TxBLEND Model Calibration and Validation for the Lavaca-Colorado Estuary and East Matagorda Bay

February 14, 2011

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Introduction

Senate Bill 137 (1975), House Bill 2 (1985), Senate Bill 683 (1987), and other legislative directives call for the Texas Water Development Board (TWDB) to maintain a data collection and analytical study program focused on determining the freshwater inflows needs which are supportive of economically important and ecologically characteristic fish and shellfish species and the estuarine life upon which they depend. More recent legislative directives, Senate Bill 1 (1997) and Senate Bill 3 (2007), also direct TWDB to provide technical assistance in support of regional water planning and development of environmental flow regime recommendations, which include consideration of coastal ecosystems. In response to these directives, the Bays & Estuaries Program at TWDB has continued to develop and implement TxBLEND, a two-dimensional, depth-averaged hydrodynamic and salinity transport model, to simulate water circulation and salinity condition within the bays. Because TxBLEND produces high-resolution, dynamic simulations of estuarine conditions over long-term periods, the model has been used in a variety of projects including freshwater inflow studies, oil spill response, forecasts of bay conditions, salinity mitigation studies, and environmental impact evaluations.

Presently, TWDB has calibrated TxBLEND models for all seven of the major estuaries in Texas including Sabine Lake, Galveston Bay, Matagorda Bay, San Antonio Bay, Aransas and Copano Bays, Corpus Christi Bay, and the Laguna Madre. In some cases, TWDB has multi-bay models, such as presented in this report. While TxBLEND continues to be the principal hydrodynamic model used by TWDB for estuary analyses, staff is exploring the use of three-dimensional hydrodynamic models for future efforts.

This report is one in a series which documents the calibration and validation of TxBLEND for the major estuarine systems. This report focuses on the calibration and validation of TxBLEND for the Lavaca-Colorado Estuary and East Matagorda Bay, but is not limited to these bay systems. Instead, the model includes Espiritu Santo Bay and San Antonio Bay to the west in order to better simulate water circulation and salinity transport within the estuary. TxBLEND was calibrated for velocity, discharge, surface elevation, and salinity. The model subsequently was validated for salinity. Model validation focused on model performance near established long-term monitoring locations. However, additional sites may be validated upon request or as data becomes available. Future updates to model calibration or validation will be documented in subsequent versions of this report.

Study System

The Lavaca-Colorado Estuary (or Matagorda Bay system) is the second largest estuary in Texas and includes Lavaca Bay, Matagorda Bay, Carancahua Bay, Tres-Palacios Bay and several smaller bays. Major freshwater inflow sources include the Colorado, Lavaca, and Tres Palacios Rivers. The Colorado River discharges into the eastern arm of Matagorda Bay via the Diversion Channel, and the Lavaca River discharges into Lavaca Bay. The Matagorda Ship Channel transverses the bay from the Gulf of Mexico through the Entrance Channel toward Lavaca Bay. A direct connection to the Gulf of Mexico exists through Pass Cavallo and the man-made Entrance Channel. Matagorda Bay's westernmost side is connected to the San Antonio Bay system (via Espiritu Santo Bay) through the Gulf Intracoastal Waterway (GIWW), Saluria Bayou and Big Bayou passes. East Matagorda Bay is included in the TxBLEND model grid, but is separated from Matagorda Bay. East Matagorda Bay has no direct source of freshwater inflow, aside from surface runoff, and has one connection to the Gulf of Mexico at Mitchell's Cut on the easternmost edge of the bay.

Figure 1. Regional map of the Lavaca-Colorado Estuary on the Texas coast. Matagorda Bay receives freshwater inflow from the Colorado and Lavaca Rivers (via Lavaca Bay) and has a direct connection to the Gulf of Mexico via the Entrance Channel and Pass Cavallo.

Model Description

TxBLEND is a computer model designed to simulate water circulation and salinity conditions in estuaries. The model is based on the finite-element method, employs triangular elements with linear basis functions, and simulates movements in two horizontal dimensions (hence vertically averaged). TxBLEND is an expanded version of the BLEND model developed by William Gray of Notre Dame University to which additional input routines for tides, river inflows, winds, evaporation, and salinity concentrations were added along with other utility routines to facilitate simulation runs specific to TWDB's needs (Gray 1987, TWDB 1999). The current version of TxBLEND being used for model applications is Version S8HH.f. Important parameters and features of the model are explained in Table 1.

Water circulation (velocity and tidal elevation) is simulated by solving the generalized wave continuity equation and the momentum equation, often jointly called the *shallow water equations* (TWDB 1999). Salinity transport is simulated by solving a mass transport equation known as the advection-diffusion equation. Several assumptions are inherent to using the shallow water equations to simulate two-dimensional flow in a horizontal plane, specifically:

1. Fluid depth is small relative to the horizontal scale of motion
2. Vertical pressure distribution is hydrostatic
3. Vertical stratification is negligible
4. Fluid density variations are neglected except in the buoyancy term (Boussinesq approximation).

Texas bays are generally very shallow, wide, bodies of water which are relatively un-stratified, thus satisfying the assumptions above.

Model output includes time-varying depth and vertically-averaged horizontal velocity components of flow and salinity throughout the model domain. TxBLEND thus provides water velocity and direction, surface elevation, and salinity at each node in the model grid (see below for details about the model grid for the Lavaca-Colorado Estuary). The model does not provide information about vertical variation within the water column, but rather provides information about horizontal variation, such as salinity zonation patterns throughout the estuary. The model is run in two or three minute time-steps, typically with hourly output. Model simulations may be run to represent brief periods of time, a week or month, or may be run for years.

Table 1. Description of TxBLEND model parameters, features, and inputs.

Feature	*Description*
Generalized Wave Continuity Equation (GWCE)	A special form of the continuity equation designed to avoid spurious oscillation encountered when solving the primitive continuity equation using the finite element method. Solved by an implicit scheme prior to solving the momentum equation. The GWCE is an established equation used to solve mass-balance or flow continuity in 2-D finite element hydrodynamic models (Kinnmark and Gray 1984).
Momentum Equation	2-D, Depth Integrated Momentum Equation is solved for most applications. Non-linear terms are neglected most of the time.
Advection-Diffusion Equation	Used to calculate salinity transport.
BigG	A parameter in the generalized wave continuity equation. Larger values of BigG reduce mass balance errors by increasing the enforcement of the continuity equation at the price of increased numerical difficulty (TWDB 1999). Typically, set at 0.01 – 0.05.
Manning's n Roughness Coefficient	Used to represent bottom friction stress. For TxBLEND, 0.015 to 0.02 is a reasonable default value, but can be increased to 0.03 or higher for a seabed with thick grasses or debris or lowered to 0.01 or less to represent a smooth bay bottom.
Turbulent Diffusion Term	A diffusion factor, representing horizontal diffusion, used to diffuse momentum as a result of the non-linear term in the momentum equation.
Boundary Conditions	Three types of boundaries form the edge of the model domain. (1) *River Boundary* – portion of river entering the bay; (2) *Tidal Boundary* – the limited portion of Gulf of Mexico included where salinity and tidal boundary conditions are set; and, (3) *Shoreline Boundary* – enclosing boundary of the bay.
Wind Stress	Used to impose the effect of wind on circulation.
Dispersion Coefficient	Uses a modified version of the Harleman's equation which contains dispersion constant (DIFCON) that can be varied depending on expectations for mixing rates and to better simulate salinity conditions. Due to variable velocities, the dispersion coefficient is updated in 30-minute intervals during simulation. For most applications, constant dispersion coefficients are used.
Coriolis Term	Used to impose the Coriolis Effect on the hydrodynamics
Tide Data	Water surface elevations at the ocean boundary are specified by input tides.
River Inflow Data	Daily river inflows are introduced at identified inflow points. The data are obtained from TWDB Coastal Hydrology estimates based on gaged and ungaged inflows.
Meteorological Data	Includes evaporation, precipitation, wind speed, and wind direction. Wind data may be input as daily average, 3-hour average, or as hourly data. Evaporation data is used to reflect the effect of evaporation on salinity (Masch 1971). Evaporation rate is a modification of the Harbeck equation to estimate daily evaporation from estuaries developed by Brandes and Masch (1972). Precipitation is input as daily values.

TxBLEND Model Domain for the Lavaca-Colorado Estuary

The TxBLEND computational grid for the Lavaca-Colorado Estuary contains 8,340 nodes and 13,389 elements (Figures 2, 3, 4, and 5). In addition to the bays of the Lavaca-Colorado Estuary system, the model grid also includes East Matagorda Bay to the east and Espiritu Santo Bay and San Antonio Bay to the west. These bays were included to yield better simulation results by modeling conditions at the boundary of the estuary, rather than prescribing pre-set boundary condition. The model grid has 15 inflow points, which correspond to freshwater inflows coming from Caney Creek, Lake Austin, Boggy Creek, Colorado River, Tres Palacios Creek, Turtle Creek, Carancahua Creek, Keller Creek, Cox Creek, Lavaca River, Garcitas Creek, Chocolate Bayou, Powderhorn Creek, Guadalupe River, and Hynes Creek (Figure 6). Bathymetry used to develop the grid was obtained from the National Oceanic and Atmospheric Administration (NOAA) *Nautical Chart 11316: Matagorda Bay and Approaches* and the Army Corps of Engineers Matagorda Bay Model, which covered Matagorda Bay and Lavaca Bay, as well as Carancahua, Chocolate, Cox, Keller, Tres Palacios, and Turtle bays. San Antonio Bay bathymetry was determined from the NOAA *Nautical Chart 11315: Intracoastal Waterway, Espiritu Santo Bay to Carlos Bay*, including San Antonio Bay and Victoria Barge Canal.

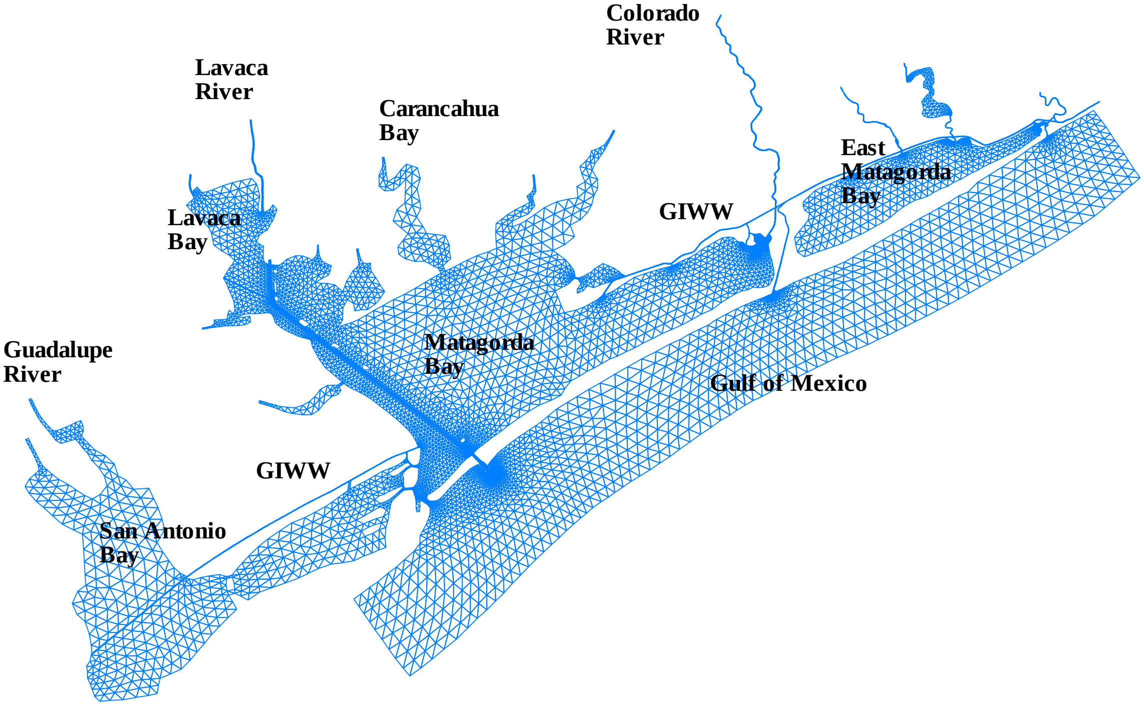


Figure 2. Computational grid for the Lavaca-Colorado Estuary model. The model grid includes East Matagorda Bay and Espiritu Santo and San Antonio bays in order to better represent boundary conditions for Matagorda Bay.

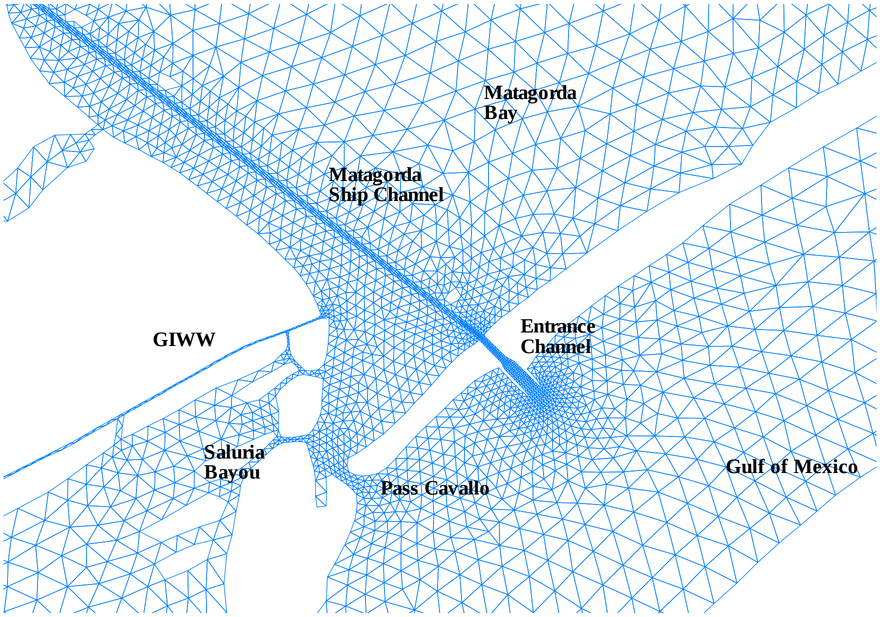


Figure 3. Close-up of the computational grid for the area near the Matagorda Bay Entrance Channel, which is the major tidal inflow point to the bay in conjunction with Pass Cavallo.

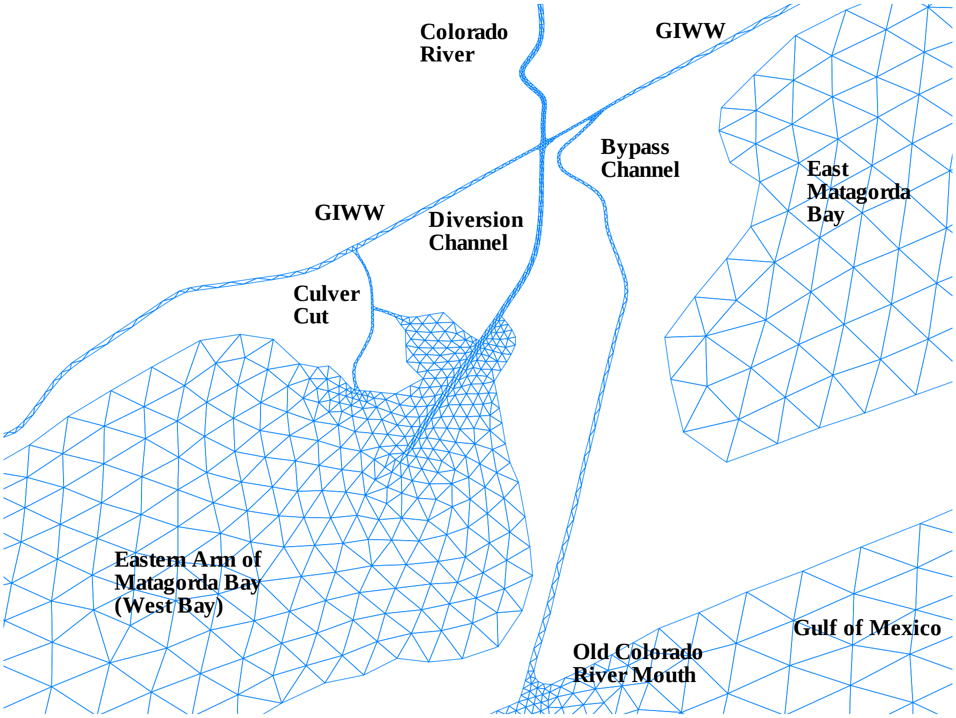


Figure 4. Close-up of the computational grid for the intersection of the Colorado River and the Gulf Intracoastal Waterway (GIWW). The Bypass Channel was a part of the Colorado River before the re-routing of the river to flow into the eastern arm of Matagorda Bay through the Diversion Channel.

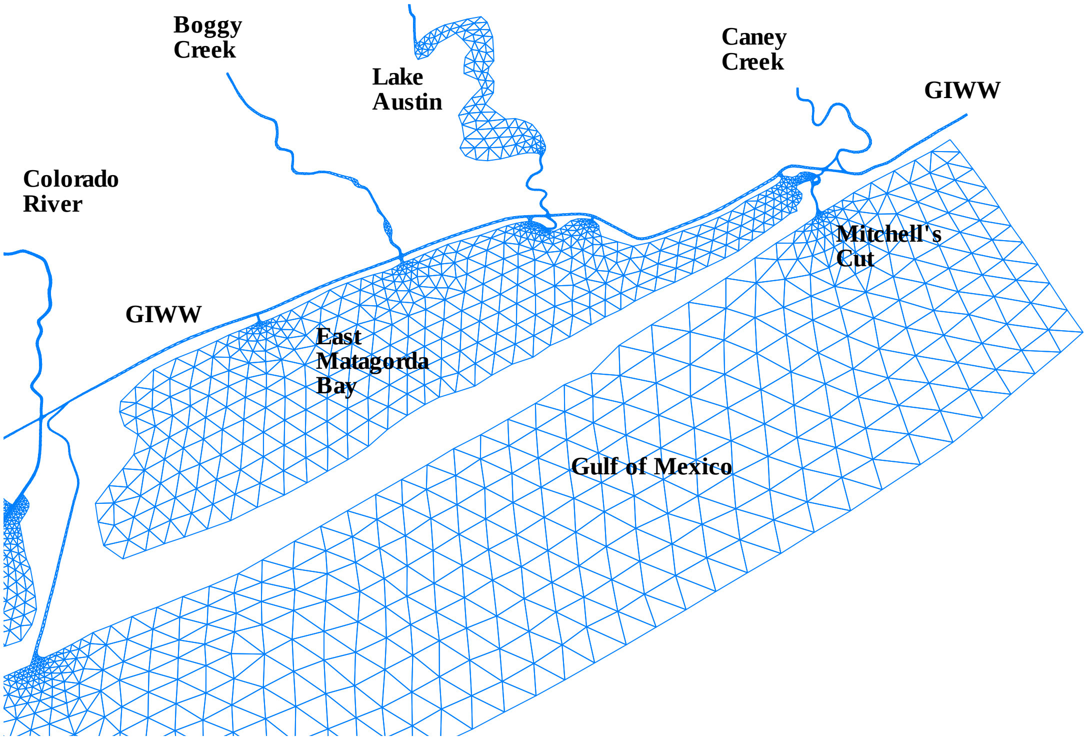


Figure 5. Close-up of the computational grid for East Matagorda Bay.

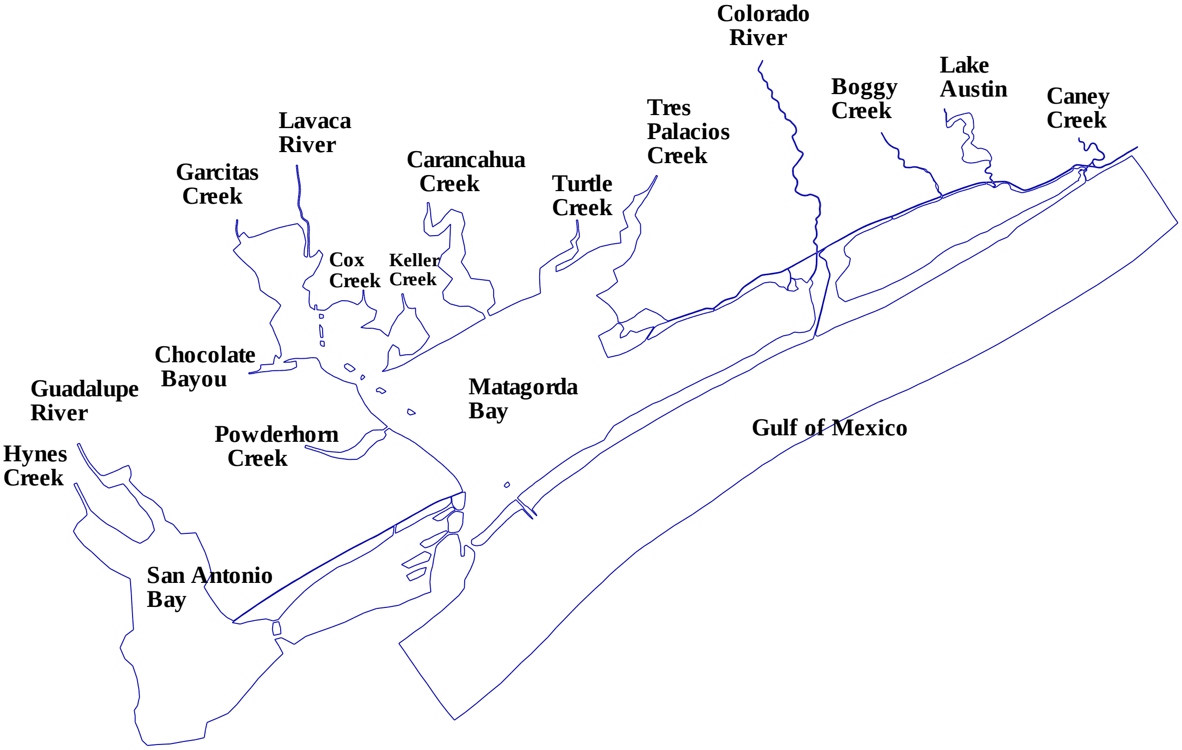


Figure 6. Fifteen inflow points for the Lavaca-Colorado Estuary TxBLEND model.

Inflows

Daily inflow values were taken from the TWDB coastal hydrology datasets version #TWDB201004 for the Lavaca-Colorado Estuary (TWDB 2011a), from Version #TWDB201004 for East Matagorda Bay (TWDB 2011b), and from Version #TWDB201004 for the Guadalupe Estuary (TWDB 2010). While these datasets extend as far back as 1941, with the exception of East Matagorda Bay which extends only to 1977, inflow values were applied only as needed depending on the time period of the model run. For model calibration, inflows from 1997 – 2003 were applied, and for the two validation periods, inflows from 1989 - 1997 and from 2005 - 2009 were applied.

Inflow datasets use measurements from U.S. Geological Survey (USGS) stream gages along with rainfall-runoff estimates from the Texas Rainfall-Runoff (TxRR) model, adjusted for known diversion and return flows obtained from the Texas Commission on Environmental Quality (TCEQ), the South Texas Water Master, and the TWDB Irrigation Water Use estimates, to develop daily inflows for the estuaries. Table 2 lists the USGS stream gages used to develop the gaged inflow component of inflows. For all hydrology datasets, approved USGS stream gage data was available through November 2009 but was provisional for December 2009. Figures 7 and 8 show the watershed boundaries, including the ungaged watersheds modeled using TxRR. Ungaged flows were estimated using precipitation data from the National Weather Service (NWS), which were complete through November 2009 but were provisional for December 2009. Diversion data was obtained from TCEQ (or its predecessor agency, the Texas Natural Resource Conservation Commission) for the period from 1941-2009. Similarly, industrial and municipal return flow data was obtained from the Texas Department of Water Resources self-reporting system from 1941-1976 (except for the East Matagorda Bay system) and from TCEQ (or its predecessor agency) from 1977-2009. Additional diversion data was obtained from the South Texas Water Master through December 2009, and additional return flow data was obtained from TWDB's agricultural return flow estimates through December 2007.

Daily inflows from the surrounding river basins and coastal watersheds were applied to the model at the 15 inflow points specified in Figure 5, according to the distribution described in Table 3. Five inflow points received gaged and ungaged inflows, including the Colorado River, Tres Palacios Creek, Lavaca River, Garcitas Creek, and the Guadalupe River inflow points. The remaining 10 inflow points received only ungaged inflows from local, surrounding watersheds. In some cases, ungaged flows from a given watershed were split between two inflow points.

Table 2. USGS streamflow gages used to develop freshwater inflow estimates for the Lavaca-Colorado and Guadalupe Estuaries.

Estuary	Gage Station Number	Gage Location	Period of Record
Lavaca-Colorado	08162500	Colorado River near Bay City	1948-Present
	08162600	Tres Palacios River near Midfield	1970-Present
	08163500	Lavaca River above Hallettsville	1939-1992
	08164000	Lavaca River near Edna	1938-Present
	08164300	Navidad River above Hallettsville	1961-Present
	08164500	Navidad River above Ganado	1939-1980
	08164503	West Mustang Creek near Ganado	1977-1980
	08164525*	Lake Texana near Edna	1980-Present
	08164600	Garcitas Creek near Inez	1970-Present
	08164800	Placedo Creek near Placedo	1970-Present
	08177500	Coleto Creek near Victoria	1941-1952 & 1978-Present
Guadalupe	08177000	Coleto Creek near Shroeder	1953-1978
	08176500	Guadalupe River at Victoria	1941-Present
	08188500	San Antonio River at Goliad	1941-Present

*USGS gage #8164525 provides lake level; however, TWDB uses release data from Lake Texana provided by the Lavaca-Navidad River Authority to estimate inflows.

Table 3. Distribution of freshwater inflows from surrounding river basins and coastal watersheds to the 15 inflow points of the Lavaca-Colorado Estuary and East Matagorda Bay TxBLEND model. Inflows to San Antonio Bay also were included to improve model boundary conditions.

Receiving Bay	**Inflow Point**	**Source of Inflows**	
		USGS Gages	**Ungaged Watersheds**
East Matagorda Bay	Caney Creek	n/a	13104 (50%), 13105, 13106, 13107, and 13108 (50%)
	Lake Austin	n/a	13101, 13104 (50%)
	Boggy Creek	n/a	13102, 13103
Eastern Arm Matagorda Bay	Colorado River	08162500	14010
	Oyster Bayou*	n/a	15010*
Tres Palacios Bay	Tres Palacios Creek	08162600	15030
	Turtle Creek	n/a	15040
Carancahua Bay	Carancahua Creek	n/a	15050 (84%)
Lavaca Bay	Keller Creek	n/a	15050 (16%)
	Cox Creek	n/a	15060
	Lavaca River	08164000,08164503, 08164500	16008, 16010, 16012, 16014
	Garcitas Creek	08164600, 08164800	17010,17030,17050
	Chocolate Bayou	n/a	17060
Matagorda Bay	Powderhorn Creek	n/a	17070
San Antonio Bay	Guadalupe River	08177500, 08177000, 08176500, 08188500	18012,18014,18020,19011,19012,24602, 24604,24605,24607,24608
	Hynes Creek	n/a	24601,24603,24606

*Ungaged watershed #15010 was not included in the TxBLEND simulation for East Matagorda Bay and the Lavaca-Colorado Estuary.

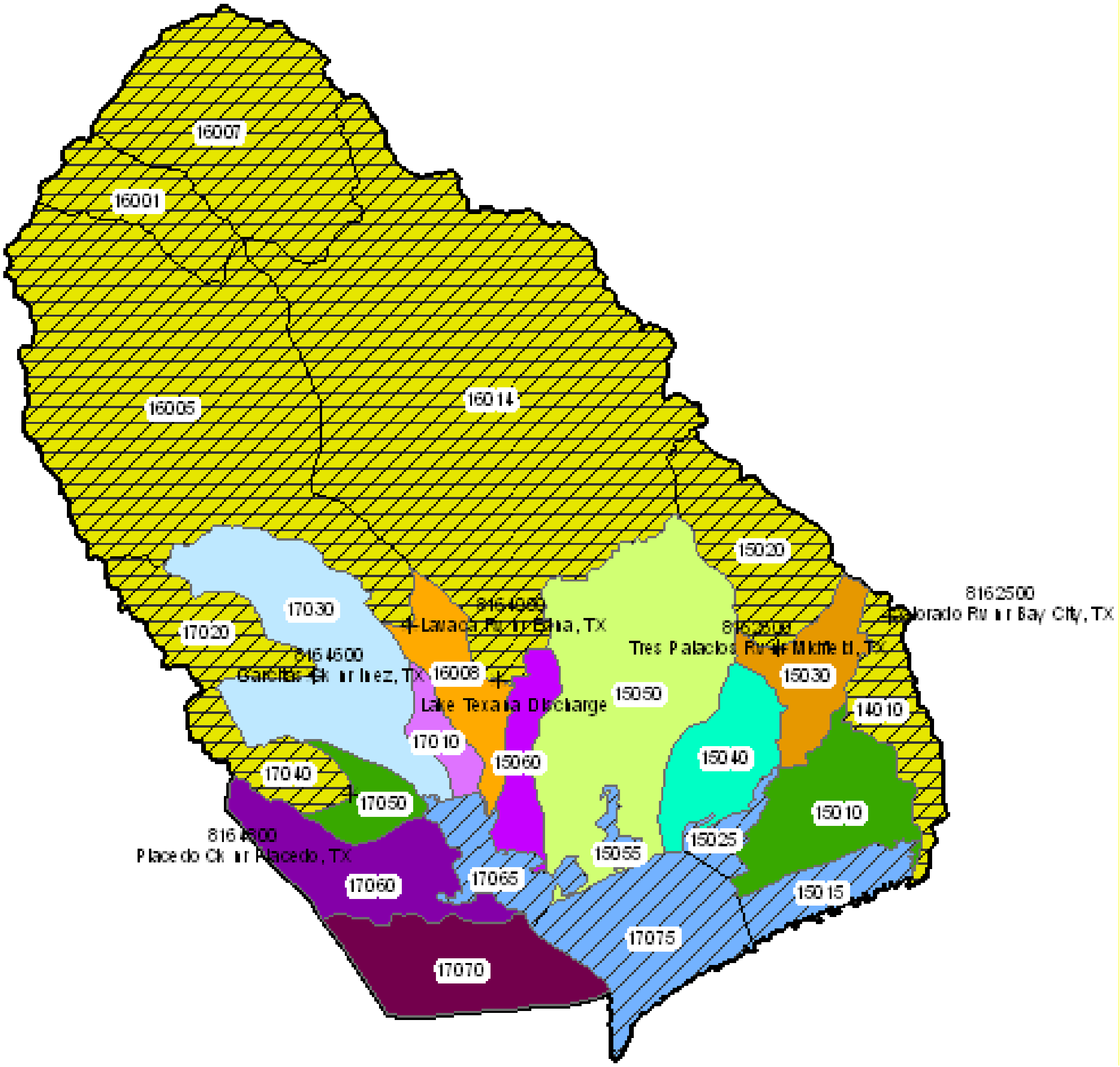


Figure 7. Ungaged watershed delineation used in TxRR to determine ungaged inflows to the Lavaca-Colorado Estuary.

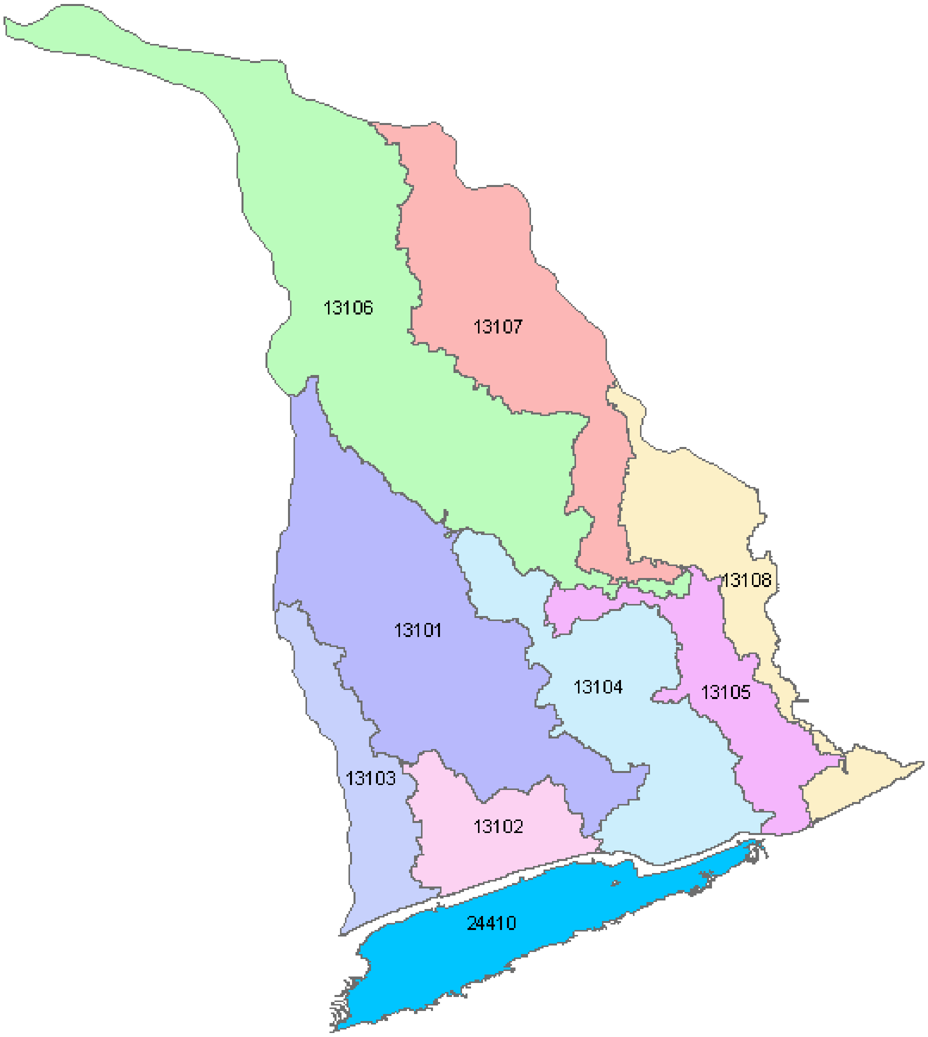


Figure 8. Ungaged watershed delineation used in TxRR to determine ungaged inflows to the East Matagorda Bay system.

Tides

Tidal elevations at Pleasure Pier in Galveston Bay were obtained from the Texas Coastal Ocean Observation Network (http://lighthouse.tamucc.edu/TCOON/HomePage) and applied at the Gulf open boundary.

Meteorology

Time-varying and spatially uniform meteorology is used to drive the model. The dataset includes wind field, air temperature, precipitation, and evaporation. A large portion of the meteorology data (wind speed and direction and air temperature) used to drive the model was obtained from the Lower Colorado River Authority (LCRA). Wind data was obtained for Palacios for the period of January 1987 through April 2003. Additional wind data was obtained from the National Climatic Data Center (NCDC) for the Victoria station to extend the dataset to December 2009. Evaporation data for Palacios was calculated based on the Harbeck Equation (Brandes and Masch 1972) using temperature data from the LCRA, providing data for the period from 1987 through 2003. Precipitation data used for model calibration and validation simulations originally were obtained from the National Weather Service (NWS) and subsequently were processed to provide an estimate of precipitation across the Lavaca-Colorado watershed. TWDB archived records of this data provided daily precipitation measurements for the period from January 1940 through December 2009.

Salinity

Salinity initial conditions were determined by setting the river inflow points at 0 ppt salinity and by using time-varying salinity boundary conditions obtained from the Texas Parks & Wildlife Department (TPWD) Coastal Fisheries database to specify salinity at the Gulf boundary off Matagorda Bay. Model runs allowed for a several year ramp-up period, prior to running simulations for model calibration or validation, to allow the model to distribute salinity appropriately. Several additional sources of salinity data were available for model calibration and validation; these sources are described in corresponding sections below.

Model Calibration

The TxBLEND model was calibrated for both hydrodynamic and salinity transport performance by using water velocity and surface elevation data from intensive field studies to calibrate the hydrodynamics and long-term time-series salinity data to calibrate salinity transport. Model calibration efforts focused on improving model performance by adjusting parameters such as the dispersion coefficient and Manning’s *n*.

Velocity and Discharge

For calibration of this TxBLEND model, four intensive inflow data sets were available. Velocity measurements were collected at eight sites in Matagorda and Lavaca Bays during an intensive inflow study from June 14 – 17, 1988 and at 12 sites from June 30 – July 3, 1993. At most locations, velocity measurements were collected at three depths, 2/10th, 5/10th, and 8/10th from the bottom substrate. Discharge measurements were collected at four sites from September 21-22, 2000 and at 14 sites from March 24-26, 2003. Discharge also was measured in 1993 at one additional site, the Matagorda Entrance Channel. Some of these locations are shown in Figures 9 and 10.

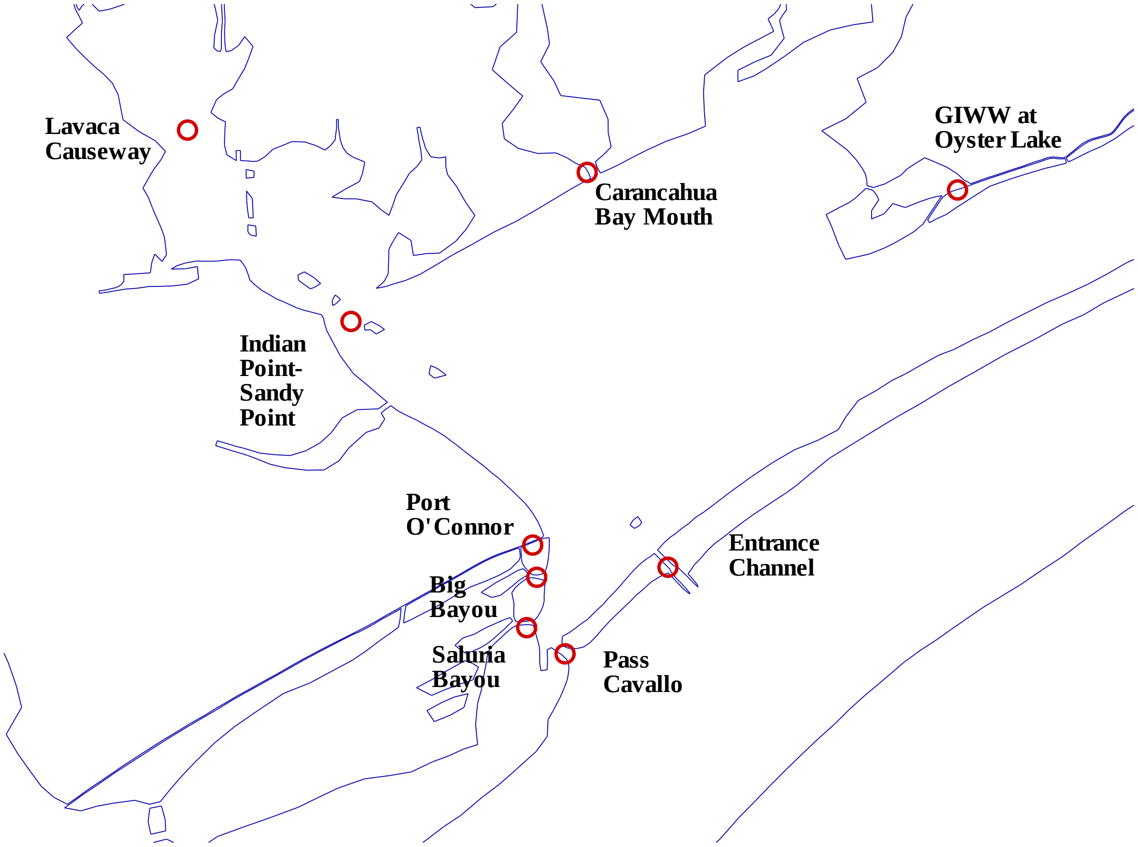


Figure 9. Velocity and discharge measurement sites during intensive inflow studies of the Lavaca-Colorado Estuary during the years 1998, 1993, 2000, and 2003.

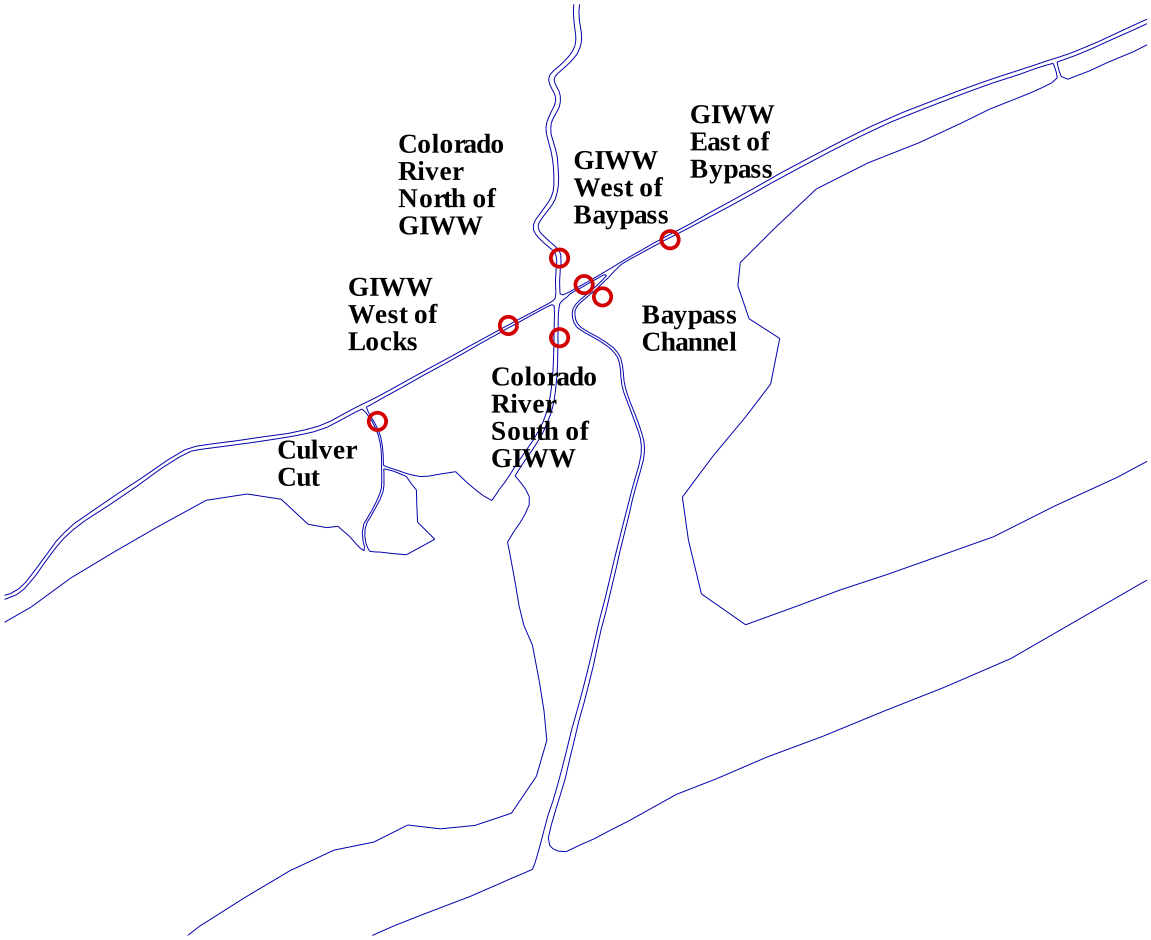


Figure 10. Velocity and discharge measurement sites in the Colorado River and GIWW intersection area during intensive inflow studies during the years 1998, 1993, 2000, and 2003.

Salinity

Long-term salinity records collected by the TWDB, TPWD, and LCRA at hourly or more frequent intervals provide important data for calibrating and validating salinity and circulation models in Texas coastal waters. Within-bay salinity data from seven LCRA long-term monitoring sites was used for model calibration and validation, including: West Bay Channel Marker 4 (1997-2003), West Bay near Sandy Point (1998-2003), Carancahua Bay (1998-2003 and 2005-2009), Palacios Channel Marker 44 (1998-2002), West Bay Tripod (1997-2002 and 2005-2009), East Bay Tripod (1998-2003 and 2005-2009), and East Bay Shellfish Marker (1999-2001 and 2005-2009). Data from TWDB's Datasonde Program at the Lavaca Causeway (1997-2009) also was used (Figure 11). Additional information for the Lavaca Causeway site can be obtained from the TWDB Datasonde Program web site (http://midgewater.twdb.state.tx.us/bays_estuaries/sondpage.html).

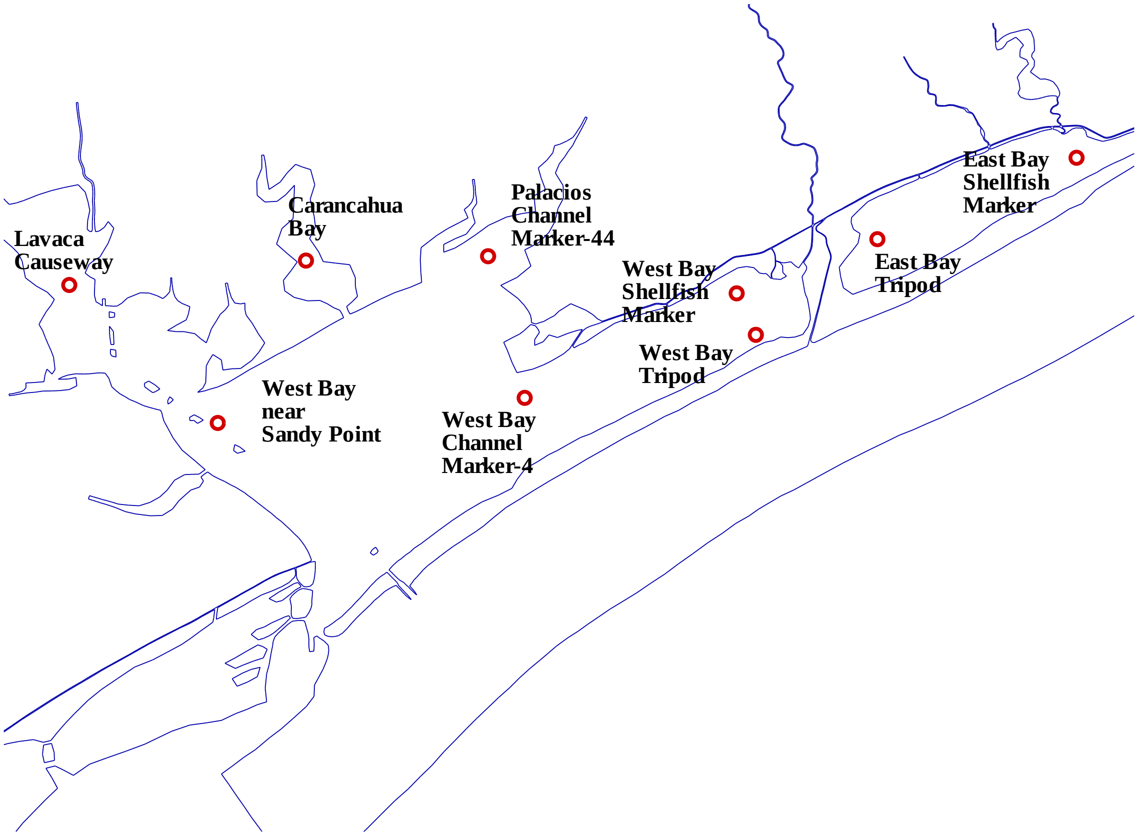


Figure 11. Nine long-term monitoring stations which provided time-series salinity data for use in model calibration and validation.

Model Calibration Parameters

Model parameters adjusted during the calibration of the TxBLEND model included BigG, the dispersion coefficient, and Manning's *n*. BigG is a non-physical parameter which ensures mass conservation and was set to 0.03. Another important parameter for hydrodynamic calibration is Manning's *n* which represents bottom roughness, where larger values of *n* slow water movement and smaller values increase water movement. Values used in the calibrated model are shown in Figures 12 and 13. Similarly, the dispersion coefficient, which represents physical mixing processes, is the key parameter for salinity calibration. The larger the dispersion coefficient, the more effectively dissolved salt disperses. Figure 14 shows values for dispersion coefficients used in the model. Larger values were assigned to the Gulf and major ship channels, and smaller values were assigned to shallow bays.

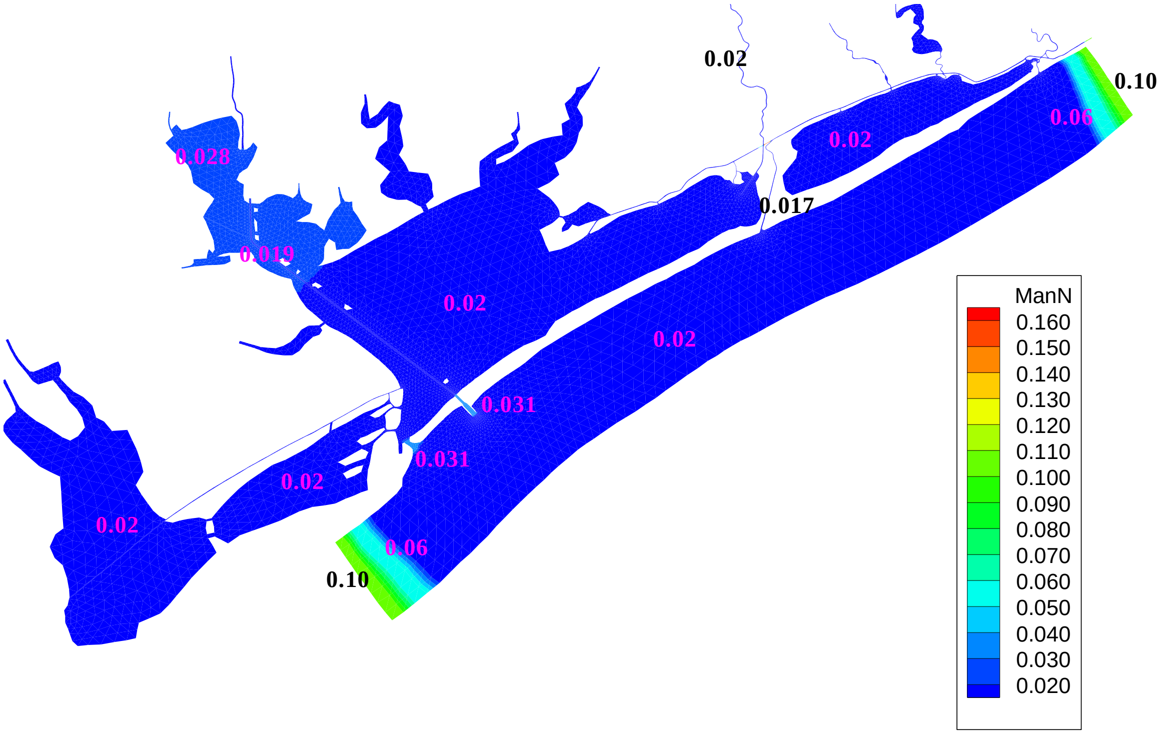


Figure 12. Values of Manning's *n* used in the calibrated Lavaca-Colorado TxBLEND model.

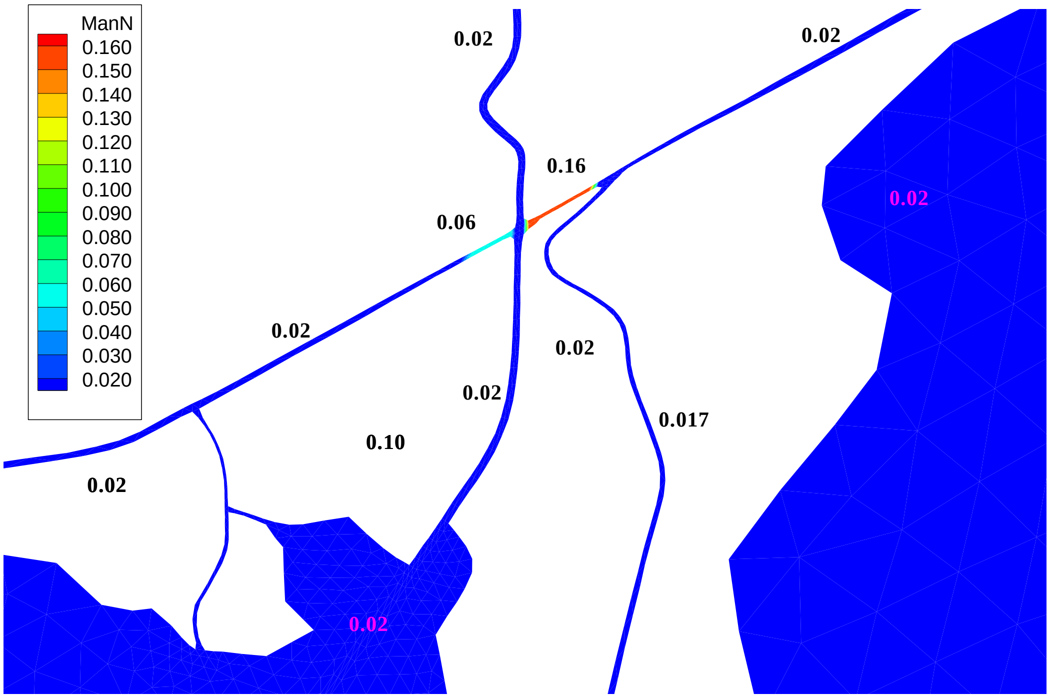


Figure 13. Values of Manning's *n* used in the calibrated TxBLEND model for the Colorado River and GIWW. Larger values of Manning's *n* were applied in the GIWW on either side of the Colorado River to reduce the exchange between the river and GIWW where locks exist.

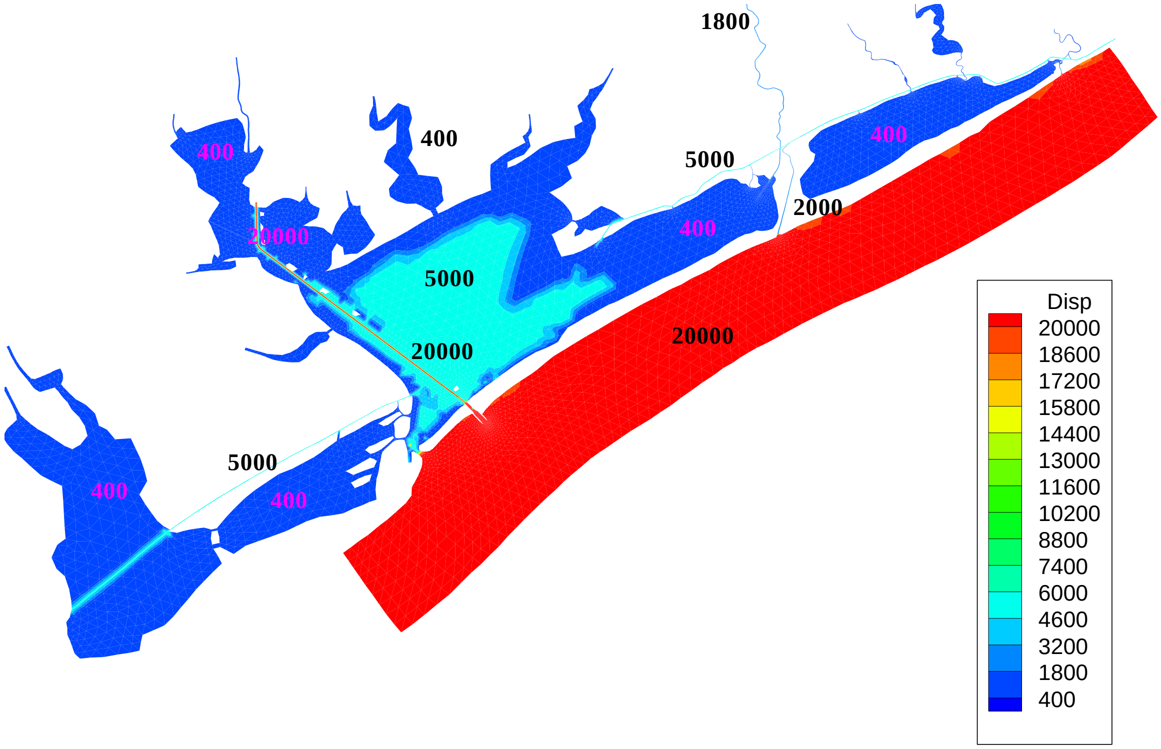


Figure 14. Values of the dispersion factor (ft^2/sec) used in the calibrated TxBLEND model for the Lavaca-Colorado Estuary. The Gulf region and the Matagorda Ship Channel were set to 20,000 ft^2/sec, and the Gulf Intracoastal Waterway (GIWW) was set at 5,000 ft^2/sec.

Calibration Results

Calibration results for velocity, discharge, surface elevation, and salinity for the Lavaca-Colorado TxBLEND model are presented below.

Velocity & Discharge Results

TxBLEND was calibrated for water velocity and discharge using data obtained from four intensive inflow studies in Matagorda Bay, specifically: June 1988, June/July 1993, September 2000, and March 2003. Calibration results are presented in a series of plots showing simulated velocities and discharges as compared to observed field measurements for a number of locations throughout the system. Figures 15 and 16 show calibration results for discharge at eight locations during the intensive inflow study from June 14-17, 1988. Simulated discharge captures the discharge magnitude and flow reversal at most stations throughout the domain very well. Flow measurements during this period show that outflux through Matagorda Channel Entrance was simulated well; whereas, the model under-predicted the outgoing flow magnitude through Pass Cavallo. Moreover, the model over-predicted the flow at the Lavaca Causeway.

Figures 17-20 show calibration results for velocity at 13 locations during the intensive inflow study from June 30-July 3, 1993. Simulated velocities are representative of observed velocities at 11 locations, but are less representative at Culver Cut. The dampening of upstream currents within the bay was captured well, and the increased currents in the narrow channels also were simulated accurately in the model. In some cases, such as at the Indian Point site, the model deviates in magnitude from the observed velocities, but still represents the overall fluctuating trends. Vertical velocity profiles measured at the Colorado River stations near Matagorda and near the diversion channel (Figure 19) show stratified flow with downstream flow occurring near the surface and no directional flow near the bottom); however, such flow patterns cannot be represented using depth averaged model.

Figure 20 shows calibration results for discharge at the Matagorda Entrance Channel in 1993. The model captured both the magnitude and phase of ingoing and outgoing fluxes very well during this period. Figure 21 shows results for discharge at four locations during an intensive inflow study from September 21-22, 2000. Figures 22-25 show results for discharge at 14 locations in the Lavaca-Colorado Estuary during an intensive inflow study from March 24-26, 2003. The model did very well in simulating discharge across all channels throughout the modeled region. An interesting comparison is observed in the discharge measurements at Pass Cavallo in 1988 (Figure 15) versus in 2003 (Figure 22). Flow through the pass declined significantly from 1988 to 2003, which may be indicative of the siltation that has occurred in Pass Cavallo. Model simulations represented this reduced flow through Pass Cavallo very well. Although few measurements are available to compare to simulated discharge to observed discharge at two sites, the GIWW near Oyster Creek and GIWW West of Locks, overall the model represents discharges in the system.

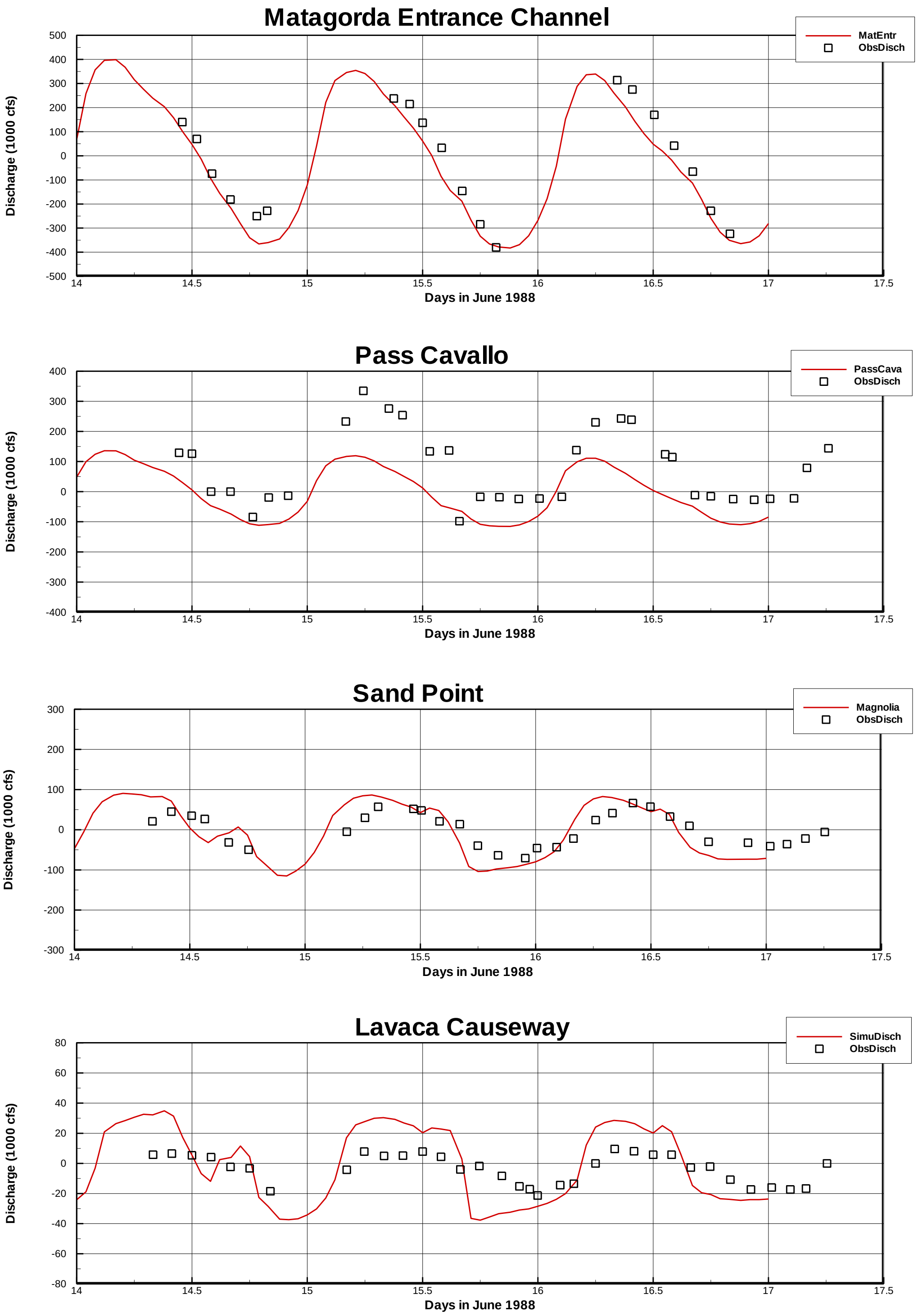


Figure 15. Simulated (red line) and observed (open symbols) discharges for the following sites from top to bottom: Matagorda Entrance Channel, Pass Cavallo, Sandy Point, and Lavaca Causeway for June 14-17, 1988 in the Lavaca-Colorado Estuary.

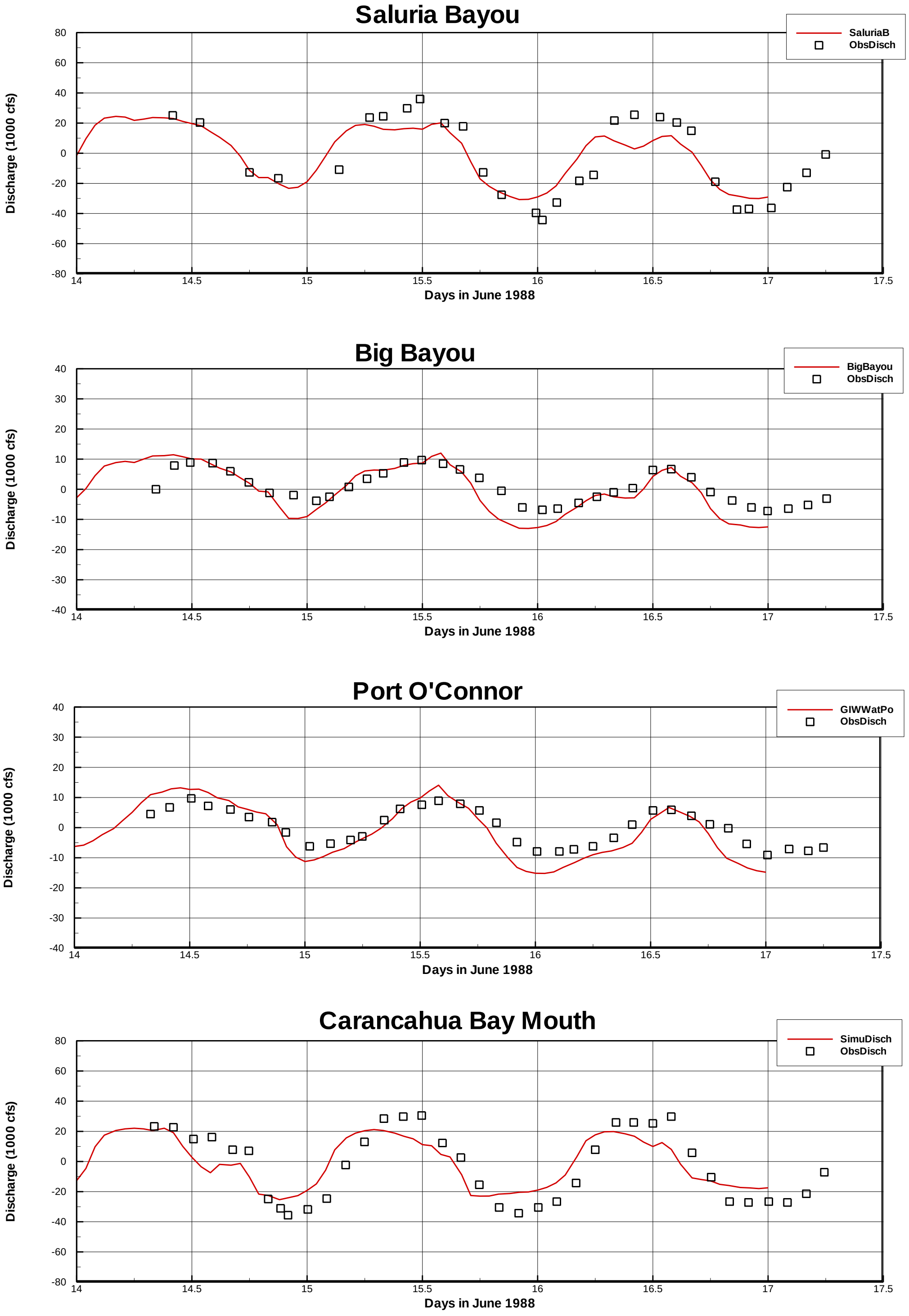


Figure 16. Simulated (red line) and observed discharges (open symbols) for the following sites from top to bottom: Saluria Bayou, Big Bayou, Port O’Connor, and Carancahua Bay mouth for June 14-17, 1988 in the Lavaca-Colorado Estuary.

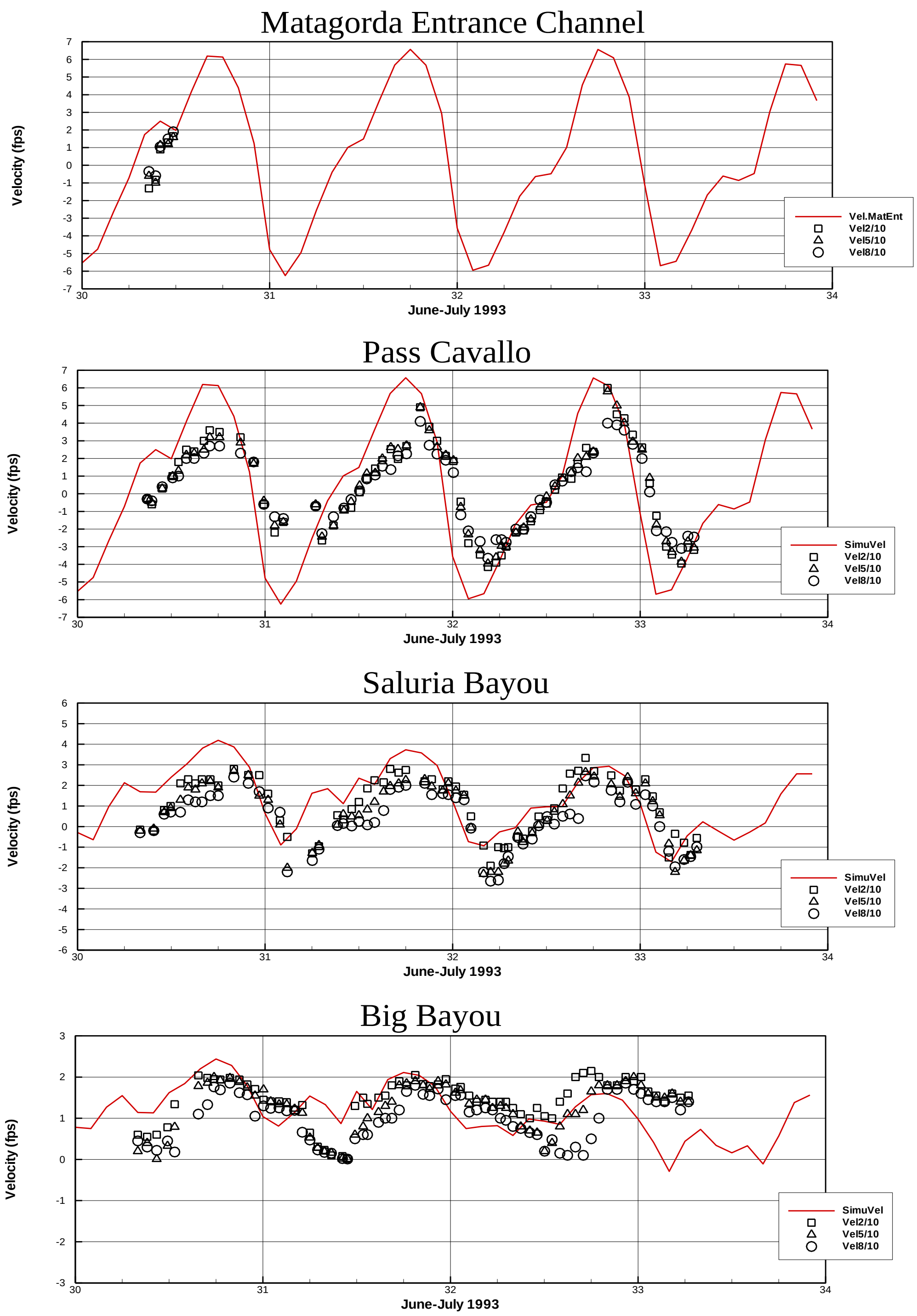


Figure 17. Simulated (red line) and observed velocities (open symbols) for the following sites from top to bottom: Matagorda Entrance Channel, Pass Cavallo, Saluria Bayou, and Big Bayou for June 30-July 3, 1993 in the Lavaca-Colorado Estuary. Velocity measurements were collected at three depths, 2/10th (□), 5/10th (△), and 8/10th (o) of water depth.

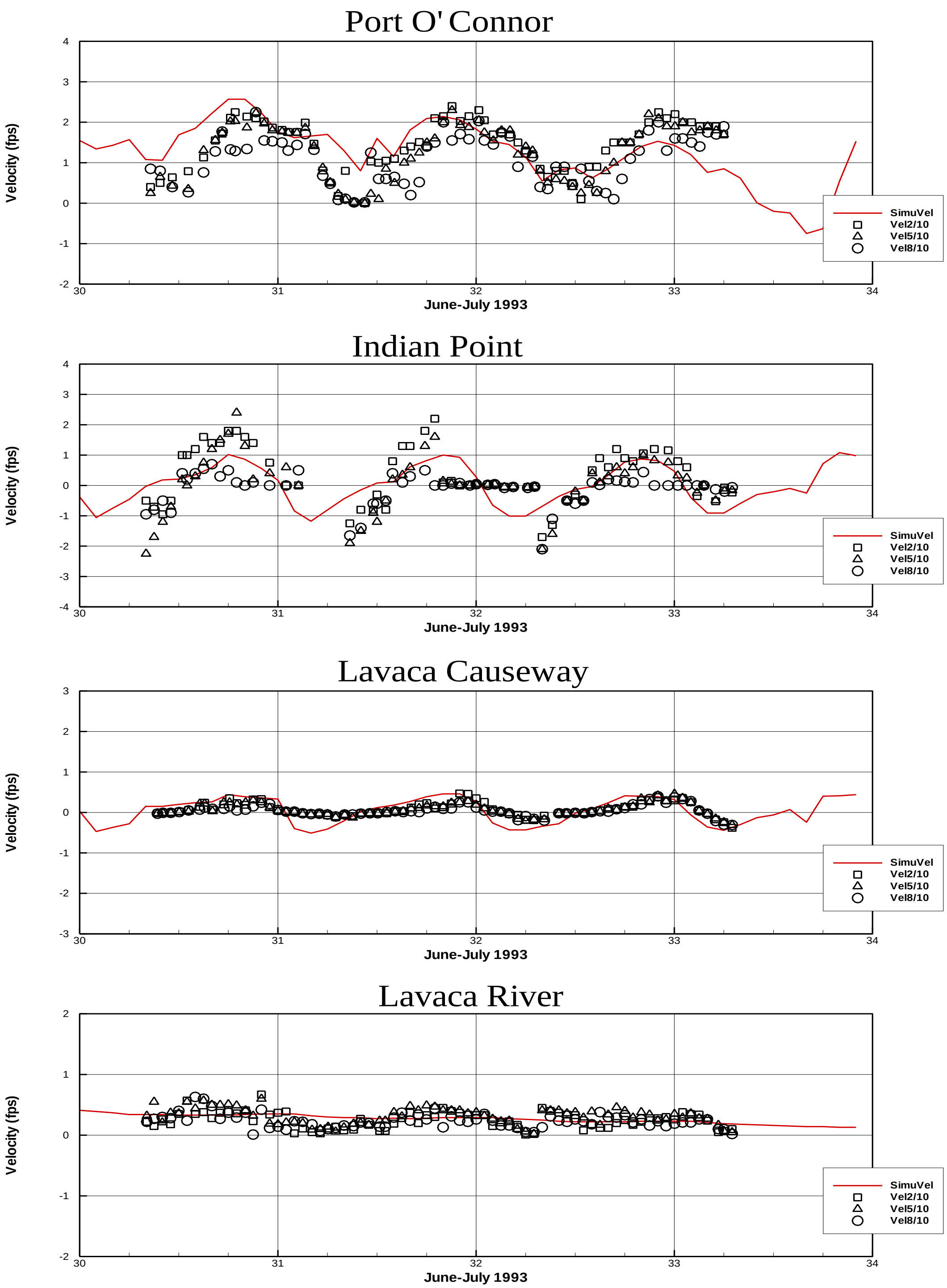
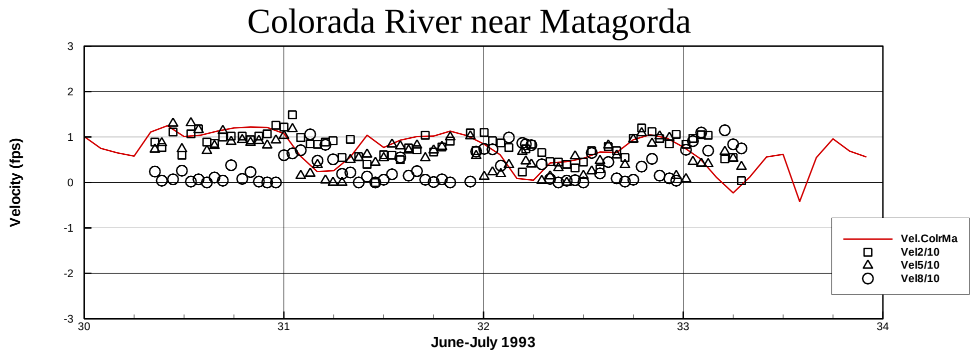
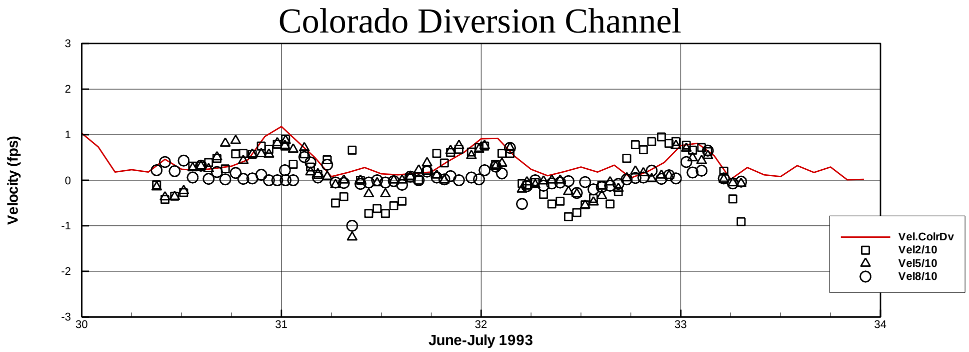
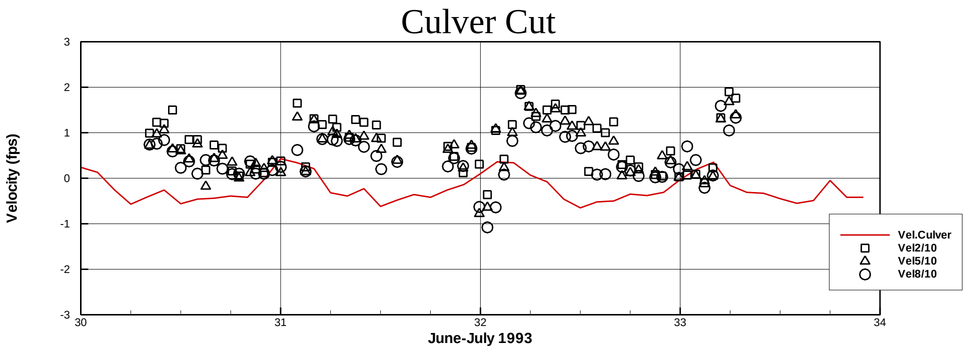


Figure 18. Simulated (red line) and observed velocities (open symbols) for the following sites from top to bottom: Port O'Connor, Indian Point, Lavaca Causeway, and Lavaca River for June 30-July 3, 1993 in the Lavaca-Colorado Estuary. Velocity measurements were collected at three depths, 2/10th (□), 5/10th (△), and 8/10th (o) of water depth.







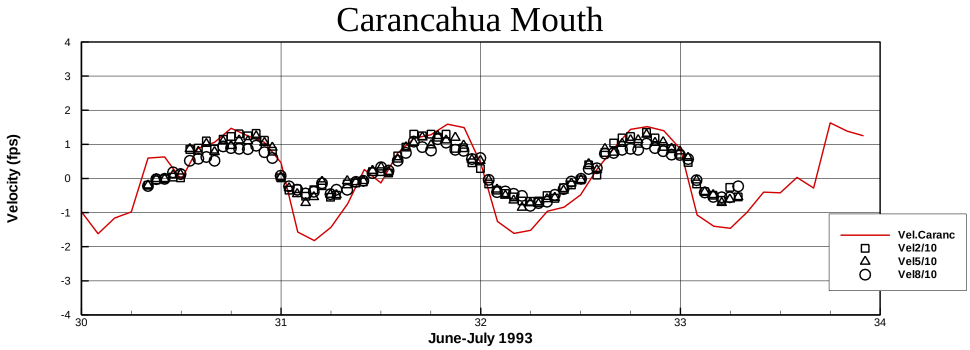


Figure 19. Simulated (red line) and observed (open symbols) velocities for the following sites from top to bottom: Colorado River near Matagorda, Colorado Diversion Channel, Culver Cut, and Carancahua Mouth for June 30-July 3, 1993 in the Lavaca-Colorado Estuary. Velocity measurements were collected at three depths, 2/10th (□), 5/10th (△), and 8/10th (o) of water depth.

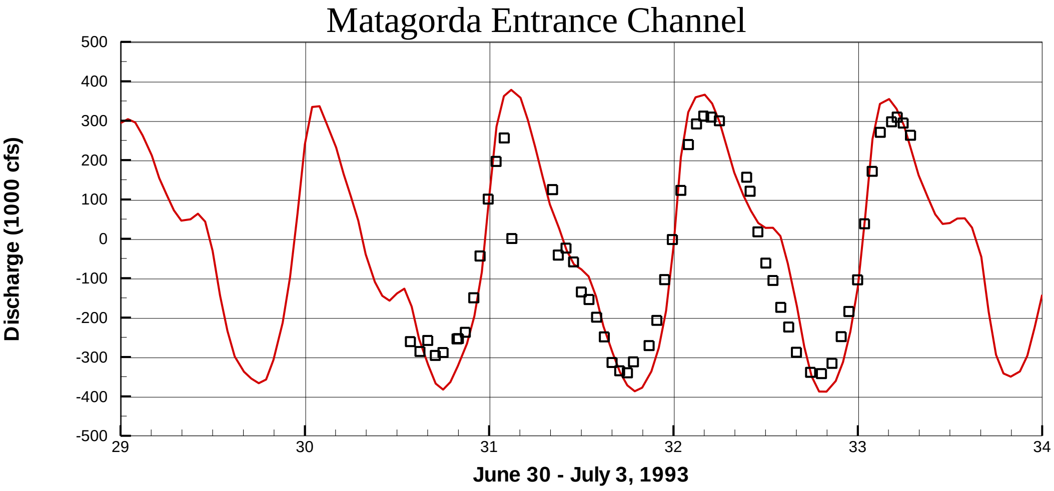


Figure 20. Simulated (red line) and observed (open symbols) discharges for the Matagorda Entrance Channel from June 30 - July 3, 1993 in the Lavaca-Colorado Estuary.

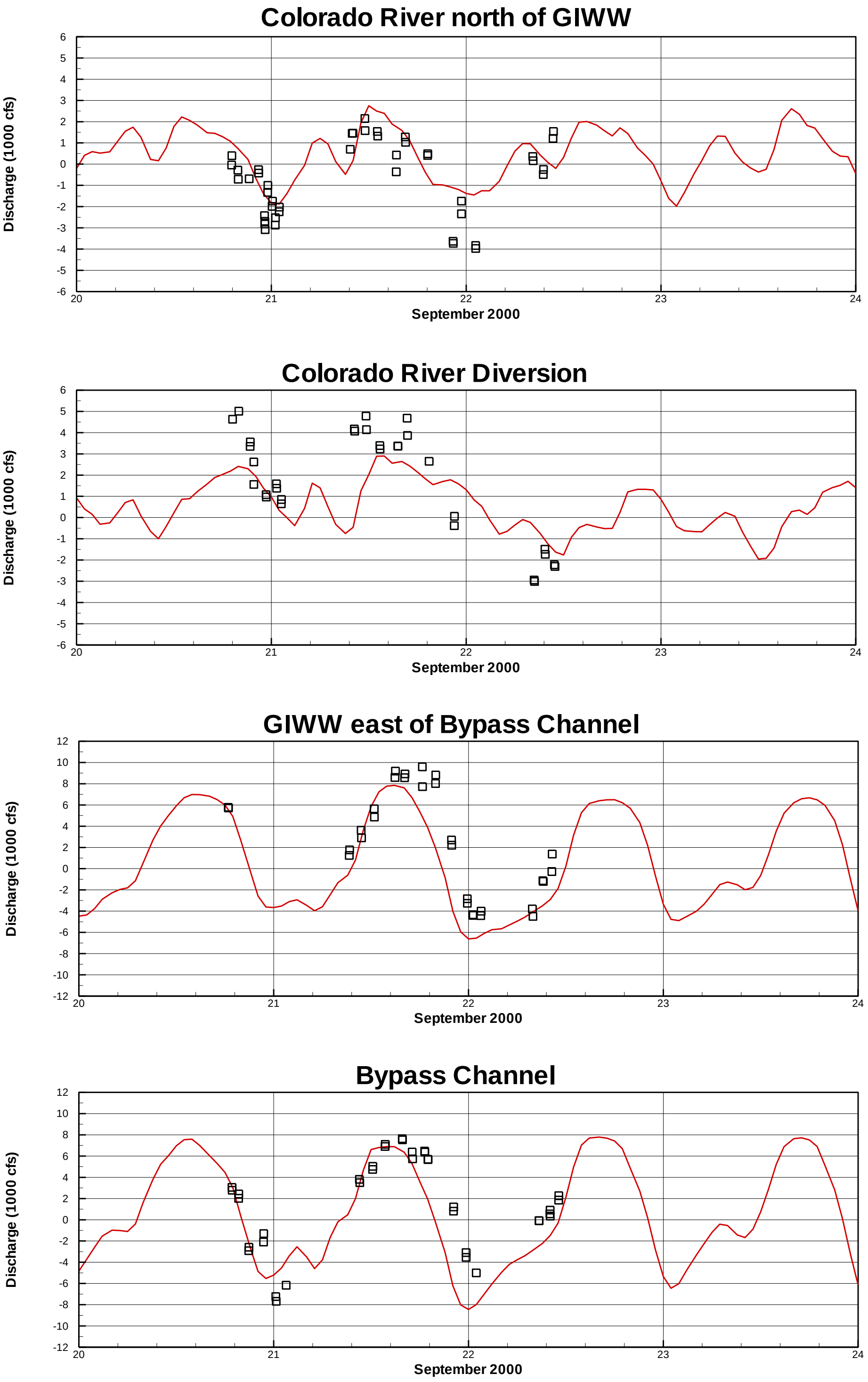


Figure 21. Simulated (red line) and observed (open symbols) discharges for the following sites from top to bottom: Colorado River North of GIWW, Colorado River Diversion, GIWW east of Bypass Channel, and Bypass Channel for September 21-22, 2000 in the Lavaca-Colorado Estuary.

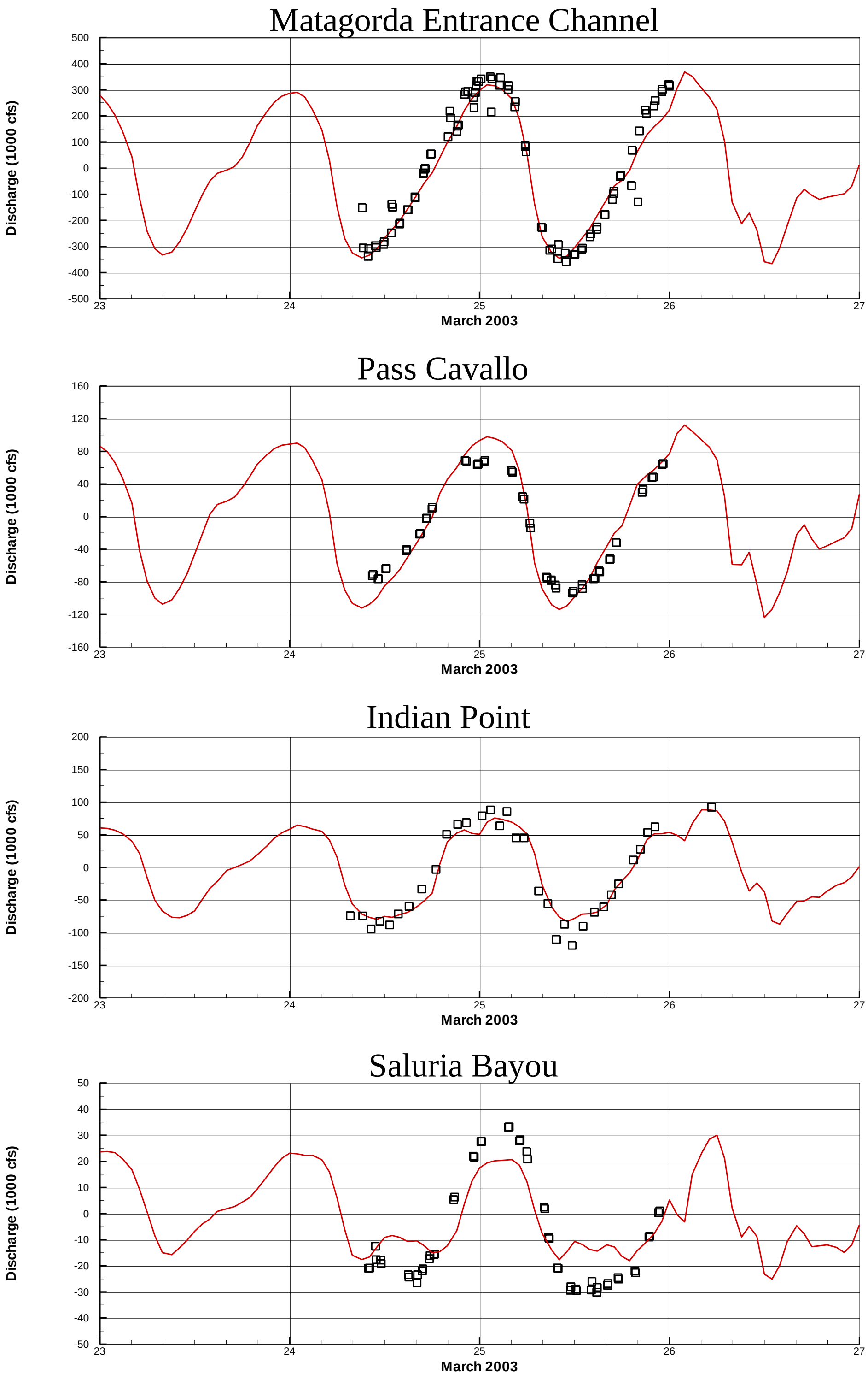


Figure 22. Simulated (red line) and observed (open symbols) discharges for the following sites from top to bottom: Matagorda Entrance Channel, Pass Cavallo, Indian Point, and Saluria Bayou for March 24-26, 2003 in the Lavaca-Colorado Estuary.

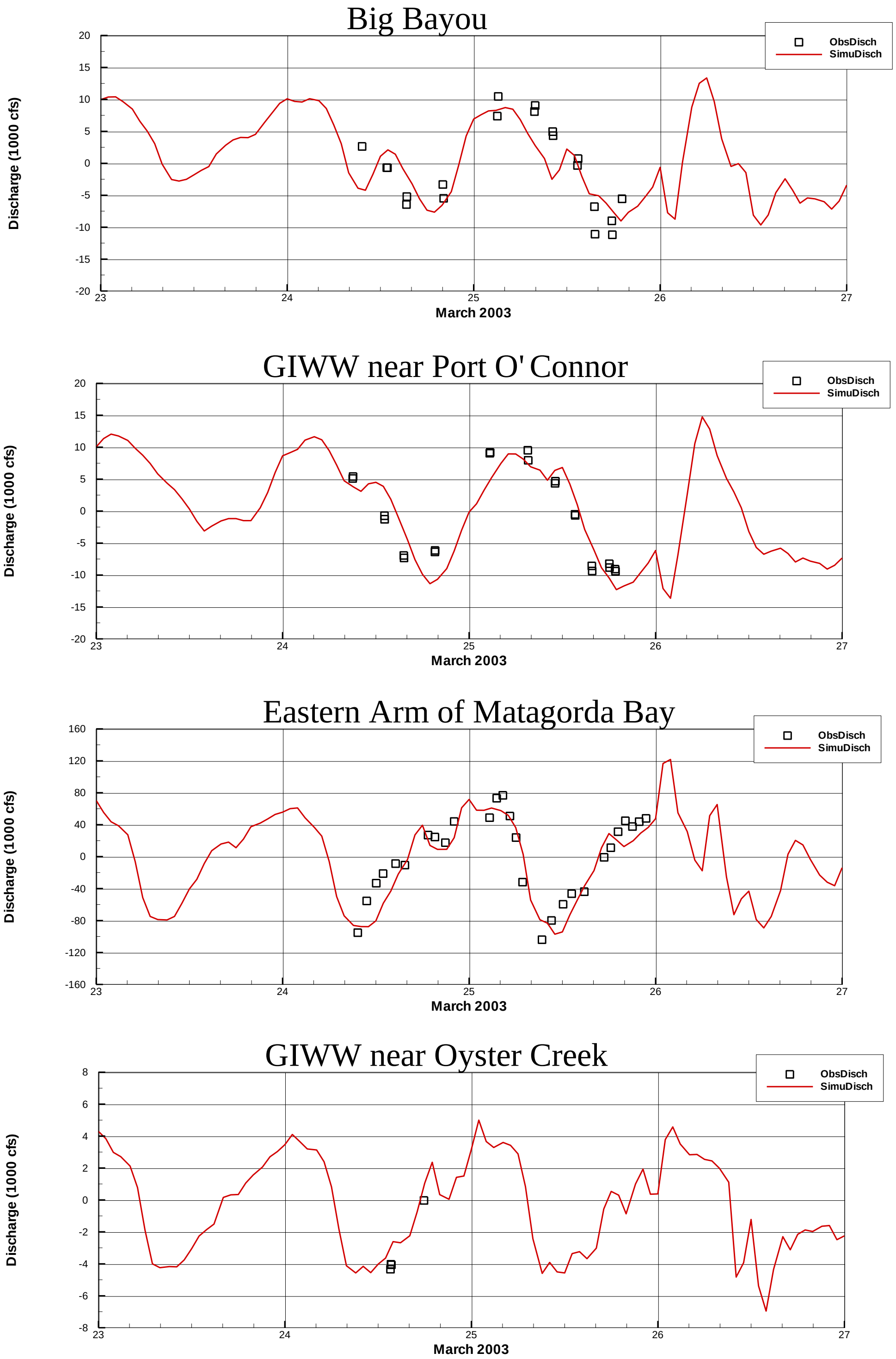


Figure 23. Simulated (red line) and observed (open symbols) discharges for the following sites from top to bottom: Big Bayou, GIWW near Port O’Connor, Eastern Arm of Matagorda Bay, and GIWW near Oyster Creek for March 24-26, 2003 in the Lavaca-Colorado Estuary.

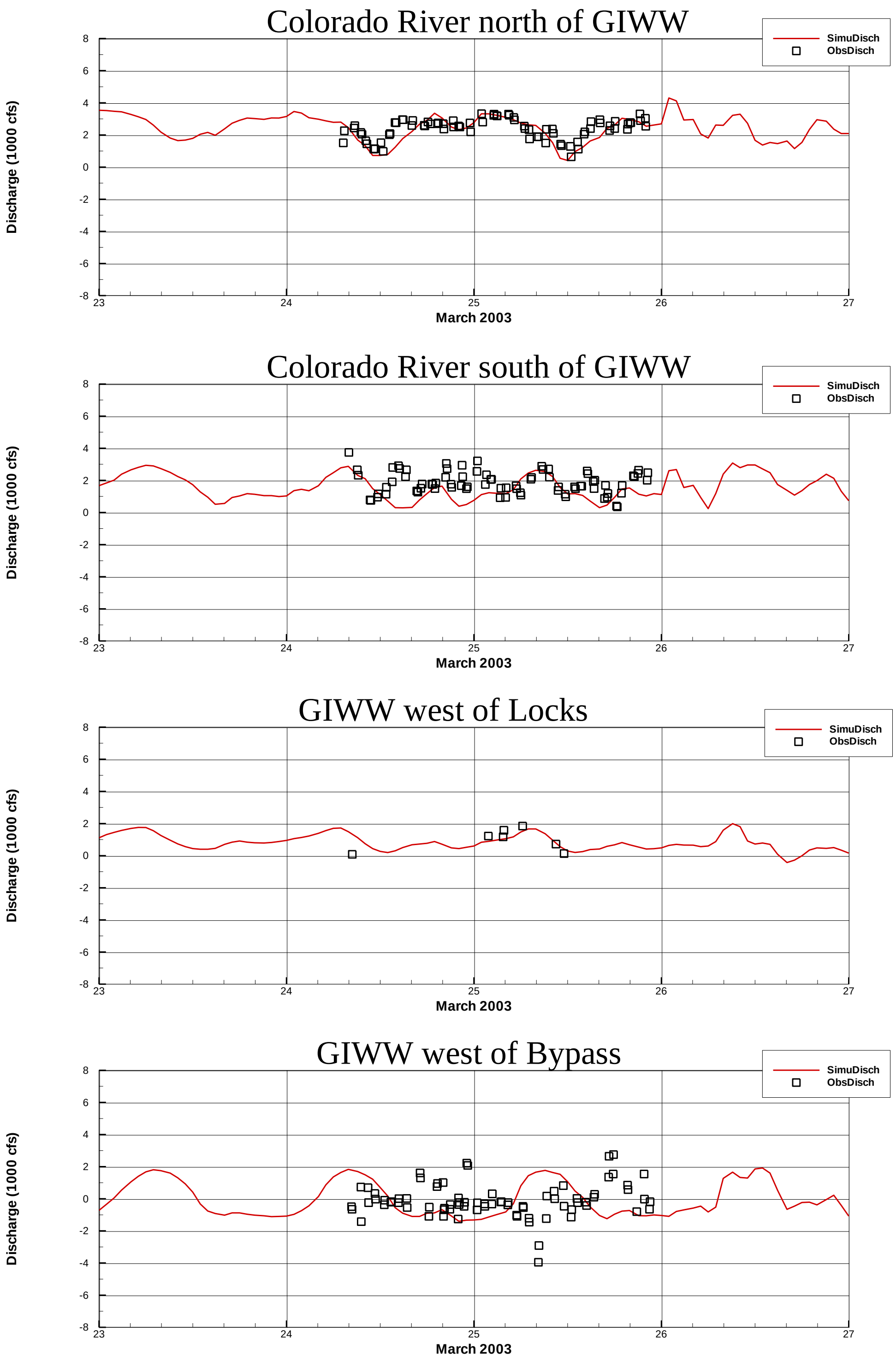


Figure 24. Simulated (red line) and observed (open symbols) discharges for the following sites from top to bottom: Colorado River North of GIWW, Colorado River South of GIWW, GIWW west of Locks, and GIWW West of Bypass for March 24-26, 2003 in the Lavaca-Colorado Estuary.

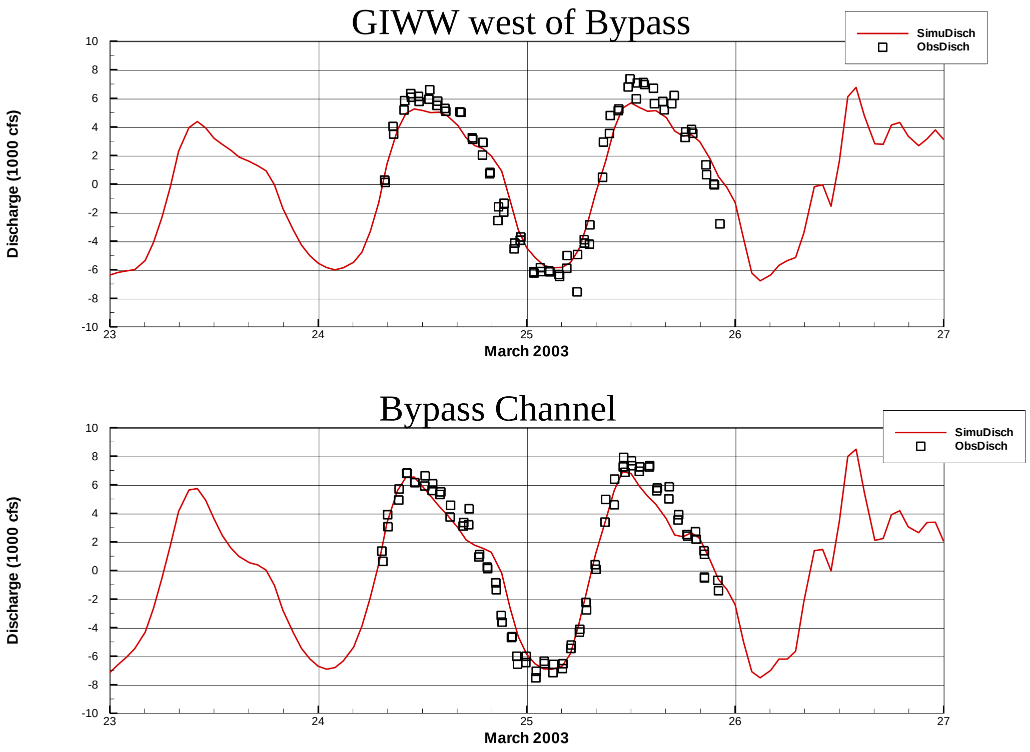


Figure 25. Simulated (red line) and observed (open symbols) discharges for GIWW West of Bypass and Bypass Channel for March 24-26, 2003 in the Lavaca-Colorado Estuary.

Water Surface Elevation Results

Figures 26-33 show generally good agreement between model simulations for water surface (tidal) elevations and observed data at four locations for different time periods with an r^2 of 0.79 – 0.93 based on hourly tidal elevation comparison. Figures 26 and 27 show measured and simulated tide at Rawling’s Bait Shop near the old Colorado River mouth for 1994 -2001. Figures 28 and 29 show tidal comparison plots at Port O’Connor from 1995-2001. Figures 30 and 31 show tidal comparisons at the Lavaca Causeway site from 1993-2001. Figure 32 shows tidal comparisons at the Palacios site from 1993-1995, and Figure 33 shows the same at East Matagorda Bay from 1993-1996.

Figure 34 displays tides at four sites for a 34-day period in 1996 to better compare the timing of simulated and observed tidal elevations. For ease of comparison, graphical presentation of observed tides was shifted by +1 ft. from the original measurement. The offset of tidal elevation difference was added to allow for easier comparison, to visually inspect the phase and amplitude. The model simulated diurnal variations in water level as well as duration excellently. The dissipation of the tidal amplitude extending away from the entrance channel was simulated well. Moreover, the magnitude of the storm surge during Tropical Storm Josephine, that peaked on September 07, 1996, was captured very well except at the East Matagorda Bay station where the model under-predicted the surge’s peak.

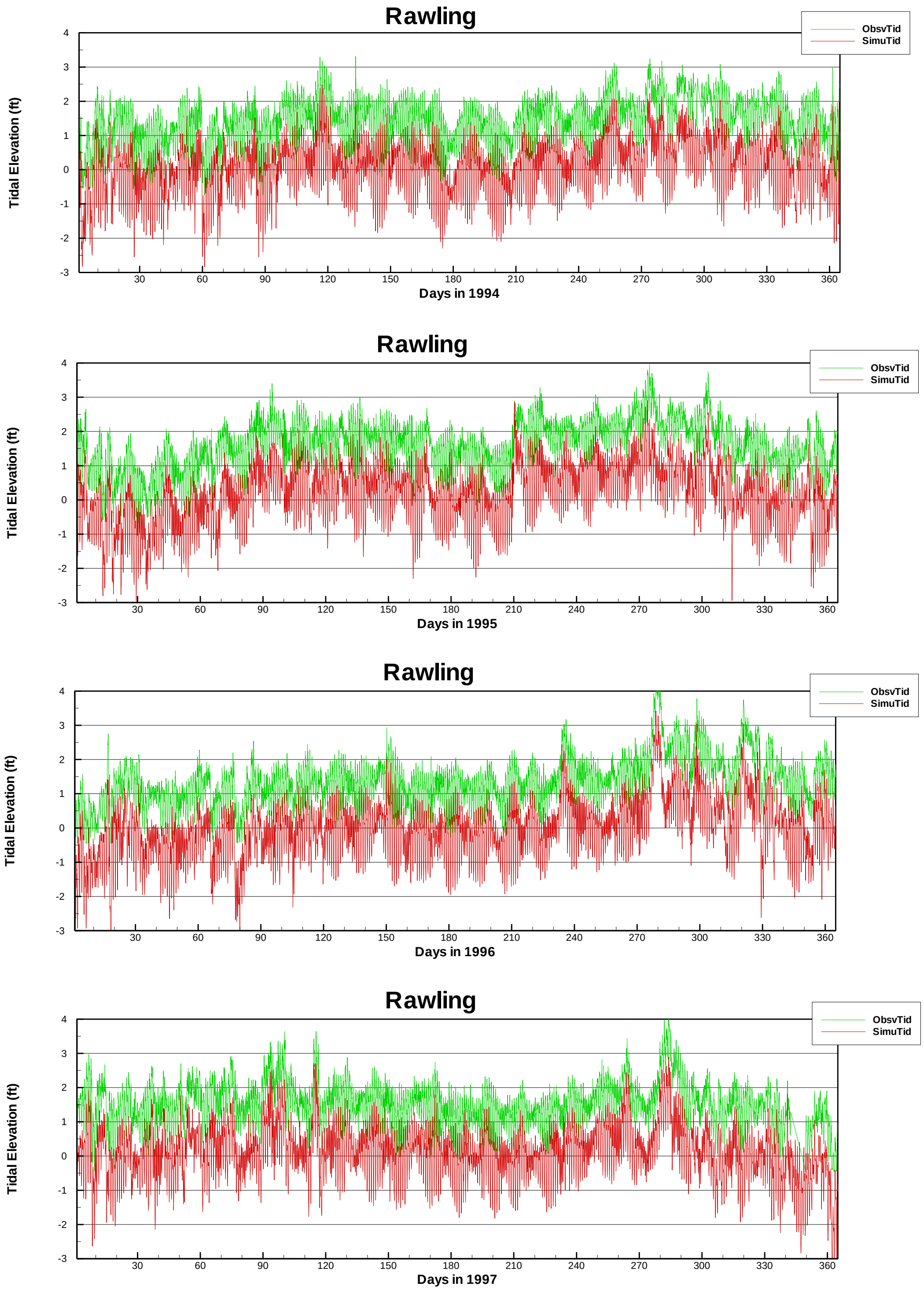


Figure 26. Time-series plots for observed (green) and simulated (red) hourly tide data at Rawling's Bait Shop for four years, from 1994-1997. *Note*: For ease of comparison, graphical presentation of observed tides was shifted by +1 ft. from the original measurement.

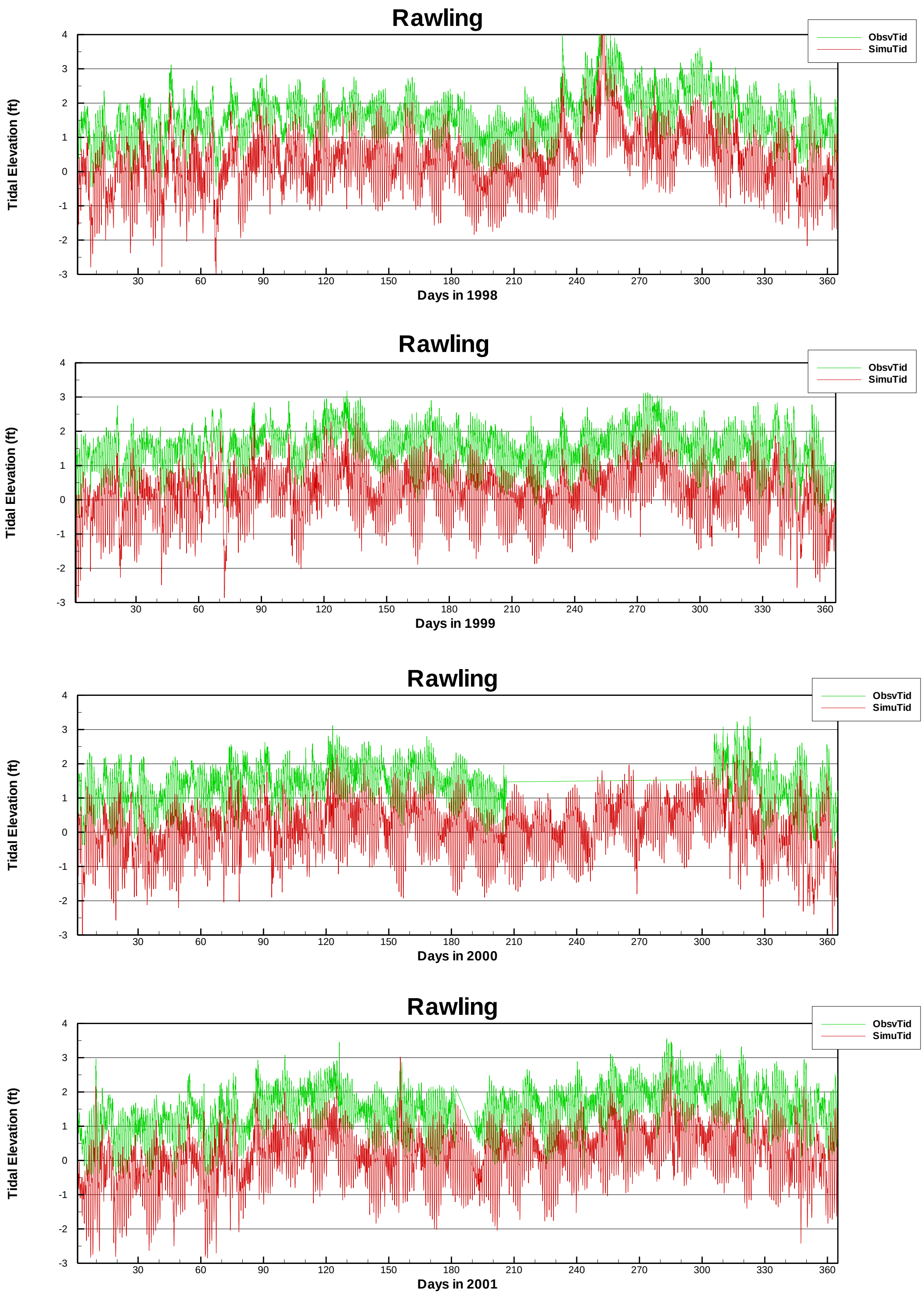


Figure 27. Time-series plots for observed (green) and simulated (red) hourly tide data at Rawling's Bait Shop for four years, from 1998-2001. *Note*: For ease of comparison, graphical presentation of observed tides was shifted by +1 ft. from the original measurement.

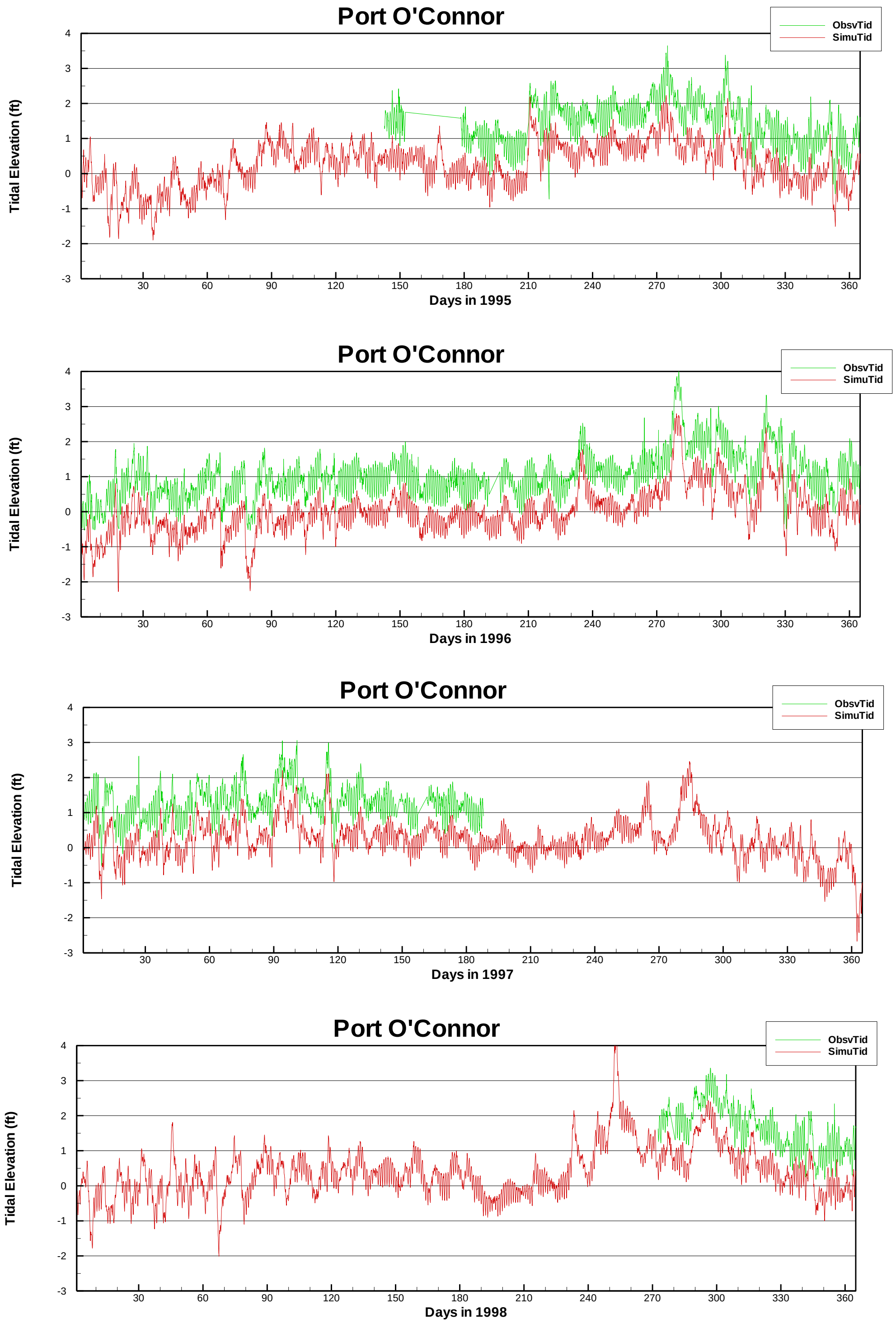


Figure 28. Time-series plots for observed (green) and simulated (red) hourly tide data at Port O' Connor for four years, from 1995-1998. *Note*: For ease of comparison, graphical presentation of observed tides was shifted by +1 ft. from the original measurement.

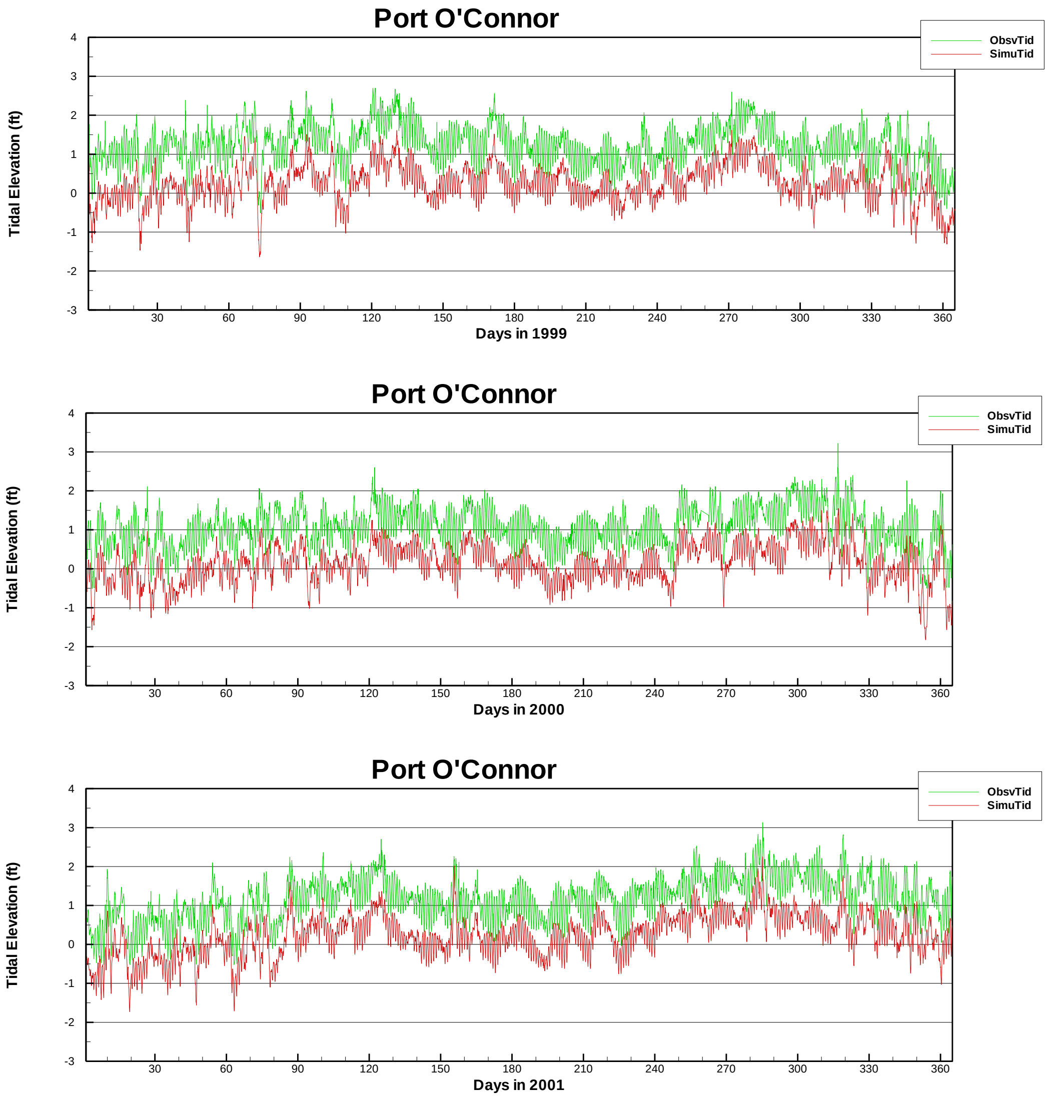


Figure 29. Time-series plots for observed (green) and simulated (red) hourly tide data at Port O' Connor for three years, from 1999-2001. *Note*: For ease of comparison, graphical presentation of observed tides was shifted by +1 ft. from the original measurement.

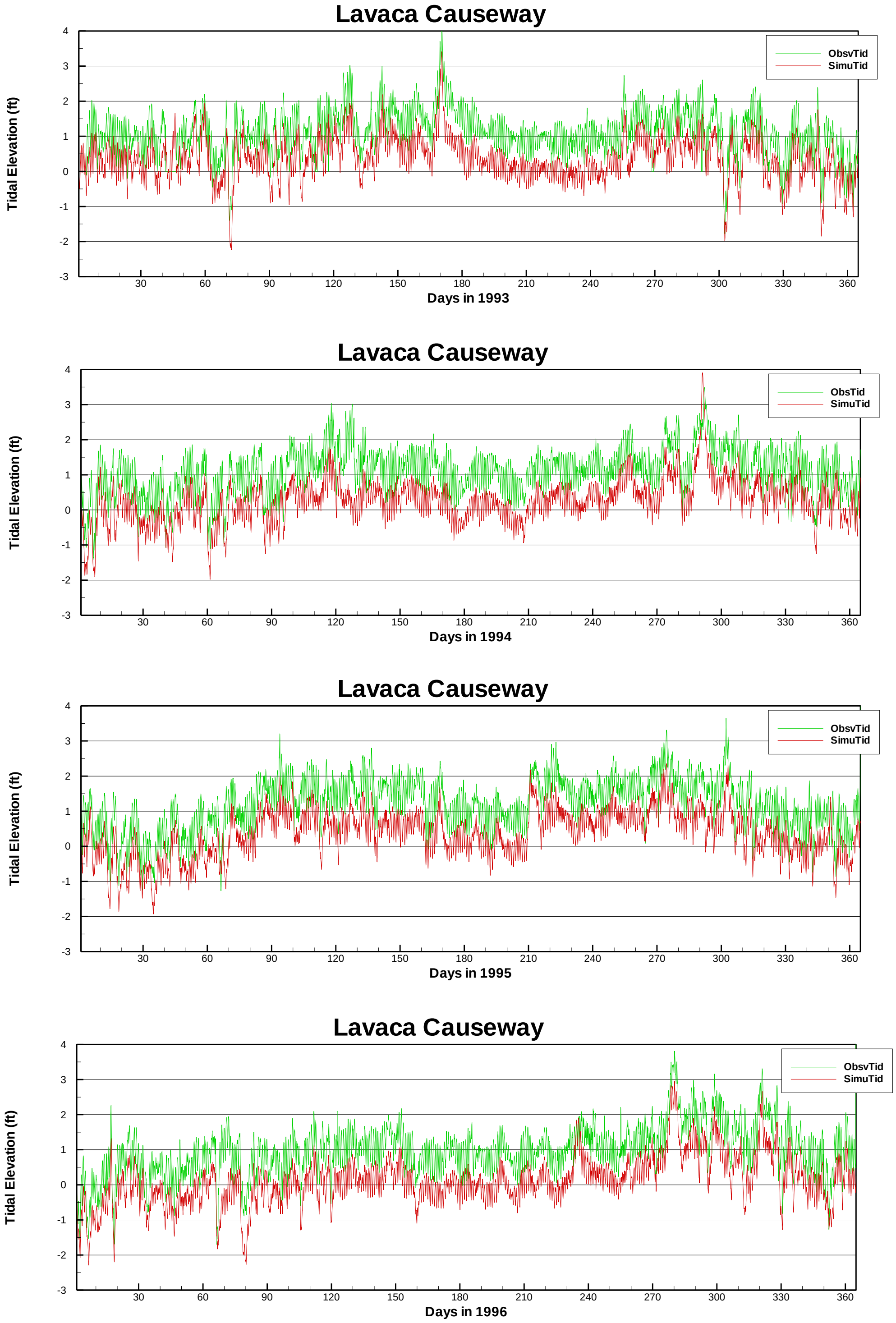


Figure 30. Time-series plots for observed (green) and simulated (red) hourly tide data at Lavaca Causeway for four years, from 1993-1996. *Note*: For ease of comparison, graphical presentation of observed tides was shifted by +1 ft. from the original measurement.

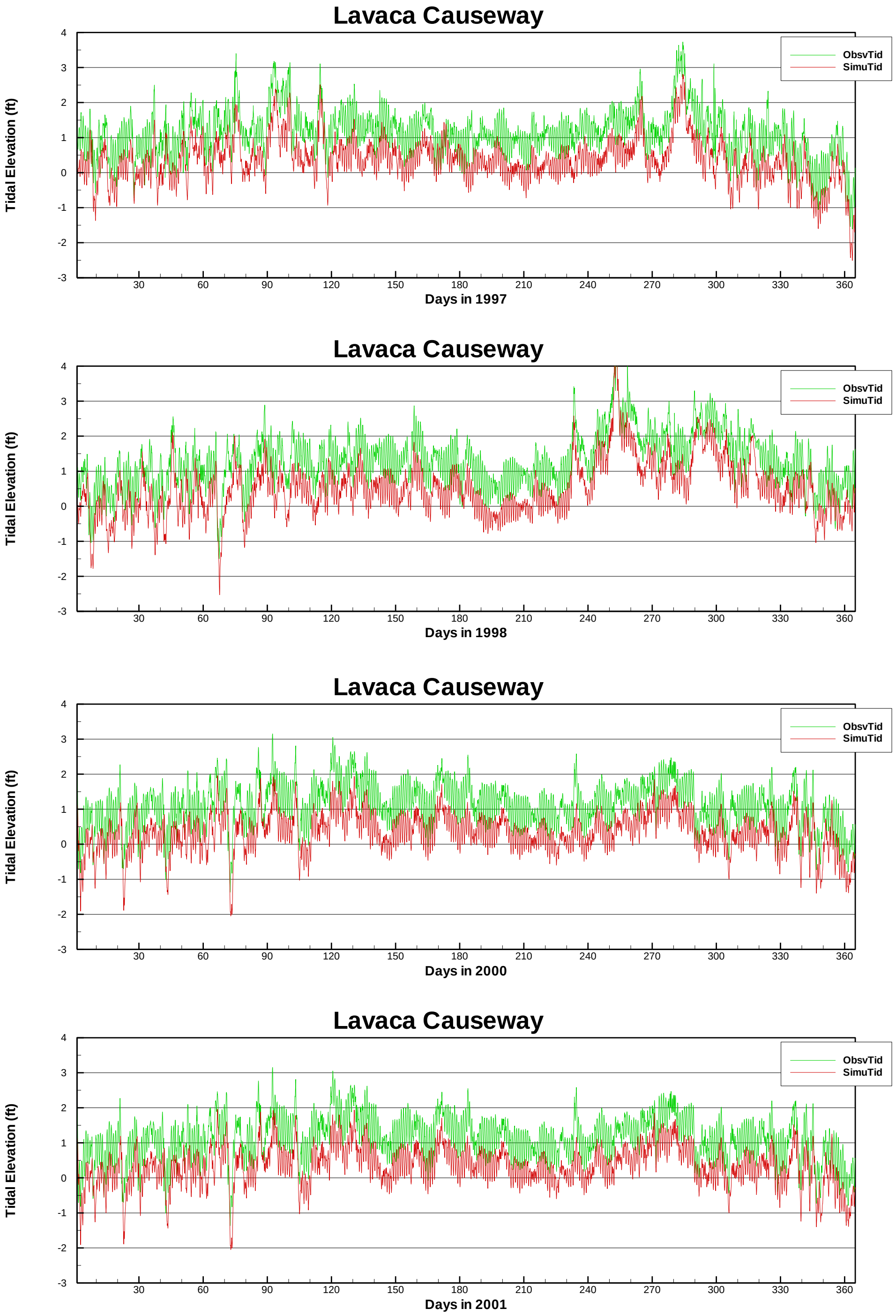


Figure 31. Time-series plots for observed (green) and simulated (red) hourly tide data at Lavaca Causeway for four years, from 1997-2001. *Note*: For ease of comparison, graphical presentation of observed tides was shifted by +1 ft. from the original measurement.

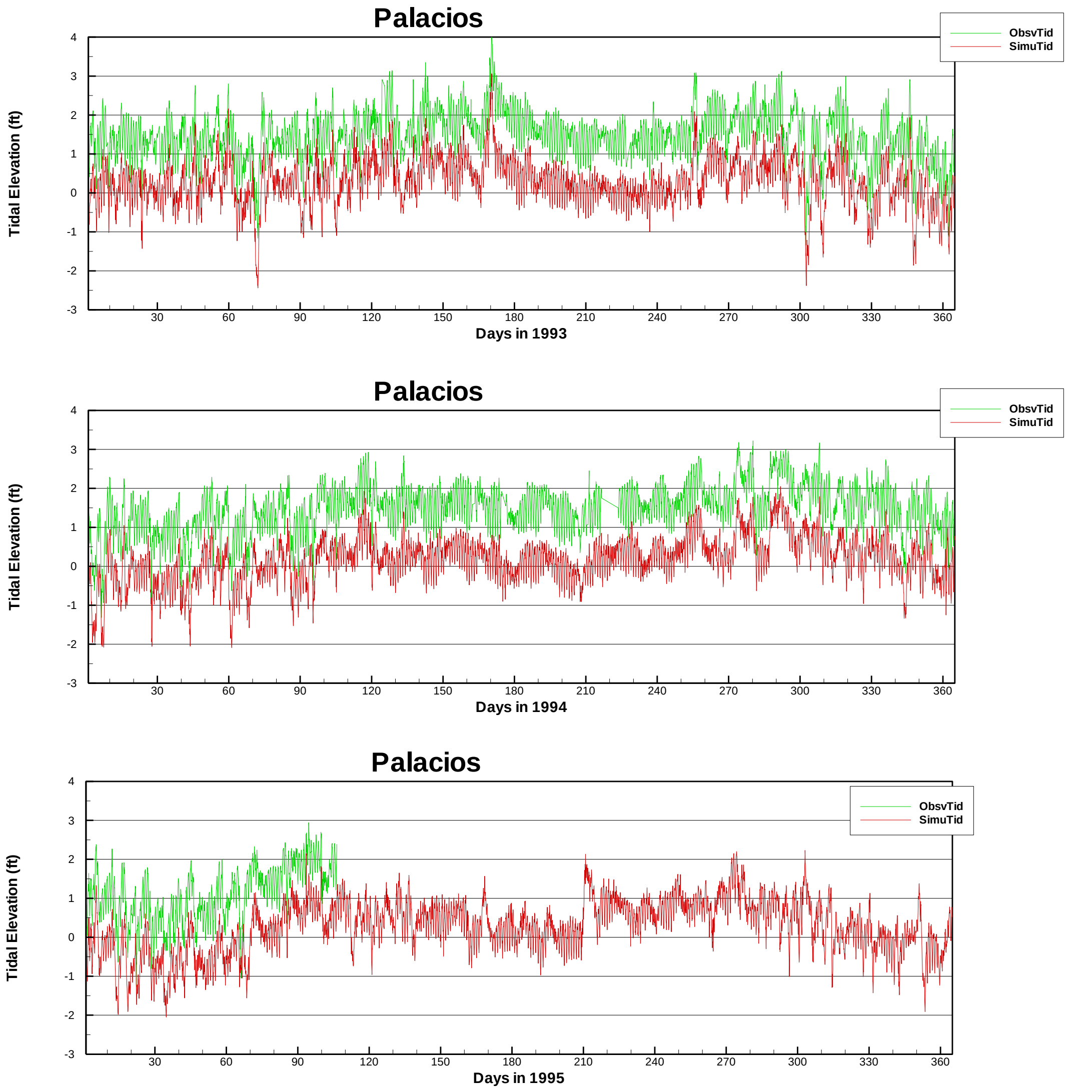


Figure 32. Time-series plots for observed (green) and simulated (red) hourly tide data at Palacios for three years, from 1993-1995. *Note*: For ease of comparison, graphical presentation of observed tides was shifted by +1 ft. from the original measurement.

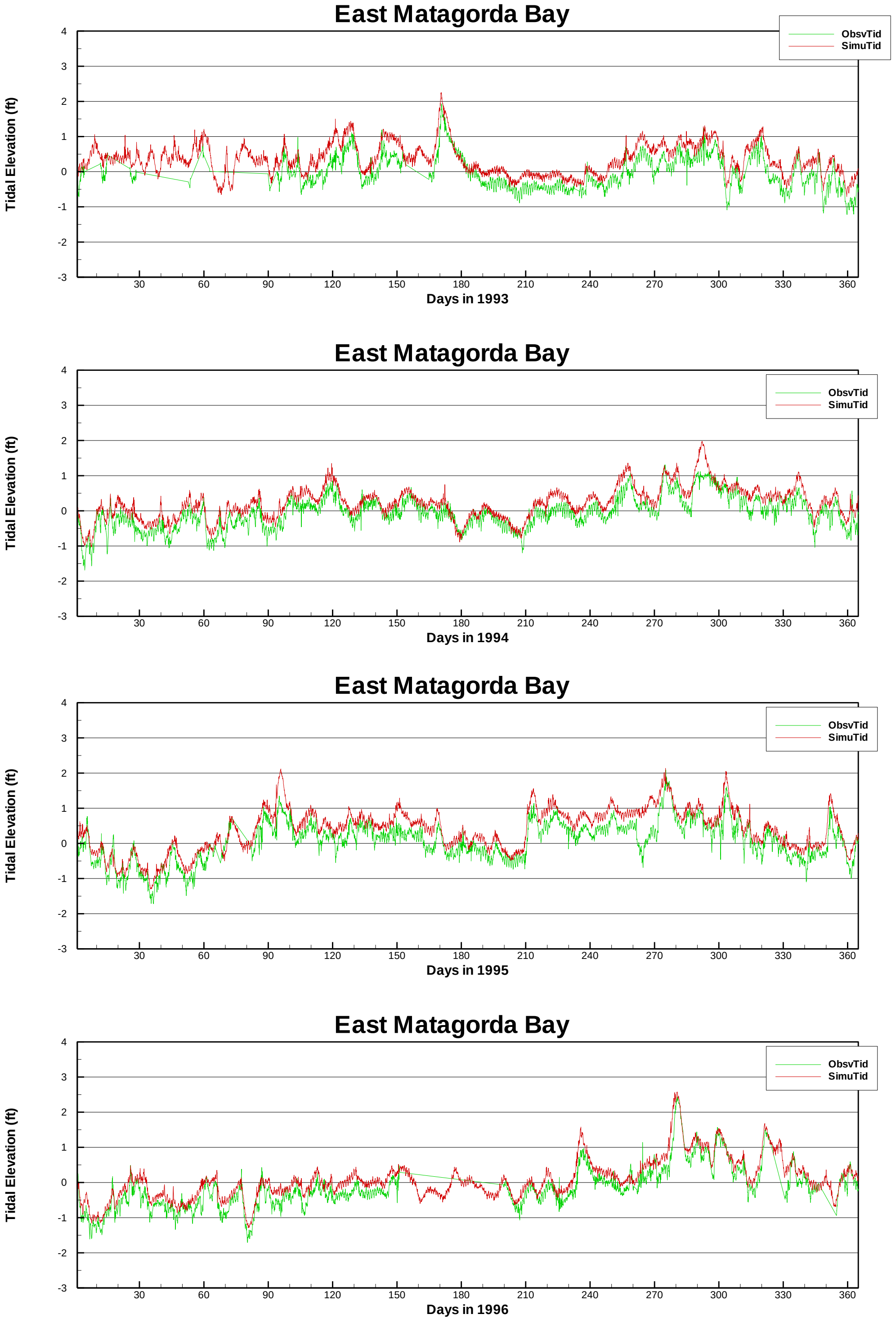


Figure 33. Time-series plots for observed (green) and simulated (red) hourly tide data at East Matagorda Bay for four years, from 1993-1996. *Note*: For ease of comparison, graphical presentation of observed tides was shifted by +1 ft. from the original measurement.

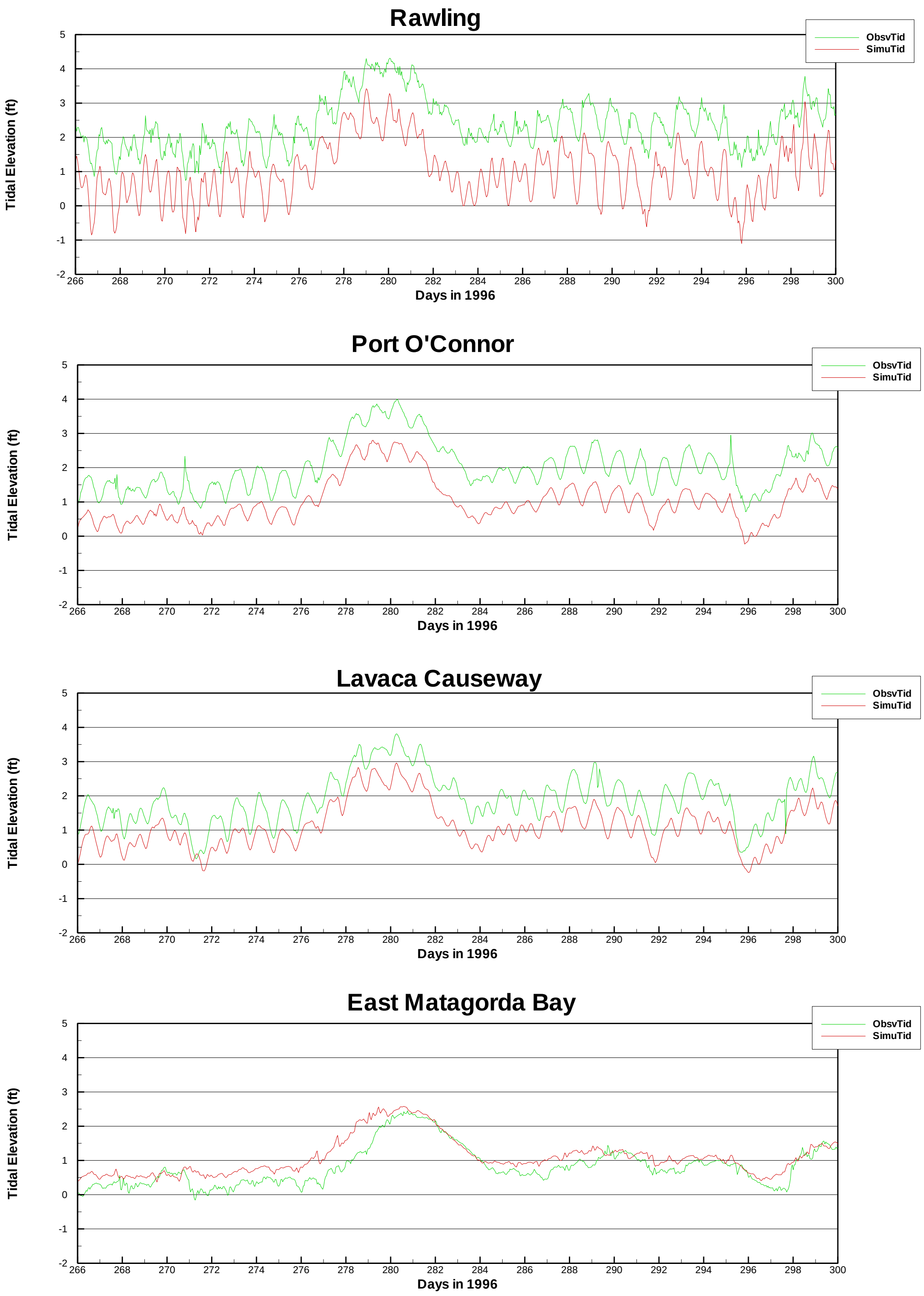


Figure 34. Time-series plots for observed (green) and simulated (red) hourly tide data at four tide gages for Days 266-300, 1996. *Note*: For ease of comparison, graphical presentation of observed tides was shifted by +1 ft. from the original measurement.

Scatter plots of the above results present another opportunity to compare observed and simulated tidal elevations (Figure 35). In addition, Table 4 shows summary statistics for hourly tides in each of the years, showing each year separately; whereas, Table 5 shows summary statistics for the daily tidal elevations across all years.

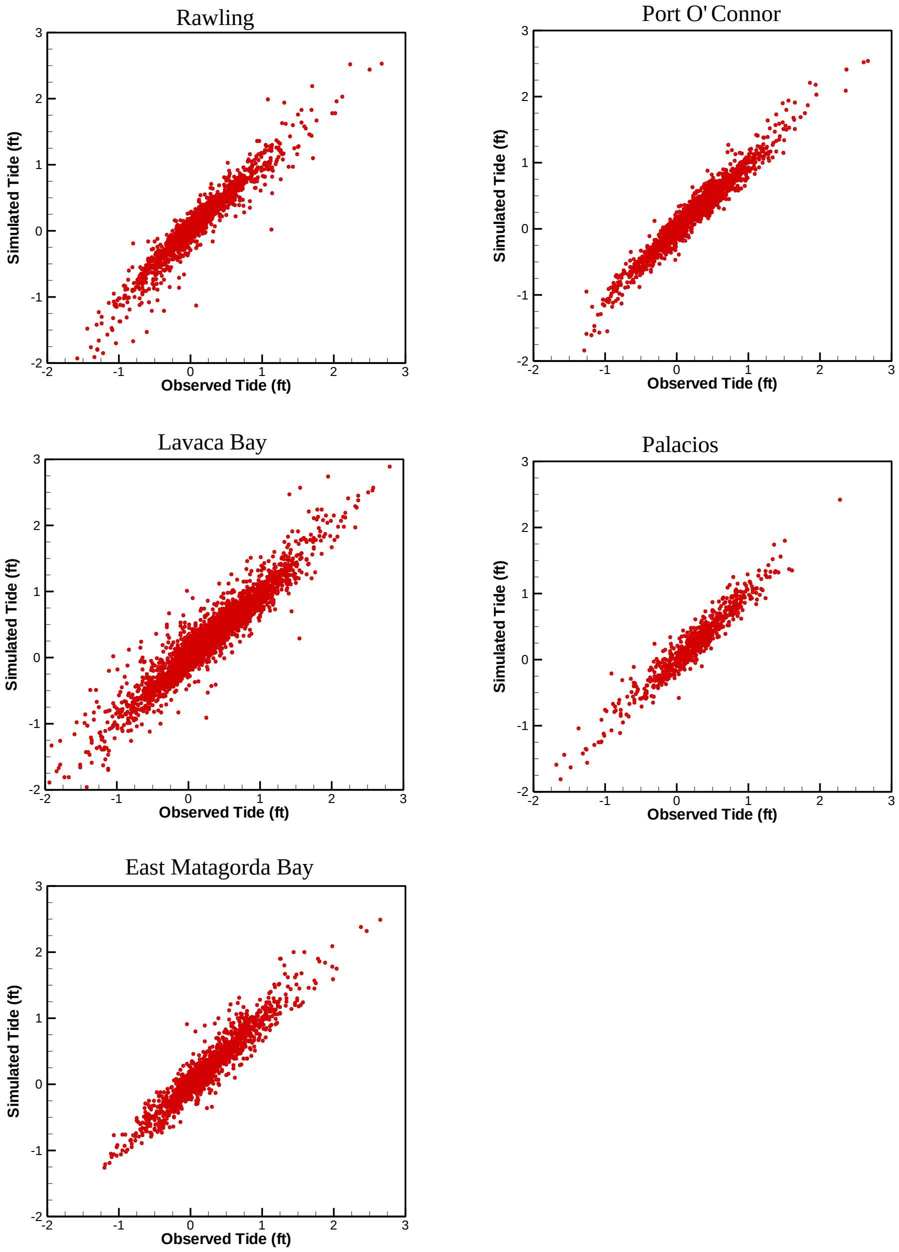


Figure 35. Scatter plots of observed versus simulated daily tidal elevations at the Rawling, Port O'Connor, Lavaca Causeway, Palacios, and East Matagorda bay locations in the Lavaca-Colorado Estuary for differing time periods.

Table 4. Statistics for hourly tidal elevations over the study periods that span from 1993 to 2001.

Location	Year	Days	n	r^2	RMS(ft)
Rawling	1994	358.0	8593	0.89	0.28
Rawling	1995	364.9	8757	0.87	0.33
Rawling	1996	363.3	8720	0.88	0.31
Rawling	1997	356.9	8566	0.86	0.30
Rawling	1998	363.9	8734	0.89	0.32
Rawling	1999	355.2	8525	0.87	0.31
Port O'Connor	1996	357.7	8585	0.93	0.18
Port O'Connor	1997	181.3	4352	0.86	0.18
Port O'Connor	1998	90.0	2159	0.92	0.19
Port O'Connor	1999	362.6	8702	0.86	0.19
Port O'Connor	2000	358.2	8598	0.90	0.17
Port O'Connor	2001	361.2	8669	0.91	0.17
Lavaca Causeway	1993	352.4	8457	0.87	0.24
Lavaca Causeway	1994	359.6	8630	0.87	0.23
Lavaca Causeway	1995	361.2	8668	0.90	0.24
Lavaca Causeway	1996	341.5	8196	0.91	0.23
Lavaca Causeway	1997	339.0	8137	0.89	0.22
Lavaca Causeway	1998	361.6	8679	0.87	0.28
Lavaca Causeway	1999	363.5	8723	0.79	0.28
Lavaca Causeway	2000	365.4	8769	0.84	0.24
Lavaca Causeway	2001	361.1	8667	0.88	0.22
Palacios	1993	360.8	8659	0.87	0.23
Palacios	1994	353.2	8478	0.90	0.20
East Matagorda Bay	1993	265.5	6371	0.84	0.19
East Matagorda Bay	1994	364.2	8741	0.86	0.17
East Matagorda Bay	1995	353.3	8479	0.86	0.22
East Matagorda Bay	1996	299.9	7197	0.92	0.18

*RMS is root mean square error.

Table 5. Statistics for daily tidal elevations over the study periods that span from 1993 to 2001.

Location	Period	Days	r^2	RMS(ft)	NSEC
Rawling	1994-2001	1,455	0.92	0.17	0.90
Port O'Connor	1996-2001	1,733	0.95	0.12	0.94
Lavaca Causeway	1993-2001	3,238	0.91	0.18	0.90
Palacios	1993-1994	722	0.92	0.14	0.92
East Matagorda Bay	1993-1996	1,307	0.91	0.16	0.90

*RMS is the root mean square error.

** Nash-Sutcliffe Efficiency Criterion (*E*) describes model performance, where E=1.0 represents a match between model output and observed data and E<0 suggests the model is a poor predictor.

Salinity Results

TxBLEND was calibrated for salinity at eight locations for the period 1997 – 2003 (see Figure 11 for map of locations). Figures 36 to 51 show that the model captured major salinity trends in the system reasonably well. For most sites, the difference between mean observed and mean simulated salinities was very small (< 2 ppt), and overall the r^2 and root mean square error for mean salinity were in the range of 0.63 – 0.86 and 2.8 – 5.9 ppt, respectively (Table 6). At Channel Marker 4, long term salinity trends were well represented by the model (Figure 36 and r^2 = 0.86), including a period of high salinities in 2000 followed by a rapid drop near the end of the same year. In subsequent years, the model's results follow observed salinity patterns, both during extended periods when salinity was high and during flushing events when salinity dropped. Moreover, the recovery of the system after flooding events was modeled very well (Figure 36). During some periods, the model was unable to capture the complete extent of the flushing in that simulated salinities did not match the lowest measured salinities, even though the flushing trend and recovery timing were captured well (*e.g.*, March 2007 and July 2002).

Salinity data at a station near Sandy Point was compared to model results for the calibration period (Figure 38). The seasonal variability in salinity was followed by the model throughout most of the seven-year period. A noteworthy strength of the model, as seen from this site, is the ability to accurately simulate drastic drops in salinity during most such events. Despite the long-term patterns being simulated very well, the lower r^2 (0.67), was related to a few days when the difference between the observed and simulated salinity was very large (*e.g.*, December 2000 and April 2002).

Comparison of simulated and observed salinities at the Lavaca Causeway station (Figure 40) shows that the model simulates salinity reasonably well (r^2= 0.73 for the calibration period). Intra-annual variability in the flushing extent at this station was captured by the model, though the model tended to under-predict rising and high salinity events. This may be attributed to either the station's location near the upstream boundary of the model grid or as a result of the manner of inflow specification (*e.g.*, due to daily averaging) which may have pronounced effect on this region of the model.

As in all other stations, the seasonal variability in salinity throughout the calibration period was captured very well in the Carancahua Bay monitoring station (Figure 42). The year-to-year variability can be seen in the model's prediction, and annual peak salinities were captured more accurately during more recent years. At the Palacios station, peak salinities during extended dry periods (*e.g.*, around December 1999 – March 2000) and seasonal fluctuations were represented well (Figure 44). At the West Bay Tripod station (Figure 46), even though long-term trends were captured well, the model was unable to reproduce the extent of short-term variability for both higher and lower salinities when salinity rapidly oscillated through a 15 – 20ppt change. Such pronounced short-term variability seems to be more common at this station and at the Lavaca Causeway station. Salinity data from two stations in East Matagorda Bay also were compared to model results at those locations (Figures 48 – 51). The results were reasonable for the calibration period, with r^2 for the East Matagorda Bay Tripod and Shellfish Marker stations equal to 0.74 and 0.63, respectively.

Overall, the model adequately simulated peak salinities, though there was a tendency for the model to under-predict salinity and to not capture rapid declines in salinity during earlier years. For example, in Figure 38 the model did not capture the sharp declines of observed salinity in 2000 and 2002 at the Sandy Point site. Model departures may occur for many reasons. One such reason could be datasonde instrument or measurement error. Departures also may be caused by localized rainfall events that were not recorded by a rainfall gage and thus not reflected in the TxRR runoff model, or as input to the TxBLEND model. As another example, Figure 46 shows that the model does not capture the variability observed in 1999 and 2000 at the West Bay Tripod site. In this case, the variability in observed salinities may have been due to a tidal signal that was not received at the site. Additionally, certain parameters in the model, such as bottom roughness (Manning's *n*), can affect the model's ability to represent the variability of tidal elevations at other locations in the estuary. Another possibility is that the observed variability in salinity could be caused by a stratified mixture of fresh and salt water oscillating back and forth over the datasonde, an effect that cannot be modeled by TxBLEND. Summary statistics, comparing simulated to observed salinities at the eight locations, are shown in Table 6.

Table 6. Statistics comparing simulated versus observed daily salinities at eight locations in the Lavaca-Colorado Estuary and in East Matagorda Bay. The quantity of observed data available for comparison varies among sites.

Location	Period	Days (n)	r^2	RMS (ppt)	Nash-Sutcliffe	Mean Salinity		Diff Sal
						Simulated	Observed	
Marker-4	1997-2003	1,119	0.86	2.8	0.85	24.0	23.9	0.1
Sandy Point	1998-2003	1,385	0.67	4.1	0.66	24.2	23.8	0.4
Lavaca Causeway	1997-2003	1,280	0.73	5.0	0.56	14.9	16.8	-1.9
Carancahua Bay	1998-2003	1,253	0.84	3.5	0.83	18.4	19.3	-0.9
Palacios	1998-2002	1,281	0.74	4.0	0.67	23.3	21.6	1.7
West Bay Tripod	1997-2003	1,457	0.73	5.9	0.59	17.7	20.2	-2.5
East Bay Tripod	1998-2003	1,542	0.74	4.3	0.69	23.5	24.9	-1.4
East Bay Shellfish Marker	1999-2001	714	0.63	4.0	0.62	27.7	27.0	0.7

*RMS is the root mean square error.

** Nash-Sutcliffe Efficiency Criterion (*E*) describes model performance, where E=1.0 represents a match between model output and observed data and E<0 suggests the model is a poor predictor.

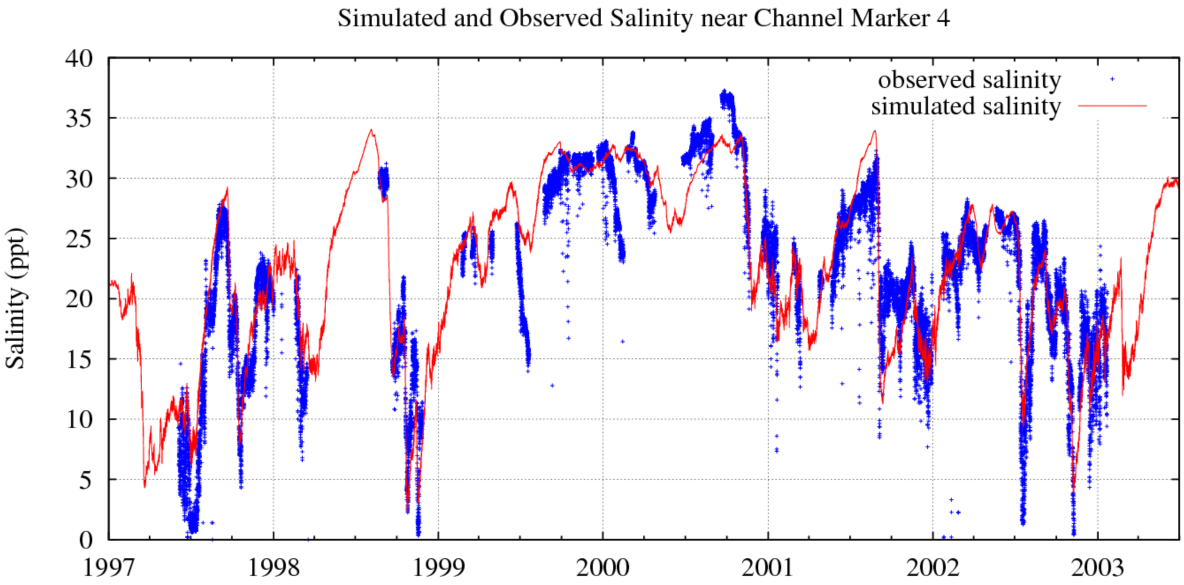


Figure 36. Observed (blue) versus simulated (red) salinities at the Channel Marker 4 site in Matagorda Bay for a period from mid-1997 through 2002.

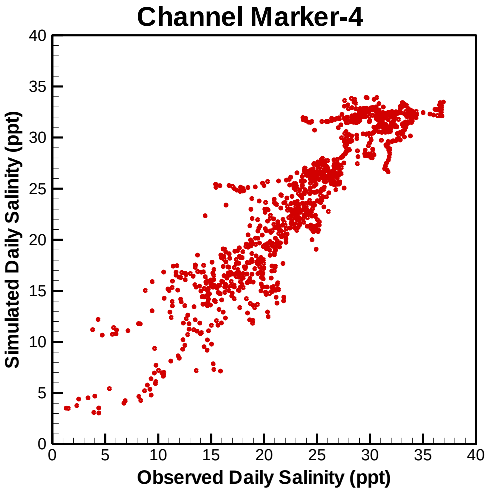


Figure 37. Scatter plot comparing simulated to observed daily salinities at Channel Marker 4 from mid-1997 through 2002, $r^2 = 0.86$.

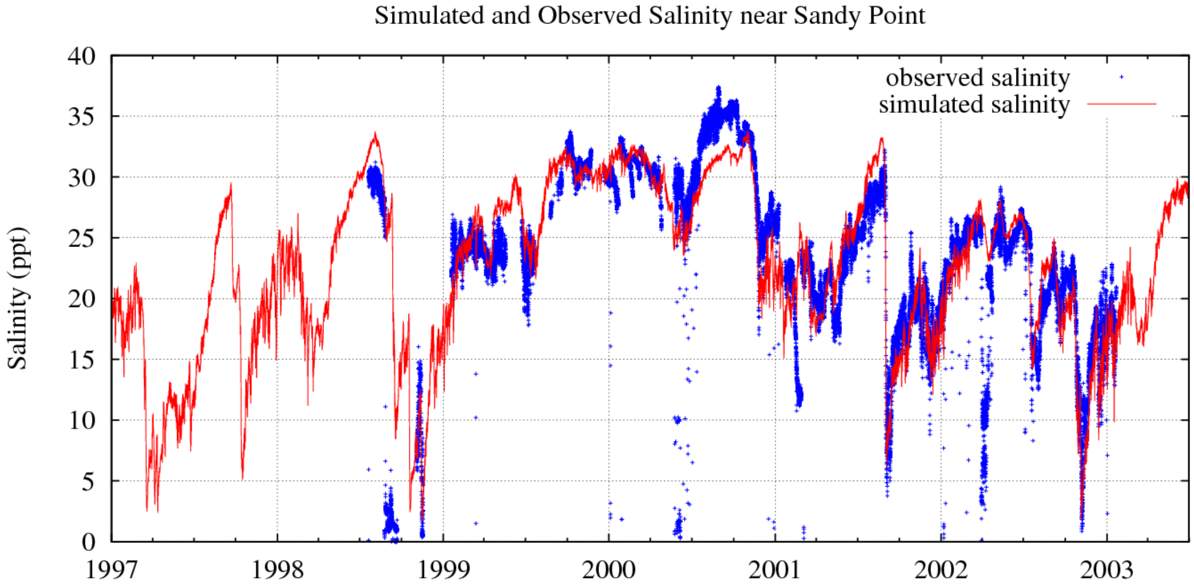


Figure 38. Observed (blue) versus simulated (red) salinities at the Sandy Point site in Matagorda Bay for a period from mid-1998 through 2002, with additional simulated salinities from 1997 to mid 1998.

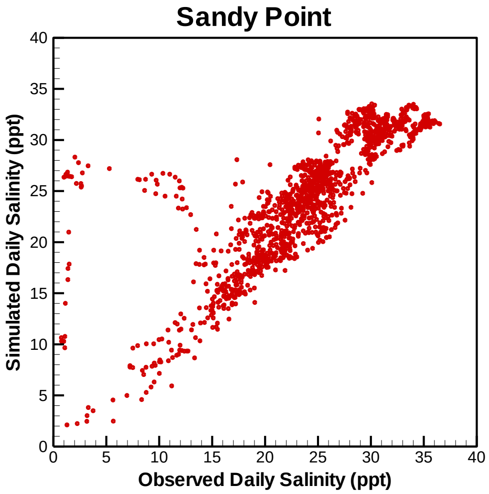


Figure 39. Scatter plot comparing simulated to observed daily salinities at Sandy Point from mid-1998 through 2002, $r^2 = 0.67$.

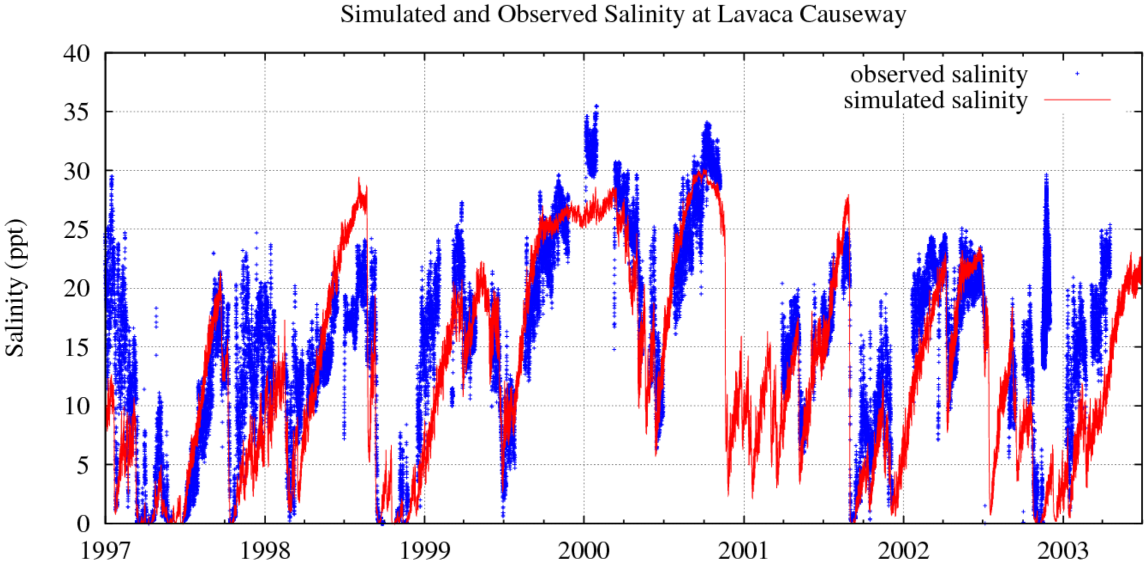


Figure 40. Observed (blue) versus simulated (red) salinities at the Lavaca Causeway site in Matagorda Bay for a period from 1997 through 2003.

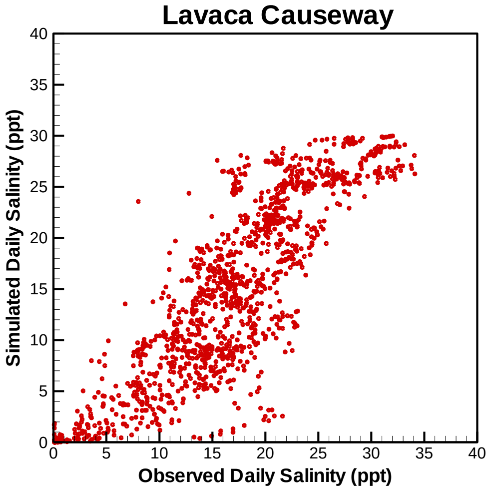


Figure 41. Scatter plot comparing simulated to observed daily salinities at the Lavaca Causeway from 1997 through 2003, $r^2 = 0.73$.

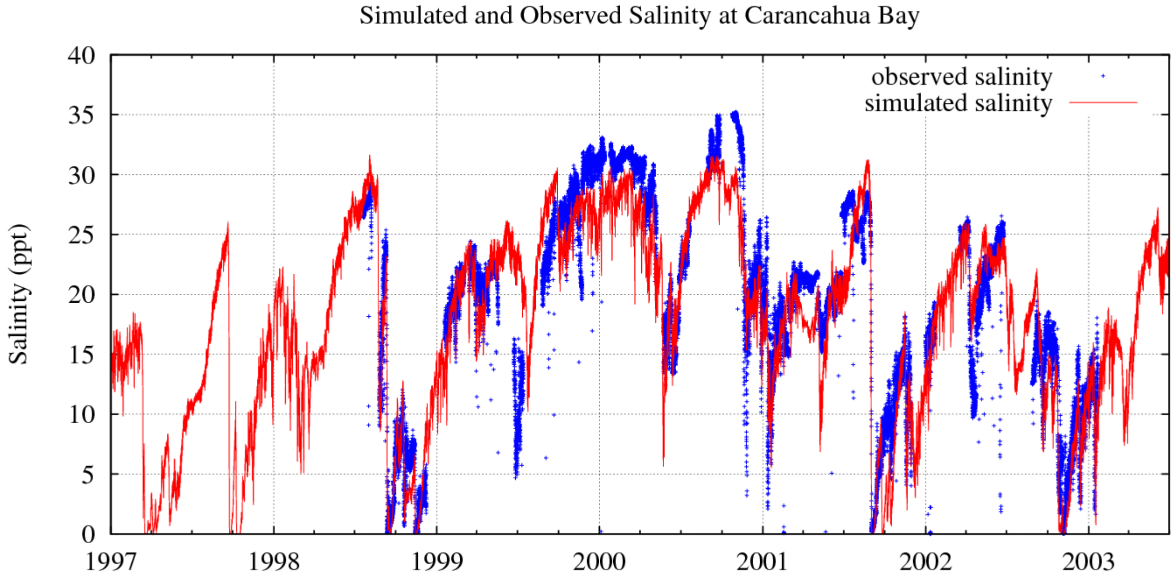


Figure 42. Observed (blue) versus simulated (red) salinities at the Carancahua Bay site in Matagorda Bay for a period from mid-1998 through 2002.

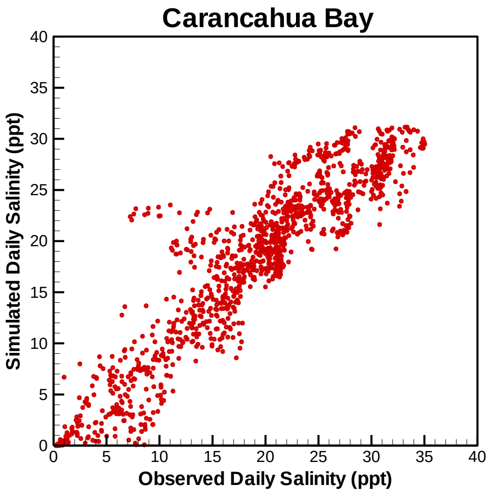


Figure 43. Scatter plot comparing simulated to observed daily salinities at Carancahua Bay from mid-1998 through 2003, $r^2 = 0.84$.

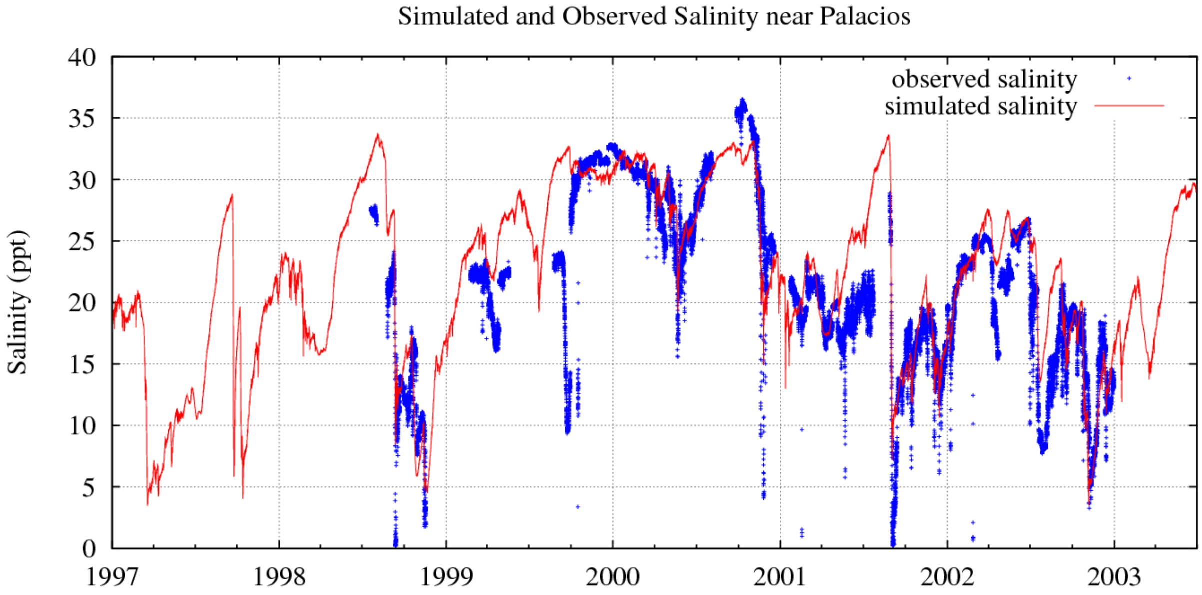


Figure 44. Observed (blue) versus simulated (red) salinities at the Palacios site in Matagorda Bay for a period from mid-1998 to 2002.

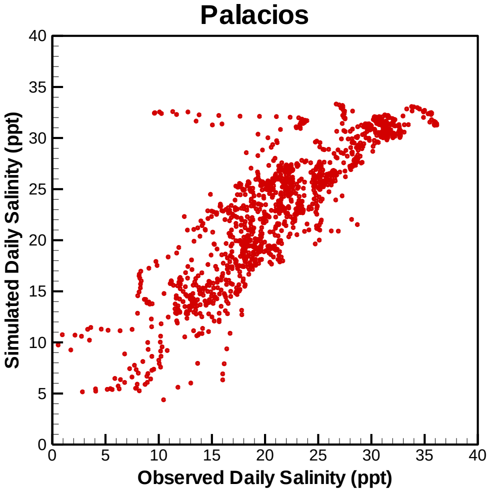


Figure 45. Scatter plot comparing simulated to observed daily salinities at the Palacios site from mid 1998 to 2003, $r^2 = 0.74$.

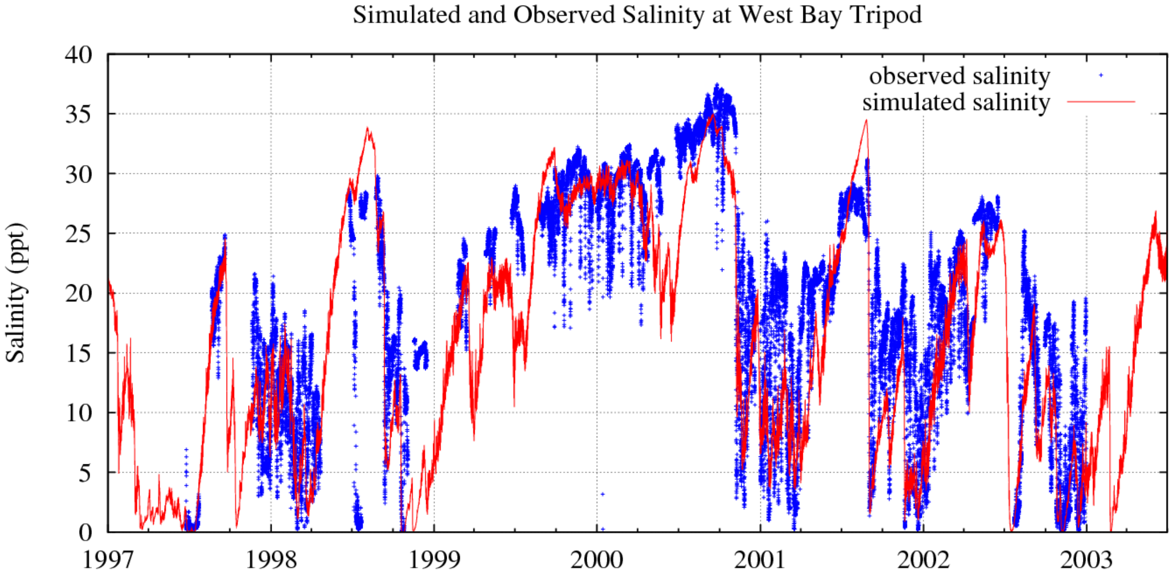


Figure 46. Observed (blue) versus simulated (red) salinities at the West Bay Tripod site in Matagorda Bay for a period from mid-1997 through 2002.

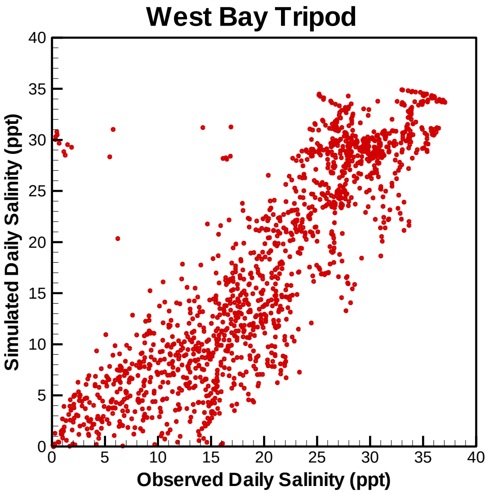


Figure 47. Scatter plot comparing simulated to observed daily salinities at the West Bay Tripod site from mid-1997 to 2003, $r^2 = 0.73$.

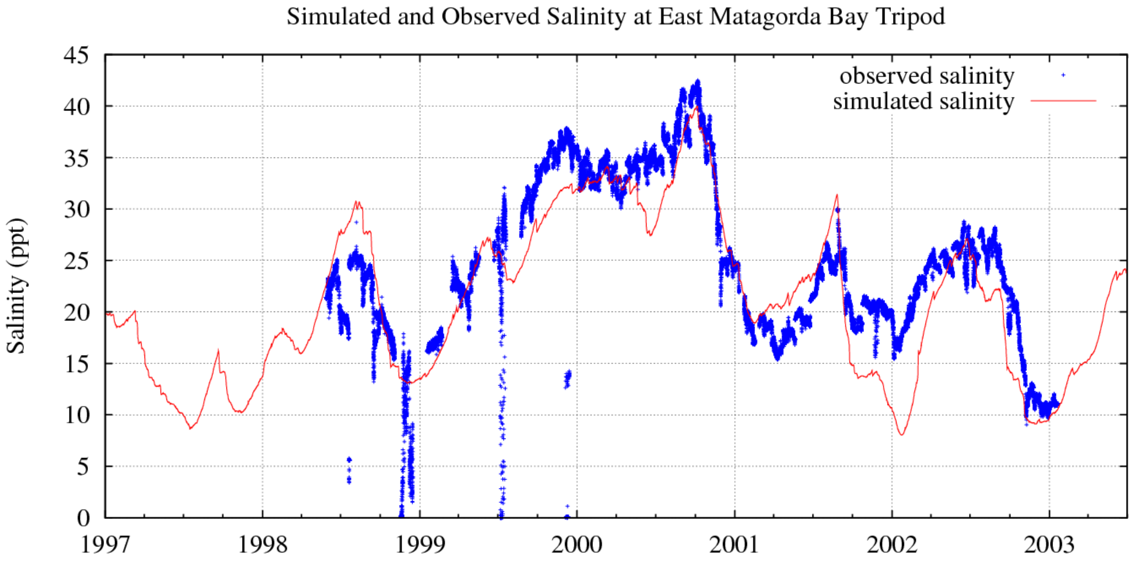


Figure 48. Observed (blue) versus simulated (red) salinities at the East Matagorda Bay Tripod site in Matagorda Bay for a period from mid-1998 through 2003, with additional simulated salinities from 1997 to mid-1988 and in 2003.

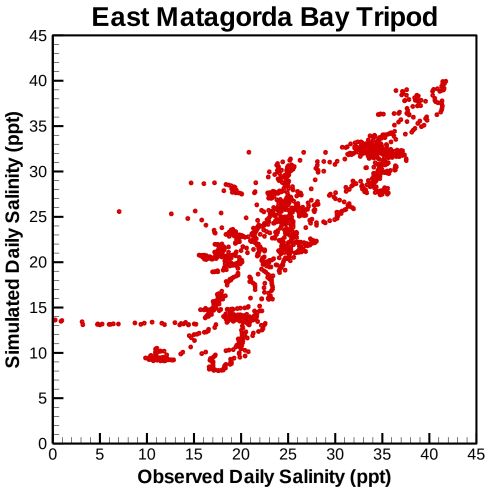


Figure 49: Scatter plot comparing simulated to observed daily salinities at the East Matagorda Bay Tripod site from mid-1998 to 2003, $r^2 = 0.74$.

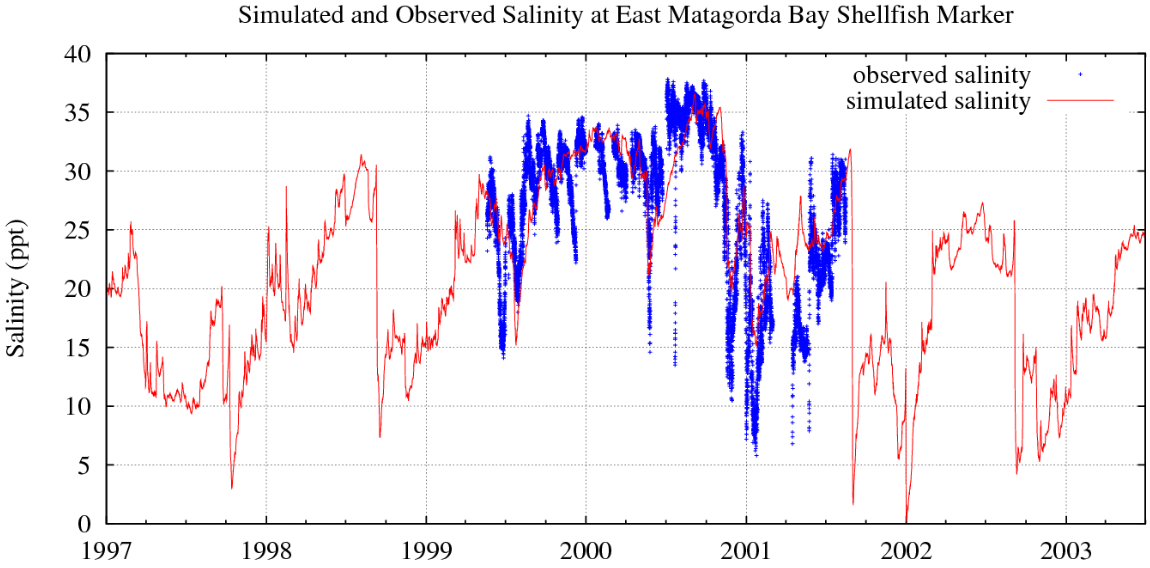


Figure 50. Observed (blue) versus simulated (red) salinities at the East Matagorda Bay Shellfish Marker site in Matagorda Bay for a period from mid-1999 through mid-2001, with additional simulated salinities from 1997 to mid-1989 and mid-2001 to 2003.

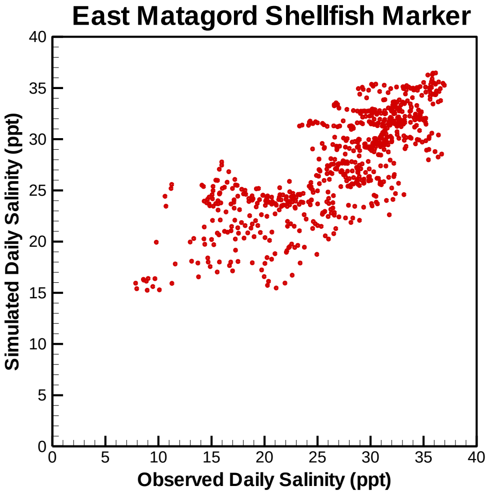


Figure 51. Scatter plot comparing simulated to observed daily salinities at the East Matagorda Bay Shellfish Marker site from mid-1999 to 2001, r^2 = 0.63.

Model Validation

To verify the validity of the calibrated Matagorda Bay and East Matagorda Bay TxBLEND model for salinity, additional model runs were conducted to simulate salinities for two different time periods, from 1989 - 1997 and from 2005 - 2009. Model outputs then were compared to TWDB/LCRA datasonde data for those sites with salinity data available after 1989 or were compared to point-measurement data obtained from TPWD's Coastal Fisheries database, the Texas Commission on Environmental Quality (TCEQ) Surface Water Quality Monitoring database, or the Texas Department of State Health Services (TDSHS) Shell Fish Safety Program for sites generally located near to the established monitoring stations presented earlier. For these datasets, data from point measurements collected within the vicinity of the datasonde site were aggregated to represent the local conditions. Their corresponding grid cell or latitude and longitude information is provided within the figures below. Because the TDSHS reports data to the TCEQ, the two databases share many data points. However for some locations, TCEQ contains more data than TDSHS and vice-versa. Therefore, either TCEQ or TDSHS data was selected to represent a site. Sites were chosen based on their closeness to the TWDB/LCRA datasondes, as well as based on the number of data points available for the site. At the Carancahua Bay, Palacios, and Sandy Point sites, point measurement data was the only data available for use in this validation exercise.

Results of Model Validation from 1989 - 1997

The first validation period from 1989 - 1997 compared simulated TxBLEND salinities to observed salinities obtained from the TWDB Datasonde Program for one site, the Lavaca Causeway (Figures 52 and 53), and from the LCRA for five additional monitoring sites, Carancahua Bay (Figures 54 and 55), Palacios Channel Marker 44 (Figures 56 and 57), West Bay near Sandy Point (Figures 58 and 59), West Bay Channel Marker 4 (Figures 60 and 61), and West Bay Tripod (Figures 62 and 63). TxBLEND model validation results also were compared to point measurement data for sites located near the established monitoring stations. Model simulations were representative of observed salinities at most locations. At sites that had datasonde data available for comparison, slight model departures from observed salinities were present in some instances, but overall long-term trends were represented well. Figures 52 through 63 show comparisons of simulated and observed salinities, both as time series plots for the period 1989-1997 and as scatter plots for the period 1989-2003 for the six sites in the Lavaca-Colorado Estuary. Table 7 lists summary statistics for these salinity comparisons.

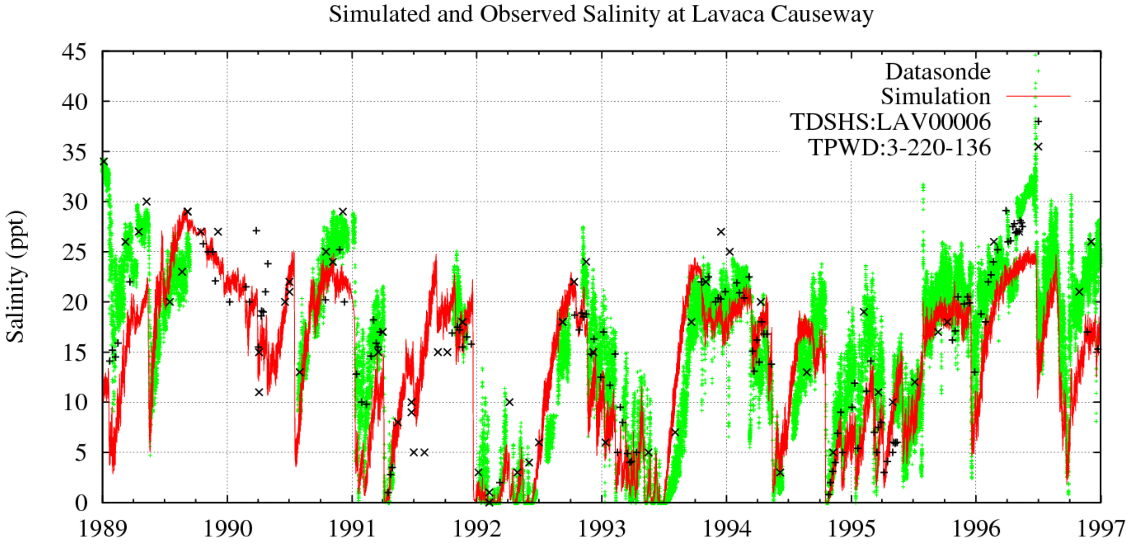


Figure 52. Simulated (red) and observed (green, +, or x) salinities at the Lavaca Causeway for the validation period 1989-1997. TWDB's Lavaca Causeway datasonde (green) is located at 28.6533 N, -96.5956 W. Data collected at the TDSHS (+) LAV00006 site was located at 28.645 N, -96.6075 W. Data collected by TPWD (x) was from grid cell 3-220-136 located at 28.6428 N, -96.6061 W.

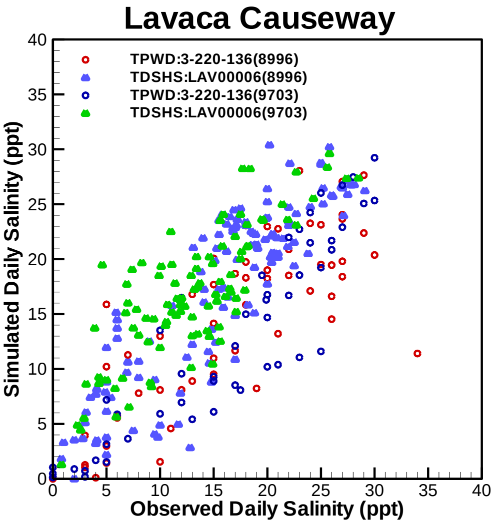


Figure 53. Scatter plot of simulated and observed daily salinity at the Lavaca Causeway site in Matagorda Bay for the validation period 1989 – 1997 (TPWD-open red; TDSHS-solid blue) with additional verification through the calibration period 1998 – 2003 (TPWD-open blue; TDSHS-green). Observed data are identified according to data source.

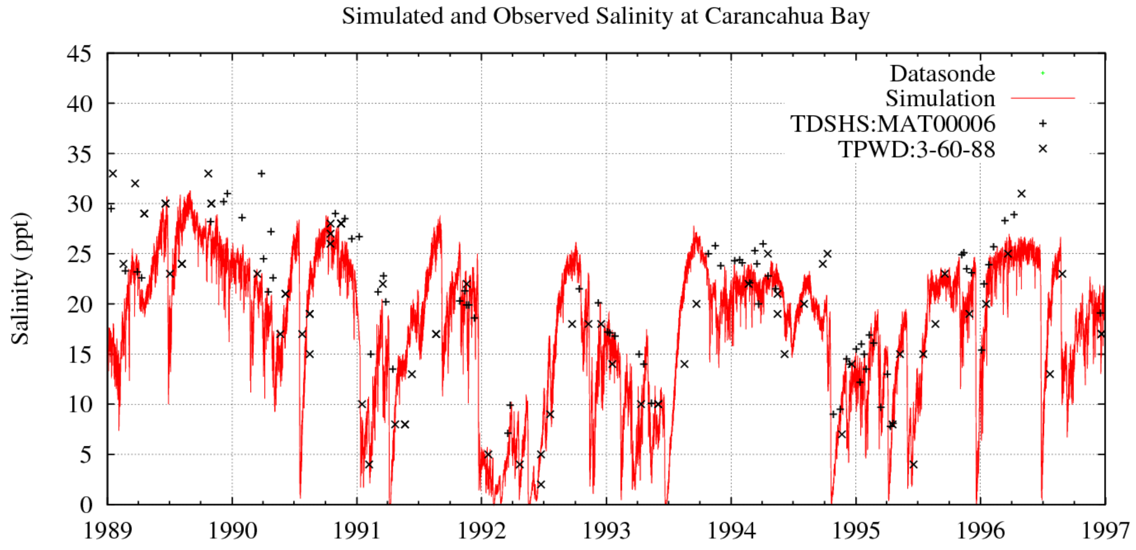


Figure 54. Simulated (red) and observed (green, + or x) salinities at Carancahua Bay for the validation period 1989-1997. TWDB's Carancahua Bay datasonde is located at 28.672 N, -96.400 W. Data collected at the TDSHS (+) MAT00006 site was located at 28.6217 N, -96.37 W. Data collected by TPWD (x) was from grid cell 3-60-88 located at 28.6723 N, -96.4058 W.

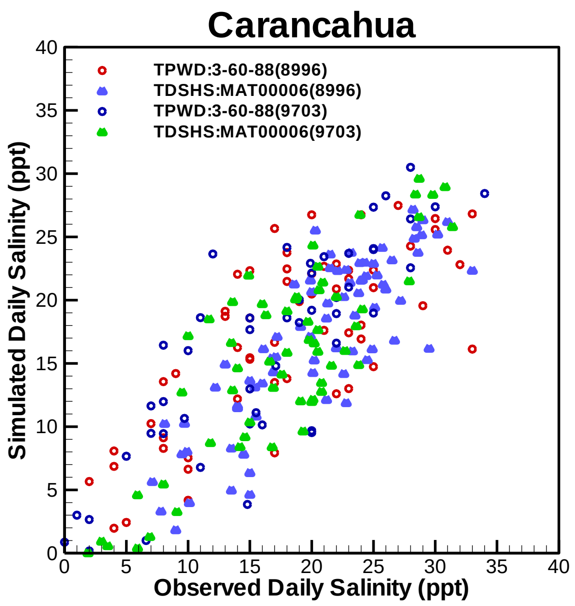


Figure 55. Scatter plot of simulated and observed daily salinity at the Carancahua Bay site in Matagorda Bay for the validation period 1989 – 1997 (TPWD-open red; TDSHS-solid blue) with additional verification through the calibration period 1998 – 2003 (TPWD-open blue; TDSHS-green). Observed data are identified according to data source.

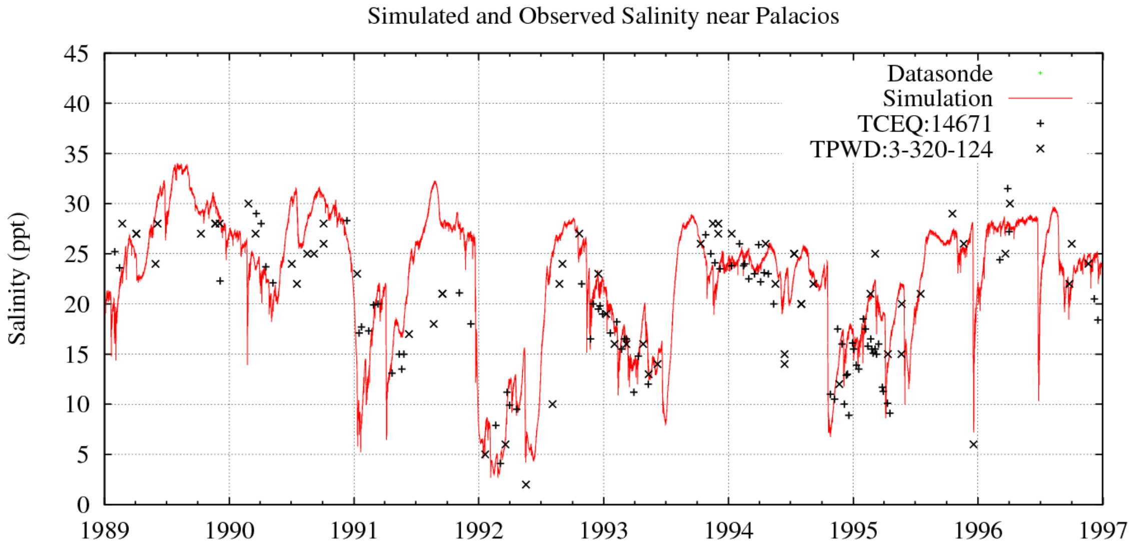


Figure 56. Simulated (red) and observed (green, + or x) salinities near Palacios for the validation period 1989-1997. TWDB's Palacios datasonde is located at 28.686 N, -96.240 W. Data collected at the TCEQ (+) 14671 site was located at 28.6445 N, -96.3039 W. Data collected by TPWD (x) was from grid cell 3-320-124 located at 28.6584 N, -96.2423 W.

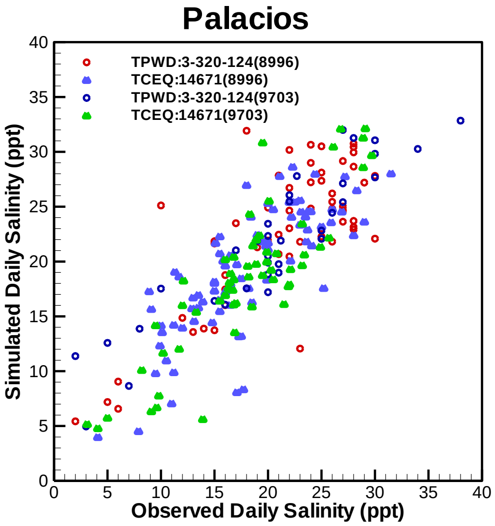


Figure 57. Scatter plot of simulated and observed daily salinity at the Palacios site in Matagorda Bay for the validation period 1989 – 1997 (TPWD-open red; TCEQ-solid blue) with additional verification through the calibration period 1998 – 2003 (TPWD-open blue; TCEQ-green). Observed data are identified according to data source.

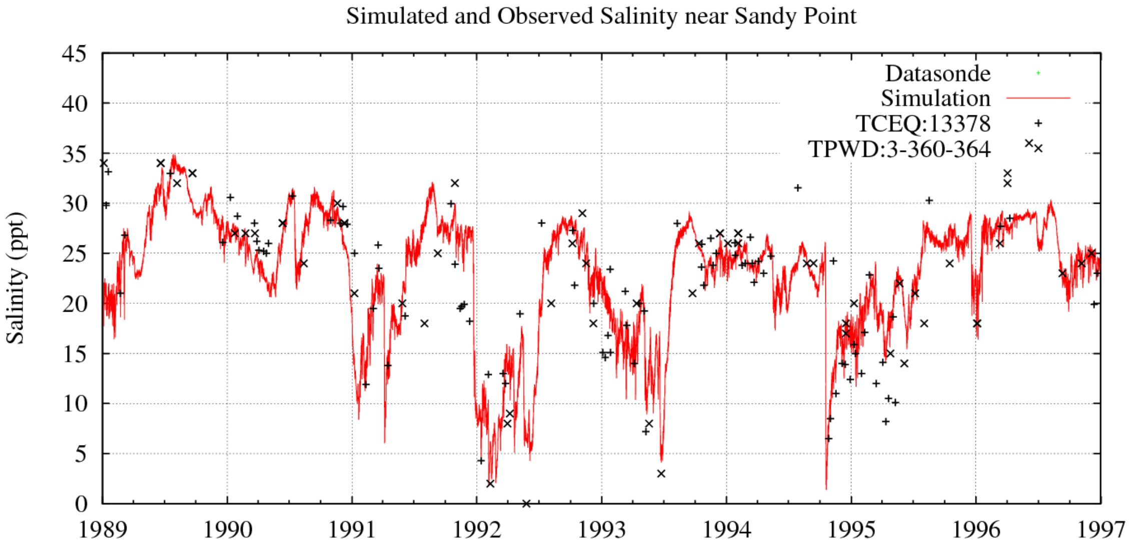


Figure 58. Simulated (red) and observed (green, + or x) salinities near Sandy Point for the validation period 1989-1997. TWDB's Sandy Point datasonde is located at 28.547 N, -96.465 W. Data collected at the TCEQ (+) 13378 site was located at 28.5256 N, -96.4667 W. Data collected by TPWD (x) was from grid cell 3-360-364 located at 28.5432 N, -96.5116 W.

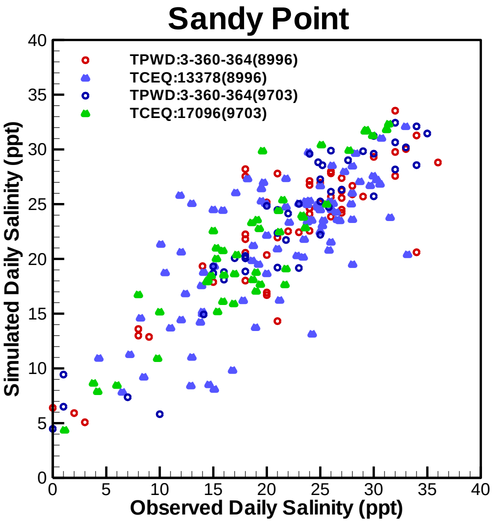


Figure 59. Scatter plot of simulated and observed daily salinity at the Sandy Point site in Matagorda Bay for the validation period 1989 – 1997 (TPWD-open red; TCEQ-solid blue) with additional verification through the calibration period 1998 – 2003 (TPWD-open blue; TCEQ-green). Observed data are identified according to data source.

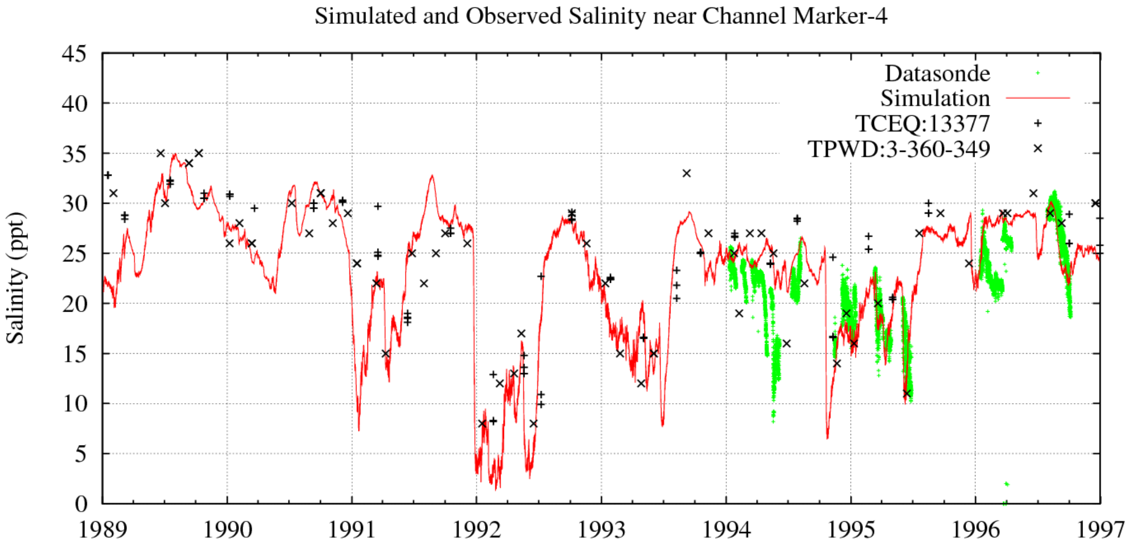


Figure 60. Simulated (red) and observed (green, + or x) salinities near the Channel Marker 4 site for the validation period 1989-1997. TWDB's Channel Marker 4 (green) datasonde is located at 28.562 N, -96.216 W. Data collected at the TCEQ (+) 13377 site was located at 28.5493 N, -96.3068 W. Data collected by TPWD (x) was from grid cell 3-360-349 located at 28.5596 N, -96.2444 W.

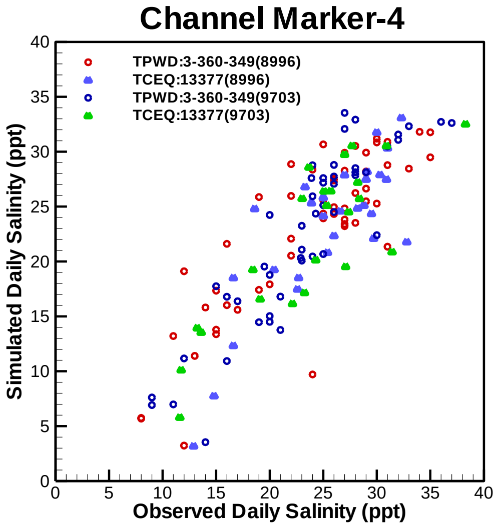


Figure 61. Scatter plot of simulated and observed daily salinity at the Channel Marker-4 site in Matagorda Bay for the validation period 1989 – 1997 (TPWD-open red; TCEQ-solid blue) with additional verification through the calibration period 1998 – 2003 (TPWD-open blue; TCEQ-green). Observed data are identified according to data source.

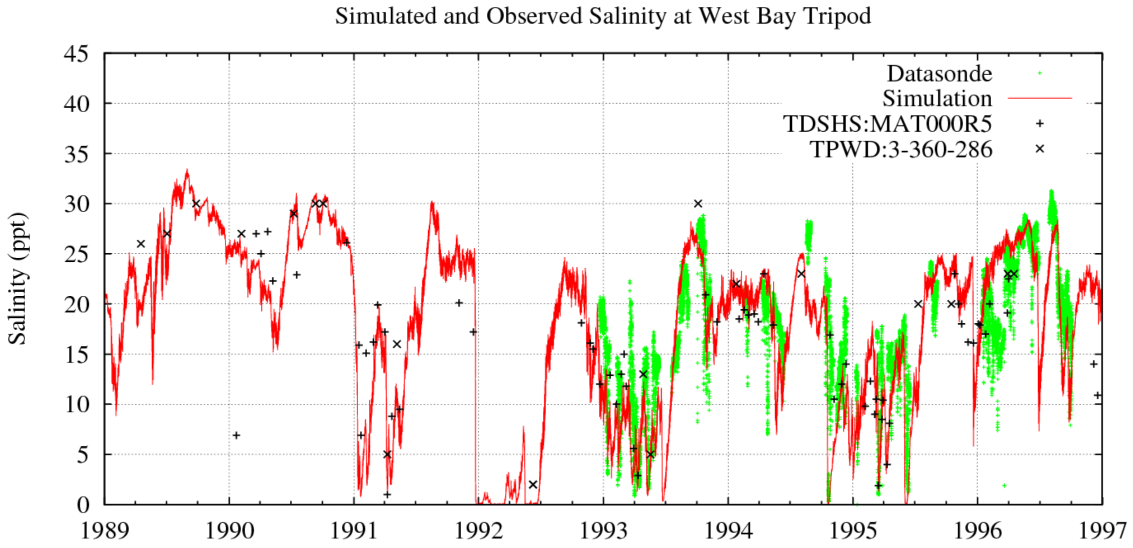


Figure 62. Simulated (red) and observed (green, + or x) salinities at the West Bay Tripod site for the validation period 1989-1997. TWDB's West Bay Tripod (green) datasonde is located at. Data collected at the TDSHS (+) MAT000R5 site was located at 28.6197 N, -96.0489 W. Data collected by TPWD (x) was from grid cell 3-360-286 located at 28.5881 N, -96.0449 W.

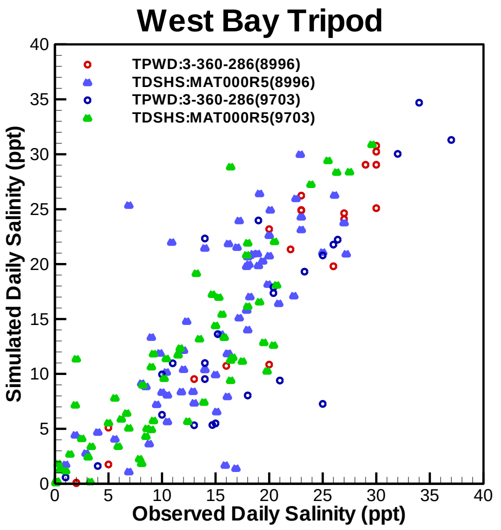


Figure 63. Scatter plot of simulated and observed daily salinity at the West Bay Tripod site in Matagorda Bay for the validation period 1989 – 1997 (TPWD-open red; TDSHS-solid blue) with additional verification through the calibration period 1998 – 2003 (TPWD-open blue; TDSHS-green). Observed data are identified according to data source.

Table 7. Summary statistics for comparisons of simulated to observed salinities for six sites in the Lavaca-Colorado Estuary during the period from 1989 - 2003, which included a model verification period from 1989 - 1997 and an extended verification through the calibration period of 1998 - 2003. State agency's data (TPWD, TDSHS, and TCEQ) for 1989 - 2003 were combined.

Location	n	r^2	RMS (ppt)	Nash-Sutcliffe	Average Simulated Salinity	Average Observed Salinity	Difference (Sim-Obs)
Lavaca Causeway	276	0.63	4.9	0.55	16.6	15.0	1.6
Carancahua Bay	242	0.64	5.0	0.55	16.6	18.5	-1.9
Palacios	232	0.70	3.9	0.65	20.3	19.2	1.1
Sandy Point	228	0.72	4.3	0.70	21.8	21.0	0.8
Marker-4	155	0.72	4.1	0.62	22.8	24.1	-1.3
West Tripod	169	0.71	4.9	0.63	13.9	15.0	-1.1

*RMS is the root mean square error.

** Nash-Sutcliffe Efficiency Criterion (*E*) describes model performance, where E=1.0 represents a match between model output and observed data and E<0 suggests the model is a poor predictor.

Results of Model Validation from 2005 - 2009

A second model validation from 2005 - 2009 compared simulated salinities to observed salinities collected by LCRA at eight sites in Matagorda Bay and East Matagorda Bay and included the following locations: West Bay near Sandy Point, Carancahua Bay, West Bay Channel Marker #4, Palacios Channel Marker #44, Shellfish Marker B, West Bay Tripod, East Bay Tripod, and East Bay Shellfish Marker (Figure 64). A ninth site was added to the validation and includes TWDB's datasonde at the Lavaca Causeway, which collected data from 2004 - 2009.

Figures 65 through 82 show comparisons of simulated and observed salinities, both as time series plots for the period 2004 - 2009 and as scatter plots for the seven sites in the Lavaca-Colorado Estuary and two sites in East Matagorda Bay. The model's performance during this validation period was comparable with results from the calibration period, with r^2 values ranging from 0.54 to 0.84 with more accurate predictions observed in sites within Matagorda Bay. As in the calibration, the model captures salinity trends in Matagorda Bay for most of the five-year validation period. While some years were characterized by salinity fluctuating over a large range for several months (such as the last six months of 2007), such variability, as well as incremental increases after flushing events, were predicted by the model reasonably well across most sites. Moreover, the model simulated salinity very well during years when salinity in the bay was persistently high (parts of 2008 and 2009). Figure 79 shows the model consistently under-predicted salinities at the East Matagorda Bay Tripod site. Model departure at this location could be due to the fact that TxBLEND is modeled with the locks at the intersection of the GIWW and the Colorado River in an open state, which would increase the amount of inflow received at this site. Moreover, the extent of short-term fluctuations at the West Bay Tripod, and at the West Bay and East Bay Shellfish markers was under-predicted by the model even though long-term trends were imitated well. Table 8 provides summary statistics for these salinity comparisons.

Figure 64. Eight LCRA datasonde sites in the Lavaca-Colorado Estuary and East Matagorda Bay.

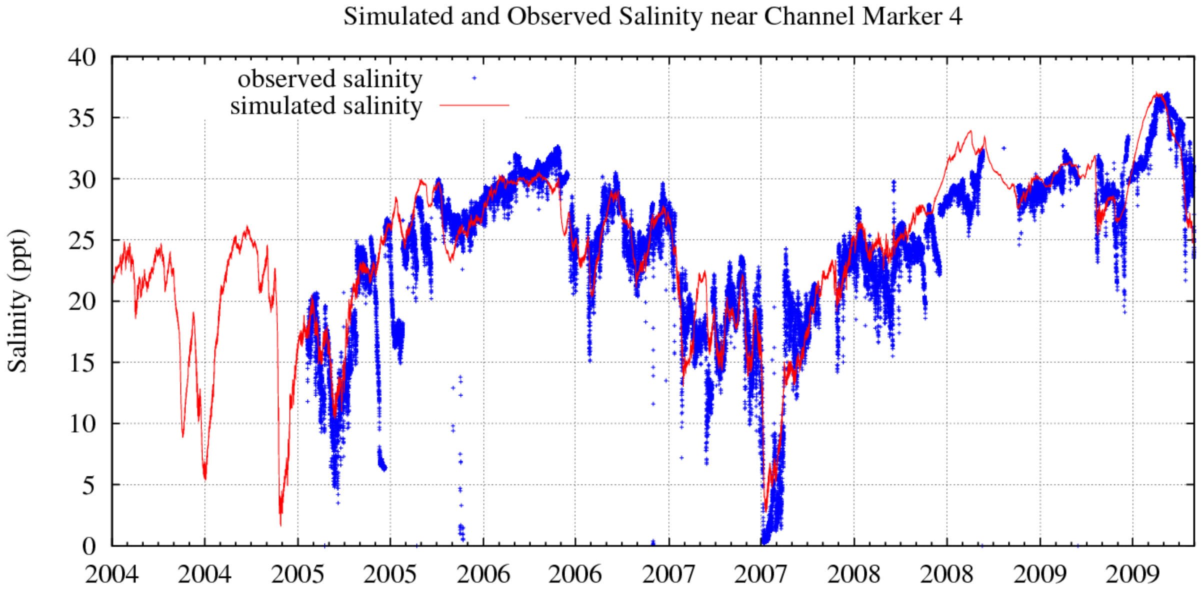


Figure 65. Observed (blue) versus simulated (red) salinities at the Channel Marker 4 site in Matagorda Bay for a period from 2005 through 2009.

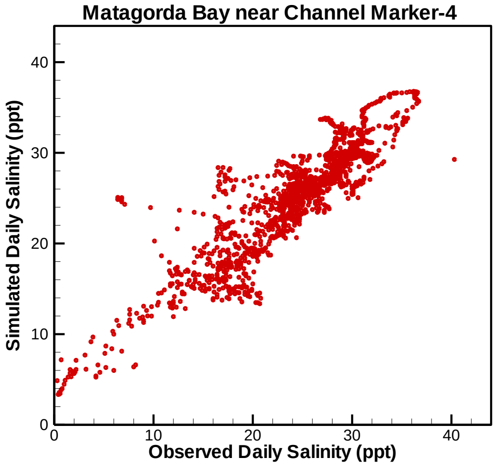


Figure 66. Scatterplot comparing simulated to observed salinities at the Channel Marker 4 site from 2005 through 2009.

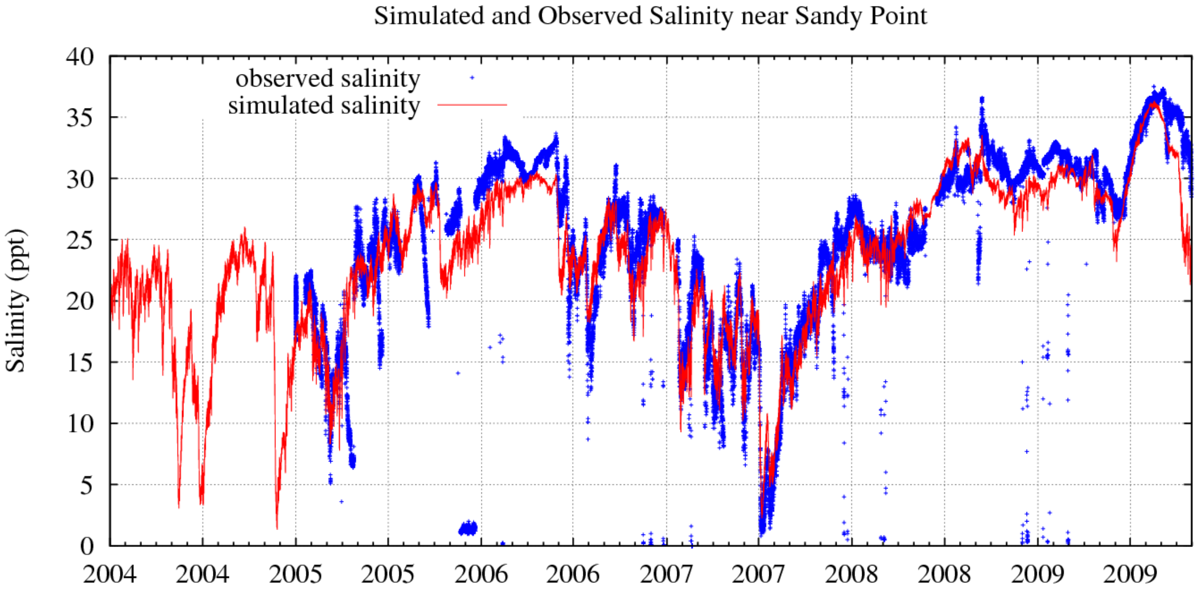


Figure 67. Observed (blue) versus simulated (red) salinities at the Sandy Point site in Matagorda Bay for a period from 2005 through 2009.

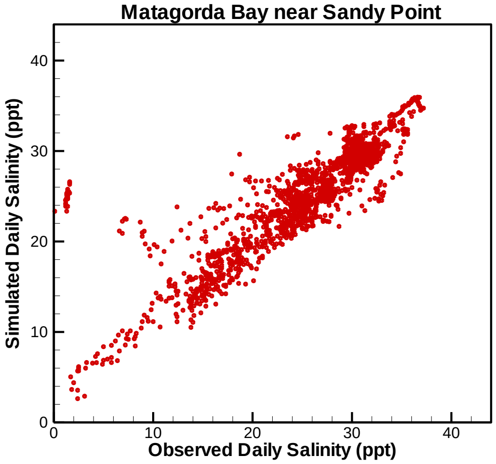


Figure 68. Scatterplot comparing simulated to observed salinities at the Sandy Point site from 2005 through 2009.

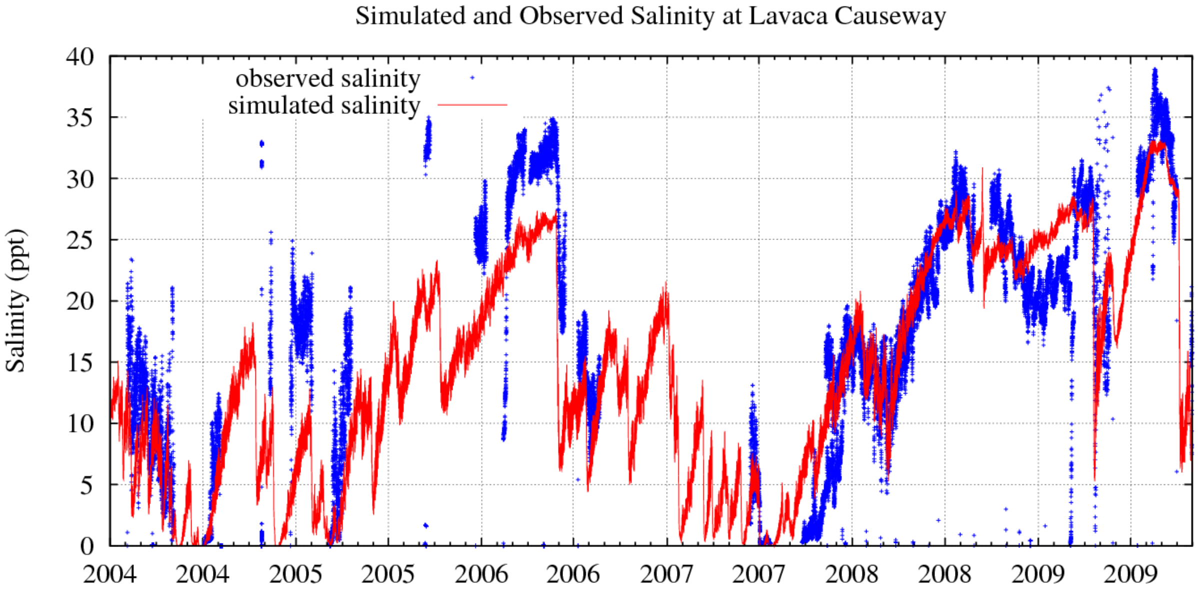


Figure 69. Observed (blue) versus simulated (red) salinities at the Lavaca Causeway site in Matagorda Bay for a period from 2004 through 2009.

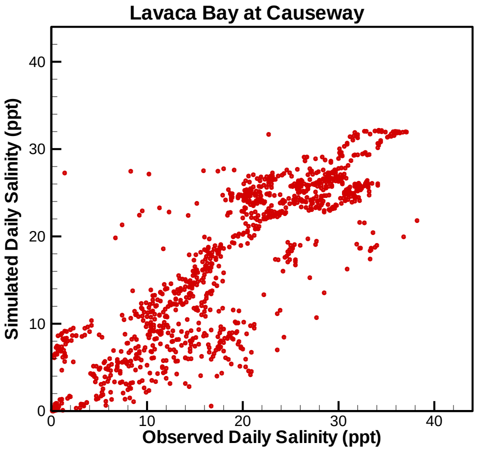


Figure 70. Scatterplot comparing simulated to observed salinities at the Lavaca Causeway site from 2005 through 2009.

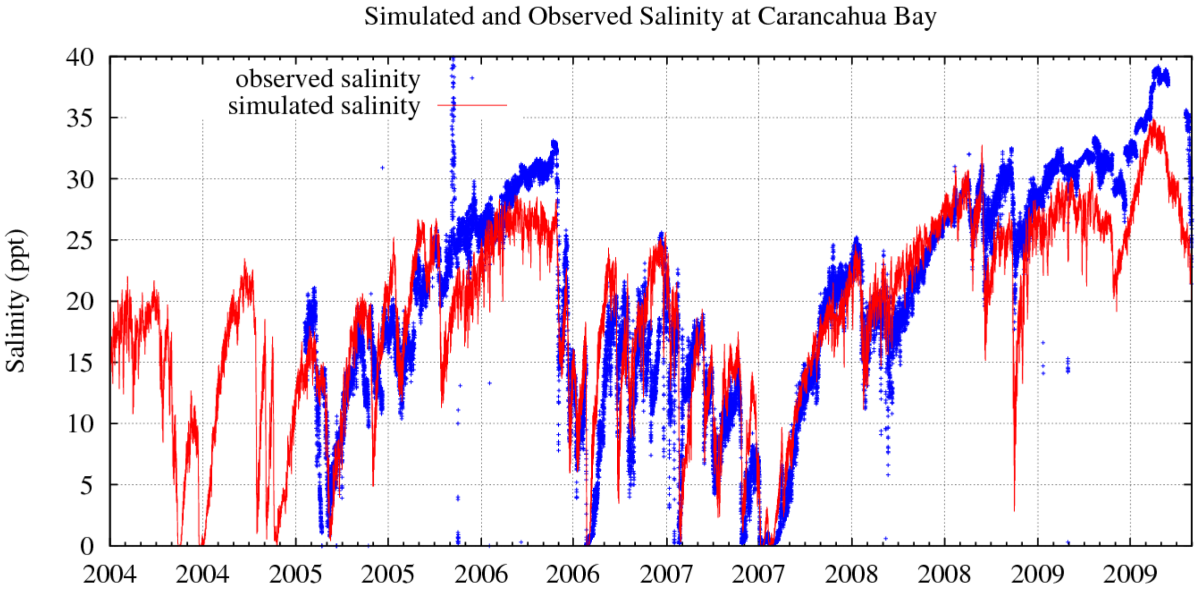


Figure 71. Observed (blue) versus simulated (red) salinities at the Carancahua Bay site in Matagorda Bay for a period from 2005 through 2009.

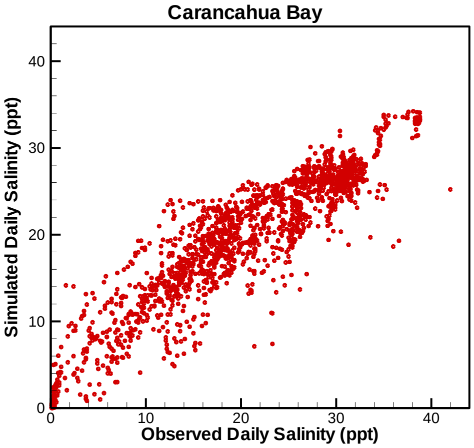


Figure 72. Scatterplot comparing simulated to observed salinities at the Carancahua Bay site from 2005 through 2009.

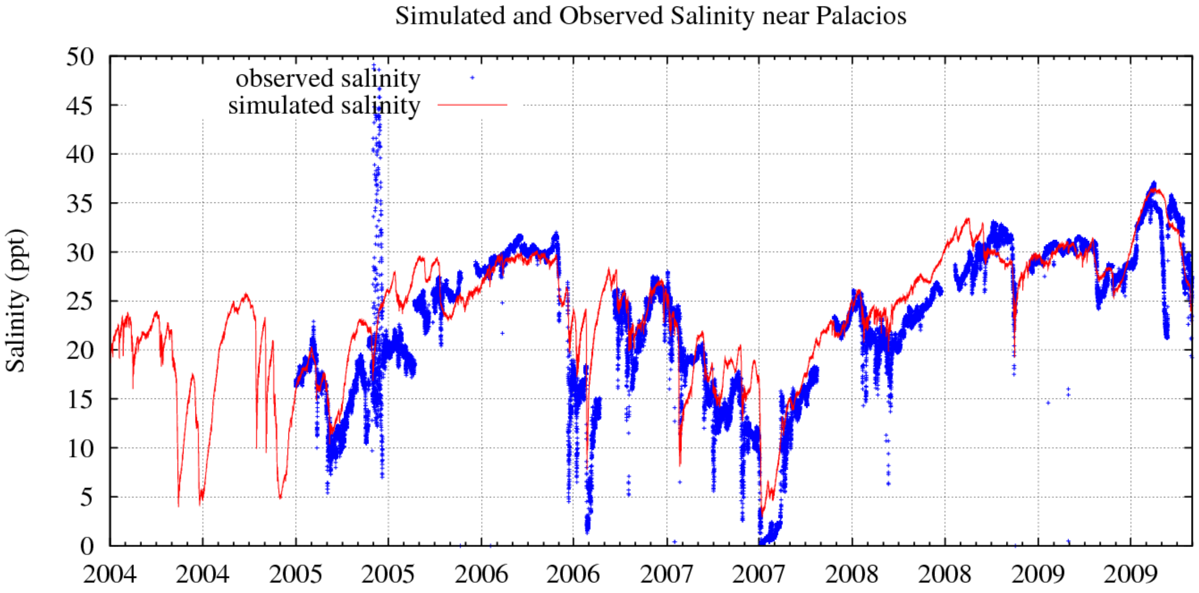


Figure 73. Observed (blue) versus simulated (red) salinities at the Palacios site in Matagorda Bay for a period from 2005 through 2009.

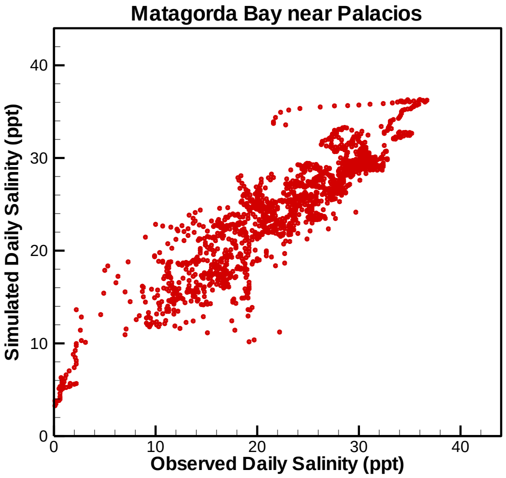


Figure 74. Scatterplot comparing simulated to observed salinities at the Palacios site from 2005 through 2009.

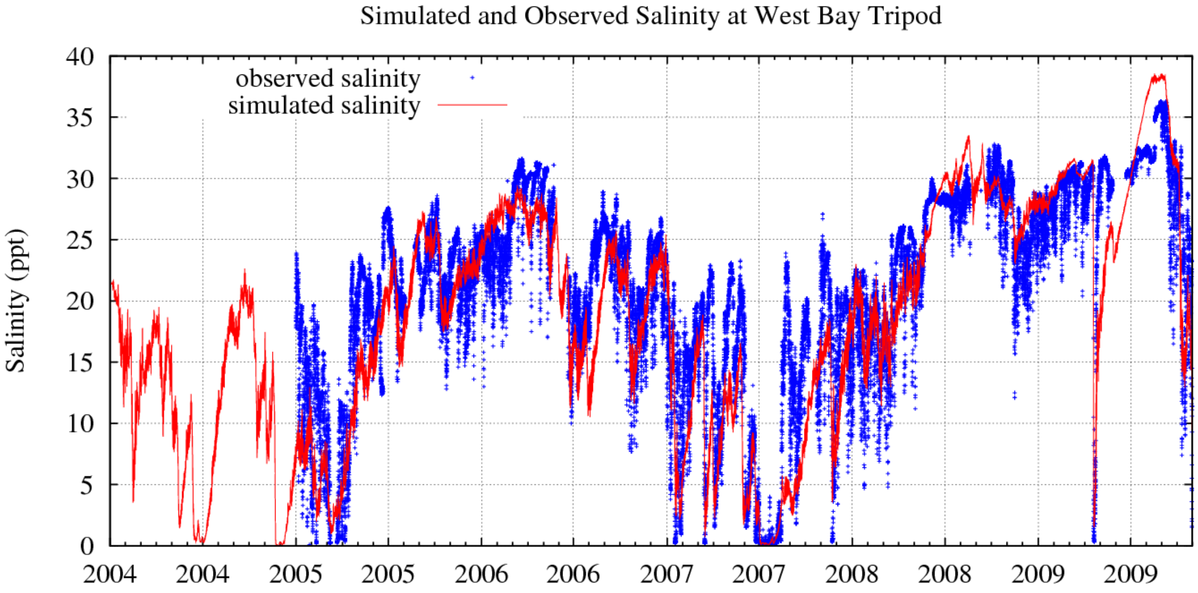


Figure 75. Observed (blue) versus simulated (red) salinities at the West Bay Tripod site in Matagorda Bay for a period from 2005 through 2009.

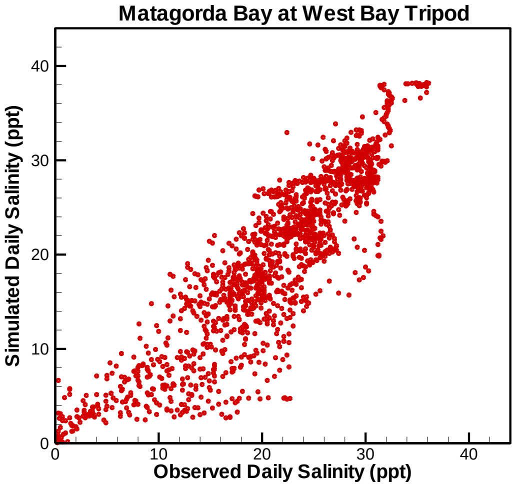


Figure 76. Scatterplot comparing simulated to observed salinities at the West Bay Tripod site from 2005 through 2009.

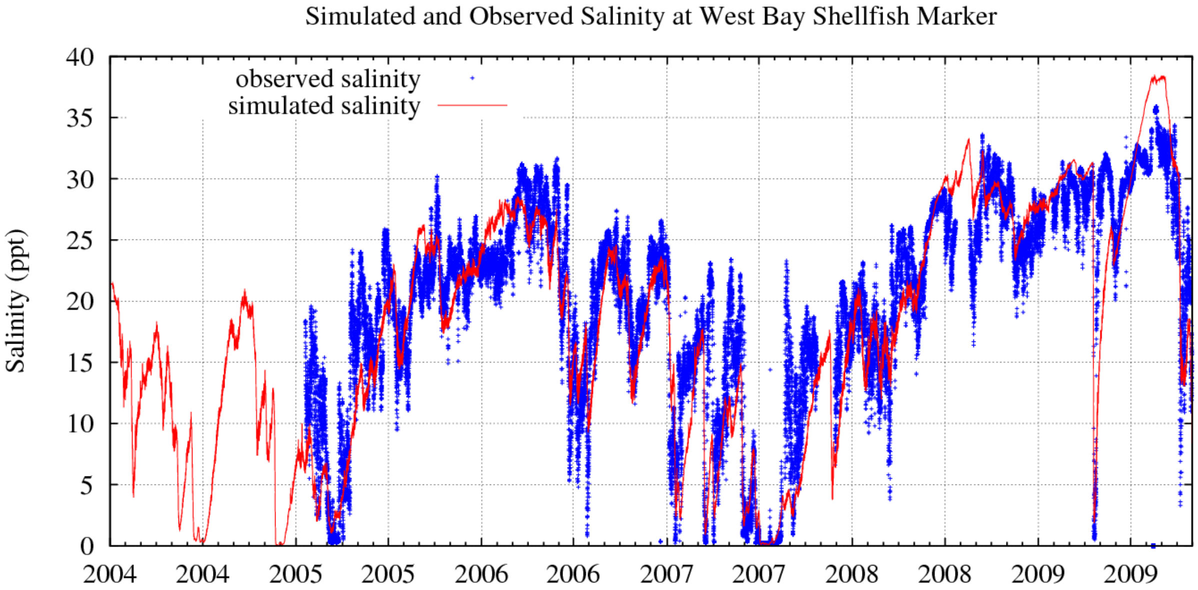


Figure 77. Observed (blue) versus simulated (red) salinities at the West Bay Shellfish Marker site in Matagorda Bay for a period from 2005 through 2009.

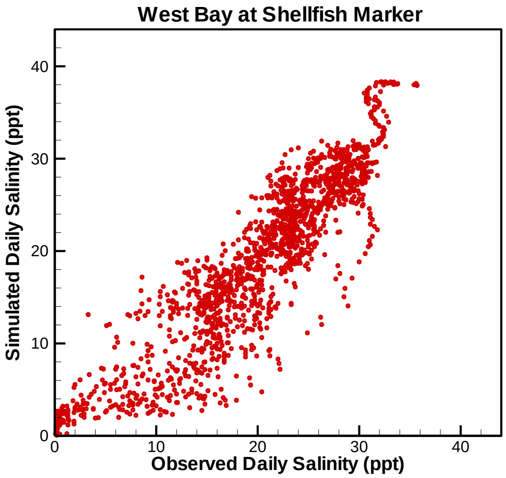


Figure 78. Scatterplot comparing simulated to observed salinities at the West Bay Shellfish Marker site from 2005 through 2009.

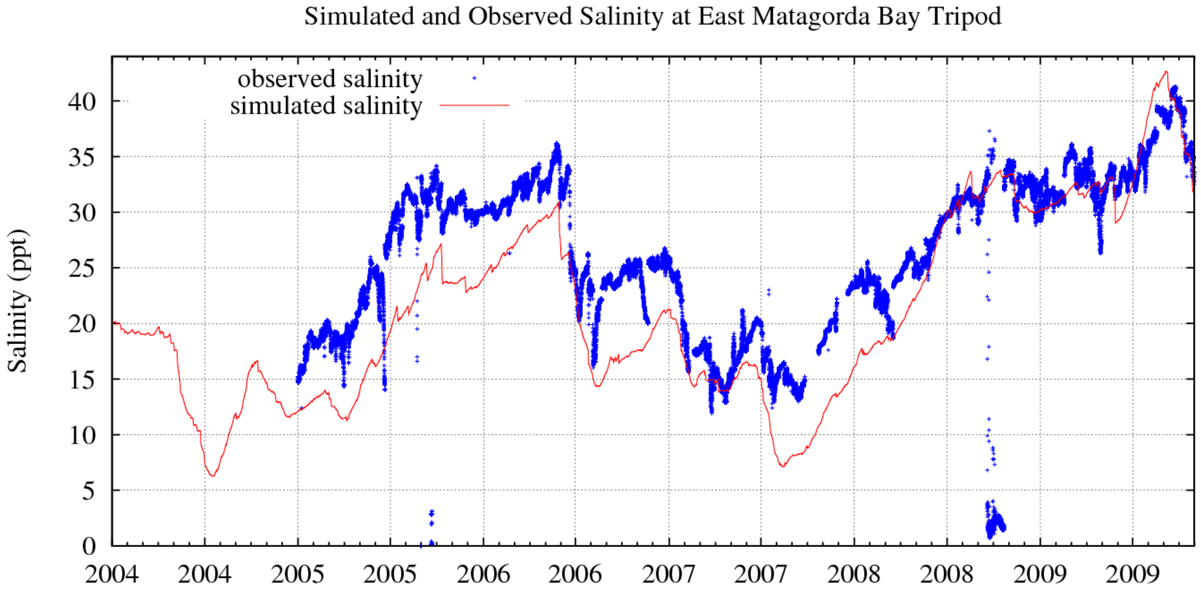


Figure 79. Observed (blue) versus simulated (red) salinities at the East Matagorda Bay Tripod site in East Matagorda Bay for a period from 2005 through 2009.

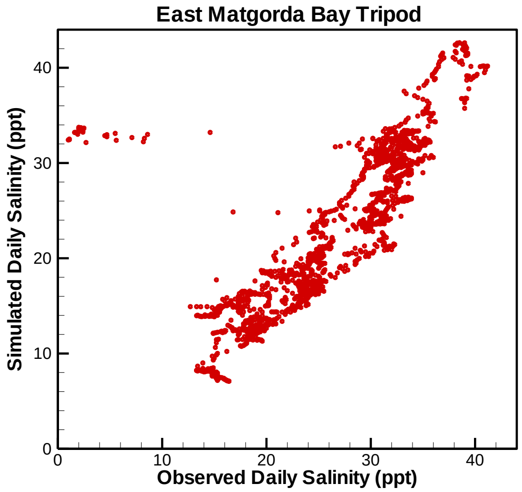


Figure 80. Scatterplot comparing simulated to observed salinities at the East Matagorda Bay Tripod site from 2005 through 2009.

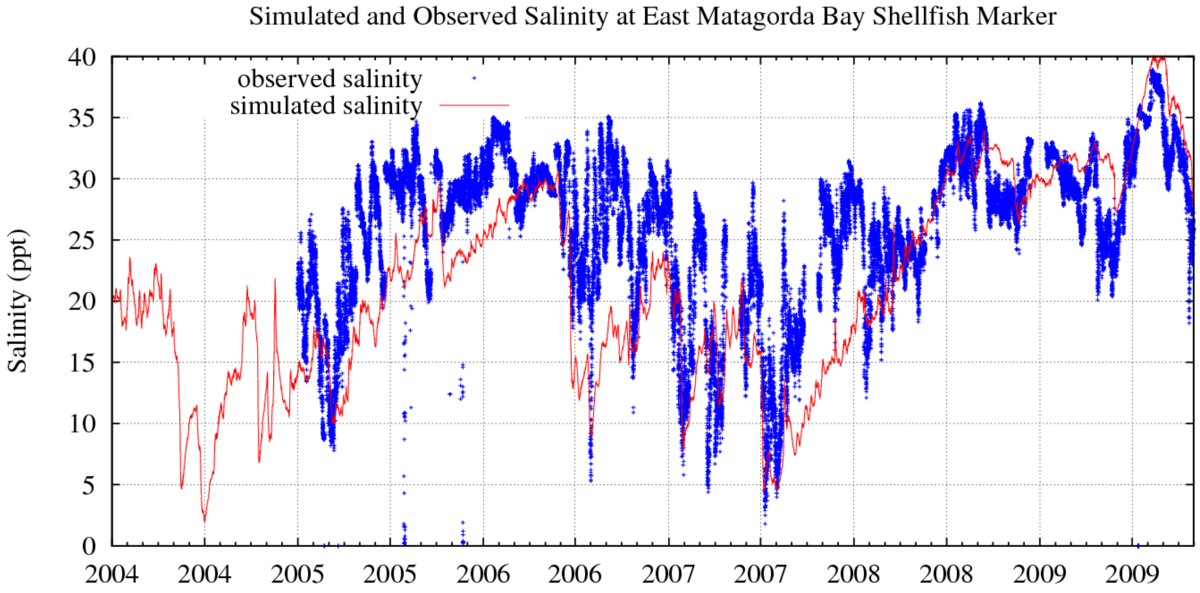


Figure 81. Observed (blue) versus simulated (red) salinities at the East Matagorda Bay Shellfish Marker site in East Matagorda Bay for a period from 2005 through 2009.

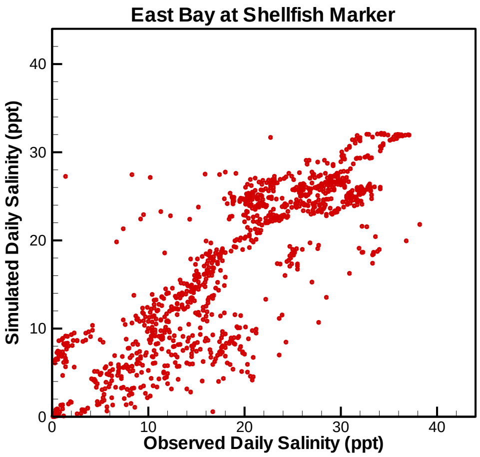


Figure 82. Scatterplot comparing simulated to observed salinities at the East Matagorda Bay Shellfish Marker site from 2005 through 2009.

Table 8. Comparison statistics for daily salinity from 2005 – 2009 at all sites, except the TWDB station at the Lavaca Causeway, which includes 2004-2009.

					Average		
Location	Days	r^2	RMS (ppt)*	NSEC	Simulated Salinity	Observed Salinity	Difference
Marker-4	1,571	0.81	3.0	0.80	25.1	24.3	0.8
Sandy Point	1,643	0.71	4.1	0.71	24.8	24.8	0.0
Lavaca Causeway**	1,075	0.74	5.3	0.69	16.9	18.7	-1.8
Carancahua Bay	1,733	0.78	5.0	0.75	19.9	21.1	-1.2
Palacios	1,600	0.84	3.5	0.78	24.4	22.8	1.6
WestBay Shellfish Marker	1,655	0.83	3.9	0.77	19.2	20.2	-1.0
West Bay Tripod	1,631	0.80	4.3	0.71	19.7	21.1	-1.4
East Bay Tripod	1,709	0.57	6.4	0.24	23.0	26.1	-3.1
East Bay Shellfish Marker	1,075	0.74	5.3	0.69	16.9	18.7	-1.8

*parts per thousand (ppt)

**Statistics for the Lavaca Causeway station are based on the period 2004-2009.

Conclusions

Results for the salinity calibration demonstrate that although short-term fluctuations are sometimes less well represented, the TxBLEND model for the Lavaca-Colorado Estuary and East Matagorda Bay captures major, long-term salinity trends reasonably well. Model calibration for discharge and velocity show that simulated discharge and velocity are representative of observed discharge and velocity at most locations, except where there are few observed measurements available for comparison. Likewise, simulated tidal elevations are representative of observed tidal elevations at all locations.

The validation exercise to simulate bay conditions for the 1989 to 1997 period shows that the model represents observed salinities from point measurements and datasonde data reasonably well. Similar to the calibration results, long-term trends are captured, but short-term variability in simulated salinity is sometimes less representative of observed salinity conditions. The validation exercise for the period 2005 to 2009 shows similar results. General, long-term salinity trends are captured, but in some cases the model either under- or over-predicts salinity during times of high variability. Additionally, summary statistics from the two validation exercises were comparable to the calibration exercise, indicating good model performance.

In cases where the model is less representative of observed salinity, many different factors, model or non-model related, may have affected model performance and contributed to model departure, including datasonde instrument error, limitations of the two-dimensional TxBLEND model, or the application of model parameters. Localized rainfall that is not recorded by a rainfall gage, and hence, not included in the model, also affects the ability to accurately represent inflows and hence limits the ability of the model to accurately predict salinities. Additionally, the TxBLEND model for the Lavaca-Colorado Estuary and East Matagorda Bay is modeled as having the locks at the intersection of the GIWW and the Colorado River open at all times, which may affect model performance at sites close to the locks in the GIWW.

In general, the TxBLEND model predicted long-term salinity trends in the Lavaca-Colorado Estuary and East Matagorda Bay reasonably well. Even though these bays, as with other Texas bays, are generally very shallow and have minimal tidal fluctuations, a two-dimensional hydrodynamic model, such as TxBLEND, presents limitations to modeling the mixing process. Thus, a three-dimensional hydrodynamic model may be a better predictor of salinity for some locations within the bays. TWDB staff will continue to explore the use of three-dimensional models for future estuary analysis efforts.

Literature Cited

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