# BEACH EROSION NEAR TIDAL INLETS
# SELECTED CASE STUDIES ALONG SOUTHWEST FLORIDA COASTLINE

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**Abstract:** This paper presents an analysis of erosion problems near tidal inlets and discusses the design and performance of erosion control structures in selected projects in Southwest Florida. The erosion control efforts included one or a combination of the following: terminal structures, T-groin headlands, breakwaters, and fill placements. The paper summarizes the regional wave climate and predominant sediment transport trends in Southwest Florida, presents the analysis of the beach erosion problems associated with selected inlets, and describes erosion control measures and their functional performance based on the available monitoring data. The paper also emphasizes the role of integrating mathematical modeling with monitoring programs for effective beach management.

## INTRODUCTION

Southwest Florida gulf coast includes numerous sandy barrier islands separated by tidal inlets. Beach erosion adjacent to tidal inlets has resulted in the construction of many erosion control projects. This paper provides a discussion of erosion problems adjacent to inlets and a review of selected erosion control projects including: Boca Grande Pass, Redfish Pass, Gordon Pass, and Caxambas Pass. Figure 1 shows the general locations of the selected inlets. The selected tidal inlets are located within a 100 km section of the southwest Florida Gulf Coast. The shoreline orientation is generally north to south. The Gulf coast is subject to relatively low wave energy; significant wave heights in deep water commonly range between 0.3 m and 1 m. Predominant wave directions are from the NW to W. The average net sediment transport is approximately 30,000 to 60,000 cubic m/year to the


**Figure 1**. Location map of selected inlets

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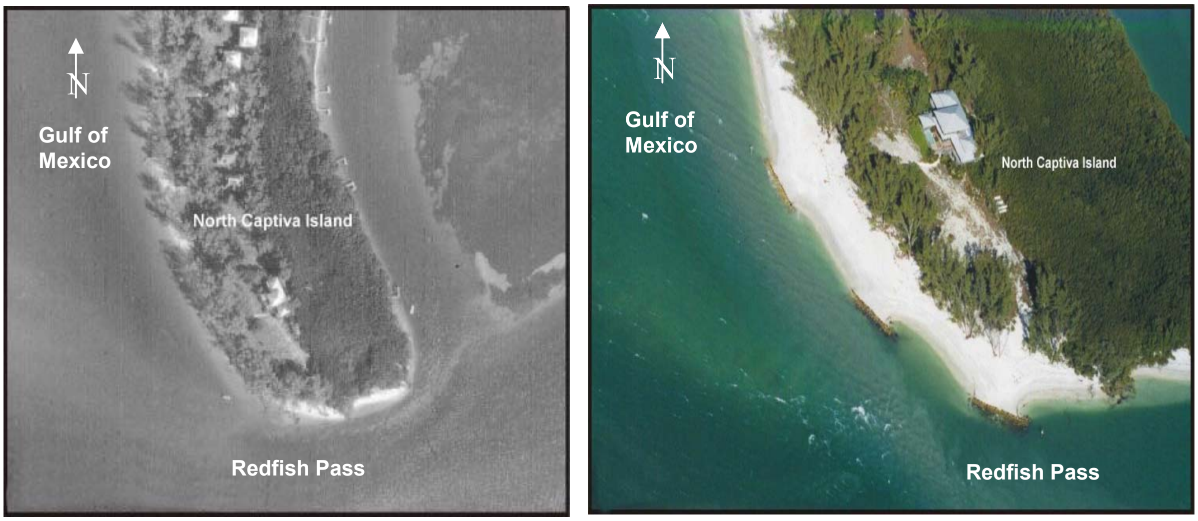
south. The beach material is composed of fine sand having an average median grain size of 0.2 mm. The tidal ranges in this region vary from approximately 0.5 m at Boca Grande Pass to approximately 1 m at Caxmabax Pass. Strong tidal currents and relatively low-energy wave climate of the Gulf of Mexico result in the formation of large offshore ebb shoals. The ebb shoal on the Gasparilla Island side of Boca Grande Pass extends over 7 kilometers offshore. Wave refraction over ebb shoals increases nearshore wave intensity and generates high sediment transport gradients along shorelines near tidal inlets. These, in addition to tidal currents, make beaches near tidal inlets subject to higher erosion stress than adjacent beach areas.

Erosion near tidal inlets results from sand deficit caused by natural inlet dynamics and anthropogenic changes. Ebb-tidal shoals influence nearshore wave conditions causing increased gradients of sediment transport along the beaches near inlets. The inlets and associated ebb- and flood-tidal shoals serve as sinks accumulating sand from the nearshore wave and current driven sediment transport. The dredging of inlets for navigation interrupts natural bypassing and contributes to the sand deficit. Therefore, beach management efforts are often necessary to sustain the coastline. Beach nourishment has been a favorite alternative in many shore-protection projects, however, it has had limited success in several inlet-related erosion areas, where erosion stress is high. A monitoring study for Perdido Key beach, Escambia County, along the Florida Gulf coast compared the performance of beach nourishments near Pensacola Pass (BROWDER and DEAN, 2000). The study analyzed 8 years of monitoring data from this large beach nourishment project. The project included placement of over 6.7 million cubic m of sand along the 7.4 km of Perdido Key adjacent to Pensacola Pass. After 8 years, the behavior of the beach fill placement varied significantly along the project length. At the center of the fill, approximately 74% of the placed volume remained within the nourished profile, whereas near the inlet boundary the profile lost 110% of the volume placed during construction. This behavior illustrates the magnitude of nourishment end losses near an unimproved tidal inlet boundary.

## EROSION CONTROL STRUCTURES

The addition of erosion control structures, such as breakwaters and T-head groins, in high erosion areas may help stabilize the beach. The design of such structures follows the concept of headland control to provide dynamic equilibrium beach shape (SILVESTRE and HO, 1972). Along the Gulf coast of southwest Florida, erosion-control structures have provided successful solutions to chronic erosion near several inlets. Monitoring data for various projects show the effectiveness of erosion control structures in stabilizing severely eroding beaches at North Captiva Island near Red Fish Pass, the south shore of Big Marco Pass, South Naples beach near Gordon Pass, and Marco Island north of Caxambas Pass (MOORE, 1999; DABEES, MOORE and KAMPHUIS 2002; DABEES and HUMISTON 2002, HUMISTON & MOORE ENG. (H&M) 2001, 2002).




Pre construction conditions (1997) Post Construction conditions (1999)

**Figure 2** North Captiva Island erosion control project

Figure 2 shows aerial photographs of pre and post construction conditions at the south end of North Captiva Island. Three t-groins were constructed to restore the beach area immediately north of Redfish pass. The project did not include any sand placement. As illustrated in Figure 2, the structures have been very effective in beach restoration and stabilization.

A similar approach was adopted on the north side of Gordon Pass where two T-groins were constructed approximately 300 m north of the inlet. The presence of an existing seawall and the sharp transition of nearshore contours created an erosion hot spot due to high sediment transport gradients, wave interaction with the seawall, and sand losses to Gordon Pass. Prior to the construction of the South Naples Erosion Control Project, which included two T-groins and two permeable wooden groins, there was no dry beach at high tide and very little if any at low tide at the T-groin locations, and erosion was undermining the existing seawall. The south Naples T-groins have succeeded in stabilizing and restoring the eroding beach and smoothing the high sediment transport gradients, without downdrift impacts. Figure 3 shows aerial photographs of pre and post construction of the south Naples T-groins. The T-groins were designed to stabilize the beach in their vicinity and allow for adequate sand bypassing to the downdrift beaches.

At the south end of Marco Island a combination of erosion control structures was constructed to stabilize the eroding beach north of Caxambas Pass. The design included a segmented offshore breakwater and two relatively short rock groins. Figure 4 shows the erosion control structures at the south end of Marco Island. Monitoring results of the project performance at south Marco Island indicate that the beach volumetric change has improved from an average loss of 27,000 cubic m/year before the project construction to an average gain of 4,400 cubic m/year after construction of the breakwater.


Pre-construction 7 months post-construction

**Figure 3.** Aerial photograph of pre and post construction of the south Naples T-groins.

## MODELING AND DESIGN OF EROSION CONTROL PROJECTS

Similar erosion control measures were adopted in the design of recent projects at Gasparilla Island and Keewaydin Island. The design is based on erosion analysis, morphology modeling, and previous experience with similar situations. The numerical modeling included wave transformation, sediment transport, and morphology modeling for various temporal and spatial scales. The wave model QREF (Kamphuis and Warner 1987) was used to provide large-scale modeling of wave transformation over the measured bathymetric surveys at various dates to relate the effects of the documented morphological changes on wave intensity and potential sediment transport. In addition, local modeling of each beach system was performed for the nearshore littoral cells. The detailed local modeling of wave transformation


**Figure 4**. South Marco Island erosion control structures

and time-dependent shoreline and beach change for each cell are used to quantify the documented changes. The contour line change model NLINE (DABEES 2000) is used to simulate the nearshore sediment transport, beach changes, and beach response to various structures. The results are used to construct sediment budget analysis, and evaluate the performance of the existing structures.

The following section describes erosion problems near tidal inlets in Southwest Florida through two different case studies. Sample results of wave and sediment transport modeling of beaches adjacent to Boca Grande Pass and Gordon Pass are discussed to illustrate such erosion problems. The Gasparilla Island erosion problem is presented to describe beach erosion on the updrift (north) side of Boca Grande Pass, and the Keewaydin Island erosion problem is presented to discuss erosion downdrift (south) of Gordon Pass. Another case study of erosion at tidal inlets at the south shore of Big Marco Pass is discussed in DABEES, MOORE, and KAMPHUIS 2002. That paper discusses the integration of monitoring programs and numerical modeling in analysis of erosion problems and design optimization.

## GASPARILLA ISLAND EROSION CONTROL PROJECT

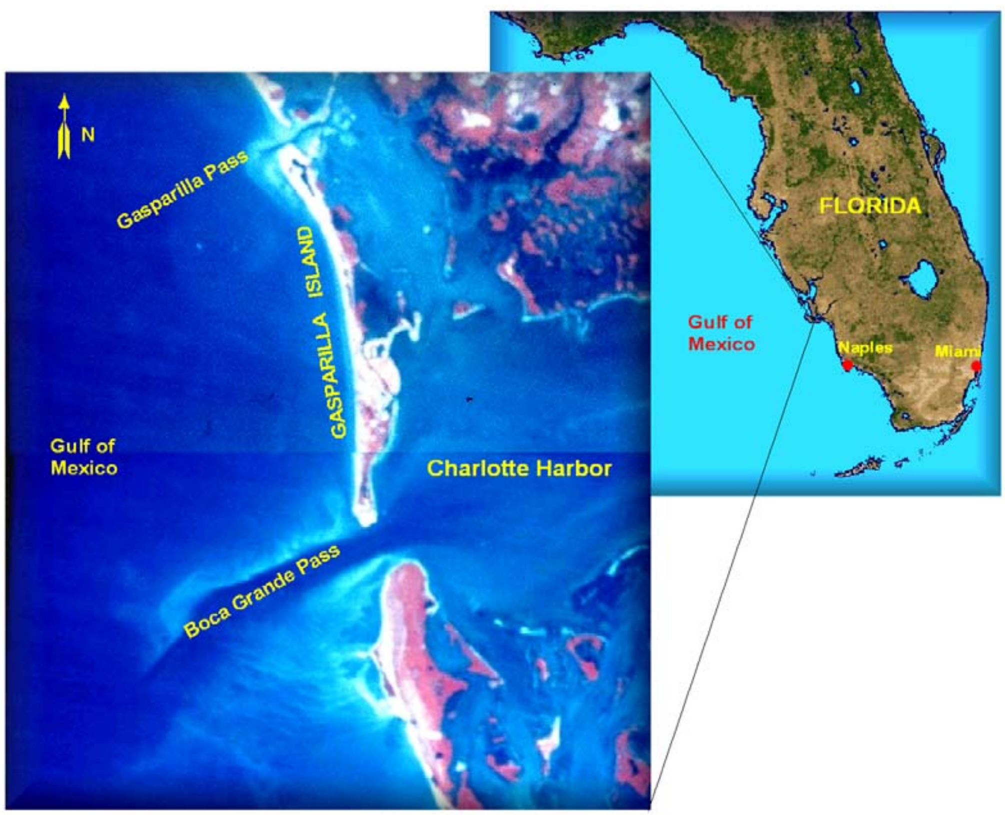



**Figure 5.** Gasparilla Island site location

Gasparilla Island is a 6.7-mile long barrier island located along the southwest coast of Florida on the Gulf of Mexico. Figure 5 is a satellite image showing the location of Gasparilla Island. Over the past twenty years, beach erosion at the south part of the island prompted several beach fill placements using the sediment dredged from the entrance channel of Boca Grande Pass. The beach fill placements have been insufficient to maintain the beach along this eroding shoreline. This study was completed as a part of the technical design to evaluate the effectiveness of various alternatives for stabilizing the south end of the island. Previous erosion control studies for Gasparilla Island documented historic shoreline changes. These studies have shown chronic erosion along the south part of the island (USACE 1991, H&M 1993, H&M 1994, USACE 1999). In the 1960's the high erosion rates near Boca Grande Pass led to the construction of an approximately 200-m long seawall, near Department of Environmental Protection (DEP)* monument R-25, to protect a paved road that was eventually abandoned as erosion progressed downdrift of the seawall. Figure 6 is an aerial view of the south end of Gasparilla Island illustrating seawall related erosion near DEP monument R-25. Following the construction of the seawall, two short terminal groins were built to stabilize the downdrift beach and reduce sand losses into the inlet. However, the existing conditions at the south part of the Island are still unstable and continued beach fill placements have been necessary.


**Figure 6. Aerial view of the south end of Gasparilla Island (July 2000)**

The shoreline change at the south end of Gasparilla Island is affected by sediment transport driven by waves and tidal currents. The large ebb shoal causes waves to refract which significantly influences magnitude and direction of sediment transport. Figure 7 shows the limits and local coordinate system of the NLINE model for South Gasparilla Island. The model works by schematizing the beach area into compartments between specific contour lines in the cross-shore direction. These contour compartments are discretized into small equal grid cells in the long-shore direction. Each contour compartment is formulated as a one-line model linked to

* The Department of Environmental Protection (formerly the Department of Natural Resources, DNR) has an established reference monument system along twenty-six (26) counties facing the Gulf of Mexico or the Atlantic Ocean. These monuments are located at approximately 300 m interval spacing along the shoreline.

adjacent compartments by cross-shore sediment transport. Wave transformation and corresponding sediment transport rates are calculated at the boundaries of each grid cell and contour line movement is evaluated by conservation of sediment within the system.

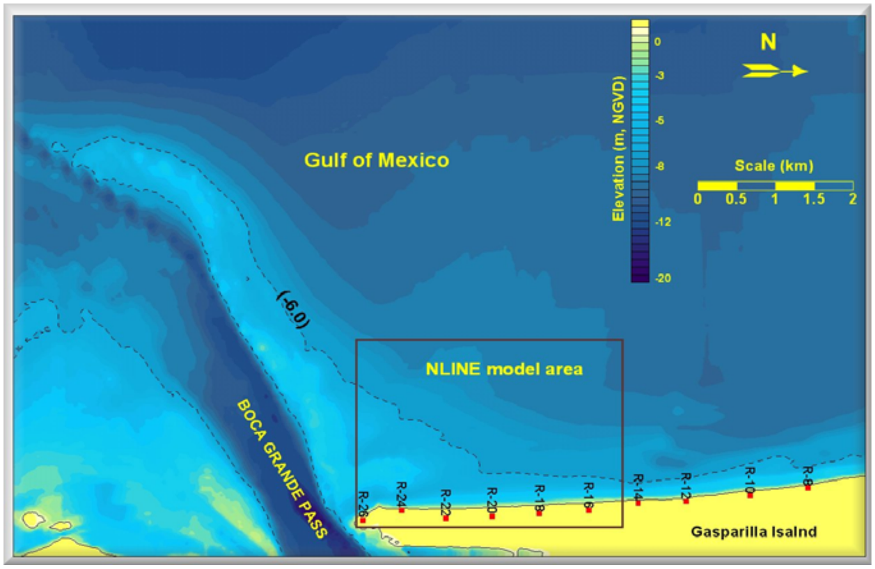



**Figure 7**. NLINE model area for south Gasparilla Island

Illustration of the calculated wave field at an intermediate time step near the south end of the island is shown in Figure 8. The typical wave event characterized in the figure is the predominant northwesterly wave condition. The calculated wave field, represented by the wave vector plot, shows the spatial variations of the nearshore wave conditions.

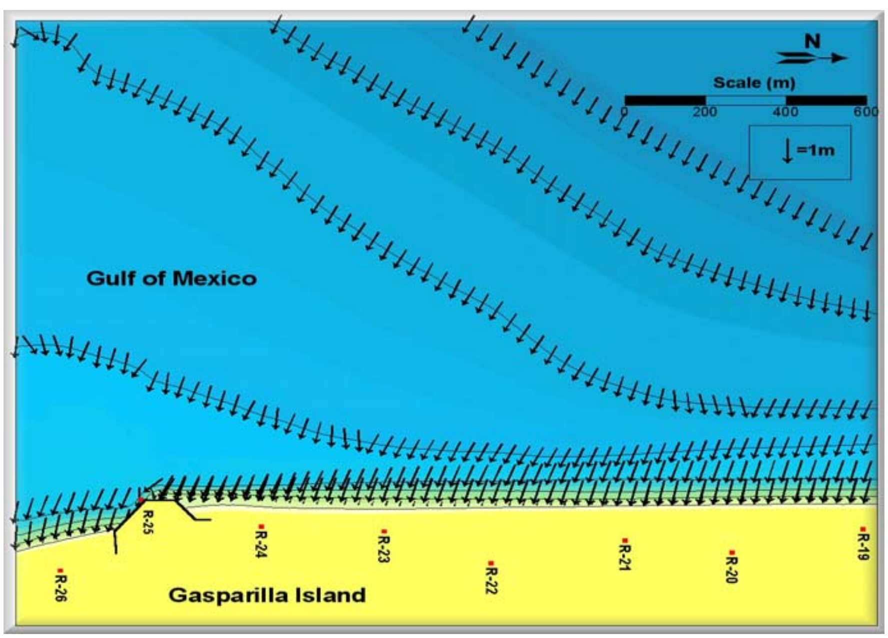



**Figure 8.** NLINE wave transformation results at the south part of Gasparilla Island

The NLINE wave calculations indicate waves at the south part of the island breaking at large oblique angles to the local shoreline. The contour alignments of the offshore shoals near the south end of the island cause a southward increase in wave angles in the nearshore area. The incoming waves from northwest undergo very limited refraction because they are almost perpendicular to the southwest-northeast orientation of the offshore contours. As a result the waves reach the nearshore, which has a north to south orientation, at large angles to the shoreline. The larger breaking wave angles toward the south end of the island generate significant southward increase of longshore sediment transport. The refraction results for different wave directions also emphasize the predominance of the southward sediment transport. The large ebb shoal refracts the incoming waves from southwest and west directions southward similarly. The resulting local breaking wave angles in all cases indicate southward sediment transport in the nearshore zone. Consequently, large quantities of sand are transported towards the deep inlet boundary where sand is transported by the strong tidal currents and deposited along the shoals. The low wave-energy climate of the gulf transports only small amounts of sand from the shoals back to the nearshore system. The southward increase in nearshore wave angles and wave intensity result in a southward increasing longshore sediment transport gradient and consequent nearshore erosion. The NLINE model results also quantify the net sediment transport at each grid cell based on the time dependent simulations of the varying wave conditions and bottom contours. Figure 9 shows the sediment transport patterns as calculated by the NLINE model at the south part of the island. The results indicate the role of the seawall at R-25 as a littoral barrier causing a significant shoreline offset between the north and south ends of the seawall.

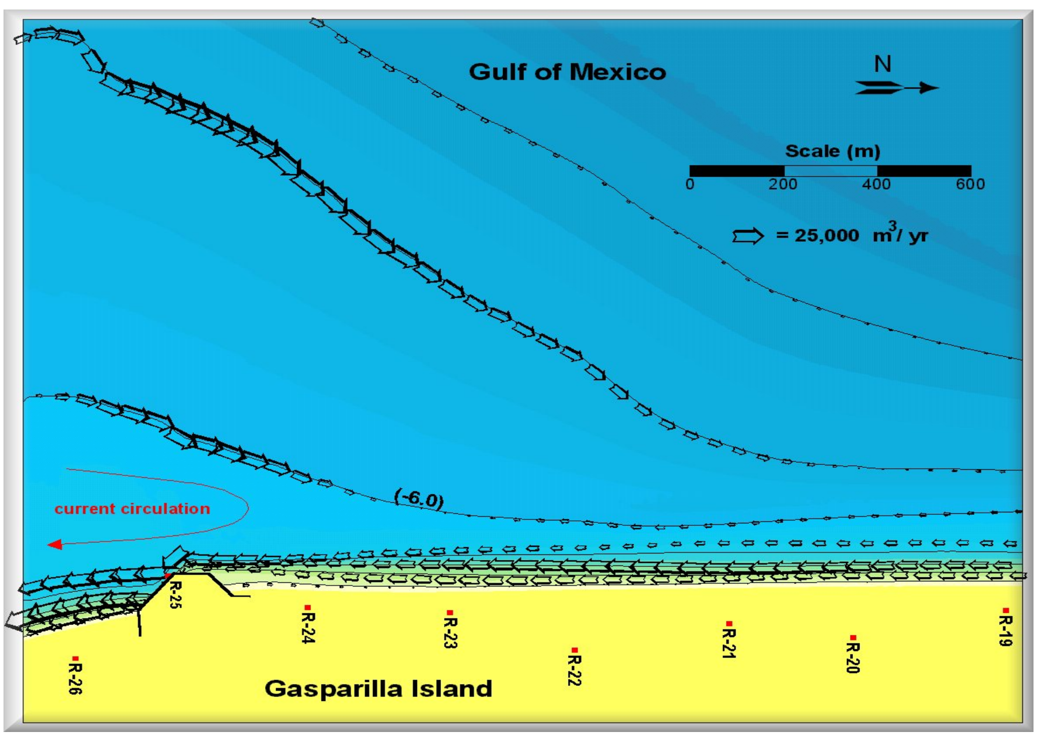



**Figure 9.** Calculated net sediment transport patterns for the south part of Gasparilla Island

The presence of the seawall interrupts the formation of a natural beach planform in equilibrium with the wave patterns in the area resulting in erosion due to increasing sediment transport gradients. Although, the model does not predict local scour due to wave reflection, the results agree with observed water depths at the seawall toe on the order of -2 meters. The results also indicate the effects of the ebb shoal on sediment transport patterns along the south part of the island. The distinct variations between the orientation of offshore and nearshore contours generate longshore transport circulation as shown in Figure 9. This variation in contour alignments causes the longshore current to move in opposite directions at the nearshore and offshore zones. At the offshore zone the large ebb shoal contour orientation results in net northward sediment transport while in the nearshore area the net transport is southward. The circulation is maintained by the strong tidal currents, which carry sand transported southward toward the inlet on flood tide and back to the ebb shoal system on ebb tide. The nearshore erosion is caused by the imbalance between the nearshore losses to the inlet and the sediment transport from the shoal to the nearshore zone. A quantitative analysis of the sediment transport exchange between the nearshore and the ebb shoal was calculated based on the NLINE model results.

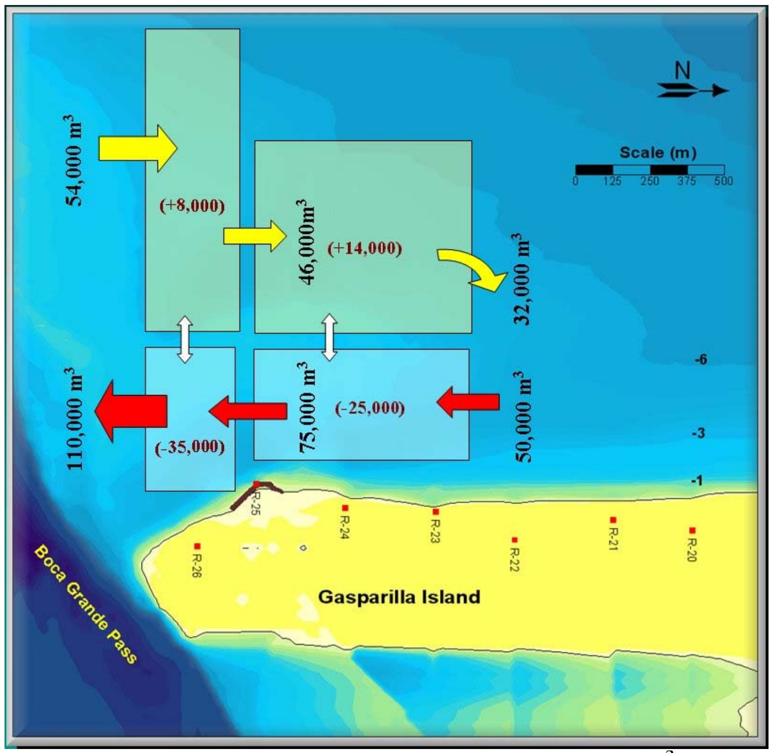



**Figure 10.** Detailed sediment budget results ($m^3$/yr)

## Detailed sediment budget

The NLINE model provides adequate details of sediment transport patterns to quantify the exchange of sediment between the nearshore, the inlet boundary, and the large ebb shoal. The longshore current circulation between the nearshore and the shoal system was discussed above (Figure 9). The two southernmost littoral cells are divided along the -3 meter contour to distinguish the opposite direction components of the sediment transport. The calculated longshore sediment transport rates are integrated along the boundaries of each of the resultant 4 cells. The results of the detailed sediment budget as shown in Figure 10 indicate the following:

- The accelerating rates of the southward sand transport in the nearshore area cause the progressive erosion problem at the south end of Gasparilla Island.
- Approximately 60,000 $m^3$/year are eroded from the nearshore along the south end of Gasparilla Island.
- Approximately 110,000 $m^3$ annually are transported into the inlet, only half of this amount is transported to the Gasparilla Island side of the ebb shoal by the tidal currents.
- The amount of sand carried back by waves to the nearshore system is approximately 32,000 $m^3$/year. The remaining 22,000 $m^3$/year are deposited on the ebb shoal.

It should be noted that as the ebb shoal retains more sand, the amount of sand available for transport to the nearshore would increase and visa versa.

**Project design**

The Gasparilla model was calibrated and verified with various data sets. The calibration and verification results are discussed in (DABEES and KAMPHUIS 2000). The final stage of Gasparilla Island design modeling was to establish an effective erosion control project design. The calibrated and verified NLINE model was used as a predictive tool to analyze various alternatives. Various configurations of erosion control structures were modeled to optimize the design. The final design, shown in Figure 11, represented a 170 m long segmented breakwater located 100 m offshore of the seawall at R-25 and two T-groins at the downdrift of the seawall. The offshore breakwater will diffract incoming waves to generate a nearshore wave field near equilibrium with the beach planform at the south part of the island. Based on hydrodynamic modeling the offshore breakwater was segmented to minimize tidal flow convergence and current acceleration in the lee of the structures. The T-groins were added to minimize potential for downdrift erosion and create a natural beach in equilibrium with the oblique wave angle at the southern most part of the island. Details of the design optimization modeling for Gasparilla Island using NLINE are discussed in (DABEES and HUMISTON 2002).

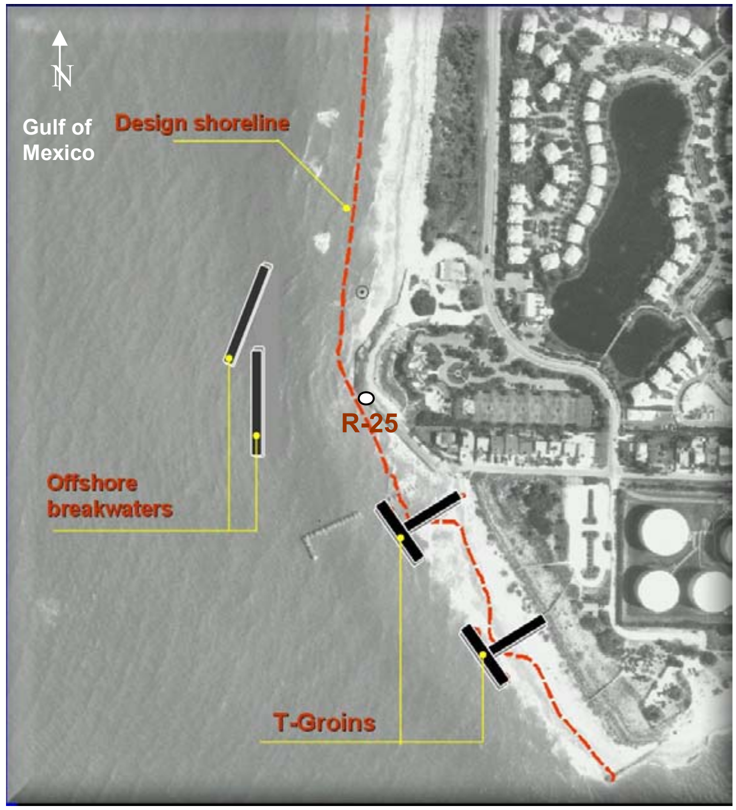



**Figure 11.** Final design for erosion control at south Gasparilla Island

**KEEWAYDIN ISLAND EROSION CONTROL PROJECT**

Keewaydin Island is located south of Gordon Pass which is a federally maintained navigation channel. The project area is located immediately downdrift of the inlet between an existing 42-year old jetty and a rock groin located approximately 300 m south of the jetty. This area has been experiencing significant erosion, particularly over the past few years. Figure 12 shows Gordon Pass and north Keewaydin Island in 1962 and 2000. The aerial photographs indicate the extent of the beach erosion on the downdrift side of Gordon Pass.

1962 2000

**Figure 12.** Aerial photographs of Gordon Pass and north Keewaydin Island

Wave refraction and sediment transport modeling for the existing conditions indicated the effects of the ebb shoal on nearshore wave conditions within the project area. Wave refraction over the ebb shoal increases nearshore wave intensity and sediment transport potential in both northward and southward directions. Figure 13 shows the calculated transport potential in both north and south directions and the net transport along the project shoreline. The sediment transport results indicate the following within approximately 600 m south of the inlet

- Higher sediment transport gradients along the project shoreline than adjacent beach areas due to wave refraction over the ebb shoal. This results in higher erosion rates.
- The large difference between the gross transport rate and the net transport rate indicates alternating sediment transport between southward and northward directions with slightly higher rates northward.
- The tidal inlet presence at the north boundary of the project site represents discontinuity of the sediment transport flow in both directions. Lack of sand supply on southward flow and loss of sand into the inlet on northward flow.
- The project area, which is confined between an inlet jetty to the north and a rock groin located approximately 300m to the south, is subjected to high erosion rates and lack of sand supply at both boundaries
- The presence of Gordon Pass creates a change in shoreline orientation in the immediate vicinity to the inlet. The general shoreline orientation of Keewaydin Island is NNW to SSE. The project area has approximately a $10^{o}$ difference in shoreline orientation toward north from the general shoreline trend. The existing rock groin creates a sharp transition between the two orientations. This change in nearshore orientation creates an unstable null sediment transport point. An unstable null point has a net transport of zero where net transport gradients diverge in opposite directions. The focus of wave energy reversal south of the inlet and lack of sand supply from

south of the existing groin results in a higher sediment transport gradient north of the null point, creating an erosion hot spot.

- Tidal currents at the inlet were not considered in the sediment transport modeling. However, those currents are strongest along the shoreline on flood tide, contributing to northward transport through the porous jetty into the inlet.

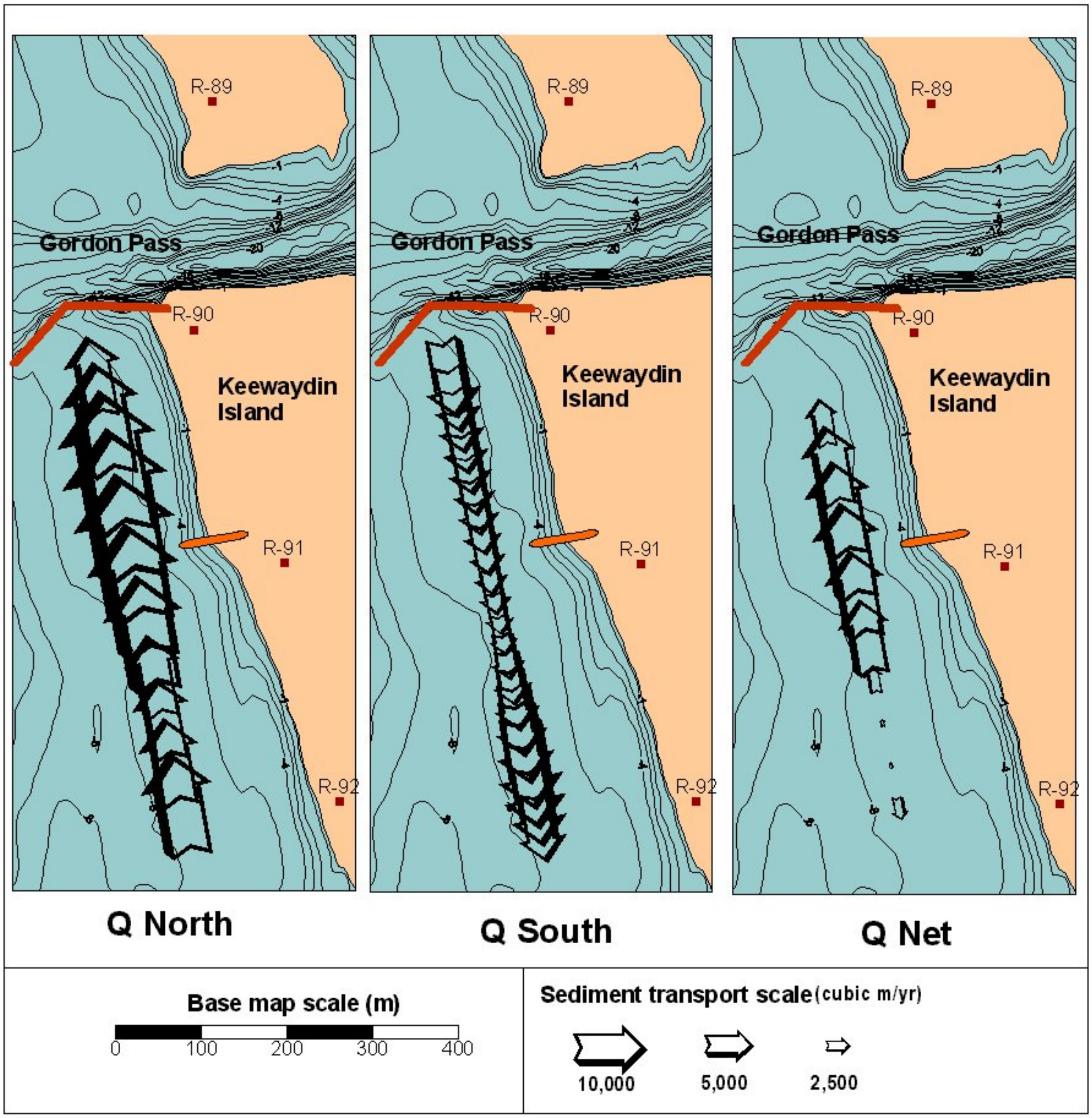



**Figure 13.** Calculated sediment transport potentials south of Gordon Pass

**Project design**

The proposed design includes two elements to address the progressive erosion along the project site. The first is tightening of the jetty on the side of the inlet to reduce sand loss into the inlet. The second is construction of a T-groin field between the jetty and existing rock groin. The T-groins are designed as shallow water erosion control structures that;

- reduce nearshore wave energy and offshore sand losses,
- reduce high sediment transport gradients and create a dynamic equilibrium between nearshore contours and prevailing wave conditions,
- and allow for sand to bypass the structures and create a smooth transition between the beach contours within the T-groin field and the adjacent beach.

Figure 14 shows the calculated sediment budget for the existing conditions and the proposed design. The sediment budgets were prepared based on numerical modeling of sediment transport and t-groin functioning. The modeling was calibrated with monitoring data of Keewaydin Island and T-groin performance north of the Gordon Pass on Naples Beach.

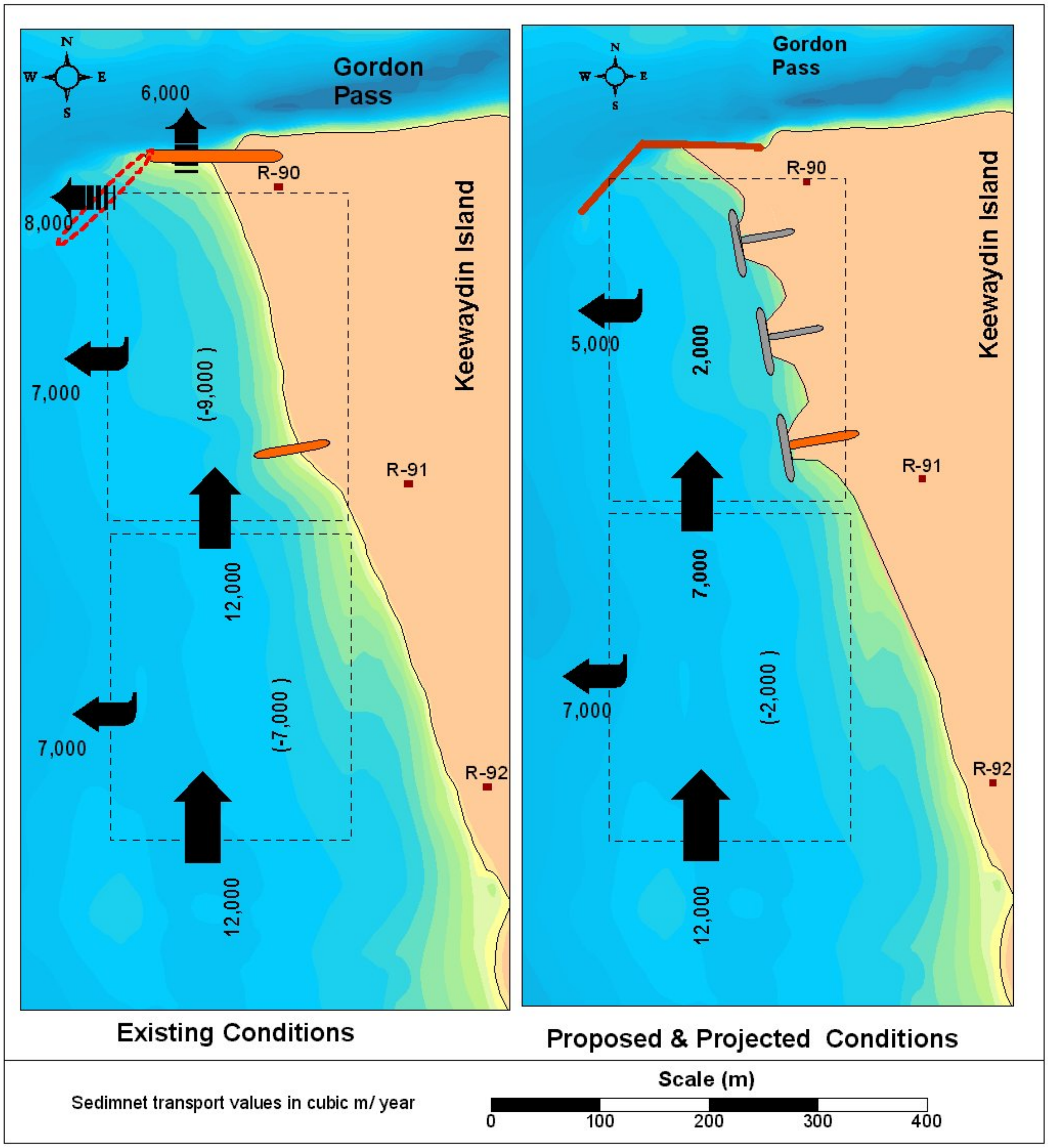



**Figure 14.** Calculated sediment budgets for existing conditions and proposed design south of Gordon Pass

## CONCLUSION

Beach erosion near tidal inlets results from sand deficit caused by natural inlet dynamics and anthropogenic changes. Understanding the natural and anthropogenic influences on the littoral system is essential for effective beach management. Beach areas near tidal inlets are influenced by a combination of coastal and tidal processes. The stochastic nature and complexity of these processes provide a unique environment for each erosion problem. Mathematical modeling and analysis of sediment system dynamics provides quantitative assessment of the factors that influence coastal changes and helps predict coastal response to erosion control projects.

This paper presents analysis of the beach erosion problems associated with selected inlets in Southwest Florida. The paper describes the erosion control measures and their functional performance based on the available monitoring data. The case studies emphasize the role of erosion control structures in stabilizing chronic erosion areas near inlets. The erosion control structures should be carefully and site-specifically designed to reshape the beach planform near equilibrium with nearshore wave conditions, and allow a certain degree of bypassing to the adjacent beaches to avoid downdrift impacts.

## REFERENCES


BROWDER, A. and DEAN, R., 2000. Monitoring and Comparison to Predictive Models of the Perdido Key Beach Nourishment Project, Florida, USA. Journal of Coastal Engineering, Vol. 39, 173-191.

DABEES M.A. and HUMISTON K. K. (2002), Modeling and Design of new T-groins along the Southwest Coast of Florida. Journal of Coastal Research, Special Issue: Functioning of Coastal Groins. In print

DABEES M.A., MOORE B. and KAMPHUIS J.W. (2002), “Combining Numerical Modeling and Monitoring Data for Analyzing Coastal Processes in Southwest Florida”, Proc., 28th International Conference on Coastal Engineering, Cardiff, UK., ASCE, In print

DABEES, M.A., 2000. Efficient Modeling of Beach Evolution. Kingston, Ontario: Queen’s University, Ph.D. thesis, 183p.

DABEES, M.A. and KAMPHUIS J.W., 2000. NLINE: Efficient Modeling of 3-D Beach Change. Proc. of the 27th International Conference on Coastal Engineering (Sydney, Australia, ASCE), pp. 2700-2713.

HUMISTON & MOORE ENGINEERS STAFF, 2002. Marco Island Segmented Breakwater-Monitoring Report No. 4, Naples FL: Humiston & Moore Engineers.

HUMISTON & MOORE ENGINEERS, 2001. 1st Interim Monitoring Report: South Naples Erosion Control Project. Naples, FL: Humiston & Moore Engineers.

HUMISTON & MOORE ENGINEERS. 2000. Lee County, Florida, Shore Protection Project, Gasparilla Island Segment, Coastal Processes Modeling and Analysis. Naples, FL: Humiston & Moore Engineers, 51p.

HUMISTON & MOORE ENGINEERS f. 1994. Gasparilla Island Erosion Control Study. Naples, FL: Humiston & Moore Engineers.

HUMISTON & MOORE ENGINEERS. 1993. Feasibility Study for an Erosion Control Project on Gasparilla Island. Naples, FL: Humiston & Moore Engineers.

KAMPHUIS, J.W. and WARNER P., 1987, A Comparison of Wave Refraction and Wave Breaking in Numerical and Hydraulic Models of Initially Conical Sand Islands, Proc. Canadian Coastal Conf., pp257-275.

MOORE, B.D., 1999. T-Groin Design and Performance as an erosion Control Alternative at Two Florida Coast Inlets. Proc. of the National Conference on Beach Preservation Technology (Florida Shore & Beach Preservation Association. Tallahassee, FL). pp. 187-203.

SILVESTER, R., and HO, S. 1972. Use of Crenulate Shaped Bays to Stabilize Coasts. Proceedings 13th Inter. Conf. Coastal Eng. , ASCE, pp1347-1365.

USACE. 1991. Charlotte Harbor Section 93311 Study with Environmental Assessment, US army Corps of Engineers. Jacksonville District.

USACE. 1999. General Reevaluation Report, Shore Protection Project, Lee County, Florida, US army Corps of Engineers. Jacksonville District.

WARNER P., (1987), "Queen's University Wave Refraction Model User Manual". Queen's University, Kingston, Ontario, Canada. 18p.

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**Keywords**

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