CHAPTER 256

INTERACTION OF THE COLORADO RIVER PROJECT, TEXAS, WITH LONGSHORE SEDIMENT TRANSPORT

Daniel J. Heilman[1], M. ASCE and Billy L. Edge[2], M. ASCE

ABSTRACT

In 1985, a weir jetty system was constructed at the mouth of the Colorado River, Texas, and river discharge was diverted from this mouth in 1992. An evaluation of project impacts on longshore sediment transport was performed to determine the effectiveness of the project at preserving an open, navigable channel while preventing excessive erosion along adjacent beaches. This evaluation included both physical and numerical analysis of pre- and post-project conditions at the Colorado River mouth. Analysis of site data revealed that under the dredging and mechanical bypassing schedule followed during the first 8 years after jetty construction, the project resulted in significant trapping and sorting of sediment transported alongshore. Numerical modeling of the design maintenance dredging plan confirmed the plan to be sufficient for achieving project objectives. However, the entrance channel has continued to shoal considerably more rapidly than was anticipated during the project design.

INTRODUCTION

General Setting

The Colorado River discharges into the Gulf of Mexico through Matagorda Peninsula on the Texas Gulf Coast about midway between Galveston and Corpus Christi (Fig. 1). With a generally linear WSW-ENE orientation, the Matagorda Peninsula outer shoreline is dominated primarily by Gulf waves from the northeast (Fig. 2), and it is subjected to a resulting longshore current that transports sediment in a southwestward direction (McGowen and Brewton 1975). The peninsula ranges in width from about 1.2 to 1.6 km with an average elevation of approximately 2 m and faces the Gulf with a moderately wide sandy beach. The tide is diurnal with a range on the order of 0.6 m (U.S. Army Corps of Engineers (USACE) 1977). As reported by Morton *et al.* (1976), the beach varies in composition and texture from fine sand to shell and rock-fragment gravel.

---

1) Research Scientist, Conrad Blucher Instit. for Surveying and Science, Texas A&M Univ.-Corpus Christi, 6300 Ocean Drive, Corpus Christi, TX 78412. Formerly M.S. student, Ocean Eng. Program, Dept. of Civil Eng., Texas A&M Univ., College Station, TX 77843.

2) Head, Ocean Eng. Program, Dept. of Civil Eng., Texas A&M Univ., College Station, TX 77843.

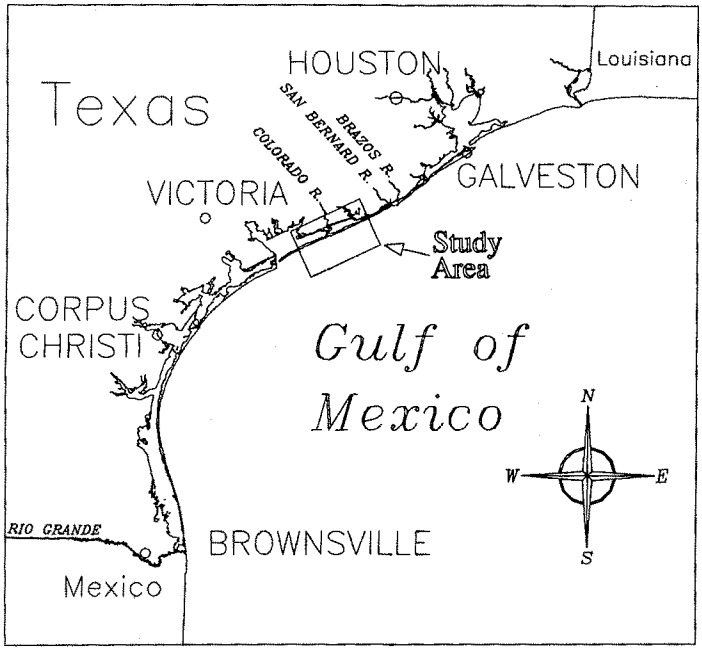

Figure 1. Site location map.

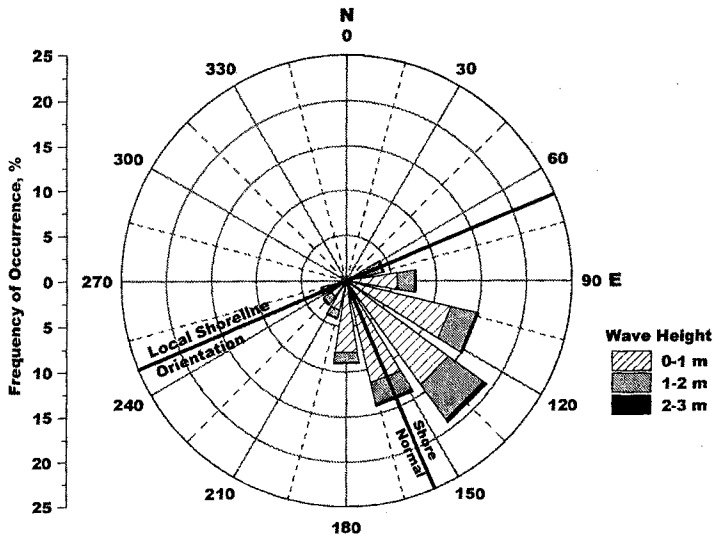

Figure 2. Wave rose for study site (data collected by USACE, CERC, May, 1990 - August, 1992).

The Colorado River Mouth

Originally discharging into a large estuary shared with the nearby Brazos River, the Colorado River began discharging into Matagorda Bay near the mainland shore at Matagorda, Texas, around 1,000 years ago (McGowen and Brewton 1975). Sediment transported by the river to the bay was restricted in the mid and late 1800s by a jam consisting of tangled masses of logs and brush embedded in silt, which was characteristic of the Lower Colorado River (Morton *et al.* 1976). By 1926, the log mass backed up in the river 74 km above Matagorda and created a lake, further restricting river sediment discharge by impounding course sediment. As shown in Fig. 3, which is a digitized rendering of a survey map prepared in January, 1839, the lake and log mass effectively prevented the river from creating a delta in the bay. In the late 1920s, a channel was dredged through the log mass, resulting in the release of trapped sediment and the rapid growth of the Colorado River delta into Matagorda Bay (Fig. 4) (Bouma and Bryant 1969). By 1935, the delta extended across Matagorda Bay to Matagorda Peninsula. In search of a direct path connecting the river to the Gulf, the Matagorda County and Reclamation District dredged a straight channel from one of the river outlets in the delta, across the bay, and through Matagorda Peninsula to the Gulf of Mexico (Morton *et al.* 1976, Ralston 1987).

The Colorado River Project

The Gulf entrance of the Colorado River has historically been subject to heavy shoaling, primarily due to longshore transport, and was often restricted enough to prevent the passage of small boats or flood flows. The major portion of the bed load material transported by the river was deposited above the GIWW in a silting basin (USACE 1977). The inlet was occasionally re-opened by high river discharges and by periodic maintenance dredging (Ralston 1987).

The shoaling which occurred at the Gulf entrance of the river continued to interrupt the capability of the river to serve as a dependable small-craft channel. In 1968, federal authorization was given for the USACE Mouth of the Colorado River Project in response to a need for a dependable, navigable channel connecting the Gulf Intracoastal Waterway (GIWW) to the Gulf of Mexico near the town of Matagorda, Texas. The project included a jettied entrance at the Gulf of Mexico, a navigation channel along the existing Colorado River through the delta, a harbor and turning basin, recreational facilities, and full, uncontrolled diversion of the Colorado River into Matagorda Bay (Fig. 5) (USACE 1977). The primary benefit from the project was dependable navigation between the Gulf and the GIWW.

The jetty system for the project was completed in 1985 and included a weir jetty on the northeast side of the inlet and an impoundment basin adjacent to the weir to accumulate southwesterly moving longshore sediment. The river diversion was completed in 1992, and construction of a 4.6-m deep and 61-m wide entrance channel and a 3.7-m deep and 30.5-m wide navigation channel extending to the GIWW

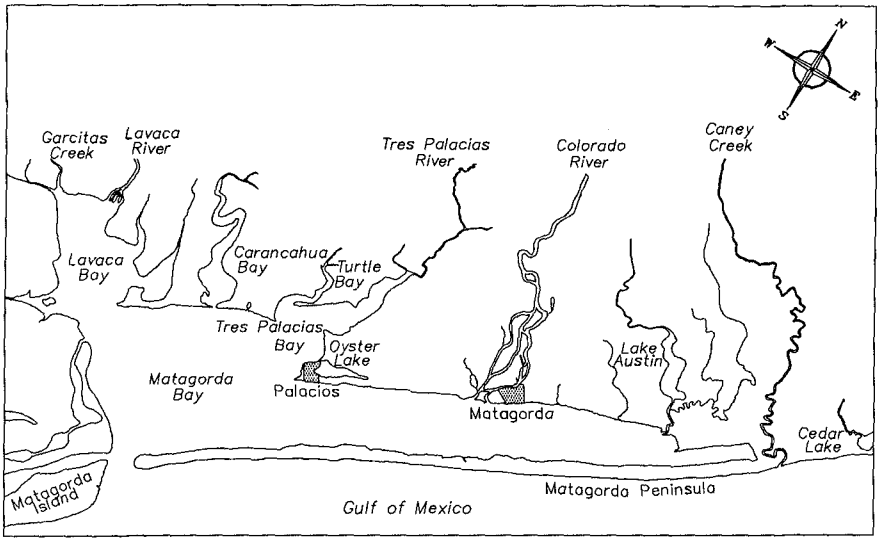

Figure 3. Survey map of Matagorda Bay, dated January 16, 1839 (original map archived by the Texas General Land Office).

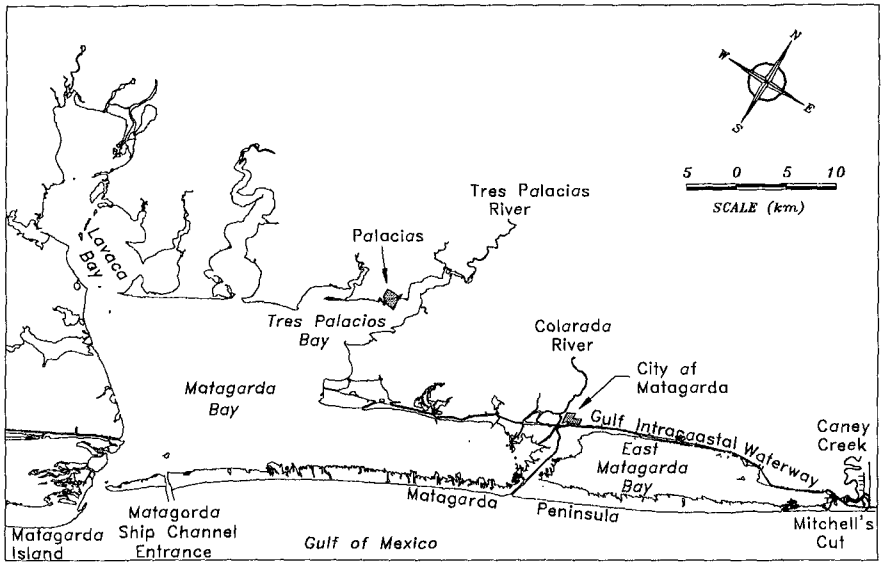

Figure 4. Map showing Colorado River delta which extended across Matagorda Bay to Matagorda Peninsula by 1935.

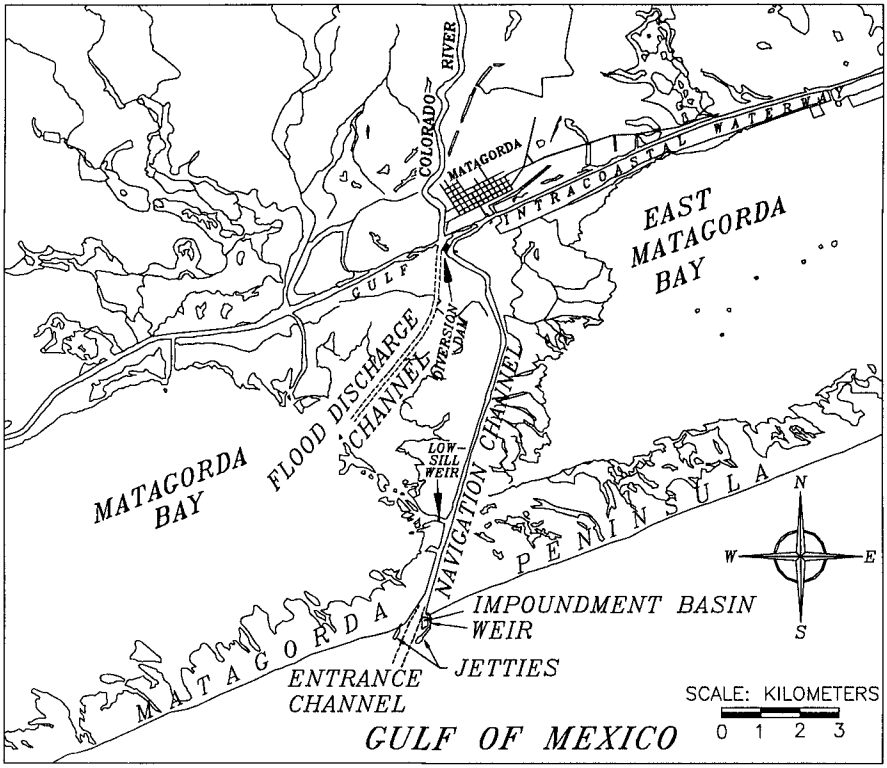

Figure 5. Features of the USACE Colorado River Project.

near Matagorda was completed by 1990 (USACE 1977). The jetties and entrance channel were aligned along the pre-existing flood discharge channel into the Gulf, with the seaward ends of the jetties spaced about 400-m apart. The weir section in the northeast jetty extended 305-m seaward from the shoreline at a crown elevation of 0 mean low tide (MLT). Past the weir section the jetty extended to the 3.7-m depth contour and was aligned to serve as a breakwater for the impoundment basin and entrance channel. The southwest jetty extended seaward to the 1.5-m depth contour.

The impoundment basin was initially designed to hold approximately 460,000 m^3 of littoral sediment (USACE 1977). Based on estimated rates of longshore sediment transport, it was assumed the basin would require dredging on average once every two years. Material dredged from the basin was to be mechanically bypassed by pipeline and discharged in the surf zone approximately 610 m downdrift of the southwest jetty (Fig. 6).

STUDY OBJECTIVES

Because the entrance to the navigation channel and the impoundment basin have accumulated sediment more rapidly than was anticipated, assumptions made about the

Figure 6. Colorado River mouth, December 12, 1992.

sediment transport rate at the mouth of the Colorado River have been in question since completion of the jetties (Rozsypal 1994). The frequent maintenance that has been required to retain an open, navigable channel has suggested the need for modification of the jetties or bypassing system. However, improvements cannot be made without accurate understanding of the interaction between the project and sediment transport processes.

To evaluate the influence of the project on longshore sediment transport, a coastal processes analysis was conducted using historical and recent data, and numerical analysis was conducted using the GENESIS shoreline change model (Hanson and Kraus 1989). The updrift and downdrift limits of inlet impact on shoreline migration were estimated, a summary of predicted longshore sediment transport rates was developed, and pre- and post-project beach profiles were used along with dredging records to quantify sediment trapping. Present and future project impacts on shoreline stability and longshore sediment transport were estimated through the use of GENESIS. Future project effectiveness was tested based on the anticipated pre-project maintenance dredging plan.

PROCEDURE

Historic Inlet Impact on Adjacent Shorelines

An evaluation of historical volumetric shoreline changes along Matagorda Peninsula was conducted using shoreline position data obtained from the University of Texas, Bureau of Economic Geology (Morton *et al.* 1976, Paine and Morton 1989). The data were compiled from topographic charts and aerial photographs and cover the period from 1855 to 1982. Based on these data, Morton *et al.* (1976) and Paine and Morton (1989) concluded that the Matagorda Peninsula Gulf shoreline is historically erosional.

Beach volume change trends were estimated by application of the equilibrium beach profile concept as presented by Moore (1982) and Dean (1991). The beach volume change trends were evaluated to a distance of 33.6 km downdrift and 11.5 km updrift. Using methods developed by Bodge (1995), whereby shoreline change data representing pre- and post-introduction of a potential sediment sink are compared, the differences between the average of the pre- and post-inlet beach volume change rates were considered to identify the net effects of the inlet (which was cut in 1935) on the adjacent beaches. In the method, all beach volume change updrift and downdrift of the inlet is attributed to the interruption of the longshore sediment transport by the inlet (i.e., the effects of hurricanes, cross-shore transport, wind-blown sand transport, etc., are neglected). Based on this assumption, the maxima in a curve plotting the difference between the averages of the pre- and post inlet volume change rates, calculated cumulatively as a function of distance from the inlet, represents the alongshore terminus of the beach segment within which the inlet influences beach volume change. As plotted in Figs. 7 and 8, the un-jettied Colorado River mouth (as existed from 1935 to 1982) may have impacted shoreline stability as far downdrift as 18.4 km and as far updrift as 5.4 km along the Gulf-facing shoreline of Matagorda Peninsula.

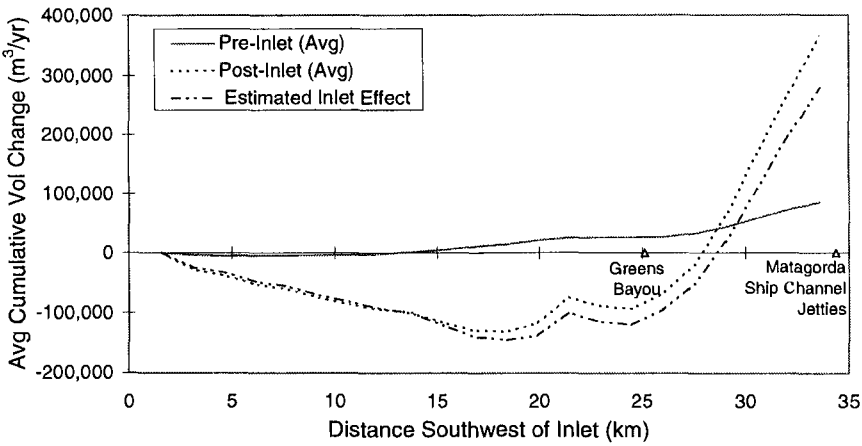

Figure 7. Cumulative annualized volume changes downdrift of the un-jettied Colorado River mouth. The pre-inlet average is based on 1855 to 1937 shoreline position data, and the post-inlet average is based on 1937 to 1982 shoreline position data.

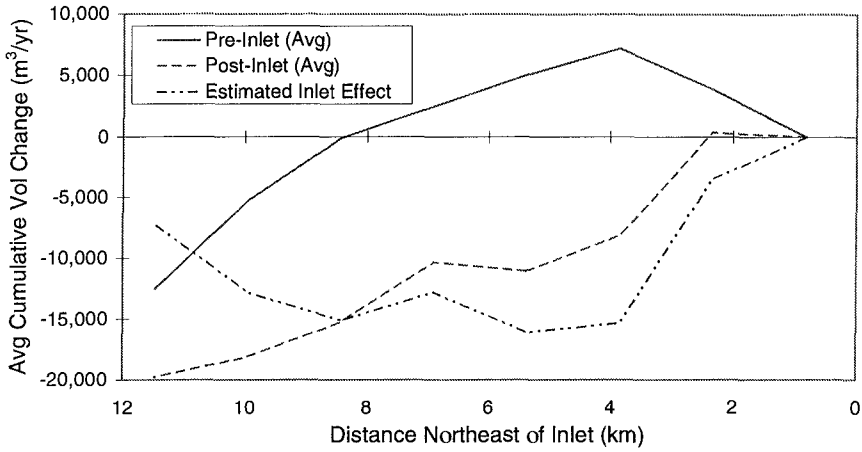

Figure 8. Cumulative annualized volume changes updrift of the un-jetticd Colorado River mouth. The pre-inlet average is based on 1855 to 1937 shoreline position data, and the post-inlet average is based on 1937 to 1982 shoreline position data.

Sediment Transport

As outlined by USACE (1984), four methods of estimating longshore sediment transport exist, including (in order of decreasing preference) calculations based on: (1) A known rate at a nearby site; (2) Measured historical changes in bathymetry or topography; (3) Wave height and direction data; (4) Only wave height data. These prediction methods can be combined to compare estimated rates or to supplement a lack of data that precludes the complete application of any one method. The traditional methods outlined by the USACE were applied to the study area, and the results are summarized in Table 1.

Calculated net longshore transport rates for the Texas Gulf Coast which are in excess of 200,000 m^3/yr appear to the authors to represent over-estimates, particularly if comparison is made to other calculations of net transport documented for harsher wave climates. For example, Bodge (1995) determined the net average longshore transport rate to be about 184,000 m^3/yr for a beach on the north Florida coast facing the Atlantic Ocean; the transport rate along Texas beaches should be less because the average wave climate is less severe. Heilman and Kraus (1995) calculated the net average transport rate along South Padre Island, Texas, to be 115,000 m^3/yr based on a sediment budget, and Kraus *et al.* (1996) calculated the net rate along Mustang and north Padre Islands to be 34,000 m^3/yr and the gross rate to be 150,000 m^3/yr based on 8 years of wave hindcast data. Also, as noted by Mason (1971), Mason and Sorensen (1971), and Kraus and Militello (1996), small cuts have historically existed near the eastern end of East Matagorda Bay. These cuts, which are not subjected to strong tidal flows, would be expected to rapidly close under a strong longshore transport rate.

Table 1. Summary of longshore transport rate estimations for Matagorda Peninsula. Net rates are to the southwest.

Method	Rate (m^3/yr)
1. Estimate based on hindcast wave data, spit growth, and beach erosion at Brown Cedar Cut, Matagorda Peninsula (Mason and Sorensen 1971).	38,000 *net* 460,000 *gross*
2. Estimation derived from sediment budget developed for nearby Sargent Beach (Seelig and Sorensen 1973).	31,000 *net*
3. Average rate based on 47 years of historical shoreline position data (Heilman 1995).	152,000 *net*
4. Estimation derived from evaluation of sediment impoundment at nearby Matagorda Ship Channel jetties (USACE 1977).	150,000 *net*
5. Estimation based on inspection of historic data at the project site, including survey data, aerial photography, and dredging records (USACE 1977).	170,000 *net*
6. Design rate used for the project based on combination of methods 2 and 3 above (USACE 1977).	230,000 *net*
7. Post-project rate based on inspection of beach profile survey data and dredging records (revised after Heilman 1995) (data obtained from USACE).	250,000 *net* 420,000 *gross*
8. Potential rate calculated from a 22-month time series of directional wave data using $K = 0.77$ (Heilman 1995) (data obtained from USACE, CERC).	310,000 *net* 580,000 *gross*

Over-prediction of sediment transport rates based on bathymetric changes at the study site may be due to use of the assumption that sediments are predominantly introduced to the system from alongshore. A significant volume of sand may be transported onshore as the historic Colorado River ebb delta (if it exists) is croded by waves (Kraus 1995). The cause of the suspected over-prediction of the longshore transport rate based on collected directional wave data is unknown, but may have occurred if the sampling period (May, 1990 to August, 1992) was not representative of the typical, long-term wave climate. A comparison between wave and wind data for the study site indicated that the measured wave directions were accurate, with the predominant direction being from the southeast and sediment transport reversals occurring only 20% of the year. The average mean wave height at a depth of 5.2 m was 0.77 m, the average wave period was 5.3 sec, and the average incident wave angle was 84 deg measured clockwise from the local shoreline orientation.

Inspection of aerial photographs and observations made at the site indicate that wind-blown sand also plays a significant role in channel infilling, as sand along the beach is transported across and around the jetties to constrict the channel opening.

This process has been noted to play an important role at other jettied Texas inlets (Kieslich 1977, Kraus and Heilman 1996).

Sediment Sorting and Trapping

Sediment grain-size data collected in August, 1994, and October, 1995, by the USACE, Galveston District, were examined to determine that finer sand (0.02 to 0.04 mm) collects in the impoundment basin than in the portion of the entrance channel adjacent to the basin (0.14 to 0.18 mm). The existence of finer sand in the impoundment basin is probably a result of: 1) the sorting of suspended-load sediments from bed-load sediments by the weir; 2) the lack of sediment sorting by currents in the deep (low-energy) basin; and 3) the transport of fluvial silts and clays to the inlet from the navigation channel during ebb flows (these fine sediments may be trapped in the basin). Analysis of survey data collected by the USACE revealed that the channel and impoundment basin fill from the weir side in a southwestward direction and that the heaviest shoaling occurs close to the shoreline.

As shown in Table 2, a comparison was made between pre- and post-project beach volume change rates near the jetties. The change from pre-project beach erosion to post-project beach accretion was considered to represent a reduction in the net longshore transport of sand past the inlet. The comparison indicated an average increase in the beach volume change rate of about 53,700 m^3/yr (the difference between -9,700 m^3/yr and +44,000 m^3/yr) between 1984 and 1992 along 3.9 km of shoreline updrift and downdrift of the channel. Based on a longshore transport rate of approximately 230,000 m^3/yr, this impoundment of sand at the inlet is equivalent to a 23% reduction in the transport of sand to beaches downdrift of the inlet.

Table 2. Comparison of pre- and post-project beach volume change rates.

	Rate of Beach Volume Change (m^3/yr)		
Period (Years)	**Updrift Beach (from 0.8 to 3.6 km from inlet)**	**Downdrift Beach (from 1.6 to 2.7 km from inlet)**	**Total (along 3.9 km of shoreline)**
1857-1935 (Pre-Inlet)	6,700	-2,800	3,900
1935-1956	13,800	22,000	35,800
1956-1965	-58,000	60,400	2,400
1965-1974	-15,400	-109,000	-124,400
1974-1982	8,100	-13,000	-4,900
1935-1982 (Average)	-7,100	-2,600	**-9,700**
1984-1992	31,000	13,000	**44,000**

Numerical Simulation of Shoreline Change

As a means of supplementing knowledge gained through evaluation of field data collected at the project site, numerical modeling was conducted to simulate shoreline change based on theory and approximation. The GENESIS model, developed by the USACE, Coastal Engineering Research Center (CERC) (Hanson and Kraus 1989) was applied to the study site to test the effectiveness of the design maintenance dredging schedule at preventing channel shoaling. Shoreline reaches updrift and downdrift of the jettied inlet were modeled separately. Details of the model setup, input, and calibration are presented in Heilman (1995).

Model results indicated that the design maintenance dredging volume of 460,000 m^3 consistently bypassed every other year is sufficient for preserving the transport of sand past the inlet and for minimizing channel shoaling. However, the model results also suggested that accelerated shoreline erosion will occur updrift of the weir due to the unidirectional transport of sediment over the weir. Based on inspection of aerial photography and visits to the site, this shoreline recession has not distinctly occurred updrift of the weir, although a series of beach profile surveys conducted by the USACE, CERC indicate beach erosion occurred within about 500 m updrift of the weir between 1984 and 1992 (Liang 1995). Model results also revealed a tendency for sediments to be temporarily stockpiled in the dredged material discharge zone (approximately 600 m downdrift) due to wave sheltering by the jetties. The sediment stockpiling process may increase rates of channel shoaling as the effective length of the downdrift jetty is reduced and northeastward-flowing sand enters the channel.

CONCLUSIONS

The Colorado River Project was a response to the need for a dependable, navigable channel connecting the GIWW to the Gulf of Mexico. Jetties were constructed in 1985 including provisions for the mechanical bypassing of littoral sediments past the entrance from an impoundment basin filled by functioning of an innovative weir. Through utilization of the bypassing system, whereby sediments are regularly dredged from the impoundment basin and discharged into the surf along the downdrift beach, the potential for accelerated beach erosion has been reduced. However, the efficiency of the system has been decreased by the unexpectedly-high infilling of the impoundment basin and resulting excessive channel shoaling, and by the sorting of littoral sediments.

Possible causes for the rapid shoaling which occurs at the Colorado River mouth include:

1. A higher than anticipated net longshore transport rate.
2. The breakup of an assumed historic Colorado River shoal.
3. The reduction in effective length of the downdrift jetty (which originally extended only to the 1.5-m depth contour) by the growth of a shoreline fillet; this process results in a nearly unimpeded transport of sediment around the jetty during longshore transport reversals.

4. The diversion of river discharge to Matagorda Bay and associated reduction in flushing of channel sediments from the channel entrance.
5. The growth of shoals across the channel adjacent to open, unvegetated areas of the beach by wind-blown sand.

Main results of this study are:

1. Historical records indicate that the un-jettied Colorado River inlet influenced migration of the Matagorda Peninsula Gulf shoreline as far updrift as 5.4 km and as far downdrift as 18.4 km. The Colorado River jetties and channel are expected to exert control on long-term shoreline migration at least as far as these extents.
2. The Colorado River jetties trap sediment despite mechanical bypassing. Some sorting occurs as the weir separates suspended and bed-load sediments.
3. A varying degree of sediment is lost from the mechanical bypassing process when more sediment reaches the impoundment basin than can be stored. Overflowing sediment may be either lost to shoals (causing navigation hazards) or transported farther downshore (starving the local beach). Numerical simulation indicates that this sediment overflow can be reduced with a consistent bypassing schedule.
4. Numerical simulation predicts that a unidirectional transport of sediment occurs across the weir, resulting in a sediment deficit directly northeast of the weir during periods when waves arrive from the southwest. The effects of this process have not been observed at the study site.

ACKNOWLEDGEMENTS

Special thanks is given to Dr. Nicholas Kraus of the Coastal Engineering Research Center (CERC) for providing technical review of this report. The authors also give thanks to Mr. T. Neil McLellan at the U.S. Army Corps of Engineers, Galveston District and to Dr. David King and Dr. Tom White, both of CERC, for providing technical assistance and data. Recognition is given to Dr. Robert Morton at the University of Texas, Bureau of Economic Geology, and Dr. Richard Seymour at Texas A&M, College Station, for their patience and cooperation in providing other needed information.

REFERENCES

Bodge, K.R. 1995. The Extent of Inlet Impacts Upon Adjacent Shorelines. *Proc. 24th International Conf. Coastal Engin.*, ASCE, 2943-2957.

Bouma, A. H., and Bryant, W. R. 1969. Rapid Delta Growth in Matagorda Bay, Texas, Lagunas Costeros Un Sinposio, Nov., 1967, 171-189.

Dean, R. G. 1991. Equilibrium Beach Profiles: Characteristics and Applications. *J. Coastal Res.*, 7(1): 53-84.

Hanson, H. and Kraus, N. C. 1989. GENESIS: Generalized Model for Simulating Shoreline Change, Report 1: Tech. Ref. Technical Report CERC-89-19. U.S. Army Coastal Eng. Res. Center, Vicksburg, Mississippi.

Heilman, D. J. 1995. The Effects of the Colorado River Project on Longshore Sediment Transport at Matagorda Peninsula, Texas. Unpublished M.S. thesis, Texas A&M Univ., Dept of Civil Eng., College Station, Texas, 105 p.

Heilman, D. J., and Kraus, N. C. 1995. Beach Fill Functional Design, Town of South Padre Island, Texas. Tech. Rep. TAMU-CC-CBI-95-14, Conrad Blucher Instit. for Surveying and Science, Texas A&M Univ.-Corpus Christi, Corpus Christi, Texas, 35 p.

Kieslich, J. M. 1977. A Case History of Port Mansfield Entrance Channel, Texas. GITI Report 12. U.S. Army Coastal Eng. Res. Center, Vicksburg, Mississippi, 66 p.

Kraus, N. C. 1995. *Personal Communication.* Director, Conrad Blucher Instit. for Surveying and Science, Texas A&M Univ.-Corpus Christi, Corpus Christi, Texas.

Kraus, N. C., Heilman. 1996. Packery Channel Feasibility Study: Inlet Functional Design and Sand Management, Report 1 of a Two-Part Series. Tech. Rep. TAMU-CC-CBI-96-06, Conrad Blucher Instit. for Surveying and Science, Texas A&M Univ.-Corpus Christi, Corpus Christi, Texas, 112 p.

Kraus, N. C., and Militello, A. 1996. Hydraulic Feasibility of Proposed Southwest Cut, East Matagorda Bay, Texas. Tech. Rep. TAMU-CC-CBI-96-03, Conrad Blucher Instit. for Surveying and Science, Texas A&M Univ.-Corpus Christi, Corpus Christi, Texas, 80 p.

Liang, G. 1995. Shoreline and Sediment Volume Changes at the Colorado River Mouth, Texas. Contract Report CERC-95-2, U.S. Army Coastal Eng. Res. Center, Vicksburg, Mississippi, 31 p.

Mason, C. 1971. Properties and Stability of a Texas Barrier Beach Inlet. M.S. thesis, Texas A&M Univ., Dept. of Oceanography, College Station, Texas, 105 p.

Mason, C. and Sorensen, R. M. 1971. Properties and Stability of a Texas Barrier Beach Inlet. TAMU-SG-71-217, COE No. 146, Depts. of Oceanography and Civil Eng., Texas A&M Univ., College Station, Texas.

McGowen, J.H. and Brewton J.L. 1975. *Historical Changes and Related Coastal Processes, Gulf and Mainland Shorelines, Matagorda Bay Area, Texas.* The Univ. of Texas at Austin: Bureau of Economic Geology, in Cooperation with The General Land Office of Texas, 72 p.

Moore, B. D. 1982. Beach Profile Evolution in Response to Changes in Water Level and Wave Height. Unpub. M.S. thesis, Univ. of Del., Newark, Delaware.

Morton, R. A., Peiper, M. J., and McGowen, J. H. 1976. Shoreline Changes on Matagorda Peninsula (Brown Cedar Cut to Pass Cavallo): An Analysis of Historical Changes of the Texas Gulf Shoreline. *Geological Circular 76-6.* The Univ. of Texas at Austin: Bureau of Economic Geology, 37 p.

Paine, J.G. and Morton, R.A. 1989. Shoreline and Vegetation-Line Movement, Texas Gulf Coast, (1974-1982). *Geological Circular 89-1.* The Univ. of Texas at Austin: Bureau of Economic Geology, 50 p.

Ralston, D. O. 1987. *Summary for Mouth of Colorado River.* 47th Meeting of the Coastal Eng. Res. Board, Corpus Christi, Texas, 19-20 May, 1987, U.S. Army Eng. District, Galveston, Texas.

Rozsypal, J. 1994. *Personal Communication.* Area Engineer, Fort Point Area Office, U.S. Army Eng. District, Galveston, Texas.

Seelig, W. N., and Sorensen, R. M. 1973. Investigation of Shoreline Changes at Sargent Beach, Texas. TAMU-SG-73-212, COE No. 169, Department of Civil Engineering, Texas A&M Univ., College Station, Texas.

U.S. Army Corps of Engineers. 1977. *General Design Memorandum (Navigation Features), Mouth of Colorado River, Texas, Phase I.* U.S Army Eng. Distriet, Galveston, Texas, 122 p.

_____. 1984. *Shore Protection Manual.* (4th ed), 2 vols, Coastal Eng. Res. Center, U.S.A.E. Waterways Expt. Sta., U.S. Govt. Printing Office, Washington, D.C.