TxBLEND Model Calibration and Validation For the Nueces Estuary

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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 Nueces Estuary and Upper Laguna Madre, including Baffin Bay, but is not limited to these bay systems. Instead, the model includes Copano and Aransas 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 Nueces Estuary consists of Corpus Christi Bay, Nueces Bay and Oso Bay, and is connected to Aransas Bay to the north and the upper Laguna Madre to the south (Figure 1). The major freshwater inflow source to the Nueces Estuary is the Nueces River via Nueces Bay, but Oso Creek also contributes to Corpus Christi Bay through Oso Bay. The Corpus Christi Ship Channel transverses the bay from the Gulf of Mexico through the Entrance Channel at Port Aransas, which provides a direct connection with the Gulf. Two power plants in the Nueces Estuary, the Nueces Bay Power Plant and the Barney Davis plant near the upper Laguna Madre, draw water from and discharge water to surrounding bays (Figure 2).

Figure 1. Regional map of the Nueces Estuary along the Texas coast. Corpus Christi Bay receives freshwater inflow from the Nueces River via Nueces Bay, and Oso Creek via Oso Bay. A direct connection to the Gulf of Mexico exists through the Entrance Channel.

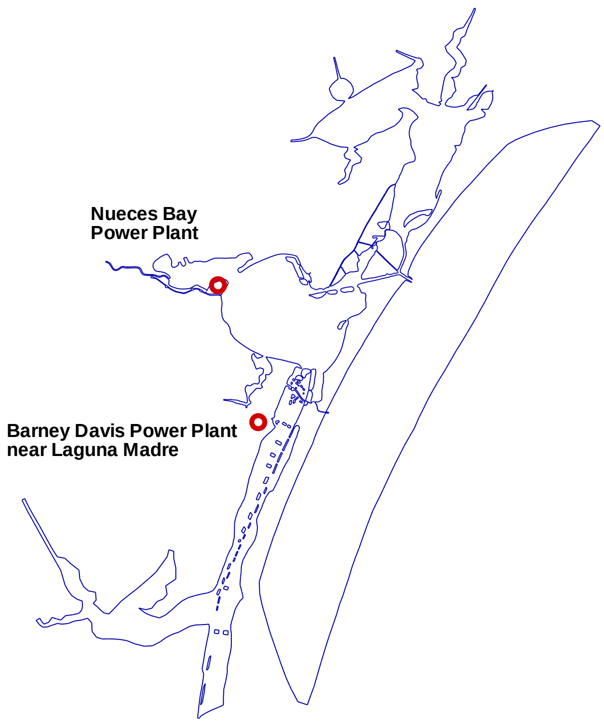


Figure 2. Nueces Bay Power Plant and Barney Davis Power Plant sites in the Nueces Estuary area which draw water for cooling purposes and discharge into neighboring bays. The Nueces Bay Power Plant intakes water from the Corpus Christi Harbor and returns the water to Nueces Bay. The Barney Davis plant intakes water from the Laguna Madre and returns it to Oso 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 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 Nueces Estuary, 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 Nueces Estuary

The TxBLEND computational grid for the Nueces Estuary contains 11,009 nodes and 19,035 triangular elements (Figure 3 - 4). In addition to the bays of the Nueces Estuary system, the model grid also represents Copano and Aransas bays to the northeast and the upper Laguna Madre and Baffin Bay to the southwest. 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 seven inflow points (Figure 5), corresponding to flows coming from the: Salt/Cavasso Creek, Copano Creek, Mission River, Aransas River, Nueces River, Oso Creek, and San Fernando Creek. Bathymetry used to develop the grid was obtained from National Oceanic and Atmospheric Administration (Nautical Chart #11314: Carlos Bay to Redfish Bay including Copano Bay; #11309: Corpus Christi Bay; #11308: Redfish Bay to Middle Ground including Baffin Bay). Bathymetry of the Corpus Christi ship channel was obtained from the Port of Corpus Christi Authority.

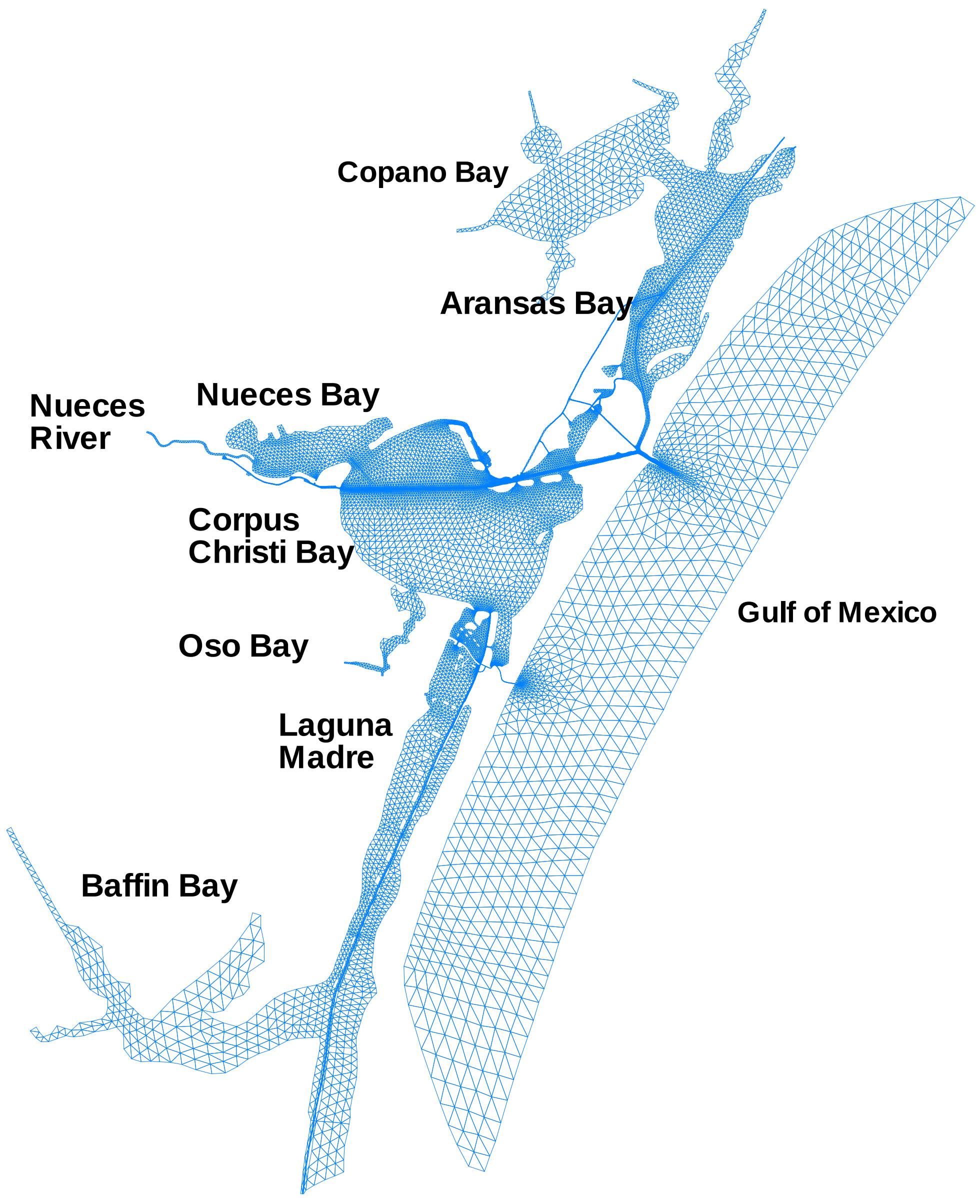


Figure 3. Computational grid for the Nueces Estuary. The model grid includes Copano and Aransas Bays to the north and the Upper Laguna Madre and Baffin Bay to the south in order to better represent boundary conditions for the Nueces Estuary.

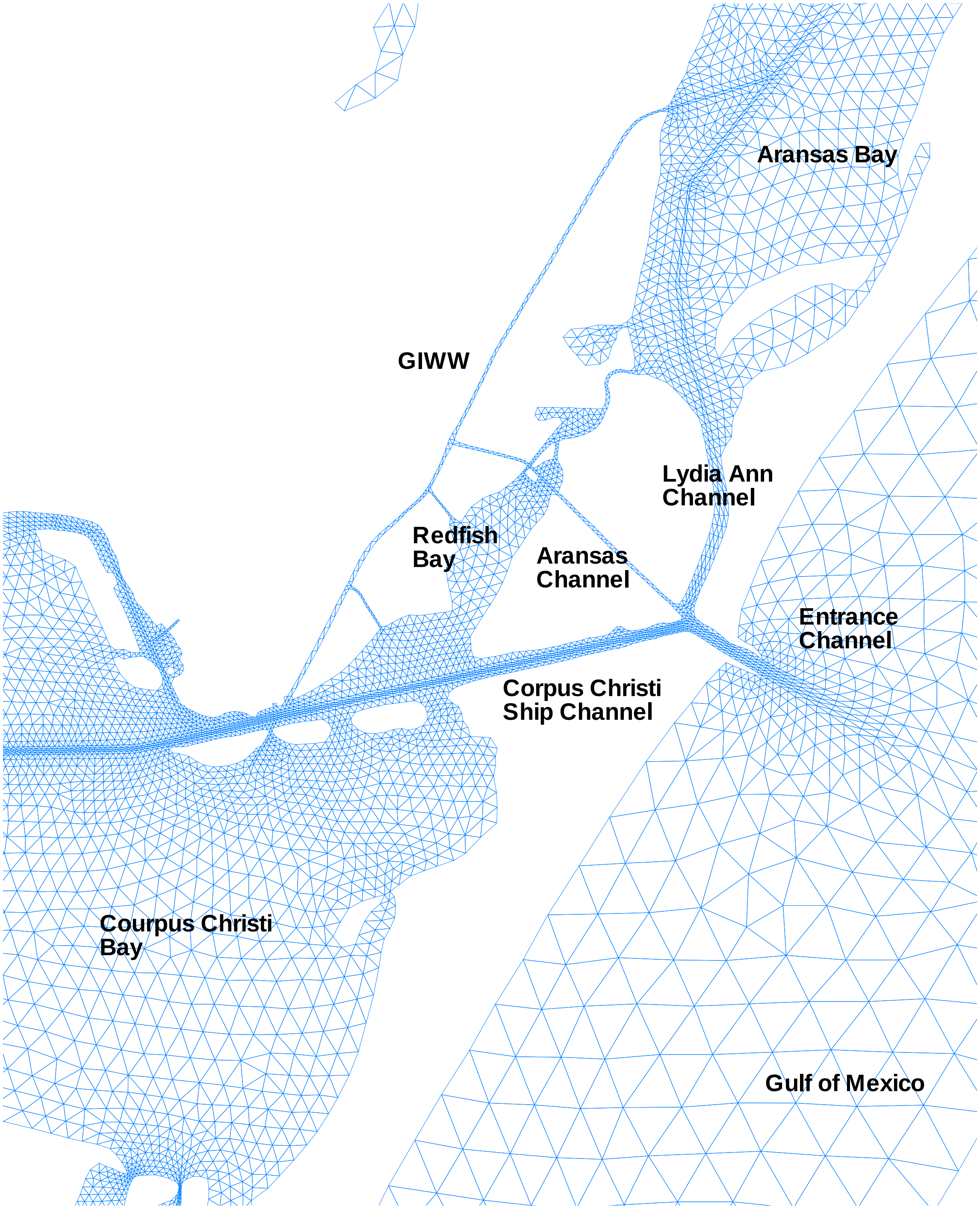


Figure 4. Close-up of the computational grid for the area near the entrance of the Corpus Christi Ship Channel to the Gulf of Mexico, which also serves as the major tidal inflow point to the Nueces Estuary.

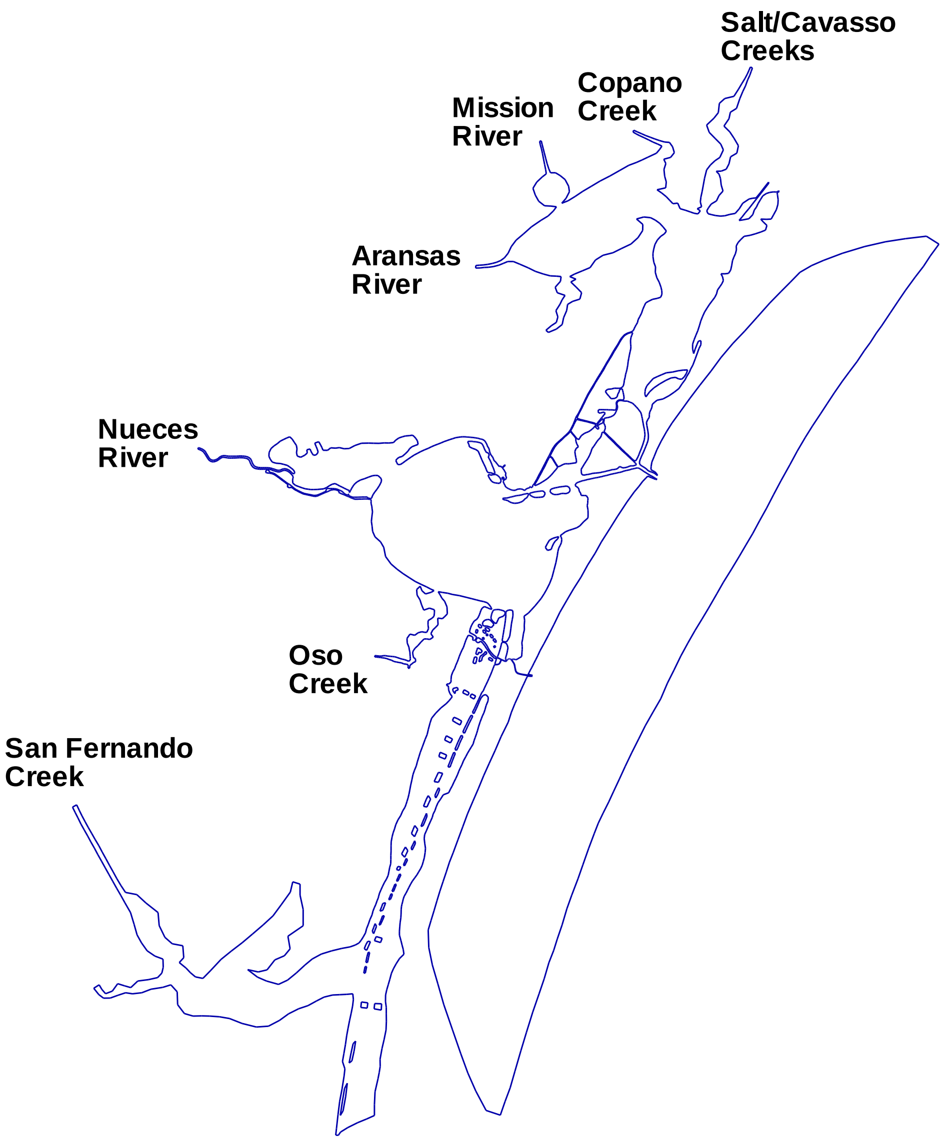


Figure 5. Seven inflow points for the Nueces Estuary TxBLEND model.

Inflows

Daily inflow values for Nueces Bay were modified from those prepared for TWDB coastal hydrology dataset version #TWDB201004 for the Nueces Estuary, which is based on gaged inflows from the U.S. Geological Survey (USGS) stream gage on the Nueces River at Mathis (Station no. 08211000, Schoenbaechler *et al*., 2011a), to better reflect inflows entering Nueces Bay via the Nueces River inflow point (see Figure 5 for inflow location). However, the modified hydrology was used only after 1989, when the Nueces River at Calallen gage (Station no. 08211500) became operational. Before then, daily inflows prepared for hydrology version #TWDB201004 (for only the portion of flows that drain to Nueces Bay) were applied to the

Nueces River Inflow Point. Specifically, those flows were based on gaged inflows from the USGS gage at Mathis, and 100% ungaged inflows from watersheds #20005, #21010, #22012, and #22013. Diversions and return flows also were accounted for in those ungaged watersheds.

Daily inflow values of the modified hydrology therefore were determined using the USGS stream gage at Calallen, due to its close proximity to the bay. Also, to account for return flows from ungaged watershed #21010, discharge from the Allison Wastewater Treatment Plant (WWTP), obtained from the Texas Commission on Environmental Quality (TCEQ), was added to flows from the USGS gage record at Calallen. Average daily discharge from the plant was calculated from 2003 – 2009 to be 10.5 acre-feet per day and applied to the model as a daily return flow value. Figure 6 shows that flows from the Calallen gage plus returns from the Allison WWTP are comparable to flows from the Mathis gage plus one downstream ungaged watershed, #21010 (refer to Figure 7 for watershed diagram). However, Figure 6 also shows that not all inflows to Nueces Bay, as calculated by hydrology version #TWDB201004 (*black line*), are captured by using either of the two aforementioned hydrology datasets. It is believed that if all flows were applied to the Nueces River inflow point, inflows would be over-represented and thus misrepresent salinity conditions within Nueces Bay. The primary difference in inflows occurs because of the addition of flows from ungaged watersheds #20005 and #22012, which do not have representative inflow points in the TxBLEND model.

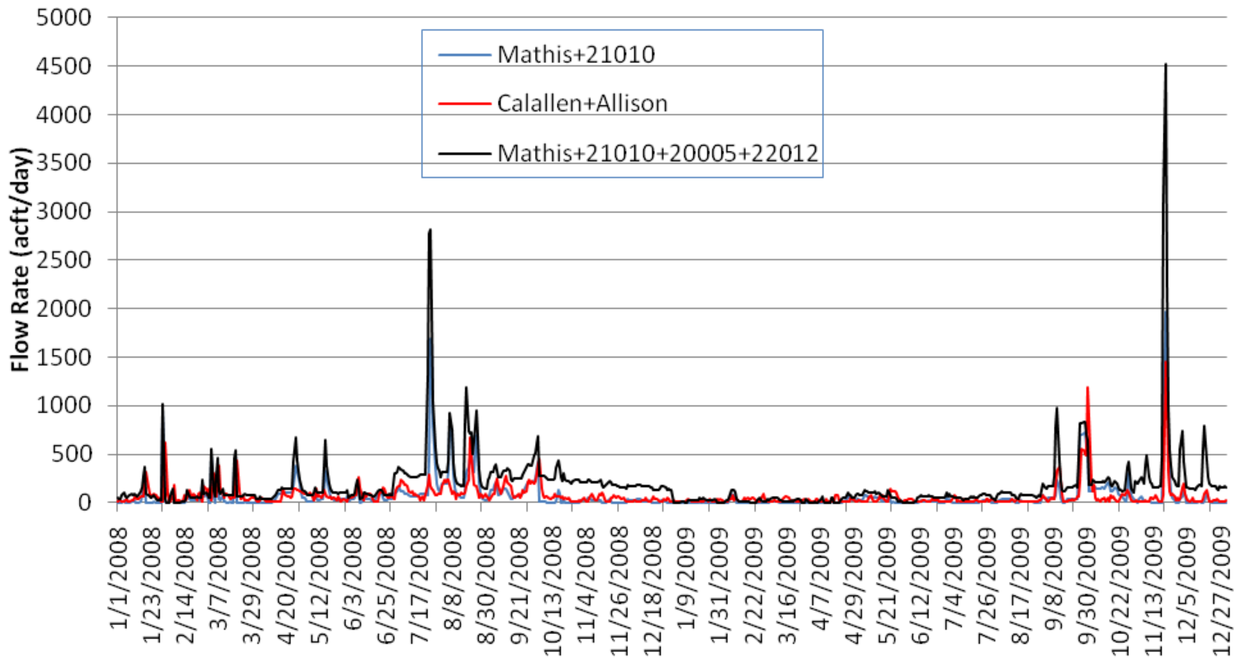


Figure 6. Comparison of inflows to the Nueces Delta as defined by: (1) Combined inflows to Nueces Bay as estimated by TWDB hydrology version #TWDB201004 for the Nueces Estuary (*black line*), (2) Inflows applied in the TxBLEND model (Calallen gage + Allison WWTP returns, *red line*), and (3) Inflows from Mathis gage + ungaged watershed #21010 (*blue line*) for the period from January 2008 through December 2009.

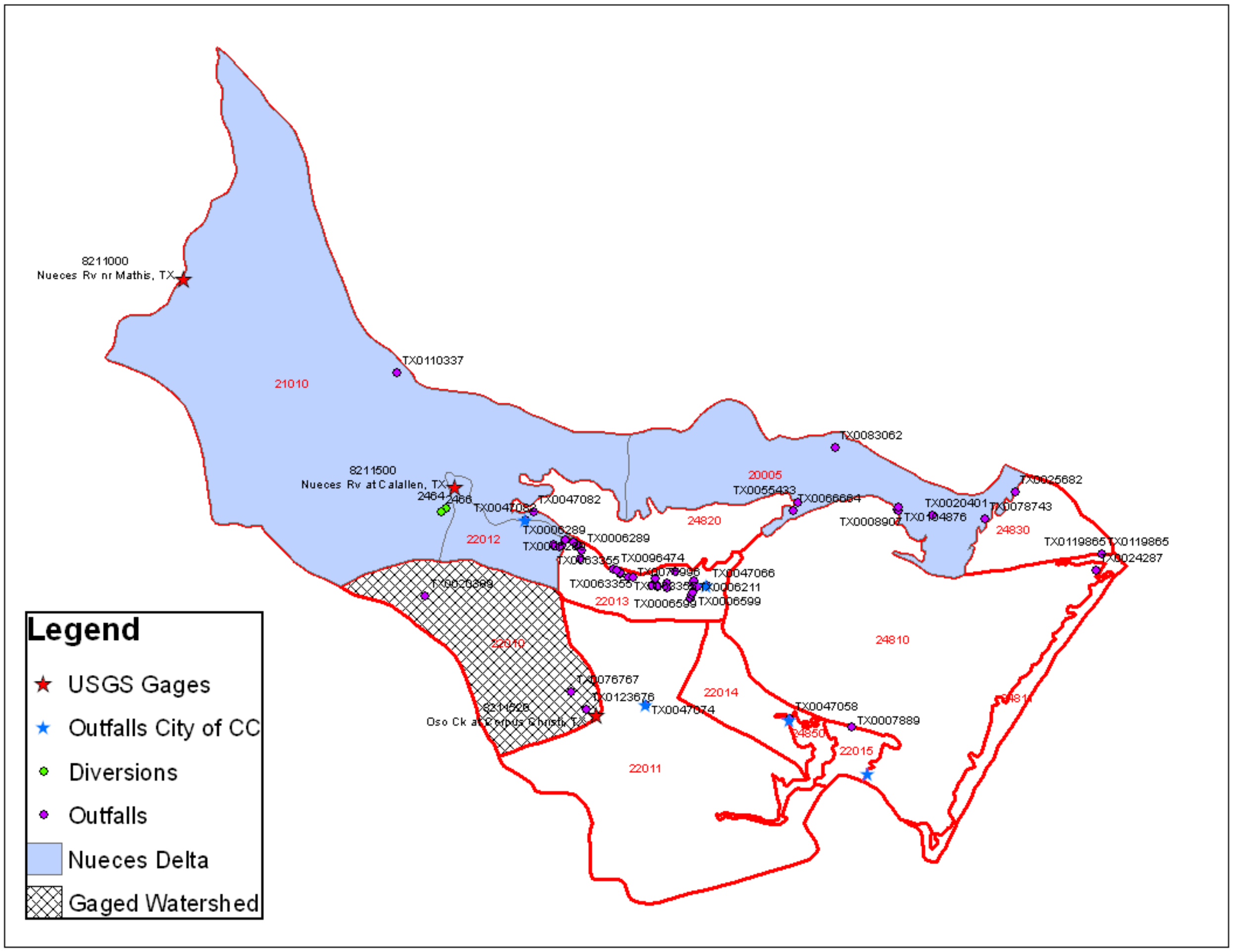


Figure 7. Location of USGS stream gages (*red stars*), permitted diversion points (*green circles*), wastewater outfalls (*purple diamonds*) and City of Corpus Christi outfalls (*blue stars*) in the Nueces Estuary watershed. Watersheds that drain to the Nueces Delta are highlighted in blue. Watershed #22010 became a gaged watershed in 1972; however, TWDB did not use the data for hydrology estimates before 1977 (*cross-hatch*).

In addition to the flows applied to the Nueces River Inflow Point, values applied to the Oso Creek Inflow Point (using USGS streamgage #08211520 on Oso Creek and three ungaged watersheds, listed in Table 3) were taken from the TWDB coastal hydrology dataset version #TWDB201004 for the Nueces Estuary. Therefore, total inflows applied to the TxBLEND model for the entire Nueces Estuary include flows from the Calallen gage, return flows from the Allison WWTP in ungaged watershed #21010, and inflows to Oso and Corpus Christi Bays. *Note*: Ungaged flows from watershed #22013 drain into the Corpus Christi Ship Channel, which is not represented by an inflow point in the TxBLEND model; therefore, these flows were not accounted for in the modified hydrology after 1990. Daily inflow values from TWDB hydrology dataset version #TWDB201004 for the Mission-Aransas Estuary (Schoenbaechler *et al.*, 2010) and from version #TWDB201101-U for the Upper Laguna Madre Estuary (Schoenbaechler *et al.*, 2011b.) also were applied to the model at the various inflow points. 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.

Inflow datasets are compiled using measurements from USGS stream gages along with rainfall-runoff estimates from the Texas Rainfall-Runoff (TxRR) model, adjusted for known diversion and return flows obtained from TCEQ, the South Texas Water Master (STWM), and the TWDB Irrigation Water Use estimates, to develop daily inflows for the estuaries. Table 2 lists USGS stream gages used to develop the gaged inflow component of estimated total freshwater inflows, and Table 3 lists the distribution of inflows from surrounding gaged and ungaged watersheds. Approved USGS stream gage data were available through November 2009 but were provisional for December 2009. Figures 8 - 10 show watershed boundaries, including the ungaged watersheds modeled using TxRR to obtain estimates of runoff. 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 for the Nueces Estuary were obtained from the STWM from 1989 - 2009 for all estuaries. Similarly, industrial and municipal return flow data were obtained from TCEQ (or its predecessor agency) from 1977 - 2009. Additional diversion data were obtained from TCEQ for the period from 2005 - 2009 and additional return flow data were obtained from TWDB's agricultural return flow estimates through December 2007.

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.

Estuary	Gage Station Number	Gage Location	Utilized Period of Record
Mission-Aransas	08189800	Chiltipin Creek at Sinton	1987 – 1991
	08189700	Aransas River near Skidmore	1987 - 2009*
	08189500	Mission River at Refugio	1987 - 2009*
	08189200	Copano Creek near Refugio	1987 - 2009*
Nueces	08211000	Nueces River at Mathis	1987 – 1989
	08211500	Nueces River at Calallen	1990 - 2009*
	08211520	Oso Creek at Corpus Christi	1987 - 2009*
Upper Laguna Madre	08211900	San Fernando Creek at Alice	1987 - 2009*
	08212400	Los Olmos Creek at Falfurrias	1987 - 2009*

*Stream gage data were provisional for the month of December 2009.

Table 3. Distribution of inflows from surrounding river basins and coastal watersheds to the seven inflow points of the Nueces Estuary TxBLEND model (Figure 5) from 1990 – 2009. Inflows from the Mission-Aransas Estuary and upper Laguna Madre and Baffin Bay also were included to improve model boundary conditions.

Receiving Bay	**Inflow Point**	**Source of Inflows**	
		USGS Gages	**Ungaged Watershed**
Copano and Aransas	Salt/Cavasso Creeks	n/a	20165, 20180, 20192, 20194, 20130, 20140
	Copano Creek	08189200	20120, 20130
	Mission River	08189500	20070, 20040, 20100, 20110
	Aransas River	08189700, 08189800	20050, 20030, 20020, 20012, 20014, 20040
Nueces*	Nueces River	08211500	none
Oso and Corpus Christi	Oso Creek	08211520	22011, 22014, 22015
Baffin	San Fernando Creek	08211900, 08212400	22026, 22020, 22021, 22024, 22025,22030, 22022, 22031, 22041, 22040, 22023, 22032

*These flows differ from TWDB hydrology version #TWDB201004 for Nueces Bay, which were computed by adding flows from the USGS gage at Mathis (#08211000), ungaged inflows from watersheds 20005, 21010, 22012, 22013, and return flows and by subtracting diversions.

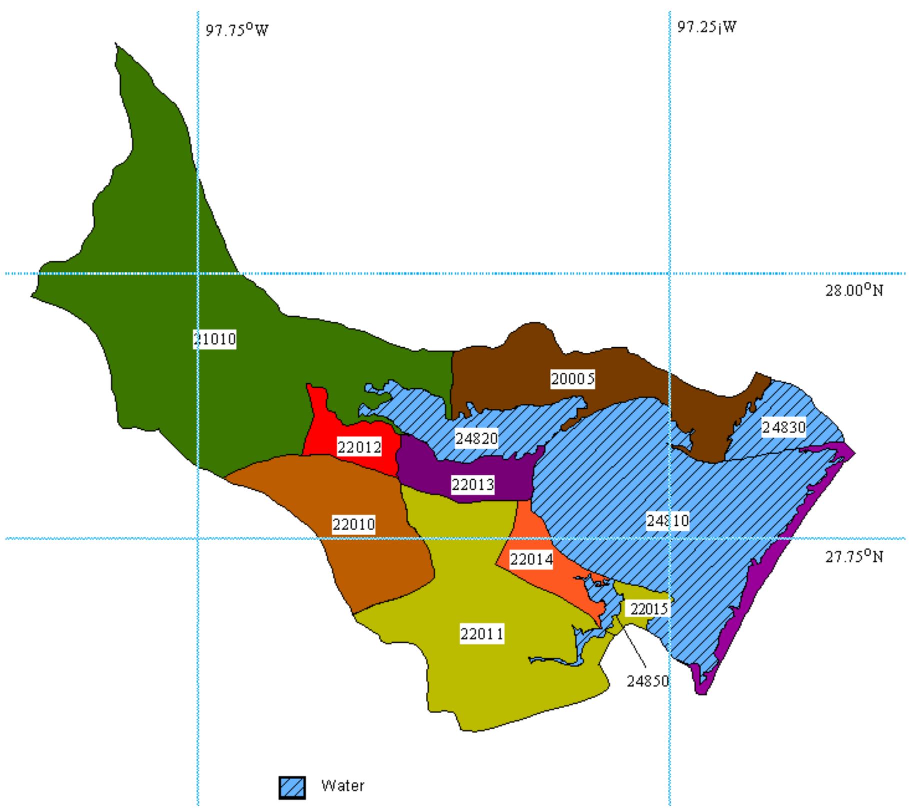


Figure 8. Ungaged watershed delineation used from 1977 to 2009 to determine ungaged inflows to the Nueces Estuary. N*ote:* Watershed #22010 became gaged in 1972, although it is not represented here as such and TWDB did not use this data in hydrology estimates before 1977.

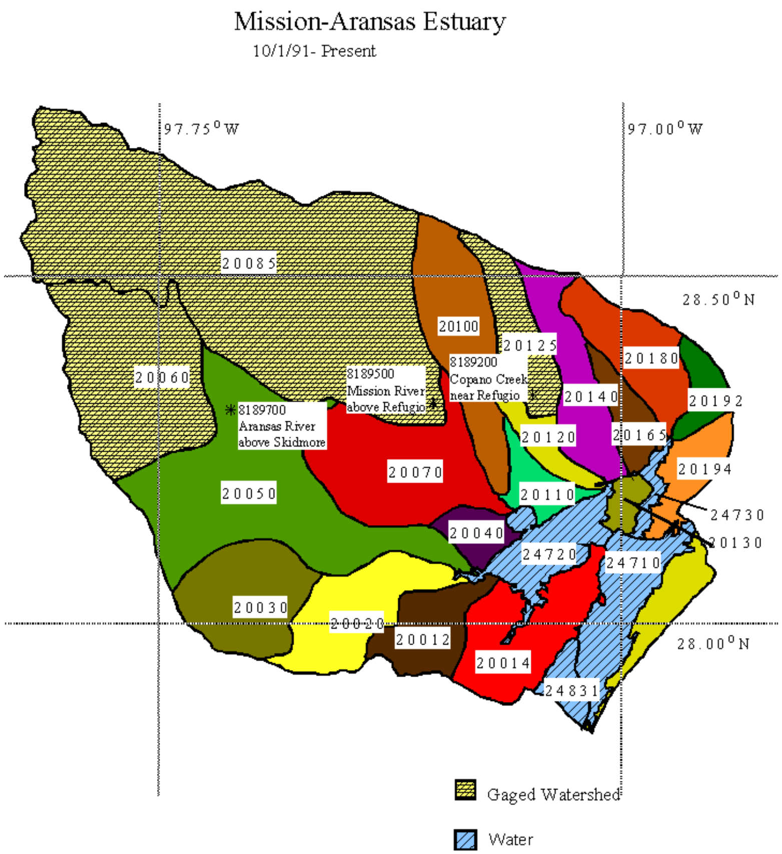


Figure 9. Ungaged watershed delineation used in TxRR to determine ungaged inflows to the Mission-Aransas Estuary (refer to Schoenbaechler *et al.*, 2010 for more details).

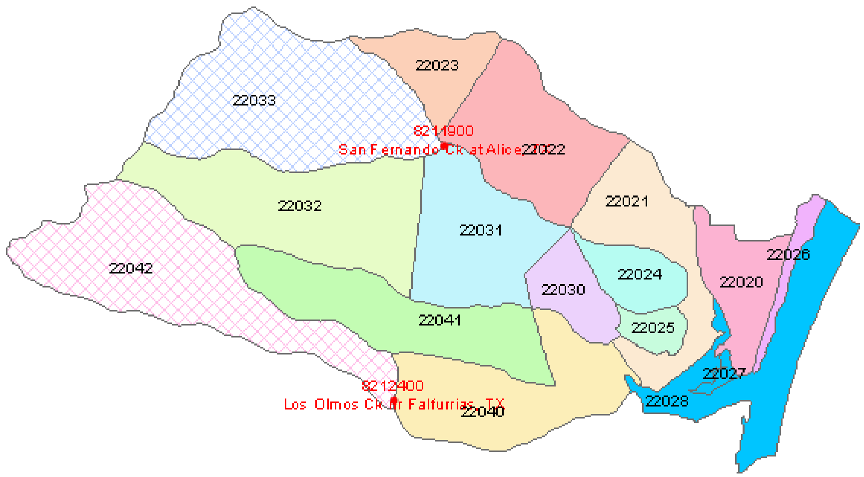


Figure 10. Ungaged watershed delineation used in TxRR to determine ungaged inflows to the upper Laguna Madre Estuary and Baffin Bay (refer to Schoenbaechler *et al.*, 2011b) for more details).

As described above, inflows applied to the TxBLEND Nueces River Inflow Point were modified from TWDB hydrology version #TWDB201004 resulting in only a portion of the known inflows being accounted for in TxBLEND simulations (refer to Figure 6). To better capture inflows entering Nueces Bay, particularly from watersheds #20005, #21010, and #22012, TWDB has run TxBLEND using an alternate hydrology in which inflows to Nueces Bay are based on the Calallen gage, plus inflows from a portion of watersheds #20005 and #21010 and all of watershed #22012, as well as the Allison WWTP returns and any other appropriate diversion and returns for these watersheds. The results are provided in the technical memo, *Comparison of Two Hydrology Datasets, as Applied to the TxBLEND Model, on Salinity Condition in Nueces Bay* (Guthrie *et al.* 2011).

Finally, it may be of interest to know how the hydrology applied in the TxBLEND model for the Nueces Estuary, as a whole, compares to TWDB estimates of total freshwater inflow to the estuary. Additionally, while the TxBLEND model relied on a modification of the most up-to-date estimates of inflow at the time of modeling (*i.e.*, version #TWDB201004), a more recent version of hydrology has since become available which improves data for diversions and returns within the basin (version #TWDB201101, Schoenbaechler *et al.*, 2011a). Figure 11 provides a visual comparison of the three estimates of hydrology. Differences between the datasets show that the inflows applied to the TxBLEND model, are at times, lower than those determined to be entering the Nueces Estuary. This is a function of the inability of the TxBLEND model to accurately represent inflows entering from ungaged watersheds, particularly during precipitation events and in wet years.

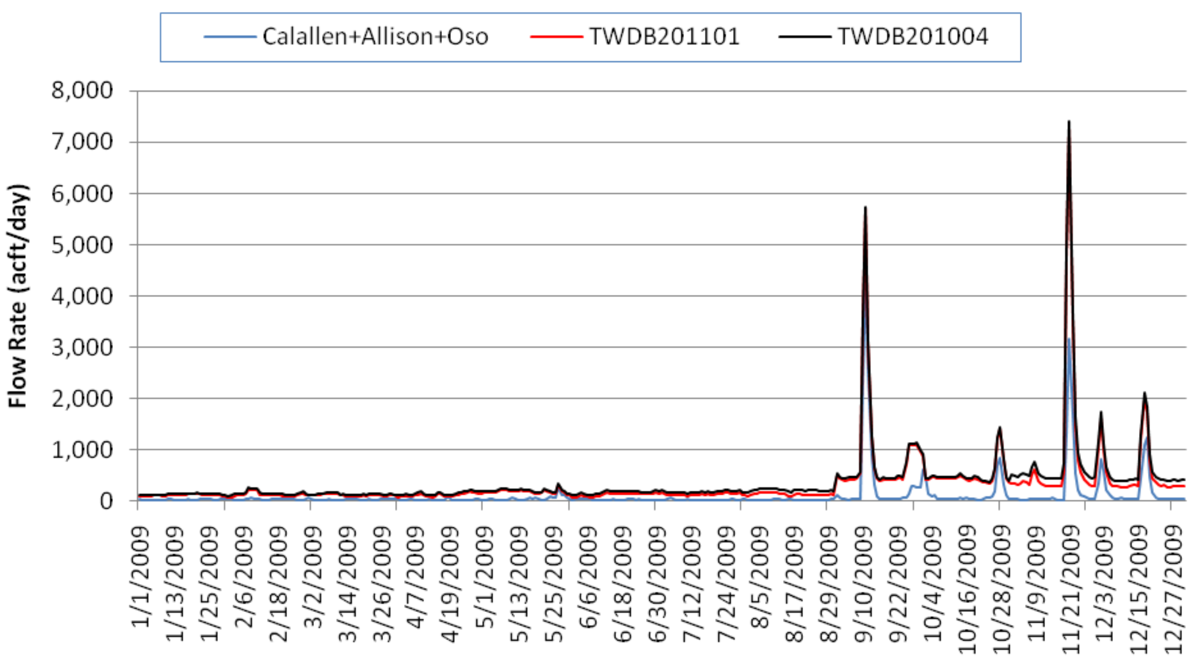


Figure 11. Comparison of flows (acre-feet/day) available for the Nueces Estuary, including those (1) Applied to the TxBLEND model for the Nueces Estuary (Calallen + Allison WWTP returns + gaged and ungaged watersheds that drain to Oso and Corpus Christi bays, *blue line*), (2) The complete TWDB coastal hydrology for the Nueces Estuary, version #TWDB201004 (*black line*), and (3) the most recent update of Nueces Estuary hydrology version #TWDB201101 (*red line*), for a one-year period.

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, air temperature, precipitation, and evaporation. A large portion of the meteorology data (wind speed and direction and air temperature) used to drive the model were obtained from the National Weather Service (NWS). Wind data were obtained for the Naval Air Station from the National Climate Data Center (NCDC) for the period from 1981 through 1994 and for Port Aransas from TCOON for the period from 1995 through 2009. Evaporation data for Corpus Christi were calculated based on the Harbeck equation (Brandes and Masch 1972) using temperature data from NCDC, providing data for the period from 1970 through 2009. Precipitation data used for model calibration and validation simulations originally were obtained from the NWS and subsequently were processed to provide an estimate of precipitation across the Nueces watershed. TWDB's archived records of this data provided daily precipitation measurements for the period from 1977 through 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 Texas Parks and Wildlife Department (TPWD) Coastal Fisheries database to specify salinity at the Gulf boundary off Corpus Christi Bay. 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. 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, three intensive inflow data sets were available. Velocity measurements were collected at 11 sites in the Nueces Estuary during an intensive inflow study from June 21 - 24, 1994 and at 11 sites during another study from June 12 - 15, 1995. At most locations, velocity was measured at three depths, 2/10th, 5/10th, and 8/10th from the bottom substrate. Discharge measurements were collected at five sites from June 21 - 24, 1994 and June 12 - 15, 1995, in addition to nine sites from May 5 - 7, 2000. Some of these locations are shown in Figure 12.

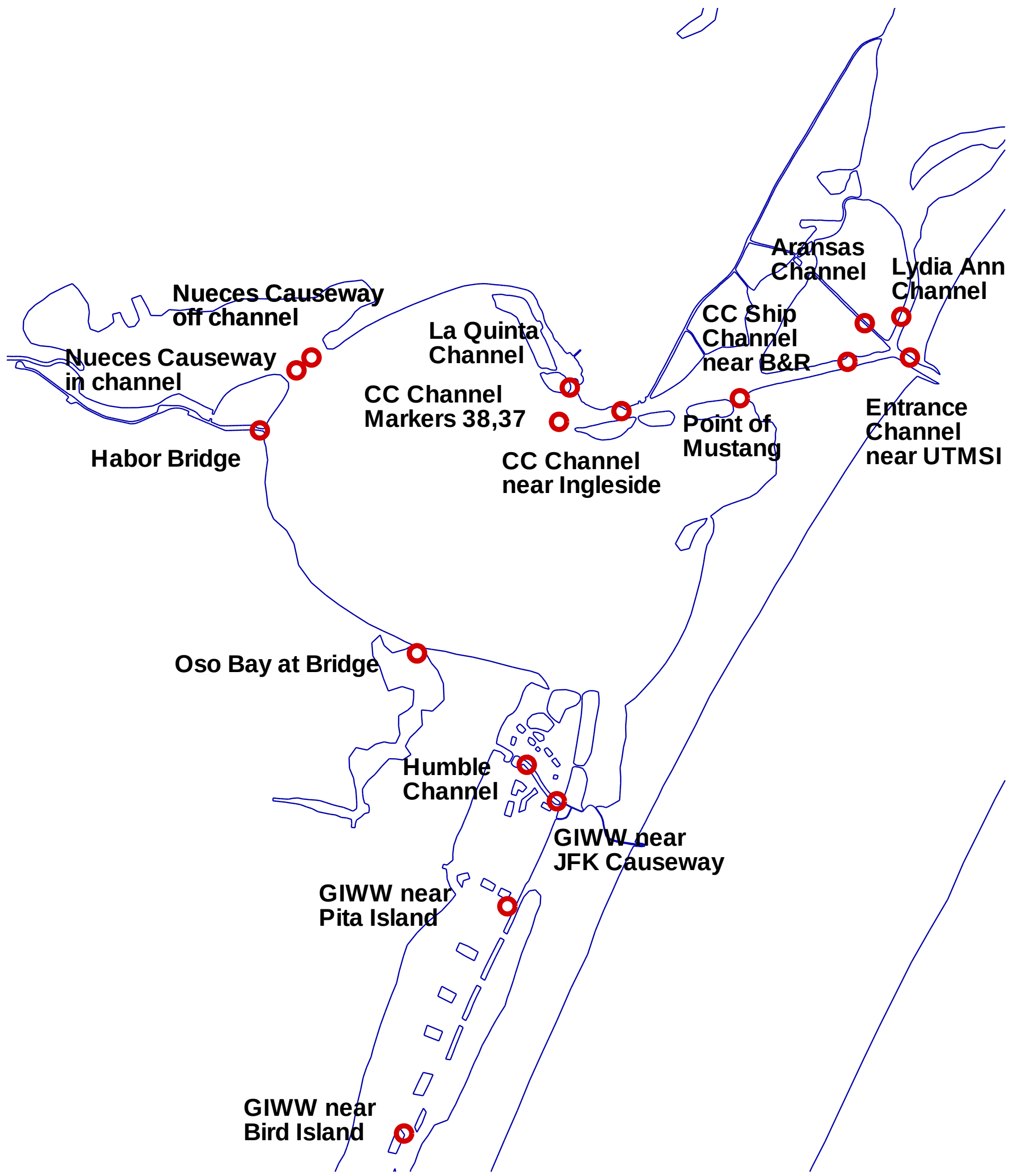


Figure 12. Velocity and discharge measurement sites for intensive inflow studies of the Nueces Estuary during the years 1994, 1995, and 2000. N*ote:* "CC Channel near Ingleside" also is referred to as "CC Channel near Sun Oil" in the following data plots.

Salinity

Long-term salinity records collected by TWDB, Division of Nearshore Research (DNR) and Texas Parks and Wildlife (TPWD) 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: Aransas Bay (1987 - 1989), Nueces Bay (1987 - 1989), Corpus Christi Bay (1987 - 1989 and 2000 - 2004), and JFK Causeway (1991 – 1996; Figure 13). TWDB's datasonde site at Nueces Bay is consistent with the location of the City of Corpus Christi and DNR's SALT01 site, which provided supplemental data for calibration of the model from 2000 – 2004 in mid-Nueces Bay. In addition, TPWD Coastal Fisheries point-measurement data, collected in the vicinity of the four Datasonde Program monitoring stations, was used to aid model calibration.

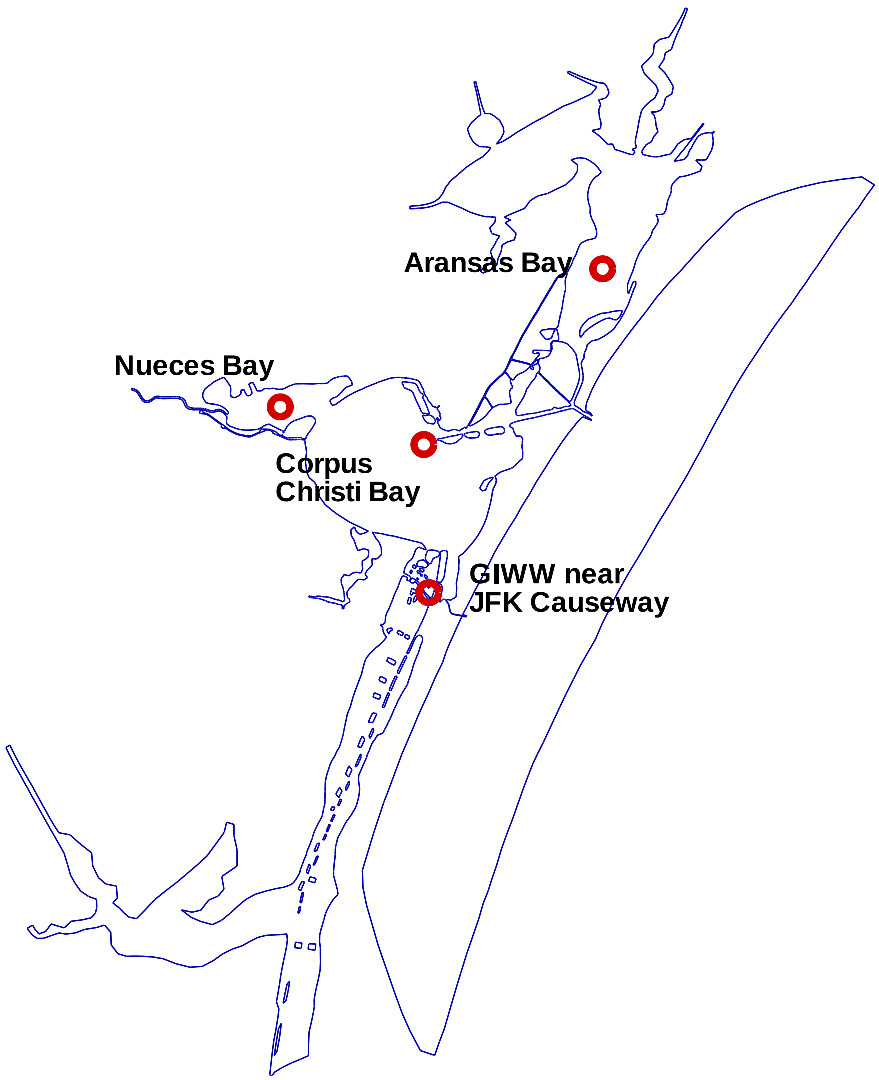


Figure 13. Four long-term monitoring stations which provided time-series salinity data for use in model calibration and validation. The Nueces Bay site is consistent with DNR's SALT01 site, which supplemented TWDB's datasonde data.

Tides

For calibration of water surface elevation of this TxBLEND model, measurements from eight TCOON gaging stations were used (Figure 14). For all of the tidal gaging stations, data from 1999 – 2004 was used for model calibration.

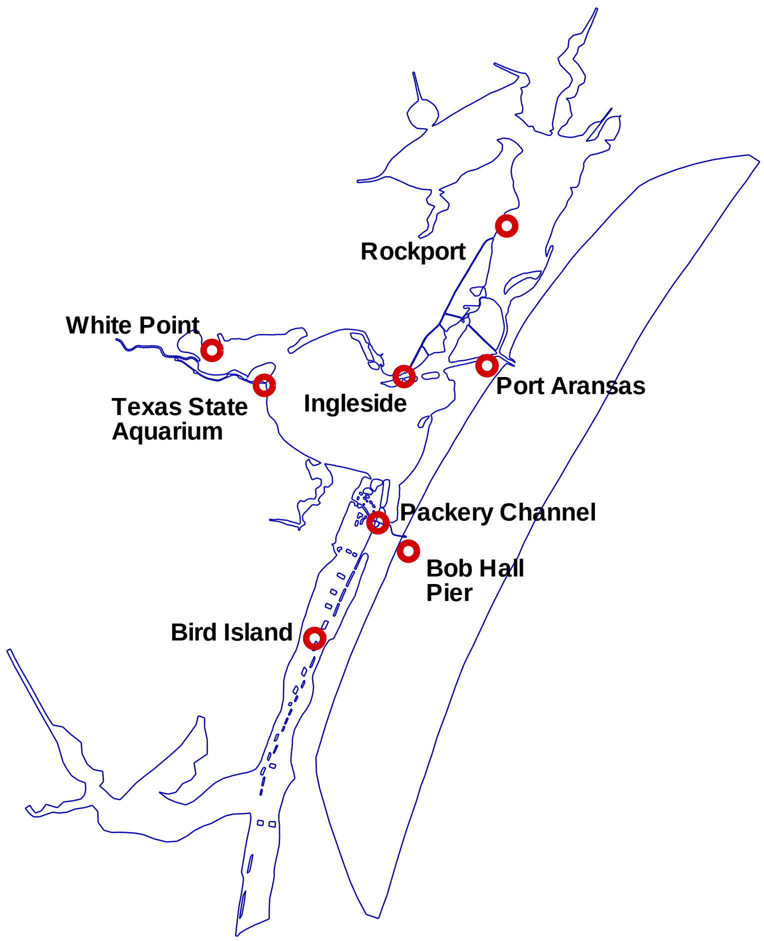


Figure 14. Eight tide gaging stations used to calibrate and validate the Nueces TxBLEND model. Gaging stations are maintained by the Texas Coastal Ocean Observation Network (TCOON).

Model Calibration Parameters

Model parameters adjusted during the 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 15. 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 16 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.

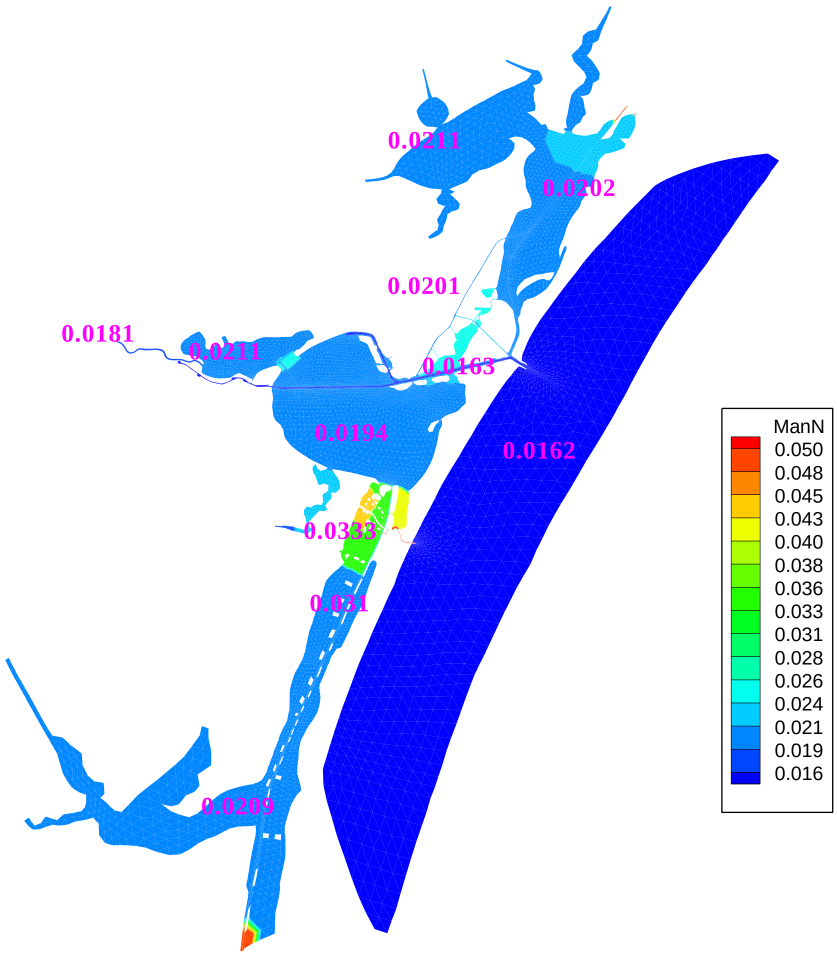


Figure 15. Values of Manning's *n* (bottom roughness coefficient) used in the calibrated Nueces Estuary TxBLEND model.

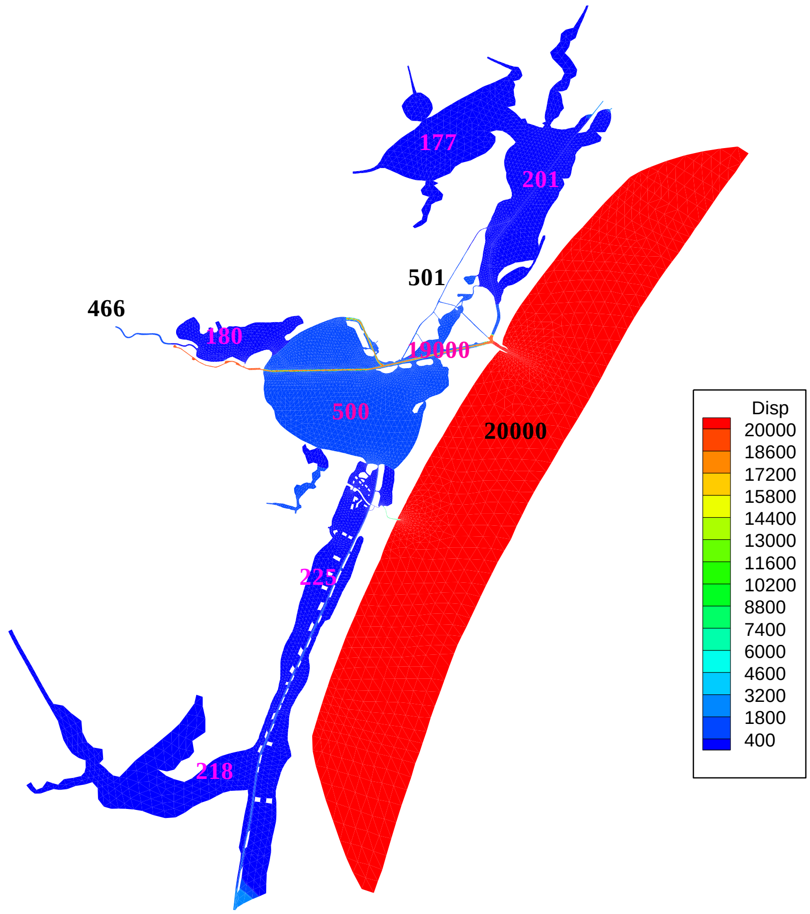


Figure 16. Dispersion factors (ft^2/sec) used in the calibrated TxBLEND model for the Nueces Estuary. The Gulf region was set to 20,000 ft^2/sec, the Corpus Christi Ship Channel to 19,000 ft^2/sec, and the Gulf Intracoastal Waterway (GIWW) to 501 ft^2/sec.

Calibration Results

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

Velocity and Discharge Results

TxBLEND was calibrated for water velocity and discharge using data obtained from three intensive inflow studies in the Nueces Estuary during June 1994, June 1995, and May 2000. 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. Figures 17 through 20 show calibration results for velocity at 11 locations during the intensive inflow study from June 21 - 24, 1994. 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.

Simulated velocities are representative of observed velocities at all sites. In particular, the model captured the swift tidal currents at the confluence of the Entrance Channel, Aransas Channel, Lydia Ann Channel and Corpus Christi Ship Channel near Brown and Roots (B&R) across all tidal cycles reasonably well. The reduced currents at the upstream sites such as Corpus Christi Channel near Ingleside and Nueces Causeway sites were captured well also. A noteworthy difference was observed between velocity measurements at the two sites in Nueces Causeway In-Channel and Off-Channel, as currents in the shallow water off the channel were much smaller than the currents in the deeper water in the channel. Even though the model represented important circulation patterns, deviations from measured velocities were noted at some locations. For example, the model over-predicted maximum velocity at the Corpus Christi Channel near B&R and Entrance Channel. This pattern could be due to the fact that the observed velocity represents an average velocity across the measured cross-section while the simulated velocity represents a point velocity within the channel. At the Aransas Channel site, the simulated velocity's phase appears to lag by up to two hours throughout the study period.

Figures 21 through 24 show calibration results for velocity at 11 locations during the intensive inflow study from June 12 - 15, 1995. For this calibration effort, simulated velocities are representative of observed velocities at most sites. The model performed better in simulating the high velocity at the Entrance and Lydia Ann Channels during this period and the phase lag observed at the Aransas Channel site during the 1994 calibration was not as persistent. However, there are instances where the model either underpredicts velocity, such as at the Oso Bay at Bridge site, or again overpredicts maximum velocity at the Corpus Christi Channel near B&R site. The model simulated the lateral velocity gradient across the mouth of Nueces Bay very well, as can be seen from the velocity comparison at Nueces Causeway Off-Channel and Nueces Causeway In-Channel sites, thereby representing the exchange between Nueces and Corpus Christi bays. Overall, the model represents observed velocities very well at most sites.

Figures 25 and 26 show calibration results for discharge at five sites from June 21 - 24, 1994 and Figures 27 and 28 show calibration results for discharge at five sites form June 12 - 15, 1995. Although maximum discharge is slightly over-predicted at the Corpus Christi Ship Channel near UTMSI and the Corpus Christi Ship Channel near B&R, discharge magnitude and flow reversal are simulated well and the comparisons indicate good model performance.

Figures 29 through 31 show calibration results for discharge at nine sites from May 5 - 7, 2000. The model simulates discharge magnitude and flow reversal very well at the Corpus Christi Ship Channel near UTMSI, Corpus Christi Ship Channel near B&R, Corpus Christi Ship Channel near Sun Oil, Corpus Christi Ship Channel near Markers 37 and 38, and at the La Quinta Channel near Ingelside. However, the model tends to slightly overpredict maximum discharges at the first four sites. Alternatively, the model slightly underpredicts flow at the Corpus Christi Ship Channel near Harbor Bridge site. At some locations, such as at the Lydia Ann Channel, Aransas Channel, and GIWW near Ingleside, there are only few measurements available for comparison between simulated and observed discharges. Overall, the model simulates discharge trends well at most sites.

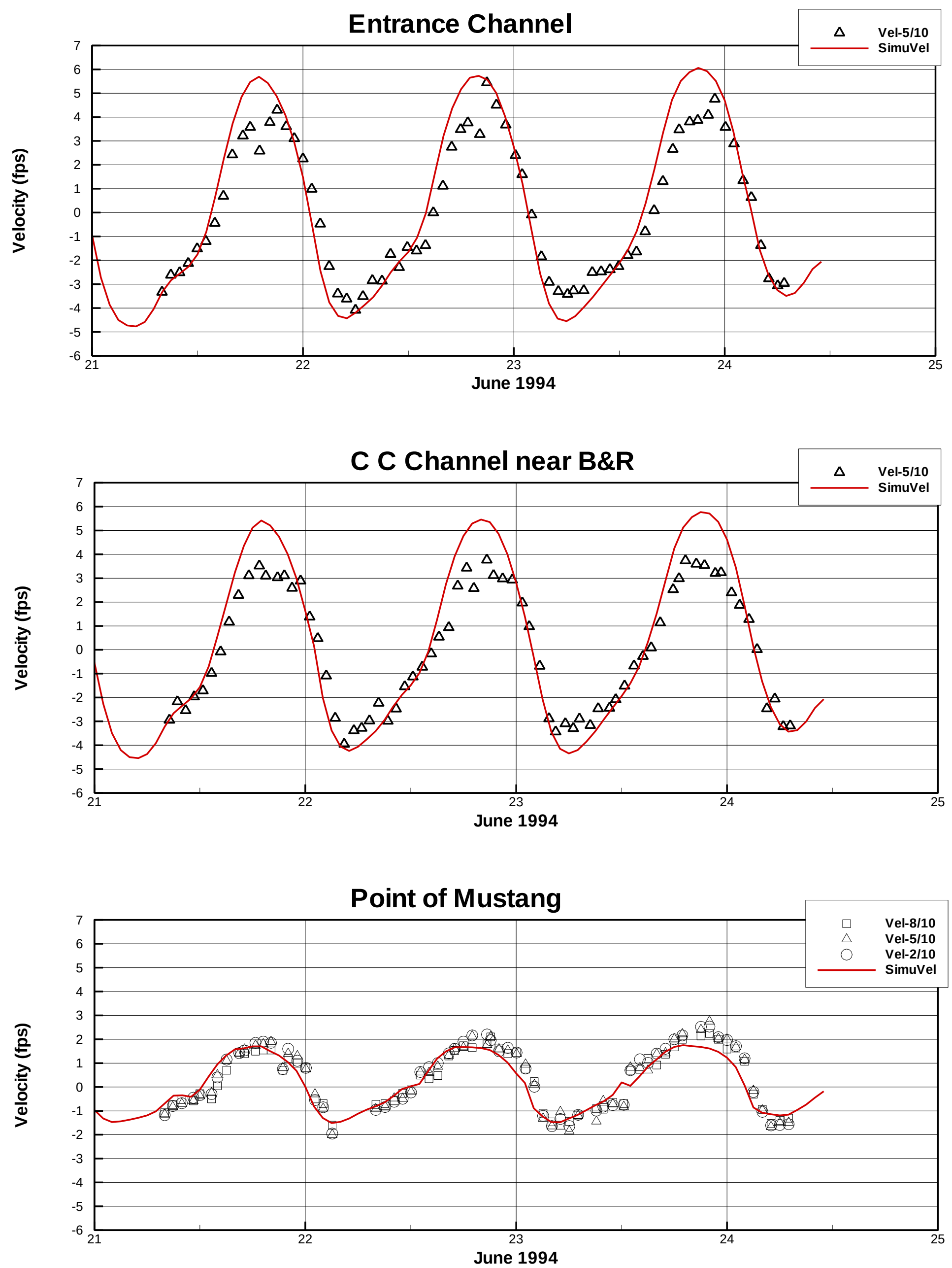


Figure 17. Simulated (*red line*) and observed (*open symbols*) velocities for the following sites from top to bottom: Entrance Channel, Corpus Christi Channel near B&R, and Point of Mustang for June 21 - 24, 1994 in the Nueces Estuary. Positive velocity values represent the ebb cycle or downstream flow and negative velocity values represent flood cycle or upstream flow.

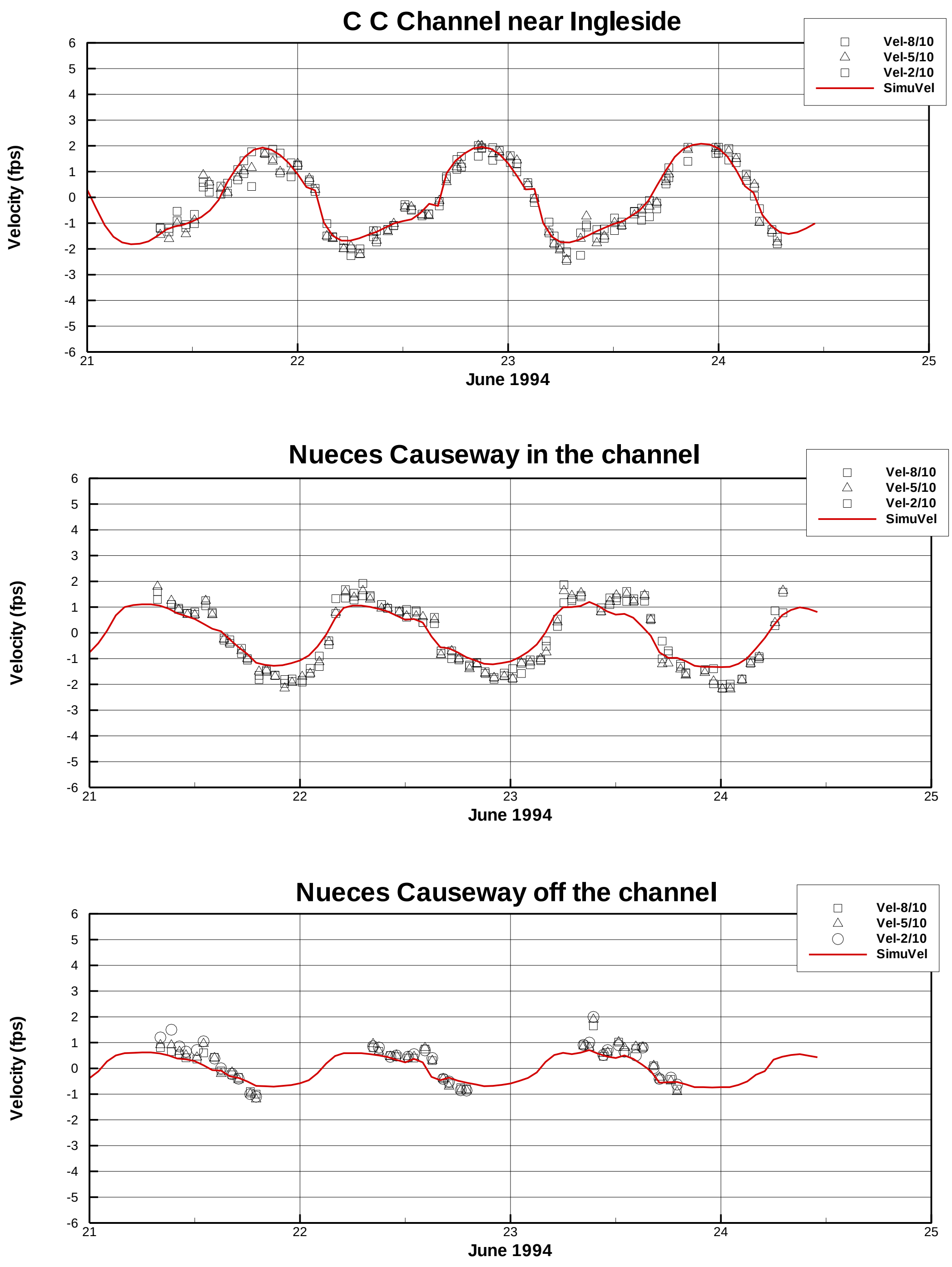


Figure 18. Simulated (*red line*) and observed (*open symbols*) velocities for the following sites from top to bottom: Corpus Christi Channel near Ingleside, Nueces Causeway in the Channel, and Nueces Causeway off the Channel for June 21 - 24, 1994 in the Nueces Estuary. Positive velocity values represent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

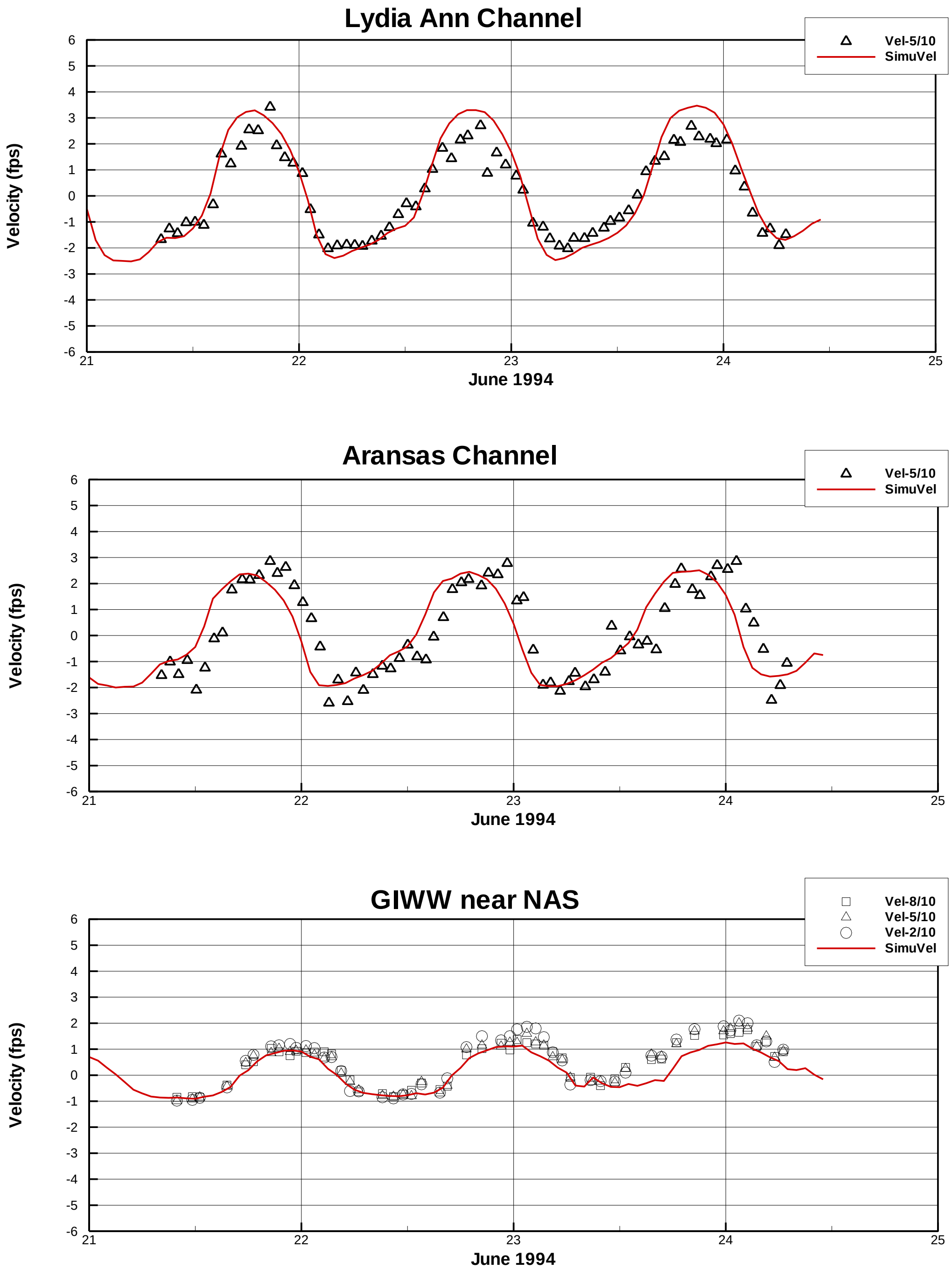
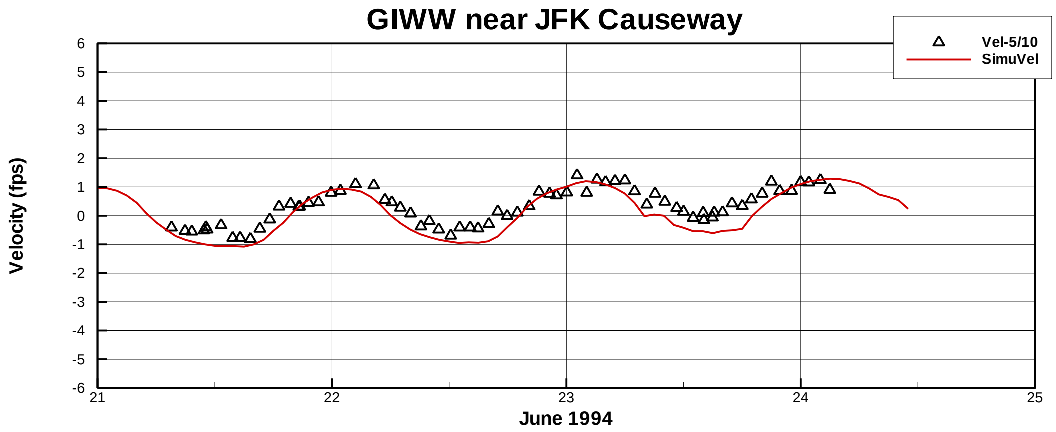


Figure 19. Simulated (*red line*) and observed (*open symbols*) velocities for the following sites from top to bottom: Lydia Ann Channel, Aransas Channel, and GIWW near NAS for June 21 - 24, 1994 in the Nueces Estuary. Positive velocity values represent the ebb cycle or downstream flow and negative velocity values represent flood cycle or upstream flow.



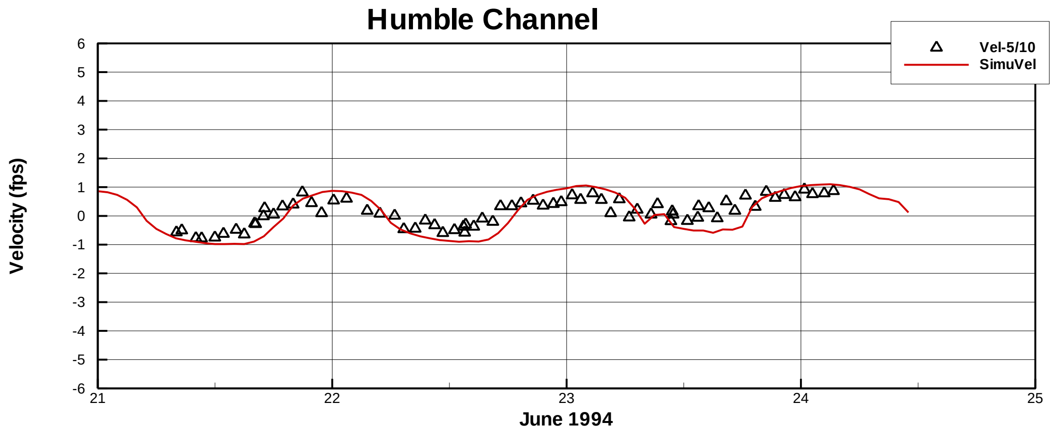


Figure 20. Simulated (*red line*) and observed (*open symbols*) velocities for the following sites from top to bottom: GIWW near the JFK Causeway and Humble Channel for June 21 - 24, 1994 in the Nueces Estuary. Positive velocity values represent the ebb cycle or downstream flow and negative velocity values represent flood cycle or upstream flow.

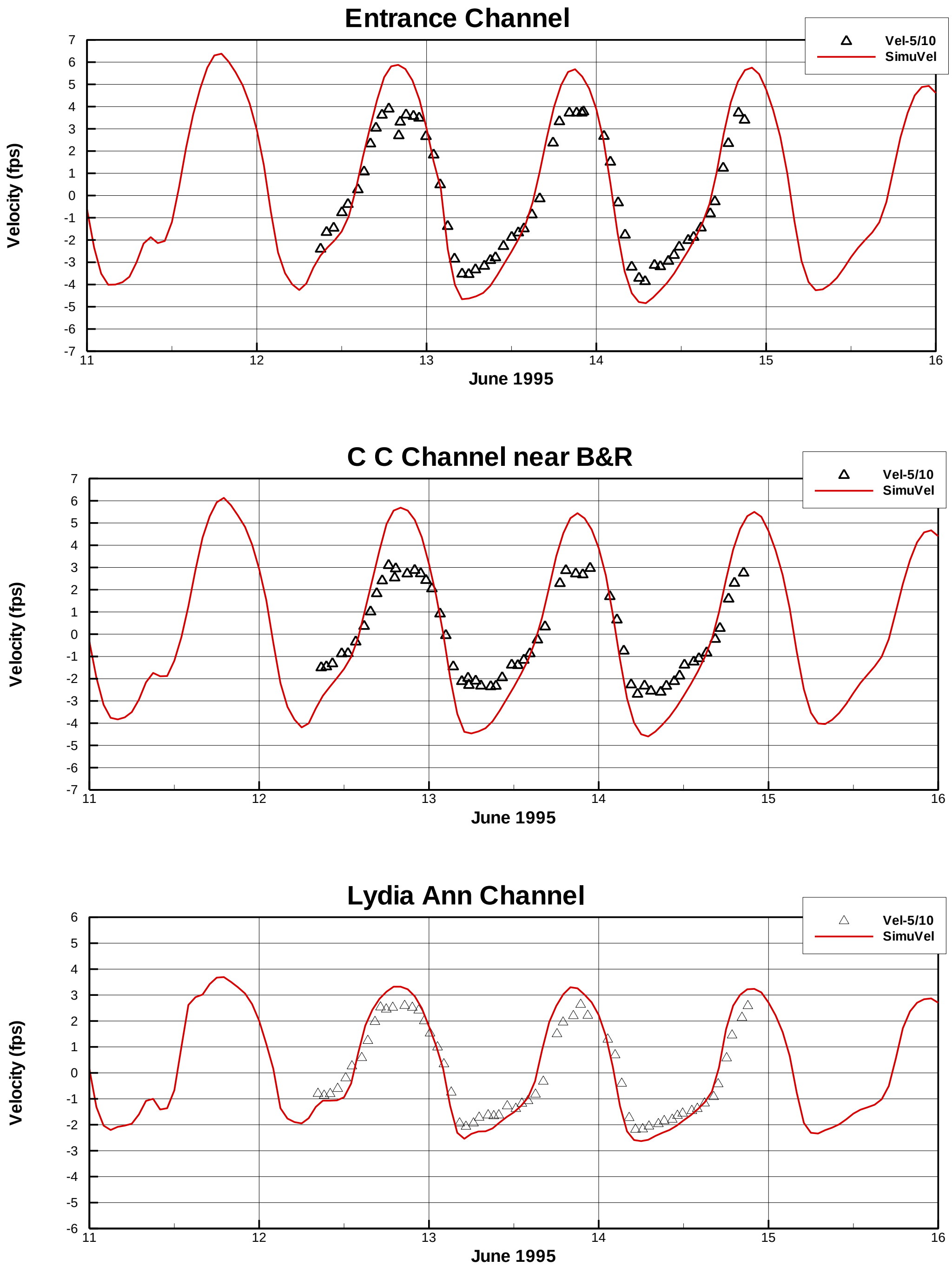


Figure 21. Simulated (*red line*) and observed (*open symbols*) velocities for the following sites from top to bottom: Entrance Channel, Corpus Christi Channel near B&R, and Lydia Ann Channel from June 12 - 15, 1995 in the Nueces Estuary. Positive velocity values represent the ebb cycle or downstream flow and negative velocity values represent flood cycle or upstream flow.

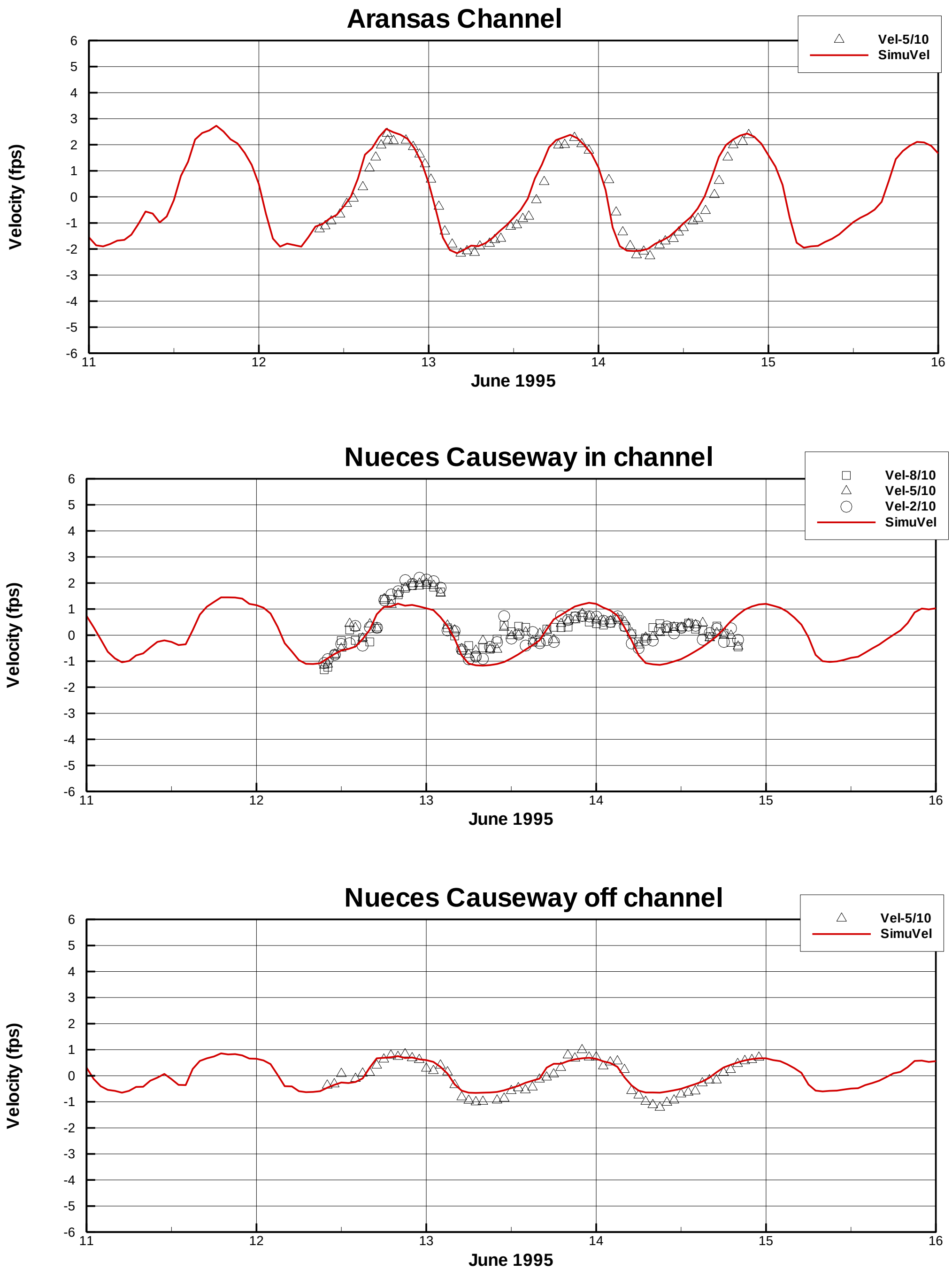
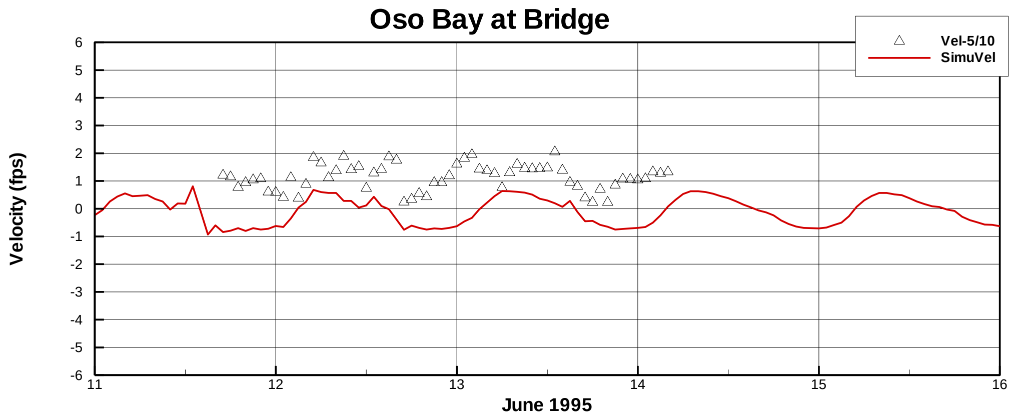
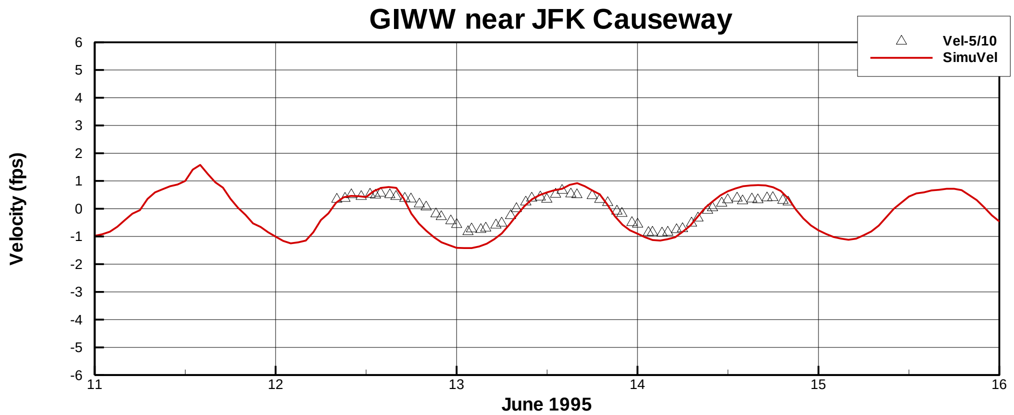


Figure 22. Simulated (*red line*) and observed (*open symbols*) velocities for the following sites from top to bottom: Aransas Channel, Nueces Causeway in channel, and Nueces Causeway off channel from June 12 - 15, 1995 in the Nueces Estuary. Positive velocity values represent the ebb cycle or downstream flow and negative velocity values represent flood cycle or upstream flow.





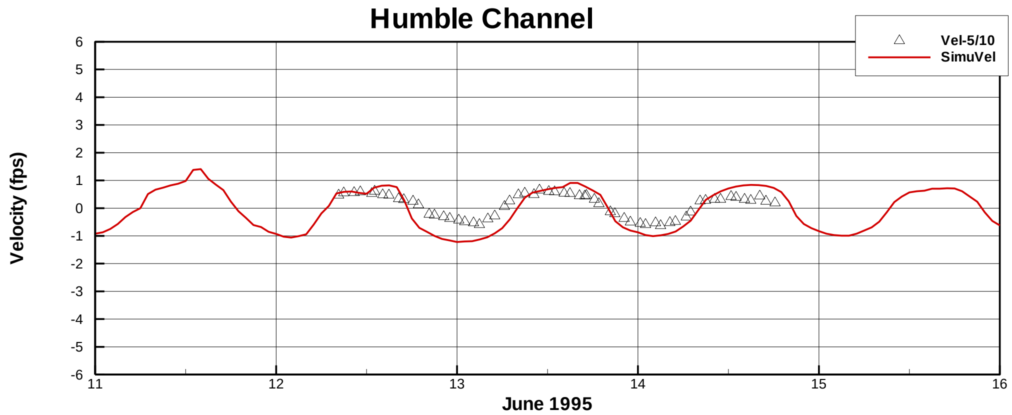


Figure 23. Simulated (*red line*) and observed (*open symbols*) velocities for the following sites from top to bottom: Oso Bay at Bridge, GIWW near JFK Causeway, and Humble Channel from June 12 - 15, 1995 in the Nueces Estuary. Positive velocity values represent the ebb cycle or downstream flow and negative velocity values represent flood cycle or upstream flow.

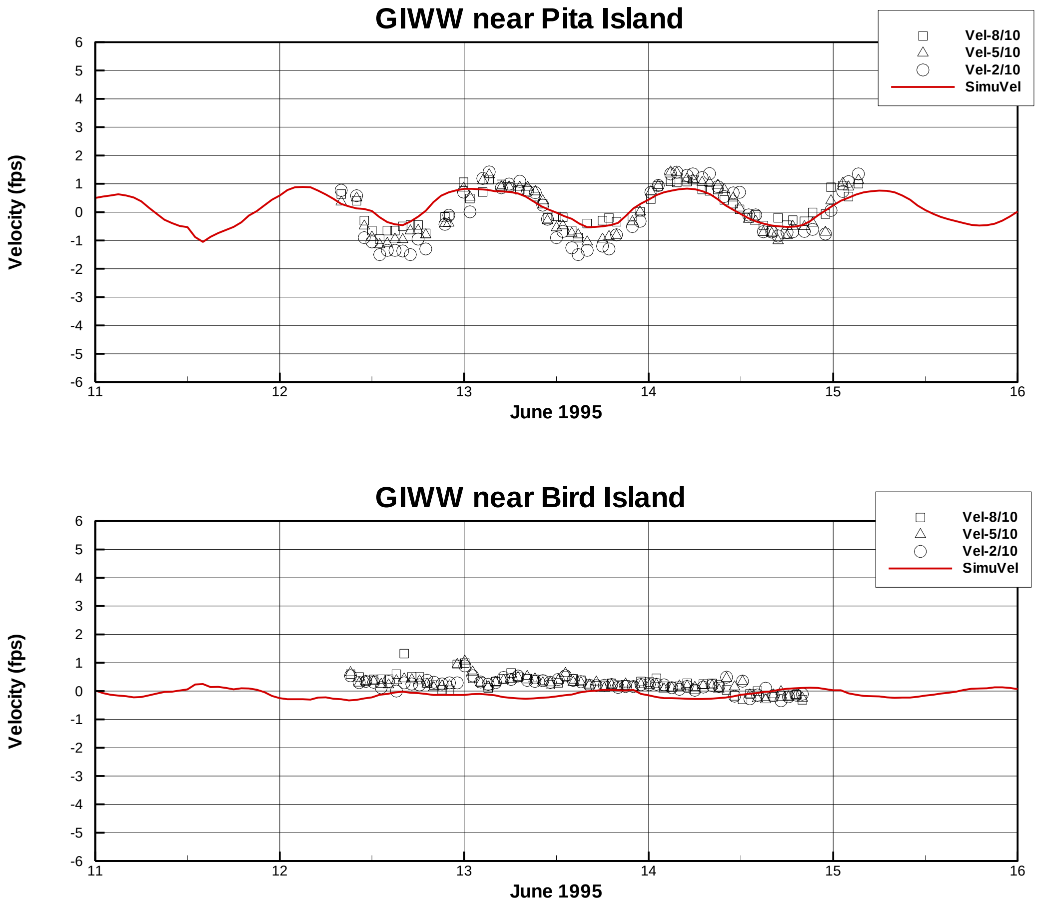


Figure 24. Simulated (*red line*) and observed (*open symbols*) velocities for the GIWW near Pita Island and the GIWW near Bird Island from June 12 - 15, 1995 in the Nueces Estuary. Positive velocity values represent the ebb cycle or downstream flow and negative velocity values represent flood cycle or upstream flow.

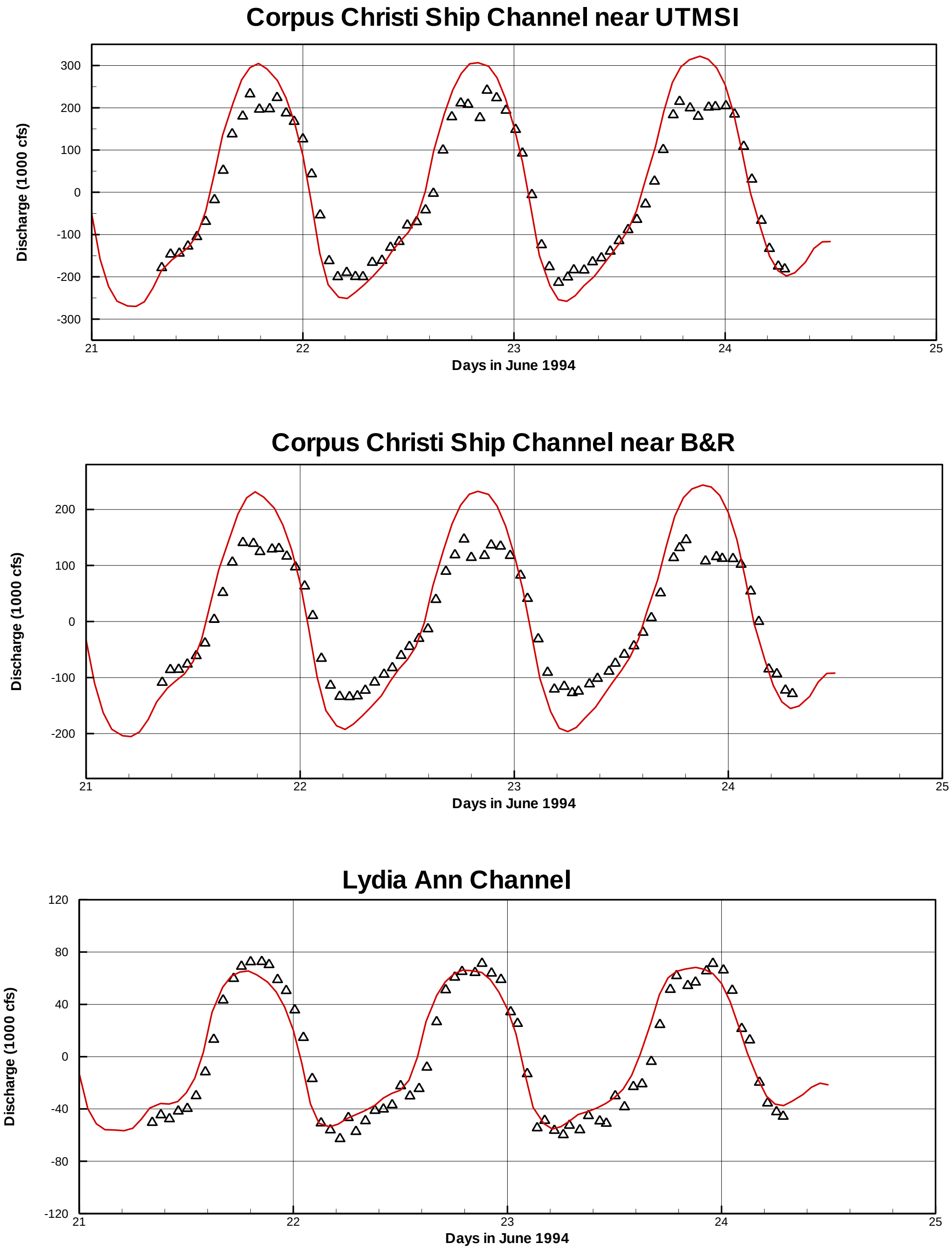


Figure 25. Simulated (*red line*) and observed (*open symbols*) discharges for the following sites from top to bottom: Corpus Christi Ship Channel near UTMSI, Corpus Christi Ship Channel near B&R, and the Corpus Christi Ship Channel near Sun Oil from June 21 - 21, 1994 in the Nueces Estuary. Positive discharge values represent the ebb cycle or downstream flow and negative discharge values represent flood cycle or upstream flow.

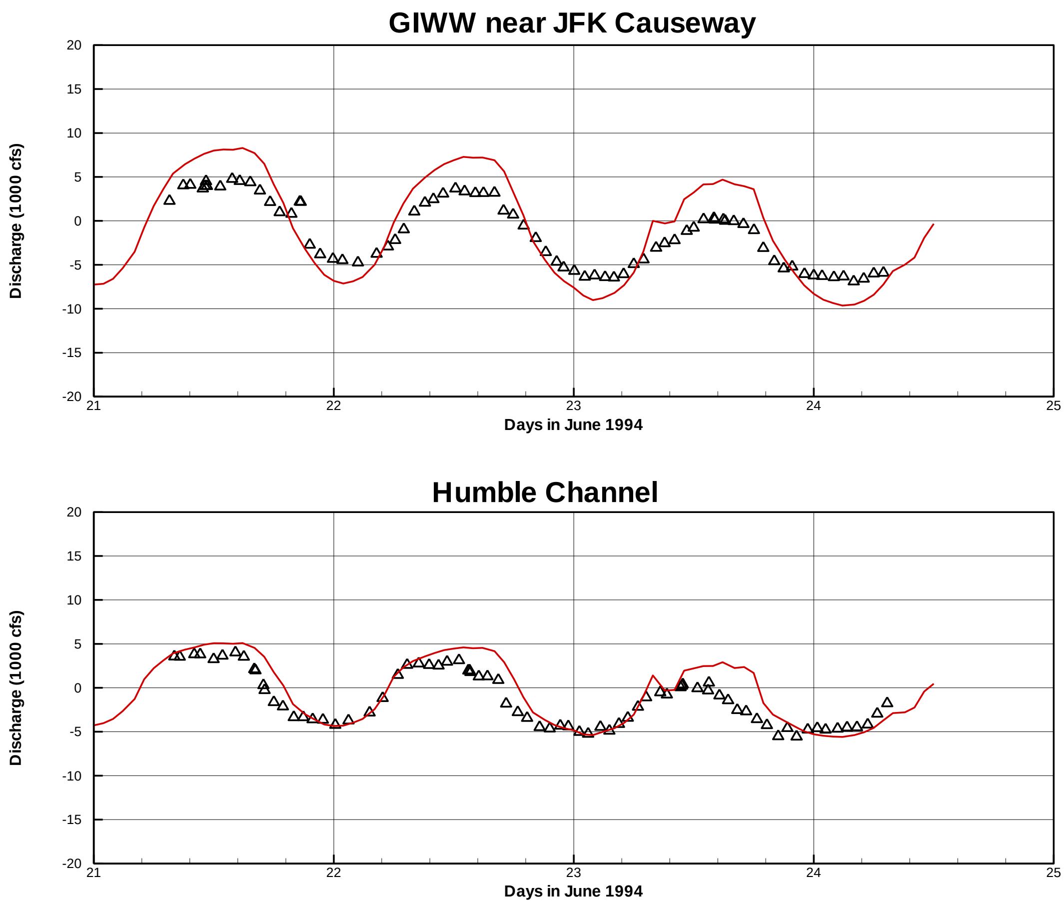


Figure 26. Simulated (*red line*) and observed (*open symbols*) discharges for the GIWW near JFK Causeway and Humble Channel from June 21 - 24, 1994 in the Nueces Estuary. Positive discharge values represent the ebb cycle or downstream flow and negative discharge values represent flood cycle or upstream flow.

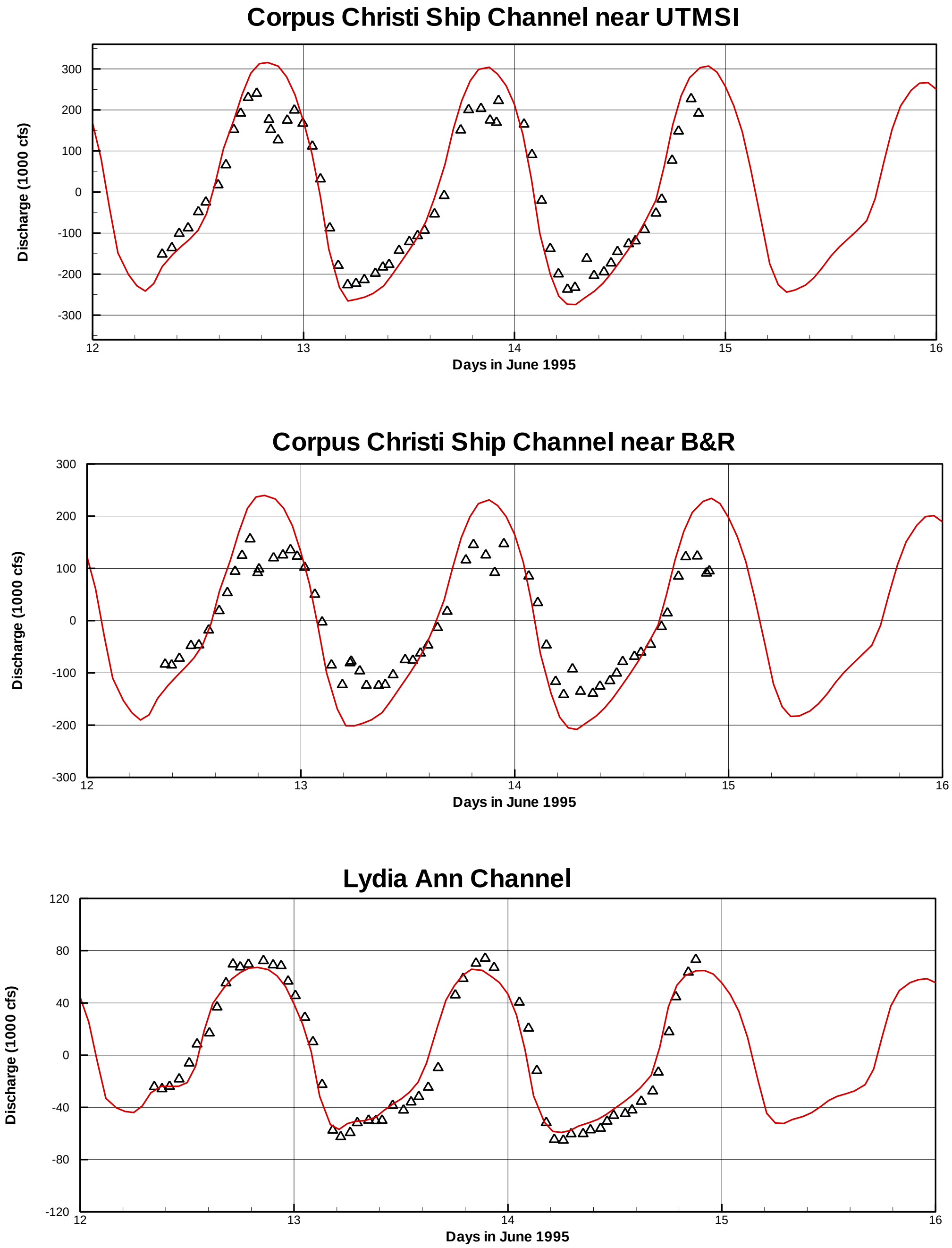
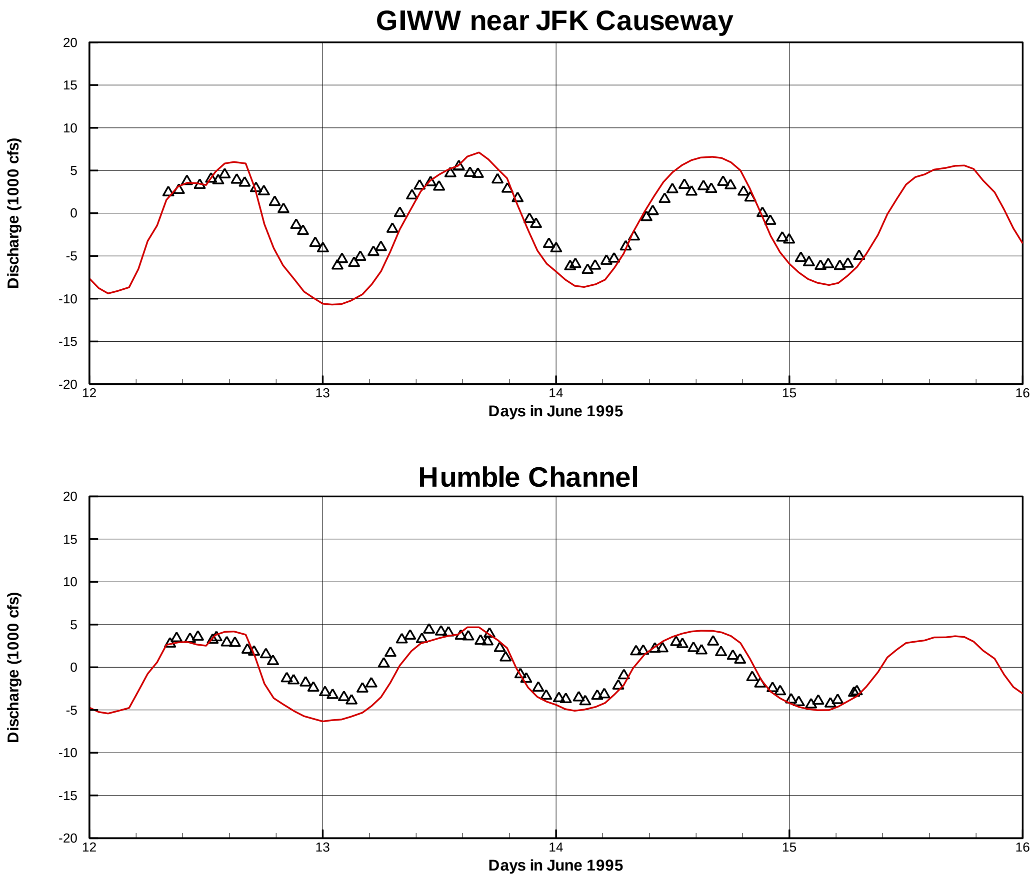
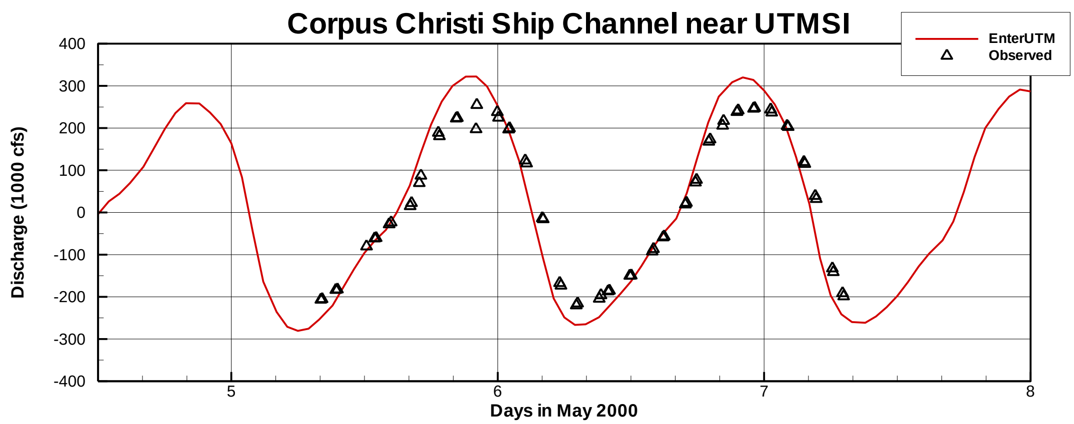


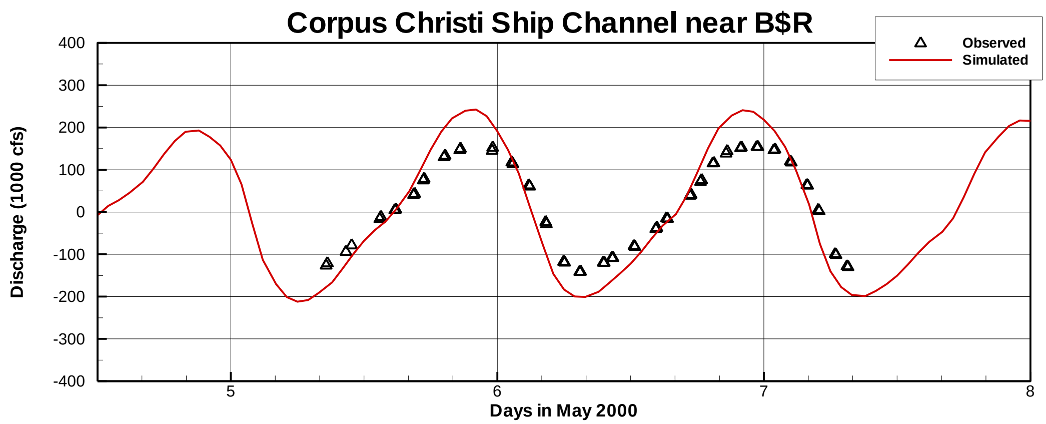
Figure 27. Simulated (*red line*) and observed (*open symbols*) discharges for the following sites from top to bottom: Corpus Christi Ship Channel near UTMSI, Corpus Christi Ship Channel near B&R, and the Lydia Ann Channel from June 12 - 15, 1995 in the Nueces Estuary. Positive discharge values represent the ebb cycle or downstream flow and negative discharge values represent flood cycle or upstream flow.



New

Figure 28. Simulated (*red line*) and observed (*open symbols*) discharges for the GIWW near JFK Causeway and the Humble Channel from June 12 - 15, 1995 in the Nueces Estuary. Positive discharge values represent the ebb cycle or downstream flow and negative discharge values represent flood cycle or upstream flow.





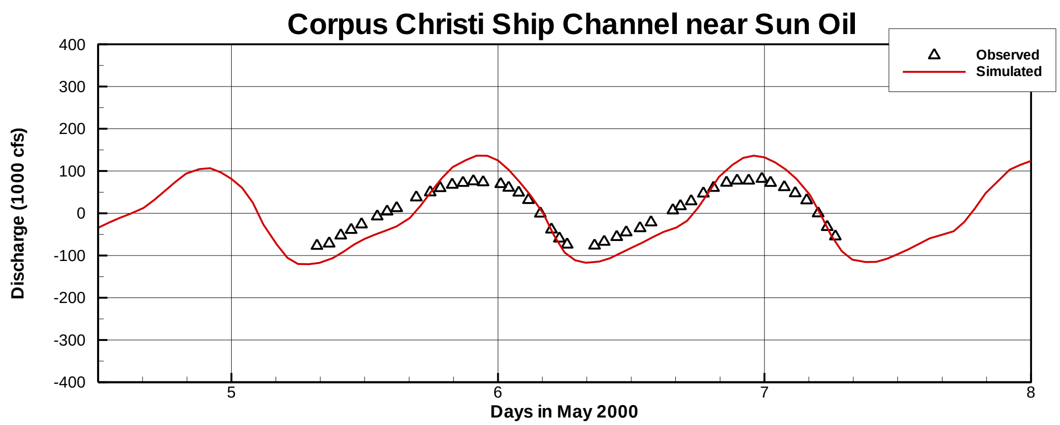


Figure 29. Simulated (*red line*) and observed (*open symbols*) discharges for the following sites from top to bottom: Corpus Christi Ship Channel near UTMSI, Corpus Christi Ship Channel near B&R, and the Corpus Christi Ship Channel near Sun Oil from May 5 - 7, 2000 in the Nueces Estuary. Positive discharge values represent the ebb cycle or downstream flow and negative discharge values represent flood cycle or upstream flow.

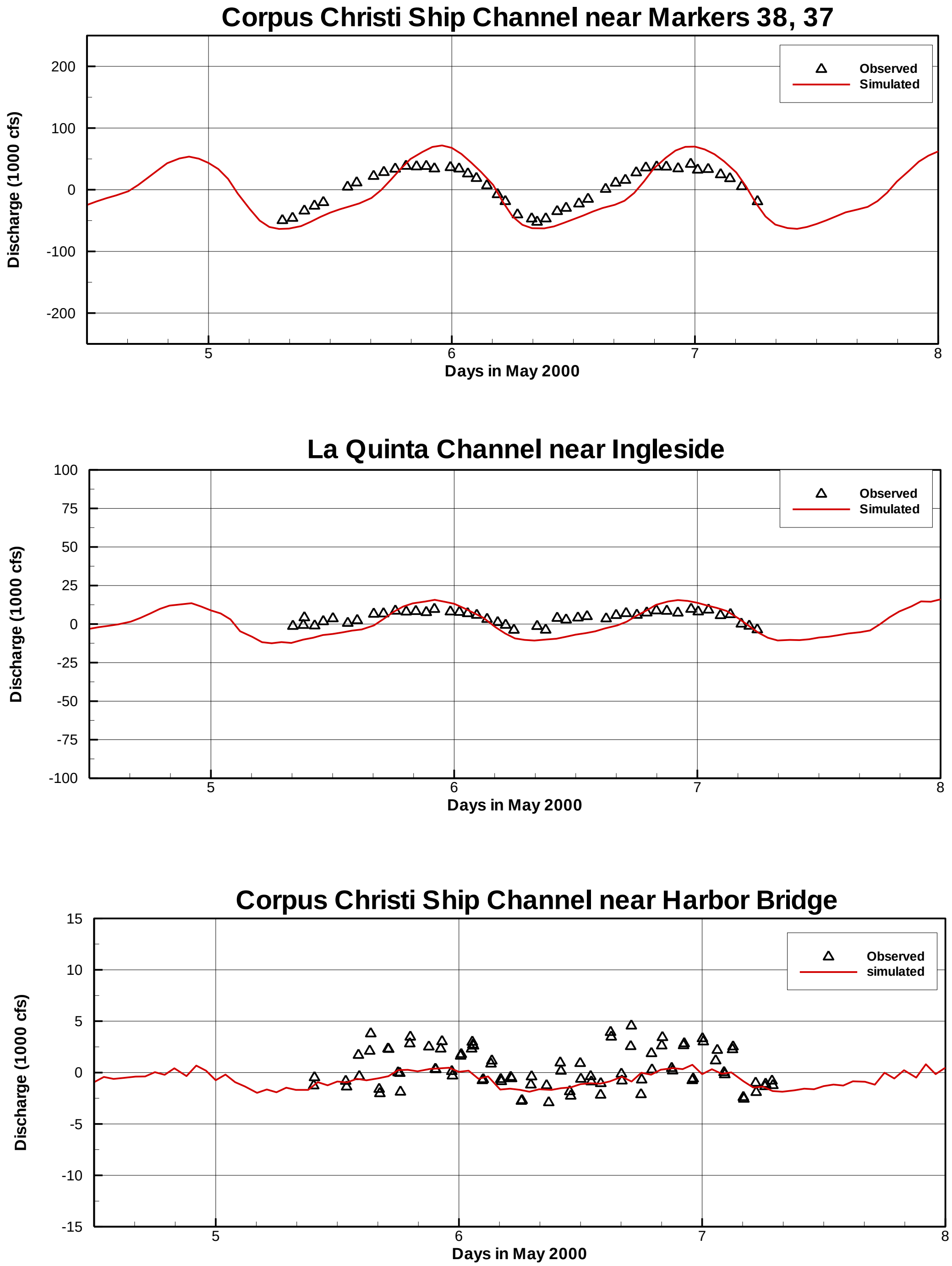


Figure 30. Simulated (*red line*) and observed (*open symbols*) discharges for the following sites from top to bottom: Corpus Christi Ship Channel near Markers 38 and 37, La Quinta Channel near Ingleside, and the Corpus Christi Ship Channel near Harbor Bridge from May 5 - 7, 2000 in the Nueces Estuary. Positive discharge values represent the ebb cycle or downstream flow and negative discharge values represent flood cycle or upstream flow.

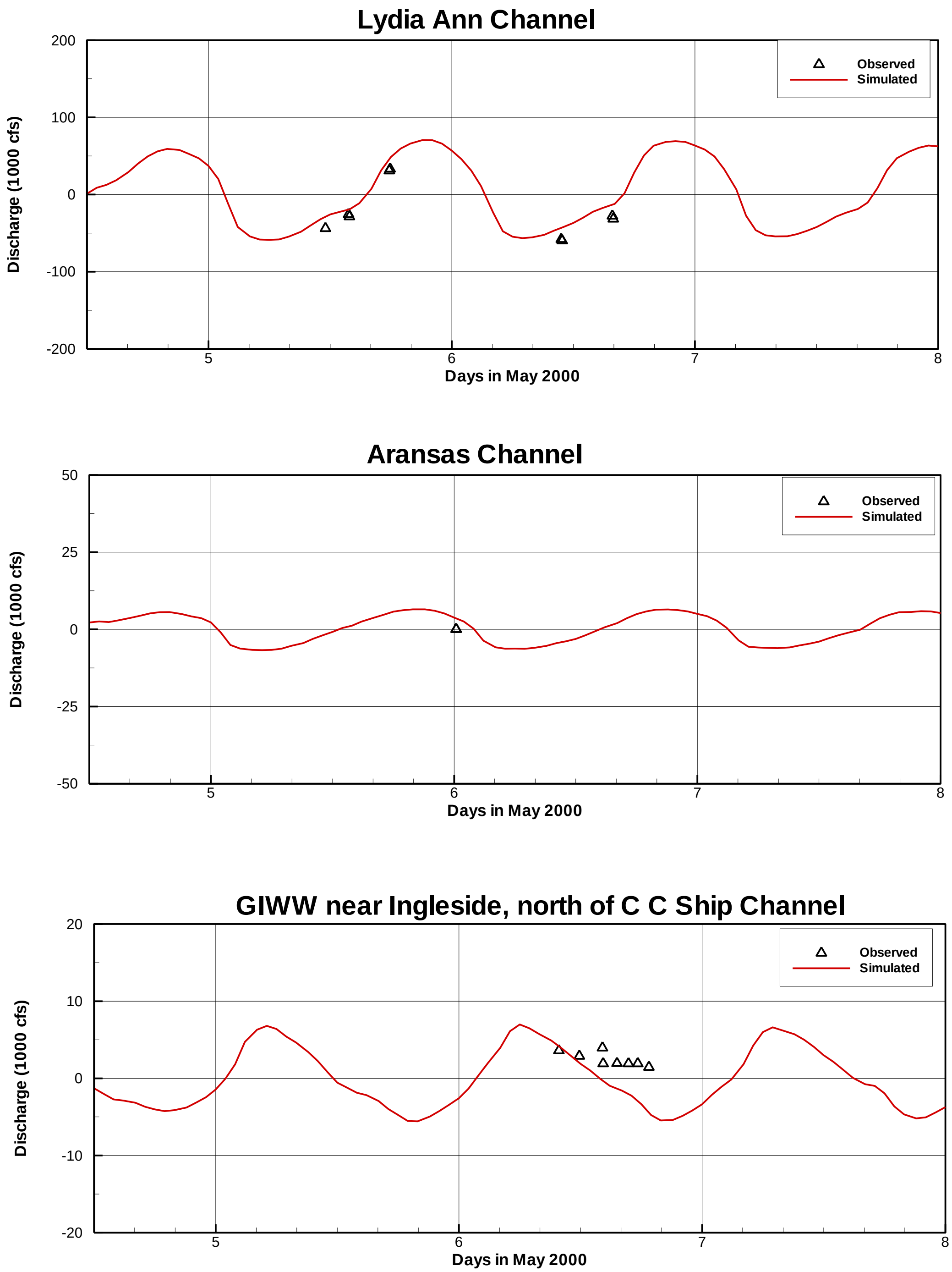


Figure 31. Simulated (*red line*) and observed (*open symbols*) discharges for the following sites from top to bottom: Lydia Ann Channel, Aransas Channel, and the GIWW near Ingleside (north of the Corpus Christi Ship Channel) from May 5 - 7, 2000 in the Nueces Estuary. Positive discharge values represent the ebb cycle or downstream flow and negative discharge values represent flood cycle or upstream flow.

Water Surface Elevation Results

Tidal comparisons were made at eight locations from 1999 through 2004. The scatter plots in Figure 32 show good agreement between model simulations for water surface elevations and observed data throughout the Nueces Estuary. Table 4 lists the comparison statistics for daily tides. To more easily visualize the comparison between simulated and observed hourly tide data, Figures 33 through 40 show times-series tide elevation data for a one-year time period at each site.

A range of r^2 values from 0.78 to 0.96 indicate good model performance (Table 4). High performance was observed at the Bob Hall Pier gage (r^2 = 0.96) and the Port Aransas gage (r^2= 0.92), lending confidence that the main exchange between the bay and Gulf was captured accurately. In some cases, such as at the Bird Island site, the observed data shows a sharp, linear decline all the way to the bottom of the plot, which is reflective of missing data. Model simulations of water elevation even capture the storm surge associated with Category 4 Hurricane Bret in August 1999 that made landfall on the south Texas coast. Although there are a few instances where the model over- or under-predicts water elevation, tidal phase and amplitude are well simulated by the model.

Table 4. Statistics for daily tidal elevations during the period 1999 - 2004 for the Nueces Estuary.

Location	**Days**	**r^2**	**RMS(ft)***	**NSEC****
Texas State Aquarium	1891	0.91	0.15	0.90
Bird Island	2186	0.91	0.14	0.89
Ingleside	2190	0.93	0.15	0.89
Packery Channel	2188	0.90	0.14	0.90
Port Aransas	2190	0.92	0.15	0.89
Rockport	2190	0.89	0.17	0.86
Bob Hall Pier	2187	0.96	0.10	0.95
White Point	1796	0.78	0.23	0.76

*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.

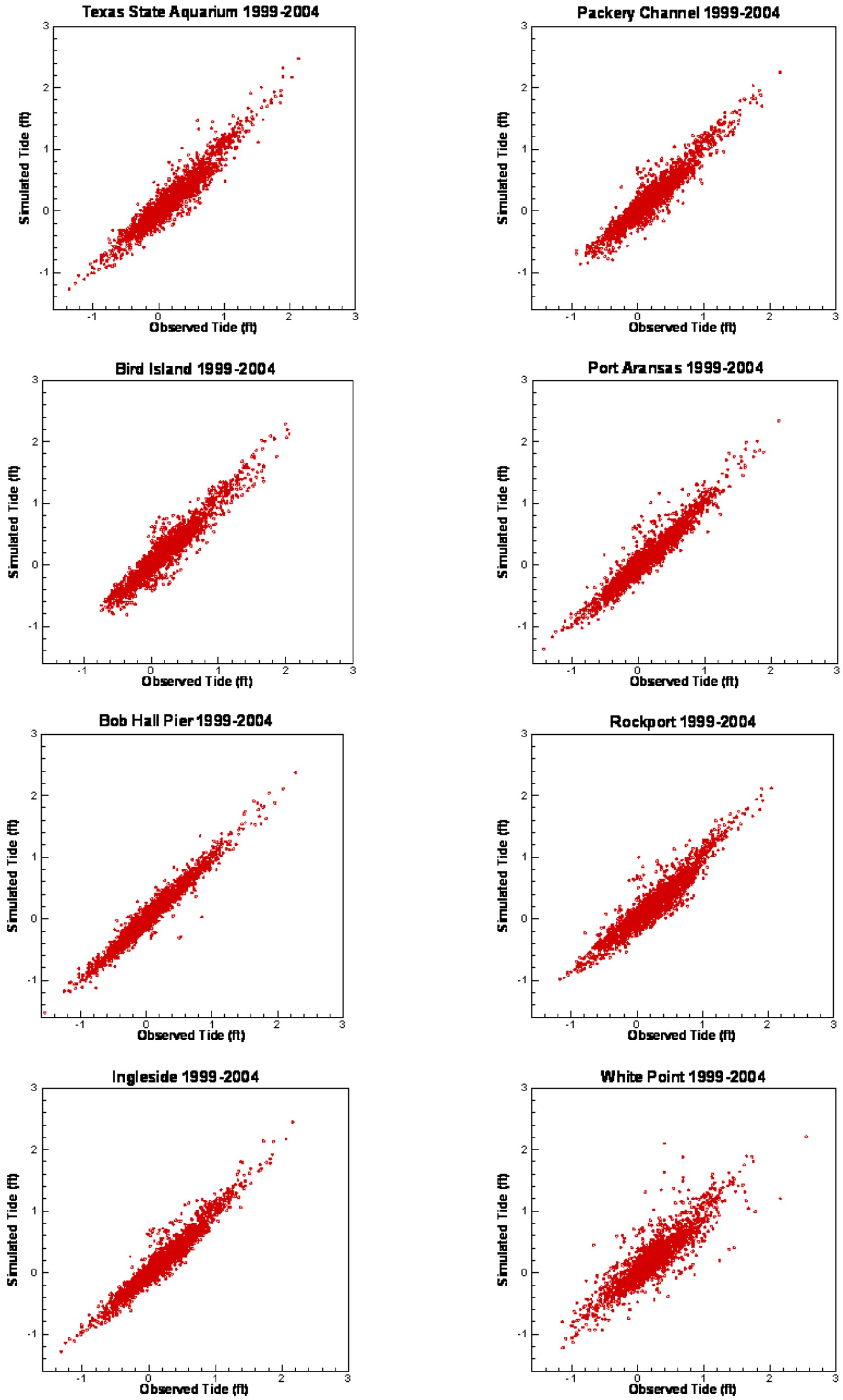


Figure 32. Scatter plots of observed versus simulated tidal elevations at (*from left to right starting at top*) Texas State Aquarium, Packery Channel, Bird Island, Port Aransas, Bob Hall Pier, Rockport, Ingleside, and White Point sites for 1999 – 2004.

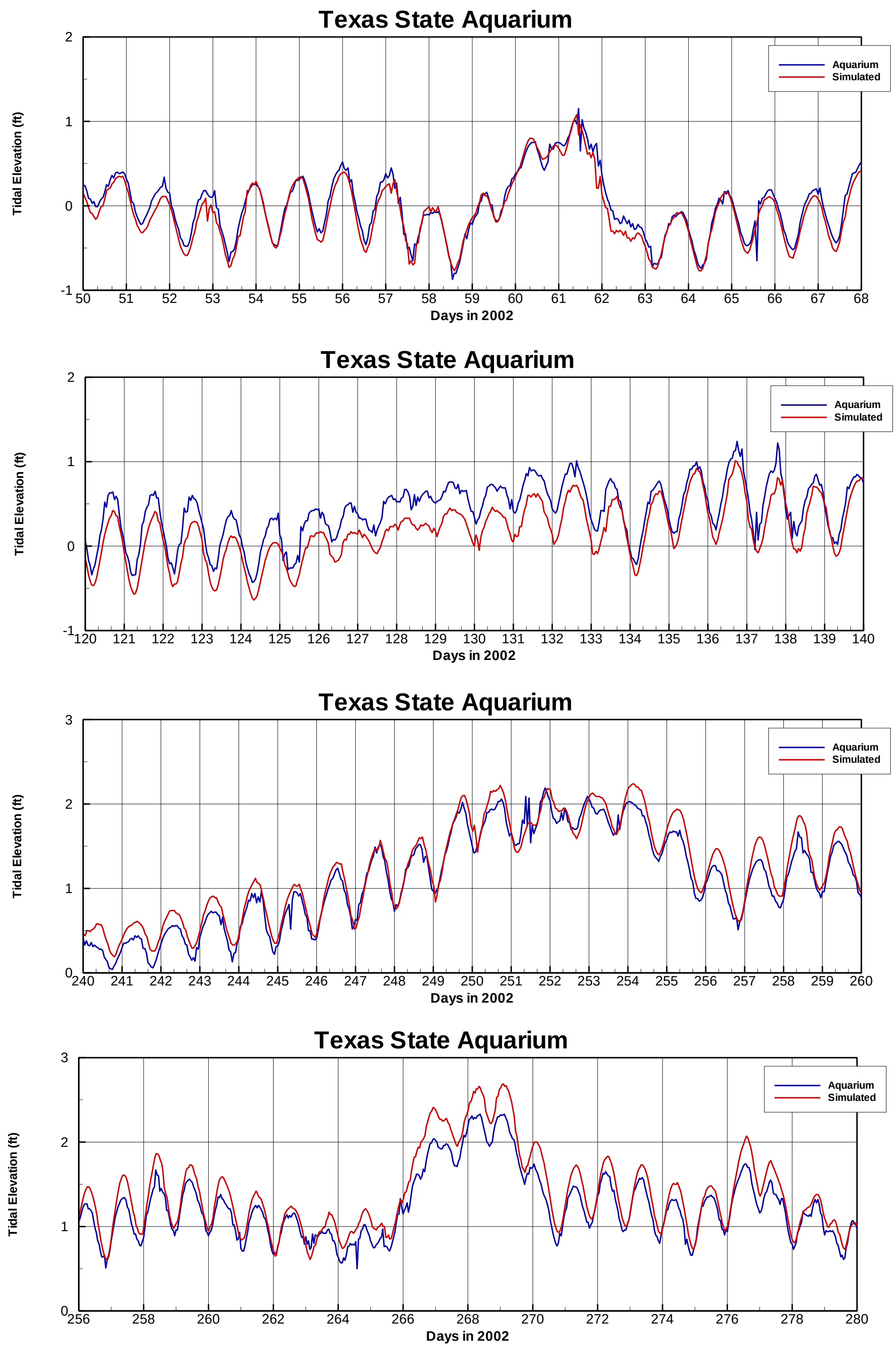


Figure 33. Time-series plots for observed (*blue*) and simulated (*red*) hourly tide data at the Texas State Aquarium during 2002.

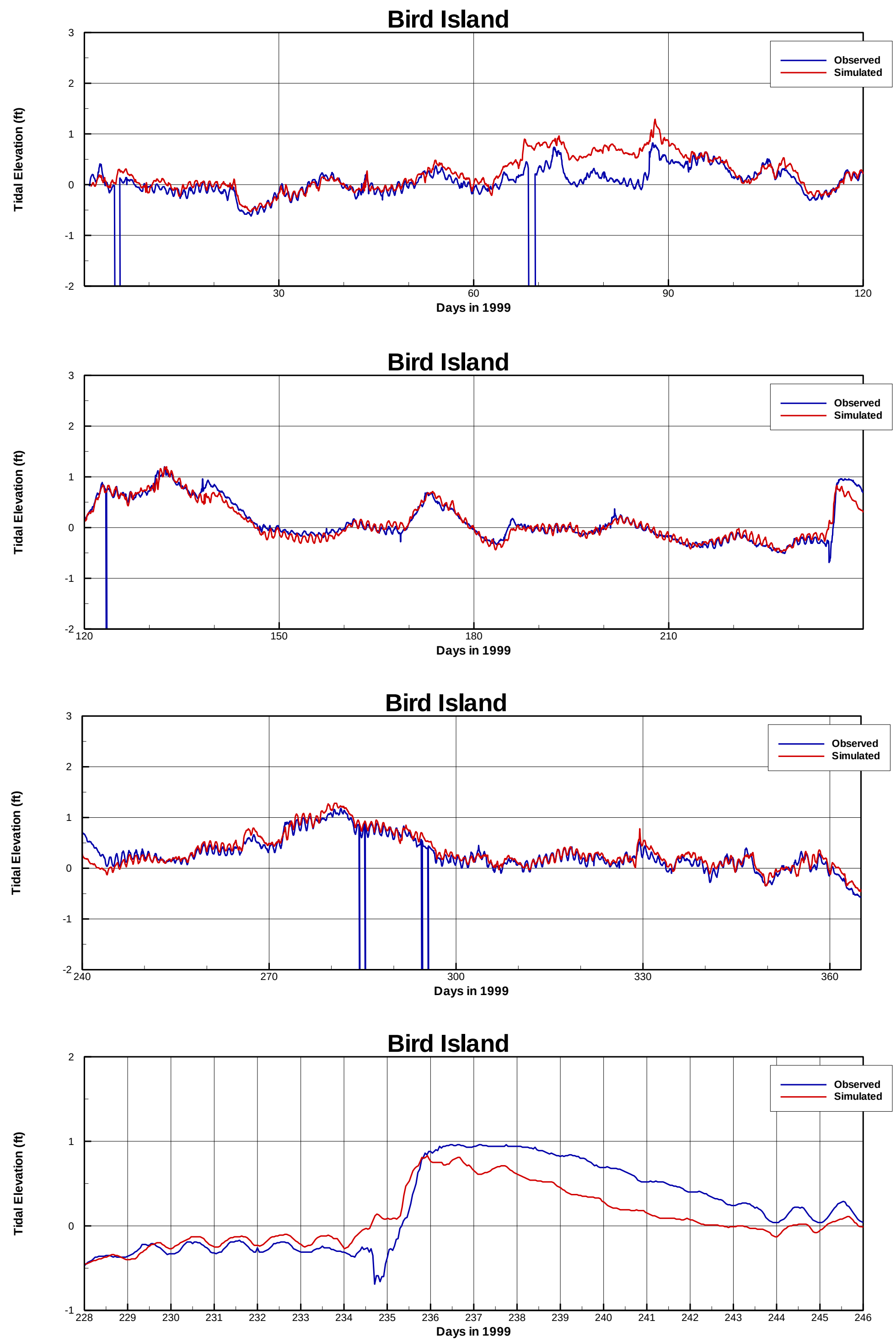


Figure 34. Time-series plots for observed (*blue*) and simulated (*red*) hourly tide data at Bird Island during 1999. The bottommost panel shows tides during an 18-day period to better compare the timing of simulated and observed tidal elevations. Data gaps in the observed record are represented by the vertical blue lines that extend to the bottom of the plot.

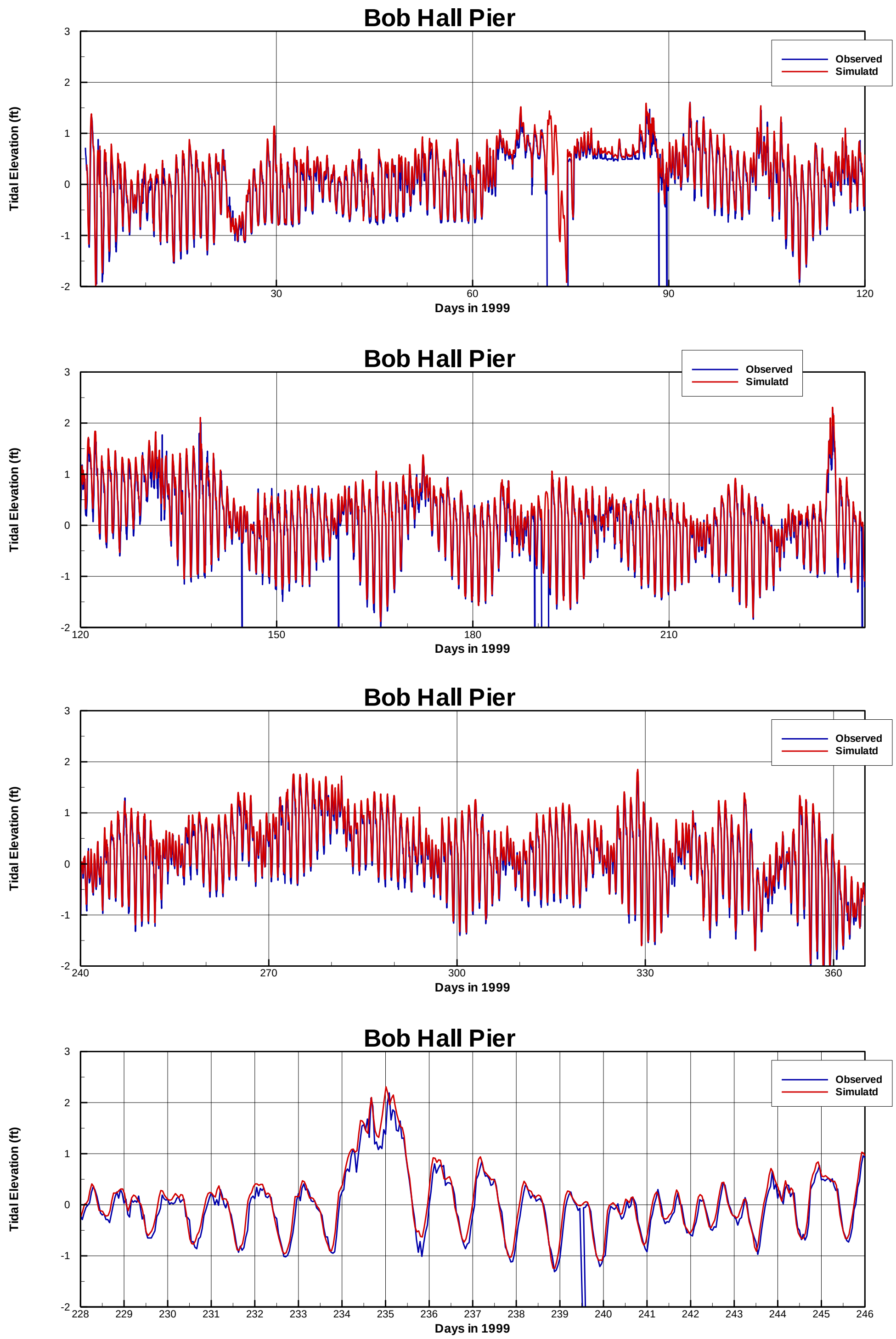


Figure 35. Time-series plots for observed (*blue*) and simulated (*red*) hourly tide data at Bob Hall Pier during 1999. The bottommost panel shows tides during an 18-day period to better compare the timing of simulated and observed tidal elevations. Data gaps in the observed record are represented by the vertical blue lines that extend to the bottom of the plot.

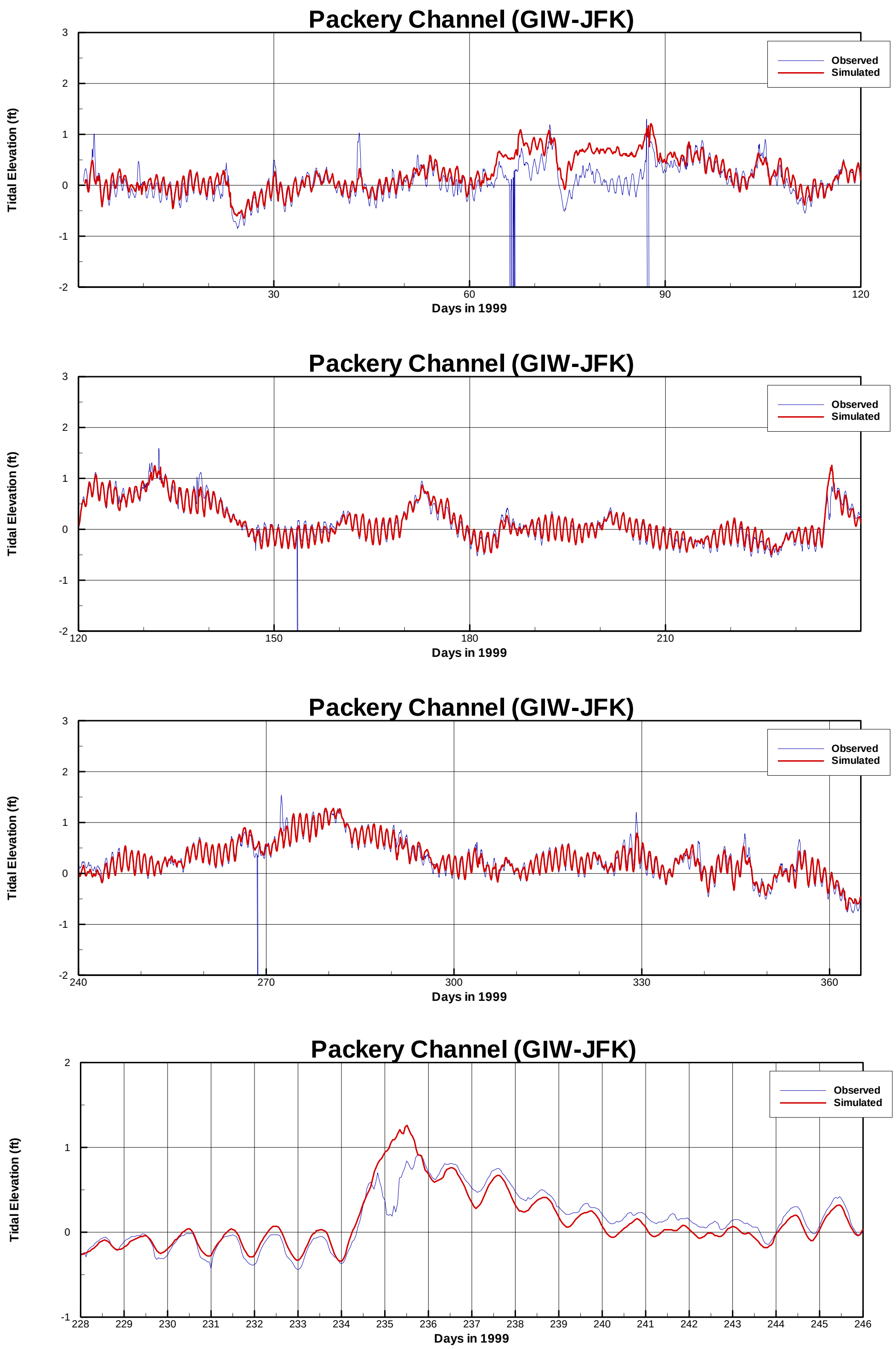


Figure 36. Time-series plots for observed (*blue*) and simulated (*red*) hourly tide data at Packery Channel during 1999. The bottommost panel shows tides during an 18-day period to better compare the timing of simulated and observed tidal elevations. Data gaps in the observed record are represented by vertical blue lines that extend to the bottom of the plot.

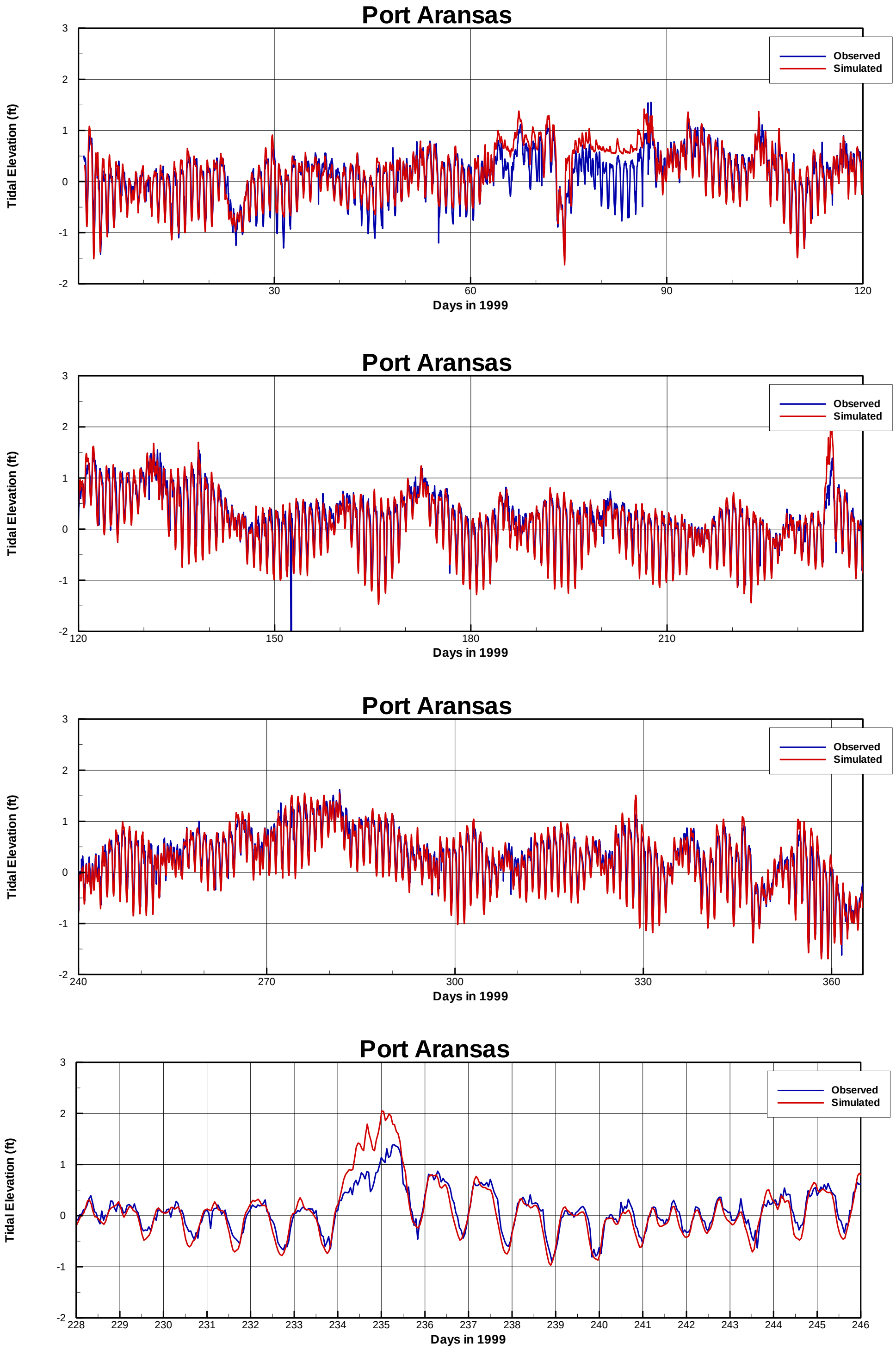


Figure 37. Time-series plots for observed (*blue*) and simulated (*red*) hourly tide data at Port Aransas during 1999. The bottommost panel shows tides during an 18-day period to better compare the timing of simulated and observed tidal elevations. Data gaps in the observed record are represented by the vertical blue line that extends to the bottom of the plot.

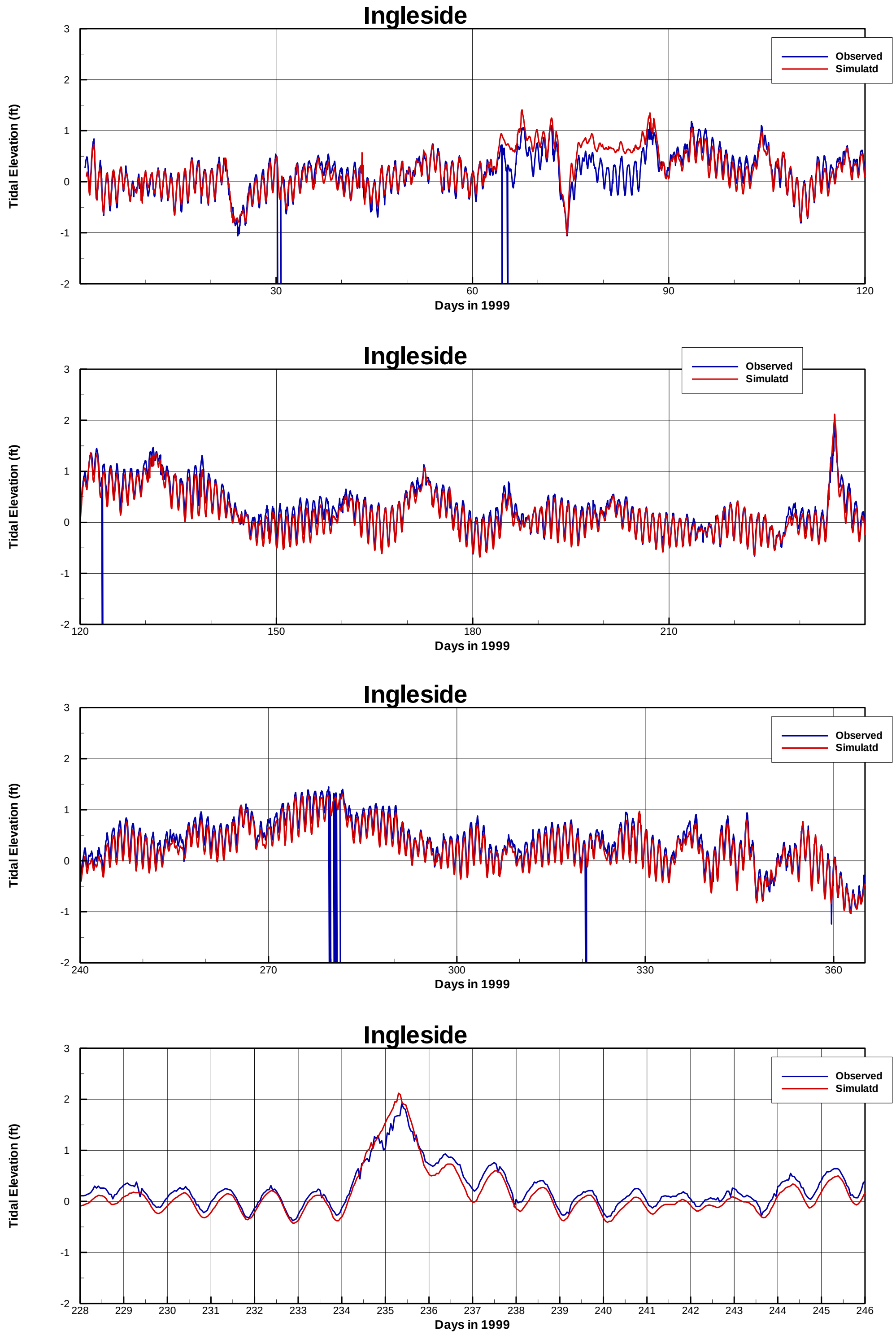


Figure 38. Time-series plots for observed (*blue*) and simulated (*red*) hourly tide data at Ingleside during 1999. The bottommost panel shows tides during an 18-day period to better compare the timing of simulated and observed tidal elevations. Data gaps in the observed record are represented by the vertical blue lines that extend to the bottom of the plot.

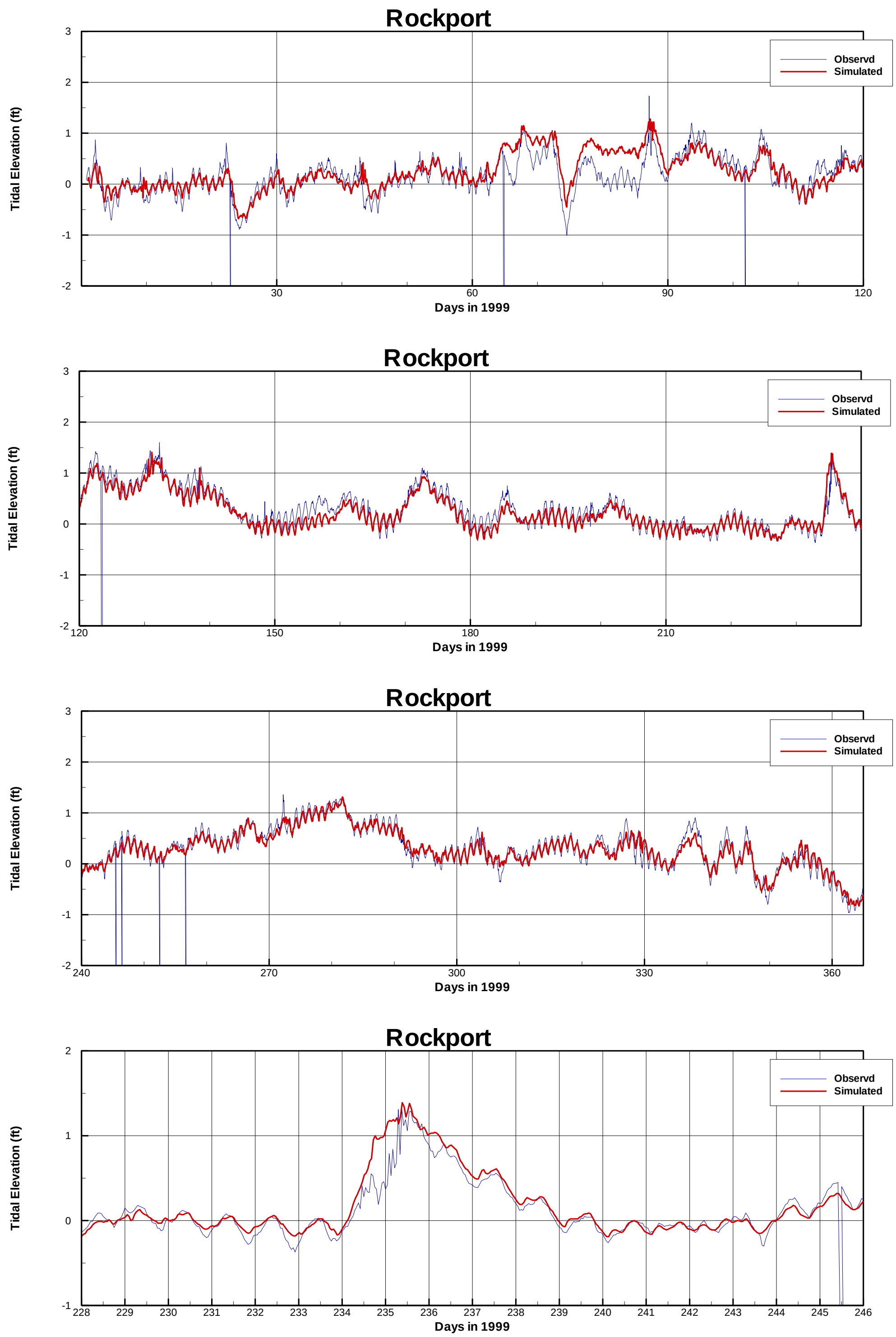


Figure 39. Time-series plots for observed (*blue*) and simulated (*red*) hourly tide data at Rockport during 1999. The bottommost panel shows tides during an 18-day period to better compare the timing of simulated and observed tidal elevations. Data gaps in the observed record are represented by the vertical blue lines that extend to the bottom of the plot.

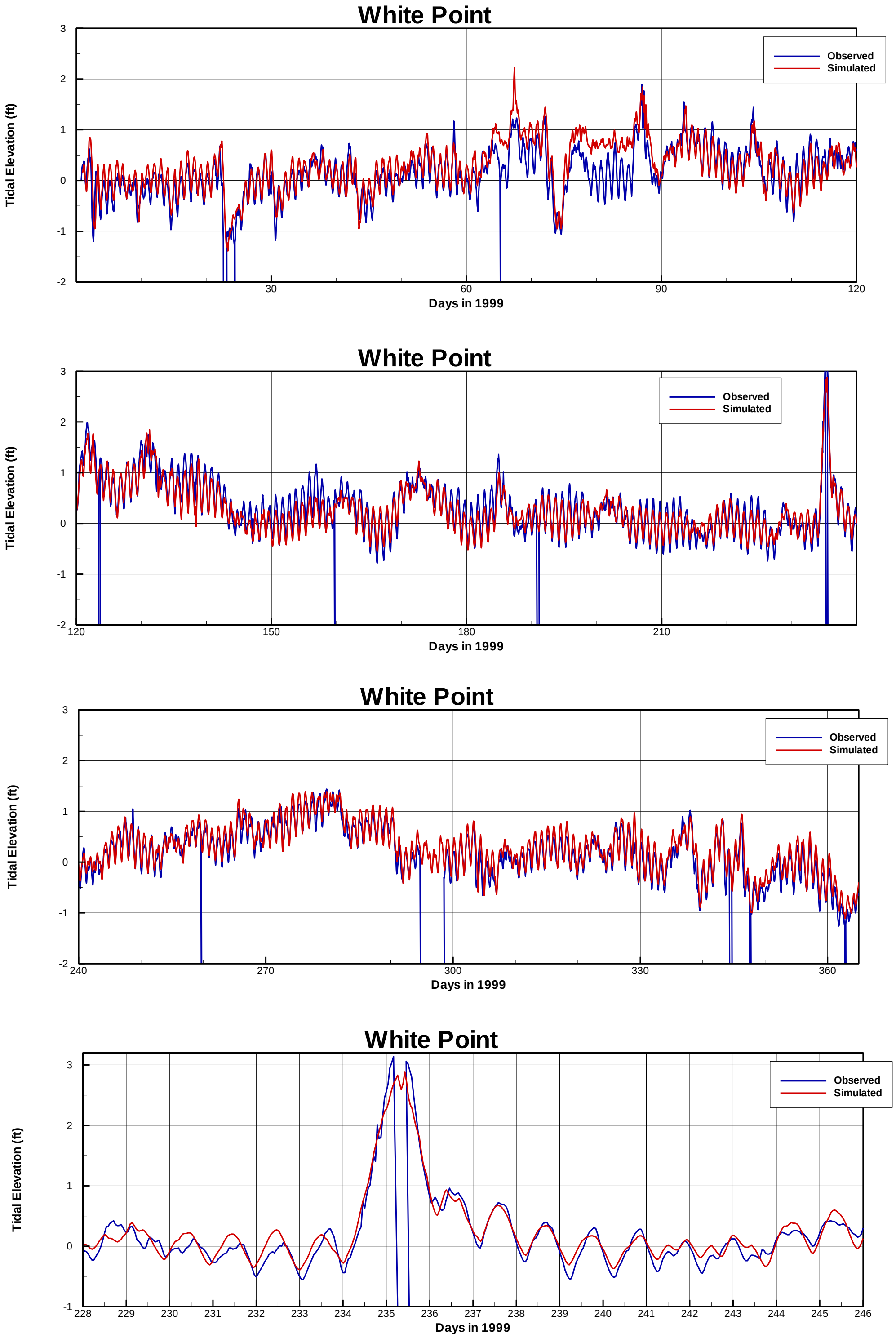


Figure 40. Time-series plots for observed (*blue*) and simulated (*red*) hourly tide data at White Point during 1999. The bottommost panel shows tides during an 18-day period to better compare the timing of simulated and observed tidal elevations. Data gaps in the observed record are represented by the vertical blue lines that extend to the bottom of the plot.

Salinity Results

TxBLEND was calibrated for salinity at four sites in the Nueces Estuary (see Figure 13 for map of locations). Data from the Corpus Christi Bay and Nueces Bay sites for the period from 1987 - 1989 and from 2000 - 2004 were used, in addition to data from the GIWW-JFK site from 1991 - 1996 and from the Aransas Bay site from 1987 - 1989. Figures 41 through 52 show observed versus simulated salinities at these sites as time-series plots and as scatter plots. For all sites, the difference between the mean simulated and observed salinity was less than 2 ppt (Table 5). At the Corpus Christi Bay site for the calibration period from 1987 - 1989, the model was not as representative of salinity when compared to other sites. Low r^2 values, high Root Mean Square (RMS) values, and low Nash-Sutcliffe Efficiency Criterion (E) values (r^2 = 0.14, RMS = 6.9, E = 0.04, Table 5) indicate poor model performance at this site; however, as Figure 41 shows, performance was only poor in a few instances such as in January 1988 where the observed data were most likely inaccurate due to datasonde failure, which thereby affects the statistics. For the 2000 - 2004 period, salinity simulation performance improved significantly at this site (r^2 = 0.54, Figures 43 - 44).

Performance measures improved greatly for the other sites as well. For instance, at the Nueces Bay site for the calibration period from 2000 - 2004, the model captured dramatic swings in salinity very well, as exhibited by an r^2 value of 0.91 (Figure 47, Table 5). Although short- and long-term variability are simulated well at the Nueces Bay site, the model tends to slightly under predict rising salinities around January 2003 and January 2004 (Figure 47), but otherwise adequately predicts rising salinity trends. This type of model behavior has been observed in TxBLEND models for other systems at the upstream boundary of model grids.

As observed both in the modeled and field data in the 2000 - 2004 calibration period, average observed salinity increased significantly from the Nueces Bay site (20.2 ppt) to the Corpus Christi Bay site (28.2 ppt). Additionally, during events when salinity decreased dramatically in Nueces Bay, the decline was not as extreme in Corpus Christi Bay, which likely is a function of proximity to freshwater inflow sources and bay size.

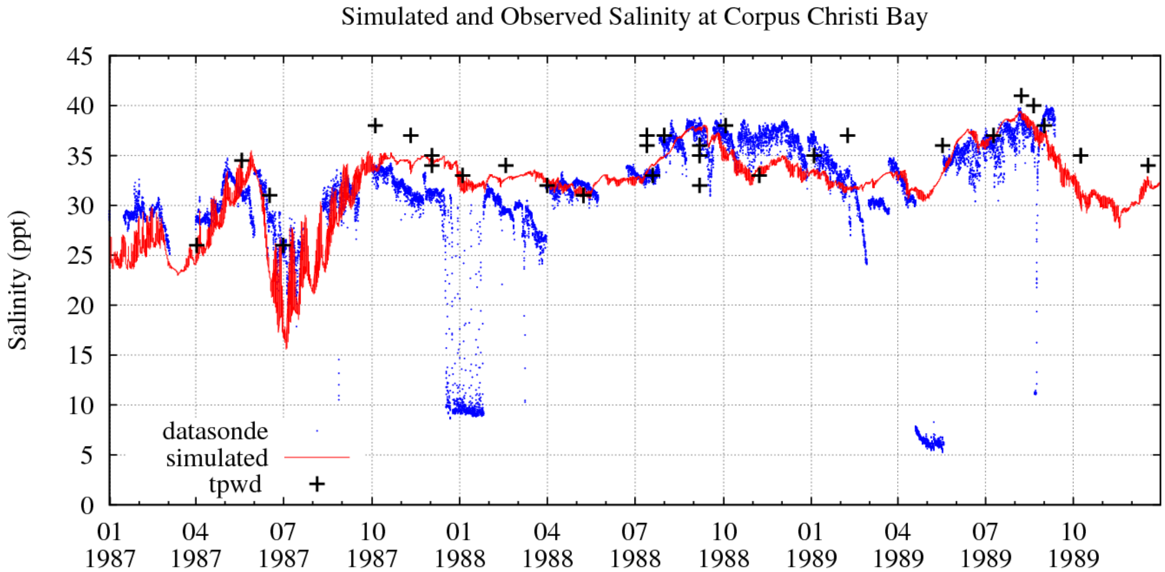


Figure 41. Observed (*blue*) versus simulated (*red*) salinities at the Corpus Christi Bay site in the Nueces Estuary for a period from 1987 - 1989. Point measurement data collected by TPWD (+) near this site also was included for comparison.

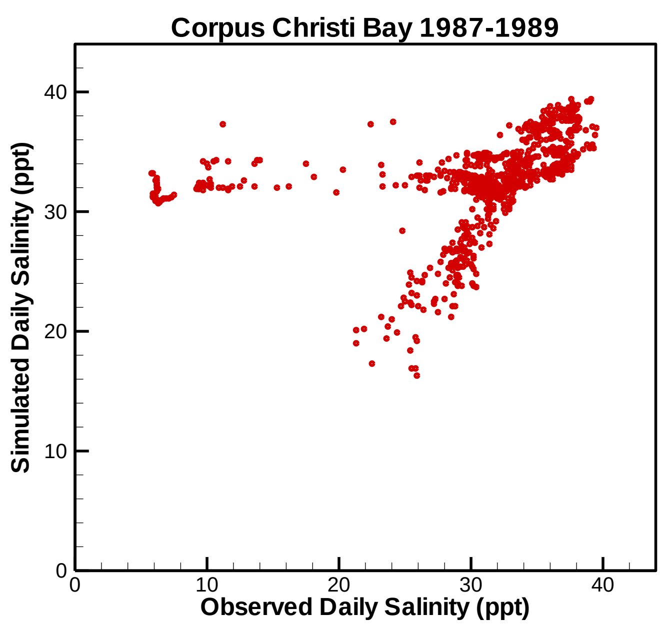


Figure 42. Scatter plot comparing simulated to observed daily salinities at the Corpus Christi Bay site for the calibration period from 1987 - 1989 ($r^2 = 0.14$).

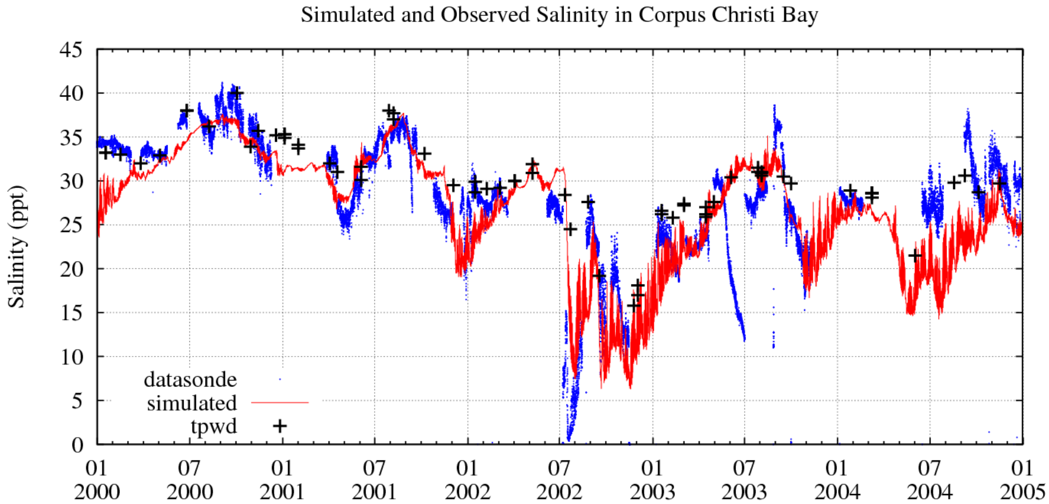


Figure 43. Observed (*blue*) versus simulated (*red*) salinities at the Corpus Christi Bay site in the Nueces Estuary for a period from 2000 - 2004. Point measurement data collected by TPWD (+) near this site was also included for comparison.

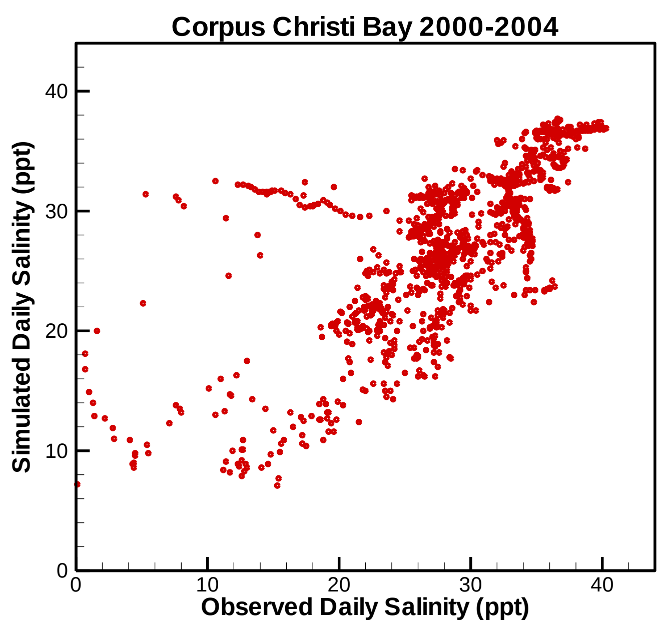


Figure 44. Scatter plot comparing simulated to observed daily salinities at the Corpus Christi Bay site for the calibration period from 2000 - 2004 ($r^2 = 0.54$).

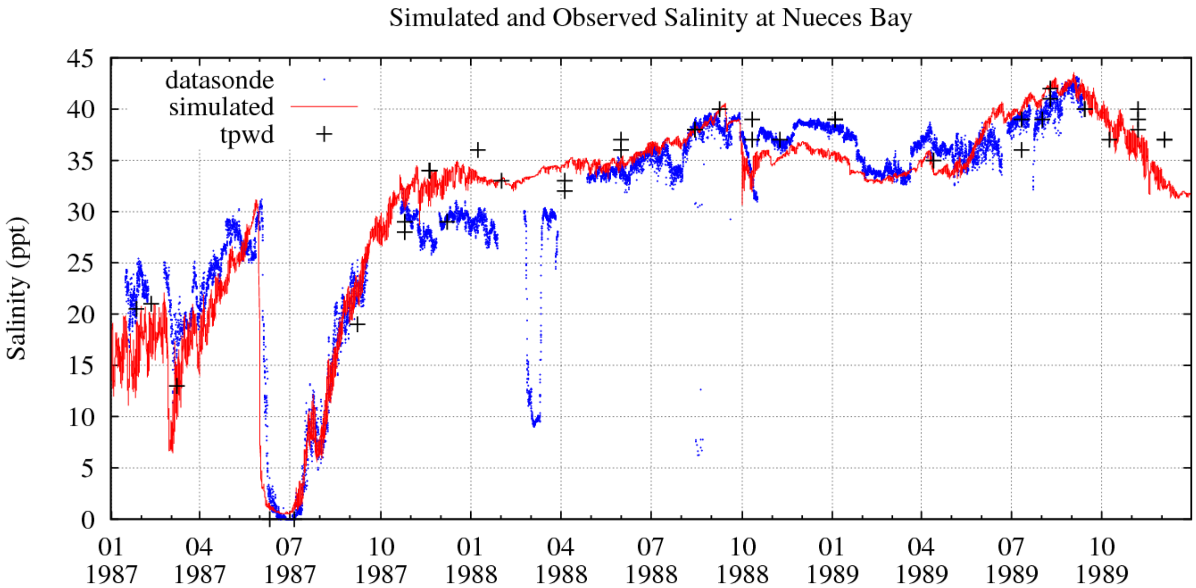


Figure 45. Observed (*blue*) versus simulated (*red*) salinities at the Nueces Bay site in the Nueces Estuary for a period from 1987 - 1989. Point measurement data collected by TPWD (+) near this site also was included for comparison.

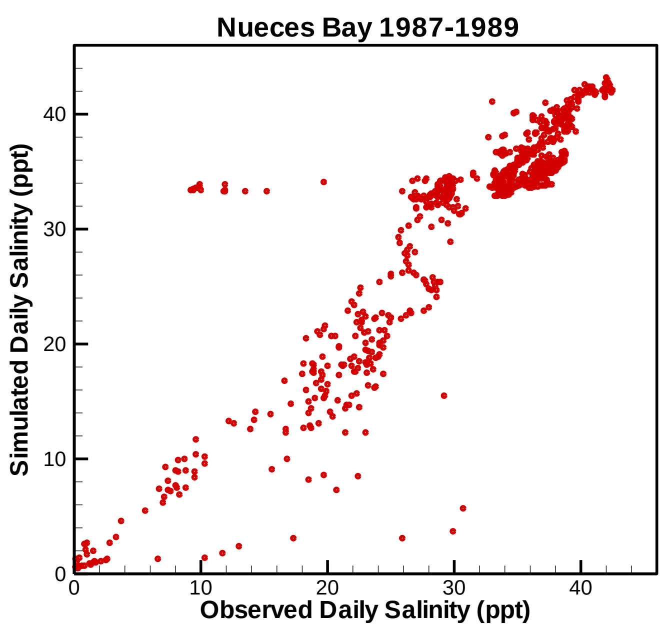


Figure 46. Scatter plot comparing simulated to observed daily salinities at the Nueces Bay site for the calibration period from 1987 - 1989 ($r^2 = 0.82$).

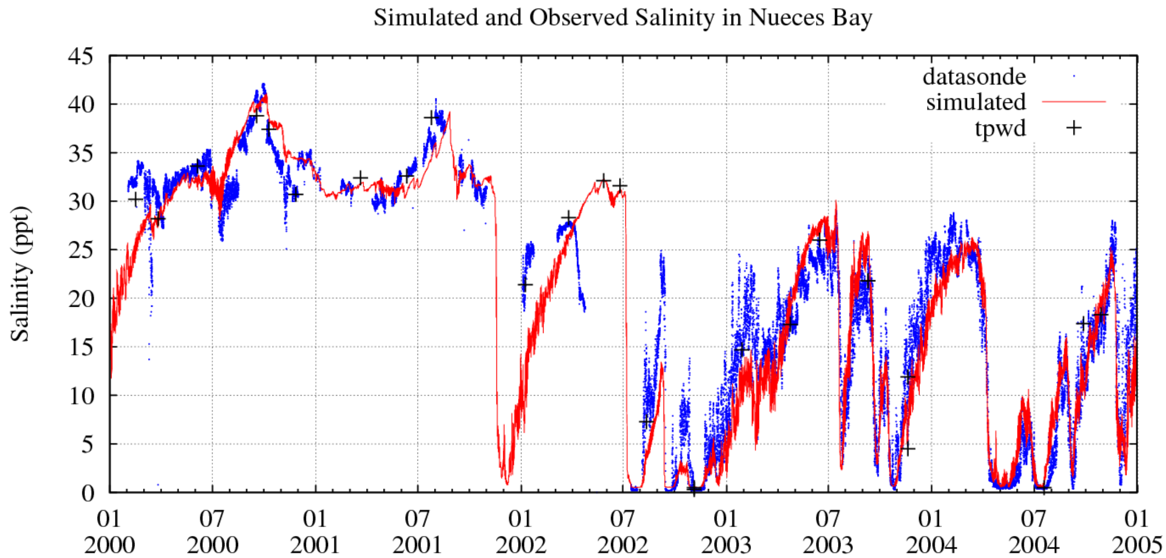


Figure 47. Observed (*blue*) versus simulated (*red*) salinities at the Nueces Bay site in the Nueces Estuary for a period from 2000 - 2004. Point measurement data collected by TPWD (+) near this site was also included for comparison.

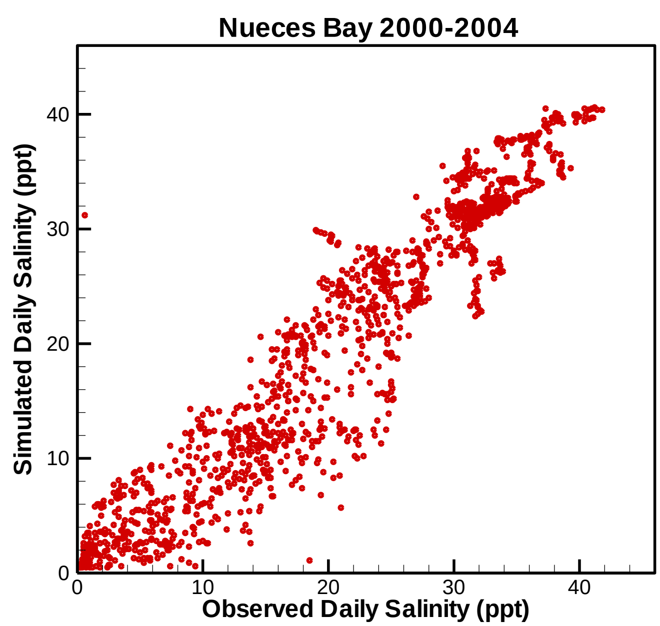


Figure 48. Scatter plot comparing simulated to observed daily salinities at the Nueces Bay site for the calibration period from 2000 - 2004 ($r^2 = 0.91$).

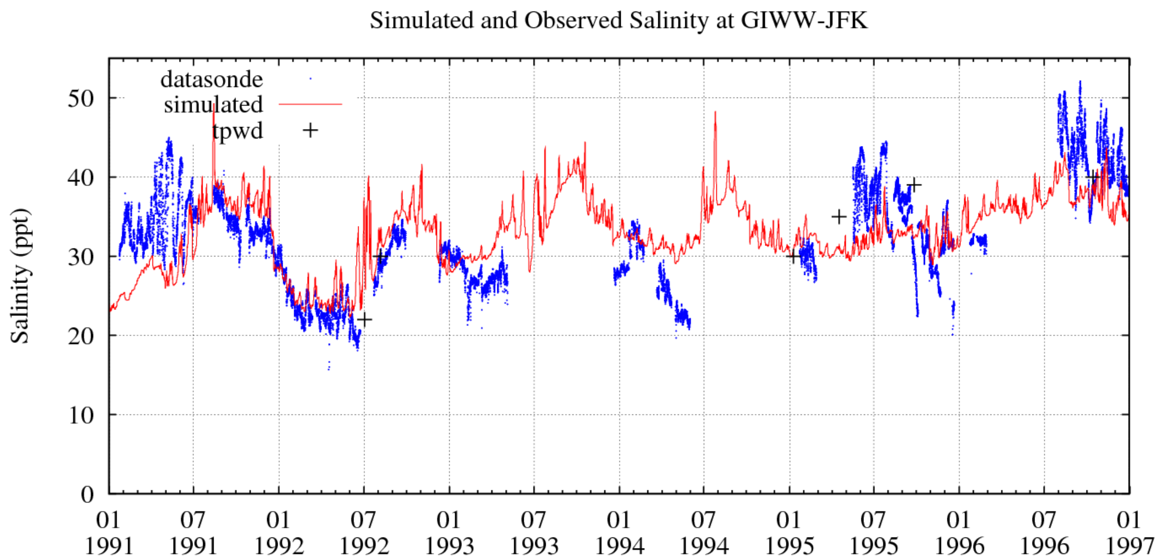


Figure 49. Observed (*blue*) versus simulated (*red*) salinities at the GIWW-JFK site in the Nueces Estuary for a period from 1991 through 1996. Point measurement data collected by TPWD (+) near this site was also included for comparison.

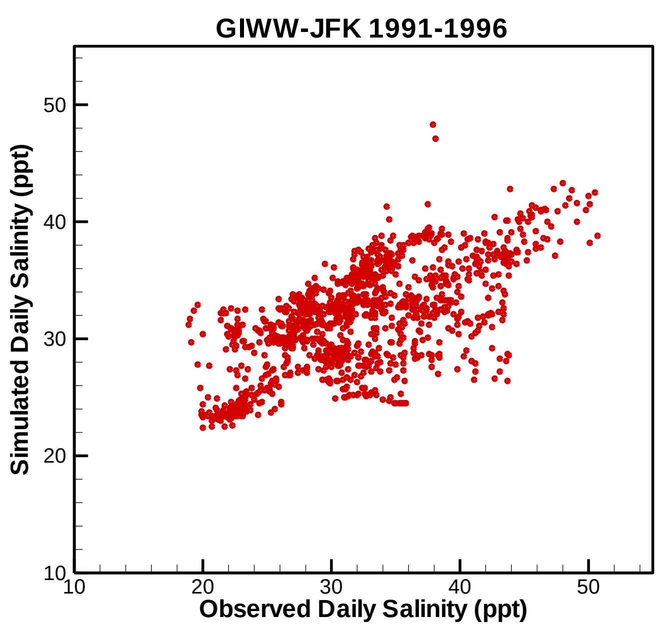


Figure 50. Scatter plot comparing simulated to observed daily salinities at the GIWW-JFK site for the calibration period from 1991 - 1996 ($r^2 = 0.44$).

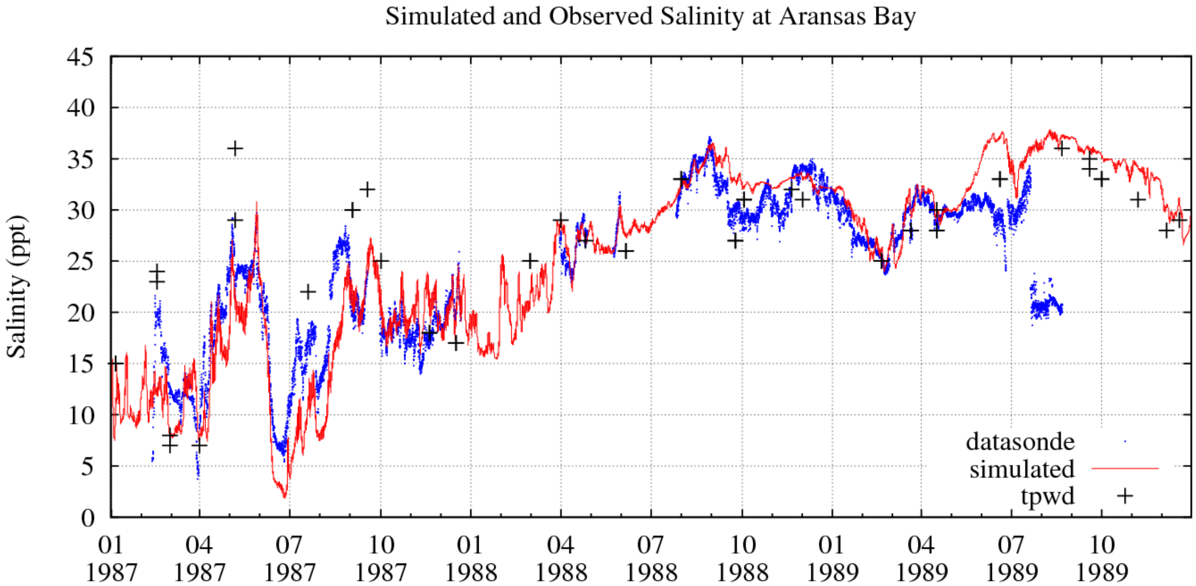


Figure 51. Observed (*blue*) versus simulated (*red*) salinities at the Aransas Bay site in the Nueces Estuary for a period from 1987 - 1989. Point measurement data collected by TPWD (+) near this site was also included for comparison.

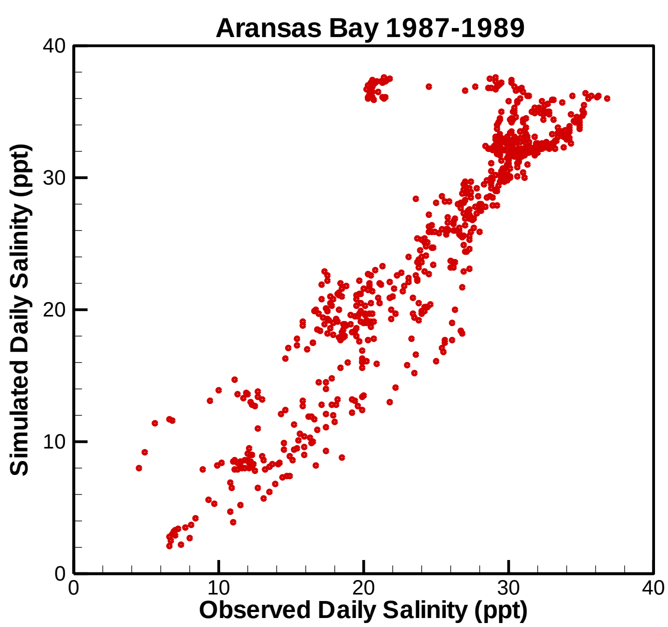


Figure 52. Scatter plot comparing simulated to observed daily salinities at the Aransas Bay site for the calibration period from 1987 - 1989 ($r^2 = 0.77$).

Table 5. Summary statistics for comparisons of simulated to observed daily salinity for four sites in the Nueces Estuary for various periods from 1987 - 2009 for calibration (*indicated by shading*) and validation efforts.

						Average Salinity (ppt)		
Location	**Period**	**Days**	**r^2**	**RMS* (ppt)**	**NSEC****	**Simulated Salinity**	**Observed Salinity**	**Difference (Sim-Obs)**
Corpus Christi Bay	1987-1989	881	0.14	6.9	0.04	32.5	30.8	1.7
	2000-2004	1197	0.54	5.1	0.48	27.3	28.2	-0.9
	2005-2009	1054	0.49	4.3	0.44	30.8	32.2	-1.4
Nueces Bay	1987-1989	853	0.82	4.4	0.79	30.4	30.2	0.2
	2000-2004	1413	0.91	3.8	0.90	19.4	20.2	-0.8
	2005-2009	1328	0.84	4.3	0.79	26.8	25.0	1.8
GIWW at JFK Causeway	1991-1996	1242	0.44	4.9	0.44	31.8	32.0	-0.2
	1997-2002	1446	0.30	6.8	0.10	30.4	32.3	-1.9
Aransas Bay	1987-1989	729	0.77	4.6	0.58	25.2	24.5	0.7
	1994-2000	1926	0.63	5.6	0.49	22.7	24.2	-1.5

*RMS is the root mean square error.
**NSEC is the Nash-Sutcliffe Efficiency Criterion (E) and 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.

Model Validation

To verify the validity of the calibrated Nueces Estuary TxBLEND model for salinity, additional model runs were conducted to simulate salinities for three different time periods, from 1994 – 2000 for Aransas Bay, 1997 - 2002 at the GIWW-JFK Causeway site, and 2005 – 2009 at the Corpus Christi and Nueces Bay sites. Model outputs were then compared to TWDB Datasonde data for all sites, except mid-Nueces Bay which was compared to DNR's SALT01 station, as well as to point-measurement data obtained from TPWD's Coastal Fisheries Database for sites generally located near the established monitoring stations. Figures 53 through 60 show results for the validation exercise as time-series plots and scatter plots. Table 5 (above) shows summary statistics for the validation exercise at each site.

Validation Results

Results of Model Validation from 1994 -2000 for Aransas Bay

The first validation period from 1994 - 2000 compares simulated TxBLEND salinities to observed salinities obtained from the TWDB's Datasonde site in Aransas Bay. The model is representative of long-term trends in salinity over the seven year period.

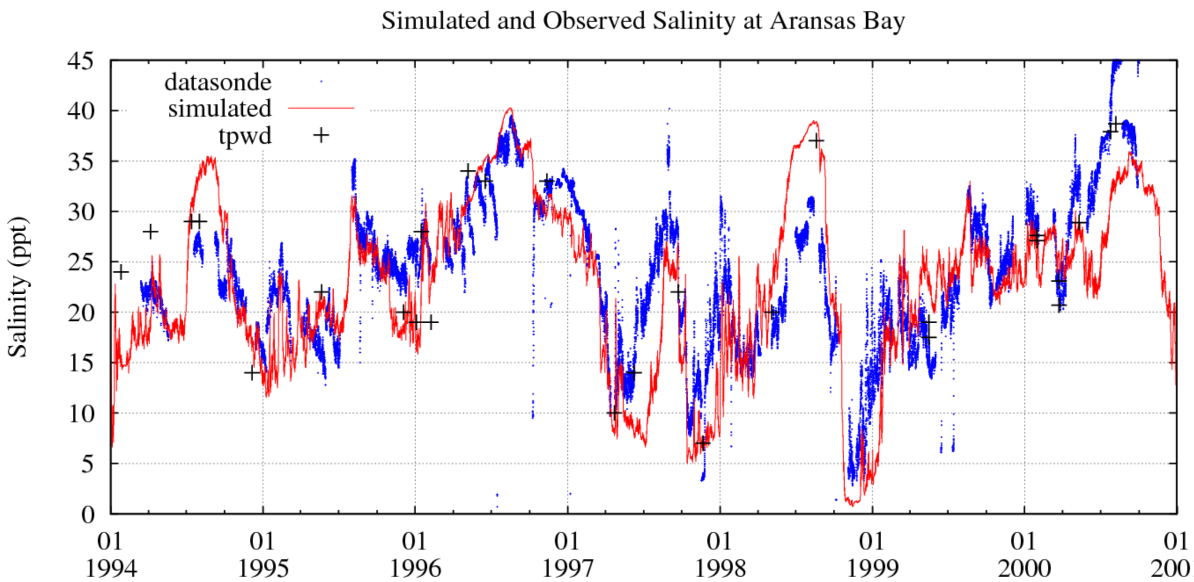


Figure 53. Simulated (*red*) and observed (*blue*) salinities at Aransas Bay for the validation period 1994 - 2000. Point measurement data collected by TPWD (+) near this site was included for comparison.

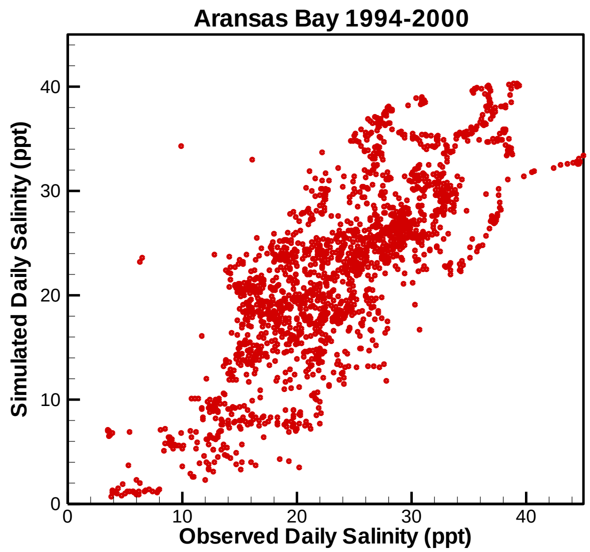


Figure 54. Scatter plot comparing simulated to observed salinities at the Aransas Bay site for the validation period from 1994 - 2000 (r^2 = 0.63).

Results of Model Validation from 1997 - 2002 for the GIWW-JFK Causeway site

The next validation period from 1997 - 2002 compares simulated TxBLEND salinities to observed salinities obtained from TWDB's Datasonde site at the Gulf Intracoastal Water Way (GIWW) at the JFK Causeway. The model predicts short-term variability, as well as long-term trends reasonably well at this site, but also under-predicts salinities from 2000 through 2002.

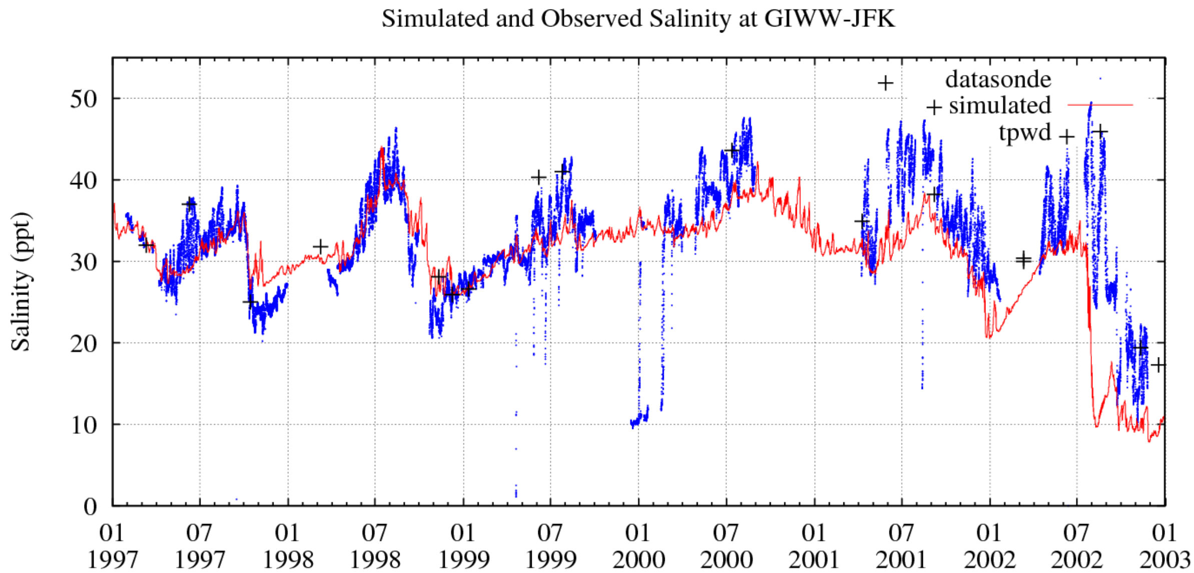


Figure 55. Simulated (*red*) and observed (*blue*) salinities at the GIWW-JFK site for the validation period 1997 - 2002. Point measurement data collected by TPWD (+) near this site was included for comparison.

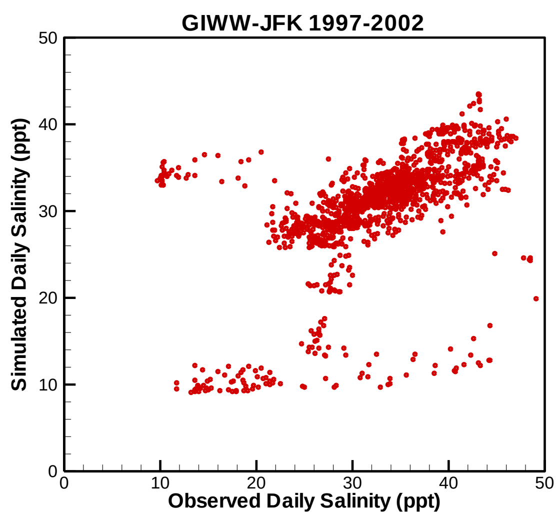


Figure 56. Scatter plot comparing simulated to observed salinities at the GIWW-JFK site for the validation period from 1997 - 2002 ($r^2 = 0.30$).

Results of Model Validation from 2005 - 2009 for Corpus Christi Bay and Nueces Bay

The last validation period from 2005 to 2009 compares simulated TxBLEND salinities to observed salinities obtained from the TWDB's datasonde sites in Corpus Christi Bay and Nueces Bay. There was slight disagreement between all three datasets of modeled data, point measurement data, and datasonde data, but long-term trends were captured. Compared to the 2000 - 2004 calibration period, the model's performance was not as good, as can be seen from the salinity comparison at the Corpus Christi Bay site (r^2 = 0.54 for calibration period (Figure 43) and r^2 = 0.49 for validation period (Figure 57)). Nonetheless, salinity response during flooding events in 2005 and 2007 were simulated well at the Nueces Bay site (Figure 59).

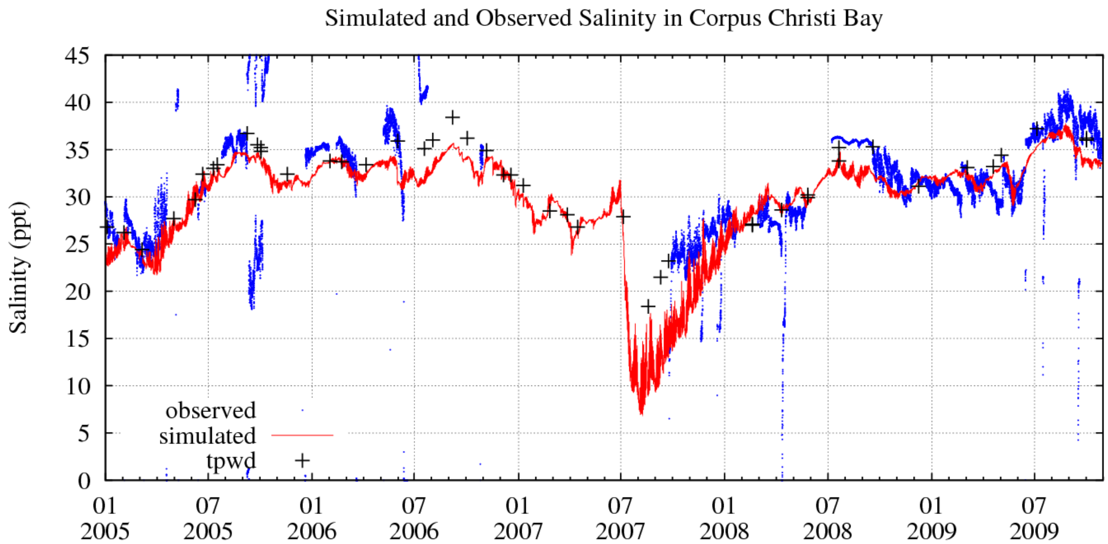


Figure 57. Simulated (*red*) and observed (*blue*) salinities at the Corpus Christi Bay site for the validation period 2005 to 2009. Point measurement data collected by TPWD (+) near this site was included for comparison.

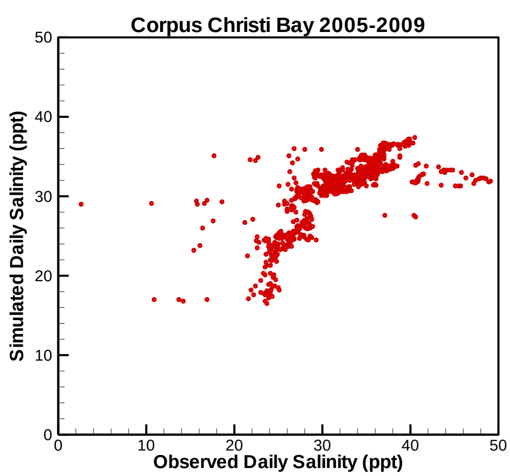


Figure 58. Scatter plot comparing simulated to observed salinities at the Corpus Christi Bay site for the validation period from 2005 to 2009 (r^2 = 0.33).

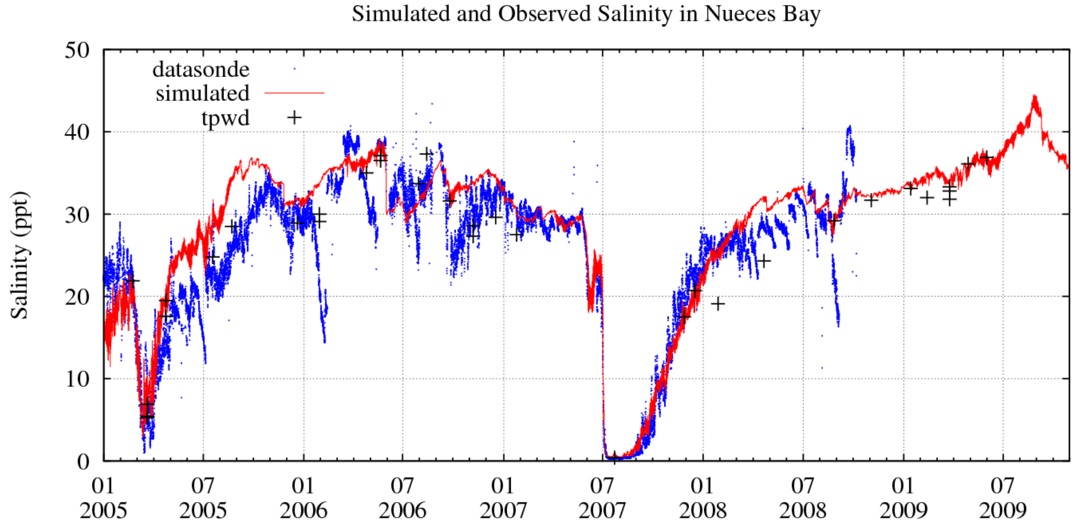


Figure 59. Simulated (*red*) and observed (*blue*) salinities at the Nueces Bay site for the validation period 2005 to 2009. Point measurement data collected by TPWD (+) near this site was included for comparison.

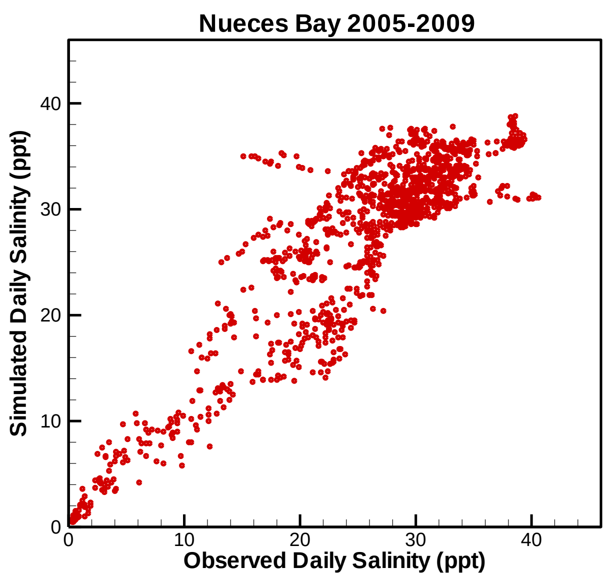


Figure 60. Scatter plot comparing simulated to observed salinities at the Nueces Bay site for the validation period from 2005 - 2009 ($r^2 = 0.84$).

Discussion

Model calibration for discharge and velocity show that the model was representative of observed discharge and velocities at most locations, except where there were few observed measurements available for comparison. Although the model slightly under-predicted or over-predicted maximum discharge and velocity in specific cases, overall trends were captured well. Increased current velocities near the entrance to the Gulf and reduced current velocities near upstream sites were well simulated. The TxBLEND model also captured the difference between increased currents in deep ship channels and reduced currents in shallower areas of the bay system. Simulated tidal elevations were representative of observed tidal elevations at most all locations, as evidenced by the high r^2 values. Maximum model performance was observed at the Port Aransas and Bob Hall Pier gages, indicating that the main tidal exchange between the bay and the Gulf of Mexico was simulated accurately.

Results for salinity calibration demonstrate that the TxBLEND model for the Nueces Estuary is representative of observed salinities. Although short- and long-term variability are simulated reasonably well at most sites, the model tended to under predict rising salinities in some cases. This type of model behavior has also been observed in TxBLEND models for other systems at locations near the upstream boundary of model grids. This pattern could be affected by multiple factors, such as application of model parameters like the dispersion coefficient or representation of salinity initial conditions which are set to 0 ppt salinity at river inflow points. Nevertheless, the difference between mean simulated salinity and mean observed salinity was less than 2 ppt at all locations, further indicative of overall model performance.

The validation exercises to simulate bay conditions for three different time periods showed that short-term fluctuations and long-term trends were reasonably well simulated. However, when compared to the 2000 - 2004 calibration period, model performance decreased, as shown by the lower r^2 values. Similar to the calibration exercises, in specific cases the model either under-predicted or over-predicted salinity. The model performed well in the validation exercise at two locations, the Nueces Bay site and the Aransas Bay site. On the other hand, the model did not perform as well at the other two locations, the Corpus Christi Bay site and the GIWW at JFK Causeway site.

In cases where the model is less representative of observed salinity measurements, many different factors, whether model or non-model related, may have affected the evaluation of model performance. Model disagreement with datasonde and TPWD observed data could be caused by instrument error, limitations of the two-dimensional TxBLEND model, or application of model parameters. Major factors that contribute to unsatisfactory salinity simulations are lack of sufficient salinity data for boundary specification and the lack of representation in the model of the exchange between wetland areas and the bays. In some cases, localized rainfall events are not recorded by a rainfall gage, and hence are not included in the model. Thus, the model does not accurately represent these inflows, which limits the ability of the model to accurately predict salinities.

In general, the TxBLEND model predicts long-term trends in the Nueces Estuary reasonably well. Nueces and Corpus Christi Bays, as with other Texas bays, are generally very shallow and have minimal tidal fluctuations. In theory, a two-dimensional hydrodynamic model such as TxBLEND should be capable of modeling the bays accurately. However, the presence of deep navigational channels and strong winds generates three-dimensional circulation features that inherently cannot be captured by a two-dimensional model. Therefore 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.

Literature Cited

Brandes, R.J. and F.D. Masch. 1972. *Tidal hydrodynamic and salinity models for coastal bays, evaporation considerations.* Report to Texas Water Development Board. F.D. Masch and Associates, Austin, Texas.

Gray, W.G. 1987. *FLEET: Fast Linear Element Explicit in Time Triangular Finite Element Models for Tidal Circulation, User's Manual*. University of Notre Dame, Notre Dame, Indiana.

Kinnmark, I.P.E. and W.G. Gray. 1984. An implicit wave equation model for the shallow water equations. *Advances in Water Resources* 7:168-171.

Guthrie, C.G., C. Schoenbaechler, Matsumoto, J., and Q. Lu. 2011. *Comparison of Two Hydrology Datasets, as Applied to the TxBLEND Model, on Salinity Condition in Nueces Bay*. Texas Water Development Board, Austin, Texas.

Masch, F.D. 1971. *Tidal hydrodynamic and salinity models for San Antonio and Matagorda Bays, Texas.* Report to Texas Water Development Board. F.D. Masch and Associates, Austin, Texas.

TWDB. 1999. *User's Manual for the Texas Water Development Board's Hydrodynamic and Salinity Model: TxBLEND*. Texas Water Development Board, Austin, Texas.

Schoenbaechler, C., C.G. Guthrie, and Q. Lu. 2010. *Coastal Hydrology for the Mission-Aransas Estuary*. Texas Water Development Board, Austin, Texas.

Schoenbaechler, C., C.G. Guthrie, and Q. Lu. 2011a. *Coastal Hydrology for the Nueces Estuary: Hydrology for Version TWDB201101 with Updates to Diversion and Return Data for 2000 - 2009*. Texas Water Development Board, Austin, Texas.

Schoenbaechler, C., C.G. Guthrie, and Q.Lu. 2011b. *Coastal Hydrology for the Laguna Madre Estuary, with Emphasis on the Upper Laguna Madre*. Texas Water Development Board, Austin, Texas.