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PREDICTING HYDRODYNAMICS OF A PROPOSED MULTIPLE-INLET SYSTEM, COLORADO RIVER, TEXAS

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Abstract: This study investigates the hydrodynamics of a multiple-inlet system encompassing the lower Colorado River (CR) and the Gulf Intracoastal Waterway, Texas. The system includes two proposed new inlets, one connecting East Matagorda Bay to the Colorado River Navigation Channel (CRNC) and the other connecting West Matagorda Bay to the CRNC. If implemented, the resultant system would be comprised of three inlets in the near field (CR entrance and two proposed inlets) and three inlets in the far (regional) field (Mitchell's Cut in East Bay; Pass Cavallo and Matagorda Ship Channel in West Bay). Engineering questions concern stability of the various inlets, channel shoaling, and navigation safety. Alternative configurations of the proposed inlets are evaluated with the ADCIRC model, verified with measurements of water level and current velocity. It is found that the current in the CRNC becomes more ebb dominant with introduction of the new inlet to the East Bay, promoting navigation channel stability. In contrast, the current in the CRNC becomes flood dominant with introduction of the new inlet to the West Bay, which would alter the pattern of sediment deposition by promoting development of a flood shoal in the CRNC.

INTRODUCTION

The mouth of the Colorado River (MCR) is located on the Texas Gulf of Mexico coast approximately midway between Galveston and Corpus Christi (Fig. 1). It allows weak water exchange between the Gulf of Mexico and East Matagorda Bay, connected through the 10.5-km long Colorado River Navigation Channel (CRNC) and

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the eastward section of Gulf Intracoastal Waterway (GIWW). The flow system connects to the MCR and is separated from West Matagorda Bay and the westward section of the GIWW by a pair of boat locks and a diversion dam (Fig. 2). Two rubble mound jetties protect the MCR, one on each side of the navigation channel, completed in 1986. The west jetty extends 442 m from shore. The east jetty consists of three sections; a 100-m long section at the shore, a 300-m long weir, and a 400-m emergent section terminating in the Gulf. A deposition basin is located on the west side of the weir. The entrance channel, nominally 5 m deep by 60 m wide and containing a flange, connects to the GIWW through a 4-m deep by 33-m wide channel.

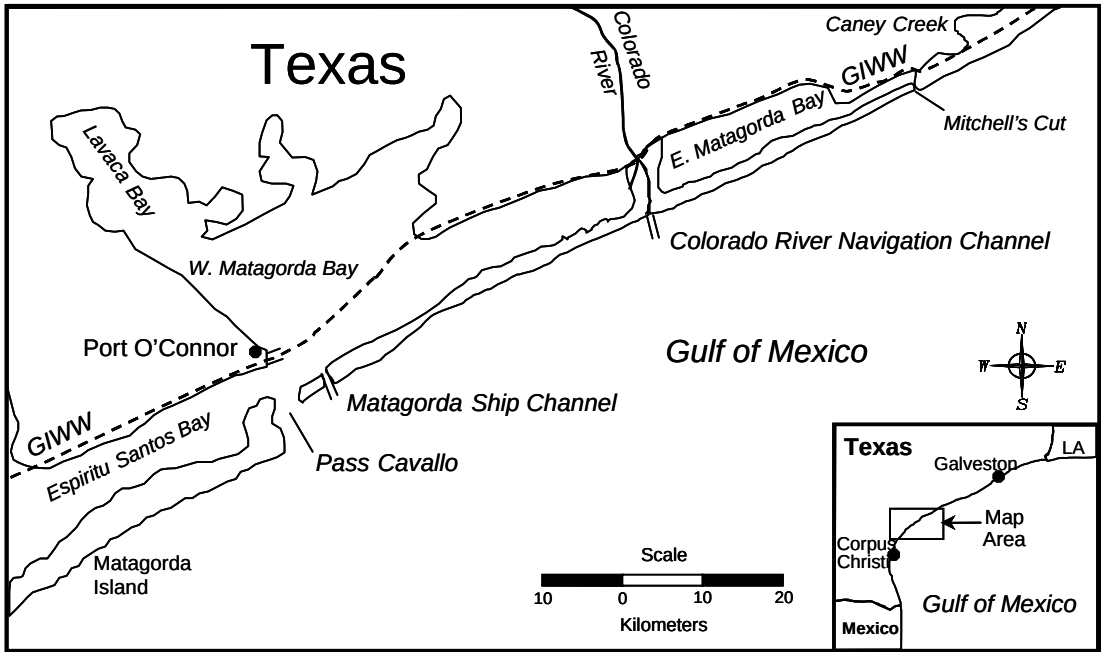

Fig. 1. Location map for study site, MCR, central Texas coast

Before 1930, East Bay and West Bay comprised a single bay (Matagorda Bay). In that era, the Colorado River discharged into Matagorda Bay rather than into the Gulf of Mexico. The bay was divided into East Bay and West Bay in 1935 when a large river delta formed and moved rapidly across the bay after a logjam was freed in the river in 1929 (USACE 1992). The Colorado River began discharging to the Gulf of Mexico in 1935. At that time, the river had a small opening to the West Bay through Parker's Cut located about 3 km upstream of the Gulf of Mexico (Fig. 2). The river also exchanged water flow to the East Bay and West Bay though the GIWW. In 1992, the Colorado River was rerouted to discharge into Matagorda Bay through a diversion channel, and Parker's Cut was closed as part of the environmental enhancement project to reduce salinity intrusion. The CRNC was separated from the main stream of the river, but is still connected to the eastward section of GIWW. In 1954, floodgates originally constructed in 1944 on the GIWW at the junction with the Colorado River were converted to the configuration of locks present today. The locks mitigate the crosscurrent at the intersection of the river and GIWW.

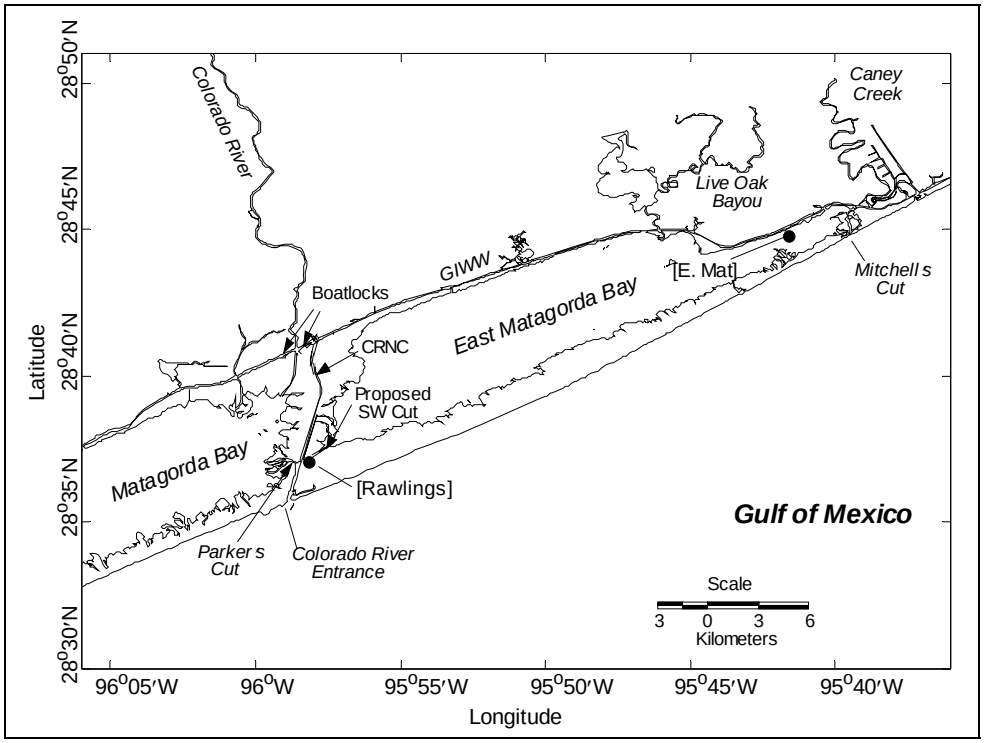

Fig. 2. Vicinity of the Colorado River entrance

As a result of the 1992 environmental enhancement, the Colorado River was diverted into West Matagorda Bay, eliminating the river discharge as a means of scouring littoral sediments from the entrance by reducing the effective tidal prism. Sediment (predominantly sand) shoaling at the entrance has greatly increased since that time. Spits now tend to form on both the east and west sides of the landward ends of the jetties, and sand collects on the entrance bar (Fig. 3). At the same time, 10.5 km northward, the current in the vicinity of the river and GIWW intersection is strong, presenting a navigation hazard to barge traffic.

Local interests have proposed opening two inlets (called “cuts” locally) to connect East and West (Matagorda) Bays to the navigation channel close to the MCR as environmental enhancements to increase salinity gradients. One proposed inlet is to reopen Parker’s Cut that was closed in 1992. This would reconnect the West Bay to the CRNC. The other inlet is a water-exchange cut connecting East Bay at its southwestern end to the CRNC. The proposed SW Corner Cut (Fig. 2) is located 3.2 km upstream of the Gulf of Mexico and has been studied previously (Kraus and Militello 1996, 1999).

The MCR includes a sediment deposition basin located between the weir section and the entrance channel (Fig. 3). The deposition basin is designed to accommodate sand bypassing to the down-drift beaches by means of pipeline dredge in the basin with discharge in the surf zone about 600 m on the west side of the MCR. The basin was designed to hold a 2-year supply of sediment or approximately 460,000 m^3 capacity (King and Prickett 1998).

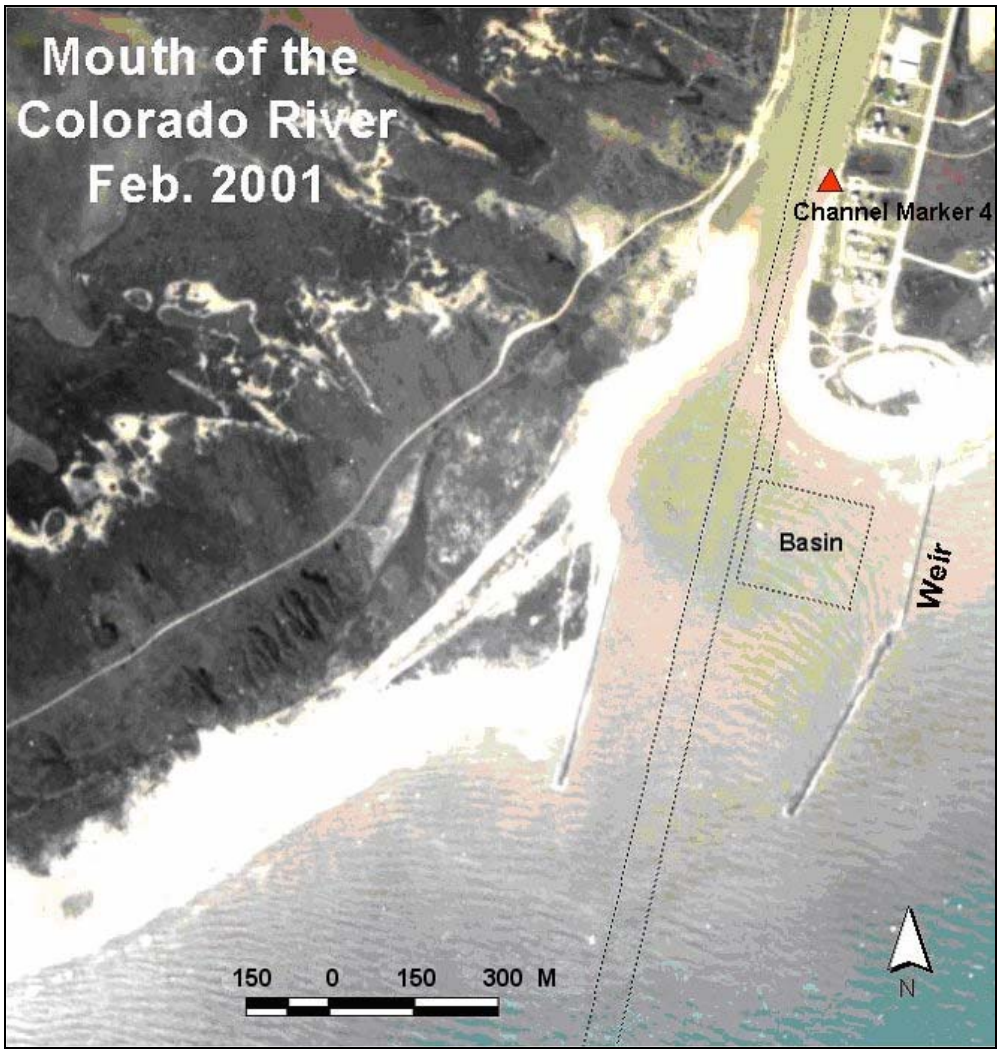

Fig. 3. Entrance of Colorado River, TX. (Note spits on both sides of the entrance channel.)

Dredging the deposition basin was completed in 1990. Since then, the basin has filled more rapidly than designed. The entrance mouth has experienced a large increase in sand shoaling, and spits tend to form on both the east and west sides of the landward ends of the jetties. This has led to frequent dredging. Figure 4 shows the volume of sediment dredged in the basin and CRNC from 1990 to 2000. The total volume of dredging annually is about 380,000 m^3 (500,000 cy) or 1.65 times the design estimate. If the two new proposed inlets were to open, the flow conditions will change and could either decrease or increase the shoaling rate at the MCR.

Opening of the two proposed new cuts will create a complex multiple-inlet system comprised of three inlets in the near field (MCR, two proposed cuts) and three inlets in the far field (Pass Cavallo and Matagorda Ship Channel in West Bay; Mitchell's Cut in East Bay). The new multiple-inlet system may have regional implications for the flows in the CRNC, GIWW, East Bay and West Bay. Additional concerns include stability of the natural inlet (Pass Cavallo) and of artificial inlets (Matagorda Ship Channel and Mitchell's Cut), sand shoaling, and navigability.

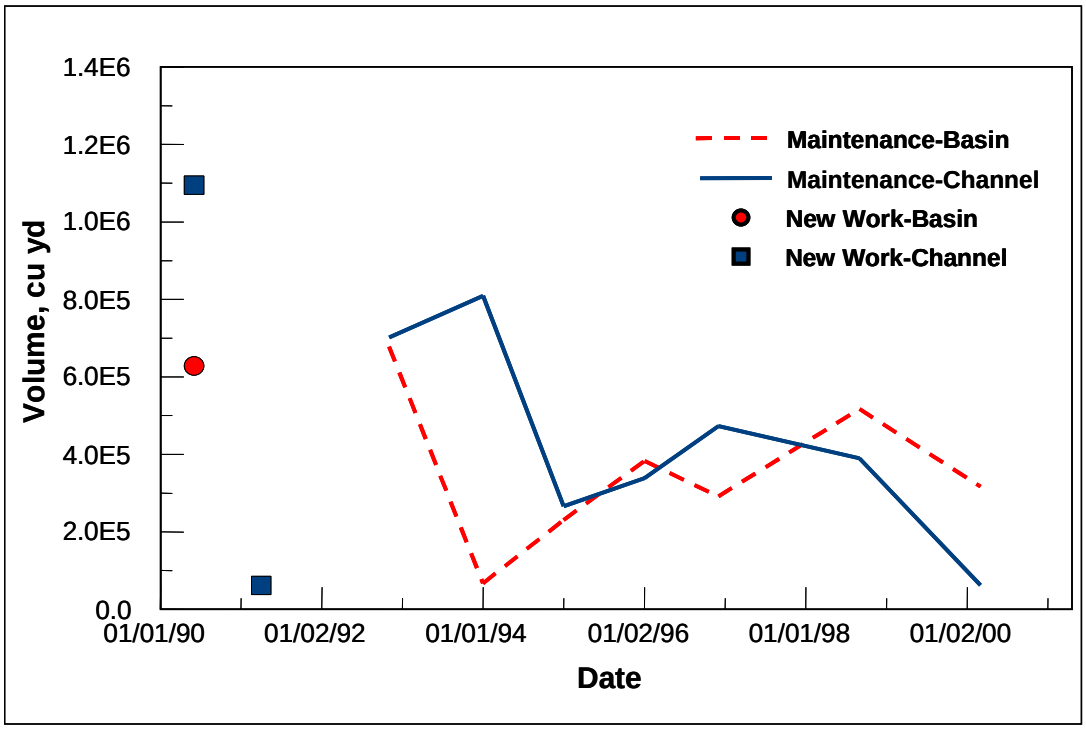

Fig. 4. Dredging volume at entrance of Colorado River, TX

This paper focuses on near-field processes at the MCR. Kraus et al. (2000) discuss regional processes in Matagorda Bay and possible closure of Pass Cavallo with prism capture by the Matagorda Ship Channel.

MEASUREMENTS AND HYDRODYNAMIC MODEL

In this study, the hydrodynamics of the multiple-inlet system under various alternatives were examined with the ADvanced CIRCulation (ADCIRC) model (Luettich et al. 1991) operated in depth-averaged mode. The model grid encompasses the MCR, East Bay, West Bay, and surrounding GIWW based upon old and new bathymetry surveys and aerial photographs. The modeling effort includes representation of the surface wind field, river inflow, and ocean boundary water surface elevation. Newly implemented weir and porous-jetty algorithms in ADCIRC were also included (Westerink et al. 2001). The model verification was based on water surface elevation measurements at two tide stations, one at the lower section of Colorado River Navigation Channel and the other at the east end of East Matagorda Bay. The model was also verified with current velocity measurements made in October-November 1995 and in July 2001.

By specifying the water surface elevation at the ocean boundary and the surface wind information over the model domain, ADCIRC can predict the hydrodynamics of the flow system with high resolution in areas of complex shoreline and bathymetry. The river discharges in the Colorado River, Caney Creek, and Live Oak Bayou were included in the simulation.

The basic bathymetric grid was based on NOAA nautical charts, supplemented by a full bathymetric survey of East Matagorda Bay conducted in 1995 (Kraus and

Militello 1996). Beach profile data and bathymetry near the MCR were obtained by the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (CHL) from October 1999 to February 2000. Aerial photographs taken periodically at the MCR furnished information on shoreline position and configuration of the jetties. Cross-sections of the CRNC were obtained by the U.S. Army Corps of Engineers, Galveston District from October 1999 to January 2000.

Wind plays a major role in controlling the water level and circulation in the shallow coastal waters of Texas (cf. review in Militello and Kraus 2001). The prevalent southeasterly summer winds and intermittent winter northerly wind fronts characterize the wind forcing on the hydrodynamics of the East Bay and West Bay. Wind information for this study was acquired from the Gulf of Mexico wind field database (1/4-deg resolution) for 1990-1999 developed recently by CHL.

ADCIRC was forced at the Gulf of Mexico with water-level measurements to capture meteorological tide as well as astronomical tide. The water surface elevations measured at the Bob Hall Pier (27° 34' 54" N and 97° 13' 00" W) and Galveston Pleasure Pier (29° 19' 36" N and 94° 41' 30" W) tide gauges were averaged for input for the Gulf boundary condition. The water surface elevations at the two tide gauges differ little in phase, but have somewhat different magnitudes. The magnitudes at the two tide gauges depends in part on local winds. The water-surface elevations measured at Rawlings (28° 37' 24" N and 95° 58' 12" W) tide gauge and East Matagorda Bay (28° 45' 42" N and 95° 39' 18" W) tide gauge served as the verification of model results. These water-level data are available at http://dnr.cbi.tamucc.edu.

Discharges in the Colorado River, Caney Creek, and Live Oak Bayou were included in the simulation of the hydrodynamics. The daily average river discharge information for the Colorado River is available from the U.S. Geological Survey National Water Information System. The river discharges for Caney Creek and Oak Bayou were approximated as one-tenth (proportion of the watershed area) of the river discharge of the San Bernard River, a small stream located about 55 km east of the Colorado River. Discharge information for both Colorado River and San Bernard River is available at http://water.usgs.gov/data.html. Daily discharges for the Colorado River and San Bernard River in 1999 are shown in Fig. 5, indicating strong seasonal variations.

Measurements of the current in the vicinity of the East Matagorda Bay tide gauge and at the entrance of the CRNC near Channel Marker 4 (Fig. 3) served for model verification. The current measurements at the East Matagorda Bay tide gauge were available for the 4-month period from October 1995 to January 1996 (Kraus and Militello 1996). The current information at the entrance of the CRNC near Channel Marker 4 was collected by CHL for the 2-week period 6-20 July 2001.

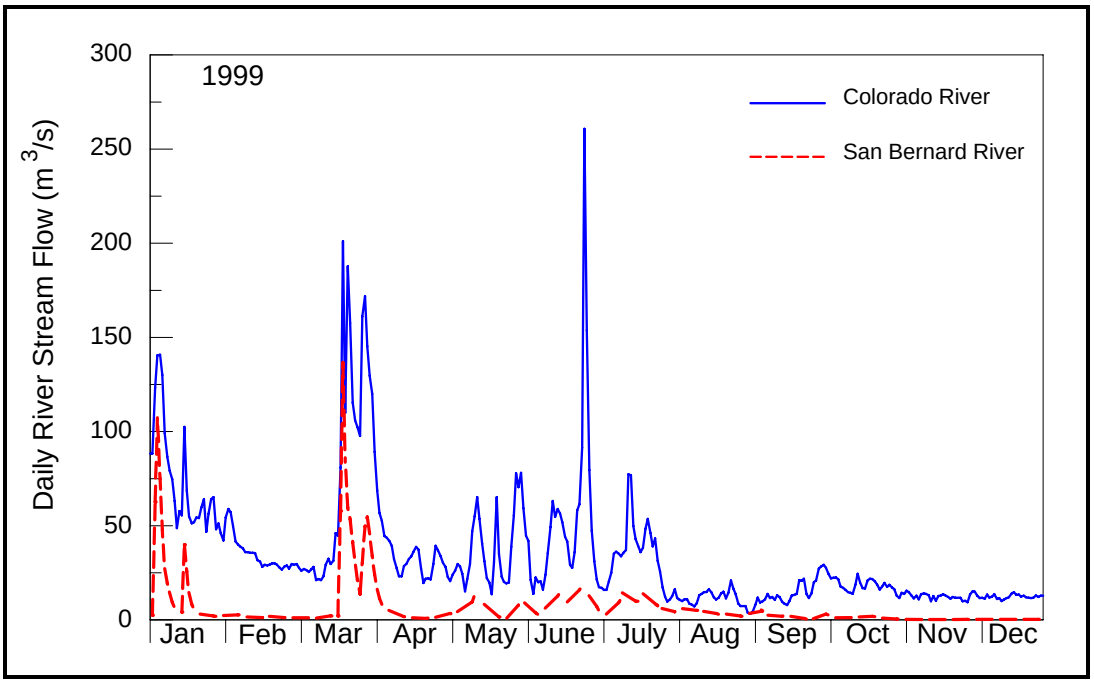

Fig. 5. Discharges at the Colorado River and San Bernard River, 1999

MODEL VERIFICATION

The unstructured ADCIRC grid for the present study is shown in Fig. 6 and represents the bathymetry of the MCR, Mitchell's Cut, Pass Cavallo, Matagorda Ship Channel, East Bay, West Bay, and the GIWW. Grid detail in the MCR and CRNC area is shown in Fig. 7, including the junction of the CR and GIWW, the diversion channel and CRNC, the proposed SW Corner Cut and Parker's Cut, and the two GIWW boat locks bracketing the CR. ADCIRC was run with 1.5-sec time step and default control parameters (τ_o=0.01; bottom friction coefficient=0.0025). The boundaries were set distant from the study site so that the six connected inlets could be represented as a regional interacting system.

Water-level elevation calculations and measurements at the Rawlings and East Matagorda Bay tide gauges for October-November 1995 are compared in Fig. 8, a period just prior to maintenance dredging. Table 1 presents the calculated bias (difference of model mean to measured mean), the root-mean-square (rms) error, and percentage error (rms error divided by tidal range) for the water level elevations. The bias are small for the predicted water level, but the rms and percentage errors are relatively large in that the model tends to overestimate high waters and underestimate low waters, likely due to inaccurate bathymetry. Figure 9 compares the east-west current components at the East Matagorda Bay tide gauge for the same time period. Figure 10 compares the north-south current components at the MCR near Channel Marker 4 after maintenance dredging. These comparisons and others not shown indicate that model predicts well the water level and current in the study area.

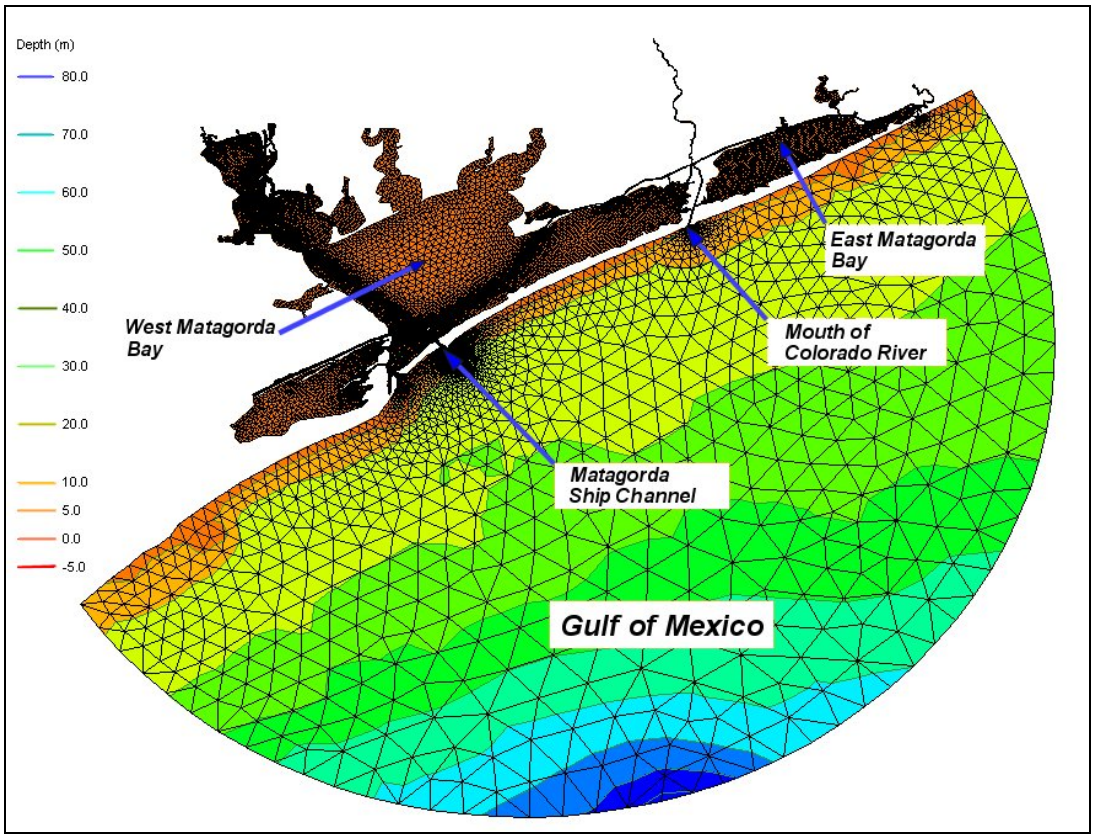

Fig. 6. Regional ADCIRC grid

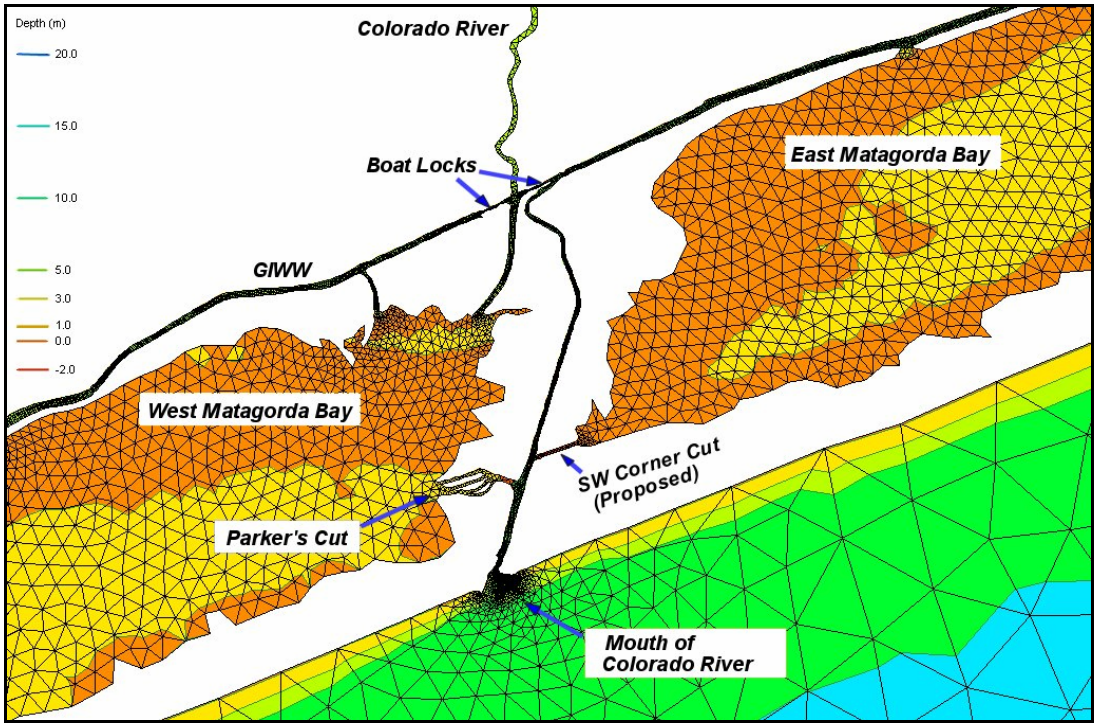

Fig. 7. Details of local grid

Table 1. Water Surface Elevation RMS Error and Percentage Error				
Period	**Station**	**Bias, m**	**RMS Error, m**	**Percentage Error**
Oct-Nov 95	Rawlings	0.0118	0.124	31
	East Matagorda Bay	0.0032	0.103	34
Remarks: Tidal range is 0.4 m at Rawlings and 0.3 m at East Matagorda Bay station (range=MHHW-MLLW)				

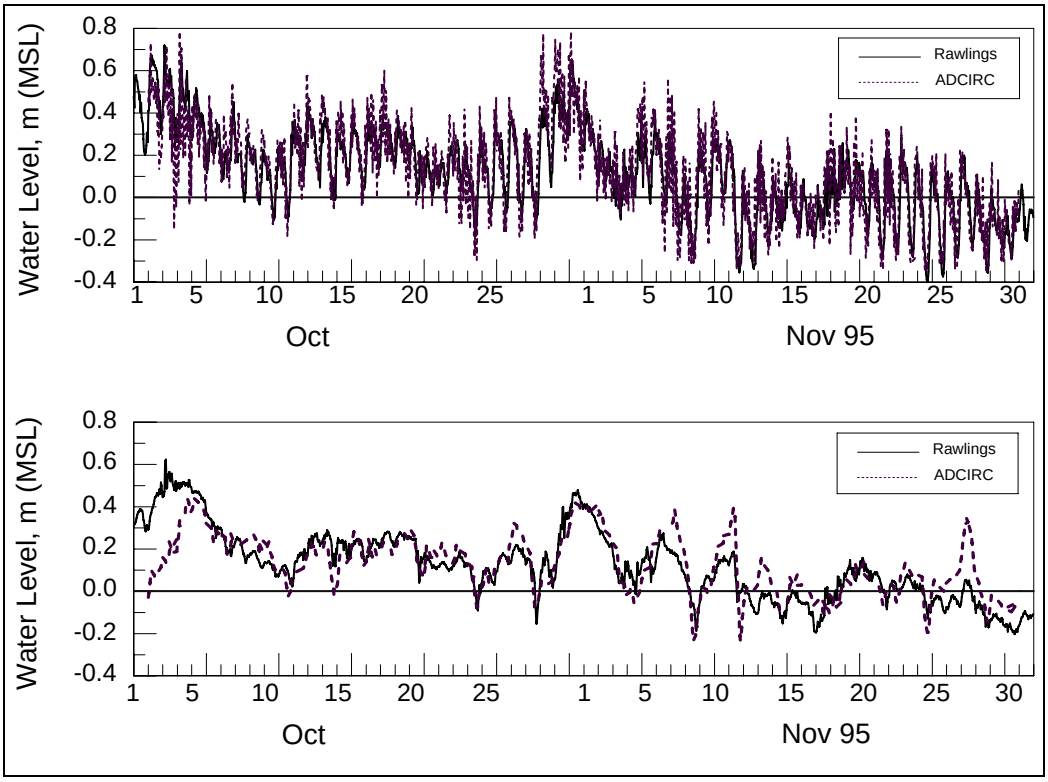

Fig. 8. Water level at the East Matagorda Bay and Rawlings tide stations

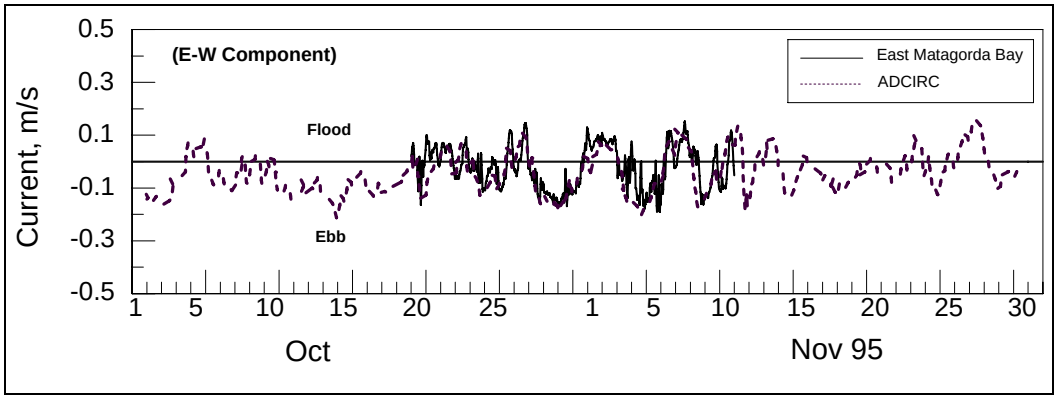

Fig. 9. East-west current component at the East Matagorda Bay tide station

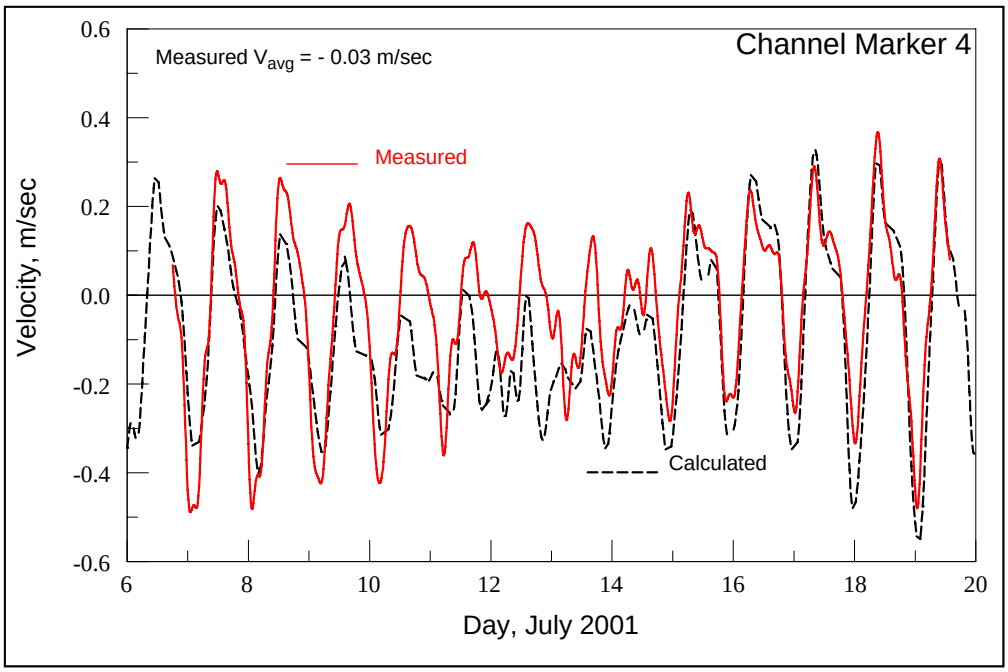

Fig. 10. North-south current component at the MCR Channel Marker 4

EVALUATION OF ALTERNATIVES

Alternatives discussed here are (1) opening of Parker's Cut, (2) opening of the SW Corner Cut, and (3) opening of both cuts. These are evaluated by comparing calculated velocities to the existing condition. For this paper, model results are shown for the current calculated at the entrance of the MCR (Channel Marker 4) for the proposed two cuts and the existing flow system. The current at the entrance is of direct interest because of its sediment-scouring role in clearing the channel.

Alternative 1: Open Parker's Cut

The proposed Parker's Cut connects the West Matagorda Bay at its eastern end and CRNC at approximately 3 km upstream of the Gulf of Mexico. Parker's Cut was modeled to be 1.7 km long, 120 m wide, and 1.2 m deep. The calculated current at the MCR in the presence of Parker's Cut is compared to that of the existing flow system in Fig. 11. The current in the existing system is slightly ebb dominant, whereas opening Parker's Cut creates significant flood dominance.

The turn to flood dominance is understood by examining water level at the bay side of Parker's Cut with respect to the water level at the MCR, Fig. 12. The tidal wave at the bay side of Parker's Cut is delayed in phase by approximately 8 hr from its entry to the bay through the Matagorda Ship Channel. The difference in water level between that corner of the bay and the MCR is overall greater during the flood period than during the ebb period. Thus, with higher water-level elevation at the MCR, water tends to move into the bay. Historic photographic evidence (Fig. 13) indicates that sediment will tend to flow into the MCR navigation channel and bay with Parker's Cut open.

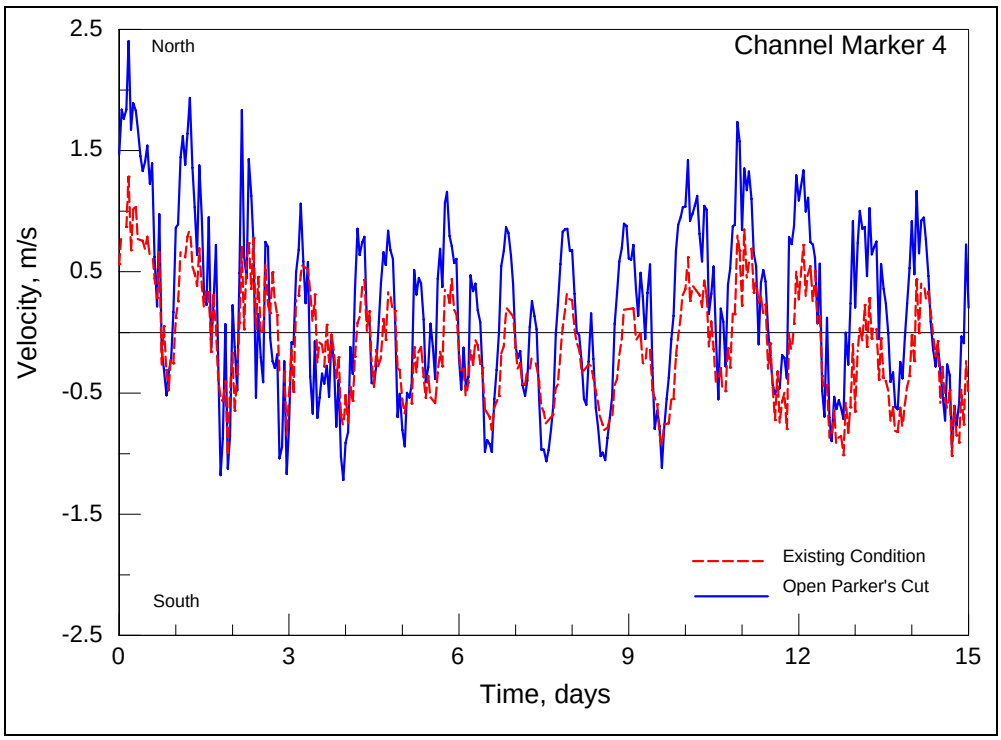

Fig. 11. Current at MCR with Parker's Cut open and existing condition

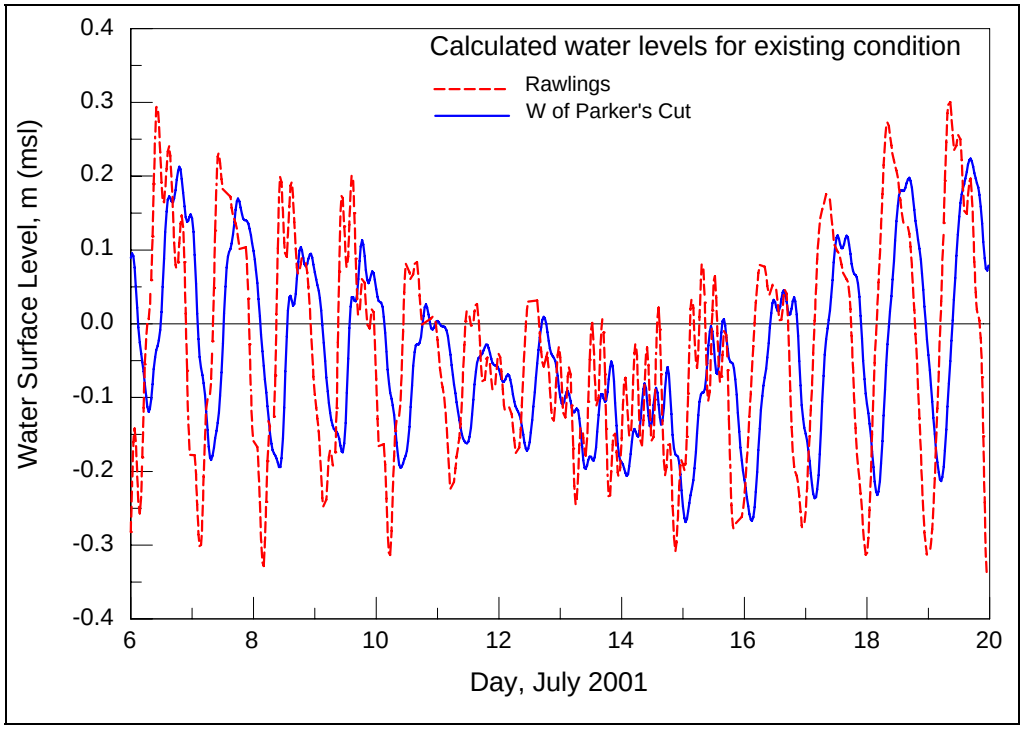

Fig. 12. Calculated water levels in West Bay near the proposed entrance to Parker's Cut and at Rawlings tide gauge in the CRNC across from the entrance

Fig. 13. MCR, 1954, showing old Parker's Cut filled with sand

Alternative 2: Open SW Corner Cut

The proposed SW Corner Cut connects East Matagorda Bay at its southwestern end and CRNC at approximately 3.2 km upstream of the MCR (Fig. 7). The SW Corner Cut is a narrow and long inlet about 80 m wide, 1.1 km long, and 1.2 m deep. Figure 14 compares calculated currents at the entrance of MCR for the opened SW Corner Cut and the existing flow system. The currents are stronger and more ebb dominant for the opened SW Corner Cut. This result agrees with the findings of a hydraulic study conducted by Kraus and Militello (1996, 1999). Opening the SW Corner Cut increases the ebb current primarily because of higher water level induced by wind set up at the southwestern end of the East Matagorda Bay. Water enters the East Bay from Mitchell's Cut, located on the northeast corner of the bay and exits at the SW Corner Cut. This increase in ebb current in the CRNC is favorable for maintaining the MCR.

Alternative 3: Open Parker's Cut and SW Corner Cut

Figure 15 shows the comparison of model currents in the case of opening both proposed cuts and the existing flow system. Opening both the Parker's Cut and SW Corner Cut will create slight flood dominance in the CRNC. Apparently, opening Parker's Cut may have a stronger influence to the existing flow system than opening the SW Corner Cut, to be further investigated in future work.

CONCLUDING DISCUSSION

Table 2 summarizes the estimated change in the average N-S current at the MCR associated with the alternatives discussed here. Opening the SW Corner Cut shows a significant (47 percent) increase in average ebb current as compared to the existing system. This suggests that opening the SW Corner Cut alone is likely to reduce littoral sand accumulation at the MCR by a creating stronger ebb current in the CRNC. In contrast, opening Parker's Cut would create flood dominance, likely to introduce more shoaling at the MCR and the southern portion of the CRNC.

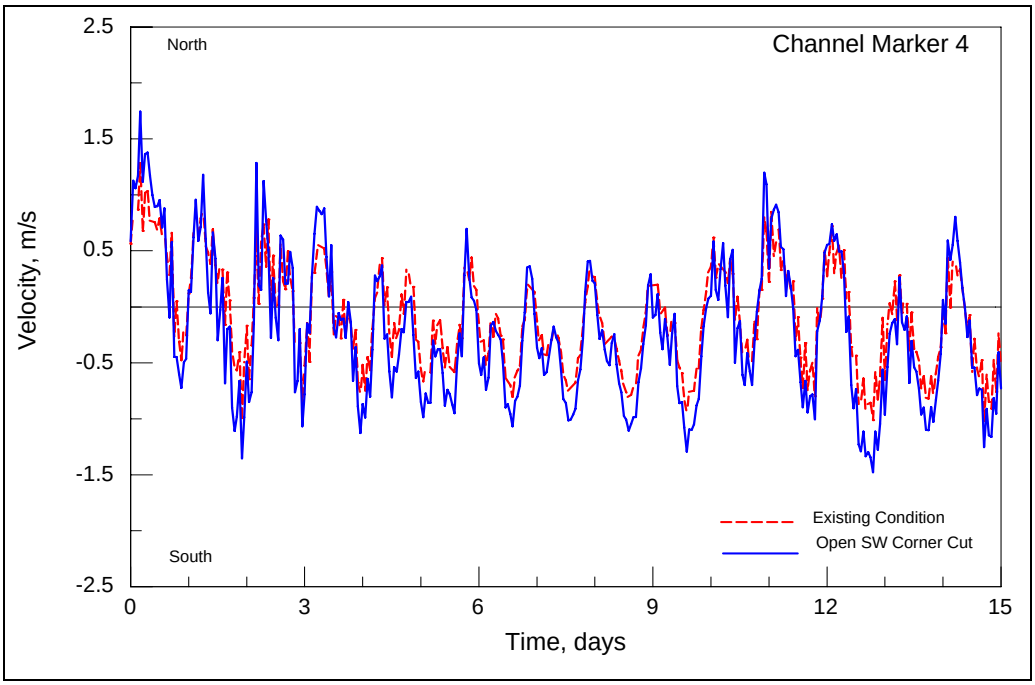

Fig. 14. Current at MCR with SW Corner Cut open and existing condition

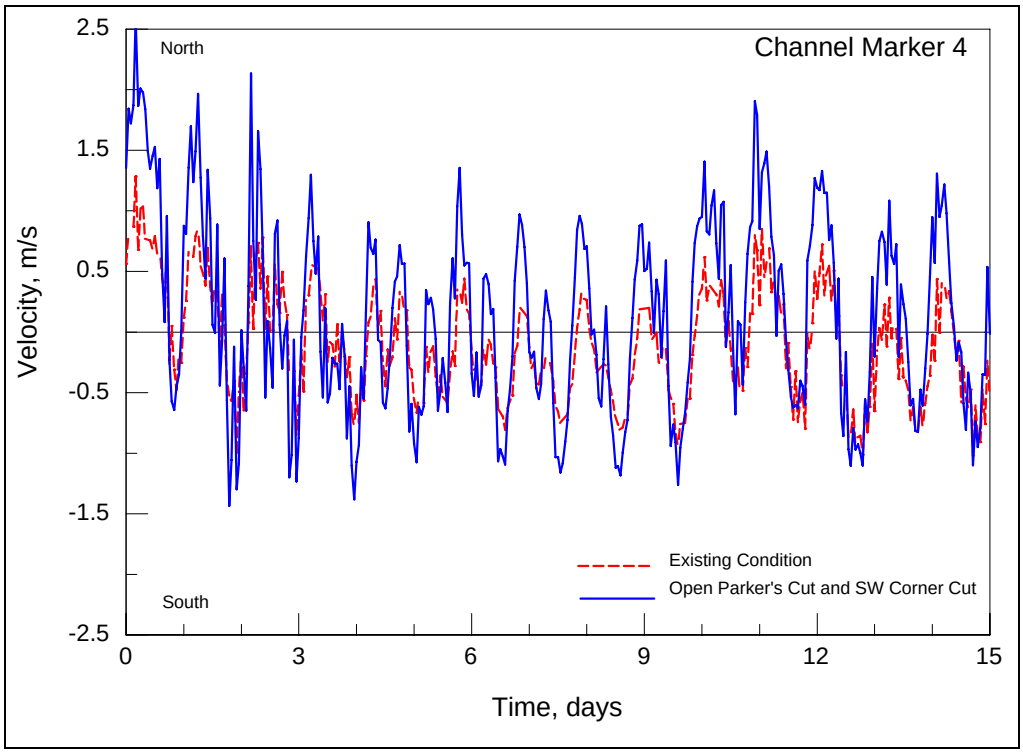

Fig. 15. Current at MCR with both Parker's Cut and the SW Corner Cut open and existing condition

Table 2. Calculated Average Current (60 tidal cycles)	
Alternative	**Average N-S Velocity, m/s**
Existing	-0.17 (toward Gulf)
1. Open Parker's Cut	0.08 (toward GIWW)
2. Open SW Corner Cut	-0.25 (toward Gulf)
3. Open both cuts (Alt's 1 &2)	0.02 (toward GIWW)

For the existing flow system, both the peak ebb and flood currents are generally rather weak, because of the diversion of the CR to West Matagorda Bay, which eliminates river flow to the MCR as well as reduces the tidal prism. Calculations described here indicate that opening the SW Corner Cut will increase these peak currents and reduce the maintenance effort. Calculations also show that the flood current is strong over the weir jetty section. The strong current near to shore indicates littoral sediment is transported efficiently and steadily into the deposition basin or along the shoreline to form a spit emanating from the east. The sediment can then enter the entrance channel as the basin fills. In addition to this problem, the calculated ebb current between the jetties is relatively weak, also favoring sediment accumulation at the MCR.

Opening of Parker's Cut will tend to change the existing ebb dominance to flood dominance, moving sand further up the CRNC. More material is expected to move across the weir with the increased magnitude of the flood current.

It is interesting to note that the tendency to promote an ebb current by opening of the SW Corner Cut is caused by wind set up in East Matagorda Bay, whereas the tendency to promote flood dominance by opening Parker's Cut is caused by a substantial phase difference in water level on each side of the cut.

Possible solutions to the substantial sediment shoaling at the MCR include shortening the weir section, adding a training structure inside the weir section by the entrance channel, and relocating the east jetty westward to increase the ebb flow between the jetties. Relocation of the east jetty westward will also better protect the shoreline landward of the west jetty by the entrance channel. Such results will be presented in a subsequent paper, based in part upon additional measurements of the current and water level presently being made.

ACKNOWLEGEMENTS

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