TxBLEND Model Calibration and Validation
For the Laguna Madre Estuary

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Bays and Estuaries Program
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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 freshwater inflow 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 Laguna Madre Estuary including Baffin Bay but is not limited to this system. Instead, the model also includes Copano, Aransas, and Corpus Christi Bays to the north 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 Laguna Madre Estuary is divided into northern and southern portions that are disconnected by a non-contributing coastal land mass. The Upper Laguna Madre (northern portion) is connected to Baffin Bay and Corpus Christi Bay to the north. The Lower Laguna Madre (southern portion) is not connected to another bay system or to the Rio Grande. Two major freshwater inflow sources in the Laguna Madre Estuary include gaged inflow from San Fernando Creek into Baffin Bay in the Upper Laguna Madre and the Arroyo Colorado in the Lower Laguna Madre. The Rio Grande does not flow into the Estuary but rather flows directly into the

Gulf of Mexico. Direct connections to the Gulf of Mexico occur only in the Lower Laguna Madre at the Port Mansfield Channel and Brazos-Santiago Pass. The Brownsville Ship Channel transverses the southernmost tip of the Lower Laguna Madre and shares a connection with South Bay.

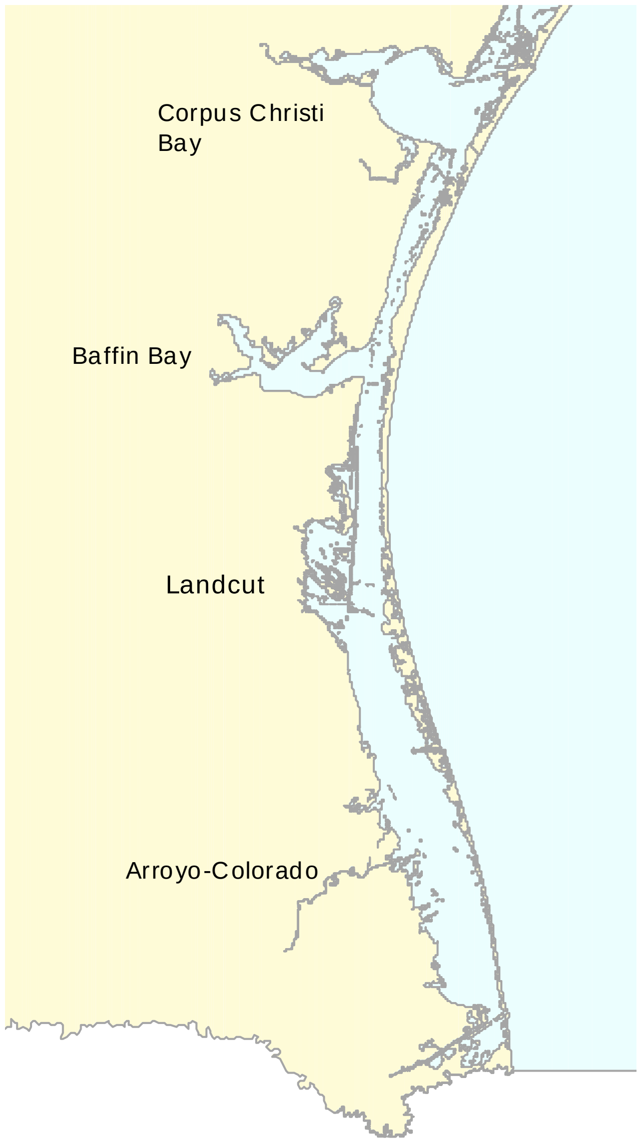


Figure 1. Regional map of the Laguna Madre Estuary along the Texas coast. The Laguna Madre is divided into northern and southern portions by a non-contributing coastal land mass (in the region identified as the Landcut). Freshwater inflow into the estuary is received from San Fernando Creek into Baffin Bay in the Upper Laguna Madre and the Arroyo Colorado in the Lower Laguna Madre. .

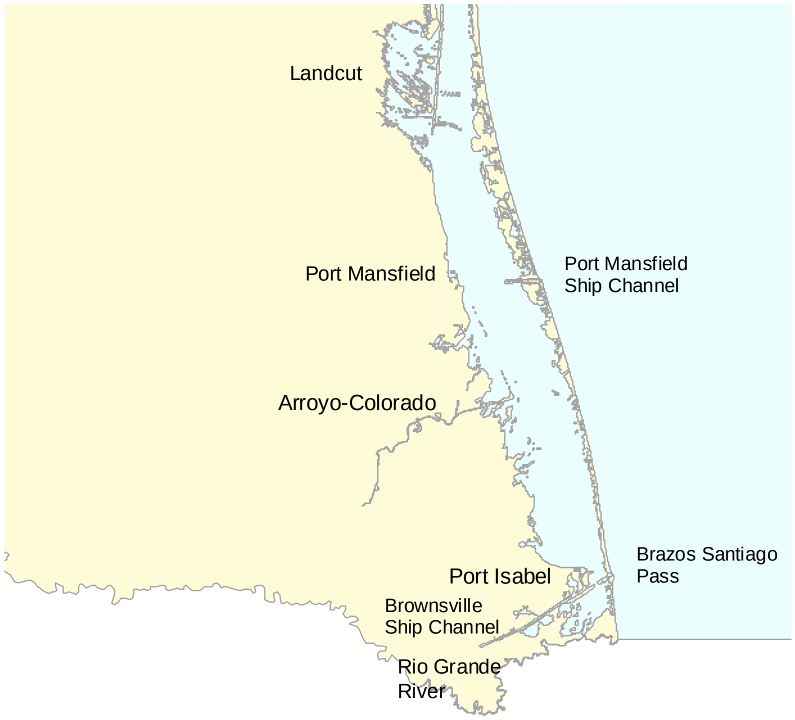


Figure 2. Close-up of the Lower Laguna Madre Estuary along the Texas coast. Freshwater inflow into the Lower Laguna Madre is received from the Arroyo Colorado. Port Mansfield Ship Channel and Brazos-Santiago Pass provide a direct connection to the Gulf of Mexico. The Brownsville Ship Channel transverses the southernmost tip of the lower Laguna Madre and shares a connection with South Bay.

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 above assumptions.

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 Laguna Madre model grid, as shown in Figures 3 and 4). 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 Laguna Madre Estuary

The TxBLEND computational grid for the Laguna Madre Estuary contains 14,933 nodes and 25,856 triangular elements (Figure 3 - 4). In addition to the bays of the Laguna Madre Estuary system, the model grid also represents Copano, Aransas, and Corpus Christi Bays to the northeast. These bays were included to yield better simulation results by modeling conditions at the boundary of the estuary, based on conditions in the neighboring bays, rather than prescribing a pre-set boundary condition. The model grid has nine inflow points (Figure 6), corresponding to flows coming from the: Salt/Cavasso Creek, Copano Creek, Mission River, Aransas River, Nueces River, San Fernando Creek, Main Floodway, North Floodway (also known as Arroyo Colorado), and San Martin. Bathymetry used to develop the grid was obtained from the U.S. Army Corps of Engineers Waterway Experiment Station and supplemental information was obtained from the National Oceanic and Atmospheric Administration navigation charts (Nautical Charts #11302: Stover Point to Port Brownsville including Brazos-Santiago Pass; #11303: Laguna Madre, Chubby Island to Stover Point including Arroyo Colorado; #11306: Laguna Madre, Middle Ground to Chubby Island; and, #11308: Redfish Bay to Middle Ground including Baffin Bay).

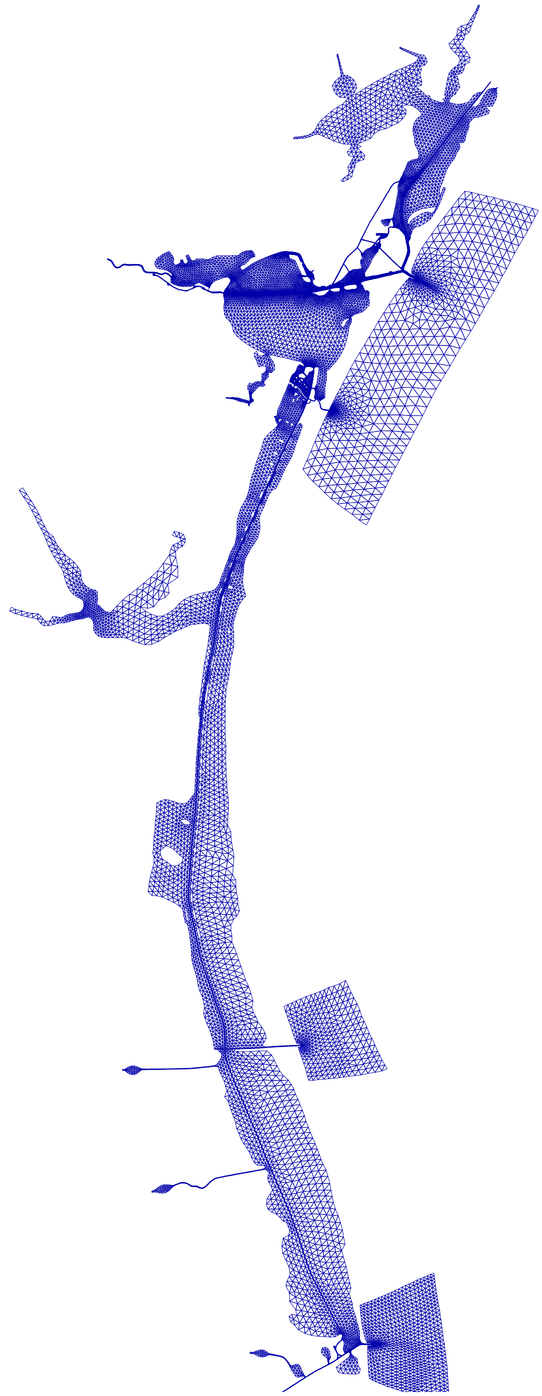


Figure 3. Computational Grid for the Laguna Madre Estuary TxBLEND model. The model grid includes Copano, Aransas, Corpus Christi, and Baffin Bays to better represent boundary conditions for the Laguna Madre Estuary.

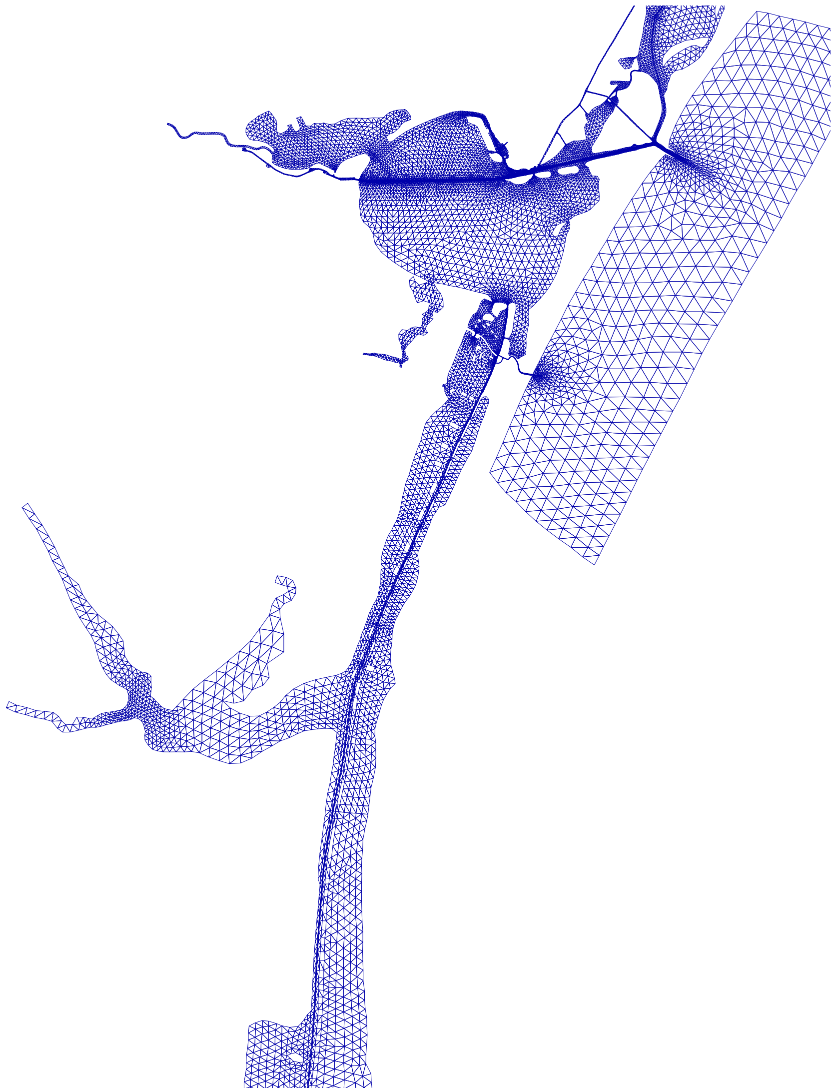


Figure 4. Close-up of the computational grid for Corpus Christi Bay, the Upper Laguna Madre and Baffin Bay.

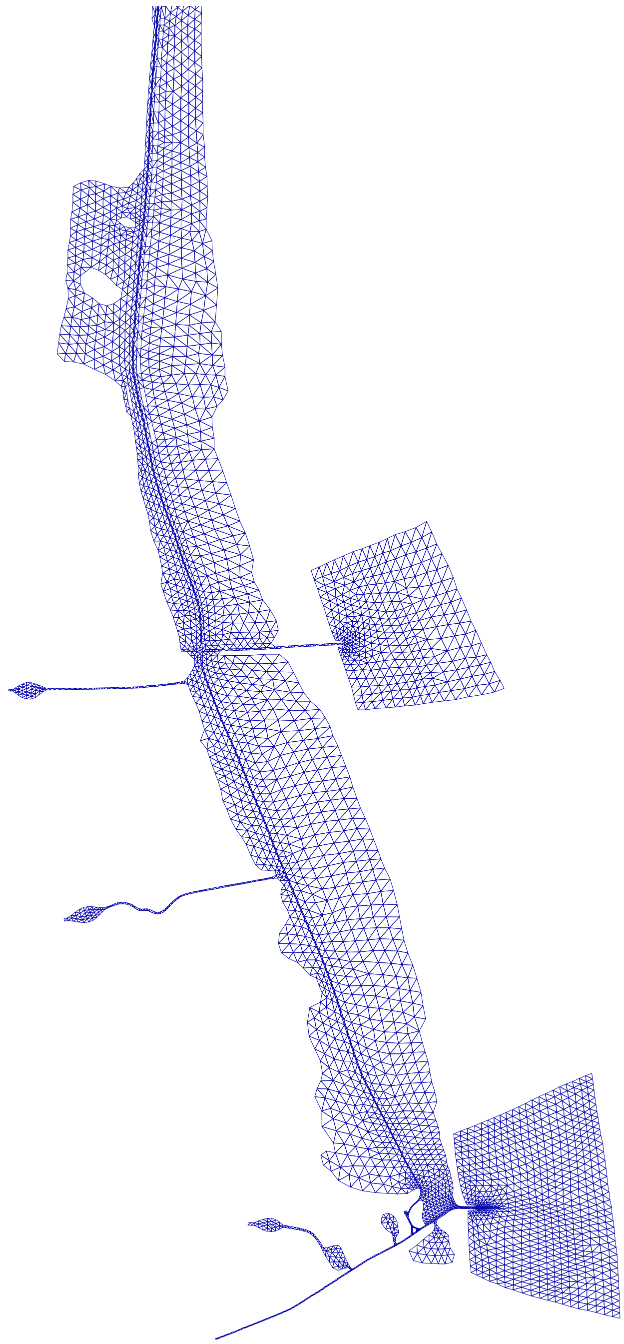


Figure 5. Close-up of the computational grid for the Lower Laguna Madre, including the three inflow points, *from top to bottom*: the Main Floodway, the Arroyo Colorado, and San Martin.

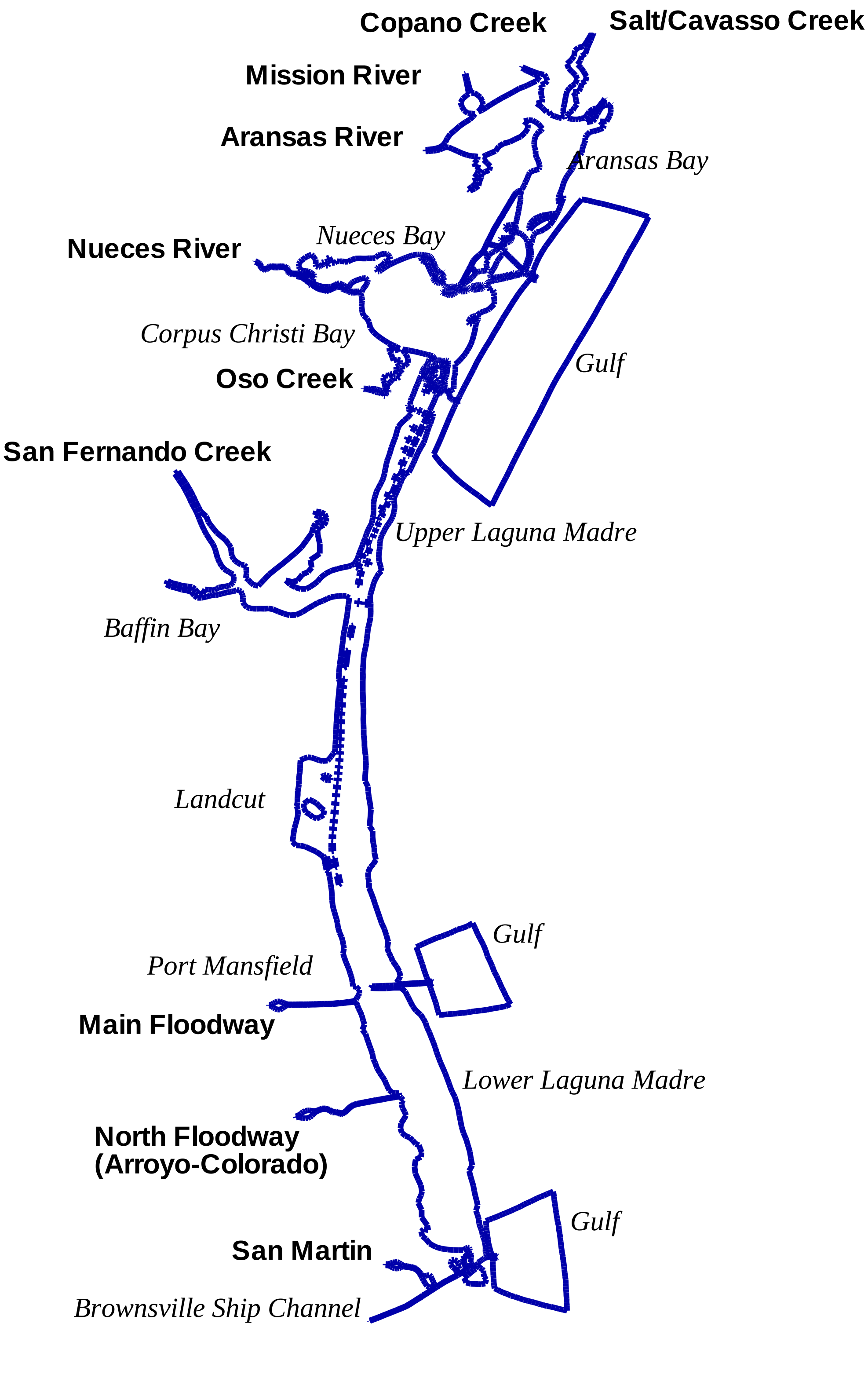


Figure 6. Ten inflow points (in bold type) and geographical features (in italic font) for the Laguna Madre Estuary TxBLEND model.

Inflows

Daily inflow values were taken from TWDB coastal hydrology dataset version #TWDB201101-L for the Lower Laguna Madre Estuary (Schoenbaechler *et al*., 2011a), from version #TWDB201004-U for the Upper Laguna Madre Estuary (Schoenbaechler *et al*., 2011b), #TWDB201004 for the Mission-Aransas Estuary (Schoenbaechler *et al.*, 2010), and from version #TWDB201004 for the Nueces Estuary (Schoenbaechler *et al*., 2011c). While these datasets extend as far back as 1941, inflow values were applied only as needed depending on the time period of the model run. Hydrology version #TWDB201101-L for the Lower Laguna Madre includes estimates for inflows through 2010 but diversion and return data were only updated through 2009. Hydrology versions #TWDB201004 for the Mission-Aransas and Nueces Estuaries and TWDB201004-U for the Upper Laguna Madre include estimates for inflows only through 2009.

Inflow datasets use measurements from U.S. Geological Survey (USGS) and International Boundary and Water Commission (IBWC) stream gages along with rainfall-runoff estimates from the Texas Rainfall-Runoff (TxRR) model. These flows are adjusted for known municipal, industrial, and agricultural diversion and return flows to develop daily inflows for the estuaries. Table 2 lists USGS and IBWC stream gages used to develop the gaged component of inflows. Figures 7 – 9 show the watershed boundaries including the ungaged watersheds that were modeled using TxRR. Ungaged flows were estimated using precipitation data from the National Weather Service. Diversion and return data were obtained from a variety of sources, including the Texas Commission on Environmental Quality (TCEQ), the South Texas Water Master (STWM), HDR, Inc., and TWDB Irrigation Water Use estimates.

Daily inflows from the surrounding river basins and coastal watersheds were applied to the model at the ten inflow points specified in Figure 6, according to the distribution scheme described in Table 3. Seven inflow points received gaged and ungaged inflow, including Copano Creek, Mission River, Aransas River, Nueces River, Oso Creek, San Fernando Creek, and Arroyo Colorado inflow points. The remaining three inflow points, Salt/Cavasso Creeks, Main Floodway, and San Martin, 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 application to TxBLEND inflow points for the Mission-Aransas, Nueces, and Upper Laguna Madre Estuaries, and IBWC gages for the Lower Laguna Madre.

Estuary	Gage Station Number	Gage Location	Utilized Period of Record
Mission-Aransas	08189800	Chiltipin Creek at Sinton	1991
	08189700	Aransas River near Skidmore	1991 - 2009*
	08189500	Mission River at Refugio	1991 - 2009*
	08189200	Copano Creek near Refugio	1991 - 2009*
Nueces	08211000	Nueces River at Mathis	1991 - 2009*
	08211520	Oso Creek at Corpus Christi	1991 - 2009*
Upper Laguna Madre	08211900	San Fernando Creek at Alice	1991 – 2009*
	08212400	Los Olmos Creek at Falfurrias	1991 – 2009*
Lower Laguna Madre	08470200	North Floodway near Sebastian	1991 – 1997†
	08470400	Arroyo Colorado at Harlingen	1991 – 2010

†This gage was non-operational from 1/1998 – 2010, and were instead modeled using TxRR during this period.
*USGS gage data was provisional for 12/2009.

Table 3. Distribution of inflows from surrounding river basins and coastal watersheds to the ten inflow points of the Laguna Madre Estuary TxBLEND model (Figure 6). Inflows from the Mission-Aransas and Nueces Estuaries also were included to improve model boundary conditions.

Inflow Point for the Laguna Madre TxBLEND Model	**Gaged Watersheds** (USGS Gage #)	**Ungaged Watersheds**	**Returns**	**Diversions**
Mission-Aransas Estuary				
Salt/Cavasso Creek	n/a	20130(50%), 20140, 20165, 20180, 20192, 20194	n/a	20192
Copano Creek	20125 (#8189200)	20120, 20130(50%)	n/a	n/a
Mission River	20085 (#8189500)	20070, 20100, 20110, 20040(50%)	20070	20070
Aransas River	20030* (#8189800) 20060 (#8189700)	20012, 20014, 20020, 20030*, 20040(50%), 20050	20012, 20014, 20020, 20030	n/a
Nueces Estuary				
Nueces River	(#8211000 nr Mathis)	20005, 21010, 22012, 22013	20005, 21010, 22012, 22013	20005, 21010
Oso Creek	22010 (#8211520)	22011, 22014, 22015	22011, 22014	22011
Upper Laguna Madre				
San Fernando Creek/Los Olmos Creek	22033 (#8211900) 22042* (#8212400)	22020, 22021, 22022, 22023, 22024, 22025, 22026, 22030, 22031, 22032, 22033, 22040, 22041, 22042*	22021, 22022, 22028, 22030, 22031, 22033	22022, 22031, 22033
Lower Laguna Madre				
North Floodway/Arroyo-Colorado	22911* (#8470200) 22909 (#8470400)	22904, 22900, 22903, 22907, 22911*	22900, 22903, 22907	22904, 22903, 22907
Main Floodway	n/a	22905, 22906	22905, 22906	n/a
San Martin	n/a	22901, 22902, 22908	22902, 22908	22902, 22908

*Watershed #20030 in the Mission-Aransas basin, #22042 in the Upper Laguna Madre basin, and #22911 in the Lower Laguna Madre basin have been gaged and ungaged throughout the history of USGS gage operation, and so were applied to the model accordingly.

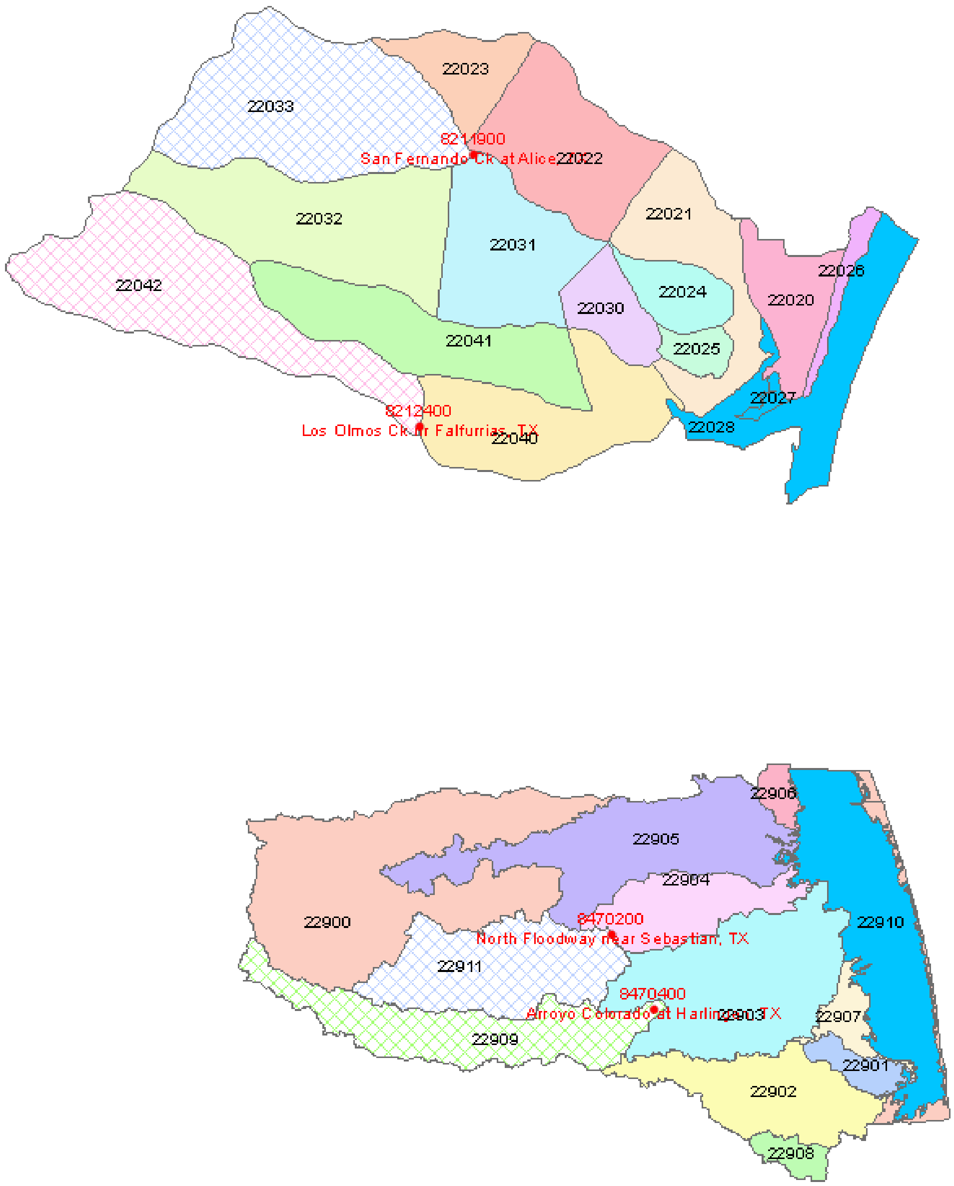


Figure 7. Ungaged watershed delineation used to determine ungaged inflows in the Laguna Madre Estuary from 1977 to present. Currently, 12 ungaged watersheds contribute to Baffin Bay and the Upper Laguna Madre, while nine ungaged watersheds contribute to the Lower Laguna Madre. Gaged watersheds are indicated by cross-hatching. *Please note:* Gaged watershed #22033 was ungaged from 1991 - 1999; gaged watershed #22042 was ungaged from 1991 - 1999; and, gaged watershed #22911 was ungaged from 1991 - 2010, during which time flows were modeled using TxRR.

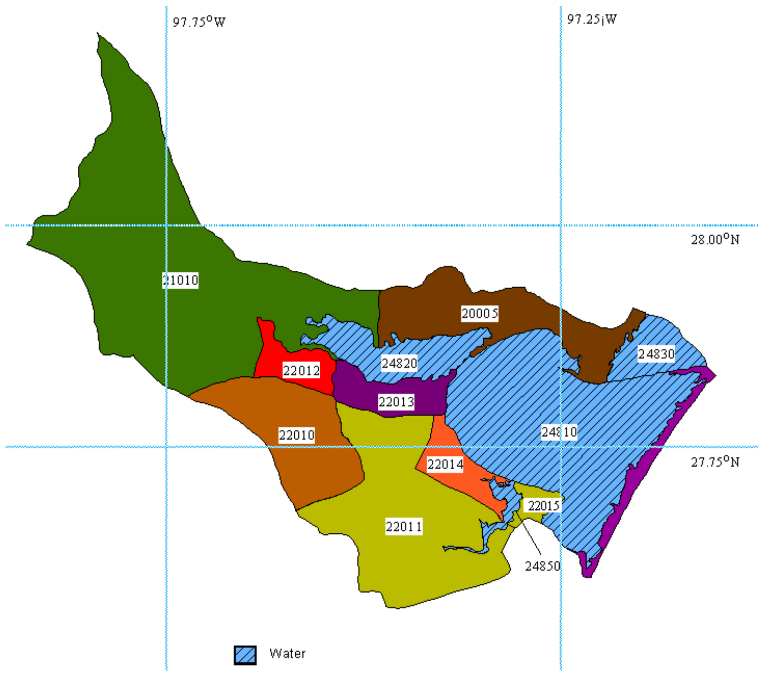


Figure 8. Ungaged watershed delineation used from 1991 to 2009 to determine ungaged inflows to the Nueces Estuary (refer to Schoenbaechler *et al.*, 2011c for more details). *Note:* Watershed #22010 is now a gaged watershed, but is not represented as such in this figure.

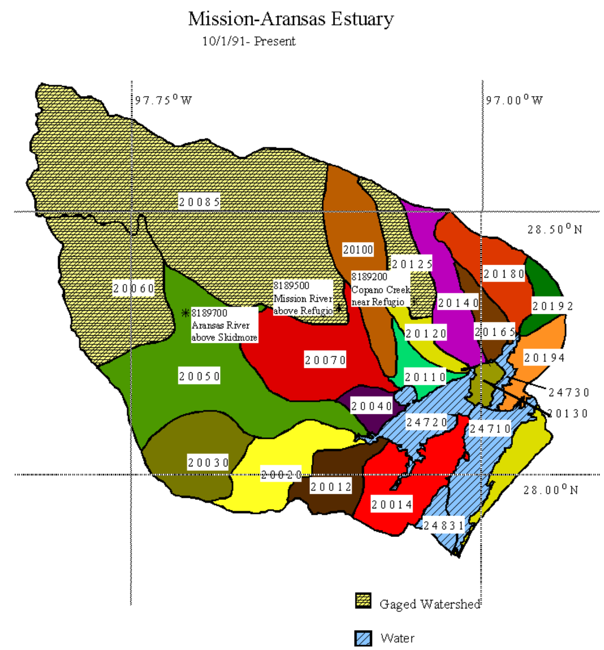


Figure 9. Ungaged watershed delineation used in TxRR to determine ungaged inflows to the Mission-Aransas Estuary (refer to Schoenbaechler *et al.*, 2010 for more details).

Tides

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

Meteorology

Time-varying and spatially uniform meteorology data was used to drive the model, including wind field, precipitation, and evaporation. A large portion of the meteorology data used to drive the model was obtained from the National Climate Data Center (NCDC) for Santa Rosa, McCook, and Weslaco. Evaporation data for the Laguna Madre was obtained from NCDC for McCook, and missing data was filled in using data from Weslaco. Precipitation data used for model calibration and validation simulations originally was obtained from NCDC for Santa Rosa and McCook and subsequently was processed to provide an estimate of precipitation across the Laguna Madre watershed. Wind data was obtained from TCOON for the South Padre Island Coast Guard Station, and missing data was filled in with data from Port Mansfield and Bob Hall Pier.

Salinity

Salinity initial conditions were determined by setting the river inflow points at 0 parts per thousand (ppt.) salinity and by using time varying salinity boundary conditions obtained from Texas Parks and Wildlife Department (TPWD) Coastal Fisheries database to specify salinity at the Gulf boundary off the Laguna Madre from 1991 - 2010. Another model run to support a special validation exercise from 2008 – 2010 used a three-day average salinity obtained from the South Padre Island Coast Guard Station to specify salinity at the Gulf boundary off the Laguna Madre. Model runs allowed for a several month ramp-up period, prior to running simulations for model calibration or validation, to allow the model to distribute salinity appropriately. 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, three intensive inflow datasets were available. Velocity measurements were collected at six sites in the Nueces Estuary during an intensive inflow study from June 21 – 24, 1994, six sites in the Upper Laguna Madre Estuary during another study from June 12 – 15, 1995, and eight sites in the Lower Laguna Madre Estuary during a study from June 19 – 22, 1997. At most locations, velocity was measured at three depths, 2/10th, 5/10th, and 8/10th from the water surface. Discharge measurements were collected at seven sites during an intensive inflow study from June 1997. All locations are shown in Figures 10 - 13.

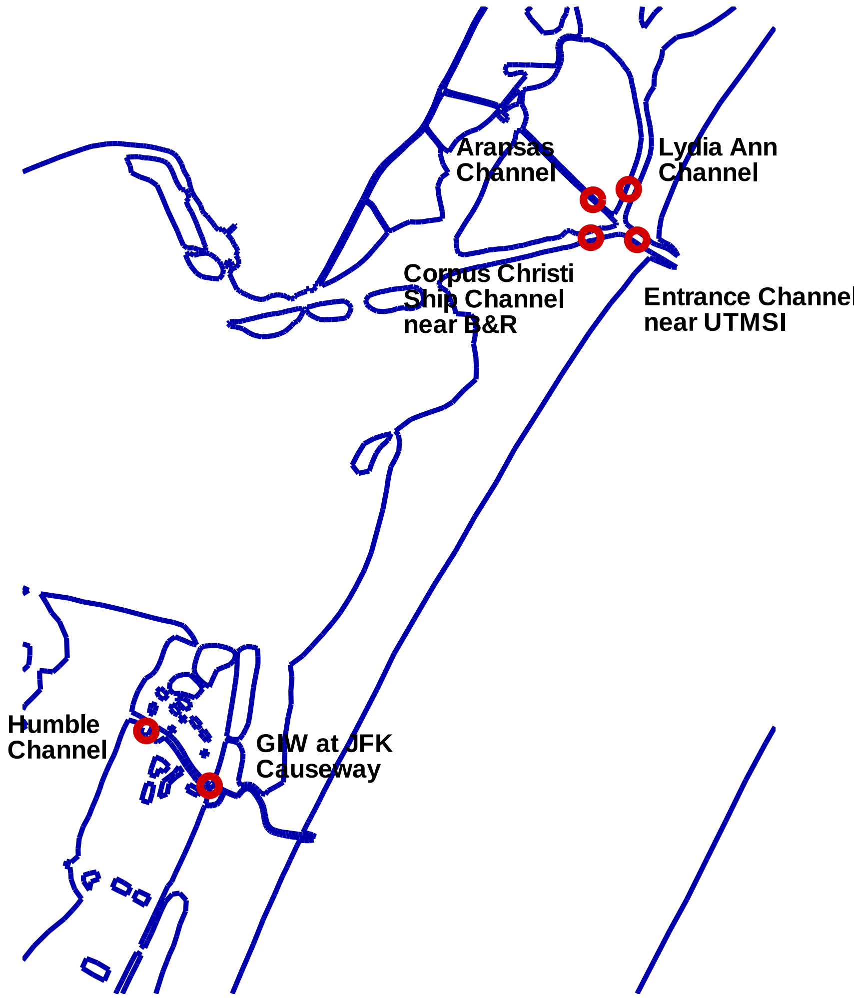


Figure 10. Velocity and discharge measurement sites for an intensive inflow study of the Nueces Estuary during June 1994.

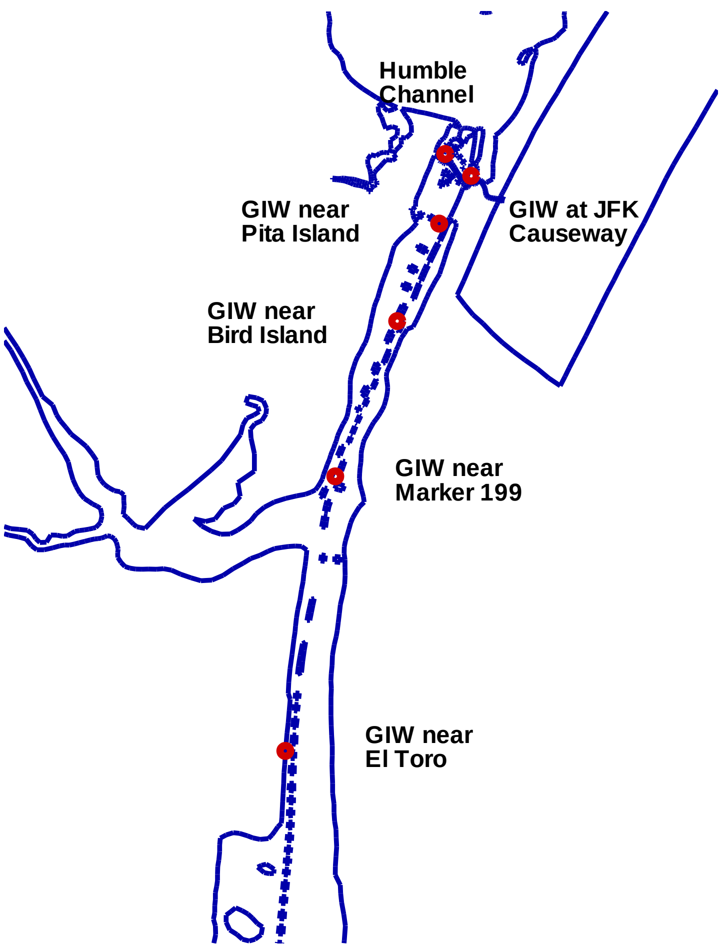


Figure 11. Velocity and discharge measurement sites for an intensive inflow study of the Upper Laguna Madre during June 1995.

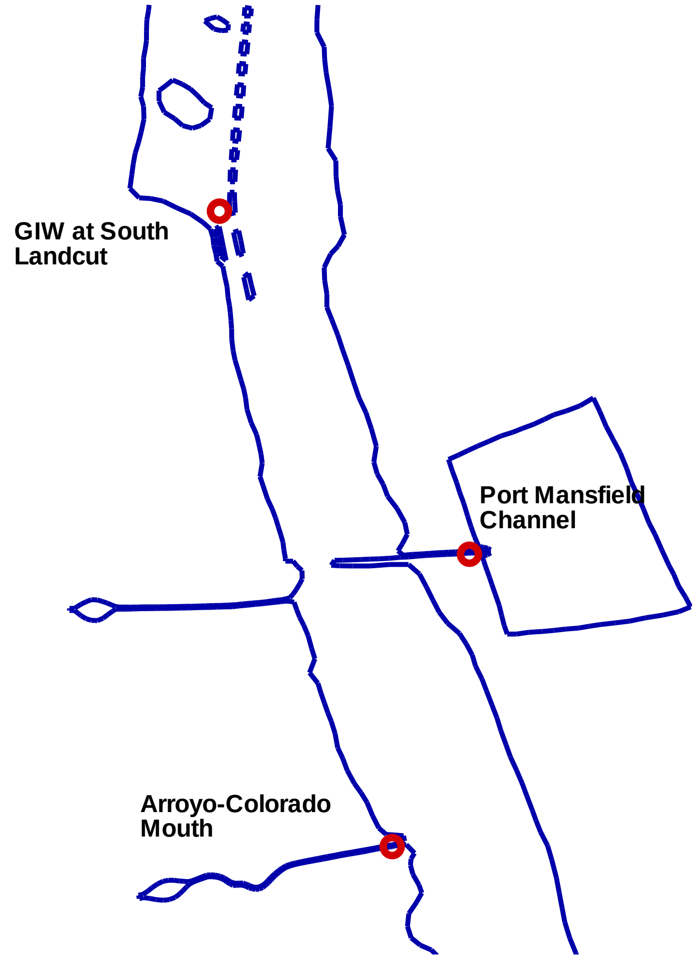


Figure 12. Velocity and discharge measurement sites for an intensive inflow study of the Lower Laguna Madre during June 1997.

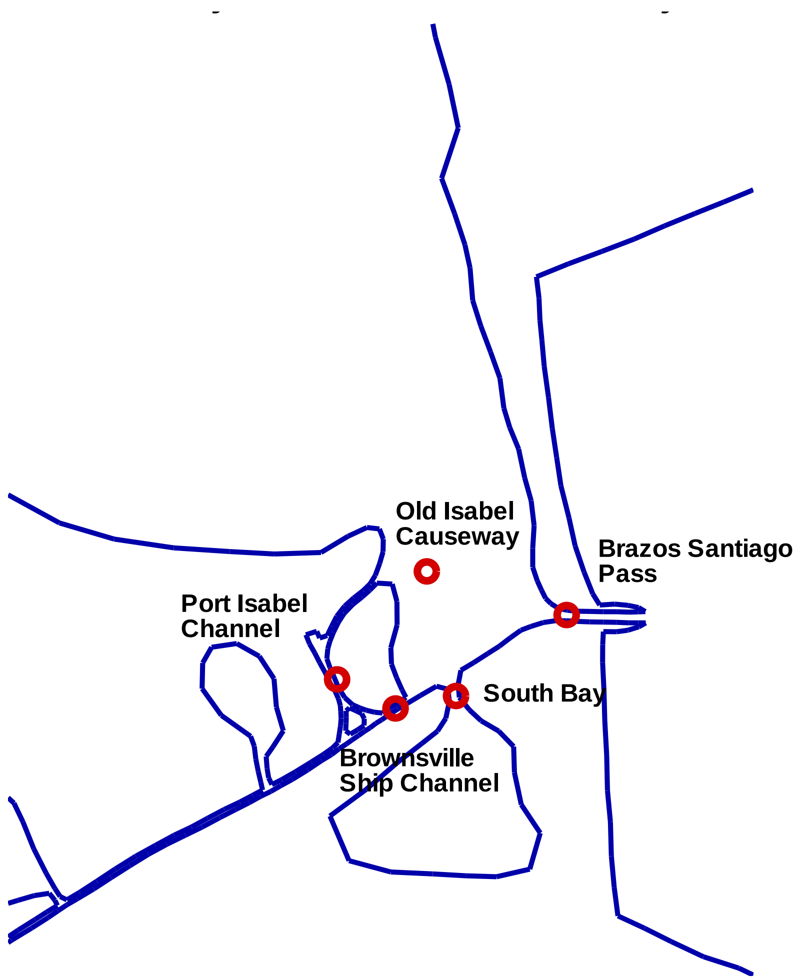


Figure 13. Velocity and discharge measurement sites in the Port Isabel area of the Lower Laguna Madre during an intensive inflow study in June 1997.

Tides

For calibration of water surface elevation in this TxBLEND model, measurements from five TCOON tide gaging stations (Bird Island, Station #013; South Landcut, also known as Rincon del San Jose, Station #003; Port Mansfield, Station #017; South Padre Island Coast Guard Station, Station #051; and Port Isabel, Station #018), for the period 1999 – 2004, were used (Figure 14).

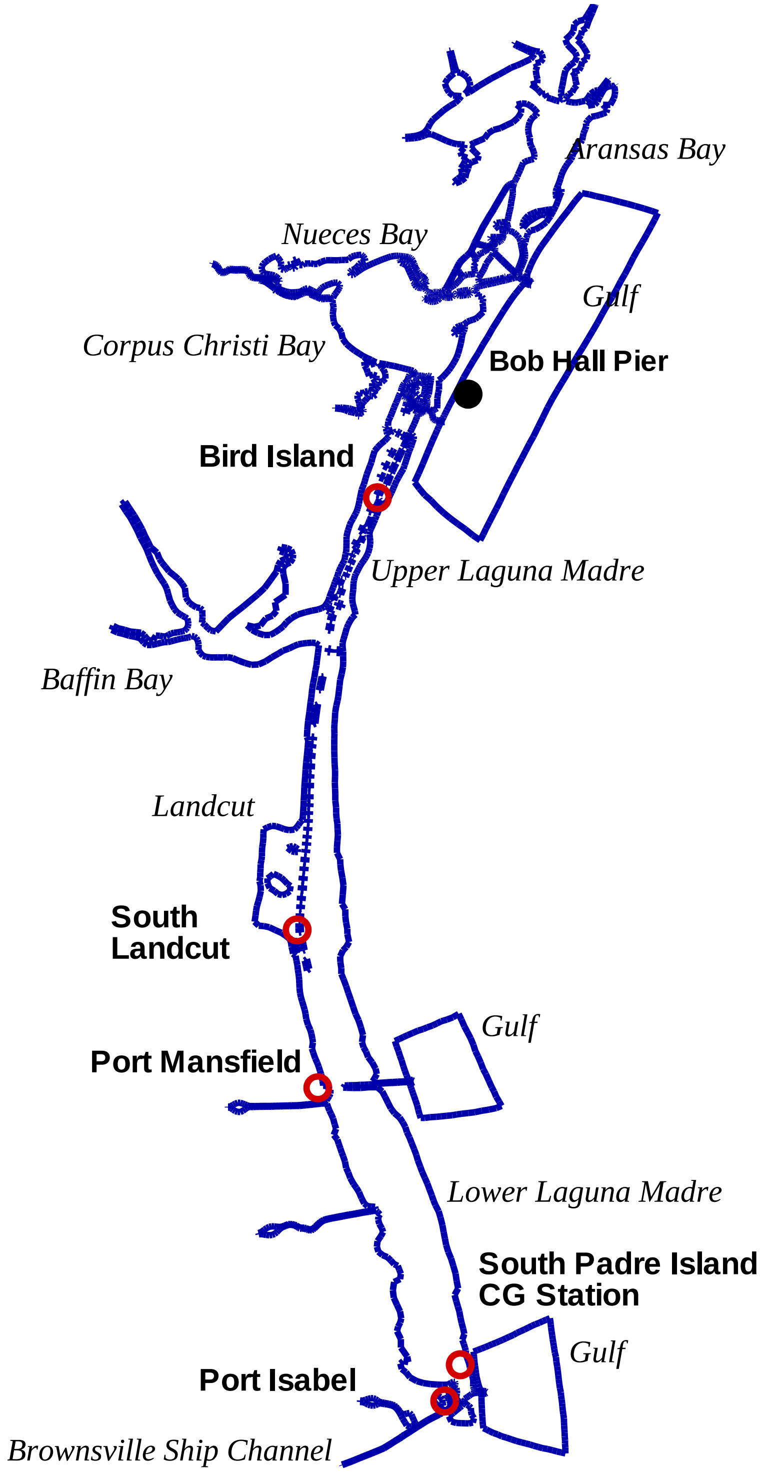


Figure 14. Five tide gaging stations used to calibrate and validate the Laguna Madre TxBLEND model for water surface elevation. Gaging stations are maintained by the Texas Coastal Ocean Observation Network (TCOON).

Salinity

Long-term salinity records collected by TWDB, TCOON, Texas Parks and Wildlife (TPWD), and The University of Texas-Pan American (UTPA) at hourly or more frequent intervals provide important information for calibrating and validating salinity and circulation models in Texas coastal waters. Data from TWDB's Datasonde Program was used for model calibration, including: Bird Island, Port Mansfield, Arroyo Colorado Mouth, and Old Isabel Causeway. In addition, TPWD Coastal Fisheries point-measurement data, collected in the vicinity of two Datasonde Program monitoring stations (Gulf Intracoastal Waterway-Arroyo Colorado and Stover Point), was used to aid model calibration. TCOON data also was used to calibrate the model at Realitos Peninsula and the South Padre Coast Guard Station sites. Furthermore, data collected by Dr. Hudson DeYoe with UTPA was used for calibration at the Green Island site.

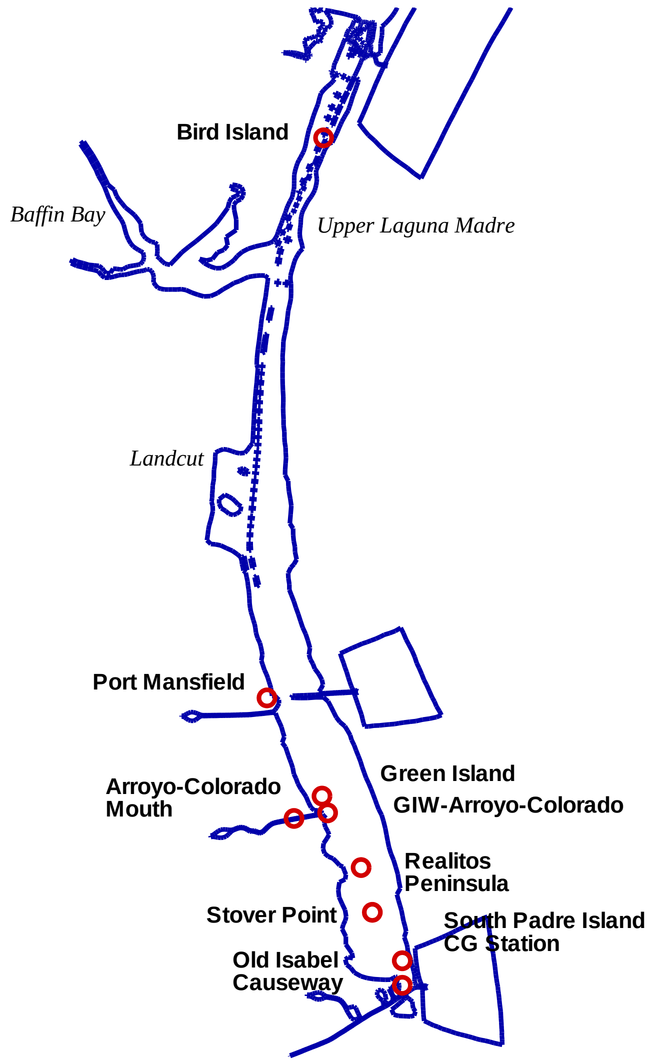


Figure 15. Nine long-term monitoring stations which provided time-series salinity data for use in model calibration and validation.

Model Calibration Parameters

Model parameters adjusted during calibration of the TxBLEND model include 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 Figure 16. Large values of Manning's n were assigned to the Landcut to represent the hydrologic disconnectivity between the Upper and Lower Laguna Madre. 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 17 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.

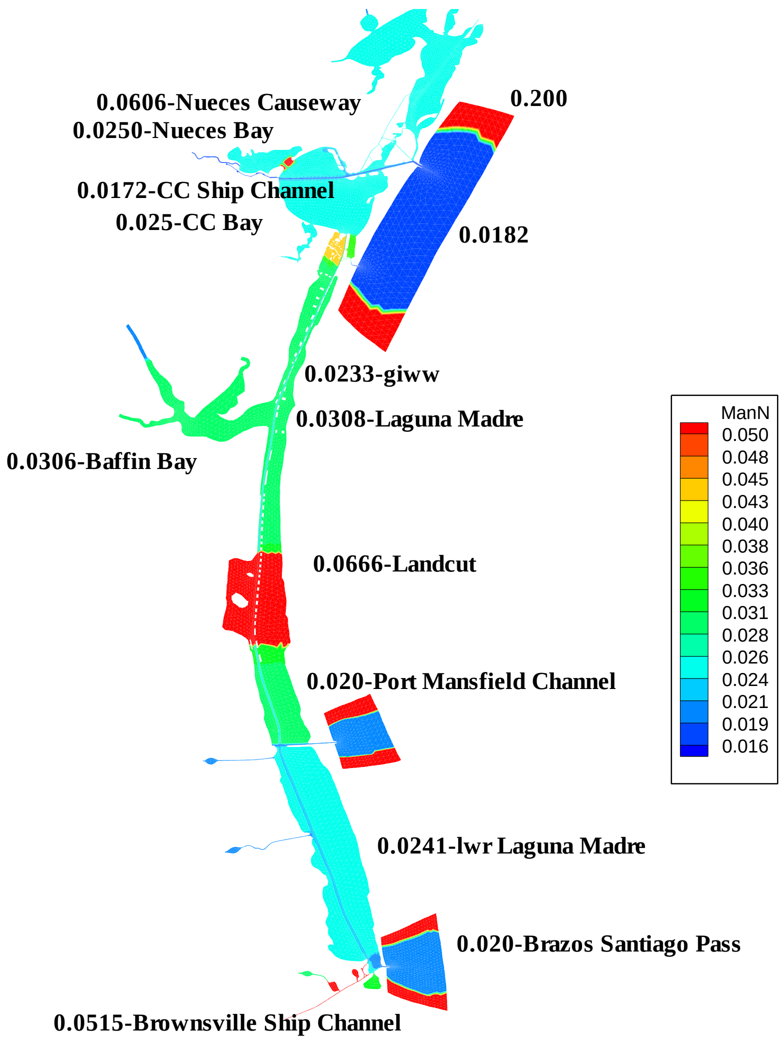


Figure 16. Values of Manning's *n* (bottom roughness coefficient) used in the calibrated Laguna Madre Estuary TxBLEND model.

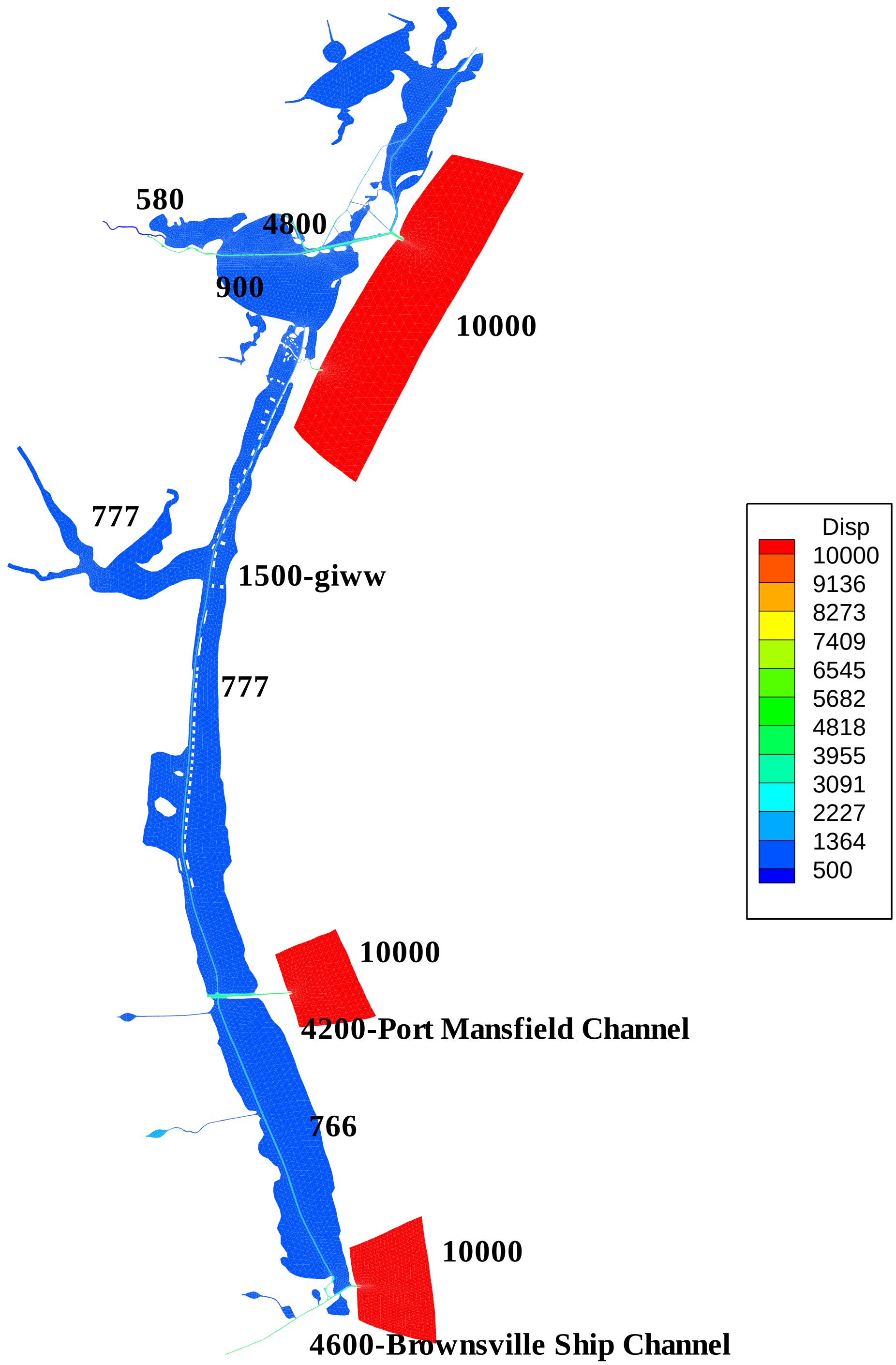


Figure 17. Values of the dispersion factor (ft^2/sec) used in the calibrated TxBLEND model for the Laguna Madre Estaury. The Gulf region was set to 10,000 ft^2/sec and the Gulf Intracoastal Waterway (GIWW) to 1,500 ft^2/sec.

Calibration Results

Calibration results for velocity, discharge, surface elevation, and salinity for the Laguna Madre TxBLEND model are presented below.

Velocity and Discharge Results

TxBLEND was calibrated for water velociy and discharge using data obtained from three intensive inflow studies in the Laguna Madre Estuary during June of 1994, 1995, and 1997. Calibration results are presented in a series of plots showing simulated velocities and discharges as compared to observed field measurements for several locations throughout the system. The depth-averaged horizontal velocity output from the model is displayed against measured velocity profiles at three depths, or at mid-depth if only one measurement is available.

Figures 18 - 19 show calibration results for velocity at six locations in the Nueces Estuary during the intensive inflow study from June 21 – 24, 1994. Simulated velocities are representative of observed velocities at all sites. The model captured swift tidal currents at the Entrance Channel near UTMSI, as well as reduced currents within the estuary, such as in the Humble Channel. The model slightly over-predicted maximum velocity at the Corpus Christi Ship Channel near Brown and Roots (B&R).

Figures 20 - 21 show calibration results for velocity at six locations in the Upper Laguna Madre Estuary during the intensive inflow study from June 12 – 15, 1995. Again, simulated velocities are representative of observed velocities at all sites. The model captured reduced currents at several locations throughout the Upper Laguna Madre, such as at the GIWW near Bird Island and the GIWW near El Toro sites.

Figures 22 – 25 show calibration results for velocity at 11 locations in the Lower Laguna Madre Estuary during the intensive inflow study from June 19 - 22, 1997, and Figures 26 –28 show calibration results for discharge at seven sites, also in the Lower Laguna Madre Estuary, during the intensive inflow study from June 19 – 22, 1997. Simulated velocities are representative of observed velocities at most locations. Measured velocities at Brazos Santiago Pass (Figure 22) were much more reduced as compared to simulated velocities. This disagreement most likely occurred, because the measurements were made near the shore, whereas the simulated velocity represents the mid-channel where swifter flow occurs. However, observed and simulated discharge at the same site (Figures 23) compare more favorably.

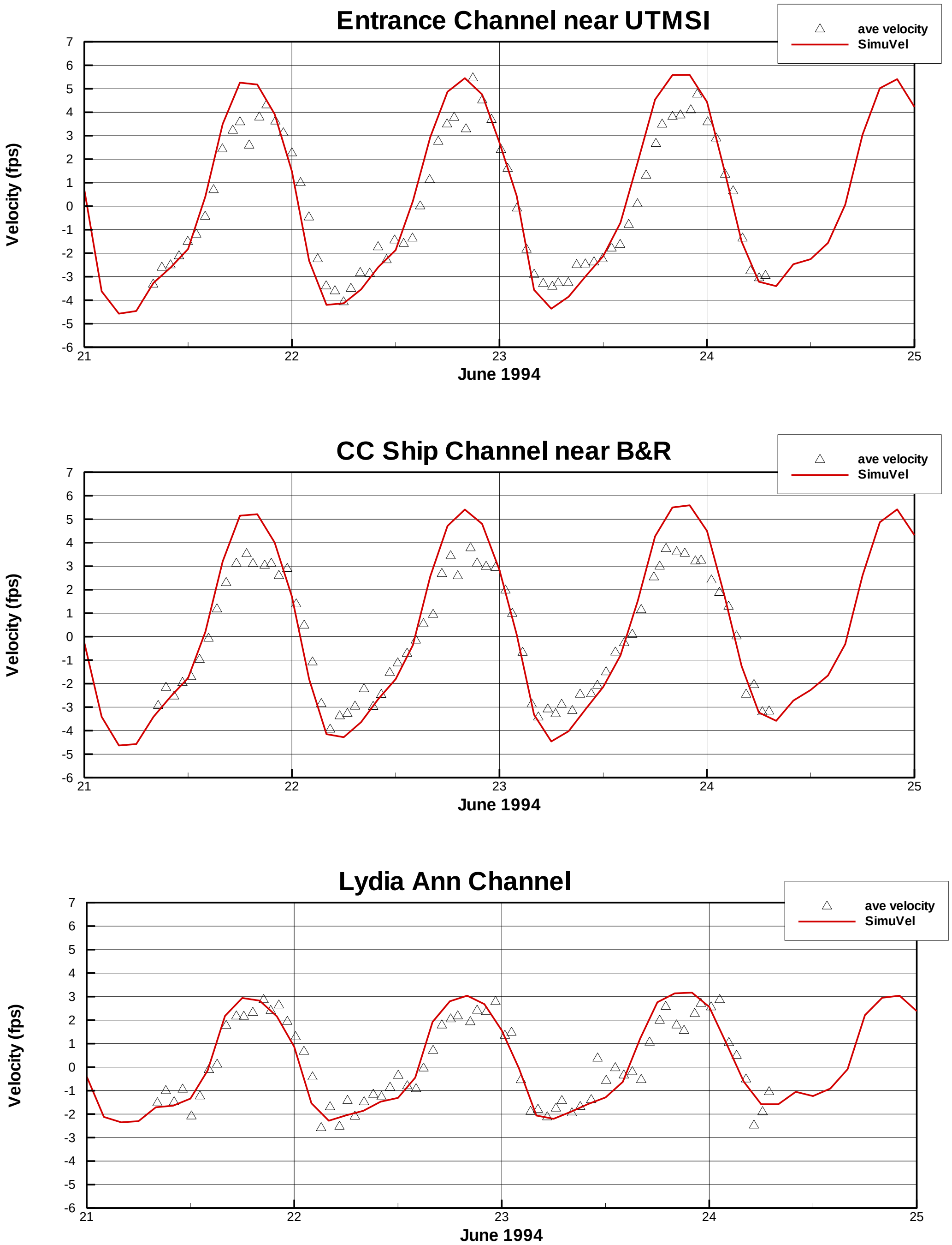
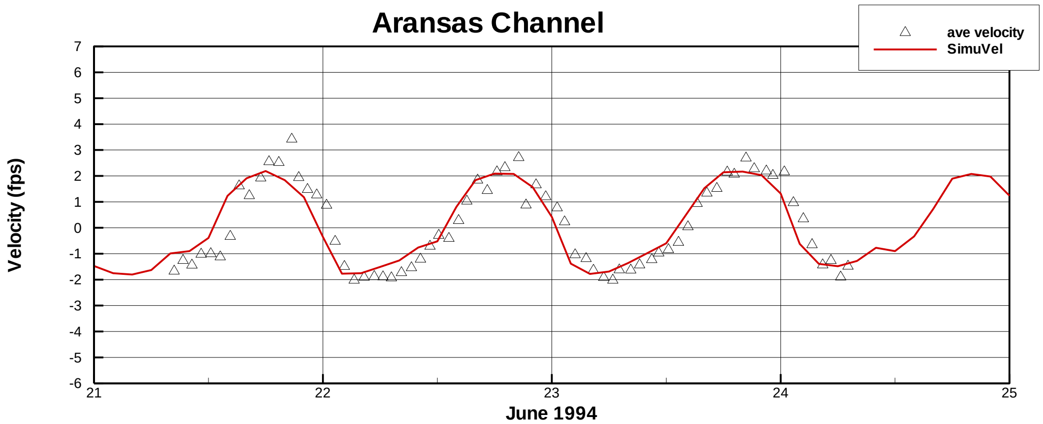
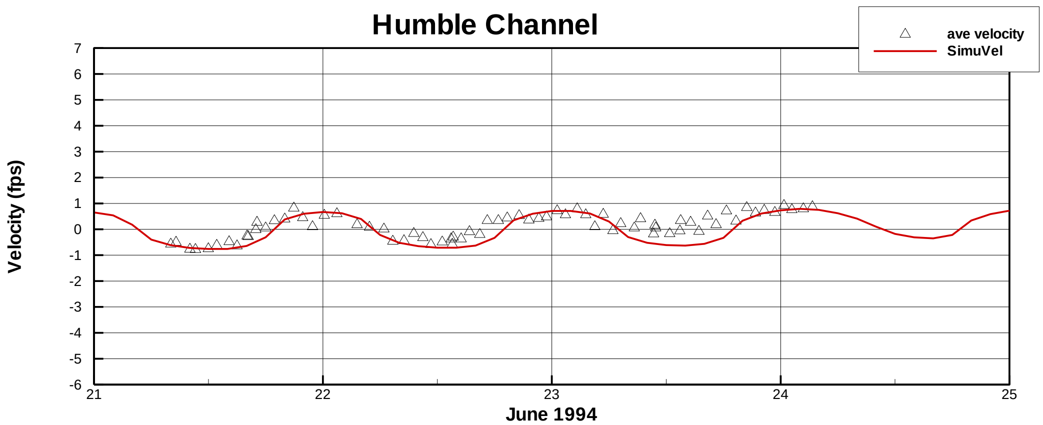


Figure 18. Simulated (*red line*) and observed (*open symbols*) velocities for the following sites from top to bottom: Entrance Channel near UTMSI, Corpus Christi Ship Channel near B&R, and Lydia Ann Channel for June 21 - 24, 1994 in the Nueces Estuary. Positive velocity values represent the ebb cycle or downstream flow and negative velocity values represent flood cycle or upstream flow.





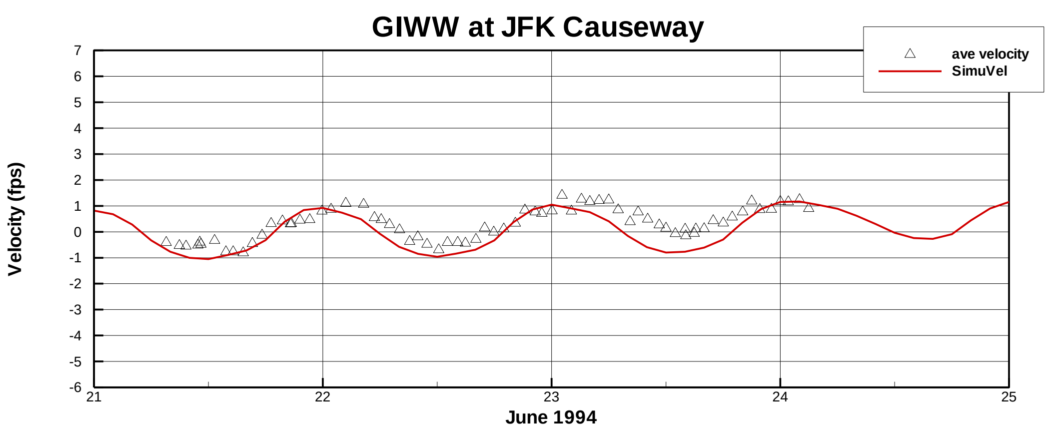


Figure 19. Simulated (*red line*) and observed (*open symbols*) velocities for the following sites from top to bottom: Aransas Channel, Humble Channel, and Gulf Intracoastal Waterway at the JKF Causeway for June 21 - 24, 1994 in the Nueces Estuary. Positive velocity values represent the ebb cycle or downstream flow and negative velocity values represent flood cycle or upstream flow.

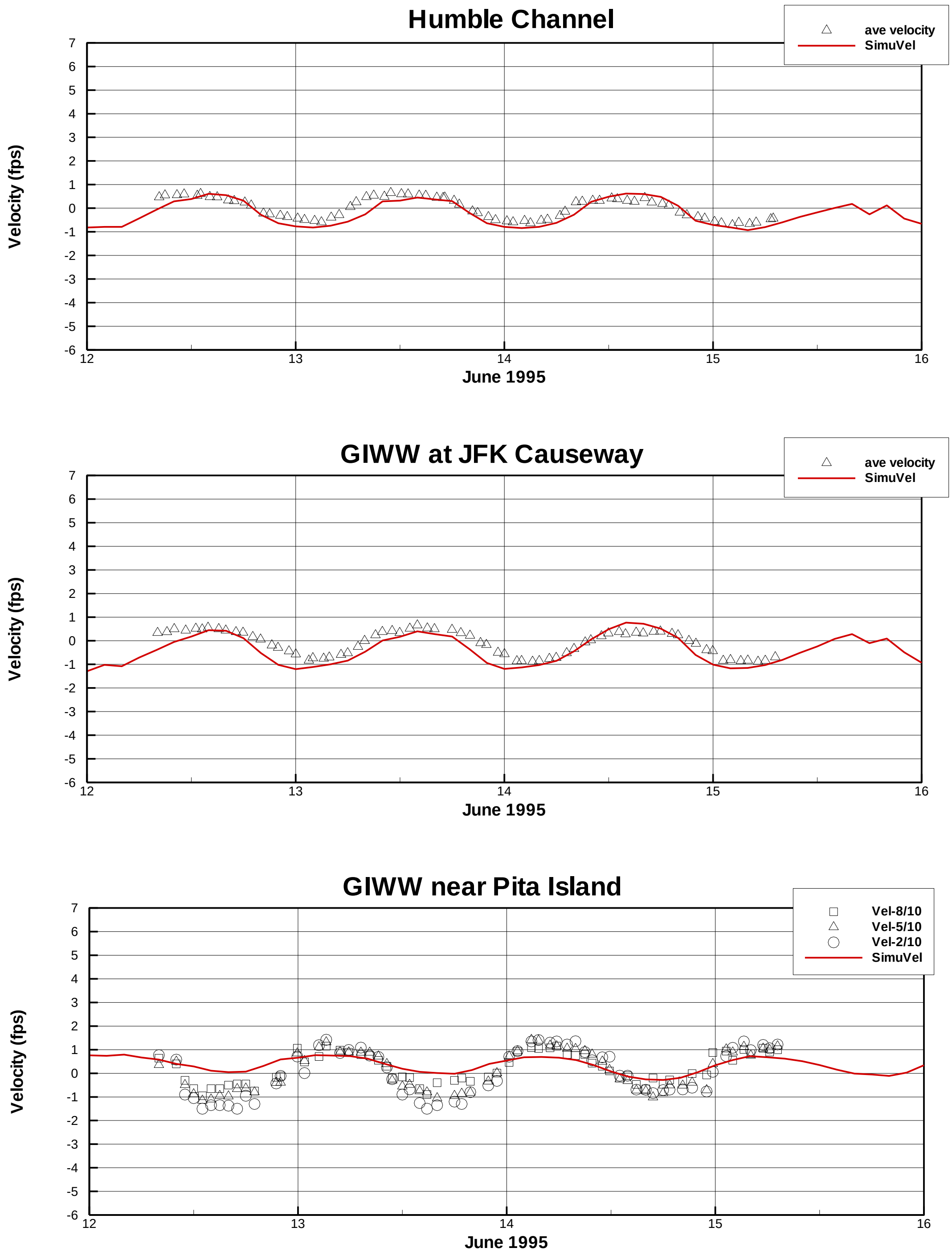
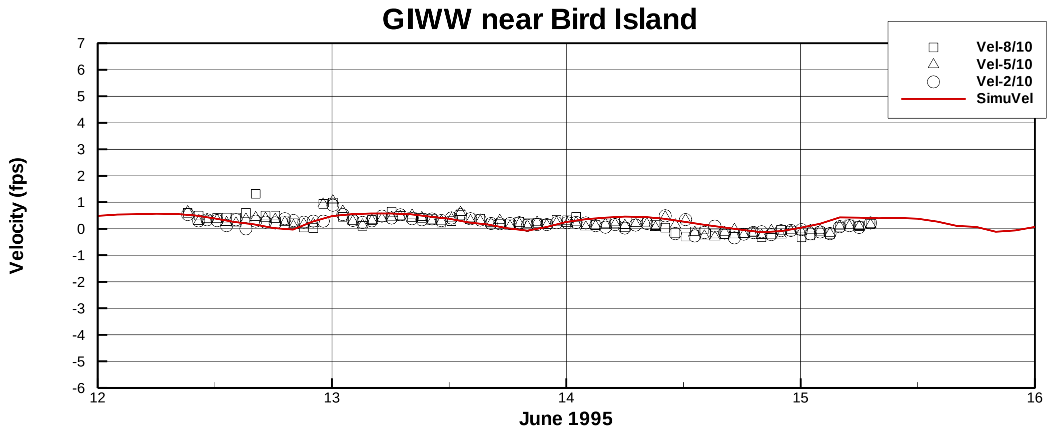
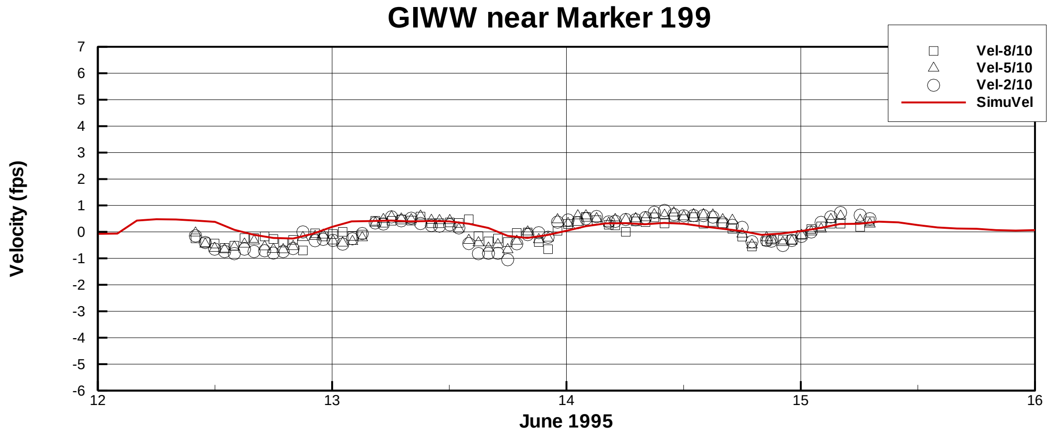


Figure 20. Simulated (*red line*) and observed (*open symbols*) velocities for the following sites from top to bottom: Humble Channel, Gulf Intracoastal Waterway at the JFK Causeway, Gulf Intracoastal Waterway near Pita Island for June 12 – 15, 1995 in the Nueces and Upper Laguna Madre Estuaries. Positive velocity values represent the ebb cycle or downstream flow and negative velocity values represent flood cycle or upstream flow.





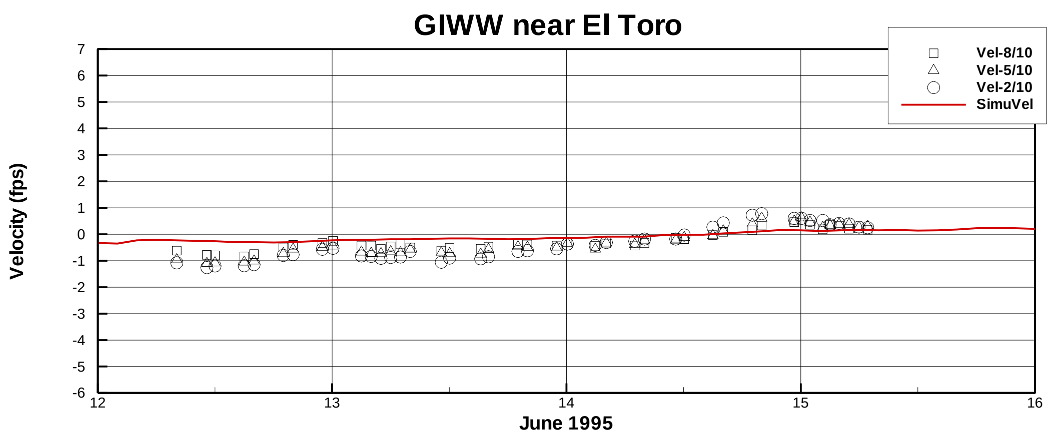
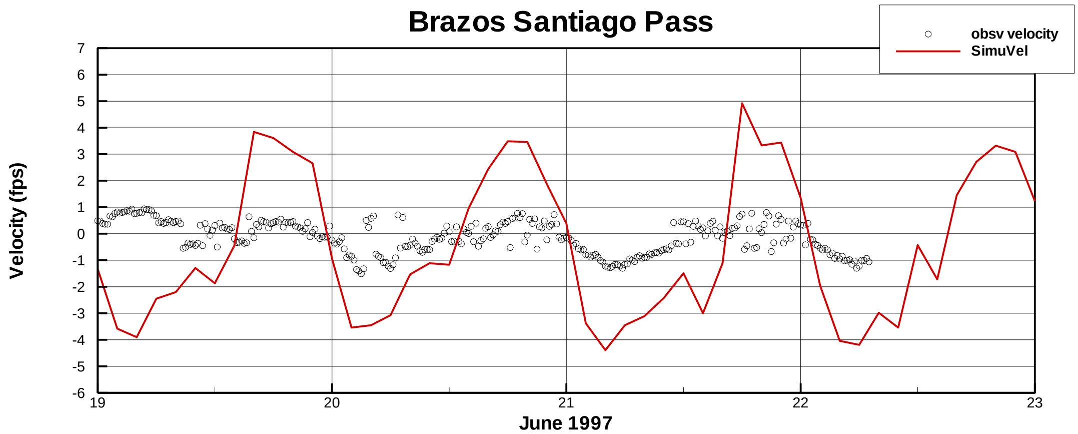
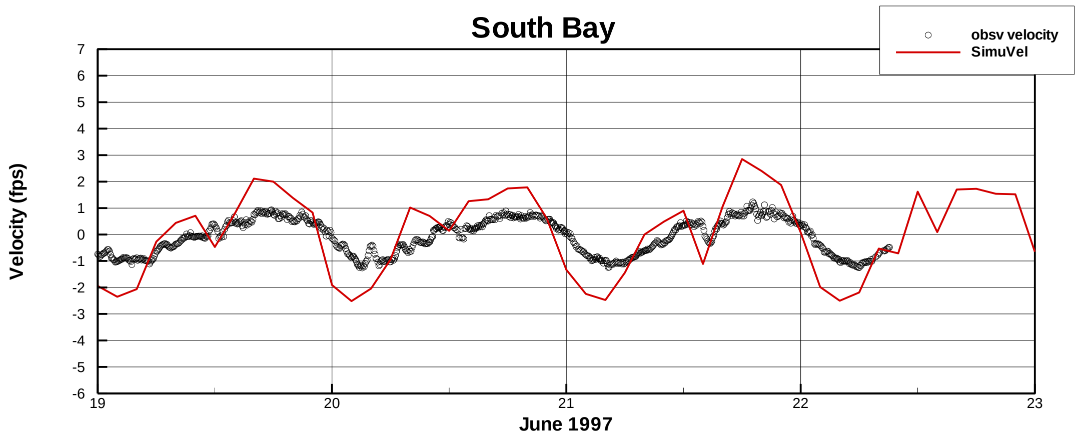


Figure 21. Simulated (*red line*) and observed (*open symbols*) velocities for the following sites from top to bottom: Gulf Intracoastal Waterway near Bird Island, Gulf Intracoastal Waterway near Marker 199, and the Gulf Intracoastal Waterway near El Toro for June 12 – 15, 1995 in the Upper Laguna Madre Estuary. Positive velocity values represent the ebb cycle or downstream flow and negative velocity values represent flood cycle or upstream flow.





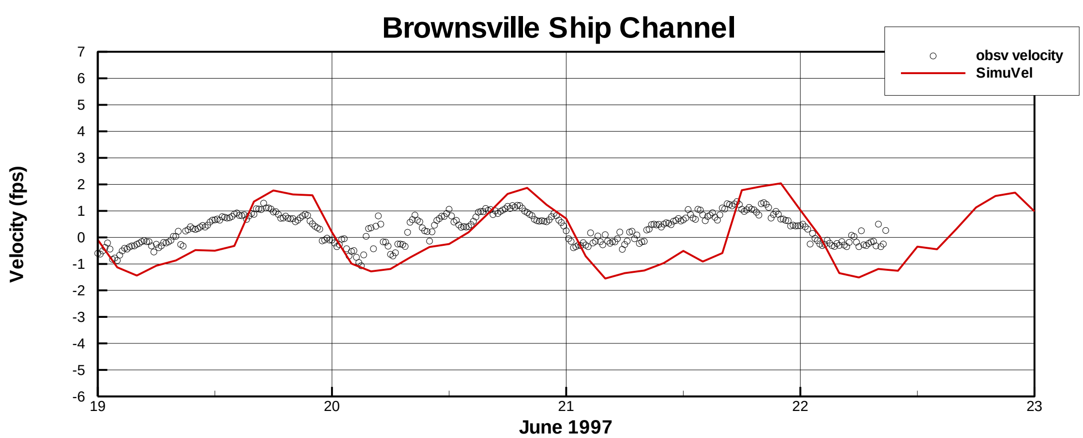


Figure 22. Simulated (*red line*) and observed (*open symbols*) velocities for the following sites from top to bottom: Brazos-Santiago Pass, South Bay, and the Brownsville Ship Channel for June 19 - 27, 1997 in the Lower Laguna Madre Estuary. Positive velocity values represent the ebb cycle or downstream flow and negative velocity values represent flood cycle or upstream flow.

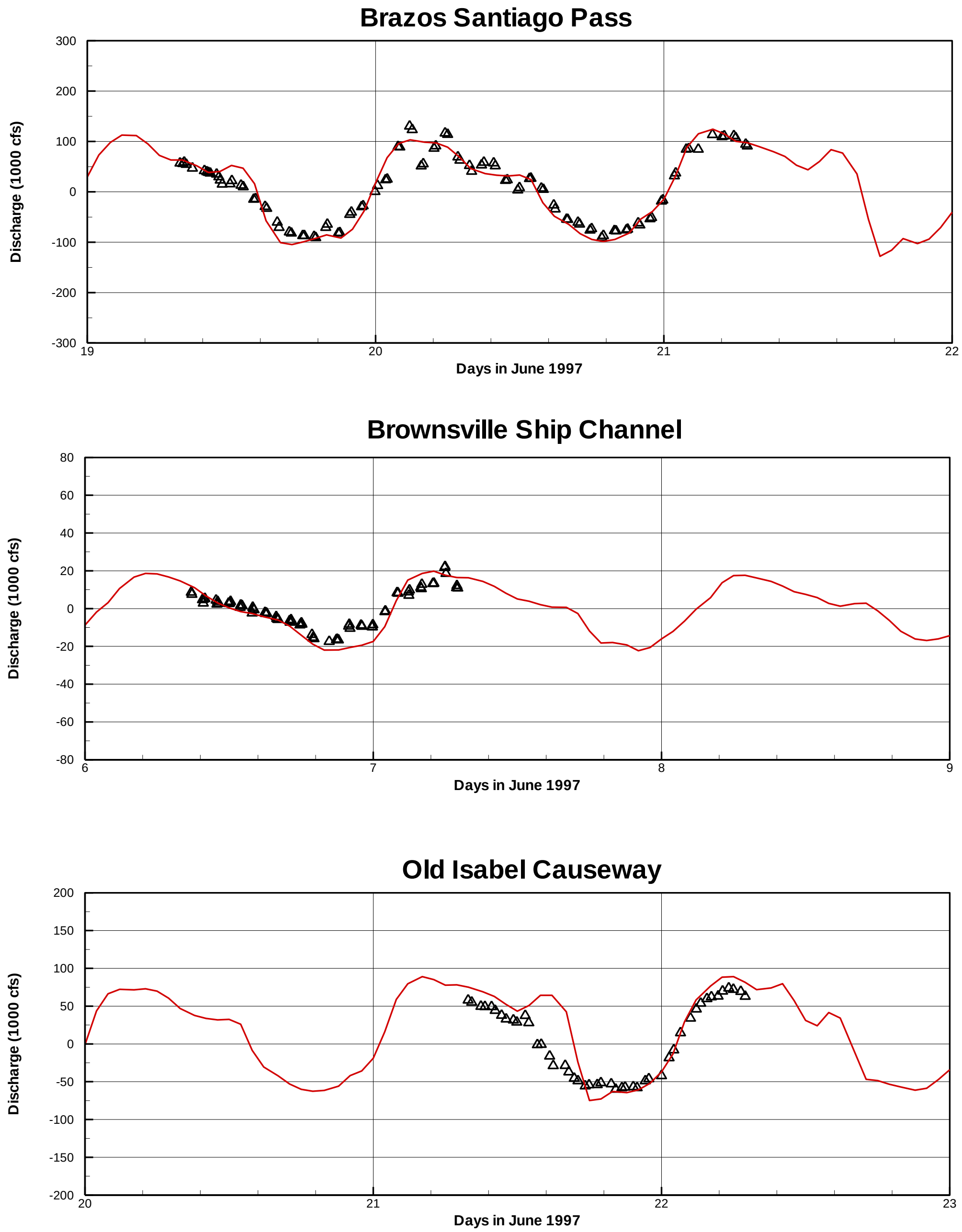


Figure 23. Simulated (*red line*) and observed (*open symbols*) discharge for the following sites from top to bottom: Brazos-Santiago Pass, Brownsvilel Ship Channel, and old Isabel Causeway for June 19 - 27, 1997 in the Lower Laguna Madre Estuary. Positive velocity values represent the ebb cycle or downstream flow and negative velocity values represent flood cycle or upstream flow.

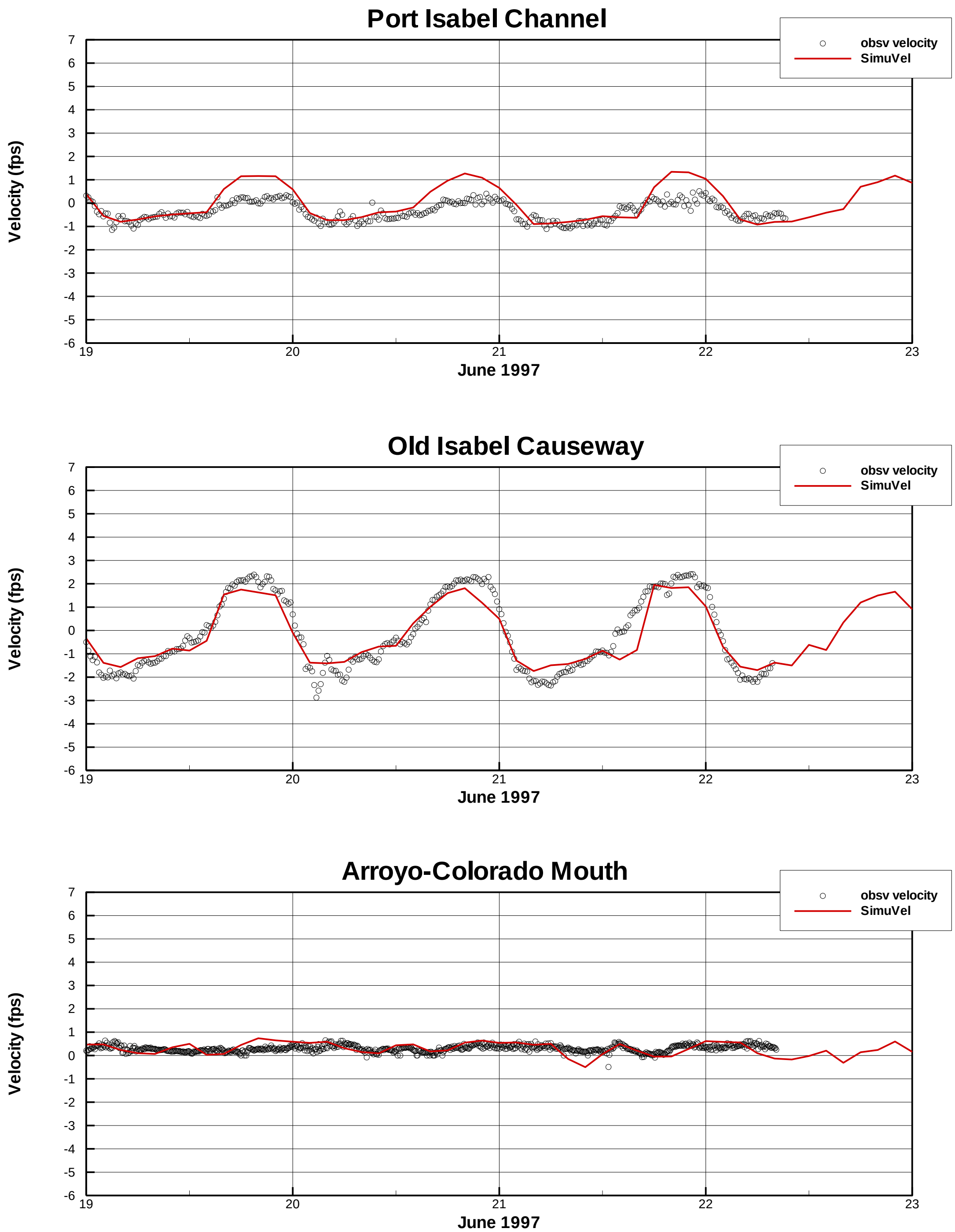
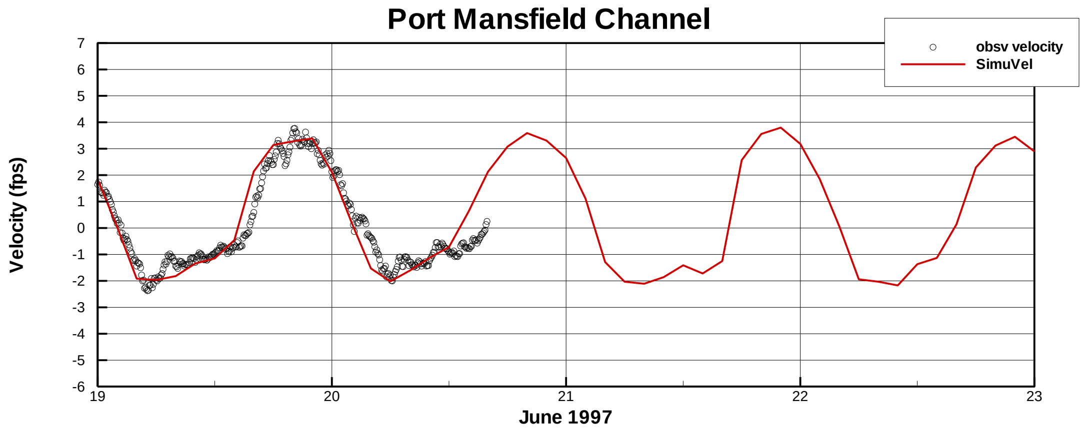


Figure 24. Simulated (*red line*) and observed (*open symbols*) velocities for the following sites from top to bottom: Port Isabel Channel, Old Isabel Causeway, and Arroyo-Colorado Mouth for June 19 - 27, 1997 in the Lower Laguna Madre Estuary. Positive velocity values represent the ebb cycle or downstream flow and negative velocity values represent flood cycle or upstream flow.



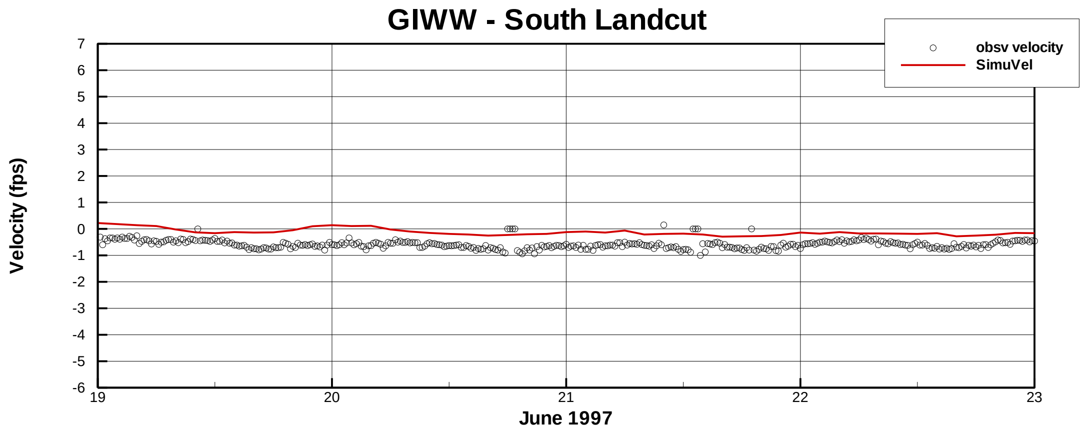


Figure 25. Simulated (*red line*) and observed (*open symbols*) velocities for the following sites from top to bottom: Port Mansfield Channel, Gulf Intracastal Waterway at South Landcut for June 19 - 27, 1997 in the Lower Laguna Madre Estuary. Positive velocity values represent the ebb cycle or downstream flow and negative velocity values represent flood cycle or upstream flow.

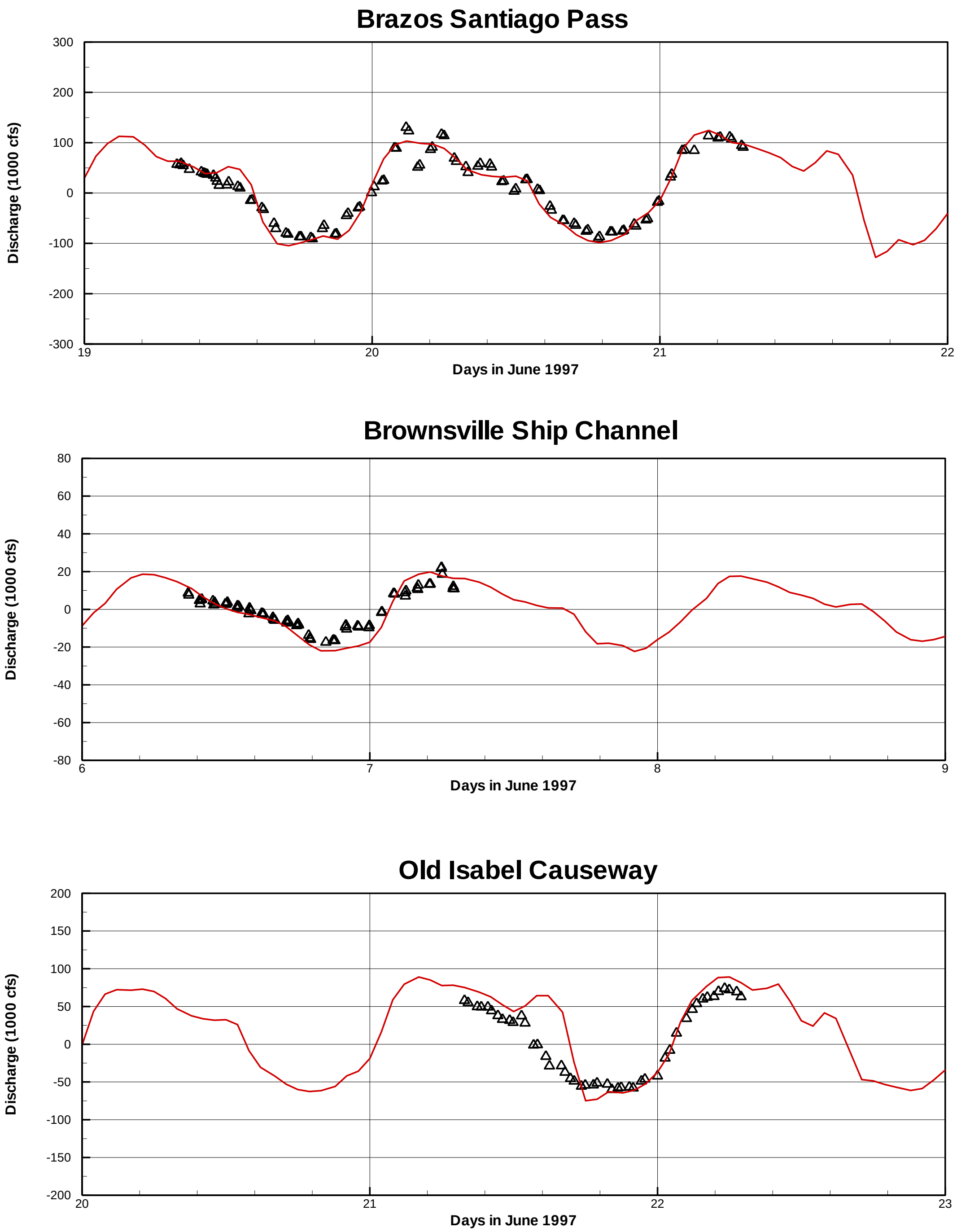


Figure 26. Simulated (*red*) and observed (*open symbols*) discharge for the following sites from top to bottom: Brazos-Santiago Pass, Brownsville Ship Channel, and Old Isabel Causeway from June 19 – 27, 1997 in the Lower Laguna Madre Estuary. Positive discharge calues represent the ebb cycle or downstrean flow and negative discharge values represent flood cycle or upstream flow.

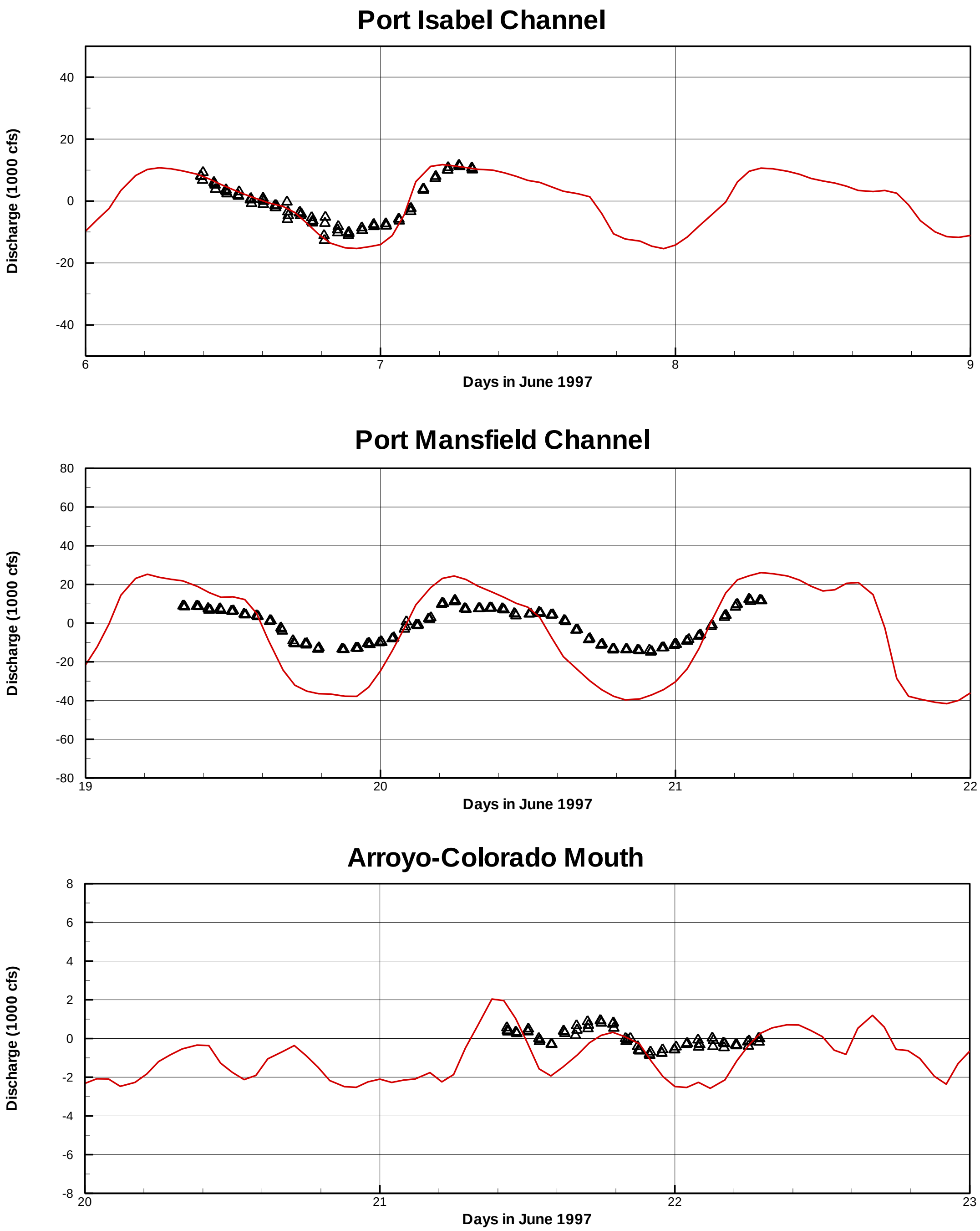


Figure 27. Simulated (*red*) and observed (*open symbols*) discharge for the following sites from top to bottom: Port Isabel Channel, Port Mansfield Channel, and Arroyo-Colorado Mouth from June 19 – 27, 1997 in the Lower Laguna Madre Estuary. Positive discharge values represent the ebb cycle or downstrean flow and negative discharge values represent flood cycle or upstream flow.

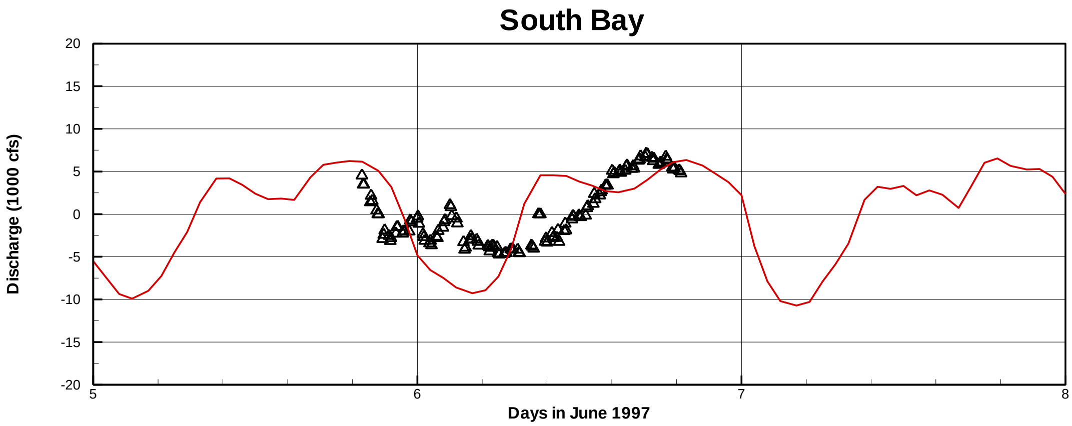


Figure 28. Simulated (*red*) and observed (*open symbols*) discharge for South Bay from June 19 – 27, 1997. Positive discharge values represent the ebb cycle or downstrean flow and negative discharge values represent flood cycle or upstream flow.

Water Surface Elevation Results

Tidal comparisons were made at five locations from 1995 - 2002. The scatter plots in Figure 29 show reasonably good agreement between model simulations for water surface elevations and observed data throughout the Laguna Madre Estuary. Table 4 lists comparison statistics for daily tides. To more easily visualize the comparison between simulated and observed hourly tide data, Figures 30 through 34 show time-series of tide elevations for a one-year time period at each site. Tidal phase and amplitude are well simulated by the model, except at the South Landcut site (Figure 31), where the model does not capture high frequency variation. The model may be unable to accurately predict tidal elevations at this site, because the wind data used in calibration was obtained from the South Padre Island Coast Guard Station site, which is located far from the South Landcut site. Furthermore, this location in the system is influenced by different tidal patterns from the upper and lower portions of the Laguna Madre.

Table 4. Comparison statistics for daily tidal elevations during the period 1995 – 2002 for the Laguna Madre Estuary.

Location	**Period**	**Days**	**r^2**	**RMS* (ft)**	**NSEC****	**Average Tide (ft)**		
						Simulated	**Observed**	**Difference**
Bird Island	1995-2002	2976	0.55	0.19	0.40	-0.06	-0.03	-0.03
South Landcut	1995-2002	2856	0.32	0.33	-0.54	-0.01	-0.38	0.37
Port Mansfield	1995-2002	2568	0.72	0.21	0.36	-0.02	-0.14	0.12
Port Isabel	1995-2002	2976	0.80	0.19	0.64	-0.10	-0.01	-0.09
S. Padre Island	1995-2002	2964	0.60	0.32	0.14	-0.14	0.07	-0.21

*RMS is the root mean square error.
**NSEC is the 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.

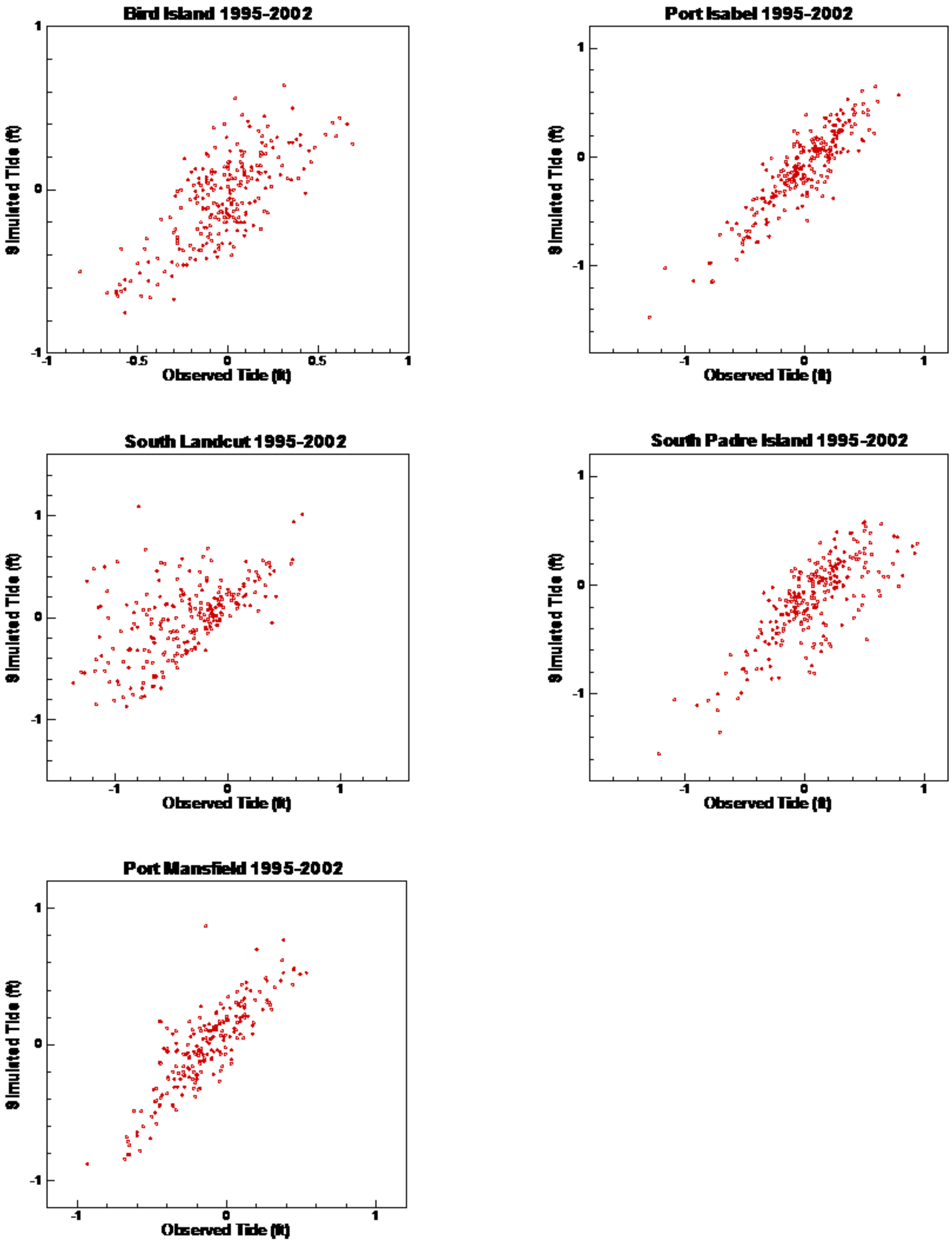


Figure 29. Scatter plots of observed versus simulated tidal elevations at *(from left to right, starting at top)* Bird Island, Port Isabel, South Landcut, South Padre Island, and Port Mansfield sites for 1995 – 2002.

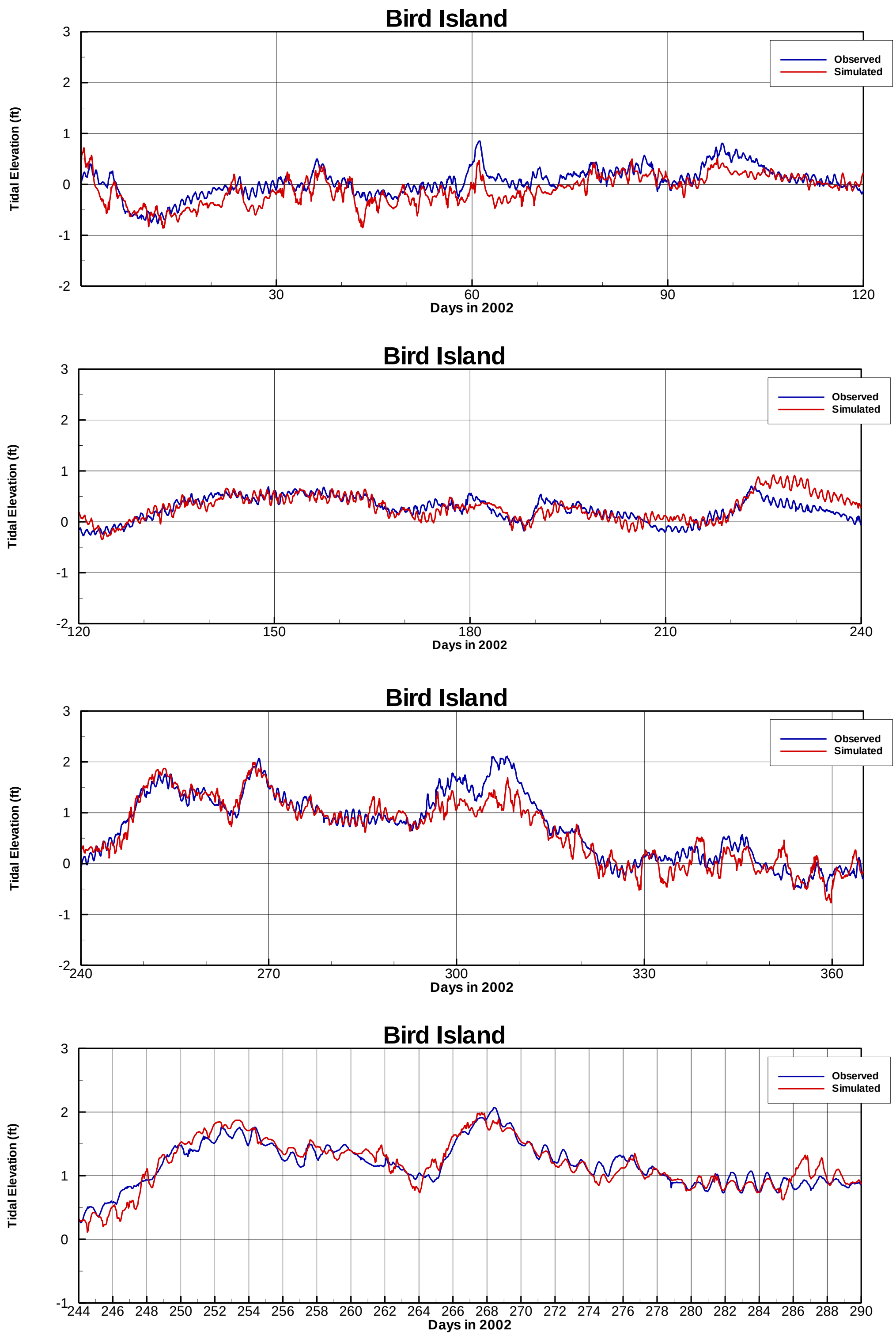


Figure 30. Time-series plots for simulated (*red*) versus observed (*blue*) hourly tide data at Bird Island during 2002. The bottommost panel shows tides during a 46-day period to better compare the timing of simulated and observed tidal elevations.

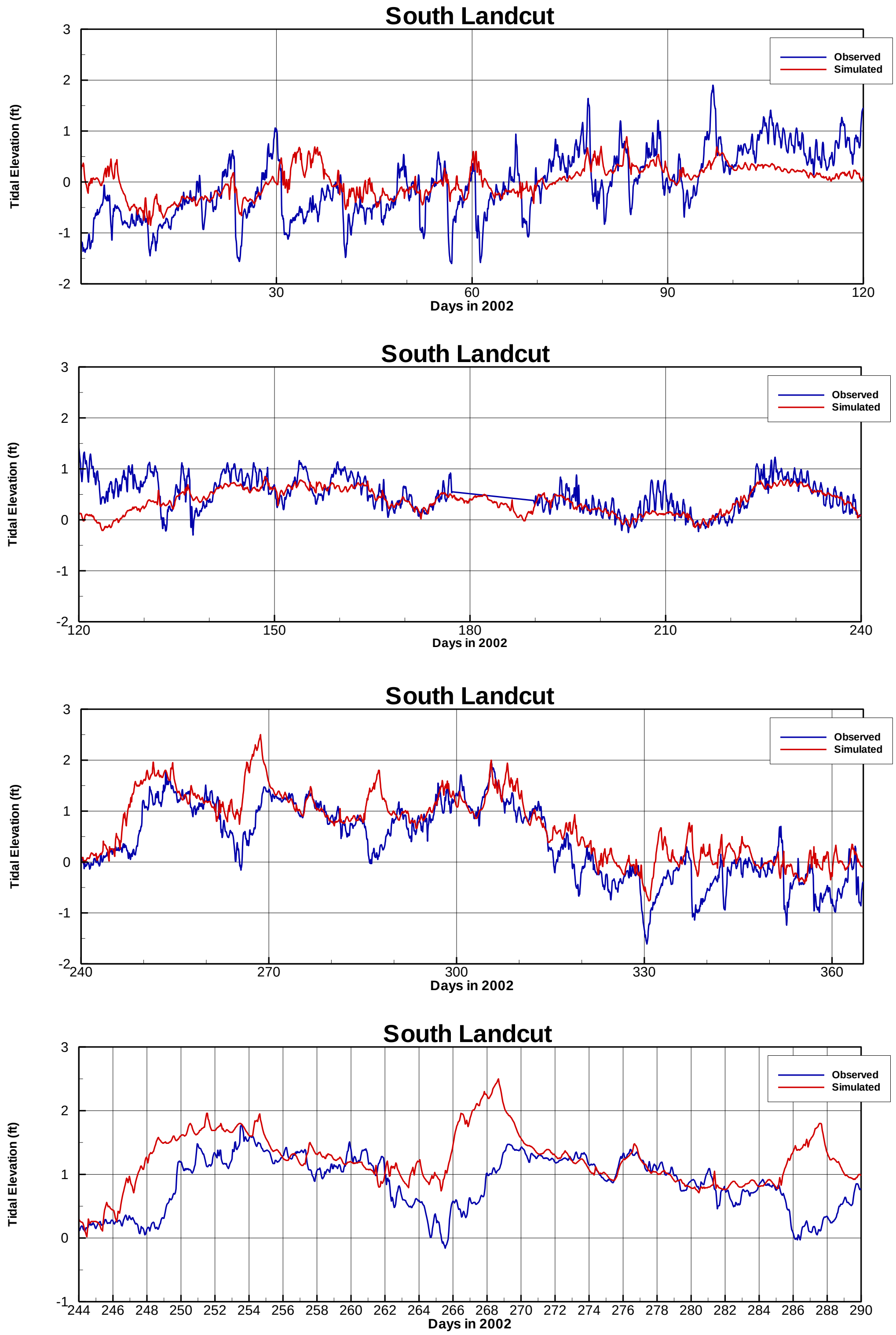


Figure 31. Time-series plots for simulated (*red*) versus observed (*blue*) hourly tide data at South Landcut during 2002. The bottommost panel shows tides during a 46-day period to better compare the timing of simulated and observed tidal elevations.

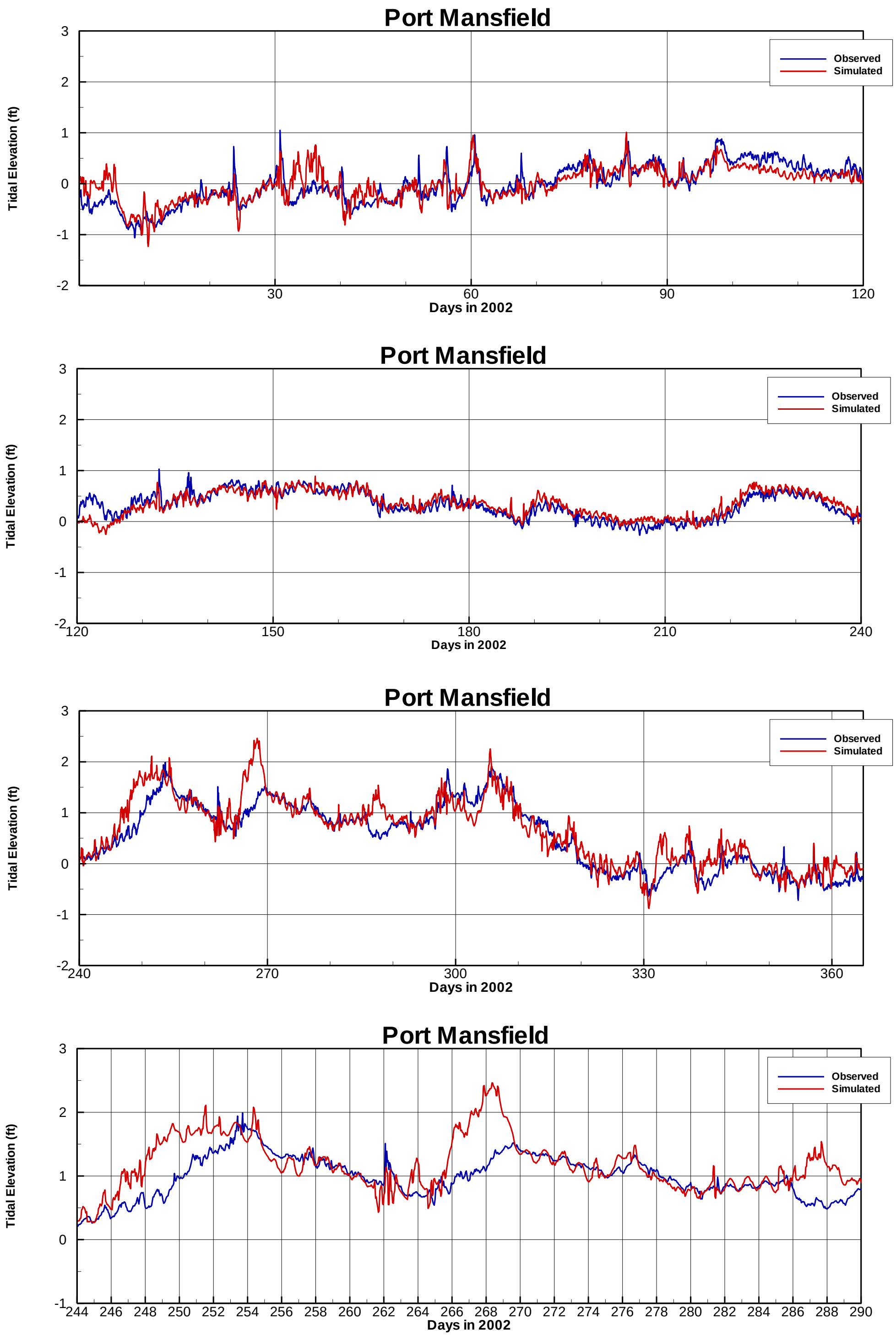


Figure 32. Time-series plots for simulated (*red*) versus observed (*blue*) hourly tide data at Port Mansfield during 2002. The bottommost panel shows tides during a 46-day period to better compare the timing of simulated and observed tidal elevations.

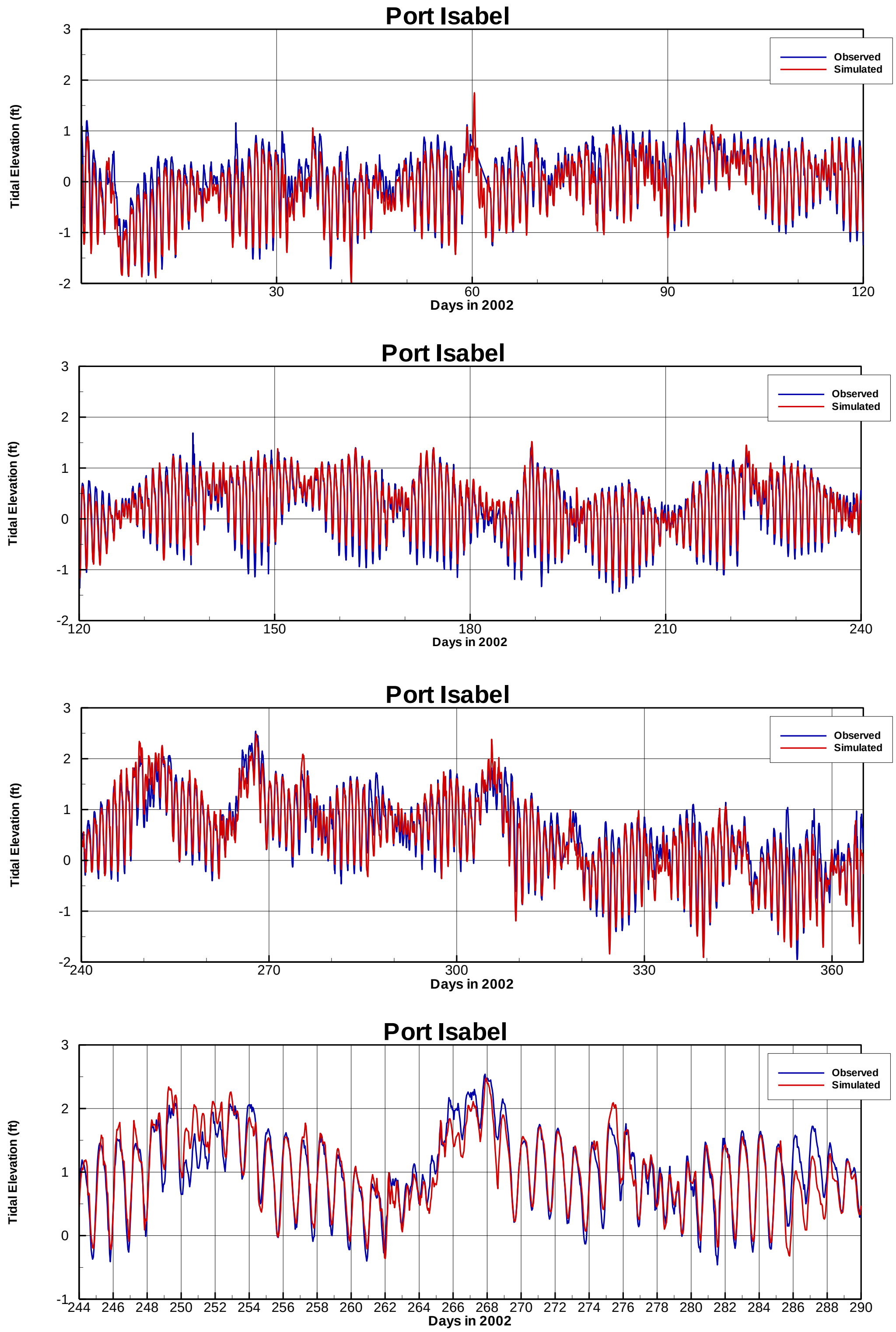


Figure 33. Time-series plots for simulated (*red*) versus observed (*blue*) hourly tide data at Port Isabel during 2002. The bottommost panel shows tides during a 46-day period to better compare the timing of simulated and observed tidal elevations.

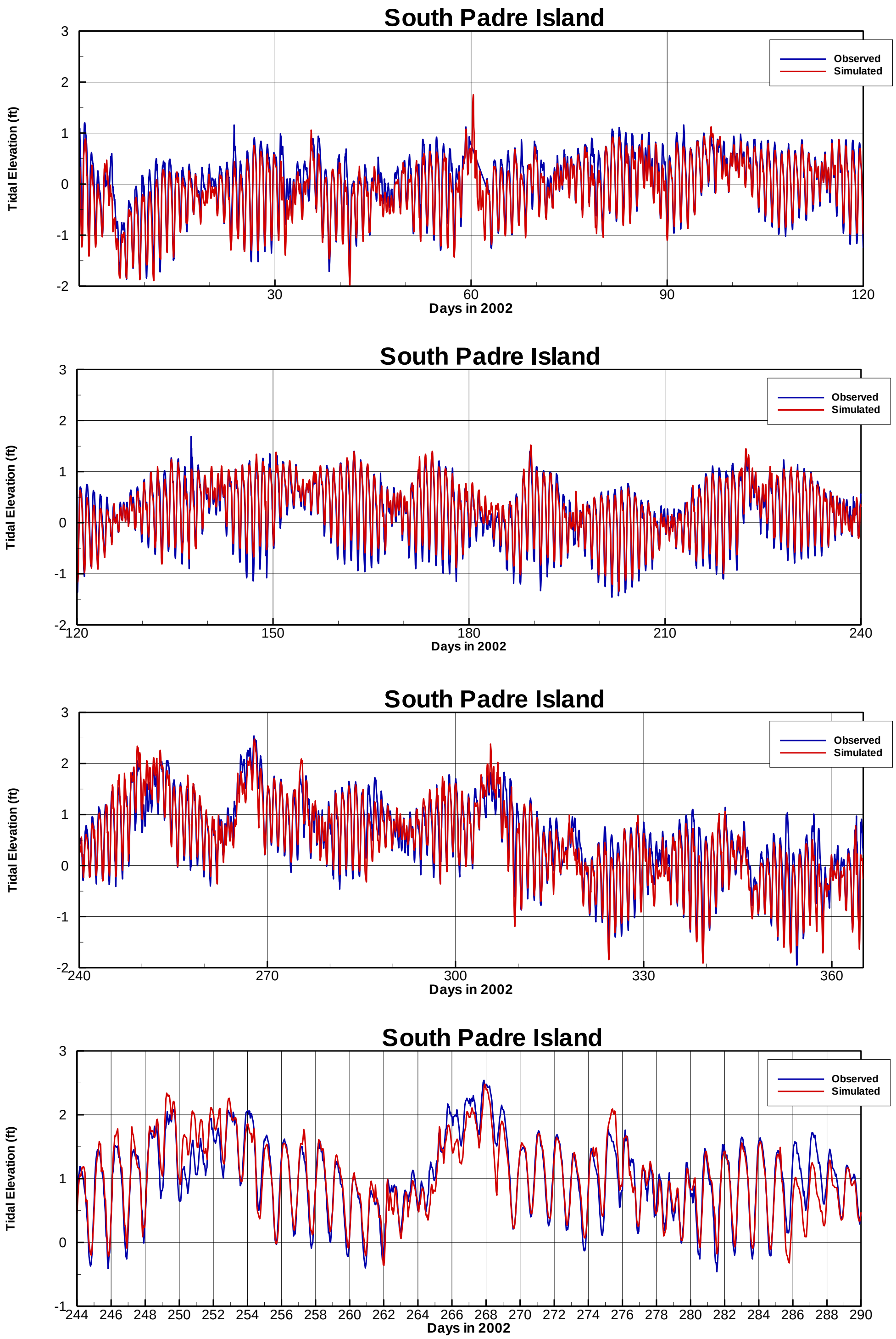


Figure 34. Time-series plots for simulated (*red*) versus observed (*blue*) hourly tide data at South Padre Island during 2002. The bottommost panel shows tides during a 46-day period to better compare the timing of simulated and observed tidal elevations.

Salinity Results

TxBLEND was calibrated for salinity at five sites in the Laguna Madre Estuary (see Figure 15 for map of locations), including at Old Isabel Causeway and the Arroyo Colorado Mouth for 1991 – 1992, as well as at Port Mansfield, Bird Island, Stover Point, and again at the Arroyo Colorado Mouth for 1995 – 2002.

Figures 35 – 46 show simulated versus observed salinities (both as time-series plots and as scatterplots) for the calibration periods at the locations listed above. The model simulated long-term trends in salinity fluctuations reasonably well, but high frequency variation was not captured as well. For instance, at the Old Isabel Causeway site, general patterns in simulated salinity follow observed salinity during the entire calibration period from 1991 - 1992, but the short-term variability is not as well captured, such as during May and June in 1991 (Figure 35). Datasondes placed deep in the channel, such as in the mouth of the Arroyo Colorado for 1991 – 1992 (Figure 37), generally measured higher salinities than the simulated salinities, which represent a depth-averaged salinity. The TxBLEND model captured depressed salinities after a small flood in late 1997, as shown at the Port Mansfield site (Figure 39), but did not capture the full extent of minimum observed salinities. The model slightly over-predicted salinity when compared to the shallow datasonde data at the mouth of the Arroyo-Colorado for 1995 - 2002, but did capture reduced salinities in late 1997 (Figure 41). Simulated salinities were generally well representative of observed salinities at the Stover Point site from 1995 - 2002 even though short-term variability was not as well captured (Figure 43). The model slightly over-predicted salinities at the Bird Island site from 1995 – 2002 (Figure 45). Table 5 shows comparison statistics between simulated and observed salinities for the calibration period at all sites.

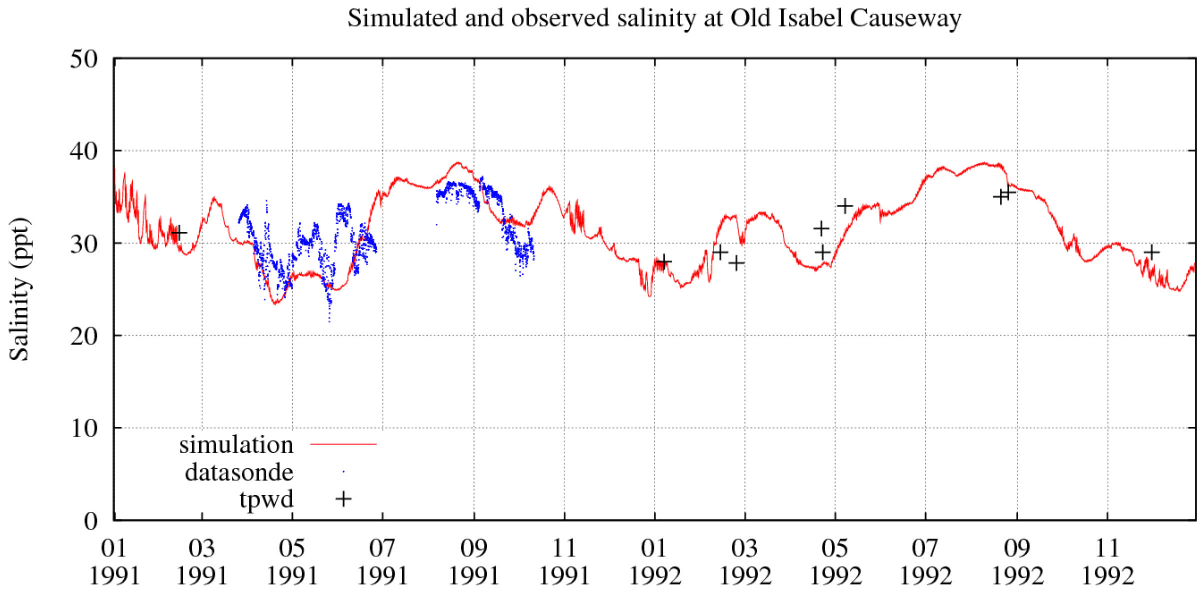


Figure 35. Simulated (*red*) versus observed (*blue*) salinities at the Old Isabel Causeway site in the Laguna Madre Estuary for 1991 – 1992. Point measurement data collected by TWPD (+) near this site also was included for comparison.

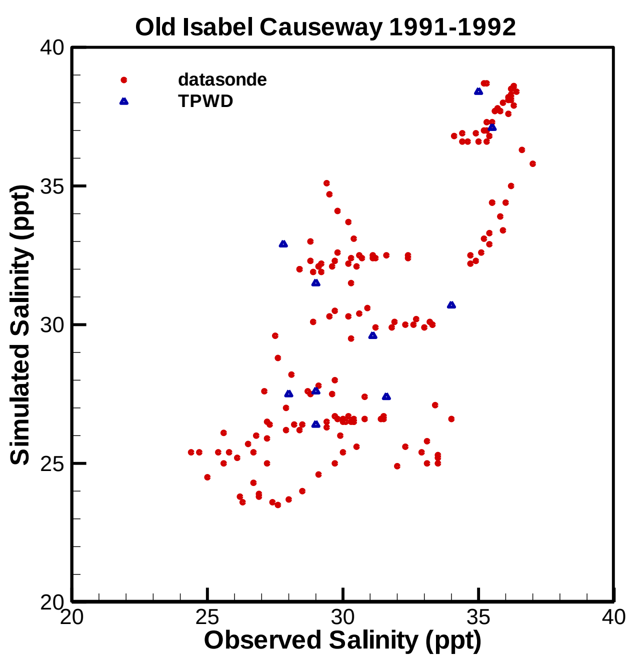


Figure 36. Scatter plot comparing simulated to observed daily salinities at the Old Isabel Causeway site for the calibration period from 1991 - 1992 ($r^2 = 0.57$ for TWDB Datasonde data and $r^2 = 0.45$ for TPWD data).

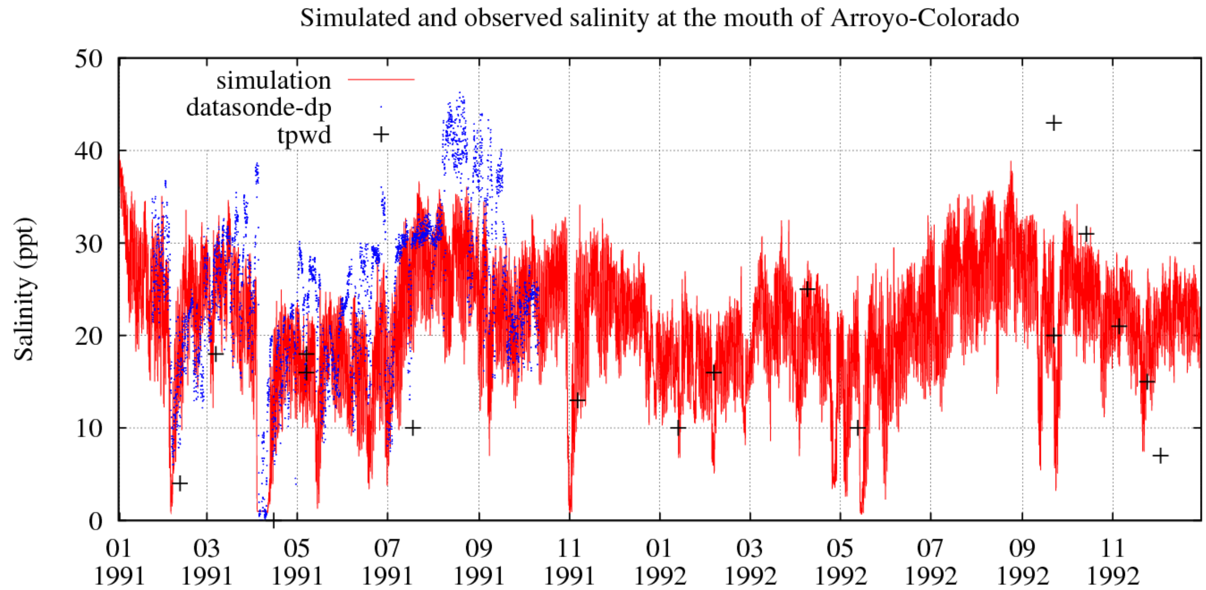


Figure 37. Simulated (*red*) versus observed (*blue*) salinities at the mouth of the Arroyo – Colorado in the Laguna Madre Estuary for 1991 – 1992. Point measurement data collected by TWPD (+) near this site also was included for comparison.

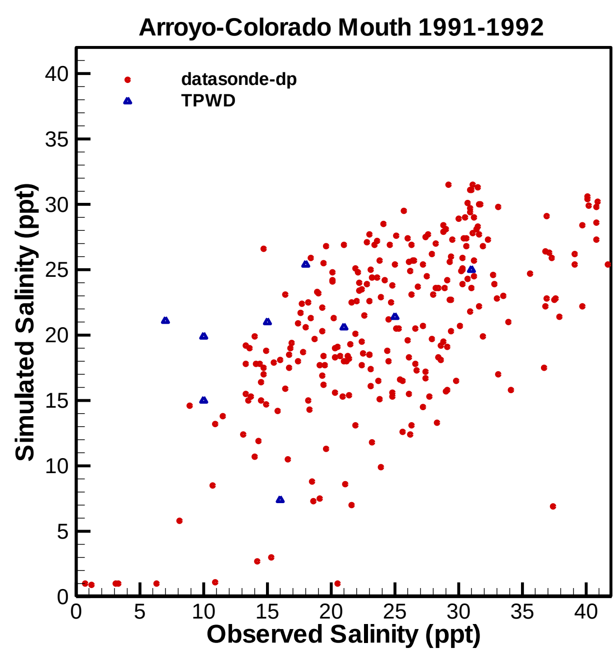


Figure 38. Scatter plot comparing simulated to observed daily salinities at the Arroyo-Colorado site for the calibration period from 1991 - 1992 ($r^2 = 0.40$ for TWDB Datasonde data and $r^2 = 0.12$ for TPWD data).

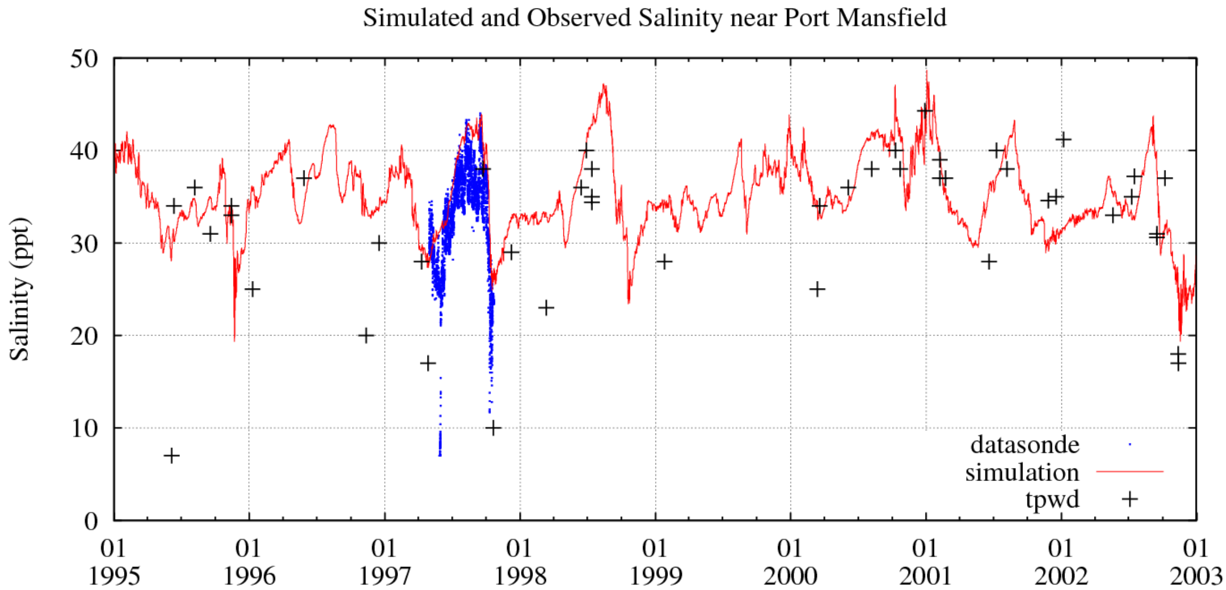


Figure 39. Simulated (*red*) versus observed (*blue*) salinities near Port Mansfield in the Laguna Madre Estuary for 1995 - 2002. Point measurement data collected by TWPD (+) near this site was also included for comparison.

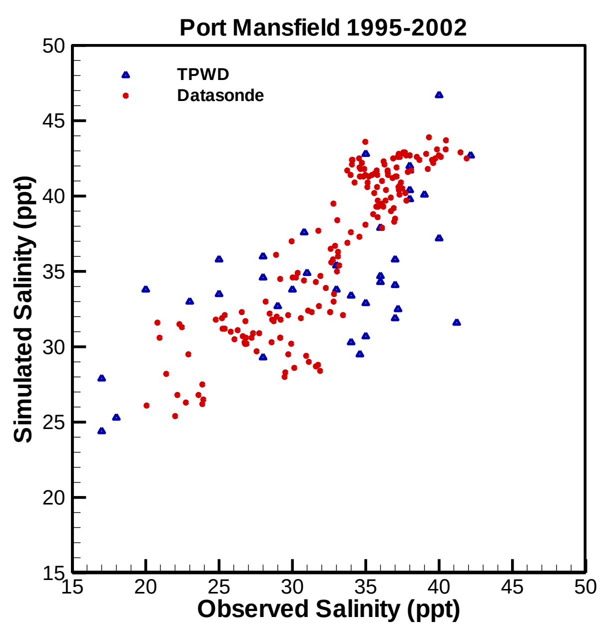


Figure 40. Scatter plot comparing simulated to observed daily salinities at the Port Mansfield site for the calibration period from 1995 - 2002 (r^2 = 0.69 for TWDB Datasonde data and r^2 = 0.43 for TPWD data).

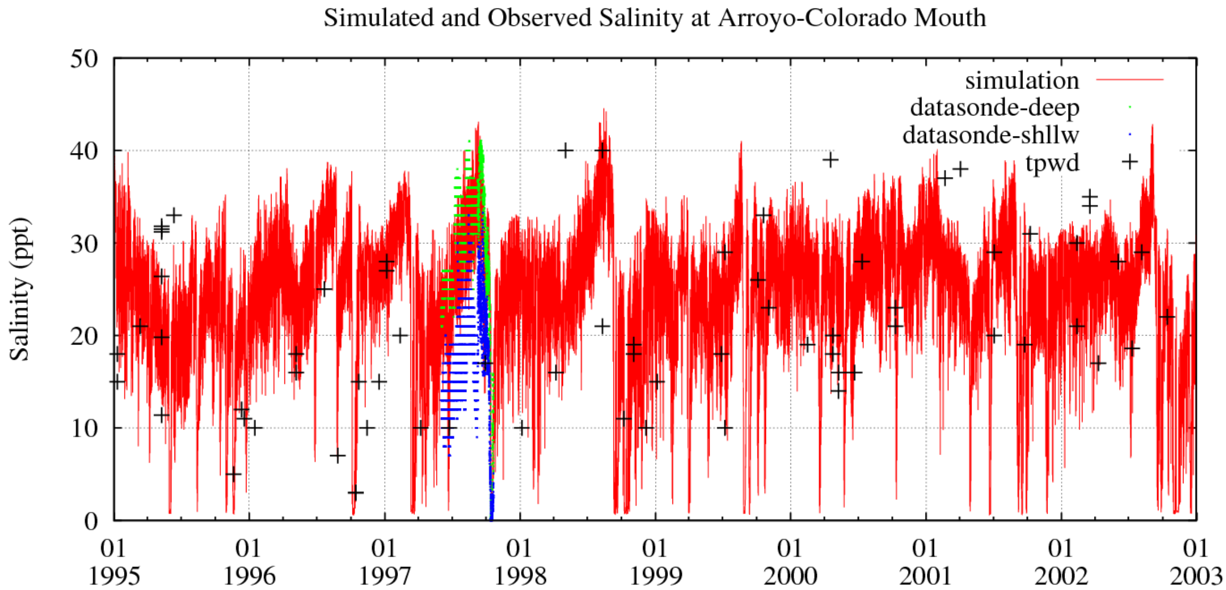


Figure 41. Simulated *(red)* versus observed *(blue and green)* salinities at the mouth of the Arroyo – Colorado in the Laguna Madre Estuary for 1995 - 2002. Datasondes that were placed deep within the bay are represented in green, while datasondes that were placed at a shallow location in the bay are represented in blue. Point measurement data collected by TWPD (+) near this site was also included for comparison.

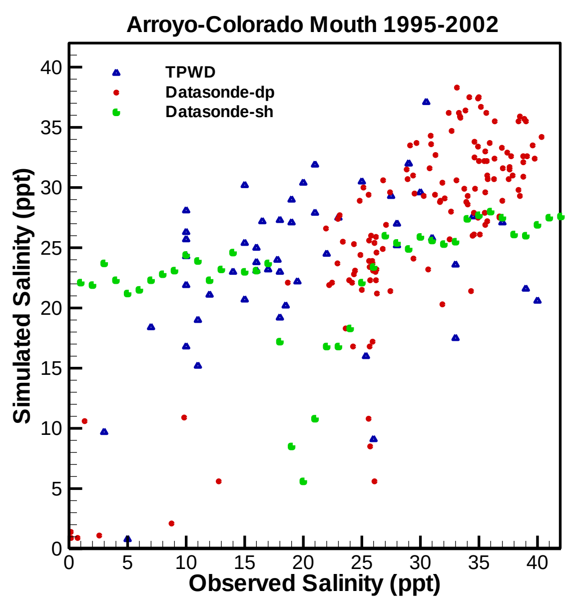


Figure 42. Scatter plot comparing simulated to observed daily salinities at the Arroyo-Colorado Mouth site for the calibration period from 1995 - 2002 ($r^2 = 0.69$ for TWDB deep datasonde, $r^2 = 0.62$ for TWDB shallow datasonde, and $r^2 = 0.13$ for TPWD data).

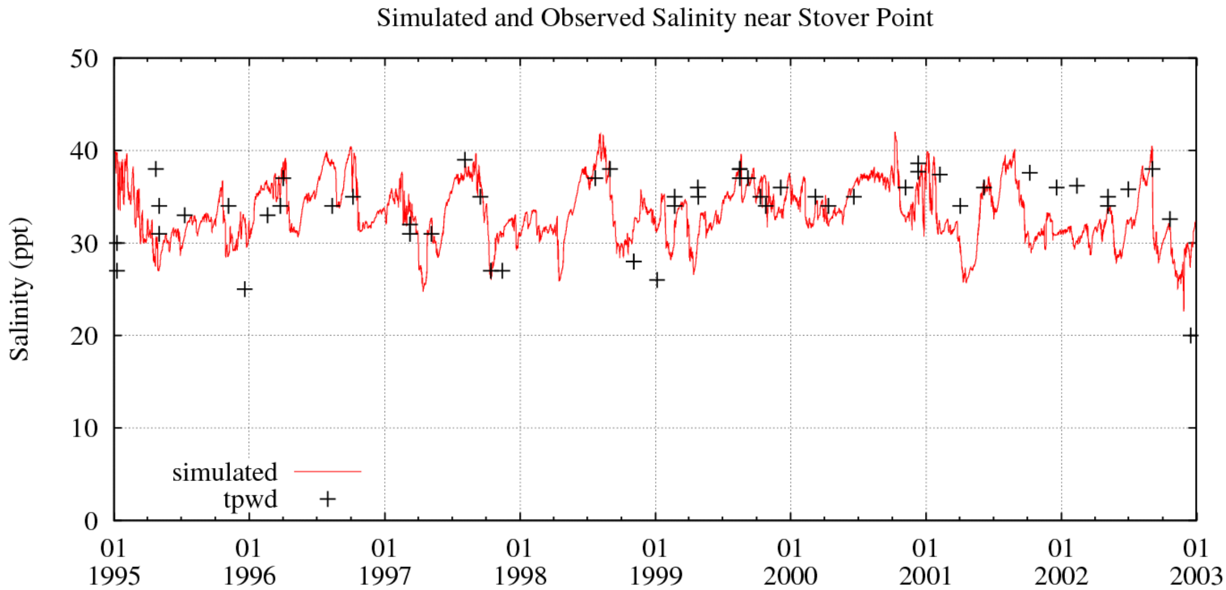


Figure 43. Simulated (*red*) versus observed (+) salinities near Stover Point in the Laguna Madre Estuary for 1995 - 2002. Although there are no Datasonde measurements at this site, it was selected for study because it is located mid-point between the Arroyo-Colorado and Old Isabel Causeway.

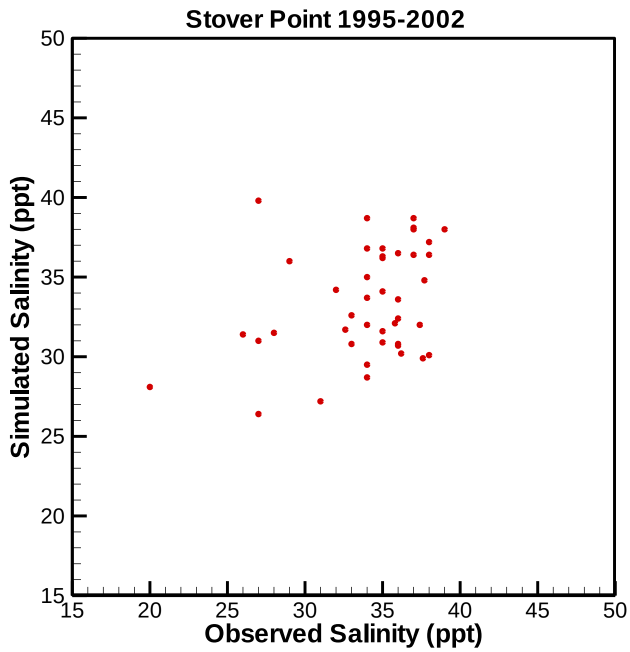


Figure 44. Scatter plot comparing simulated to observed daily salinities at the Stover Point site for the calibration period from 1995 - 2002 ($r^2 = 0.12$).

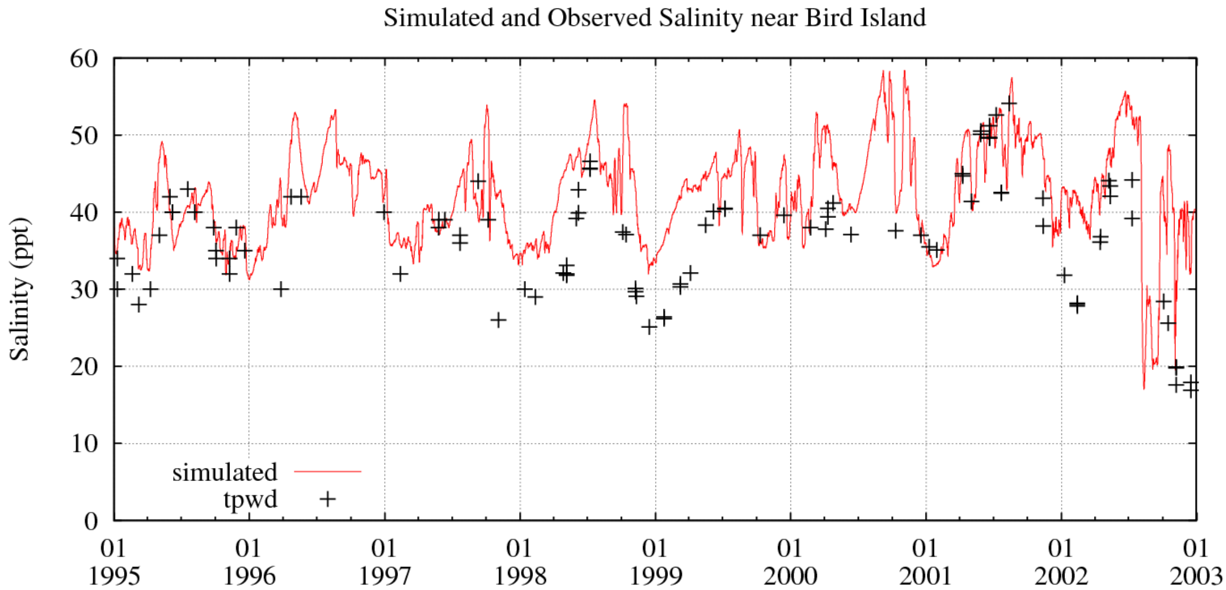


Figure 45. Simulated (*red*) versus observed (+) salinities near Bird Island in the Laguna Madre Estuary for 1995 - 2002.

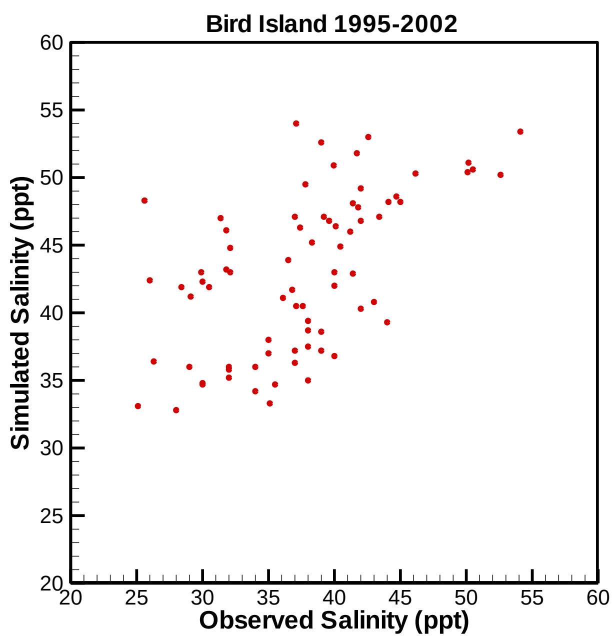


Figure 46. Scatter plot comparing simulated to observed daily salinities at the Bird Island site for the calibration period from 1995 - 2002 ($r^2 = 0.39$).

Table 5. Comparison statistics of daily salinity for calibration and validation. Data sources are (a) TWDB Datasonde, (b) TCOON Datasonde, (c) TPWD Coastal Fisheries data, and (d) Dr. Hudson DeYoe and UTPA. Calibration periods are shaded in grey.

<table>
<tr><th colspan="2" rowspan="2">Location</th><th rowspan="2">Data Source</th><th rowspan="2">Period</th><th rowspan="2">Days</th><th rowspan="2">r^2</th><th rowspan="2">RMS (ppt)</th><th rowspan="2">NSEC</th><th colspan="3">Average Salinity (ppt)</th></tr>
<tr><th>Simulated</th><th>Observed</th><th>Difference</th></tr>
<tr><td colspan="2" rowspan="2">Old Isabel Causeway</td><td>c</td><td>1991-1992</td><td>10</td><td>0.45</td><td>2.9</td><td>-0.12</td><td>30.9</td><td>31.0</td><td>-0.1</td></tr>
<tr><td>a</td><td>1991</td><td>161</td><td>0.57</td><td>3.1</td><td>0.09</td><td>30.5</td><td>31.3</td><td>-0.8</td></tr>
<tr><td rowspan="3">Arroyo-C Mouth</td><td rowspan="2">deep</td><td>a</td><td>1991</td><td>262</td><td>0.40</td><td>7.7</td><td>0.09</td><td>20.8</td><td>25.0</td><td>-4.2</td></tr>
<tr><td>a</td><td>1997</td><td>139</td><td>0.69</td><td>5.5</td><td>0.55</td><td>27.1</td><td>29.8</td><td>-2.7</td></tr>
<tr><td>shallow</td><td>a</td><td>1997</td><td>139</td><td>0.62</td><td>11.8</td><td>-2.98</td><td>27.1</td><td>16.4</td><td>10.7</td></tr>
<tr><td colspan="2" rowspan="3">Arroyo-C Mouth</td><td>c</td><td>1991-1992</td><td>10</td><td>0.12</td><td>9.9</td><td>0.10</td><td>19.9</td><td>19.6</td><td>0.3</td></tr>
<tr><td>c</td><td>1995-2002</td><td>51</td><td>0.13</td><td>9.6</td><td>-0.14</td><td>23.8</td><td>20.2</td><td>3.6</td></tr>
<tr><td>c</td><td>2003-2009</td><td>44</td><td>0.28</td><td>8.0</td><td>0.03</td><td>22.3</td><td>19.4</td><td>2.9</td></tr>
<tr><td colspan="2">Arroyo-GIWW</td><td>c</td><td>2003-2009</td><td>54</td><td>0.21</td><td>9.7</td><td>-0.08</td><td>34.2</td><td>29.3</td><td>4.9</td></tr>
<tr><td colspan="2">Green Island</td><td>d</td><td>2003-2009</td><td>14</td><td>0.55</td><td>2.6</td><td>0.51</td><td>34.1</td><td>34.1</td><td>0.0</td></tr>
<tr><td colspan="2" rowspan="3">Port Mansfield</td><td>a</td><td>1997</td><td>175</td><td>0.69</td><td>5.2</td><td>0.15</td><td>36.5</td><td>32.4</td><td>4.1</td></tr>
<tr><td>c</td><td>1995-2002</td><td>40</td><td>0.43</td><td>7.1</td><td>0.28</td><td>34.5</td><td>31.3</td><td>3.2</td></tr>
<tr><td>c</td><td>2003-2009</td><td>35</td><td>0.26</td><td>6.1</td><td>0.01</td><td>34.4</td><td>31.3</td><td>3.1</td></tr>
<tr><td colspan="2" rowspan="3">Bird Island</td><td>c</td><td>1995-2002</td><td>77</td><td>0.39</td><td>8.0</td><td>-0.32</td><td>42.6</td><td>37.0</td><td>5.6</td></tr>
<tr><td>a</td><td>2003-2005</td><td>596</td><td>0.06</td><td>9.7</td><td>-0.21</td><td>34.0</td><td>32.5</td><td>1.5</td></tr>
<tr><td>c</td><td>2003-2009</td><td>55</td><td>0.39</td><td>6.6</td><td>0.29</td><td>38.4</td><td>36.5</td><td>1.9</td></tr>
<tr><td colspan="2" rowspan="2">Stover Point</td><td>c</td><td>1995-2002</td><td>43</td><td>0.12</td><td>4.2</td><td>-0.16</td><td>33.4</td><td>33.9</td><td>-0.5</td></tr>
<tr><td>c</td><td>2003-2009</td><td>45</td><td>0.16</td><td>4.5</td><td>-0.02</td><td>32.5</td><td>34.1</td><td>-1.6</td></tr>
<tr><td colspan="2">Realitos Peninsula</td><td>b</td><td>2009-2010</td><td>515</td><td>0.56</td><td>4.7</td><td>0.48</td><td>29.7</td><td>28.0</td><td>1.7</td></tr>
<tr><td colspan="2">S Padre Island CG</td><td>b</td><td>2009-2010</td><td>528</td><td>0.95</td><td>0.7</td><td>0.95</td><td>29.5</td><td>29.4</td><td>0.1</td></tr>
</table>

*RMS is root mean square error.
**NSEC is the Nash-Sutcliffe Efficiency Criterion (E) and describes model performance, where E=1.0 represents a perfect match between model output and observed data; when E < 1, the model is a poorer predictor.

Model Validation

To verify the validity of the calibrated Laguna Madre model for salinity, additional model runs were conducted from 2003 – 2009 at four locations, including Port Mansfield, mouth of the Arroyo Colorado, GIWW-Arroyo Colorado (including Green Island), and Stover Point. Two additional model runs were conducted at Realitos Peninsula and the South Padre Island Coast Guard Station from 2008 – 2010 using a different Gulf salinity boundary from previous validations. Model outputs were then compared to TWDB Datasonde data, point measurement data obtained from TPWD's Coastal Fisheries database, TCOON Datasonde data, and data collected by Dr. Hudson DeYoe from UTPA. Figures 47 through 58 show results for the validation excerise as time-series plots and scatter plots. Table 5 (above) shows summary statistics for the validation exercise at each site.

Validation Results for Salinity from 2003 - 2009

The validation period from 2003 – 2009 at the Port Mansfield site simulates general trends in salinity reasonably well, but does not capture all variability (Figure 47). The validation exercise at the mouth of the Arroyo Colorado compares simulated TxBLEND salinities to observed salinities obtained from TPWD's Coastal Fisheries database (Figure 49). The model captured the wide variability in salinity that occurs at the mouth of the Arroyo Colorado well. Point measurement data from TPWD's Coastal Fisheries database was available to compare against simulated salinities at the GIWW-Arroyo Colorado site, in addition to data provided by Dr. Hudson DeYoe from UTPA at Green Island, a location near to the GIWW-Arroyo Colorado site (Figure 51). Simulated salinity follows the general trend in observed salinities, but does not capture all of the high-frequency variability. When compared to TPWD point measurement data near to the GIWW-Arroyo Colorado site, the model appears to have missed an inflow event that decreased salinities in late 2003. Although there was no Datasonde data available at the Stover Point site (Figure 53), this location was chosen for salinity comparison as a check, because it is located mid-way between the Arroyo-Colorado and Old Isabel Causeway. The model simulation follows the general trends in salinity of the observed data at this location. At the Bird Island site, the model either consistently over-predicts or under-predicts salinity (Figure 55). The Bird Island site is located far from the location where wind data was obtained (South Padre Island Coast Guard Station), and thus inaccuracies may have contributed to decreased model performance at this site.

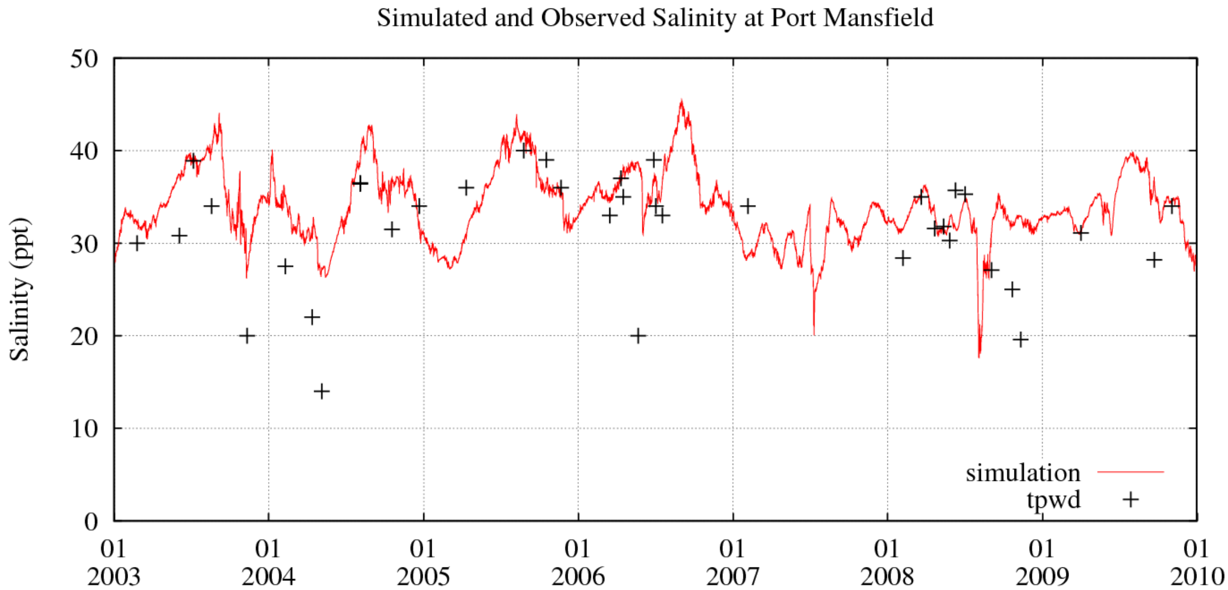


Figure 47. Simulated (*red*) versus observed (+) salinities at Port Mansfield in the Laguna Madre Estuary for the validation period from 2003 – 2009.

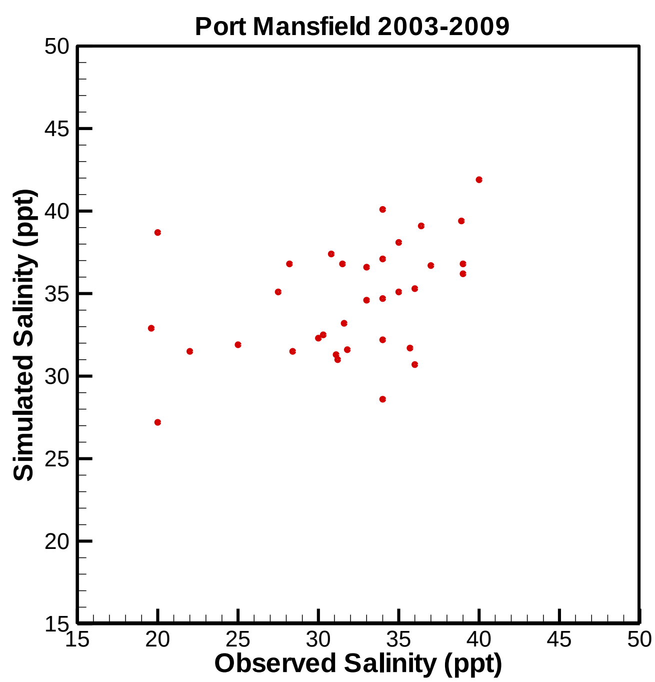


Figure 48. Scatter plot comparing simulated to observed daily salinities at the Port Mansfield site for the validation period from 2003 - 2009 ($r^2 = 0.26$).

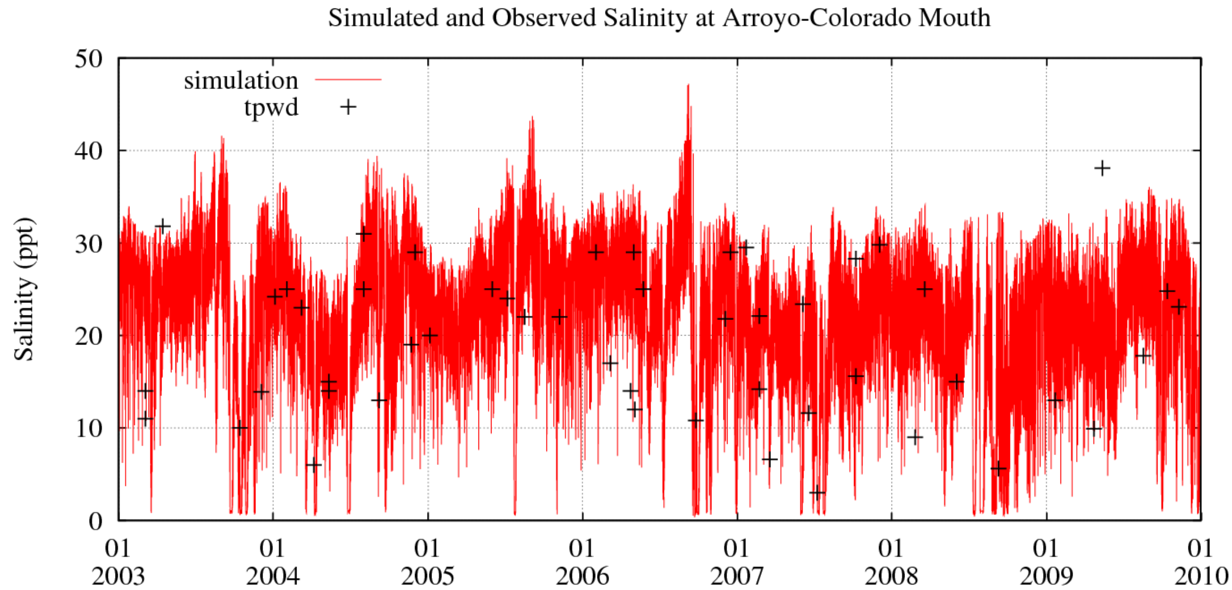


Figure 49. Simulated (*red*) versus observed (+) salinities at the mouth of the Arroyo Colorado in the Laguna Madre Estuary for 2003 – 2009. Datasonde data was not available at this location.

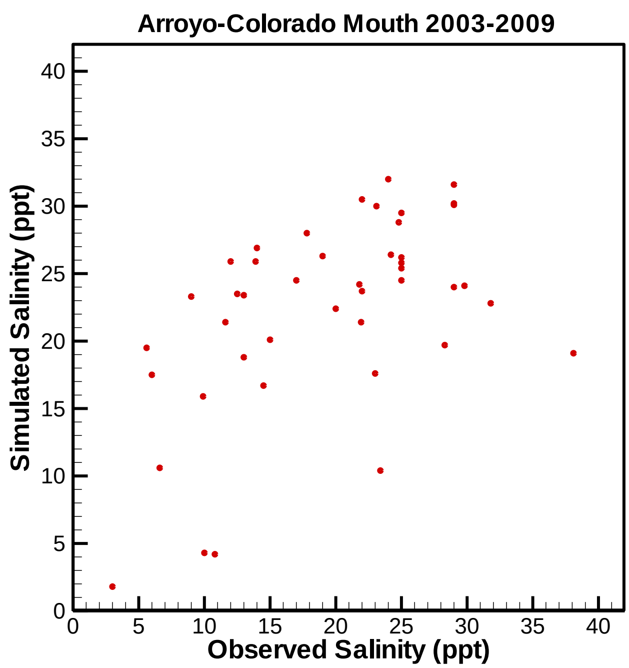


Figure 50. Scatter plot comparing simulated to observed daily salinities at the Arroyo-Colorado Mouth site for the validation period from 2003 - 2009 ($r^2 = 0.28$).

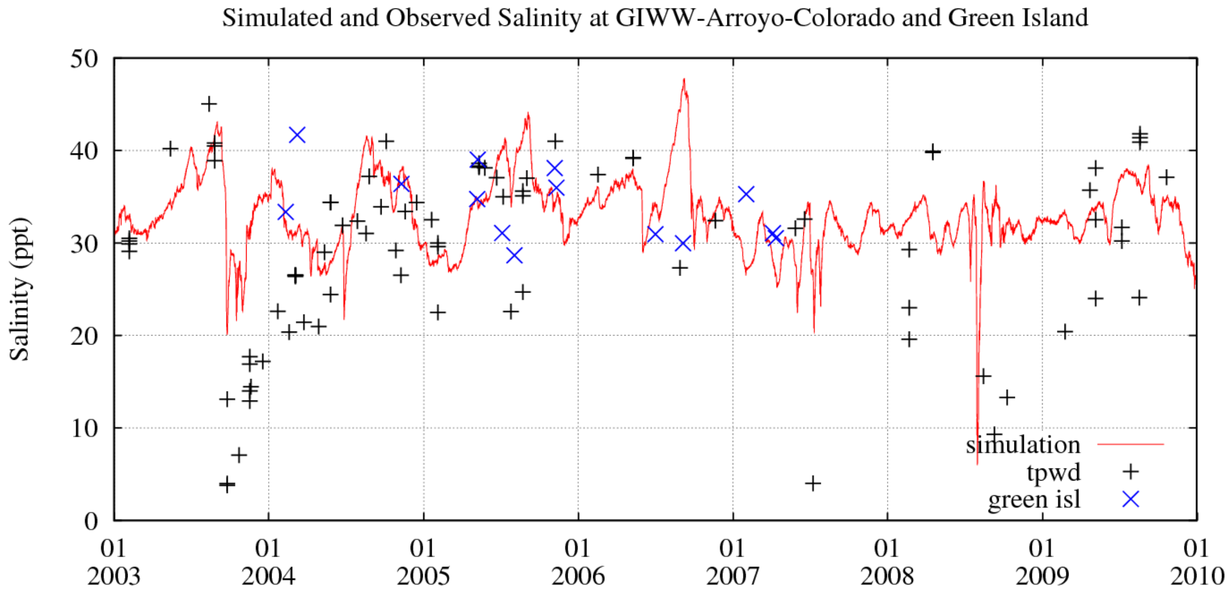


Figure 51. Simulated (*red*) versus observed (+ and x) salinities at the GIWW-Arroyo Colorado site in the Laguna Madre Estuary for 2003 - 2009. Point measurement data collected by TWPD (+) near this site was also included for comparison, as well as data from the nearby Green Island site (x), collected by Dr. Hudson DeYoe.

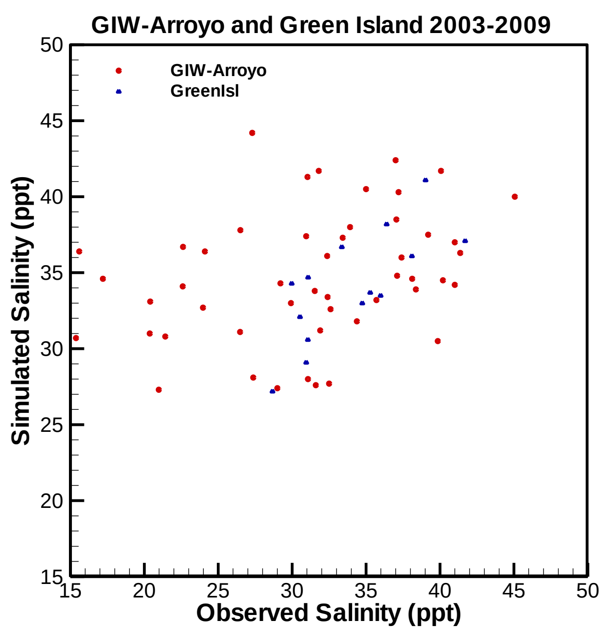


Figure 52. Scatter plot comparing simulated to observed daily salinities at the GIWW-Arroyo-Colorado and Green Island site for the validation period from 2003 - 2009 (r^2 = 0.21 for TPWD data and r^2 = 0.55 for Green Island data).

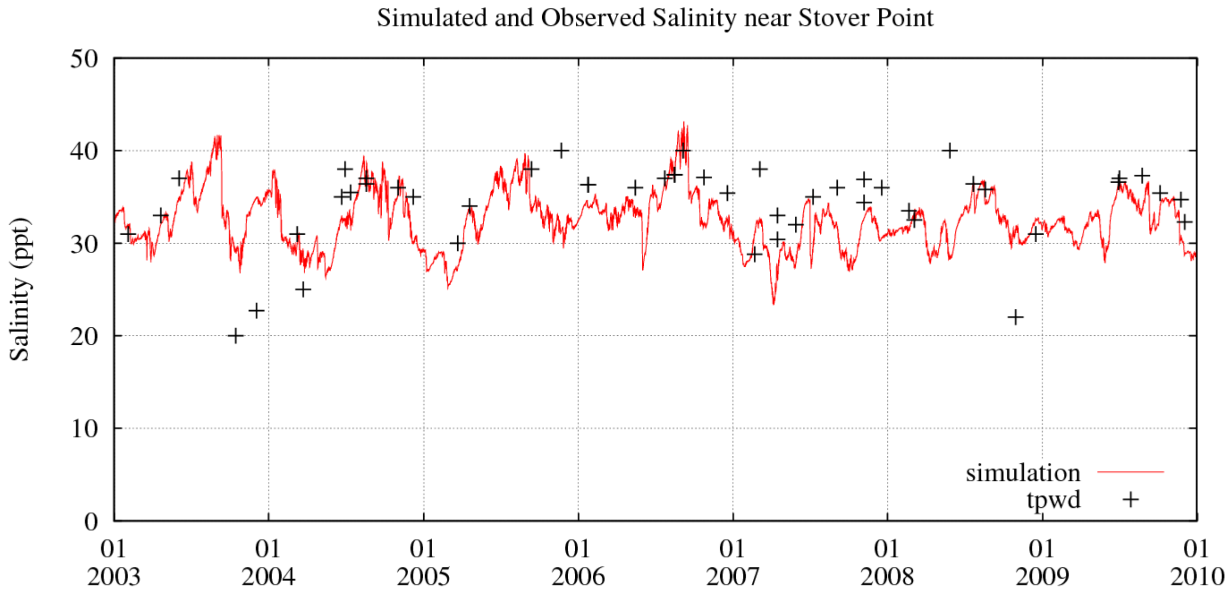


Figure 53. Simulated (*red*) versus observed (+) salinities at Stover Point in the Laguna Madre Estuary for 2003 – 2009. Although there are no Datasonde measurements available, this location was selected for study because it is located mid-point between the Arroyo-Colorado and Old Isabel Causeway.

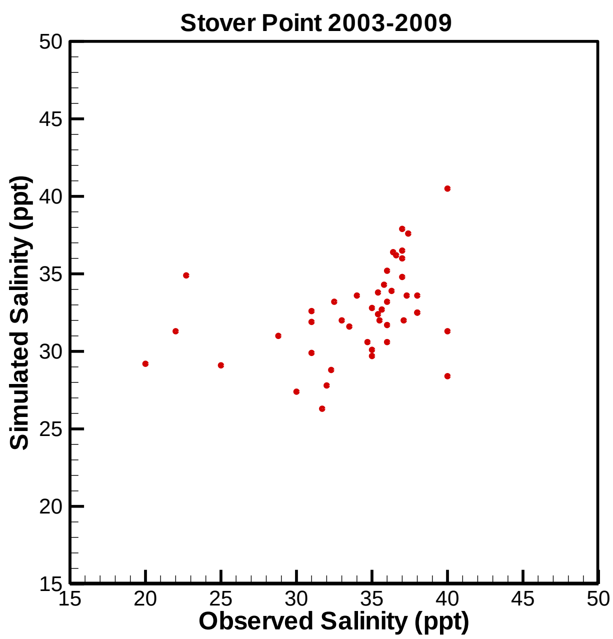


Figure 54. Scatter plot comparing simulated to observed daily salinities at the Stover Point site for the validation period from 2003 - 2009 ($r^2 = 0.16$).

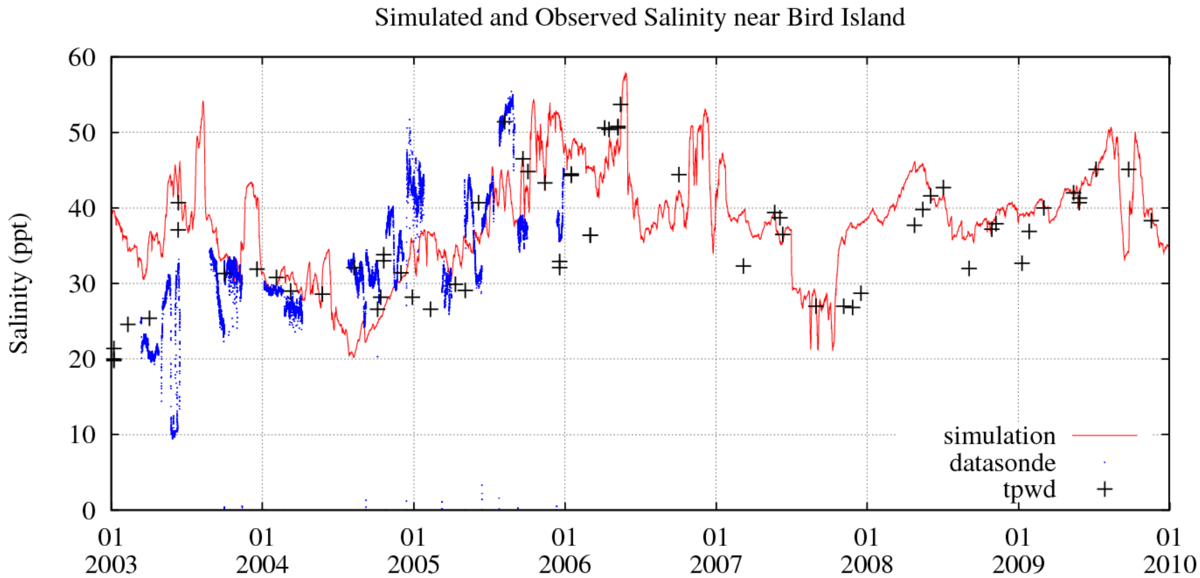


Figure 55. Simulated (*red*) versus observed (*blue*) salinities near Bird Island in the Laguna Madre Estuary for 2003 – 2009. Point measurement data collected by TPWD (+) near this site were also included for comparison. The simulation was compared against TPWD point measurement data through 2009.

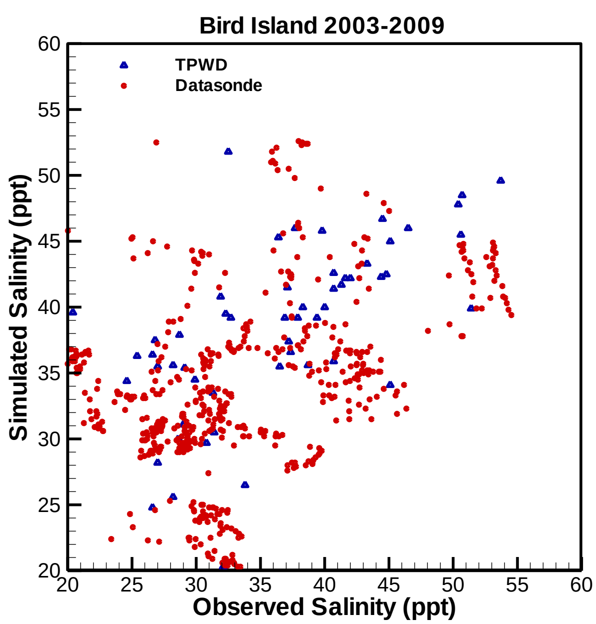


Figure 56. Scatter plot comparing simulated to observed daily salinities at the Stover Point site for the validation period from 2003 - 2009 ($r^2 = 0.16$).

Results from Additional Validation for 2008 – 2010

A separate validation exercise was conducted for 2008 – 2010 at the Realitos Peninsula site and at the South Padre Island Coast Guard Station site, using a different salinity condition at the Gulf boundary from what was used in previous calibration and validation exercises. Rather than using data from TPWD's Coastal Fisheries database to define the Gulf salinity boundary, a three-day average salinity from the South Padre Island Coast Guard Station was used. This model validation run was conducted to determine how Gulf salinity influences salinity at Realitos Peninsula, a location within the Laguna Madre. At the Realitos Peninsula site, the model tends to either over- or under-predict salinity, but the model follows the long-term trend well and accurately predicts decreasing salinity after the flood in July 2010 (Figure 57). Comparisons at the South Padre Island Coast Guard Station show almost a perfect match between simulated and observed salinities, with an r^2 value of 0.95 (Figures 59 and 60). As can be expected, Gulf salinity influences salinity at Realitos Peninsula most of the time. However, during particular events, such as high temperature and very low inflow, the middle and upper estuary influence salinity at Realitos Peninsula more than the Gulf (*i.e.*, August 2009). Similarly, during a flood event, freshwater inflow from the Arroyo Colorado influences system-wide salinity more than the Gulf (*i.e.*, flood of July 2010).

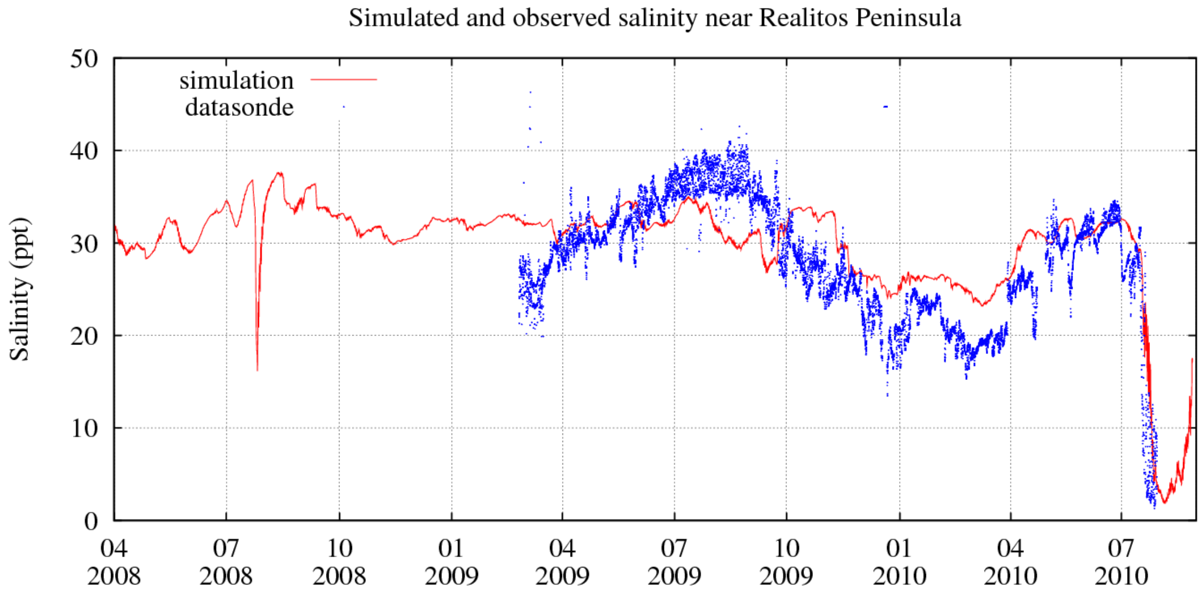


Figure 57. Simulated (*red*) versus observed (*blue*) salinities near Realitos Peninsula in the Laguna Madre Estuary for 2008 – 2010. Note that the flood of late July 2010 reduced salinity at this site, which was well captured by the model.

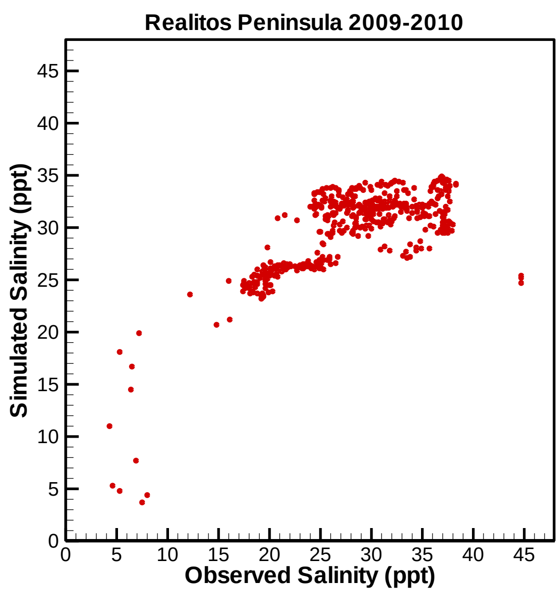


Figure 58. Scatter plot comparing simulated to observed daily salinities at the Realitos Peninsula site for the validation period from 2009 - 2010 ($r^2 = 0.56$).

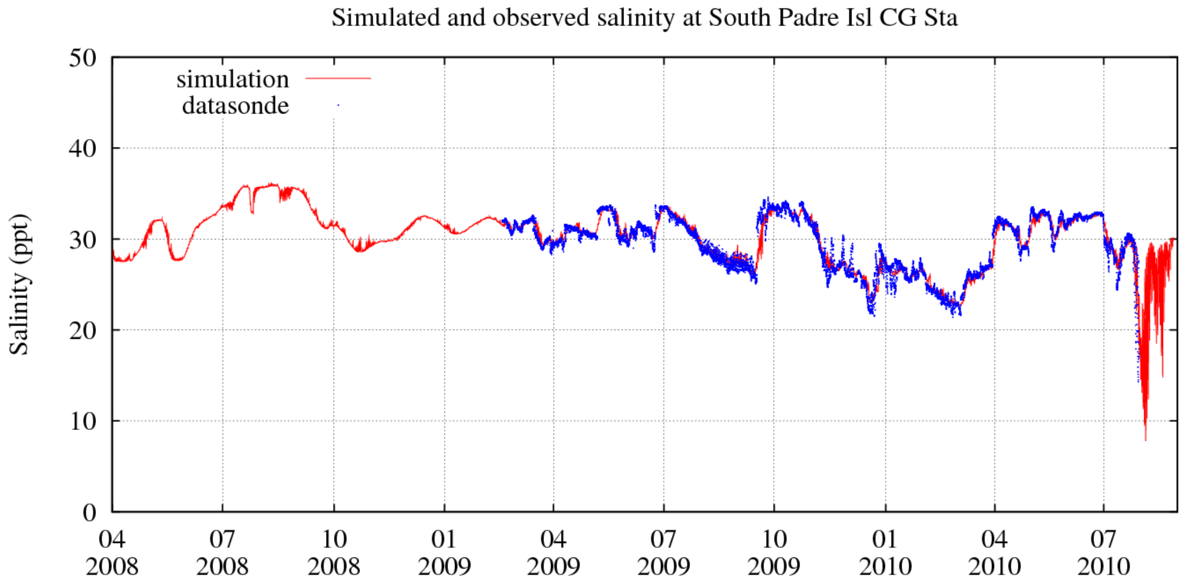


Figure 59. Simulated (*red*) versus observed (*blue*) salinities at the South Padre Island Coast Guard Station in the Laguna Madre Estuary for 2008 – 2010. *Note:* For the 2008 – 2010 validation, TxBLEND Gulf boundary salinity was generated based on a three-day average salinity from this site, resulting in an almost perfect match between simulated and observed salinity.

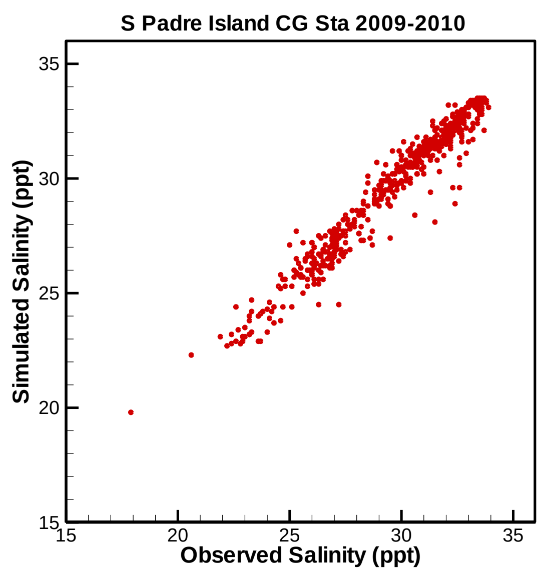


Figure 60. Scatter plot comparing simulated to observed daily salinities at the South Padre Island Coast Guard Station site for the validation period from 2009 – 2010 (r^2 = 0.95).

Discussion

Model calibration for discharge and velocity showed that the model was representative of observed discharge and velocities at most locations throughout the Laguna Madre Estuary. Although the model slightly under-predicted or over-predicted discharge and velocity in specific cases, overall trends were captured well. Increased current velocities near the entrance to the Gulf and reduced current velocities within the Laguna Madre were well simulated.

Observed tides at Bob Hall Pier were applied to the Gulf Boundary to drive the model. Simulated tidal elevations were representative of observed tidal elevations throughout the system. One exception was at the Landcut, which is located at the most remote site from the Gulf. A local detailed wind dataset may improve the simulation at this site.

Results for salinity calibration demonstrate that the TxBLEND model for the Laguna Madre Estuary is representative of observed salinities. Although general, long-term trends were simulated reasonably well, the model does not capture short-term, high-frequency variability as well. In some cases, the model either over-predicted or under-predicted salinity. The calibration exercise for all sites yielded a range of r^2 values from 0.12 to 0.69. Root Mean Square Error (RMS) ranged from 2.9 ppt to 11.8 ppt. Another measure of model performance is the Nash-Sutcliffe Efficiency Criterion (E) which describes model performance, where E = 1.0 represents a perfect match between model output and observed data, and when E < 1, the model is considered a poorer predictor. Calibration exercises yielded E values ranging from -2.98 to 0.55. The average salinity difference between simulated and observed salinity for all calibration exercises was 1.75 ppt, and ranged from -4.2 ppt to 10.7 ppt. The Laguna Madre Estuary is a long and slender system with few inflow points and in combination with limited Datasonde data available for model calibration, the model may not perform as well as in some of the other bay systems in Texas. However, given the challenges to modeling the hydrodynamics and predicting salinity in this system, the TxBLEND model for the Laguna Madre Estuary is capable of simulating salinity reasonably well.

Results from the validation exercise from 2003 - 2009 to simulate bay conditions were similar to the calibration results, in that long-term trends were reasonably well simulated but short-term fluctuations were less well represented, and sometimes the model either over- or under-predicted salinity. When compared to the calibration period, the model exhibited a larger range of r^2 values (0.06 to 0.95), lower RMS values (0.7 to 9.7), and higher E values (-0.21 to 0.95). The average salinity difference between simulated and observed salinity for the 2003 – 2009 validation period was 1.6 ppt. The model performed well in the additional validation exercise from 2008 to 2010 at two locations, the Realitos Peninsula site (r^2 = 0.56) and the South Padre Island Coast Guard Station site (r^2 = 0.95). Good model performance resulted mainly because the three-day average salinity from the U.S. Coast Guard Station was applied to the Gulf boundary to drive the model, resulting in an almost perfect match between simulated and observed salinity at the South Padre Island Coast Guard Station.

The Laguna Madre, as with other Texas bays, is generally very shallow and has minimal tidal fluctuations which are features that satisfy the assumptions of two-dimensional hydrodynamic modeling. However, to expand modeling capabilities and improve model predictability in this system, TWDB staff continues to explore the use of a three-dimensional hydrodynamic model for future efforts.

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