

MATAGORDA SHIP CHANNEL AND ITS ENTRANCE'S NAVIGATION EFFICIENCY AND SAFETY IMPROVEMENT VIA ADCIRC & CMS MODEL SIMULATION

Lihwa Lin¹, Zeki Demirbilek¹, and Tzeng-Huey, Shih²

The present study investigated alternatives including deepening/widening of Matagorda Ship Channel in the south central coast of Texas to improve navigation safety through entrance inlet channel by using ADCIRC and CMS numerical models. The alternatives modify bayside channel depths from 38 ft to 50 ft, referenced to Mean Lower Low Water (MLLW), and widths from 200 ft to 600 ft, and deepen the entrance channel from 38 ft to 55 ft MLLW and widen the channel from 300 ft to 600 ft. The alternatives include seven new dredged material placement areas along the ship channel. Model results show the proposed ship channel dimensions will slightly increase flow efficiency and current magnitude in Matagorda Bay. Current velocities in and around ship channel tend to increase with alternatives, large river input and future sea level rise in the region. However, the current effect becomes more pronounced during tropical storms.

Keywords: Matagorda Ship Channel improvement project; Advanced Circulation Model, Coastal Modeling System

INTRODUCTION

Matagorda Ship Channel (MSC) is located in the south central coast of Texas about 130 km (80 miles) northeast of Corpus Christi and 200 km (125 miles) southwest of Galveston. The MSC runs through a jettied entrance at the southwest end of Matagorda Bay and extends 38 km (24 miles) into Matagorda Bay and Lavaca Bay (Fig.1). The ship channel terminates at a wide turning basin at Port of Port Lavaca - Point Comfort in Lavaca Bay that serves as a gateway to world market for the Texas mid-coast region. The MSC intercepts the Gulf Intracoastal Waterway (GIWW) in the lower Matagorda Bay provides pathways to Port O'Connor and to Port Palacios through Palacios Boat Channel on Palacios Bay. The Federal navigation project in Matagorda Bay maintains MSC, GIWW, and Palacios Boat Channel in the region.

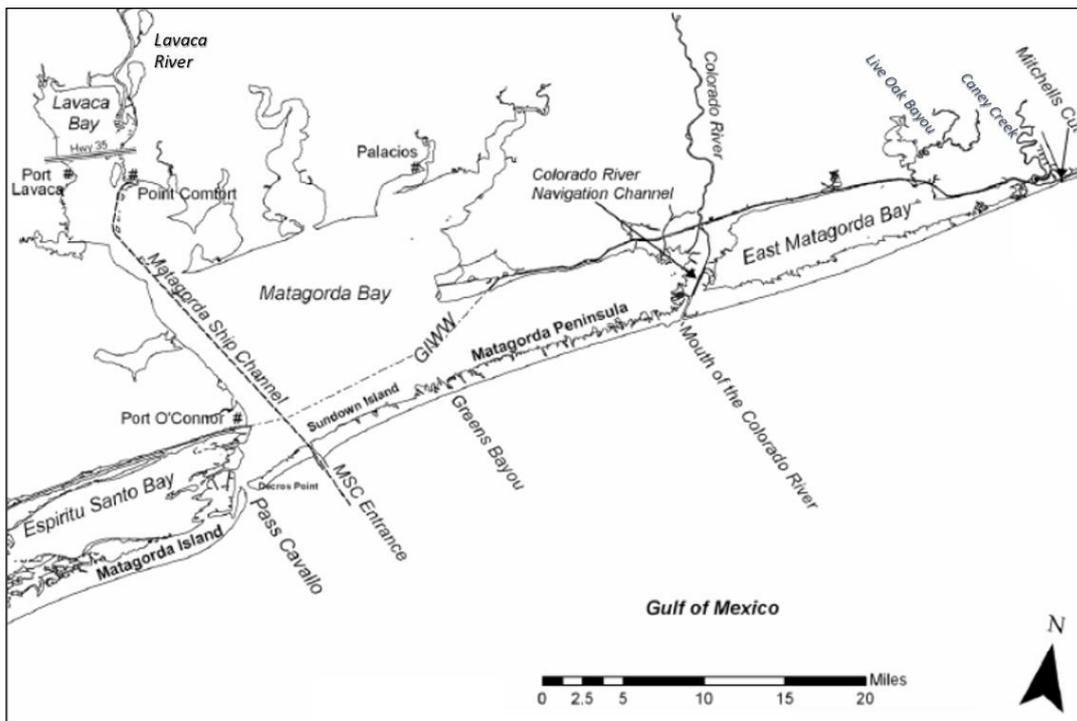


Figure 1. Location map of Matagorda Ship Channel, Gulf Intra-coastal Waterways, and Matagorda Bay.

¹ Coastal and Hydraulics Laboratory, US Army Engineer Research and Development Center, 3909 Halls Ferry Road, Vicksburg, Mississippi, 39180, USA

² New Orleans District, US Army Corps of Engineers, 7400 Leake Avenue, New Orleans, Louisiana, 70118, USA

Matagorda Bay connects to East Matagorda Bay to the east, and Espiritu Santo Bay to the west with rather small flow exchange between Matagorda Bay and these two bays. The MSC jettied entrance and Pass Cavallo are two main inlets connecting Matagorda Bay and Gulf of Mexico. Pass Cavallo is a smaller natural opening approximately 8 km (5 miles) west of the MSC entrance. It is a historically unstable inlet that connected the Gulf of Mexico and Matagorda Bay prior to the construction of MSC entrance channel in 1963-1964. After construction of the MSC, tidal hydraulics became much more efficient through the MSC entrance than Pass Cavallo.

Matagorda Bay, with a surface area of approximately 920 square km (360 square miles), is meteorologically dominated as consequence of the large surface area with the intensity and variability of atmospheric forcing. The tide in the Gulf of Mexico and Matagorda Bay is strongly mixed and is usually classified as diurnal. The mean tidal range, between Mean Low Water (MLW) and Mean High Water (MHW), is small in the bay, approximately 0.22 m (0.72 ft) at Port O'Connor and 0.26 m (0.85 ft) at Port Lavaca. Actual tidal range in Matagorda Bay can vary greatly due to seasonal meteorological and regional oceanographic effects. Winds are generally mild to moderate in the bay, with predominant wind direction from the southeast and east-southeast. Typically, the bay water level shows two monthly maxima, centered on May and October, and two minima, centered on January and July.

Matagorda Bay receives freshwater mainly from the Colorado River (CR) through a diversion channel opened in March 1995 and from the Lavaca River (LR). The freshwater inflow is typically less than 10 percent of the daily tidal exchange; therefore, an increase in bay volume by river flow is of minor importance in the control of the geomorphology of the two gulf entrances.

US Army Corps of Engineers (USACE) Galveston Office has proposed an improved channel configuration for the present MSC. The proposed improvements include widening and deepening the offshore and inshore portions of the channel and expanding the turning basin at the Port of Port Lavaca - Point Comfort. It is proposed to widen and deepen the present dimensions of 61 m (200 ft) bottom width and 11 m (36 ft) MLW depth to 122 m (400 ft) bottom width and 13.4 m (44 ft) depth for the inshore segments of the channel. The offshore segment is proposed to be improved from its present dimension (width and depth) of 91.5 m (300 ft) by 11.6 m (38 ft) to 183 m (600 ft) by 14 m (46 ft). Note that these depths are project depths and do not include proposed advanced maintenance of 0.6 m (2 ft) and allowable overdepth dredging of 0.6 m (2 ft) inshore and 0.9 m (3 ft) offshore. A wider turning basin at Point Comfort is also proposed to accommodate larger and newer modern vessels. The alternatives include seven new dredged material placement areas (PA) along the MSC. Figure 2 shows the location map of deepening/widening MSC with new PA configurations (blue box). The improvements of the MSC will help keep pace with petrochemical industry's prosperity and increase the annual revenue to about \$6.5 million for Port of Port Lavaca - Point Comfort.

Over the last few decades, the USACE Engineer Research and Development Center (ERDC) studied literature published by outside entities and performed modeling studies to investigate navigation safety at the MSC (Kraus et al. 2006). The flow pattern (current magnitude and direction) at the MSC was simulated first by the ADCIRC hydrodynamic model (Luettich et al. 1992). The geometry file of the ADCIRC model was updated later for applying the USACE Coastal Modeling System (CMS) numerical models (Demirbilek and Rosati, 2011) to investigate the flow circulation and sedimentation at the bayside of the MSC entrance. The CMS included wind wave generation in the bay with tides and coastal waves in the Gulf approaching the MSC entrance.

The objectives of the present study are to investigate alternatives including deepening/widening MSC and new placement areas to improve navigation safety through entrance inlet channel by using ADCIRC and CMS numerical models.

DATA USED IN THE STUDY

Digital shoreline data were extracted from the National Geophysical Data Center (NGDC, <https://www.ngdc.noaa.gov/mgg/shorelines/>), and a georeferenced image downloaded from Google Earth Pro 7.3 (<https://www.google.com/earth/>). The bathymetry data were obtained from various sources and previous studies (Kraus et al. 2006; Maynard et al. 2011; Lambert et al. 2013; Wood et al. 2017) covering the land, bays, rivers, waterways, nearshore, and offshore area. For the present modeling, the update of bathymetry data along the Gulf coast is based on NOAA nautical charts (<https://www.charts.noaa.gov/InteractiveCatalog/nrnc.shtml>). Bay and land elevations were based on NOAA DEMs (<https://www.ngdc.noaa.gov/mgg/coastal/crm.html>), NOAA Lidar data (<https://www.coast.noaa.gov/dataviewer/#/>), and USACE channel surveys (<https://navigation.usace.army.mil/Survey/Hydro>).



Figure 2. Location of MSC improvement, new Placement Areas (blue box), and Port Comfort Turning Basin.

The long-term water level and river discharge data are available from several NOAA coastal stations (<https://tidesandcurrents.noaa.gov/>) and USGS river stations (<https://waterdata.usgs.gov/nwis/rt>): (1) NOAA Sta 8775870 (MQTT2) at Bob Hall Pier, (2) NOAA Sta 8773767 (MBET2) at MSC Entrance Channel, (3) NOAA Sta 8773701 (PCNT2) at Port O'Connor, (4) NOAA Sta 8773259 (VCAT2) at Lavaca Bay Bridge, (5) USGS Sta 8162500 at CR near Bay City, (6) USGS Sta 8162000 at CR near Wharton, (7) USGS Sta 8164000 at LR near Edna, and (8) USGS Sta 8164800 at Placedo Creek near Placedo. River discharges to Matagorda Bay are generally small. Large river discharge can occur during occasional tropical cyclones, and by thunderstorms and winter storms. Figure 3 shows the location map of the NOAA coastal stations and USGS river gauges.

Long- and short-term wind data are available from NOAA Sta 8773767 (MBET2), Sta 8773701 (PCNT2), Sta 8773259 (VCAT2), and Sta 8773146 (EMAT2) at East Matagorda Bay. National Data Buoy Center (NDBC) Station 42019, approximately 110 km (70 miles) south of Freeport (Fig.3), collects long-term wind and wave data.

NUMERICAL MODELING

ADCIRC Model

The ADCIRC model was applied to simulate regional water levels and circulation. It calculates the water surface fluctuation and subsurface current with high resolution in areas of complex shoreline configuration and bathymetry. The model is based on a finite-element algorithm that allows for flexible spatial discretization of the computational domain. Forcing functions include time-varying water surface elevation, wind shear stress, river inflow, and wave radiation stress if operated together with a wave model.

The ADCIRC model solves the two-dimensional (2-D), depth-integrated shallow water equations or the three-dimensional (3-D) equations of motion for conservation of mass and momentum (Luettich et al. 1992). The model can be applied to a large domain encompassing the ocean, continental shelves, coastal seas, and estuarine systems. The ADCIRC 2-D version was applied without wave forcing to the model in the present study. It was served as a regional hydrodynamic model to provide boundary conditions as input to the CMS modeling. Figure 4 shows the ADCIRC mesh and CMS model domain (red box area) for the study area. The mesh has finer cell spacing around 25 m (80 ft) along the ship channel and coarser resolution to 6,000 m (20,000 ft) along the offshore open boundary.



Figure 3. Location of NOAA coastal stations and USGS river gauges.

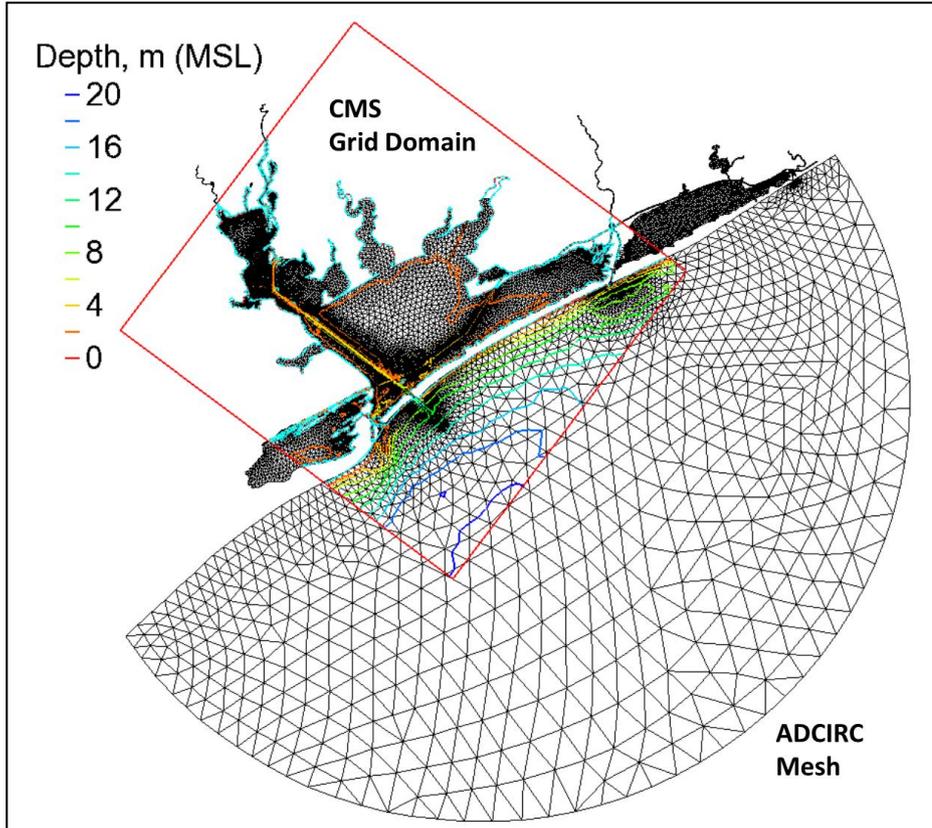


Figure 4. ADCIRC mesh and CMS model domain (red box area).

The ADCIRC mesh covers a large multiple-inlet system that includes the Matagorda Ship Channel (MSC) and Pass Cavallo in Matagorda Bay, Mitchells Cut in East Matagorda Bay, and the Colorado River Navigation Channel (CRNC), and the Mouth of Colorado River (MCR) between two bays (Fig.4). The vertical datum is referenced to the Mean Sea Level (MSL). Both the entrance of the MSC and MCR are protected by jetty structures. The freshwater input to this large system mainly come from four river streams. The CR and LR discharge to the northeast and northwest ends, respectively, of Matagorda Bay while Caney Creek and Live Oak Bayou discharge to the northeast end of East Matagorda Bay (Fig.1). The water exchange between Matagorda Bay and East Matagorda Bay is rather weak through the GIWW and controlled by a pair of boat locks at the junction with CR, and through a small diversion channel connecting the lower CR and CRNC.

CMS Models

The CMS is a suite of numerical wave, hydrodynamic and sediment transport models (Demirbilek and Rosati, 2011) consisting of CMS-Wave and CMS-Flow. CMS-Wave is a finite-difference, 2-D steady-state wave spectral transformation model that calculates wave propagation, generation, refraction, diffraction, reflection, transmission, run-up, and wave-current interaction (Lin et al. 2008, 2011). CMS-Flow is a finite-difference time-dependent circulation model which also calculates sediment transport and morphology changes (Buttolph et al. 2006). Forcing functions include water surface elevation, wind field, river inflow, and wave radiation stress if operated with wave model.

CMS-Wave and CMS-Flow can be coupled on a non-uniform Cartesian grid. In the coupling mode, the variables passed from CMS-Wave to CMS-Flow are the significant wave height, peak wave period, wave direction, wave breaking dissipation, and radiation stress gradients. CMS-Wave uses the update bathymetry, water levels, and currents from CMS-Flow. The coupling can be operated through the Surface-water Modeling System (SMS, Zundel, 2006). Coupling CMS-Wave and CMS-Flow can simulate many important coastal processes like wave-current interaction, longshore current, channel infilling, beach erosion, coastal inundation, storm surge, and storm damage to nearshore structures.

The CMS model grid covered a rectangular area approximately 66 km x 71 km (41 mile x 44 mile). It contains Matagorda Bay and Lavaca Bay with two major inlets MSC and Pass Cavallo, located to the southwest end of Matagorda Bay. Figure 5 shows the CMS model bathymetry domain.

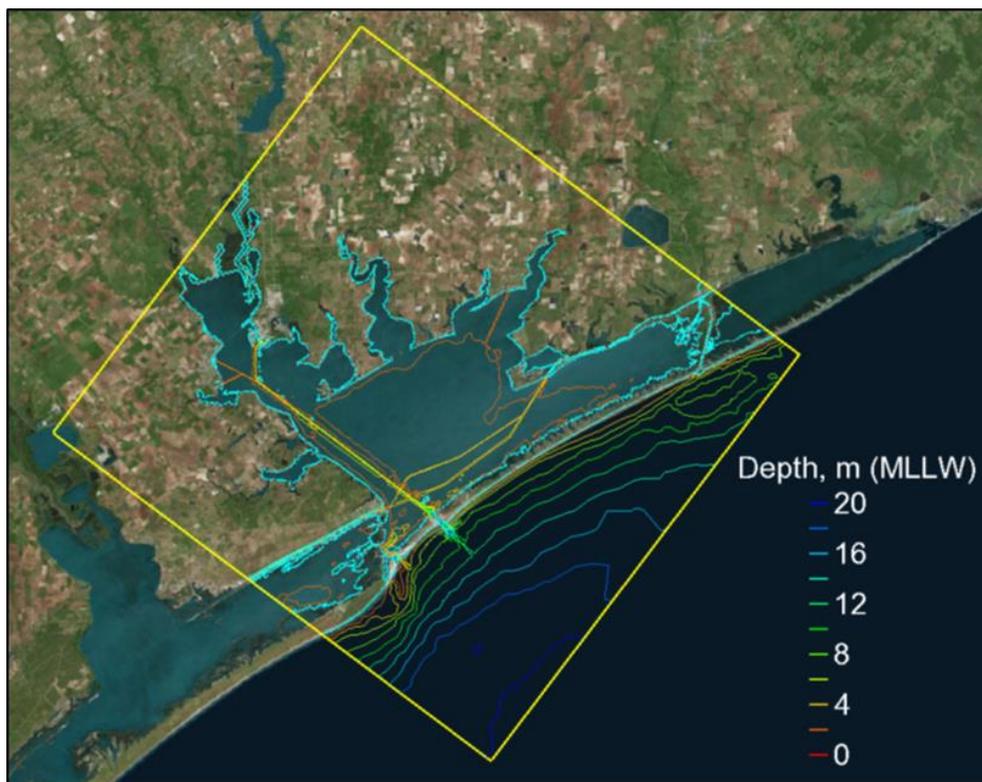


Figure 5. CMS model domain and bathymetry.

The freshwater input to the CMS models for Matagorda Bay mainly come from two river streams: the CR discharging to eastern end of Matagorda Bay and LR at the northern end of Lavaca Bay. The CMS wave and flow model grid domain extended northward to include lower reaches of LR, and southward to the 20-m (66-ft) depth, MLLW, in the Gulf of Mexico. The east boundary reached the tidal flat of East Matagorda Bay and MCR. The west boundary reached the eastern part of Espiritu Santo Bay. The CMS model cell resolution varies from 20 m (66 ft) around the MSC to 500 m (1,640 ft) in the offshore area.

MODELING SCENARIOS AND RESULTS

Both ADCIRC and CMS models were calibrated for the Matagorda Ship Channel and Matagorda Bay in the previous studies (studies (Kraus et al. 2006; Maynard et al. 2011; Wood et al. 2017). The present modeling effort includes three river flow conditions, high, medium, and low flows, and two historical hurricanes, Rita (2005) and Harvey (2017) affecting the study area. The water level input for the open boundary in the GOM includes two levels: the presentative present and future water levels. The presentative present water level is based on the projection of Sea Level Rise (SLR) for 2024 while the future level is based on the projection of SLR for 2074 or a 50-year future level from 2024. The ADCIRC results provided open water boundary conditions (water levels and currents) for the CMS. The modeling scenarios were categorized into four groups: (1) PWOP - Present water levels without (W/O) Project (i.e., the existing ship channel configuration), (2) PWP - Present water levels With Project (i.e., with ship channel deepening/widening alternatives), (3) FWOP - Future water levels W/O Project, and (4) FWP - Future water levels With Project.

The alternatives (with project in PWP and FWP) includes deepening/widening the existing ship channel, expanding existing PA's at Bird Island and Point Comfort, and adding five new PA's along the west side of MSC. These PA's are filled up with the maximum elevation equal to 0.61 m (2 ft) above the MLLW. Because these new PA's are close to the MSC, their elevation could be lowered (submerged) and limited to -0.61 m (-2 ft), MLLW for environmental concerns.

The representative of the present water level is specified by the projection of 2024, which uses 2017 water level (MLLW) + 0.061 m (0.2 ft) for the projected SLR. The future water level is based on the projection of 2074, or a 50-year future water level from 2024, which is equal to 2017 water level (MLLW) + 0.573 m (1.88 ft) for the projected SLR.

Table 1 presents the modeling scenarios. Table 2 presents the simulation period and river flow input condition. For two hurricanes and "high river flow" scenarios, field data collected in 2005 and 2017 were applied for the model input. For the "medium river flow" condition, river inflow rates of 40, 10, and 4 m³/sec were used for CR, LR, and Garcitas Creek, respectively. For the "low river flow" condition, river inflow rates of 17, 2, and 1.5 m³/sec were used for CR, LR, and Garcitas Creek, respectively. It is noted that the "low river flow" condition was exceeded approximately 95% of the time in Matagorda Bay. In each of PWOP, PWP, FWOP, and FWP, the river inflow to the Matagorda Bay and Lavaca Bay from CR and LR was simulated for two historical hurricanes, Rita (2005) and Harvey (2017), and three representative "high river flow", "medium flow", and "low flow" conditions. Therefore, a total of 4 x 5 = 20 modeling scenarios were modeled (marked with x in Table 1).

River Inflow Condition	Present/Future Water Level and MSC Configuration			
	PWOP (present without project)	PWP (present with project)	FWOP (future without project)	FWP (future with project)
Hurricane Rita (2005)	X	X	X	X
Hurricane Harvey (2017)	X	X	X	X
High river flow	X	X	X	X
Medium river flow	X	X	X	X
Low river flow	X	X	X	X

Table 2. Model simulation period and river inflow conditions.			
River Inflow Condition	Simulation period	River inflow discharge	Wind and water level input
Hurricane Rita (2005)	8-30 Sep, 2005	field data	field data
Hurricane Harvey (2017)	10 Aug – 10 Sep, 2017	field data	field data
High river flow	10 Feb – 10 Mar, 2017	field data	field data
Medium river flow	1 July – 20 Aug, 2017	54.0 m ³ /sec	field data
Low river flow	1 July – 20 Aug, 2017	20.5 m ³ /sec	field data

The analysis of model results includes comparison of differences between PWP and PWOP (i.e., PWP – PWOP), and between FWP and FWOP (i.e., FWP – FWOP). The statistics of maximum, average, and minimum of PWP – PWOP and FWP – FWOP were compared for model water levels and current speeds in the bay. Figures 6 and 7 show, as examples, the difference of model maximum and average current magnitude fields, respectively, from Hurricane Harvey for PWP – PWOP. Figures 8 and 9 show the difference of model maximum and average current fields, respectively, from Hurricane Harvey for FWP – FWOP. In the modeling of Hurricane Harvey, the difference of average current speeds between PWP and PWOP (or PWP – PWOP), and between FWP and FWOP (FWP – FWOP), is small, within +/- 0.1 m/sec. The currents along and near MSC are slightly stronger in scenarios with the project than without the project. In the lower Matagorda Bay, these currents get slightly stronger in future scenarios than present scenarios.

Baywards of Bird Island, the maximum current speeds become larger with the project (PWP and FWP) and the difference of current speeds is greater with the present scenarios (PWP – PWOP) than the future scenarios (FWP – FWOP). For Harvey, the maximum current along and around MSC can be 0.5 m/sec greater with project than without project.

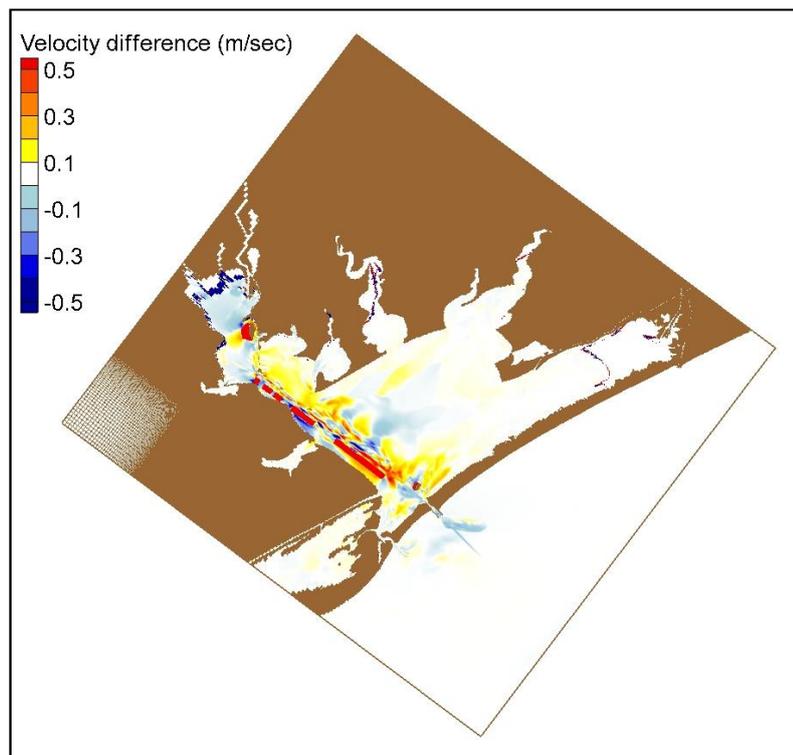


Figure 6. Difference of maximum current speeds from Hurricane Harvey for PWP-PWOP.

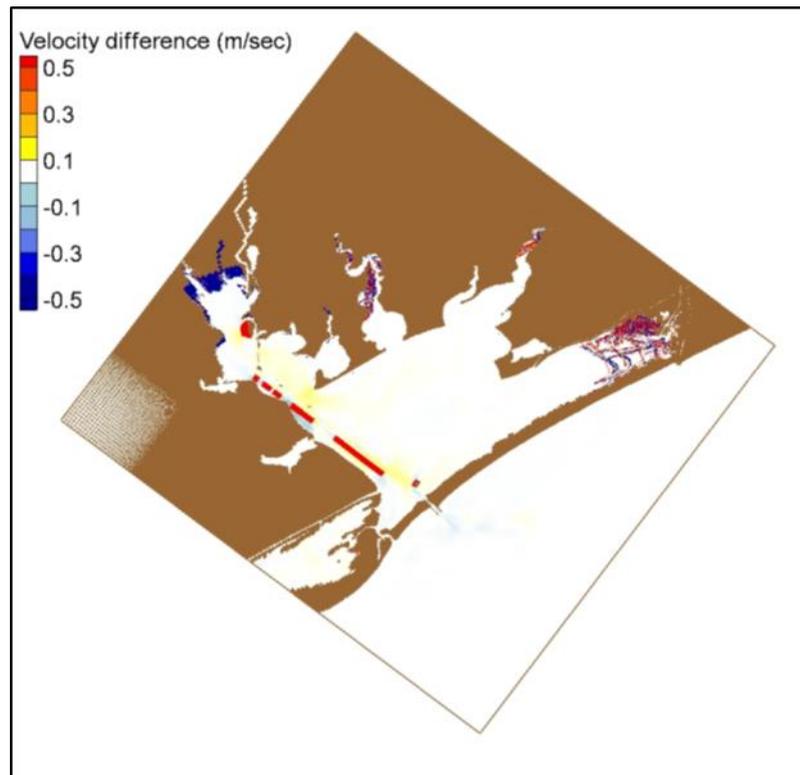


Figure 7. Difference of average current speeds from Hurricane Harvey for PWP-PWOP.

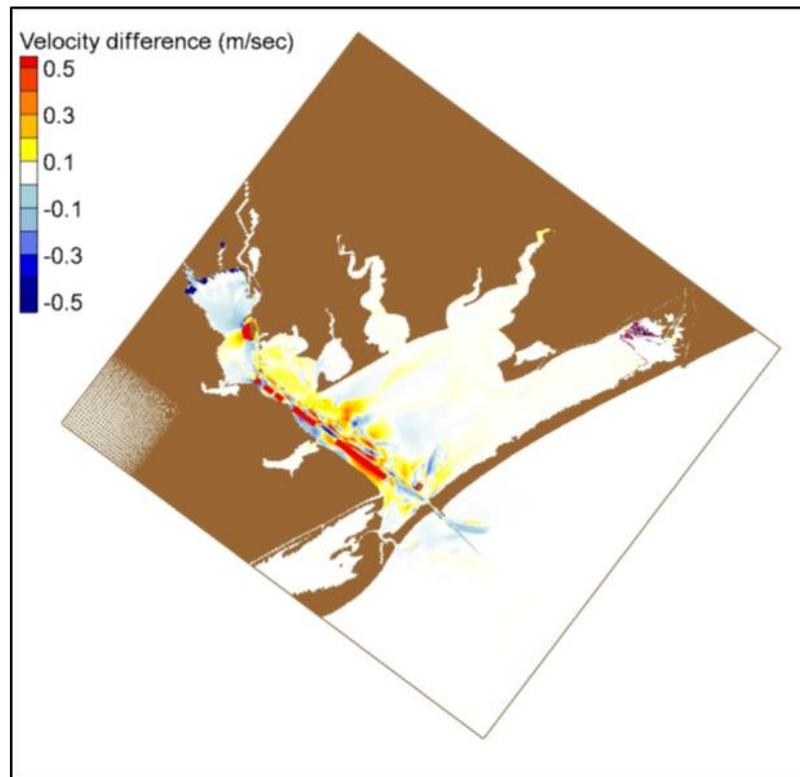


Figure 8. Difference of maximum current speeds from Hurricane Harvey for FWP-FWOP.

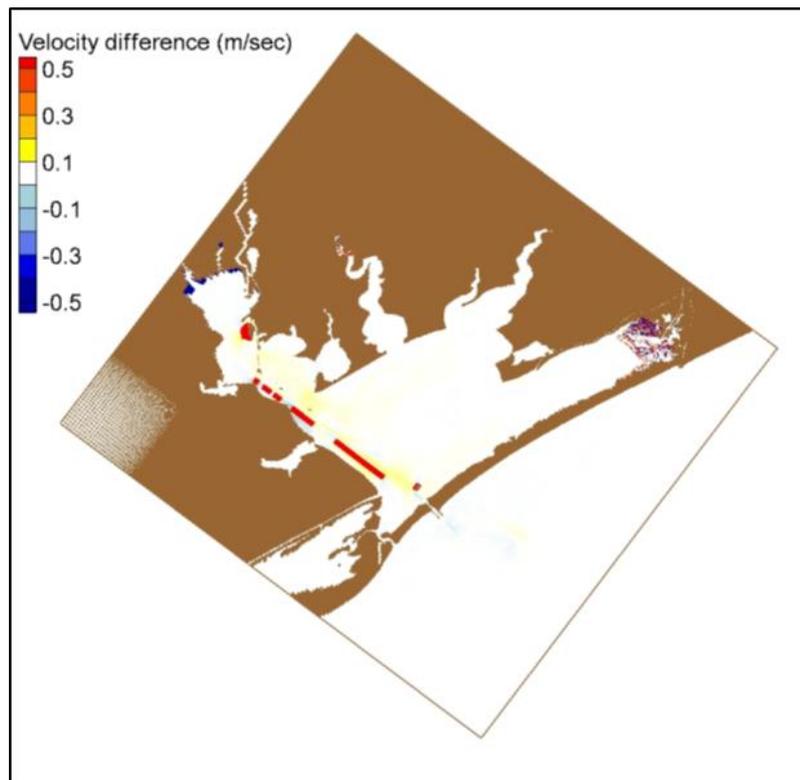


Figure 9. Difference of average current speeds from Hurricane Harvey for FWP-FWOP.

In Matagorda Bay, the difference of model water levels between PWOP and PWP, and between FWOP and FWP, is overall small, within ± 0.05 m for Rita, “high river flow”, “medium flow” and “low flow” excluding PA areas. The difference is more significant for Harvey, within ± 0.5 m and ± 0.2 m in PWP – PWOP and FWP – FWOP, respectively. Water levels in the bay tend to increase slightly with project and with greater river inflow. The water level change in the bay is less sensitive in future scenarios with higher water level input than in present scenarios.

CONCLUSIONS AND RECOMMENDATION

The present study applied the ADCIRC and CMS models to evaluate changes to hydrodynamics from a proposed deepening/widening configuration of Matagorda Ship Channel. The modeling includes simulations for the present and future water levels. The model grid/mesh bathymetry were updated from previous studies (Kraus et al. 2006; Maynard et al. 2011; Wood et al. 2017) with recent Lidar data and channel surveys. The ADCIRC was served as a regional hydrodynamic model to cover Matagorda Bay, East Matagorda Bay, and long open Gulf coast outside the bay area. It provided boundary conditions as input to the CMS for modeling the MSC alternatives. The water level data collected from NOAA Coastal Sta 8775870 (MQTT2) at Bob Hall Pier, Corpus Christi, were used for the seaward boundary condition in ADCIRC.

The Port Comfort Authority and USACE Galveston Office have proposed a deepening/widening configuration for the present Matagorda Ship Channel. The proposed plan is to modify the offshore entrance channel with new width of 600 ft from 300 ft and new depth of 49 ft from 40 ft, MLLW. The channel side slope is 5H: 1V. For the entrance channel between dual jetties, the new width is 600 ft from 300 ft, and new depth is 47 ft from 38 ft. Bayside of the inlet entrance, the new channel width is in transition from 600 ft to 350 ft, and new depth is 47 ft from 38 ft. In Matagorda Bay and Lavaca Bay, the new width is 350 ft from 200 ft, and new depth is 47 ft from 38 ft. The channel side slope is 3H: 1V. The MSC alternatives modeled in the present investigation includes the proposed deepening/widening channel, new placement areas along the ship channel, and a wider turning basin at Port of Port Lavaca - Point Comfort. All new placement areas inside the bay were filled up with the elevation equal to 2 ft, MLLW (i.e., 2 ft above the MLLW). It is noted that for environmental concerns

the elevation of these new placement areas could be kept at 2 ft below MLLW in practice and in the field operation.

Modeling scenarios include two input water levels in the Gulf of Mexico, the present and future water levels, and two channel configurations, the existing MSC and a proposed ship channel deepening/widening project. These modeling scenarios are categorized into four groups: (1) PWOP - Present water levels Without (W/O) Project, (2) PWP - Present water levels With Project, (3) FWOP - Future water levels W/O Project, and (4) FWP - Future water levels With Project. In each of PWOP, PWP, FWOP, and FWP, the river inflow to the Matagorda Bay system from CR and LR was simulated for two historical hurricanes, Rita (2005) and Harvey (2017), and three representative “high river flow”, “medium river flow”, and “low river flow” conditions (Tables 1 and 2).

The analysis of model results shows the proposed improvements (i.e., with alternatives or project) will slightly increase flow efficiency and current speed in the channel except for Harvey which is an extraordinary storm on the Texas coast. With the project (PWP and FWP), the deepened and widened ship channel tends to increase the flow efficiency at the Matagorda Ship Channel Entrance and, accordingly, increase the average water levels inside the bay as compared to scenarios without the project (PWOP and FWOP). This effect is more pronounced in scenarios with the present water level (PWP) than the future water level (FWP).

The effect of the proposed improvements to water levels and current velocities is generally insignificant. Water levels in the bay tend to increase slightly with project and with larger river inflow. The water level change in the bay is less sensitive in future scenarios with higher water level input than in present scenarios. Current velocities in and around MSC tend to increase with project (with proposed ship channel improvements) and also with larger river input and higher water level input (future scenarios). The difference of model maximum current speeds with project and without project is normally within +/-0.1 m/sec for “high river flow”, “medium river flow”, and “low river flow” conditions. For Harvey, the difference of model maximum current speeds with and without project increases to +/-0.5 m/sec.

Navigation safety is expected to be improved by reducing current velocities approximately 20 to 30 percent by modifying the MSC inlet entrance to have the same top width as the gulf-ward rock jetties and implementing a pair of rock flares at the entrance’s bay side. Installing a pair of rock flares with training spurs at the bay side will guide the ebb current towards the center of the entrance, inhibiting growth of the existing scour for safer navigation condition.

The MSC Tentatively Selected Plan (TSP) is to deepen the channel from the beginning to the end of the main channel to 47 - 50 ft with 2-ft advanced maintenance and 2-ft over depth and widen the channel width to 350 - 600 ft from the Gulf entrance to the main channel, except for a segment between Matagorda Peninsula and Bird Island which is shifted and realigned westward of the existing channel. The TSP includes the expansion of turning basin diameter to 1,200 ft at Port Comfort for the design ship category. Future studies are recommended for investigation of sediment transport and potential increase of channel shoaling rate due to the proposed ship channel improvement project.

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