawdown (figure 7).

The Wetland Value Assessment

The Wetland Value Assessment (WVA) is a modification of the Habitat Evaluation Procedure (HEP) developed by the U.S. Fish and Wildlife Service. The WVA provides a measure of the environmental effectiveness of a proposed wetland restoration project by using existing or readily available data.

The WVA utilizes mathematical models requiring the input of baseline ecological data and projections of future ecological conditions for "future-with-project" and "future-without-project" (FWP/FWOP) scenarios. The underlying assumption for the WVA is that optimal wetland habitat conditions can be characterized and used to provide an index of habitat suitability or "habitat suitability index" (HSI) relative to the optimal conditions. The WVA models are designed to operate at the ecological community level rather than at the species level, and therefore attempt to define the optimal conditions for all fish and wildlife species utilizing a given marsh type over time. The habitat suitability indices are multiplied by the acreage of the project area and a variable time interval (usually 20 years) to compute the number of habitat unit (HUs) for FWP and FWOP scenarios. Computed habitat units are annualized over the project life to generate the average annual habitat units (AAHUs). The AAHU is essentially the unit by which the benefit of the project is estimated The net change in AAHUs from the FWP and FWOP is the measure of the project's predicted environmental benefit.

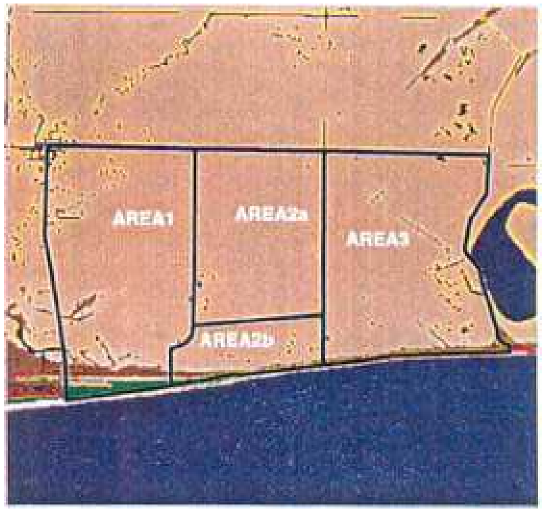
Environmental Impact Analysis

The project area was subdivided into four subareas based on the predicted degree of deterioration that would result if no protective measures are employed (figure 6). The subareas are, to varying extent, hydrologicly separated by shell roads and levees. Culverts beneath the roads and through the levees provide some hydrologic connection between subareas. Background land loss calculations are based on rates provided by the USACE from the period 1983–1990.

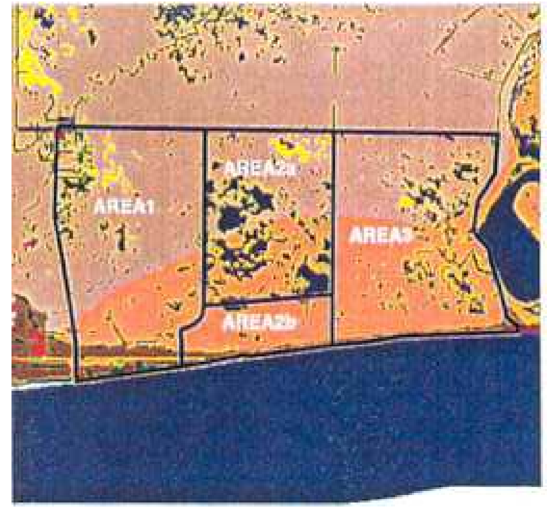
Environmental effects of all alternatives are estimated over a 20-year project life.

Alternative 1: No-Action

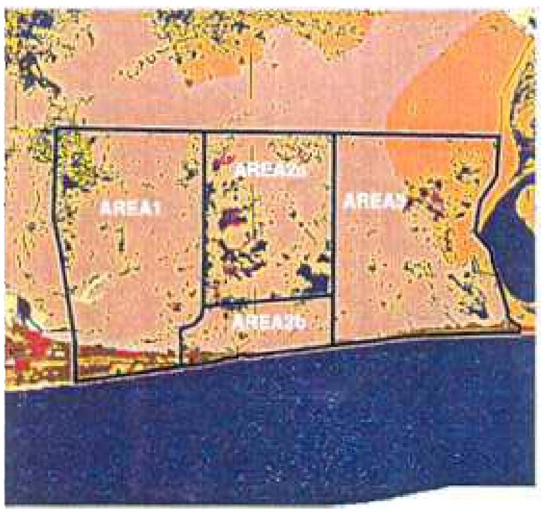
Under the No-Action Alternative, wave activity from the Gulf of Mexico are projected to continue undermining Hwy. 82, resulting in caving of the highway at numerous locations within five years. This would provide avenues for saltwater and tidal action into the project area, causing severe marsh die-back and tidal export of the organic marsh surface. The result would be a habitat shift from healthy, intermediate marsh to large, shallow saline ponds. It is expected that some of the remaining marsh would respond to these conditions with a vegetative shift to more salt-tolerant species and become more stable. Submerged aquatic vegetation (SAV) that now dominates shallow water ponds in the area is projected to suffer dramatic die-back, with only minimal recovery, and shift to more salt-tolerant species. Table 11 presents a summary of forecasted marsh loss by subarea generated by the WVA.



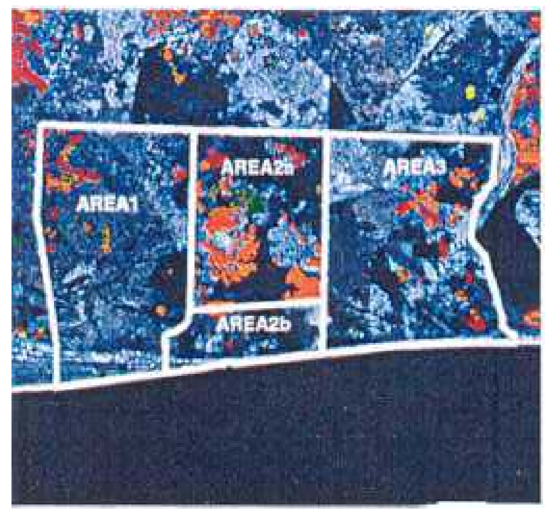
1956 Habitat Data



1978 Habitat Data

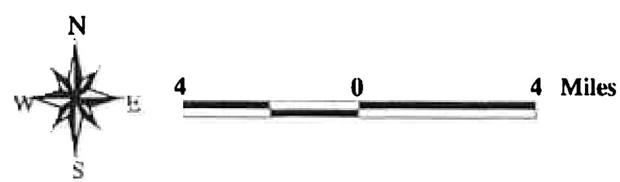


1988-90 Habitat Data



1956-90 Land Loss Data

Class	1956	1978	1988-90
Water (acres)	358.776	3191.005	3530.982
Marsh (acres)	29180.454	25606.963	25756.531
Beach/Upland (acres)	1517.586	2257.071	1768.038
Total (acres)	31056.816	31055.039	31055.551



Map ID: 97-06-004 produced by the Louisiana Department of Natural Resources GIS Section

GIS land cover change and habitat statistics for Holly and Constance beaches (1956-1990).

Table 11. Wetland loss with the No-Action Alternative.

Subarea	Acres Lost in 20 Years
Area 1	457
Area 2a	4,111
Area 2b	1,500
Area 3	5,731
Totals	**11,799**

Alternative 2: Breakwater Enhancement and Sand Management

Under this alternative, the beach, highway, and marsh would be protected. Beach habitat will be preserved and the marsh is expected to remain relatively stable with low background loss rates similar to the present day conditions. With beach renourishment, breakwater enhancement, and sand management, the frequency of overwash would be reduced and the potential for highway failure would be significantly reduced. Table 12 presents a summary of predicted marsh loss by subarea, generated by the WVA.

Table 12. Wetland loss with the Breakwater Enhancement and Sand Management Alternative.

Subarea	Acres Lost in 20 Years
Area 1	356
Area 2a	35
Area 2b	257
Area 3	112
Totals	**760**

Alternative 3: Seawall Construction along Louisiana Highway 82

The wetland benefits of constructing a seawall along the south side of Hwy. 82 are expected to be the same as those projected for Alternative 2, above. In terms of environmental benefit, the seawall alternative differs from the breakwater enhancement alternative only in that the beach would be lost. Loss of the beach habitat would reduce feeding and resting habitat for shorebirds and fish that utilize the surf zone for foraging. The recreational and aesthetic value of the beach would also be lost.

Summary

Table 13 below summarizes the coastal wetland benefits generated using the Wetland Value Assessment.

Table 13. Marsh protection benefits associated with Alternatives 2 and 3.

Subarea	FWOP loss (ac)	FWP loss (ac)	Acres Protected (FWOP-FWP)	AAHUs
Area 1	457	356	101	2254
Area 2a	4111	35	4076	2663
Area 2b	1500	257	1243	872
Area 3	5731	112	5619	3102
Totals	**11799**	**760**	**11039**	**8891**

SECTION IV: RECOMMENDED PLAN

Alternative 2, Enhance Existing Breakwaters and Sand Management, has been selected as the recommended plan. The selection of this alternative as the recommended plan was based on several factors. One factor was that this plan is considered a continuation of the initial breakwater project. Breakwater design is not an exact science, due to the site-specific nature of the dynamic environment in which breakwaters are built, and there is no standardized method for their design. The design of breakwater projects includes initial design and placement (based on site-specific conditions), monitoring, and modification (if necessary) based on monitoring data. Based on the available monitoring data, the existing breakwaters are not currently performing as effectively as desired in their current configuration; therefore, breakwater modification and sand management is considered necessary for the future success of the project.

The recommended plan was chosen over the seawall alternative primarily because of the enormous costs and time involved in seawall construction. The cost of breakwater enhancement and sand management is roughly 25% of the cost of seawall construction. Under this alternative, the beach, highway, and marsh would be protected. Beach habitat will be preserved and the marsh is expected to remain relatively stable with low background loss rates similar to the present-day conditions. With beach renourishment, breakwater enhancement, and sand management, the frequency of overwash would be reduced and the potential for highway failure would be significantly reduced, thereby reducing highway maintenance costs. Also, a seawall could cause increased erosion to adjacent shorelines which would warrant future seawall lengthening or some other type of action to address the problem. Breakwater enhancement/sand management should eliminate these types of future problems while concurrently providing adequate shoreline protection at a fraction of seawall costs.

The No-Action scenario was not chosen as the recommended plan because it would inevitably cause catastrophic marsh habitat destruction and property damage. This scenario would also mean that the state would essentially be abandoning a multimillion dollar breakwater project after only 2 years of operation. It would also warrant probable future costs for the removal of the breakwaters due to the navigational hazard they will pose as the shoreline retreats and the breakwaters sink below MSL. Table 14 below compares the three alternative plans.

Table 14. Comparison of alternative plans.

Project Component/Parameter	No-Action	Breakwater Enhancement/Sand Management	Galveston-Type Seawall
Construction Costs	n/a	$11,734,000	$67,322,500
Dredging Costs	n/a	$5,046,100	n/a
Operations, Maintenance and Management Costs	n/a	$6,280,000	$15,960,500
Monitoring Costs	$500,000	$500,000	$500,000
Total Costs	**$500,000**	**$23,560,100**	**$83,783,000**
Speed of Implementation	n/a	3 years	6-7 years
Marsh Acreage Lost/Protected	-11,799	11,039	11,039
Cost per Benefitted Acres	**n/a**	**$2,134/ac**	**$7,590/ac**

SECTION V: POTENTIAL FUNDING SOURCES

With the total first costs of the preferred alternative approaching $23 million, it is considered desirable that the state apply for matching federal funding for project implementation. In the event that full funding of the preferred alternative is not available, it may be feasible to take a phased approach to implementation. This would entail constructing components of the preferred alternative that will protect the sections of beach and highway most vulnerable to highway breaching and overwash. Although this approach would increase the overall cost of the project, it may be more desirable, given the constraints on project funding.

It is beyond the scope of this preliminary report to prepare an exhaustive analysis of potential funding sources, however some potential funding sources are described below.

Breaux Act

At the present, nearly all coastal restoration activities in the state are funded under this legislation. The Breaux Act, in conjunction with matching state funds, provides up to $40 million of federal funds per year for construction of wetland restoration projects in Louisiana. Funding for The Breaux Act coastal restoration projects is based on a 75% federal, 25% state cost share. At the present, the state's cost share is funded through the Wetlands Conservation and Restoration Trust Fund. In addition to construction funds, The Breaux Act provides $5 million per year for large-scale planning efforts. The total allocated Breaux Act fully funded costs as of January 1997 are $166,582,738 (LDNR 1997) and have provided for the planning, construction, maintenance, and monitoring of 67 coastal restoration projects.

Water Resources Development Act (WRDA)

The Water Resources Development Act is generally reauthorized by Congress every 2 years and is administered by the Secretary of the Army. Funding levels and project eligibility requirements vary with each authorization. Major environmental restoration projects, such as this, require a detailed feasibility study, environmental impact assessment, and compliance with federal *Principals and Guidelines for Water Resources Development Act Projects*. Funding of WRDA projects is currently based on a 65% federal and 35% nonfederal cost share.

Currently, the Breaux Act Task Force and state of Louisiana are engaging in this process as part of the ongoing Barrier Shoreline Feasibility Study, Phase 1, component. The Phase 1 study is evaluating restoration of barrier islands in the Barataria and Terrebonne basins to identify the best island configuration for the protection of coastal resources. The feasibility study will be followed by development of an environmental impact statement. These reports will then be forwarded to USACE headquarters for review and consideration for future WRDA funding. Phase 2 of the Barrier Shoreline Feasibility Study will evaluate the best means of restoring and protecting the chenier plain shoreline and is expected to follow the same procedure for WRDA funding in the future has not been committed for Phase 2 of the Barrier Shoreline Feasibility Study by the Breaux Act Task Force as of this writing.

Louisiana Wetlands Conservation and Restoration Fund

The fund is generated by monies received by the state each fiscal year from mineral revenues. It provides for a minimum of $5 million and maximum of $25 million for coastal protection and restoration activities in the state. When mineral revenues exceed $600 million, the fund receives an additional $10 million. When mineral revenues exceed $650 million, the fund receives another $10 million, such that an annual maximum of $25 million can go to this fund. The balance of the fund shall not exceed $40 million.

Currently, virtually all of this fund is being applied as the state match for Breaux Act funded coastal restoration projects.

National Coastal Wetland Conservation Grants

The goal of these grants is to create, restore, protect, enhance and conserve coastal wetlands for fish and wildlife, waterfowl, and migratory birds. The grants provide up to $15 million per year for these projects nationally. A 25% state cost share is required. This funding source cannot be combined with The Breaux Act. These grants are extremely competitive.

- North American Wetlands Conservation Act of 1989

The goal of this act is to protect, enhance, restore, and manage an appropriate distribution and diversity of wetland ecosystems and other habitats for migratory birds. The act provides $30 million/year of which 30–50% can be allocated in the United States. Projects must be consistent with the North American Waterfowl Plan and National Environmental Policy Act. Projects should provide long-term protection (25 years or longer). A 50% state cost-share or in-kind match is required.

Capitol Outlay

The state can request capitol outlay funding for this project, however, there would be no federal match and the high cost of this project may make funding difficult.

State General Fund

LDOTD Highway Maintenance Funding

LDOTD hopes to be able to commit approximately $5 million to roadway repairs in this area, however, this is probably insufficient to maintain the road for an extended period unless proactive measures are taken to stabilized the shoreline.

- Multiple Source Funding

It may be possible to utilize Breaux Act, LDOTD highway maintenance funds, and the Louisiana Coastal Wetlands Conservation Fund to collectively fund this project.

The area has great potential for eco-tourism, and without Hwy. 82 as a viable hurricane evacuation route, the residents would be at much greater risk. This could also affect real estate values in the area. In conclusion, this area is in critical need of stabilization, and the consequences of not doing this will be catastrophic.

REFERENCES

Byrnes, M.R. and R.A. McBride 1995. Preliminary Assessment of Beach Response to a Segmented Breakwater System: Constance Beach and Vicinity, 1990–1994. Coastal Studies Institute, Louisiana State University, Baton Rouge LA., 26 p.

Dally, W.R. and J. Pope 1986. Technical Report CERC-86-1 Detached Breakwaters for Shore Protection. U.S. Army Corps of Engineer Waterways Experiment Station, Coastal Engineering Research Center, 62 p.

Harris, M.M. and J.B. Herbich 1986. Effects of Breakwater Spacing on Sand Entrapment, Journal of Hydraulic Research, Vol. 24, No. 5, International Association of Hydraulic Research.

Louisiana Department of Natural Resources 1997. Breaux Act Summary (unpublished data).

Louisiana Department of Natural Resources, Louisiana Geological Survey, Coastal Geology Program n.d. Nearshore Sand Resource Inventory for the Chenier Ronquille, Isles Dernieres and Holly-Peveto Beach Pilot Protection Projects, Preliminary Report, Act 41. 29 pp.

USACE 1971. Survey of Holly Beach and Vicinity, Louisiana, Series Number 95. U.S. Army Corps of Engineers, New Orleans District, LA. 19 p.

USACE 1984. Shore Protection Manual, 4th Edition, Vol. 1&2. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

USACE 1992. Engineering Manual 1110-2-1617 Coastal Groins and Nearshore Breakwaters. U.S. Army Corps of Engineers, Washington, D.C.

USACE n.d. Engineering Manual 1110-2-2904 Design of Breakwaters and Jetties. U.S. Army Corps of Engineers, Washington, D.C.

USACE n.d. Engineering Manual 1110-2-1614 Design of Coastal Revetments, Seawalls and Bulkheads. U.S. Army Corps of Engineers, Washington, D.C.

USACE 1993. Technical Report CERC-93-19 Engineering Design Guidance for Detached Breakwaters as Shoreline Stabilization Structures. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

U.S. Army Corps of Engineers. See USACE.