Marsh Elevation Survey

Marsh surface elevation greatly influences the vegetative composition as well as the vulnerability of the marsh to degradation from prolonged flooding and soil anoxia. LDNR contracted with John E. Chance and Associates, Inc., Lafayette, Louisiana, to develop a network of GPS elevational benchmarks and survey marsh elevations at strategically selected locations. In the Calcasieu-Sabine Basin, where land loss relates more to saltwater intrusion than to excessively high water levels, we wanted to gain a better understanding of how marsh elevation may relate to proposed hydrologic alterations of current freshwater inflow regimes of the Sabine River.

Establishing a comprehensive network of GPS elevational benchmarks throughout the Louisiana Chenier Plain will greatly facilitate our understanding of system hydrology. Once the GPS network is established, determining wetland elevation at almost any location in the region will be relatively simple and inexpensive. These data will be critical to future modeling efforts, but more importantly, they will immediately improve our ability to effectively plan, implement, and monitor restoration projects. Over a period of 10-15 years, these benchmarks and elevations will assist in the development of a technically sound estimate of near-surface subsidence in the region.

The purpose of the RTK (Real-Time Kinematic) Survey was to establish accurate horizontal and vertical positions on existing marsh at strategically selected transect and sampling locations previously occupied under the Chabreck and Linscombe (1997) vegetative survey. Ten marsh elevation readings were collected at each sample location using an RTK data collector. These locations were determined in the field by Louisiana Department of Natural Resources, Coastal Restoration Division personnel at the time of survey.

The survey collected a total of 177 marsh elevation measurements at 16 locations over a 2-day period in September 1999. Average marsh elevation was 1.58 ft NAVD-88 with a standard deviation of 0.17 ft. The highest marsh elevation recorded was 2.09 ft NAVD-88 and the lowest was 1.14 ft NAVD-88.

Additional information on the methodology of this marsh elevation survey can be found in Appendix D.

Hydrodynamic Modeling of the Calcasieu-Sabine Basin

Background

We carried out hydrologic modeling of the Calcasieu-Sabine Basin to achieve a better understanding of flow patterns within the basin and the effects of future hydrologic alterations. Hydrodynamics of the Calcasieu-Sabine Basin involve a combination of estuarine processes, including saltwater intrusion induced through navigation channels, meteorological and wind-driven tides, freshwater and saltwater mixing, and the development of high-velocity currents in nearshore shallow regions. Because the basin is affected by navigation channels that are strongly stratified by salinity differences, we chose a three-dimensional model. A robust, flexible, and efficient numerical model is required to incorporate all of these processes in an operational program.

For this study, we used a three-dimensional finite-difference hydrodynamic model (H3D) to simulate the hydrodynamic characteristics of the Calcasieu-Sabine estuarine system. H3D provides the three components of velocity (two horizontal and one vertical), as well as scalar quantities, such as water levels, temperature, and salinity distribution, on a Cartesian three-dimensional grid. The model is fully unsteady, meaning that it responds to time-varying salinity and water level forcing at open boundaries, time-varying river inputs, and time-varying wind stress.

We calibrated and validated the H3D model using a 1-yr record of hourly water levels and salinity values representing a full seasonal cycle at different measuring stations strategically located within the Calcasieu-Sabine Basin. Because the H3D system is a physically-based model, it can be used to simulate flow and salinity patterns for the basin outside the range of the calibration field data for different hydrologic conditions. Therefore, after the model has been calibrated and validated, it can be used to simulate the effects of human-induced hydrologic changes in the basin. The model can be modified to simulate changes in salinity, water level, flow pattern, and velocities induced by the addition of hydraulic structures, widening or deepening of navigation channels, or changing the volumes of freshwater inflow to the basin.

Model Development

Geographic and Topographic Data

We used USGS 7.5-minute quadrangle maps to digitize the boundaries of the different rivers, bayous, channels, and lakes within the Calcasieu-Sabine Basin. We also acquired the geometric properties of the flow cross sections of the different streams, such as width and depth, and incorporated them into the digitized map. In addition, we used NOAA navigation charts to extract bathymetric information for the Calcasieu and Sabine lakes, which was also incorporated into the digitized map. Finally, we produced a complete digitized grid of the Calcasieu-Sabine Basin with all the relevant topographic and bathymetric details. Figure 38 illustrates the general layout of the model grid and boundaries used to describe the Calcasieu-Sabine Basin.

Boundary Conditions

We collected the necessary boundary information for the Calcasieu-Sabine Basin, then compiled it and used it as input for the H3D model. The boundary conditions include hourly values for the freshwater discharges of the Calcasieu, Sabine, and Neches rivers, wind speed and directions within the basin, water temperatures, and water level and salinity

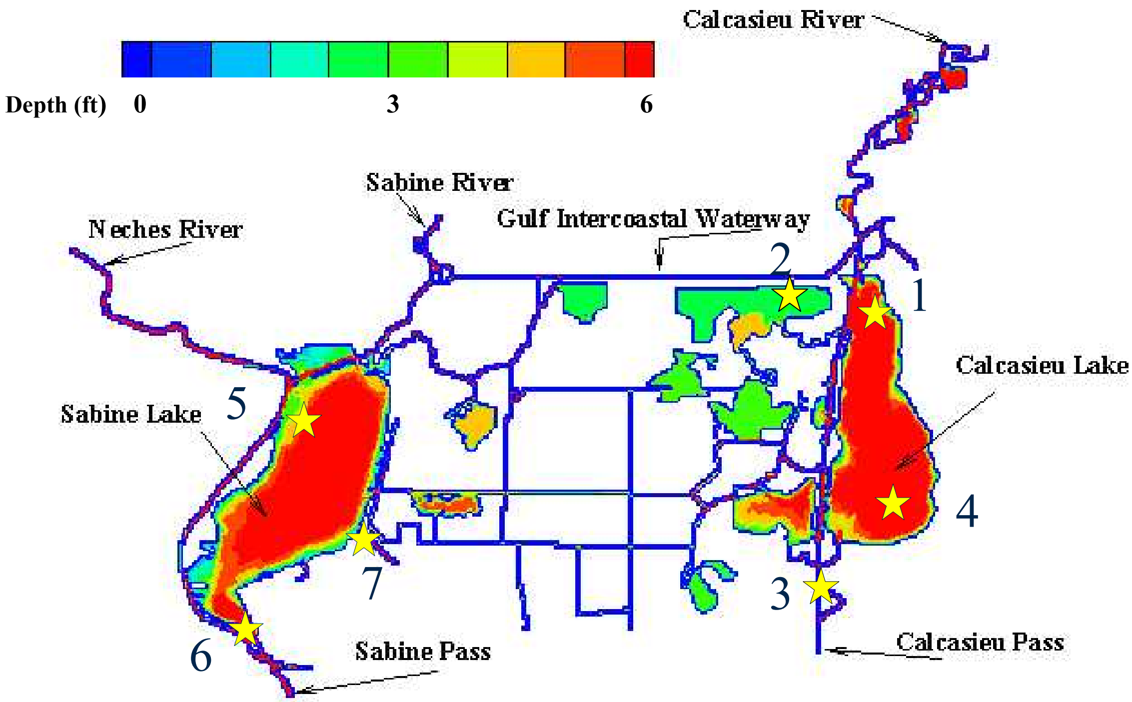

Figure 38. General layout of the grid and boundaries used to describe the Calcasieu-Sabine Basin, showing the location of the seven gauge stations used for model calibration.

records at Calcasieu and Sabine passes near the Gulf of Mexico. We determined that 1998 represented the most complete data set, so these data were used for model calibration and validation.

Model Calibration and Validation

We compiled hourly water level and salinity records for seven gauge stations within the Calcasieu-Sabine Basin. Once set up with digitized topographic and bathymetric details of the basin and boundary conditions, the H3D was then set to simulate the hydrodynamics for the Calcasieu-Sabine estuarine system for a 1-yr simulation. The resulting modeled values were compared with their corresponding water level and salinity records at the different gauge stations. The H3D model successfully reproduced water level and salinity patterns within the Calcasieu-Sabine Basin, indicating that the model is capable of simulating hydrodynamics for the different hydrologic conditions in the basin that fall outside the range of tested conditions.

Results

Calibration and Validation Results

The modeled values compared well with their corresponding recorded water level and salinity values at the seven gauge stations (Figures 39-45).

To quantitatively assess the accuracy of H3D, we compiled the root mean square (RMS) errors between the modeled and measured values of water levels and salinities. Table 19 shows a summary of the results of the error analysis between the modeled and recorded values, giving RMS error values and percentages for each station.

As shown in Table 19, for all the stations along the full seasonal cycle the RMS error values ranged between 1.94 and 4.93 ppt for salinities, and between 0.29 and 0.6 ft for water levels. RMS error percentages ranged between 12.39 and 17.47% for salinities and between 5.59 and 10.88% for water levels. Given that these error values also account for the sometimes-inherent inconsistency of the measured values due to human errors or equipment malfunction, these results represent a reasonable agreement between the recorded and modeled values for all the stations.

The results depicted here and the findings of our error analysis demonstrate that the flow and salinity pattern relationships provided by H3D can reasonably represent the hydrodynamics of the Calcasieu-Sabine Basin.

The results of the H3D model can be presented in an animated fashion to better understand the dynamics of water flow and salinity variation with time. These movies present a visual depiction of water flow and salinity patterns over time. The movies can present these patterns either for the entire Calcasieu-Sabine Basin as a plan view of a certain

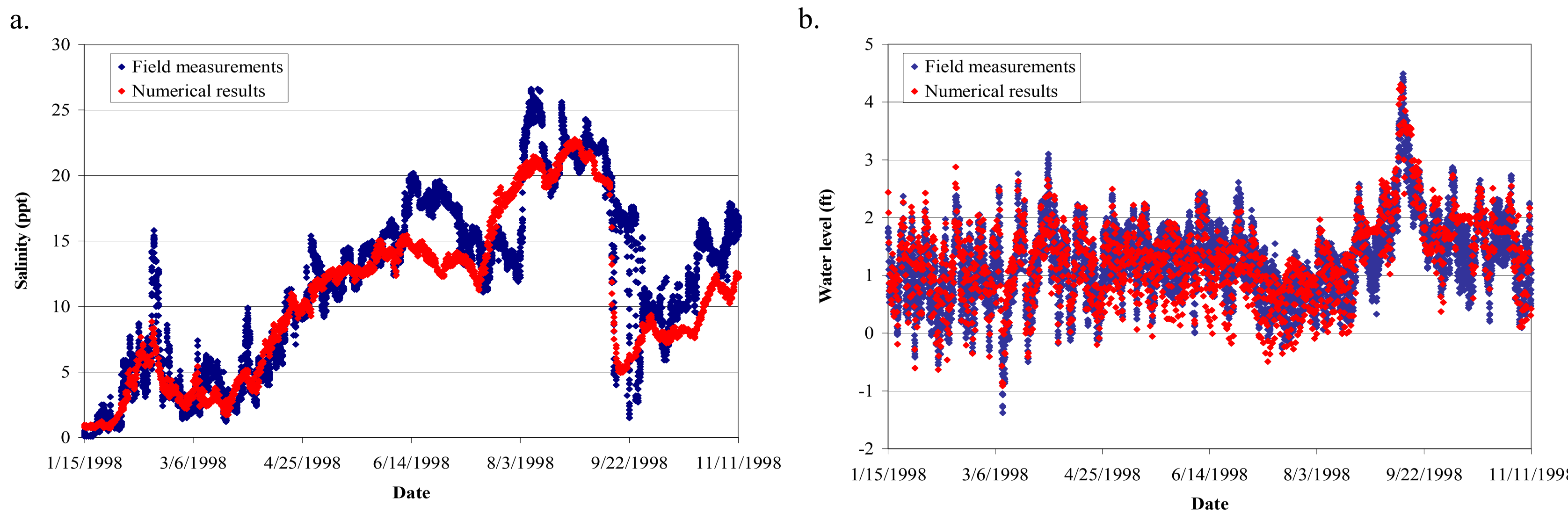

Figure 39. Comparison between measured and modeled a. salinity values, and b. water level values at North Calcasieu Lake near Hackberry, Louisiana (USGS Gauge Station 08017095).

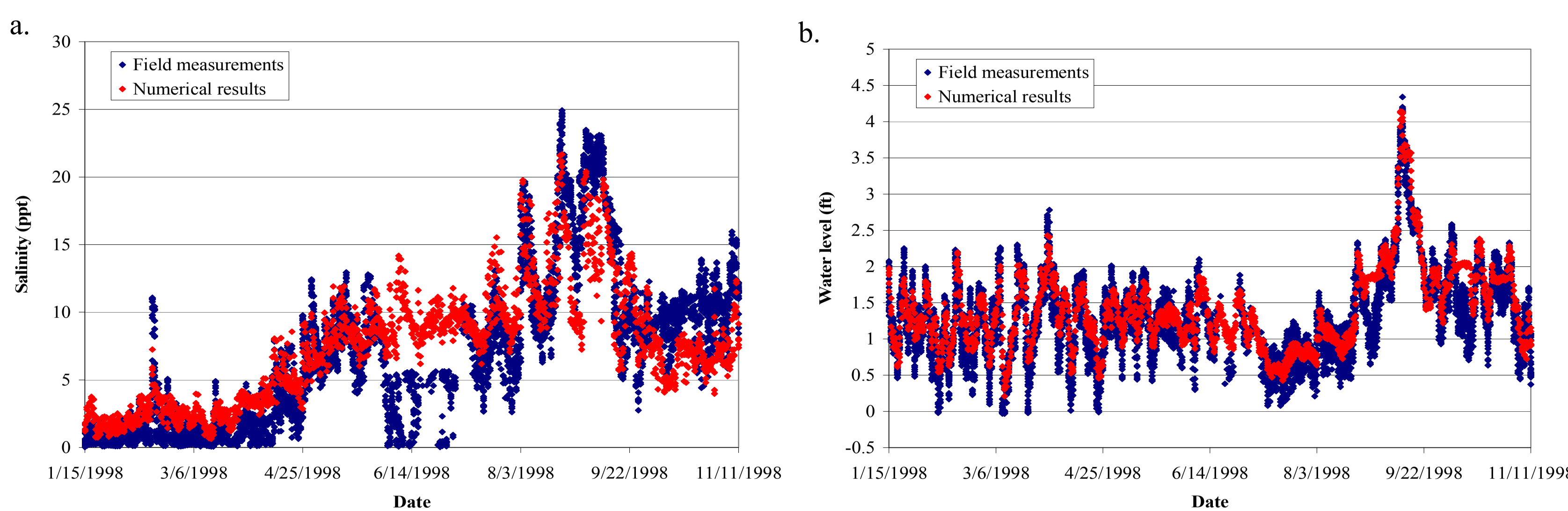

Figure 40. Comparison between measured and modeled a. salinity values, and b. water level values at Brown Lake (Station CS09-02R).

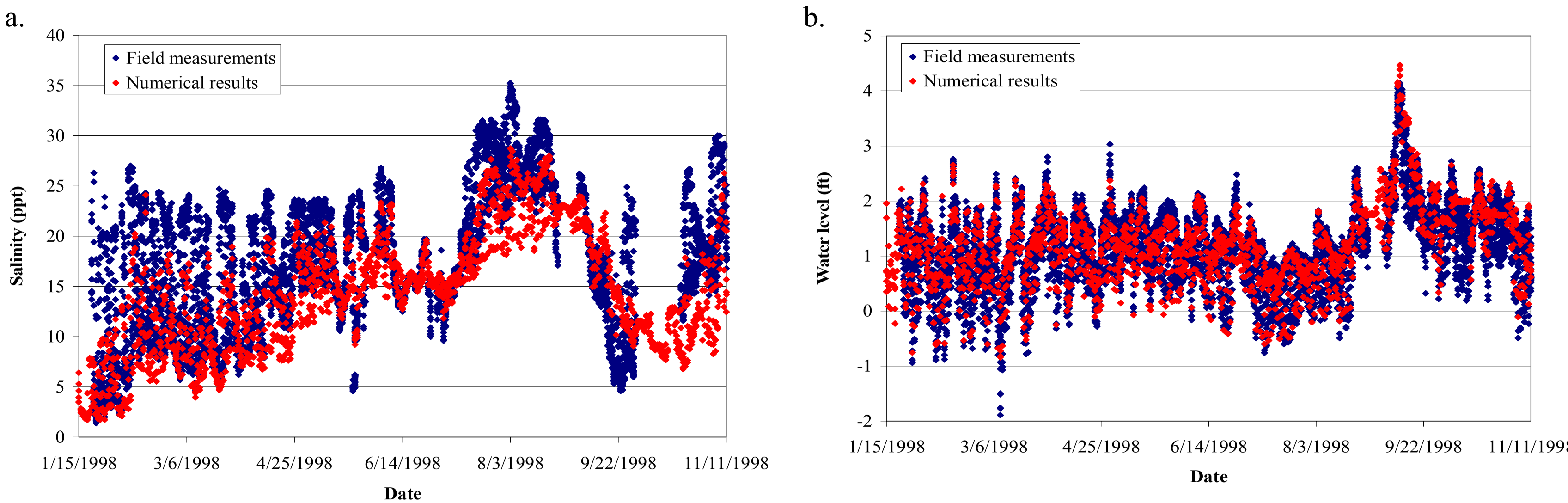

Figure 41. Comparison between measured and modeled a. salinity values, and b. water level values at Calcasieu River at Cameron, Louisiana (USGS Gauge Station 08017118).

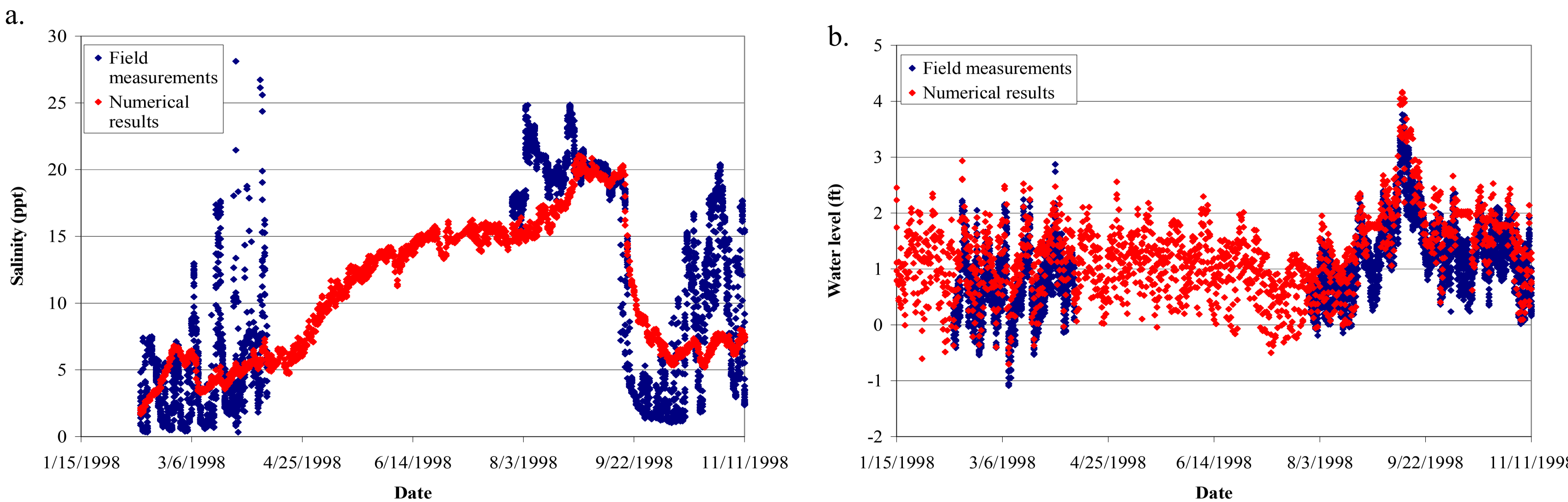

Figure 42. Comparison between measured and modeled a. salinity values, and b. water level values at South Calcasieu Lake (Station CS17-1R).

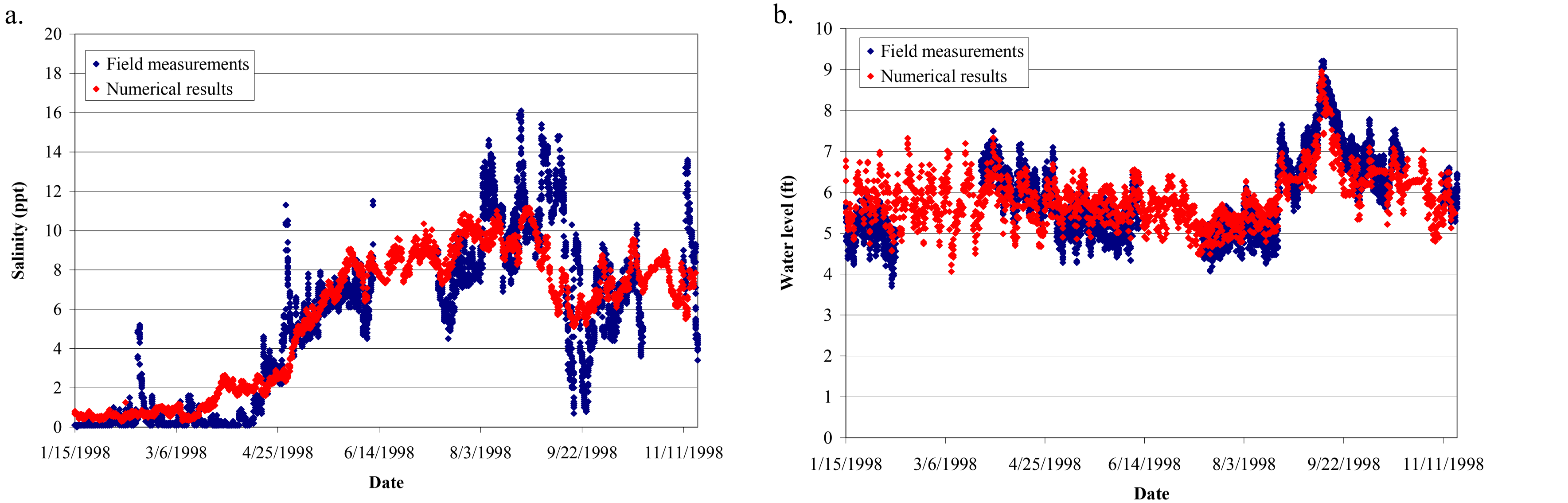

Figure 43. Comparison between measured and modeled a. salinity values, and b. water level values in Upper Sabine Lake at Platform A.

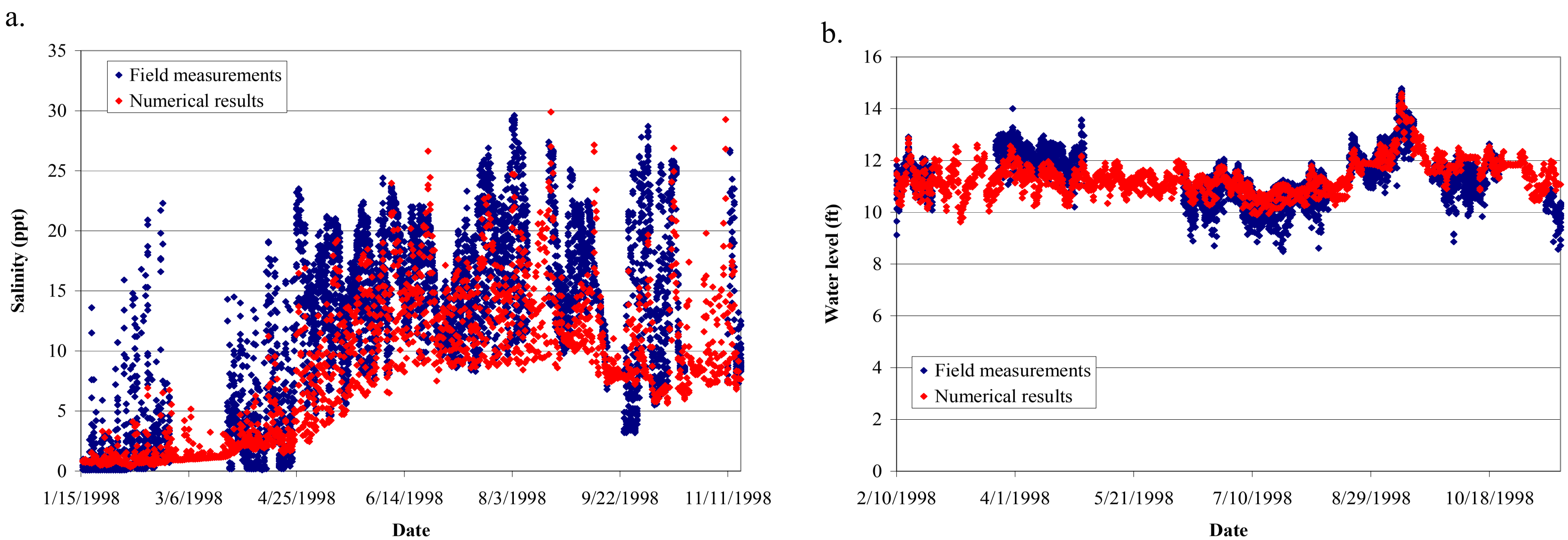

Figure 44. Comparison between measured and modeled a. salinity values, and b. water level values at Lower Sabine Lake.

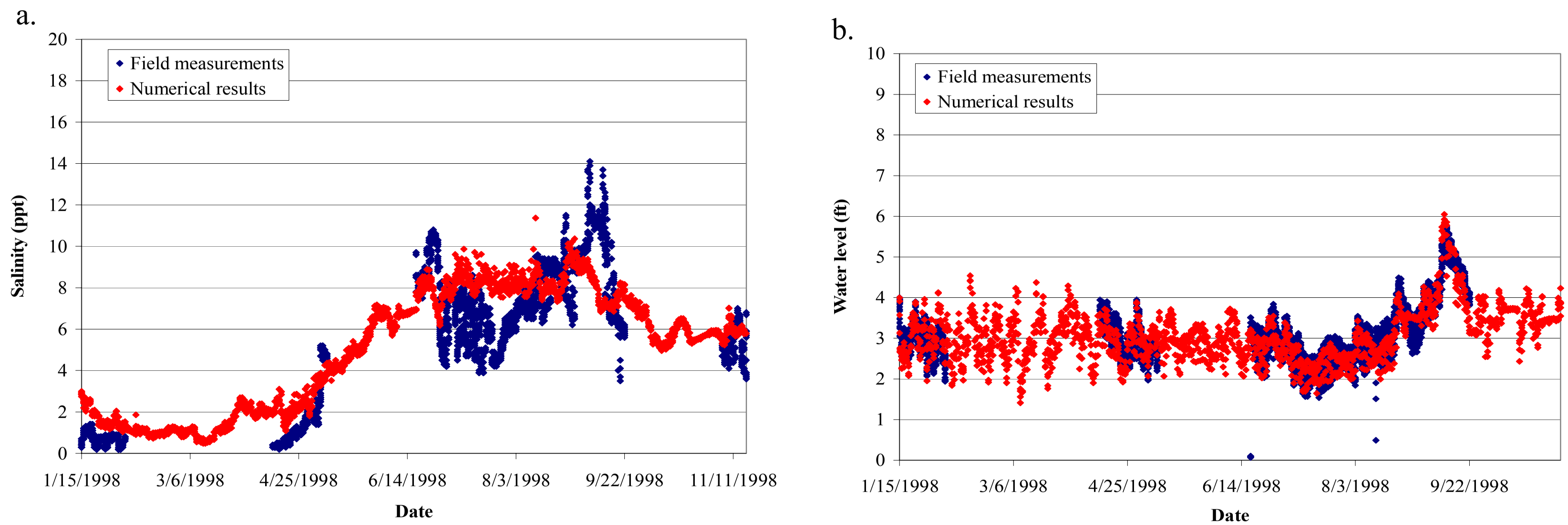

Figure 45. Comparison between measured and modeled a. salinity values, and b. water level values at Johnson's Bayou.

Table 19. Summary of error analysis of the H3D model.

Station	Salinity data			Water level data		
	Correlation coefficient (%)	RMS error (ppt)	RMS error (%)	Correlation coefficient (%)	RMS error (ft)	RMS error (%)
09-2R	80.95	3.41	14.09	89.23	0.29	6.57
95	88.64	3.27	12.39	89.71	0.32	5.65
118	81.42	4.86	14.37	90.40	0.32	5.59
17-1R	80.85	4.61	17.47	88.07	0.51	10.88
Johnson's Bayou	85.15	1.94	14.19	88.94	0.37	8.92
Lower Sabine	82.06	4.93	16.88	79.55	0.60	9.51
Upper Sabine	81.22	2.20	13.93	89.46	0.49	8.33

layer, or as a vertical slice along a specific area. Figure 46 shows a "snapshot" frame of the salinity contour map at the water surface for the Calcasieu-Sabine estuary. Similarly, Figure 47 shows a snapshot frame of the longitudinal profile of salinity (i.e., salinity distribution along the depth) along the Sabine-Neches Ship Channel.

Simulation of the Sabine-Neches Ship Channel Expansion

After calibrating and validating the H3D model, we used it to simulate the effects of proposed Sabine-Neches Ship Channel expansion on the flow and salinity patterns within the Calcasieu-Sabine Basin. Changes were incorporated into the model grid to increase the existing channel dimensions of 400-ft width and 40-ft depth to the proposed dimensions of 500 ft and 50 ft, respectively. Although the Sabine-Neches Ship Channel continues south through Sabine Pass to the Gulf of Mexico, the current model boundary is at Sabine Pass; therefore, the results presented herein should be considered only qualitatively. Deepening of the Sabine-Neches Ship Channel to the 50-ft contour in the Gulf of Mexico would entail deepening of the channel from Sabine Pass gulfward over a distance of more than 30 mi to reach the 50-ft depth. Based on the assumption that a deeper, wider, and longer channel will carry more saltwater into the basin during the flood tide, the model results represent a conservative simulation of projected salinity increases.

For the three Sabine gauge stations, the modeled water level and salinity values under conditions of the simulated channel expansion were compared with their corresponding modeled values for existing conditions. The simulated proposed expansions resulted in increased salinity values at these stations (Figures 48-50).

To present the effect of the proposed expansions visually, we generated movie representations of flow and salinity variation with time. The movies presented the patterns for the entire Calcasieu-Sabine Basin as a plan view of the surface layer, and as a vertical slice along Sabine Channel and Sabine Lake. Visual inspections of these movies and those representing existing conditions are very useful for enhancing an understanding and evaluation of the effects of the proposed expansions.

Simulation of the Gated Sabine Channel

We also used the H3D model to simulate the salinity control that could be attributed to the installation of a navigable gate in conjunction with the Sabine-Neches Channel expansion. The proposed gate has a 100-ft-wide and 9-ft-deep opening when it is closed, to allow for drainage and ingress and egress of estuarine organisms. This cross-sectional area is similar to the 1908 dimensions of the Sabine-Neches Channel. The location of the simulated gate is immediately south of Station 6 (Figure 38). In the simulation, the gate was assumed to be in the closed position. For the three Sabine gauge stations, the modeled water level and salinity values with the gate were compared to their corresponding modeled values for both existing and channel expansion conditions (Figures 48-50). The simulated salinity reduction at these stations caused by the constriction of the flow from the gulf at the channel suggests

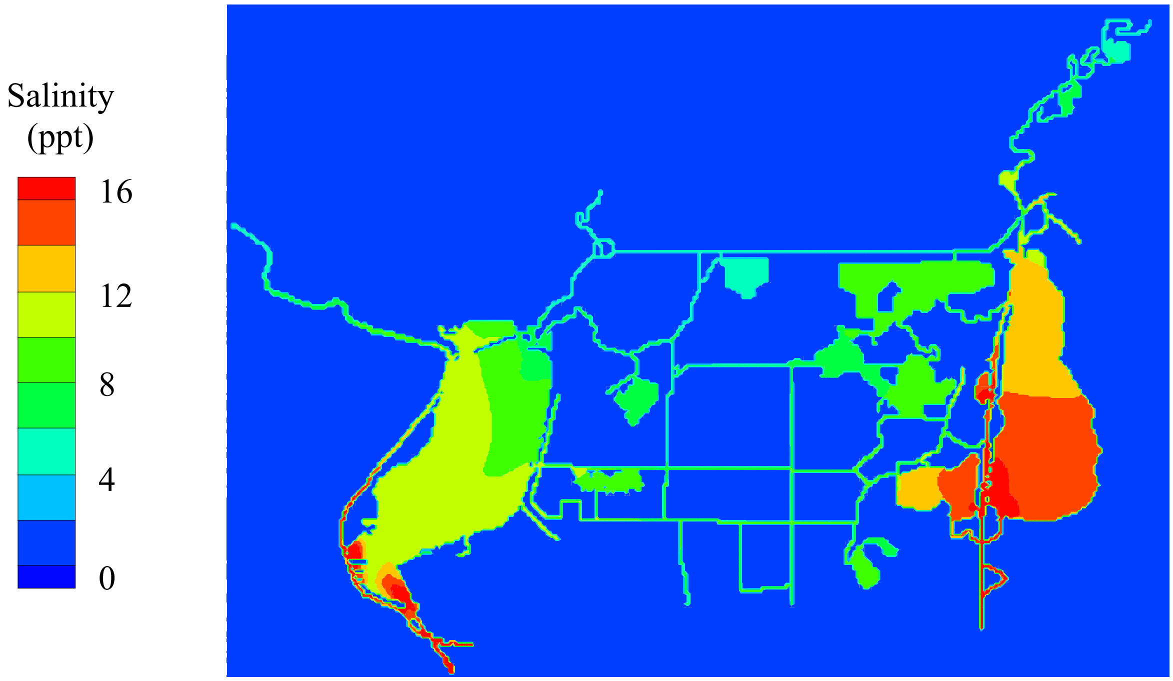

Figure 46. Typical model output showing a salinity map of the water surface for the Calcasieu-Sabine Basin, 17 July 1998.

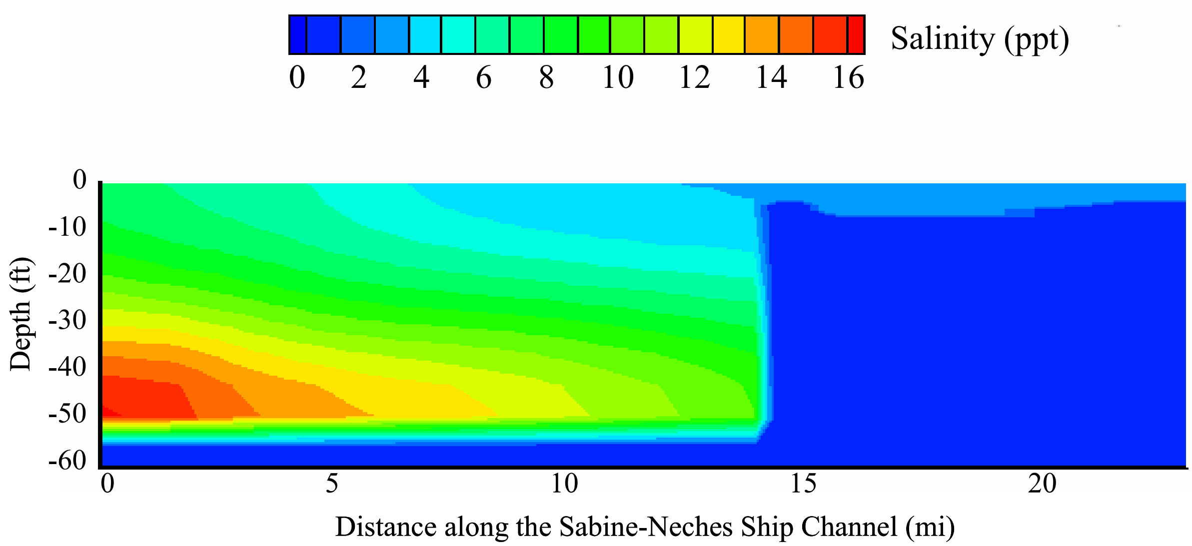

Figure 47. Typical model output showing a longitudinal profile of salinity along the Sabine-Neches Ship Channel, 7 April 1998.

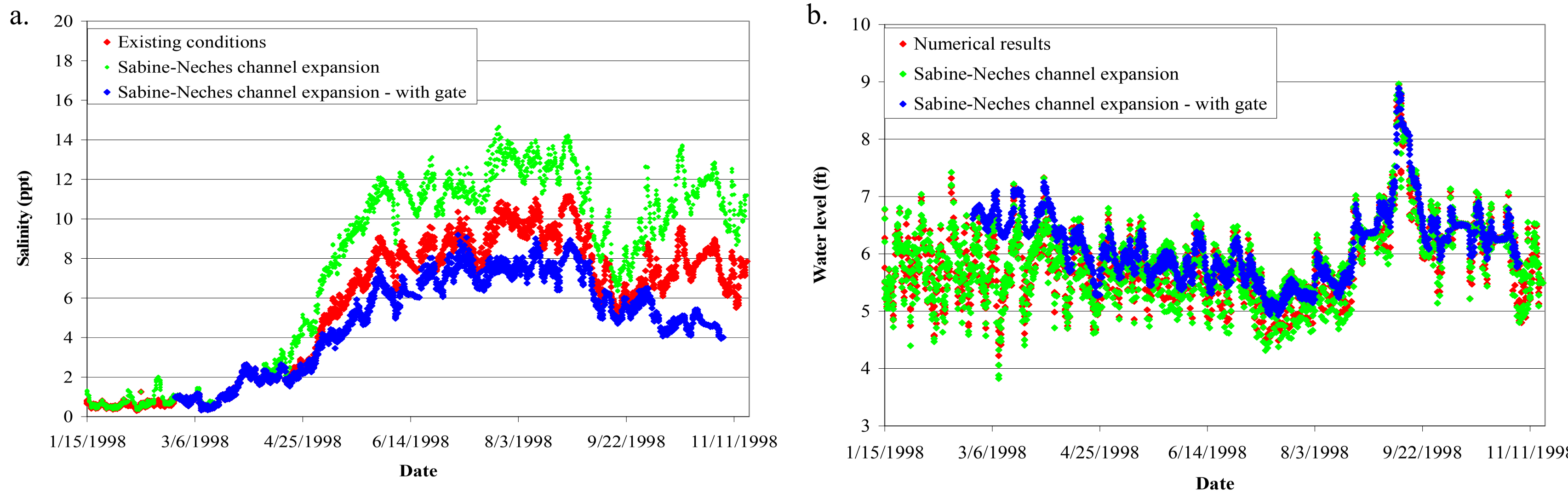

Figure 48. Comparison between modeled a. salinity values, and b. water level values for existing conditions, proposed Sabine-Neches channel expansions, and a navigable gate at Sabine Pass in Upper Sabine Lake at Platform A.

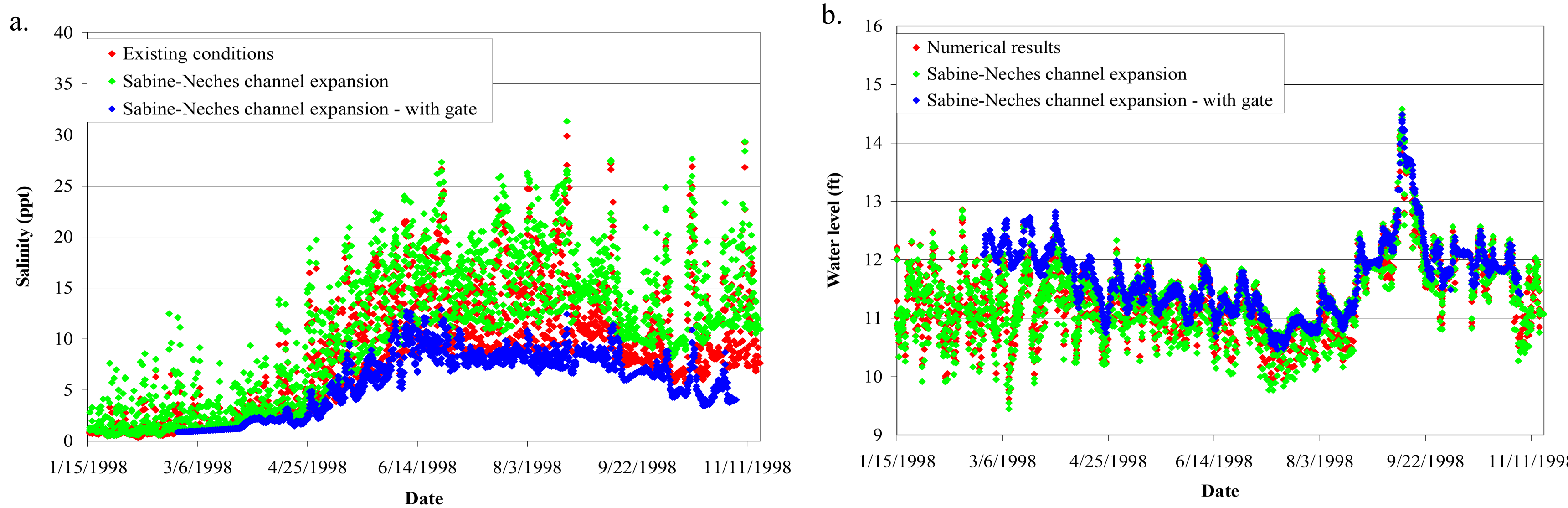

Figure 49. Comparison between modeled a. salinity values, and b. water level values for existing conditions, proposed Sabine-Neches channel expansions, and a navigable gate at Sabine Pass in Lower Sabine Lake.

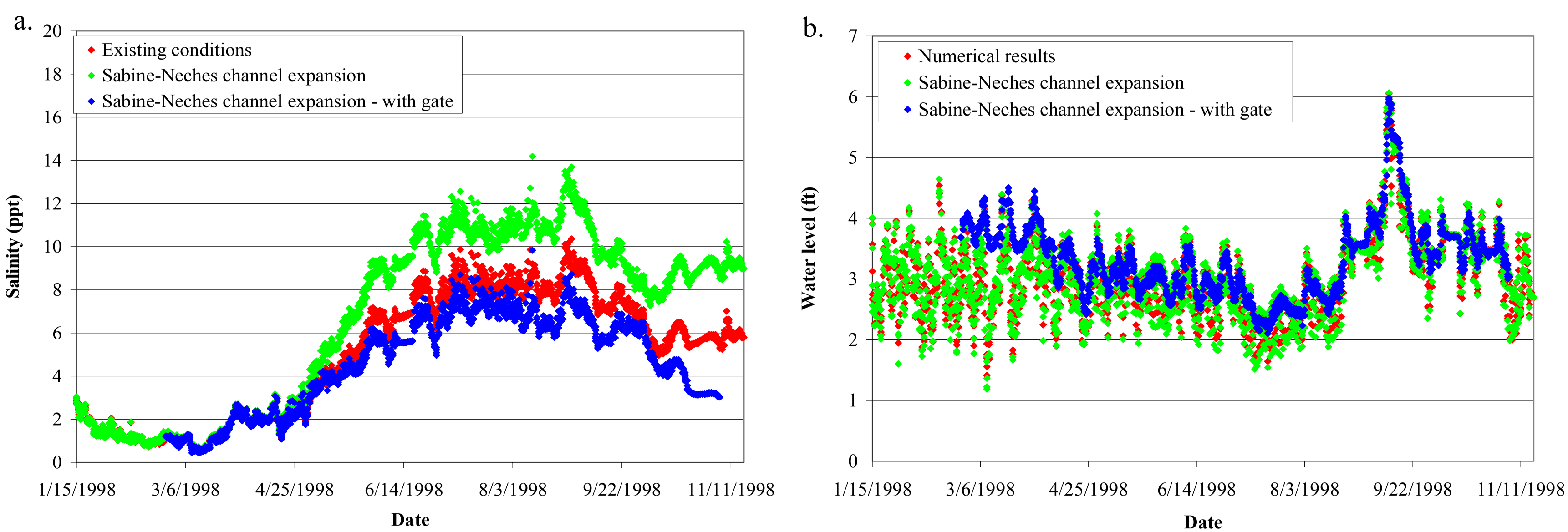

Figure 50. Comparison between modeled a. salinity values, and b. water level values for existing conditions, proposed Sabine-Neches channel expansions, and a navigable gate at Sabine Pass at Johnson's Bayou.

that the introduction of such a constriction could reduce salinity to values less than those under existing conditions.

For a visual presentation of the effect of the proposed expansions, we generated a movie representation of salinity variation with time along a vertical slice of the Sabine Channel and Sabine Lake. The movie provides a very useful visual inspection that facilitates the understanding and evaluation of the effect of the introduction of the gate.

Calcasieu-Sabine Basin: Management Recommendations

Human-induced hydrologic alterations caused largely by navigation corridors and oil and gas exploration have resulted in dramatic changes to the Calcasieu-Sabine estuarine landscape. Incremental expansions of the Sabine-Neches Ship Channel and the Calcasieu Ship Channel have occurred to the extent that the present-day channel cross-sectional areas are more than forty times larger than when the channels were first dredged in the late 1800s. These changes have affected the hydrology of the Calcasieu-Sabine Basin in three ways: the channelization of saltwater into the historical low-salinity estuary, a more rapid loss of riverine freshwater inflows when the tide ebbs, and increased tidal amplitude.

Construction of the Gulf Intracoastal Waterway bisected the Gum Cove Ridge, connecting the Calcasieu Ship Channel and the Sabine-Neches Ship Channel. Hydrologically, this resulted in the coupling of the Calcasieu and Sabine basins, which historically shared very little water exchange, into one single basin. It also dramatically altered hydrologic circulation by “short circuiting” the historical north-south estuarine gradient to divert upland freshwater inflows to the east and west.

Historical patterns and causes of habitat change are all tied directly to human activities, primarily those associated with the exploration, development, and transportation of petrochemicals. Although natural resource management activities have had a lesser effect, they have led to landscape changes and freshening trends in the present-day Sabine National Wildlife Refuge impoundments and the Cameron-Creole Watershed Project. These impoundments now include most of the fresh marsh in the Calcasieu estuary, but they have also resulted in deliberate land loss, as evidenced in the Pool Three unit of the SNWR.

In general, the salinity regime of the Calcasieu-Sabine Basin is reflected in the marsh habitat types that exist there today. Analyses of habitat shifts reveal no basin-wide shift toward more saline environments since 1949, but there have been site-specific shifts toward more saline environments adjacent to the Calcasieu Ship Channel. That is not to say that habitats have remained stable. Saltwater intrusion induced through navigation channels, petrochemical exploration, storms, and herbivory have cumulatively caused catastrophic land loss and major plant community changes over the past 50 years. The greatest evidence of this is the loss of saw grass as the dominant wetland community in the late 1950s and early 1960s. Marsh plant communities are determined, in large part, by the salinity regime to which they are exposed. We have shown that the salinity regime in the Calcasieu-Sabine Basin varies substantially spatially as well as temporally across the seasonal, annual, and decadal time scales. Historical marsh habitat maps illustrate the continual dynamic of habitat changes toward fresher or more saline habitat types and then back again.

We have identified and depicted a strong negative correlation between Sabine River discharge and salinity across the Calcasieu-Sabine Basin. This negative correlation suggests that Sabine River discharges may be a factor in moderating salinities in upper Calcasieu Lake during part of the year. In general, we surmise that salinity spikes occur whenever Sabine River discharge dips below roughly 5,000 cfs. Conversely, whenever Sabine River inflow exceeds roughly 15,000 cfs, most of the estuary is fresh. The average discharge of the Sabine River is approximately 8,600 cfs, with peaks approaching 50,000 cfs and low discharges dropping below 1,000 cfs.

Most of the salinity sampling stations across the basin are more strongly correlated with Sabine River discharge than with Calcasieu River stage. Rainfall and wind-driven tides undoubtedly also play important roles in moderating salinity, but our records are insufficient to make a strong statistical correlation between salinity and rainfall.

Two ongoing activities threaten the freshwater inflows into the Calcasieu-Sabine Basin. Our primary concern is with a proposal by the Jefferson County Navigation District of Beaumont, Texas, to further expand the Sabine-Neches Ship Channel to 50 ft deep and 500 ft wide, from the Gulf of Mexico to the Port of Beaumont. This proposal is currently under feasibility study by the USACE Galveston District. A wider, deeper channel would be expected to exacerbate saltwater intrusion during the flood tide and freshwater outflow during the ebb tide. These changes would result in still less freshwater in the marsh and thus higher salinities.

Hydrologic modeling of the proposed channel expansion simulated that a channel of these dimensions would increase salinity on average by 2-3 ppt in the Calcasieu-Sabine Basin. That simulation used 1998 Sabine and Neches river inflows and represents a fairly average inflow year. Presumably, increases in salinity would be even greater during periods of drought and very low freshwater inflows into the estuary. Regardless, a salinity increase of this magnitude can have adverse impacts on fresh and intermediate wetlands in the region. The increase may be sufficient to cause the loss of fresh marsh to open water or at least a conversion to an intermediate marsh type. It also may be sufficient to cause a shift from intermediate marshes to brackish ones. If either or both of these conditions occur, a substantial decrease in biodiversity can be expected, as well as associated impacts to nonrenewable natural resources. A model simulation of the channel cross section similar to the 1908 condition, with a navigable gate installed at Sabine Pass, produced a very different result: a corresponding reduction in the current salinity regime by 2-3 ppt.

The other cause for concern over reductions of freshwater inflow in the Calcasieu-Sabine Basin arises from the East Texas Water Plan as developed under Texas Senate Bill One (Region I). Although this program’s projected inflow reduction is relatively small, its environmental impact should be considered cumulatively with that of digging a deeper ship channel.

We believe that the ecological sustainability of the Calcasieu-Sabine Basin is imperiled to the point that historical, healthy habitats are no longer stable and are undergoing rapid shifts. If we maintain the status quo, the estuary faces very real threats from continuing and potentially worsened saltwater intrusion induced by navigation channels. That is the bad news for this ecosystem, but the good news is that it need not end up this way. We can take two obvious paths toward coastal restoration efforts in the Calcasieu-Sabine Basin. With one, we continue a very localized approach of installing structures along the perimeter of the basin and quasi-isolating the estuary in the hope that we can stave off the ongoing loss of habitat and biodiversity. Our other option is a potentially more innovative approach to addressing saltwater and tidal intrusion at its sources. This involves installing navigable gates or locks at the mouths of the Sabine-Neches Waterway and the Calcasieu Ship Channel while maintaining more historical channel cross-sections for drainage and organism ingress and egress. We should utilize state-of-the-art technology to create solutions to the obvious conflicts with navigation interests that require the deep-draft channels for national commerce. Both the environmental and business communities will benefit by not focusing on perceived conflicts between protecting ecosystem integrity and economic gain, but rather on finding solutions that are workable and mutually acceptable.

The achievability of long-term sustainability and a naturally functioning ecosystem requires the restoration of a more natural hydrologic regime. This is within our grasp for the Calcasieu-Sabine Basin.

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