# ATTACHMENT N

## Cross Florida Greenway: Watershed Evaluation Evaluation of Alternative Flow Scenarios

SUBMITTED BY DAN HILLIARD

# Cross Florida Greenway: Watershed Evaluation Evaluation of Alternative Flow Scenarios Using Hydrodynamic Models

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# EXECUTIVE SUMMARY

Changes to the Lower Withlacoochee River due to construction of portions of the Cross Florida Barge Canal have reduced flows to the tidal portion of the river from those that were observed historically. Concerns have been raised regarding the effects of the decline in flows through the system on the lower river's biota. These concerns are related to the death and stress of bald cypress trees along the lower river, and to other changes in vegetation and associated decline in fish habitat. A study completed for the District (Stahl and Griffin, 2006) included sampling a subset of the dead cypress trees along the lower river. This study concluded that the ten trees sampled died between 1981 and 2004, and that eight of them died between 1997 and 2001.

Since no salinity data existed from the right time and place to determine if increases in salinity contributed to the bald cypress deaths, a model was developed to predict salinity throughout the river as a function of river flow. The model was used to hindcast salinity within the river for the 1998-2002 period, when six of the trees died. The output from this model was then used to develop relationships between river inflows and salinity within the river for application to the other years during which cypress trees died. This allowed a determination of whether increases in salinity were implicated in the deaths, and what river flows should be to protect existing cypress trees.

The monthly and annual locations of the salinity levels important for bald cypress were estimated for 1970-2004. Bald cypress cannot withstand persistent salinities of 2-3 ppt, so the locations of the 2 ppt bottom isohaline were estimated. These locations, and their durations, were compared to the locations of the dead cypress trees. All the dead trees were between 2 and 4 km upstream from the mouth of the river (Figure ES-1). This analysis determined that most of the dead trees had been exposed to median monthly salinities greater than 2 ppt for relatively long periods of time, in excess of 12 months for most of the trees. Elevated salinity levels may have been a contributing factor to eight of the ten bald cypress deaths during this period.

To address this problem, the SWFWMD developed alternative flow scenarios for the river focused on increasing the amount of freshwater entering the river when additional water is available in the system. These alternative flow scenarios were used as input to the modeling tool, which provided expected changes in the salinity regime for evaluation. The alternative flow scenarios as designed would provide increased flows to the lower river, but primarily during the wet season, when appropriate salinity regimes typically already exist in the lower river. During dry periods, flows to the river resulting from these alternative scenarios could only increase if additional water were available in the system. For those periods when extended low flows occurred, most notably in 2000-2001 when three of the trees died, there was little additional water in the system to increase the flows in the river.

To aid in the evaluation of the alternative flow scenarios, water quality data and benthic data were also examined. Dissolved oxygen values in the river, important for fish and benthos, showed no relationship with flow, with very little evidence of poor conditions, so that changes in the freshwater inflow to the river would not likely improve dissolved oxygen. The benthic community in the river is dominated by organisms preferring salinities greater than 7 ppt. There is only one non-invasive species with a central salinity preference less than 5 ppt. Based on the alternative flow scenarios provided for this evaluation, the volume of water less than 5 ppt would sometimes increase and sometimes decrease, depending on the available water in the system, with no overall benefit to the benthos.

Given the information provided above, any additional alternative flow scenarios should be evaluated with respect to their ability to extend the period of relatively high flows to the river into the typical dry season. To keep the 2 ppt bottom isohaline downstream of the bald cypress trees, at 2 km from the mouth of the river, average flows of 1300 cfs are necessary, and 1100 cfs to keep the isohaline at 3 km from the mouth. Most of the bald cypress deaths occurred during or immediately following periods when typical dry season conditions extended for long periods, with low flows resulting in movement of the 2 ppt bottom isohaline upstream of 4 km from the mouth for 12 consecutive months or more. The alternative flow scenarios evaluated here do not provide for any improvement in this situation, primarily because there are times when there is not enough water available in the system, such as 2000-2001.


**Figure ES-1. Locations of dead cypress trees and year of death, with river kilometer system (modified from Stahl and Griffin, 2006).**

# 1. INTRODUCTION

Changes to the Lower Withlacoochee River due to construction of portions of the Cross Florida Barge Canal (CFBC) have changed flows to the tidal portion of the river from those that were observed historically, with a present day maximum discharge of 1540 cfs. Historical flows have been estimated as 1900 cfs on an annual basis, with monthly maximum flows exceeding 7000 cfs.

Concerns have been raised regarding the effects of the decline in flows through the system on the lower river's biota. These concerns are related to the death and stress of bald cypress trees along the lower river, and to other changes in vegetation and associated decline in fish habitat. One of the most visible changes in the lower river's biota is the death of bald cypress trees along the lower river, which may be related to low river flows. A study has been completed for the District (Stahl and Griffin, 2006) identifying the years that ten of the trees died, and concluded that the ten trees died over 1981-2004, with eight of the deaths between 1997 and 2001. This study could not definitively conclude that increases in salinity resulted in these deaths, however.

To understand if the bald cypress deaths were related to increases in salinity, and thus to lower than normal river flows, it would be most appropriate to utilize salinity data collected during 1981-2004 in this portion of the lower river. If these data existed, they could be used to examine the role of salinity as a potential contributor to the tree deaths. However, the only data available were collected at two sites along the river sampled monthly since 1996, upstream of the sampled dead trees, and thus insufficient to examine the conditions which existed when the tree deaths occurred. Therefore, a method has been developed to hindcast the salinity regime in the river using hydrodynamic models for 1998-2002, allowing examination of the salinity regime in the river during the period when six of the trees died. Development of relationships between river flows and salinity also allows examination of the salinity when the remaining tree deaths occurred.

The Southwest Florida Water Management District is assessing the potential for restoring freshwater inflows to the estuary by modifying the structures in the Lower Withlacoochee River. The Withlacoochee River Basin Board provided funding in fiscal year 2003 for a Basin Initiative to investigate the restoration alternatives of the Western Terminus of the Cross Florida Greenway. In fiscal year 2005 the Board provided additional funding to further evaluate impacts to the estuary and the potential water quality and natural systems benefits of increasing freshwater flows to the lower river.

As part of this evaluation, the goals of this portion of the project are to:

1. develop three-dimensional hydrodynamic models of the Lower Withlacoochee River and contiguous inshore waters of the Gulf of Mexico,

2. apply the models to examine the effects of various freshwater inflows on the circulation and salinity structure of the estuary and the shelf region,

3. compile existing information on the biota of the lower river, including collection of tree cores from riparian trees, and

4. assess whether changes in freshwater inflows have affected the benthos, fish, and vegetation of the lower river.

The first goal has been completed, and is described in a previous report (Janicki Environmental, 2006). In that report, the three-dimensional hydrodynamic models of the Lower Withlacoochee River and the contiguous inshore waters of the Gulf of Mexico were described. The calibrations of the models were discussed, with comparison of model predictions to the observed data. The models are a large-scale Gulf Coast Shelf Model (GCSM), and a higher-resolution Lower Withlacoochee River Model (LWRM). These models are described later in this report.

The third goal has been addressed in a report presenting the results of tree coring of living and dead bald cypress trees (Stahle and Griffin, 2006). The results indicated that six of the ten dead trees died during the 1998-2002 period, but did not provide sufficient information to link these deaths to increases in salinity.

The second and fourth goals of the project are addressed in this report. This includes model implementation of flow restoration scenarios utilizing the models developed, and comparison of results from various flow scenarios. Additionally, this report provides descriptions of the likely responses of the biota of the system to flow changes in the system. The results from the tree coring study are incorporated into the analyses presented in this report.

The remainder of this report provides the specific objectives of this work effort, descriptions of the proposed restoration alternatives, descriptions of the models used to examine these alternatives, and evaluation of the results of the restoration alternatives.

## 2. OBJECTIVES

The objectives of the work effort described in this report are as follows:

***Assess the differences in salinity structure in the Lower Withlacoochee River resulting from potential flow scenarios through application of the three-dimensional hydrodynamic model of the contiguous inshore waters of the Gulf of Mexico (the Gulf Coast Shelf Model – GCSM) and the three-dimensional hydrodynamic model of the lower Withlacoochee River (the Lower Withlacoochee River Model – LWRM).***

Discussion with the District identified four scenarios for analysis. These scenarios are:

- Observed Conditions October 1983–March 1986:
  observed freshwater inflows for comparison to an existing salinity dataset,

- Observed Conditions 1998-2002:
  observed freshwater inflows for baseline,

- Alternative 3 1998-2002:

freshwater inflows resulting from implementation of proposed flows of 2500 cfs maximum to the river (Alternative 3), and

- Modified Alternative 3 1998-2002:
  freshwater inflows resulting from implementation of proposed flows of 3500 cfs maximum to the river (modification of Alternative 3).

The model results are used to assess the effects of salinity structure on the biotic systems of the river for which data are available (benthos and vegetation).

## 3. MODEL SCENARIOS

This section provides descriptions of and rationale for the four model scenarios completed.

Observed Conditions October 1983–March 1986: Data were collected by the District, USGS, and Mote Marine Lab during January 1984 through February 1986 in the river and just outside the mouth (M.S. Flannery, pers. comm.). These data were collected along the longitudinal axis of the river on a given date, at various depths, including the surface. Most of the sampling was completed at high tide conditions, but a few sampling events were during low tide events. This time period had higher than average flows. Average annual flows for the 1970-2003 period were 1040 cfs, while during 1983-1986 the average was 1220 cfs. Comparison of the model output to the observed data serves as a verification of the LWRM. These comparisons are discussed in Appendix A.

Observed Conditions 1998-2002: For the 1998-2002 period, salinity and temperature data were collected by the COAST monitoring program at sites from Anclote to the Withlacoochee (Appendix A, Figure A-1). The calibration report (Janicki Environmental, 2006) compared observed data to model output for the calibration period, March-September 2002. The longer 1998-2002 period provides additional verification data for both the GCSM and the LWRM (Appendix A). The LWRM for this period using observed flows also serves as the baseline for comparison to the other two 1998-2002 scenarios, which incorporate higher flow limits down the Withlacoochee River. The 1998-2002 period includes very high discharge (the El Niño event of winter 1997-1998) and very low discharge (the drought of 2000-2001), and so is a good period for examination of the models' responses to a wide range of flow conditions. This time period had lower than average flows. Average annual flows for the 1998-2002 period were 850 cfs, approximately 200 cfs less than the 1040 cfs average annual flow during 1970-2003. Based on the tree coring study (Stahle and Griffin, 2006), six of the ten bald cypress deaths in the lower river occurred during the 1998-2002 period.

Alternative 3 1998-2002: This scenario implements Alternative 3, as described in URS (2004). Alternative 3 increases the capacity of the Bypass Channel from the current maximum of 1540 cfs discharge to the Lower River to 2500 cfs maximum. To model this scenario, the total discharge from the combined discharges to the Lower River and the Barge Canal was split so that up to 2500 cfs was discharged to the Lower River when available, with the remainder discharged to the Barge Canal. Additionally, when there would be no discharges to the Barge Canal for a one-week period under this scenario, 400 cfs was released to the Barge Canal for one day, as specified in the Alternative 3 definition

(URS, 2004). For the purposes of this modeling effort, if a minimum of 400 cfs was not available from the combined discharges to the Lower River and the Barge Canal on the given day, the difference was made up with additional water release from the Inglis Dam. This condition occurred 27 times during the 1998-2002 simulation, with a maximum quantity of 82 cfs needed to make up the 400 cfs pulse.

Modified Alternative 3 1998-2002: At the request of the District, this scenario employs a maximum discharge to the river of 3500 cfs. Other than this modification, the scenario is the same as the 2500 cfs maximum flow scenario.

For all three 1998-2002 scenarios, the GCSM was implemented using observed flows. Both the Barge Canal and the Lower Withlacoochee River discharge to the same cell of the GCSM, so that no additional GCSM runs were needed to establish downstream boundary conditions.

# 4. MODEL DESCRIPTIONS

This section provides descriptions of the two hydrodynamic models utilized in this work effort. A large-scale model has been developed for the Gulf coast to provide boundary conditions for the higher-resolution lower river model. Detailed discussions of the calibrations of both these models are provided in Janicki Environmental (2006).

## 4.1. Gulf Coast Shelf Model Description

The large-scale Gulf Coast Shelf Model (GCSM) domain extends from the mouth of Tampa Bay to Cape San Blas, as shown in Figure 4-1. The GCSM contains 2155 horizontal cells, with ten layers in the vertical. The model grid cells are approximately rectangular, with dimensions of about six km by four km, with some variation. The map of the bathymetry utilized for the GCSM is shown in Figure 4-2. A map showing the locations of USGS flow gages and other monitoring sites used to estimate freshwater inflows to the system is provided in Figure 4-3. The locations of stations used for atmospheric forcing data are shown in Figure 4-4. Offshore water surface elevations were obtained from the Eastcoast 2001 tidal constituent database (Mukai, 2001). Each of these data sources is described more fully in the hydrodynamic model calibration report (Janicki Environmental, 2006).

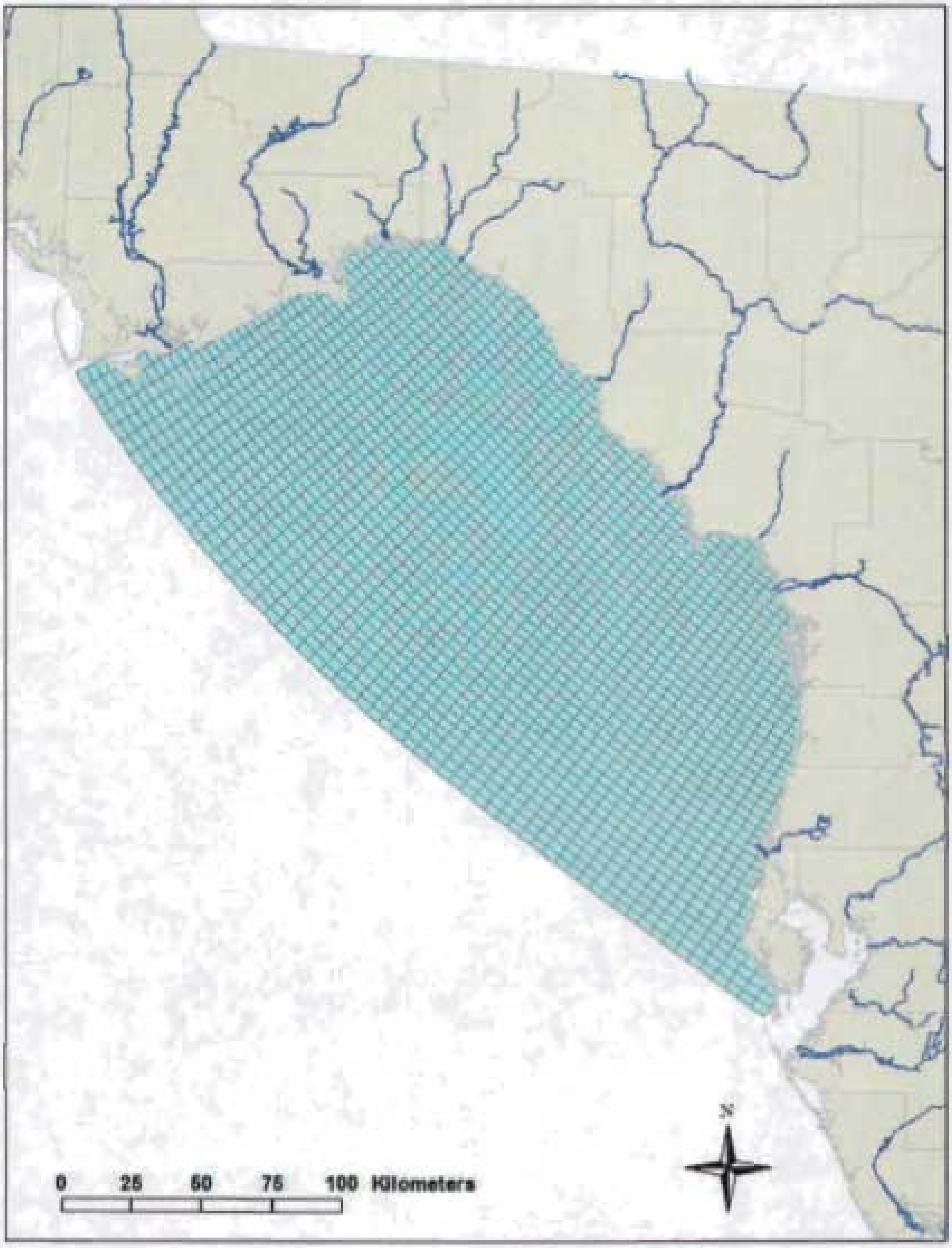


Figure 4-1. Model domain for the large-scale Gulf Coast Shelf Model.

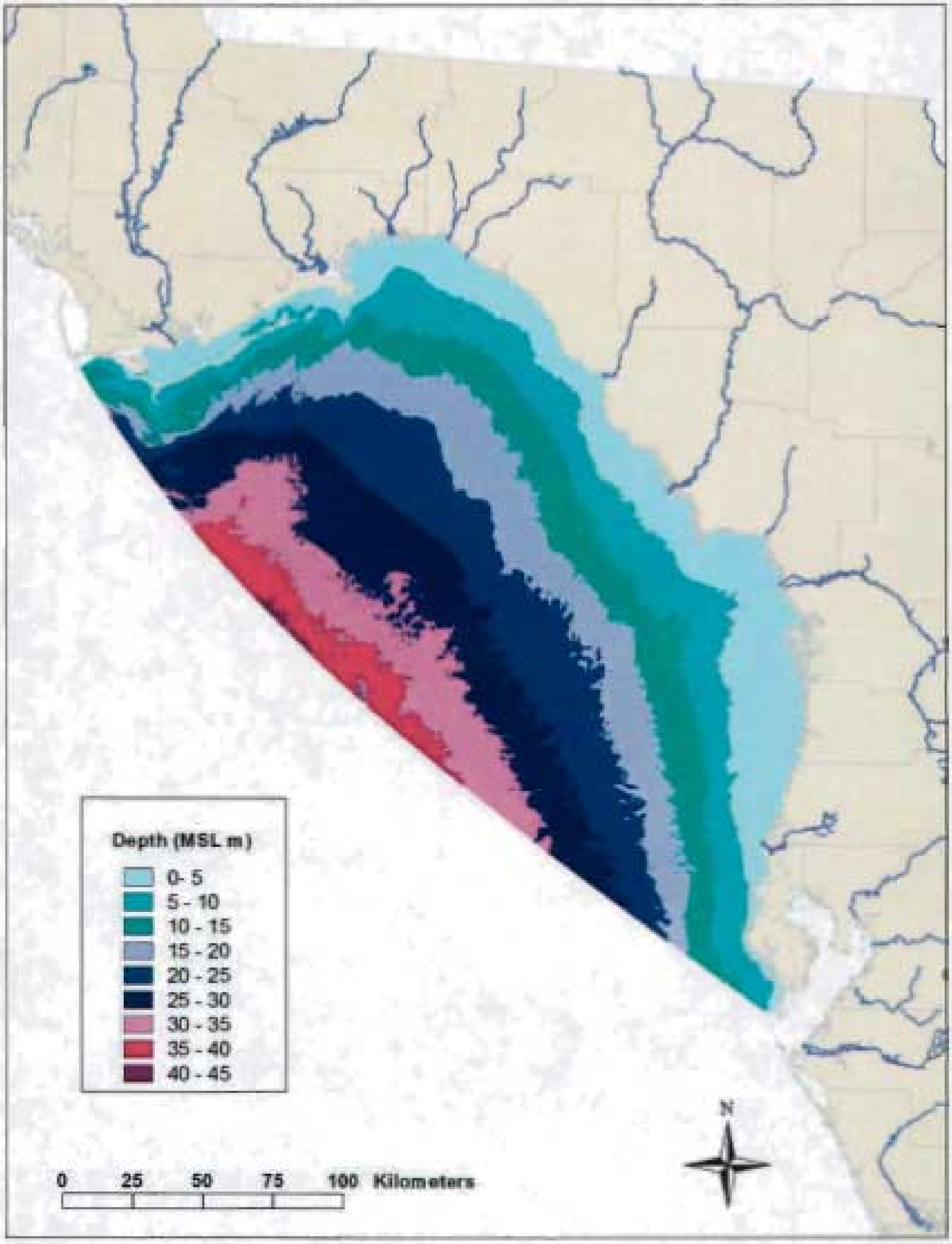



Figure 4-2. Bathymetry for the large-scale Gulf Coast Shelf Model.

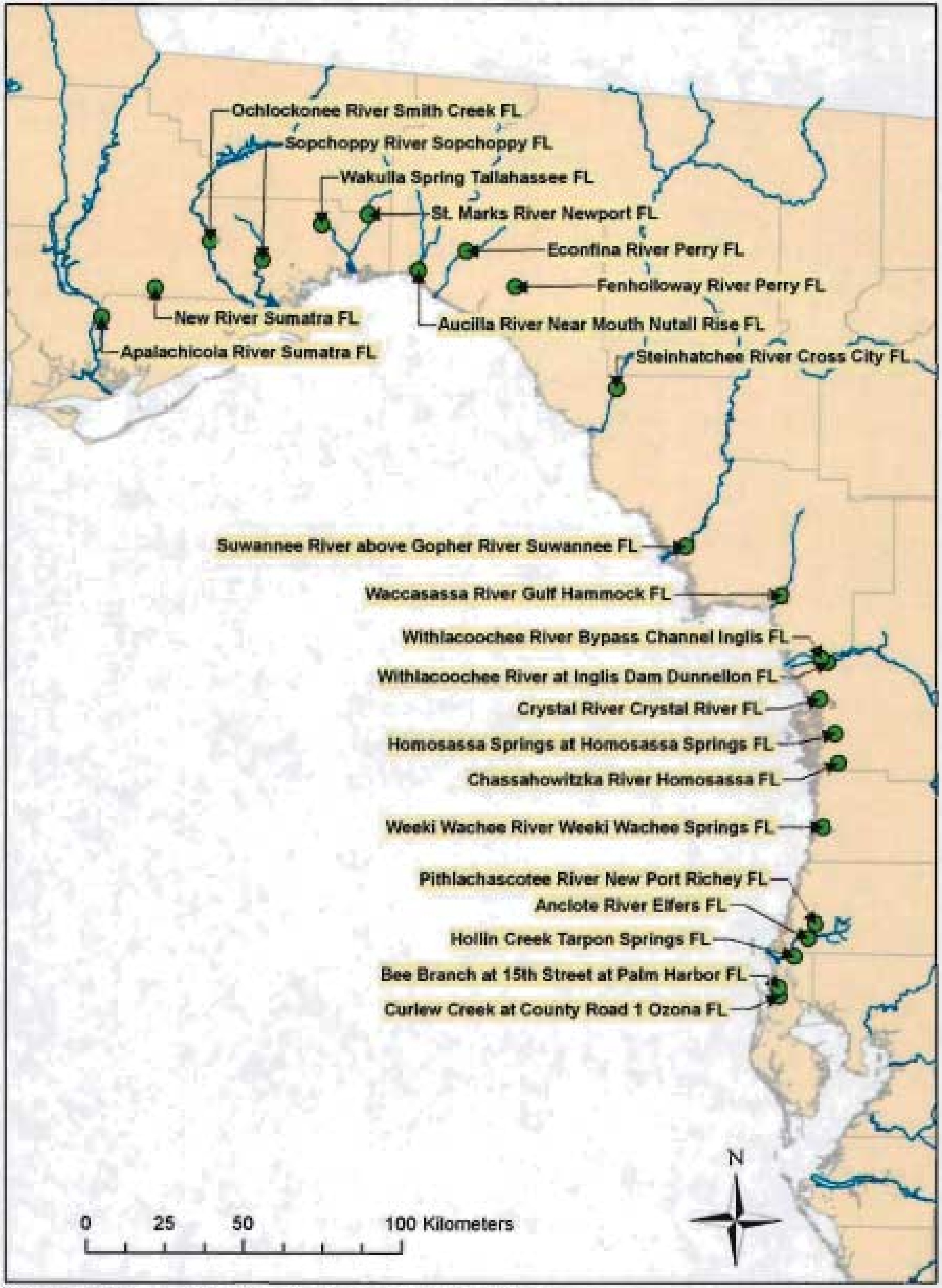



**Figure 4-3. River and spring discharge station locations.**


Figure 4-4. Locations of atmospheric data stations.

## 4.2. Lower Withlacoochee River Model Description

The Lower Withlacoochee River Model (LWRM) domain extends from the western end of Lake Rousseau to the nearshore area of the Gulf of Mexico, and includes the Barge Canal, the tidally influenced portion of the Lower Withlacoochee River, and the estuary region within 4.5 km of the mouth. Model output from the GCSM supplies the boundary conditions for water surface elevation, salinity, and water temperature. Figure 4-5 displays the LWRM grid system with the GCSM large grid system overlay.

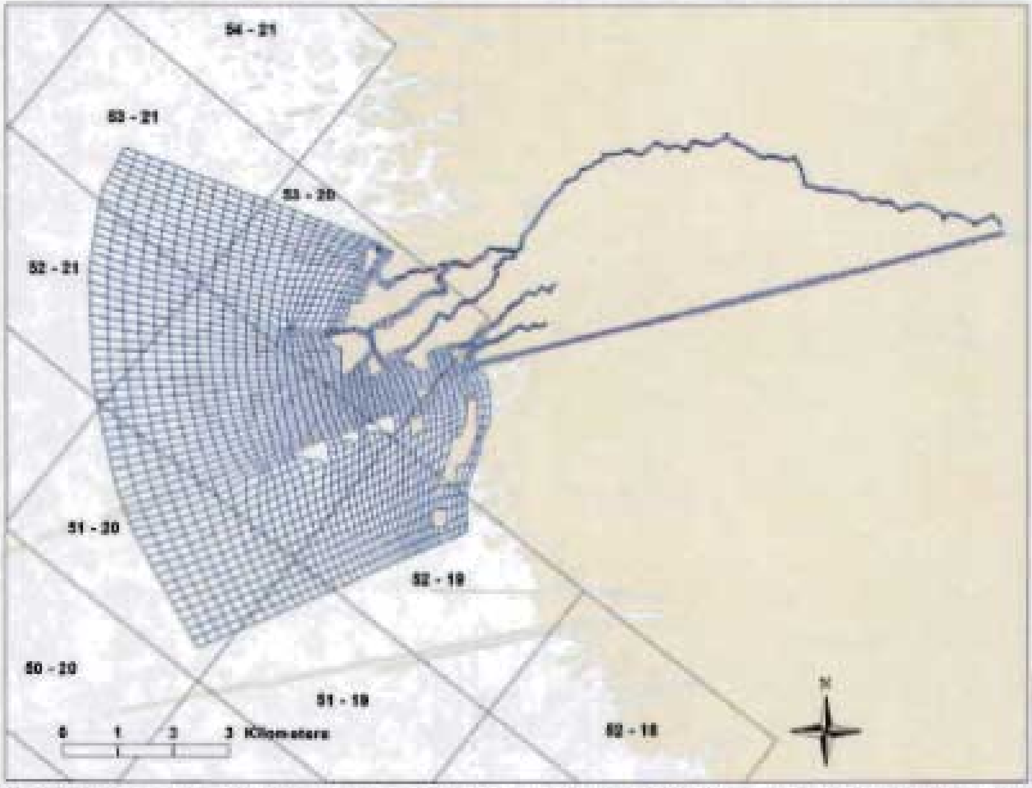



**Figure 4-5. Lower Withlacoochee River Model grid. GCSM cell identifiers are shown in black.**

The LWRM grid contains 2442 horizontal cells, and four vertical layers. The vertical layers within each horizontal grid cell are of equal depth, so that each layer is one-fourth of the water column. Cell dimensions range from 8 m to 369 m in the x-direction (east-west) and from 5 m to 351 m in the y-direction (north-south). Larger cells are in the offshore area, with smaller cells in the tidal creeks and river. Bathymetric data were collected specifically for this project by Dr. Ping Wang of USF (Wang, 2006), and are displayed in Figure 4-6. Freshwater inflows were obtained from the USGS for the Lower Withlacoochee River and Barge Canal, with the locations of these two gages shown in Figure 4-7. The Withlacoochee River at Inglis Dam discharges from Lake Rousseau to the Barge Canal, and the Withlacoochee River Bypass Canal discharges to the lower river. For atmospheric data, a subset of the stations used for the GCSM was used for the LWRM, as described in Janicki Environmental (2006).

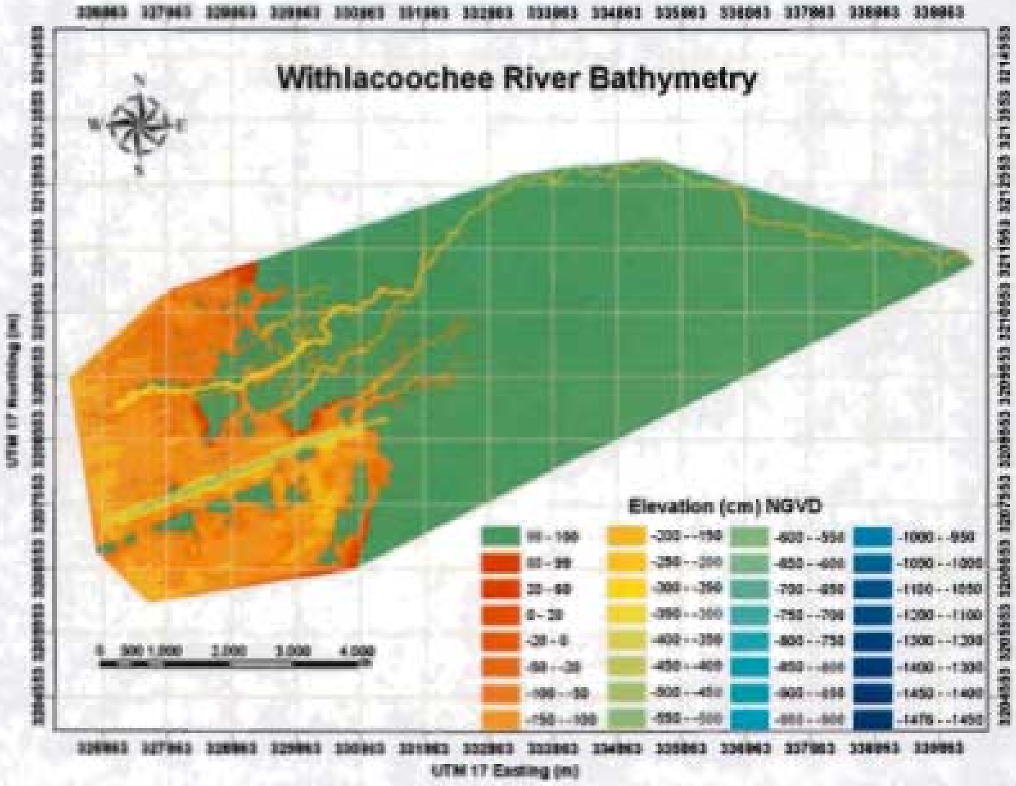



Figure 4-6. Map of Lower Withlacoochee River and nearshore bathymetry (developed by Dr. Ping Wang, USF).

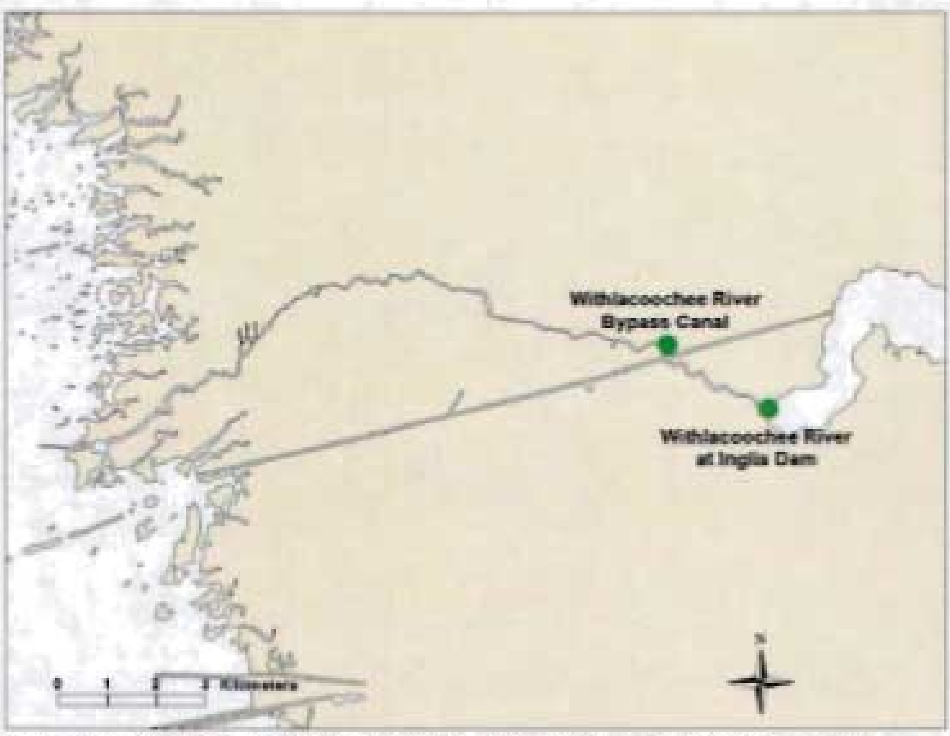



Figure 4-7. Locations of USGS flow gages for the Lower Withlacoochee River.

# 5. EVALUATION OF RESTORATION ALTERNATIVES

This section provides an analysis of the differences in salinity predictions for the three LWRM model scenarios of 1998-2002, with primary attention given to the predicted responses of important biological salinity boundaries within the river. To aid in this discussion, biologically important salinity regimes are first defined, including the salinity requirements for bald cypress. Next, a comparison of river flow and its effects on salinity prior to and following construction of the Barge Canal are provided, along with an analysis of the effects of flow on water quality.

The analysis of salinity differences is then presented, and the salinity fields resulting from the observed condition flows for the 1998-2002 period are examined with respect to benthic community needs and locations of the dead bald cypress trees, with the potential effects of flow alternatives evaluated. A discussion of the impacts of model error on the prediction of isohaline locations is also provided.

A discussion of sea level rise in the area is provided using data from Cedar Key, with implications for any potential flow regime modifications. Finally, equations relating the locations of isohalines to river flows are provided, useful for developing the flows necessary to maintain the desired isohaline locations.

## 5.1. Ecologically Important Salinity Zones

One of the most well known salinity zonation schemes is the Venice System. The Venice System breaks down estuarine salinity ranges into five ecologically important zones:

- limnetic: 0 - 0.5 ppt,
- oligohaline: 0.5 - 5 ppt,
- mesohaline: 5 - 18 ppt,
- polyhaline: 18 - 30 ppt, and
- euhaline: > 30 ppt.

Brief descriptions of each of the four lower salinity zones are provided in the following. The euhaline zone is typically marine, and is rarely found within the river.

Difficulty exists in establishing biologically meaningful salinity zones that can be applied universally. Salinity changes represent a gradient of conditions and depending on the system, as particular threshold salinities may vary. The Venice System (1958 and 1959) is one of the oldest and most widely used salinity classifications. Cowardin et al. (1979) and Bulger et al. (1993) have also established salinity classifications. Cowardin's system represents only a slight modification to the Venice System and is the same except in the manner in which it groups salinities over 30 ppt. The salinity classification developed by Bulger et al. (1993) is fairly similar to the Venice System, with each salinity group differing by only a few ppt. The main difference of the Bulger system is that it classifies all salinities below 4 ppt into a single group. While no classification system exists without some degree of criticism (Hartog, 1974 and 1960), the Venice System remains widely used and has been applied to the modeling developed for this project.

Limnetic zone:
The limnetic zone (0.0-0.5 ppt) represents the most downstream extent of freshwater dominated conditions. This zone is not typically influenced by tidal input and is characterized by freshwater species. At the lowest extent of this zone, slight tidal influence may result in the occurrence of tidal freshwater marshes. Several important habitats located in the limnetic zone are riparian woody snags, floodplain wetlands, and tidal freshwater marsh.

Snag habitat (i.e., areas of large woody debris submerged in the river channel) is known to support high biological diversity and production (Dolloff, 1994; Maser and Sedell, 1994) especially in southeastern streams (Benke et al., 1984; Benke et al., 1985). Snags provide important structure and food sources for aquatic invertebrates and fishes. Much of the fish production in southeastern streams is associated with snag habitat (Benke et al., 1985; Smock and Gilinsky, 1992).

Floodplain wetlands are also known to be important components of the river ecosystem because of their roles in nutrient cycling, production of organic matter, sediment dynamics, and fish and wildlife habitat (Wharton, et al. 1982; Mitsch and Gosselink, 1986; Schlosser, 1991; Light et al., 1998). Specifically, cypress swamps dominated by bald cypress *(Taxodium distichum)* and other freshwater riparian vegetation provide important habitat and generally have low tolerances to salinity intrusion. Pezeshki et al. (1987) found that bald cypress seedlings exhibited reduced photosynthetic rates at salinity of 2 ppt and higher. Allen et al. (1997) found that bald cypress had the highest mean leave, stem, and root biomass at salinities of 0 ppt and 2 ppt. Increases in salinity in a previously freshwater zone can cause undesirable shifts in species composition of the canopy, sub-canopy, or groundcover plant communities and cause encroachment of saline species further upstream and the loss of acreage of specific forest types.

Tidally influenced rivers typically have a gradient of marsh types that corresponds to the gradient of salinity. The general structure and function of tidal marshes has been described by Odum et al. (1984). Tidal freshwater marshes are found in the upstream, lowest salinity reach, and generally have the highest plant diversity of all the marsh types. The fisheries habitat value of this marsh type is likely equivalent to that of the more saline marshes occurring further downstream, but far less studied than salt marsh fish communities (Odum et al., 1984). Tidal freshwater marshes were designated as a high priority habitat target for conservation in the northern Gulf of Mexico by Beck et al. (2000).

Oligohaline zone:
The oligohaline zone (0.5-5.0 ppt) represents the most upstream part of the system that is regularly influenced by tidal input. Most freshwater species can not handle the increased salinity and are replaced by euryhaline species. Oligohaline habitat is important for many commercially and recreationally important fish species, and is used as nursery grounds for the early larval stages (Rozas and Hackney, 1983; Comp and Seaman, 1985). It is also an important area for estuarine-dependent fishes which rely on low salinity habitat to complete a portion of their life cycle. The oligohaline environment is also important for many invertebrate species. However, compared to higher salinity habitats, the transition area from freshwater to estuary is typically species poor in terms of benthic invertebrates (Flink and Kalke, 1985; Gaston et al., 1988; Rabalais, 1990; Rakocinski et al., 1991). Oligohaline

marshes were designated as priority habitat target for conservation in the northern Gulf of Mexico by Beck et al. (2000).

Mesohaline and Polyhaline zones:
The mesohaline (5.0-18.0 ppt) and polyhaline zones (18.0-30.0 ppt) are heavily utilized by many species of fish, including those of marine origin, estuarine residents, and various life stages of estuarine-dependent species. Additionally, along with the previously described marsh types, these higher salinity marshes also provide important habitat. The combination of marsh and tidal creeks provide nursery habitat for many fishes of commercial and/or recreational importance, particularly during the early larval stages (Rozas and Hackney, 1983; Comp and Seaman, 1985). In benthic invertebrate communities, higher salinity is often associated with higher species diversity and sandier sediments (lower percent silt-clay) (Flink and Kalke, 1985; Gaston et al., 1988; Rabalais, 1990; Rakocinski et al., 1991). Mesohaline and polyhaline marshes were also identified by Beck et al., (2000) as priority habitat target for conservation in the northern Gulf of Mexico.

The limnetic and oligohaline zones are used when discussing the model results to provide bounding isohaline locations and volumes, since the 18 ppt isohaline is often outside the mouth of the river.

In addition to the locations of the 0.5 ppt and 5 ppt isohalines, the 2 ppt and 3 ppt isohaline locations are also tracked. Various studies have indicated that bald cypress cannot withstand persistent salinities of 2-3 ppt (Brown and Montz, 1986; Allen et al., 1996; Allen et al., 1997; Pezeshki et al., 1987).

### 5.2. Pre- and Post-Barge Canal Conditions

The construction of the Barge Canal during the 1960s and dredging of the lower river in the 1940s resulted in changes to the relationship between flow and salinity in the river. Given a smaller cross-sectional area prior to dredging, and greater river flows prior to diversions to the Barge Canal, the lower river historically was less salty, and the locations of low-salinity isohalines further downstream. The District requested that the LWRM be used to provide an estimate of the differences between pre- and post-Barge Canal conditions in the lower river, including the likely differences in water quality constituents other than salinity.

#### 5.2.1. Differences in Isohaline Locations

The LWRM model was modified to provide estimates of isohaline locations resulting from bathymetry representative of pre-dredging conditions. Approximate river channel dimensions prior to dredging were discussed with District staff, resulting in modifications to the existing bathymetry to recreate an approximation of the pre-dredging bathymetry. To accomplish this, the existing bathymetry, as defined by the bathymetry cross-section data collected for the District for this project, was modified so that the river channel for 35 feet on both sides of the centerline (deepest channel) was raised to match the depths along the sides of the channel, in keeping with the dredged channel being 70 feet wide along the centerline. This was done for the bathymetry from the mouth of the river to the US 19 crossing. The greatest difference in isohaline locations within the river is expected to be during periods when relatively low flows occurred, so that the pre-construction scenario was run for March-May 2000, a period of very low flows. Comparison of the results of this run was made with the results from the existing conditions run.

The downstream locations of the surface and bottom 0.5 ppt and 5 ppt isohalines are provided in Table 5-1 for both the historical and existing conditions for March-May 2000. The river kilometer system is provided in Figure 5-1. The locations of the historical surface 0.5 ppt isohalines average 3.8 km downstream of those from the existing condition, and the historical surface 5 ppt isohalines average 2.0 km downstream of those from the existing condition. For the bottom isohalines, the differences are even greater, as the shallower bathymetry does not allow higher salinity waters to move up the river as far. The locations of the historical bottom 0.5 ppt isohalines average 6.8 km downstream of those from the existing condition, and the historical bottom 5 ppt isohalines average 4.3 km downstream of those from the existing condition.

It is apparent that the shallower bathymetry of the river prior to dredging allowed for more downstream locations of low salinity isohalines, as saltier water did not reach up river as far as it does currently. It is not only at low flow conditions that these differences between pre-dredging and current conditions may be found, however. Even during high flows, the effects of the dredging on isohaline locations is expected to result in isohaline locations further upriver than would be the case given pre-dredging bathymetry, although the differences between isohaline locations when comparing current and pre-dredging conditions likely would not be as great as they are under low flow conditions. Deeper channels allow more upstream incursion of saltier water under any flow conditions.

### 5.2.2. Effects on Other Water Quality Constituents

To address the expectations as to what changes occurred in the Lower Withlacoochee resulting from construction of the Cross Florida Barge Canal (CFBC), an analysis was completed in which hypothetical flows were estimated in the absence of the CFBC for the 1970-2003 period. The hypothetical flows were estimated as the sum of the observed flows at the dam and through the Bypass Canal to the lower river. The time series of these flows, and the observed flows in the river, are displayed below for daily (Figure 5-2), mean monthly (Figure 5-3) and mean annual (Figure 5-4) periods.

As seen in Figure 5-3, for all months, flows would be greater on average over the 1970-2003 period without the CFBC, and especially during January-April and August-October. During both of these periods, the flows without the CFBC are about 400 cfs greater than the flows with the CFBC.

As seen in Figure 5-4, for almost all years, the flows without the CFBC are greater than the flows with the CFBC. Note, however, that in 1999-2002, the flows are not very different, with differences of 100 cfs or less.

The most obvious expected difference in indicators is salinity. However, for the 1999-2002 period, the annual average locations of the isohalines are not expected to differ by much, since the annual flows are very similar, without considering differences in bathymetry, as addressed above is section 5.2.1. For those years during which large differences in flows are shown in Figure 5-4, it is expected that the locations of the surface isohalines would be shifted downstream given flows without the CFBC.

| Table 5-1. Locations of monthly median isohalines for current and historical bathymetry, March-May 2000. | | | |
|---|---|---|---|
| Isohaline/Month | Historical Condition Location (River Km) | Existing Condition Location (River Km) | Difference (Km) |
| 0.5 ppt March Surface | 1.7 | 4.2 | 2.5 |
| 0.5 ppt April Surface | 1.7 | 4.9 | 3.2 |
| 0.5 ppt May Surface | 2.2 | 8.0 | 5.8 |
| **0.5 ppt Surface Average** | **1.9** | **5.7** | **3.8** |
| 0.5 ppt March Bottom | 1.9 | 7.0 | 5.1 |
| 0.5 ppt April Bottom | 1.8 | 8.8 | 7.0 |
| 0.5 ppt May Bottom | 2.2 | 10.6 | 8.4 |
| **0.5 ppt Bottom Average** | **2.0** | **8.8** | **6.8** |
| 5 ppt March Surface | 0.7 | 2.3 | 1.6 |
| 5 ppt April Surface | 0.2 | 2.3 | 2.0 |
| 5 ppt May Surface | 0.3 | 2.7 | 2.4 |
| **5 ppt Surface Average** | **0.4** | **2.4** | **2.0** |
| 5 ppt March Bottom | 1.7 | 4.1 | 2.4 |
| 5 ppt April Bottom | 1.5 | 5.7 | 4.2 |
| 5 ppt May Bottom | 1.8 | 8.4 | 6.6 |
| **5 ppt Bottom Average** | **1.7** | **6.0** | **4.3** |

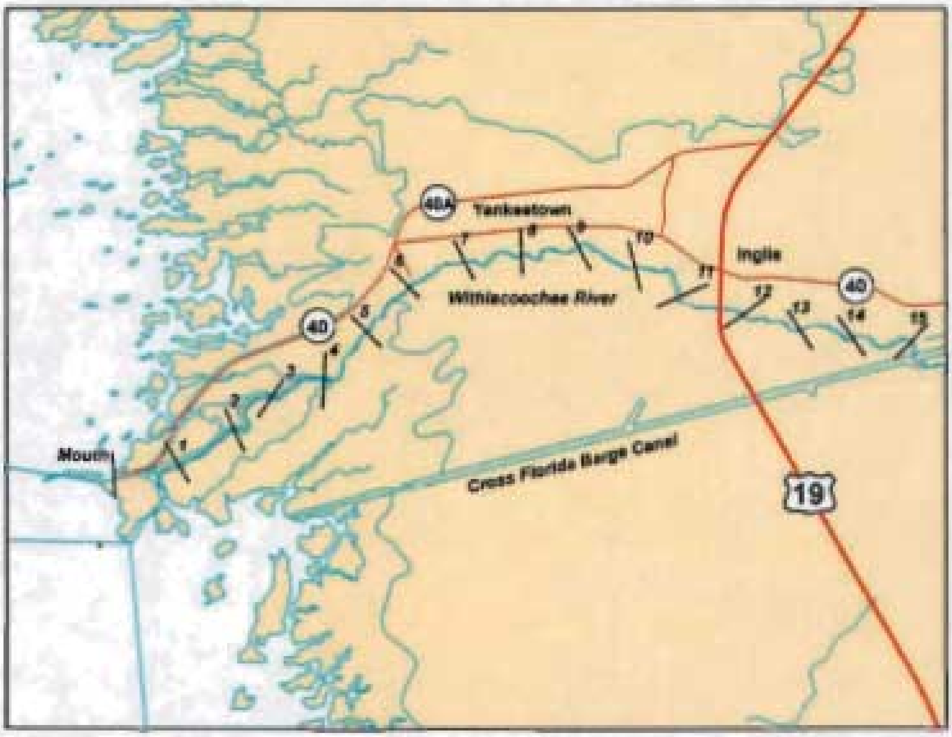



**Figure 5-1. River kilometer system for the Lower Withlacoochee River.**

Other water quality indicators may be important to the system as well. Relationships often exist in river systems between dissolved oxygen and flow, and bottom DO is an indicator of benthic health as well as an expression of nutrient loadings and algal biomass. An examination of bottom DO and flow relationships in the Withlacoochee River, however, shows no relationship between the two. As an example, bottom DO from Station 1, at River Km 4.8, of the Mote 1984-1985 study is plotted against flow in Figure 5-5. For the remainder of the 10 sites sampled by Mote during this period, the same lack of pattern is seen. Most importantly, based on the Mote data, very little evidence of low bottom DO (<4 mg/L) is seen. There is also no relationship between surface DO and flow using data collected as part of the COAST monitoring program at two sites in the river between 1996 and 2004, as shown in Figure 5-6.

As for bottom and surface DO, examination of the relationships between flow and nutrients and chlorophyll indicates that in the lower river, nutrients and chlorophyll concentrations do not serve as indicators of health. Figures 5-7 and 5-8 show TN and TP concentrations, respectively, as functions of flow. Concentrations of these nutrients increase with increasing flows. As seen in Figure 5-9, which shows chlorophyll concentrations in relation to flows, these increases in nutrient concentrations do not result in increased chlorophyll concentrations. This is at least in part due to the decreased residence time of the nutrients in the river during higher flows, allowing less time for algal uptake and increases in chlorophyll concentrations. It appears that the primary indicator of system health is the locations of the isohalines, which determine habitable zones for benthos and vegetation.

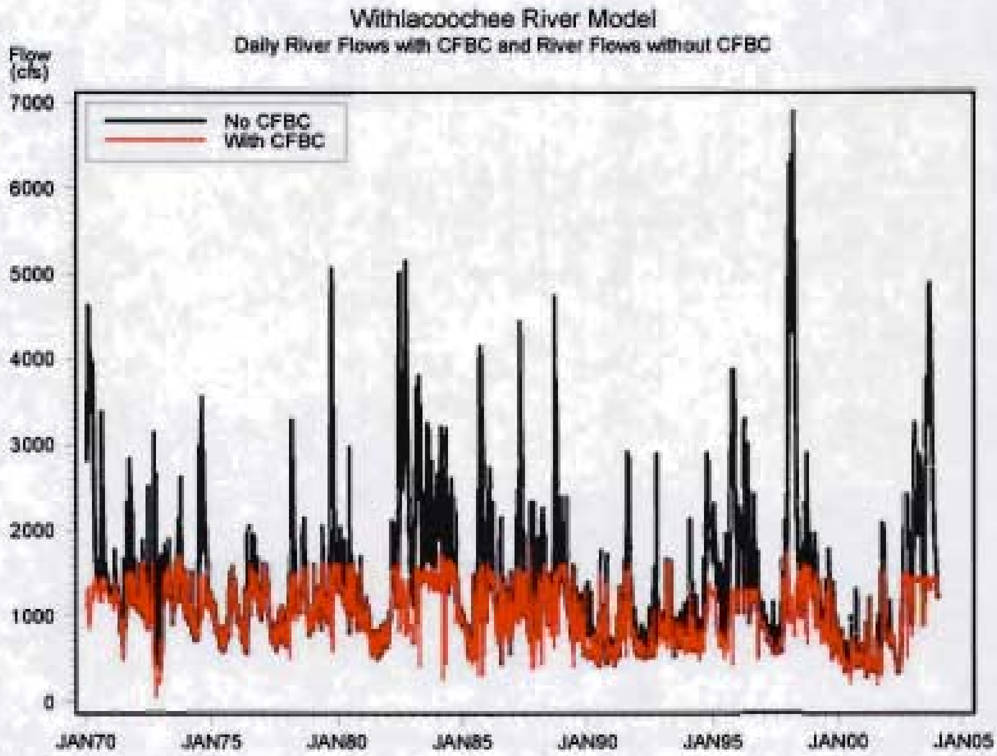



Figure 5-2. Daily flows in the Withlacoochee River with and without the CFBC.

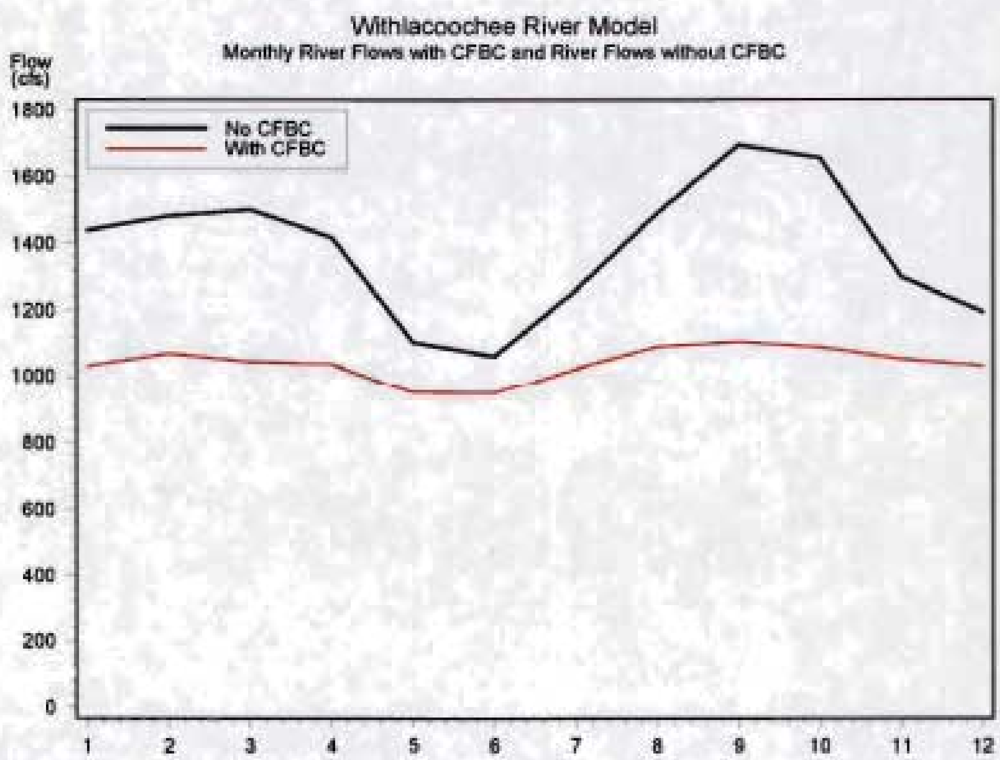



Figure 5-3. Mean monthly flows in the Withlacoochee River with and without the CFBC.

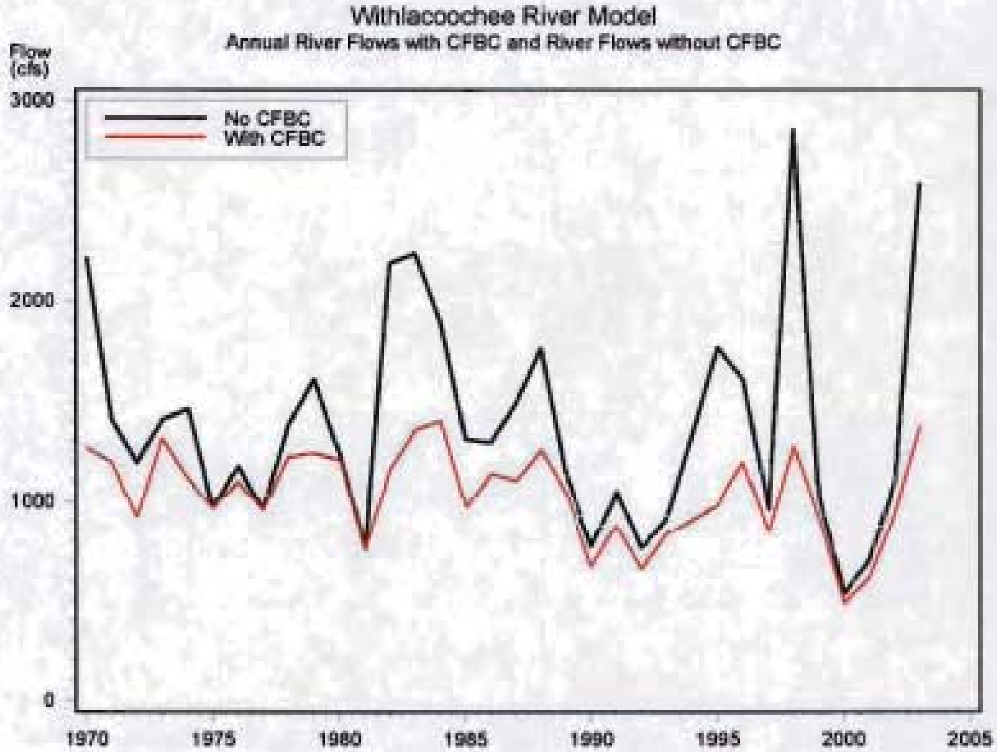



Figure 5-4. Mean annual flows in the Withlacoochee River with and without the CFBC.

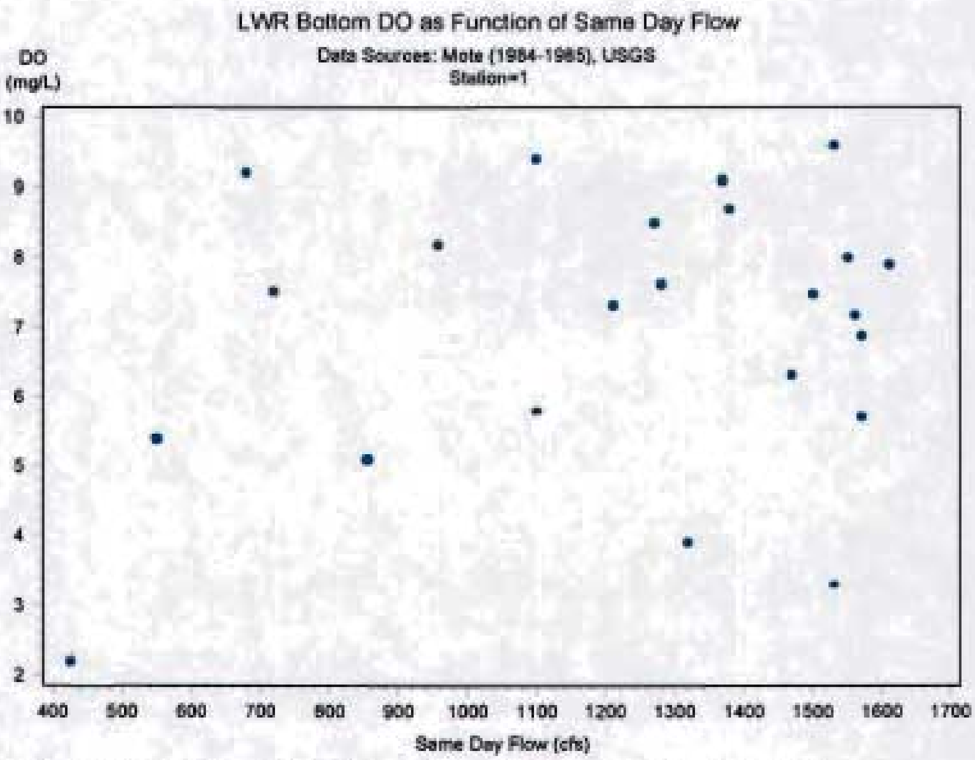



Figure 5-5. Bottom DO as a function of same day flow, at River Km 4.8.

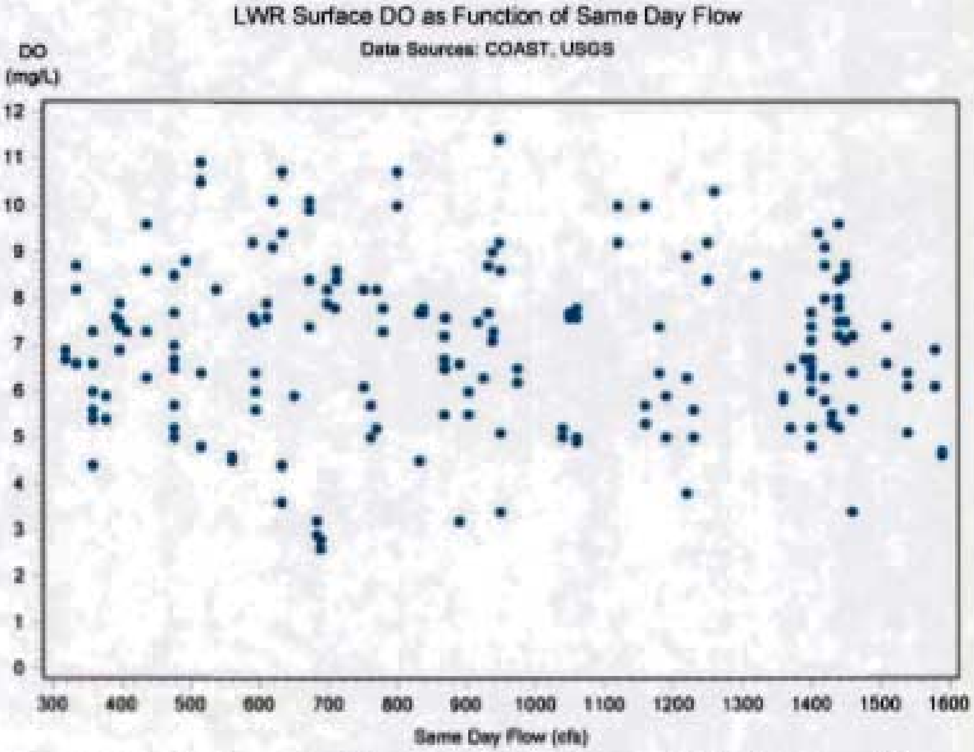



**Figure 5-6. Surface DO as a function of same day flow, at COAST sites 2 and 3.**

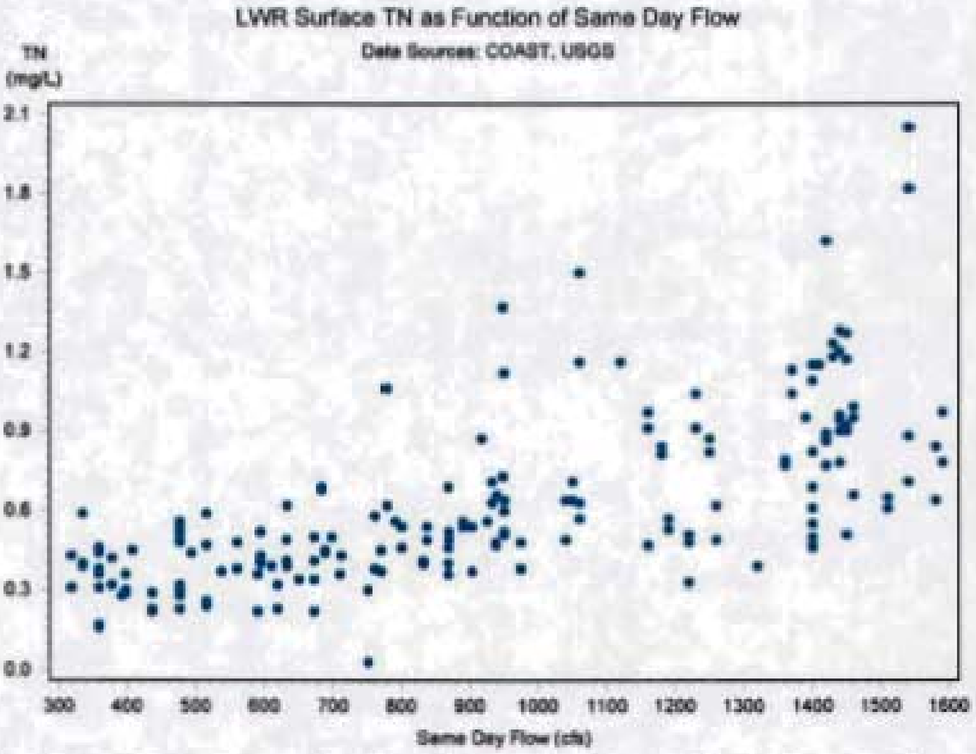



**Figure 5-7. Surface TN as a function of same day flow, at COAST sites 2 and 3.**

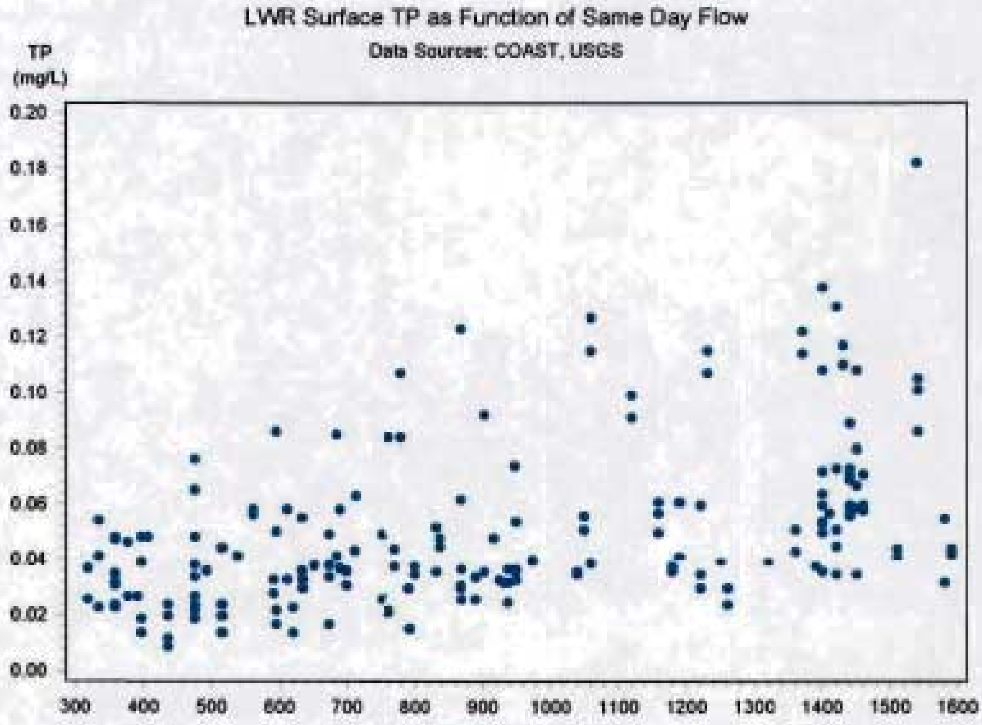



Figure 5-8. Surface TP as a function of same day flow, at COAST sites 2 and 3.

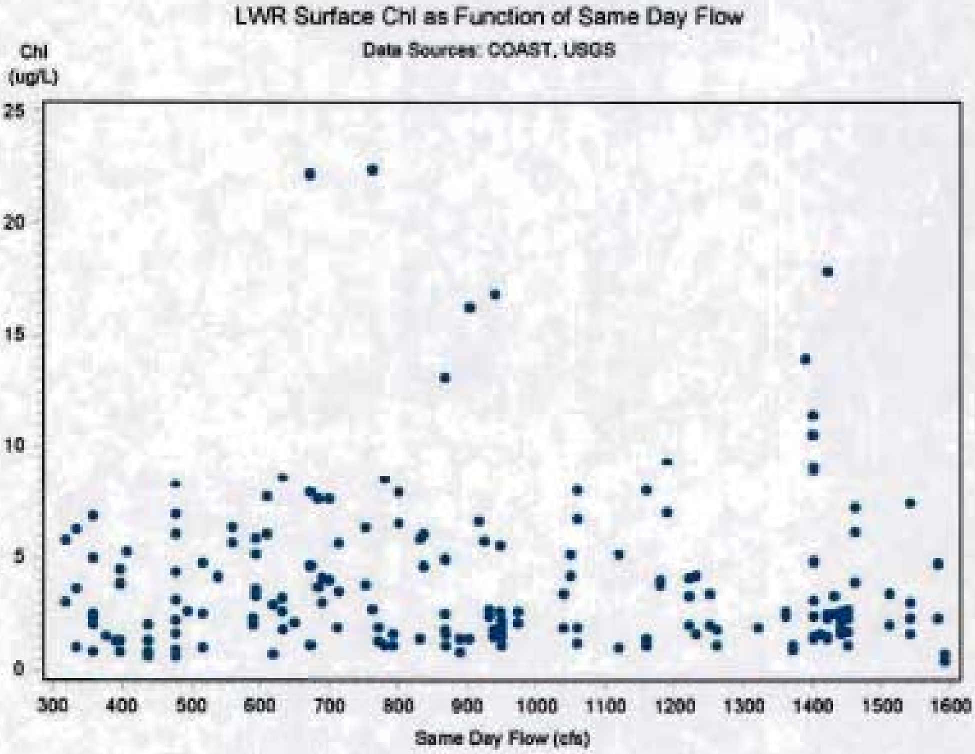



Figure 5-9. Surface chlorophyll as a function of same day flow, at COAST sites 2 and 3.

### 5.3. Comparisons of Results of Scenarios

This section provides the comparisons of the results of the flow scenarios, and discusses these results with respect to ecologically important salinity zones described above in section 5.1. Initially, a comparison between the 1983-1986 and 1998-2002 observed conditions scenarios is made. Then, the results of the three 1998-2002 scenarios are presented.

#### 5.3.1. Differences Between 1983-1986 and 1998-2002 Periods

The primary difference between the two time periods is the discharge to the river, resulting in differences in isohaline locations. Discharge during the 1983-1986 period averaged 1220 cfs, 200 cfs greater than the 34-year (1970-2003) mean. During 1998-2002, the average annual discharge was 850 cfs, 200 cfs less than the 34-year mean.

As a result of the flow differences, isohaline locations were typically much further upstream during the 1998-2002 period than during the 1983-1986 period, with the exception of early 1998, during the high-flow period associated with the El Niño of winter 1997-1998.

For the 1998-2002 period, using observed flows, the monthly median locations of the daily downstream extent of the surface 0.5 ppt isohaline were as far upriver as 9.9 km during June 2000, and was upstream of the 6 km mark during May and June, 2000, during September 2000-January 2001, and during May and June 2001.

For the 1983-1986 period, using observed flows, the maximum upstream excursion of the monthly median location of the surface 0.5 ppt isohaline was 3.6 km, during May 1985.

Other differences in driving mechanisms existed as well, although these differences were small. Tides during 1983-1986 were approximately 2-3 cm lower than in 1998-2002. Wind speeds input to the models were slightly lower in the 1983-1986 run than in the 1998-2002 run, by approximately 1 m/s, possibly due to different sources being used for the wind data. The 1983-1986 run used Tampa International Airport winds, while the 1998-2002 run used Cedar Key winds.

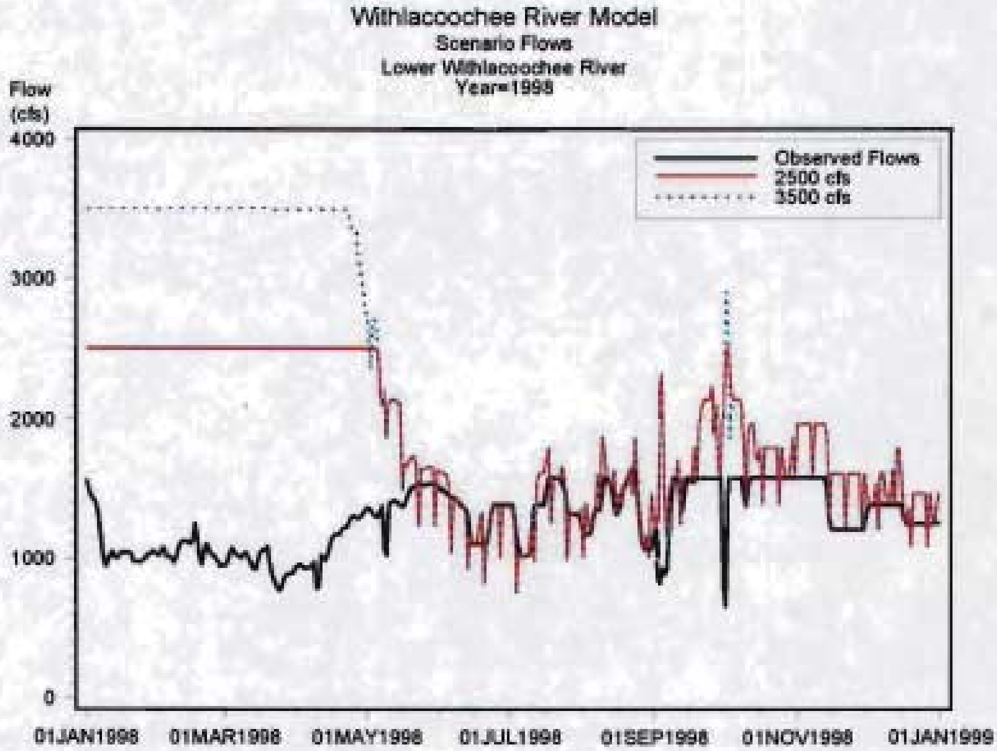
#### 5.3.2. Differences Between 1998-2002 Scenarios

The 1998-2002 scenarios differ only in flows to the lower Withlacoochee River and to the Barge Canal. Time series plots of the daily flows for the three scenarios, observed conditions, 2500 cfs alternative, and 3500 cfs alternative, are provided for each year (1998-2002) in Figures 5-10 through 5-14. As seen in these figures, the only year during which flows differ between the 2500 cfs alternative and the 3500 cfs alternative is 1998.

During 1998, as seen in Figure 5-10, an unusually large amount of water was discharged from the Withlacoochee system, especially during the first four months of the year. Up to 7000 cfs was discharged on a given day. The 2500 cfs alternative would have resulted in approximately 1500 cfs more than in the observed scenario each day going to the river during this four month period, and the 3500 cfs alternative in approximately 2500 cfs more each day. As shown in Figures 5-15 through 5-18 below, the surface 0.5 ppt isohaline would be translated downstream more than 2 km during January-April 1998 under the alternatives.

Conversely, during September-December of 2000, extremely low flows occurred. For the alternative scenarios (for which both the 2500 cfs and 3500 cfs scenarios had the same flows during this period), less river flow occurred than for the observed conditions. This is the result of the one day per week release of 400 cfs to the Barge Canal per the alternative scenarios, in contrast to the observed conditions of 70 cfs baseflow from the dam during low flow conditions. The location of the surface 0.5 ppt isohaline for the alternative flow scenarios is upstream of its location for the observed conditions during each of these months, as shown in Figures 5-19 through 5-22, by as much as 3 km.

As stated above, for low flow conditions, the proposed and modified alternative scenarios resulted in discharges to the lower river less than those observed. The 400 cfs weekly one-day discharge from Inglis Dam to the Barge Canal as included in the alternative scenarios is not an operational requirement and is not proposed for implementation. These weekly discharges were used to investigate water quality benefit to the portion of the lower river downstream of the dam and upstream of the Barge Canal. Isohaline results under observed flows during the low flow periods should be considered rather than the proposed and modified alternative scenario results, which reflect the 400 cfs releases.



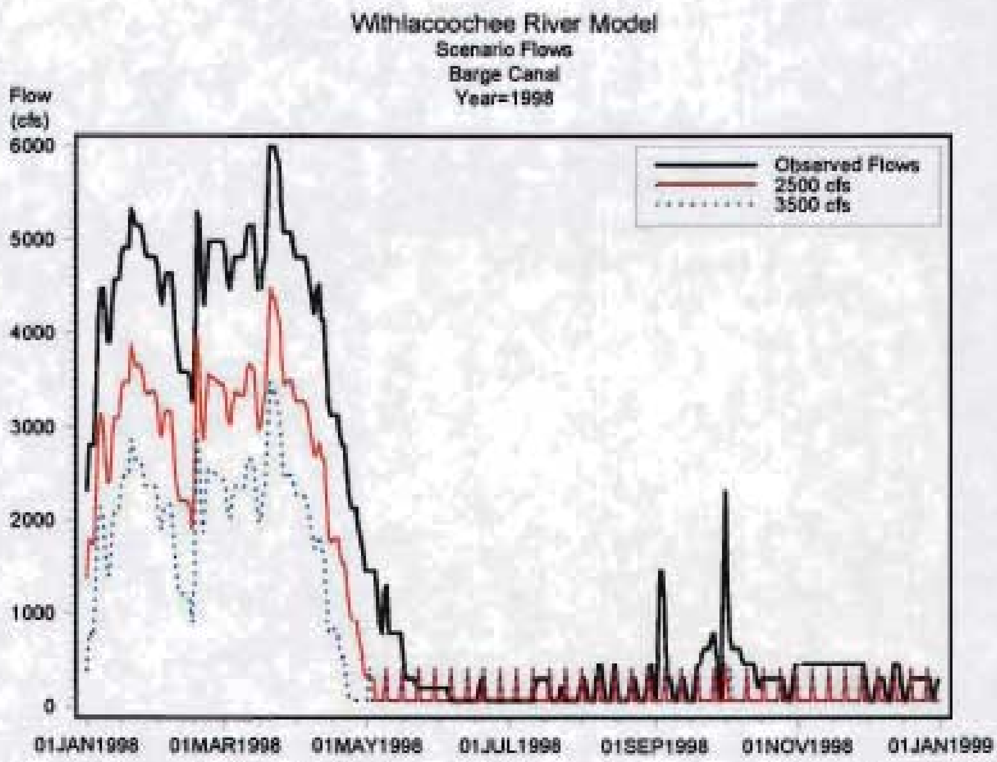
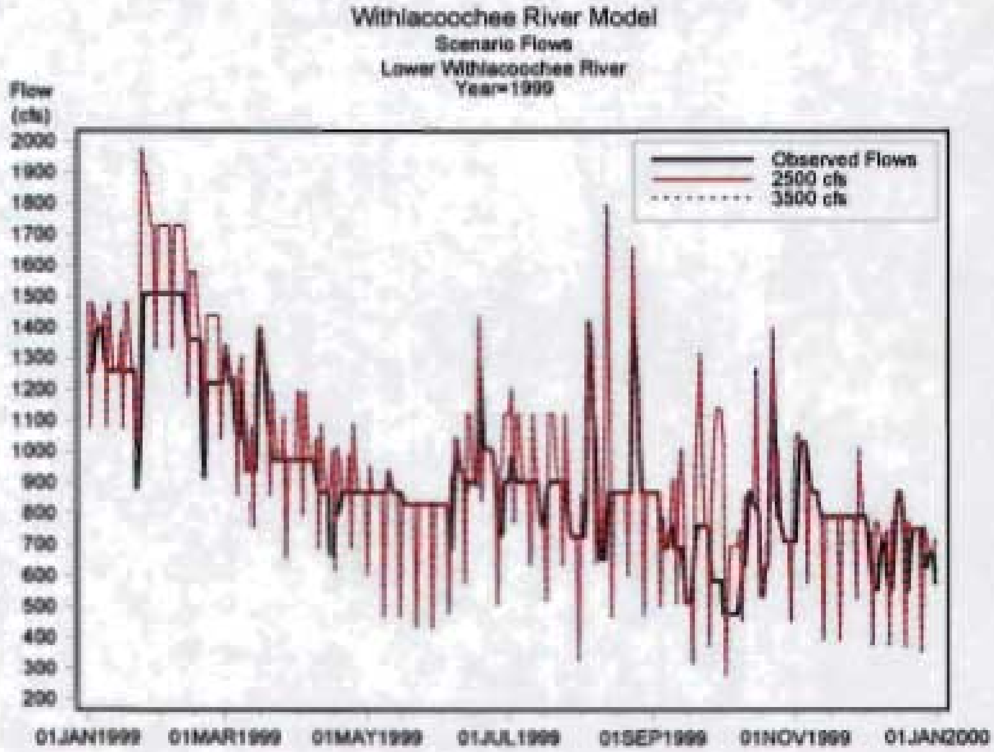




**Figure 5-10. Scenario flows in the Lower Withlacoochee River and Barge Canal, 1998.**



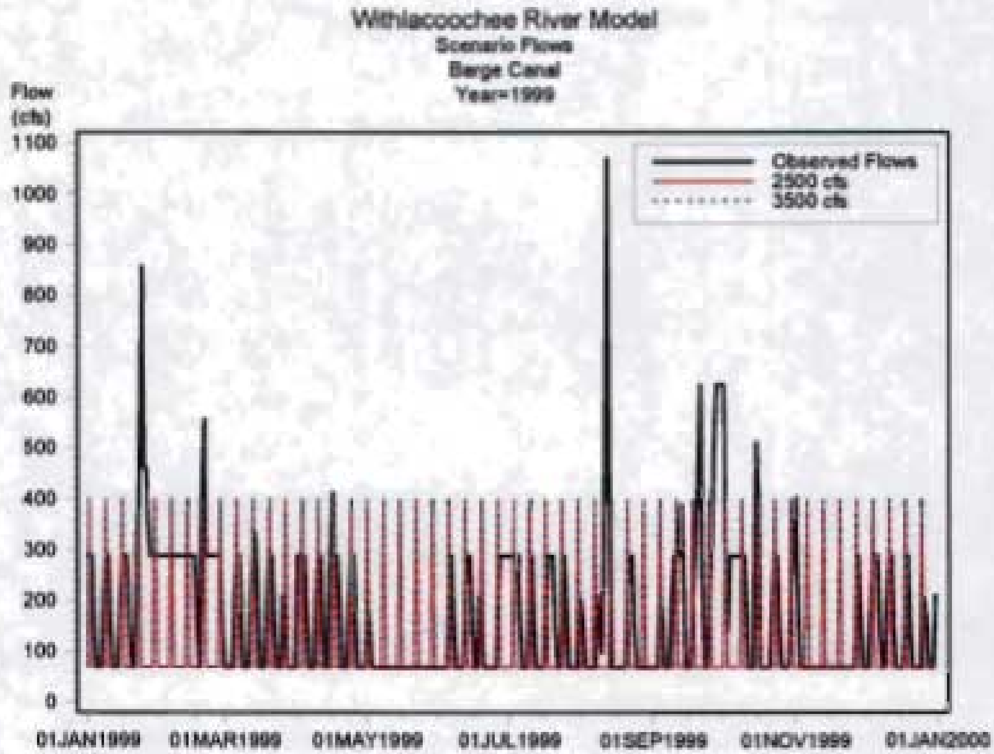
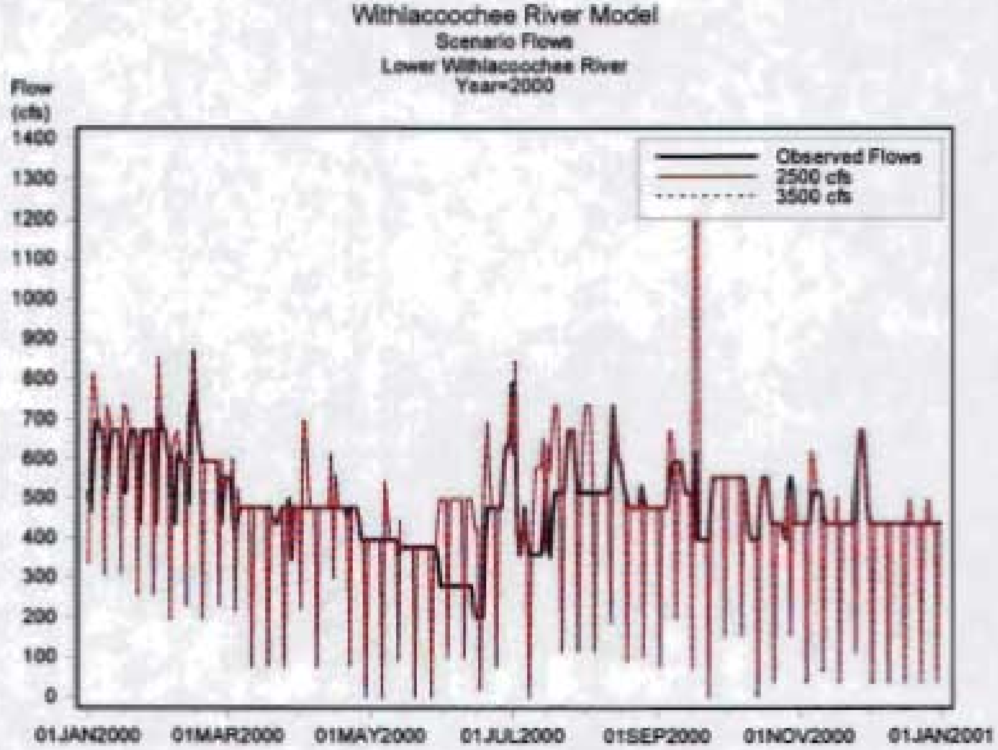




**Figure 5-11. Scenario flows in the Lower Withlacoochee River and Barge Canal, 1999.**



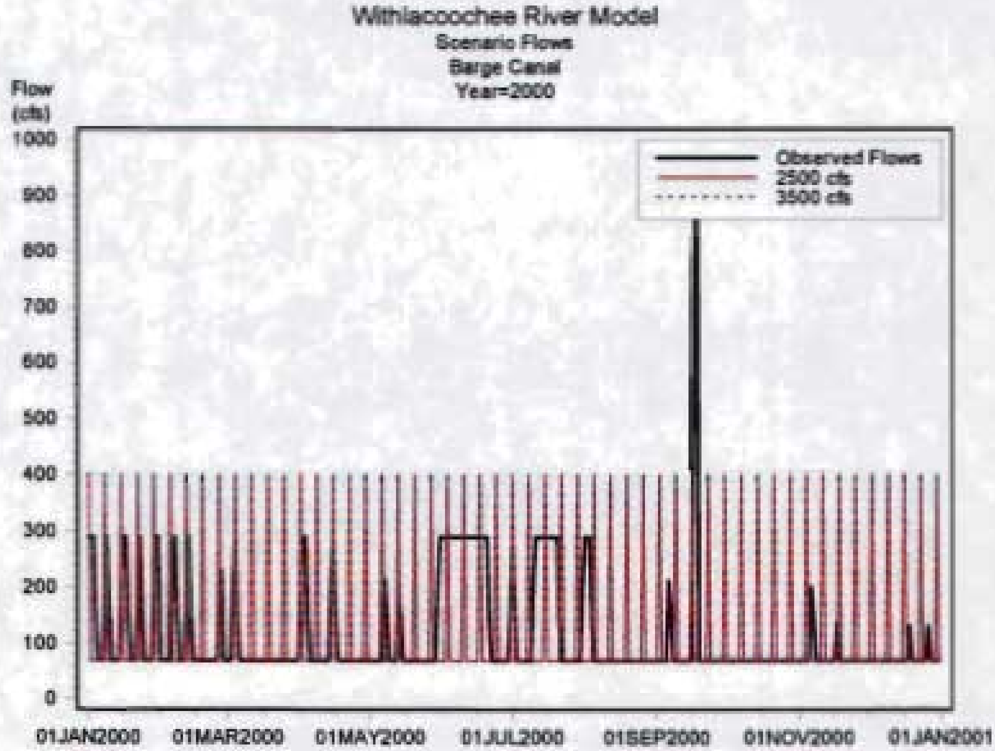
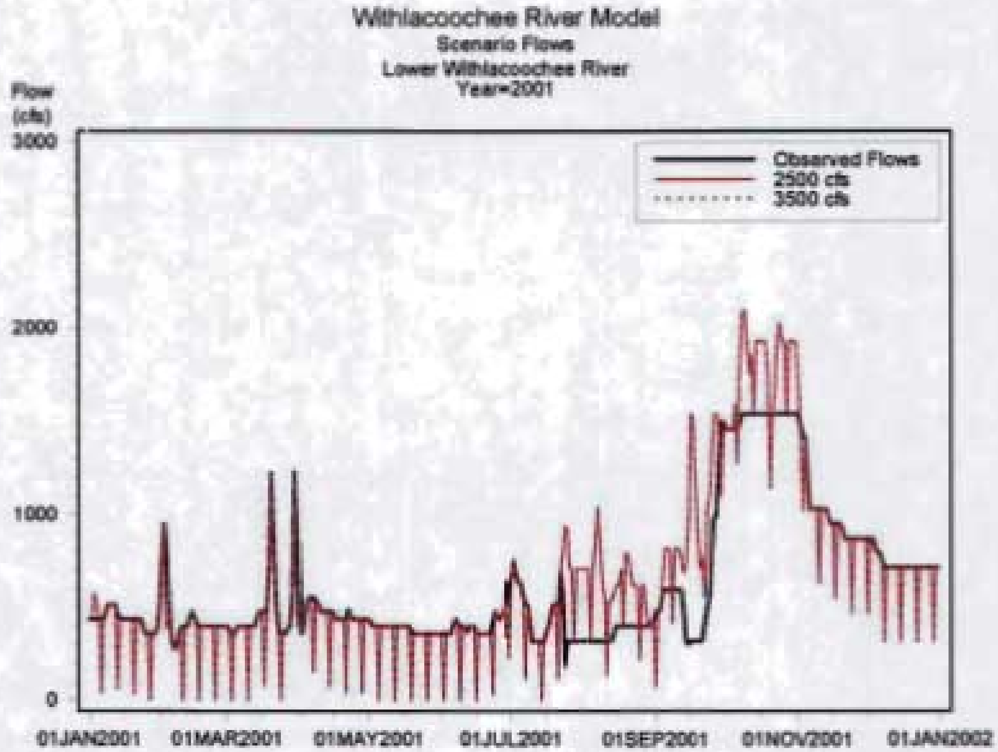




**Figure 5-12. Scenario flows in the Lower Withlacoochee River and Barge Canal, 2000.**



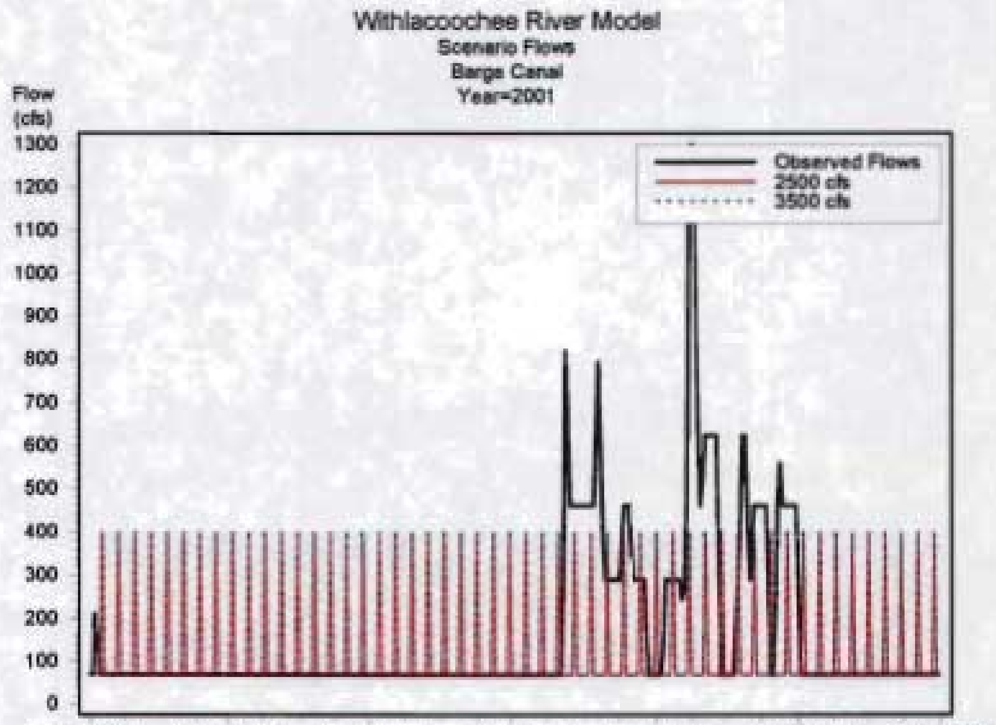
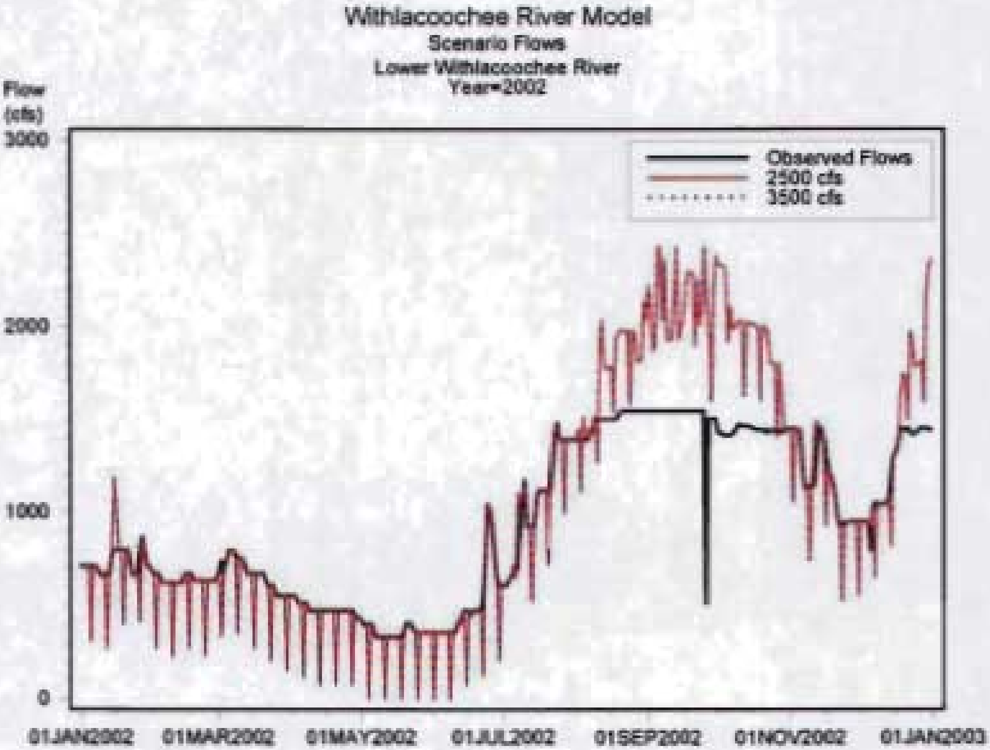




**Figure 5-13. Scenario flows in the Lower Withlacoochee River and Barge Canal, 2001.**



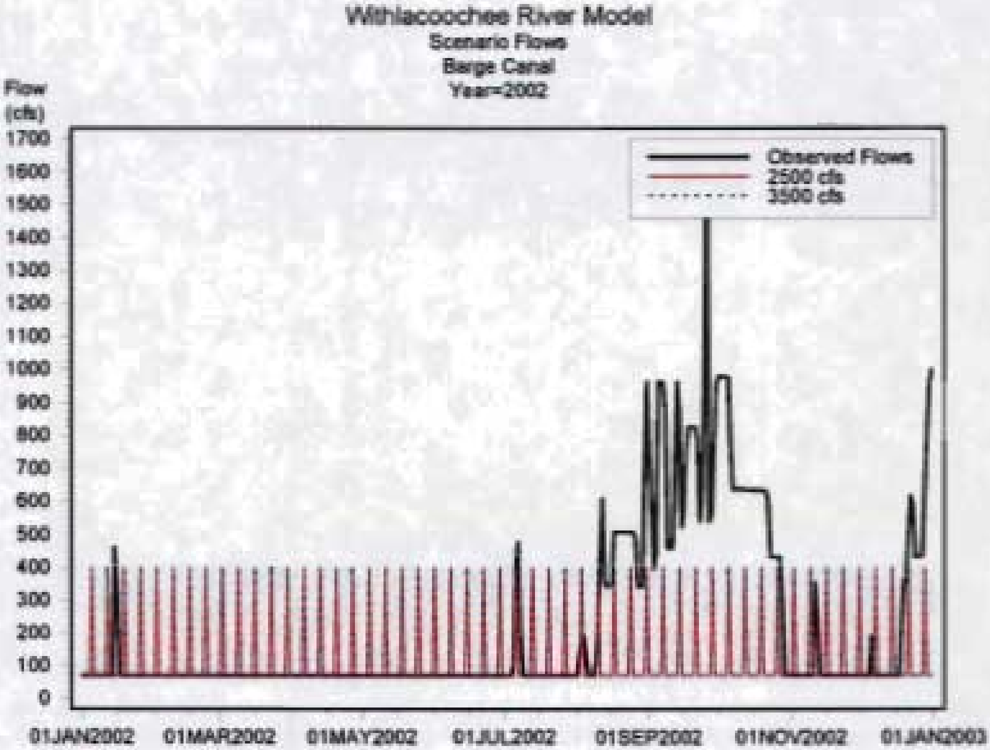




**Figure 5-14. Scenario flows in the Lower Withlacoochee River and Barge Canal, 2002.**

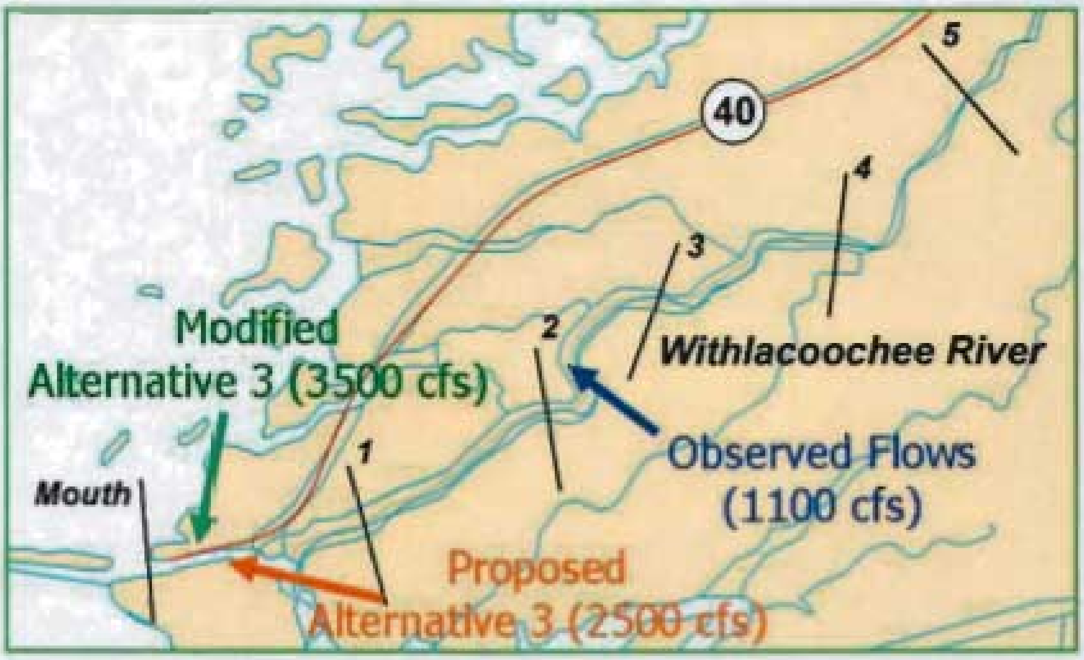



Figure 5-15. Median monthly locations of surface 0.5 ppt isohalines for flow scenarios, January 1998, during high flow conditions.

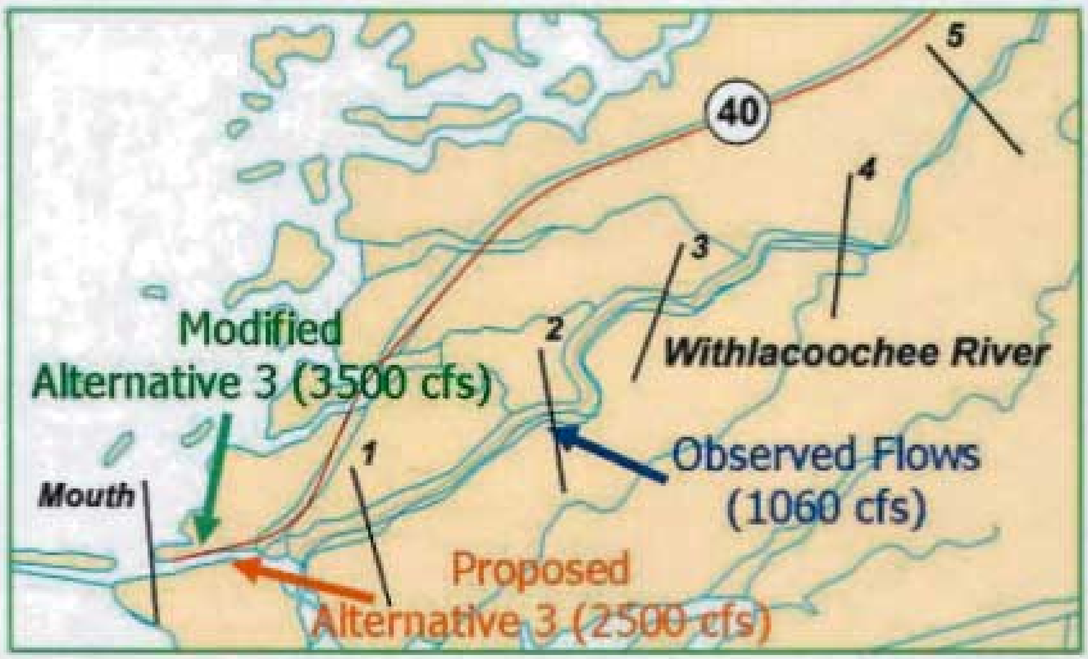



Figure 5-16. Median monthly locations of surface 0.5 ppt isohalines for flow scenarios, February 1998, during high flow conditions.

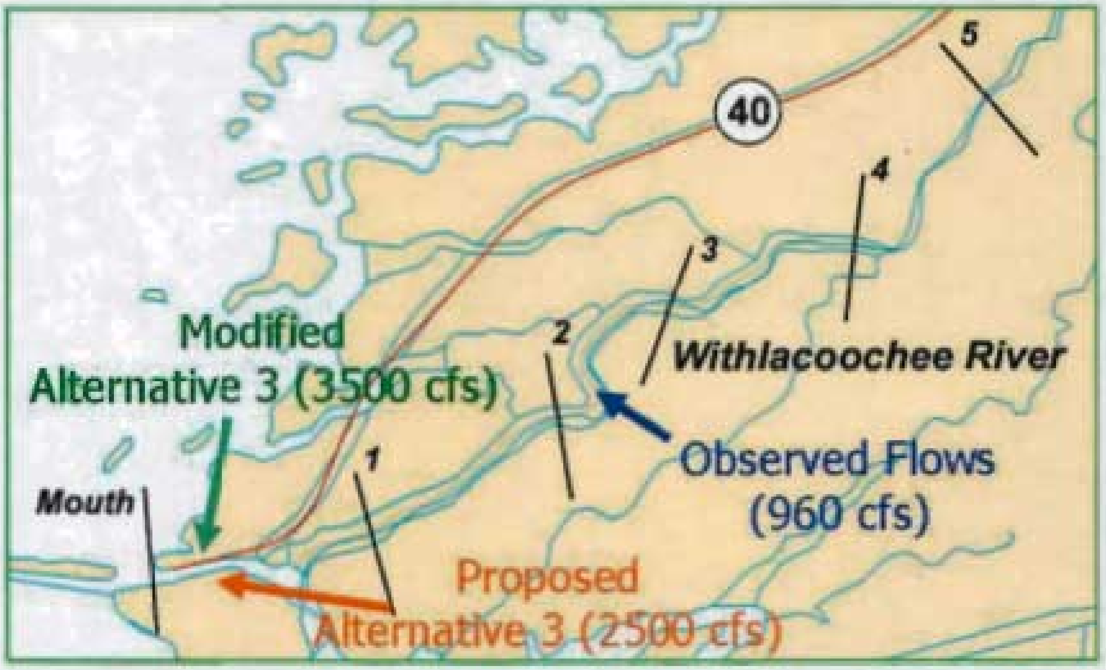



Figure 5-17. Median monthly locations of surface 0.5 ppt isohalines for flow scenarios, March 1998, during high flow conditions.

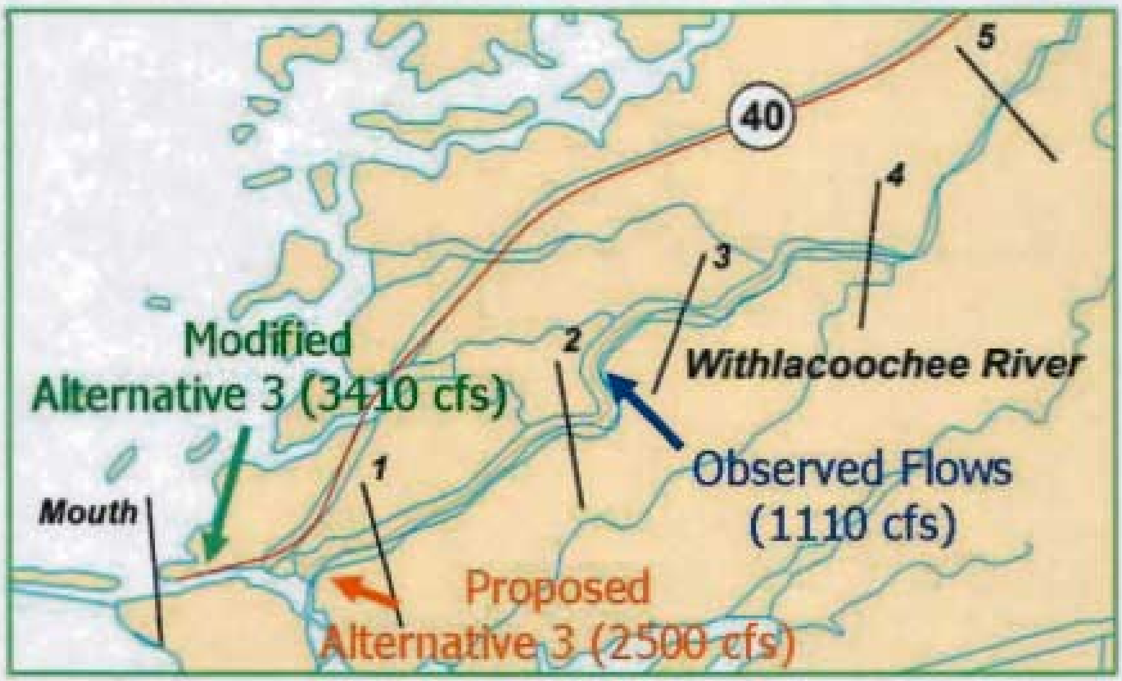



Figure 5-18. Median monthly locations of surface 0.5 ppt isohalines for flow scenarios, April 1998, during high flow conditions.

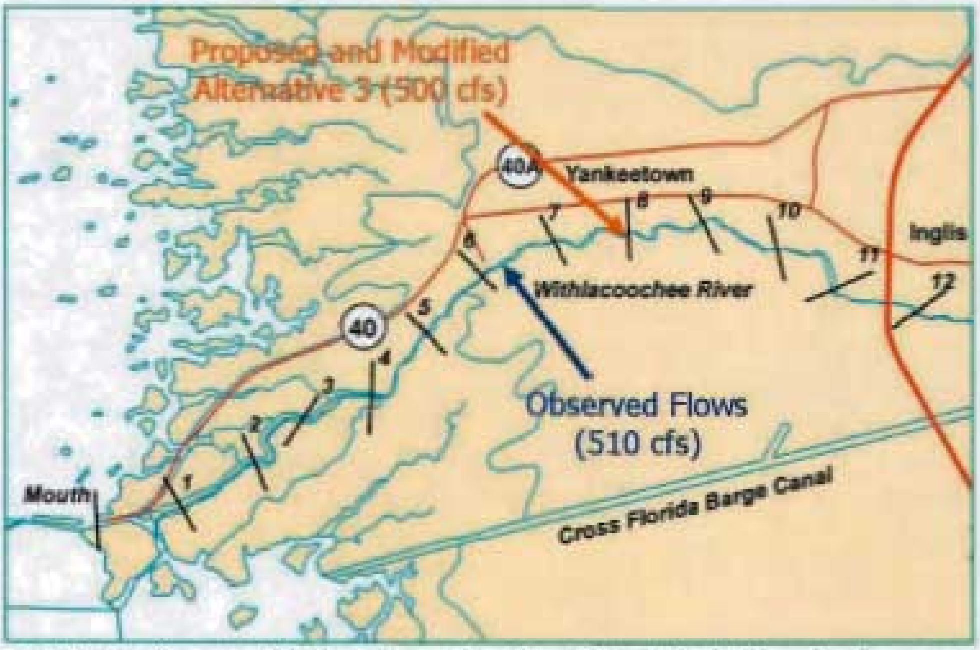



Figure 5-19. Median monthly locations of surface 0.5 ppt isohalines for flow scenarios, September 2000, during low flow conditions. Proposed and Modified Alternative 3 scenarios include conditions which will not be implemented (the 400 cfs one day/week discharge to the Barge Canal), so that the location of the isohaline resulting from the observed flows should be considered.


Figure 5-20. Median monthly locations of surface 0.5 ppt isohalines for flow scenarios, October 2000, during low flow conditions. Proposed and Modified Alternative 3 scenarios include conditions which will not be implemented (the 400 cfs one day/week discharge to the Barge Canal), so that the location of the isohaline resulting from the observed flows should be considered.

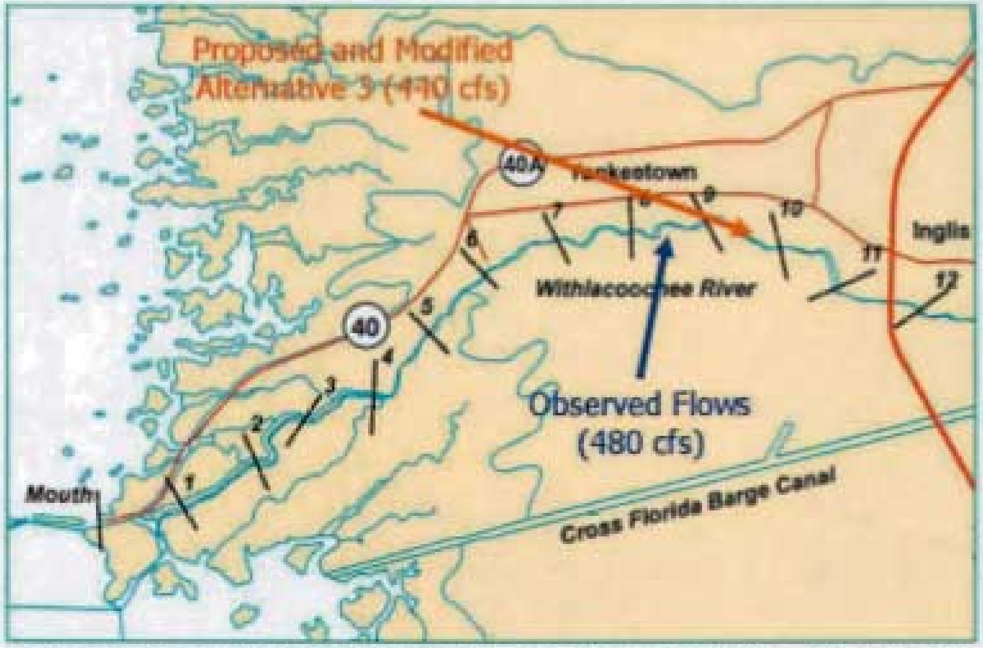



Figure 5-21. Median monthly locations of surface 0.5 ppt isohalines for flow scenarios, November 2000, during low flow conditions. Proposed and Modified Alternative 3 scenarios include conditions which will not be implemented (the 400 cfs one day/week discharge to the Barge Canal), so that the location of the isohaline resulting from the observed flows should be considered.

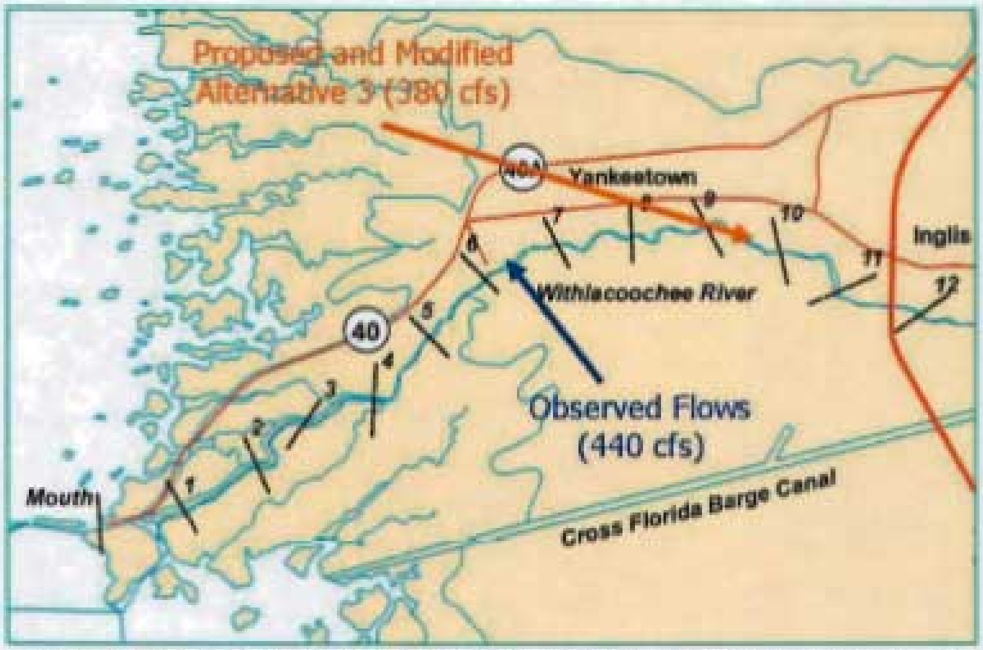



Figure 5-22. Median monthly locations of surface 0.5 ppt isohalines for flow scenarios, December 2000, during low flow conditions. Proposed and Modified Alternative 3 scenarios include conditions which will not be implemented (the 400 cfs one day/week discharge to the Barge Canal), so that the location of the isohaline resulting from the observed flows should be considered.

Comparison of the locations of specific isohalines within the river demonstrates the effects of the potential flow modifications to the Lower Withlacoochee River. The monthly median locations of specific surface isohalines, 0.5, 2, 3, and 5 ppt, within each year are shown in Appendix B. The locations of the isohalines for the 3500 cfs alternative are different from those of the 2500 cfs alternative only during 1998, as the flows are the same for the two alternatives for the remainder of the model period. The river kilometer system utilized is that shown in Figure 5-1.

A comparison of the 0.5 and 5 ppt surface and bottom isohaline locations are provided in Figures 5-23 and 5-24, respectively. As shown by the time series of isohaline locations, during times when flows are high enough so that more water may be directed down the lower river in the 2500 cfs alternative, as in early 1998, the isohalines are displaced further downriver than in the baseline condition. However, at other times, such as in 2000 and 2001 when observed flows were extremely low, the 2500 cfs scenario can actually result in isohaline locations upstream of those in the baseline condition. As seen when examining Figures 5-12 and 5-13, this is the result of supplying the once per week one-day 400 cfs flow to the Barge Canal as provided for in the alternative scenario.

As seen in Figures 5-11 through 5-14, for scenario flows during 1999-2002, proposed and modified alternative scenario flows to the lower river were often less than those observed. This was especially true during 2000-2001 and the first half of 2002. For this period, the analysis results from the observed condition should be considered, as the 400 cfs one day per week discharge to the Barge Canal, as reflected in the proposed and modified alternative scenarios, would not actually be implemented.

An additional analysis examined the effects of the flow modifications over all the channels included in the model domain. For this analysis, the Barge Canal was excluded, so that only the river and the other channels, from the Gulf shore inland, are included (Figure 5-25). The volumes of specific salinity regimes within the system were calculated for the alternative scenarios, and compared to the salinity regime volumes in the baseline scenario. The monthly comparison of volumes for each year for the 0-0.5 ppt and 0.5-5 ppt volumes are provided in Appendix C. Here, the relative volumes for the 2500 and 3500 cfs alternatives are shown separately for 1998, but for the remaining years, when the flows and thus the volumes are the same, only the 2500 cfs alternative volumes are shown.

The review of the scenario comparisons indicates that alternative scenarios would result in changes in the amount of freshwater in the Lower Withlacoochee River. However, these changes do not always represent an increase in freshwater volume, as the weekly one-day 400 cfs discharge to the Barge Canal can result in less total freshwater in the lower river than found in the baseline. The modifications to isohaline locations and salinity regime volumes are dependent on the total amount of water available in the combined discharge to the Lower River and the Barge Canal, and the Barge Canal discharge schedule. The ability to increase the volume and extent of low salinity regimes in the river is enhanced during wet periods, but decreases during dry periods, with very low flow periods resulting in decreases in low-salinity volumes for the 2500 and 3500 alternatives as compared to the existing baseline flow scenario, most notably as in 2000 and 2001.

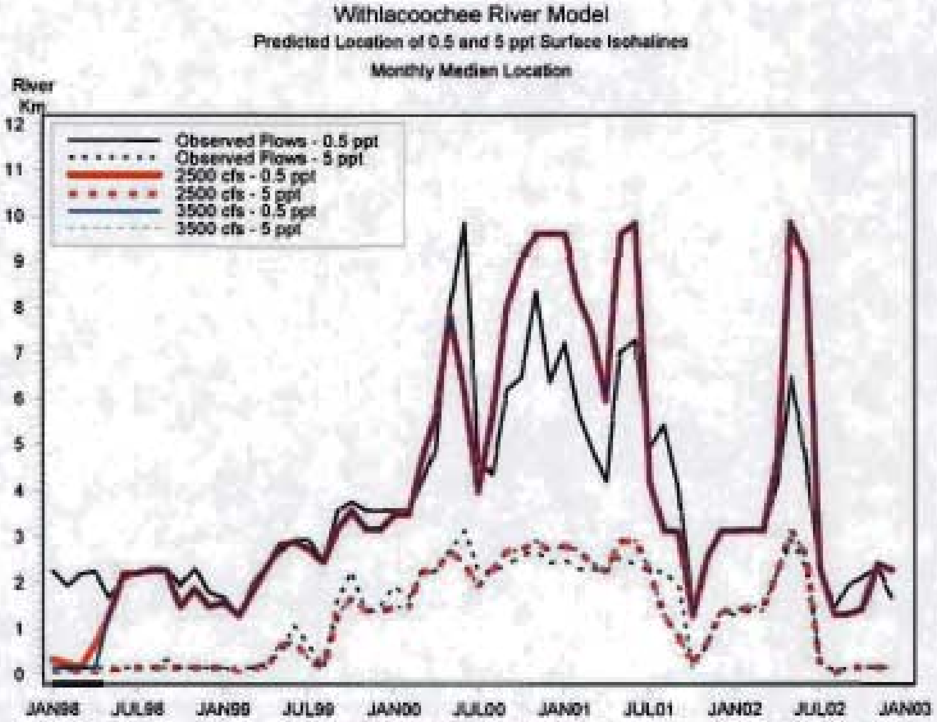



Figure 5-23. Monthly median locations of surface 0.5 and 5 ppt isohalines, baseline, 2500 cfs alternative, and 3500 cfs alternative.

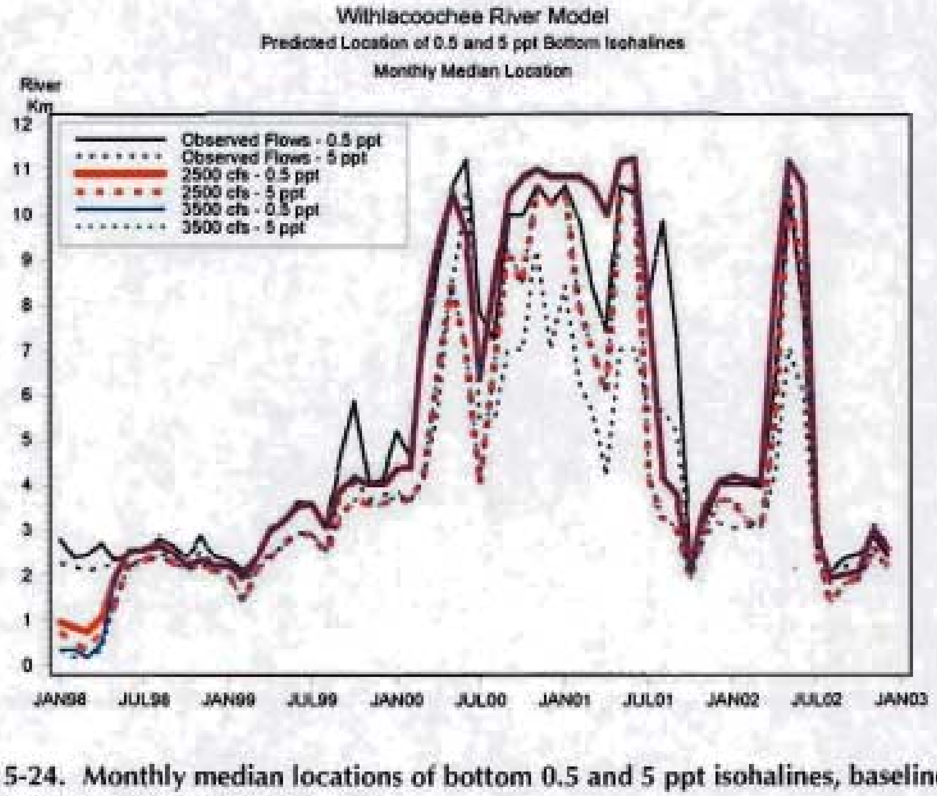



Figure 5-24. Monthly median locations of bottom 0.5 and 5 ppt isohalines, baseline, 2500 cfs alternative, and 3500 cfs alternative.

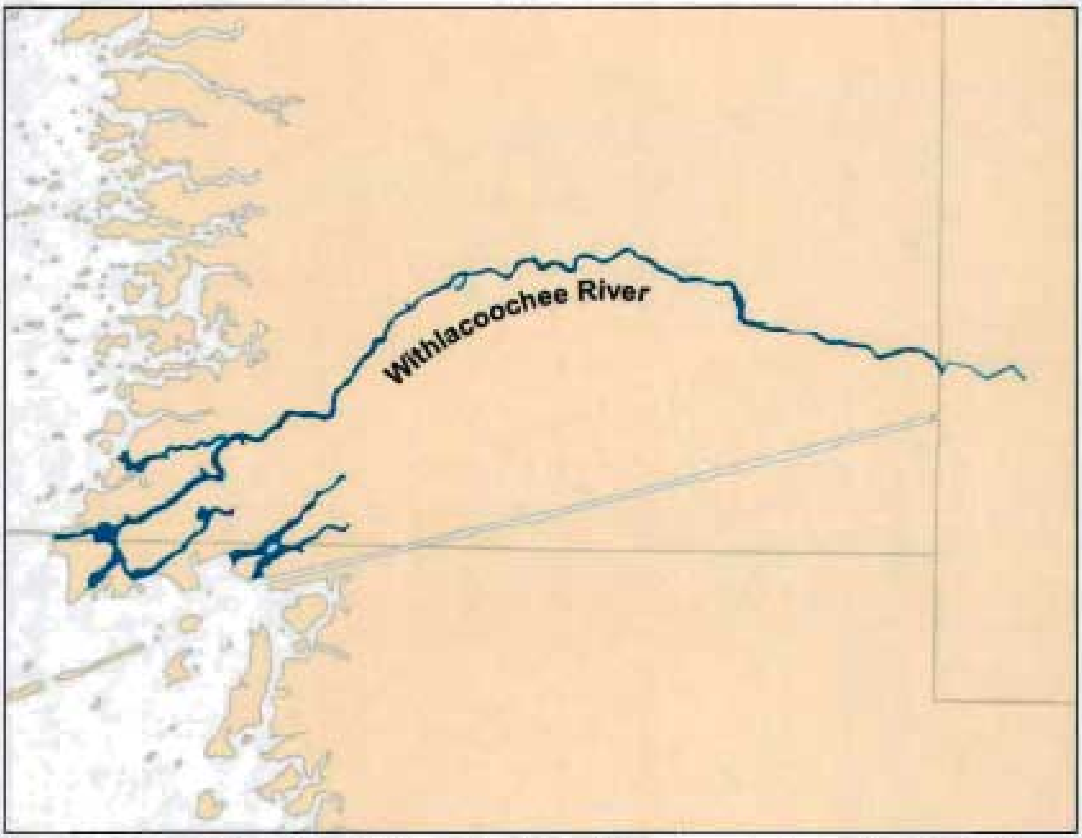



**Figure 5-25. Region of model domain for which comparative volume analysis was completed.**

## 5.4. Salinity and Benthos in the Lower Withlacoochee River

This section provides a description of the benthic community in the Lower Withlacoochee River, details the salinity requirements for the community, and discusses the benefits and drawbacks of flow modifications with respect to these requirements.

The number of benthic samples collected in the Lower Withlacoochee River by calendar month is summarized in Table 5-2. These samples were collected by FDEP (1975-1981, 48 samples) and Mote Marine Laboratory (1984-1985, 24 samples).

**Table 5-2. Numbers of benthic samples collected by month.**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Withlacoochee | 7 | 10 | 0 | 7 | 9 | 5 | 7 | 8 | 2 | 11 | 6 | 0 | 72 |

Analysis of benthic sampling data reveals three salinity classes (<7 ppt, 7 - 18 ppt, and 18 - 29 ppt) in the Lower Withlacoochee River (Table 5-3). Because salinities in the lower river are typically in the range of the classically defined oligohaline habitat (0 - 5 ppt), the species in the <7 ppt class (Table 5-3) will be discussed further. The breakdown of the data into the three salinity classes results in an extension of the oligohaline class (defined in the

Venice system as 0.5-5 ppt) over the salinity range 0-7 ppt. This class contains those benthos found in the 0.5-5 ppt range, with preferred ranges included in the 0-7 ppt range.

Janicki Environmental (2007) developed optimum salinity plots for benthic species in the Coastal Springs zone which includes the Lower Withlacoochee River. Salinity optima for the most abundant species in the <7 ppt salinity class are presented in Figures 5-26 to 5-31. The two most abundant species in the <7 ppt salinity class (Table 5-3) have "optimum" salinities in the mesohaline salinity class (7-18 ppt). Therefore, an upstream migration of the 5 ppt isohaline would not have a negative impact on the abundance of these species. *Polymesoda caroliniana* (marsh clam) prefers very low salinity water, but can be found in salinities as high as 20 ppt. *Corbicula fluminea* (Asiatic clam), an invasive species, can occur at salinities greater than 10 ppt, but prefers fresh to very low salinity water. A downstream migration of the 0.5 ppt isohaline would increase the amount of available habitat for *Corbicula*.

Based on these data, most of the benthic species found in the 0-7 ppt salinity regime show central salinity preferences greater than 5 ppt. The only non-invasive species with a central salinity preference less than 5 ppt in the Coastal Springs region is *Polymesoda*. This is the one non-invasive species that would likely benefit from a downstream movement of the low-salinity isohalines, and more habitat available in the oligohaline and mesohaline zones. It should be noted, however, that the invasive species *Corbicula* would also likely benefit from this downstream movement. As seen when comparing Figures 5-28 and 5-29, the invasive *Corbicula* preference range is for oligohaline waters (<5 ppt), whereas the more estuarine *Polymesoda* has a much wider preference range, over the oligohaline and mesohaline zones. This indicates that if more oligohaline (<5 ppt) habitat were provided in the lower river, the invasive *Corbicula* would likely benefit more than the more estuarine *Polymesoda* from the extension of oligohaline habitat.

**Table 5-3. Most abundant benthic taxa (as % composition) in the Withlacoochee River, by salinity class and the "optimum" salinity class (based upon logistic regression analysis) (Adapted from: Janicki Environmental, 2007).**

| **Oligohaline Salinity Class (<7 ppt)** | % Composition | Optimum Salinity Class in Springs Coast Rivers (Logistic Regression Analysis) |
|---|---|---|
| *Laeonereis culveri* (clam worm) | 18.7 | Mesohaline |
| *Cyathura polita* (isopod) | 13.1 | Mesohaline |
| *Corbicula fluminea* (Asiatic clam) | 7.3 | (Oligohaline) |
| *Polymesoda caroliniana* (marsh clam) | 5.0 | Oligohaline |
| *Amphicteis gunneri* (polychaete) | 5.0 | Mesohaline |
| *Grandidierella bonnieroides* (amphipod crustacean) | 4.5 | Mesohaline |
| **Mesohaline Salinity Class (>7≤18 ppt)** | | |
| *Grandidierella bonnieroides* (amphipod crustacean) | 7.1 | Mesohaline |
| *Laeonereis culveri* (clam worm) | 7.1 | Mesohaline |
| *Amphicteis gunneri* (polychaete) | 7.1 | Mesohaline |
| *Cyathura polita* (isopod) | 7.1 | Mesohaline |
| *Halmyrapseudes bahamensis* (tanaidacean crustacean) | 7.1 | Mesohaline |
| *Cerapus benthophilus* (amphipod crustacean) | 4.3 | Mesohaline |
| *Streblospio gynobranchiata* (spionid polychaete) | 3.8 | Mesohaline |
| *Edotea montosa* (isopod) | 3.8 | Mesohaline |
| *Hargeria rapax* (tanaidacean crustacean) | 3.8 | (Euhaline) |
| **Polyhaline Salinity Class (>18≤29 ppt)** | | |
| *Halmyrapseudes bahamensis* (tanaidacean crustacean) | 8.2 | Mesohaline |
| *Cyathura polita* (isopod) | 7.0 | Mesohaline |
| *Xenanthura brevitelson* (isopod) | 5.9 | (Polyhaline) |
| *Grandidierella bonnieroides* (amphipod crustacean) | 5.1 | Mesohaline |
| *Laeonereis culveri* (clam worm) | 4.7 | Mesohaline |
| *Tagelus plebeius* (stout razor clam) | 3.8 | Mesohaline |
| *Heteromastus filiformis* (capitellid polychaete) | 3.4 | NS |
| *Cerapus benthophilus* (amphipod crustacean) | 3.4 | Mesohaline |
| *Parandalia Americana* (polychaete) | 3.2 | NS |
| *Streblospio gynobranchiata* (spionid polychaete) | 3.0 | Mesohaline |
| *Mediomastus ambiseta* (capitellid polychaete) | 2.4 | Euhaline |
| *Ampelisca holmesi* (amphipod crustacean) | 2.4 | Euhaline |

( ) = logistic regression significant for "all rivers" but not for Springs Coast Rivers alone
NS = logistic regression not significant

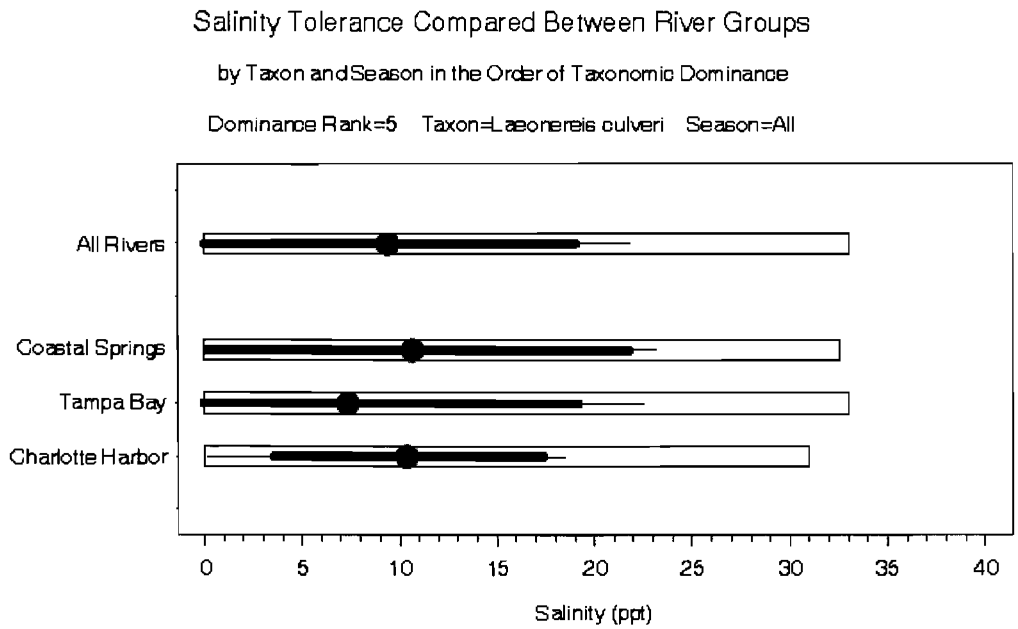



**Figure 5-26. Optimum (circle), preference range (thick solid bar), and 10th to 90th percentile (thin solid bar) of salinity for *Laeonereis culveri* (Polychaeta), by river group and season, based upon logistic regression analysis. Open bar represents range of observed salinities. The absence of symbols indicates that the relationship was not statistically significant. (Source: Janicki Environmental, 2007).**

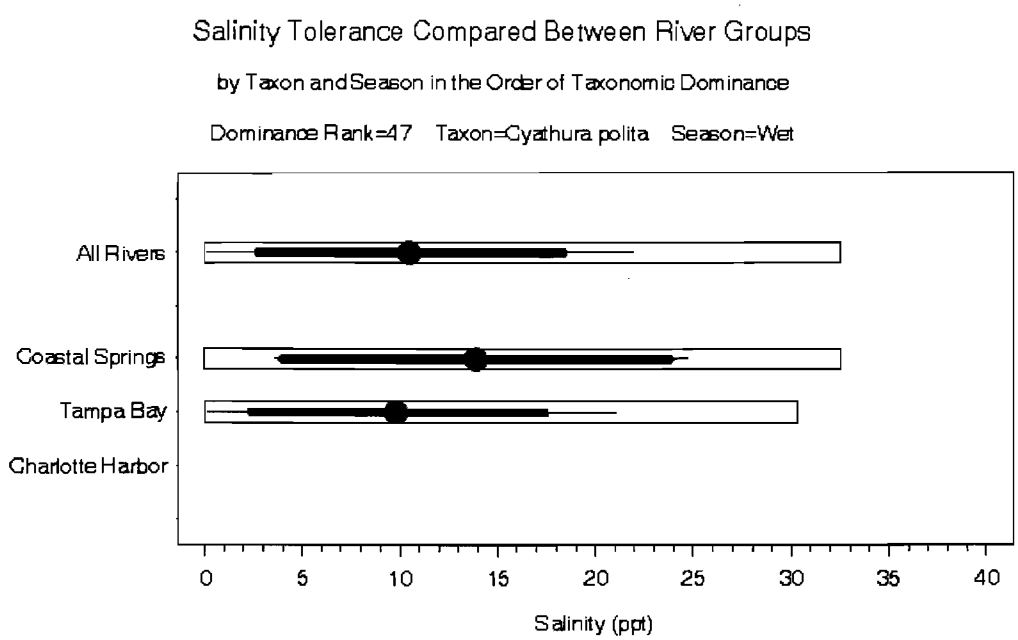



**Figure 5-27. Optimum (circle), preference range (thick solid bar), and 10th to 90th percentile (thin solid bar) of salinity for *Cyathura polita* (Isopoda), by river group and season, based upon logistic regression analysis. Open bar represents range of observed salinities. The absence of symbols indicates that the relationship was not statistically significant. (Source: Janicki Environmental, 2007).**

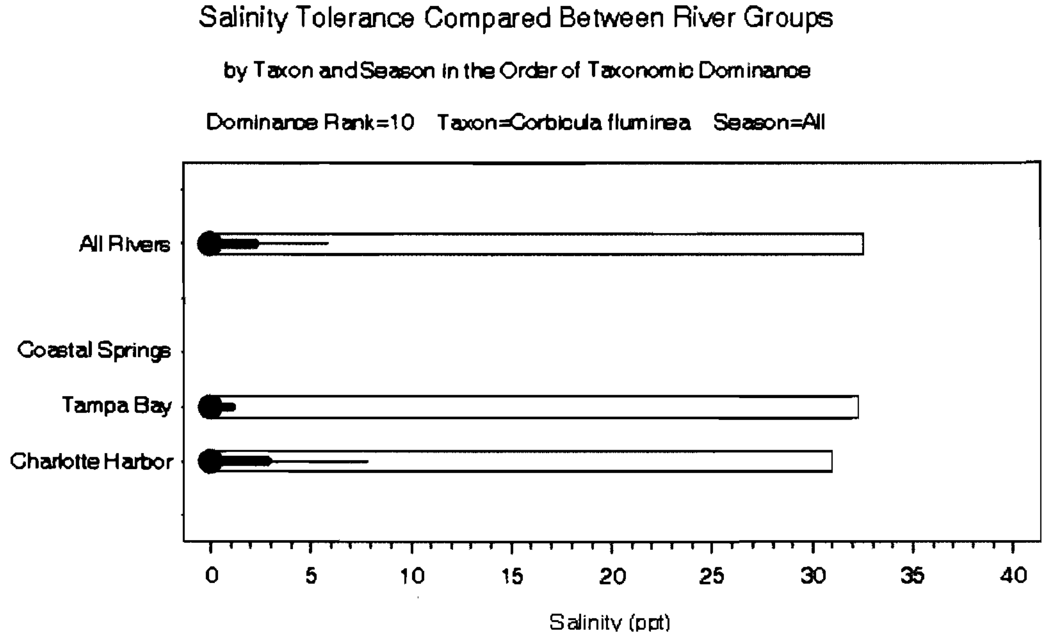



**Figure 5-28.** Optimum (circle), preference range (thick solid bar), and 10th to 90th percentile (thin solid bar) of salinity for *Corbicula fluminea* (Bivalvia) (Asiatic clam), an invasive species, by river group and season, based upon logistic regression analysis. Open bar represents range of observed salinities. The absence of symbols indicates that the relationship was not statistically significant. (Source: Janicki Environmental, 2007).

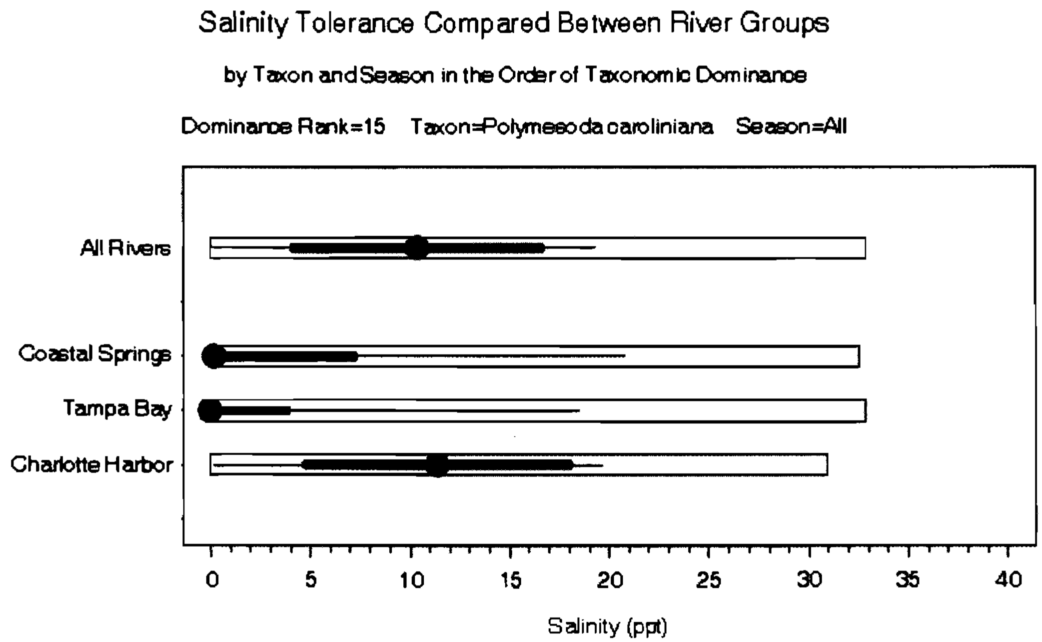



**Figure 5-29.** Optimum (circle), preference range (thick solid bar), and 10th to 90th percentile (thin solid bar) of salinity for *Polymesoda caroliniana* (Bivalvia) (marsh clam), by river group and season, based upon logistic regression analysis. Open bar represents range of observed salinities. The absence of symbols indicates that the relationship was not statistically significant. (Source: Janicki Environmental, 2007).

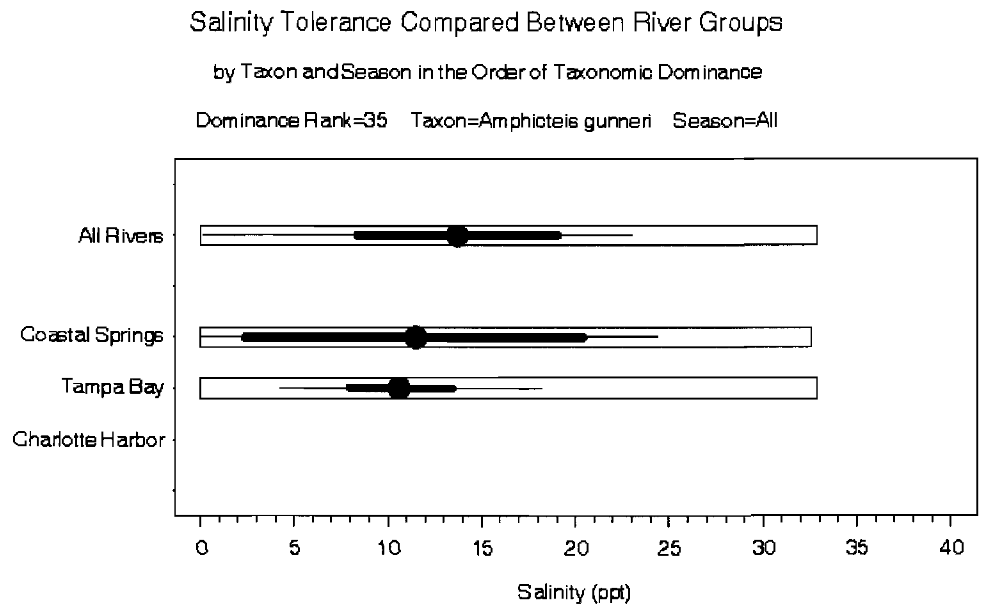



**Figure 5-30. Optimum (circle), preference range (thick solid bar), and 10th to 90th percentile (thin solid bar) of salinity for *Amphicteis gunneri* (Polychaeta), by river group and season, based upon logistic regression analysis. Open bar represents range of observed salinities. The absence of symbols indicates that the relationship was not statistically significant. (Source: Janicki Environmental, 2007).**

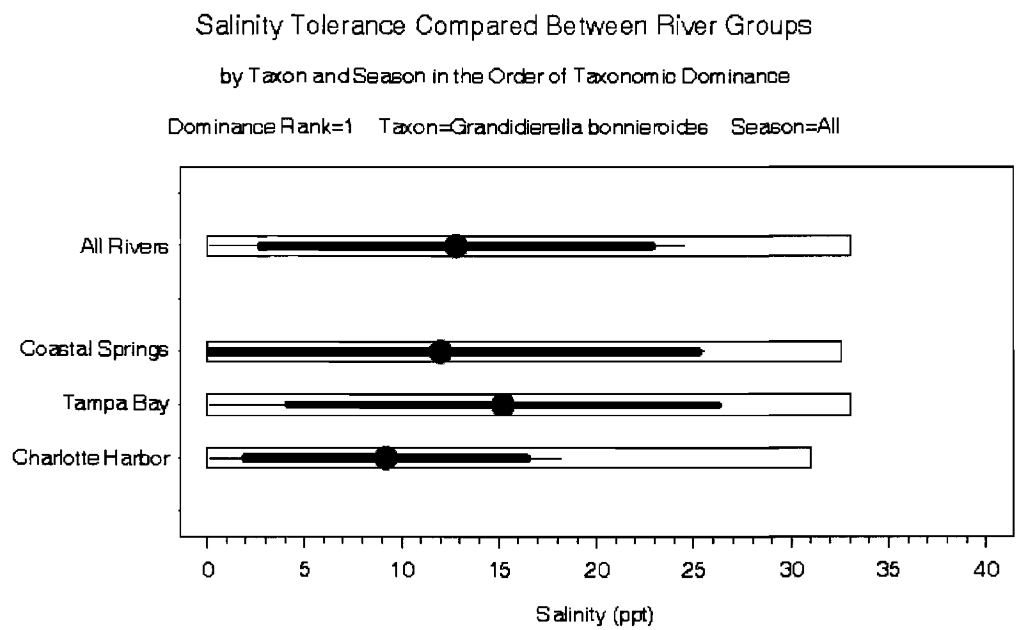



**Figure 5-31. Optimum (circle), preference range (thick solid bar), and 10th to 90th percentile (thin solid bar) of salinity for *Grandidierella bonnieroides* (Amphipoda), by river group and season, based upon logistic regression analysis. Open bar represents range of observed salinities. The absence of symbols indicates that the relationship was not statistically significant. (Source: Janicki Environmental, 2007).**

## 5.5. Salinity and Bald Cypress in the Lower Withlacoochee River

This section provides a discussion of the results of the bald cypress study with respect to isohaline locations. Included is a discussion of the impacts of model error on prediction of isohaline locations.

Stahle and Griffin (2006) sampled ten dead cypress trees found along the Lower River. Of these ten dead trees, six died during the 1998-2002 period. Three of these trees died during 1998-1999, while the remaining three died during 2000-2001.

Following is an examination of river flows and resultant isohaline locations and durations during the years of the trees' deaths. The locations of the dead trees, as provided in Stahle and Griffin (2006), are shown in Figure 5-32. For reference to the river kilometer system, the tree locations are also provided in Figure 5-33. Note that all the dead bald cypress trees are between RKm 2 and 4.

As noted previously, studies have indicated that bald cypress cannot withstand persistent salinities of 2-3 ppt. It has been noted, however, that little information exists on the long-term effects of elevated salinity in mature coastal forests (Conner and Inabinette, 2003), so that the definition of "persistent" is inexact. It is likely that during a "normal" year under natural conditions, the cypress trees along the river were subjected to higher salinities during the dry season and fresh water during the wet season. When the wet season does not provide relief from the higher salinities, however, as during a prolonged (multi-year) drought, the cypress trees are provided no period of relief from the higher salinity environment. Such a period occurred during 2000-2001.

The monthly median locations of the surface and bottom isohalines for both 2 and 3 ppt are provided in Figures 5-34 and 5-35, respectively, for 1998-2002. Note that surface salinity isohalines for both 2 and 3 ppt are typically downstream of RKm 4, and seldom upstream of RKm 3 (Figure 5-34). The locations of the bottom isohalines, however, are upstream of RKm 4 for a long period. The median monthly location of the 2 ppt bottom isohaline for the observed baseline condition was upstream of RKm 4 from December 1999 through September 2001, or for 22 straight months. Similarly, the location of the 3 ppt bottom isohaline was upstream of RKm 4 for March 2000 through September 2001, or for 19 straight months. Elevated salinity levels during 2000-2001 may well have been a contributing factor to the three bald cypress deaths during this period.

During 1998, two tree deaths occurred at about RKm 3.0. During all of 1998, the median monthly locations of the 2 and 3 ppt bottom isohaline were downstream of here. However, the median monthly locations of the 2 ppt bottom isohaline was upstream of RKm 4 during October 1996-September 1997, so that the trees may have been impacted by this long period (12 months) of relatively high salinity. The isohaline locations for 1996-1997 were estimated utilizing the relationships between flow and isohaline location described below in Section 5.7.

During 1999, one tree death occurred at about RKm 2.5. During 1999, the median monthly locations of the 2 and 3 ppt bottom isohalines were upstream of here during April-December, but averaged only 0.7 km upstream of RKm 2.5. It is possible that elevated salinity over this nine month period contributed to this death, but the flows during this period were not exceptionally low, and the resultant relevant isohaline locations were not exceptionally far upstream.

From this analysis, it appears that exposure to salinities in excess of 2 or 3 ppt for prolonged periods of one year or more may play a role in the deaths of the bald cypress along the lower river. During 2000-2001, when three of the 10 sampled bald cypress deaths occurred, exposures to elevated salinities, in excess of 3 ppt, were for 19 months or more.

The predictions of the isohaline locations should be viewed with an appreciation for the errors associated with these predictions. All predictive methods inherently contain errors. For simulation modeling, this error is quantified through use of various statistical measures of error (mean error, root mean squared error, absolute mean error). Acceptable values for these statistical measures instill confidence in the robustness of the model in recreating observed conditions.

The statistical measures of error for the GCSM and LWRM are within acceptable values (see Appendix A). This gives confidence that comparison of results from the various flow scenarios provides a meaningful estimate of the changes to be expected from implementation of a flow alternative. Some error in the prediction of isohaline locations exists, and may be estimated by examining the locations of isohalines within 1 ppt of each other, such as the 2 and 3 ppt isohalines. As the mean errors for the two models are less than 0.5 ppt, this should provide a sufficient bound for possible isohaline locations.

The differences between the predicted 2 and 3 ppt isohaline locations for the baseline existing conditions, as seen in Figures 5-34 and 5-35, averages 0.4 km for the surface isohalines and 0.3 km for the bottom isohalines. The greatest mean annual differences between the locations for the bottom 2 and 3 ppt isohalines are 0.6 km, during 2000 and 2001. This implies that for a conservative estimate of salinity prediction error of 1 ppt, the bottom isohaline location would be off by as much as 0.6 km. This represents an upper bound to the potential error in the predictions of the locations of the bottom isohalines, as the mean error in the salinity predictions is less than 0.5 ppt.

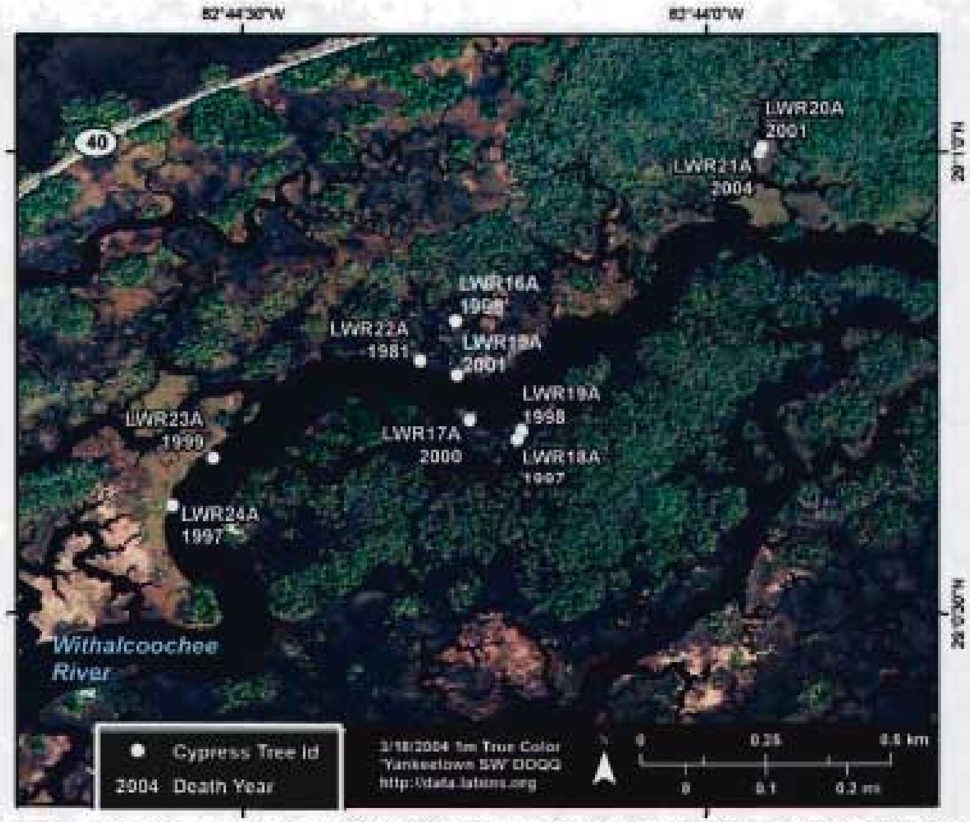



Figure 5-32. Locations, specimen identification numbers, and death dates of bald cypress trees along the Lower Withlacoochee River, from Stahle and Griffin, 2006.

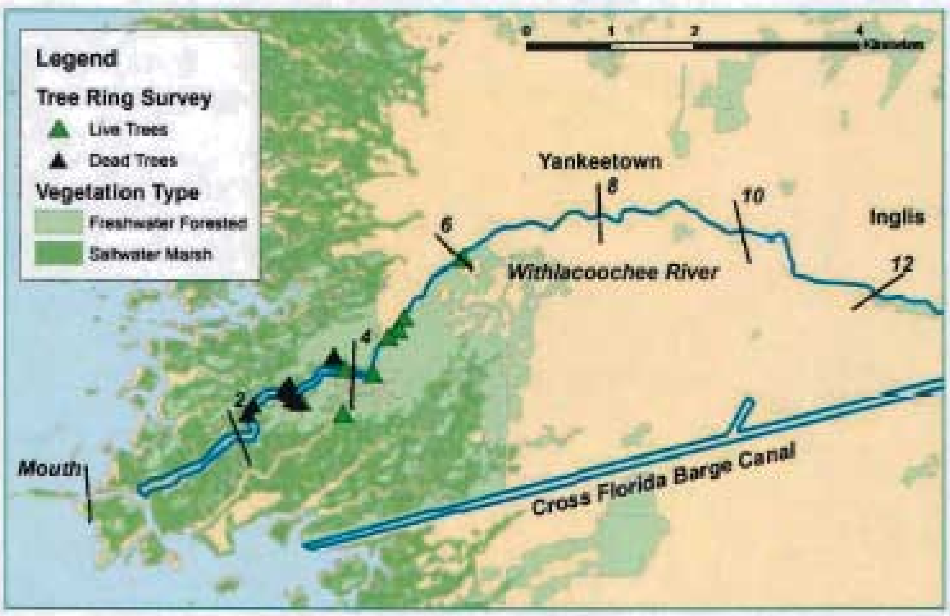



Figure 5-33. Locations of sampled bald cypress trees along the lower river in relation to the river kilometer system.

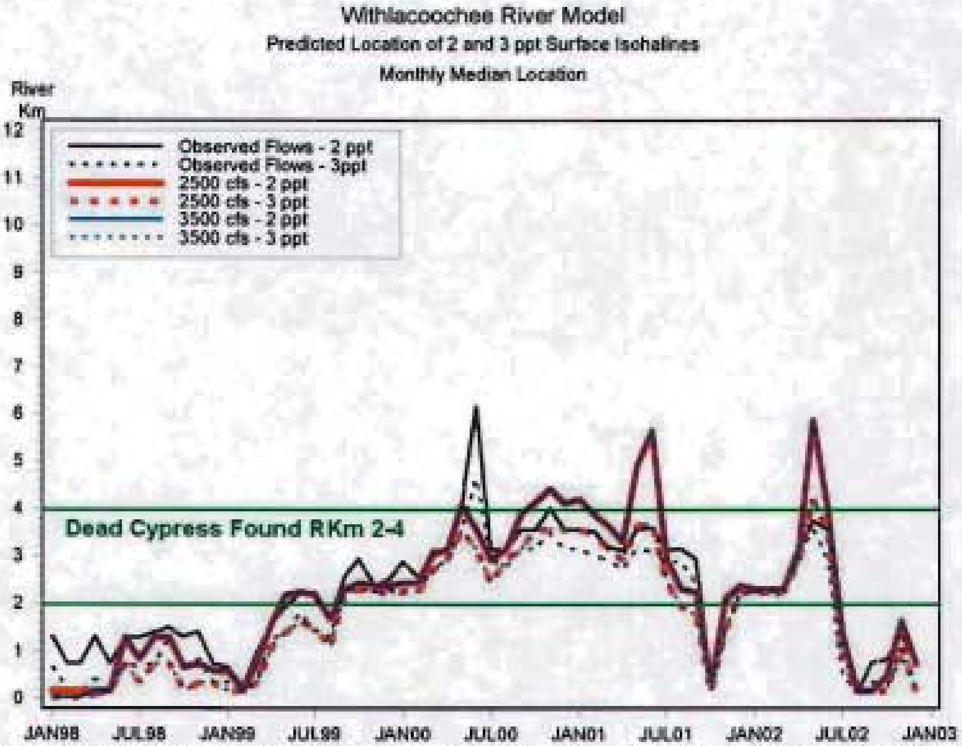



Figure 5-34. Monthly median locations of surface 2 and 3 ppt isohalines, baseline, 2500 cfs alternative, and 3500 cfs alternative.

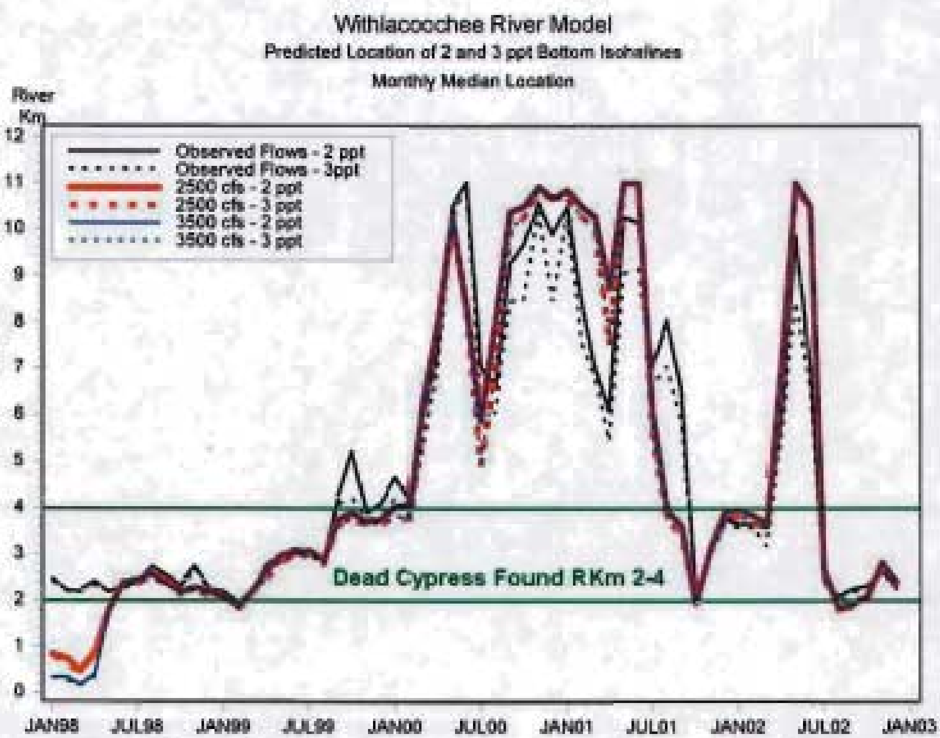



Figure 5-35. Monthly median locations of bottom 2 and 3 ppt isohalines, baseline, 2500 cfs alternative, and 3500 cfs alternative.

### 5.6. Sea Level Rise

Increasing sea level in the western Gulf of Mexico is an important consideration when evaluating any potential flow modification scenario for increasing low-salinity habitat in the river. Costs associated with flow modification must be weighed against the likelihood that sea level rise will obviate any gains in low-salinity habitat in the long term.

Sea level records exist for Cedar Key, just north of the Withlacoochee River, since 1914. Based on the monthly mean sea level, NOAA estimates sea level rise here to be 1.87 mm/year, or 0.61 ft/century if the trend remains the same (http://tidesandcurrents.noaa.gov). An increase in tidal level of this magnitude will result in increased upstream migration of isohaline locations due solely to higher water surface elevations at the mouth of the river. Estimation of the magnitude of this migration, and the effects of various flow regimes, may be obtained via modification of the existing models for the Gulf coast and lower river, utilizing estimated sea level increases as boundary conditions for predictive runs to estimate potential effects on isohaline locations. This modeling effort may be performed in the future if the District so desires.

### 5.7. Isohaline Locations in Response to River Flow

To aid in estimating the flows necessary to maintain specific isohaline locations in the river, relationships between daily flow and isohaline locations as predicted by the baseline model run were developed for the 0.5, 2, 3, and 5 ppt surface and bottom isohalines. A plot of daily surface 0.5 isohaline locations as a function of flow is provided in Figure 5-36, and Figure 5-37 shows a similar plot for the surface 5 ppt isohaline locations.

Linear relationships were developed for each isohaline by log-transforming the flow term. The equations relating isohaline locations to same-day flow are provided below.

*Surface 0.5 ppt Location (R Km)=28.95311-3.79580*ln[flow(cfs)],* with an $r^2$ of 0.73
*Bottom 0.5 ppt Location (R Km)=43.33141-5.72812*ln[flow(cfs)],* with an $r^2$ of 0.79

*Surface 2 ppt Location (R Km)=17.79367-2.34108*ln[flow(cfs)],* with an $r^2$ of 0.81
*Bottom 2 ppt Location (R Km)=39.97063-5.28288*ln[flow(cfs)],* with an $r^2$ of 0.75

*Surface 3 ppt Location (R Km)=16.70229-2.24335*ln[flow(cfs)],* with an $r^2$ of 0.84
*Bottom 3 ppt Location (R Km)=37.27137-4.91364*ln[flow(cfs)],* with an $r^2$ of 0.72

*Surface 5 ppt Location (R Km)=14.21276-1.95444*ln[flow(cfs)],* with an $r^2$ of 0.86
*Bottom 5 ppt Location (R Km)=31.41245-4.10688*ln[flow(cfs)],* with an $r^2$ of 0.66

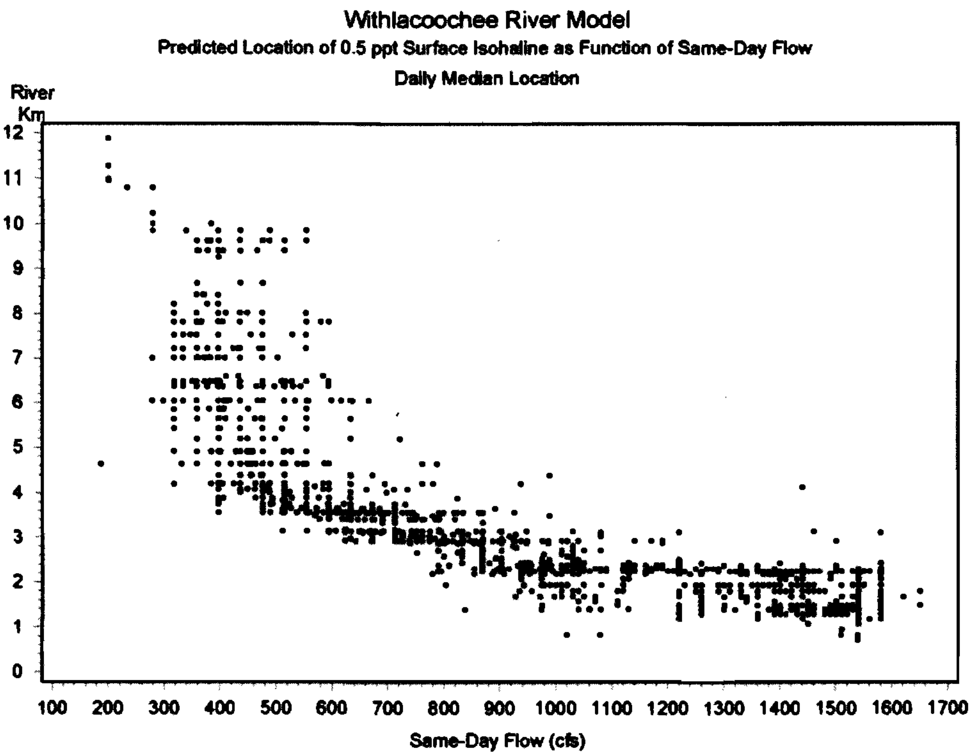



Figure 5-36. Location of surface 0.5 ppt isohaline as a function of same-day flow.

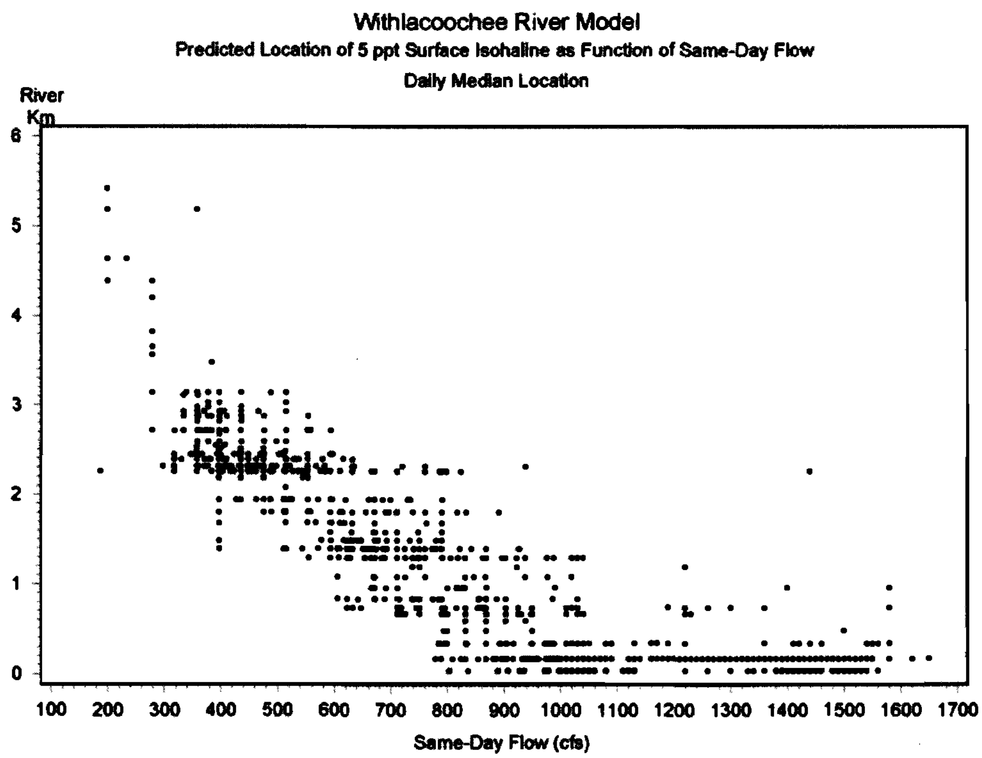



Figure 5-37. Location of surface 5 ppt isohaline as a function of same-day flow.

# 6. CONCLUSIONS

Hydrodynamic models were developed to aid in examination of the potential impacts to salinity regime in the Lower Withlacoochee River resulting from modifications to the system due to construction of portions of the Cross Florida Barge Canal. These modifications have reduced flows to the tidal portion of the river from those that were observed historically. Concerns have been raised regarding the effects of the decline in flows through the system on the lower river's biota, specifically with respect to the deaths of bald cypress trees along the lower river. A study has been completed for the District (Stahl and Griffin, 2006) identifying that ten sampled trees died between 1981 and 2004, and that eight of the ten died between 1997 and 2001.

The model was used to hindcast salinity within the river for the 1998-2002 period, when six of the trees died. The output from this model was then used to develop relationships between river inflows and salinity within the river for application to the other years during which cypress trees died. This allowed a determination of whether increases in salinity were implicated in the deaths, and what river flows should be to protect existing cypress trees.

The monthly and annual locations of the salinity levels important for bald cypress were estimated for 1970-2004. Bald cypress cannot withstand persistent salinities of 2-3 ppt, so the locations of the 2 ppt bottom isohaline were estimated. These locations, and their durations, were compared to the locations of the dead cypress trees. All the dead trees were between 2 and 4 km upstream from the mouth of the river. Except for the trees that died in 1999 and 2004, the remaining dead trees had been exposed to median monthly salinities greater than 2 ppt for relatively long periods of time, in excess of 12 months for most of the trees. Elevated salinity levels may have been a contributing factor to eight of the ten bald cypress deaths during this period.

To address this problem, the SWFWMD developed alternative flow scenarios for the river focused on increasing the amount of freshwater entering the river when additional water is available in the system. The alternative flow scenarios as designed would provide increased flows to the lower river, but primarily during the wet season, when appropriate salinity regimes typically already exist in the lower river, and increased flows provide minimal benefits. During dry periods, flows to the river resulting from these alternative scenarios could only increase if water were available in the system. For those periods when extended low flows occurred, most notably in 2000-2001 when three of the trees died, there was little additional water in the system to increase the flows in the river.

To aid in the evaluation of the alternative flow scenarios, water quality data and benthic data were also examined. Based on these analyses, modifications to freshwater inflows would not result in improvement in water quality or benthic habitat availability in the lower river.

The alternative flow scenarios evaluated in this report did not provide any increased freshwater to the system in the periods when freshwater inflows would be most beneficial, i.e. the observed low flow periods. Any additional alternative flow scenarios should be evaluated with respect to their ability to extend the period of relatively high flows to the river into the typical dry season. The relationships developed between freshwater inflow and important isohaline locations for bald cypress habitat were used to estimate necessary flows. To keep the 2 ppt bottom isohaline downstream of the bald cypress trees, at 2 km from the mouth of the river, average flows of 1300 cfs are necessary, and 1100 cfs to keep the isohaline at 3 km from the mouth. Most of the bald cypress deaths occurred during or immediately following periods when typical dry season conditions extended for long periods, with low flows resulting in movement of the 2 ppt bottom isohaline upstream of 4 km from the mouth for 12 consecutive months or more. The alternative flow scenarios evaluated here do not provide for any improvement in this situation, primarily because the prolonged upstream movement of the 2 ppt bottom isohaline coincides with times when there is not enough water available in the system to prevent this movement, such as 2000-2001.

Based on this evaluation, modification of the operations of the CFBC structures would not provide any benefit to the system, as the cypress deaths occurred during and following periods when sufficient water was not available to prevent >2 ppt water from moving upstream.

# 7. REFERENCES


Allen, J.A., S.R. Pezeshki, and J.L. Chambers. 1996. Interaction of flooding and salinity stress on baldcypress (*Taxodium distichum*). Tree Physiol. 16:307-313.

Allen, J.A., J.L. Chambers, and S.R. Pezeshki. 1997. Effects of salinity on bald cypress seedlings: physiological responses and their relation to salinity tolerance. Wetlands 17(2):310-320.

Bales, J.D., S.A. Tomlinson, and G. Tillis. 2006. Flow and salt transport in the Suwannee River Estuary, Florida, 1999-2000: Analysis of data and three-dimensional simulations. Prepared in cooperation with the Suwannee River Water Management District. Professional Paper 1656-B, U.S. Geological Survey.

Beck, M. W., M. Odaya, J. J. Bachant, J. Bergan, B. Keller, R. Martin, R. Mathews, C. Porter, and G. Ramseur. 2000. Identification of Priority Sites for Conservation in the Northern Gulf of Mexico: An Ecoregional Plan. Report prepared for the USEPA Gulf of Mexico Program. The Nature Conservancy, Arlington, VA. 48 pp.

Benke, A. C., T. C. Van Arsdall, Jr., D. M. Gillespie, and F. K. Parrish. 1984. Invertebrate productivity in a subtropical black-water river: the importance of habitat and life history. Ecological Monographs 54(1): 25-63.

Benke, A. C., R. L. Henry, III, D. M. Gillespie, and R. J. Hunter. 1985. Importance of snag habitat for animal production in southeastern streams. Fisheries 10(5): 8-13.

Brown, Clair A. and G.N.Montz. (1986). Baldcypress: The Tree Unique, The Wood Eternal. Baton Rouge. Claitors Publishing Division. 92-93

Bulger, A.J., B.P. Hayden, M.E. Monaco, D.M. Nelson, M.G. McCormick-Ray. 1993. Biologically-based estuarine salinity zones derived from a multivariate analysis. Estuaries 16:311-322.

Cerco, C.F. 2003. Final report for application of CE-QUAL-ICM to the Lower St. Johns River, Florida.

Comp, G. S. and W. Seaman, Jr. 1985. Estuarine habitat and fishery resources of Florida. Pp. 337-435 IN: W. Seaman, Jr. (ed.), Florida Aquatic Habitat and Fishery Resources. Florida Chapter, American Fisheries Society, Kissimmee, FL.

Conner, W.H., and L.W. Inabinette. 2003. Tree growth in three South Carolina (USA) swamps after Hurricane Hugo: 1991-2001. Forest Ecology and Management 182, 371-380.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U.S. Department of Interior, FWS/OBS-79/31, Washington, D.C. 131 p.

Dolloff, C. A. 1994. Large woody debris – the common denominator for integrated environmental management of forest streams. Pp. 93-108 IN: J. Cairns, Jr., T. V. Crawford, and H. Salwasser (eds.), Implementing Integrated Environmental Management. Virginia Polytechnic Institute and State University, Blacksburg, VA.

Flannery, M.S. SWFWMD, personal communication.

Flint, R. W. and R. D. Kalke. 1985. Benthos structure and function in a south Texas estuary. Contributions in Marine Science 28:33-53.

Gaston, G. R., D. L. Lee, and J. C. Nasci. 1988. Estuarine macrobenthos in Calcasieu Lake, Louisiana: Community and trophic structure. Estuaries 11: 192-200.

Hartog, C. den. 1960. Comments on the Venice system for the classification of brackish waters. Int. Rev. gesamten Hydrobiol. 45: 481-485.

Hartog, C. den. 1974. Brackish-water classification, its developments and problems. Aquatic Ecology 8(1-2): 15-28.

Janicki Environmental, Inc., 2007. Development of analytical tools for the establishment of minimum flows based upon benthic macroinvertebrate communities of southwest Florida tidal rivers. Prepared for Southwest Florida Water Management District (in revision).

Janicki Environmental, Inc. 2006. Cross Florida Greenway: Watershed Evaluation Hydrodynamic Models Draft. Prepared for Southwest Florida Water Management District, Brooksville, FL.

Light, H. M., M. R. Darst, and J. W. Grubbs. 1998. Aquatic Habitats in Relation to River Flow in the Apalachicola River Floodplain, Florida. U. S. Geological Survey Professional Paper 1594. 77 pp.

Maser, C. and J. R. Sedell. 1994. From the Forest to the Sea. The Ecology of Wood in Streams, Rivers, Estuaries and Oceans. St. Lucie Press, Delray Beach, FL. 200 pp.

Mitsch, W. J. and J. G. Gosselink. 1986. Wetlands. Van Nostrand Reinhold, New York, NY. 539 pp.

Mukai, A.Y., Westerink, J. J., and Luettich, R. A.. (2001). "Guidelines for using Eastcoast 2001 database of tidal constituents within Western North Atlantic Ocean, Gulf of Mexico and Caribbean," Coastal and Hydraulics Engineering Technical Note CHETN-IV-40, U.S. Army Engineer Research and Development Center, Vicksburg, MS.
Web address: http://chl.wes.army.mil/library/publications/chetn.

Odum, W. E., T. J. Smith, III, J. K. Hoover, and C. C. McIvor. 1984. The ecology of tidal freshwater marshes of the United States east coast: a community profile. U. S. Fish Wildl. Serv. FWS/OBS-83/17. 177 pp. http://cuadra.nwrc.gov/Techrept/83-17.pdf

Pezeshki, S.R., R.D. Delaune, and W.H. Patrick, Jr. 1987. Response of bald cypress (*Taxodium distichum*) to increases in flooding salinity in Louisiana's Mississippi River deltic plain. Wetlands 7:1-10.

Rabalais, N. N. 1990. Biological communities of the south Texas continental shelf. American Zoologist 30:77-87.

Rakocinski, N. N, R. W. Heard, T. Simmons and D. Gledhill. 1991. Macroinvertebrate associations from beaches of selected barrier islands in the Northern Gulf of Mexico: Important environmental relationships. Bulletin of Marine Science 48:689-701.

Rozas, L. P. and C. T. Hackney. 1983. The importance of oligohaline estuarine wetland habitats to fisheries resources. Wetlands 3: 77-89.

Schlosser, I. J. 1991. Stream fish ecology: a landscape perspective. BioScience 41(10): 704-712.

Smock, L. A. and E. Gilinsky. 1992. Coastal Plain Blackwater Streams. Pp. 271-313 IN: C. T. Hackney, S. M. Adams, and W. H. Martin (eds.), Biodiversity of the Southeastern United States. Aquatic Communities. J. Wiley and Sons, Inc., New York, NY.

Stahle, D.W., and R.D. Griffin. 2006. Tree-ring chronology development and analysis on the Withlacoochee River, F.orida: A final report prepared for the Southwest Florida Water Management District, Brooksville, Florida.

Symposium on the Classification of Brackish Waters. 1958. The Venice System for the classification of marine waters according to salinity. Oikos 9: 311-312.

URS Corporation Southern. 2004. West Terminus – Cross- Florida Greenway Assessment, Work Order 2 Final Report, Lower Withlacoochee River Restoration Alternatives Feasibility Study. Prepared for Southwest Florida Water Management District, Brooksville, FL.

Venice System. 1959. Final resolution on the classification of brackish waters. Archo. Oceanogr. Limnol. 11 (suppl): 243-248.

Vincent, M.S., M. Luther, D. Burwell, and B. Galperin. 2000. A numerical modeling investigation of a proposed desalination facility at Big Bend, Tampa Bay, Florida. Phases I and II: Model calibration and individual effects. Prepared for: S&W Water LLC Poseidon Resources Corporation. Prepared by: Ocean Modeling and Prediction Lab, College of Marine Science, University of South Florida.

Wang, P. 2006. Bathymetric survey at Withlacoochee River system. Prepared for: Southwest Florida Water Management District.

Wharton, C. H., W. M. Kitchens, E. C. Pendleton, and T. W. Snipe. 1982. The ecology of bottomland hardwood swamps of the southeast: a community profile. U. S. Fish and Wildlife Service, Biological Services Program, Washington, D.C. FWS/OBS-81/37. 133 pp. http://cuadra.nwrc.gov/Techrept/81-37.pdf

Yobbi, D.K., and L.A. Knochenmus. 1989. Effects of river discharge and high-tide stage on salinity intrusion in the Weeki Wachee, Crystal, and Withlacoochee river estuaries, Southwest Florida. USGS Water Resources Investigations Report 88-4115.

# Appendix A
# Comparisons of Observed Conditions Simulation Results to Observed Data:
# GCSM 1998-2002
# LWRM 1983-1986
# LWRM 1998-2002

## A.1. Gulf Coast Shelf Model, 1998-2002

The GCSM observed conditions run for 1998-2002 provides model output for comparison to salinity and temperature measured at the COAST sites shown in Figure A-1. Comparison to these observed data provides verification of the GCSM, which was calibrated using March-September 2002 data (Janicki Environmental, 2006).

Location maps of the COAST sites combined with the GCSM grid cell locations are provided in Appendix A.1.

### A.1.1. Elevation

Predicted water surface elevations are compared to observed water surface elevations at Clearwater Beach and Cedar Key (Figure A-2). Observed data were obtained from the Center for Operational Oceanographic Products and Services (CO-OPS) maintained by NOAA's National Ocean Service, at hourly frequency.

Time series plots of predicted and observed elevations, at hourly frequency, over 1998-2002 are provided in Figures A-3 and A-4 for Clearwater Beach and Cedar Key, respectively. Statistical summaries of the relationships between predicted and observed data are provided in Table A-1. These statistics, and the time series plots, indicate that the model predicts the observed tidal range well, with a mean error (ME) of -4 cm at Cedar Key, and -2 cm at Clearwater Beach. The lower $r^2$ value at Cedar Key is indicative of a slight offset in the tidal signal in time, but the tidal range is simulated appropriately.

**Table A-1. Statistical summary of comparison of hourly predicted and observed water surface elevation, GCSM.**

| Statistic | Clearwater Beach | Cedar Key |
|---|---|---|
| $r^2$ | 0.81 | 0.76 |
| RMSE (m) | 0.12 | 0.19 |
| ME (m) | -0.02 | -0.04 |
| AME (m) | 0.09 | 0.15 |

### A.1.2. Salinity and Temperature

Observed salinity and temperature values from the COAST sites from Anclote to the Withlacoochee (Figure A-1) were compared to predicted salinity and temperature over the entire 1998-2002 period. For this comparison, the instantaneous measurements of surface salinity and temperature at the COAST sites were plotted as time series along with the hourly model output for the surface.

The model output is representative of the entire grid cell, which covers an area of approximately 24 $km^2$. It is possible that several COAST sites fall within a given cell. To get a better understanding of the comparison of predicted values over a large area to observed values representative of specific points, the predicted salinity and temperature for a given cell are compared to the data from one or more COAST sites.

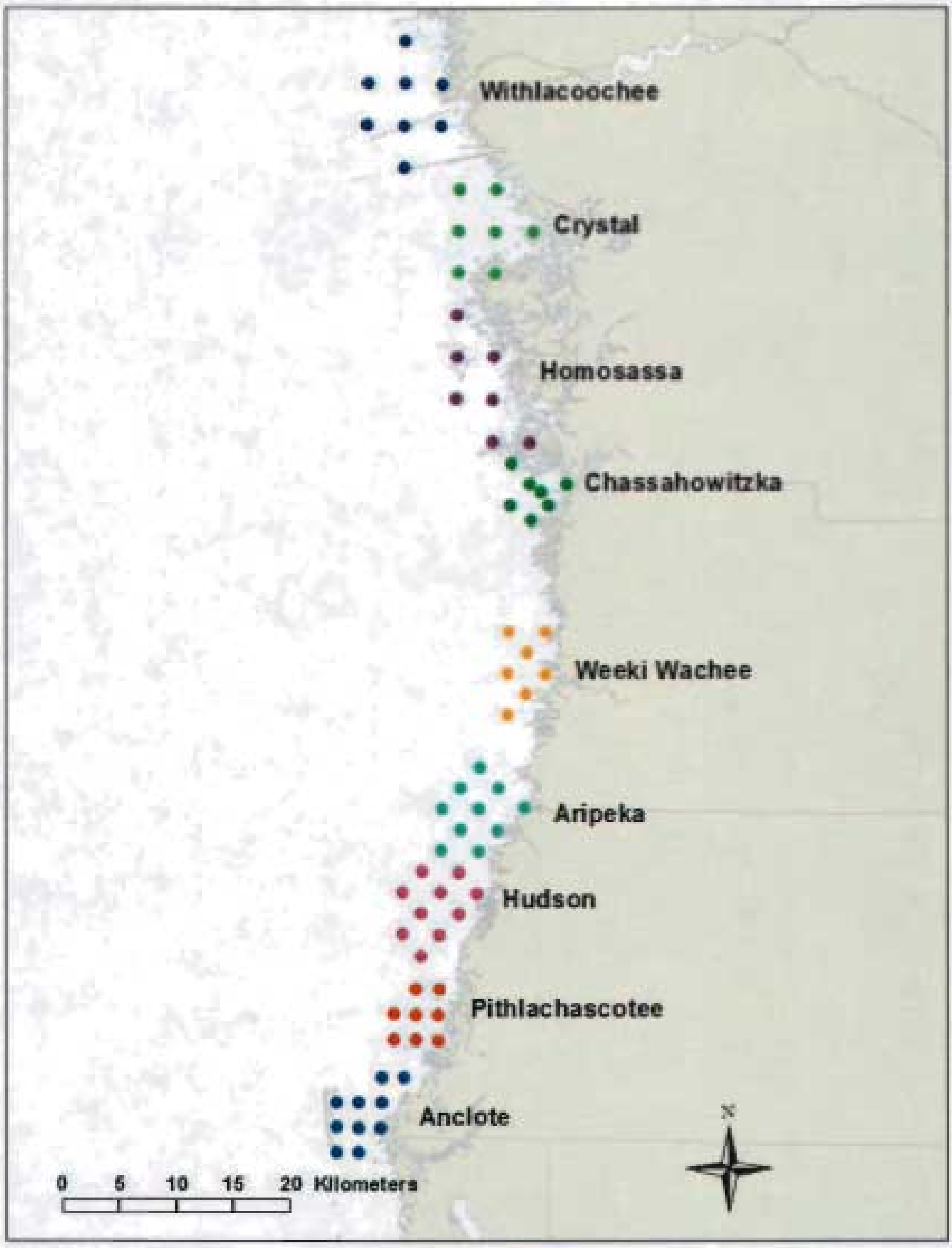



Figure A-1. Project COAST sites used for comparison to GCSM output.


Figure A-2. Locations of water surface elevation comparison points for GCSM.

The COAST sites selected for comparison to a given cell are either within the cell or nearby (see Appendix A.1 for locations of COAST sites and grid cells). A single COAST site may be used for comparison to more than one grid cell. Table A-2 provides a listing of the COAST sites compared with each model grid cell. The time series plots are provided in Appendix A.2 (salinity) and Appendix A.3 (temperature). Each time series graphic is for a specific grid cell, identified by the (i,j) coordinates in the figure title.

**Table A-2. COAST sites compared to GCSM grid cells for plots in Appendices B and C.**

| Grid Cell (i,j) | COAST Sites | Grid Cell (i,j) | COAST Sites |
|---|---|---|---|
| (26,10) | AN-4,5,6,7 | (41,13) | WE-10 |
| (27,10) | AN-1,2,3,4 | (44,14) | CH-5,6,7,8,9 |
| (27,11) | AN-3,8 | (45,14) | CH-7,10 |
| (28,10) | AN-2,9,10 | (45,15) | CH-10, HO-9 |
| (29,10) | AN-10, PI-8,10 | (46,15) | HO-7,8,9 |
| (30,10) | PI-4,6 | (46,16) | HO-2,6,7 |
| (30,11) | PI-5,6 | (47,16) | HO-2,3 |
| (31,10) | PI-6,7 | (47,17) | HO-1,2 |
| (31,11) | PI-6, HU-8,10 | (48,17) | HO-1, CR-8 |
| (32,11) | HU-6,8,9,10 | (49,17) | CR-8,9 |
| (33,11) | HU-4,6 | (50,17) | CR-6,9 |
| (33,12) | HU-1,3 | (50,18) | CR-5,6 |
| (34,11) | HU-2, AR-6 | (50,20) | WI-10 |
| (34,12) | AR-6 | (51,17) | CR-6,7 |
| (35,11) | AR-4,7 | (51,18) | CR-2,6 |
| (35,12) | AR-4,10 | (51,20) | WI-8,9 |
| (36,11) | AR-1,2,5 | (51,21) | WI-4,7,8 |
| (36,12) | AR-2,9 | (52,20) | WI-5,9 |
| (37,12) | AR-1,8 | (52,21) | WI-1,4,5 |
| (39,12) | WE-7,8,9 | (53,20) | WI-6 |
| (40,12) | WE-6,7,9 | (53,21) | WI-1 |
| (41,12) | WE-5,6 | | |

Table A-3 provides a salinity calibration summary for those cells near the mouth of the Withlacoochee River, and over all cells shown in Appendix A.2. The COAST data were typically collected between 10 AM and 3 PM. The mean predicted salinity for the period 10 AM - 3 PM of each day for a given grid cell was compared to the COAST salinity data collected on that day. Over all cells listed in Table A-2 above, the model does well, with a mean error (ME) of -3.2 ppt, an absolute mean error (AME) of 4.0 ppt, and a relative error (RE) of 16%. These differences would be smaller if the first half of 1998 were excluded from the model, as the El Niño event during the typically dry season resulted in relatively low salinities within much of the comparison cells, while the model did not predict salinities as low as those observed.

For those cells near the mouth of the Withlacoochee River (Table A-3), the model predictions were very good, as denoted by the small relative errors of 13% or less, and the mean error difference of 2.0 ppt or less.

| Table A-3. Salinity comparison statistics for cells near Withlacoochee River mouth, and over all cells, GCSM. | | | | |
|---|---|---|---|---|
| **Grid Cell (I,J)** | **RMSE (ppt)** | **ME (ppt)** | **AME (ppt)** | **RE (%)** |
| (51,21) | 3.8 | -0.6 | 2.4 | 9 |
| (51,20) | 4.9 | -2.0 | 3.0 | 13 |
| (52,21) | 3.2 | 0.1 | 2.2 | 9 |
| (53,21) | 3.1 | 1.3 | 2.1 | 9 |
| All Cells | 5.6 | -3.2 | 4.0 | 16 |

A similar analysis was completed for temperature, as this model may well be utilized in the future for examination of potential temperature responses to changes in flow. Table A-4 provides the temperature calibration summary for those cells near the mouth of the Withlacoochee River, and over all cells shown in Appendix A.3. As for salinity, the mean predicted temperature for the period 10 AM - 3 PM of each day for a given grid cell was compared to the COAST temperature data collected on that day. Over all cells listed in Table A-2 above, the model does well, with a mean error (ME) of -1.0 °C, an absolute mean error (AME) of 1.7 °C, and a relative error (RE) of 7%.

| Table A-4. Temperature comparison statistics for cells near Withlacoochee River mouth, and over all cells, GCSM. | | | | |
|---|---|---|---|---|
| **Grid Cell (I,J)** | **RMSE (°C)** | **ME (°C)** | **AME (°C)** | **RE (%)** |
| (51,21) | 2.0 | -0.9 | 1.4 | 6 |
| (51,20) | 1.9 | -0.2 | 1.3 | 6 |
| (52,21) | 2.3 | -1.3 | 1.6 | 7 |
| (53,21) | 2.5 | -1.6 | 1.8 | 8 |
| All Cells | 2.3 | -1.0 | 1.7 | 7 |

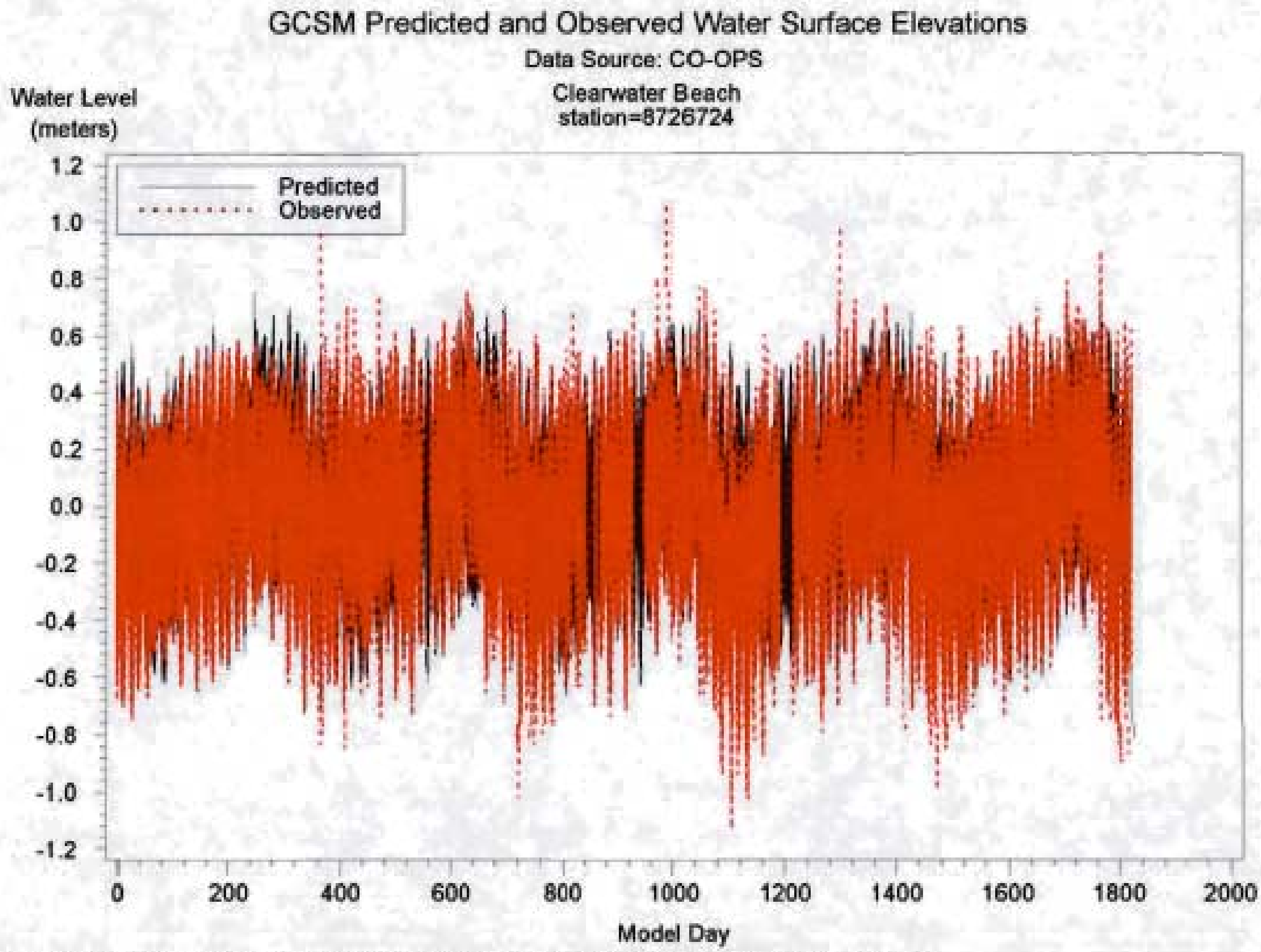



Figure A-3. Time series of predicted and observed tidal record at Clearwater Beach.

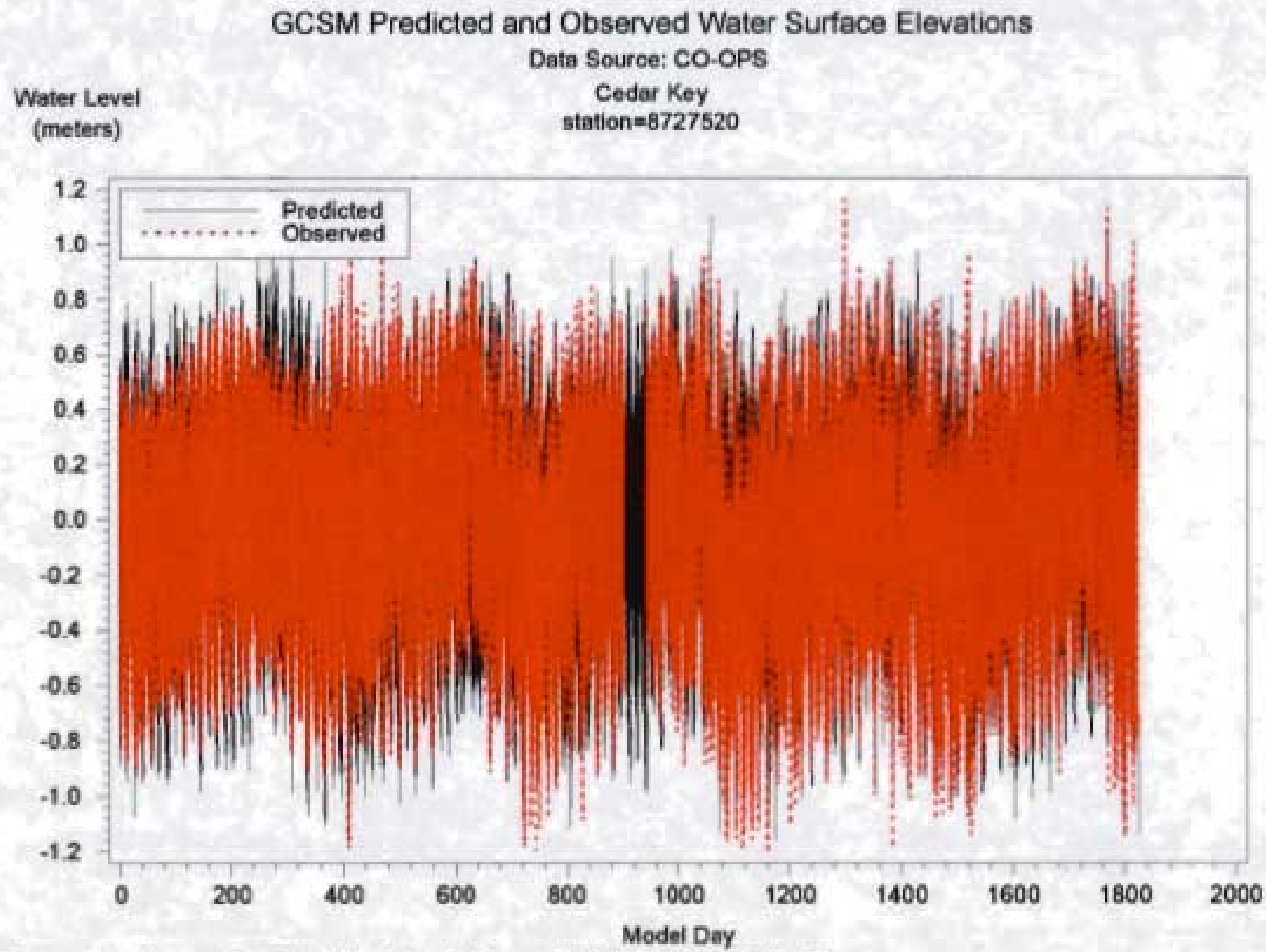



**Figure A-4. Time series of predicted and observed tidal record at Cedar Key.**

### A.2. Lower Withlacoochee River Model, 1983-1986

The LWRM was implemented for the period September 1, 1983 through March 31, 1986. The locations of the COAST salinity and temperature sites in relation to the LWRM grid system are shown in Figure A-5. The GCSM was also run for the same period, so that downstream salinity and temperature boundary conditions and offshore water surface elevations could be developed. The results of this model implementation are for comparison to observed data collected from January 1984 through February 1986 along the axis of the river. Time series of the daily flows during this period for the Lower Withlacoochee River and Inglis Dam (locations shown in Figure 1-7) are provided in Figure A-6

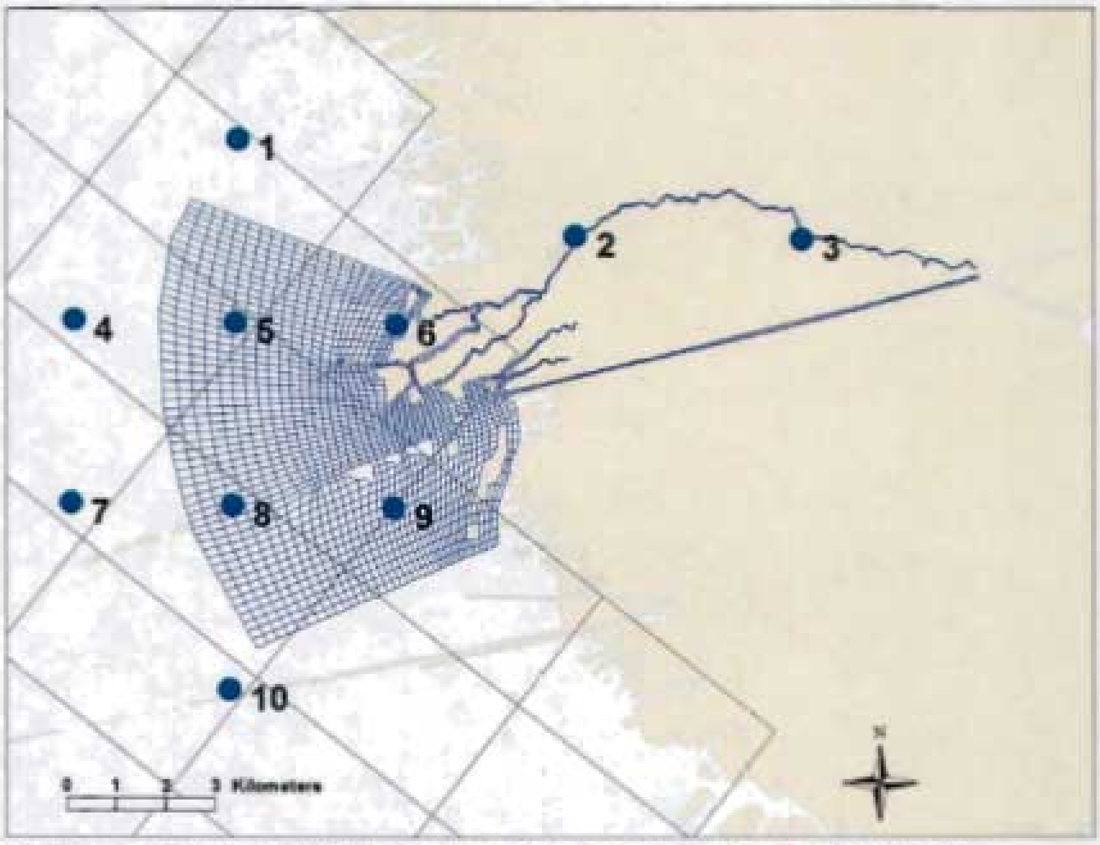



Figure A-5. Locations of Withlacoochee COAST sites in relation to LWRM grid.

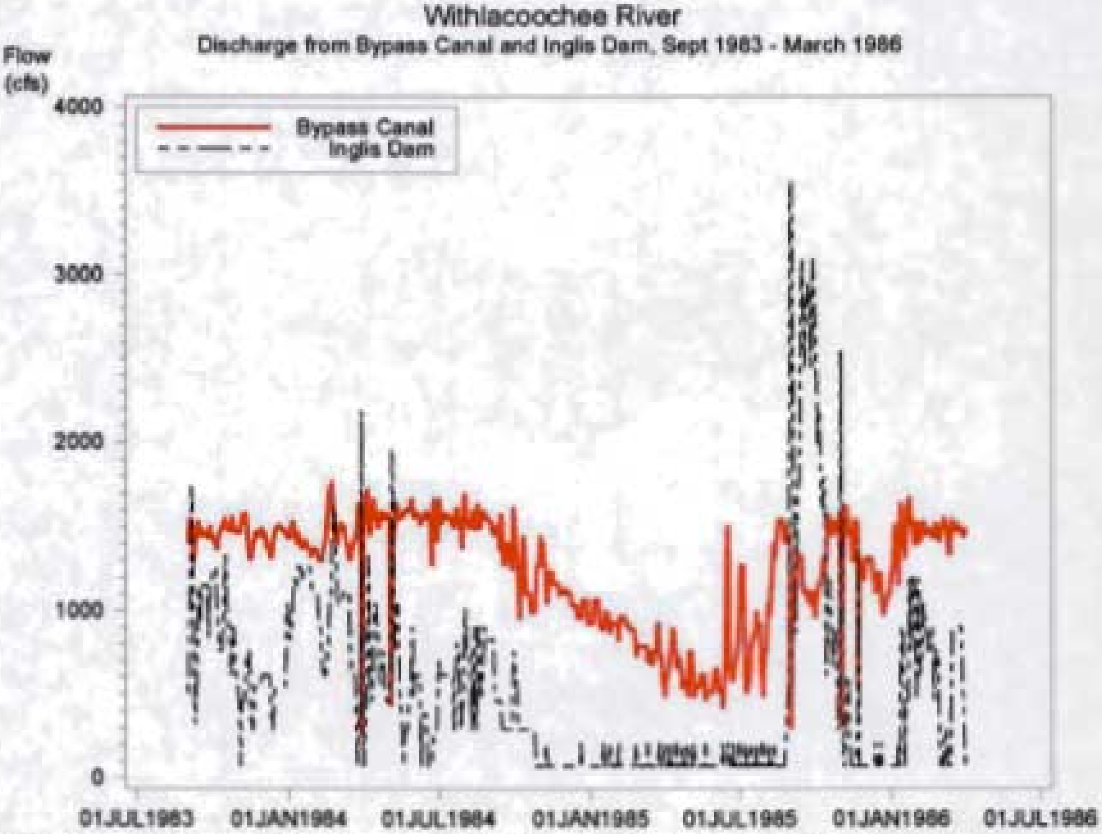



**Figure A-6. Flows in from Bypass Canal to river and Inglis Dam to Barge Canal.**

The model output is compared graphically to the data collected by Mote Marine Lab, SWFWMD, and USGS during the 1984-1986 period. For each data collection event, the tidal stage was noted (high or low), and the model output for the same day and same tidal condition was compared to the observed data. Graphical presentations of the river axis salinity profiles, both observed and predicted, are provided in Appendix A.4. For location reference, Figure A-7 provides the river kilometer system.

A total of 46 horizontal profiles of surface salinity along the axis of the river were taken. Of these, the model results match very well with 35 of the profiles. For the remaining profiles, the model predicts the locations of the 0.5 and 5.0 ppt surface isohalines further downstream than observed. Since 76% of the predicted profiles match with the observed data, it is unlikely that the underlying hydrodynamics of the system are being misrepresented by the model. Potential causes of the differences include several candidates. For example, the model is driven by daily constant freshwater inflows over the full 24 hours of the day, so that any deviation from a real-world constant discharge over the entire day will result in differences between predicted and observed salinity structure. Similarly, the winds used to force the GCSM and the LWRM are not site-specific to the Lower Withlacoochee River, and so variations in wind patterns may result in tidal elevation differences between predicted and observed, and different upstream incursion of saline water. However, the very good agreement between 76% of the predicted profiles and the observed profiles is indicative that the model correctly predicts the tidal signal in the river and nearshore area.

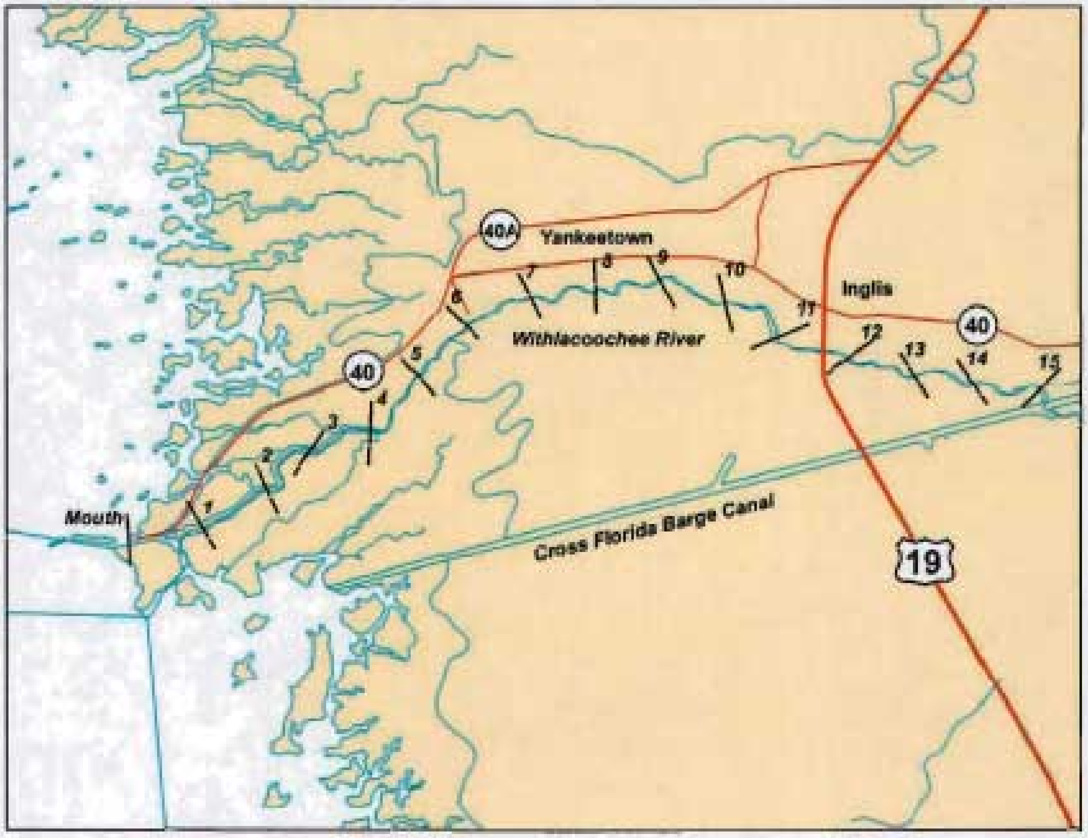



**Figure A-7. River kilometer system for the Lower Withlacoochee River.**

### A.3. Lower Withlacoochee River Model, 1998-2002

The LWRM receives freshwater inflow from the Bypass Canal at the upstream extent of the river domain, and from the Inglis Dam to the Barge Canal. Offshore boundary conditions of elevation, salinity, and temperature are provided by the GCSM, at the western, northern, and southern boundaries of the LWRM grid outside the mouth of the river. Calibration of the LWRM was to the tidal gage near the mouth of Bird Creek, and to the surface salinity and temperature observations at the COAST sites within the model domain.

#### A.3.1. Elevation

A time series plot of predicted and observed water surface elevation at the Bird Creek site is provided in Figure A-8 for hourly values for the May-September 2002 period (the Bird Creek record begins in May 2002). A statistical summary of the comparison between predicted and observed water level is provided in Table A-5. Here $r^2$ is the coefficient of determination, RMSE is the root mean square error, ME is the mean error, and AME is the absolute mean error.

| Table A-5. Statistical summary of comparison of hourly predicted and observed water surface elevation, LWRM, May-December 2002. | |
|---|---|
| **Statistic** | **Bird Creek** |
| $r^2$ | 0.71 |
| RMSE (m) | 0.27 |
| ME (m) | -0.13 |
| AME (m) | 0.21 |

The comparison shows good agreement between predicted and observed hourly water surface elevations, with the AME of 21 cm, and the ME of -13 cm indicating slight overprediction of water surface elevations, at the tidal maxima, compared to observed values over the time period.

### A.3.2 Salinity and Temperature

Observed salinity and temperature values from the COAST sites from the Withlacoochee that fell within the model domain were compared to predicted salinity and temperature. For this comparison, the instantaneous measurements of surface salinity and temperature at the COAST sites were plotted as time series along with the hourly model output for the surface.

The COAST sampling monitors two sites within the river (Figure A-5), Station 2 approximately 5.6 km (3.5 mi) upstream of the mouth, and Station 3 about midway between Station 2 and the Bypass Channel. Outside the mouth of the river, four additional COAST sites fall within the LWRM domain, including Station 6 between the mouths of the Withlacoochee River and Bird Creek.

As discussed in the calibration report (Janicki Environmental, 2006), it appears that the COAST salinity data from Station 2 are unreasonable. Thus, the verification comparison is confined to the remaining stations within the LWRM model domain.

The time series plots of observed and predicted salinity are provided in Appendix A.5 for COAST stations 3, 5, 6, 8, and 9, and for observed and predicted surface temperature in Appendix A.6. Table A-6 provides a salinity calibration summary for each COAST site used, and over all sites. The COAST data were typically collected between 10 AM and 3 PM. The mean predicted salinity for the period 10 AM - 3 PM of each day for a given grid cell was compared to the COAST salinity data collected on that day.

| Table A-6. Salinity comparison statistics for LWRM COAST sites, and over all cells. | | | | |
|---|---|---|---|---|
| **COAST Station** | **RMSE (ppt)** | **ME (ppt)** | **AME (ppt)** | **RE (%)** |
| 3 | 0.3 | 0.0 | 0.1 | 45 |
| 5 | 4.6 | 2.1 | 3.7 | 15 |
| 6 | 5.6 | -1.1 | 4.6 | 33 |
| 8 | 5.2 | -0.1 | 3.8 | 16 |
| 9 | 5.6 | 1.2 | 4.4 | 20 |
| All Stations | 4.7 | 0.4 | 3.3 | 20 |

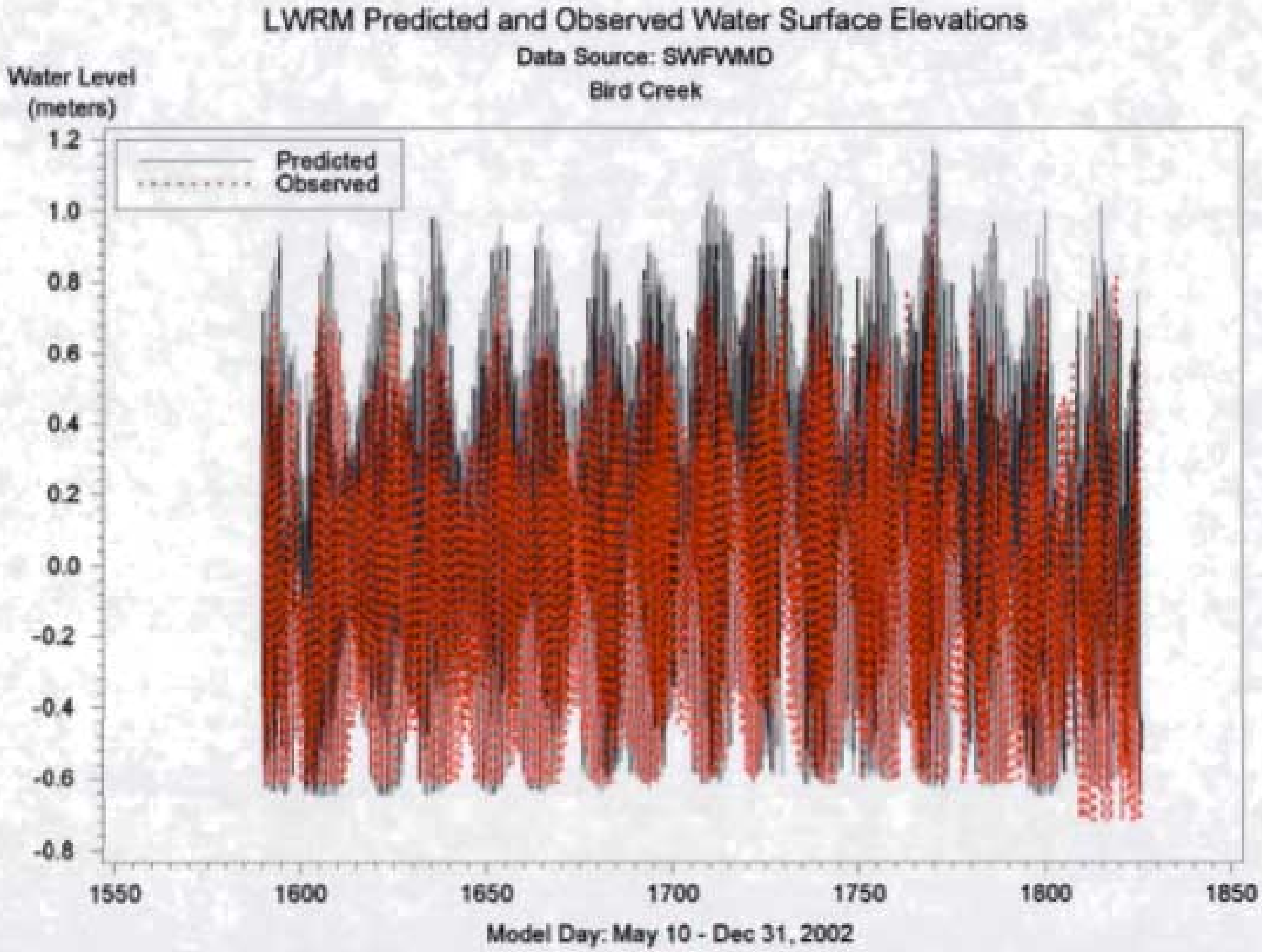



**Figure A-8. Time series of predicted and observed tidal record at Bird Creek.**

The river model does well in predicting both the magnitude and signal in salinity. The mean errors of 2.1 ppt or less indicate that the model is predicting magnitude correctly, and visual inspection of the figures in Appendix A.5 shows that the seasonal patterns are predicted accurately.

A similar analysis was completed for temperature. Table A-7 provides the temperature calibration summary for those cells containing COAST sites. As for salinity, the mean predicted temperature for the period 10 AM - 3 PM of each day for a given grid cell was compared to the COAST temperature data collected on that day. As seen from the temperature time series plots (Appendix A.6), the model does well, with a mean error (ME) over all sites of 1.4 °C, an absolute mean error (AME) of 2.3 °C, and a relative error (RE) of 10%.

**Table A-7. Temperature comparison statistics for cells near Withlacoochee River mouth, and over all cells, LWRM.**

| COAST Station | RMSE (°C) | ME (°C) | AME (°C) | RE (%) |
|---|---|---|---|---|
| 3 | 3.7 | 2.6 | 3.0 | 13 |
| 5 | 2.1 | 0.4 | 1.5 | 7 |
| 6 | 2.0 | -0.9 | 1.5 | 7 |
| 8 | 2.4 | 1.1 | 2.0 | 8 |
| 9 | 4.2 | 3.7 | 3.7 | 15 |
| All Stations | 3.0 | 1.4 | 2.3 | 10 |

### A.4. Comparison of Model Statistics

To provide a measure of the ability of the GCSM and LWRM to simulate salinity conditions, a comparison is provided between the salinity comparison statistics for these two models and three other hydrodynamic model applications in Florida. Three models for comparison are the Suwannee River (SW) EFDC model developed by the USGS (Bales et al., 2006), the Indian River Lagoon (IRL) EFDC model developed for the Lower St. Johns River (Cerco, 2003), and the Tampa Bay (TB) ECOM-3D model (Vincent et al., 2000).

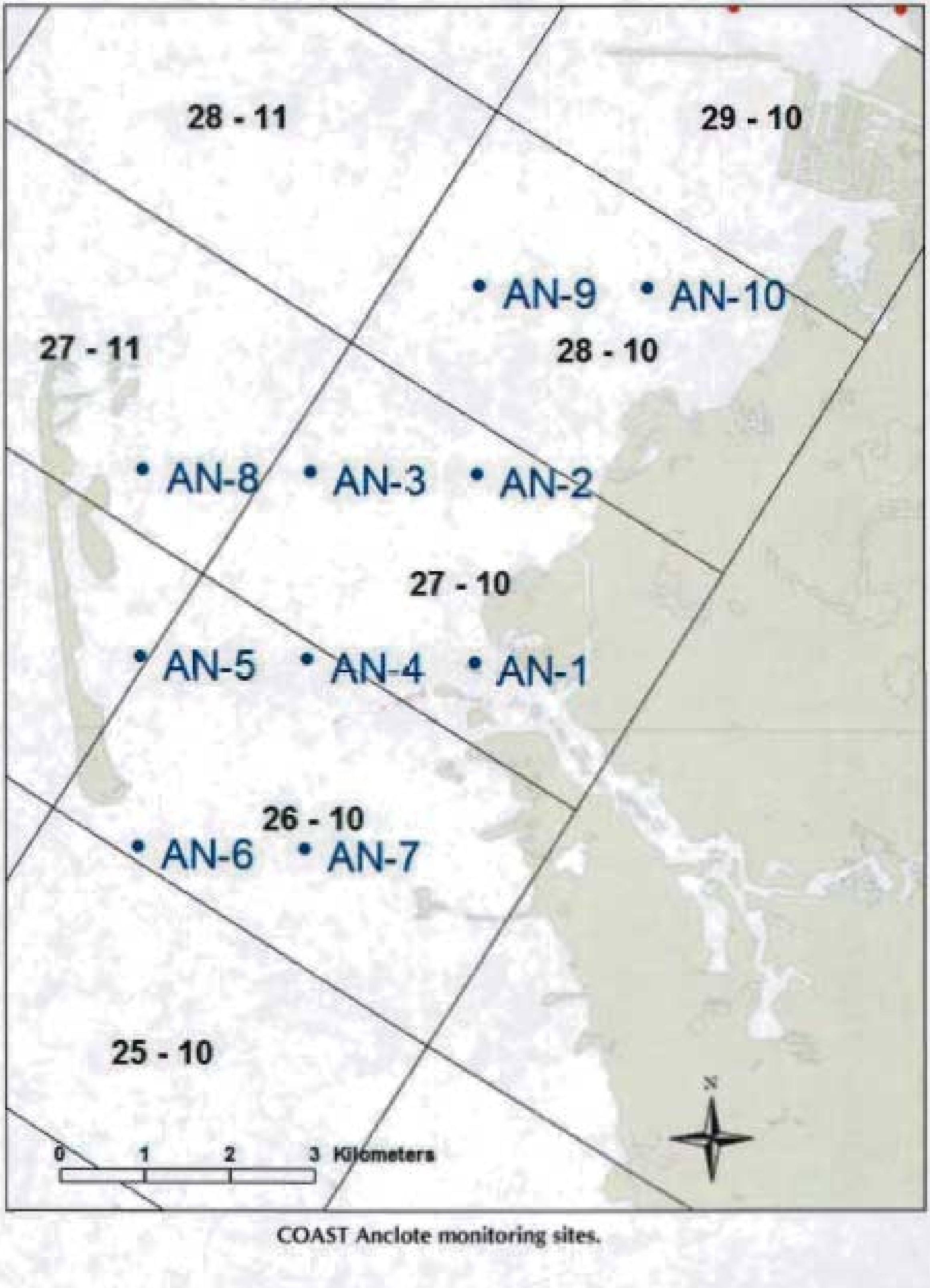
For the Suwannee River, comparison statistics are for four salinity sites near the mouth of the river. All sites in the Indian River Lagoon model are used, as are all sites in the Tampa Bay model. For the Withlacoochee River models, the five cells near the mouth of the river were used for comparison from the GCSM, and the five COAST sites provided (Tables A-6 and A-7) were used for comparison from the LWRM.

**Table A-8. Comparison of salinity statistics from GCSM, LWRM, and other hydrodynamic models applied in Florida.**

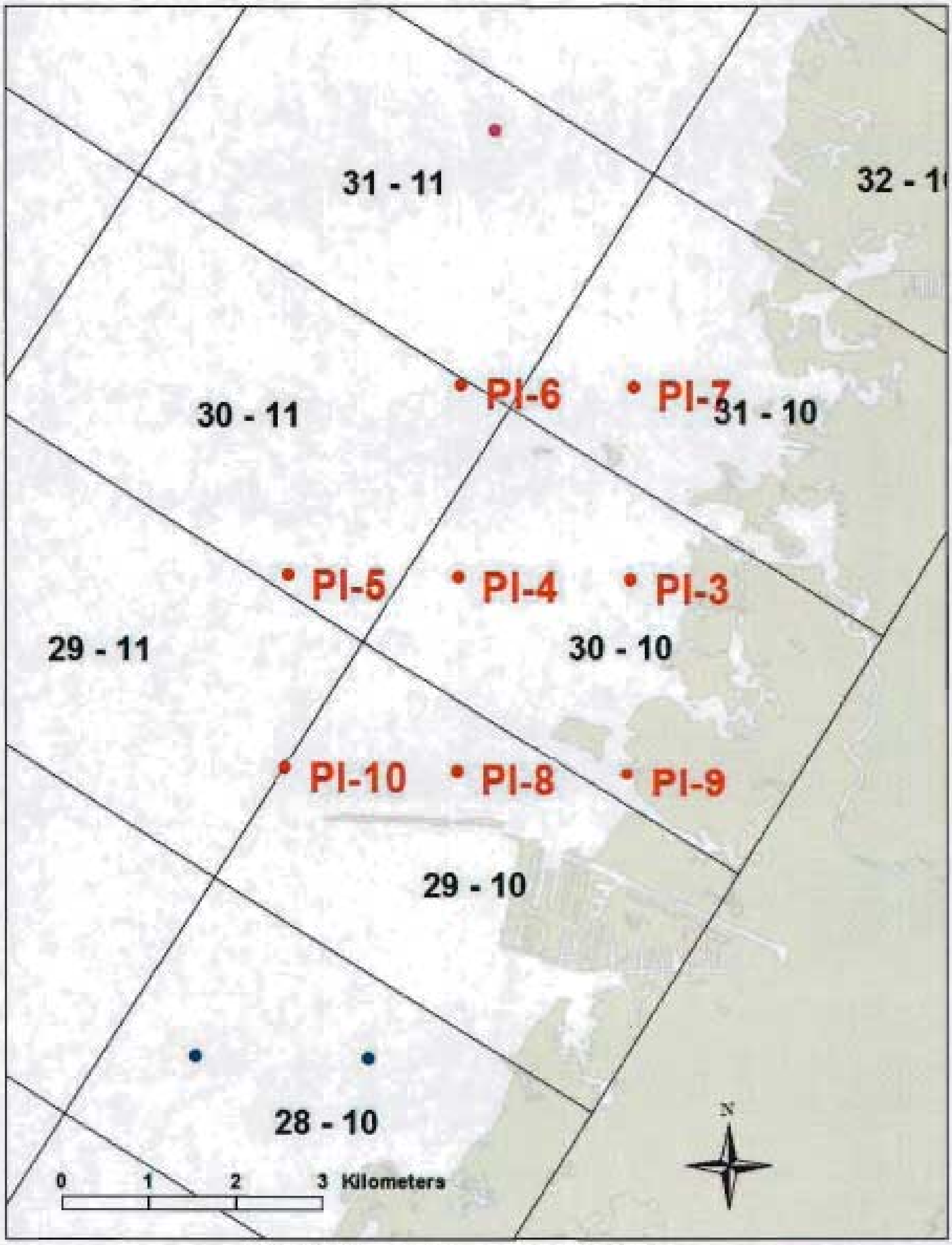
| Statistic | Model | | | | |
|---|---|---|---|---|---|
| | GCSM | LWRM | IRL | SW | TB |
| Mean Error (ME) | -0.3 | 0.4 | -0.2 | 1.0 | -1.3 |
| Root Mean Squared Error (RMSE) | 3.8 | 4.7 | 4.0 | - | - |

The GCSM and LWRM calibrations compare very well to those of other models.

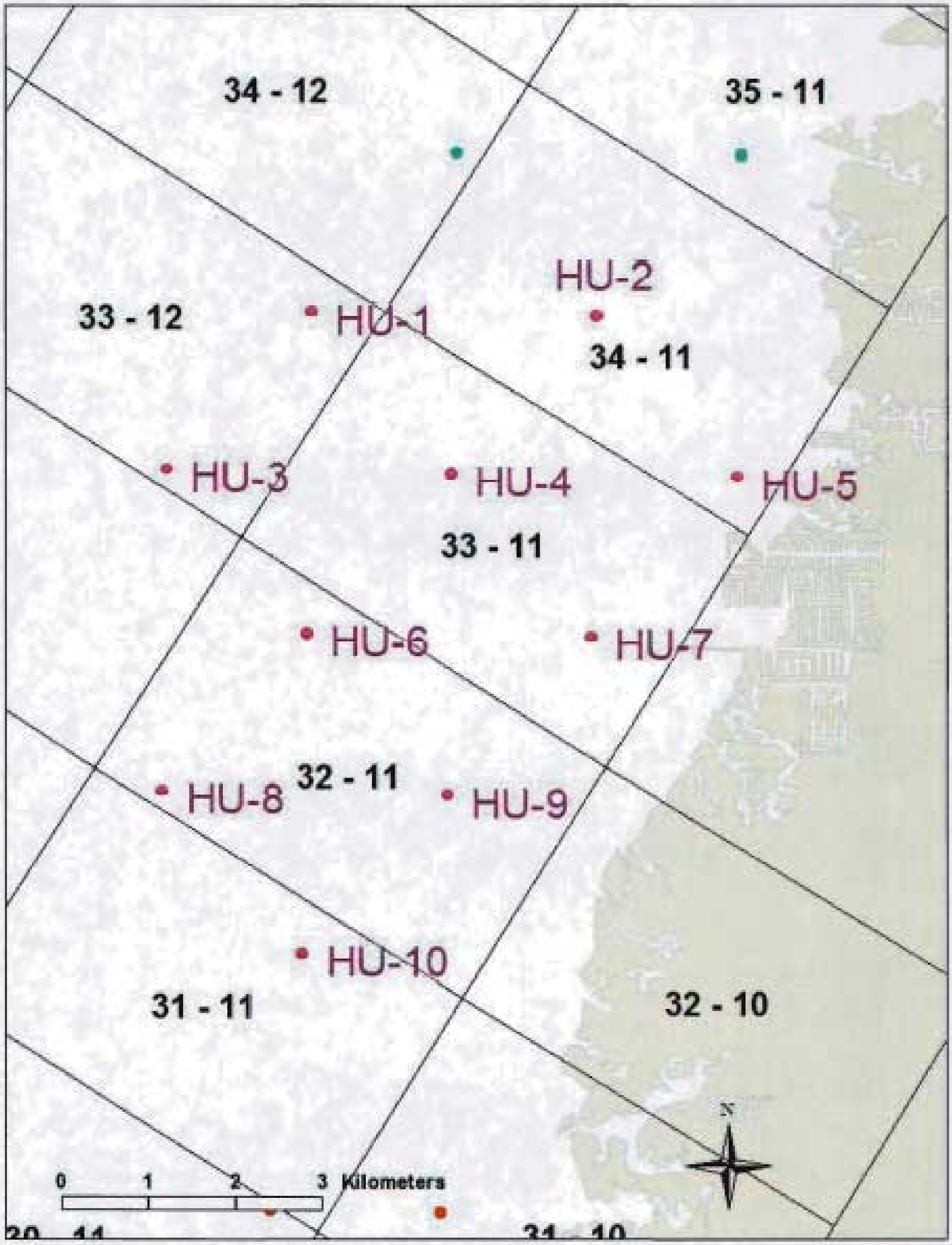
## Appendix A.1
## Locations of COAST Monitoring Sites and GCSM Grid Cells
## COAST Sites are in Color, Grid Cells I-J in Black



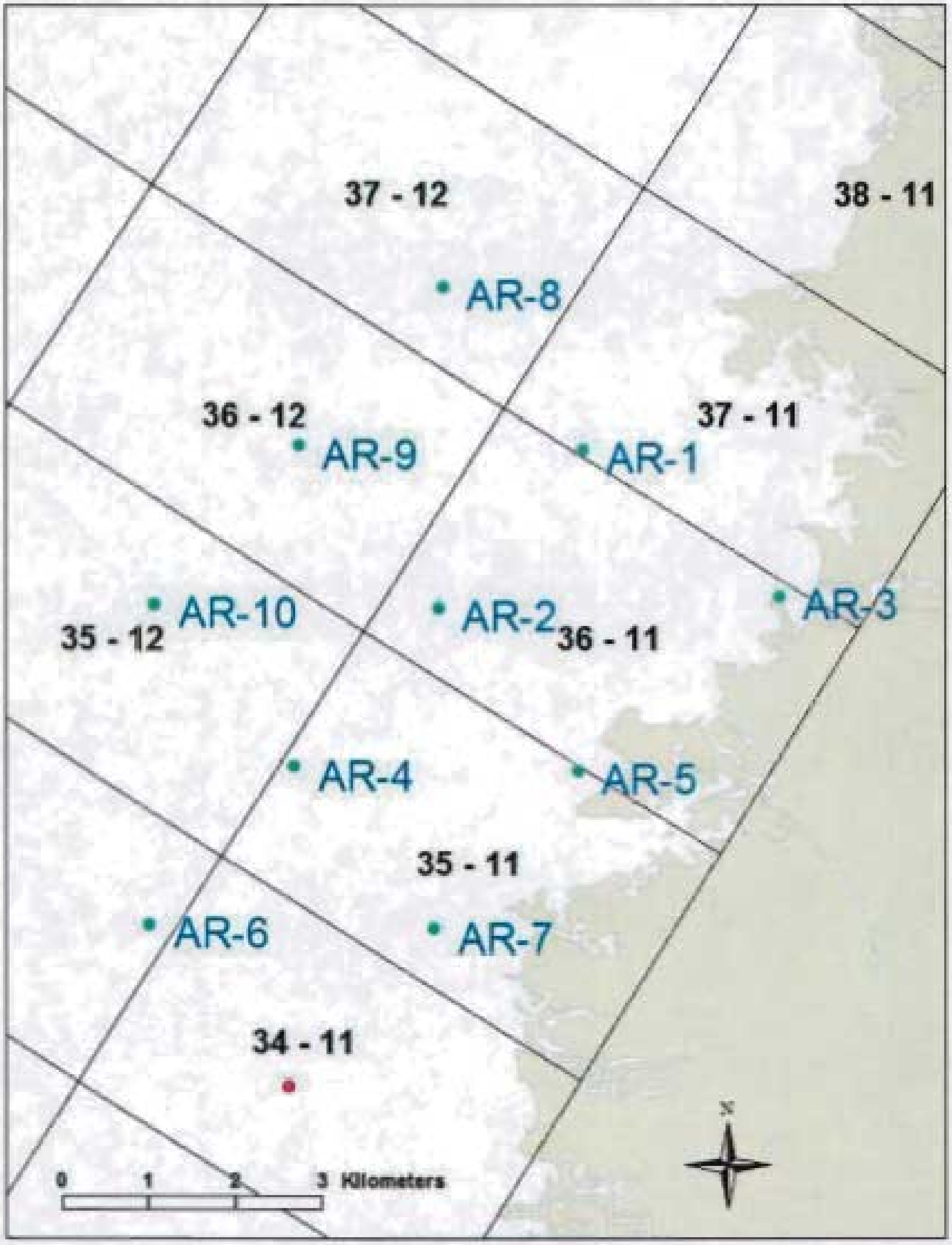

COAST Anclote monitoring sites.



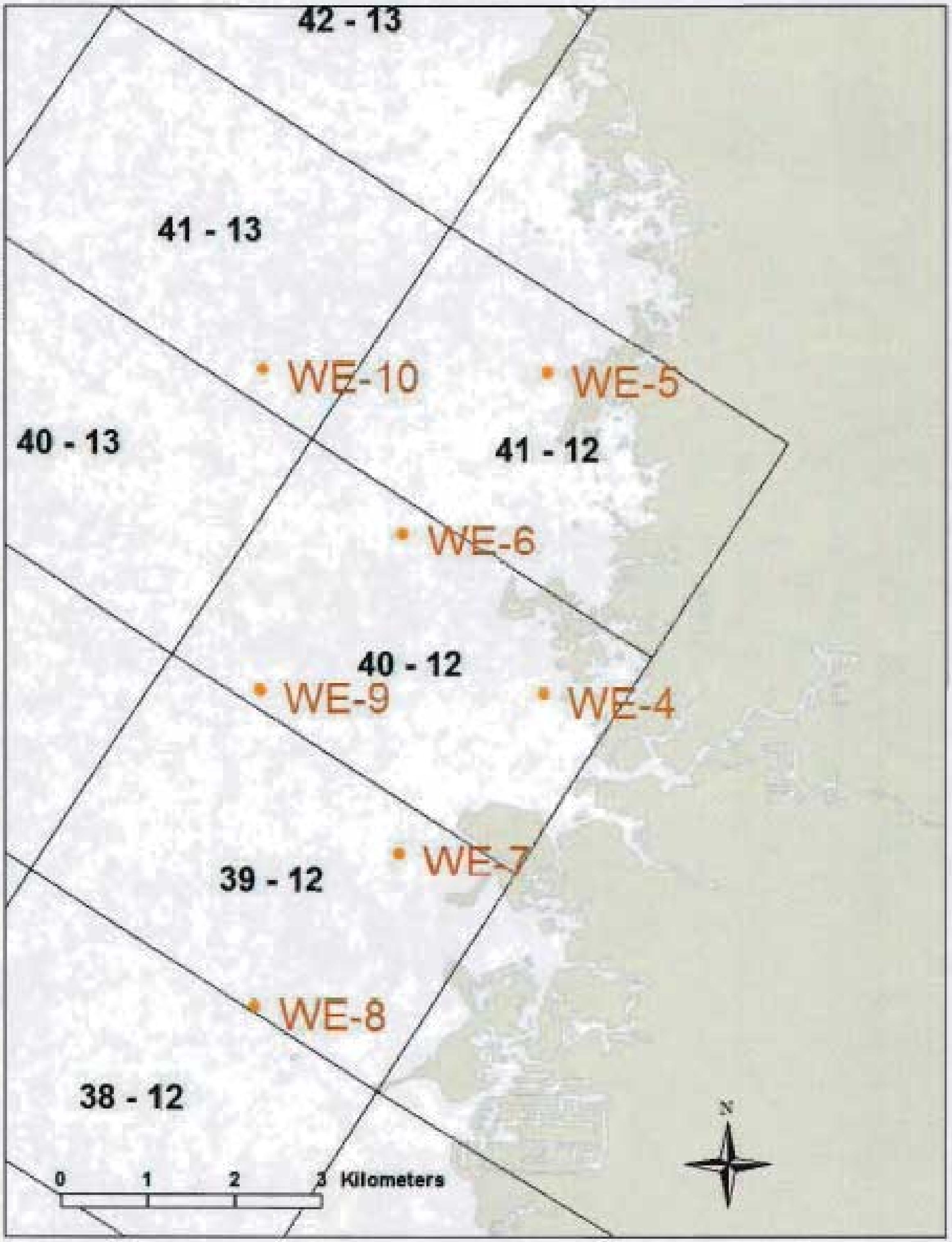

COAST Pithlachascotee monitoring sites.



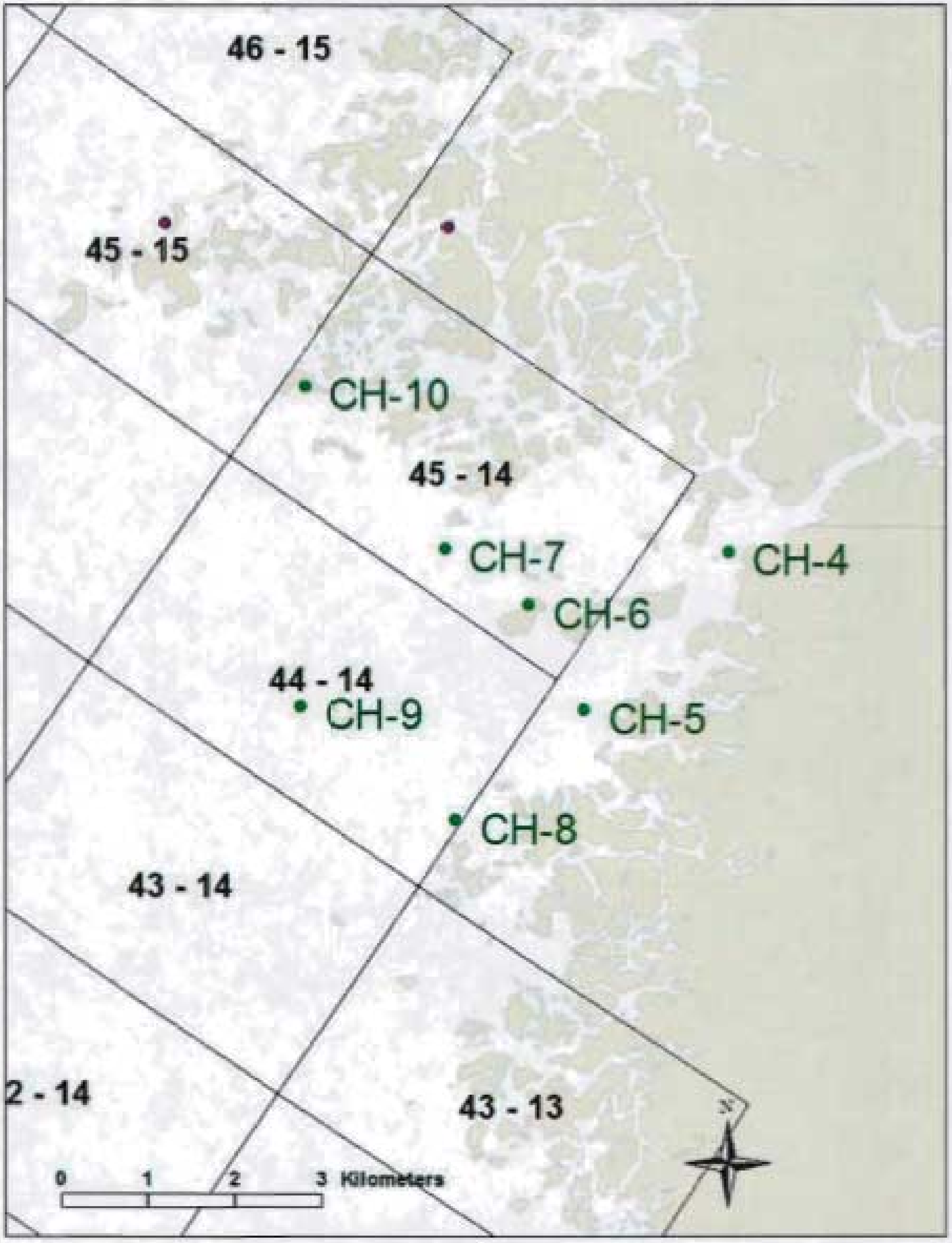

COAST Hudson monitoring sites.



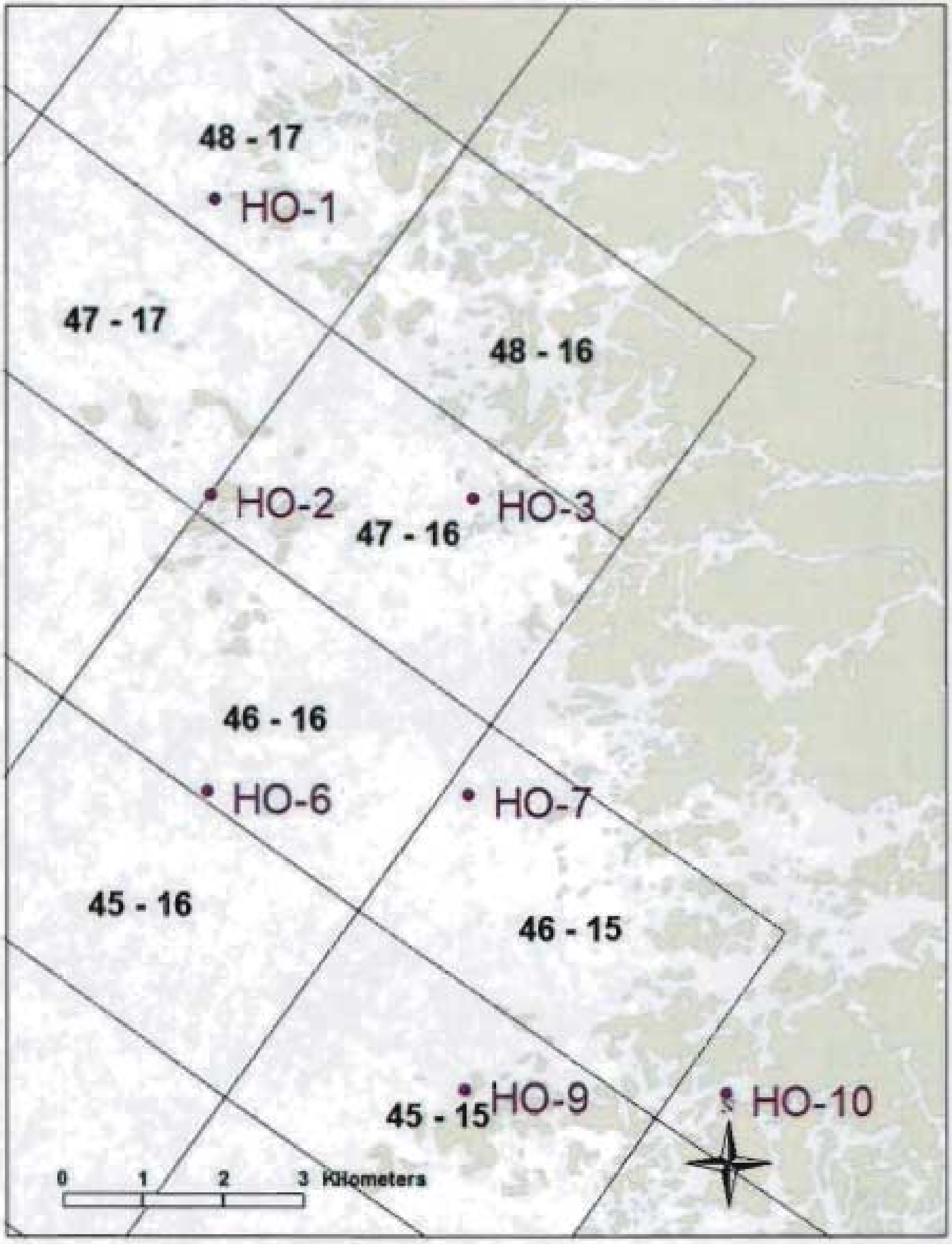

COAST Aripeka monitoring sites.



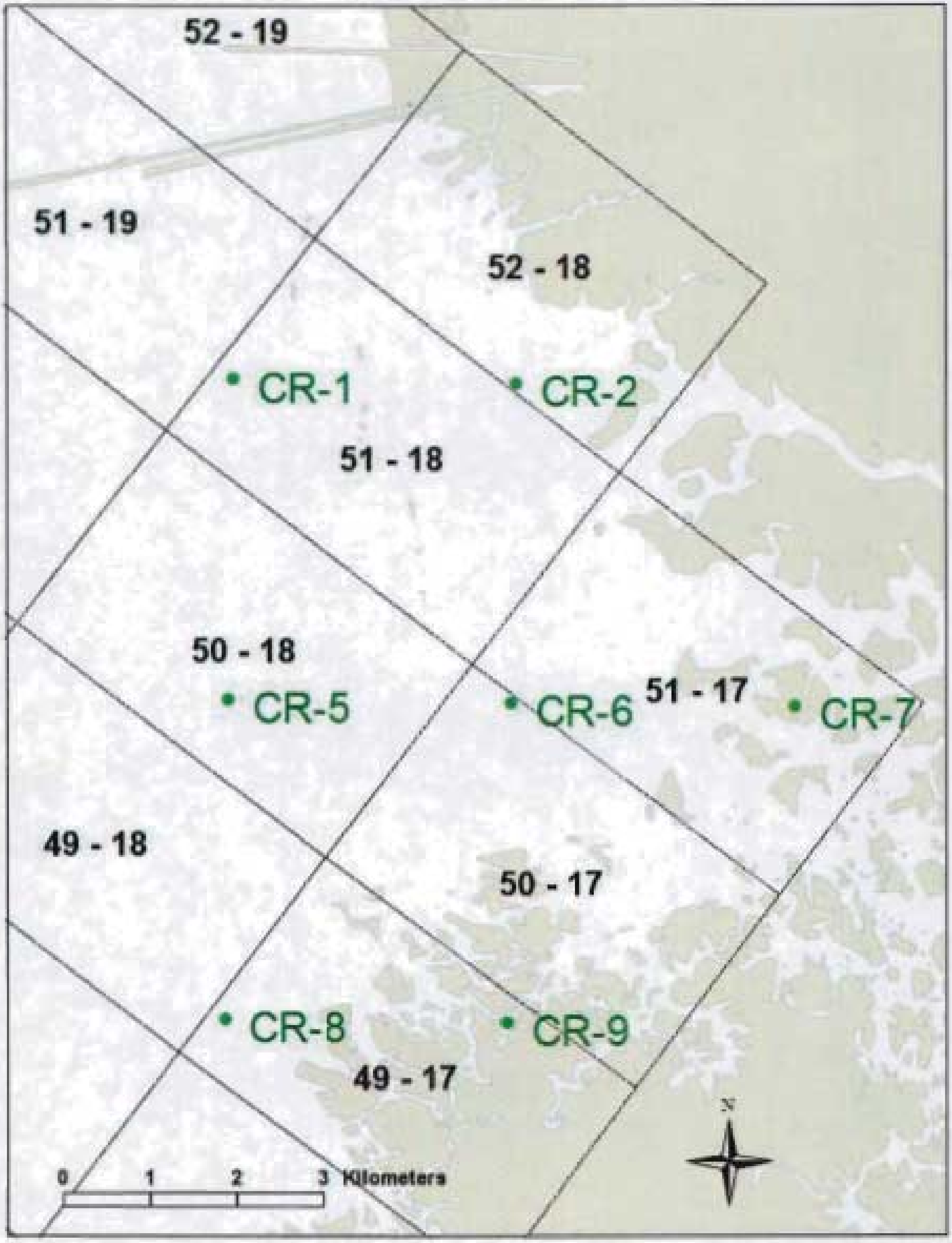
COAST Weeki-Wachee monitoring sites.



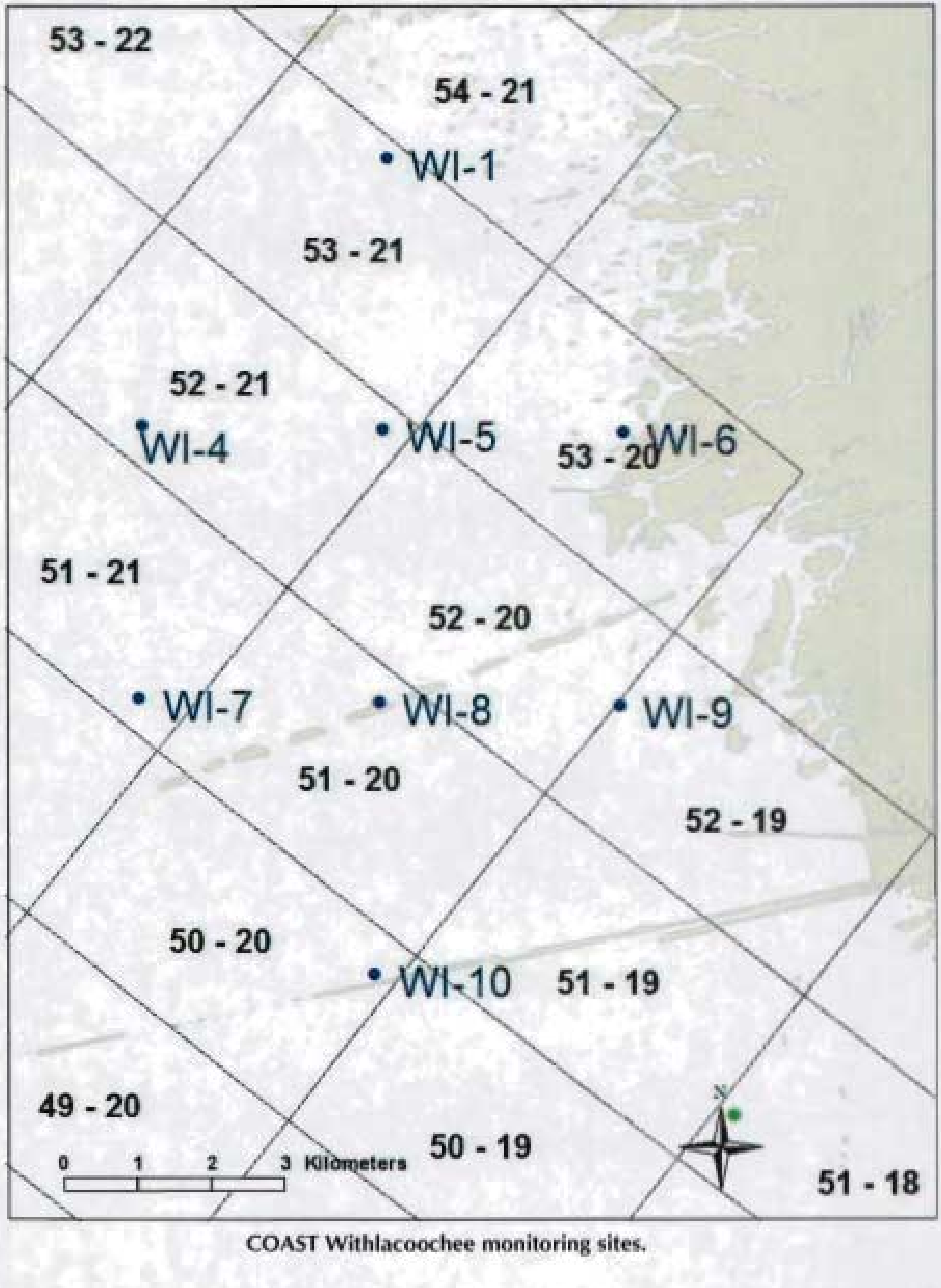

COAST Chassahowitzka monitoring sites.




COAST Homosassa monitoring sites.

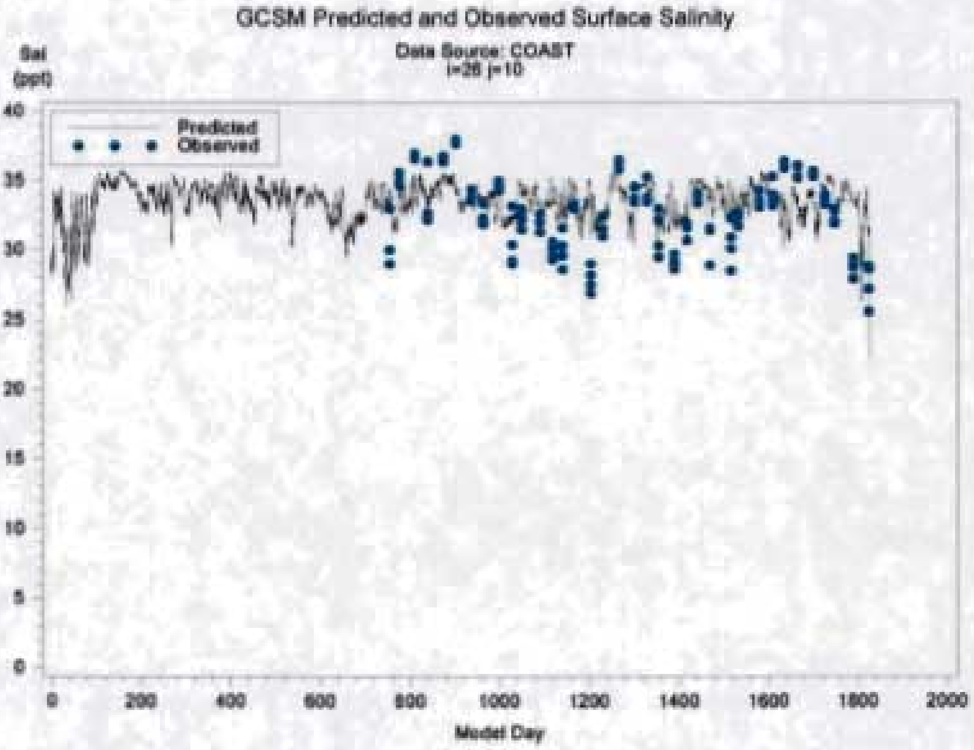


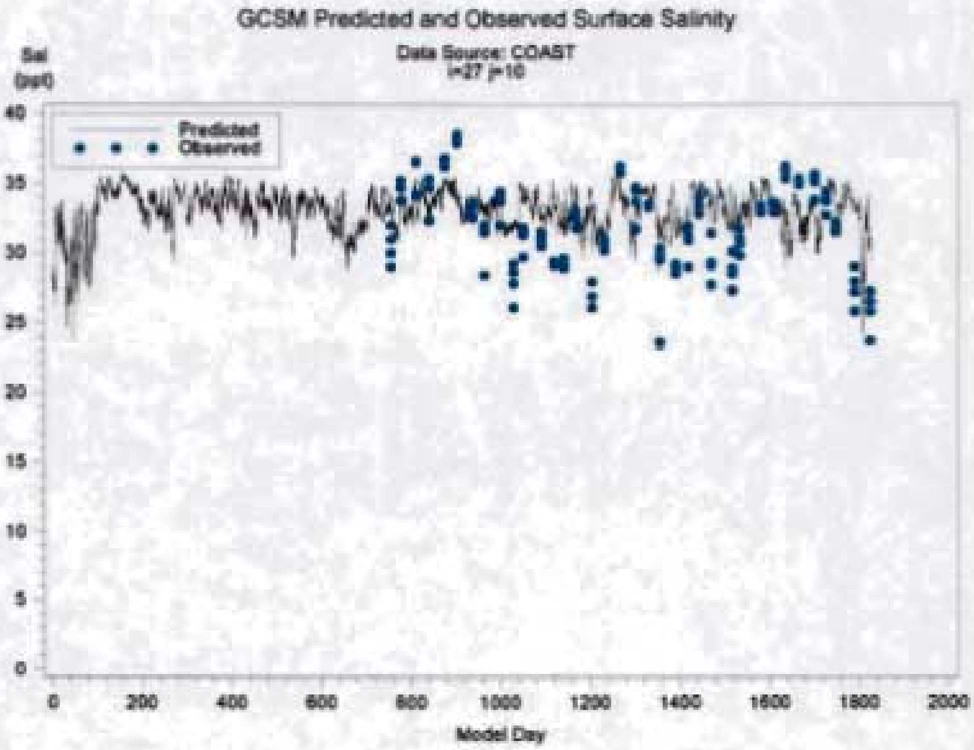

COAST Crystal River monitoring sites.



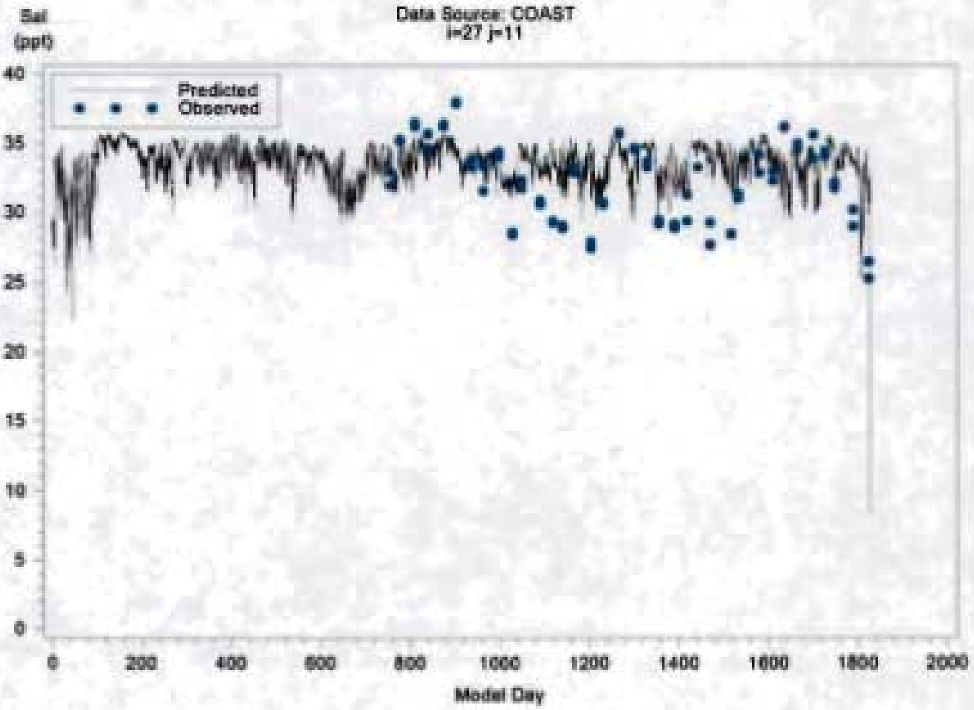

COAST Withlacoochee monitoring sites.

# Appendix A.2
# GCSM: Time Series Predicted and Observed Surface Salinity at Grid Cells and COAST Sites 1998-2002

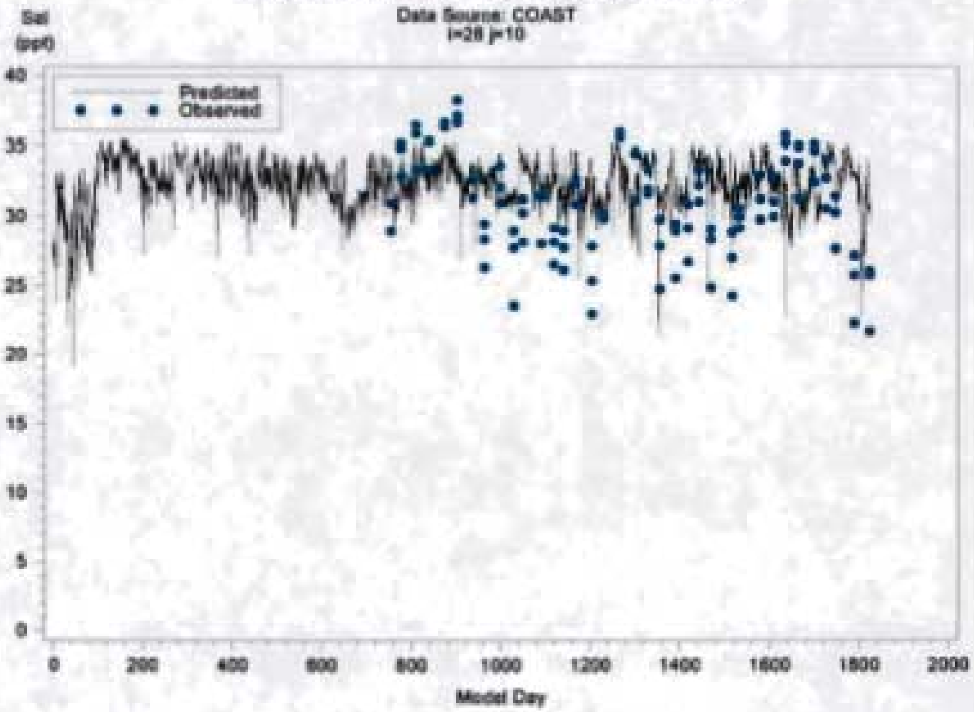

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=26 j=10
Sal
(ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

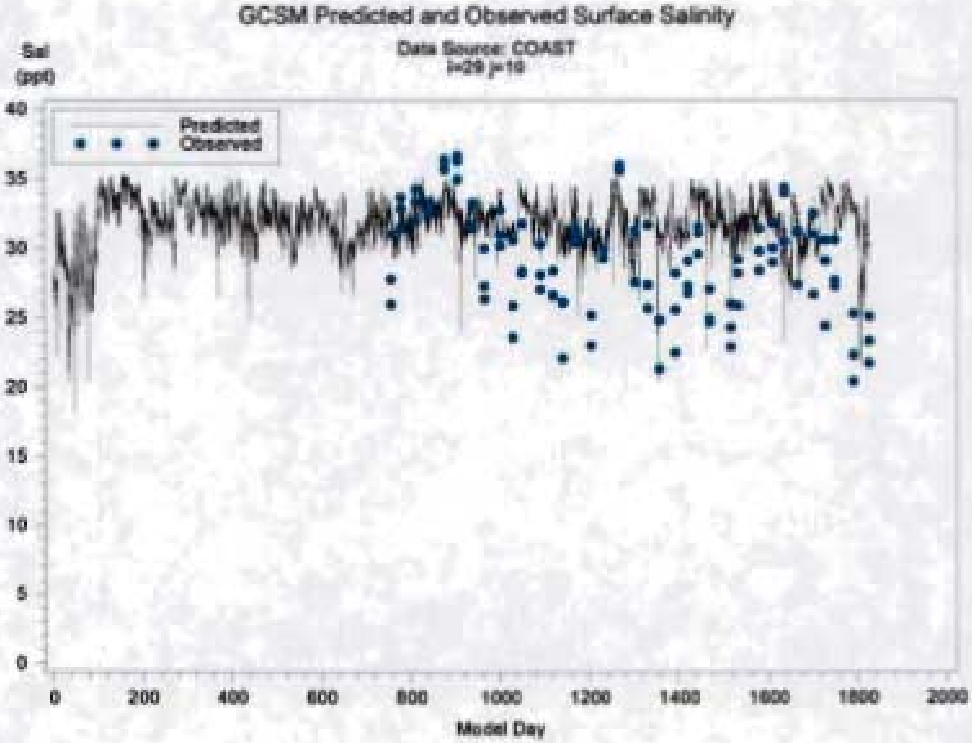

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=27 j=10
Sal
(ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

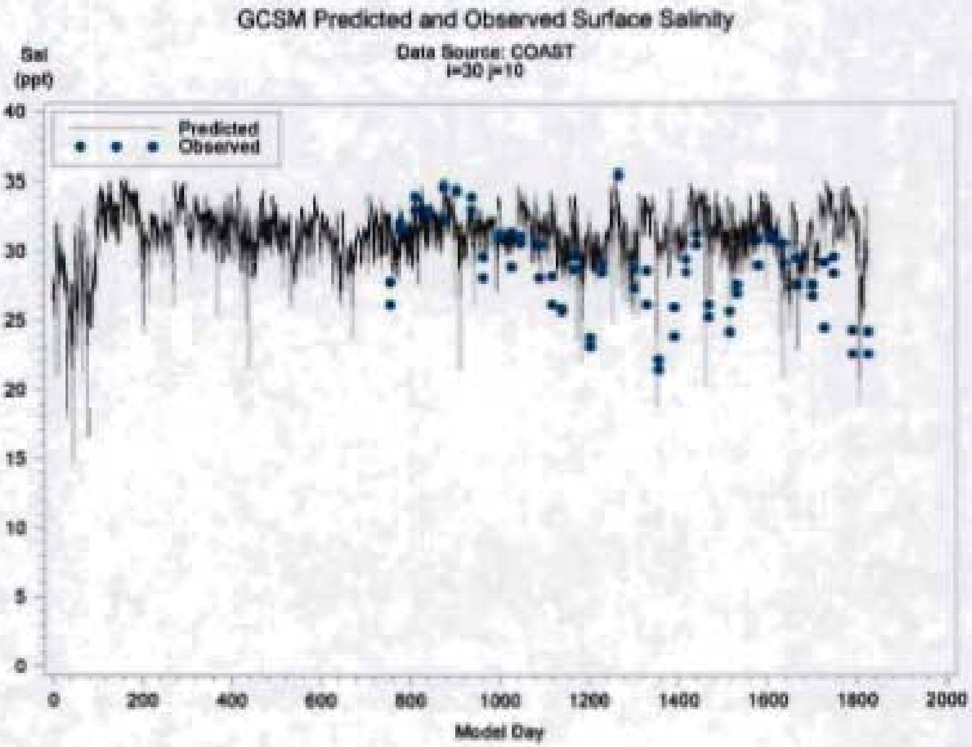
GCSM Predicted and Observed Surface Salinity

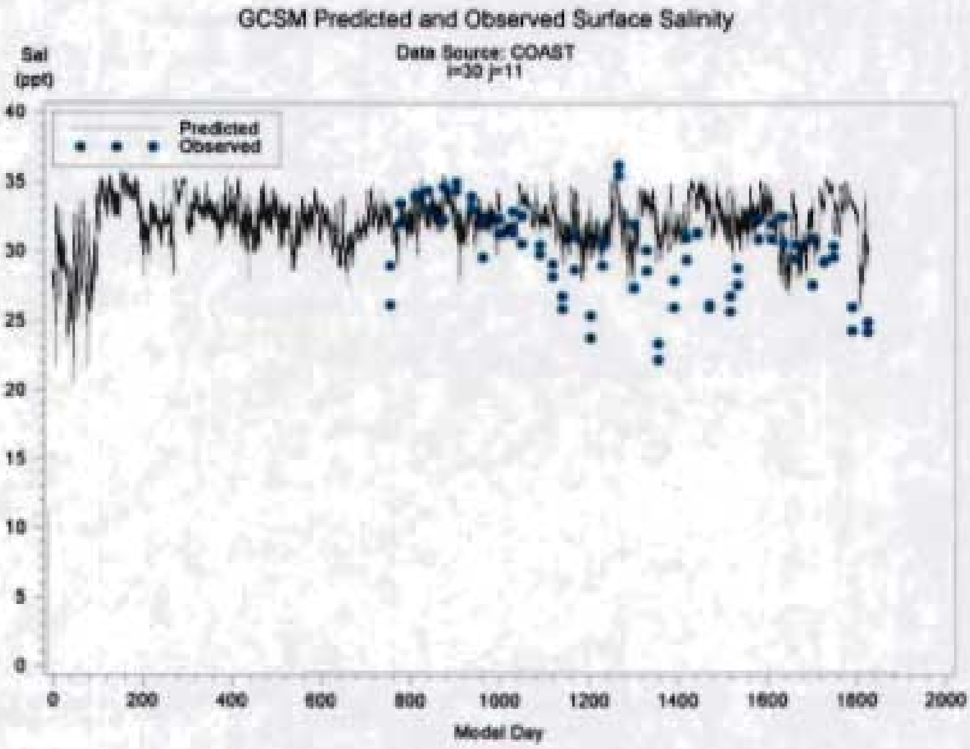


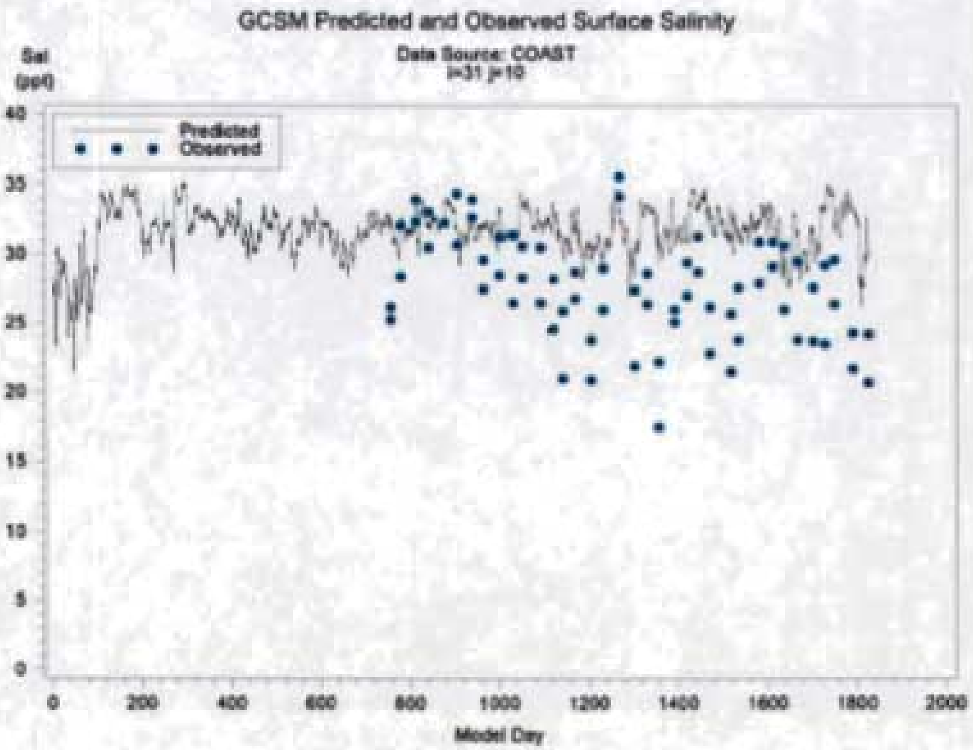

GCSM Predicted and Observed Surface Salinity

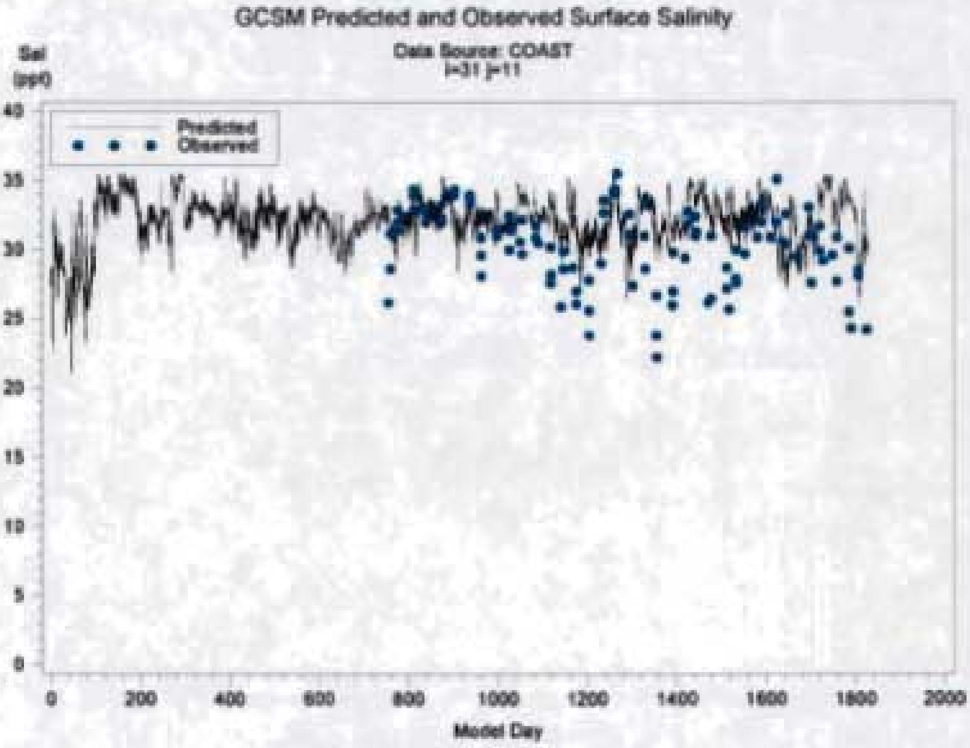


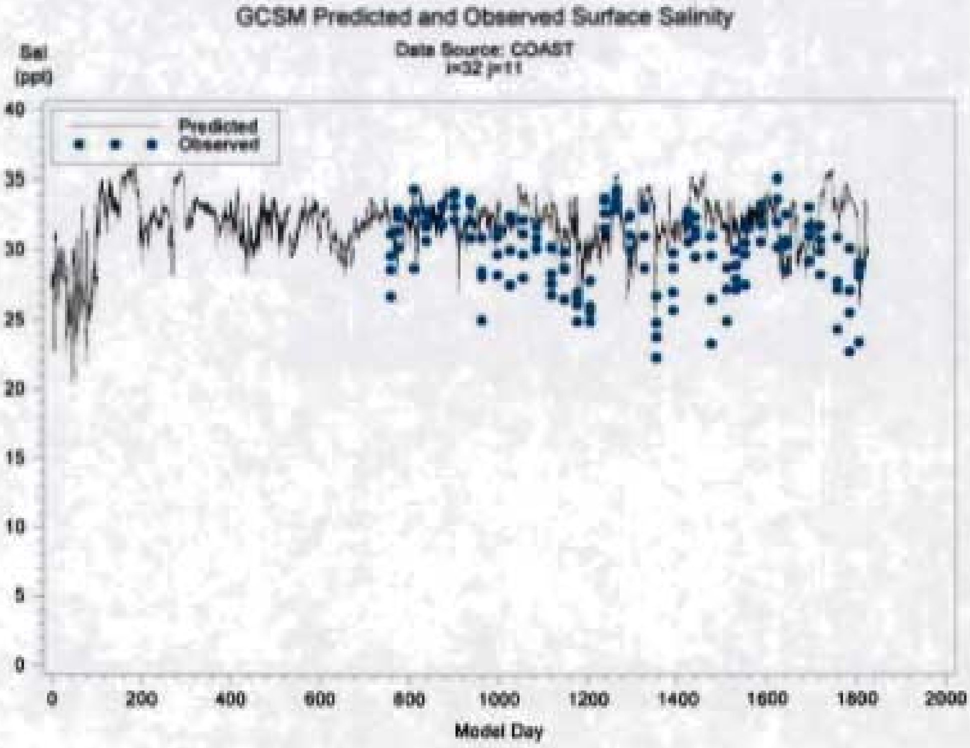

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=29 j=10
Sal
(ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day


GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=30 j=10
Sal
(ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day


GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=30 j=11
Sal (ppt)
Predicted
Observed
Model Day

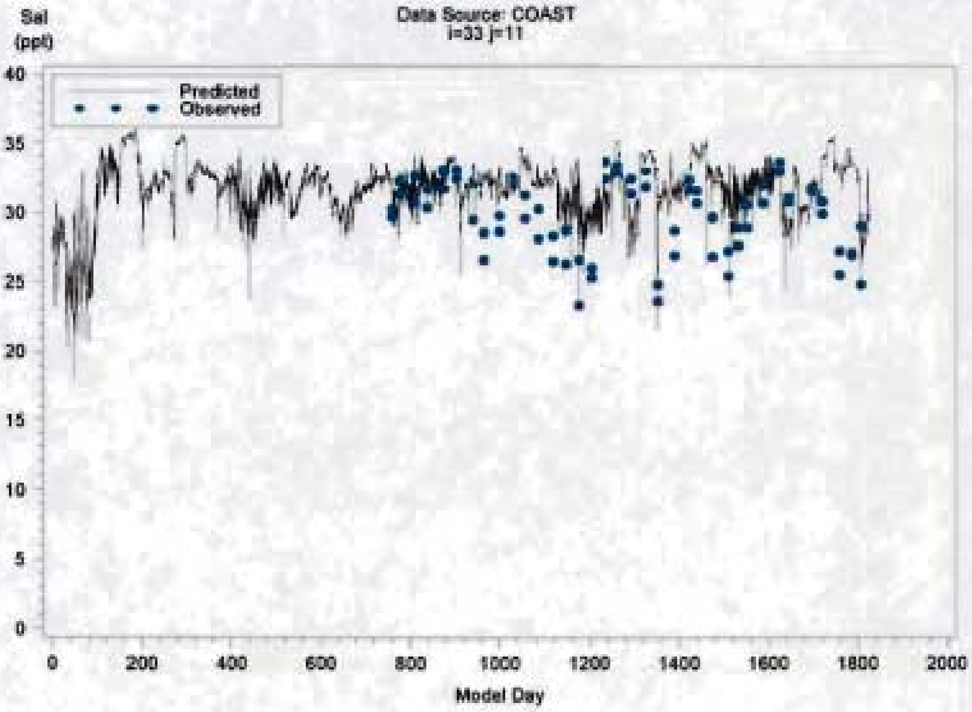

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=31 j=10
Sal (ppt)
Predicted
Observed
Model Day


GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=31 j=11
Sal
(ppt)
Predicted
Observed
40
35
30
25
20
15
10
5
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day


GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=32 j=11
Sal
(ppt)
Predicted
Observed
40
35
30
25
20
15
10
5
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

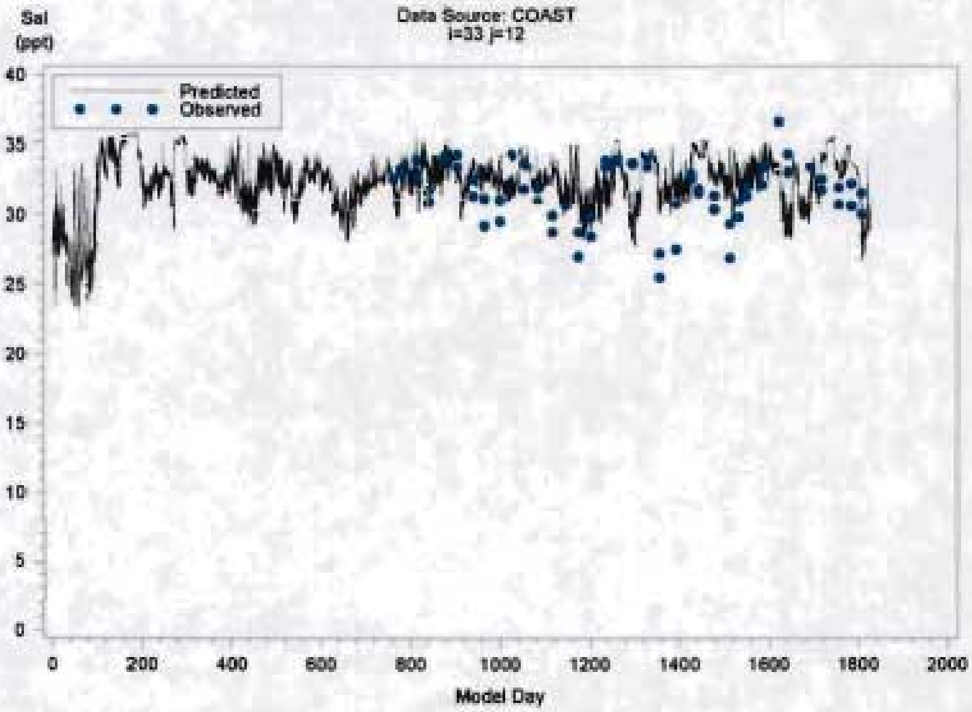
GCSM Predicted and Observed Surface Salinity

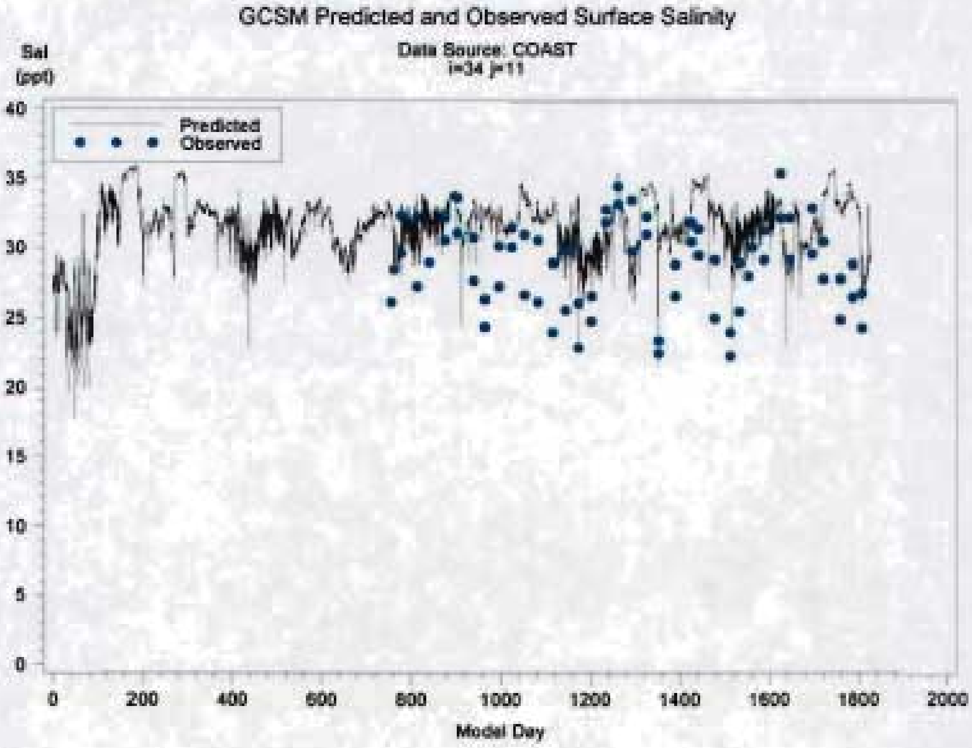
Data Source: COAST
i=33 j=11

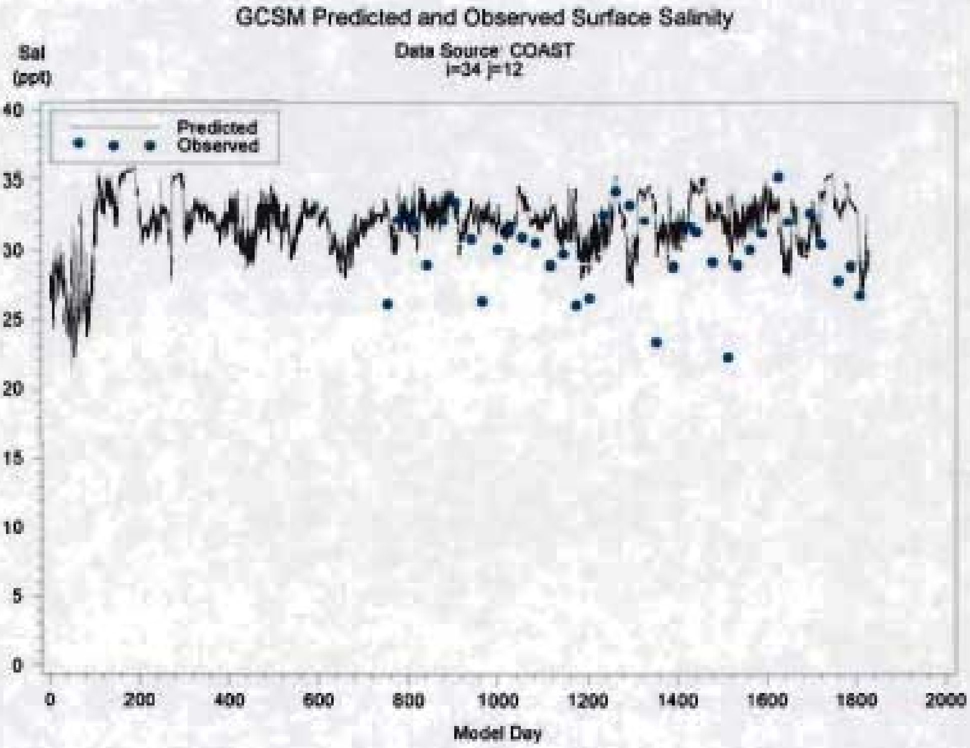


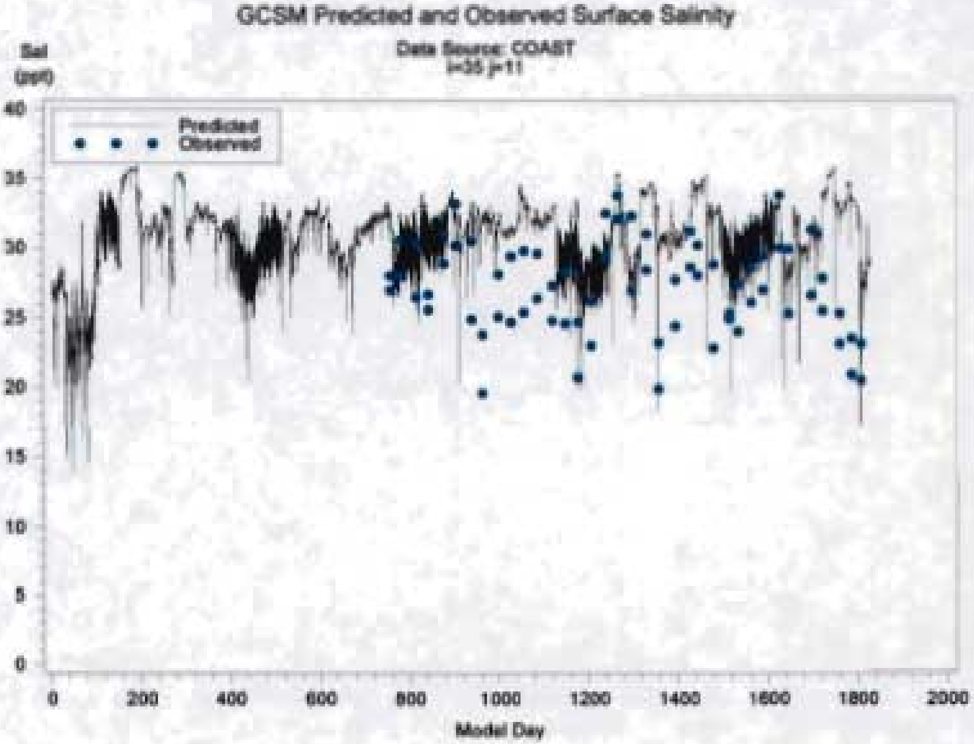

GCSM Predicted and Observed Surface Salinity

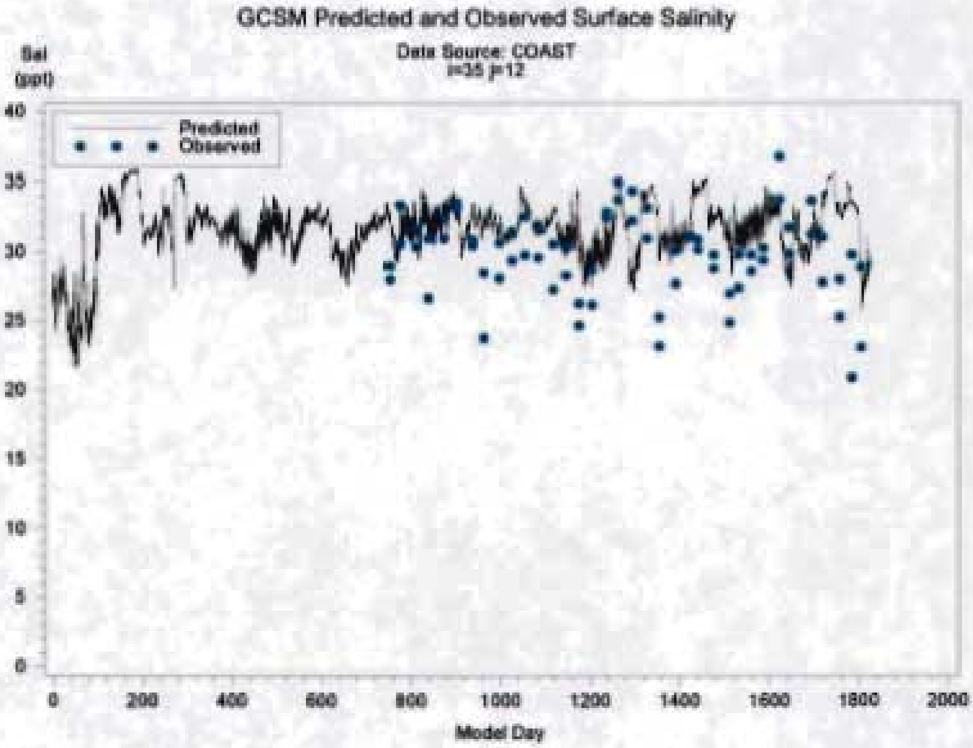
Data Source: COAST
i=33 j=12

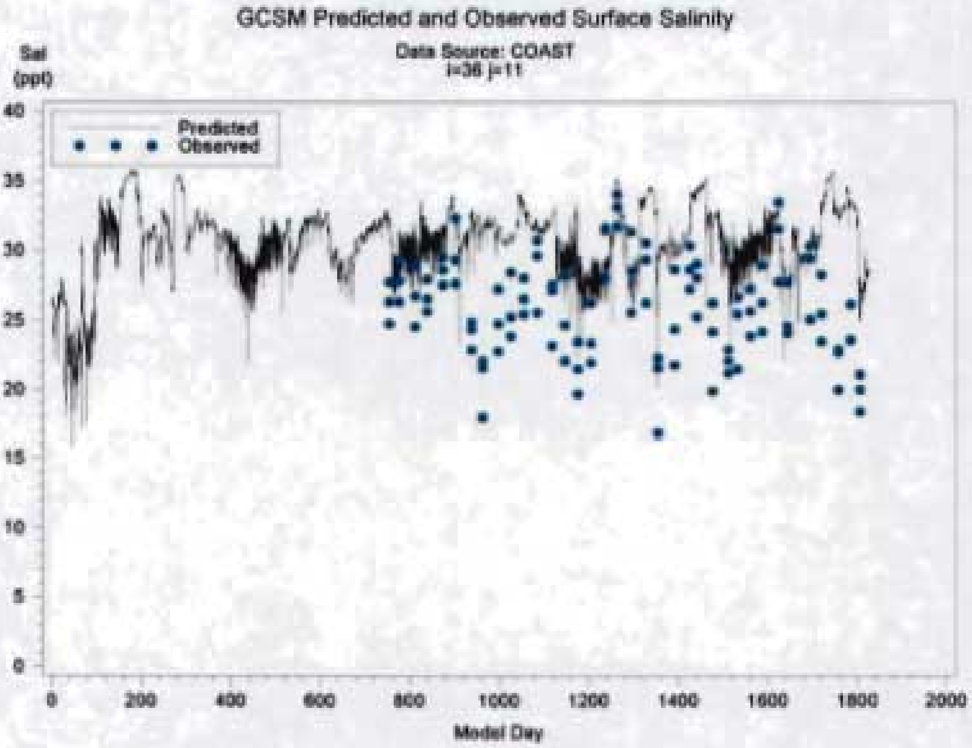


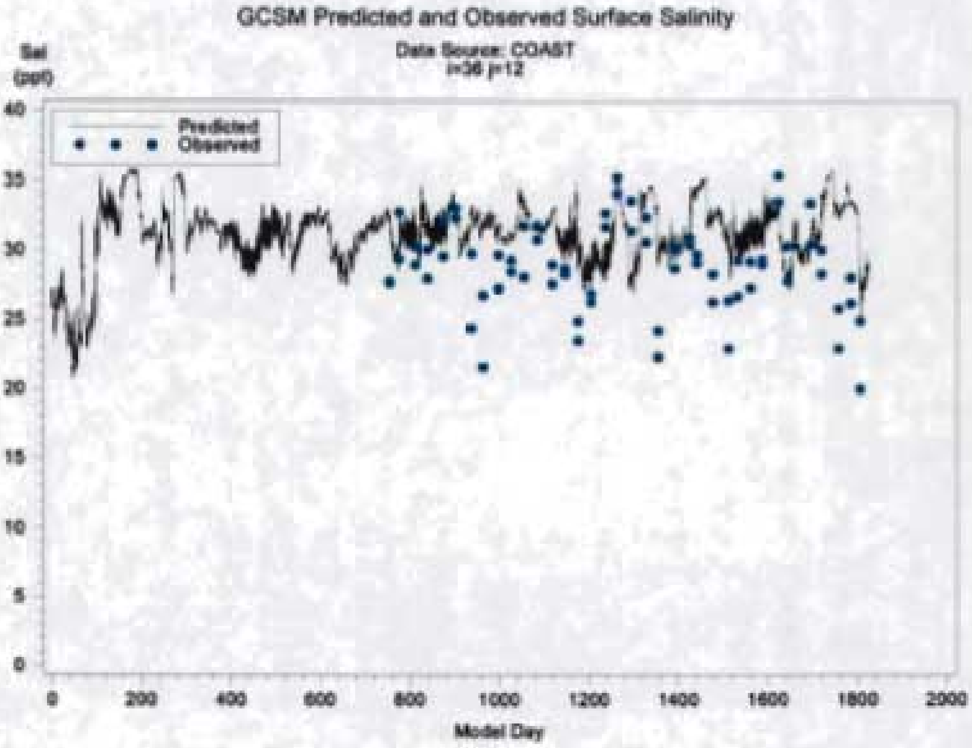

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=34 j=11
Sal
(ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day


GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=34 j=12
Sal
(ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

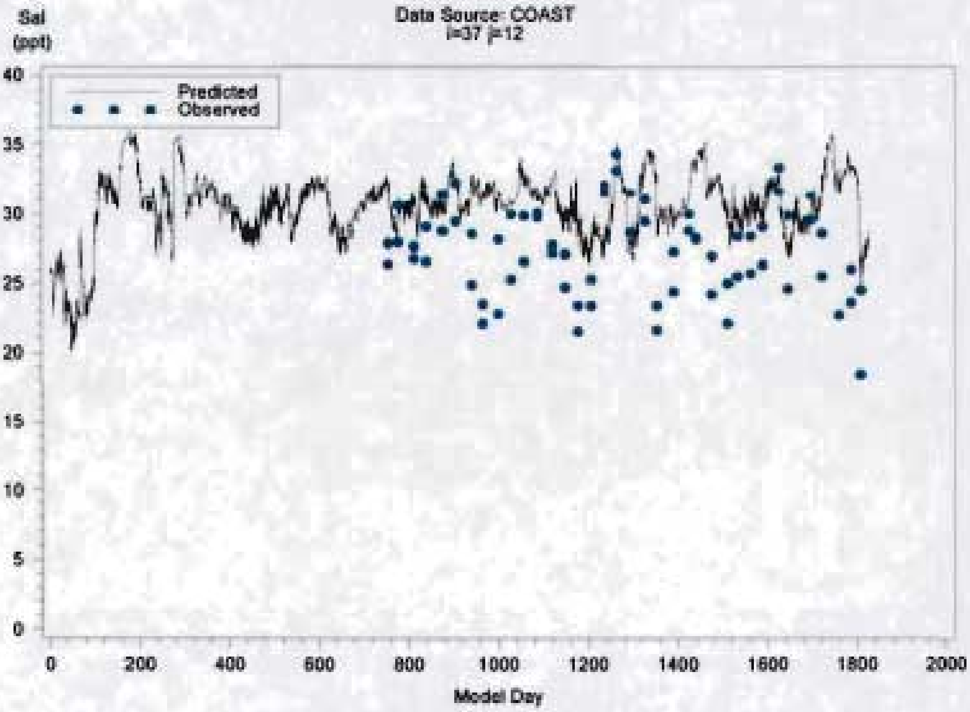

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=35 j=11
Sal
(ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day


GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=35 j=12
Sal
(ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

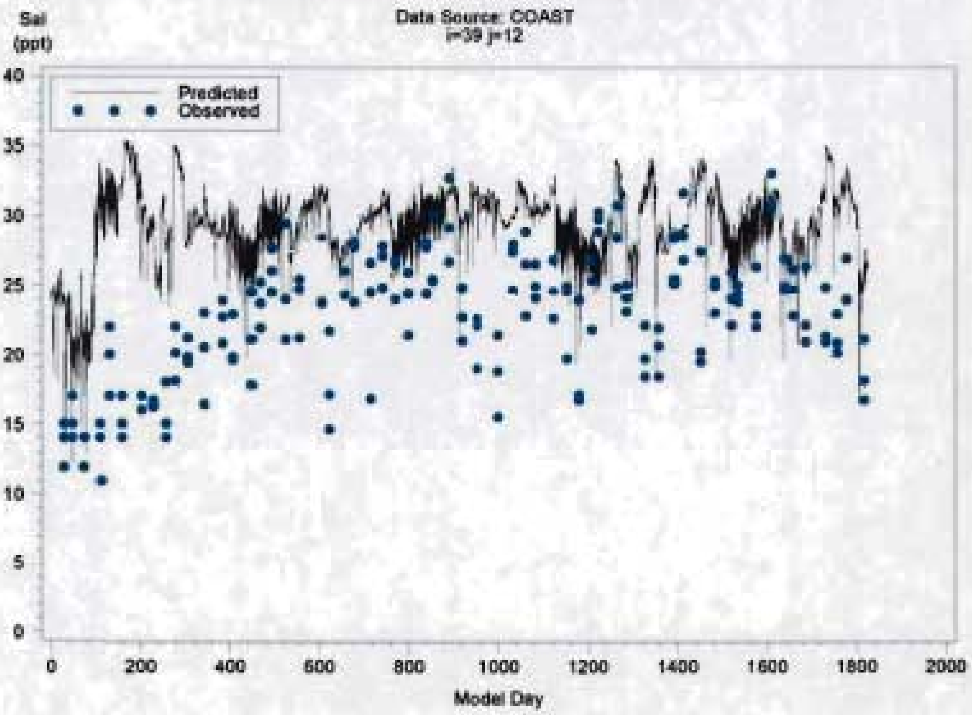

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=36 j=11
Sal
(ppt)
Predicted
Observed
40
35
30
25
20
15
10
5
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

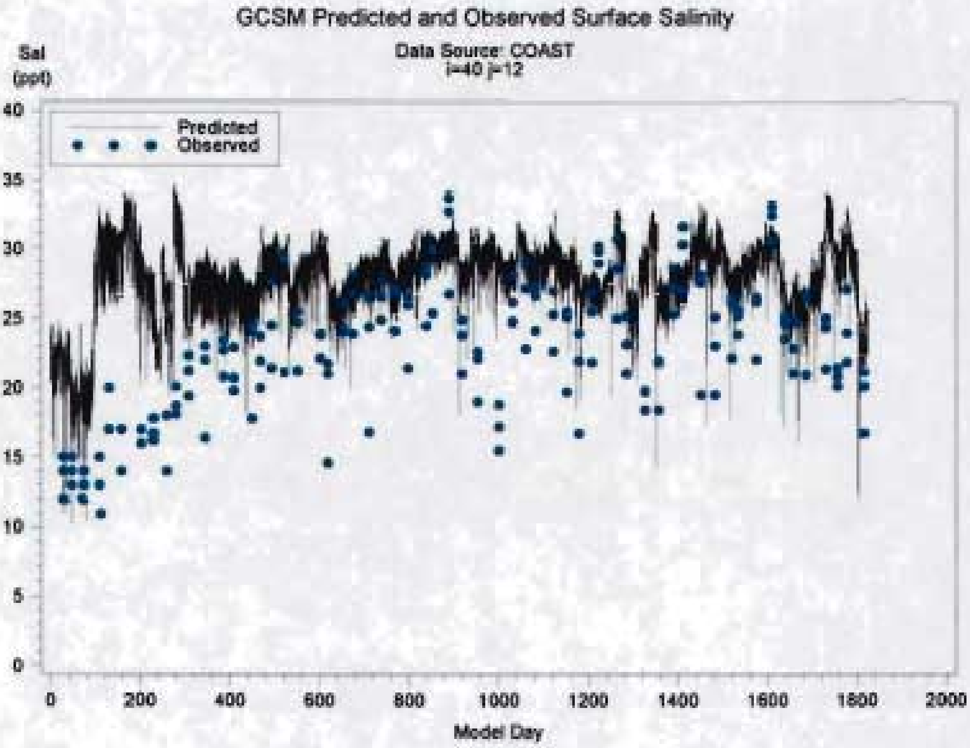

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=36 j=12
Sal
(ppt)
Predicted
Observed
40
35
30
25
20
15
10
5
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

GCSM Predicted and Observed Surface Salinity

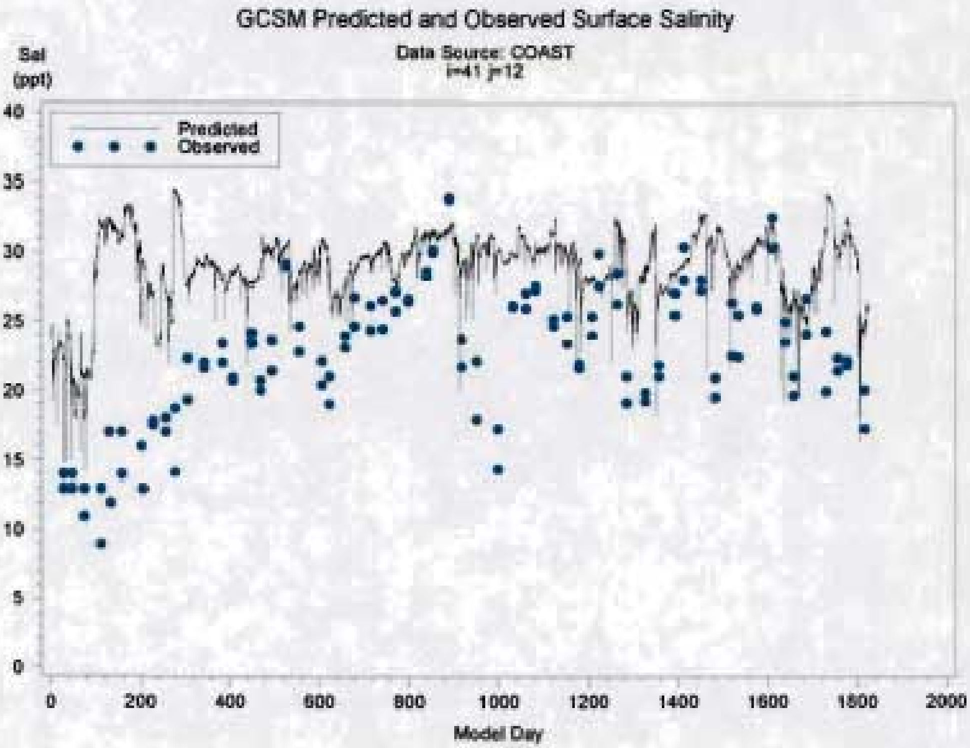



GCSM Predicted and Observed Surface Salinity

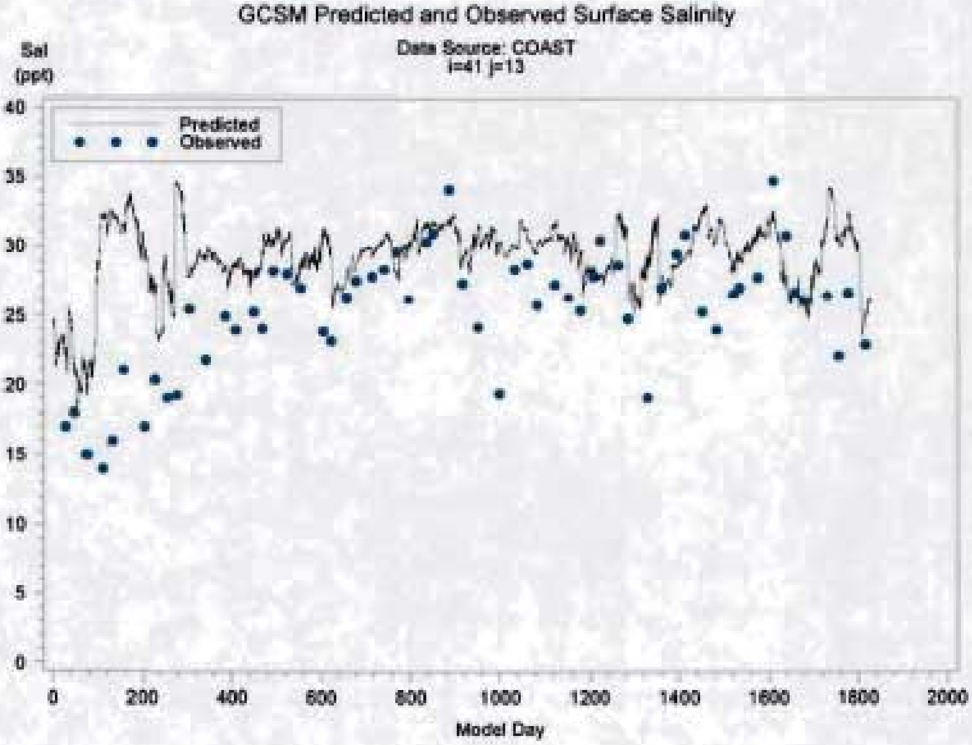


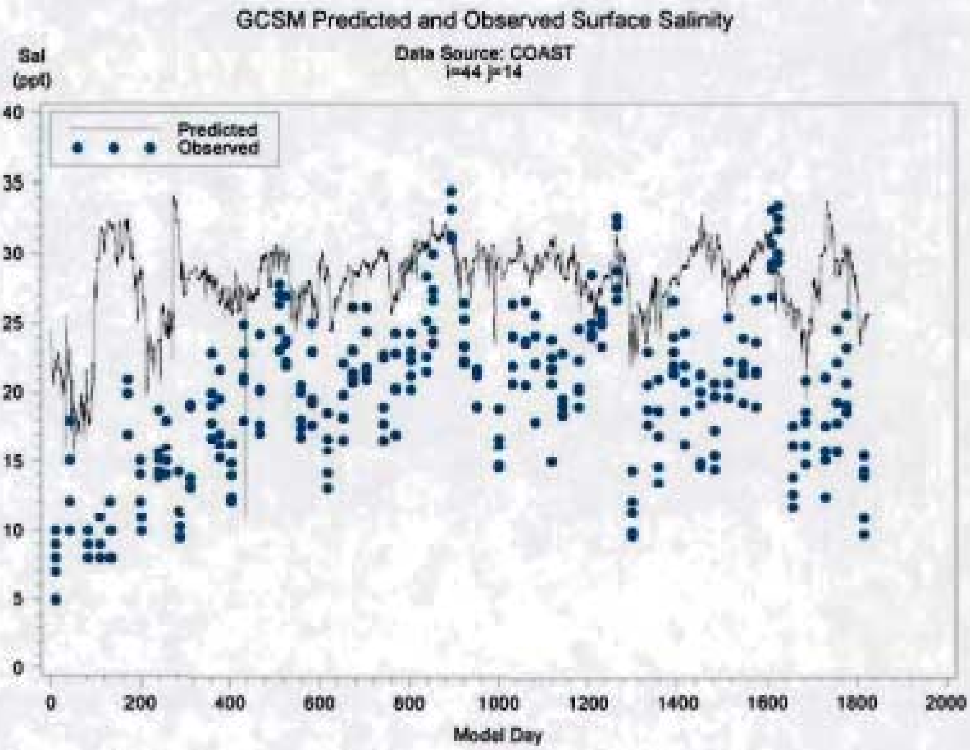


GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=40 j=12
Sal (ppt)
Predicted
Observed
Model Day

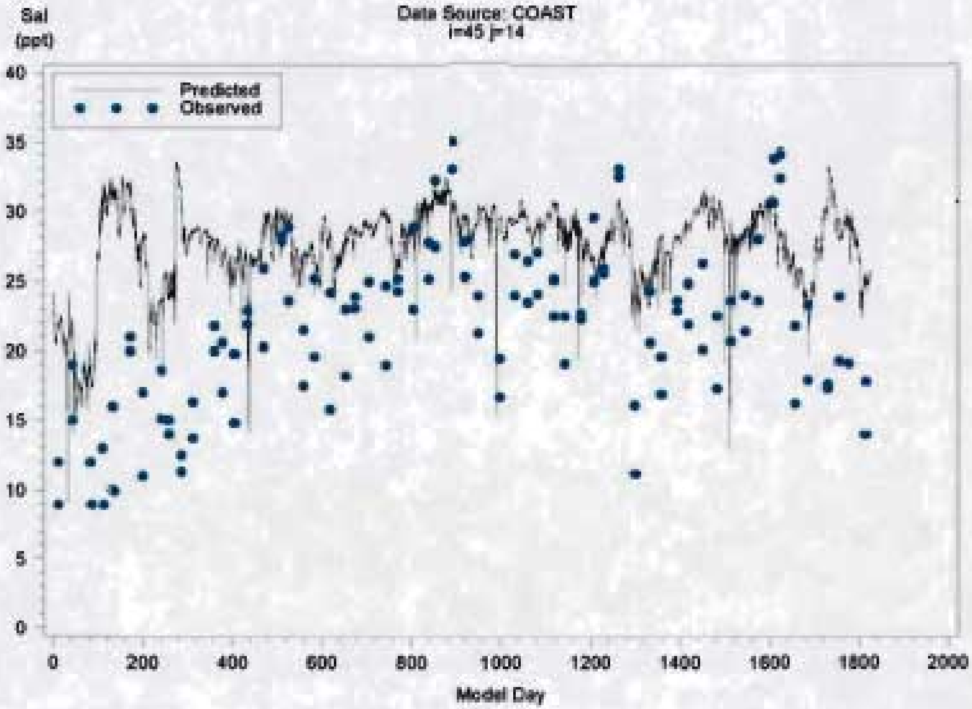



GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=41 j=12
Sal (ppt)
Predicted
Observed
Model Day

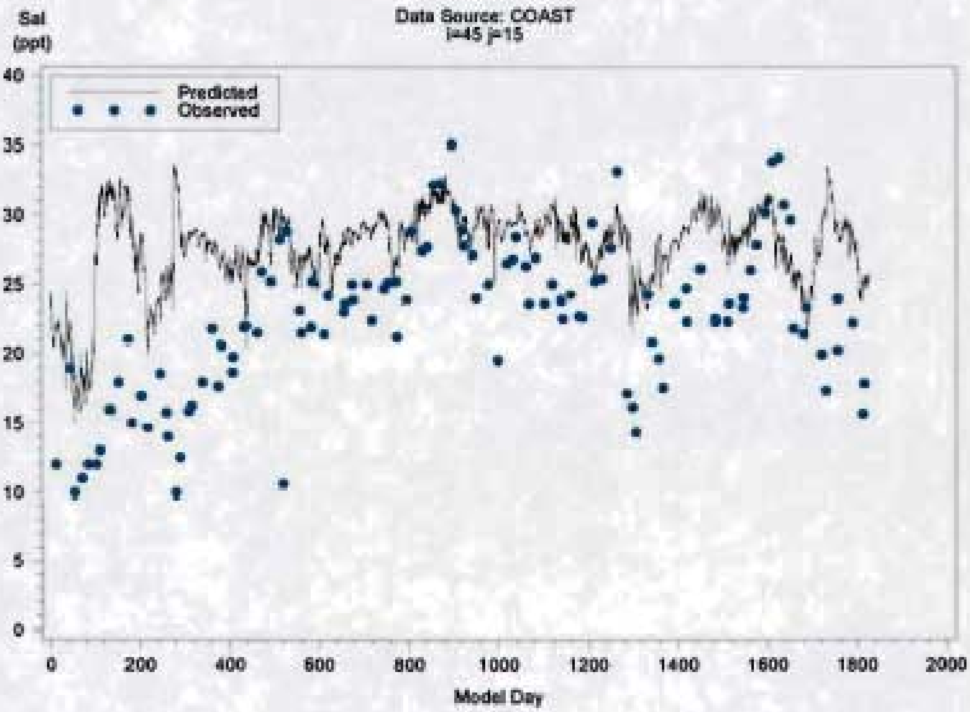

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=41 j=13
Sal (ppt)
Predicted
Observed
Model Day


GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=44 j=14
Sal (ppt)
Predicted
Observed
Model Day

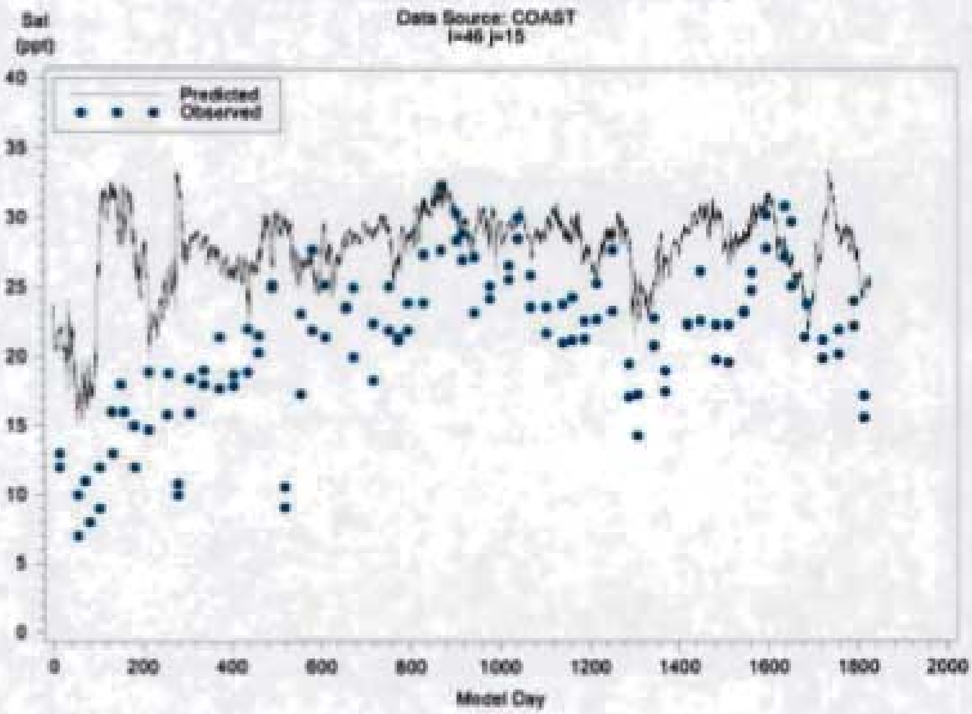
GCSM Predicted and Observed Surface Salinity



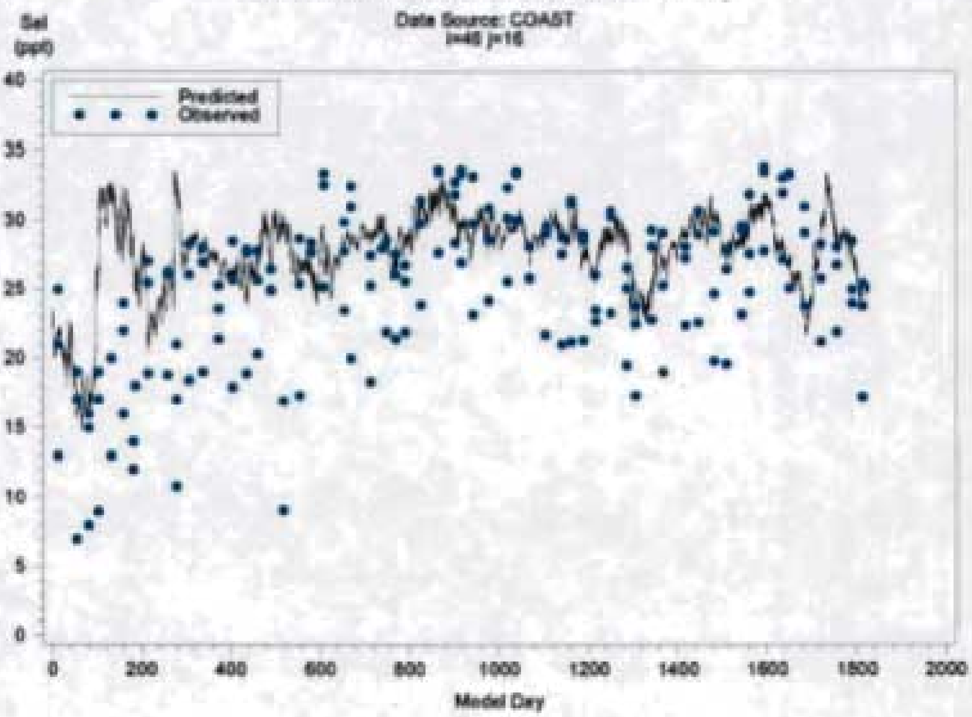

GCSM Predicted and Observed Surface Salinity

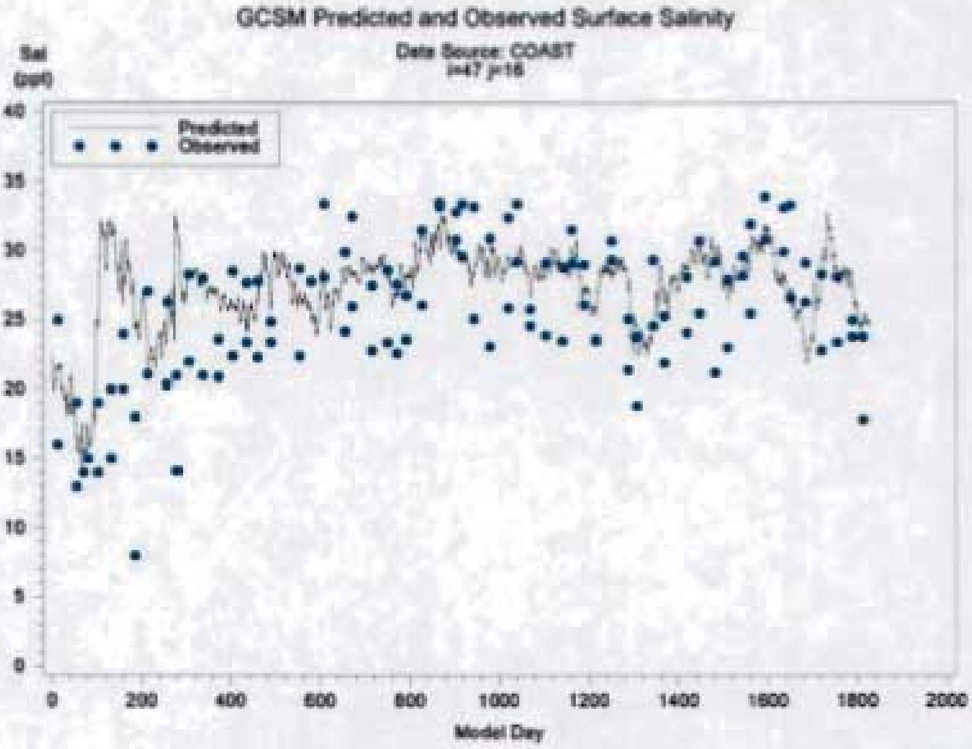


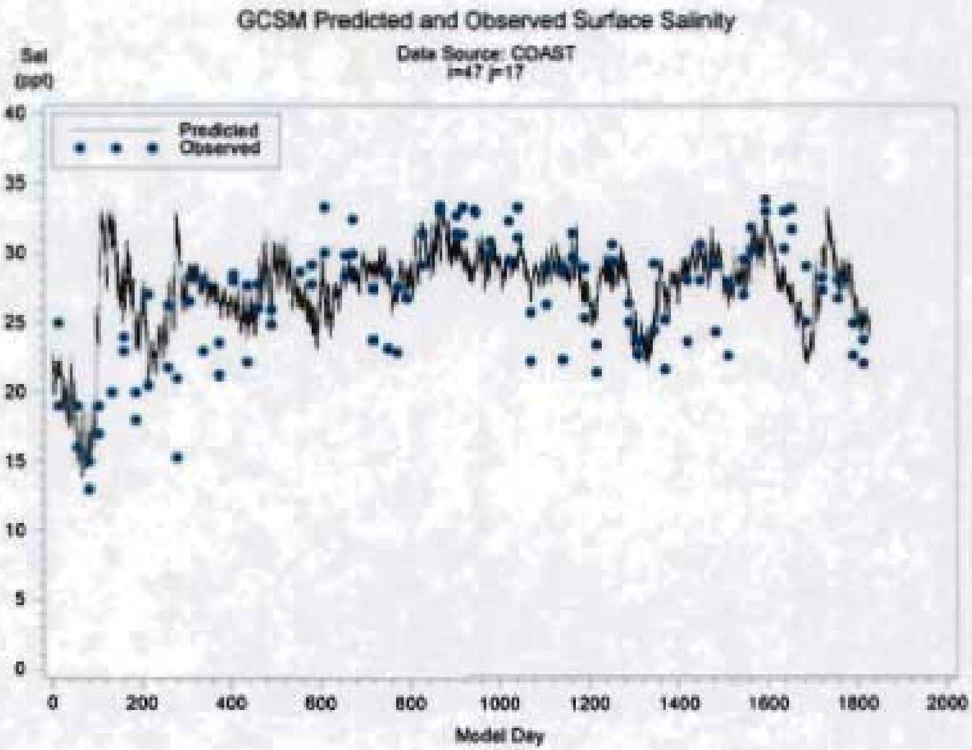
GCSM Predicted and Observed Surface Salinity

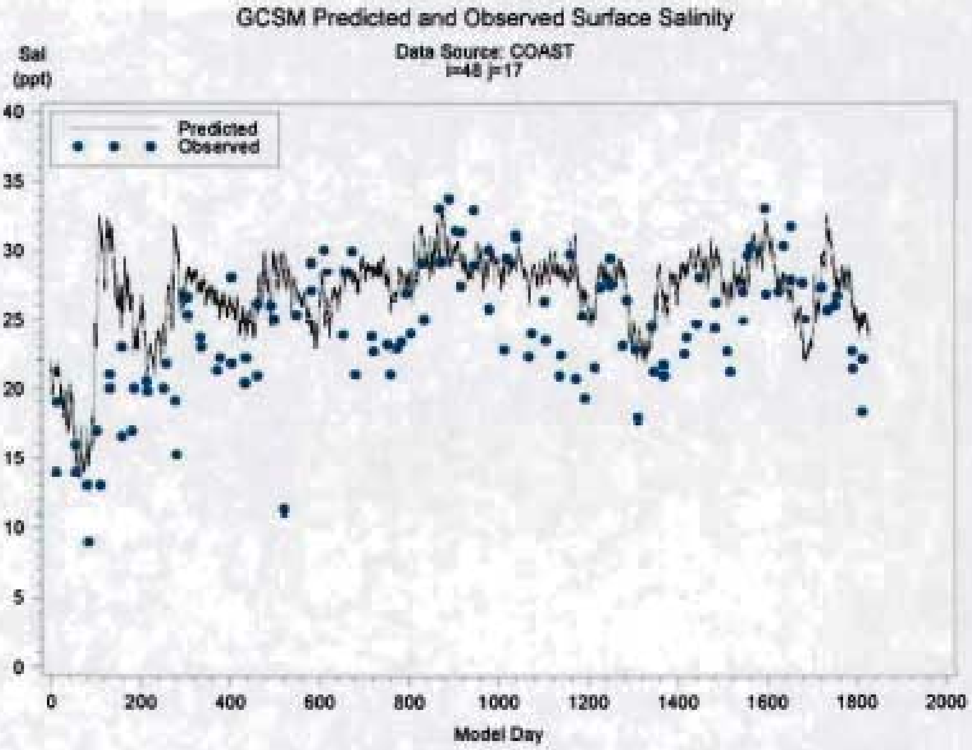


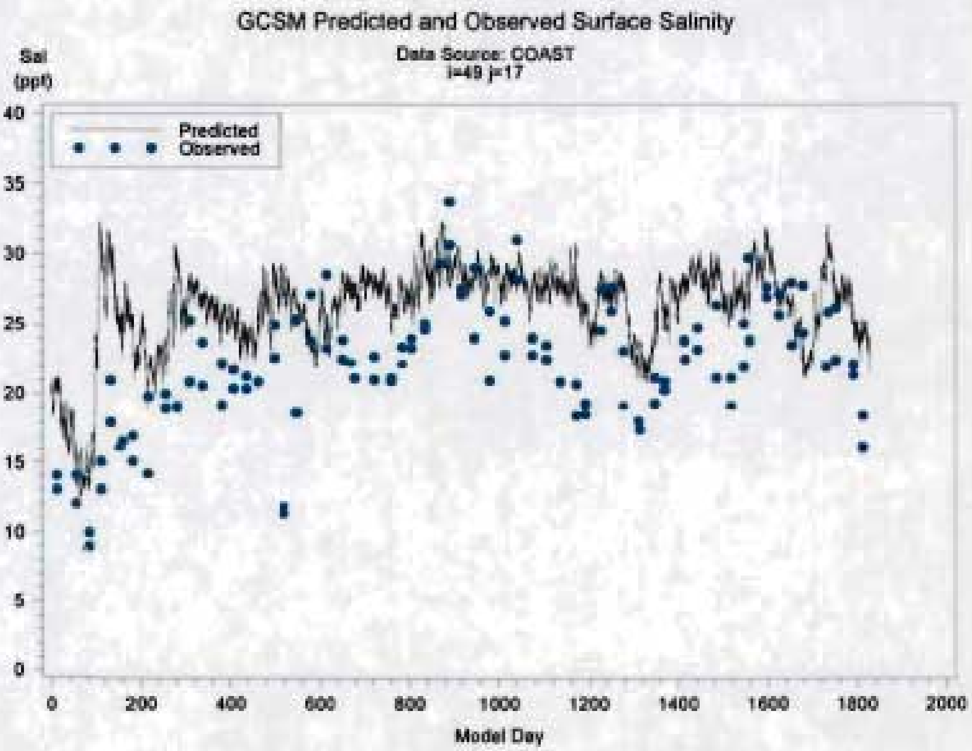

GCSM Predicted and Observed Surface Salinity

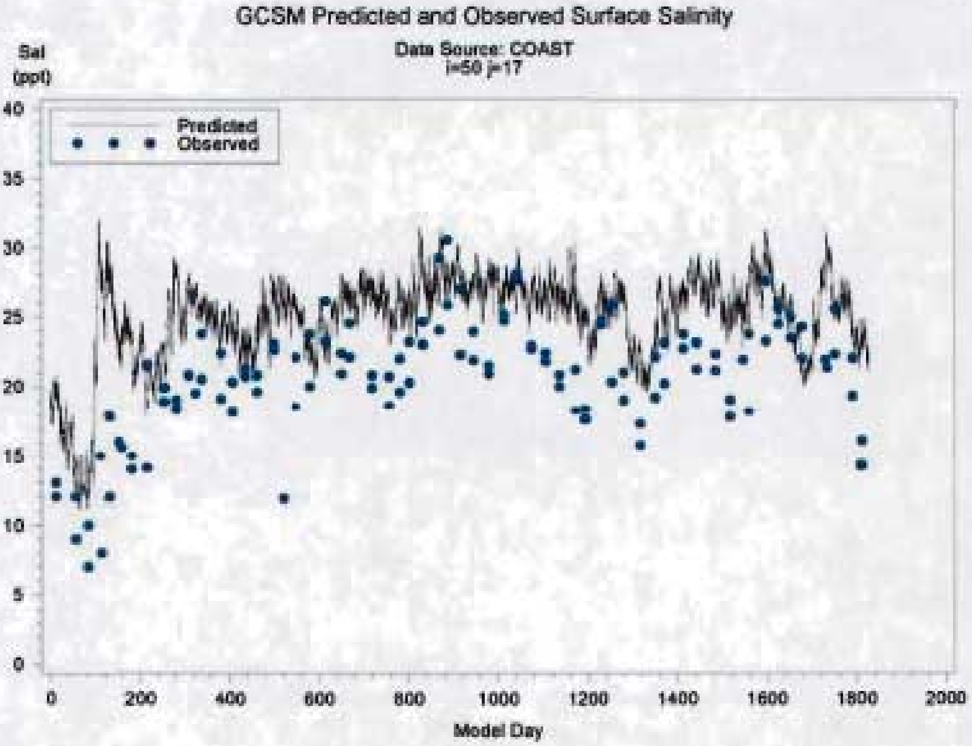


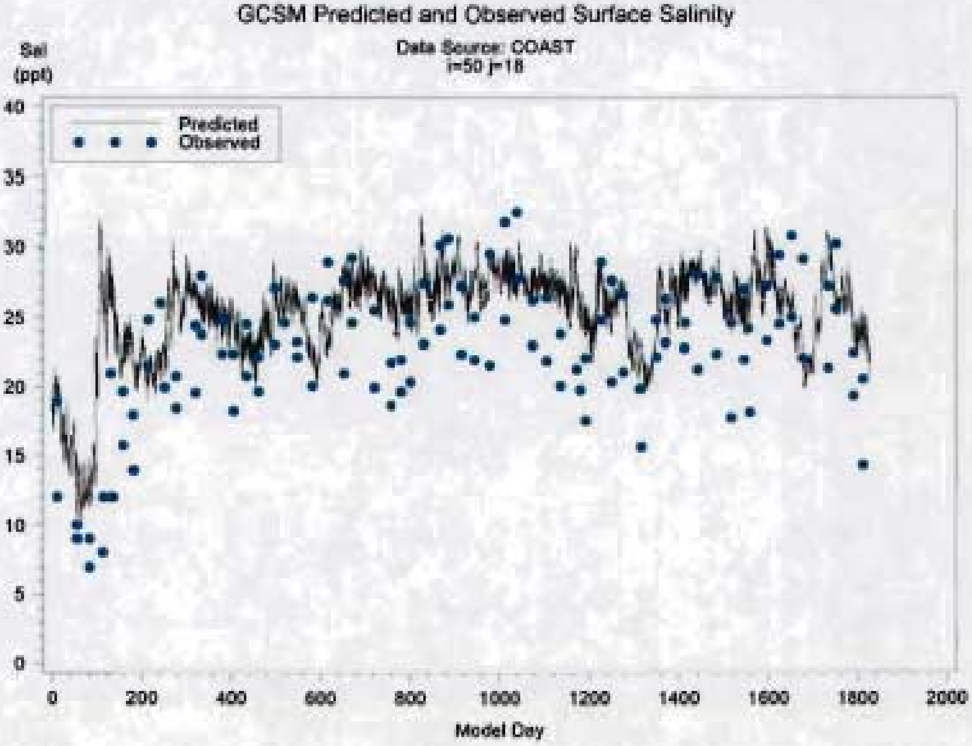

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=47 j=16
Sal (ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

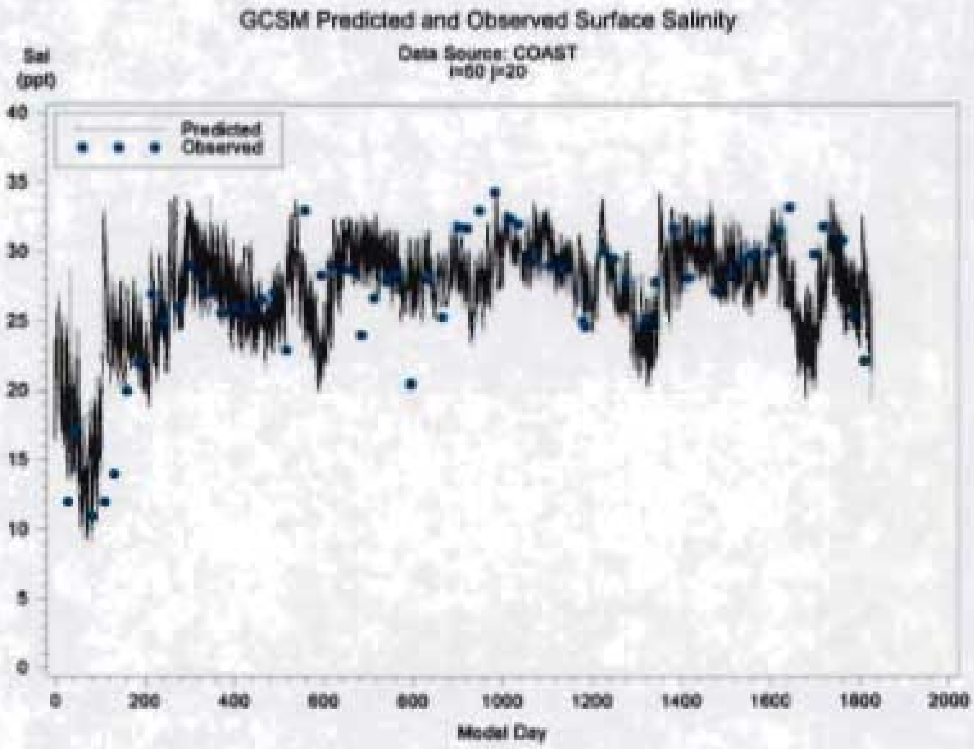

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=47 j=17
Sal (ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

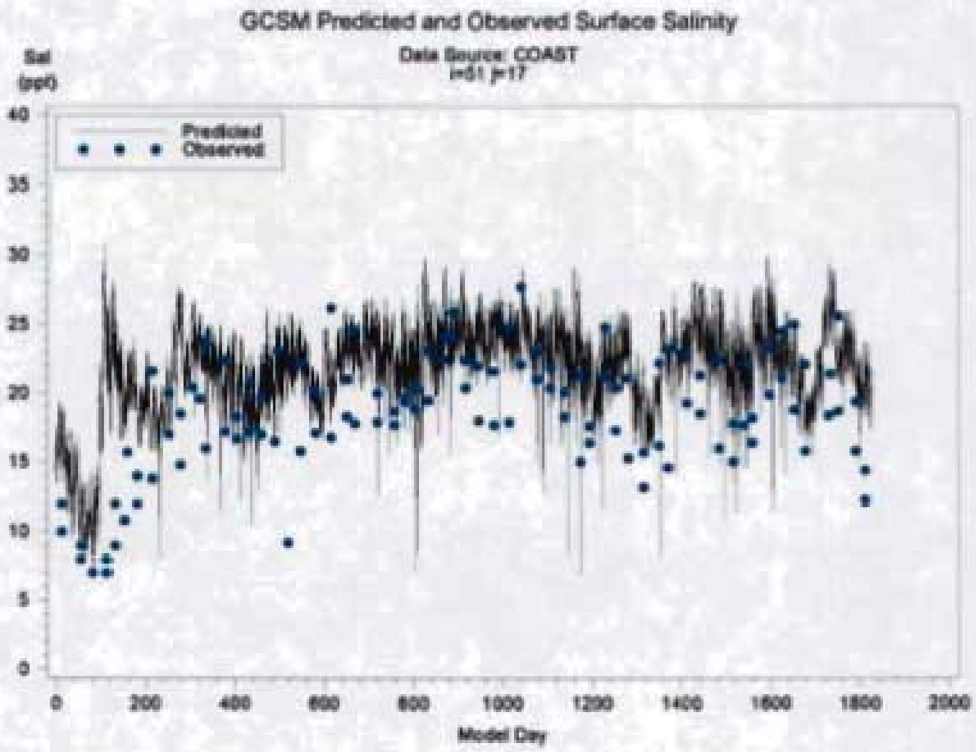

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=48 j=17
Sal
(ppt)
Predicted
Observed
Model Day
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
5
10
15
20
25
30
35
40

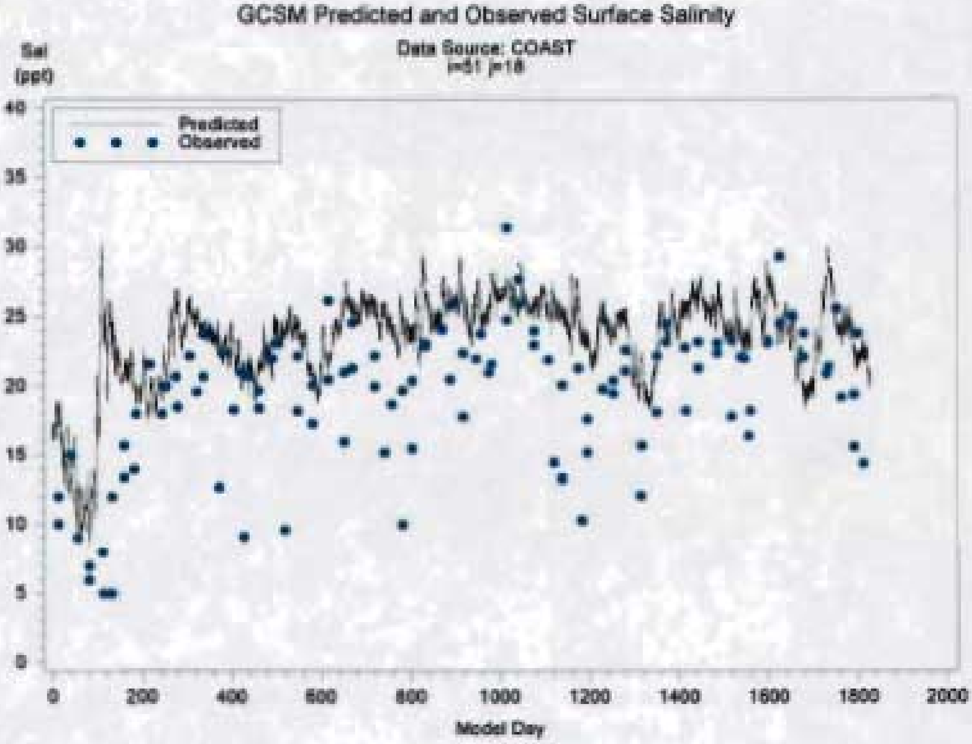

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=49 j=17
Sal
(ppt)
Predicted
Observed
Model Day
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
5
10
15
20
25
30
35
40

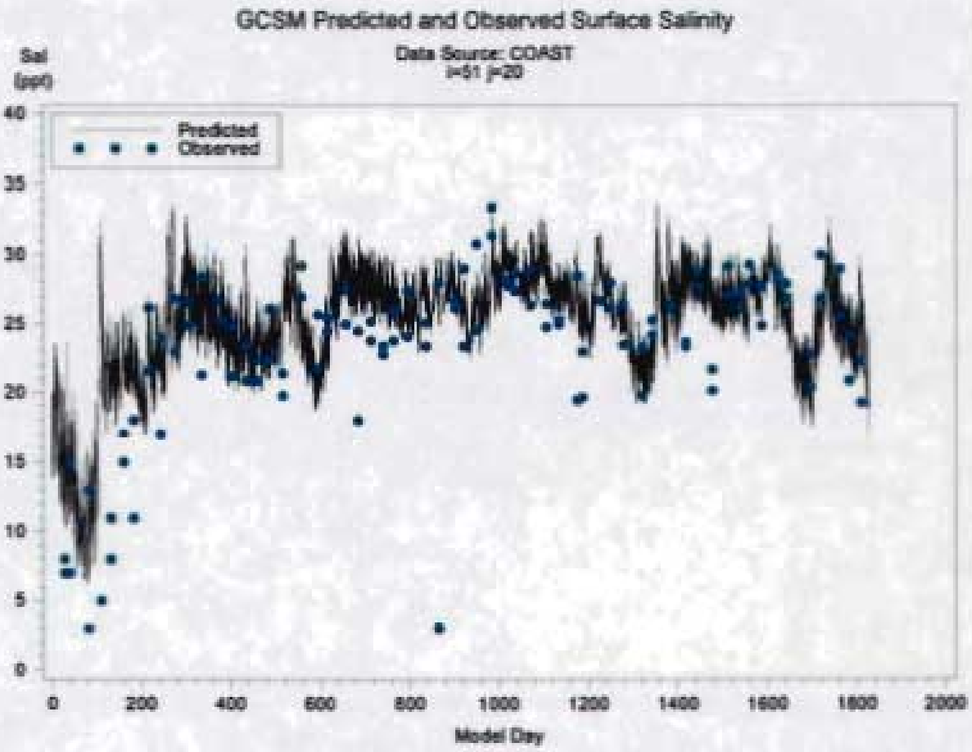

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=50 j=17
Sal (ppt)
Predicted
Observed
Model Day

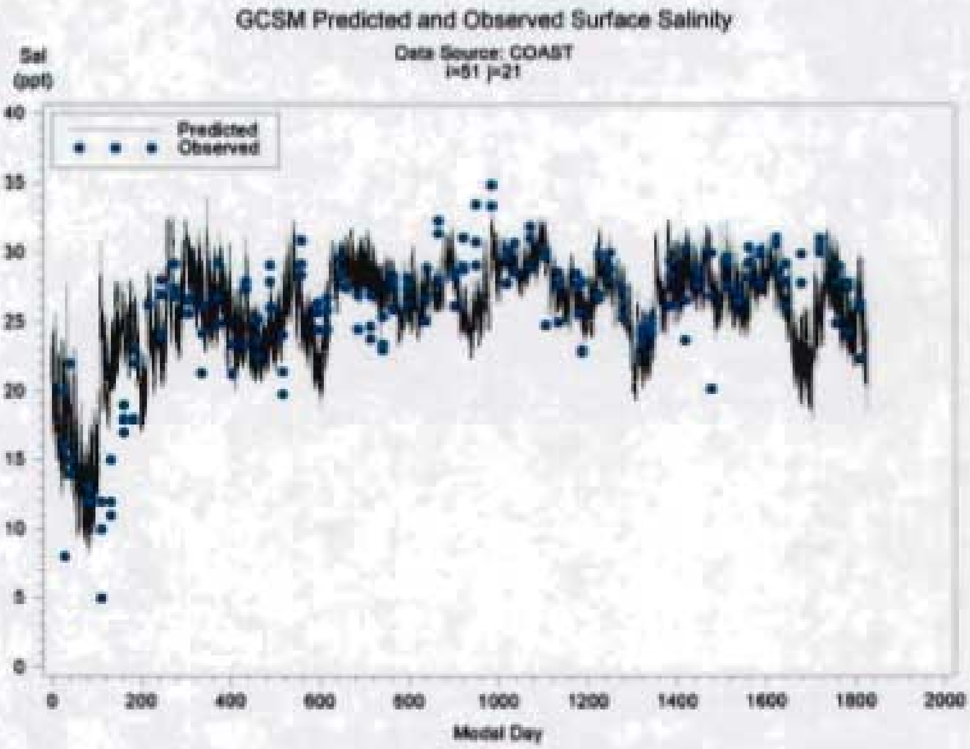

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=50 j=18
Sal (ppt)
Predicted
Observed
Model Day

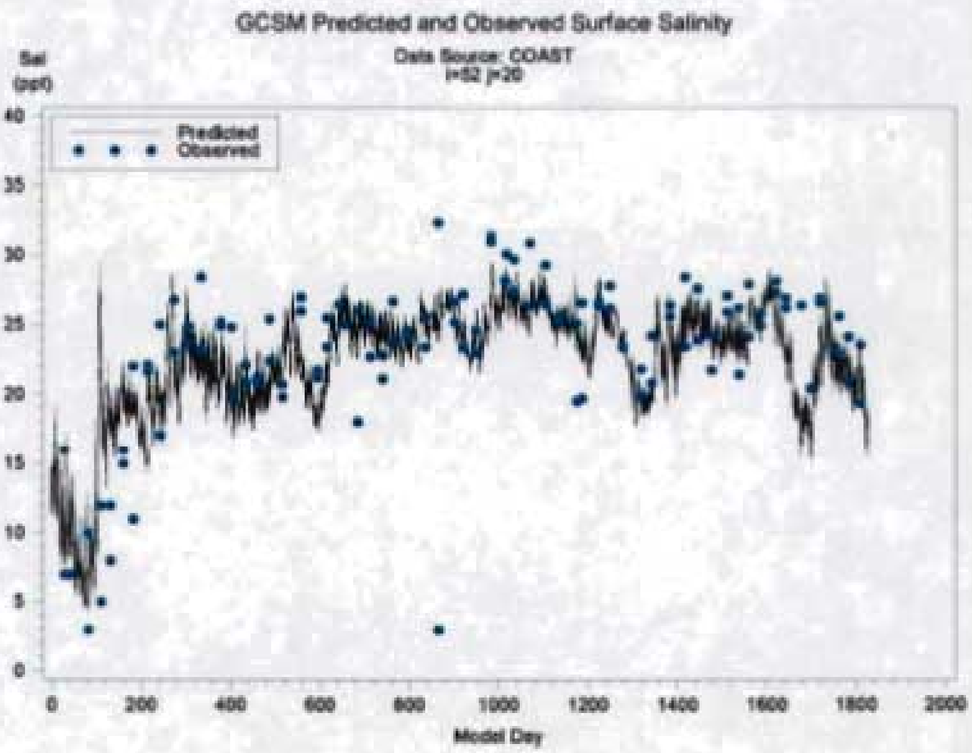

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
Sal
(ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

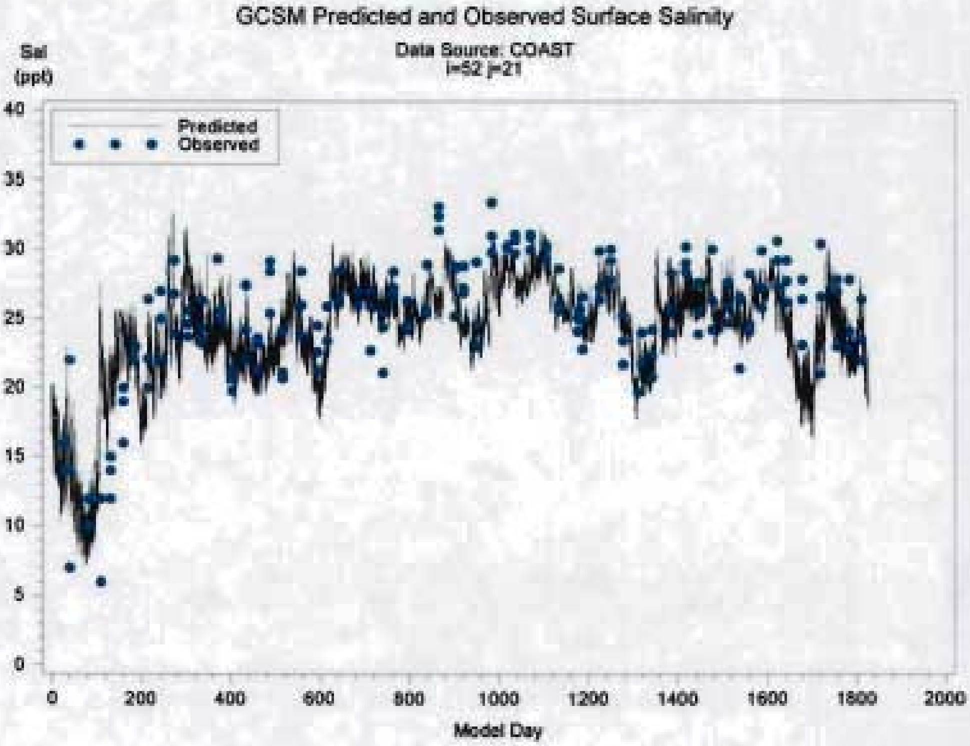

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=51 j=17
Sal
(ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day


GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=51 j=18
Sal
(ppt)
Predicted
Observed
Model Day

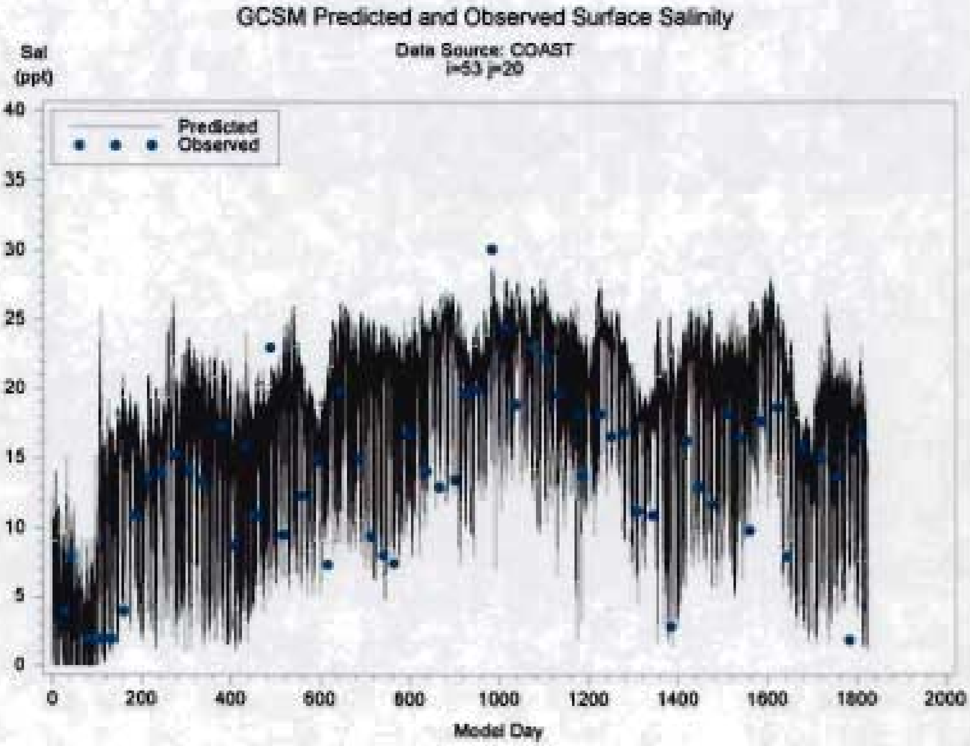

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=51 j=20
Sal
(ppt)
Predicted
Observed
Model Day


GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=51 j=21
Sal
(ppt)
Predicted
Observed
40
35
30
25
20
15
10
5
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

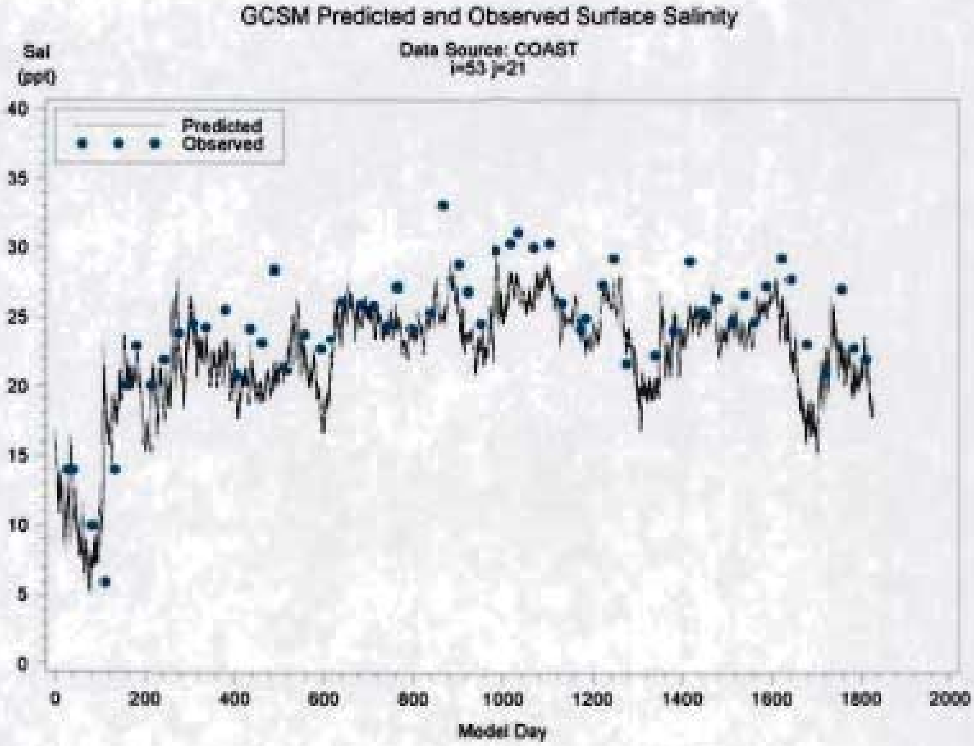

GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=52 j=20
Sal
(ppt)
Predicted
Observed
40
35
30
25
20
15
10
5
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day



GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=52 j=21
Sal (ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

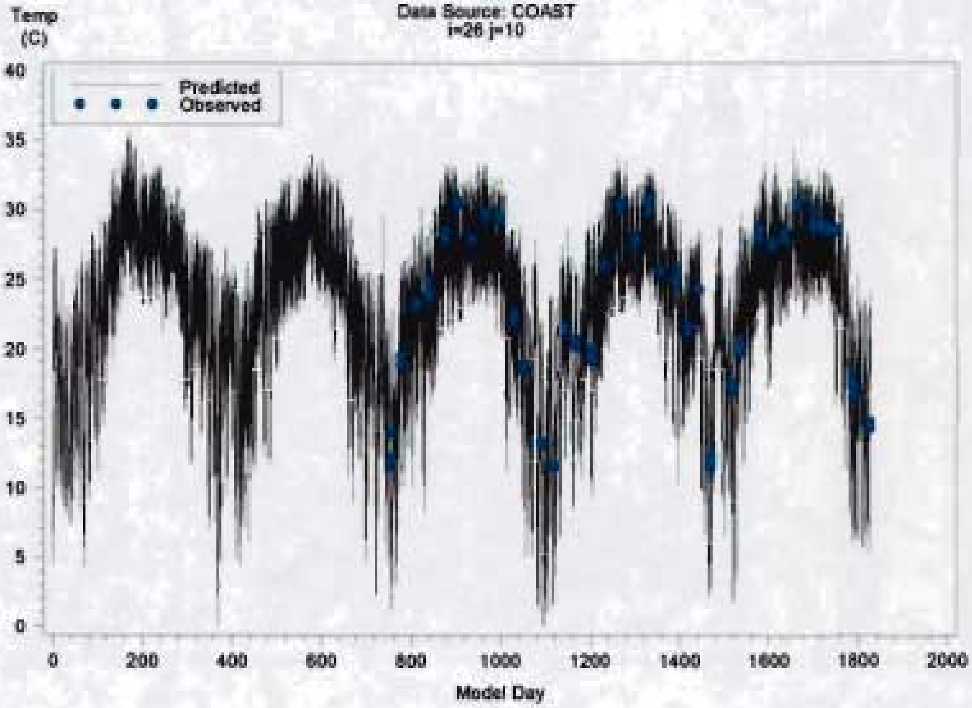
GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=53 j=20
Sal (ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day


GCSM Predicted and Observed Surface Salinity
Data Source: COAST
i=53 j=21
Sal
(ppt)
Predicted
Observed
Model Day
0
5
10
15
20
25
30
35
40
200
400
600
800
1000
1200
1400
1600
1800
2000

# Appendix A.3
# GCSM: Time Series Predicted and Observed Surface Temperature at Grid Cells and COAST Sites 1998-2002

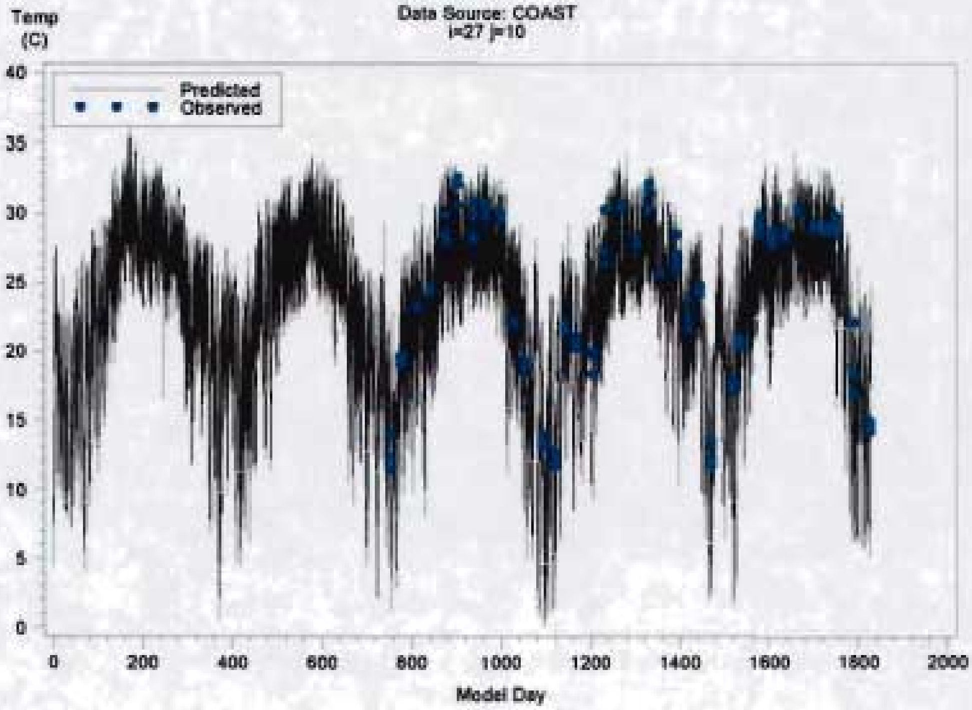
GCSM Predicted and Observed Surface Temperature

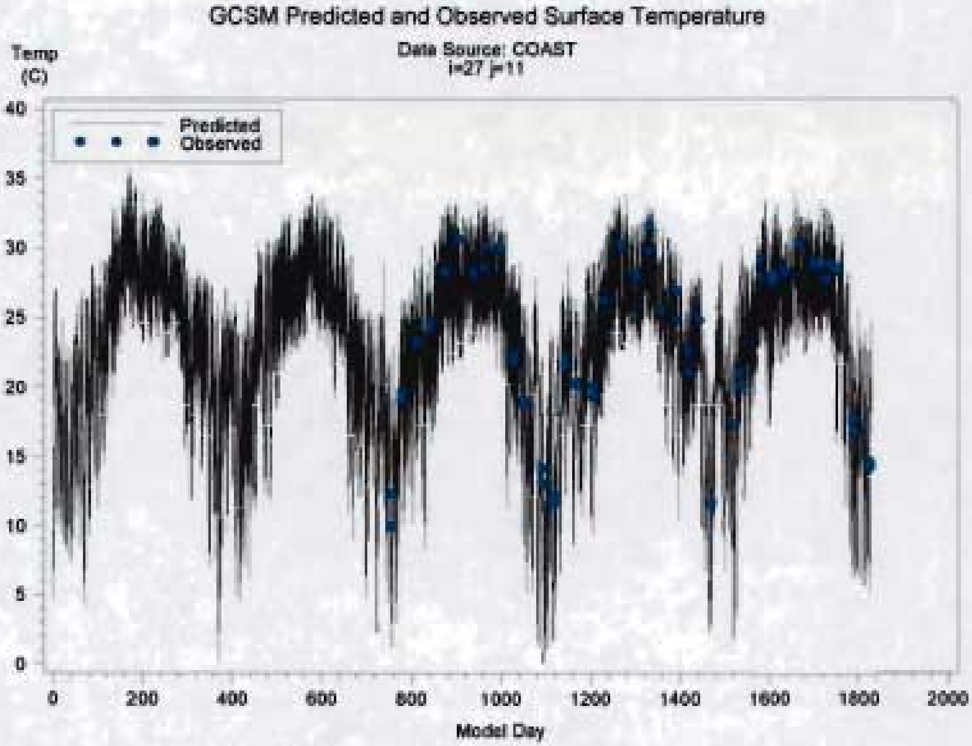
Data Source: COAST
i=26 j=10

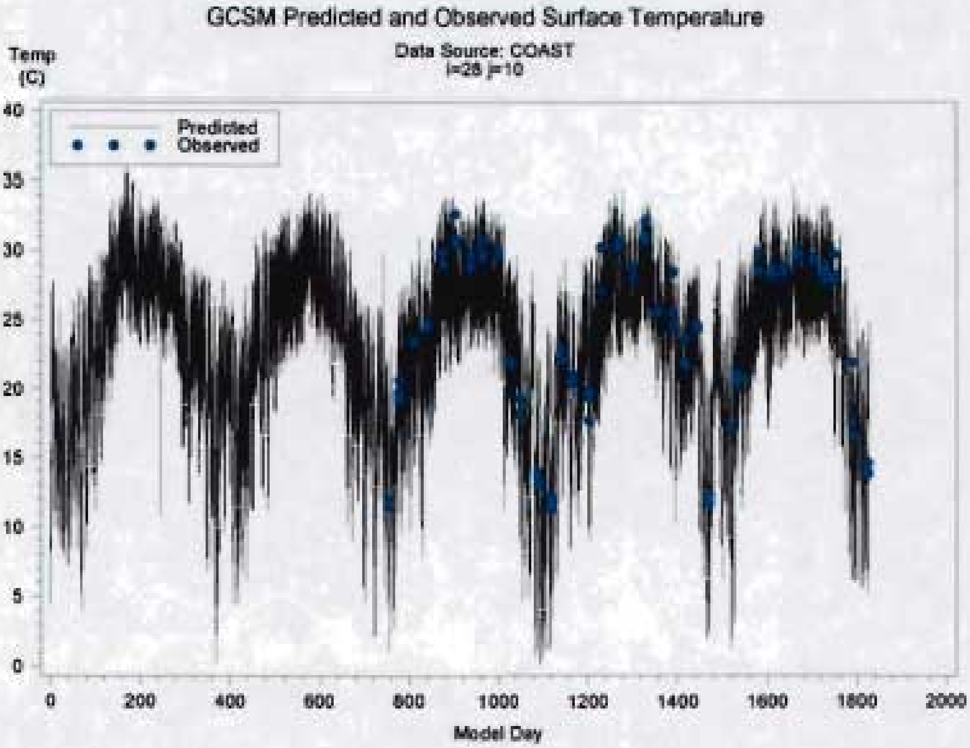


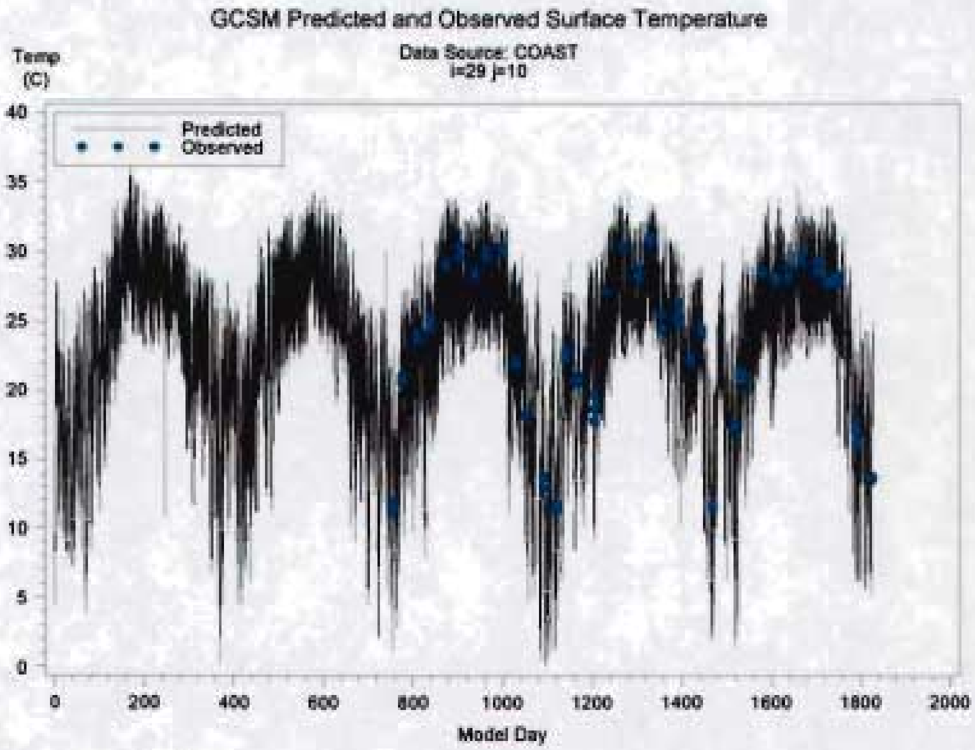

GCSM Predicted and Observed Surface Temperature

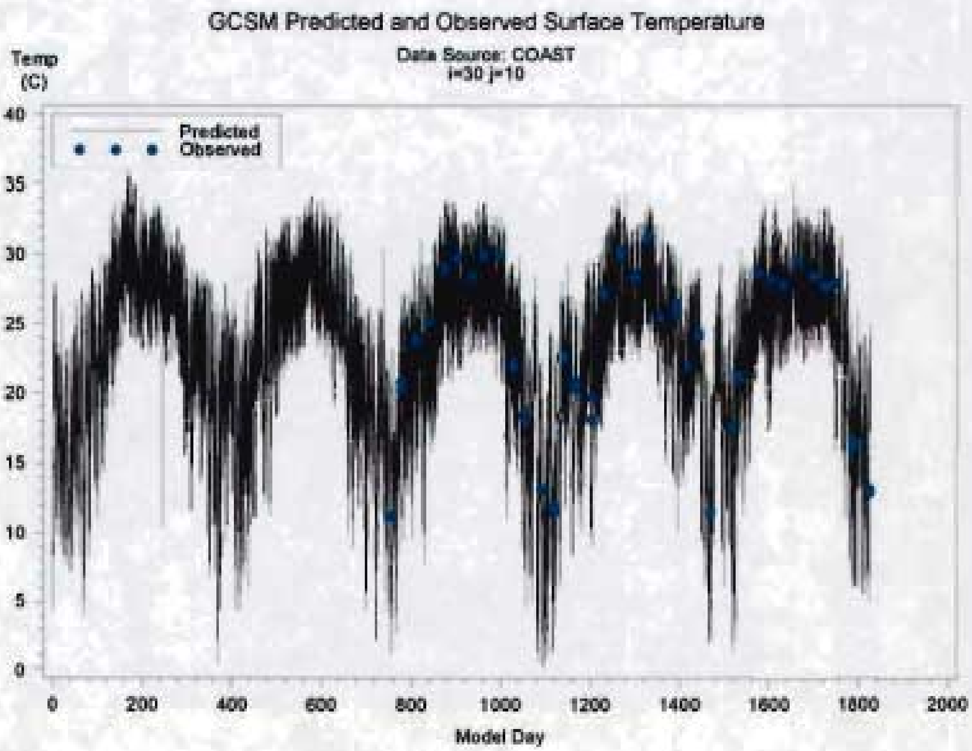
Data Source: COAST
i=27 j=10

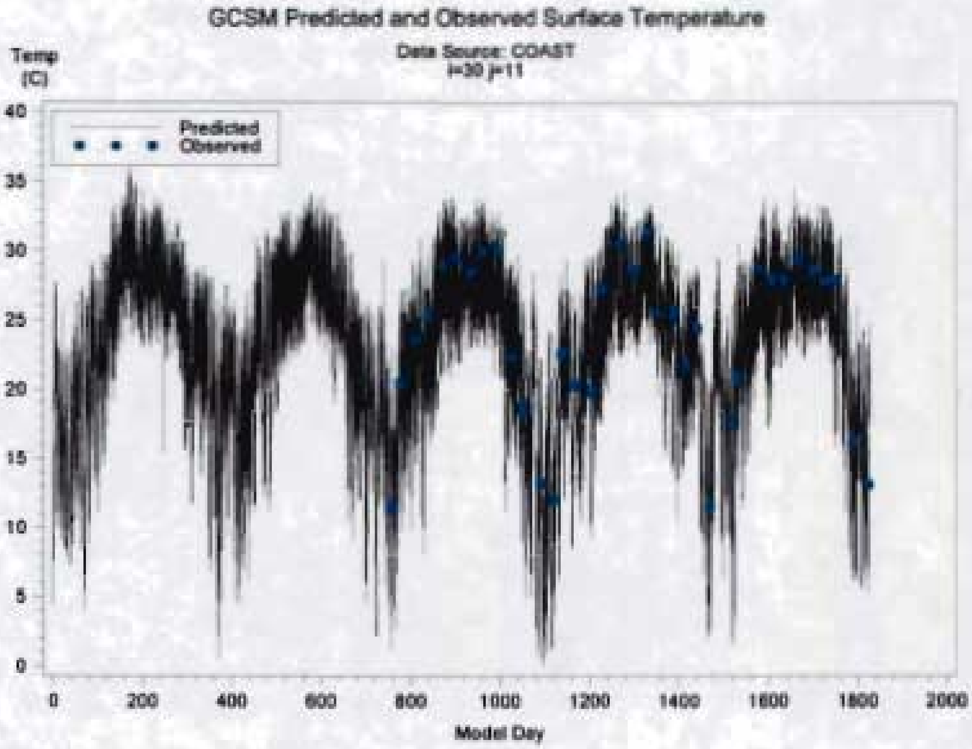


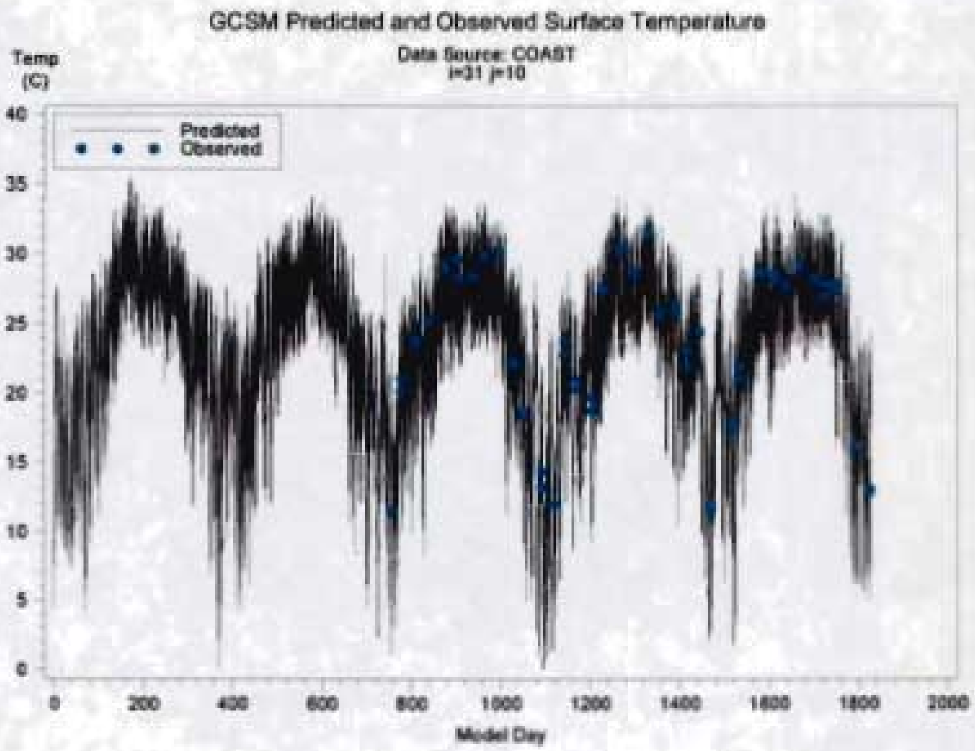

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=27 j=11
Temp (C)
Predicted
Observed
Model Day
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000

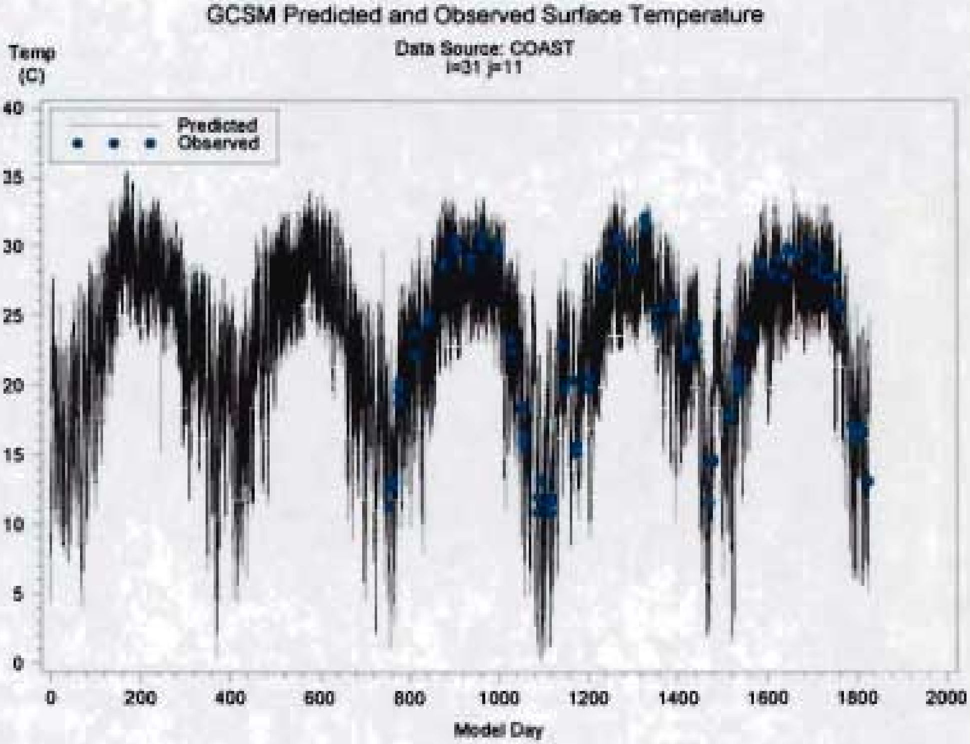

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=28 j=10
Temp (C)
Predicted
Observed
Model Day
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000

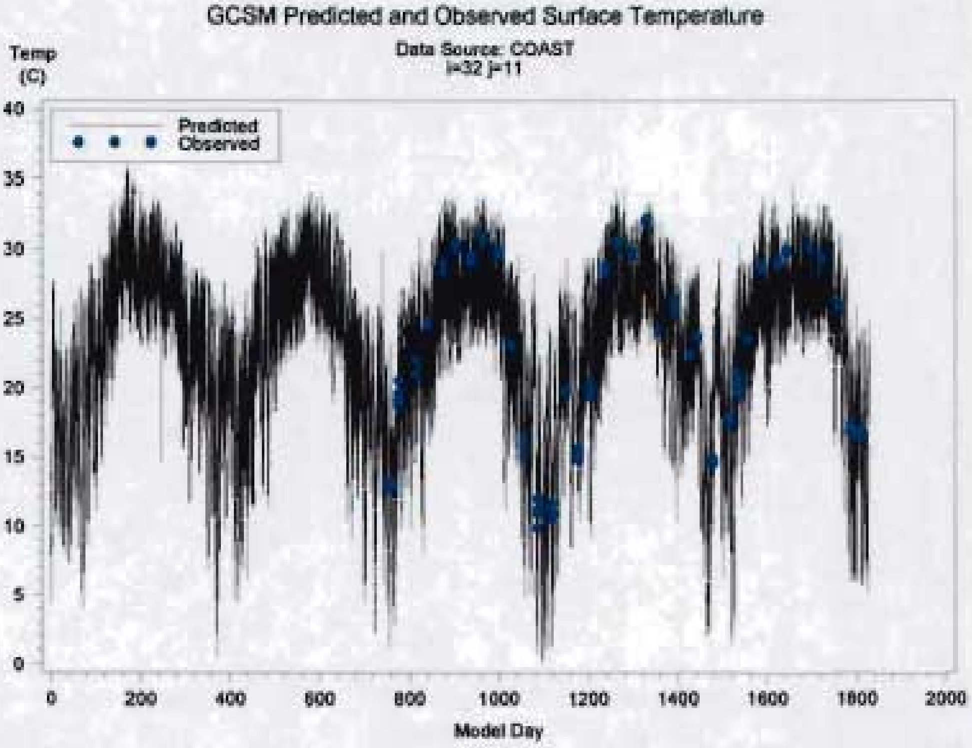

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=29 j=10
Temp
(C)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

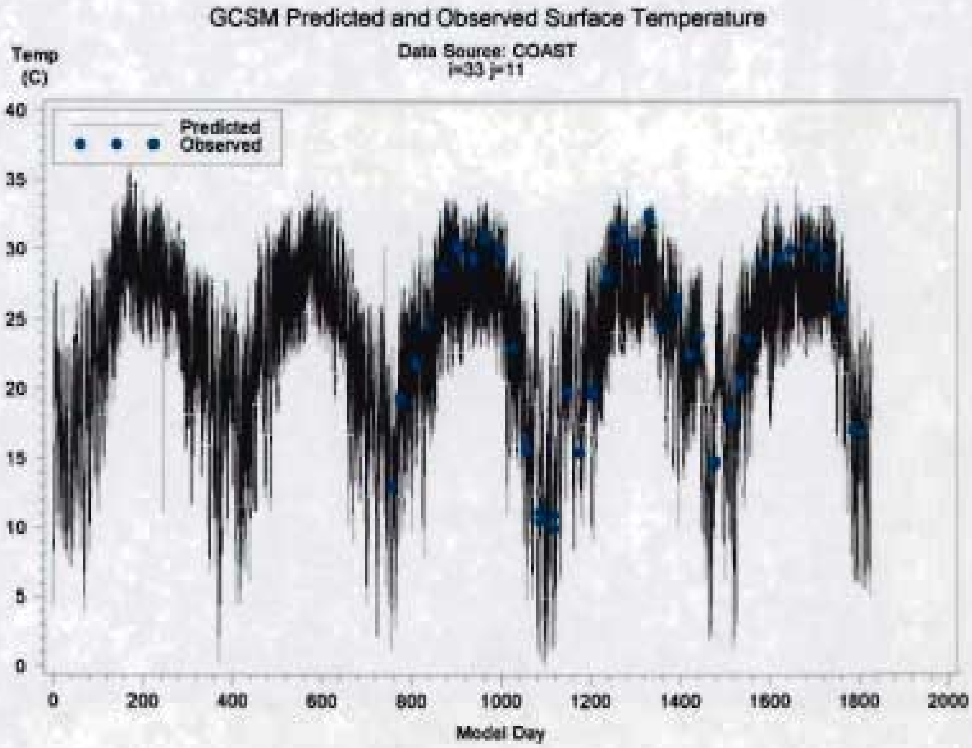

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=30 j=10
Temp
(C)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

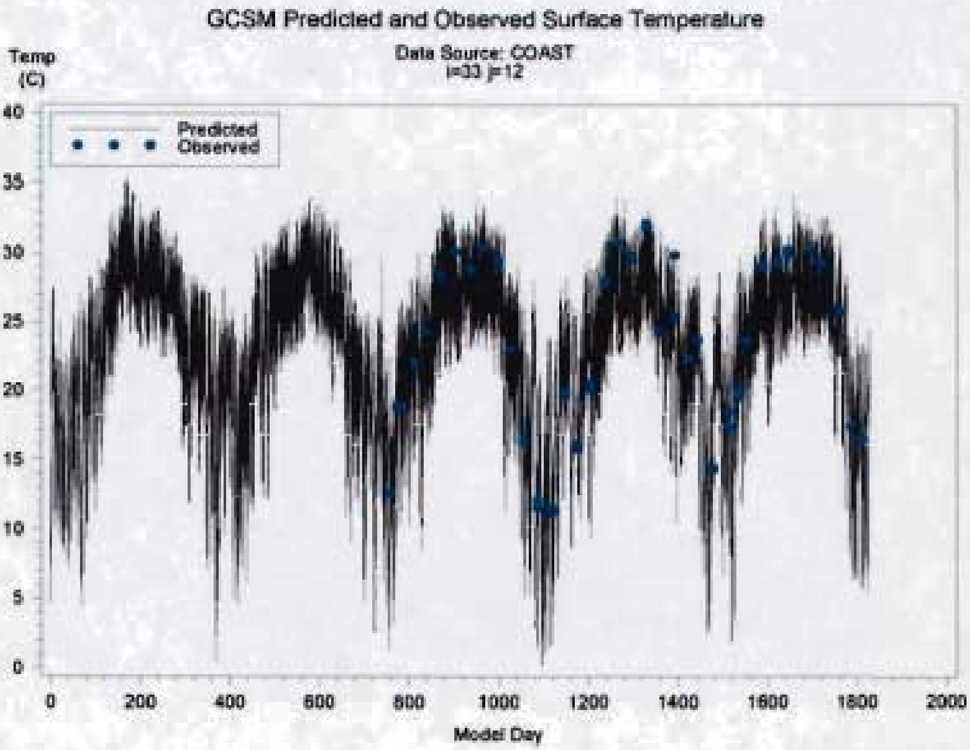

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=30 j=11
Temp (C)
Predicted
Observed
Model Day

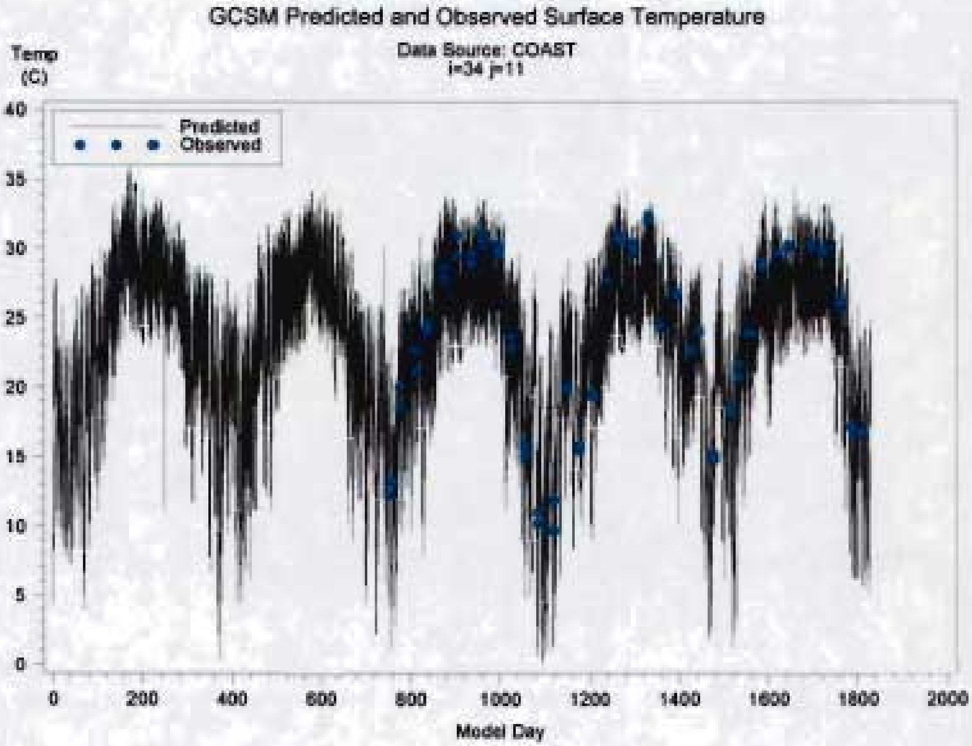

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=31 j=10
Temp (C)
Predicted
Observed
Model Day

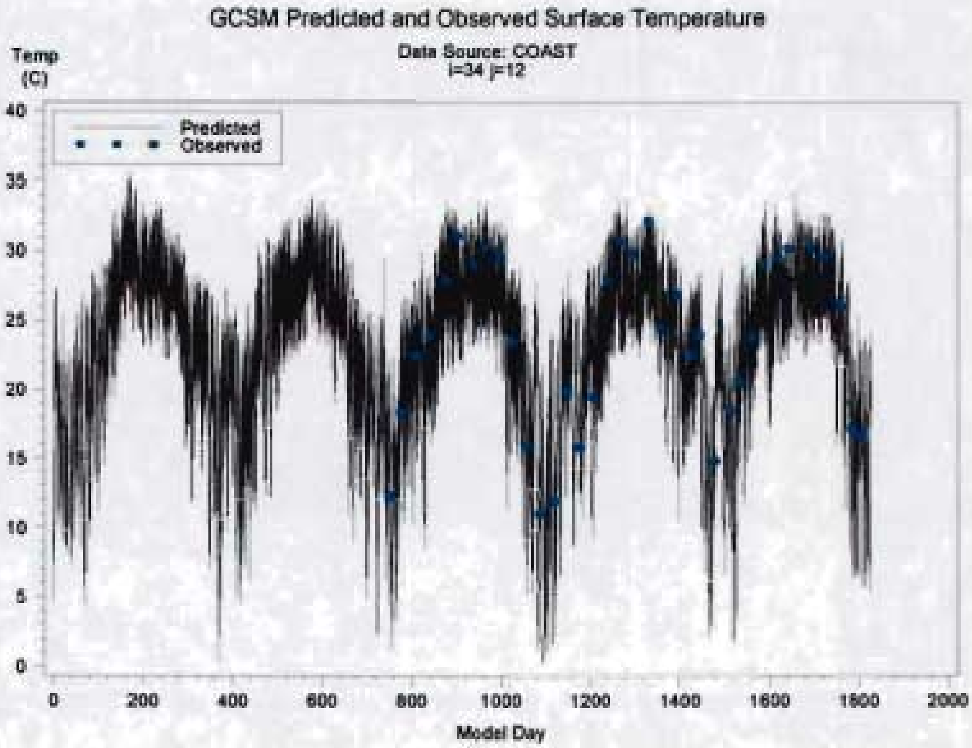

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=31 j=11
Temp (C)
Predicted
Observed
Model Day

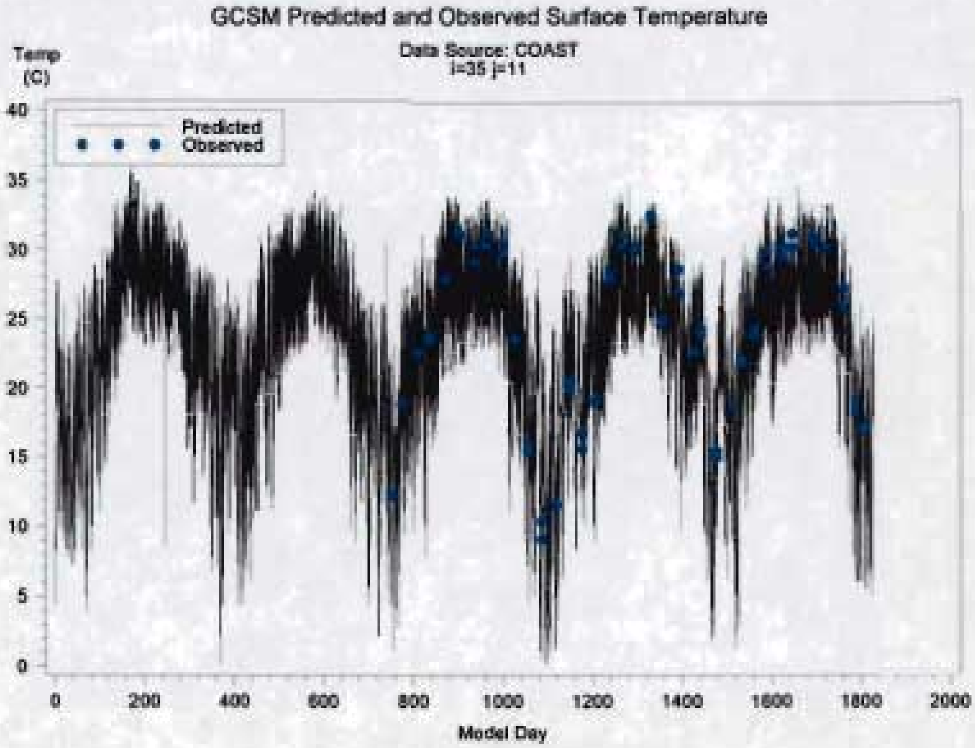

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=32 j=11
Temp (C)
Predicted
Observed
Model Day

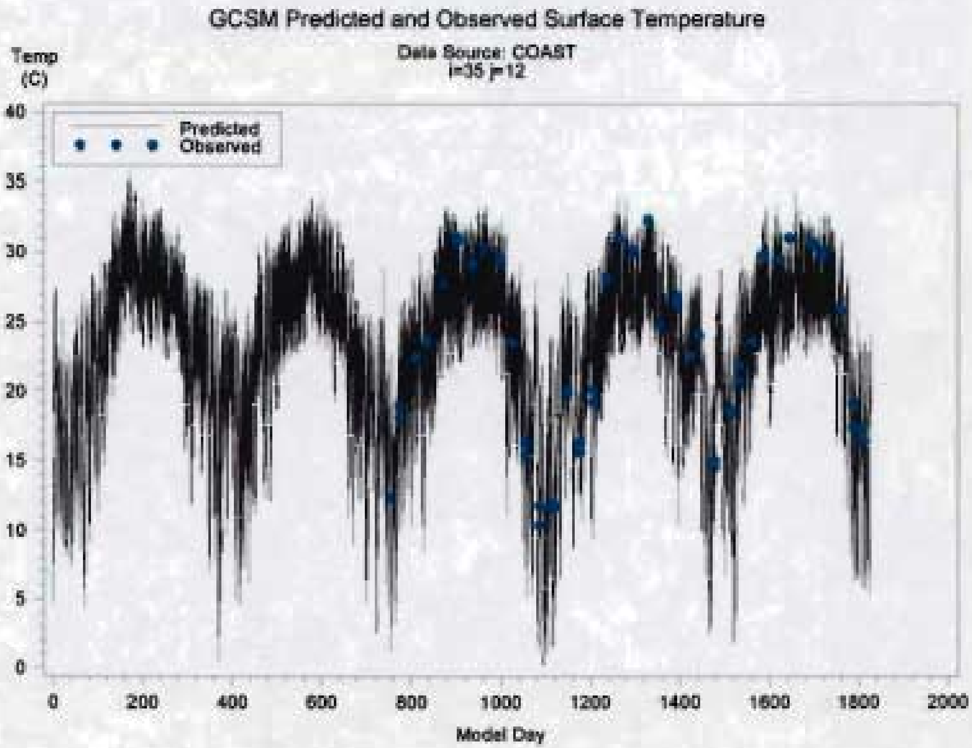

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=33 j=11
Temp (C)
Predicted
Observed
Model Day

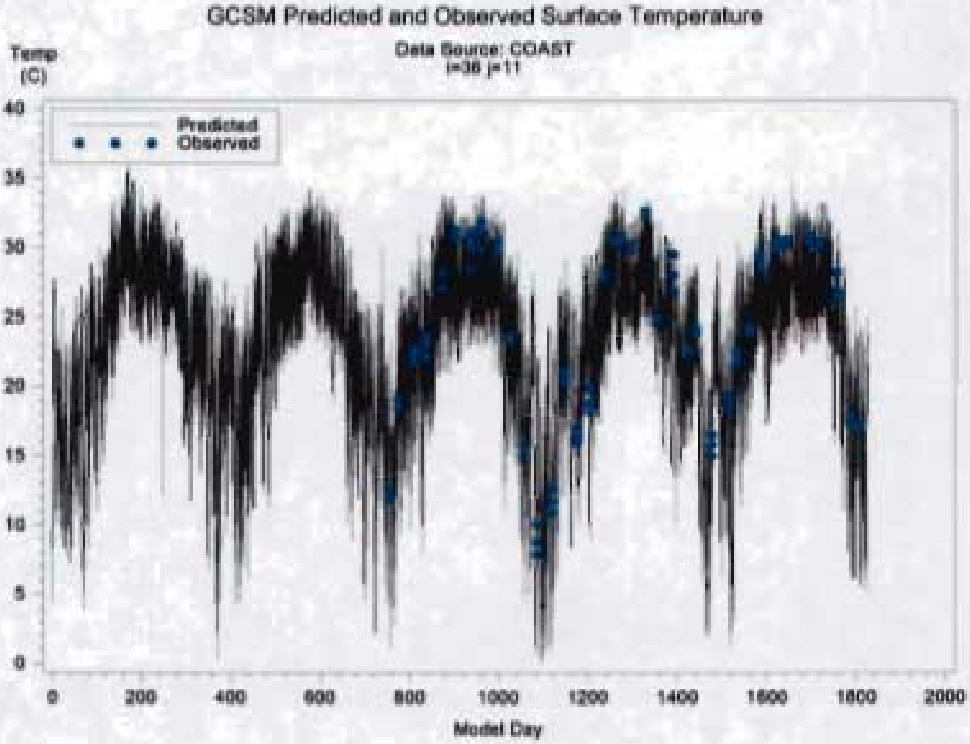

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=33 j=12
Temp (C)
Predicted
Observed
Model Day

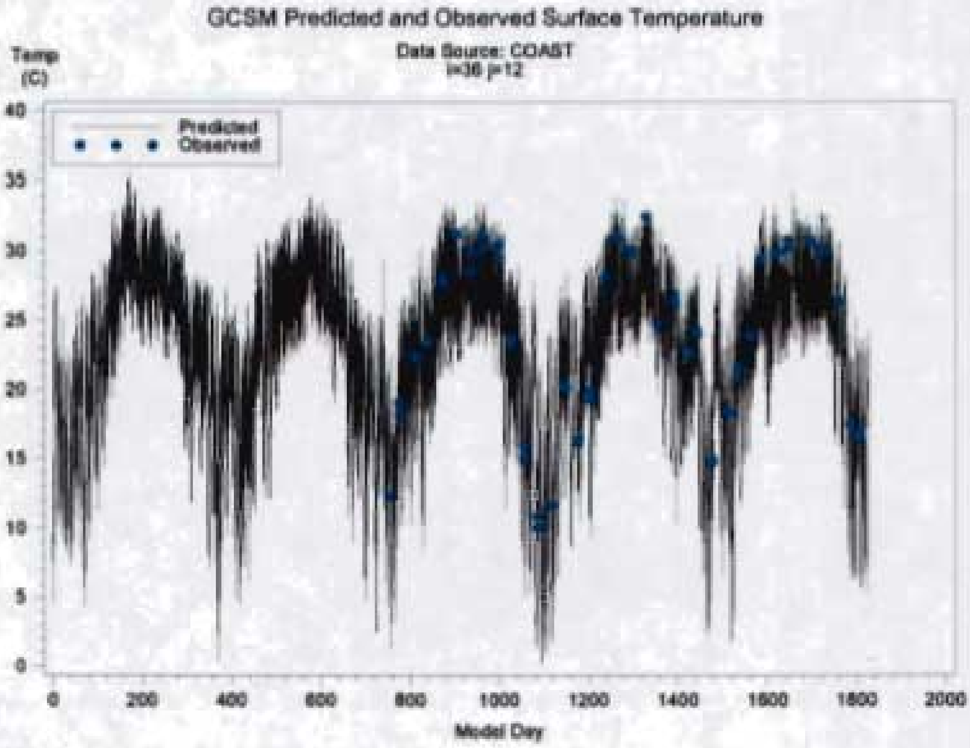

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=34 j=11
Temp (C)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day


GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=34 j=12
Temp (C)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day


GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=35 j=11
Temp (C)
Predicted
Observed
Model Day

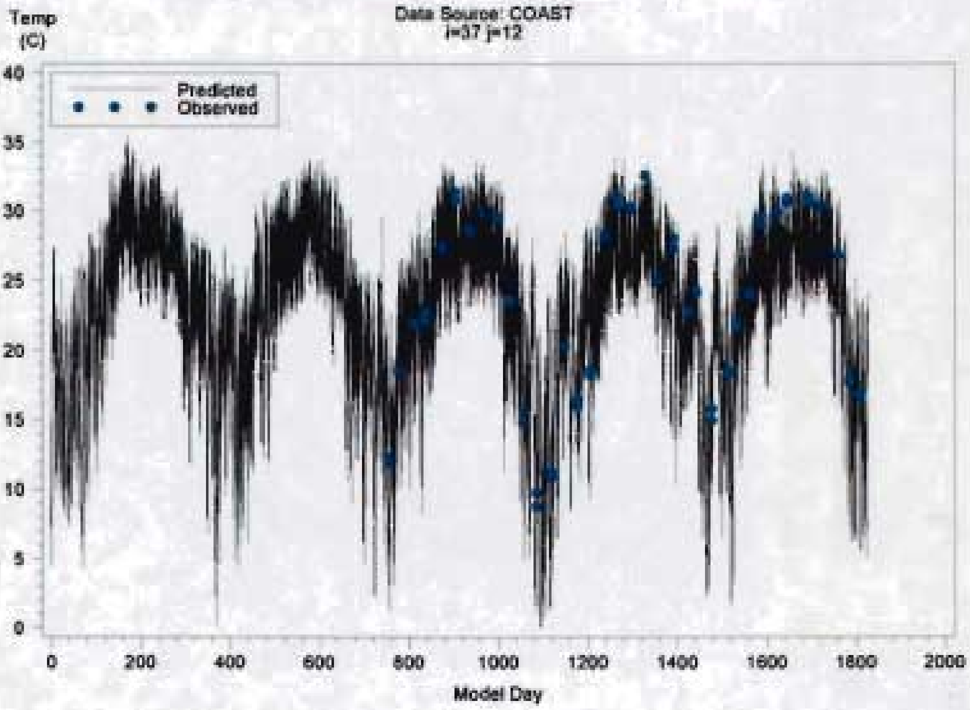

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=35 j=12
Temp (C)
Predicted
Observed
Model Day


GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=36 j=11
Temp (C)
Predicted
Observed
Model Day


GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=36 j=12
Temp (C)
Predicted
Observed
Model Day

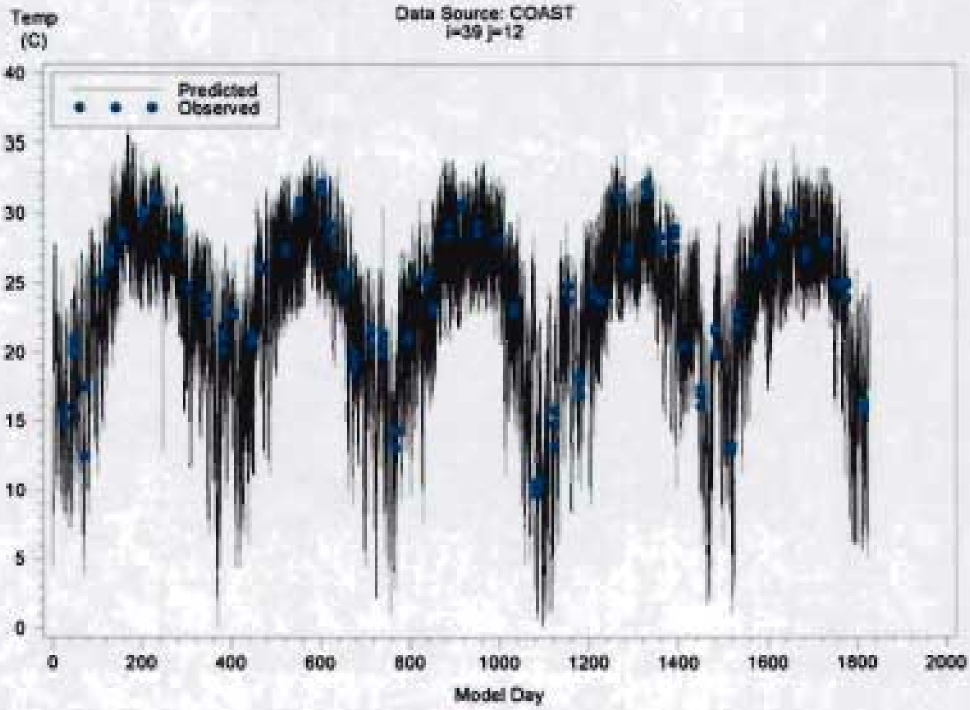
GCSM Predicted and Observed Surface Temperature

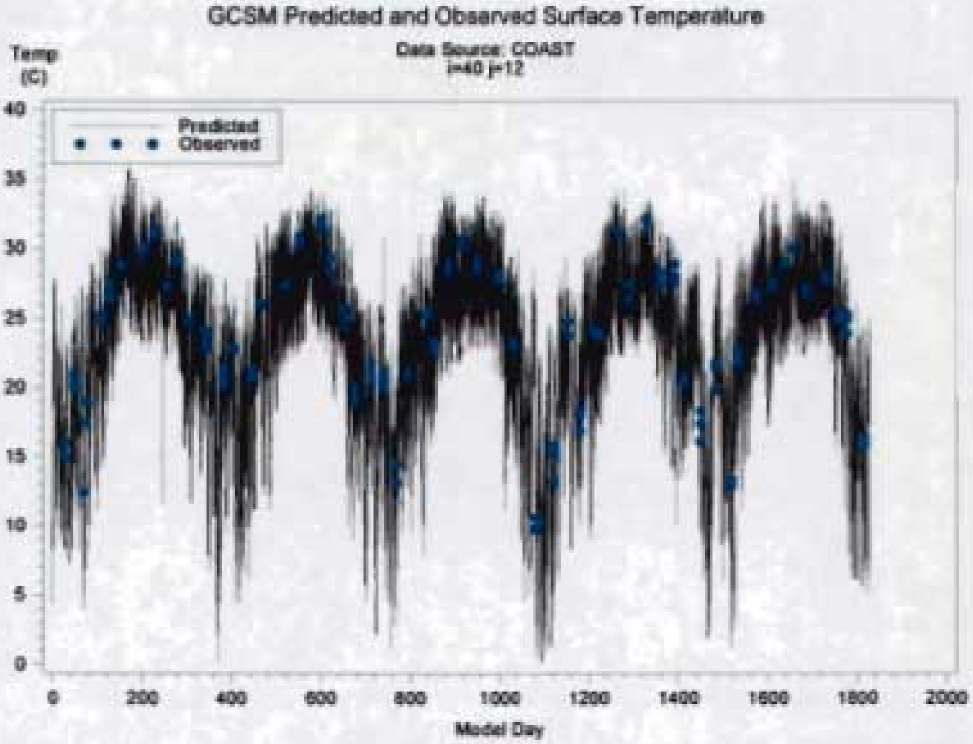
Data Source: COAST
i=37 j=12

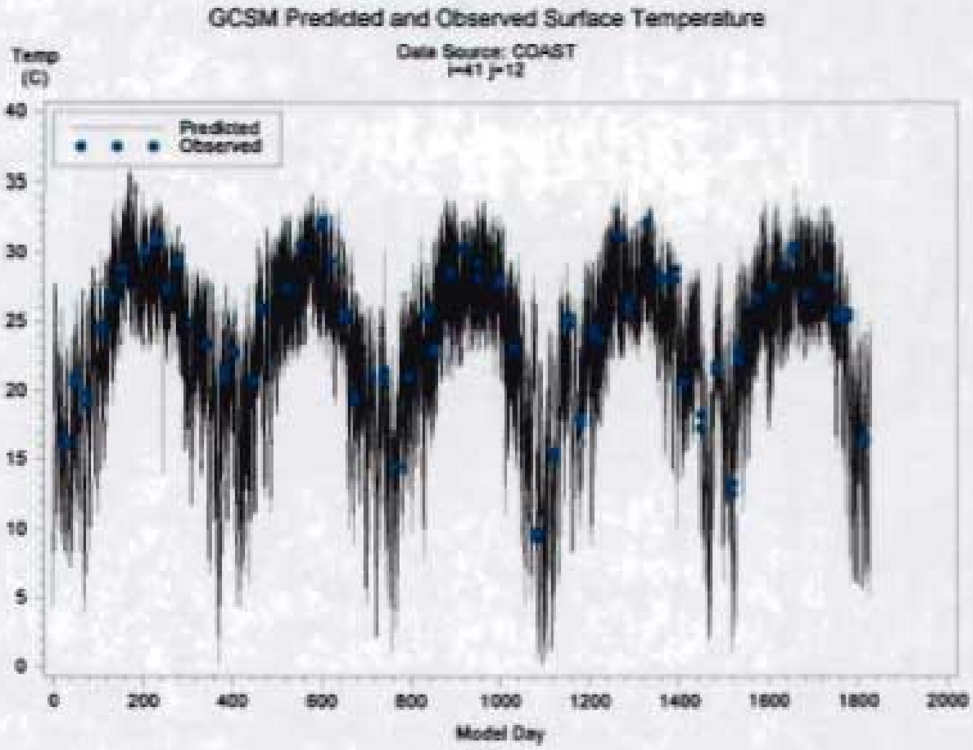


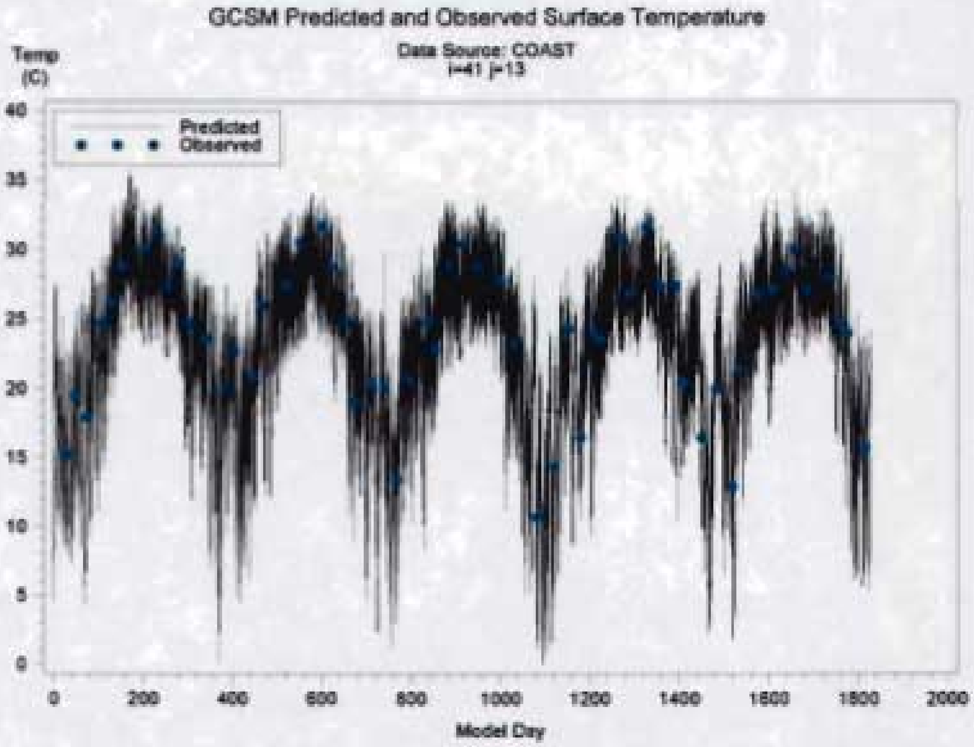

GCSM Predicted and Observed Surface Temperature

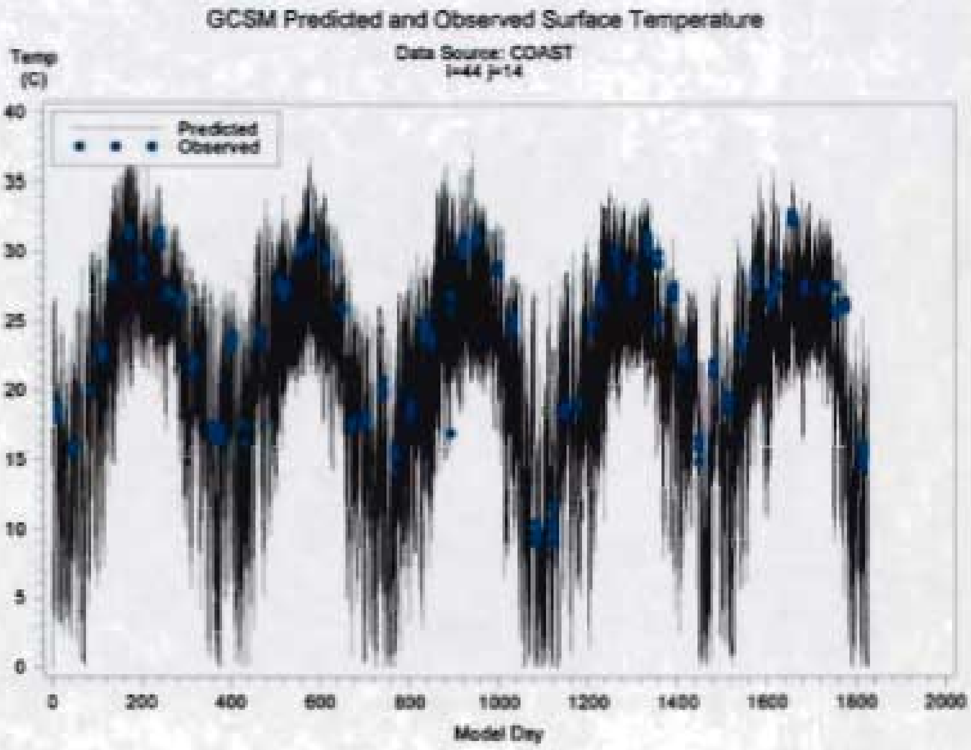
Data Source: COAST
i=39 j=12

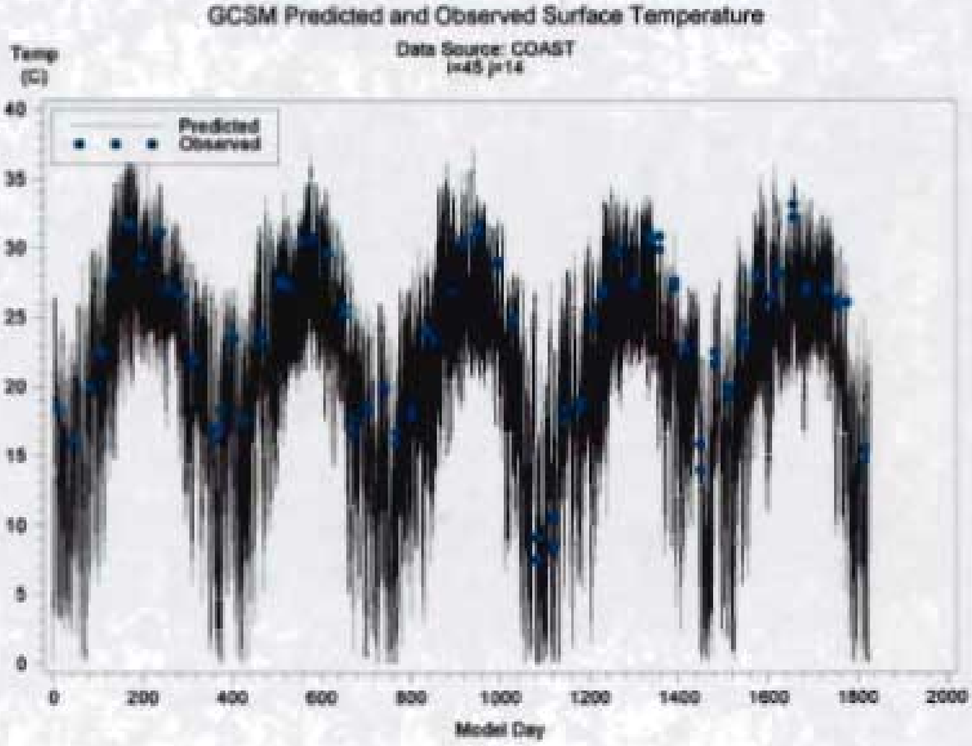


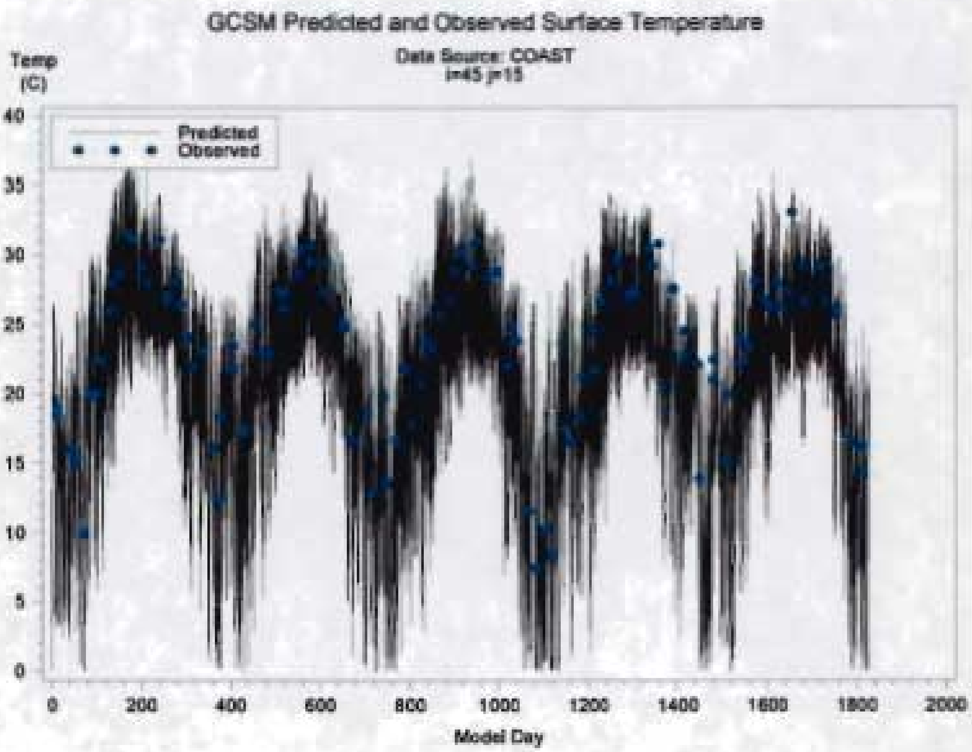

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=40 j=12
Temp (C)
Predicted
Observed
Model Day

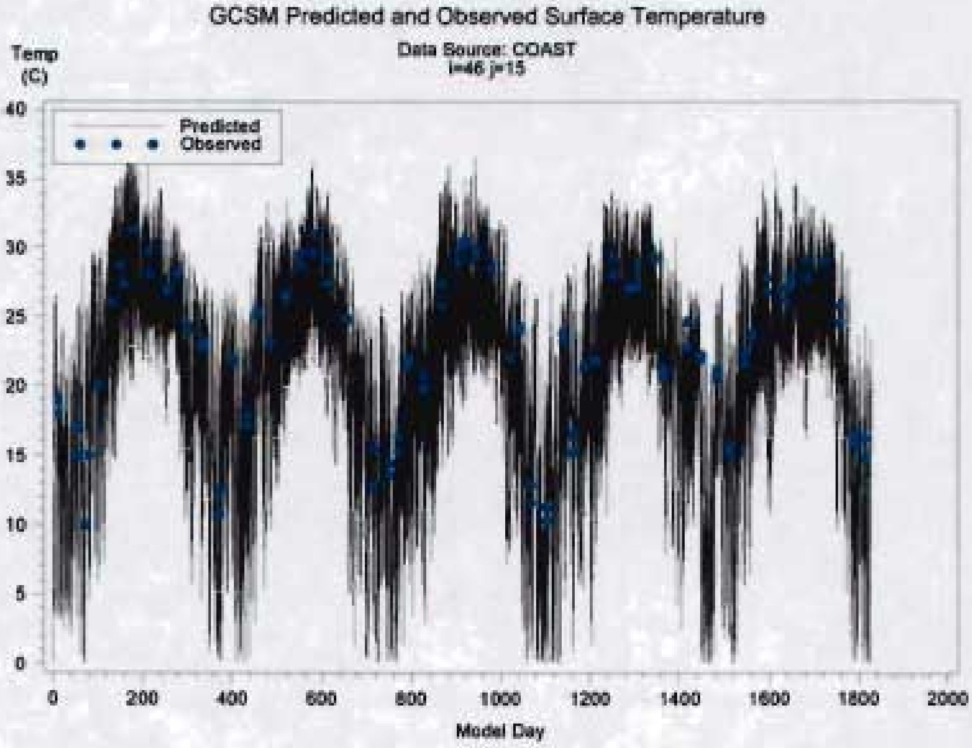

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=41 j=12
Temp (C)
Predicted
Observed
Model Day

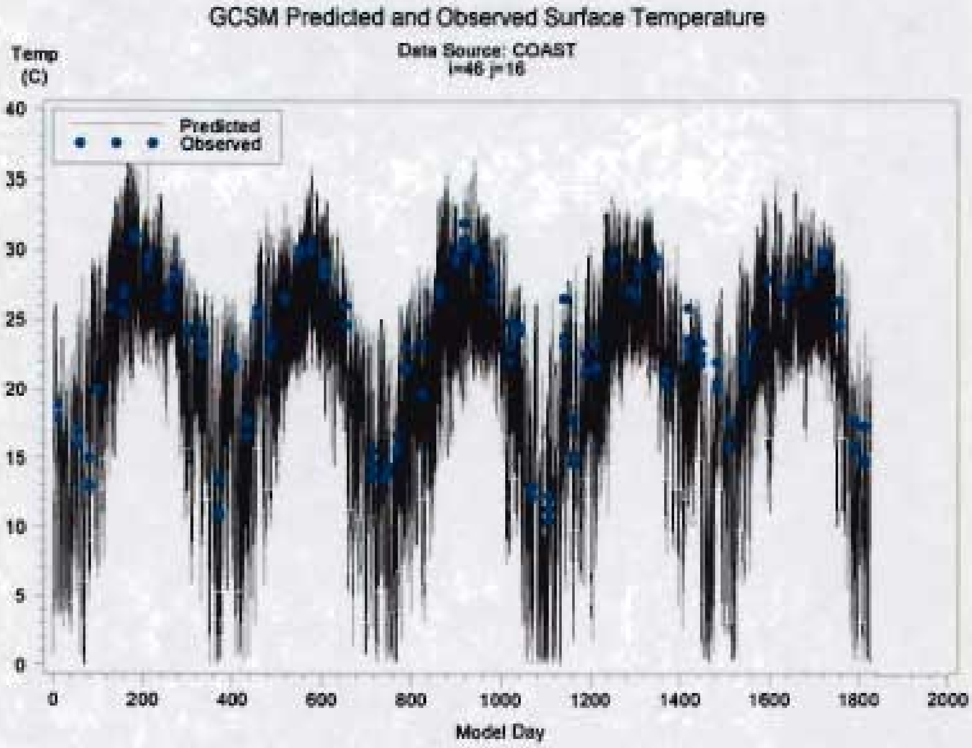

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=41 j=13
Temp (C)
Predicted
Observed
Model Day

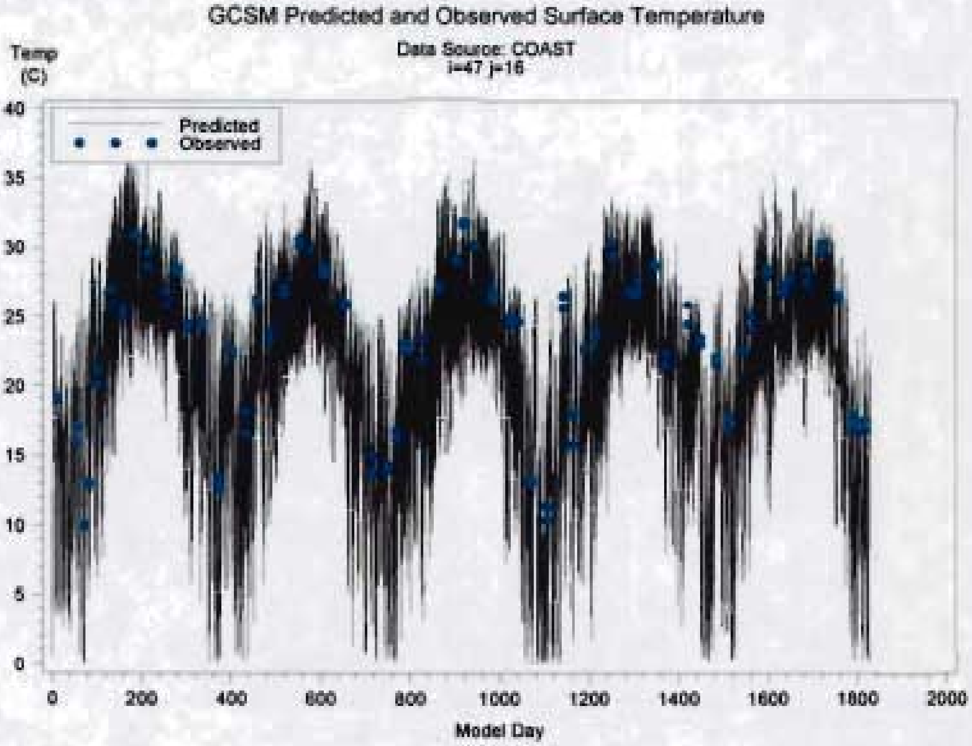

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=44 j=14
Temp (C)
Predicted
Observed
Model Day

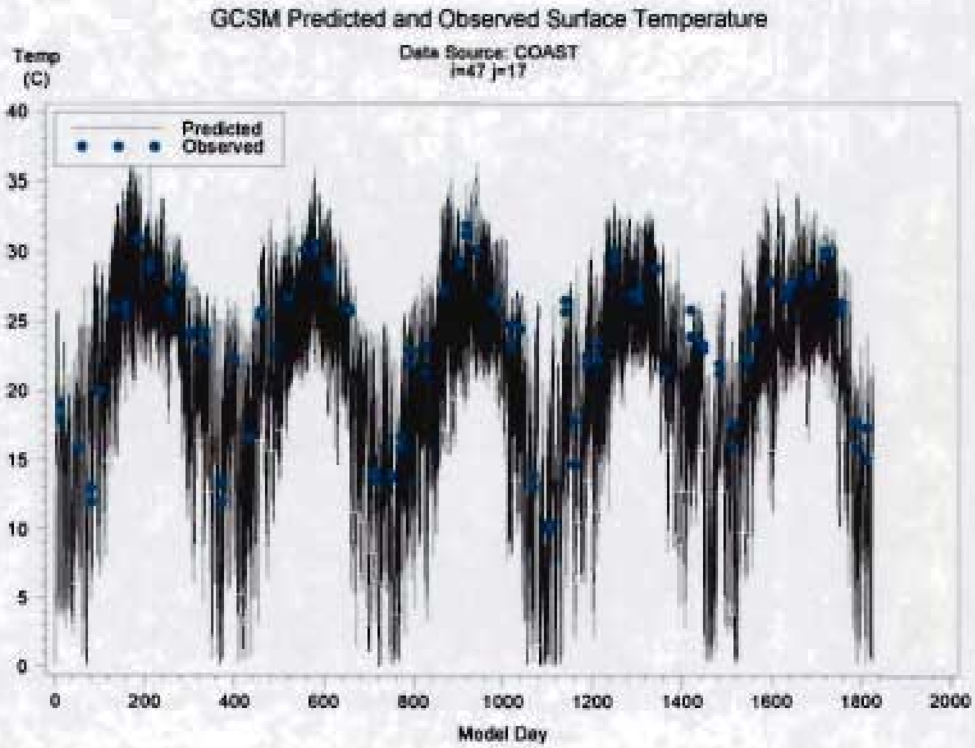

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=45 j=14
Temp (C)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

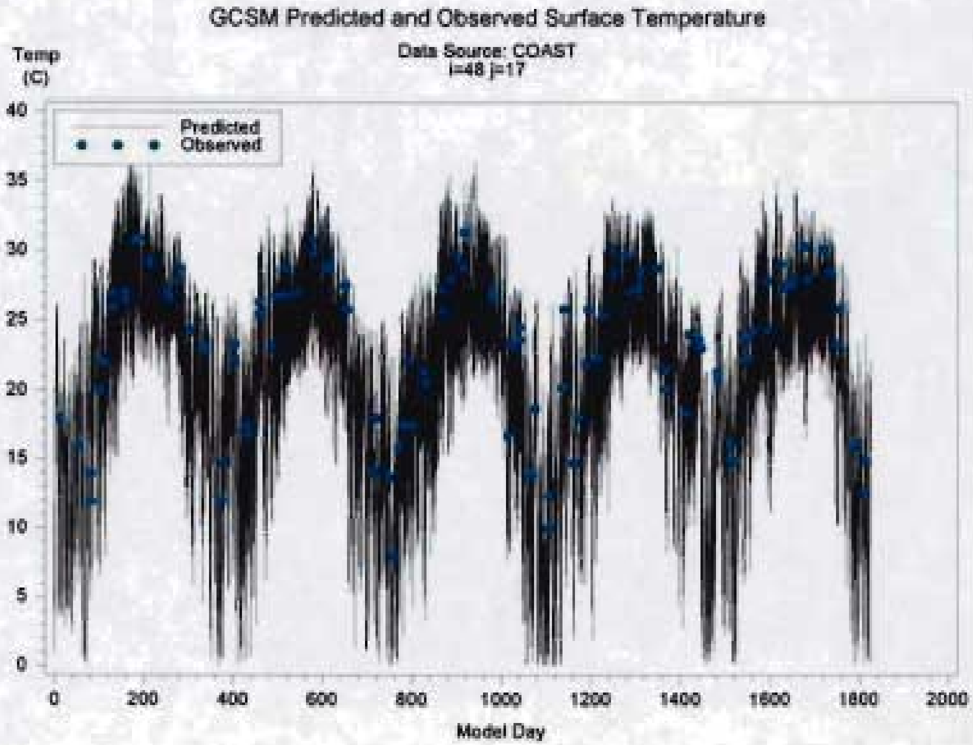

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=45 j=15
Temp (C)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

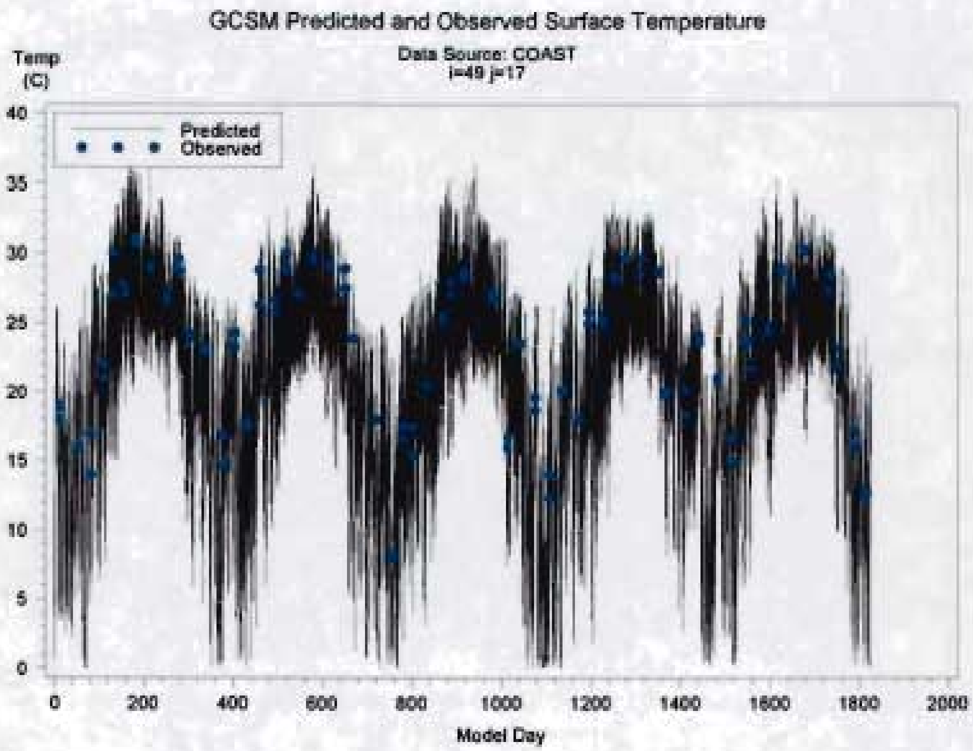

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=46 j=15
Temp
(C)
Predicted
Observed
Model Day
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000

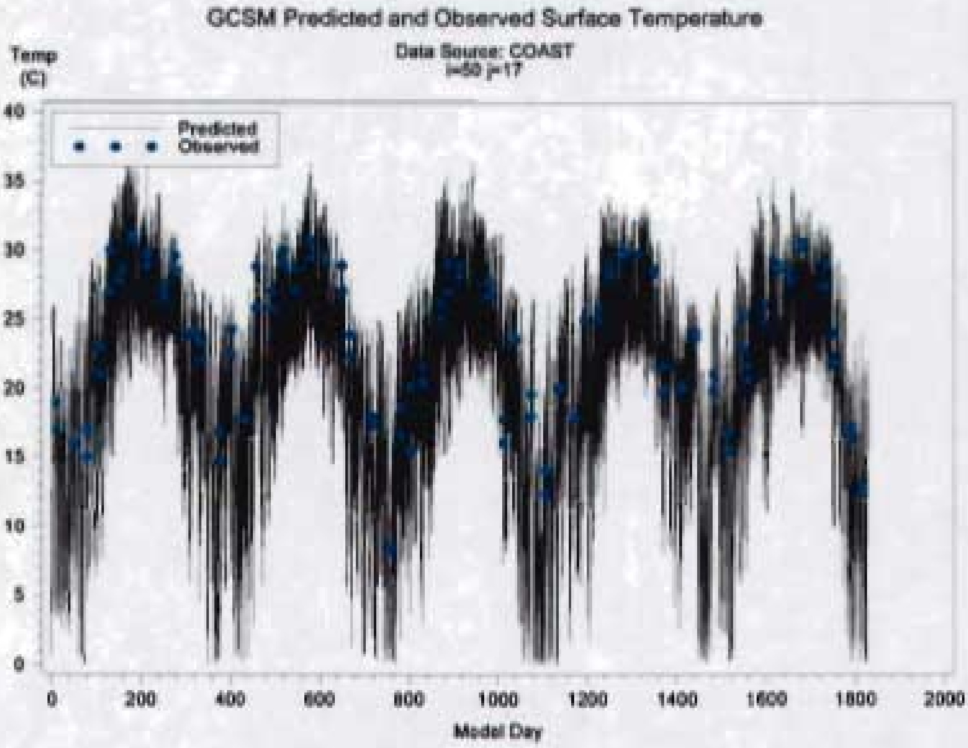

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=46 j=16
Temp
(C)
Predicted
Observed
Model Day
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000

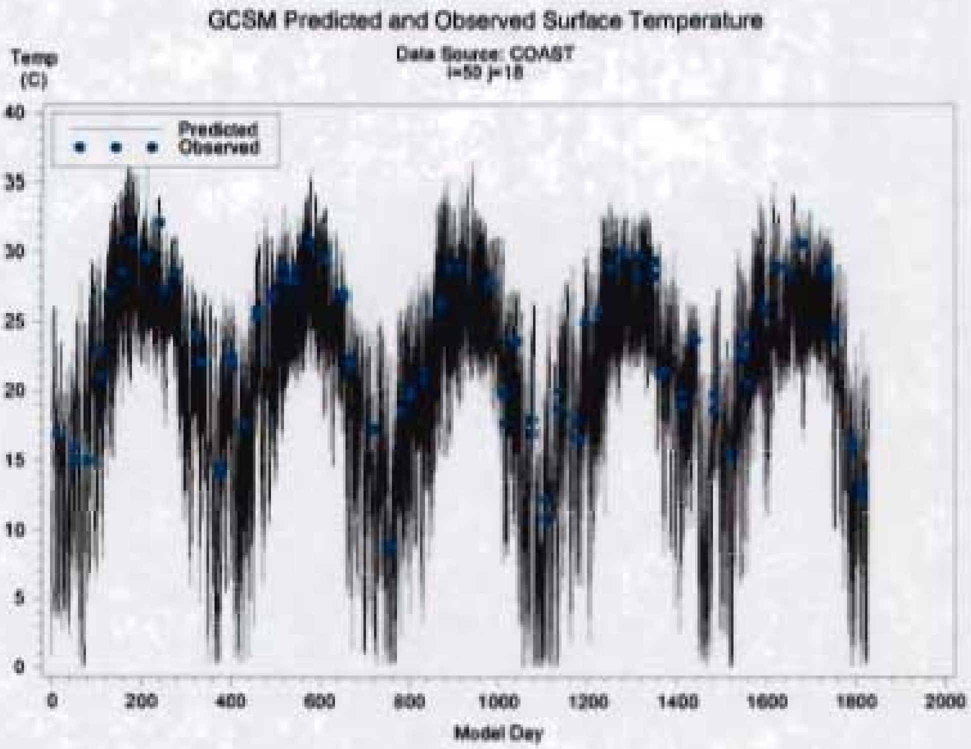

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=47 j=16
Temp
(C)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

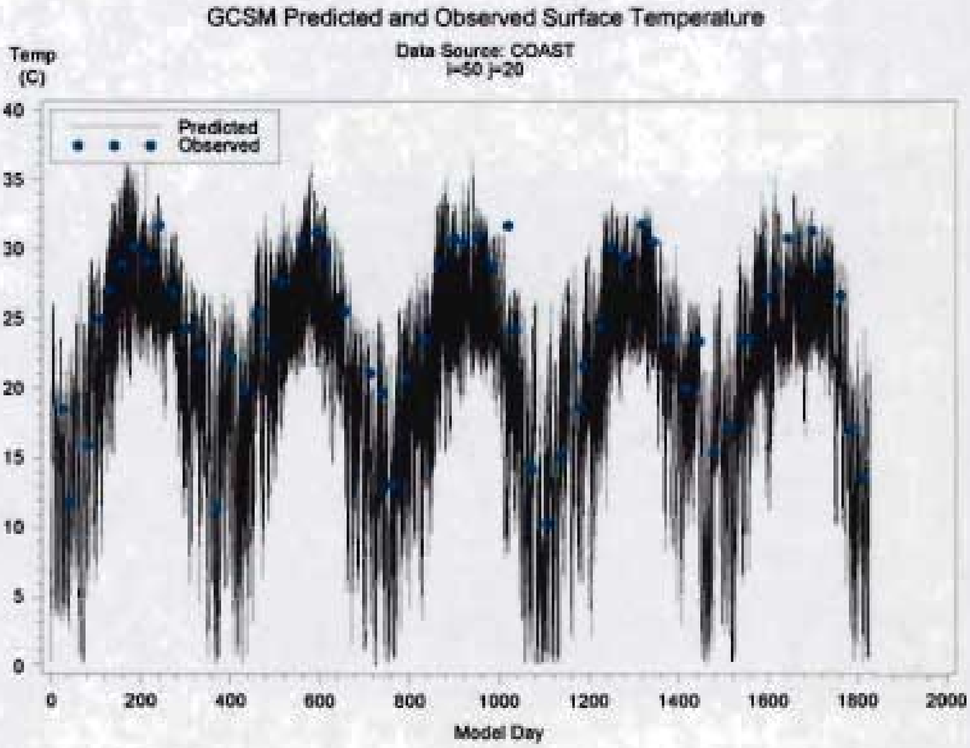

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=47 j=17
Temp
(C)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day

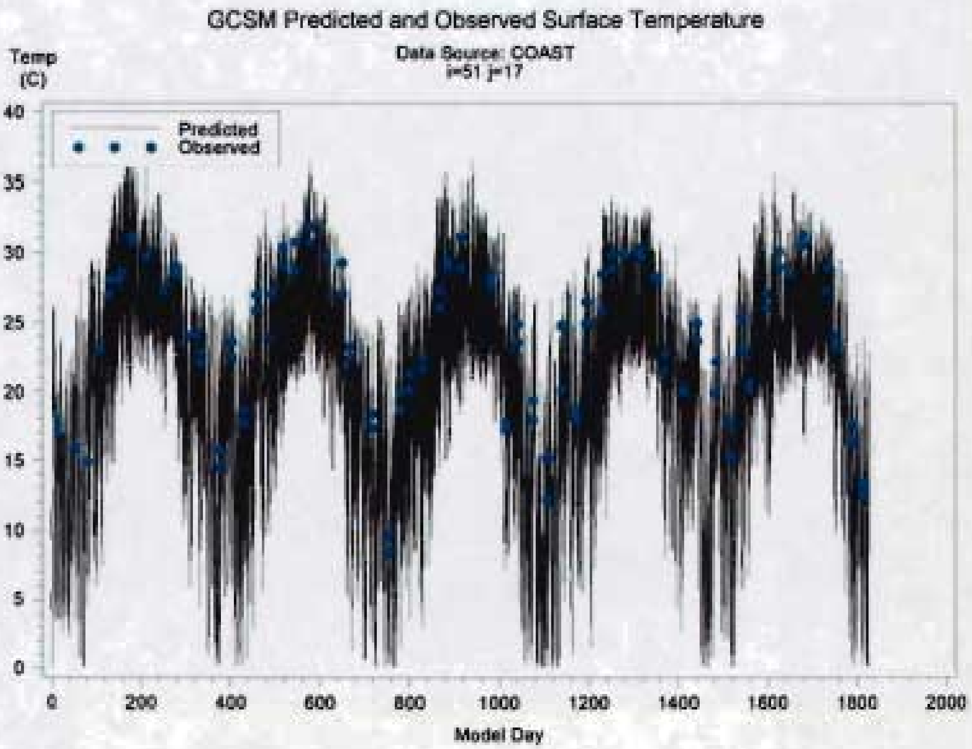

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=48 j=17
Temp (C)
Predicted
Observed
Model Day
0
5
10
15
20
25
30
35
40
200
400
600
800
1000
1200
1400
1600
1800
2000

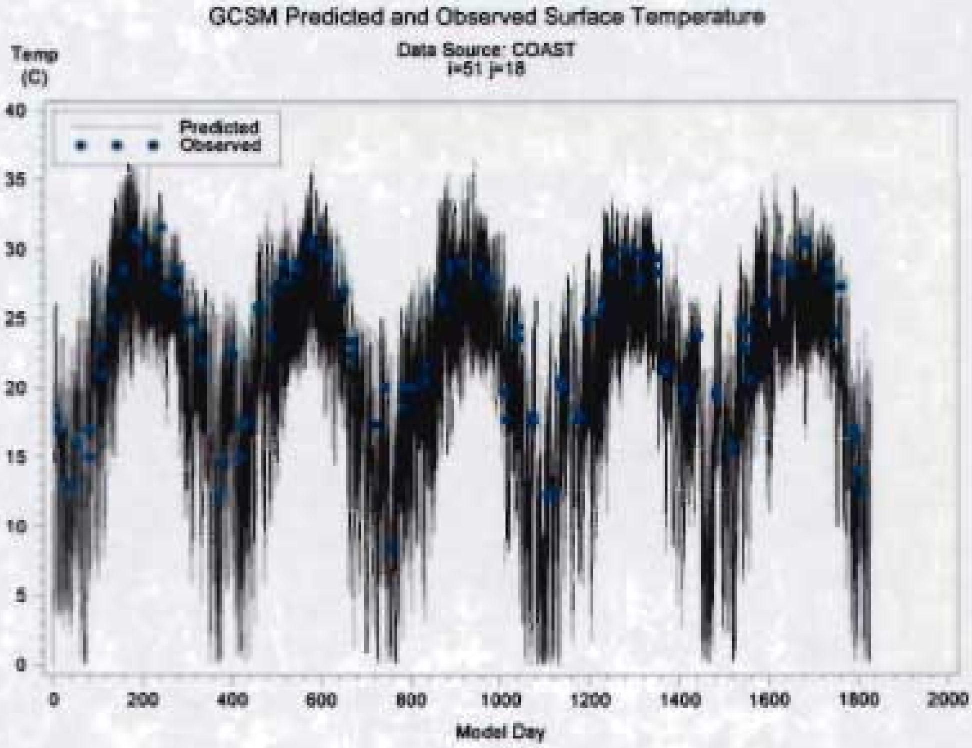

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=49 j=17
Temp (C)
Predicted
Observed
Model Day
0
5
10
15
20
25
30
35
40
200
400
600
800
1000
1200
1400
1600
1800
2000

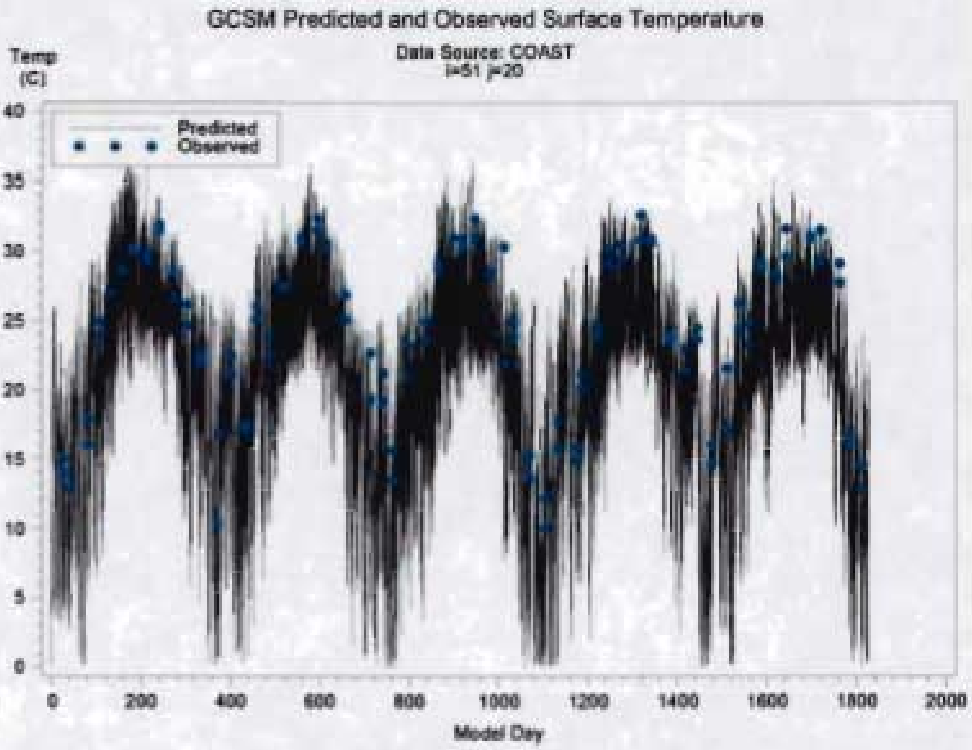

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=50 j=17
Temp (C)
Predicted
Observed
Model Day


GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=50 j=18
Temp (C)
Predicted
Observed
Model Day

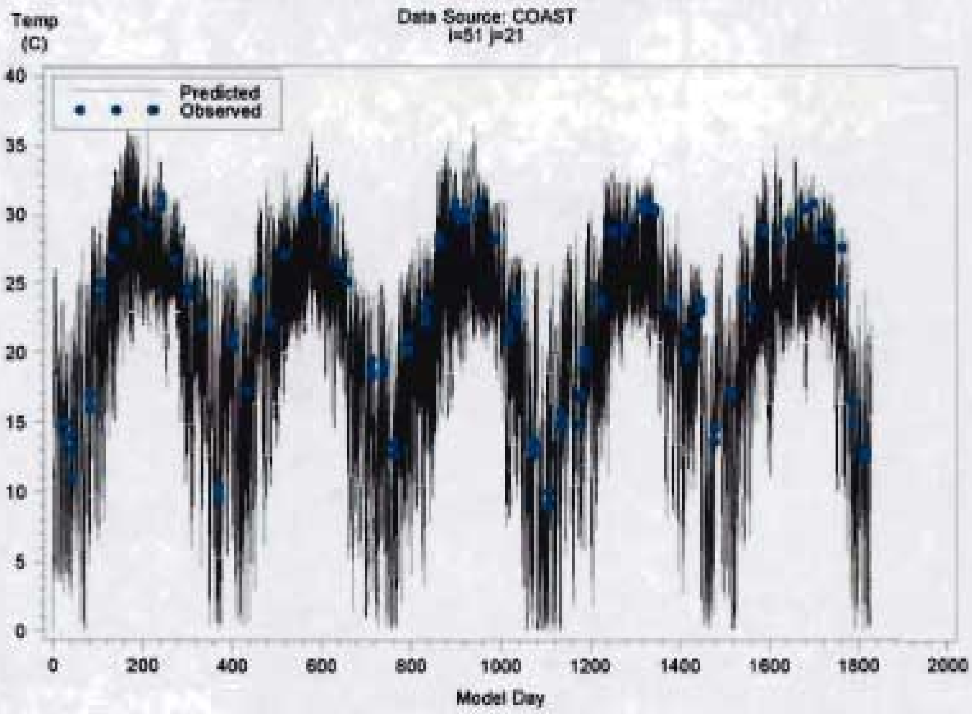

GCSM Predicted and Observed Surface Temperature
Temp (C)
Data Source: COAST
i=50 j=20
Predicted
Observed
Model Day


GCSM Predicted and Observed Surface Temperature
Temp (C)
Data Source: COAST
i=51 j=17
Predicted
Observed
Model Day

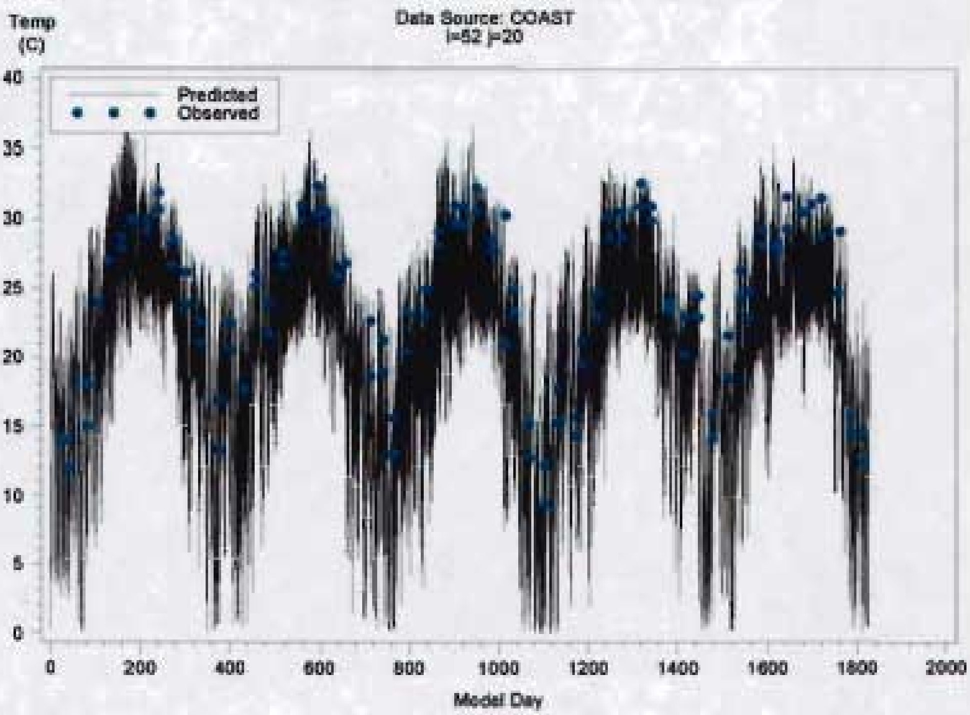

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=51 j=18
Temp (C)
Predicted
Observed
Model Day

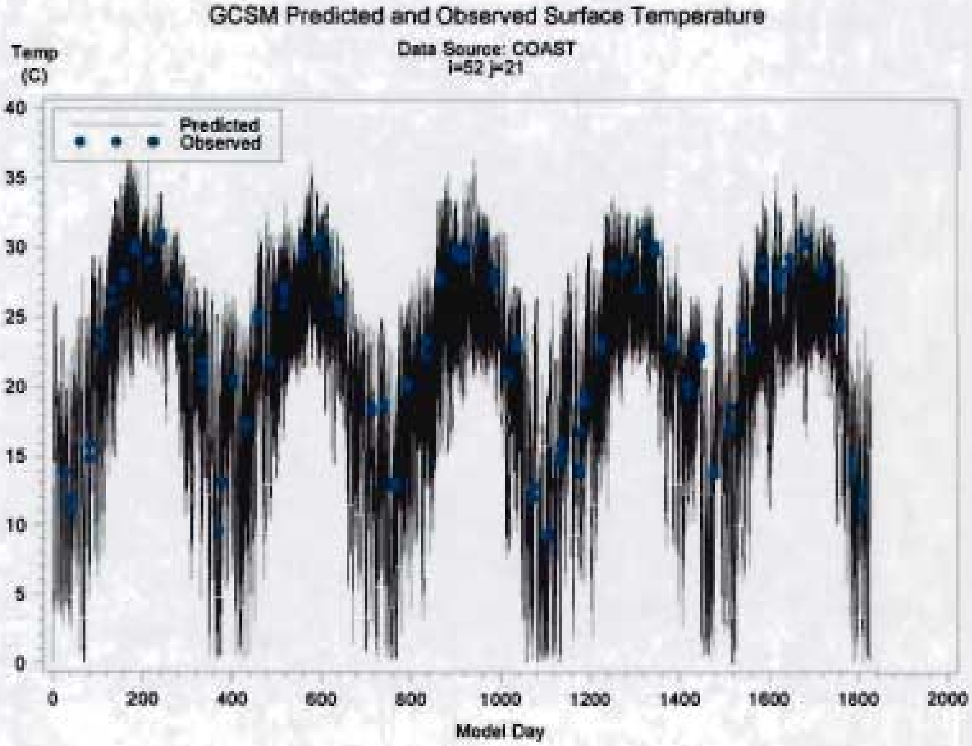

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=51 j=20
Temp (C)
Predicted
Observed
Model Day

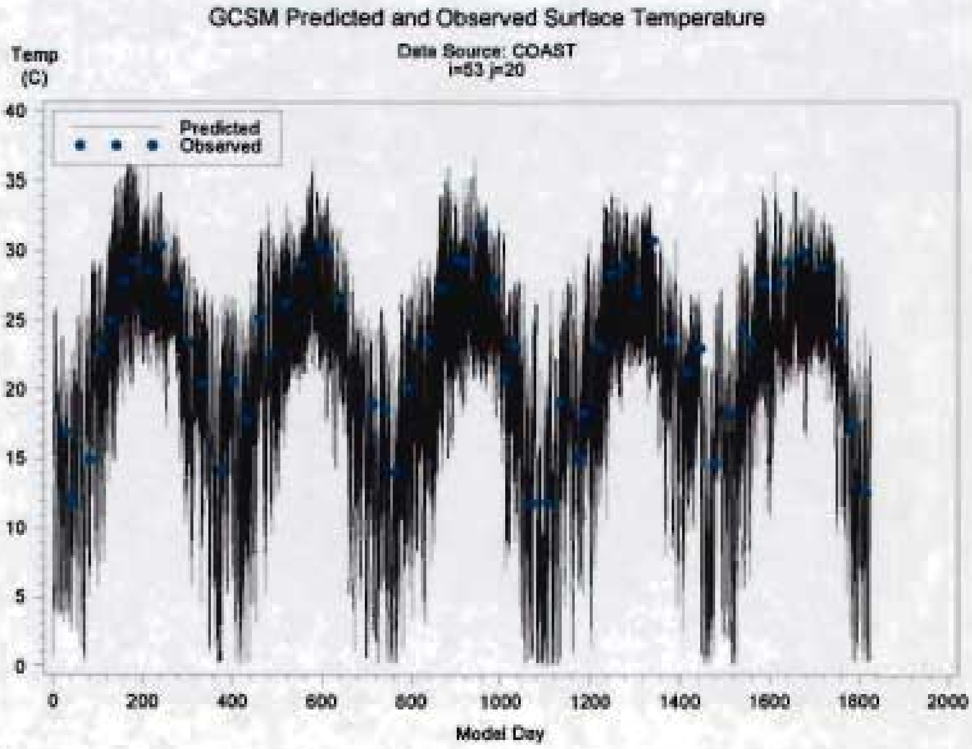
GCSM Predicted and Observed Surface Temperature

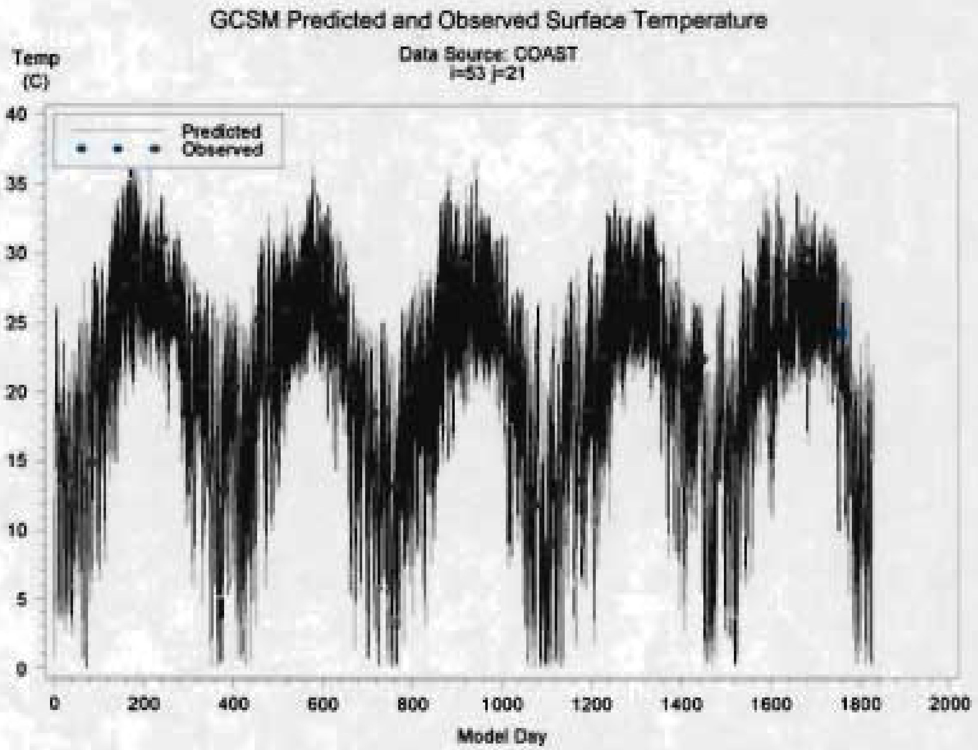



GCSM Predicted and Observed Surface Temperature

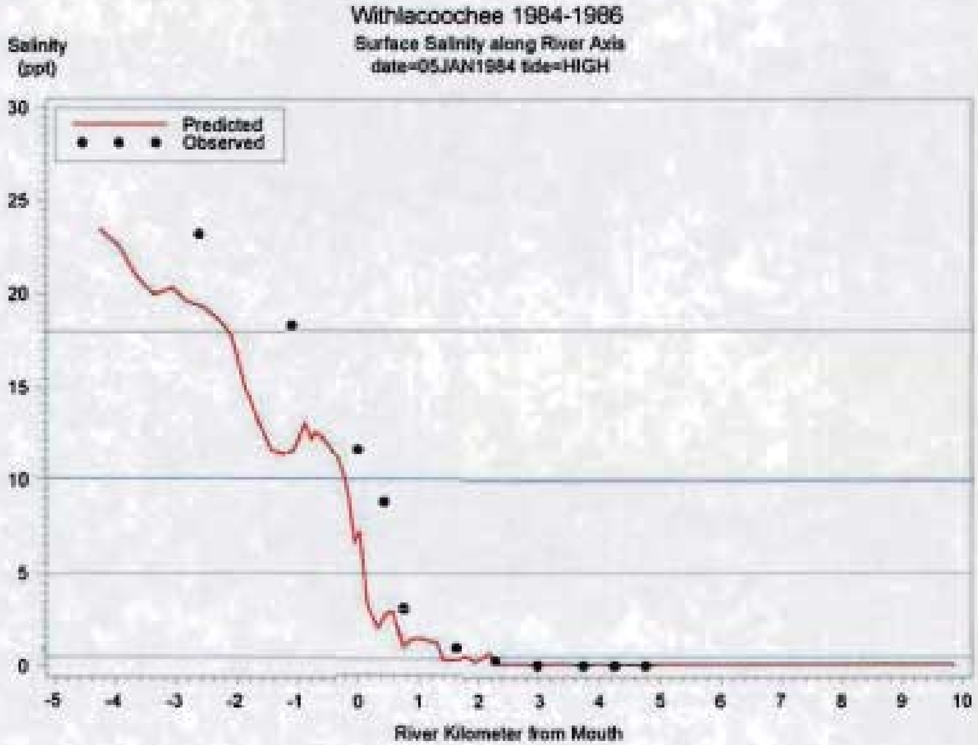


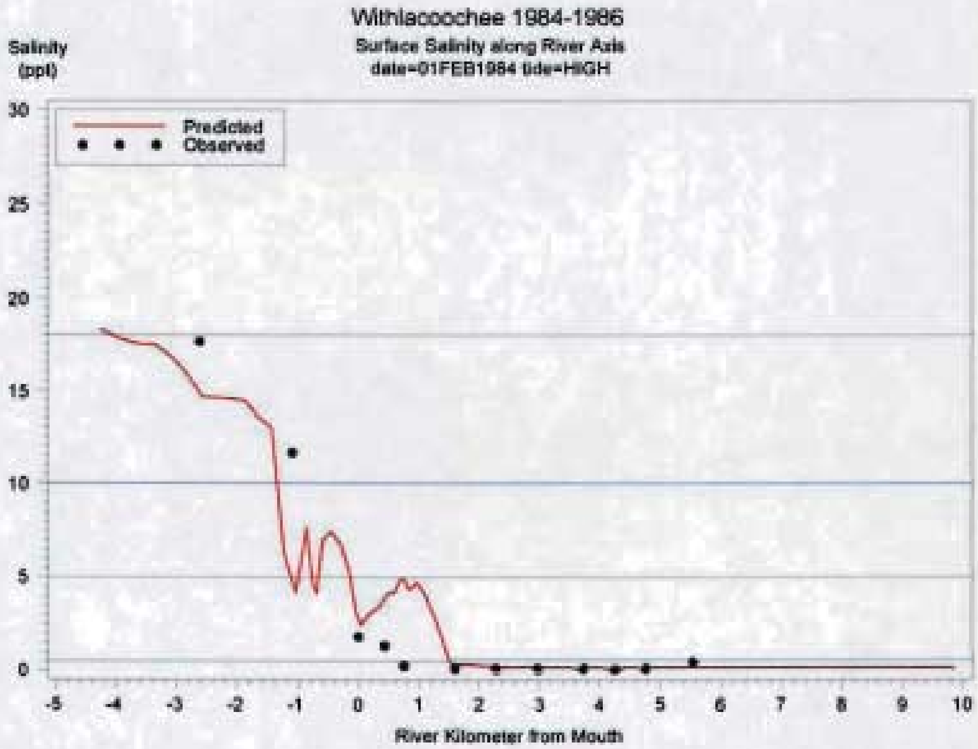

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=52 j=21
Temp (C)
Predicted
Observed
Model Day
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
5
10
15
20
25
30
35
40

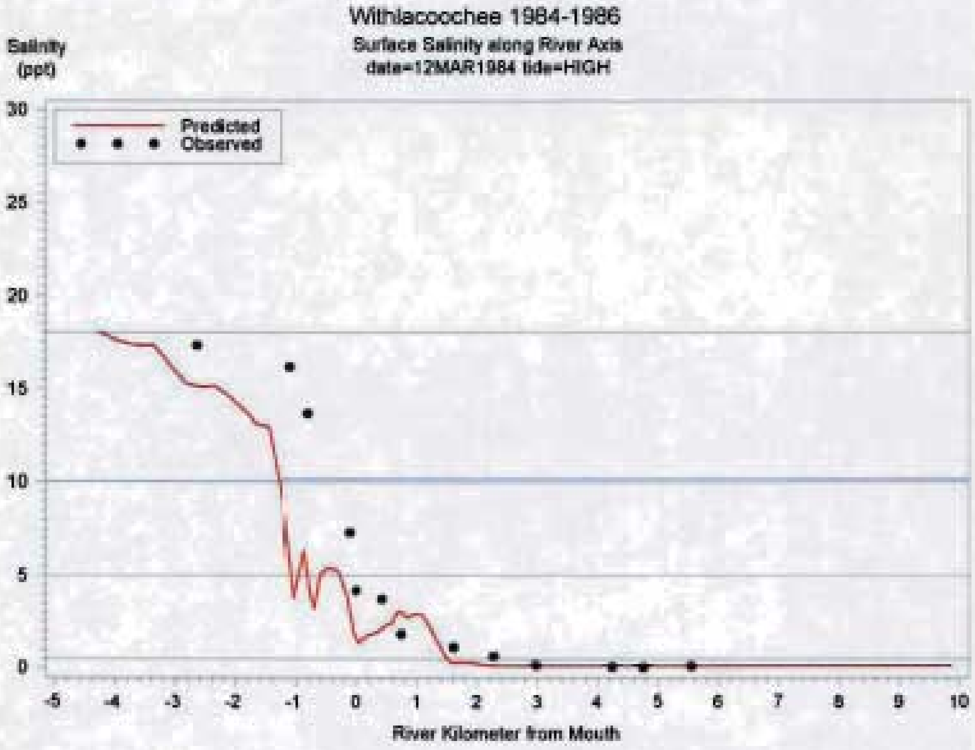

GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=53 j=20
Temp (C)
Predicted
Observed
Model Day
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
5
10
15
20
25
30
35
40


GCSM Predicted and Observed Surface Temperature
Data Source: COAST
i=53 j=21
Temp
(C)
Predicted
Observed
Model Day
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
5
10
15
20
25
30
35
40

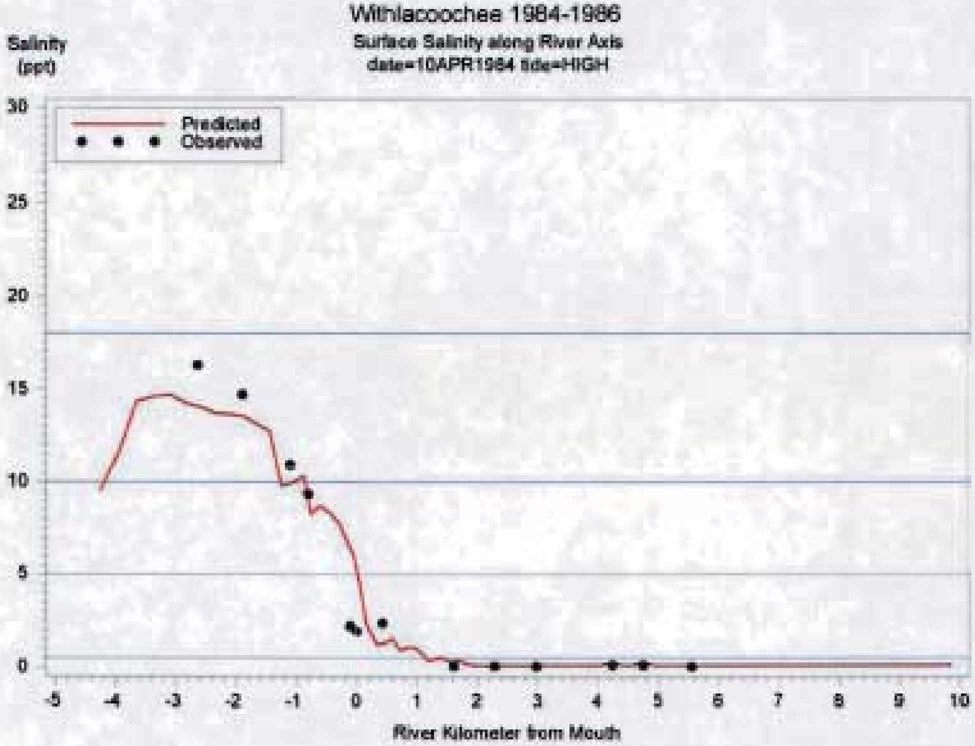
# Appendix A.4
# LWRM 1984-1986: River Axis Plots of Predicted and Observed Surface Salinity


Withlacoochee 1984-1986
Surface Salinity along River Axis
date=05JAN1984 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

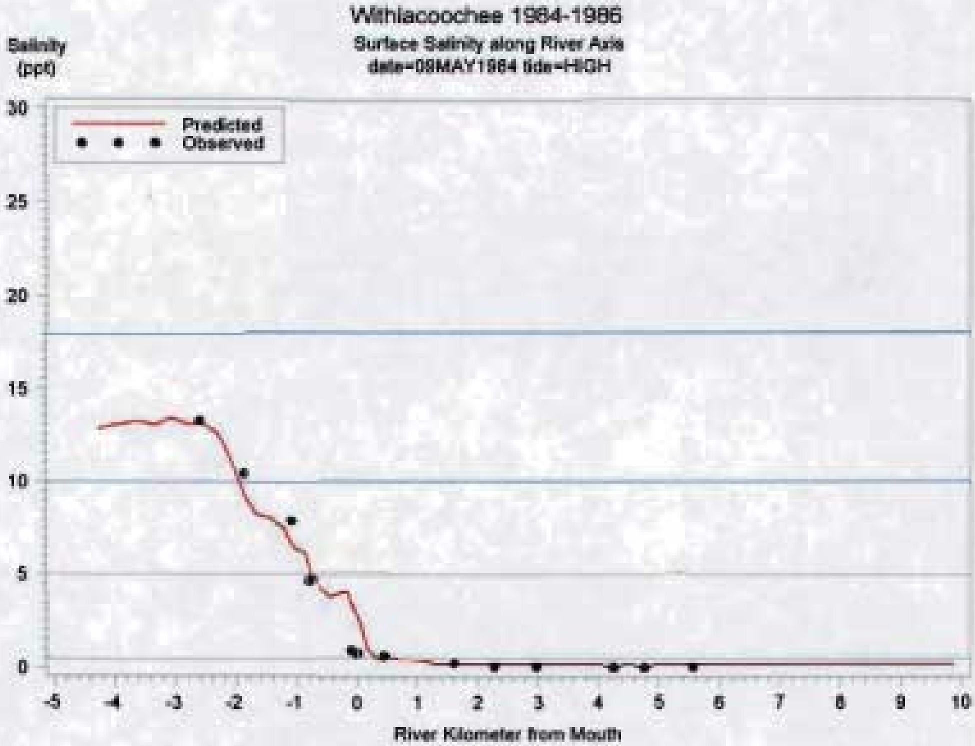

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=01FEB1984 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

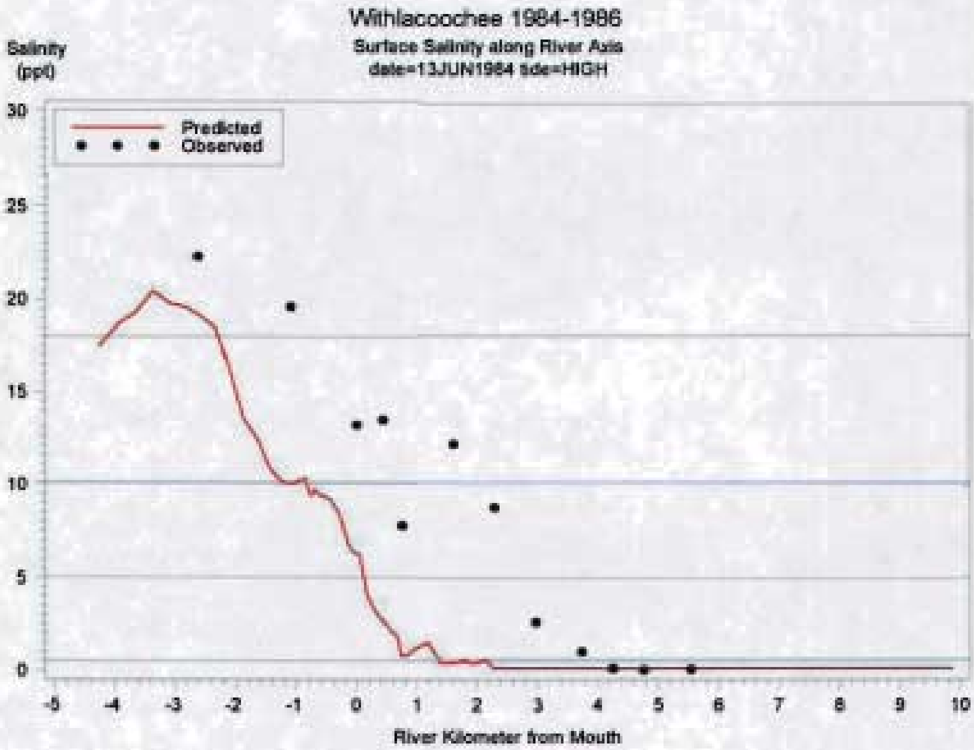


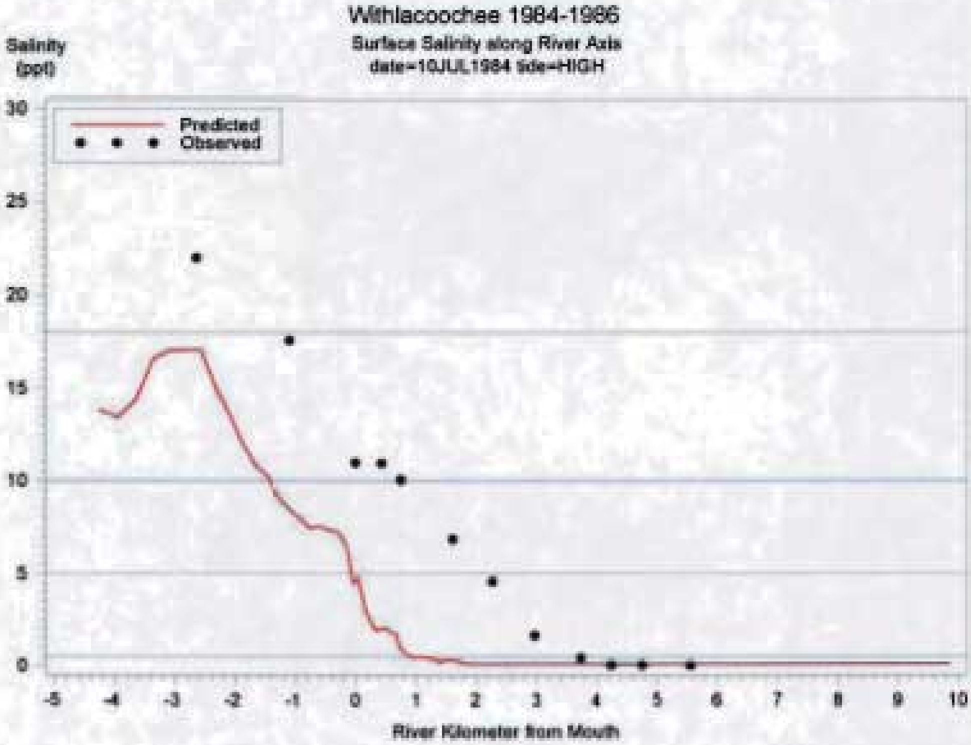
Withlacoochee 1984-1986
Surface Salinity along River Axis
date=12MAR1984 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

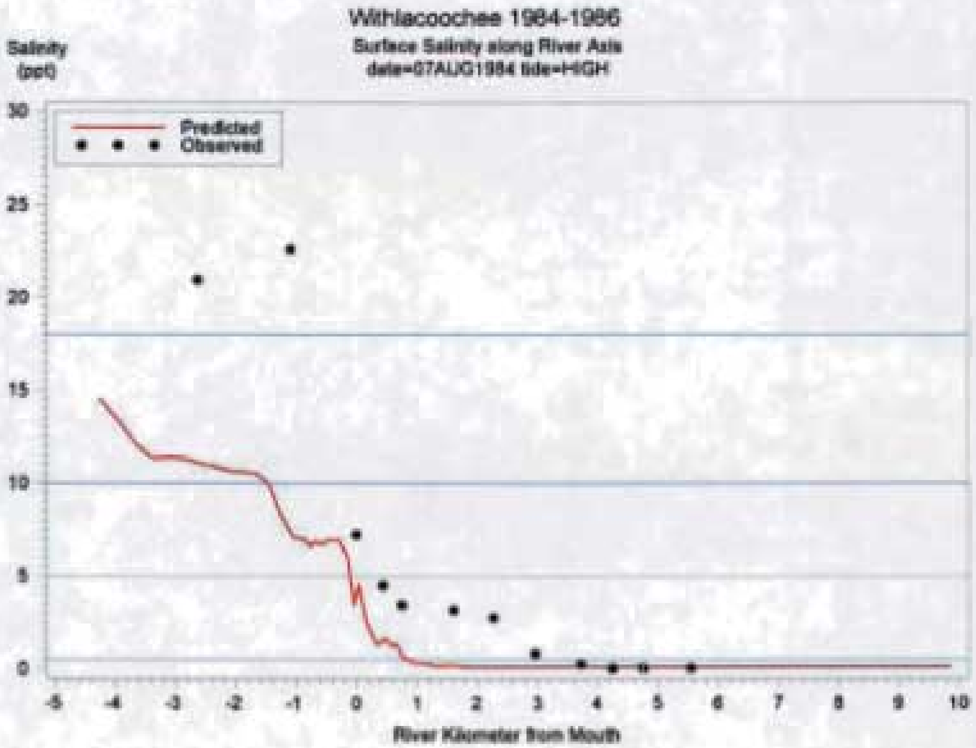



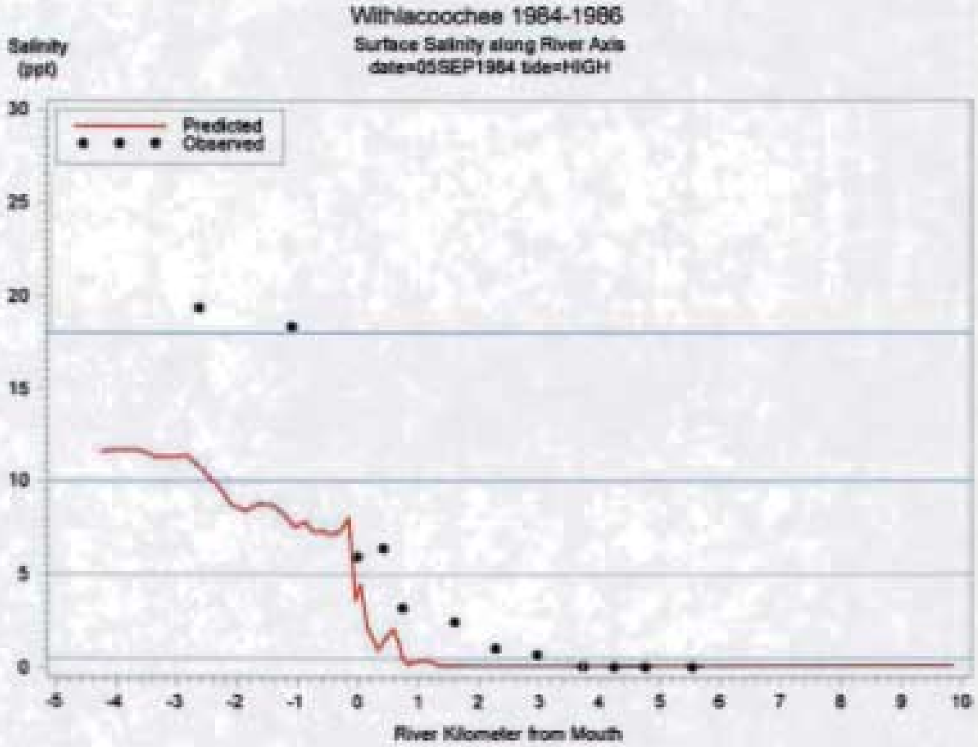
Withlacoochee 1984-1986
Surface Salinity along River Axis
date=10APR1984 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

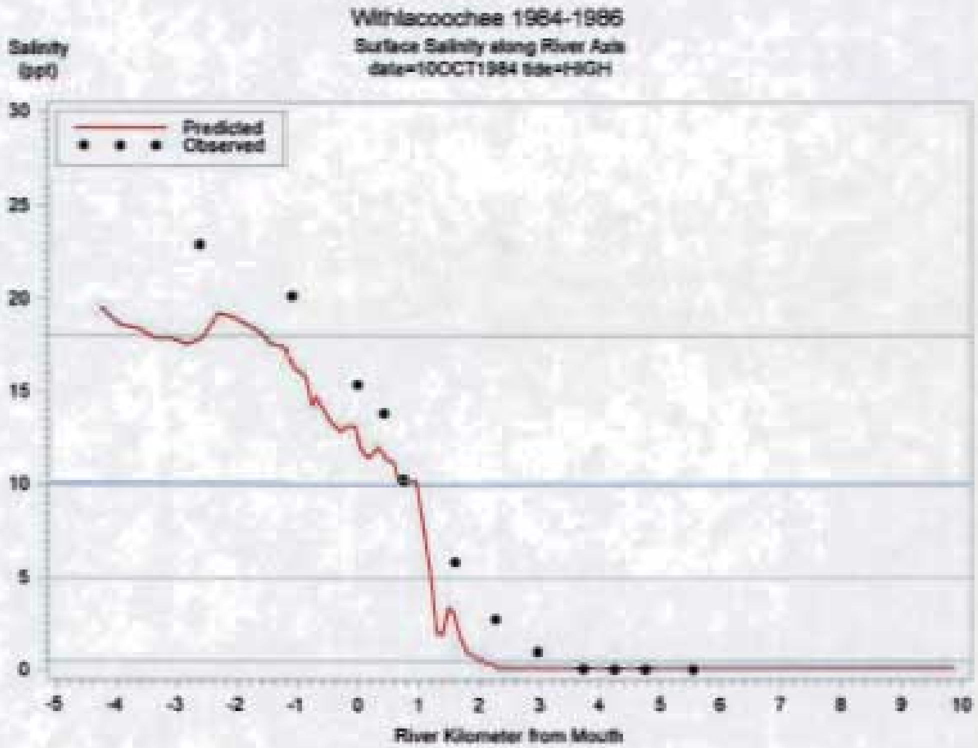

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=09MAY1984 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

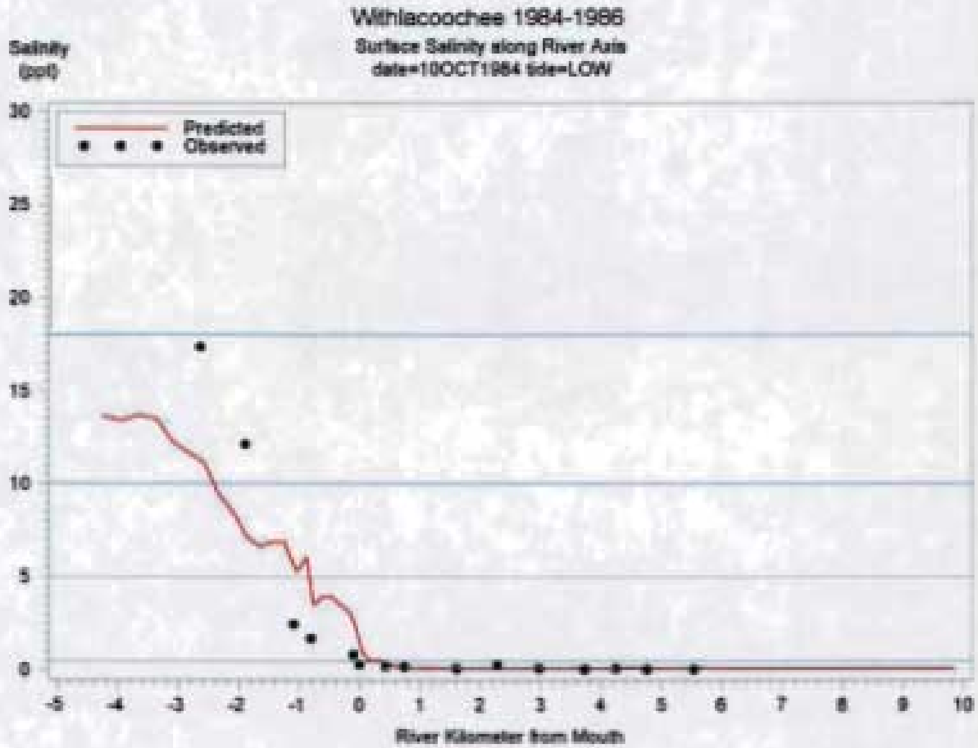

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=13JUN1984 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth


Withlacoochee 1984-1986
Surface Salinity along River Axis
date=10JUL1984 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

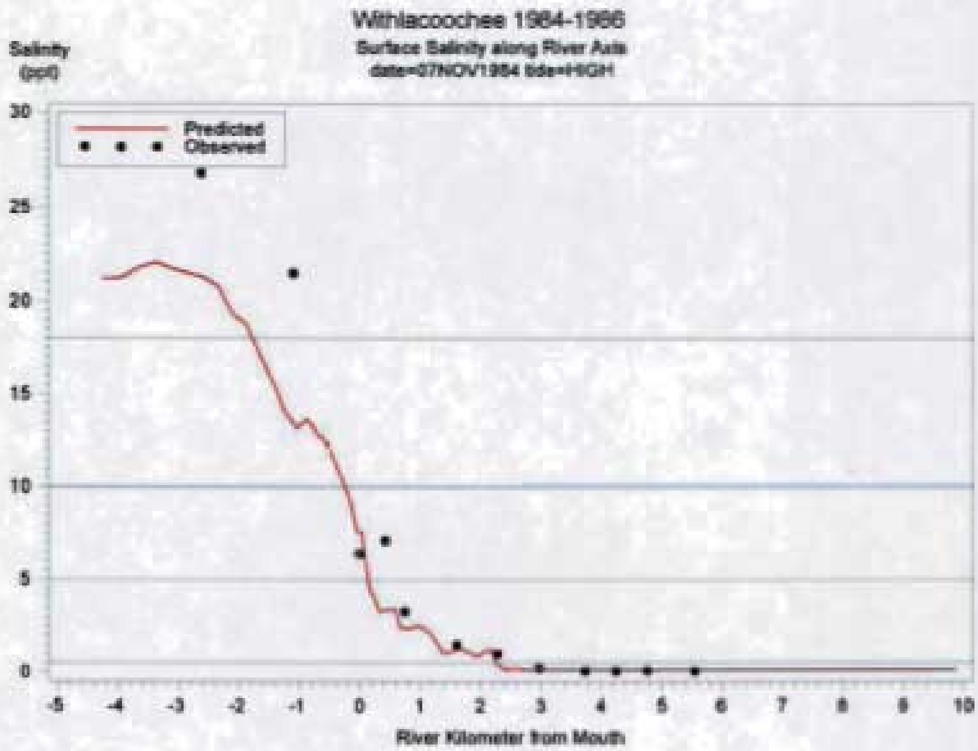

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=07AUG1984 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth


Withlacoochee 1984-1986
Surface Salinity along River Axis
date=05SEP1984 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

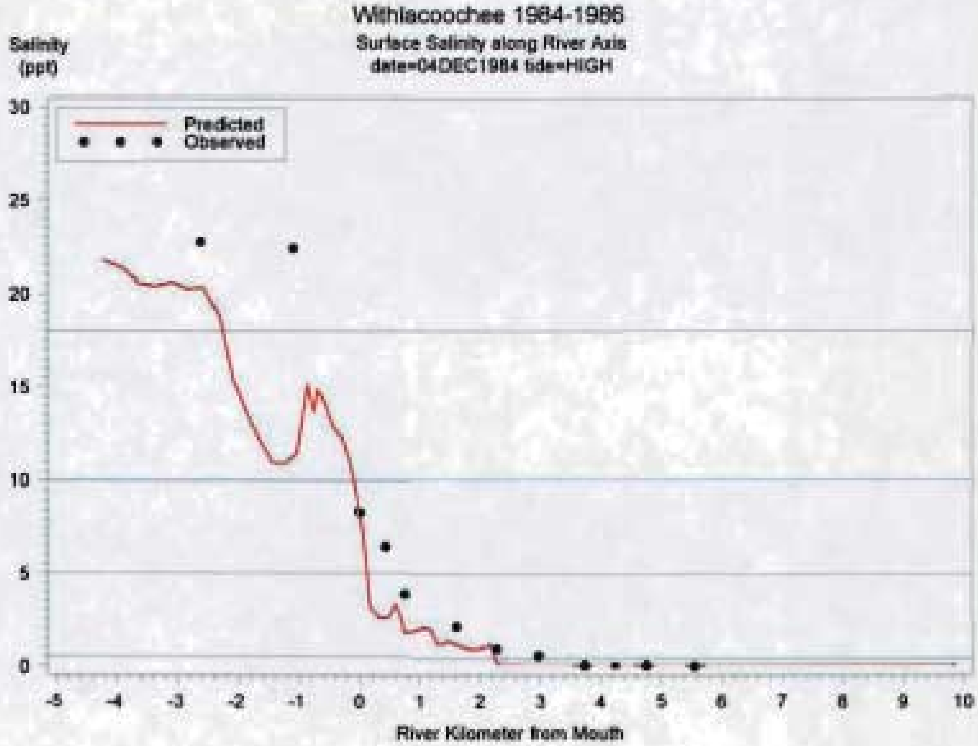

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=10OCT1984 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

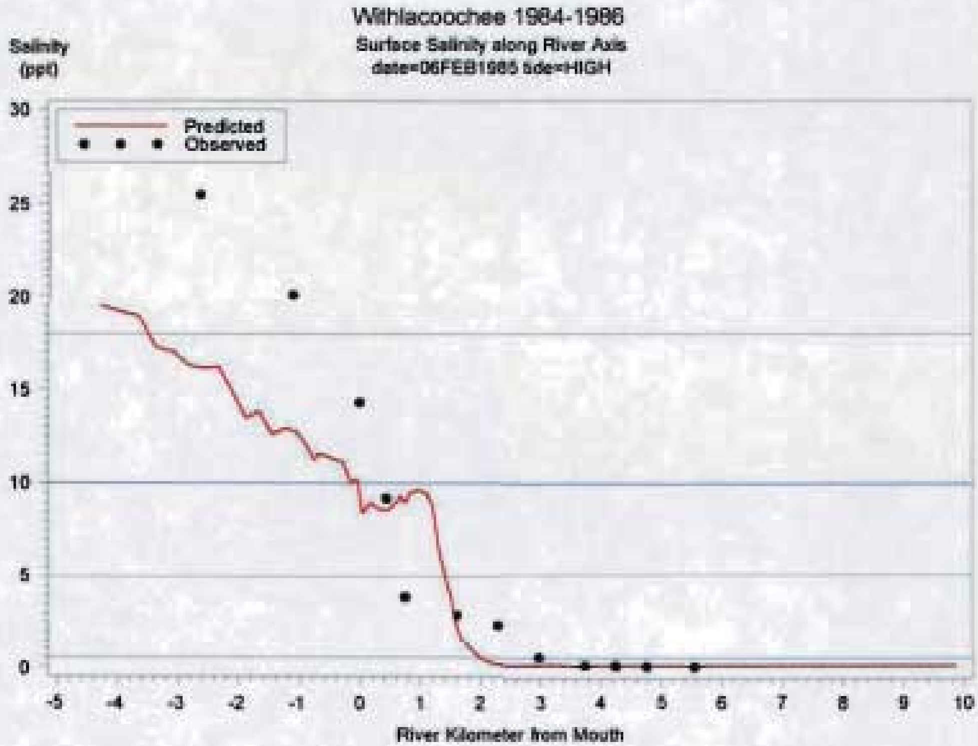


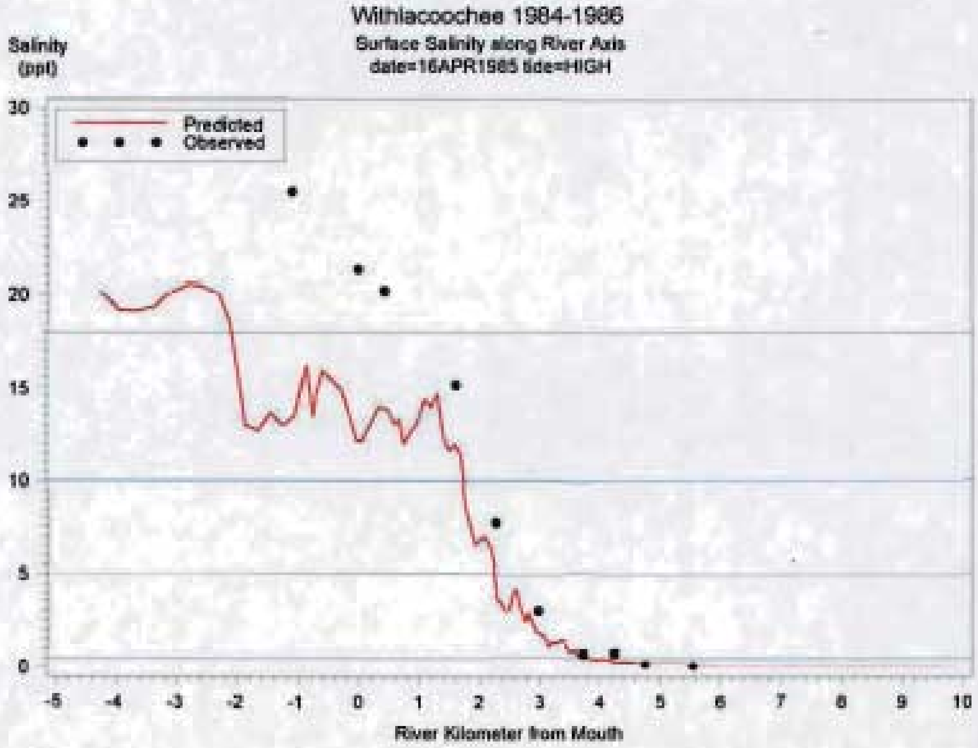
Withlacoochee 1984-1986
Surface Salinity along River Axis
date=10OCT1984 tide=LOW
Salinity
(ppt)
Predicted
Observed
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
River Kilometer from Mouth

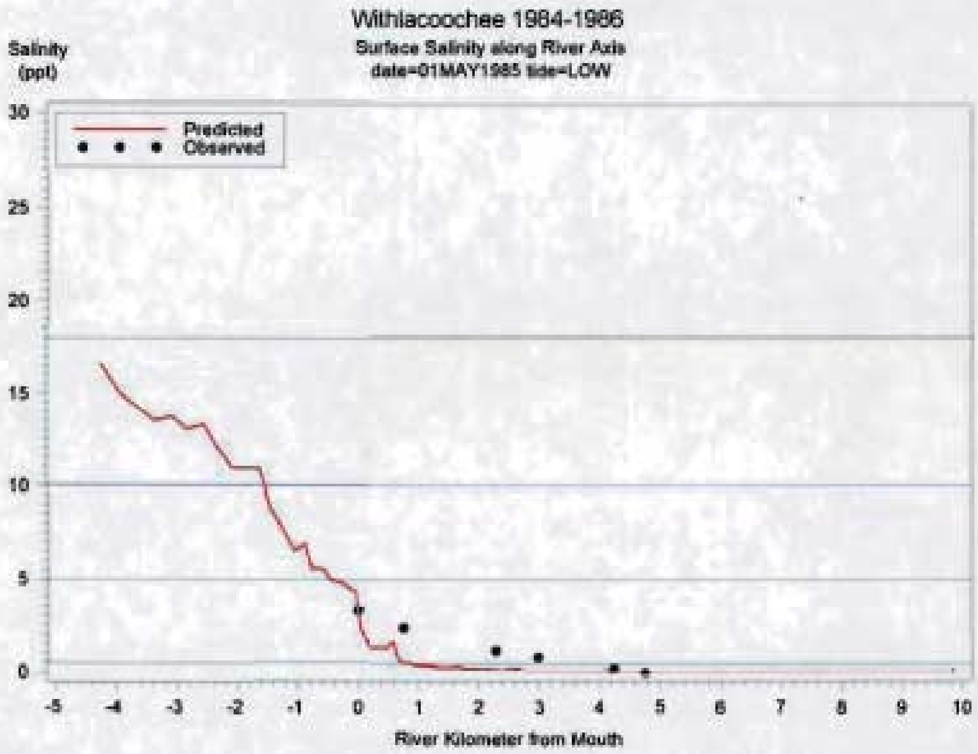



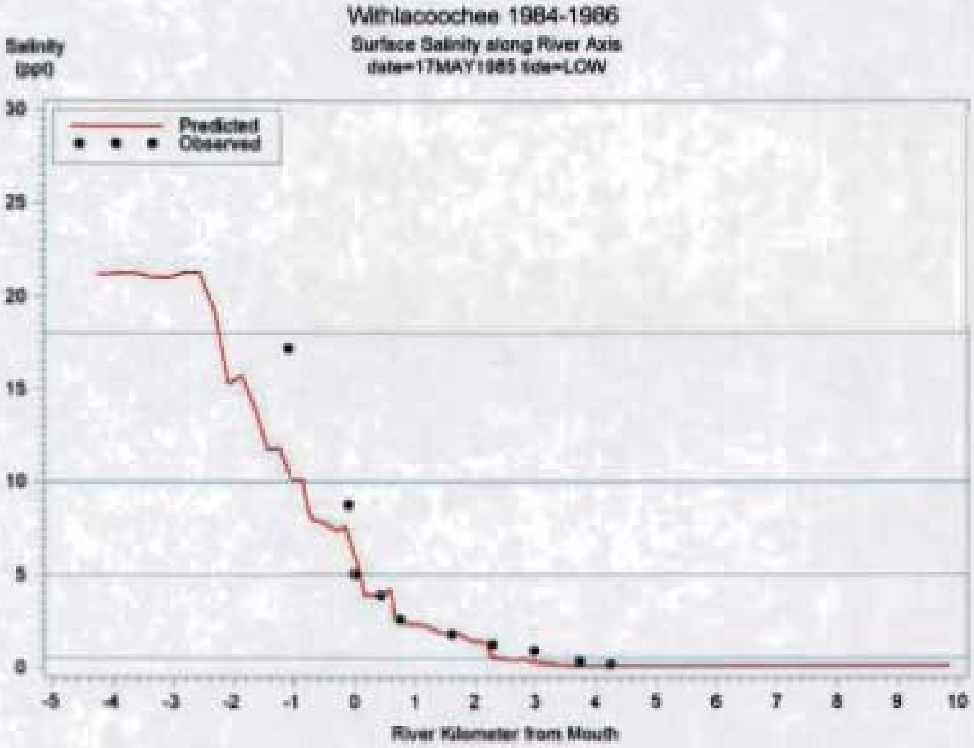
Withlacoochee 1984-1986
Surface Salinity along River Axis
date=07NOV1984 tide=HIGH
Salinity
(ppt)
Predicted
Observed
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
River Kilometer from Mouth

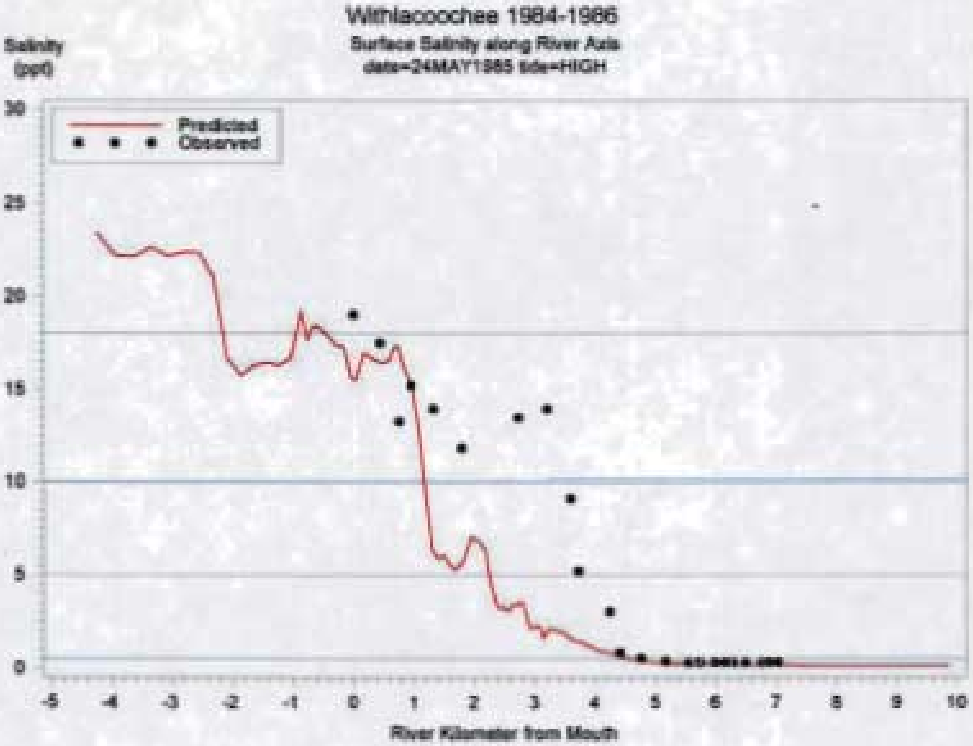

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=04DEC1984 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

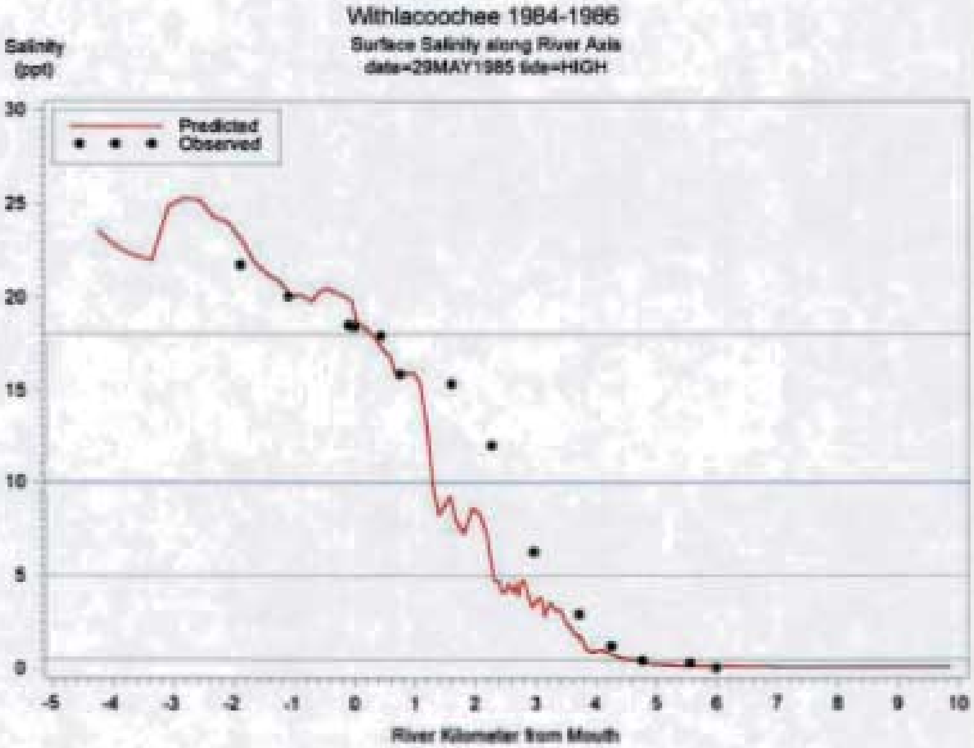

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=06FEB1985 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

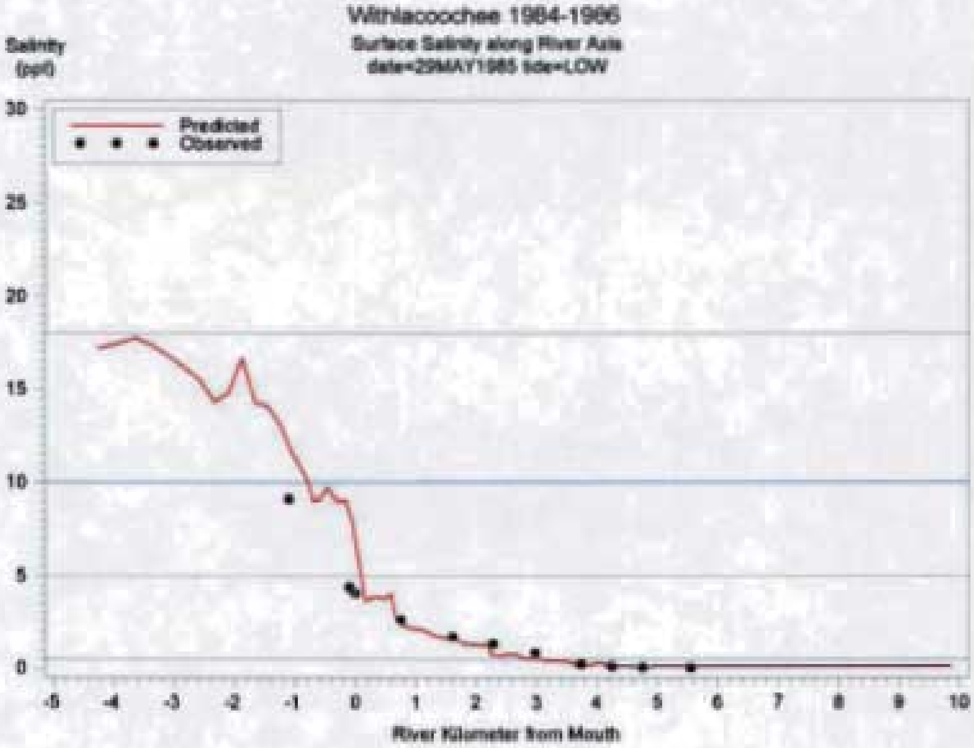

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=16APR1985 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

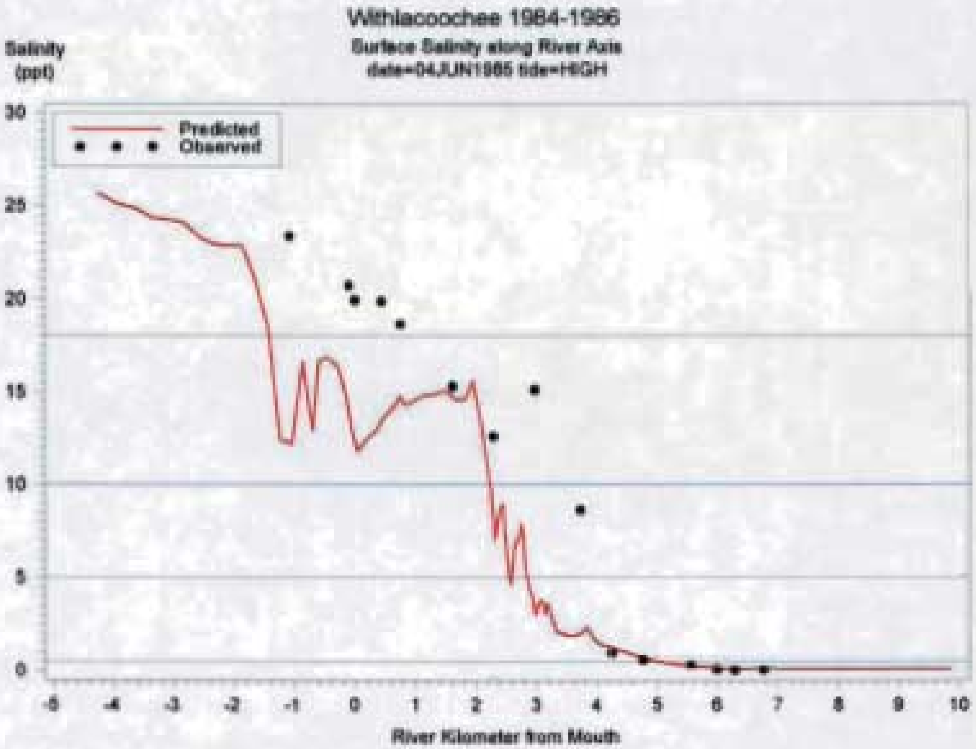

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=01MAY1985 tide=LOW
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth


Withlacoochee 1984-1986
Surface Salinity along River Axis
date=17MAY1985 tide=LOW
Salinity
(ppt)
Predicted
Observed
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
River Kilometer from Mouth

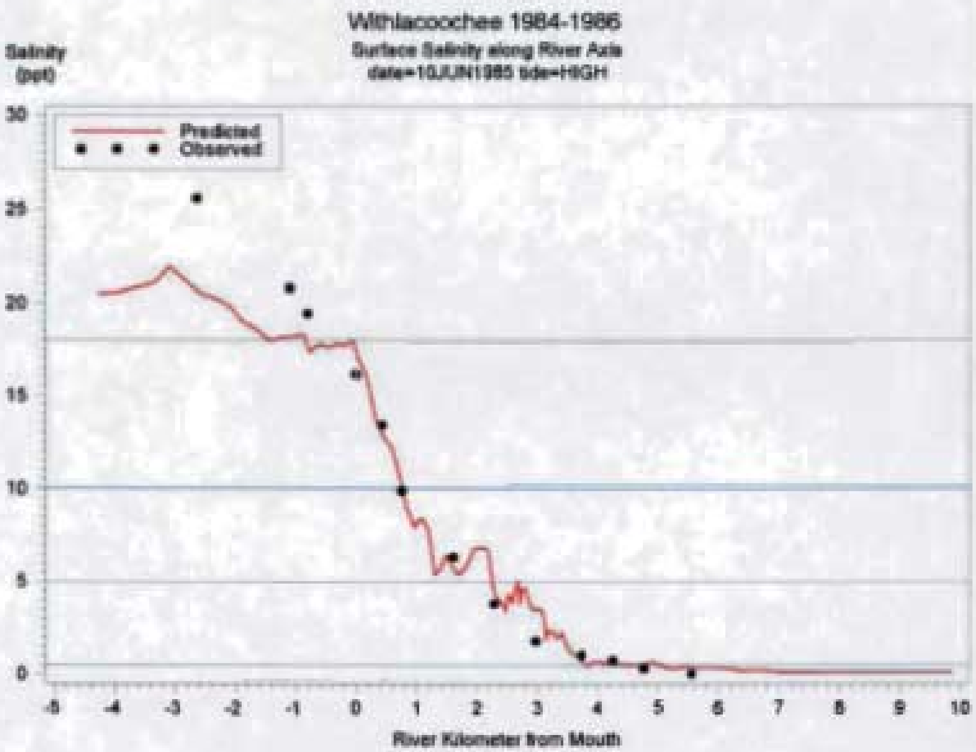

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=24MAY1985 tide=HIGH
Salinity
(ppt)
Predicted
Observed
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
River Kilometer from Mouth


Withlacoochee 1984-1986
Surface Salinity along River Axis
date=29MAY1985 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

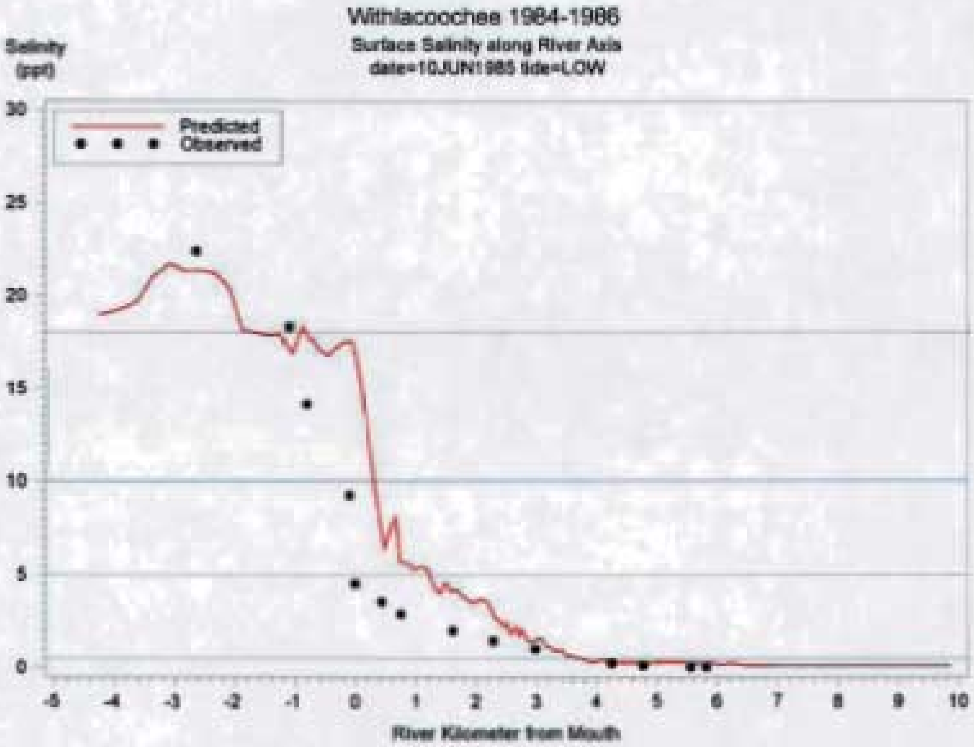

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=29MAY1985 tide=LOW
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

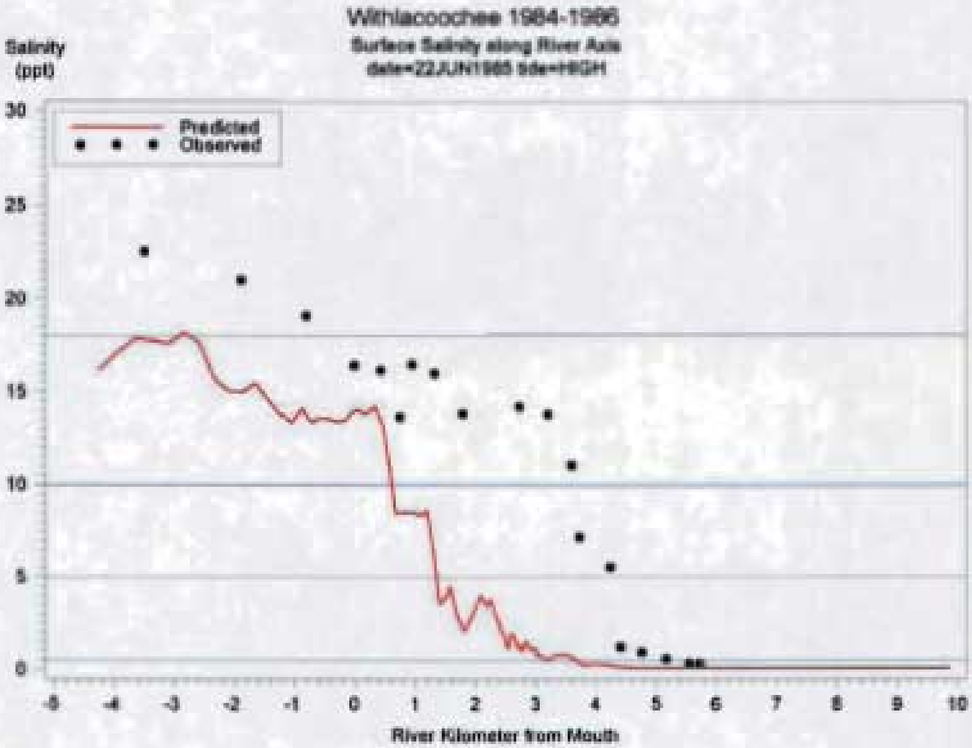


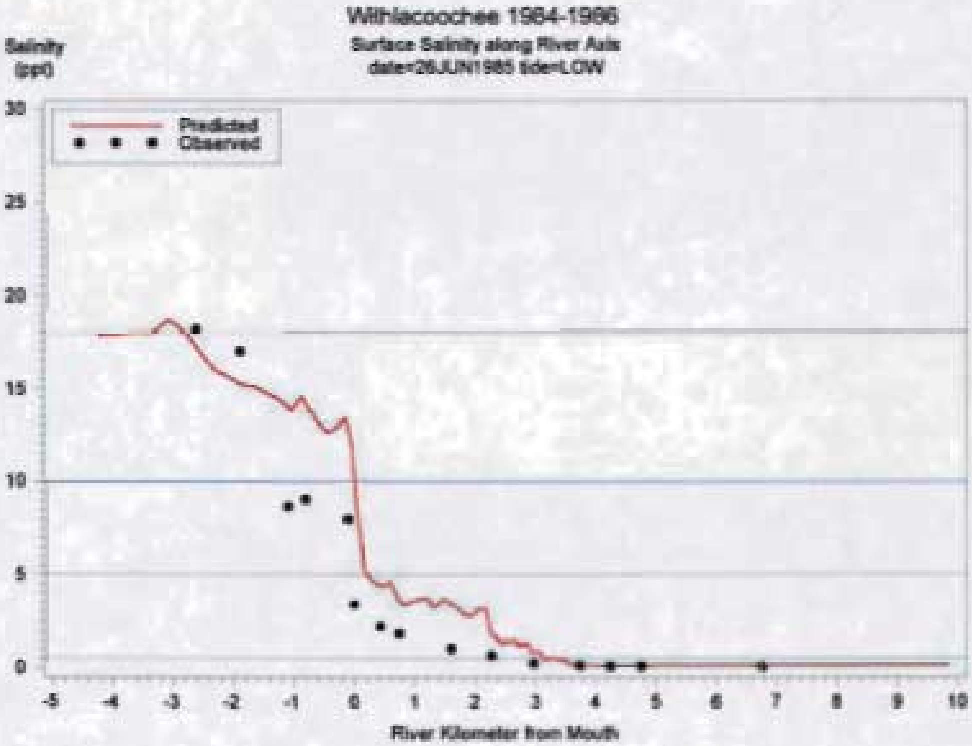
Withlacoochee 1984-1986
Surface Salinity along River Axis
date=04JUN1985 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

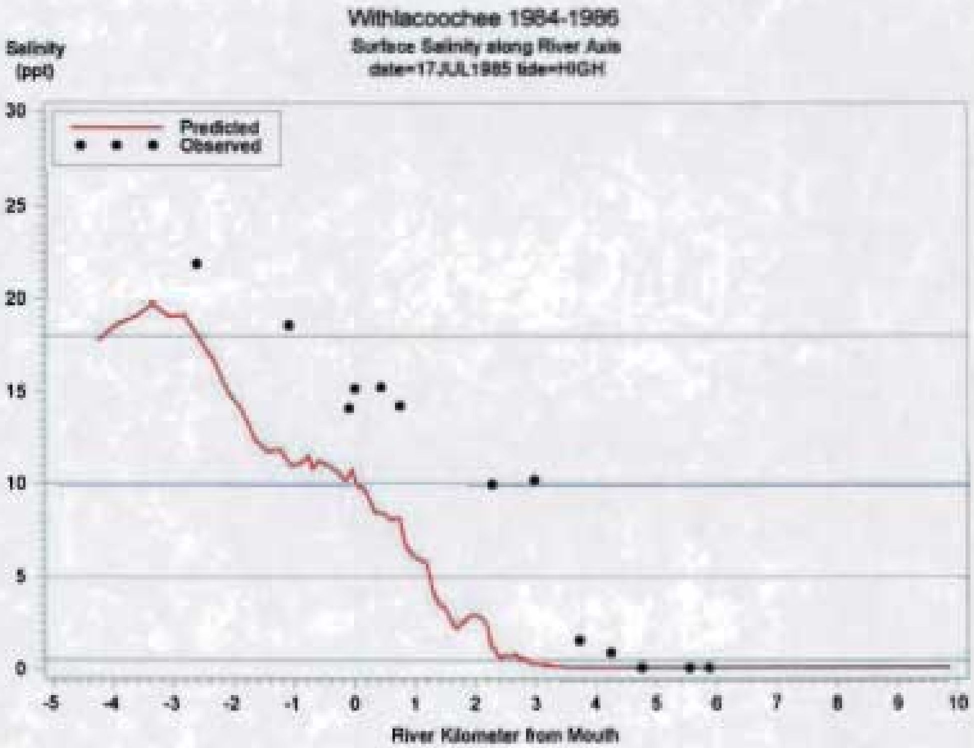



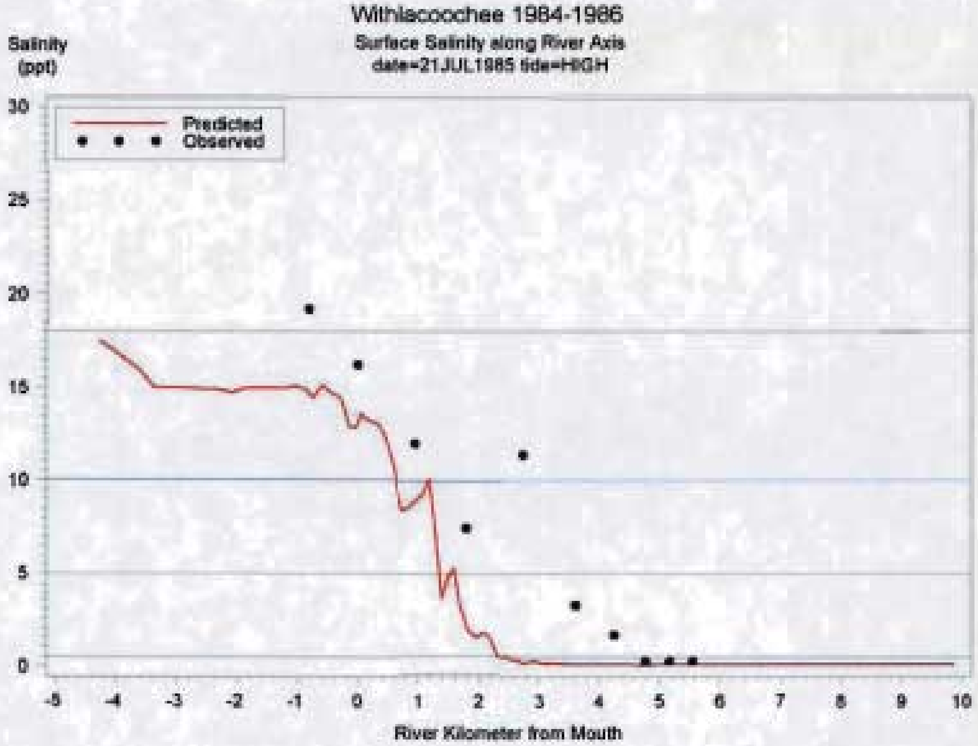
Withlacoochee 1984-1986
Surface Salinity along River Axis
date=10JUN1985 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

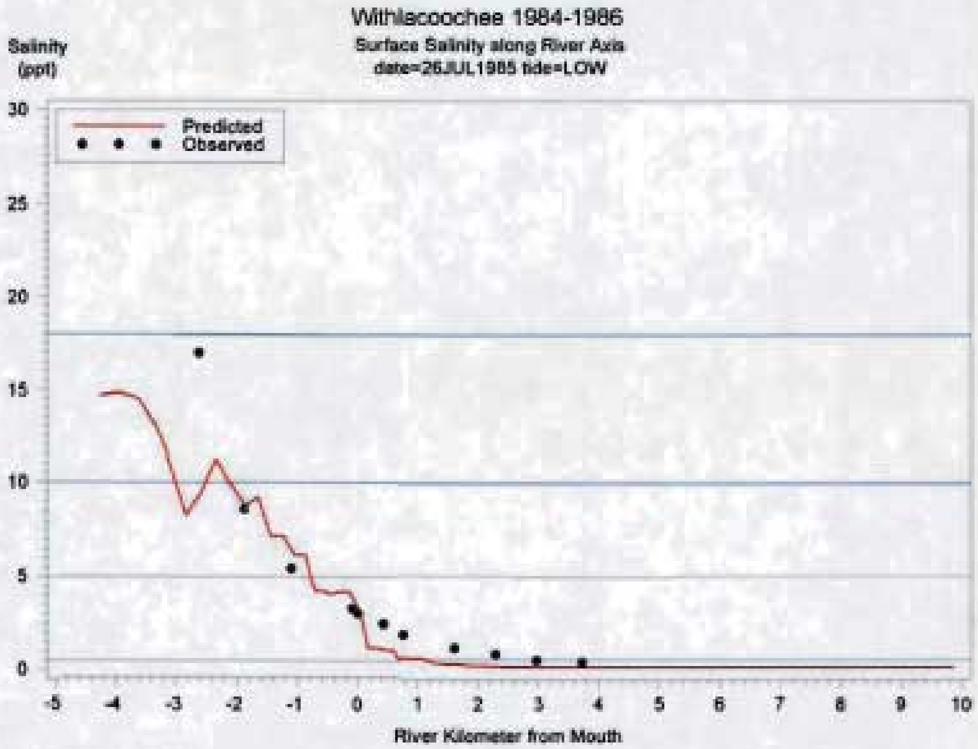

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=10JUN1985 tide=LOW
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

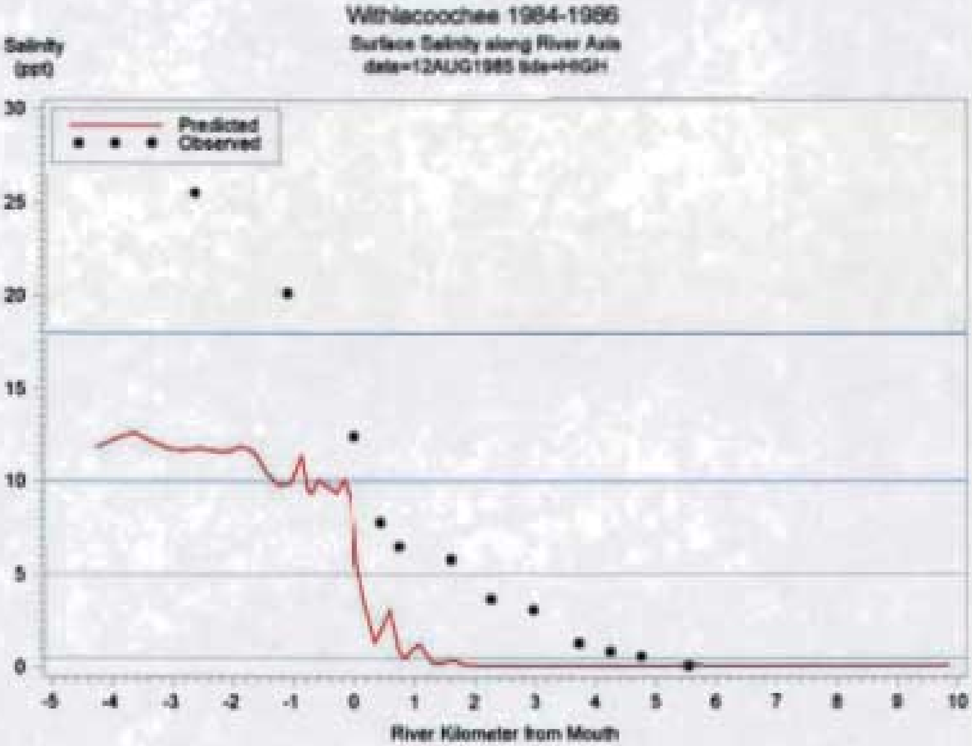

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=22JUN1985 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

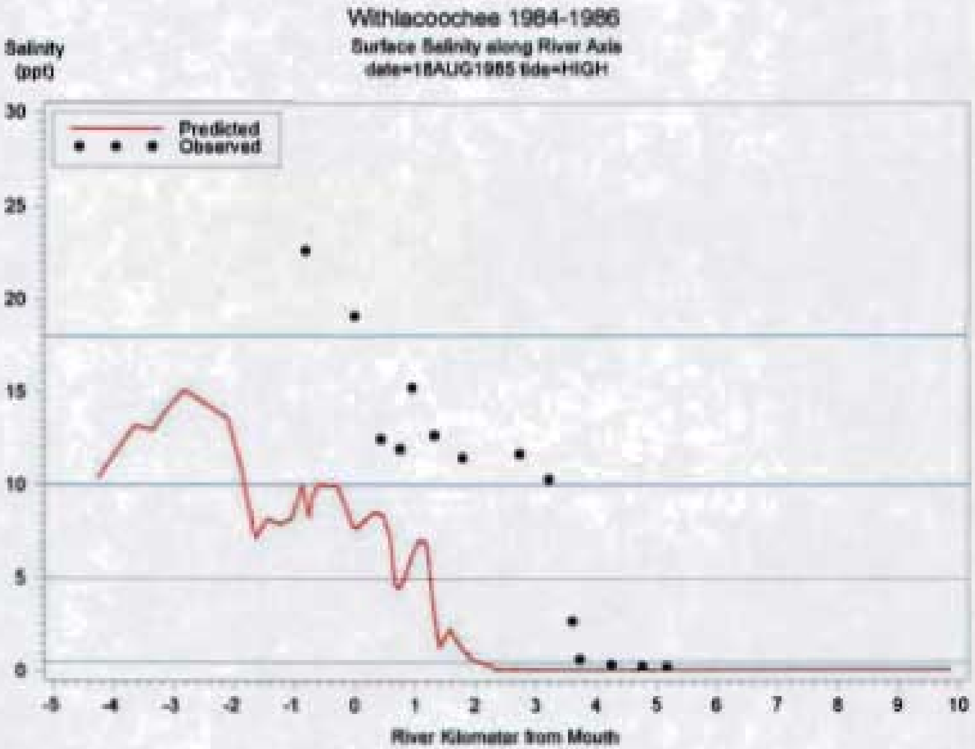

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=26JUN1985 tide=LOW
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

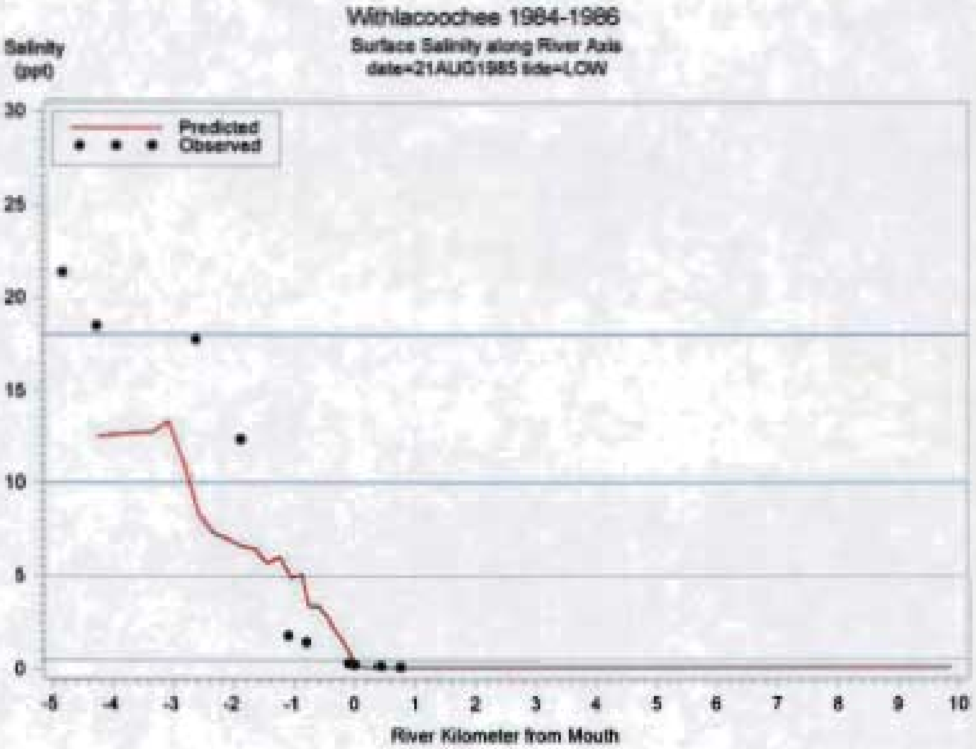

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=17JUL1985 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth


Withlacoochee 1984-1986
Surface Salinity along River Axis
date=21JUL1985 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

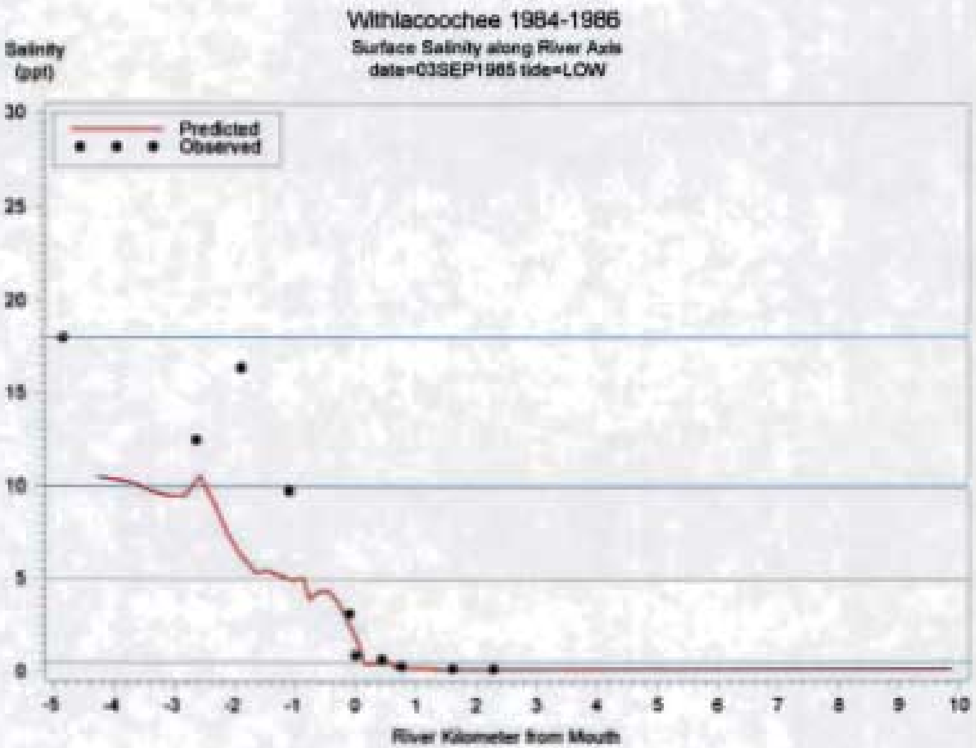

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=26JUL1985 tide=LOW
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth


Withlacoochee 1984-1986
Surface Salinity along River Axis
date=12AUG1985 tide=HIGH
Salinity (ppt)
Predicted
Observed
30
25
20
15
10
5
0
-5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
River Kilometer from Mouth

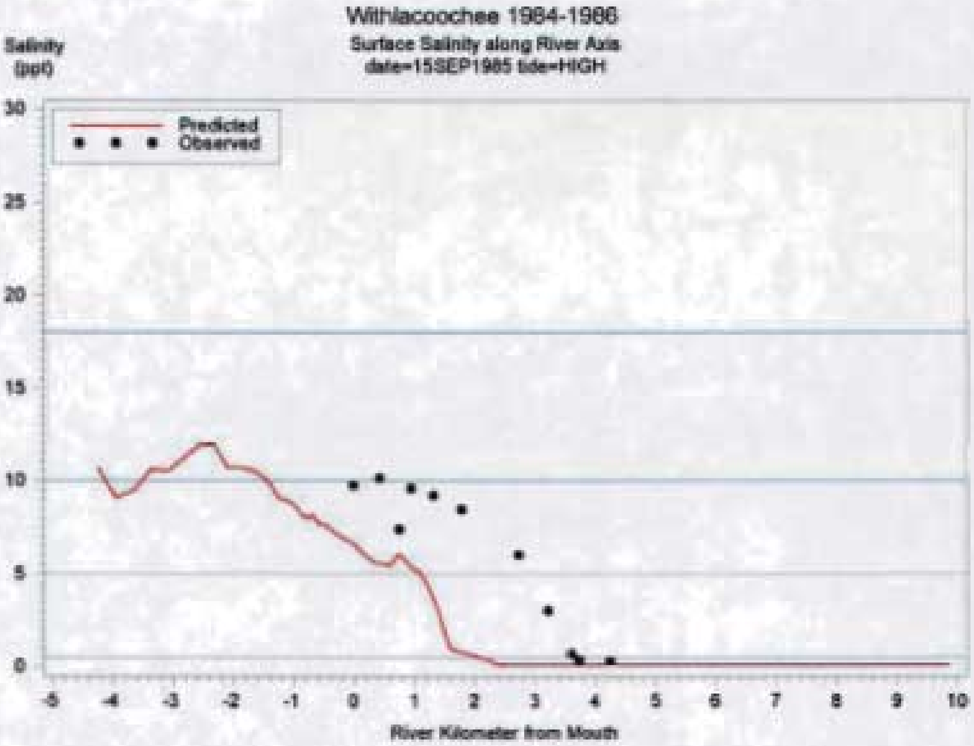

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=18AUG1985 tide=HIGH
Salinity (ppt)
Predicted
Observed
30
25
20
15
10
5
0
-5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
River Kilometer from Mouth

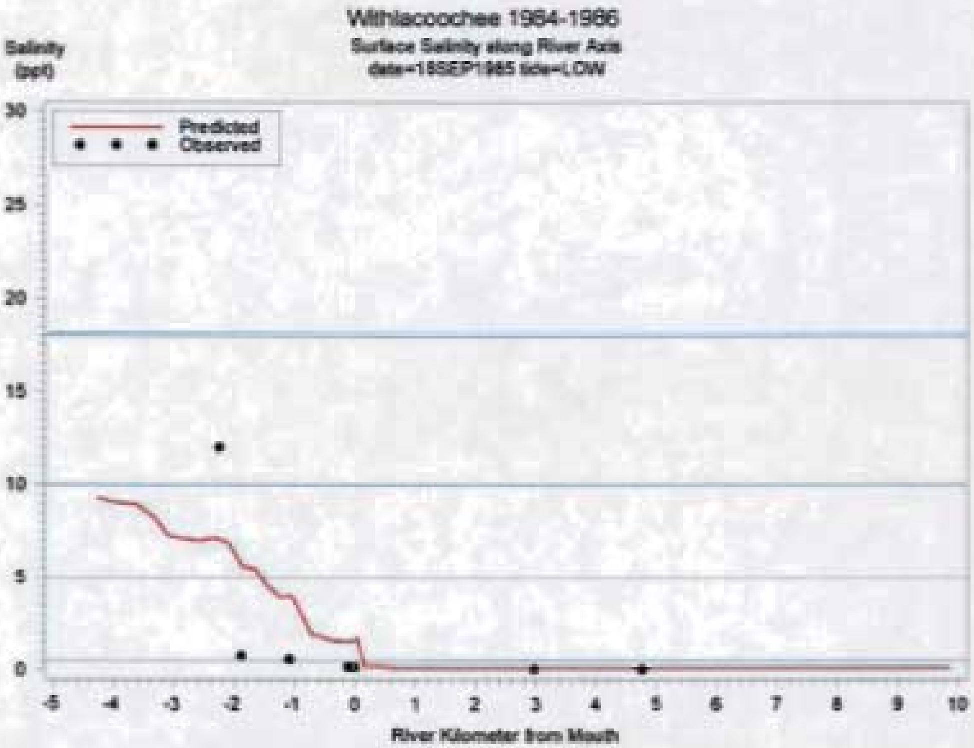


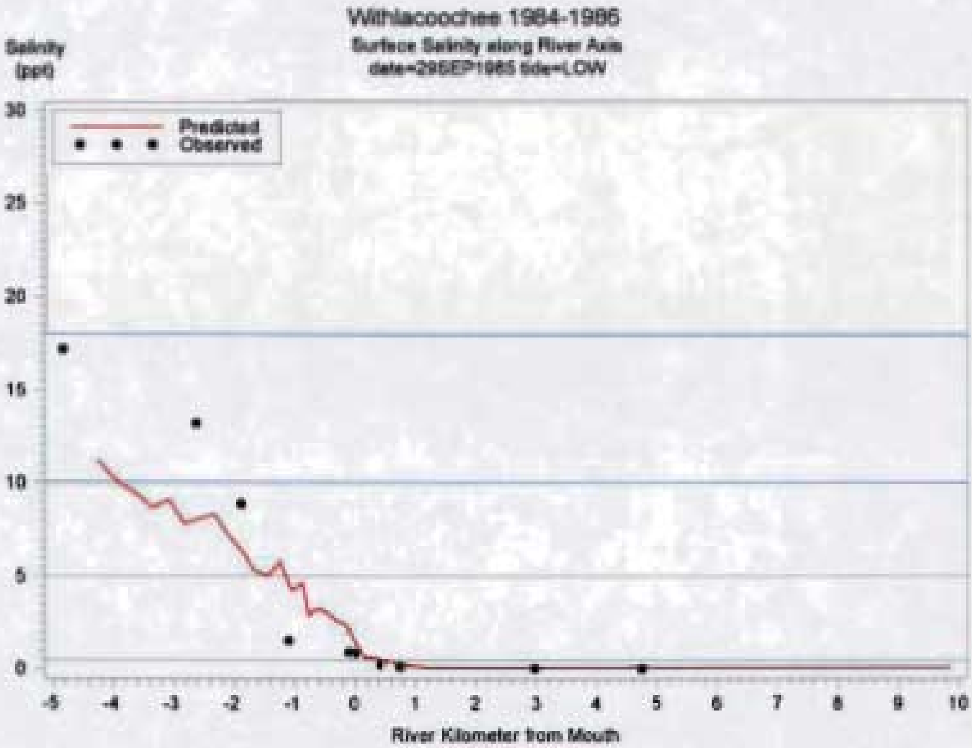
Withlacoochee 1984-1986
Surface Salinity along River Axis
date=21AUG1985 tide=LOW
Salinity
(ppt)
Predicted
Observed
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
River Kilometer from Mouth

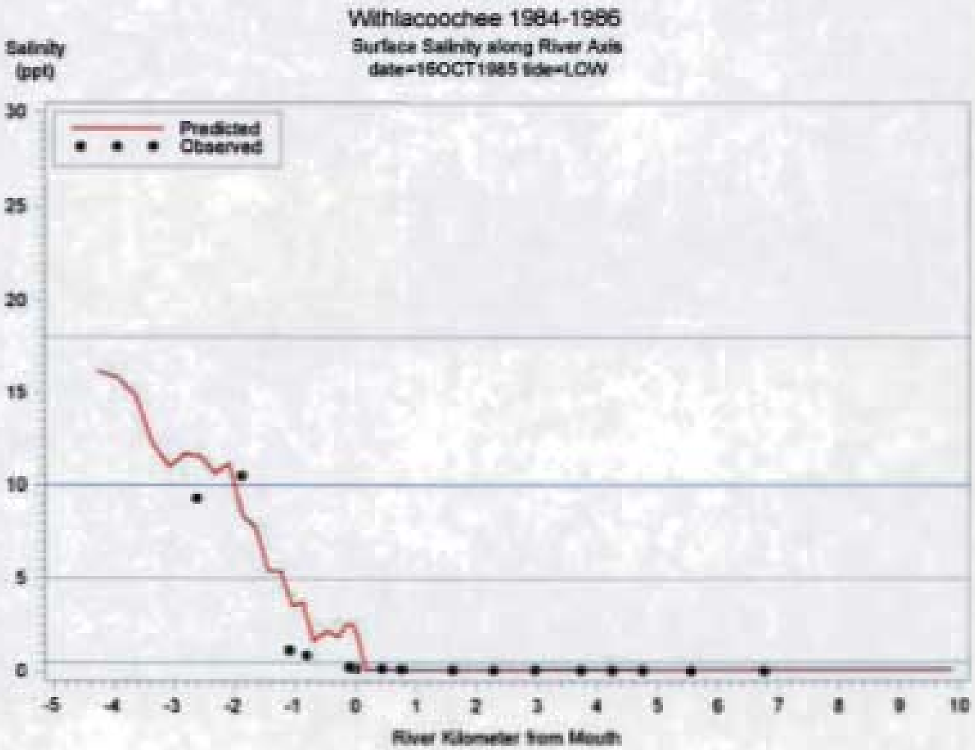
Withlacoochee 1984-1986
Surface Salinity along River Axis
date=03SEP1985 tide=LOW
Salinity
(ppt)
Predicted
Observed
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
River Kilometer from Mouth


Withlacoochee 1984-1986
Surface Salinity along River Axis
date=15SEP1985 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

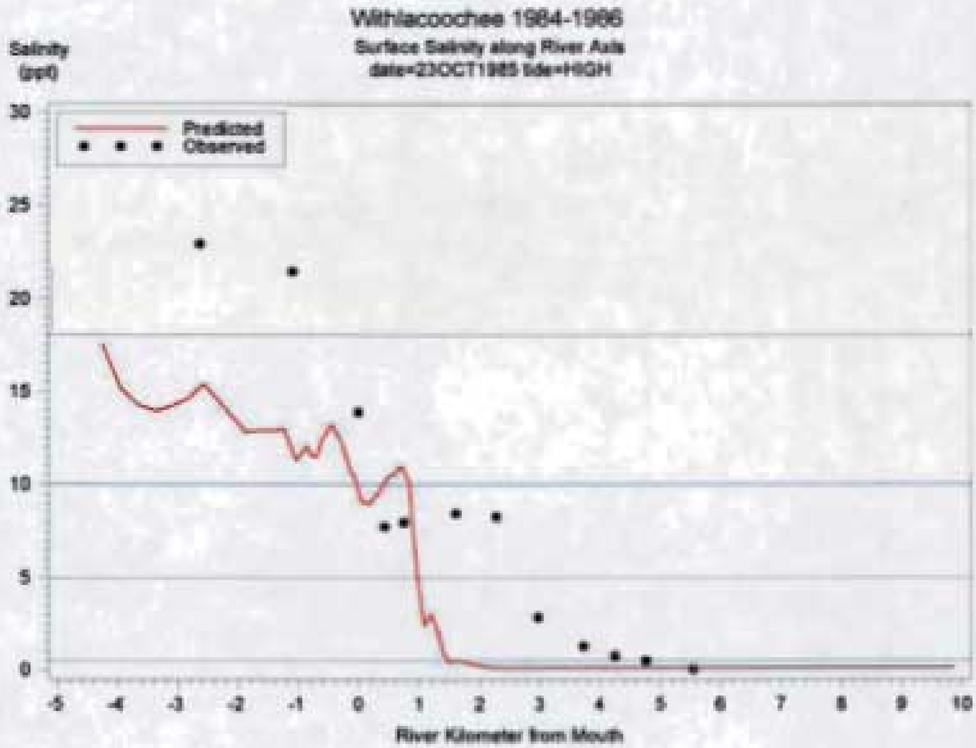

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=18SEP1985 tide=LOW
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth



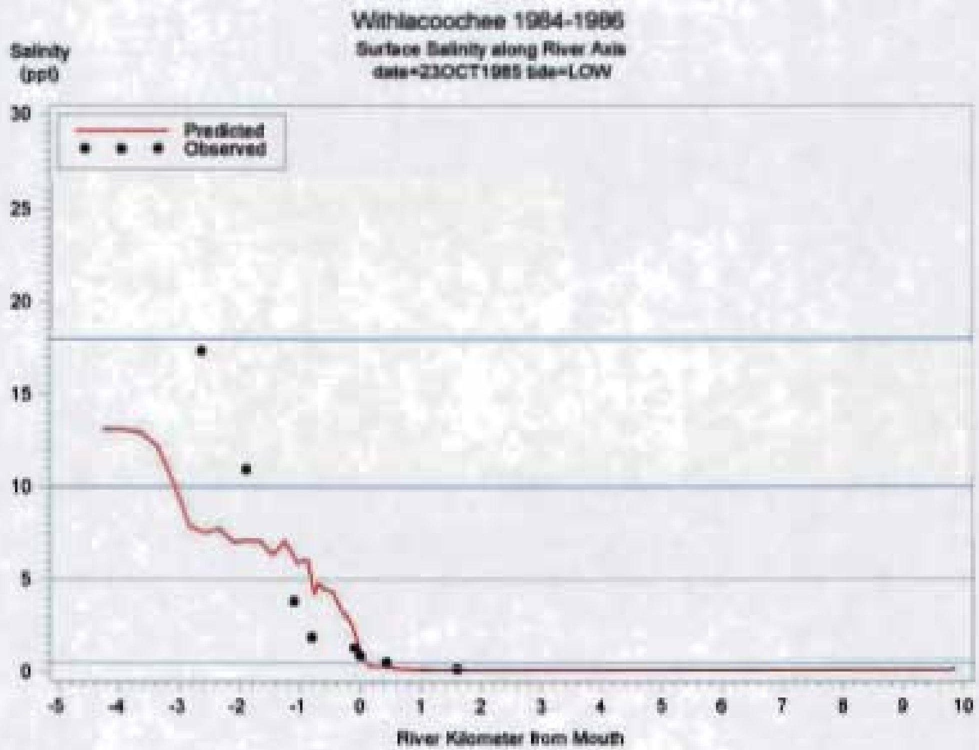
Withlacoochee 1984-1986
Surface Salinity along River Axis
date=29SEP1985 tide=LOW
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

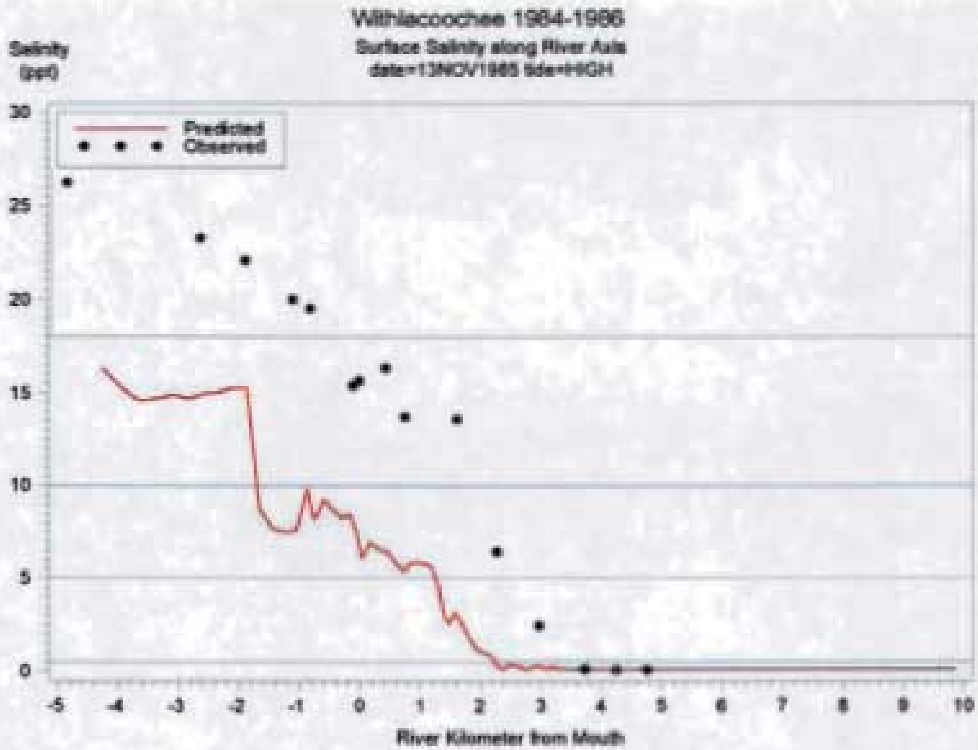
Withlacoochee 1984-1986
Surface Salinity along River Axis
date=16OCT1985 tide=LOW
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

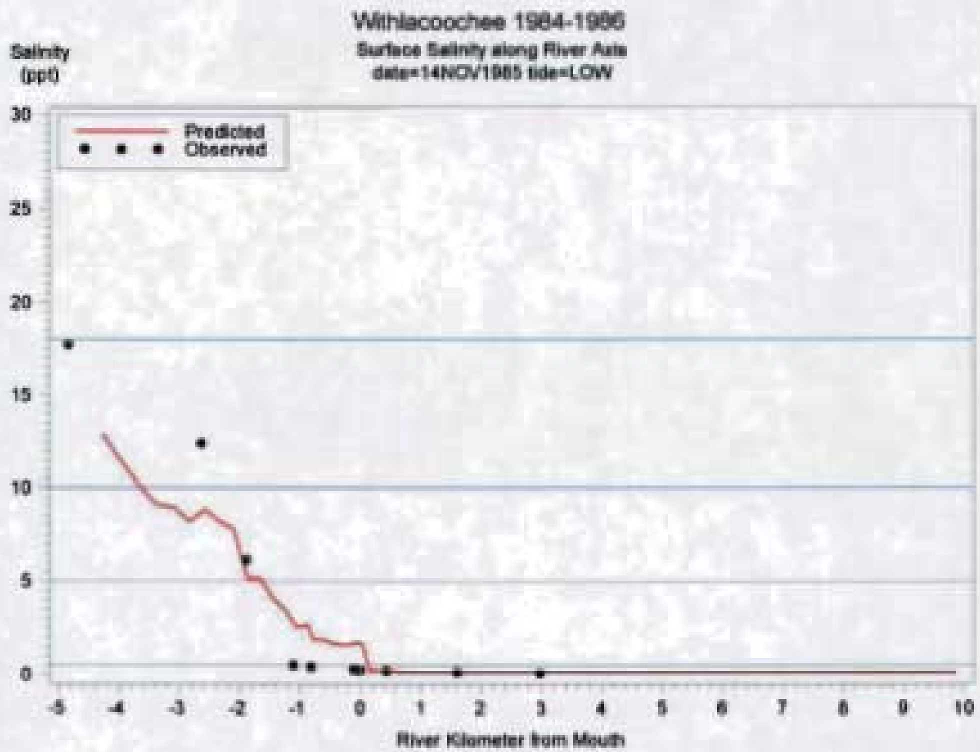


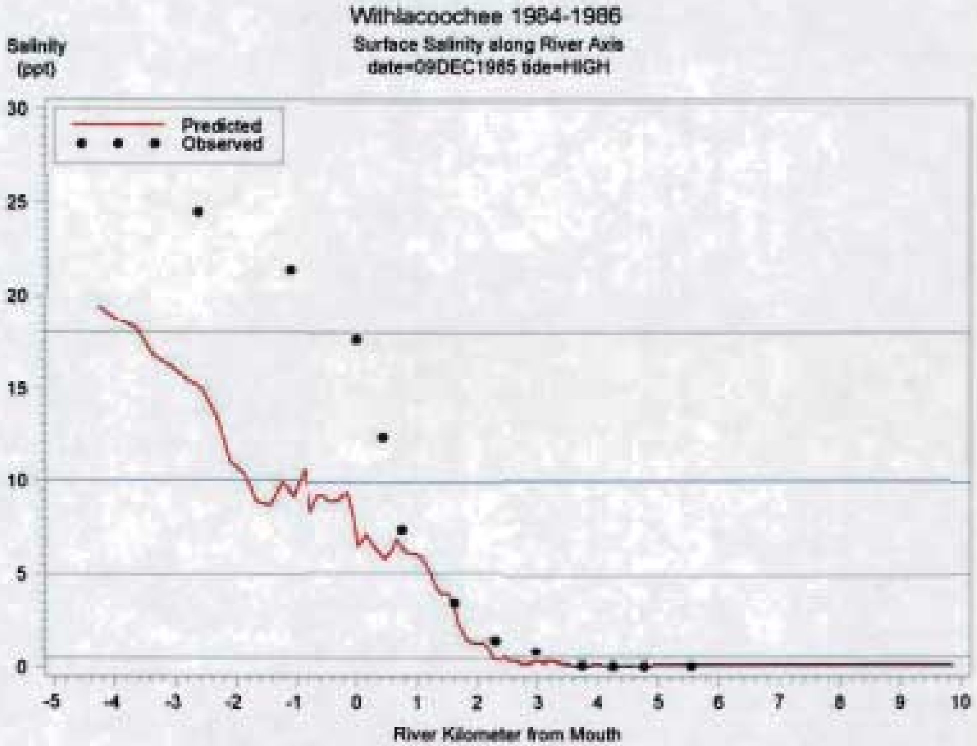
Withlacoochee 1984-1986
Surface Salinity along River Axis
date=23OCT1985 tide=HIGH
Salinity (ppt)
Predicted
Observed
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
River Kilometer from Mouth

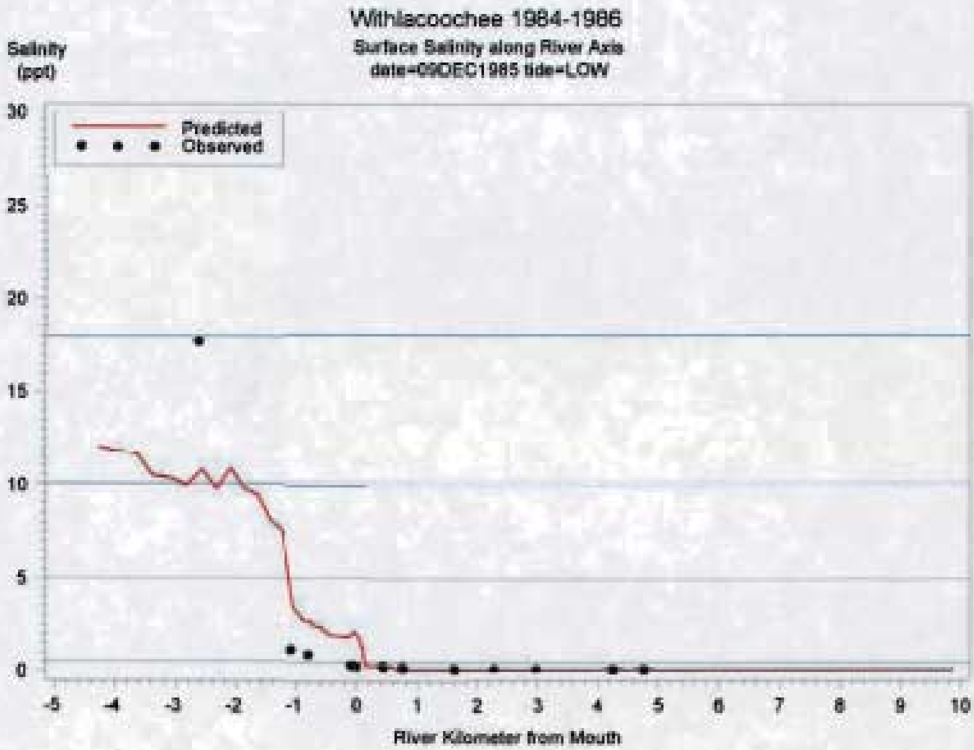
Withlacoochee 1984-1986
Surface Salinity along River Axis
date=23OCT1985 tide=LOW
Salinity (ppt)
Predicted
Observed
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
River Kilometer from Mouth


Withlacoochee 1984-1986
Surface Salinity along River Axis
date=13NOV1985 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

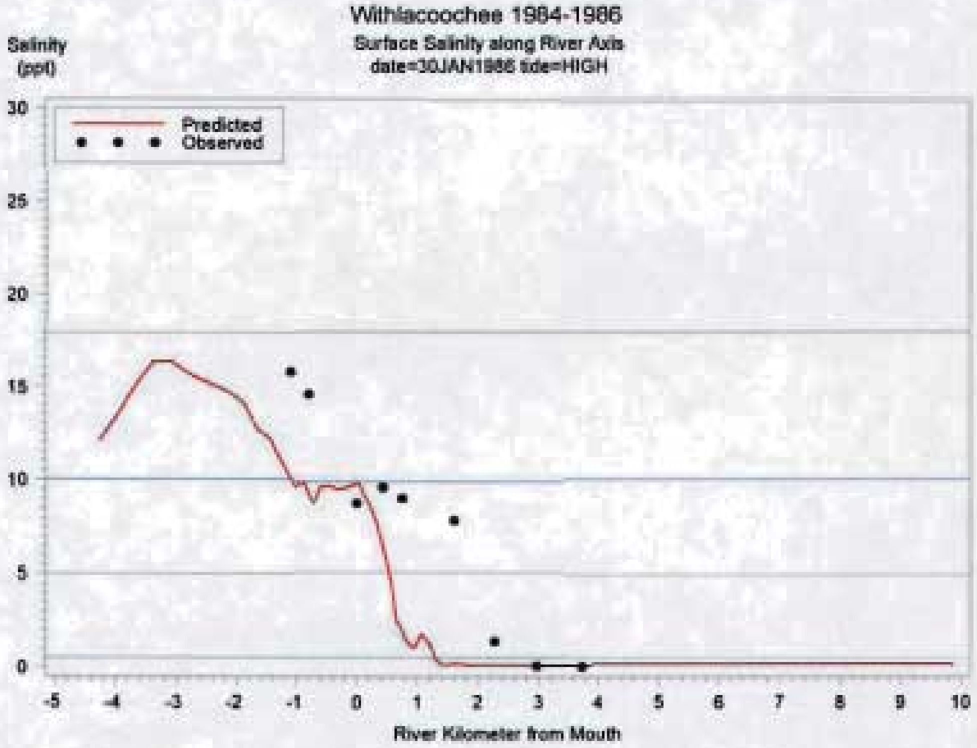

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=14NOV1985 tide=LOW
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

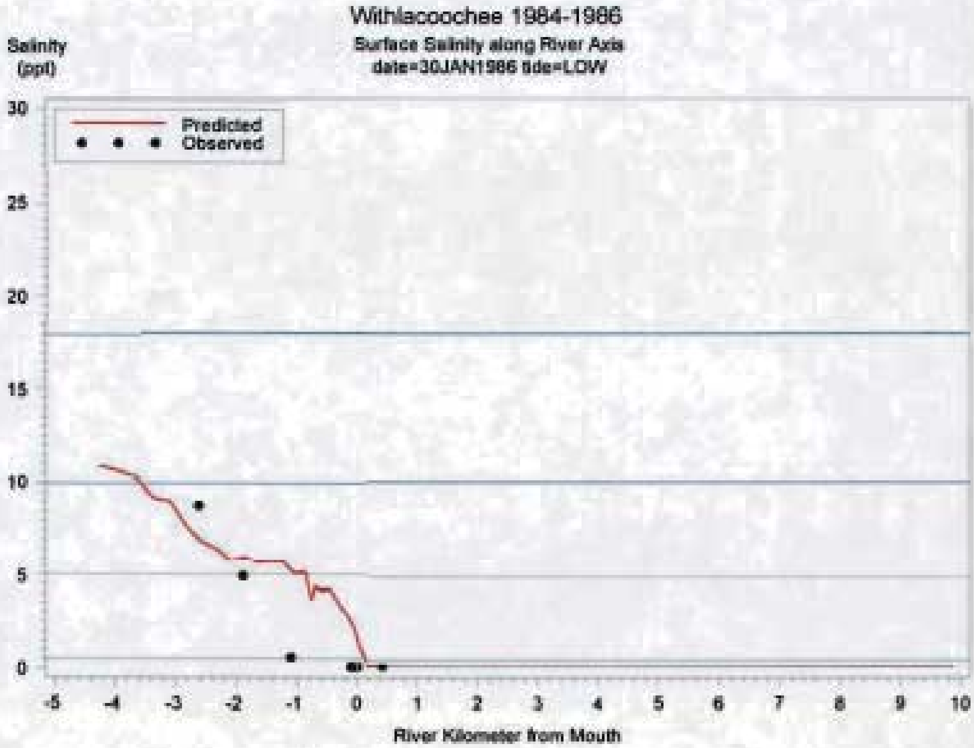


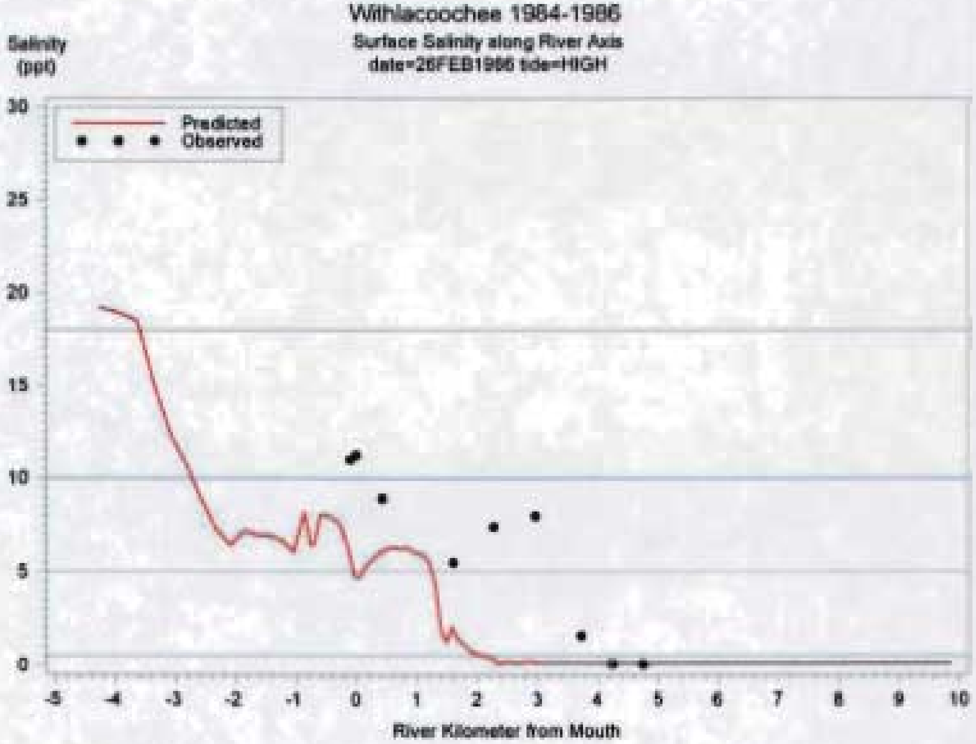
Withlacoochee 1984-1986
Surface Salinity along River Axis
date=09DEC1985 tide=HIGH
Salinity (ppt)
30
25
20
15
10
5
0
Predicted
Observed
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
River Kilometer from Mouth

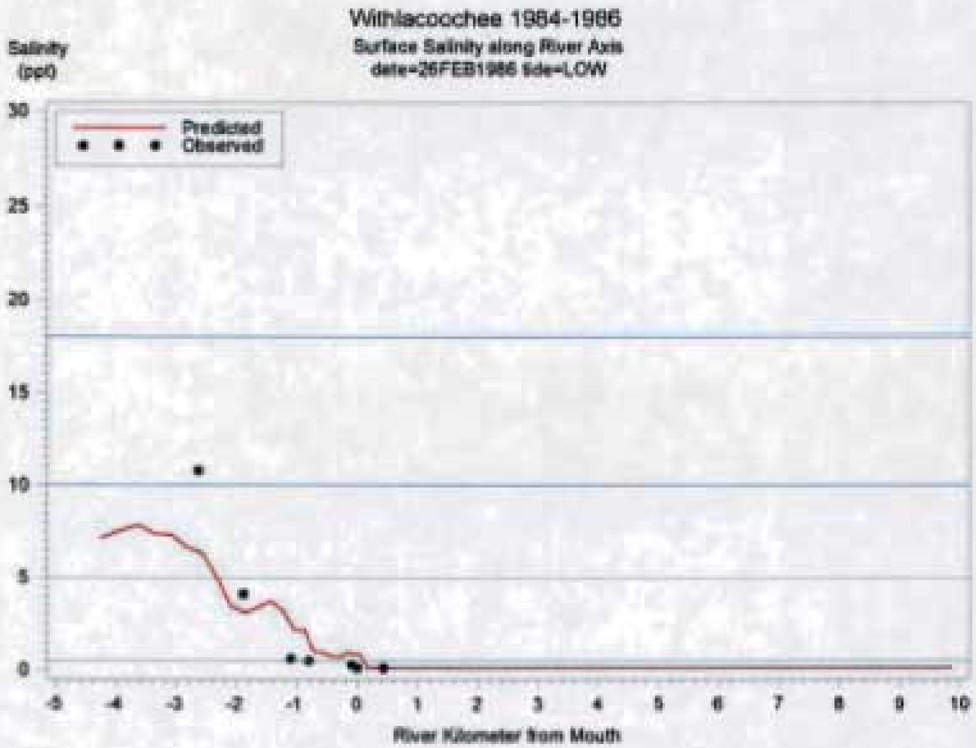



Withlacoochee 1984-1986
Surface Salinity along River Axis
date=09DEC1985 tide=LOW
Salinity (ppt)
30
25
20
15
10
5
0
Predicted
Observed
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
River Kilometer from Mouth

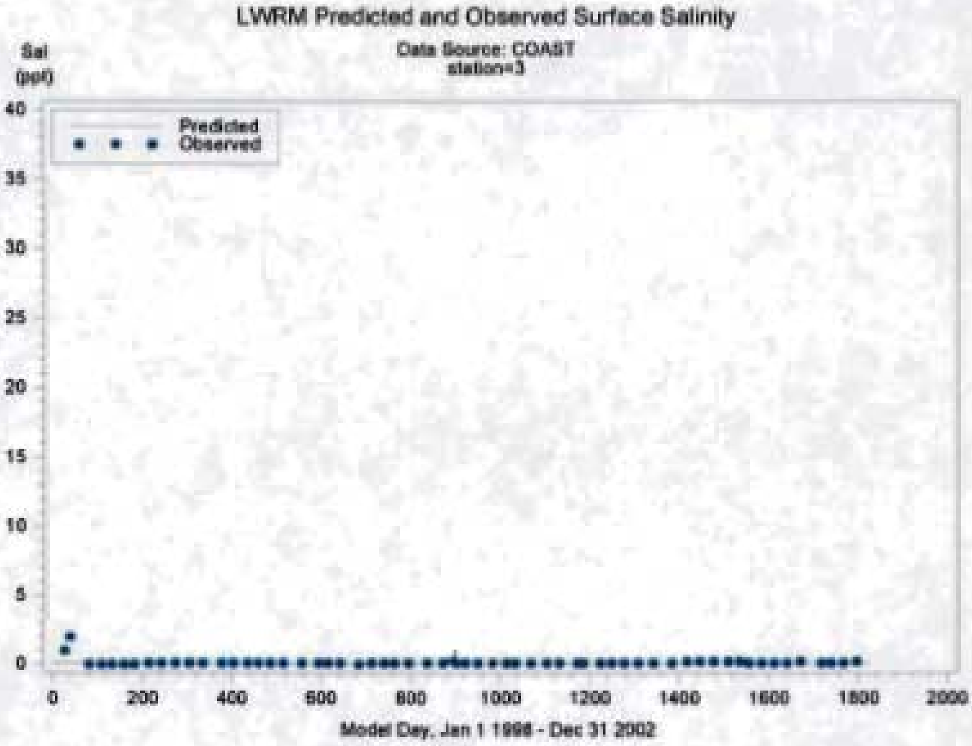

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=30JAN1986 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

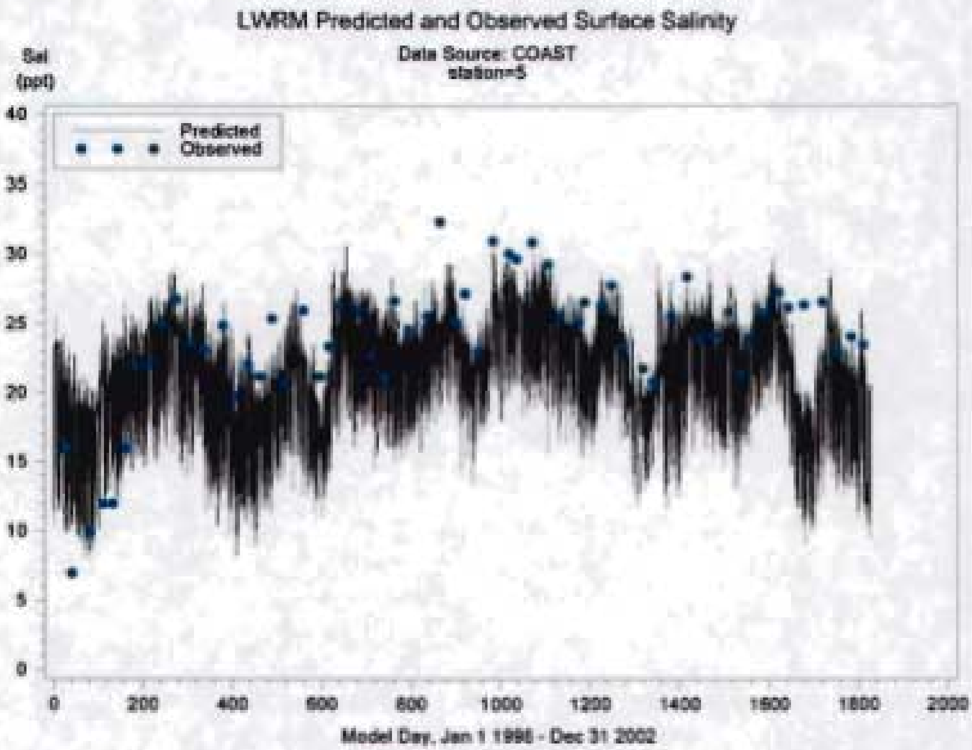

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=30JAN1986 tide=LOW
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

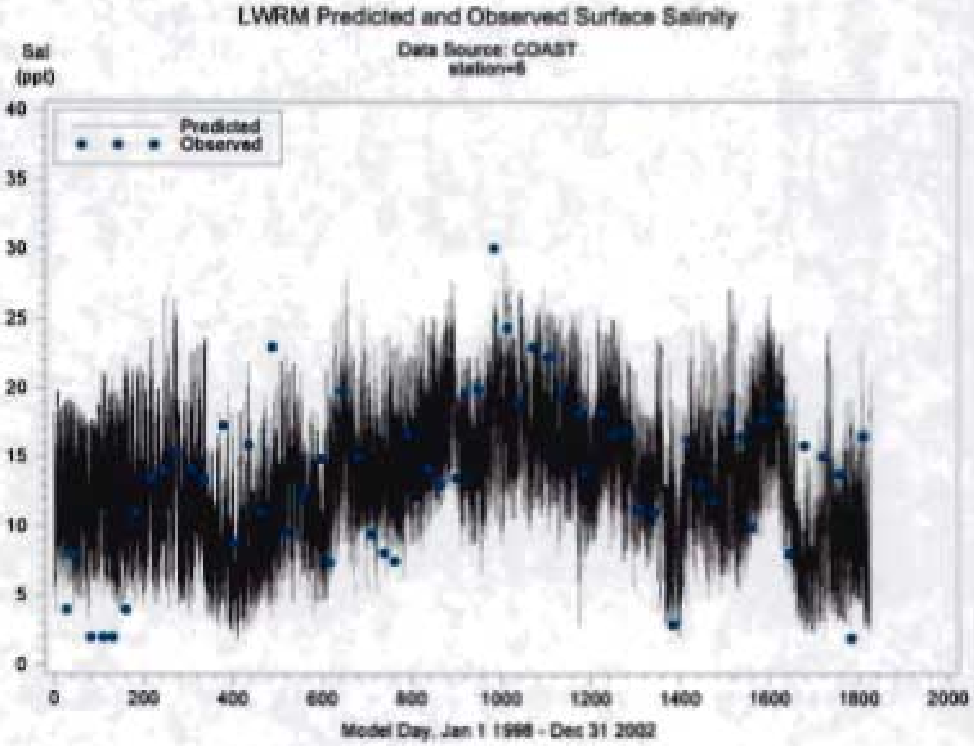

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=26FEB1986 tide=HIGH
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

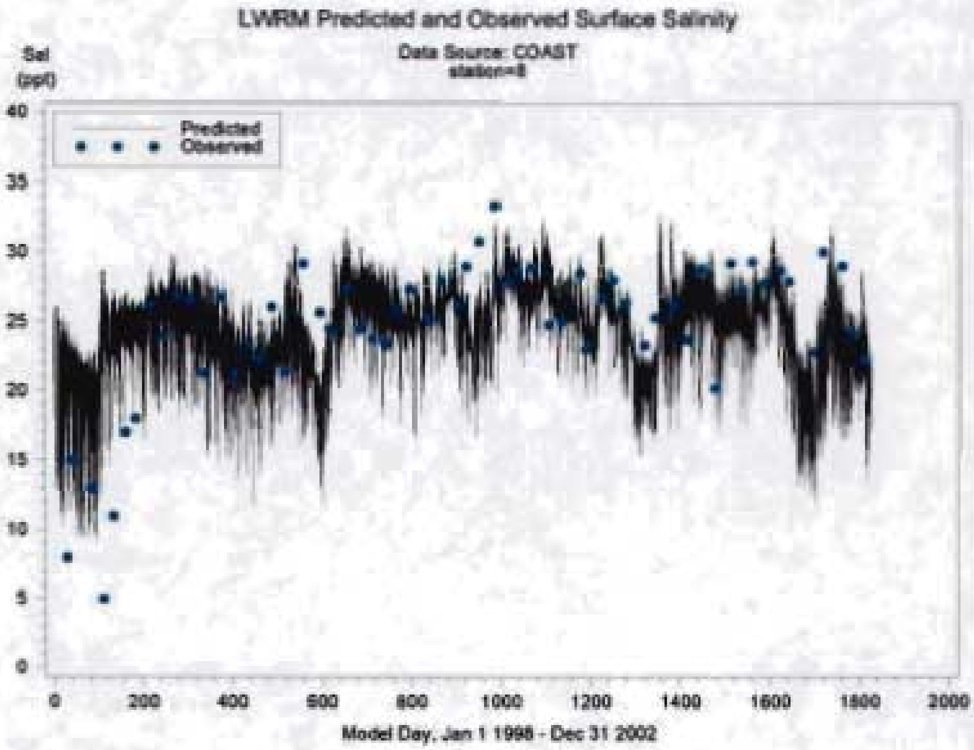

Withlacoochee 1984-1986
Surface Salinity along River Axis
date=26FEB1986 tide=LOW
Salinity (ppt)
Predicted
Observed
River Kilometer from Mouth

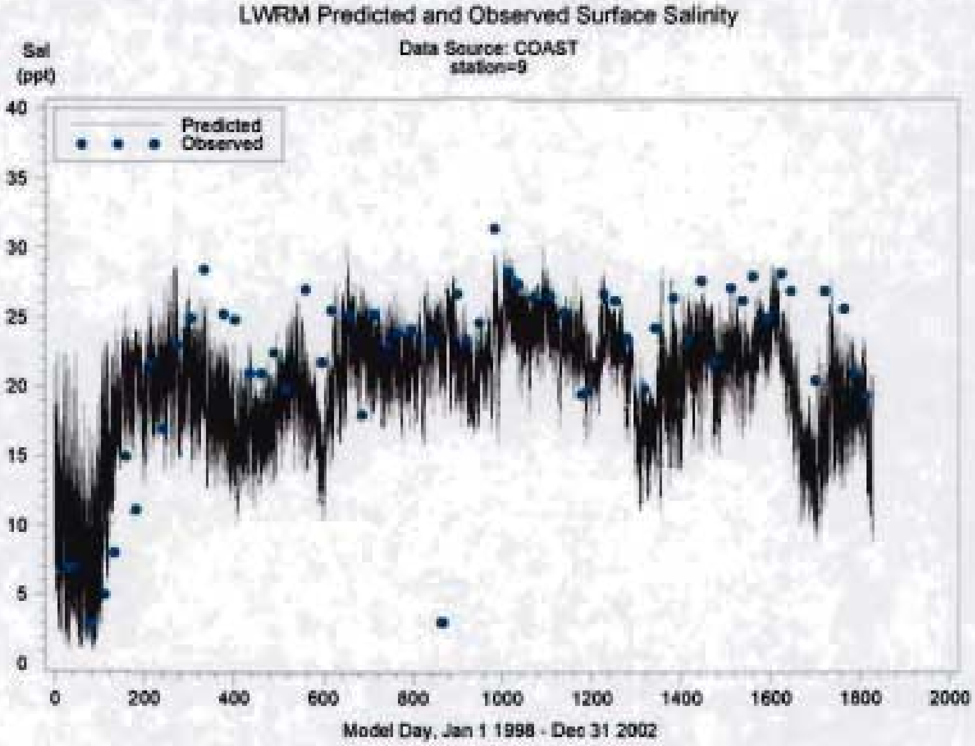
# Appendix A.5
# LWRM: Time Series Predicted and Observed Surface Salinity at COAST Sites
# 1998-2002


LWRM Predicted and Observed Surface Salinity
Data Source: COAST
station=3
Sal
(ppt)
Predicted
Observed
Model Day, Jan 1 1998 - Dec 31 2002

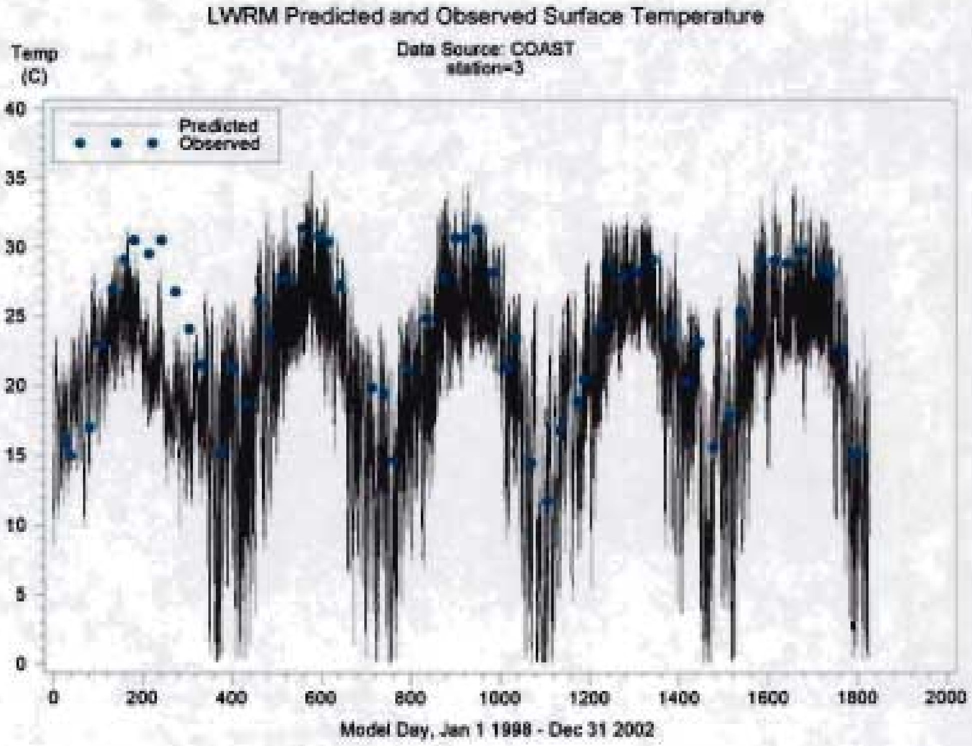

LWRM Predicted and Observed Surface Salinity
Data Source: COAST
station=5
Sal
(ppt)
Predicted
Observed
Model Day, Jan 1 1998 - Dec 31 2002

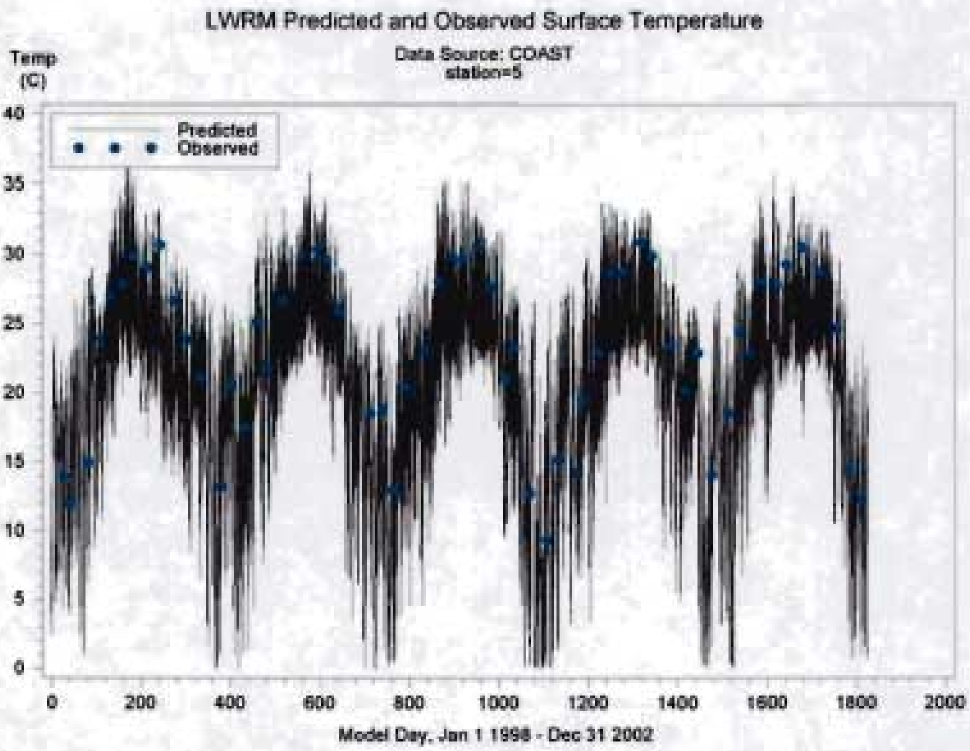

LWRM Predicted and Observed Surface Salinity
Data Source: COAST
station=6
Sal
(ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day, Jan 1 1998 - Dec 31 2002

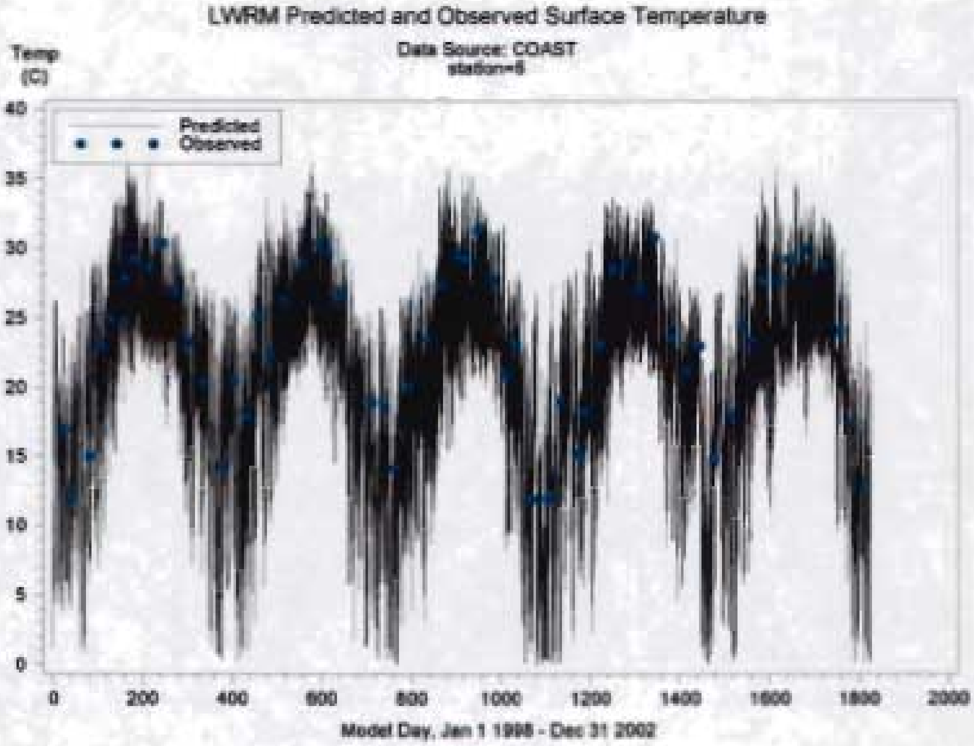

LWRM Predicted and Observed Surface Salinity
Data Source: COAST
station=8
Sal
(ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day, Jan 1 1998 - Dec 31 2002

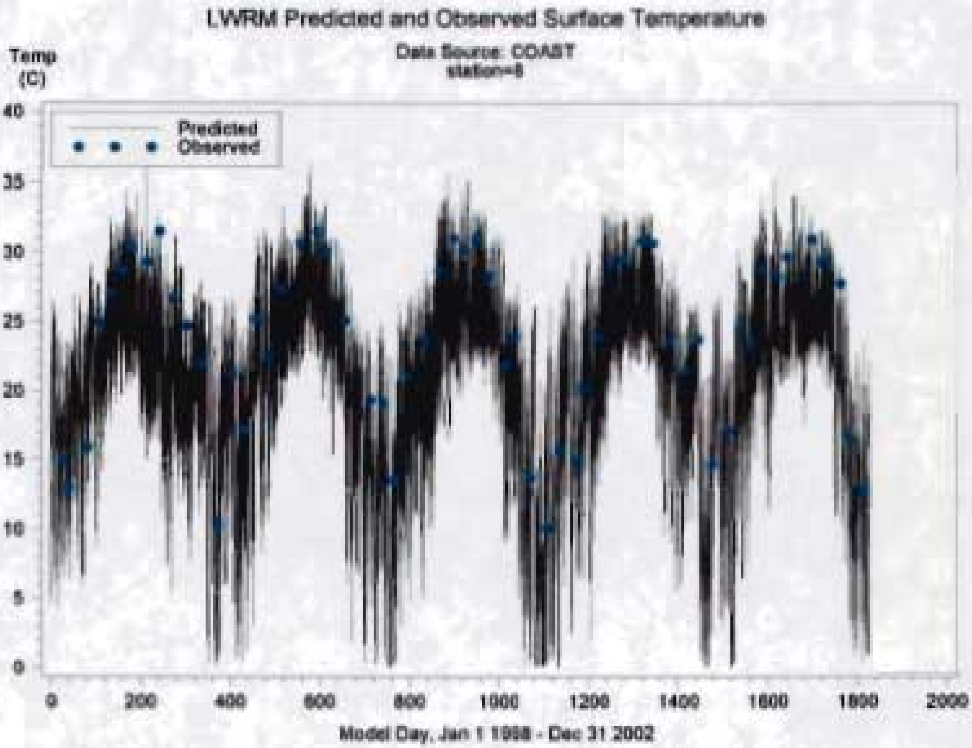

LWRM Predicted and Observed Surface Salinity
Data Source: COAST
station=9
Sal
(ppt)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day, Jan 1 1998 - Dec 31 2002

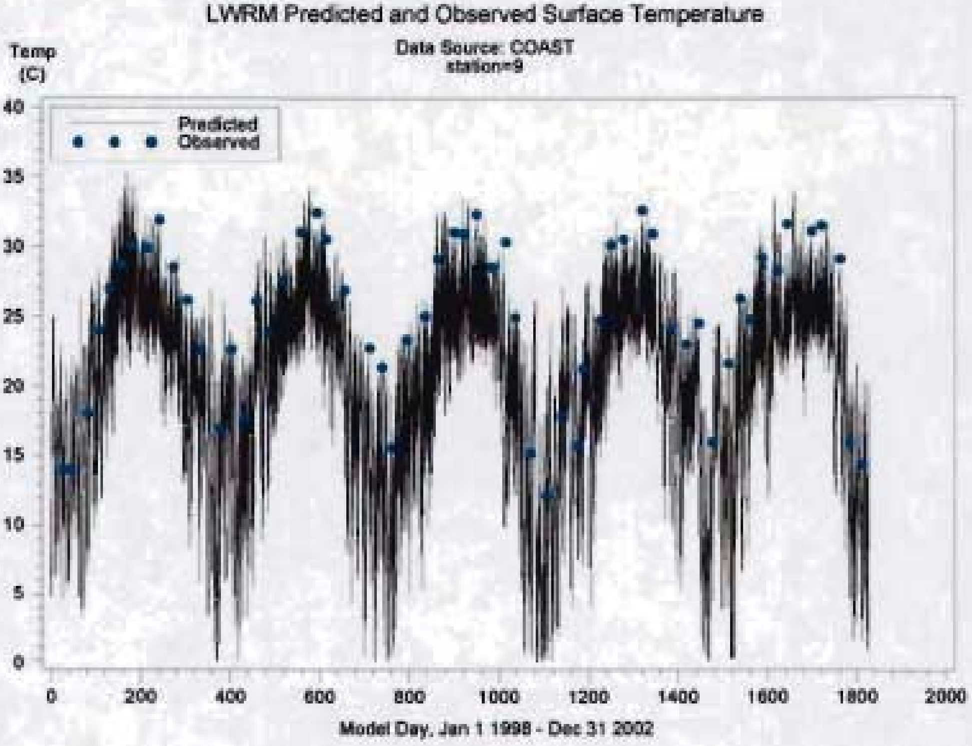
# Appendix A.6
# LWRM: Time Series Predicted and Observed Surface Temperature at COAST Sites
# 1998-2002


LWRM Predicted and Observed Surface Temperature
Data Source: COAST
station=3
Temp (C)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day, Jan 1 1998 - Dec 31 2002

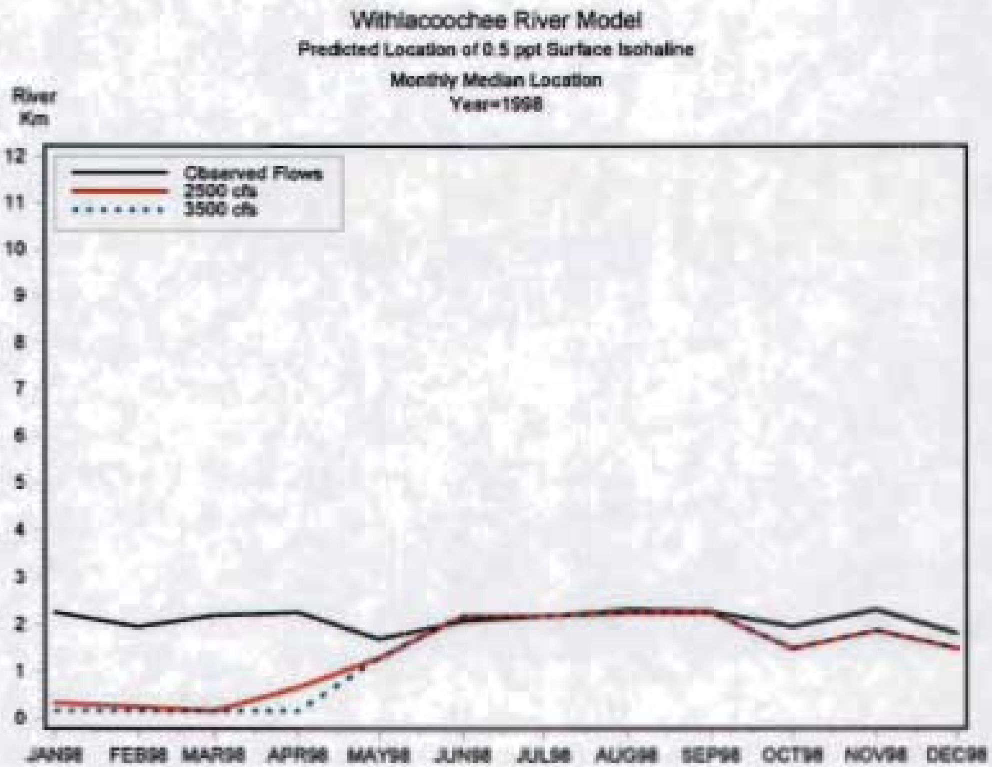

LWRM Predicted and Observed Surface Temperature
Data Source: COAST
station=5
Temp (C)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day, Jan 1 1998 - Dec 31 2002

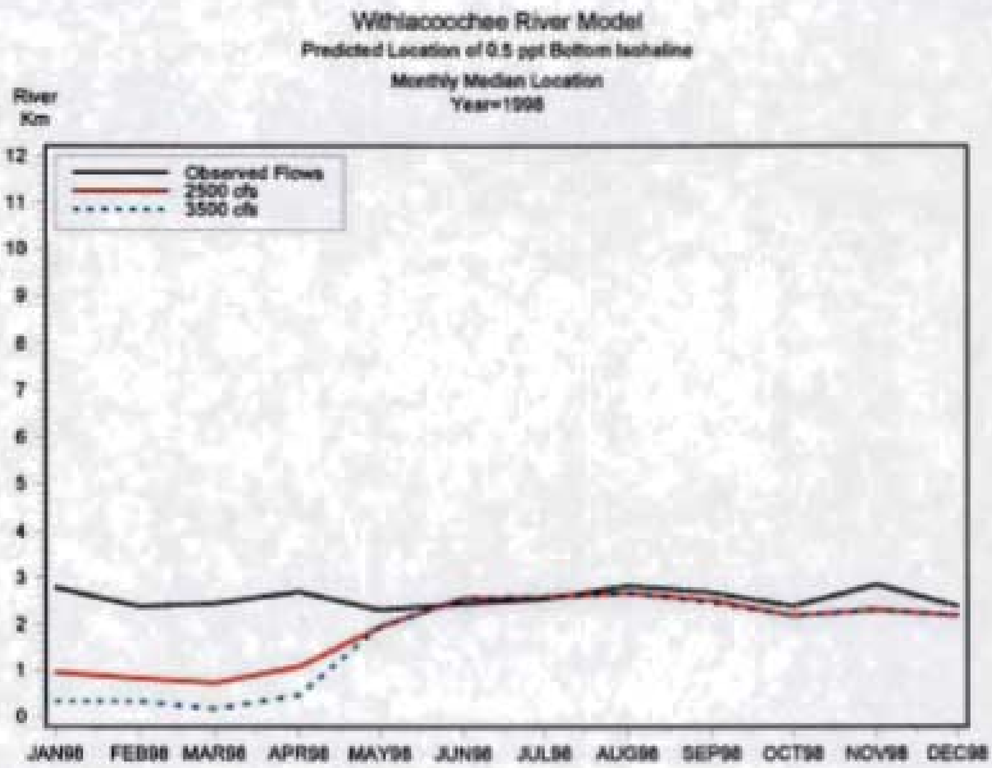

LWRM Predicted and Observed Surface Temperature
Data Source: COAST
station=8
Temp
(C)
40
35
30
25
20
15
10
5
0
Predicted
Observed
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day, Jan 1 1998 - Dec 31 2002


LWRM Predicted and Observed Surface Temperature
Data Source: COAST
station=8
Temp
(C)
40
35
30
25
20
15
10
5
0
Predicted
Observed
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day, Jan 1 1998 - Dec 31 2002

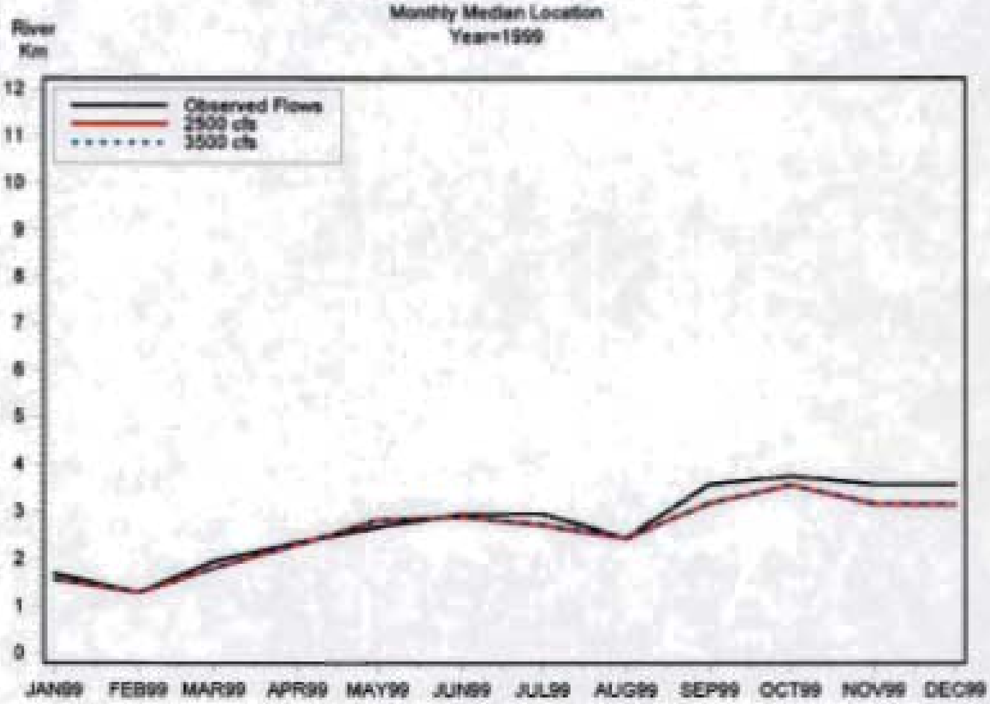

LWRM Predicted and Observed Surface Temperature
Data Source: COAST
station=9
Temp (C)
Predicted
Observed
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Model Day, Jan 1 1998 - Dec 31 2002

# Appendix B
## LWRM Scenarios: Monthly Median Locations of 0.5, 2, 3, and 5 ppt Surface and Bottom Isohalines, by Year, 1998-2002

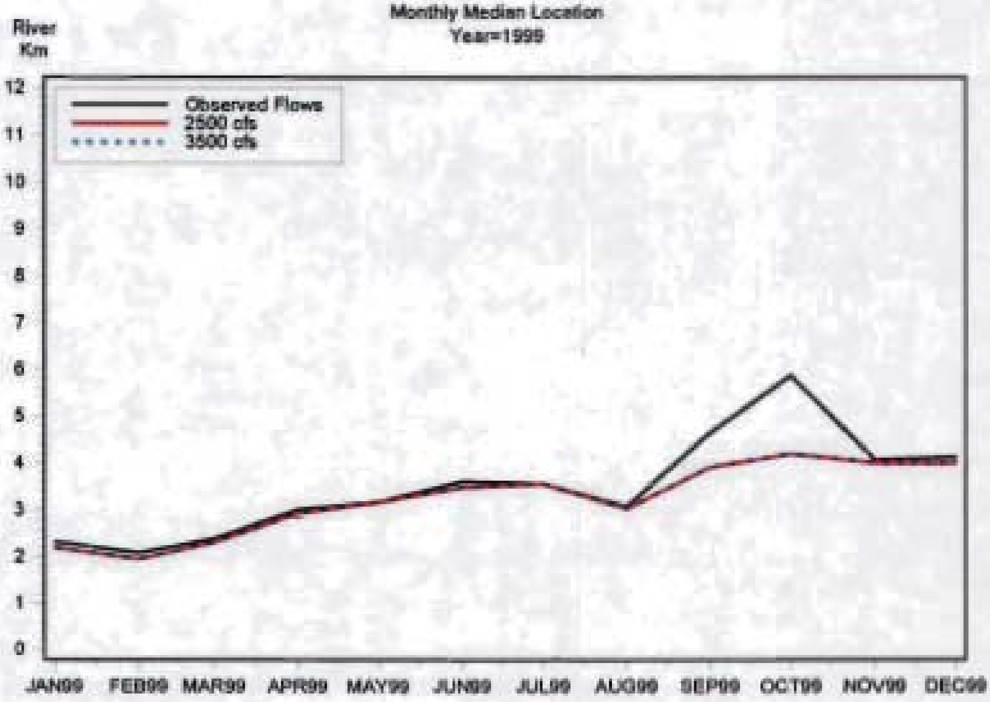

Withlacoochee River Model
Predicted Location of 0.5 ppt Surface Isohaline
Monthly Median Location
Year=1998
River Km
Observed Flows
2500 cfs
3500 cfs
JAN98
FEB98
MAR98
APR98
MAY98
JUN98
JUL98
AUG98
SEP98
OCT98
NOV98
DEC98

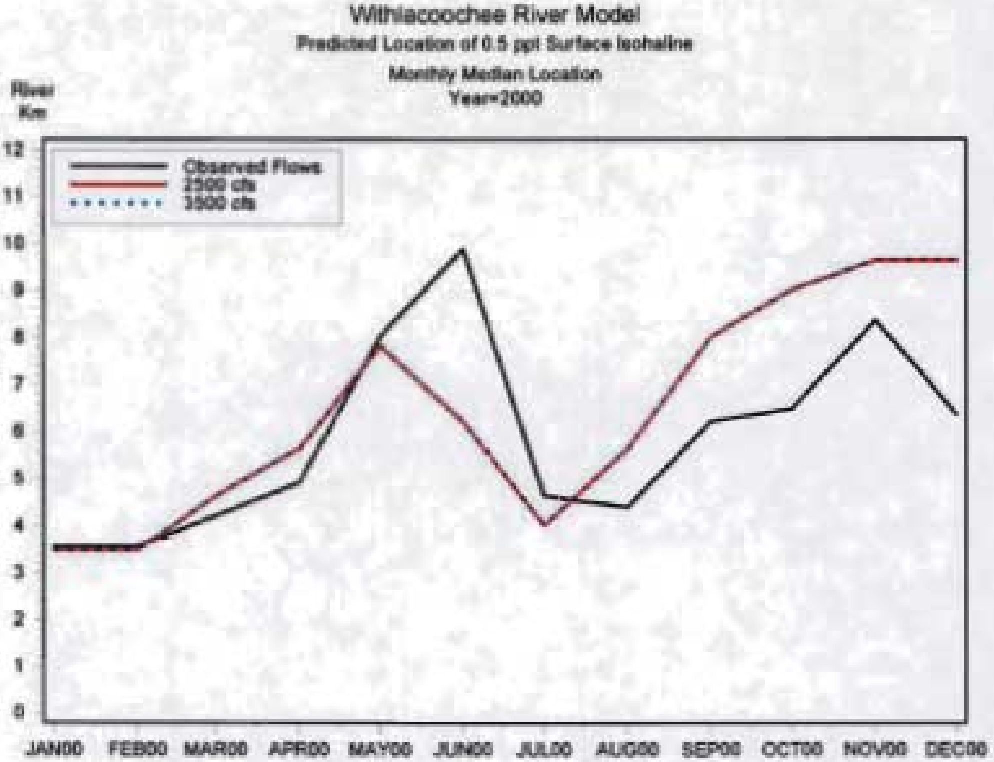

Withlacoochee River Model
Predicted Location of 0.5 ppt Bottom Isohaline
Monthly Median Location
Year=1998
River Km
Observed Flows
2500 cfs
3500 cfs
JAN98
FEB98
MAR98
APR98
MAY98
JUN98
JUL98
AUG98
SEP98
OCT98
NOV98
DEC98

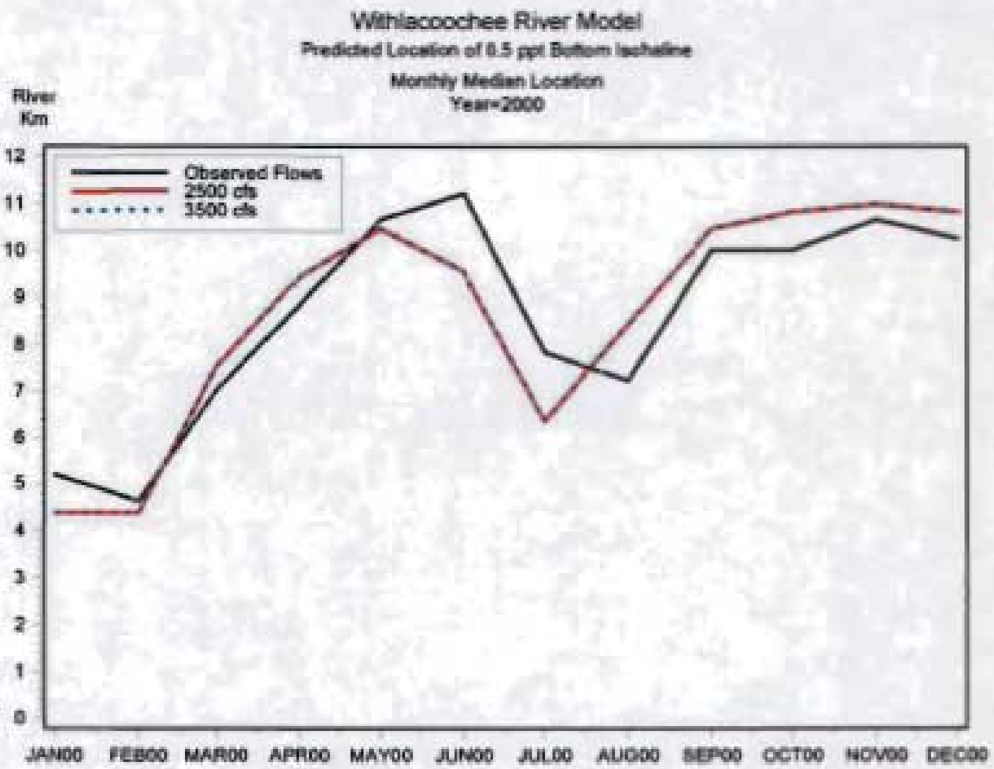
Withlacoochee River Model
Predicted Location of 0.5 ppt Surface Isohaline
Monthly Median Location
Year=1999

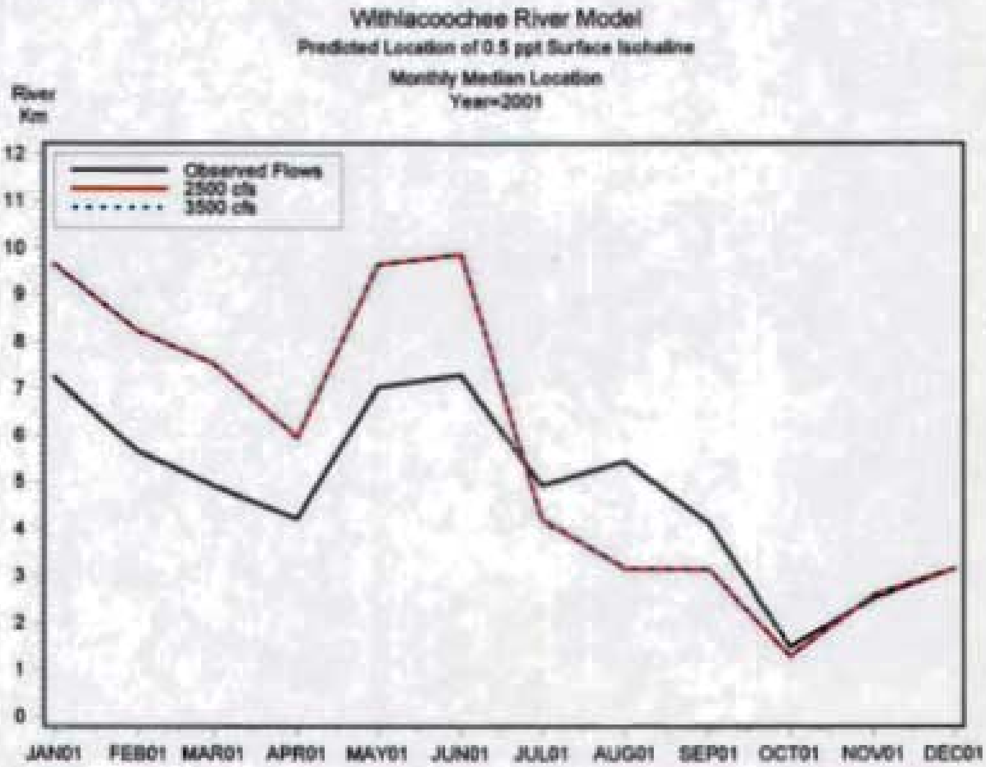


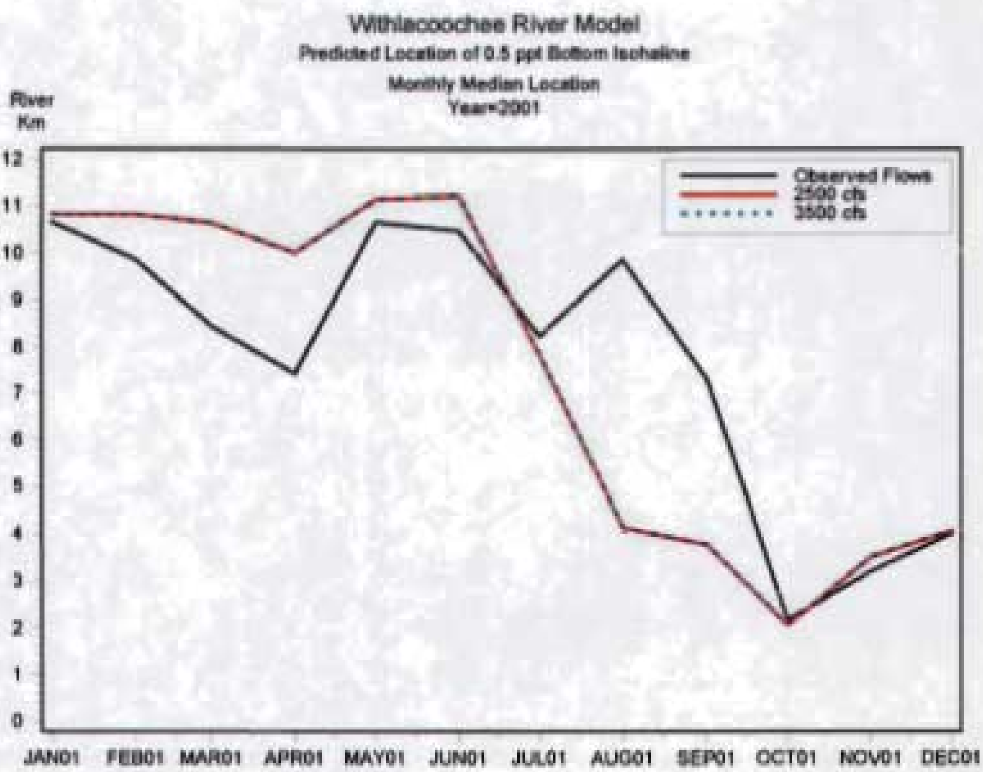

Withlacoochee River Model
Predicted Location of 0.5 ppt Bottom Isohaline
Monthly Median Location
Year=1999

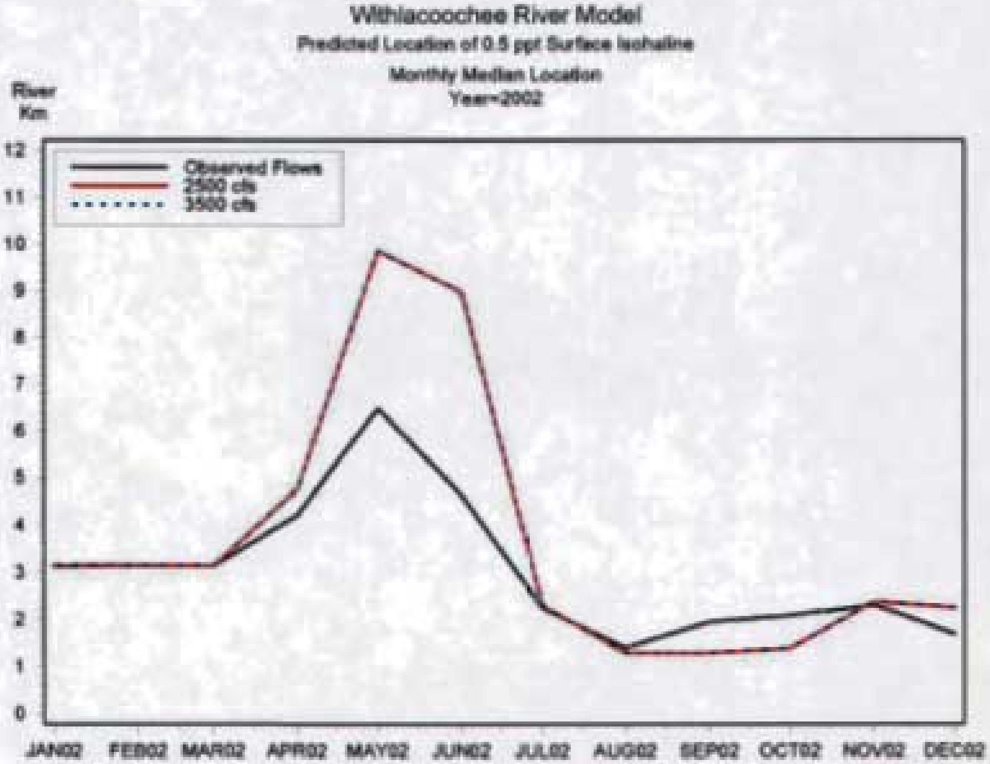



Withlacoochee River Model
Predicted Location of 0.5 ppt Surface Isohaline
Monthly Median Location
Year=2000
River Km
Observed Flows
2500 cfs
3500 cfs
JAN00
FEB00
MAR00
APR00
MAY00
JUN00
JUL00
AUG00
SEP00
OCT00
NOV00
DEC00

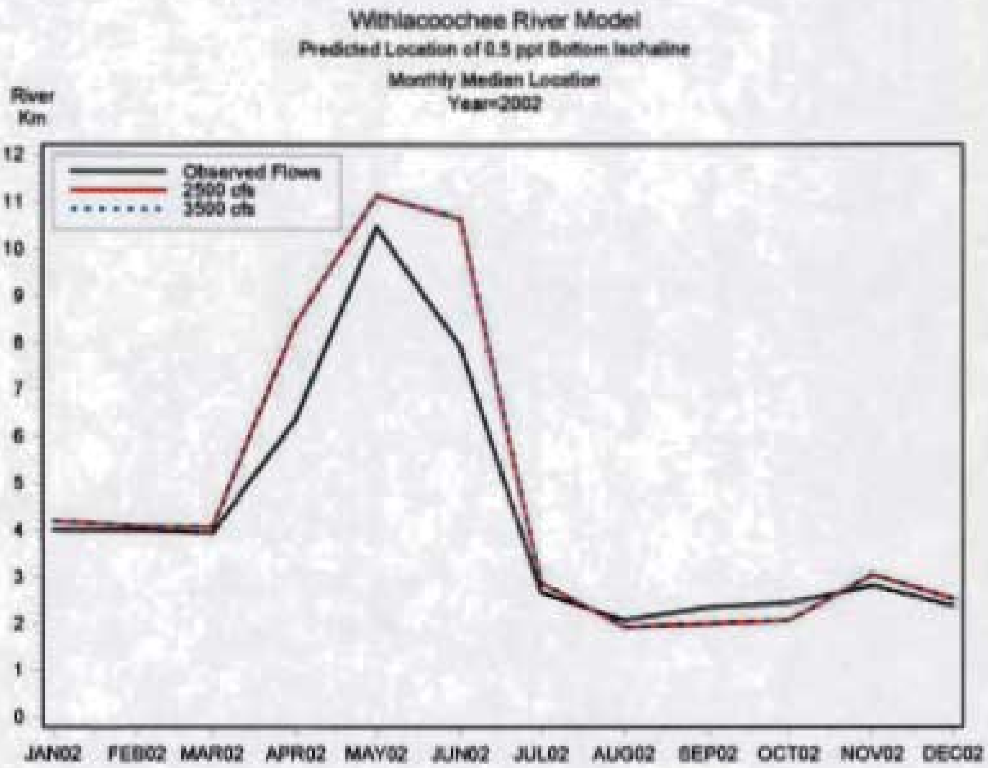

Withlacoochee River Model
Predicted Location of 0.5 ppt Bottom Isohaline
Monthly Median Location
Year=2000
River Km
Observed Flows
2500 cfs
3500 cfs
JAN00
FEB00
MAR00
APR00
MAY00
JUN00
JUL00
AUG00
SEP00
OCT00
NOV00
DEC00


Withlacoochee River Model
Predicted Location of 0.5 ppt Surface Isohaline
Monthly Median Location
Year=2001
River Km
Observed Flows
2500 cfs
3500 cfs
12
11
10
9
8
7
6
5
4
3
2
1
0
JAN01
FEB01
MAR01
APR01
MAY01
JUN01
JUL01
AUG01
SEP01
OCT01
NOV01
DEC01


Withlacoochee River Model
Predicted Location of 0.5 ppt Bottom Isohaline
Monthly Median Location
Year=2001
River Km
Observed Flows
2500 cfs
3500 cfs
12
11
10
9
8
7
6
5
4
3
2
1
0
JAN01
FEB01
MAR01
APR01
MAY01
JUN01
JUL01
AUG01
SEP01
OCT01
NOV01
DEC01



Withlacoochee River Model
Predicted Location of 0.5 ppt Surface Isohaline
Monthly Median Location
Year=2002
River Km
Observed Flows
2500 cfs
3500 cfs
12
11
10
9
8
7
6
5
4
3
2
1
0
JAN02
FEB02
MAR02
APR02
MAY02
JUN02
JUL02
AUG02
SEP02
OCT02
NOV02
DEC02

Withlacoochee River Model
Predicted Location of 0.5 ppt Bottom Isohaline
Monthly Median Location
Year=2002
River Km
Observed Flows
2500 cfs
3500 cfs
12
11
10
9
8
7
6
5
4
3
2
1
0
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FEB02
MAR02
APR02
MAY02
JUN02
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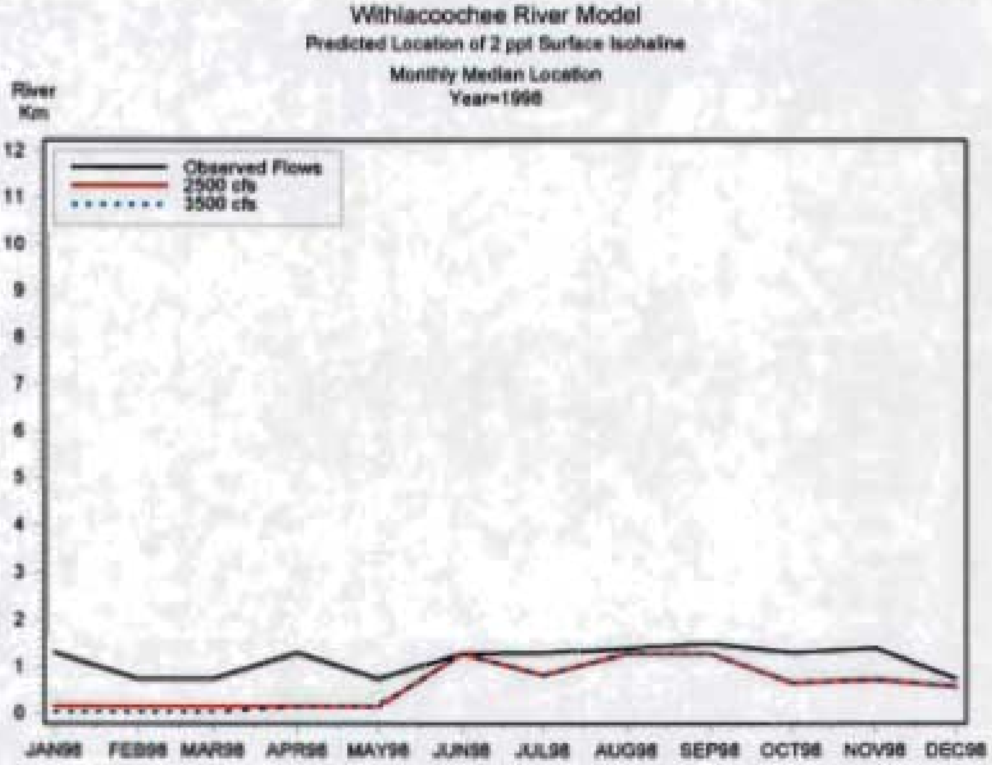
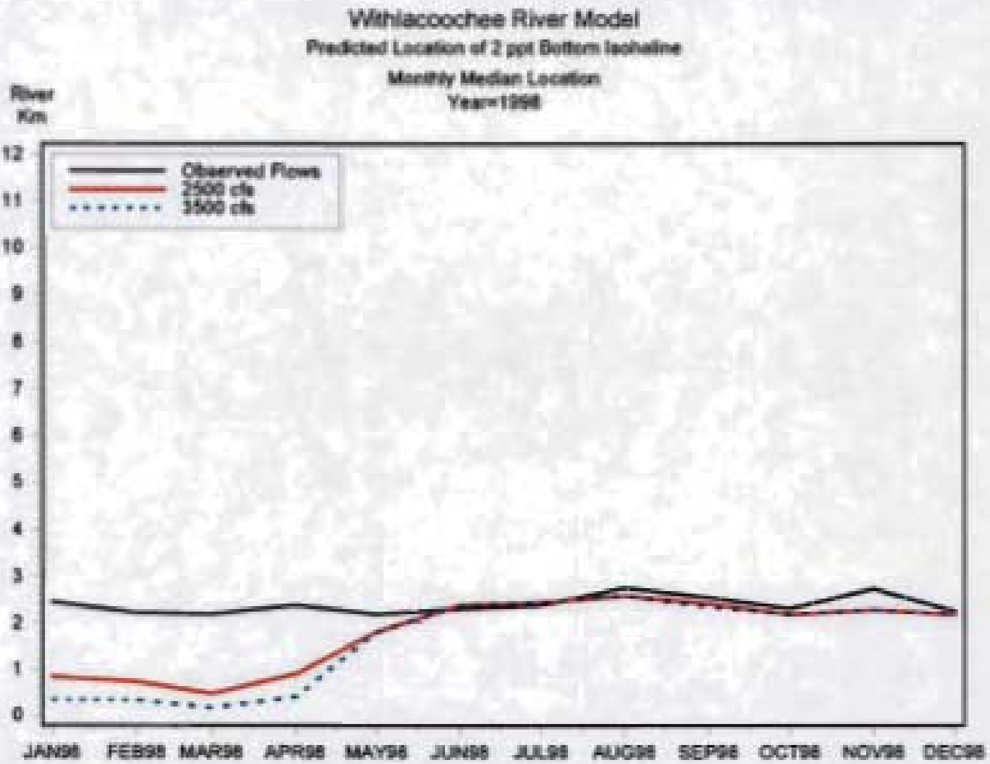
AUG02
SEP02
OCT02
NOV02
DEC02


Withlacoochee River Model
Predicted Location of 2 ppt Surface Isohaline
Monthly Median Location
Year=1998
River Km
Observed Flows
2500 cfs
3500 cfs
JAN98 FEB98 MAR98 APR98 MAY98 JUN98 JUL98 AUG98 SEP98 OCT98 NOV98 DEC98


Withlacoochee River Model
Predicted Location of 2 ppt Bottom Isohaline
Monthly Median Location
Year=1998
River Km
Observed Flows
2500 cfs
3500 cfs
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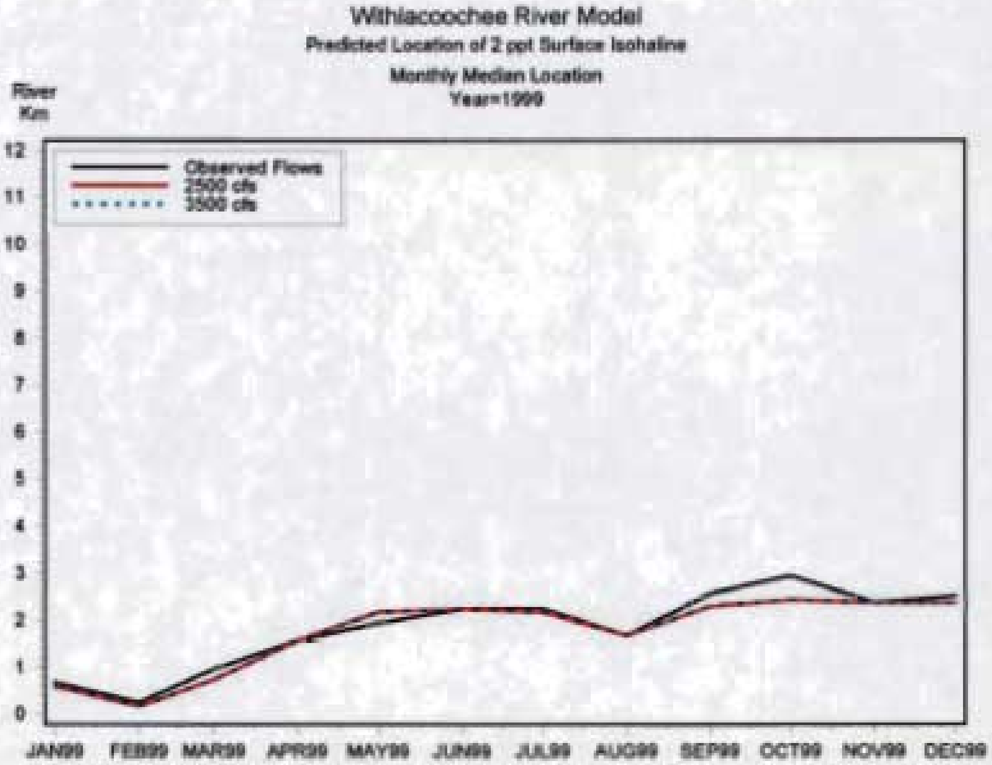
Withlacoochee River Model
Predicted Location of 2 ppt Surface Isohaline
Monthly Median Location
Year=1999
River Km
Observed Flows
2500 cfs
3500 cfs
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FEB99
MAR99
APR99
MAY99
JUN99
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AUG99
SEP99
OCT99
NOV99
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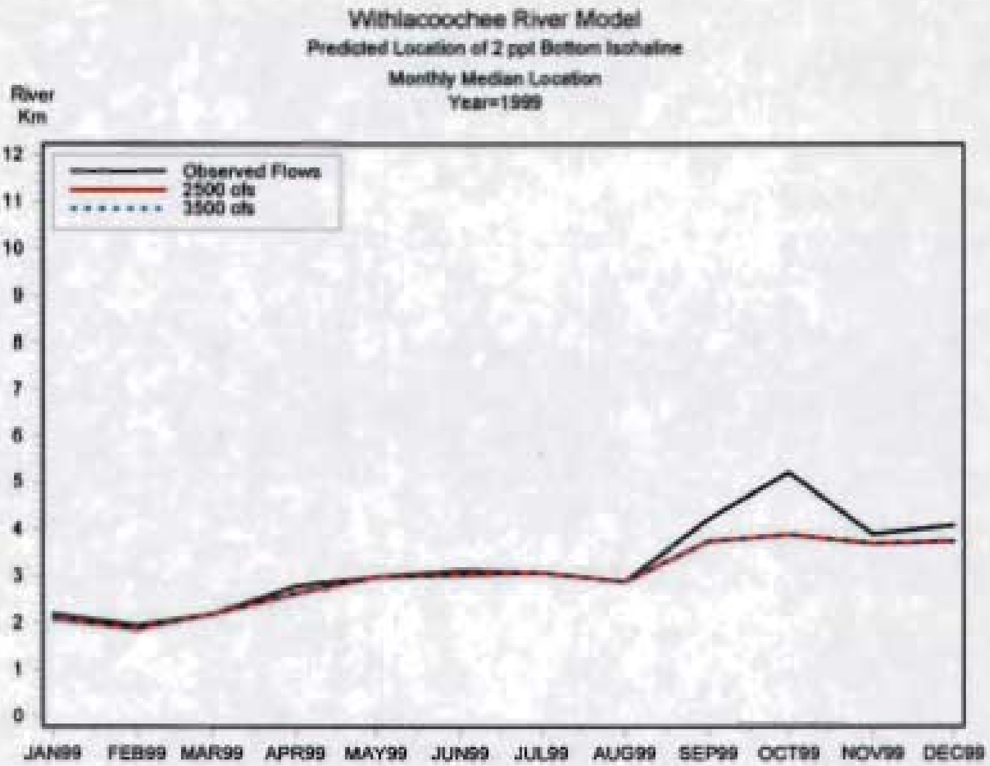
Withlacoochee River Model
Predicted Location of 2 ppt Bottom Isohaline
Monthly Median Location
Year=1999
River Km
Observed Flows
2500 cfs
3500 cfs
JAN99
FEB99
MAR99
APR99
MAY99
JUN99
JUL99
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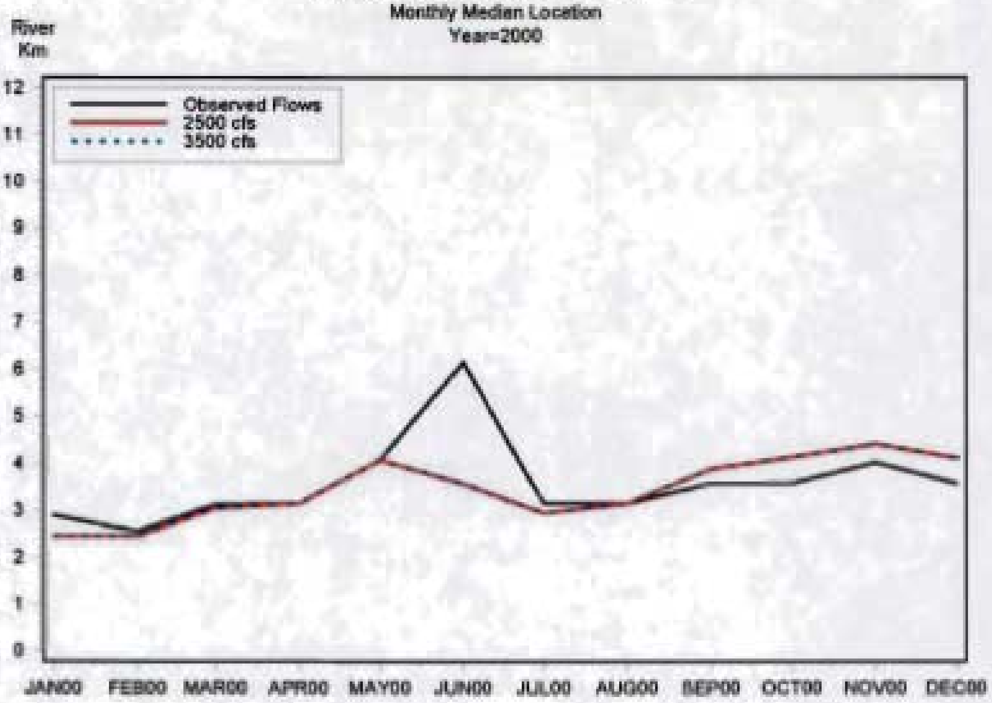
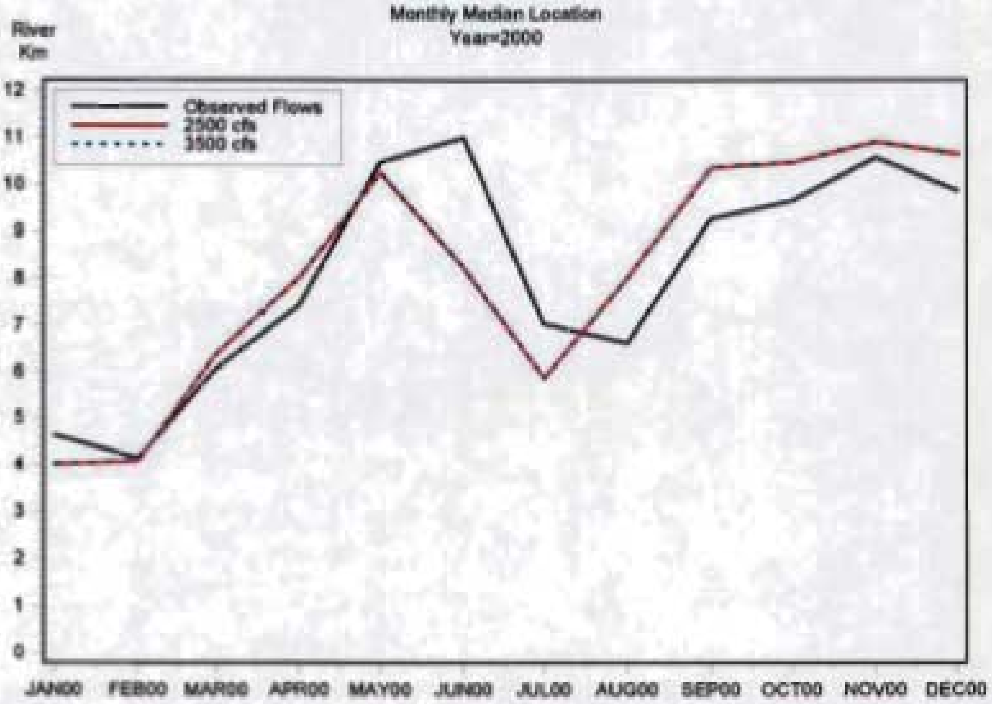
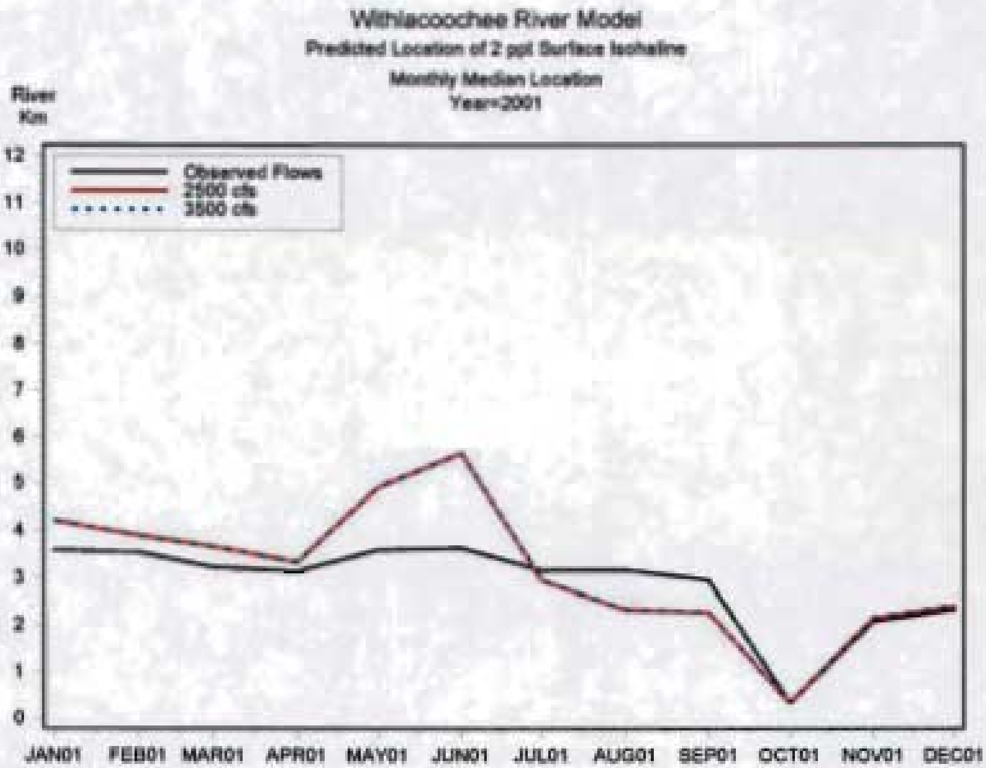
OCT99
NOV99
DEC99

Withlacoochee River Model
Predicted Location of 2 ppt Surface Isohaline
Monthly Median Location
Year=2000

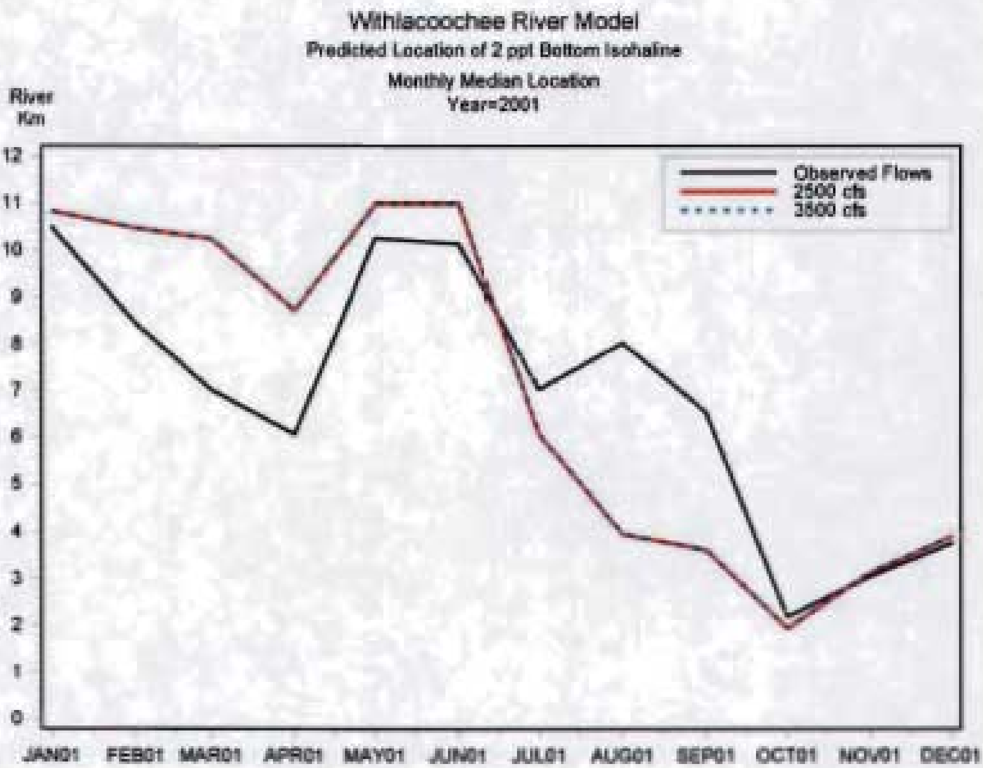



Withlacoochee River Model
Predicted Location of 2 ppt Bottom Isohaline
Monthly Median Location
Year=2000





Withlacoochee River Model
Predicted Location of 2 ppt Surface Isohaline
Monthly Median Location
Year=2001
River Km
Observed Flows
2500 cfs
3500 cfs
0
1
2
3
4
5
6
7
8
9
10
11
12
JAN01
FEB01
MAR01
APR01
MAY01
JUN01
JUL01
AUG01
SEP01
OCT01
NOV01
DEC01

Withlacoochee River Model
Predicted Location of 2 ppt Bottom Isohaline
Monthly Median Location
Year=2001
River Km
Observed Flows
2500 cfs
3500 cfs
0
1
2
3
4
5
6
7
8
9
10
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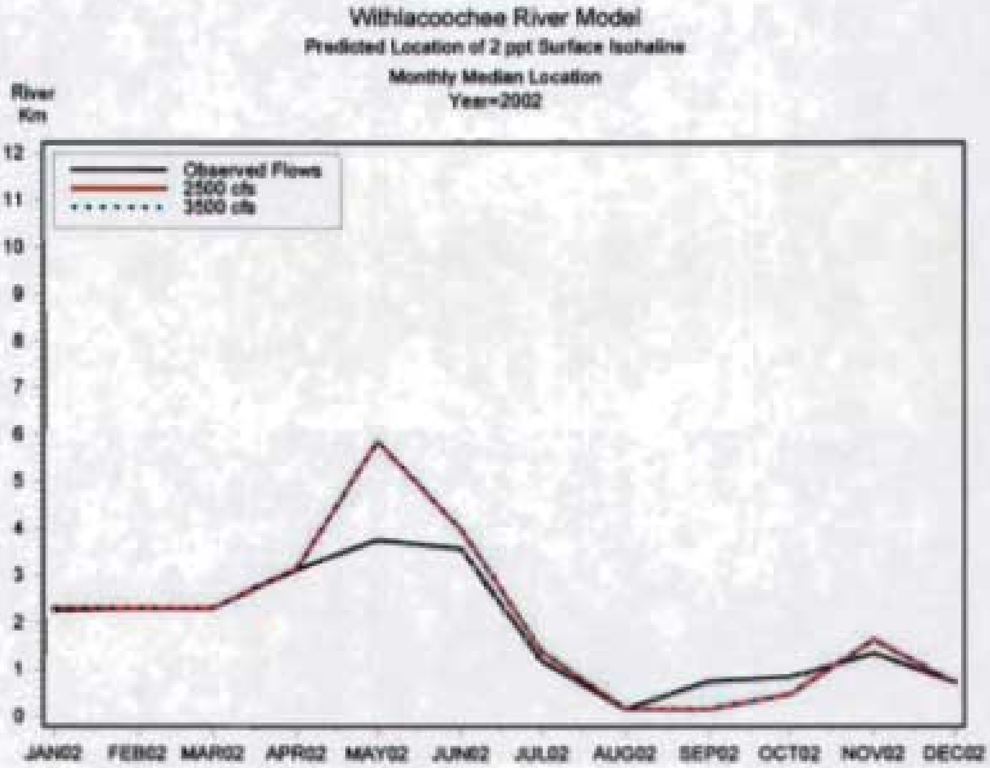
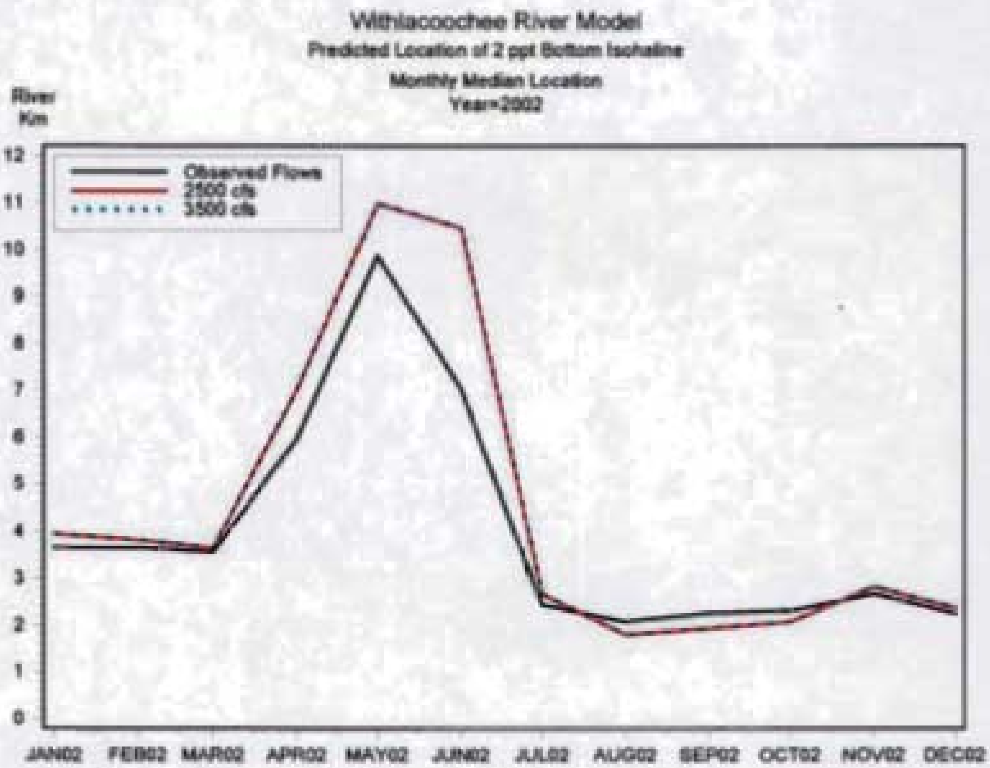
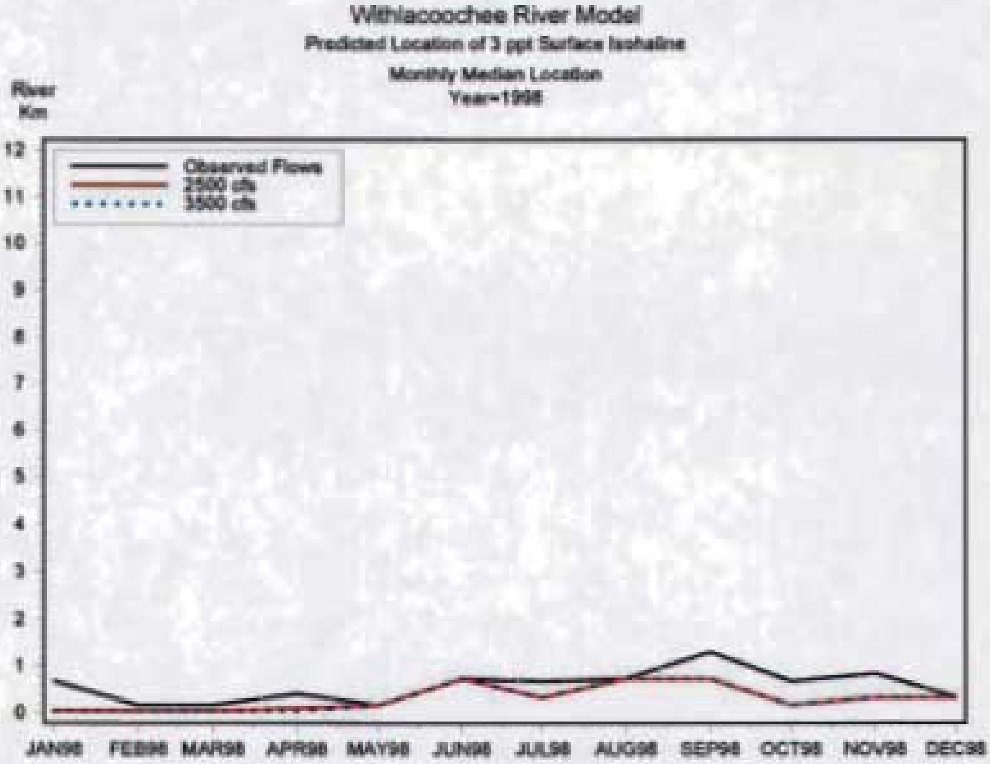
OCT01
NOV01
DEC01



Withlacoochee River Model
Predicted Location of 2 ppt Surface Isohaline
Monthly Median Location
Year=2002
River Km
Observed Flows
2500 cfs
3500 cfs
JAN02 FEB02 MAR02 APR02 MAY02 JUN02 JUL02 AUG02 SEP02 OCT02 NOV02 DEC02

Withlacoochee River Model
Predicted Location of 2 ppt Bottom Isohaline
Monthly Median Location
Year=2002
River Km
Observed Flows
2500 cfs
3500 cfs
JAN02 FEB02 MAR02 APR02 MAY02 JUN02 JUL02 AUG02 SEP02 OCT02 NOV02 DEC02


Withlacoochee River Model
Predicted Location of 3 ppt Surface Isohaline
Monthly Median Location
Year=1998
River Km
Observed Flows
2500 cfs
3500 cfs
12
11
10
9
8
7
6
5
4
3
2
1
0
JAN98
FEB98
MAR98
APR98
MAY98
JUN98
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AUG98
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OCT98
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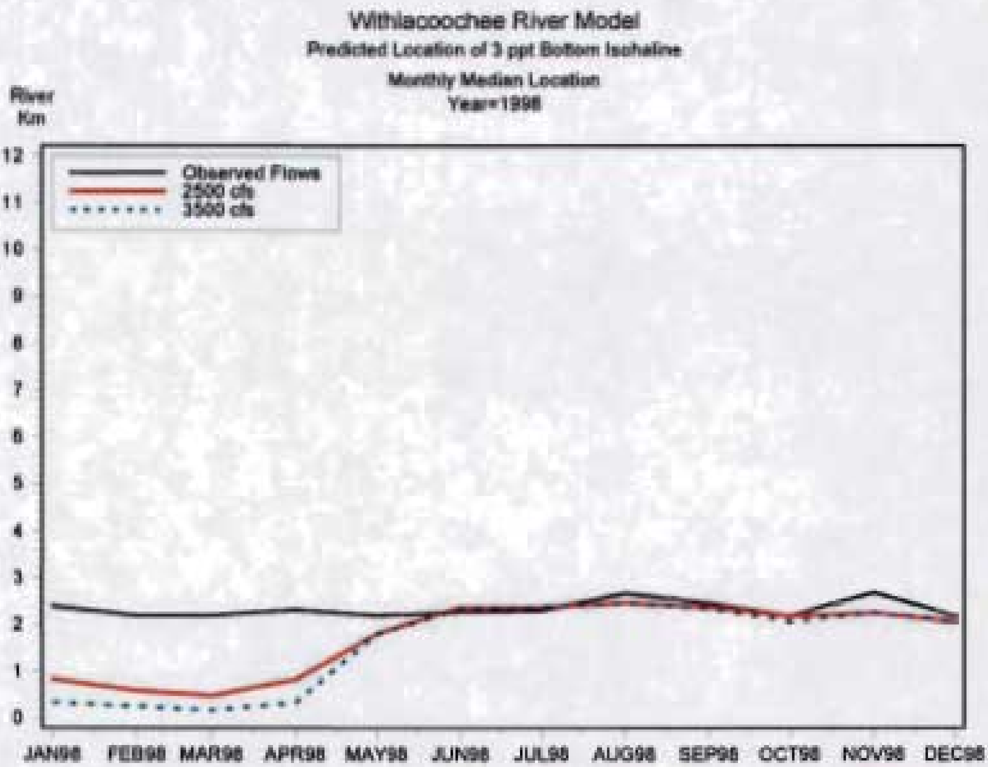
DEC98


Withlacoochee River Model
Predicted Location of 3 ppt Bottom Isohaline
Monthly Median Location
Year=1998
River Km
Observed Flows
2500 cfs
3500 cfs
12
11
10
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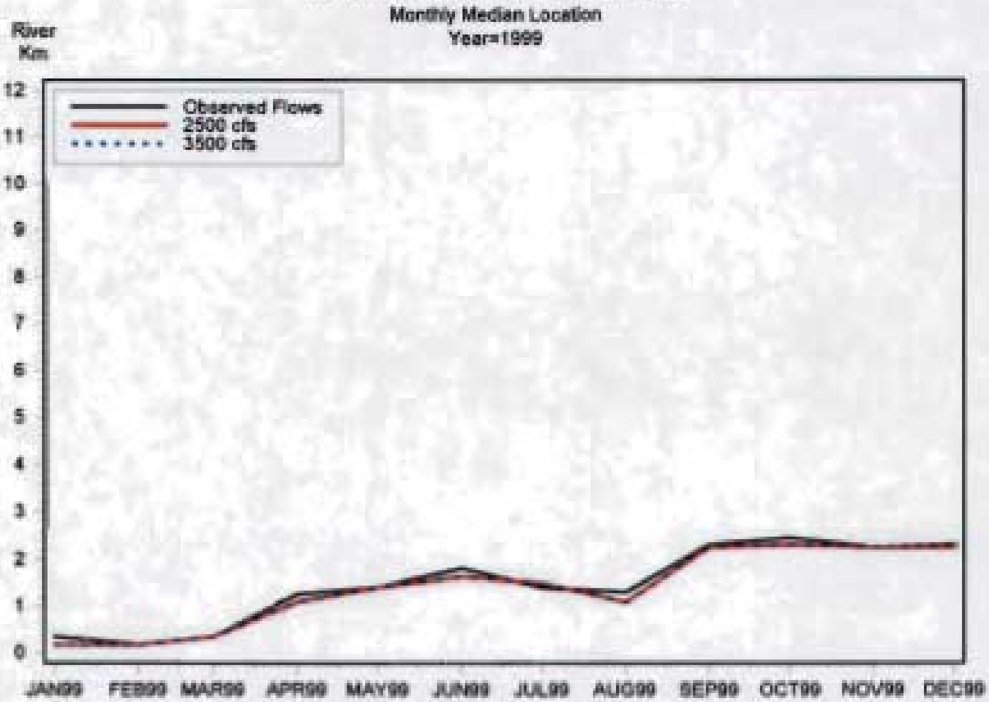
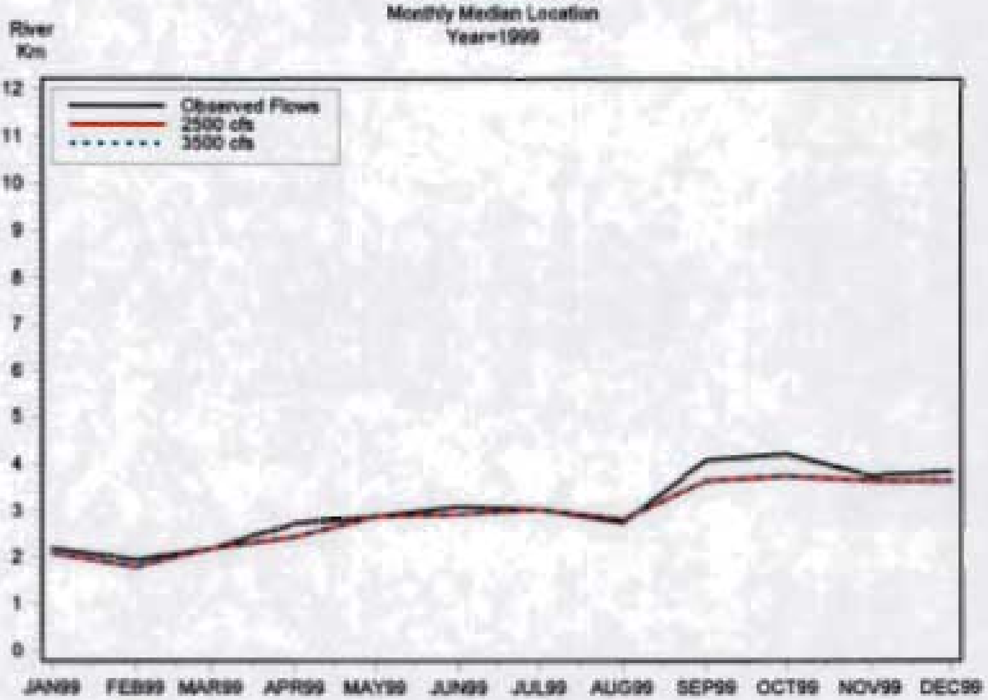
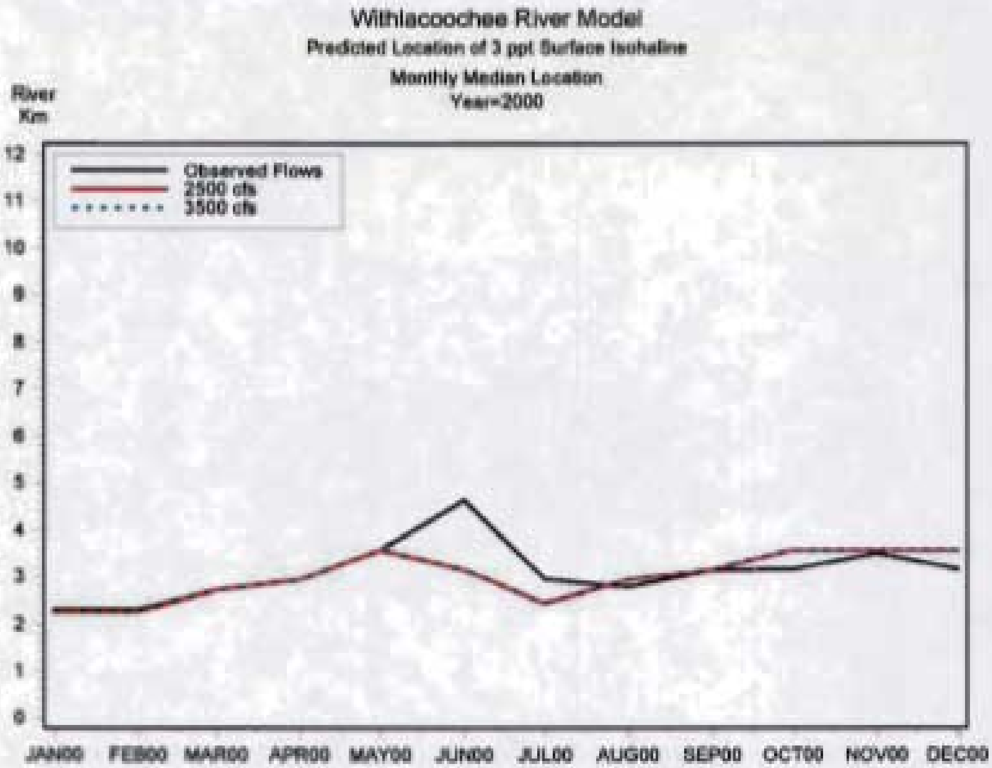
JAN98
FEB98
MAR98
APR98
MAY98
JUN98
JUL98
AUG98
SEP98
OCT98
NOV98
DEC98

Withlacoochee River Model
Predicted Location of 3 ppt Surface Isohaline
Monthly Median Location
Year=1999




Withlacoochee River Model
Predicted Location of 3 ppt Bottom Isohaline
Monthly Median Location
Year=1999




Withlacoochee River Model
Predicted Location of 3 ppt Surface Isohaline
Monthly Median Location
Year=2000
River Km
Observed Flows
2500 cfs
3500 cfs
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1
2
3
4
5
6
7
8
9
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12
JAN00
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MAR00
APR00
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AUG00
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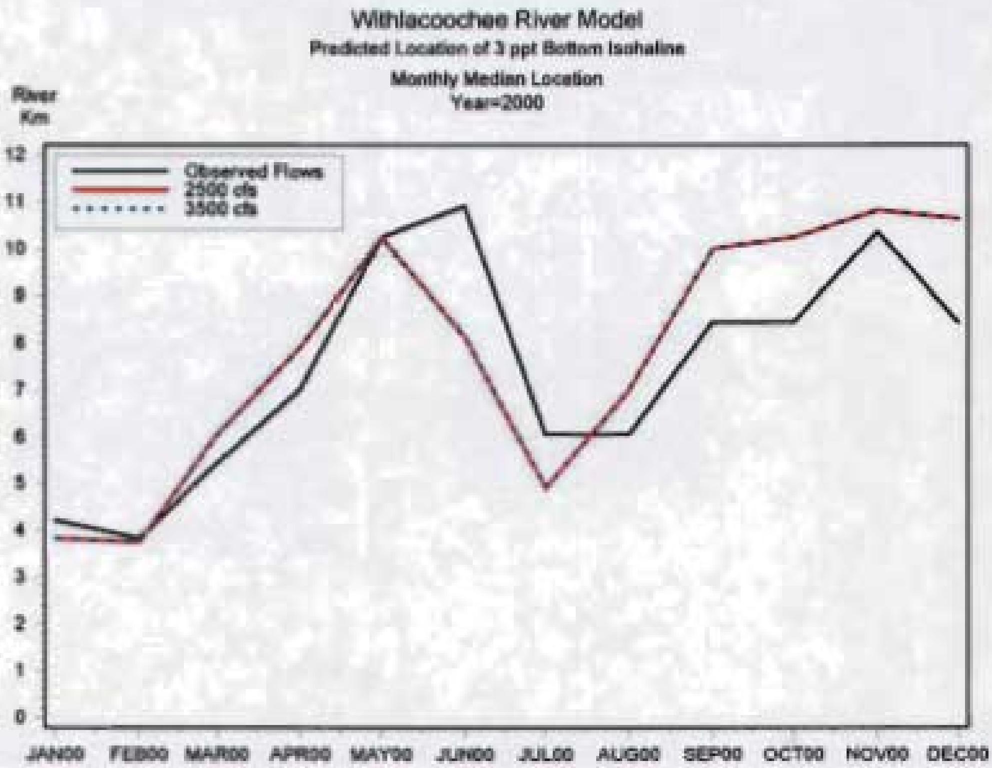
Withlacoochee River Model
Predicted Location of 3 ppt Bottom Isohaline
Monthly Median Location
Year=2000
River Km
Observed Flows
2500 cfs
3500 cfs
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1
2
3
4
5
6
7
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JAN00
FEB00
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APR00
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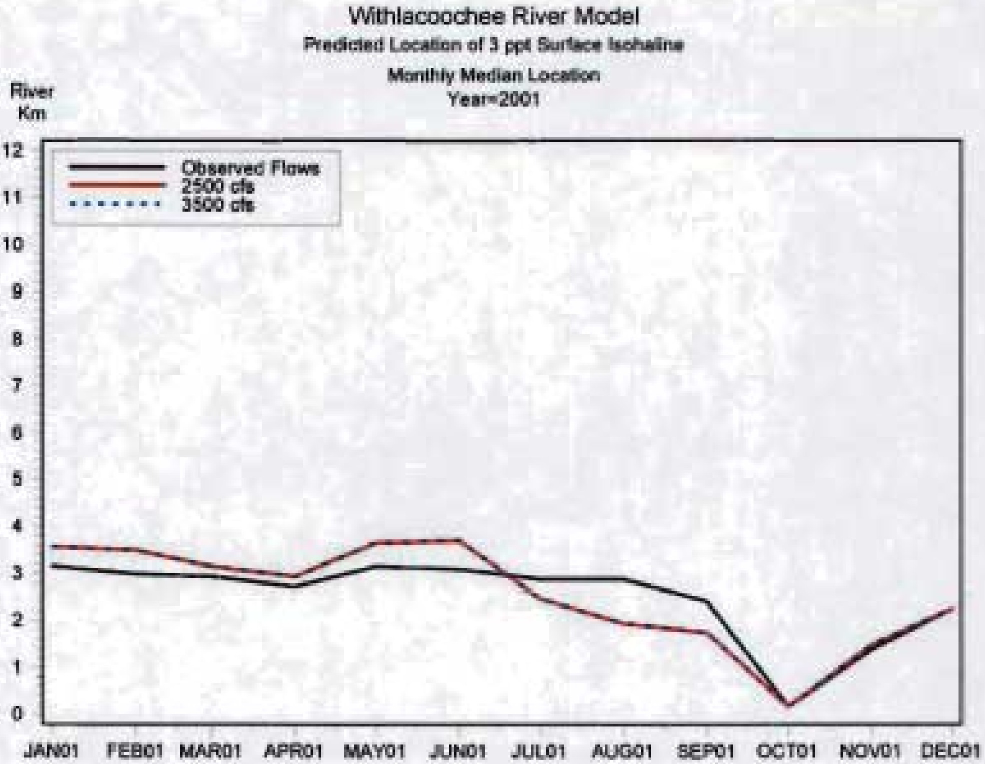
Withlacoochee River Model
Predicted Location of 3 ppt Surface Isohaline
Monthly Median Location
Year=2001
River Km
Observed Flows
2500 cfs
3500 cfs
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2
3
4
5
6
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APR01
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AUG01
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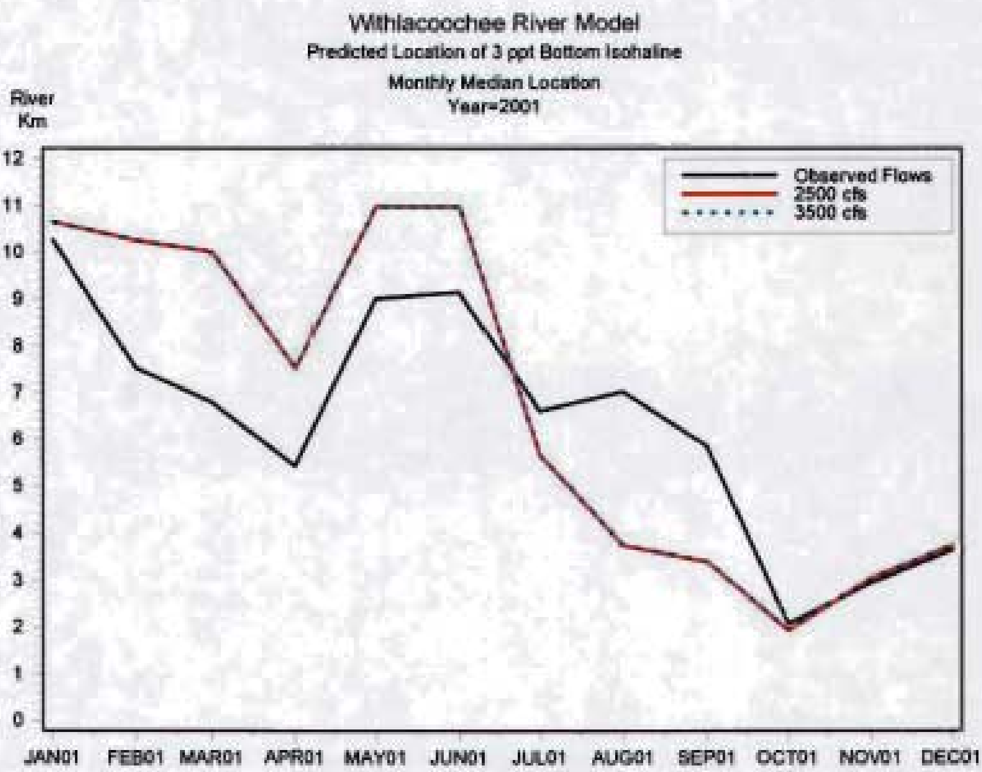
Withlacoochee River Model
Predicted Location of 3 ppt Bottom Isohaline
Monthly Median Location
Year=2001
River Km
Observed Flows
2500 cfs
3500 cfs
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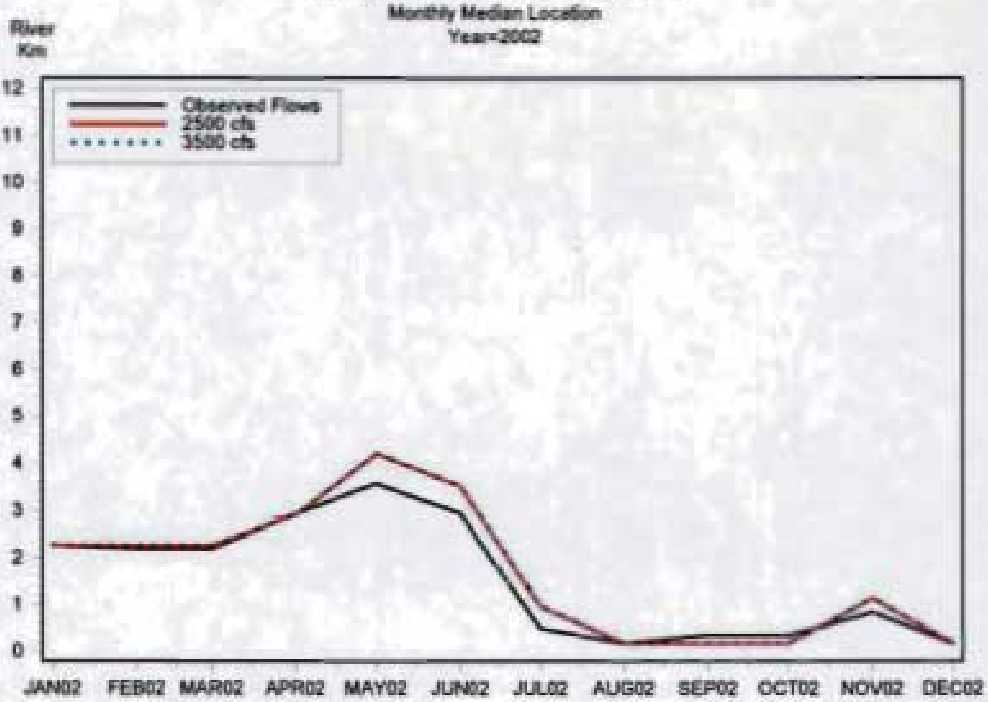
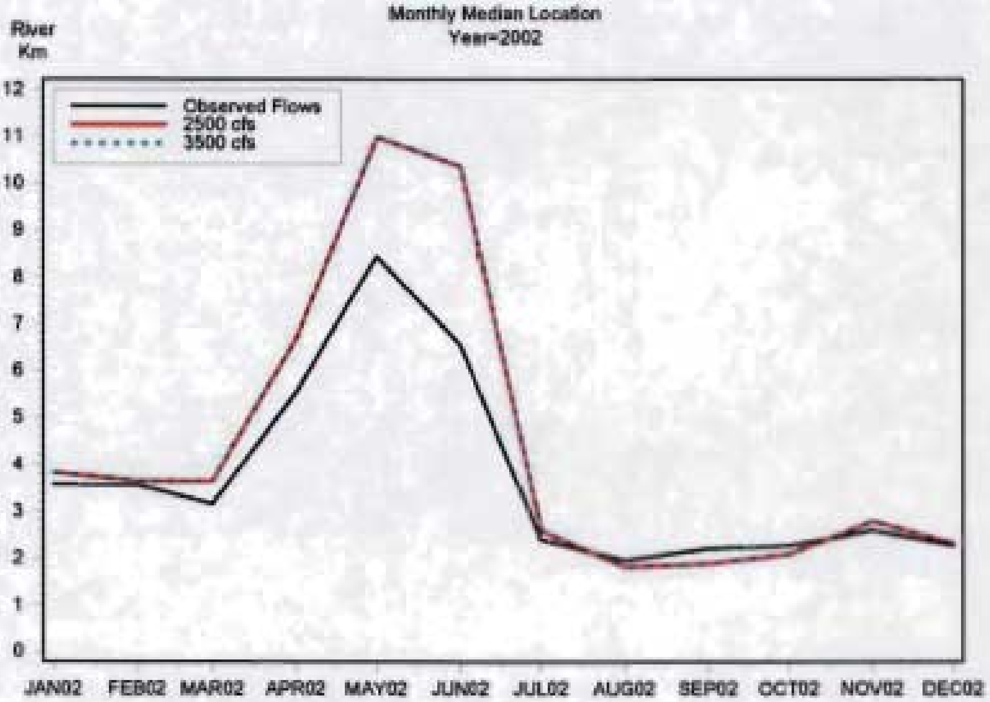
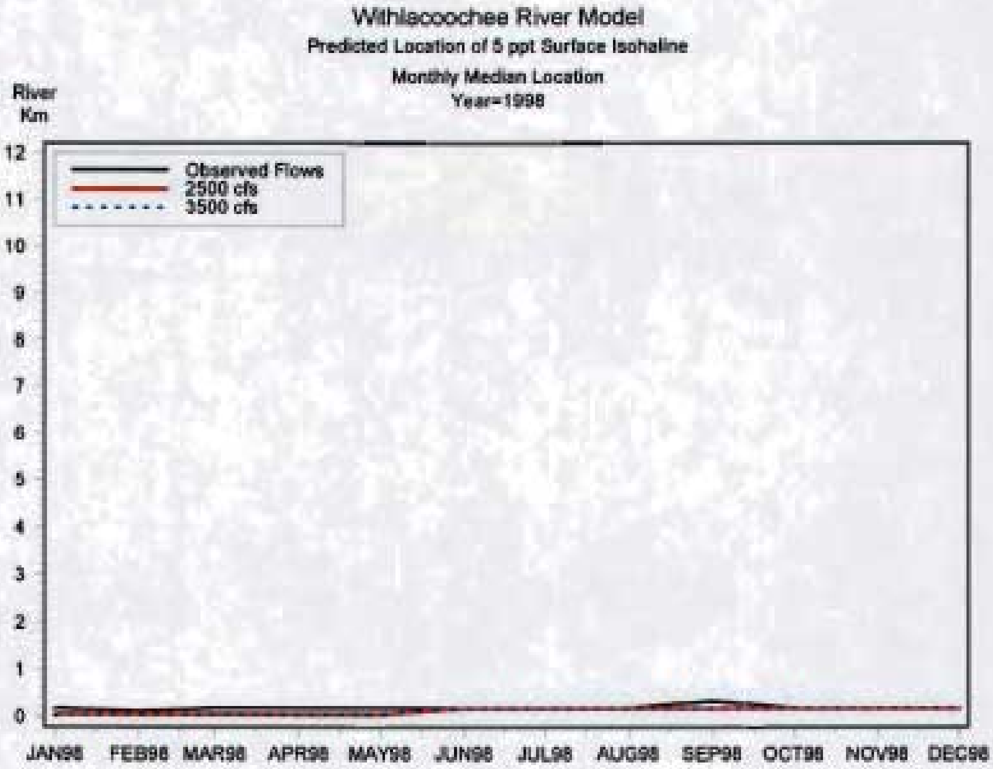
1
2
3
4
5
6
7
8
9
10
11
12
JAN01
FEB01
MAR01
APR01
MAY01
JUN01
JUL01
AUG01
SEP01
OCT01
NOV01
DEC01

Withlacoochee River Model
Predicted Location of 3 ppt Surface Isohaline
Monthly Median Location
Year=2002




Withlacoochee River Model
Predicted Location of 3 ppt Bottom Isohaline
Monthly Median Location
Year=2002




Withlacoochee River Model
Predicted Location of 5 ppt Surface Isohaline
Monthly Median Location
Year=1998
River Km
Observed Flows
2500 cfs
3500 cfs
JAN98
FEB98
MAR98
APR98
MAY98
JUN98
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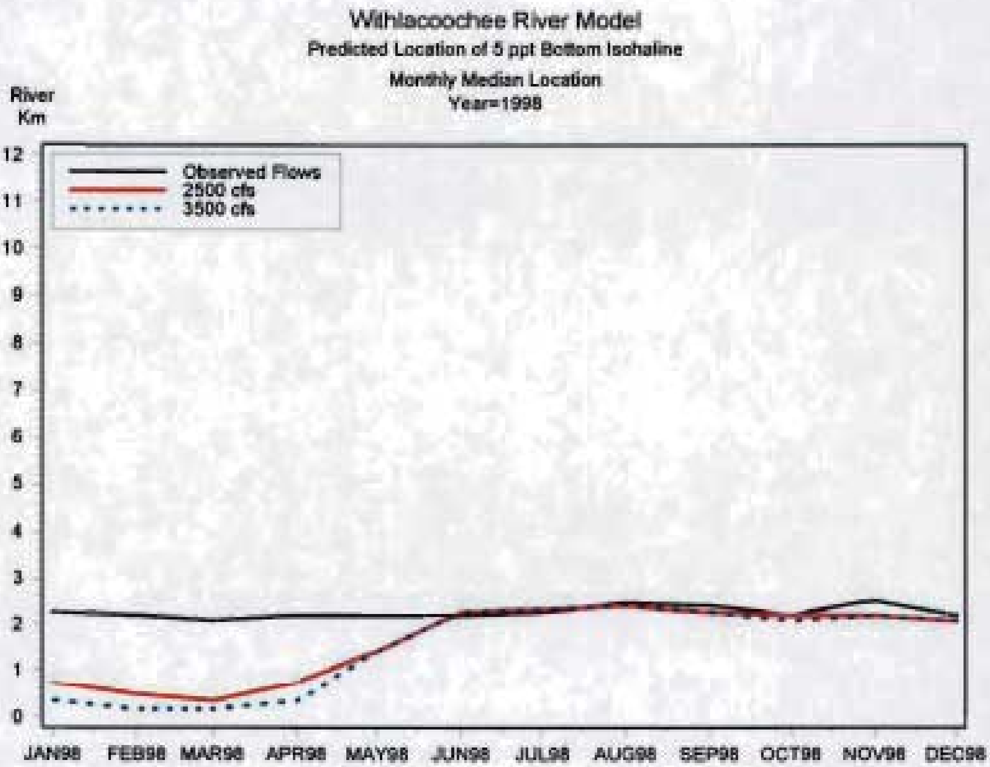
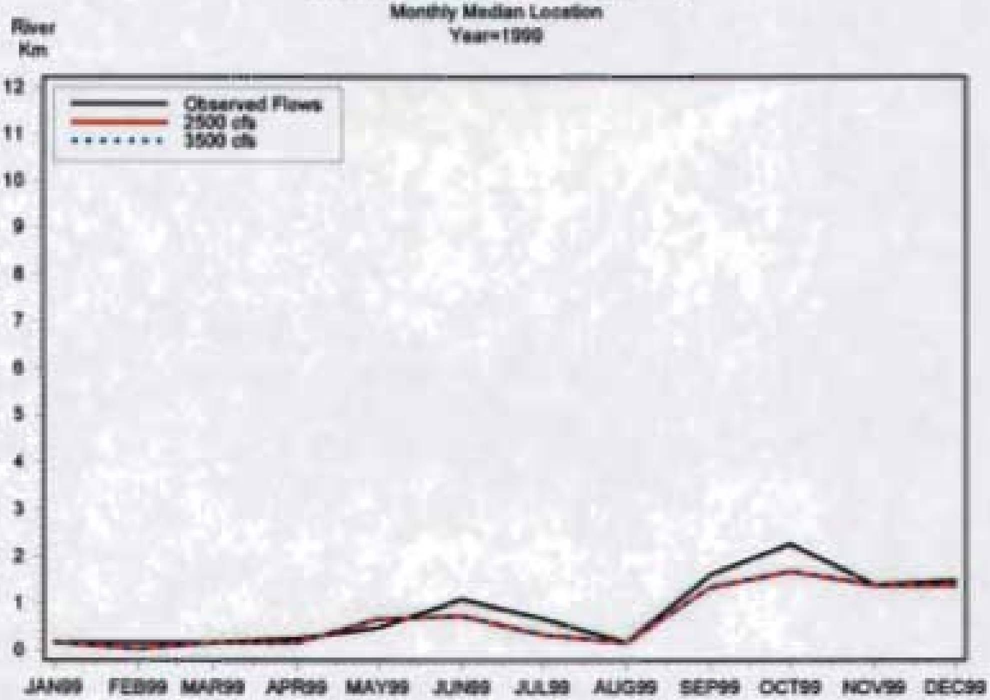
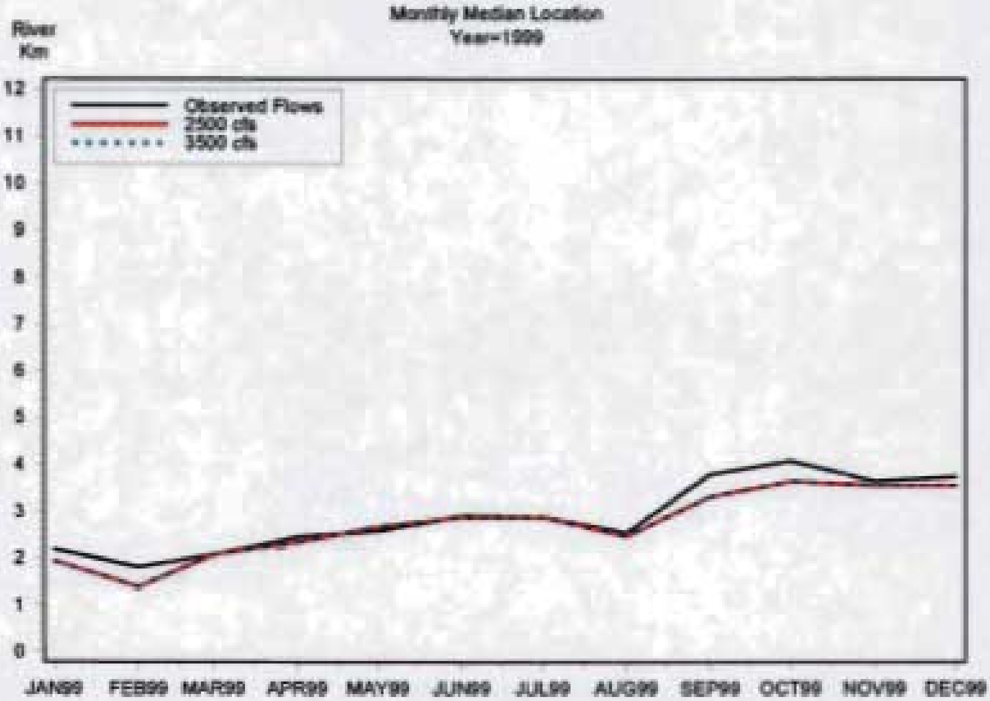
AUG98
SEP98
OCT98
NOV98
DEC98

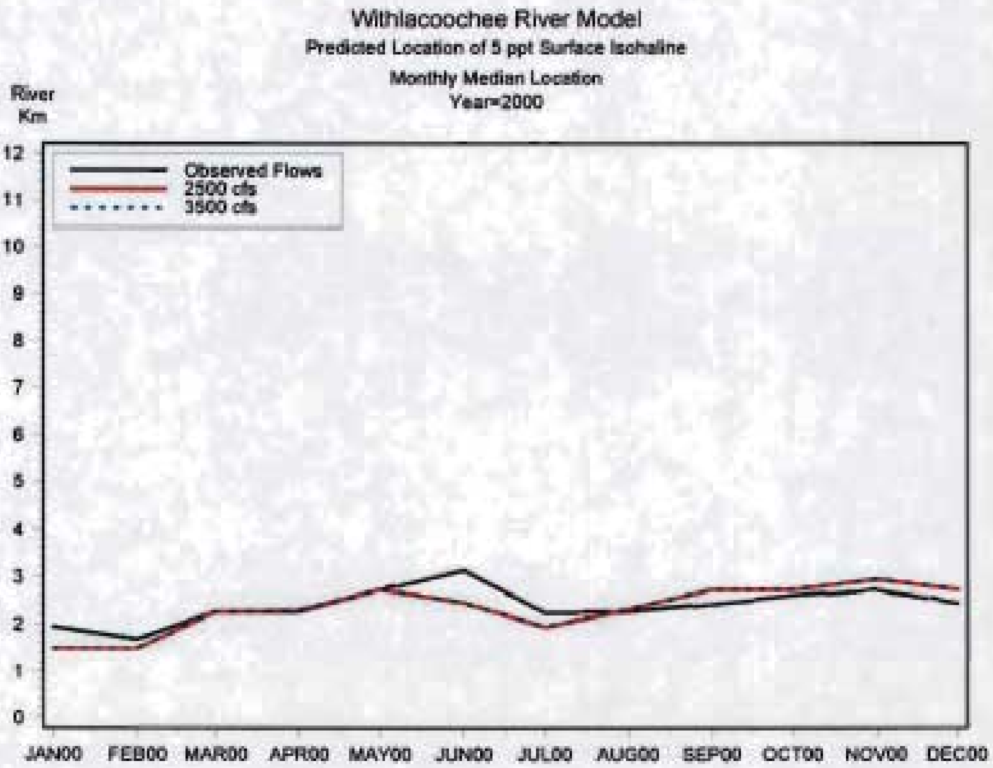

Withlacoochee River Model
Predicted Location of 5 ppt Bottom Isohaline
Monthly Median Location
Year=1998
River Km
Observed Flows
2500 cfs
3500 cfs
JAN98
FEB98
MAR98
APR98
MAY98
JUN98
JUL98
AUG98
SEP98
OCT98
NOV98
DEC98

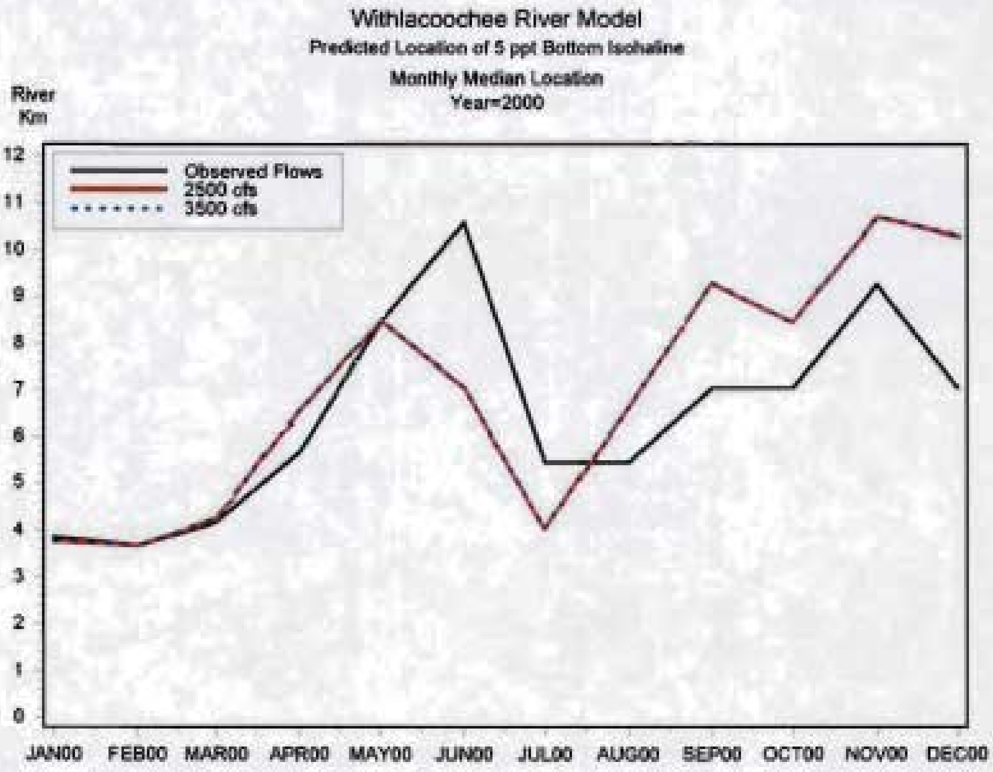
Withlacoochee River Model
Predicted Location of 5 ppt Surface Isohaline
Monthly Median Location
Year=1999

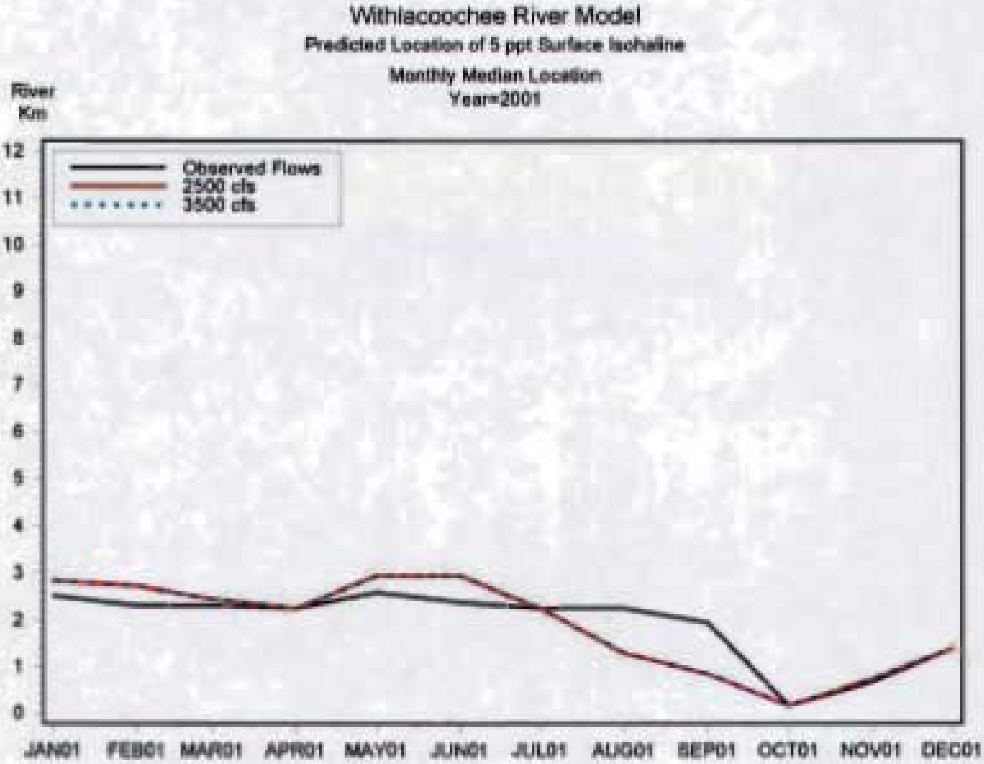



Withlacoochee River Model
Predicted Location of 5 ppt Bottom Isohaline
Monthly Median Location
Year=1999




Withlacoochee River Model
Predicted Location of 5 ppt Surface Isohaline
Monthly Median Location
Year=2000
River Km
Observed Flows
2500 cfs
3500 cfs
JAN00 FEB00 MAR00 APR00 MAY00 JUN00 JUL00 AUG00 SEP00 OCT00 NOV00 DEC00


Withlacoochee River Model
Predicted Location of 5 ppt Bottom Isohaline
Monthly Median Location
Year=2000
River Km
Observed Flows
2500 cfs
3500 cfs
JAN00 FEB00 MAR00 APR00 MAY00 JUN00 JUL00 AUG00 SEP00 OCT00 NOV00 DEC00


Withlacoochee River Model
Predicted Location of 5 ppt Surface Isohaline
Monthly Median Location
Year=2001
River Km
Observed Flows
2500 cfs
3500 cfs
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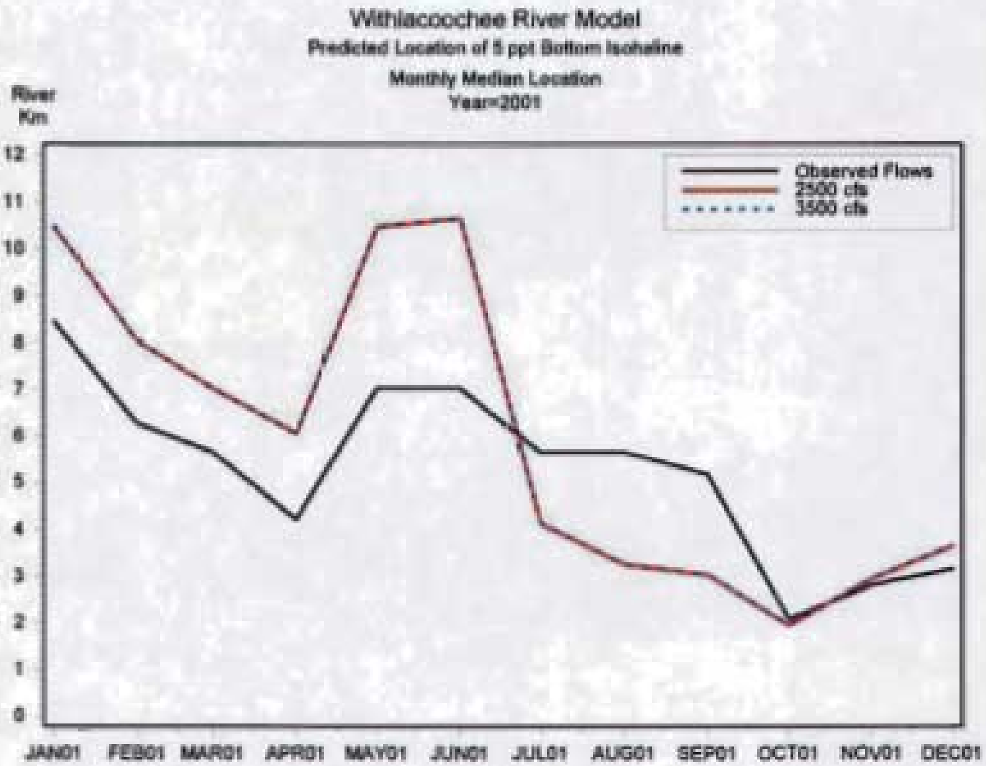
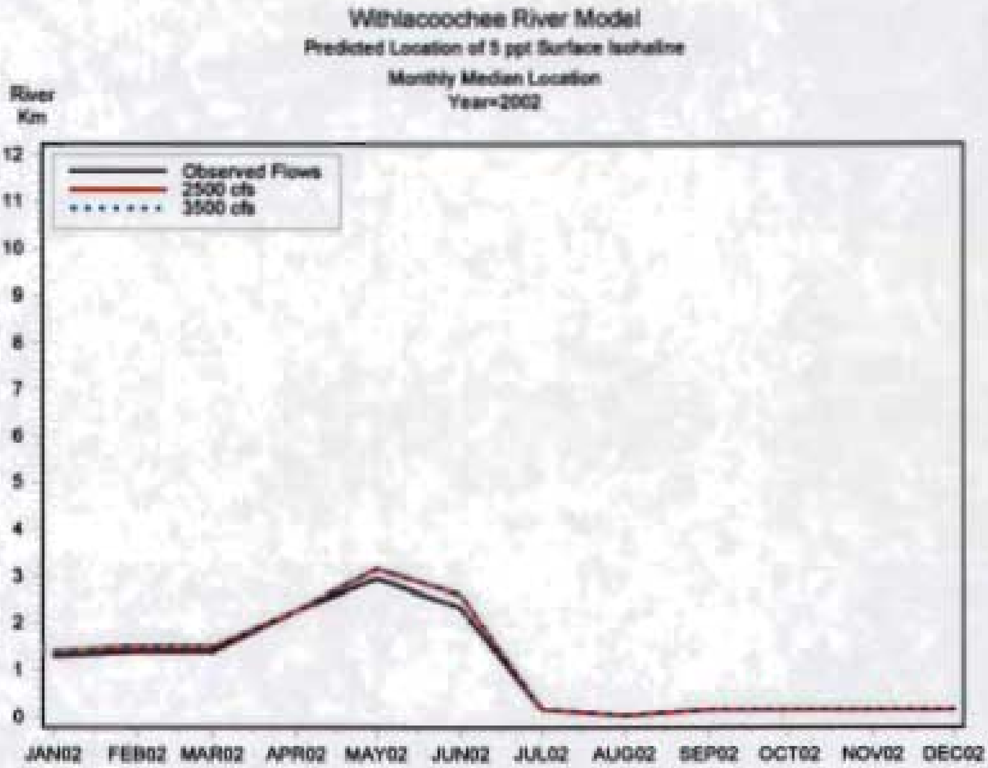
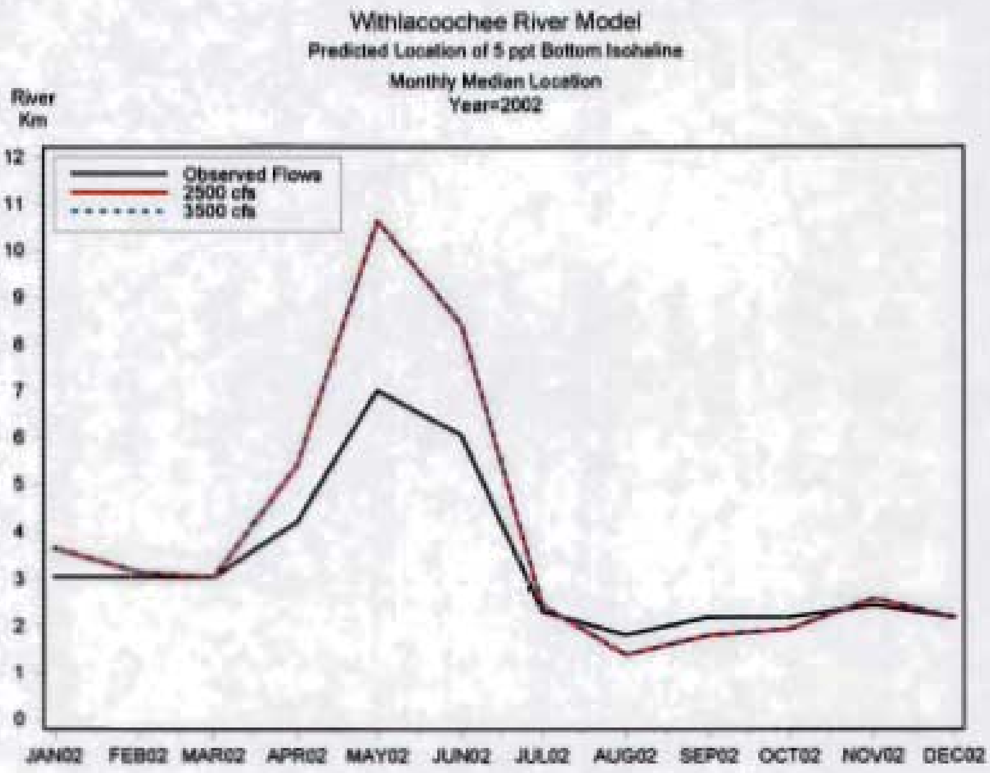
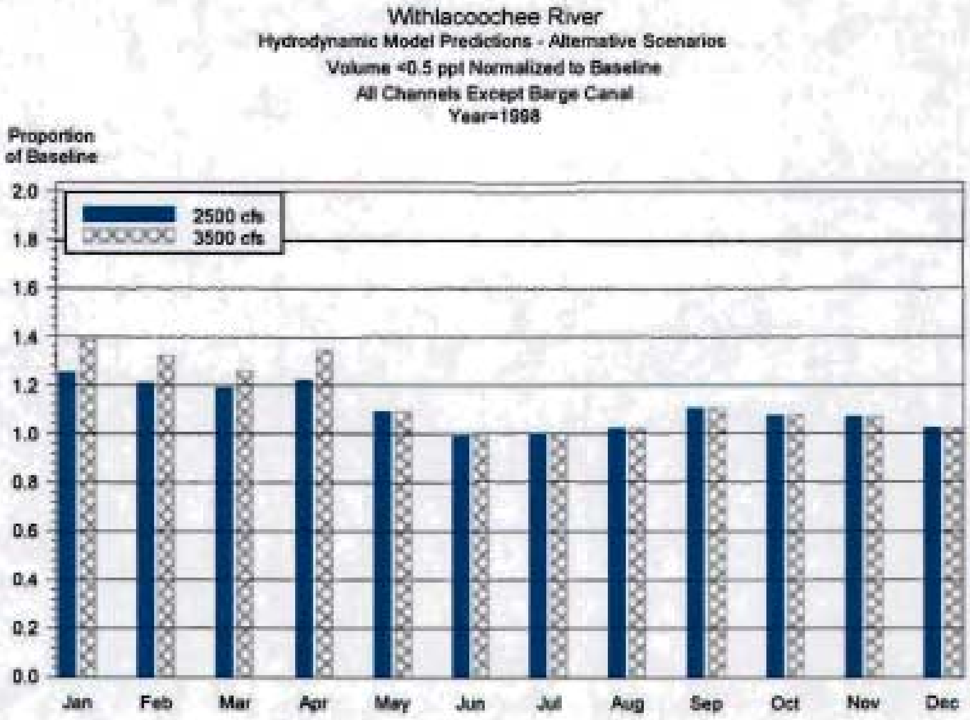
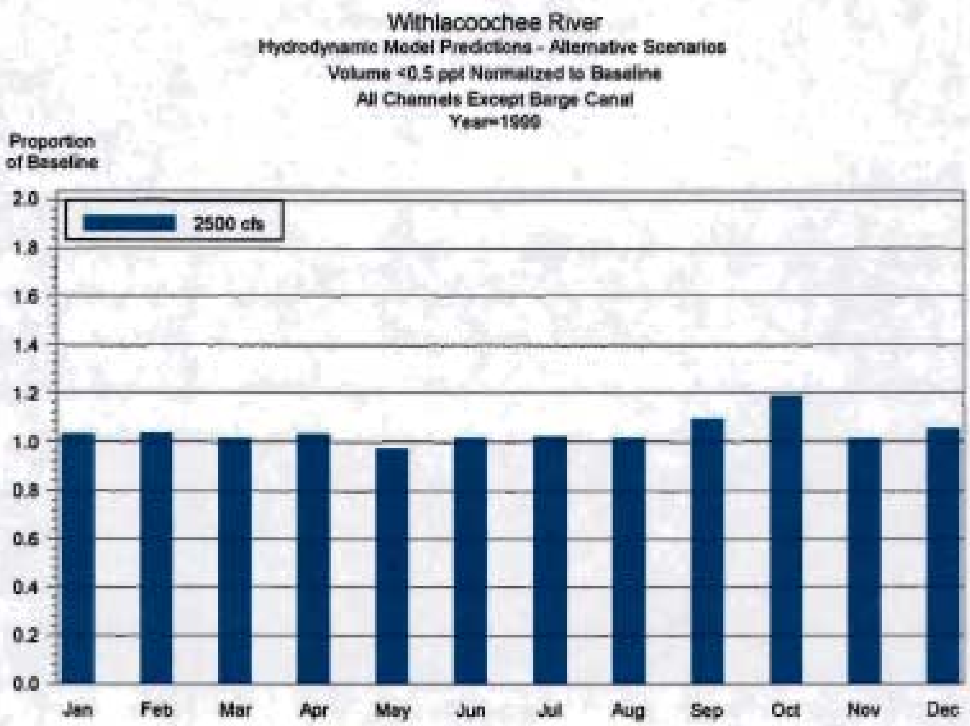

Withlacoochee River Model
Predicted Location of 5 ppt Bottom Isohaline
Monthly Median Location
Year=2001
River Km
Observed Flows
2500 cfs
3500 cfs
JAN01 FEB01 MAR01 APR01 MAY01 JUN01 JUL01 AUG01 SEP01 OCT01 NOV01 DEC01

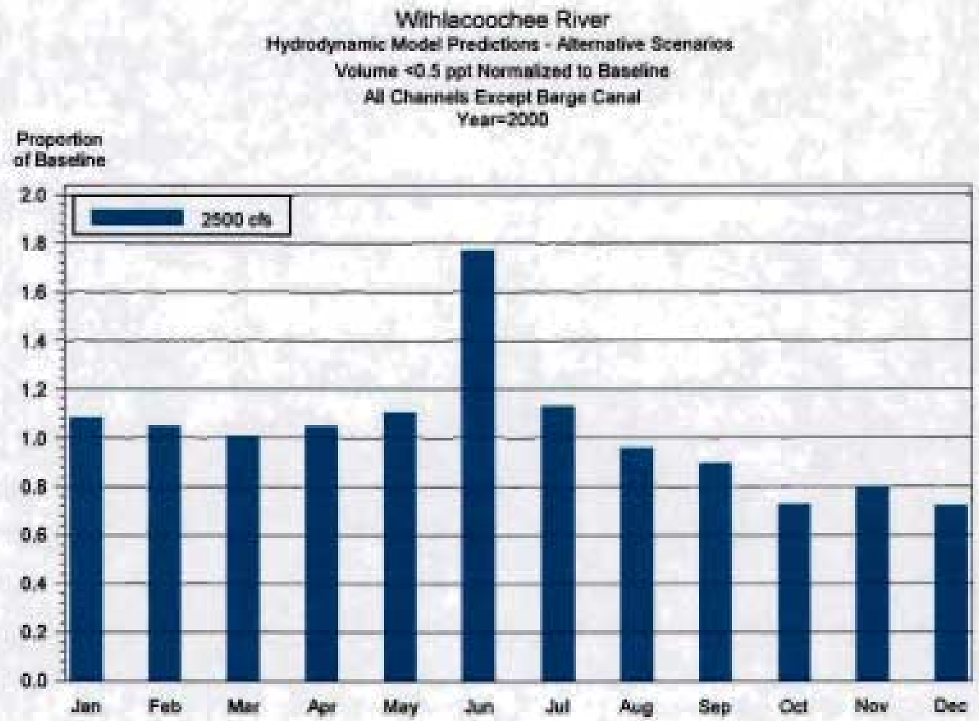

Withlacoochee River Model
Predicted Location of 5 ppt Surface Isohaline
Monthly Median Location
Year=2002
River Km
Observed Flows
2500 cfs
3500 cfs
JAN02 FEB02 MAR02 APR02 MAY02 JUN02 JUL02 AUG02 SEP02 OCT02 NOV02 DEC02

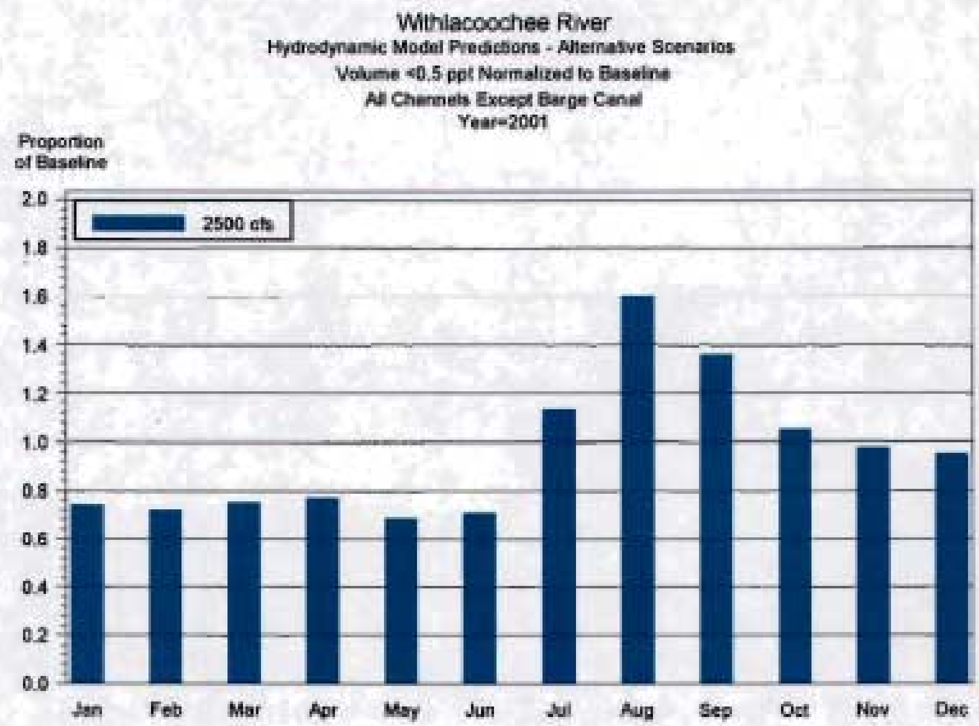

Withlacoochee River Model
Predicted Location of 5 ppt Bottom Isohaline
Monthly Median Location
Year=2002
River Km
Observed Flows
2500 cfs
3500 cfs
JAN02 FEB02 MAR02 APR02 MAY02 JUN02 JUL02 AUG02 SEP02 OCT02 NOV02 DEC02

# Appendix C
# LWRM Scenarios: Comparison of Monthly Median Volumes of 0-0.5 ppt and 0.5-5 ppt Salinity Regimes in All Channels Excluding the Barge Canal, by Year, 1998-2002

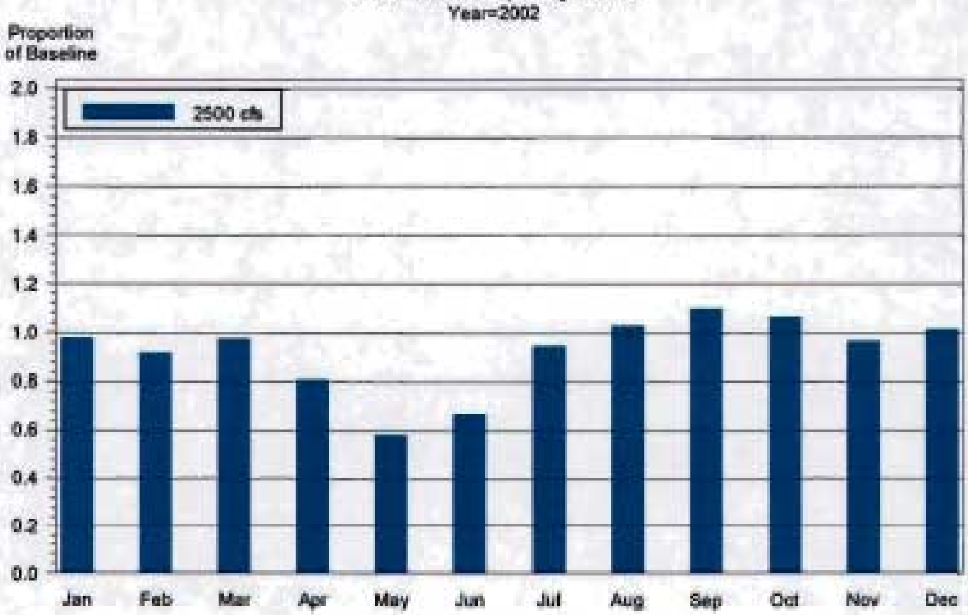

Withlacoochee River
Hydrodynamic Model Predictions - Alternative Scenarios
Volume <0.5 ppt Normalized to Baseline
All Channels Except Barge Canal
Year=1998
Proportion of Baseline
2500 cfs
3500 cfs
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Withlacoochee River
Hydrodynamic Model Predictions - Alternative Scenarios
Volume <0.5 ppt Normalized to Baseline
All Channels Except Barge Canal
Year=1999
Proportion of Baseline
2500 cfs
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Withlacoochee River
Hydrodynamic Model Predictions - Alternative Scenarios
Volume <0.5 ppt Normalized to Baseline
All Channels Except Barge Canal
Year=2000
Proportion of Baseline
2500 cfs
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

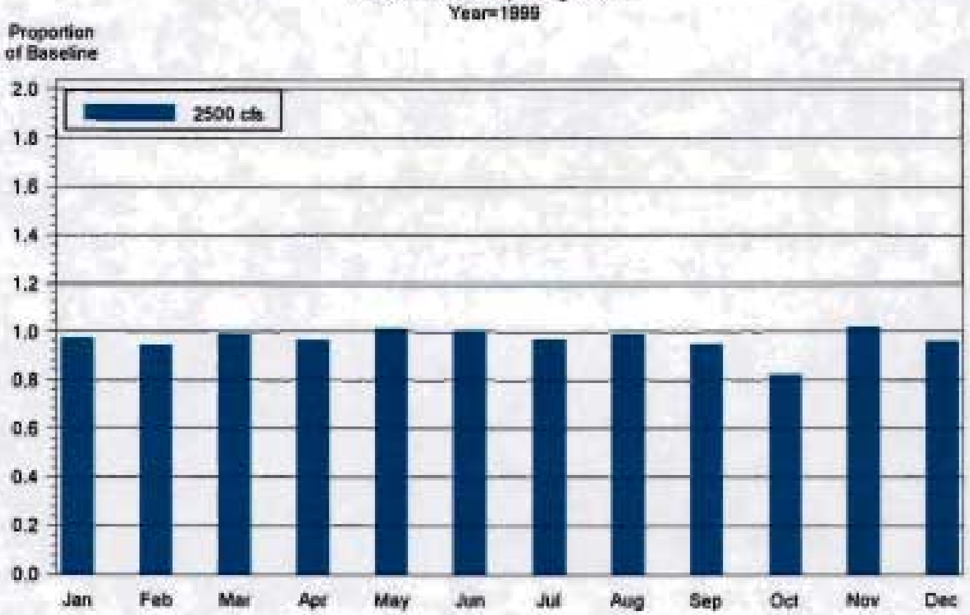

Withlacoochee River
Hydrodynamic Model Predictions - Alternative Scenarios
Volume <0.5 ppt Normalized to Baseline
All Channels Except Barge Canal
Year=2001
Proportion of Baseline
2500 cfs
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

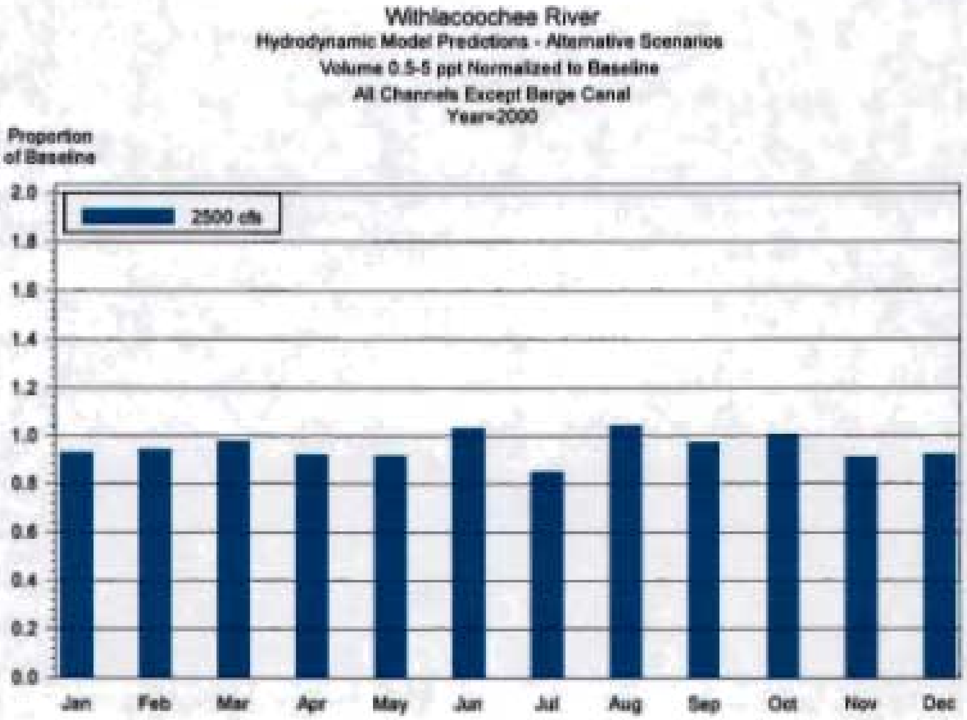
Withlacoochee River
Hydrodynamic Model Predictions - Alternative Scenarios
Volume <0.5 ppt Normalized to Baseline
All Channels Except Barge Canal
Year=2002



Withlacoochee River
Hydrodynamic Model Predictions - Alternative Scenarios
Volume 0.5-5 ppt Normalized to Baseline
All Channels Except Barge Canal
Year=1998


Withlacoochee River
Hydrodynamic Model Predictions - Alternative Scenarios
Volume 0.5-5 ppt Normalized to Baseline
All Channels Except Barge Canal
Year=1999




Withlacoochee River
Hydrodynamic Model Predictions - Alternative Scenarios
Volume 0.5-5 ppt Normalized to Baseline
All Channels Except Barge Canal
Year=2000
Proportion of Baseline
2500 cfs
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan
Feb
Mar
Apr
May
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Jul
Aug
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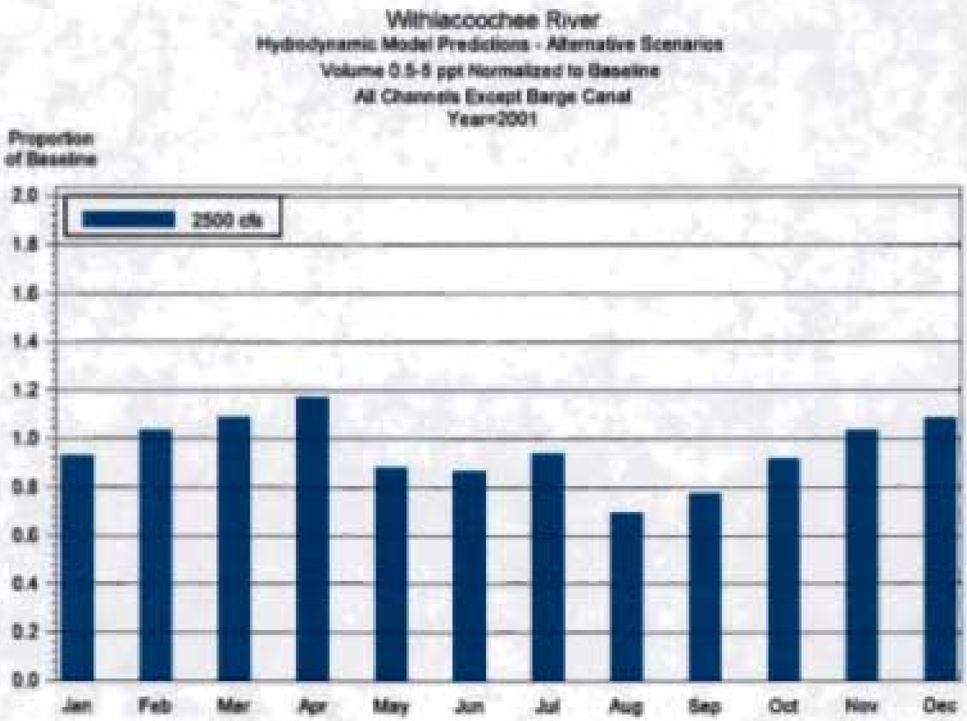
Oct
Nov
Dec


Withlacoochee River
Hydrodynamic Model Predictions - Alternative Scenarios
Volume 0.5-5 ppt Normalized to Baseline
All Channels Except Barge Canal
Year=2001
Proportion of Baseline
2500 cfs
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Withlacoochee River
Hydrodynamic Model Predictions - Alternative Scenarios
Volume 0.5-5 ppt Normalized to Baseline
All Channels Except Barge Canal
Year=2002