FINAL REPORT

FATHOM Enhancements and Implementation to Support Development of Minimum Flows and Levels for Florida Bay

Contract C-C-15975-WO05-05

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EXECUTIVE SUMMARY

This project updated and enhanced existing models of salinity in Florida Bay (FATHOM) and hydrology in the Taylor Slough C111 wetland basin (PHAST) and implemented FATHOM with input from the South Florida Water Management Model (SFWMM) to evaluate the effects of water management alternatives. General information on the hydrogeomorphic setting of Florida Bay and the upstream wetlands was compiled and the FATHOM and PHAST models were described as used in previous work for Everglades National Park (ENP).

The FATHOM and PHAST models were adapted for the needs of the South Florida Water Management District (SFWMD) related to setting minimum flows and levels (MFL) criteria for Florida Bay. The model enhancements incorporate up-to-date bathymetric information, refine the representation of salinity variation along the western boundary of Florida Bay, implement calculations of residence time, improve estimates of freshwater inflow from the Taylor Slough and C111 wetland basin, and assemble input data to support long-term calculations of salinity. Although direct measurements of inflows to Florida Bay are only available beginning in 1996, observed climate and hydrology data are sufficient to indirectly construct a 31-year water budget for Florida Bay (1970 through 2000) and calculate the variation in salinity over this period. This is used as the MFL base case. Data to estimate inflow to Florida Bay from the wetlands are not available prior to 1970. The input data assembled for this MFL base case were described. The results of calculations of salinity and residence time for this period were reported.

A sensitivity analysis validates the selection of the input data and model parameters for the MFL base case and documents the errors associated with the salinity calculations. Because some of the input data assembled for the MFL base case (1970 – 2000) must be estimated indirectly from long term regional indices of rainfall, wetland hydrology and meteorological conditions, an additional source of uncertainty is introduced to the salinity calculations. The sensitivity analysis evaluates the error in the salinity calculations using the MFL base case and is compared to salinity simulations using alternative input data and parameter values. Overall the FATHOM model with the MFL base case input data and parameter values explains about 81% of the observed variation in salinity variability in Florida Bay for the period 1991 through 2000.

The reconstructed water budget based on the MFL base case input data spans a period of significant change in inflow from the wetlands and variation in climate. Rainfall and evaporation dominate the freshwater budget in both the whole Bay and in the central and northeast regions. On an annual basis, inflow from the Taylor Slough C111 wetland basin contributes only about one tenth as much freshwater to the Bay as rainfall. However, during the wet season it accounts for a large portion of the net supply of freshwater to Florida Bay. In the northeast region of Florida Bay, year-to-year differences in peak annual salinity values vary in response to changes in inflow from the wetlands, but in the central region of the Bay the response is not as strong. This may simply reflect the fact that very little or no inflow reaches the central region during dry years; therefore it cannot moderate high salinity values there. Even so, the response of model efficiency in the central region to inflow alternatives examined in the sensitivity analysis provides evidence that salinity does respond in a limited manner to changes in inflow to the central region as it does in the northeast region.

Enhancements to the FATHOM salinity model provide water managers the ability to evaluate changes that will occur in Florida Bay as the result of operations. Output from the SFWMM defines hypothetical scenarios of inflow from the Taylor Slough C111 wetland basin that correspond to different regional water management alternatives. FATHOM extends the analysis of these management alternatives to include changes to salinity in Florida Bay. This is accomplished by using the output from the SFWMM as input for wetland inflow and western boundary salinity in FATHOM. Salinity simulations were generated using the MFL base case, FATHOM model for four water management alternatives; B2000, B20501, CERP1 and NSM. Compared to the other three alternatives, increased inflow to the central region of the Bay provided by the NSM alternative depresses salinity values there when salinity is already low, but not during periods when salinity is high. Higher salinity occurs when conditions are dry throughout the region.

In summary, the FATHOM model has been upgraded and prepared for use in setting MFLs. Overall model efficiency Bay-wide is a respectable 81%, though there are certain basins that may show improved simulation performance with some site-specific parameter modifications that are beyond the scope of this project. PHAST was also upgraded to include the Long Pine basin, but it was found that the direct application of SFWMM flows in the same proportion as the U.S. Geological Survey (USGS) flow data performed just as well and was less cumbersome.

Taking Florida Bay as a whole, as was expressed in the approved work plan, the MFL base case defines the set of model input data and parameters that provided the best performance in calculated salinity. Specific locations where improvements to model fidelity may be possible include Manatee Bay, Joe Bay, Terrapin Bay, and Whipray Basin.

1 INTRODUCTION

The South Florida Water Management District (District) is working to establish minimum flows and levels criteria (MFL) for Florida Bay. In support of this work, the District contracted with Environmental Consulting & Technology, Inc. (ECT) to adapt two existing hydrologic models for this use, an estuarine salinity model (FATHOM) and a wetland hydrology model (PHAST). Everglades National Park previously supported the authors in the development of these models (Cosby et al. 1999, Nuttle et al. 2000, Nuttle and Teed 2002, Nuttle 2004, Cosby et al. 2004). This report documents the work by ECT to refine the FATHOM and PHAST models so that they meet the District's present MFL needs.

Enhancements to the FATHOM model provide water managers with the ability to evaluate the effect on the salinity of Florida Bay from changes in management operations. Salinity serves as an important indicator for the effect of water management activities on the Florida Bay ecosystem. The amount, timing and distribution of freshwater flowing into an estuary influence its ecology through the effect that freshwater has on salinity. Operations of the District's regional water management system have some influence on the inflow of freshwater into Florida Bay. These operations have the potential to alter salinity, and through this also affect the Bay's valued ecological components.

Work on this project provides the following information of use to water managers:

- a reconstruction of the hydrology of Florida Bay and fluctuations in salinity for the period 1970 through 2002;
- an analysis and compilation of a water budget for Florida Bay identifying areas where changes in the inflow of freshwater has influenced salinity; and
- a comparison of the projected effects of four alternative water management scenarios described by output from the South Florida Water Management Model.

This project estimates rainfall and evaporation in Florida Bay and inflow from the adjacent wetlands for the period 1970 through 2002, and it applies this information to reconstruct salinity changes in the Bay over this period. By the early 1970s, there was sufficient concern over the consequences of water management activities in South Florida to motivate actions intended to mitigate the effect in Everglades National Park and Florida Bay. Comprehensive monitoring of rainfall and salinity in Florida Bay did not begin until the early 1990s, and measurement of creek flows into Florida Bay until the mid-1990's. Because of this, regional hydrologic data provide the basis for estimating freshwater fluxes over longer periods.

This report analyzes Florida Bay's water budget and salinity simulations for the period 1970 through 2000. South Florida experienced several periods of high rainfall, as well as drought in this period. Salinity fluctuations track changes in regional rainfall. Rainfall is the largest direct source of freshwater to Florida Bay, and rainfall also supplies freshwater that is detained in the upstream wetlands. In addition, the completion of a major portion of the South Dade Conveyance System significantly increased the amount of water delivered to the wetland areas that discharge into the northeast part of Florida Bay in the early 1980s. Analysis of the compiled hydrologic data and simulated salinity results facilitate identification of areas in Florida Bay where wetland inflow has the greatest influence on salinity.

This report uses output from the South Florida Water Management Model (SFWMM or 2X2 Model) as input to FATHOM, producing estimates of salinity for different scenarios or management alternatives. The SFWMM simulates water levels and flows in the Everglades based on actual climate conditions in Calendar Years 1965-2000 and scenarios of assumed water management operations. Included in this task was the development of protocols for applying this output as input to FATHOM. This project assembled input data sets for FATHOM based on the following SFWMM runs: base 2000 (B2000), base 2050 (B2050), CERP1, and the natural system model (NSM).

1.1 Objectives and Approach

The overall objectives for this work were to: a) enhance and extend the FATHOM and PHAST models so that they better represent wetland hydrology and estuarine salinity within Florida Bay, b) apply the enhanced models to various water management scenarios to examine their effects on Florida Bay salinity conditions, and c) use this information to establish scientifically defensible relationships between freshwater inflows and estuarine salinity response that can be used to establish minimum flows and levels criteria for Florida Bay.

Work on this project was organized into the following tasks:

Task 1 **Project Communication and Coordination** - communication between the ECT project team and the rest of the study team and overall coordination of the work by the ECT project team that is described in detail in the following sections.

Task 2 **Develop the Work Plan** - draft the Final Work Plan for the project, including descriptions of the approach to be taken, information required and a detailed schedule for each of the tasks.

Task 3 **Model Improvements/Enhancements** - make the improvements and enhancements to the existing versions of the PHAST and FATHOM models.

Task 4 **Model Calibration and Verification** - establish the values of model parameters, select the data that describe the boundary conditions for the application of the models, and estimate the error in model predictions of salinity.

Task 5 **Model Applications** - apply the enhanced, calibrated models to examine the salinity response in Florida Bay over the period from 1970 through 2002, and simulate salinity conditions in Florida Bay that correspond to alternative water management scenarios defined by output from the SFWMM.

Task 6 **Water Budget Development** – develop summary descriptions for the main elements of the freshwater budgets for Florida Bay and for the PHAST wetland basins in the Long Pine, Taylor Slough, and C111 basins.

Task 7 **Final Report & Technical Presentation of Results** - document the technical aspects of the model(s) and the results over the entire project.

1.1.1 Organization of Final Report and Supporting Materials

This report describes the overall results obtained and serves as the final deliverable from ECT for this project. Sections 2 and 3 describe the models. Section 4 describes the input data and parameter values selected in the model calibration. Section 5 presents the results of a sensitivity analysis conducted to verify the selected input data and parameter values. Sections 6 and 7 present the results of water budget development and model applications.

In addition to this report, three progress reports document the progression and intermediate results of work performed. These reports contain details of parameter selection and the initial sensitivity analyses.

Progress Report 1 Documents the enhancements to the PHAST wetland hydrology model, implementation of the PHAST and FATHOM models for the period 1996 through 2000 with existing bathymetry data, and results of the initial sensitivity analysis for this period.

Progress Report 2 Documents the methods used to construct long-term input data sets for the period 1965 through 2002 using the existing bathymetry and the sensitivity analysis for this period.

Progress Report 3 Documents the selection of the parameters for the MFL base case (input data sets and parameter values for the MFL model), detailed model results for the sensitivity analysis around the base case, analysis of the water budget, residence time calculations, and salinity estimates for four water management alternatives defined by the output from runs of the SFWMM.

Also as part of this work, ECT has provided the District with a number of working versions of the FATHOM salinity model, instruction on the application of this model, and copies of the input files and summary output for the model runs performed.

1.1.2 Project Complexities

The availability and completeness of data needed to construct the input data sets for the period 1965 through 2002 presented the major challenges in this project. Some examples include the following:

- Coverage by the most recent bathymetry data, intended to update the previous FATHOM bathymetry, proved to be incomplete. From the beginning of the project, the intent was to utilize the most up-to-date data from the most recent survey by the U.S. Geological Survey (USGS). However, shallow areas excluded from this bathymetric survey cover a significant fraction of the Bay. By virtue of their spatial arrangement, these areas exert critical control on circulation and tidal exchange. Therefore, techniques had to be developed to estimate the bathymetry in the shallow areas not covered by the USGS survey.
- Direct measurements of rainfall in the Bay are available only since the early 1990s, and measurements of inflow from the wetlands are available only since 1996. Multi-year estimates of evaporation do not exist. Components of the Bay's water budget had to be

indirectly estimated from other information on regional hydrology and climate available to extend the period of analysis before the 1990's. Though the SFWMM can produce freshwater flow estimates back to 1965, the period of record for the regional information related to inflow only extends to 1970.

- The last ten years, for which the data on conditions in Florida Bay are most complete, may not be representative of the full range of hydrologic and climatic variation that was experienced for the previous or the next twenty years. Regionally, the 1990s have seen wetter conditions in the Everglades and more moderate salinity conditions in Florida Bay compared to the preceding period, 1970-1990.
- The records of rainfall in Florida Bay contain significant gaps. Rain gauges normally under-report rainfall depths by ten percent even in the best conditions (Sieck et al. 2003).
- Available data on inflows underestimate the total amount of flows into the Bay. Direct measurements of freshwater flow rates by the USGS are in only five estuarine creeks. Ungauged flow estimated by the USGS (Hittle et al. 2001) in four other creeks amounts to additional flows of about 23 percent of the gauged inflow. Large amounts of ungauged flow likely occur under conditions of high water levels when over bank flooding and overflow supplements creek flow through the mangrove swamps.

To overcome these challenges the project team adopted an approach to populate and verify the models that relied on selection of the best available estimates for the input data and model parameters to the extent that these could be independently identified, and to confirm these selections with a sensitivity analysis. The progress reports contain the detailed results from several iterations of this approach. This report documents the final selection of input data and model parameters for the MFL model, and it summarizes the results of the final sensitivity analysis. The alternative input data sets and parameter values examined in the final sensitivity analysis were chosen based on consideration of the uncertainties inherent in the construction of the input data sets and selection of model parameters.

1.2 Description of Florida Bay and Contributing Watershed

Florida Bay lies between the southern tip of the Florida mainland and the island chain known as the Florida Keys. Over 85 percent of the Bay's 2200 km^2 area lies within Everglades National Park, and the Florida Keys National Marine Sanctuary contains much of the rest. The Bay includes over 200 small islands, many of which are rimmed with mangroves. Florida Bay supports numerous protected species including the roseate spoonbill, the bottle-nosed dolphin, the American crocodile, the West Indian manatee, and several species of sea turtles. Moreover, Florida Bay provides critical habitat for commercially important species, such as spiny lobsters, stone crabs, and many important finfish species, and it serves as the principal nursery for the offshore Tortugas pink shrimp fishery.

1.2.1 Geographic Setting

Florida Bay, as a receiving water body, is an important component of the much larger South Florida drainage basin that is the focus of the Comprehensive Everglades Restoration Plan (CERP). The Bay receives freshwater inflow from the Everglades, a large portion of which is managed discharge from canals in the region. Decisions guiding the restoration of the Everglades carry implications for future conditions in Florida Bay, just as the development of the regional water management system over the past fifty years or so influenced present conditions. Although a specific restoration target has not yet been defined for Florida Bay per se, it is expected that restoration of more natural hydrologic conditions in the Everglades will move the Bay toward an ecological state more typical of the period prior to the time of engineered changes imposed on the regional South Florida system.

Rapid ecological changes are thought to have occurred in Florida Bay between 1987 and 1991. These came at the end of a multi-year drought that had elevated salinity values in the central portion of the Bay to nearly 70, double the typical salinity of seawater. Large areas of seagrasses began to die late in 1987. Concurrently, the shrimp harvest on the Tortugas Grounds, which depends on Florida Bay as a nursery area, declined to record lows. In 1991, turbidity and plankton concentrations increased dramatically, reducing the supply of light to the remaining seagrass beds through the previously "gin-clear" Bay waters. Mass mortality of sponges, which help to filter the Bay's waters and provide habitat for juvenile lobster, followed in the path of the plankton blooms. By the end of 1991, there was widespread concern for the health of the Florida Bay ecosystem.

The climate of South Florida is subtropical with a comparatively small annual temperature range but distinct wet (summer/fall) and dry (winter/spring) seasons. During the wet season, showers occur virtually daily with the afternoon southeastern sea breeze, and tropical storms are transient occurrences. During the dry season, cold fronts pass through the region on an about a weekly basis with accompanying increased wind speeds and clockwise rotating wind directions from westerly to northerly with the passing of the front.

Oceanographically, the entire coastal system of south Florida is one integrated system (Fig. 1.1). Florida Bay is connected to the southwest Florida shelf, and on occasion to more remote regions of the Gulf of Mexico. As a result, western Florida Bay can be influenced by inputs of freshwater from rivers discharging in the Ten Thousand Islands region and along the west coast of Florida (i.e.the Shark, Broad, Harney, and Lostmans rivers). These river waters can be transported southward along the southwest Florida coastline and around Cape Sable, in a general pattern of outflow through the Keys to the reef tract (Lee et al., 2001a; 2001b). The influence of freshwater inflow from remote Gulf regions is more likely during summer and fall, and has been shown to even include the influence of Mississippi River floods (Ortner et al., 1995). Subsequent transport of this water into Florida Bay and to the Keys is aided by oceanic flows, the Gulf Loop Current, and the Florida Current.

Circulation of water in western Florida Bay and adjacent coastal regions on subtidal time scales is also strongly influenced by local wind forcing resulting in seasonal flow patterns within the Bay that is southward toward the Keys in winter and spring, northwestward into the Gulf in summer, and southwestward toward the Tortugas in the fall. Episodic transport processes deliver warm, salty water to the reef tract from Florida Bay in the spring and early summer. Cold, turbid intrusions can occur in the winter.

The wetlands in the Taylor Slough C111 wetland basin, north of Florida Bay, occupy a broad, flat, freshwater-contributing area with ill-defined drainage patterns in the southeast portion of Everglades National Park. This project divides this area into three wetland sub-basins, Long

Pine, Taylor Slough and C111 (Figure 1.2). Long Pine Key and the main Park road to Flamingo form a surface water divide that isolates the Long Pine sub-basin from surface water in Shark Slough. Surface water flow within the Taylor Slough C111 wetlands is divided between flow following the natural course of Taylor Slough, south of the Park road gauging station (TSB), and sheet flow in the C111 basin fed by overflow from the C111 canal. The source of water in Taylor Slough is overflow from Shark Slough, rainfall on the Rocky Glades area of the Park, direct rainfall on the Slough, and discharge of the S332 and S332D pump stations. The source of sheet flow in the C111 basin is overflow from the C111 canal between the S18C and S197 structures (not shown on Figure 1.2). In general, groundwater flows are thought to be small relative to other components of the wetland water budget (Price 2001, Sutula et al. 2001), and these are not accounted for directly in this work.

Figure 1.1: Schematic representation of the average flow patterns in the interconnected South Florida coastal circulation system. The dark arrows indicate locations and relative magnitude of freshwater inflow (i.e. Shark River and Taylor Slough) that influence salinity in Florida Bay (from Florida Bay Science Program 2003).

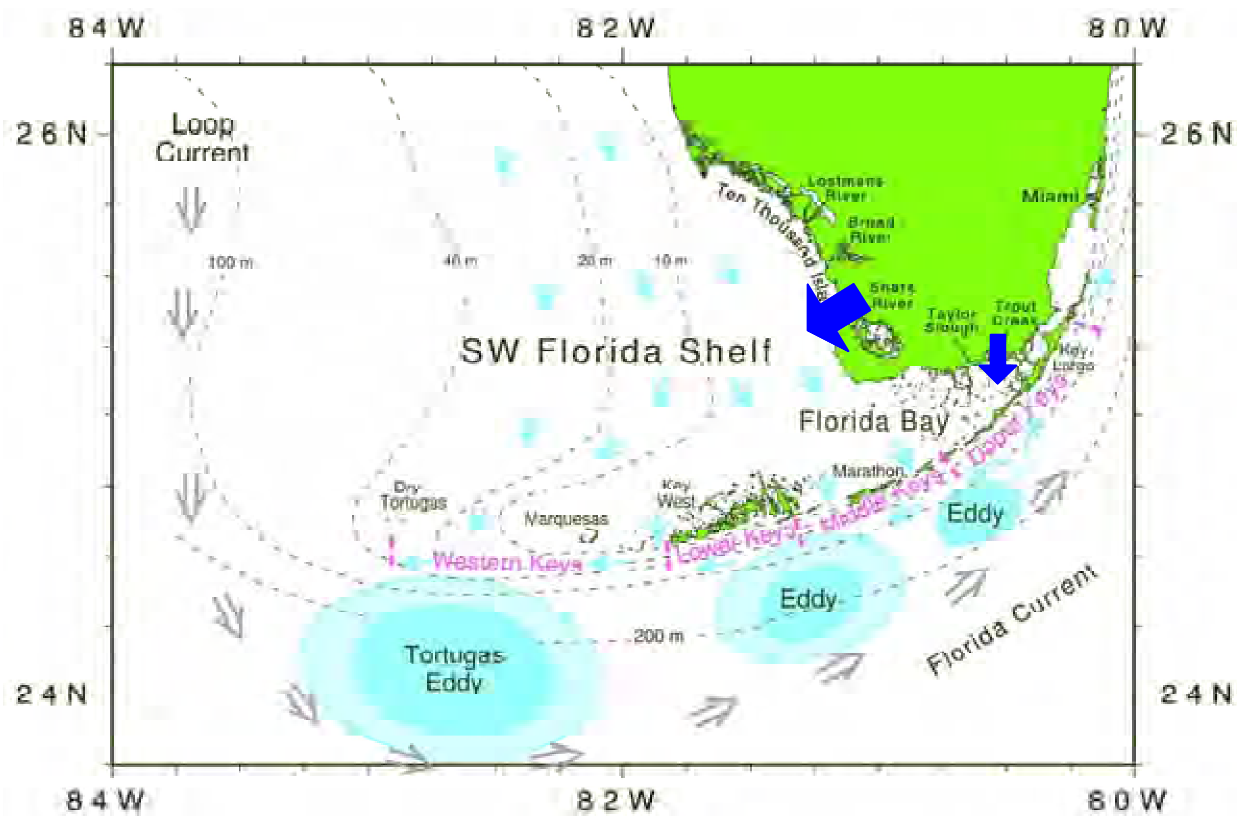
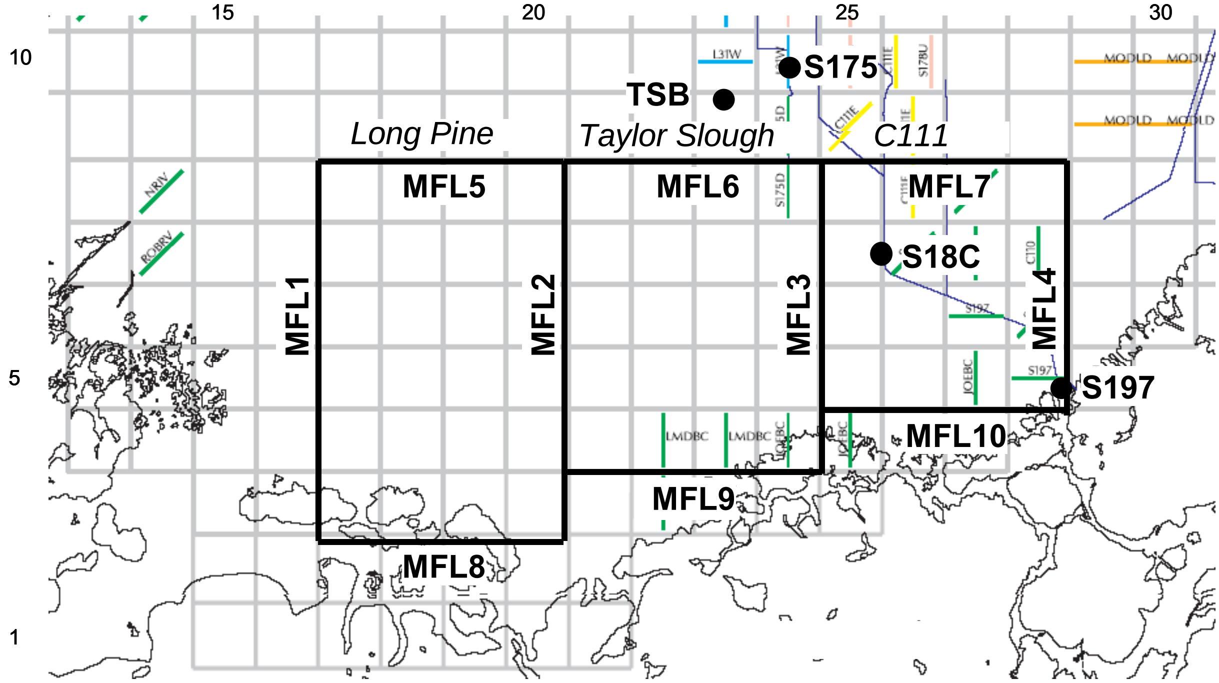


Figure 1.2: Wetland basins used to describe freshwater inflow from the wetlands north of Florida Bay. The locations of the MFLx flow transects are superimposed on the grid of the SFWMM model. Also shown are locations for flow (TSB, S175, S18C, and S197) data used in this study.



1.2.2 Florida Bay Regions

Salinity varies markedly in time and space in Florida Bay. Hypersaline conditions (>40) in one part of the Bay frequently coexist with more usual estuarine conditions (<30) in another (NOAA 1996, Boyer et al. 1997, Everglades National Park 2001). At some interior embayments, salinity regularly fluctuates between hypersaline and nearly fresh conditions (Fourqurean and Robblee 1999, Frankovich and Fourqurean 1997). This variation occurs in response to the direct effects of freshwater inflow, rainfall, and evaporation and to the indirect influence of flux from oceanographic processes outside of the bay on the southwest Florida Shelf.

Florida Bay can be divided into four regions subject to different geophysical forcing, topographic constraints, and freshwater inputs (Figure 1.3). The northeast region of Florida Bay is not significantly affected by tides, and is mostly isolated from influence by the marine waters of the Florida Straits and Gulf of Mexico. Salinity in the embayments along the northern boundary of the northeast region responds very rapidly to rainfall and inflow from the estuarine creeks (Figure 1.4). High inflow causes dramatic freshening in the small bays along the northern boundary. Subsequently, freshwater from these embayments slowly mixes with more saline Florida Bay waters to the south and southwest over a period of weeks to months (Johns et al., 2001).

The central part of Florida Bay receives only direct freshwater inflow that from McCormick Creek into Terrapin Bay or Alligator Creek into Garfield Bight (Figure 1.4). During times of low rainfall and high evaporation the central region can become hypersaline with values often in excess of 40, and historically as high as 70 (Boyer, 2004; Robblee et al., 2001). High salinity can persist in this central region over periods of weeks to months to years (as it did in the late 1980's), indicating that, like the northeastern region, waters of the central region have a relatively long residence time.

The western region of Florida Bay is the least isolated, sharing an open boundary with the Gulf of Mexico and experiencing relatively robust tidal influence. Residence times in the western region are shorter than in the central and northeastern regions, and average salinity is higher. Salinity in the western region can exhibit a relatively rapid response to meteorological events such as tropical storms and cold fronts, but the range of variation is reduced relative to the northeast region.

The south region of Florida Bay is similar to the west region except that it receives influence from the Florida Straits through the middle Keys passages. The south region of Florida Bay is a source of water to the coral reef areas of the Florida Keys National Marine Sanctuary (FKNMS).

1.2.3 SFWMD Areas of Interest

Early in the project, the study team identified several Bay basins of interest for setting MFL criteria. The selected basins include Long Sound (8), Joe Bay (10), Little Madeira Bay (11/23), Duck Key/Trout Cove (9), Whipray Basin (13), Garfield Bight / Rankin Lake (14/15), and Rabbit Key Basin (19) (Figure 1.5). The numbers in parentheses refer to a SERC / FIU monitoring station of salinity observations. These basins of interest were selected based on knowledge of where valued ecological components likely are thought to be sensitive to the influence of freshwater inflow. In addition, the zones of interest identified for the District's Florida Keys Feasibility Study are used to evaluate model performance throughout the Bay; these zones include Butternut Key Basin (24) and Park Key Basin (23) in addition to the basins presented above. Results of the FATHOM salinity calculations and evaluation of the model performance by comparison to salinity data reference these basins and zones.

Figure 1.3: LANDSAT-7 extended thematic map image of Florida Bay, showing its shallow bank bathymetry and four principal regions (from Florida Bay Science Program 2003).

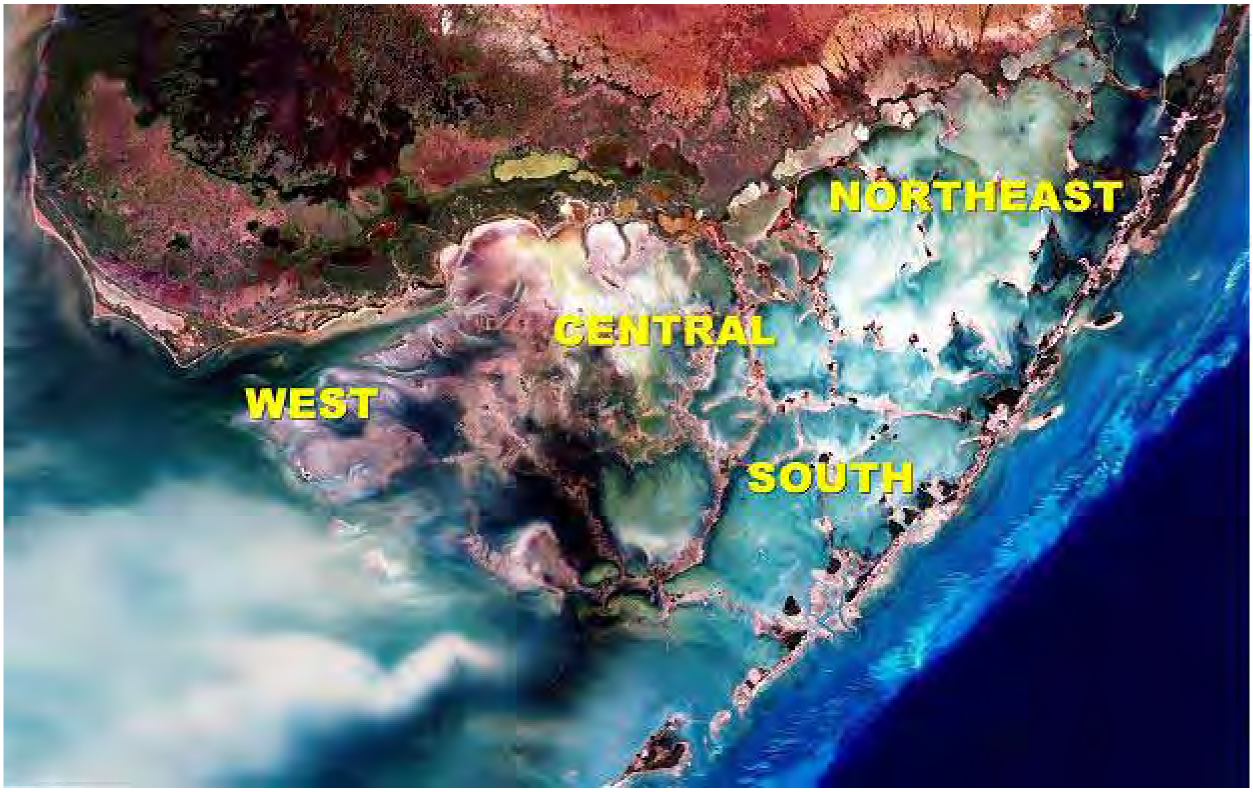
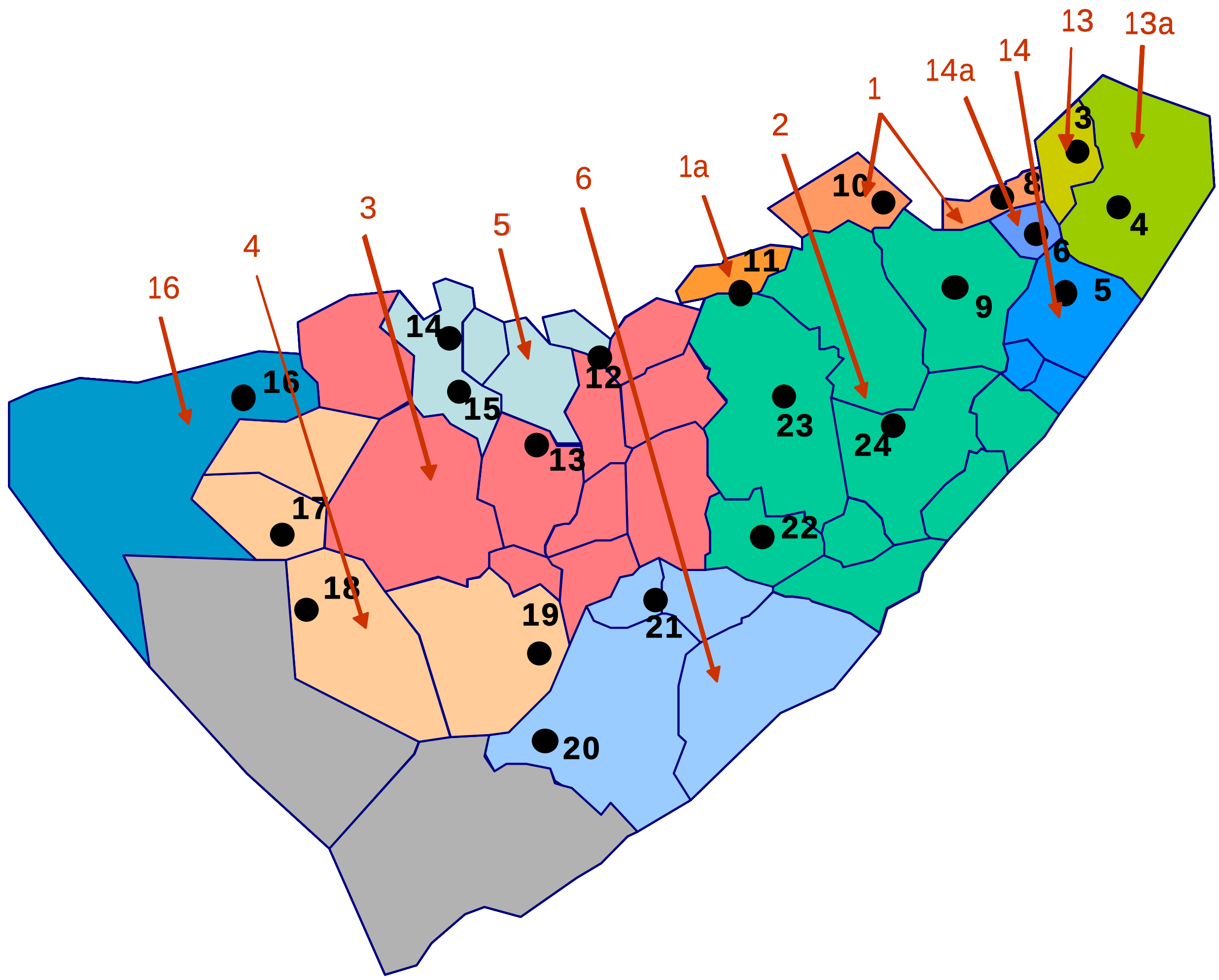


Figure 1.4: Location of principal points of freshwater inflow measured by the USGS (from Hittle et al. 2001)

Figure 1.5: Map of Florida Bay basins showing the FATHOM basins, the Florida Bay and Florida Keys Feasibility Study Zones (colored zones and red numbers), and the locations (in black) where monthly SERC/FIU salinity measurements were taken.



1.3 Description of Models

1.3.1 FATHOM – Florida Bay Salinity

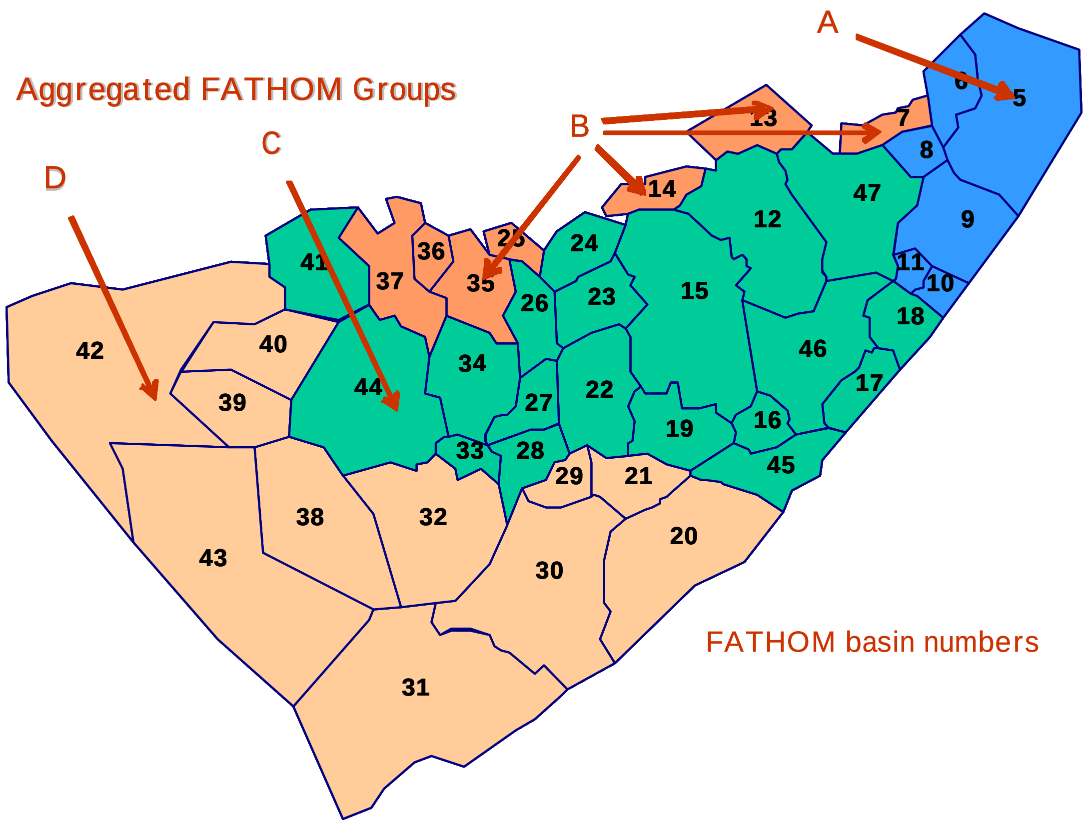
FATHOM is a dynamic, spatially explicit, mass-balance numeric model designed to investigate the response of salinity in Florida Bay to runoff, climate and variation in salinity on the Florida Shelf (Cosby et al. 1999, Nuttle et al. 2000, Cosby et al 2004). The model maintains a running account of the water and salt budgets in each well-mixed basin within the Bay (Figure 1.6). Circulation within Florida Bay and exchange with the Florida Shelf are controlled by the Bay's network of shallow banks (Figure 1.3). The basins defined by these banks offer a natural framework for mass-balance accounting.

FATHOM represents Florida Bay as a collection of well-mixed basins. Circulation and exchange are driven primarily by tides imposed along the western boundary. At each time step, the model solves for uniform hydraulic flow across each bank based on the depth, width, and frictional roughness of the bank, and water levels in the upstream and downstream basins. By this mechanism, tidal forcing at the boundary propagates into the Bay and drives the exchange of water and solutes among the basins. Solute fluxes are then calculated from water fluxes and the salinity of water on each bank. Details of the representation of flow over the banks and the hydraulic equations are given in Cosby et al. (1999).

Despite the model's computational simplicity, FATHOM requires highly detailed information about the bathymetry in Florida Bay. Bathymetric data are entered into a GIS database that classifies the depth at a resolution of 20 by 20 meters (the pixel resolution of the data) into one of 11 classes (i.e.1 land surface class and 10 depth classes). The depth classes covered the range from 0 to 10 feet in one-foot increments. Areas deeper than 10 feet occur locally in the Bay, but (based on these data) such areas are not extensive and occur infrequently. These depth-class data provide the basis for describing the hypsometry for each basin and the depth and widths of the shoals for the calculation of exchange fluxes between basins.

The total length of the line segments that describe the shallow banks is 626 km (Figure 1.6). Along the boundaries, the line segments follow the mainland coastline and the keys, and in the interior of the Bay the lines traverse or connect islands. About 276 km of the "shoals" defined for FATHOM are dry land (no-flow boundaries). Greater than 70% (252 km) of the wetted length of the shoals is shallower than 1 foot. A small proportion of the 21% of shoal length with depth greater than 3 feet represents cuts and channels through the shoals. Most of the deeper shoals are located in the western and southwestern part of the Bay. These were defined as shoals to establish a basin boundary in the model.

Figure 1.6: The numbered polygons identify the Bay basins used in FATHOM calculations. The color-coded regions and the alphabetic destinations identify the FATHOM groups used to summarize the results of salinity calculations.



The solution scheme depends on the calculation of water velocity independently for each depth increment of each shoal. Conceptually, water flow from one basin to another over a bank in the Bay can be treated as flow over a broad crested weir with friction. Flow velocity across the weir depends on the difference in water levels on each side of the weir and (perhaps) the occurrence of critical flow. If critical flow occurs, then velocity does not depend on the water level on the outflow side. The influence of bottom friction may or may not have an important effect, depending on the velocity and the depth of flow. The difference in water levels across the weir provides the specific energy for the flow.

There is no direct simulation of wind shear on the water surface in FATHOM. A key aspect of the conceptual basis of FATHOM is the assumption that the major effects of wind shear on circulation in Florida Bay can be accounted for by the structural assumptions and the inputs to the model, without having to be modeled explicitly. Effects of wind have been incorporated in FATHOM in two ways: 1) by the assumption that each basin is well mixed (i.e., the "local" effect of the wind is to stir the basins, but not to move much water among them); and 2) by the incorporation of water level changes in addition to tides and sea-level patterns at the Gulf and Atlantic ocean boundaries (i.e., the "remote" effect of the wind is to cause a sea level setup of varying magnitude and duration along the different parts of the Bay boundaries).

As a consequence of the assumptions described above, salinity calculated by FATHOM represents a time-averaged value with a period of about one month. Even though circulation and exchange in the model are driven by tides, data on other processes such as rainfall and freshwater inflow are provided as monthly values. Also, the assumption of basins as well-mixed imposes constraints on the time scale on which salinity calculations can be taken as comparable to observations at any particular location.

Bay-wide inputs required by FATHOM include time series of rainfall and evaporation for each basin in the Bay. The model structure allows these inputs to be specified individually for each basin to reproduce spatial gradients in these forcing functions. In practice, however, observed data are not sufficient to support more than a regional approach to the spatial distribution of climate inputs. That is, the Bay must be divided into a few regions for which climate inputs are applied uniformly to the model. Groundwater inputs to the basins can also be specified, but these have not been employed in the simulations performed for this project.

Time series of freshwater inflow volumes are required at the terrestrial boundaries of the Bay. Inflow (where it occurs) is specified as an input separately into each of the boundary basins along the Everglades coastline, though not all of the boundary embayments receive inflow. To compare the effects on the Bay of different runoff regimes, the distribution of inflow among the small embayments at the northern edge of the Bay was varied and analyzed. Along the Keys, inflows of freshwater are small, and these are not included in the FATHOM inputs.

In addition to the runoff data at the terrestrial boundaries, FATHOM requires tide, sea level and salinity time series to set the open water boundary conditions for the Bay. The model allows these boundary conditions to vary spatially along the boundaries.

1.3.2 PHAST – Wetland Hydrology

The PHAST wetland hydrology model (Nuttle and Teed 2002, Nuttle 2004) calculates inflow to Florida Bay from the wetland sub-basins in the Taylor Slough C111 wetland basin, (Figure 1.2). The influence of water management operations on the Bay occurs primarily through changes in the inflow of fresh water from these wetlands. Within the context of this project, the PHAST wetland hydrology model was investigated as one approach to estimating freshwater inflow. One objective of this project was to extend the PHAST model to include the water balance of the Long Pine Basin in the water budget for the calculation of inflow; the prior implementation of PHAST (Nuttle 2004) excluded the Long Pine basin.

The PHAST wetland model calculates inflow to Florida Bay by simulating water levels in each wetland sub-basin based on the hydraulics of overland flow. In effect, the model treats the wetland basins as shallow reservoirs (Figure 1.7). Calculated water levels in the wetlands fluctuate depending on the balance between inflow from rainfall $\boldsymbol{r}$ and surface water sources $\boldsymbol{Q_{in}}$ and outflow from evapotranspiration $\boldsymbol{e}$ and discharge to Florida Bay $\boldsymbol{Q_{out}}$. Any imbalance between inflows and outflows results in a loss or gain in water storage, which is reflected as a change in water level, and consequent changes to the outflow, Equation 1.1.

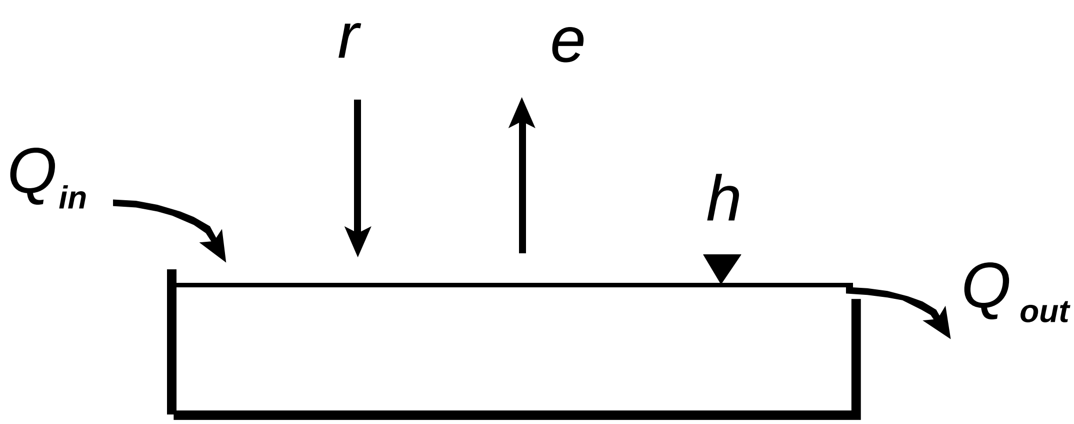
$$A\frac{dh}{dt} = Q_{in} + A(r - e) - Q_{out} \tag{1.1}$$

The model represents instantaneous discharge $\boldsymbol{Q_{out}}$ as a generalized power function of water level, measured above a zero-discharge threshold $\boldsymbol{h_{sill}}$, Equation 1.2. Calculations were carried out with a weekly time step. The parameter β was assigned the value 1.67, which is consistent with representing surface flow occurring in a broad, shallow channel (Wong 2002). (Note: The flow units and time step used for calculation of the wetland water budget in PHAST differ from the flow units used in FATHOM as these reflect a prior, independent application of the PHAST model.)

$$Q_{out} = \alpha(h - h_{sill})^{\beta} \tag{1.2}$$

The input data required for the PHAST wetland hydrologic model included time series of weekly rainfall and surface inflow into each wetland basin. Long-term data on evapotranspiration were not available for this area, so this flux was estimated within the PHAST model by an empirical relationship based on time of year and rainfall (Nuttle 2004). Observations of wetland water levels were used for calibrating the unknown parameters, i.e. α and $\boldsymbol{h_{sill}}$ in Equation 1.2. Parameters that describe how surface flows into the Taylor Slough C111 basin were allocated among the wetland sub-basins. Calculated inflow to Florida Bay was verified by comparison with the USGS measured estuarine creek discharge (Figure 1.4). These flow data were not used in the calibration of PHAST.

Figure 1.7: Elements of a water budget for a wetland basin.



1.4 Model Enhancements and Implementation

The work plan for this project identified the following specific model enhancement tasks:

- incorporate the latest bathymetric data into FATHOM;
- integrate the PHAST wetland basin hydrology models into FATHOM as one option for generating freshwater discharge into the northeast region of Florida Bay;
- link the time series of salinity values on the western boundary to hydrologic conditions and/or flows in Shark River;
- incorporate an algorithm for estimating freshwater discharge into Florida Bay from the Long Pine wetland basin;
- provide the capability of calculating residence time in each FATHOM basin;
- gather the available long-term hydrologic data and construct input data that are compatible with the long-term data used to drive the SFWMM for regional hydrology simulations over the time period 1965 through 2000; and
- use output from the SFWMM to estimate freshwater inflow into the northeast region of Florida Bay and for computation of salinity values on the western boundary of the Bay using regression equations.

The general nature of these enhancements was to refine the representation of the boundary conditions required by the FATHOM model, to account for the effects of water management operations and to estimate Florida Bay salinity over the period 1965 through 2000. In the end, the availability of data for estimating inflow limited the period over which historical salinity calculations could be performed to the period 1970 through 2002. Sufficient data were available so that salinity calculations could be performed with FATHOM over the period 1965 through 2000 when output from the SFWMM is used to specify freshwater inflow.

Constructing the FATHOM input data sets beginning in 1970 entailed making choices among alternative methods for assembling each component of the input data. For example, three methods for estimating the time series of rainfall over the Bay were considered. Model performance with different choices of inputs was evaluated by comparing calculated salinity with salinity measurements that were available for the period 1991 through 2002. A systematic sensitivity analysis verified the choice of the "best" combination of inputs that would ultimately comprise the MFL base case, which can then be used for MFL analysis. The sensitivity analysis also quantified the uncertainty in calculated salinity related to the uncertainty in the input data sets.

The sensitivity analysis provided three types of information. First, it tested whether the selected input data and parameters were optimum. An input data set was considered optimum if making alternative choices did not improve the performance of the model. Second, the sensitivity analysis provided information about how different assumptions made in assembling the input data affected the calculated salinity. This information was important in deciding how to represent the contribution of ungauged flow in estimating the freshwater inflow into the northeast and central regions of the Bay. Third, the sensitivity analysis provided information about the degree to which uncertainty in the input data and model parameters affected the error in calculated salinity that was apparent in the comparison between model results and salinity measurements.

The following sections describe the results obtained by this project:

Section 2.0 describes the enhancements to the FATHOM model; specifically the updated bathymetry, the method used to assemble a time series of western boundary salinity, and the residence time calculations.

Section 3.0 describes how freshwater inflow was estimated; specifically the enhancements made to the PHAST model, results of calibrating the enhance PHAST model, but also the alternative methods used in estimating inflow.

Section 4.0 provides a complete description of the base case, specifically the selected input data and parameter values, and presents results of the salinity and residence time calculations for 1970 through 2002.

Section 5.0 presents the approach used in the sensitivity analysis and the results.

Section 6.0 provides an analysis of the water budget for Florida Bay and areas of the Bay where high salinity values are sensitive to changes in inflow based on the MFL base case data and salinity calculations.

Section 7.0 describes the coupling of the SFWMM output to FATHOM and presents results of salinity calculations based on four water management scenarios.

2 ENHANCEMENTS TO THE SALINITY MODEL – FATHOM

Enhancements to the FATHOM salinity model for MFL development purposes incorporated the most recent bathymetry data, linked variation of salinity along the western boundary to discharge from Shark Slough, calculated residence time, and assembled input data sets to support calculation of salinity simulations for CERP water management alternatives over the period 1965 through 2002. This section describes these enhancements.

2.1 MFL Bathymetry

This project utilizes a Florida Bay bathymetric survey completed in 1990 (Hansen and Dewitt, 2000) and other recent survey data into FATHOM. The product is referred to as the MFL bathymetry. The MFL bathymetry still relies on the previous survey data to describe the bathymetry of the shallowest areas in the Bay. This is because the equipment used for the new bathymetric survey was restricted to areas where water depths were greater than about 51 cm. These areas are relatively extensive in Florida Bay, and needed to be resolved. The previous versions of the FATHOM model relied on bathymetric data that had been compiled from several sources (Cosby et al. 2004, Nuttle et al. 2000). Some of this information dated back to the original survey of the Bay conducted in the late 1880s. Other information quantified the local knowledge of boaters about the extensive shallow banks and the channels used for boat access across the banks. The new survey data replaced much of the out-of-date data from previous surveys.

The new bathymetric data and the data on the shallow areas were compiled by the District into a GIS database for the entire Bay. This database was queried at each 20 m by 20 m area within in the Bay to produce the depth class information needed to describe the volume of the basins and conformation of the banks in FATHOM. These data are the MFL base case bathymetry parameters for FATHOM.

District staff used a variety of elevation datasets for Florida Bay and surrounding water bodies, mainland, and island areas to compile the basis for the new bathymetry database. These datasets included:

- USGS High Resolution Bathymetric Survey of Florida Bay (http://sofia.usgs.gov/projects/bathymetry/).
- NOAA GEODAS Survey Database for Barnes Sound (Survey 4H05542 HYD9303F11484, entered into GEODAS 12/31/1979, referenced to MLW).
- ACOE LIDAR of Eastern Dade County (processed in 2003, referenced to NAVD 88, feet).
- USGS high accuracy elevation survey of the Everglades (http://sofia.usgs.gov/projects/elev_data/).

In addition, the District digitized areas with missing elevation data, including bank and land areas, and channel cuts not surveyed by any of the above. The elevations for these areas that were not surveyed were estimated from surrounding data and from photo interpretation of recent USGS-DOQ and DOT images. A buffer was applied to the banks polygon dataset to remove "stair steps" in the final surface.

The process to combine these datasets included the following steps by the District in ArcGIS:

(1) Convert all point data to common horizontal (FL East NAD83 Harn Feet) and vertical (NAVD88) datum, using referenced benchmarks where available. (http://140.90.78.170/benchmarks/8723534.html).
(2) Merge points into one dataset and create a triangulated irregular network (TIN) surface from these points.
(3) Add estimated data for banks and land areas (polygons) and channels (lines) to a TIN surface.
(4) Convert the TIN surface to a raster grid surface with 50-foot cells.

The process to convert the grid data into a format usable by FATHOM included the following steps in ArcView 3.2:

(1) Change the vertical reference point of the grid from NAVD88 to MSL, using elevations for the Key West benchmark station (http://co-ops.nos.noaa.gov/benchmarks/8724580.html) (i.e. adding 0.869 ft (0.265 meters) to the NAVD88 grid with the Map Calculator function).
(2) Symbolize the MSL converted grid to show one foot elevation classes.
(3) Add themes for FATHOM basins (polygon shape file) and shoals (line shape file) to the view.
(4) Perform Histogram by Zone analysis of MSL grid (represented in one foot elevation classes) for Shoals and Basins themes (respectively); this analysis calculated the number of grid cells within each elevation class for each Shoal and Basin, and produced a temporary .dbf file with the results.
(5) Convert the .dbf file in MS Excel into a format usable by FATHOM.

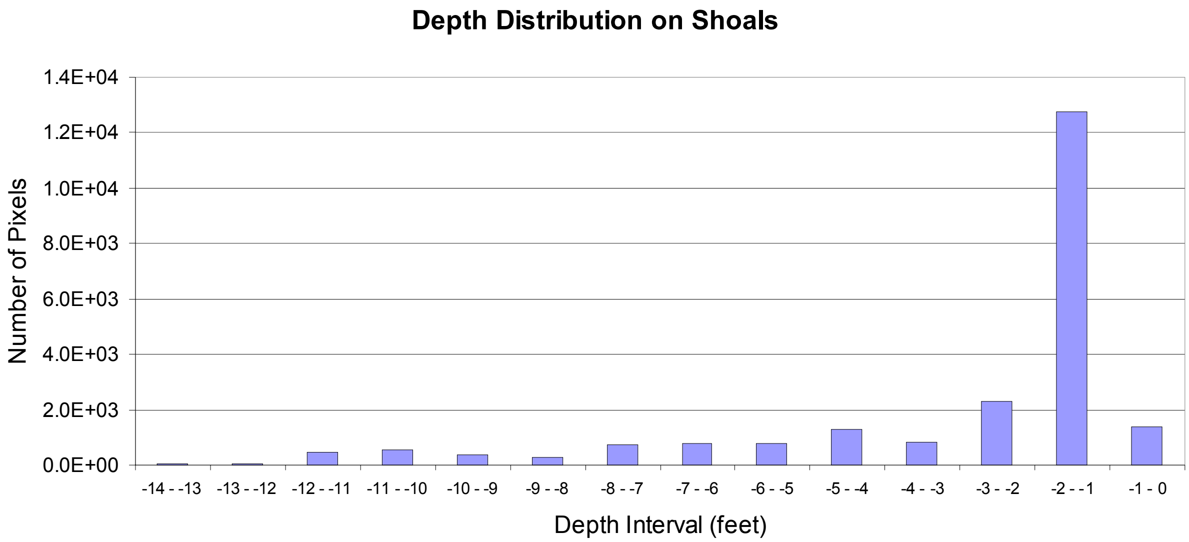
Inspection of these output led to some concern about the accuracy of the estimated elevations of the areas that had not been surveyed. Therefore, a technique was used that took advantage of the USGS data in Florida Bay where available, and used the previous bathymetry data for the Florida Bay basins with little USGS survey data. With this approach, the shoals within each basin and a criterion was developed for assigning elevations on the shoals. Then, the additional survey data described above was added to fill in the needed gaps. This process created the MFL bathymetry.

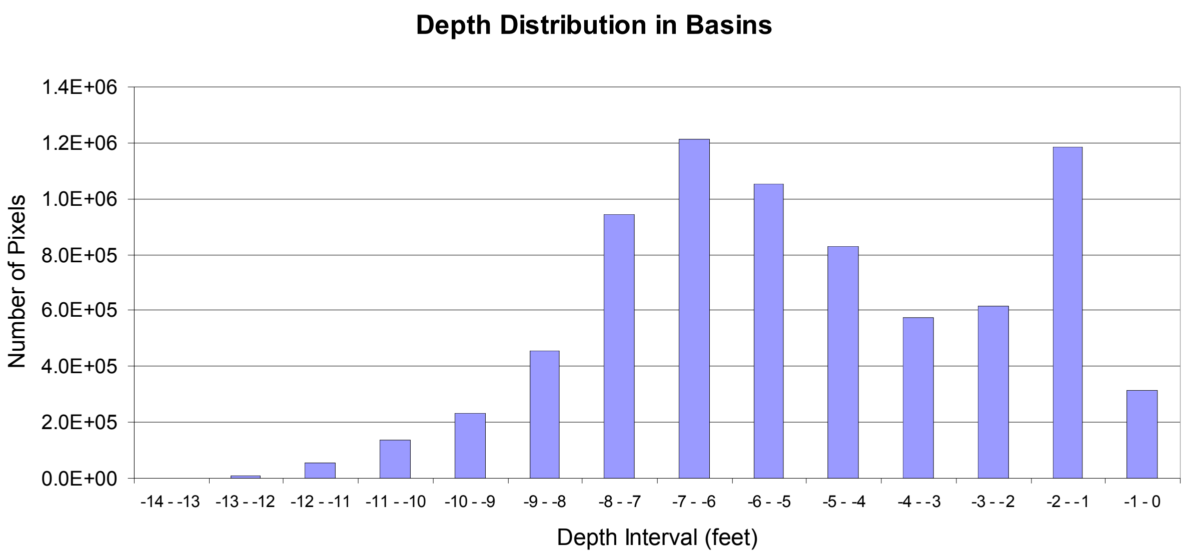
In basins where survey points were more than 50% of the basin area, the USGS survey data were used for the entire basin. There were 8 basins where the coverage was less than 50%. There were also two basins that were east of U.S. Highway 1 that were not included in the USGS survey. This means that there were ten basins with the previous Everglades National Park (ENP) bathymetry (18% of the wetted area), and 33 basins with the USGS data (82% of the wetted area).

For the shoal (banks) areas, the prior ENP bathymetry was used where the ten basins that had the prior ENP bathymetry for the open water areas. For the other 33 basins, if greater than half of the wetted shoal length was greater than one foot in depth, the USGS data were used. If less than half of the wetted length was greater than one foot in depth, the prior bathymetry data were used. Using these selection criteria, 202 of the shoals (55% of the total length) used the prior ENP bathymetry, and 176 shoals (45% of the total length) used the recent, USGS bathymetry data.

The resulting depth distributions for the shoals and in the basins reinforced the importance of the network of shallow banks in controlling circulation and exchange in Florida Bay, (Figure 2.1). An overwhelming majority of the shoal pixels fell into the one to two foot depth class. As discharge calculated with Manning's equation increases non-linearly with depth, the most significant exchange between basins was concentrated in the relatively few deep areas. By contrast, the open-water basins were about four or five feet deep on average. Even so, there is a significant representation in the one to two foot depth class that reflects the generally shallow conditions in the basins in the central and western regions of the Bay.

Figure 2.1: Depth distribution on shoals and in basins for the MFL bathymetry (as totals across all shoals and all basins, excluding land areas).





2.2 Boundary Salinity

Along the southwest Gulf coast, freshwater from Shark Slough discharging through the Shark River alters the salinity of the shallow coastal waters that form the western boundary of the FATHOM model domain. For the FATHOM MFL model, this relationship was described through empirically derived (regression) models that related salinity at the boundary (Figure 2.2) to the flow and stage in Shark Slough. The water level data were taken from the long-term data record at the P33 gauge in Shark Slough, and the inflow into Shark Slough was estimated by discharge from the four S12 structures upstream (total flow = S12T) (Figures 2.3 and 2.4).

The results from the SERC/FIU monthly salinity monitoring program were data used in this project. Beginning in the early 1990s, the Southeast Environmental Research Program (SERC) at Florida International University (FIU) has conducted a long-term program to monitor water quality in the coastal waters of South Florida. This program visited 24 stations in Florida Bay and 21 stations along the southwest coast on a monthly basis (Figure 1.5). Water samples were analyzed for salinity among with a suite of nutrient and other water quality parameters. The report by Jones and Boyer (2001) summarized the results and discussed long-term trends in water quality on a regional basis.

For the purpose of estimating boundary salinity, regression equations were developed to predict salinity on the practical salinity scale at SERC stations 25, 26, 27, and 28 (Figure 2.5) based on the monthly values of P33 water stage and S12T flow as regional indices of hydrologic variation. Linear regression equations were formulated using the observed data collected in the period 1991 through 2000. Table 2.1 shows the results of this analysis. The selected models incorporated a lagged response of salinity to variations in Shark Slough hydrology with lags up to three months investigated. Multiple variable regression equations that combined information based on both P33 and S12T results were better at predicting salinity variation than equations that used either data set alone. Multi-variate regression techniques have been used successfully to predict salinity within Florida Bay from marsh stage, sea surface elevation, and wind data using a similar regression method (Marshall (2004) and Marshall et al. (2004)).

The same approach was used to describe the variation of salinity on the boundary in the extreme east end of Florida Bay at SERC station 1 in Card Sound. Because the hydrologic conditions vary coherently throughout the area south of Tamiami Trail, there was a strong statistical relationship between salinity in Barnes and Card Sound and the indices of hydrologic variation in Shark Slough used for the western boundary salinity simulations.

Figure 2.2: Basin numbers and regional groups used in the FATHOM model. Dots identify locations of SERC salinity measurements used to define variable salinity boundary conditions.

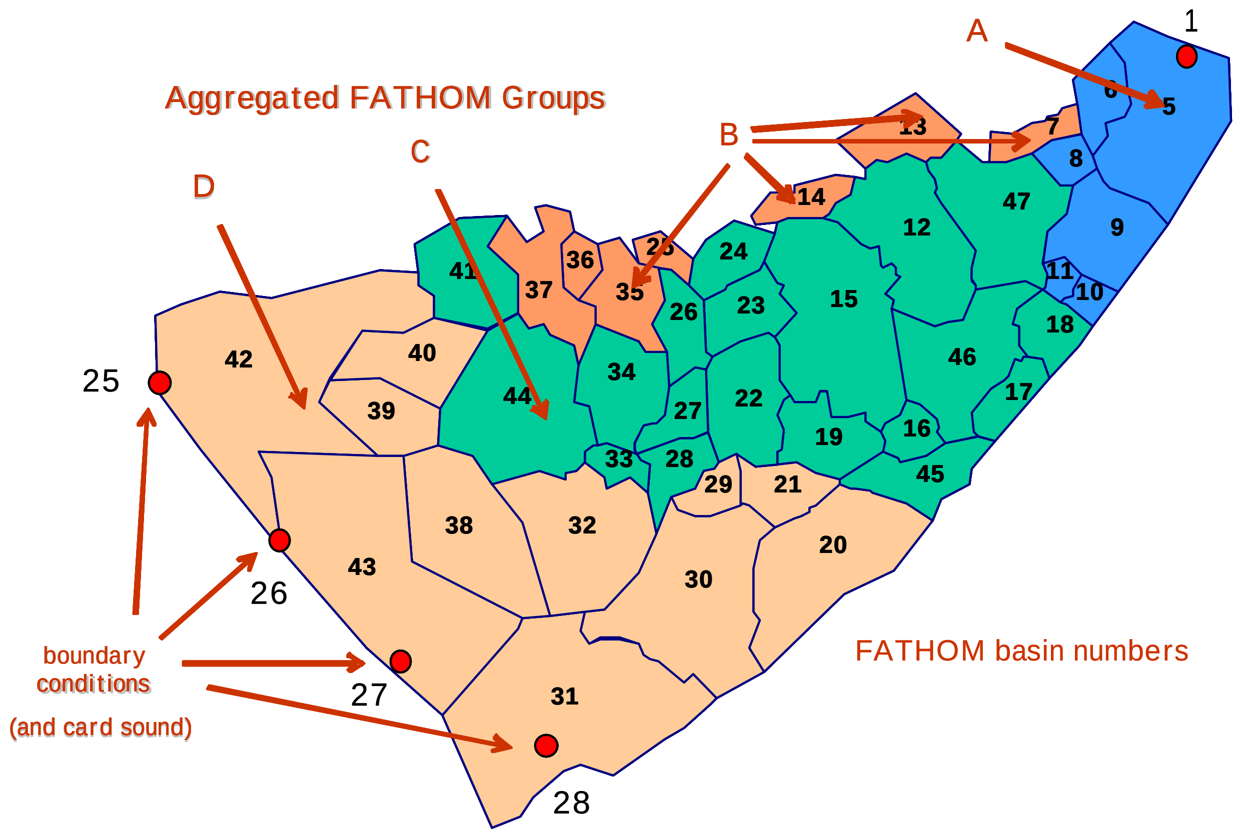


Figure 2.3: Locations of the sources of long-term data on regional hydrologic conditions that affect Florida Bay.

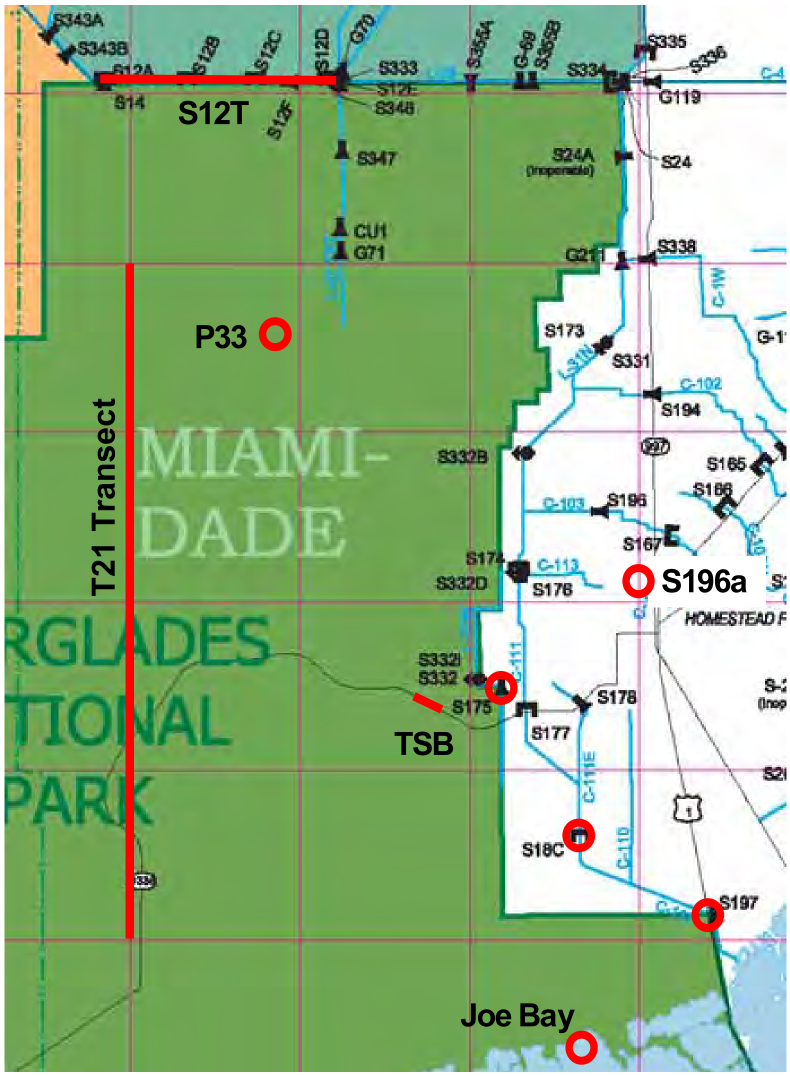


Figure 2.4: Regional indices for boundary salinity along the western and far eastern boundary of the Bay.

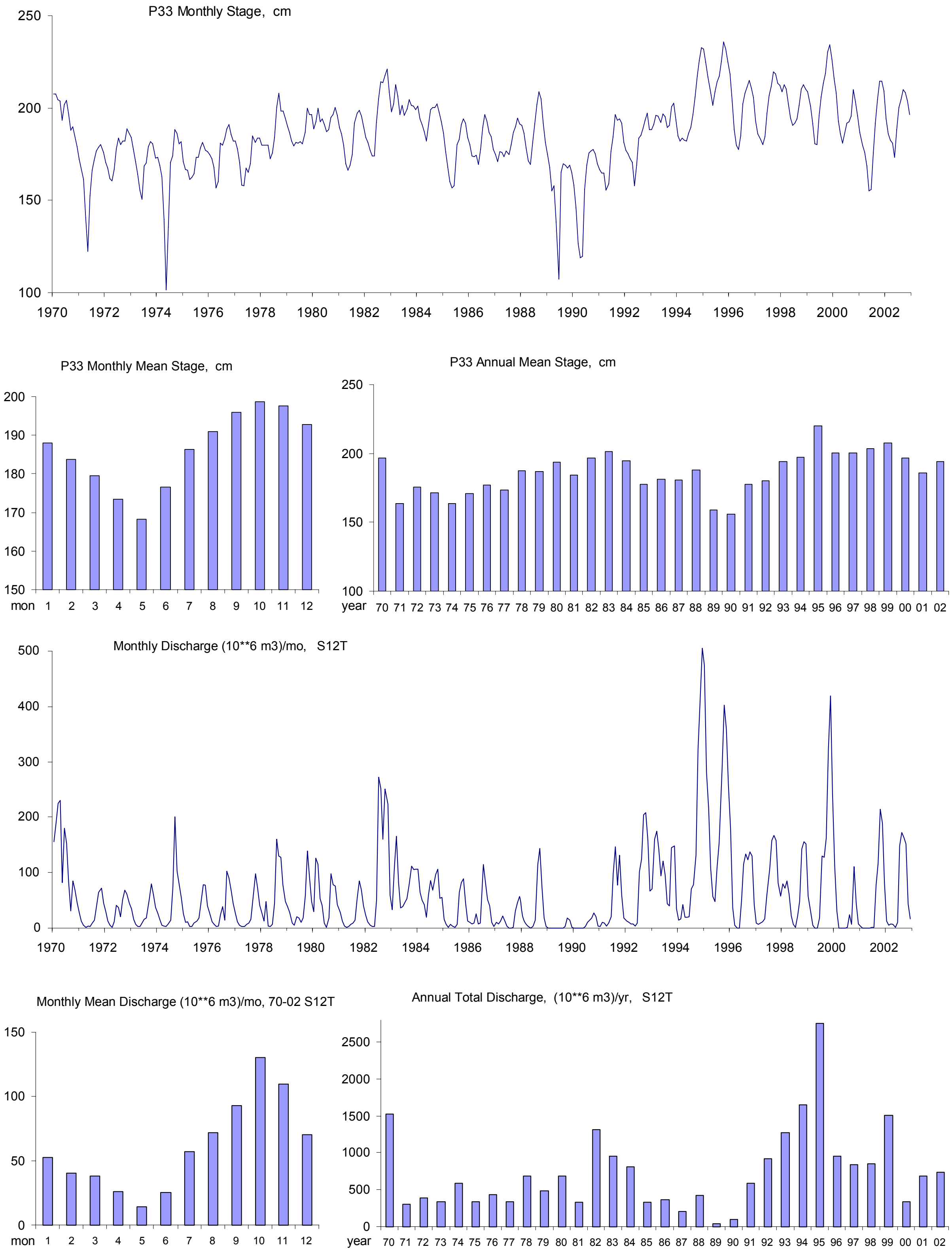


Figure 2.5: Time series of monthly boundary salinity 1991 through 2002.

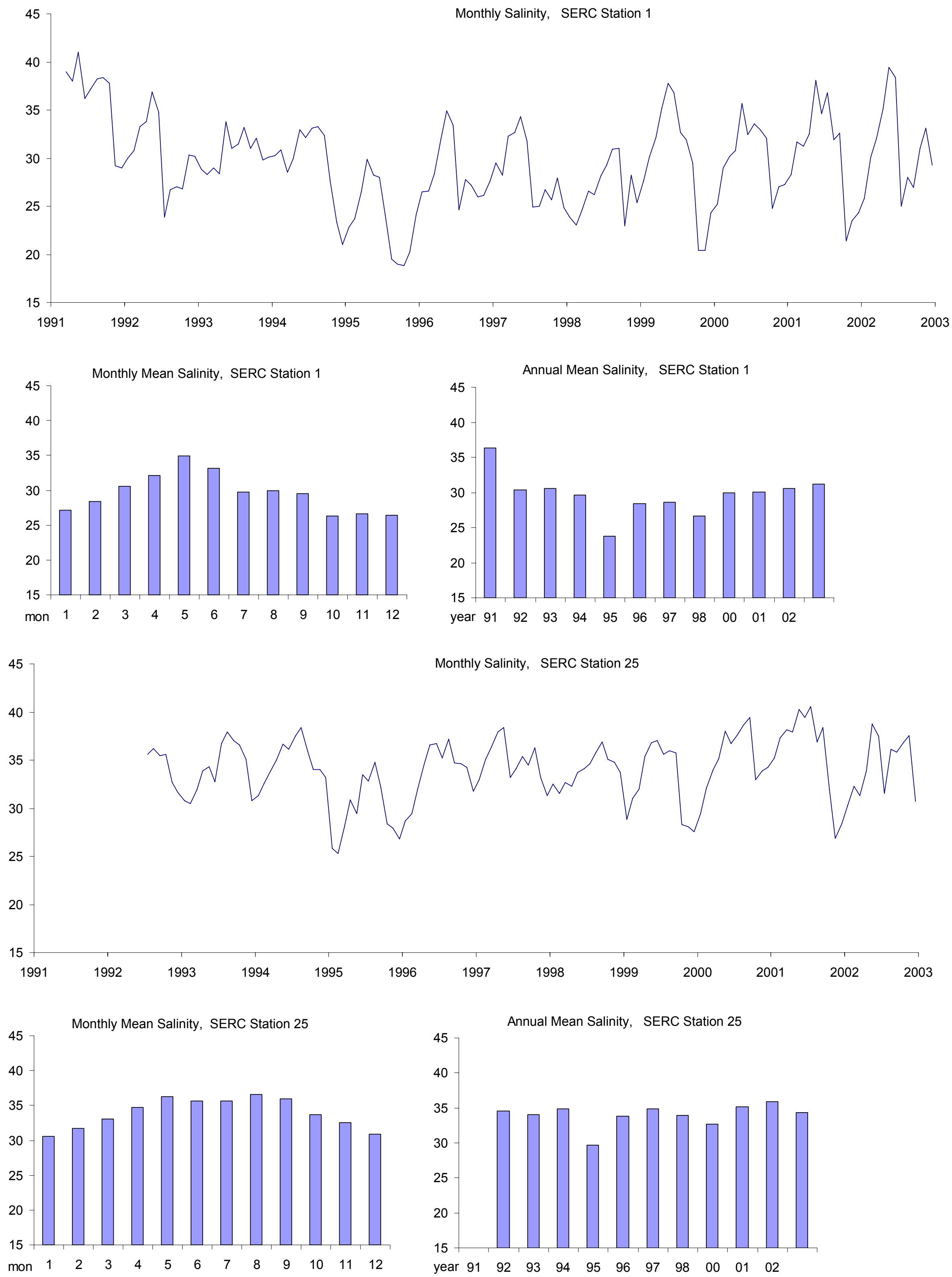


Figure 2.5: Time series of monthly boundary salinity 1991 through 2002 (cont.).

Figure 2.5: Time series of monthly boundary salinity 1991 through 2002 (cont.).

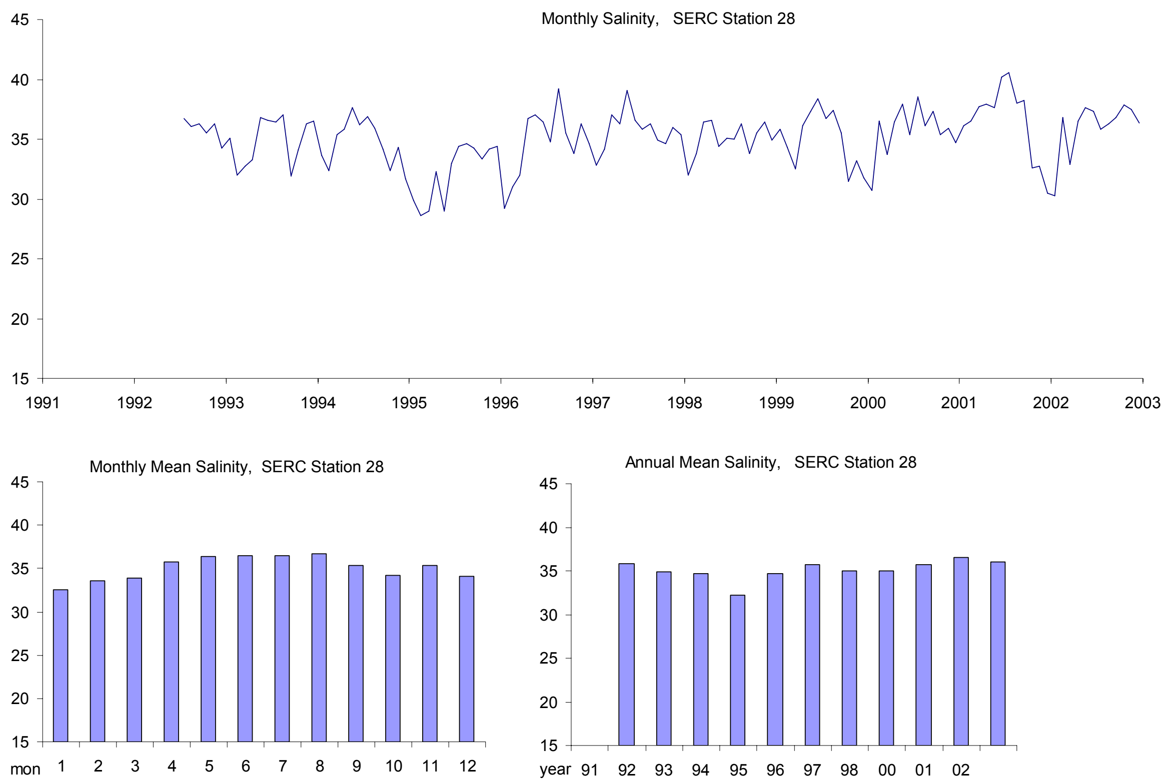


Table 2.1: Summary of regression models used to estimate salinity on the western boundary and at Card Sound (SERC station 1) based on S12T flow and P33 level for the MFL base case (1970 through 2002).

SERC Station	Lag (months)	S12T Flow Coefficient	P33 Level Coefficient	Intercept Mult	iple R^2
25 2		-0.014	-0.079	51.03	0.66
26 2		-0.013	-0.065	48.54	0.64
27 2		-0.012	-0.046	44.58	0.57
28 2		-0.009	-0.052	46.19	0.53
1 0		-0.009	-0.016	61.60	0.63

2.3 Calculation of Residence Time

FATHOM calculates residence time based on diagnostic statistics compiled for each basin and each month of simulation time. Two definitions of residence time were used: turnover time and decay half-life.

Turnover Time – Turnover time was calculated on a monthly basis for each basin, and was defined as the monthly average volume of water in a basin divided by the monthly total influx of water into the basin (including flood tides, rainfall and runoff), with the results expressed in days. Turnover time (T_T) is mathematically equivalent to the classically defined hydraulic retention time of a basin defined as

$$T_T = V / Q, \qquad 2.1$$

where V is the volume of the basin and Q is the water flux.

Decay Half-life – The decay half-life was operationally defined on a monthly basis for each basin by simulating the addition of a tracer at the beginning of each month and measuring the amount of tracer remaining in the basin at the end of the month. Each basin had its own unique tracer so that decay half-lives could be calculated simultaneously for all basins during a simulation. The Decay Half-life (D_H) for a given basin and month was calculated by solving for D_H (in days) in the following equation:

$$C_t = C_o * \exp(- t / D_H) \qquad 2.2$$

where C_o is the concentration of the tracer at the beginning of the month, C_t is the concentration at the end of the month and t is the number of days in the month.

2.4 Long Term Input Data for Salinity Calculations

The approach taken in estimating boundary salinity from Shark Slough hydrology, in section 2.2, also served as the general approach for estimating other input data for the historical reconstruction period 1970 through 2002. Measurements of components of the Florida Bay water budget, such as rainfall and inflow, were not available prior to 1996. Recent monitoring efforts have been in place for only about the past ten years. They include monthly measurements of water quality (SERC), continuous measurements of rainfall, salinity and water temperature at fixed stations by Everglades National Park (MMN), and continuous measurement of flow and salinity in estuarine creeks in the central and northeast region of the Bay (USGS), (Table 2.2).

The available direct data were used to establish relationships between water budget components and longer term indirect data that represented the regional indices of climate and hydrology. The indirect data were long-term data sets of sea level and tides, wetland water levels, rainfall, and estimated water flow through water management structures (i.e. weirs, gated structures, and pumps). The indirect data represented variations in regional climate that drive changes in the hydrology of South Florida and in salinity in Florida Bay.

This section describes the indirect data that were used to estimate the long-term input data sets required by FATHOM, (Table 2.2) for the period 1970 through 2002. The methods used to construct the FATHOM input data sets from these indirect data are described in Section 2.1 (bathymetry), Section 3 (inflow), and Sections 4.1 and 4.2 (rainfall and evaporation).

2.4.1 Rainfall

Long-term input data for rainfall were available from the records at Flamingo, Royal Palm and Tavernier monitoring stations, (Figures 2.6 and 2.7), and the Division 7 rainfall data product by the National Climatic Data Center (NCDC) (Table 2.2 and Figure 2.7). The Division 7 rainfall data were collected by primary and cooperating monitoring stations throughout Florida Bay and the Keys, and includeed the Tavernier station. Rainfall results at Flamingo, Royal Palm, Tavernier, and the NCDC Division 7 provided the basis for estimating long-term rainfall in Florida Bay for the MFL base case. Royal Palm rainfall was also used to estimate the contribution of rainfall to freshwater inflow from the wetlands in the Taylor Slough C111 wetland basin.

2.4.2 Evaporation

Long-term input data for evaporation patterns can be developed using the records of mean air temperature, (Figure 2.8), and range of air temperature (monthly maximum minus monthly minimum), (Figure 2.9) for Flamingo, Royal Palm and Tavernier. Relative humidity and wind speed data were from Joe Bay (Figures 2.1, 2.10 and 2.11). Only the seasonal pattern of humidity and wind speed were used, because the period of record for these data at Joe Bay covered only the period 1990 through 2002.

These results were used in three approaches for estimating long-term evaporation. Air temperature, humidity and wind speed were used in a Dalton Law calculation of evaporation. The temperature range was used to estimate atmospheric transmissivity in a radiation-based approach to estimating evaporation, and temperature alone was used to calculate potential evaporation based on the empirical Thornthwaite method.

2.4.3 Boundary Salinity

The indirect data used to estimate boundary salinity were the S12T flow and P33 water level data compiled by the South Florida Water Management District (DBHYDRO). Section 2.2 describes these data and their application to estimate boundary salinity values. For CERP alternative simulations the input data sets from the SFWMM was used.

2.4.4 Fresh Water Inflow from Wetlands

Because freshwater inflow is a primary component of the MFLs, the estimation of inflow is described in its own section of this report. Section 3 describes the methods used to estimate freshwater inflow from the Taylor Slough and C111 wetland basin.

2.4.5 Sea Level

Long-term input data for the water level in Florida Bay over the 1970 – 2000 period was taken from the record of monthly mean sea level at Key West (Figures 2.12 and 2.13). At supratidal and longer time scales, changes in water level were coherent over the whole Bay and with water level measured at the Key West gauge (Wang et al. 1994; Smith 1997). It was assumed that over the long term, biogenic accretion maintains the depth of the carbonate banks relative to mean sea level. Therefore, the (small) trend of increasing mean sea level over the period 1970 through 2002 was been removed from the sea level index data. Seasonal and year-to-year changes in mean sea level remain in the de-trended data.

Table 2.2: Information sources used for developing FATHOM input data to support simulation of salinity in Florida Bay for the period 1970 through 2002.

FATHOM Input	Direct Data	Indirect Data
Rainfall	ENP platform data (POR: 1996-2002, for this study)	Flamingo, Royal Palm, Tavernier, NCDC Division 7
Evaporation	N/A	Air temperature (mean and range) from Flamingo, Royal Palm and Tavernier; relative humidity and wind speed (seasonal pattern) from Joe Bay
Boundary salinity	SERC monthly data for stations 25, 26, 27, 28 and 1. (POR: 1991-2002)	S12T flow, P33 level, season (month) of the year
Inflow	USGS measured creek discharge (POR:1996-2000)	TSB flow, S18c flow, S197 flow, Royal Palm rainfall, USGS creek discharge (spatial distribution)
Sea level	ENP platform data (summarized by Smith 1997)	Key West sea level

Figure 2.6: Locations of indirect data sources for rainfall (Royal Palm, Flamingo, Tavernier) and the regions where each set of data were applied as FATHOM input.

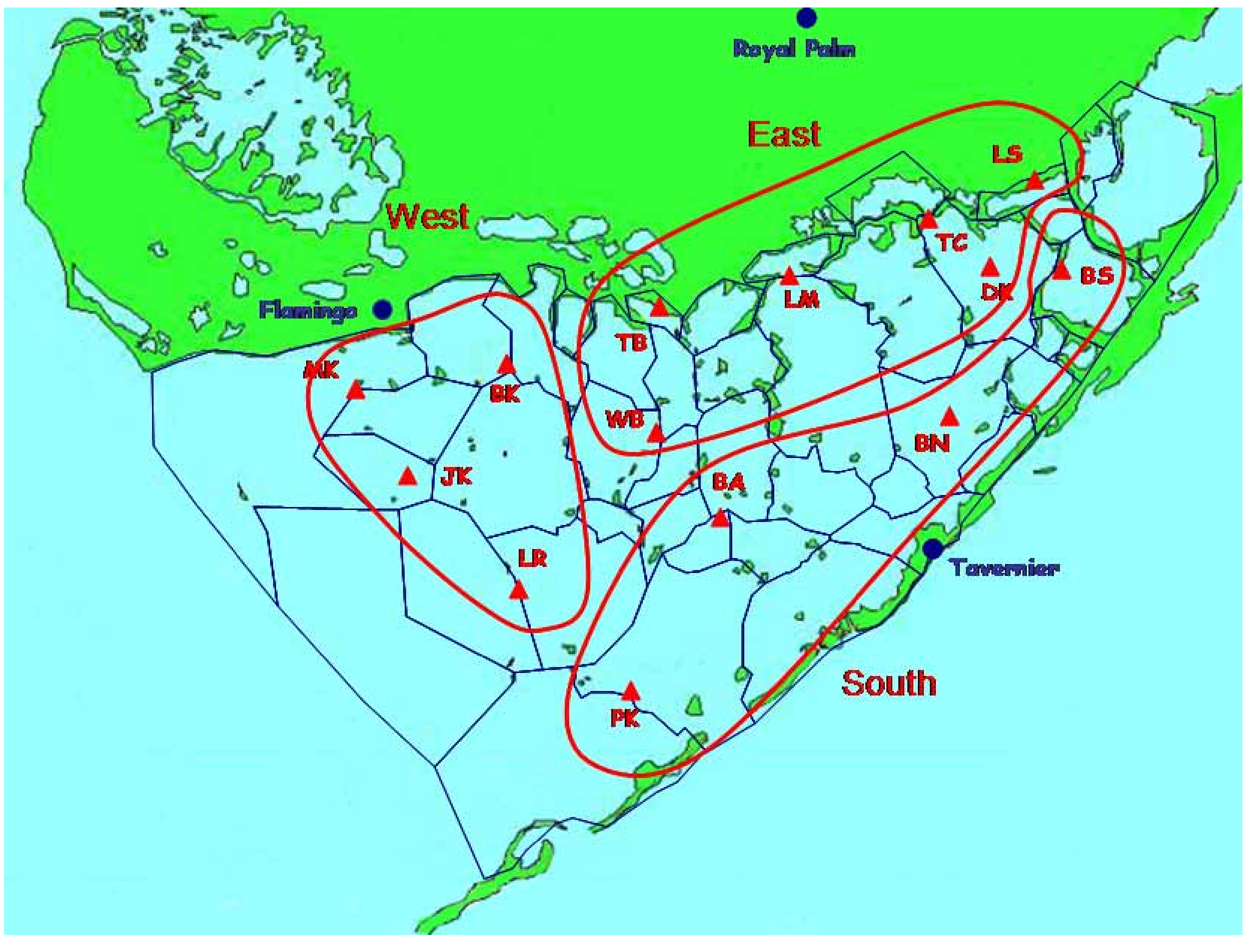


Figure 2.7: Indirect data used for regional rainfall indices.

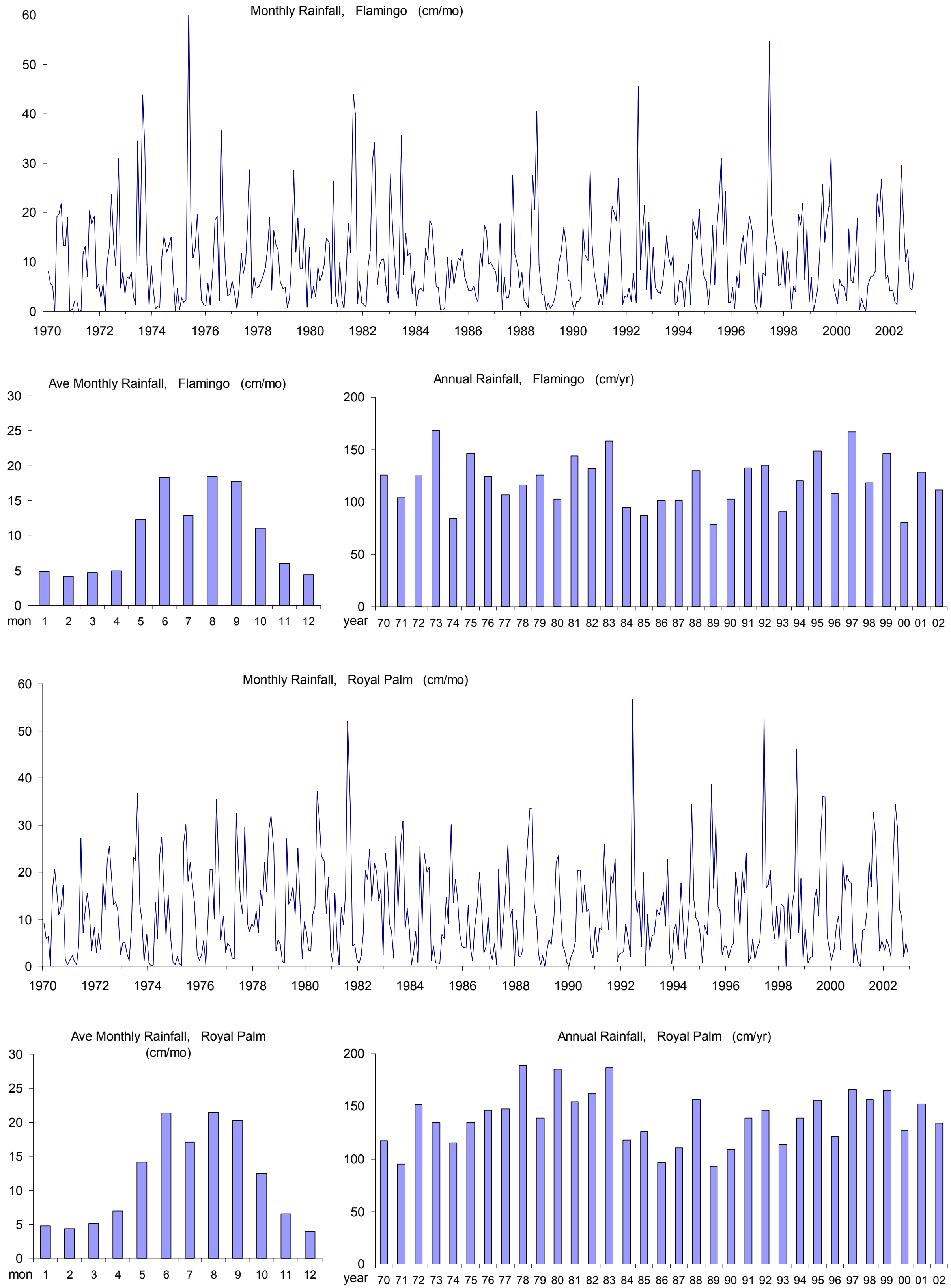


Figure 2.7: Indirect data used for regional rainfall indices (cont.).

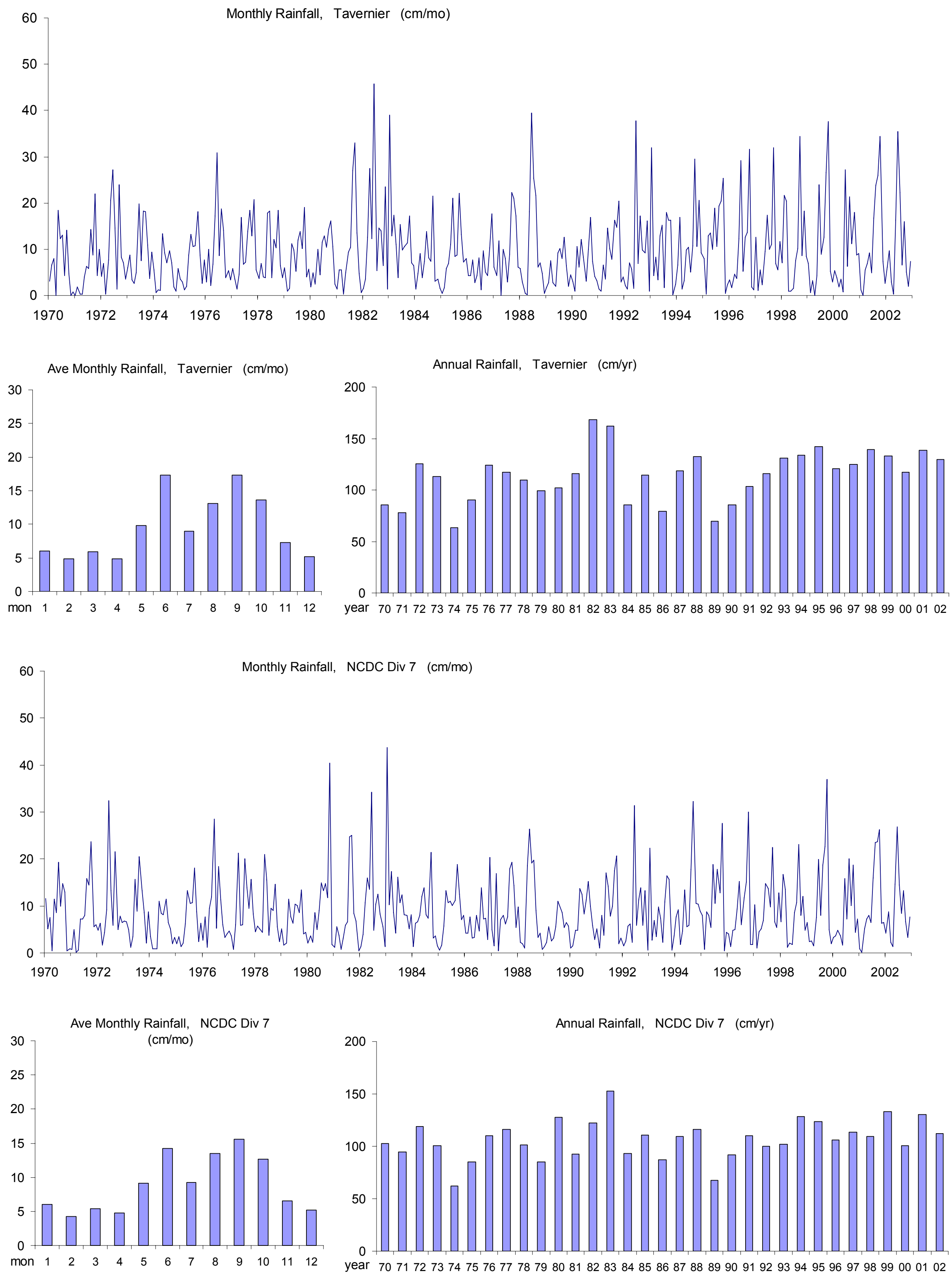


Figure 2.8: Indirect data used for regional indices of air temperature.

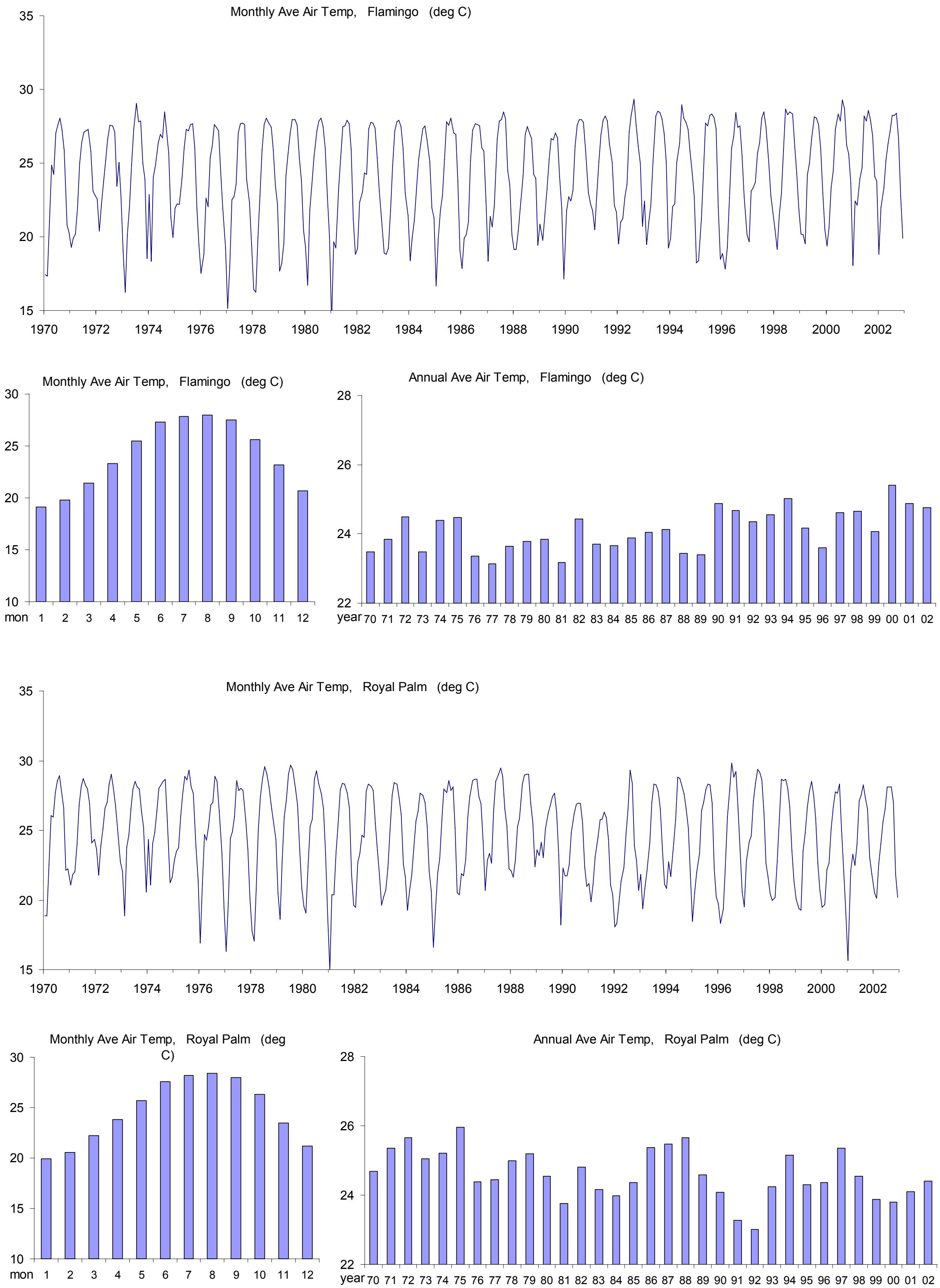
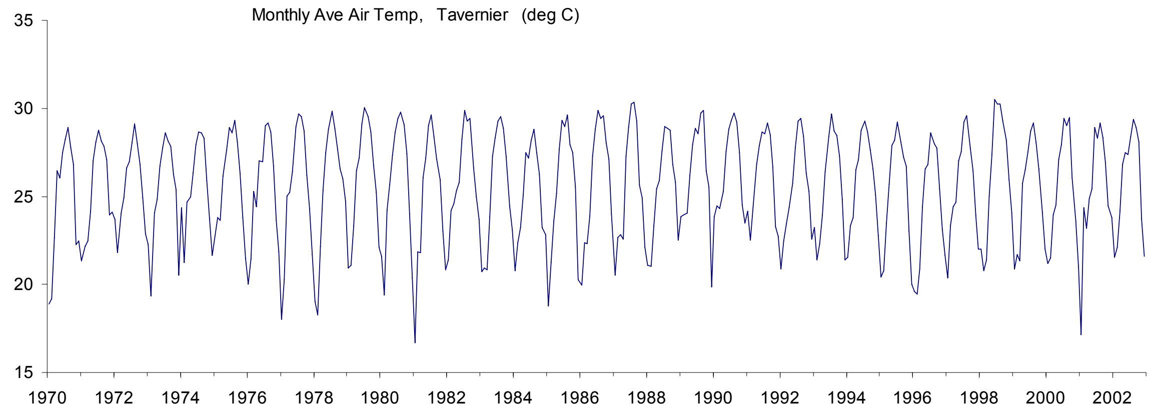
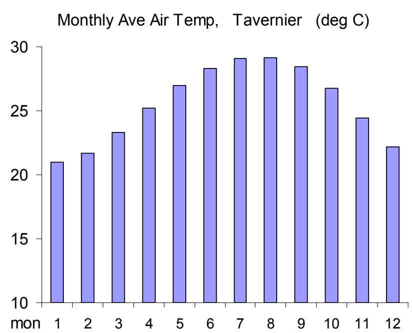
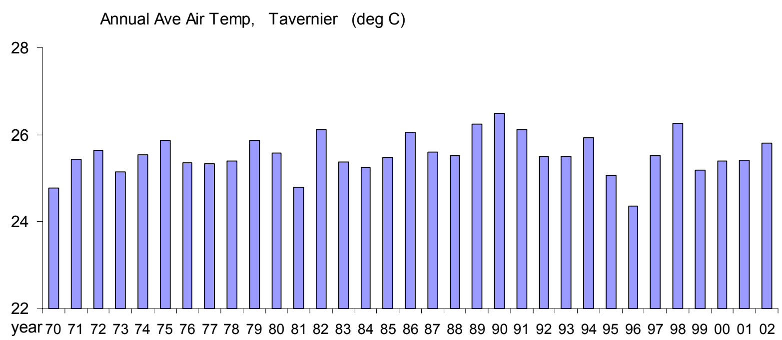
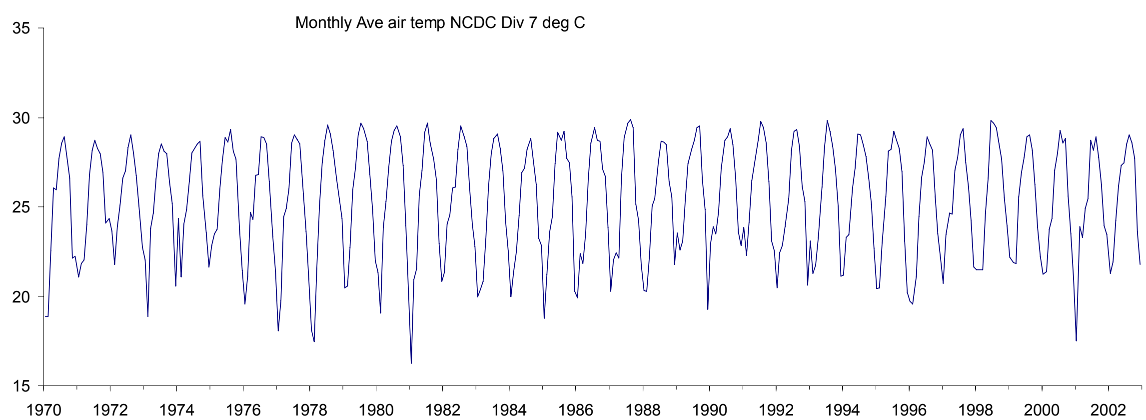


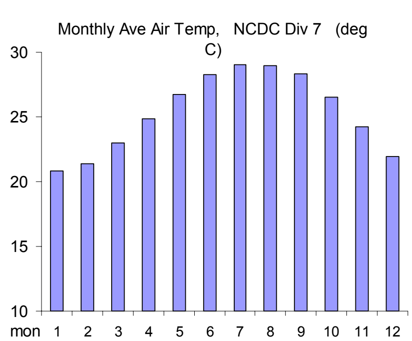
Figure 2.8: Indirect data used for regional indices of air temperature (cont..











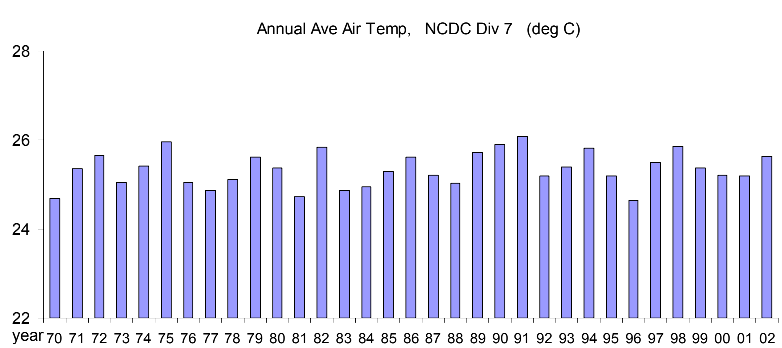


Figure 2.9: Indirect data used for regional indices of air temperature range.

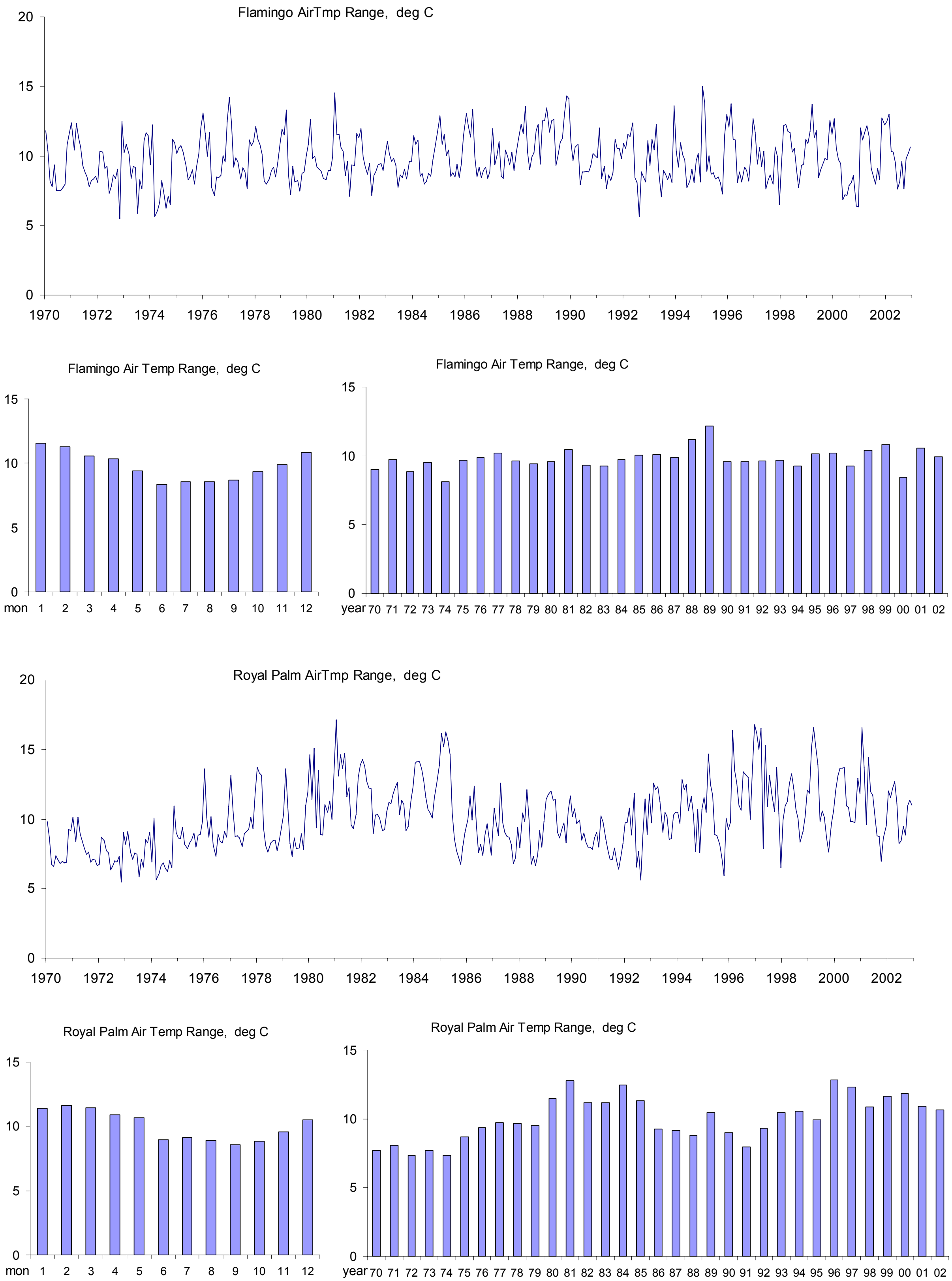


Figure 2.9: Indirect data used for regional indices of air temperature range (cont.).

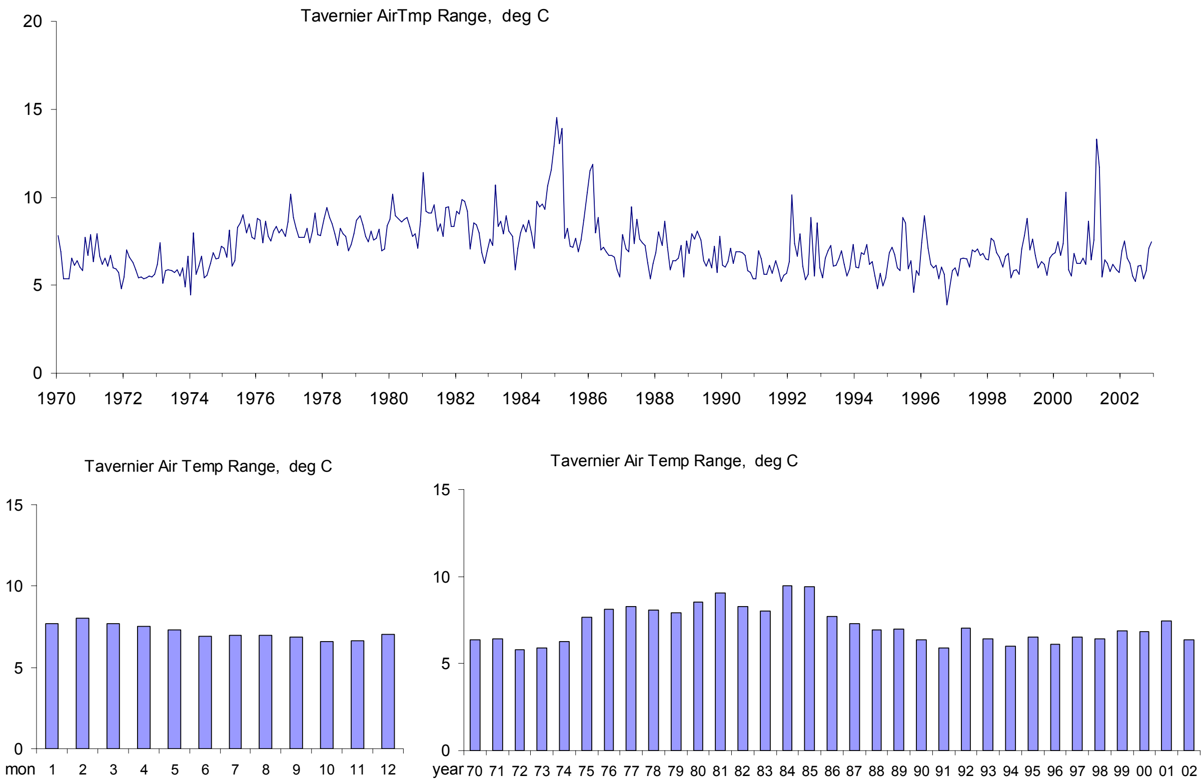


Figure 2.10: Indirect data used for the seasonal pattern of relative humidity.

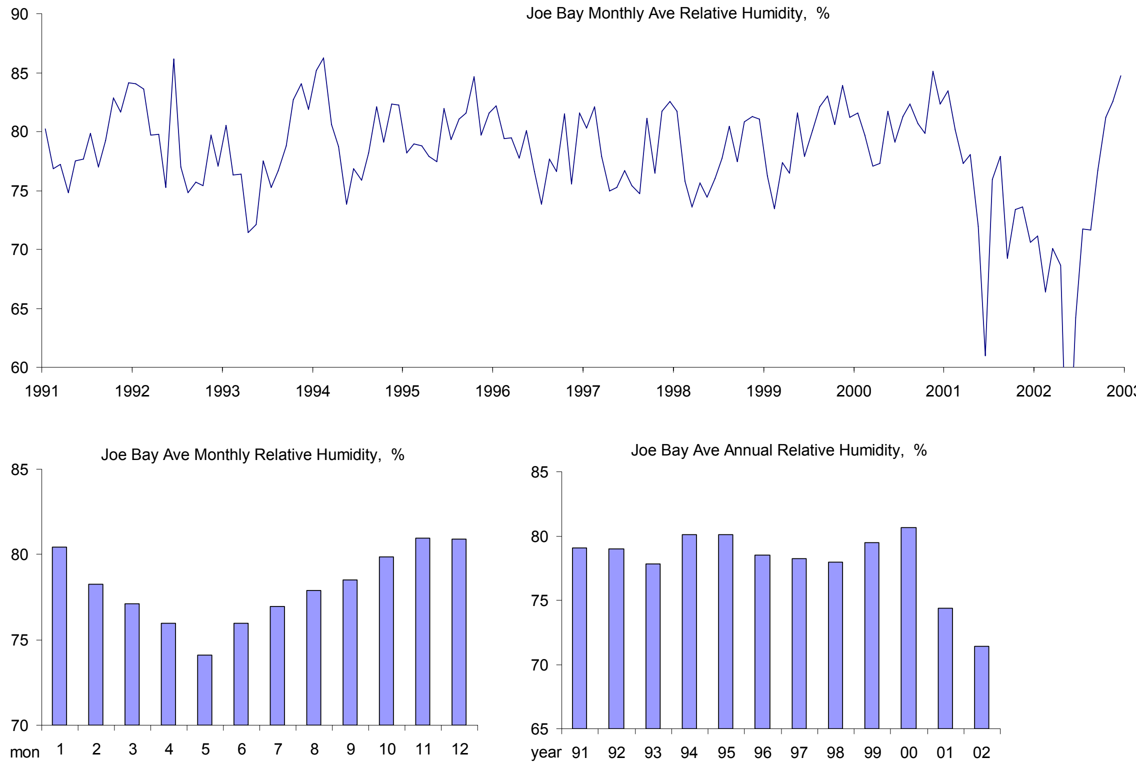


Figure 2.11: Indirect data used for the the seasonal pattern of wind speed.

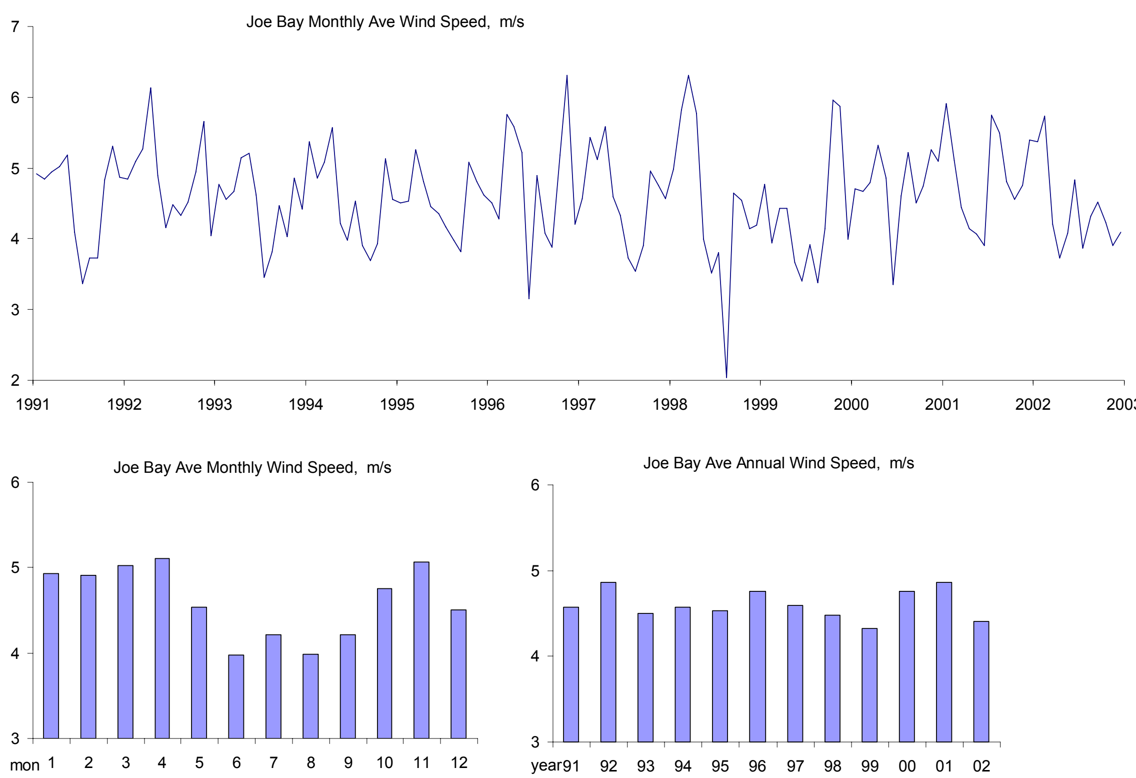


Figure 2.12: Locations for indirect sea level data.

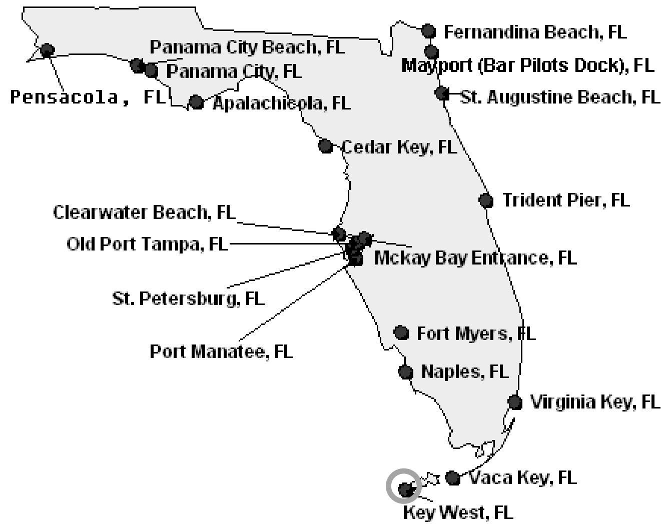
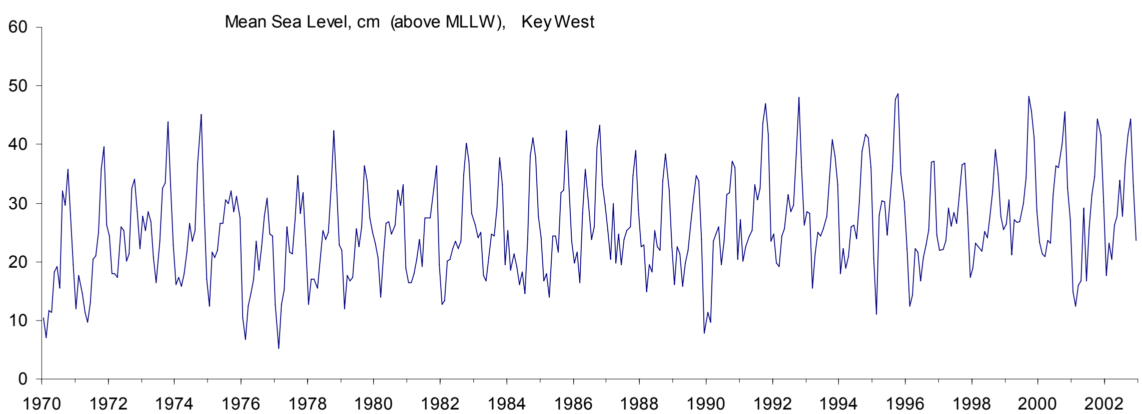
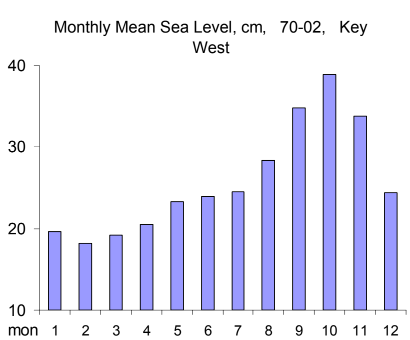
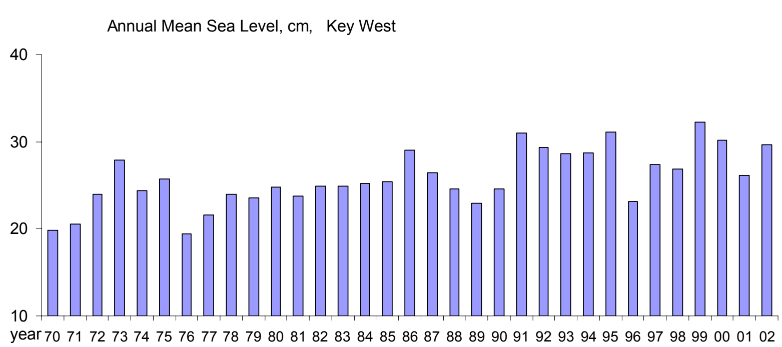


Figure 2.13: Indirect data for sea level used as a regional index.







3 ESTIMATES OF FRESHWATER INFLOW FROM WETLANDS

Three characteristics define the inflow of freshwater from the adjacent wetlands into Florida Bay: 1) the magnitude of flow, 2) its timing, and 3) its distribution along the north shore of the Bay. As with boundary salinity, estimates of inflow for the historical salinity reconstruction over the period 1970 through 2002 must be derived from indirect data rather than on direct measurements. Direct measurements of inflow have been made by the USGS since 1996 on five estuarine creeks (Figure 1.4). These data provided a basis for estimating inflow over the longer period. However, the approach to estimating long-term inflow into Florida Bay must also account for an unknown amount of ungauged inflow that was not measured.

The estimation of long-term inflow utilized a water budget approach. As originally conceived for this project, the PHAST wetland hydrology model was intended to serve this function. Enhancements to the PHAST model attempted to improve estimates of the contribution by the Long Pine wetland basin to inflow. This was of particular interest in estimating the inflow of fresh water into the central region of the Bay where hypersaline conditions are prone to develop. However, after enhancements and recalibration, the PHAST model was unable to satisfactorily account for the measured inflow plus ungauged inflow estimated by the USGS for the period 1996 through 2000. As an alternative, estimates of long-term inflow were made using a simple mass accounting approach that maked explicit assumptions about the amount of ungauged inflow and how this is allocated geographically as input to the FATHOM model.

This section describes the MFL base case inflow input data and the alternative inflow data sets used in the sensitivity study (Section 5), and it documents the data and analysis on which these estimates of inflow were based. The wetland water budget for the period covered by the available USGS inflow data, February 1996 through September 2000, served as the benchmark for compiling the long-term estimates of inflow. The compilation of the water budget is described first for this benchmark period. Then a discussion of the PHAST model enhancements follows, including the results of model calibration and an evaluation of the enhanced model. Based on this evaluation, it was decided not to base the estimation of wetland inflow only on the enhanced PHAST model. The section closes with a description of how freshwater inflow from the wetlands was estimated for the MFL base case and alternative inflow data sets used in the sensitivity analysis.

3.1 Wetland Water Budget - 1996 through 2000

The wetland sub-basins and fluxes across the related transects defined in Figure 3.1 defined the framework for compiling the wetland water budget in the Taylor Slough C111 wetland basin. The fluxes designated MFLx are surface water fluxes that link the three wetland basins of the PHAST model to the surrounding wetland and to Florida Bay. This same framework was used to examine the output from the SFWMM (section 7), so for convenience the boundaries of the sub-basins follow the cell boundaries in the SFWMM. In addition to the MFL fluxes, each wetland sub-basin gained water as the net of rainfall minus evaporation [R-E]. The term del S accounted for changes in storage in each basin as the effective net flux over a period of time. The del S flux can be large over short periods, especially between the wet season and dry season within a year.

Over longer periods, such as that considered here, changes in storage did not contribute significantly to the water budgets.

Flow in Taylor Slough (TSB) (Figure 3.2), and discharges from the S175 structure and the S18C structure on the C111 Canal were the major sources of surface flow data into the Taylor Slough C111 wetland basin. Table 3.1 identifies the long-term data used to estimate components of the wetland water budget. Discharge through the S197 structure into Manatee Bay accounted for the large flux of surface water out of the basin (Figure 3.3). Several of the surface water fluxes either could not be estimated from the available data, or the temporal coverage by available data was poor. This was the case for virtually all of the surface water fluxes in the water budget of the Long Pine basin.

Based on the USGS studies of creek flow, the Central Region of Florida Bay (via McCormick Creek) received very little fresh water inflow from the mangrove wetlands. The greatest rate and annual volume of inflow occured through Trout Creek into Joe Bay (Figure 3.4). Large flows were also discharged into Manatee Bay when the S197 structure was opened during extreme (but recurring) wet conditions to alleviate upstream flooding.

Estimates of inflow for the long-term input data set were made on the basis of the USGS gauged inflow for the period 1996 through 2000. This amounted to 311 million cubic meters per year, or 252 thousand acre-feet per year. The period of record actually begins in March 1996 and ends with October 2000, but it is referred to in this report as 1996 through 2000. Figure 3.5 indicates estimates of the surface water fluxes, as annual averages, from the data described above. This compilation accounted for the major surface water fluxes in the basin, even though there were insufficient data to estimate some of the fluxes. The excess of rainfall over evapotranspiration in the basin accounted for most of the difference between total flows in (TSB plus S175 plus S18c) and total flows out (the gauged USGS flows plus the discharge of S197 into Manatee Bay). Hittle et al. (2001) estimated flows in four ungauged creeks were an additional 23 percent above the gauged flows, and this total (386 million cubic meters per year, or 313 thousand acre-feet per year) should be taken as the lower limit on actual inflow into Florida Bay during the period 1996 through 2000.

Figure 3.1: Wetland sub-basins used to estimate freshwater inflow from the wetlands in the Taylor Slough C111 wetland basin. The locations of the MFLx flow transects are shown superimposed on the SFWMM grid. Also shown are locations for flow (TSB, S175, S18C, and S197) and rainfall (RPL) data used to estimate the inflow to Florida Bay for the period 1970 through 2002. The wetland water level data (CP and EPSW) were used to calibrate the PHAST model.

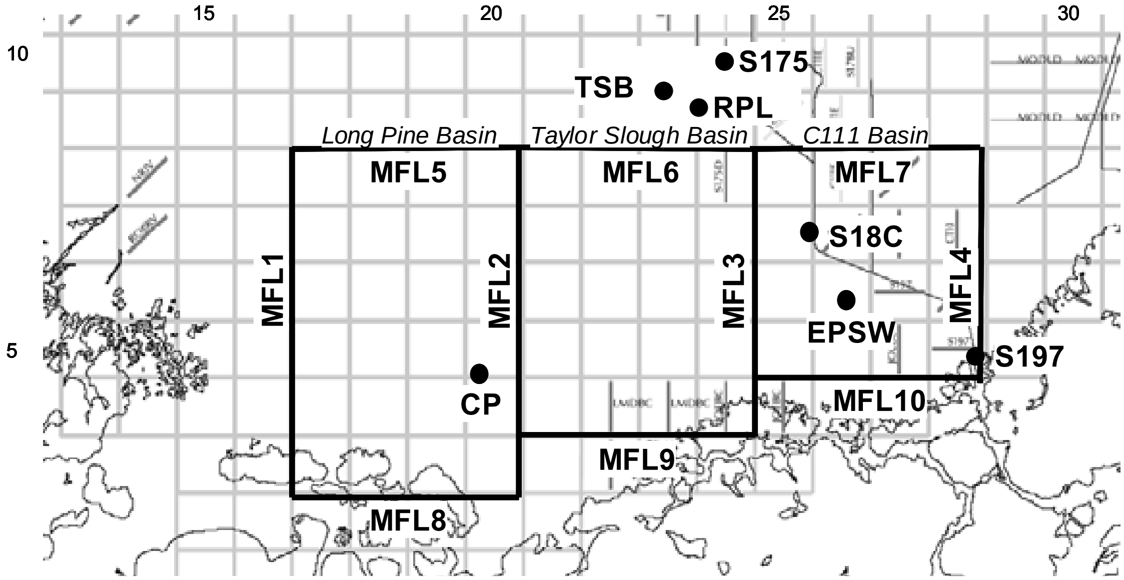


Table 3.1: Sources of information for estimating the water budget and calculating salinity in Florida Bay for the period 1970 through 2002.

Wetland Water Budget	Direct Data (1996-2000)	Physics-based Model	Indirect Data (1970 – 2002)
Rainfall	Craighead Pond (CP), Joe Bay (JBTS), P37, Royal Palm (RPL), S18C, Terrapin Bay (TB), Trout Cove (TC), Taylor River (TR)	N/A	Royal Palm rainfall, "excess rainfall" (see text)
Evaporation	German (2000)	SFWMM potential evapotranspiration (SFWMD 2000)	Estimated Florida Bay evaporation (Nuttle et al. 2003)
Surface Water Inflow into Wetlands	TSB flow, S18c flow, S197 flow, S175 flow	N/A N/A	
Fresh water to Florida Bay	USGS creek discharge (1996 – 2000)	PHAST, SFWMM (for water management alternatives)	Alternative Inflow Scenarios

N/A – no information available

Figure 3.2: Data used for regional indices of freshwater discharge into the Taylor Slough C111 wetland basin.

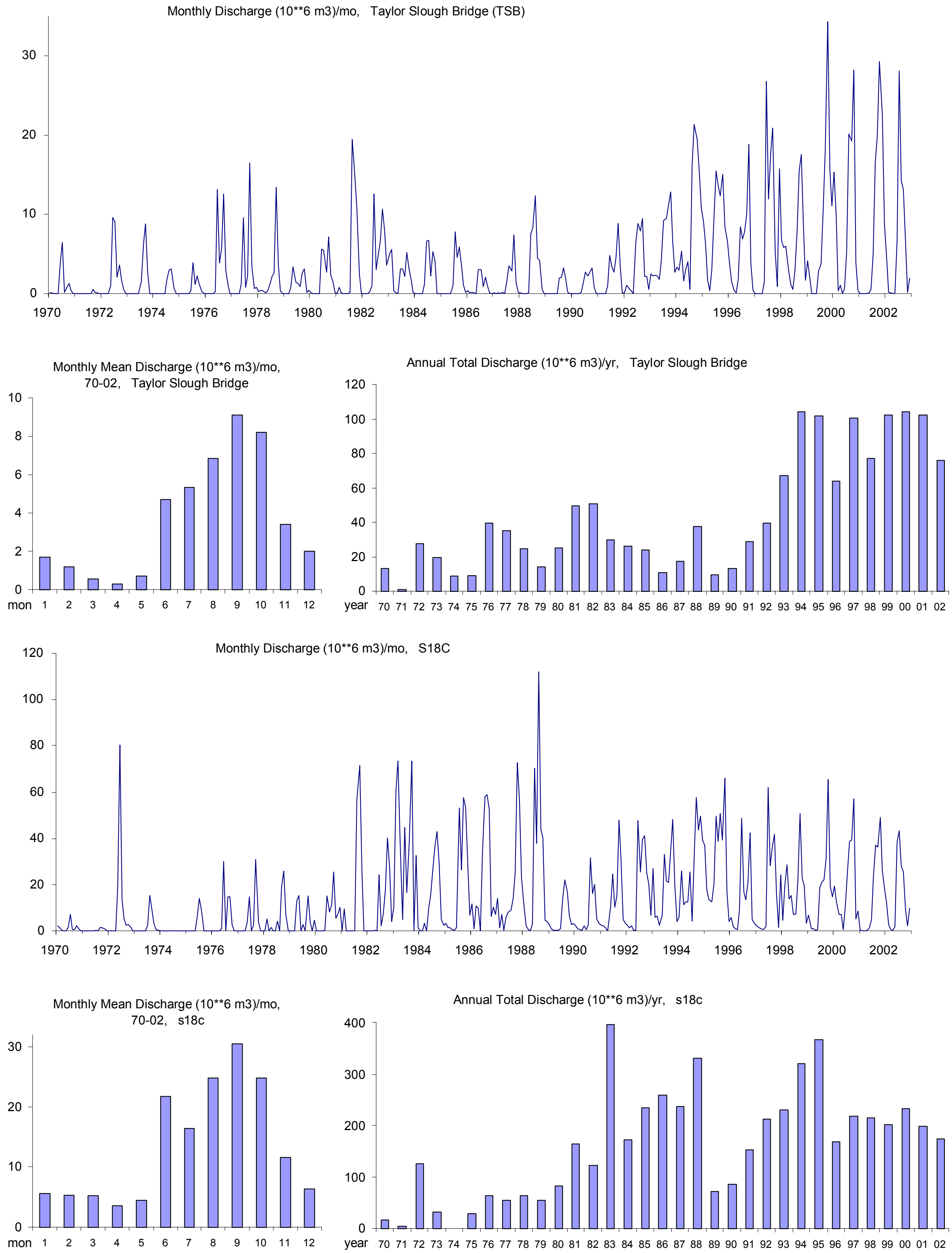


Figure 3.2: Data used for the regional indices of freshwater discharge into the Taylor Slough C111 wetland basin (cont.).

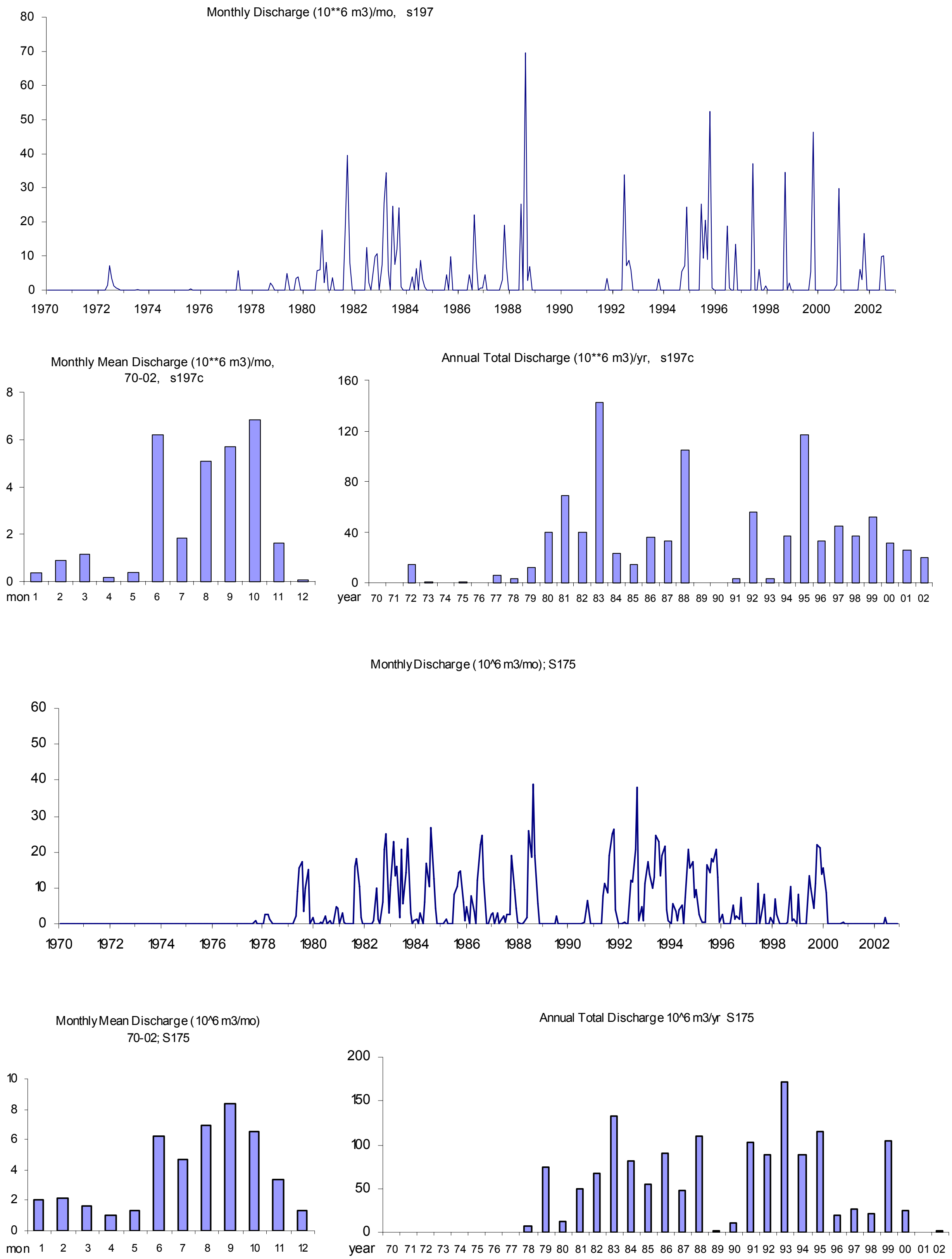


Figure 3.3: Monthly values of total inflow measured at the USGS estuarine creek monitoring stations (Figure 1.4).

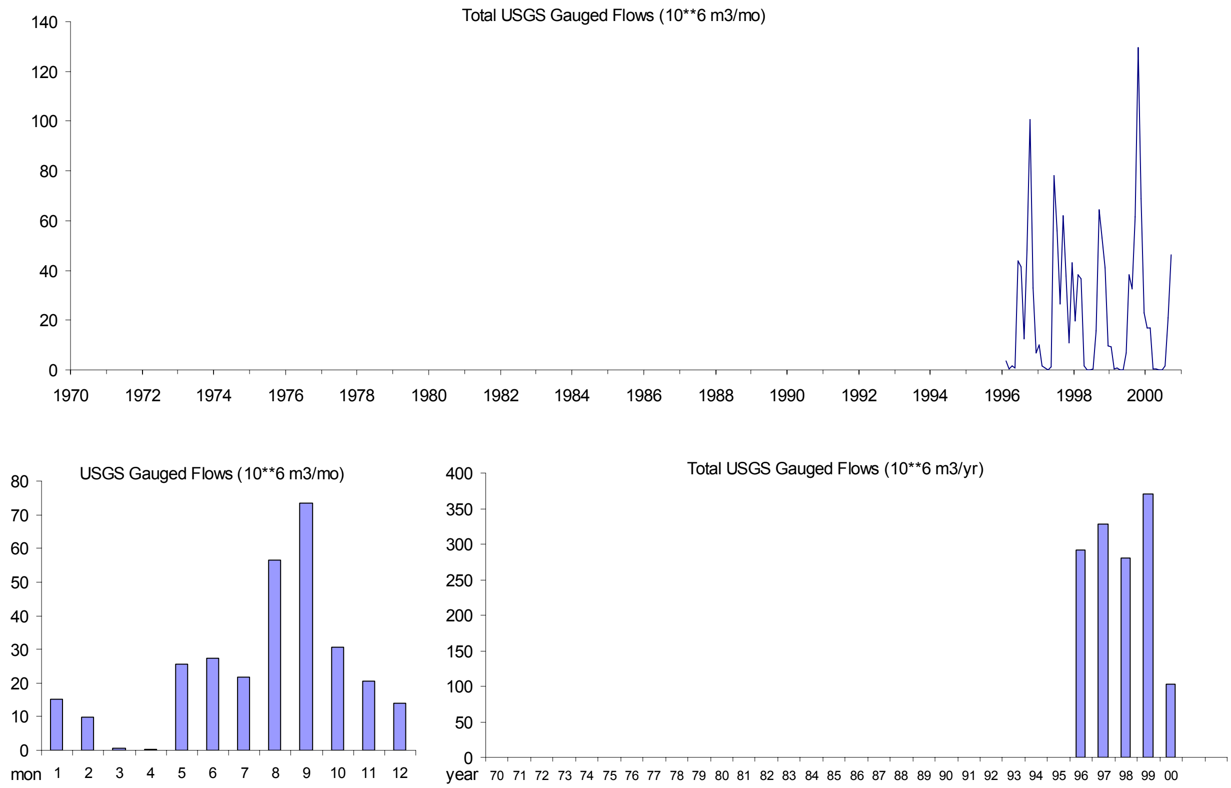


Figure 3.4: Distribution of annual average inflow measured at the USGS estuarine creek monitoring stations; McCormick Creek (MC), Taylor River (TR), Mud Creek (MUD), Trout Cove (TC), and West Highway Creek (WHC).

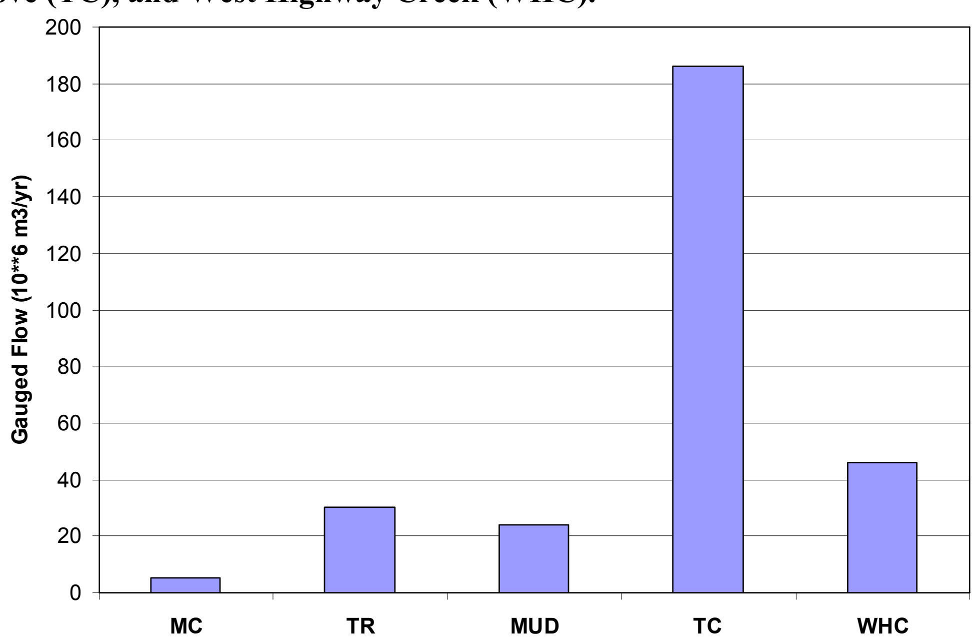
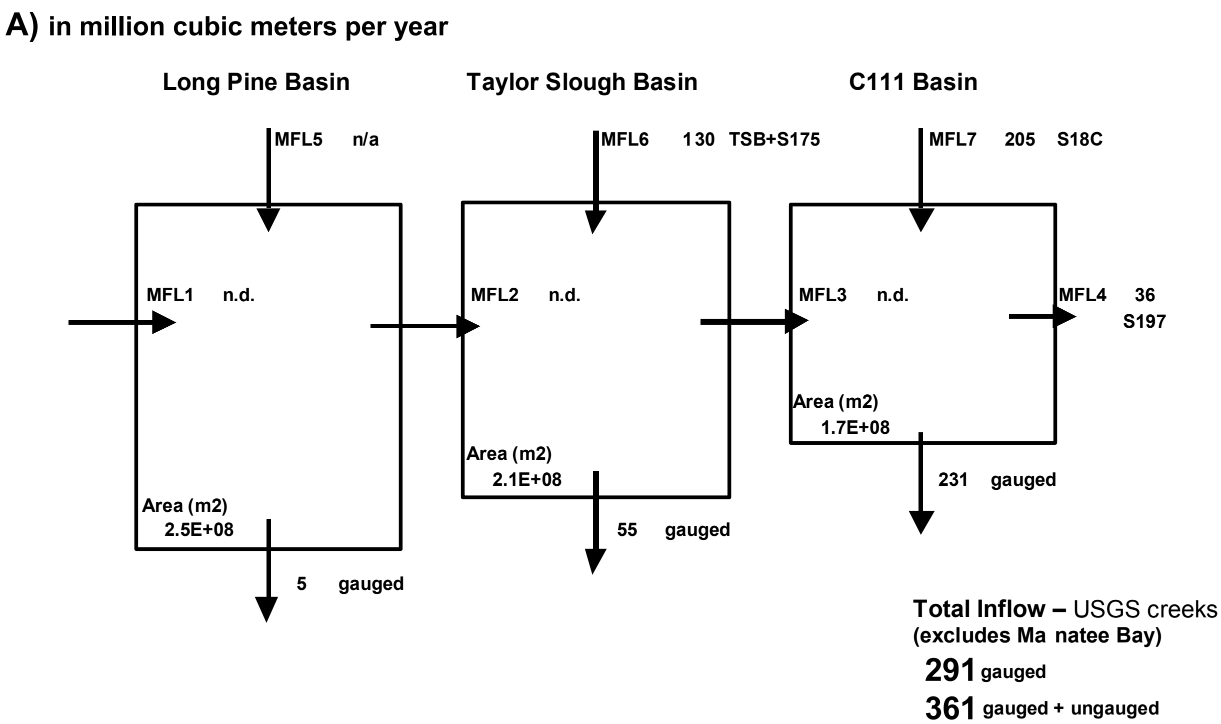
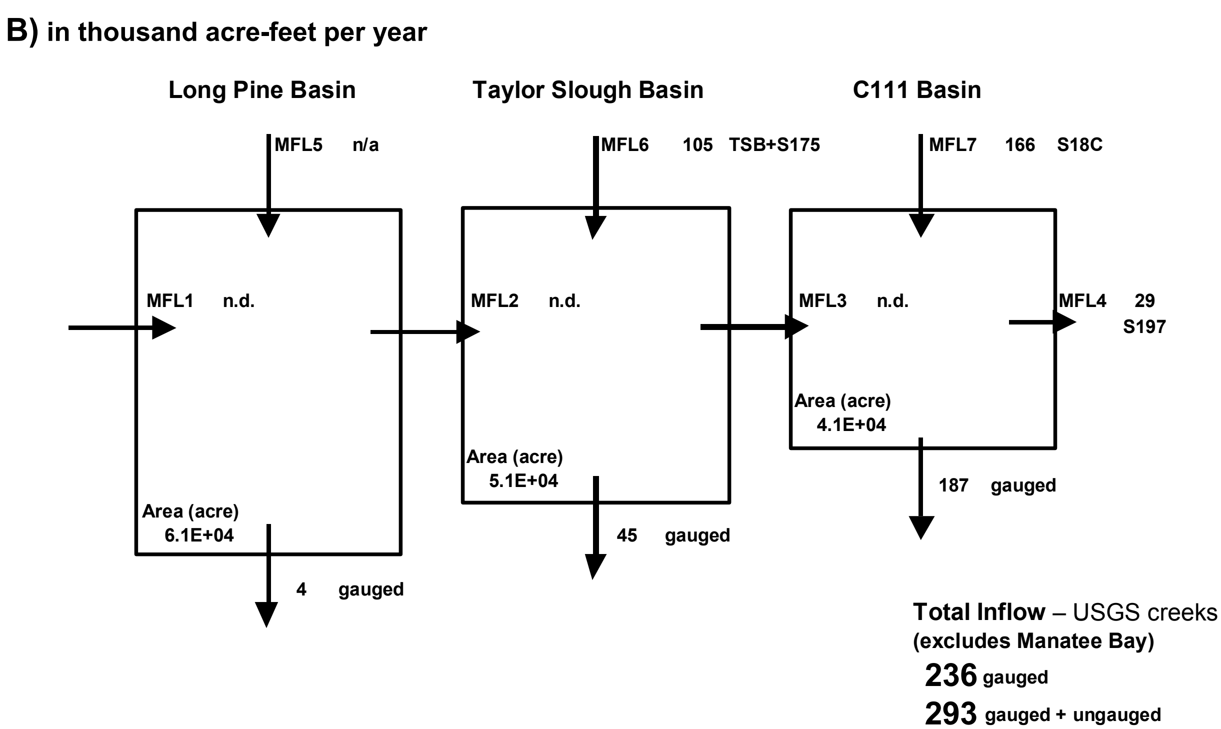


Figure 3.5: Wetland water budget components for the period March 1996 through October 2000 estimated directly from data. Fluxes are in units of A) millions of cubic meters per year and B) thousands of acre-feet per year.





Enhancements to the Wetland Hydrology Model - PHAST

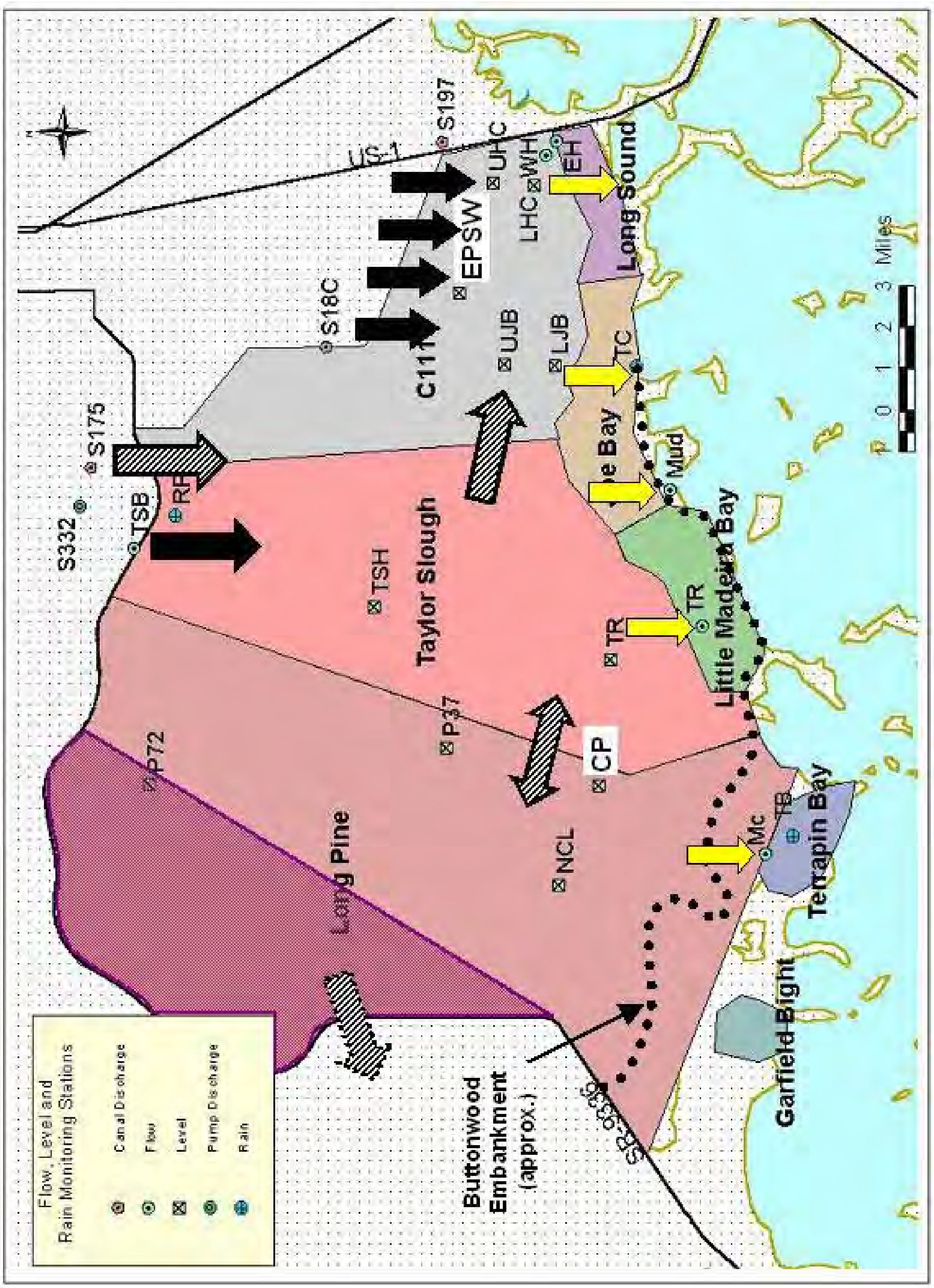
3.2.1 Long Pine Basin

For this project, the wetland basin hydrology model (PHAST) was enhanced by extending water budget and discharge calculations to include the Long Pine sub-basin. In contrast to the Taylor Slough and C111 wetland sub-basins, discharge from the Long Pine sub-basin was primarily the result of rainfall in excess of evapotranspiration in the sub-basin. No large tributary surface flows occured into or out of the sub-basin. The Everglades Park Road controls flow across the north and west sides of this sub-basin, and the flow that occurs through the culverts in the road is minor. Incorporating this sub-basin into the wetland basin models required adopting a rational scheme for allocating the total discharge estimated from excess rainfall among possible flow paths. Flow can occur in both directions across the boundary with the Taylor Slough basin. Flow in McCormick Creek, the major identified surface water discharge directly out of Long Pine sub-basin, occured only intermittently. Additionally, the nature of the hydrologic connection between the sub-basin and areas north and west of the Park Road is poorly understood.

A number of culverts allow the exchange of surface water across the Park Road that bounds the Long Pine sub-basin on the north and the west. Flow in these culverts was not monitored continuously, but various measurements have been made over a number of years. Tillis (2001) and Stewart et al. (2002) reviewed these measurements. In general, the average direction of surface flow across the Park Road is directed out of the sub-basin. *Based on this information, it is assumed that excess rainfall from one third of the Long Pine sub-basin discharges north and west through the culverts under the Park Road.*

The Buttonwood Embankment (Figure 3.6) impedes the discharge of surface water directly out of the Long Pine sub-basin south into the central region of Florida Bay. Lorenz (2000) and Holmes et al. (no date) described this geomorphic feature and trace its influence on the hydrology of Florida Bay and the coastal mangroves in this area. The embankment extends east as far as Joe Bay, and restricts the southward discharge of surface water out of the Taylor Slough sub-basin. Based on the USGS creek flow data, it appeared that most of the surface water discharged from the Taylor Slough basin occured as an eastward flow into the extreme southwest portion of the C111 sub-basin and eventually to Joe Bay.

Figure 3.6: Wetland hydrology basins used in PHAST showing surface inflows included in water balance calculations (black), locations of USGS measured creek flow (light-colored arrows), and surface fluxes calculated internally (hatched).



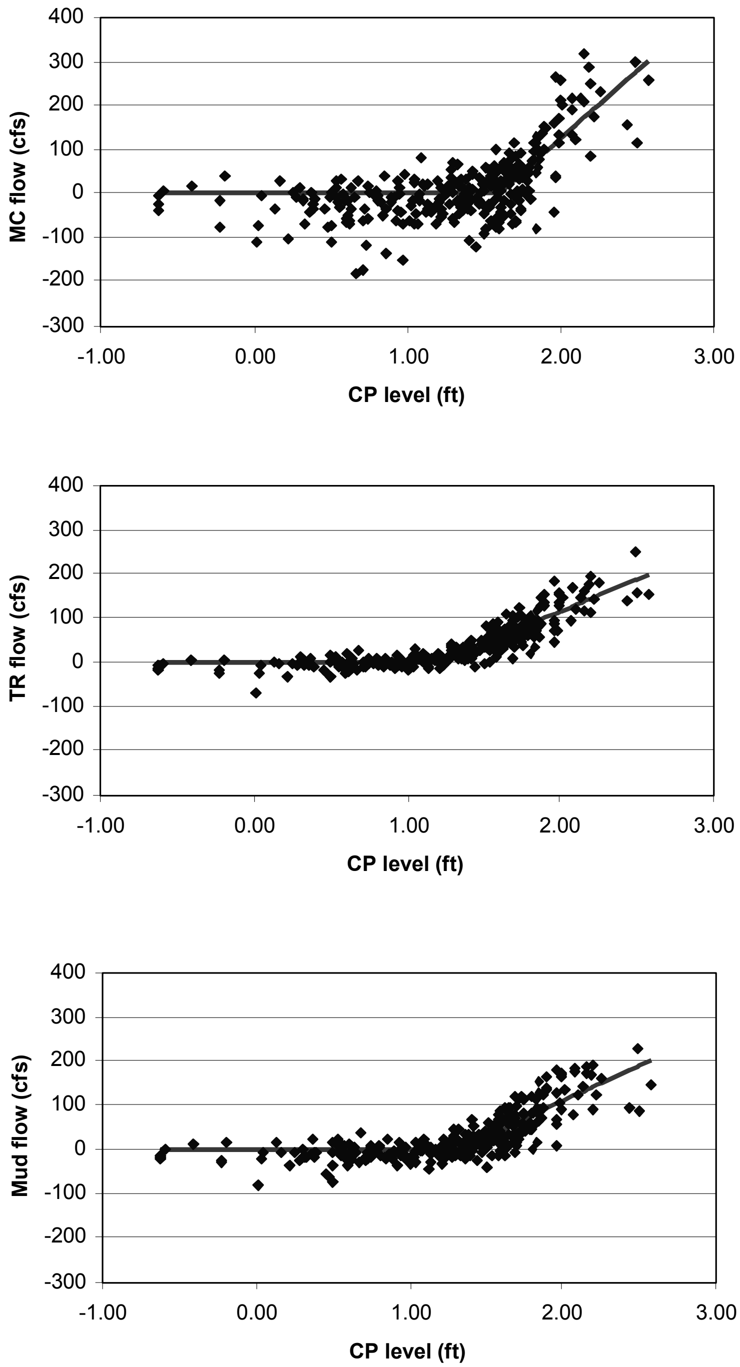
The influence of the Buttonwood Embankment on discharge from the Long Pine and Taylor Slough sub-basin was evident when the USGS creek flow data (aggregated weekly) for the creeks that breach the embankment (i.e. McCormick Creek, Mud Creek and Taylor River) were plotted relative to wetland water levels measured at CP, (Figure 3.7). The plots demonstrate the existence of a threshold in wetland water level between 1.0 and 2.0 feet that water levels must exceed before discharge occurs. The negative (upstream) flows and the scatter around the trend lines reveal the influence of additional forcing by wind, tides and variations in sea level on flows in the estuarine creeks. The threshold for wetland discharge into McCormick Creek across the Buttonwood Embankment is higher than for discharge through Mud Creek and Taylor River.

Based on this information, the area of the remaining two thirds of the Long Pine sub-basin that was not assumed to discharge across the Park road was combined with the area of the Taylor Slough sub-basin for purposes of estimating rainfall in excess of evapotranspiration. Discharge from the combined sub-basins across the Buttonwood Embankment was assumed to follow the form of the discharge relationships that are evident in Figure 3.7, Table 3.2. This means that the zero discharge thresholds were held at the values shown in Table 3.2, and the values of α, the slopes of the discharge curves enter the calibration of the models as minimum values. The additional discharge that occurs from the combined basins east into the C111 sub-basin was assumed to follow the general discharge relation described by equation 1.2.

Table 3.2: Parameters for discharge rating curves for flow measured at selected USGS creeks as a function of water level at CP. The parameters were as defined in Equation 1.2, and units for the parameters were consistent with the implementation within the PHAST model.

Parameter	MC	Mud	TR
α ($10^{36}ft^3$/week)	186	97.8	89.1
h_{sill} (ft)	1.6	1.3	1.3
β	1	1	1

Figure 3.7: Discharge rating curves for flow measured at selected USGS creeks as a function of water level at CP (MC = McCormick Creek, Mud = Mud Creek, and TR = Taylor River).



3.2.2 Calibration

Calibration of the revised wetland models followed the approach described by Nuttle (2004) with the resulting parameter estimates reported in Table 3.3. The method of calibration minimized the sum of squared deviations between modeled and observed water levels at CP for the Long Pine/Taylor Slough combined sub-basin, and at EPSW for the C111 sub-basin model. Optimization was performed using the solver routine in Microsoft Excel. In general, the basin hydrology models succeeded in fitting the fluctuations in water levels measured at CP and EPSW, (Figure 3.8). Parameters of the discharge relation reported for the Taylor Slough sub-basin are for discharge east into the C111 sub-basin and ultimately Joe Bay. Calibrated values for discharge south through the Buttonwood Embankment match the minimum values reported in Table 3.2.

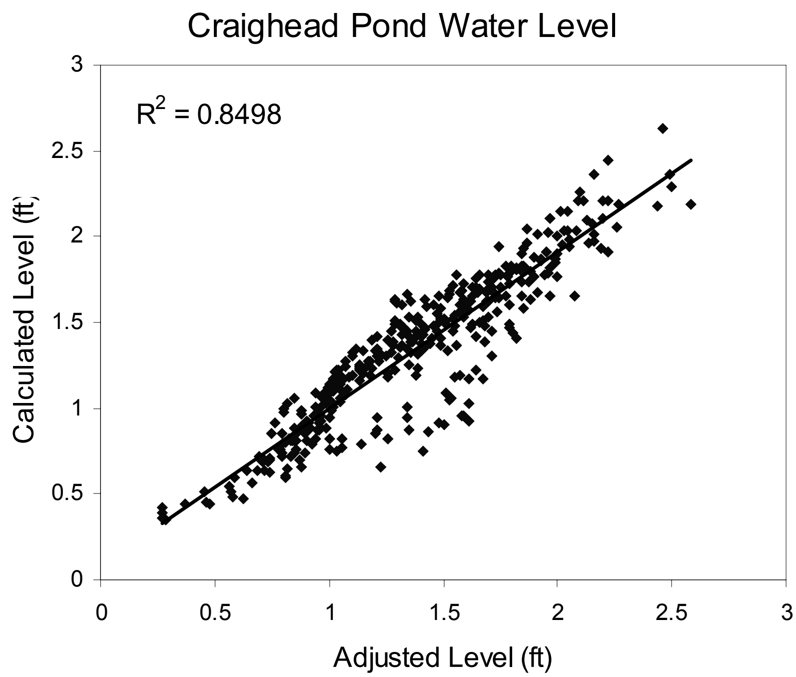
Table 3.3: Calibrated parameter values for the wetland basin hydrology models.

Parameter	Taylor Slough	C111
α (10^6 ft^3/week)	911 688	
h_{sill} (ft) 1.6		1.27
A^1 (million ft^2) 4900		1400
wet fraction	0.82	1.00
S175 fraction	1.0	0.0
Evap const.	-0.65	-0.75

[1] Set to measured basin area

The calibration of the PHAST model to match the observed fluctuation in Everglades water level also determined the amount and timing of freshwater inflow from the wetland basins into Florida Bay. The measured USGS creek flows were not used in the calibration. Therefore, the USGS inflow measurements were independent of the inflows calculated by the PHAST model (Figure 3.9). The volume of inflow to Florida Bay calculated by the PHAST model was sensitive to assumptions made in the representation of the water budget in the Long Pine sub-basin. In particular, the assumed proportion of surface flow out of the Long Pine sub-basin that flows west and north across the Park Road was not well characterized. The few measurements that have been made of this flow (Stewart et al. 2002) were inadequate to test the assumption that was used. The inflow calculated by PHAST was also sensitive to errors in the calculation of wetland evapotranspiration within the PHAST model.

Figure 3.8: Results of calibration of the wetland hydrology PHAST model to water levels sampled weekly from time series of daily average values for Craighead Pond and EPSW locations.



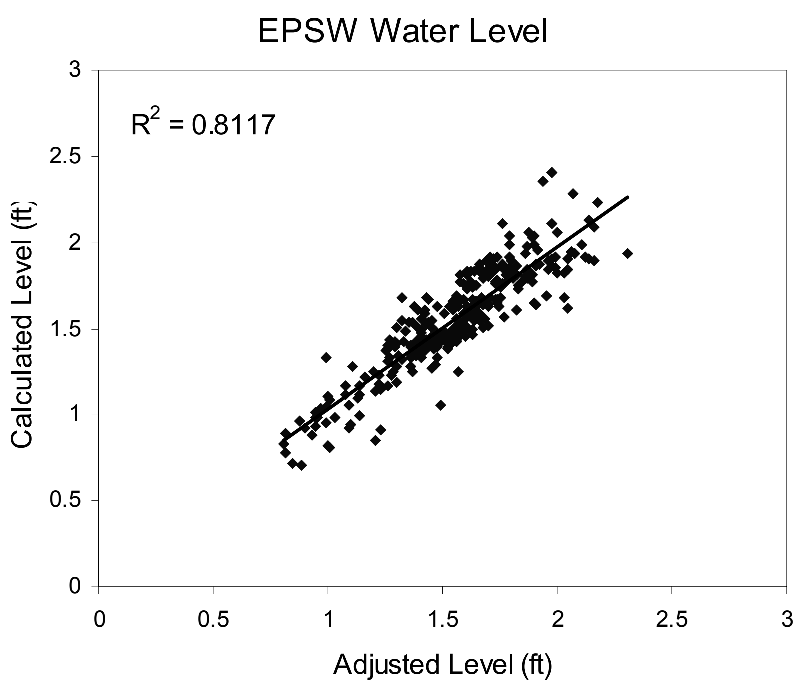
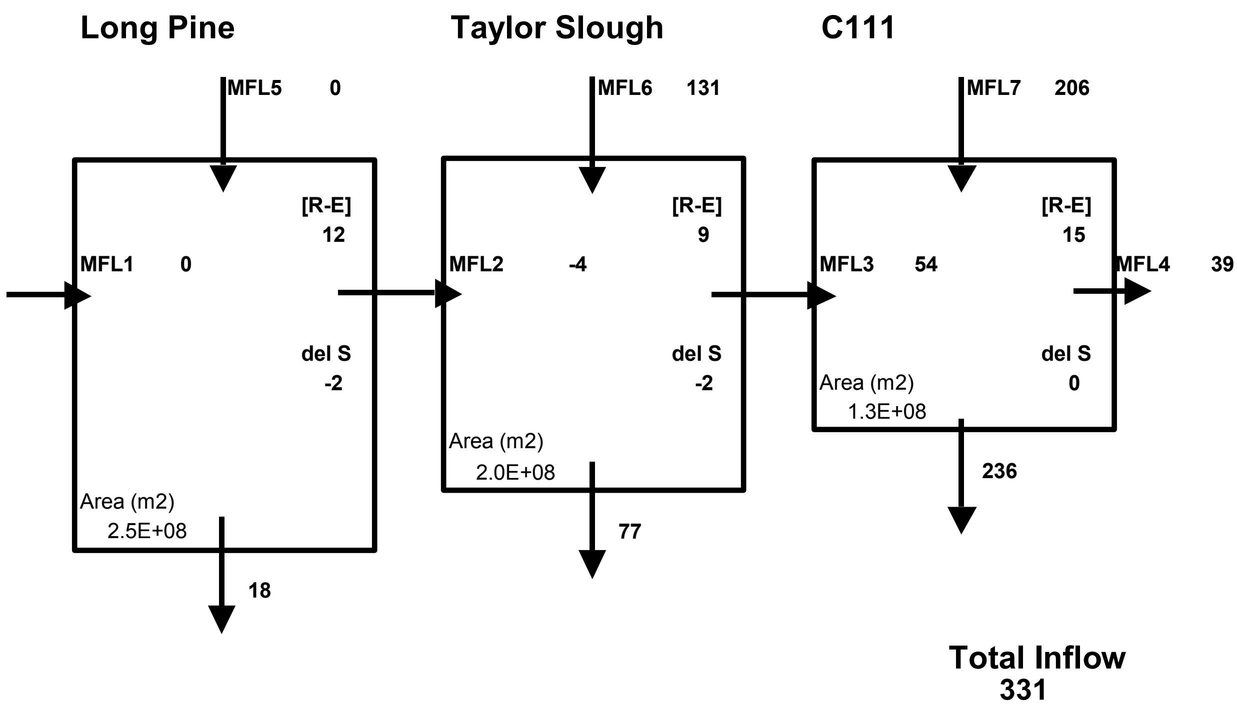


Figure 3.9: Summary of water budget supporting inflow to Florida Bay calculated from the PHAST wetland hydrology model for the period 1996 through 2000. All fluxes are in units of millions of cubic meters per year. See Figure 3.1 for reference map.



3.2.3 Evaluation of PHAST Model

The inflow to Florida Bay calculated by the PHAST suffers from large uncertainties related to the estimation of evapotranspiration. Both rainfall and evapotranspiration are large components of the wetland water budget, and individually their magnitudes exceeded those of the surface water fluxes measured in the wetland basin (Figure 3.5). Inflow to Florida Bay depends on the difference between rainfall and evapotranspiration, and this calculation amplifies the relative error in the result. The volume of inflow estimated by the PHAST wetland hydrology model for 1996 through 2000 (330 million cubic meters per year) underestimateed by 15 percent the minimum inflow estimated from the USGS monitoring of creek flows (386 million cubic meters per year). This discrepancy indicates the magnitude of the errors associated with the estimation of inflow based on an exact reconstruction of the water budget in the Taylor Slough C111 wetland sub-basin. These errors could not be reduced without a better estimate of evapotranspiration.

3.3 Estimates of Freshwater Inflow from Wetlands - 1970 through 2002

In light of the errors apparent in the inflow estimate based on PHAST, an alternative approach was taken to constructing the inflow data for FATHOM. For this use of the model, inflow was calculated indirectly by estimating the various components of the wetland water budget from the available regional hydrological and climatic data. This alternative approach maintained the framework of the wetland water budget for combining information from long-term data sets. The approach dealt explicitly with the uncertainty related to the amount of ungauged freshwater inflow that occured in addition to what was measured. The amount and location of the ungauged portion of inflow varied between the MFL base case and alternative inflow data sets, and a sensitivity analysis examined the effect on the FATHOM salinity calculations of the uncertainty related to ungauged inflow.

The **timing** of changes in inflow was controlled entirely by the variation in the long-term data sets used to construct the inflow estimate for the historical reconstruction of salinity, 1970 through 2002. These were the measured surface water flows in Taylor Slough (TSB) and in the C111 canal (S18C and S197, Figure 3.1), and excess rainfall (rainfall minus evapotranspiration) at Royal Palm, (Figure 3.11). Temporary storage and release of water in the wetland sub-basins also influenced the timing of changes in inflow. Results from the initial implementation of the PHAST model (Nuttle and Teed 2002) indicated that this dynamic introduces about a one-month delay, on average, in the timing of the annual peak inflow to Florida Bay relative to the timing of peak surface water flows into the wetlands.

Spatial distribution of inflow was defined by grouping FATHOM input basins into three inflow groups (Figure 3.10): 1)the central inflow group, 2) the northeastern inflow group, and 3) the eastern inflow group. The eastern inflow group consisted of Manatee Bay, where the C111 canal discharged freshwater to the coast through the S197 control structure. The northeastern inflow group consisted of inflow regions in FATHOM that received flow from creeks monitored by the USGS (Figure 1.4). The central inflow group consisted of the inflow regions in FATHOM, that did not receive flow from creeks monitored by the USGS, except for Manatee Bay. The distribution of flows to each of the FATHOM surface water basins within each inflow group was also presented on Figure 3.10.

Figure 3.10: FATHOM inflow groups showing the distribution of flow among the basins in each group. Percentages give a distribution of total inflow within each group.

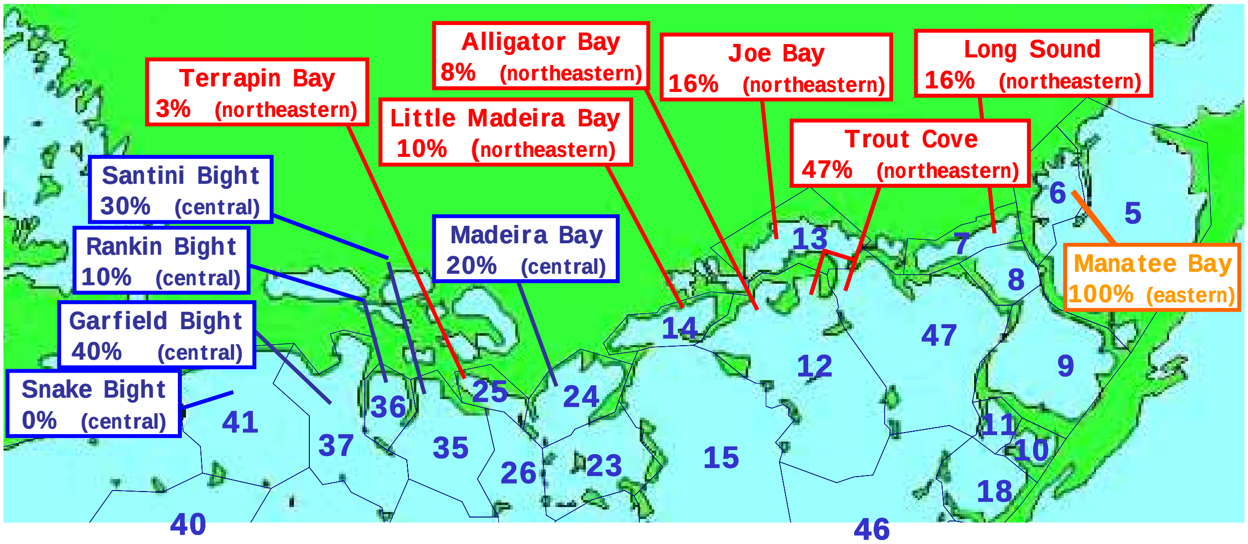
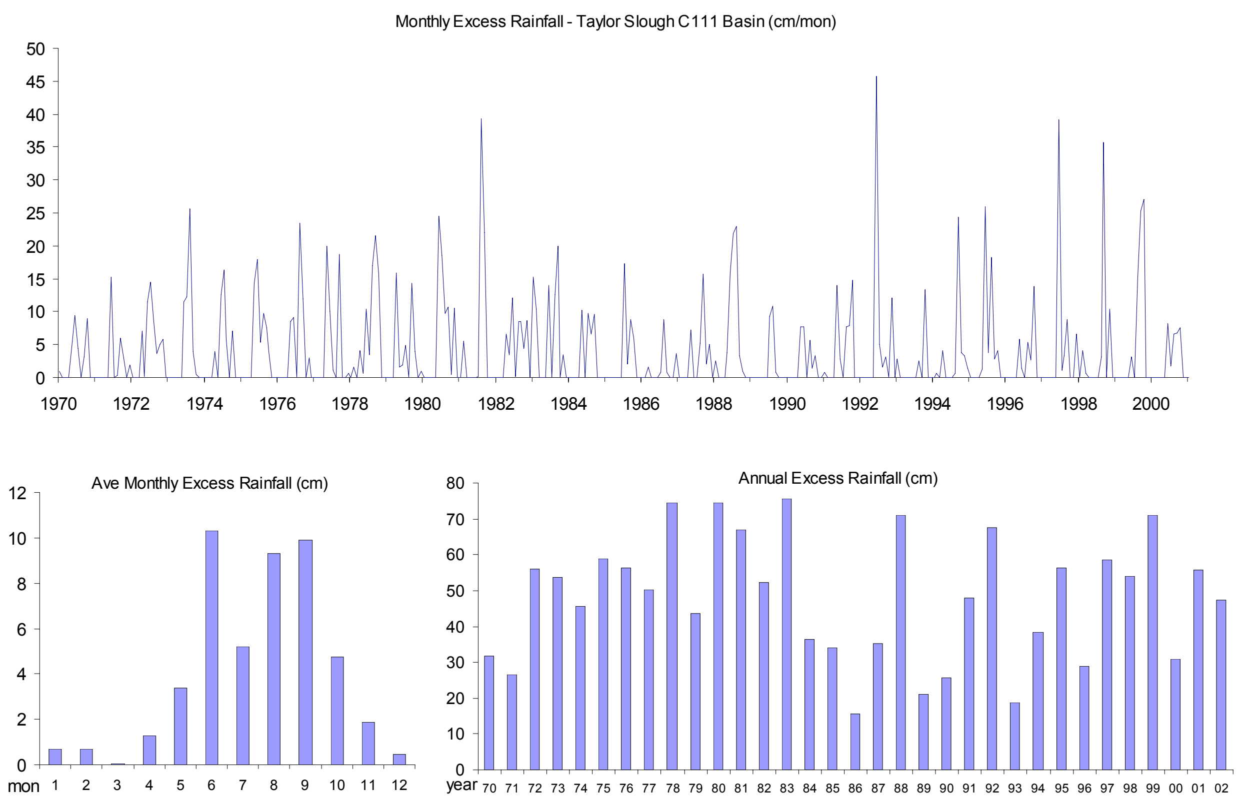


Figure 3.11: Excess rainfall for Taylor Slough C111 wetland basin.



The **distribution** of inflow into the FATHOM basins always remained the same within each inflow group. However, the distribution of inflow among the inflow groups changed between the MFL base case and the inflow alternatives examined in the sensitivity analysis. The eastern inflow group provided inflow only to Manatee Bay. The distribution of inflow from the northeastern inflow group into the FATHOM basins matched the distribution of inflow measured at the USGS monitoring sites (Figure 3.4). The distribution of inflow from the central inflow group into the FATHOM basins was determined so that each basin received the same depth of inflow, distributed over the surface of the basin with the exception of FATHOM basin 41. Basin 41 (Snake Bight) received no inflow in any of the inflow alternatives examined.

The **magnitude** of inflow assigned to the inflow groups varied depending on what assumptions were made about how much the total inflow exceeded the amount measured at the USGS monitoring stations, and how this additional inflow was distributed between the central and northeastern inflow groups (Table 3.4). The inflow measured at the USGS monitoring stations from February 1996 through September 2000 provided the basis for calibrating estimates of inflow for the long-term period 1970 through 2002. It also served as the basis for characterizing the magnitude of additional, "ungauged" flow included in the estimated inflow. The detailed description (below) of how the MFL base case inflow was constructed illustrates the approach used to construct four alternative inflow data sets (Table 3.5). A fifth alternative inflow data set was based on inflow calculated by the enhanced PHAST wetland hydrology model.

The inflow data for the MFL base case was compiled from remote data on surface flows, rainfall and evaporation in the Taylor Slough C111 wetland sub-basin by the following detailed procedure:

- Monthly volumes of flow assigned to the **eastern inflow group** (Manatee Bay) were equal to the monthly flows measured at the S197 control structure.

- Monthly volumes of flow assigned to the **northeastern inflow group** were the sum of two components. The first component consisted of the monthly volumes of the surface water discharge into the Taylor Slough C111 wetland sub-basin after accounting for the discharge into the eastern inflow group through S197. This first component was the sum of measured flows in Taylor Slough (TSB) and the C111 canal (S18C) minus the flow measured at the S197 control structure. The second component accounted for the additional inflow to Florida Bay generated by rainfall over the Taylor Slough C111 wetland sub-basin in excess of evapotranspiration. For the MFL base case, the inflow assigned to the northeastern inflow group was calculated as the sum of all of the surface flow (TSB + S18C – S197) and 12 percent of the calculated excess rainfall. Adding 12 percent of the excess rainfall calibrated the total inflow assigned to the northeast inflow group so that it equaled the total inflow measured at the USGS monitoring stations for the period February 1996 through September 2000.

  In the calculation of excess rainfall, evapotranspiration was calculated as a fraction (53 percent) of estimated total solar radiation by the method described by Abtew (1996) for South Florida. Total solar radiation was estimated from radiation incident at the top of the atmosphere, for given time of year, reduced by an amount to account for attenuation by moisture in the air. The attenuation factor was estimated from the daily range of temperatures measured at Royal Palm using the method developed by the SFWMD (2003). Monthly values of excess rainfall volume were calculated from the difference of Royal Palm rainfall minus estimated evapotranspiration and multiplied by the area of the Taylor Slough C111 wetland sub-basin (620 million square meters). Values of excess rainfall were set equal to zero in months when evapotranspiration exceeded rainfall.

- The magnitude of inflow assigned to the **central inflow group** in the MFL base case was equal to 20 percent of the gauged flow measured by the USGS at their estuarine creek monitoring stations (Figure 1.4), for the period February 1996 through September 2000. The USGS data were the only direct estimates of inflow to Florida Bay, and the total volume of measured inflow provided a logical reference in reporting the volume of "ungauged" flow included in the estimated inflow data. The 20 percent of additional inflow included in the MFL base case as ungauged-flow was comparable to the magnitude of inflow estimated by the USGS in four ungauged creeks (Hittle et al. 2001) for the same period. For the historical reconstruction, creek flows were not available prior to 1996. Therefore, the monthly values for inflow assigned to the central inflow group were calculated as the measured monthly flow into Taylor Slough (TSB) multiplied by 0.67, which was approximately equal to 20% of the USGS creek flows. Of the two major sources of surface discharge into the Taylor Slough C111 wetland sub-basin, the flow measured at TSB was closer to the central region of Florida Bay, and thus it was considered to characterize better the temporal variation in the availability of surface water for inflow to Florida Bay from the western portion of the wetland basin. (Note that the addition of ungauged flow to the estimated inflow occured only in the reconstruction of the historical inflow; no additional ungauged flow was included when inflow data are taken from output of the SFWMM.)

Table 3.4: Comparison of the amount and distribution of freshwater discharged for each inflow alternative. Estimated inflow was reported for the period 1996 through 2000 for comparison with the inflow measured by the USGS creek monitoring. For all cases, additional discharge of 39 units was routed to Manatee Bay (Eastern Group) through the S197 structure.

Annual Average Runoff (10^6 m^3/yr)

	Central Group	NE Group	Fl Bay Total	Eastern Group
MFL base	60	293	354	39
RN-1	60	352	412	39
RN-2	60	235	295	39
RN-3	120	293	414	39
RN-4	0	293	293	39
RN-5	0	347	347	39

Annual Average Runoff (10^3 Ac-ft/yr)

	Central Group	NE Group	Fl Bay Total	Eastern Group
MFL base	49	238	287	32
RN-1	49	286	334	32
RN-2	49	190	239	32
RN-3	97	238	335	32
RN-4	0	238	238	32
RN-5	0	281	281	32

Table 3.5: Summary of inflow alternatives.

Data Set	Description
MFL Base Case	***Eastern Inflow Group*** - Monthly inflow was measured discharge at the S197 structure. All inflow was applied to Manatee Bay. ***Northeastern Inflow Group*** - Monthly inflow was calculated from measured discharge in Taylor Slough (TSB) and in the C-111 canal (difference in measured discharge between the S18C and S197 structures). Excess rainfall from the wetland basin was added in the amount needed for the total amount of inflow for the period 1996-2000 (surface flow plus excess rainfall) to equal the total discharge measured by the USGS from 1996-2000 in five creeks (McCormick C., Taylor R., Mud C., Trout C., West Highway C.) The monthly simulated inflow was applied to the FATHOM basins in this group based on the observed USGS discharge proportions in the five creeks for 1996-2000. (USGS estimates of un-gauged discharges into this group are not included). ***Central Inflow Group*** - Monthly inflow added to the central inflow group was proportional to the monthly measured discharge in Taylor Slough (TSB). The total amount added in the period 1996 through 2000 is equal to 20% of the flow in the Northeastern group. Central group inflow was added to Madeira Bay, Santini Bight, Garfield Bight and Rankin Lake. There is no inflow to Snake Bight *(The MFL base case inflow data set is the same as the RN-a alternative in Progress Report II and Progress Report III.)*
Alternate 1 (RN-1)	***Eastern Inflow Group*** – same as base simulation ***Northeastern Inflow Group*** – all monthly values increased by 20% from the base case ***Central Inflow Group*** – same as base simulation *(The RN-1 inflow data set is the same as the RN-b alternative in Progress Report II and Progress Report III.)*
Alternate 2 (RN-2)	***Eastern Inflow Group*** – same as base simulation ***Northeastern Inflow Group*** – all monthly values decreased by 20% from the base case ***Central Inflow Group*** – same as base simulation *(The RN-2 inflow data set is the same as the RN-c alternative in Progress Report II and Progress Report III.)*
Alternate 3 (RN-3)	***Eastern Inflow Group*** – same as base simulation ***Northeastern Inflow Group*** – same as base simulation ***Central Inflow Group*** – all monthly values increased to double the base case *(The RN-3 inflow data set is the same as the RN-d alternative in Progress Report II and Progress Report III.)*
Alternate 4 (RN-4)	***Eastern Inflow Group*** – same as base simulation ***Northeastern Inflow Group*** – same as base simulation ***Central Inflow Group*** – all monthly values set to zero *(The RN-4 inflow data set is the same as the RN-e alternative in Progress Report II.)*
Alternate 5 (RN-5)	***Eastern Inflow Group*** – same as base simulation ***Northeastern Inflow Group*** – Inflow estimated from PHAST wetland hydrology model ***Central Inflow Group*** – all monthly values set to zero *(The RN-5 inflow data set is the same as the RN-f alternative in Progress Report II and Progress Report III.)*

4 MFL BASE CASE CALCULATED SALINITY RECONSTRUCTION - 1970 THROUGH 2002

The MFL base case input data represent the "best available" information on the freshwater budget for Florida Bay in the period 1970 through 2002. Salinity calculations based on the MFL base case input data and parameter values awe the best estimate of salinity conditions that occurred historically in Florida Bay. This section describes the input data and parameter values that comprise the MFL base case, and it summarizes the simulated salinity and calculated residence times based on these inputs. The freshwater input from the upstream wetland basins is described in detail in the previous section.

The input data consist of the following time series of monthly data:

- Rainfall,
- Evaporation,
- Inflow,
- Boundary Salinity, and
- Sea level.

The model parameters include:

- Tides (semi-diurnal, diurnal, and the spring-neap cycle),
- Bathymetry, and
- Bottom Friction (in flow over banks).

Table 4.1: Sources of input data to FATHOM for the MFL base case. Input data covered the period 1970 through 2002. Sources of the data are indicated in parentheses.

FATHOM Input	Indirect Data (Regional Index)
Rainfall	Flamingo, Royal Palm, Tavernier (NCDC)
Evaporation	Air temperature (mean and range) from Flamingo, Royal Palm and Tavernier (NCDC), relative humidity and wind speed (seasonal pattern) from Joe Bay (DBHYDRO)
Boundary salinity	S12T flow, P33 level (DBHYDRO)
Inflow	TSB flow, S18c flow, S197 flow, S175 flow (DBHYDRO)
Sea level	Key West sea level (NOAA)

In absence of data available to provide direct information needed by the model, various techniques had to be applied to construct the needed information from indirect data (Table 4.1). As an example, direct precipitation to Florida Bay was only measured since 1996. In order to construct a 31-year time series of direct rainfall, estimates were constructed from long-term rain data measured at onshore locations. In the case of evaporation, neither direct data nor indirect measurements of evaporation were available, so a variety of physics-based models were evaluated for use. Similarly, the PHAST wetland hydrology model was evaluated, along with other simpler techniques, as a method of estimating freshwater inflow into the central and northeast regions of the Bay based on related components of the water budget in the wetlands upstream. The input data that consistently provided the best fit to the existing salinity data using FATHOM were chosen for the base case reconstruction. Progress Reports 1 and 2 document the details of these investigations, but are not included in this report.

The MFL base case runs were constrained to begin in 1970 because regional hydrological data needed to construct the time series of inflow from the Taylor Slough C111 wetland basin were missing prior to 1970. This restriction was relaxed when FATHOM was used to simulate salinity for the analysis of the water management alternatives described later in this report because the SFWMM was the source of the inflow data for this application, and the time series data for the alternatives covers the period from 1965 to 2000, a 36-year period.

4.1 Estimated Input Data

4.1.1 Rainfall

The time series of estimated monthly rainfall for the MFL base case was compiled from the records of rainfall at Tavernier, Flamingo, and Royal Palm (Figure 2.6). The spatial variation of rainfall across the Bay was represented in FATHOM by specifying uniform amounts for each of five regions (Figure 4.1). These same regions were also used to describe evaporation inputs to the model. Monthly rainfall amounts for each of these regions were calculated from the three long-term data records using weights based on Thiessen polygons. Mean annual rainfall varied little across the Bay (Table 4.2). Average rainfall for the entire Bay was plotted in Figure 4.2.

Table 4.2: Mean annual estimated rainfall (in cm) for each of the FATHOM input regions.

Region 1	Region 2	Region 3	Region 4	Region 5
125	118	118	120	114

Figure 4.1: Regions used to define rainfall input to FATHOM.

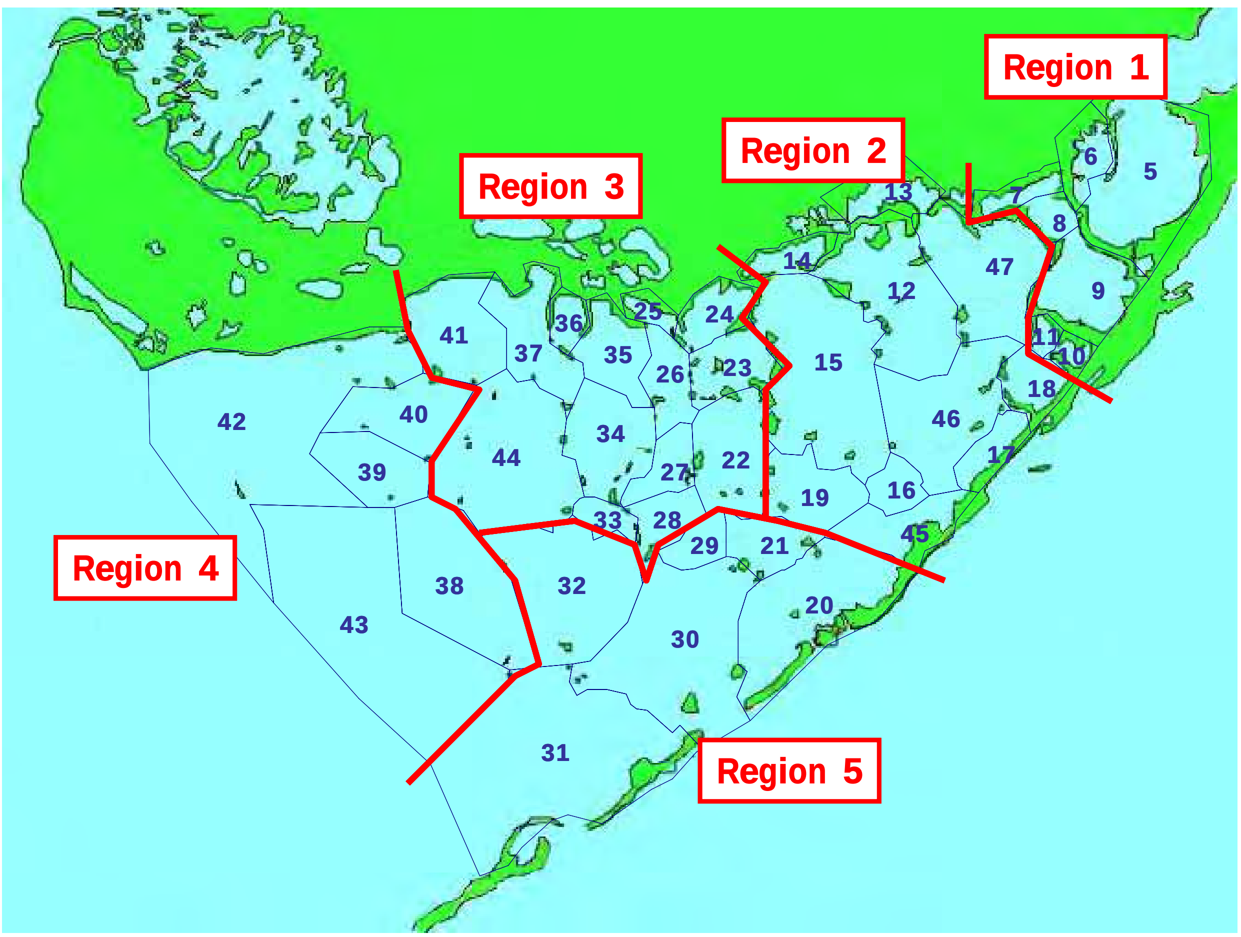
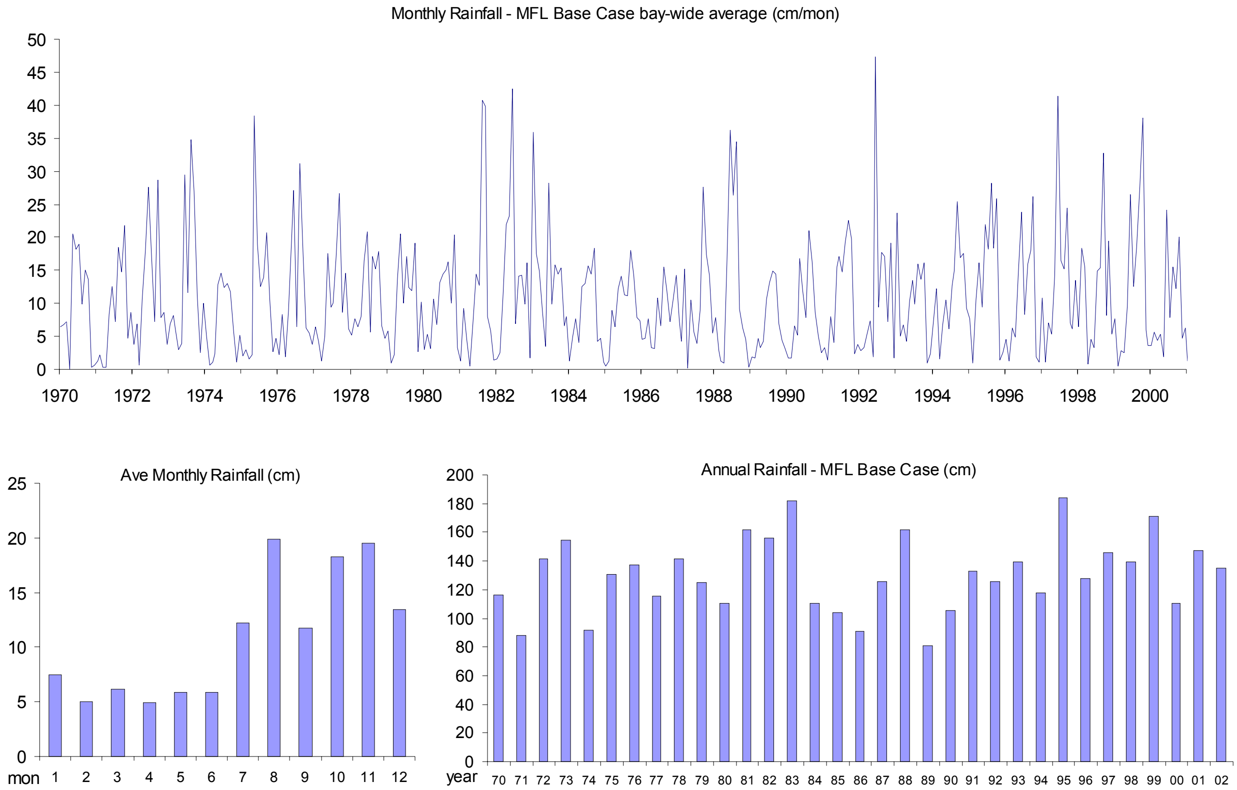


Figure 4.2: Estimated monthly rainfall input to MFL base case, averaged across the five input regions.



4.1.2 Evaporation

Relative to rainfall, there were few data available from which to estimate evaporation for Florida Bay. However, from the observed data from Florida Bay (Nuttle et al. 2003) and in the Everglades (German 2000), it appears that evaporation has been less variable than rainfall viewed at comparable scales, both temporally and spatially. A variety of sources provided information about the likely long-term average annual rate of evaporation (Table 4.3). Eliminating estimates at the high and low ends puts the likely value in the range of between 130 and 170 cm/yr.

Evaporation for the MFL base case was estimated using a Dalton's Law (mass transfer) approach. The Dalton's Law approach assumes that evaporation is proportional to the difference between saturation vapor pressure at the water surface (corresponding to the surface water temperature) and the unsaturated water content of the air (corresponding to air temperature and relative humidity), and to a function of the mean wind speed:

$$\mathbf{Evap = F * f(u) * (e_{sat} - e_{air})}, \qquad 4.1$$

where e_{sat} is the saturation vapor pressure at the water surface, e_{air} is the vapor pressure of the air, $f(u)$ is the function of the mean wind speed and F is a factor used to scale the annual average evaporation to a fixed value.

Monthly air temperature for NCDC Division 7 (Figure 2.8) was used with the relative humidity to calculate air vapor pressure e_{air}. Monthly patterns of relative humidity and wind speed were derived from the Joe Bay weather tower (Figures 2.10 and 2.11). The average monthly pattern of these variables over the period 1991 to 2002 was used for every year of evaporation inputs.

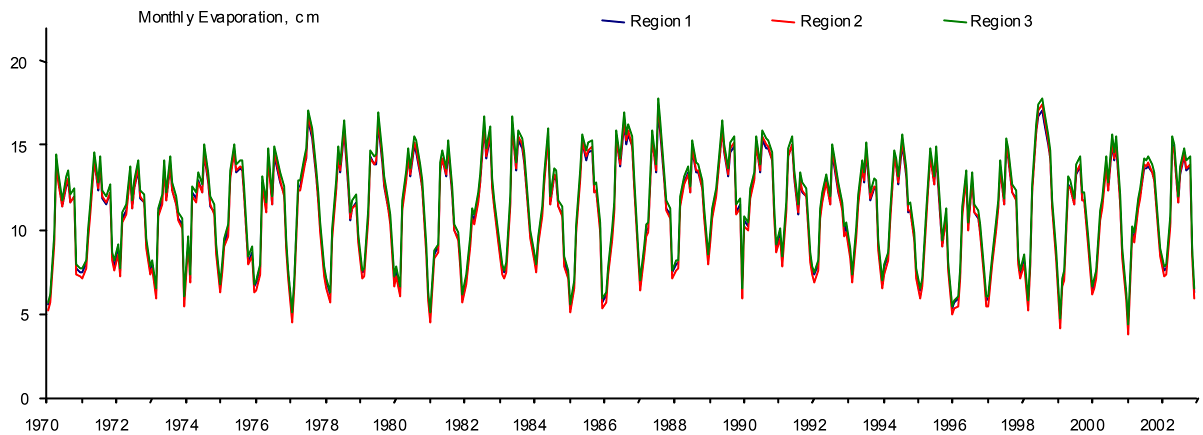
Saturation vapor pressure e_{sat} is calculated from the temperature of the water. Surface water temperature data were estimated for the Everglades National Park Marine Monitoring Network stations by extrapolation based on correlation between water temperature at each station and air temperature measured at Tavernier, Flamingo, and Royal Palm (Figure 2.6).

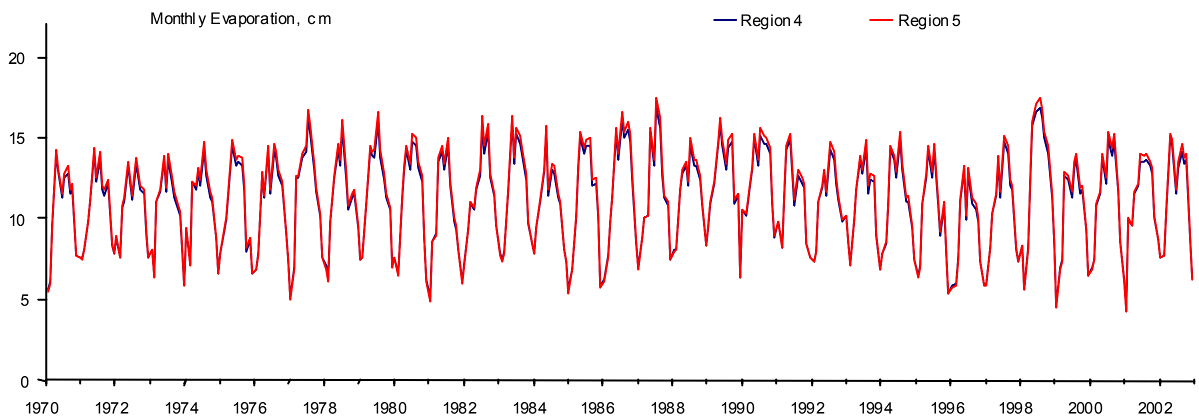
The estimated monthly evaporation inputs are shown in Figure 4.4 for the MFL base case. Based on best professional judgement, the wind function was scaled so that the long-term (1991-2002) annual average evaporation from the Bay was 135 cm/year.

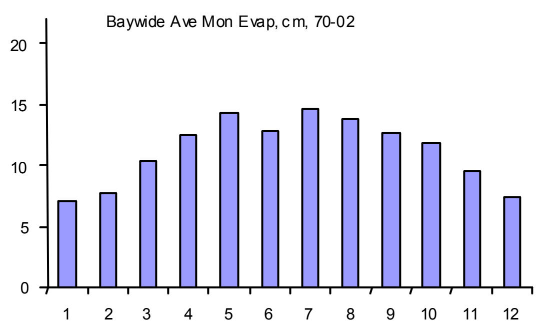
Table 4.3: Estimates of mean annual evaporation from Florida Bay.

Source	Estimate (cm/year)
Flamingo evaporation pan (NCDC/NOAA data)	210
Lake Okeechobee water budget Morton (1986)	160
Everglades “wet” evaporation – Bowen ratio German (2000)	160
Florida Bay – Dalton Law, USACOE platforms Pratt and Smith (1999)	75
Florida Bay – steady state salinity box model Nuttle et al. (2000)	110
Florida Bay – Dalton Law, Long Key data Smith (2000)	160
Florida Bay – Dalton Law, Univ. Miami platforms Nuttle et al. (2003)	150
Florida Bay – Priestly-Taylor (radiation) method Nuttle et al. (2003)	170
Florida Bay – dynamic salinity box model Nuttle et al. (2003)	140 (+/-10)

Figure 4.4: Time series of evaporation for the MFL base case.







4.1.3 Boundary Salinity

Boundary salinity for the MFL base case in each of ten input regions was specified based on monthly values at SERC monitoring stations on the model boundary (Figure 4.5) predicted by the regression models (Table 2.1). The regression models related salinity at SERC stations 25, 26, 27, 28, and 1 from the monthly flow through the S12 structures (S12T) along Tamiami Trail and monthly average water levels at P33 in Shark Slough. Section 2.2 describes the development of these regression models. Figure 4.6 shows the boundary salinity time series provided as input to FATHOM.

Figure 4.5: Location of boundary salinity regions for FATHOM input. Boundary salinity values for the MFL base case are derived from data collected by the SERC estuarine monitoring program and by the Florida Keys National Marine Sanctuary (NMS).

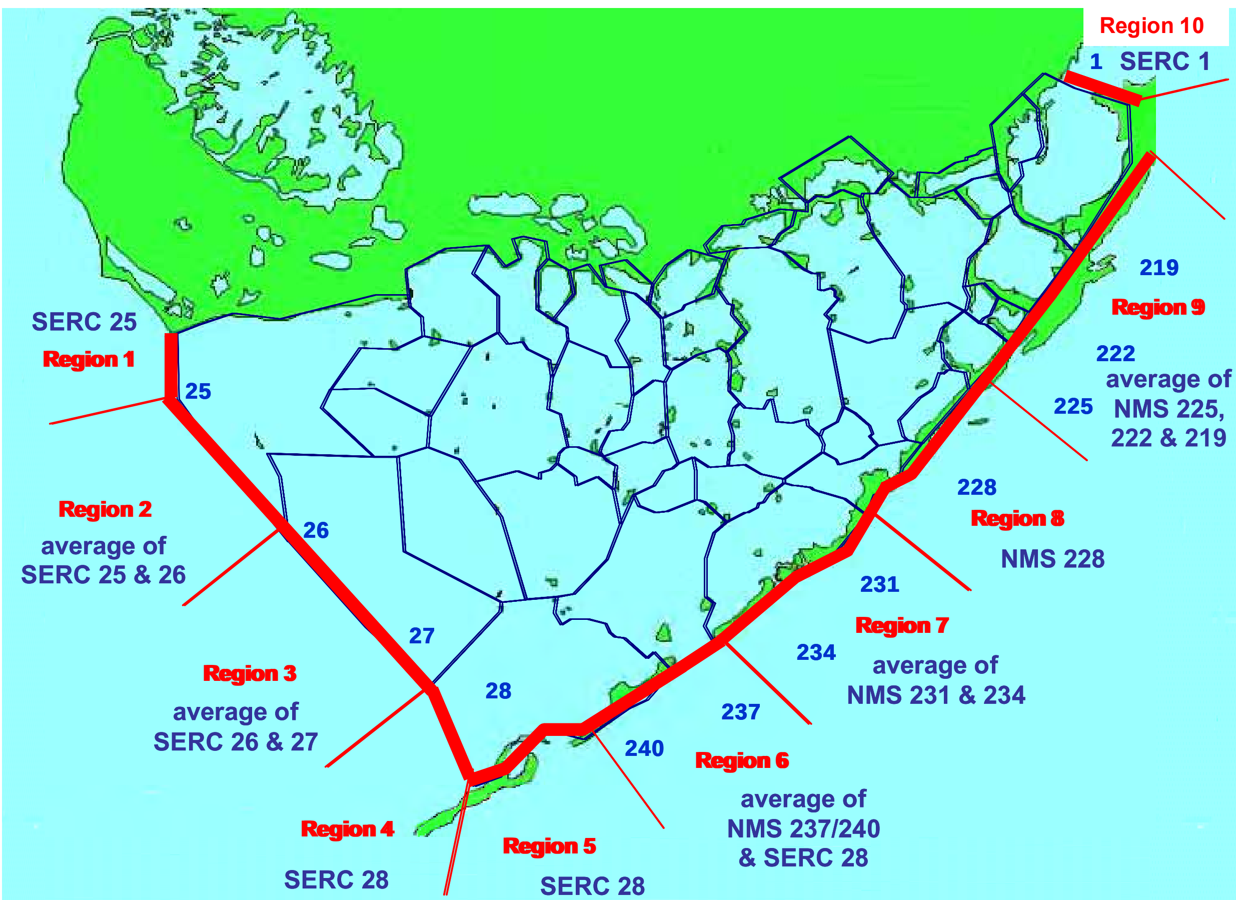
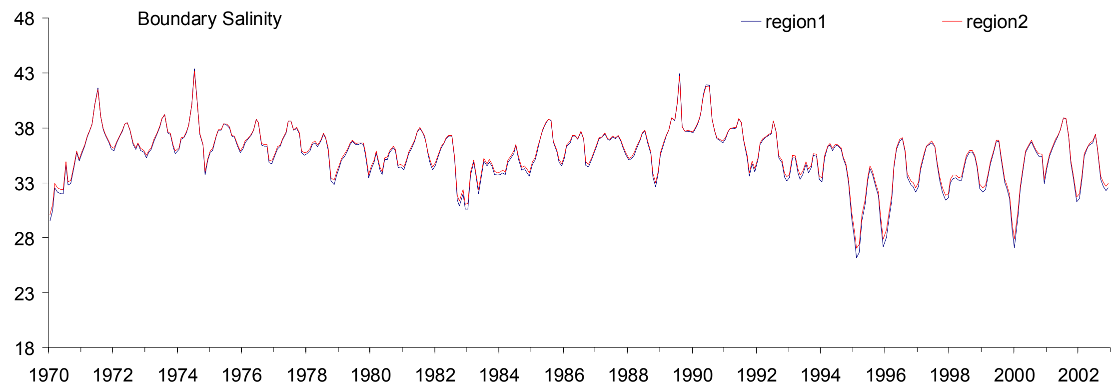
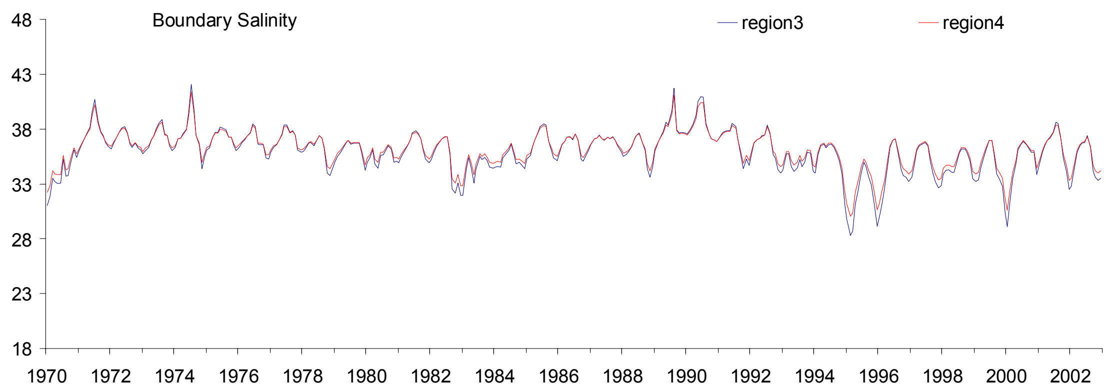
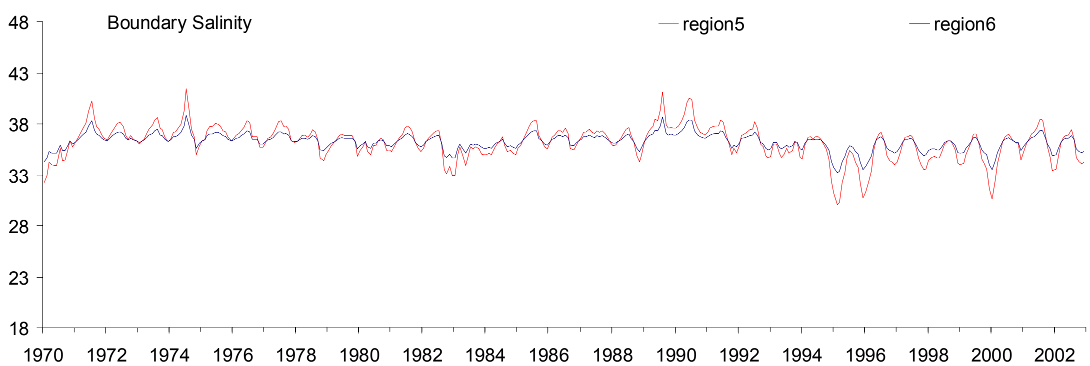


Figure 4.6: Time series of boundary salinity for MFL base case.







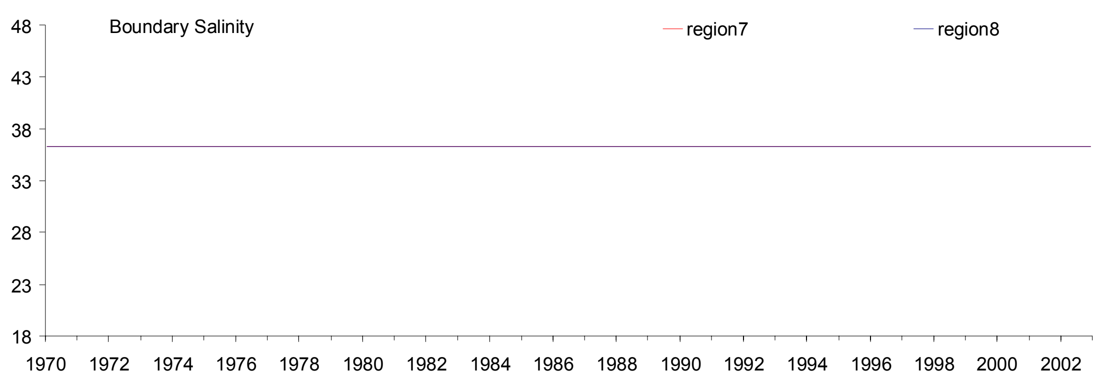
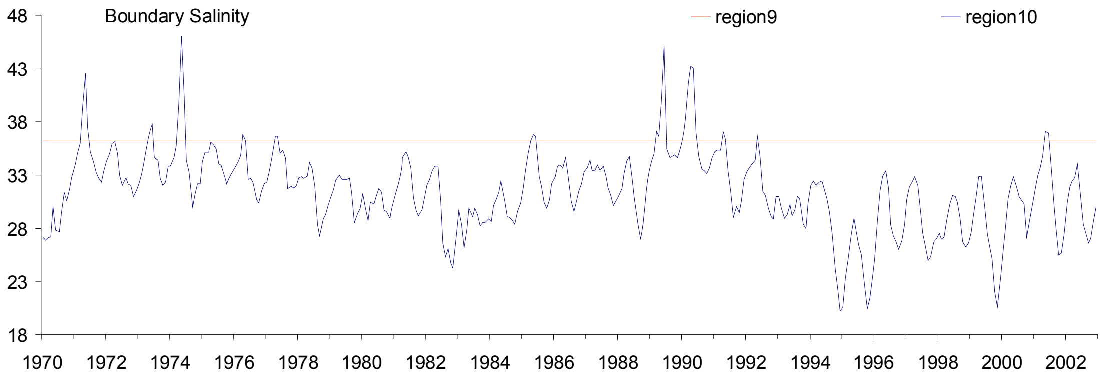
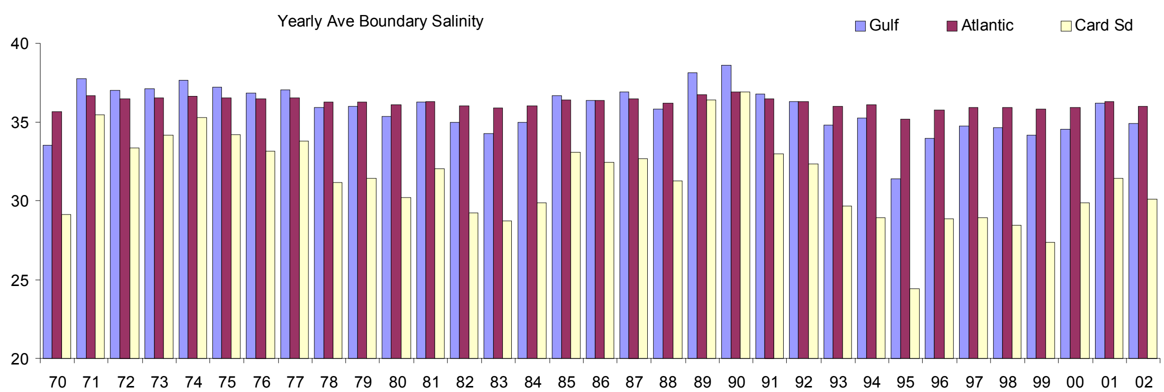
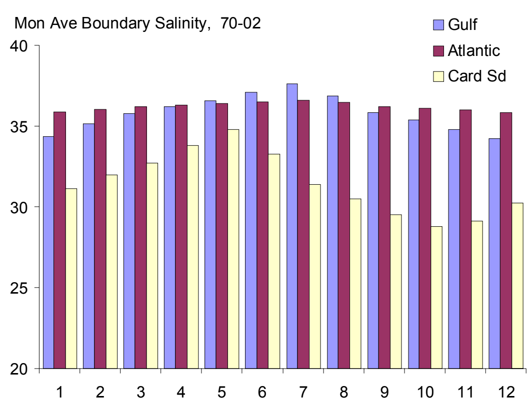


Figure 4.6: Time series of boundary salinity for MFL base run (cont.).





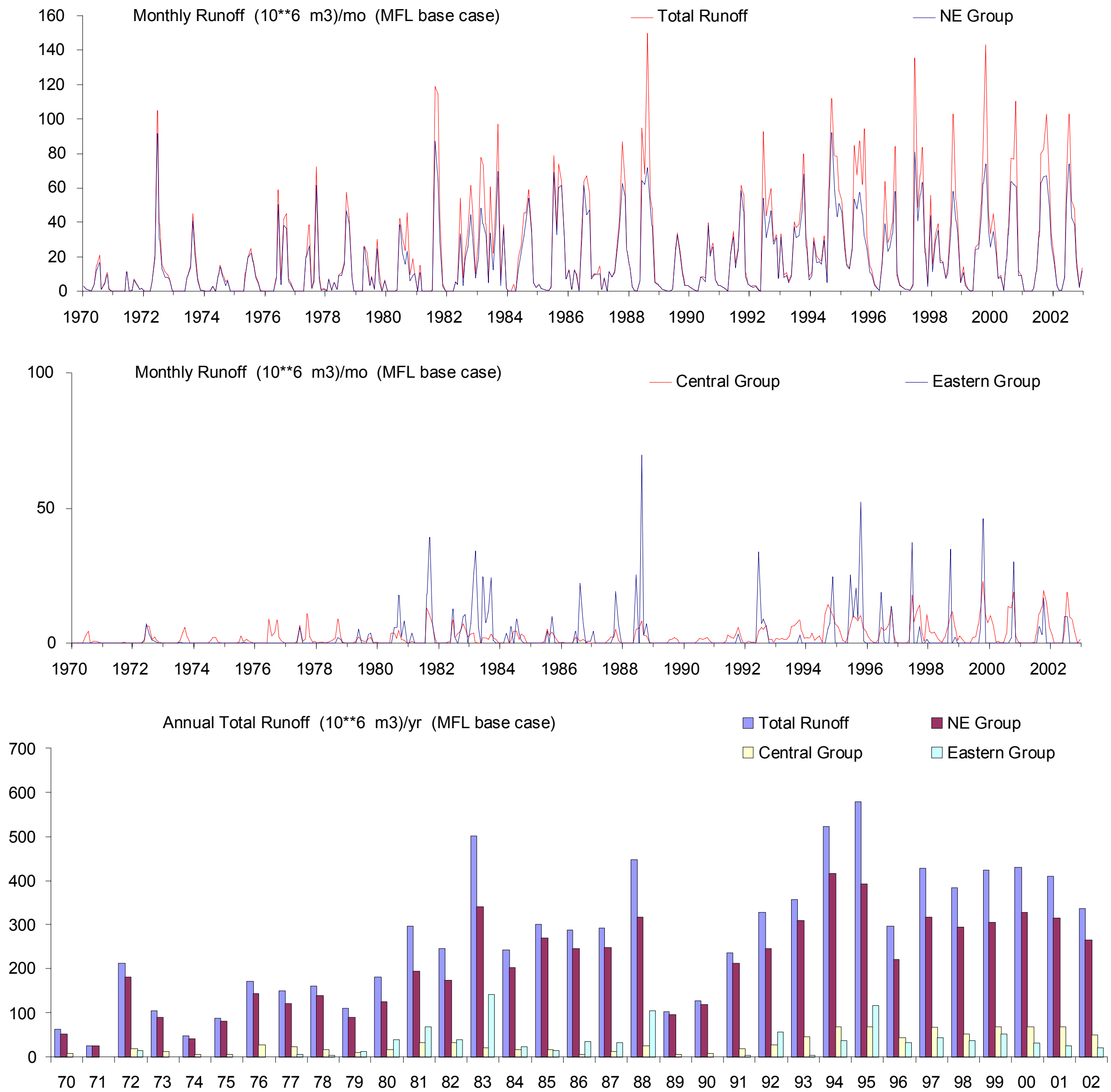


4.1.4 Freshwater Inflow from Wetlands

MFL base case monthly inflow into the Bay was estimated from flow measured at Taylor Slough Bridge (TSB) and in the C111 Canal (S18C and S197), and from rainfall at Royal Palm in excess of potential evapotranspiration. Section 3.3 describes these calculations in detail. The total inflow estimated from these sources was assigned to FATHOM basins through inflow groups (Figure 3.10). Figure 4.7 plots the monthly inflow volumes estimated for the MFL base case. A more detailed description of the quantity, timing, and spatial distribution of freshwater inflows can be found in the previous section of this report. It is summarized here.

The estimated total inflow was based on a simple accounting of the water budget for the wetlands in the Taylor Slough and C111 sub-basin. This simple accounting included an explicit estimate of the ungauged volume of inflow that was presumed to occur above what was measured at the USGS estuarine creek monitoring stations. For the MFL base case, the total ungauged inflow was estimated as 67% of the Taylor Slough flow, which was roughly equivalent to twenty percent of the flow at the USGS monitoring locations. This inflow was assigned to the central inflow group only, with no ungauged flow augmenting estimated creek flows to the northeastern region.

Figure 4.7: Time series of freshwater inflow for MFL base case by FATHOM inflow group.



4.1.5 Sea Level

The input data for sea level specified monthly values for two input regions (Figure 4.8). The Key West measured sea level data were applied directly to sea level input region 1. The sea level applied to the boundary region 2, adjacent to southern Biscayne Bay, was increased by 3 cm above the Key West data. This offset accounted for water level set up in the interior of Florida Bay as a result of non-linear interactions of the Gulf of Mexico tides with the shallow mud banks (Wang 1994). Figure 4.9 is a plot of the monthly average sea level in the MFL base case.

Figure 4.8: Location of region for input of sea level into FATHOM.

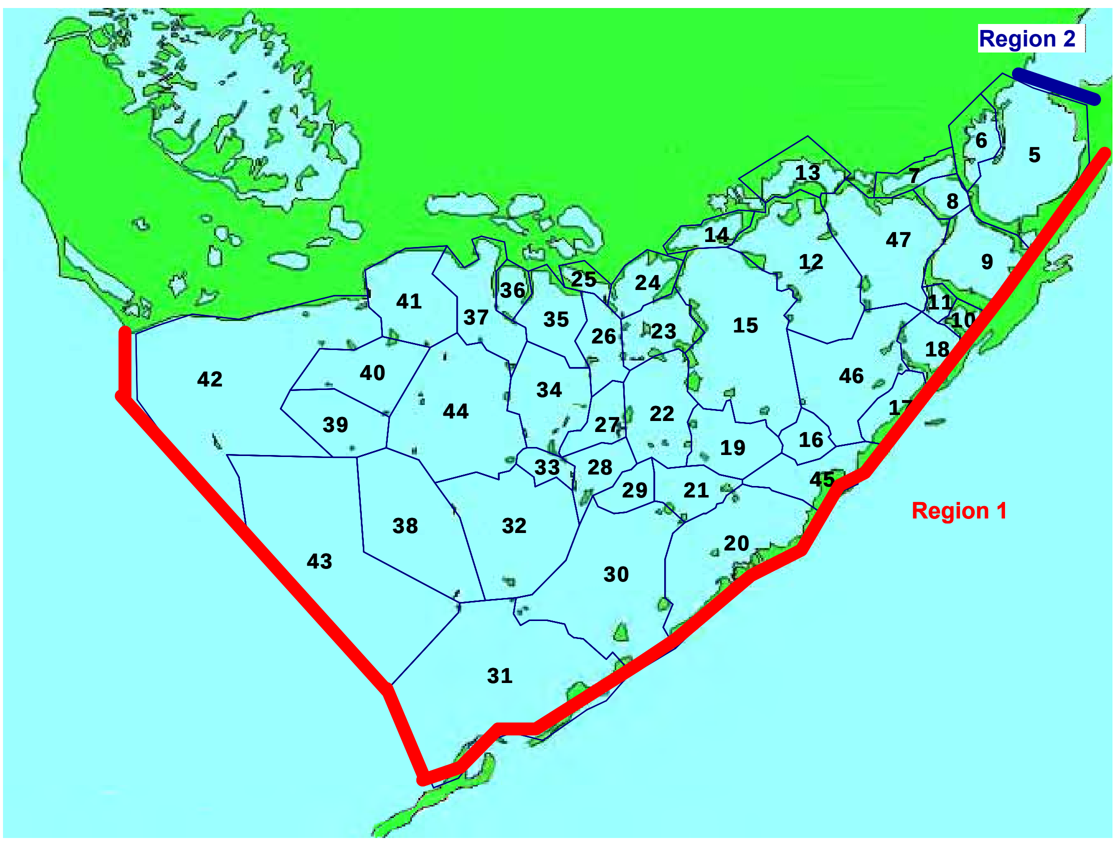
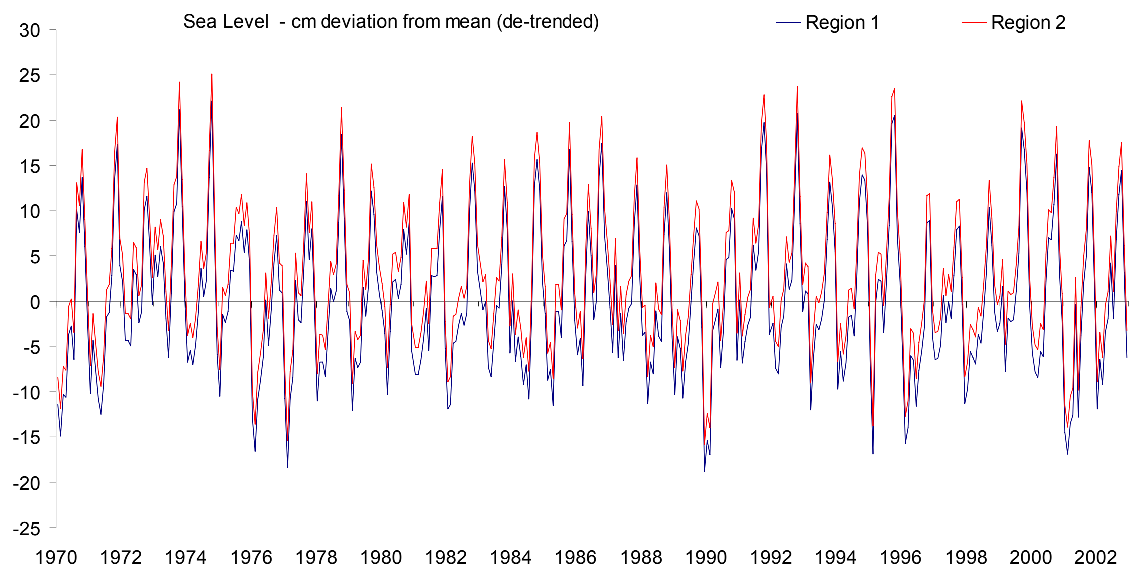
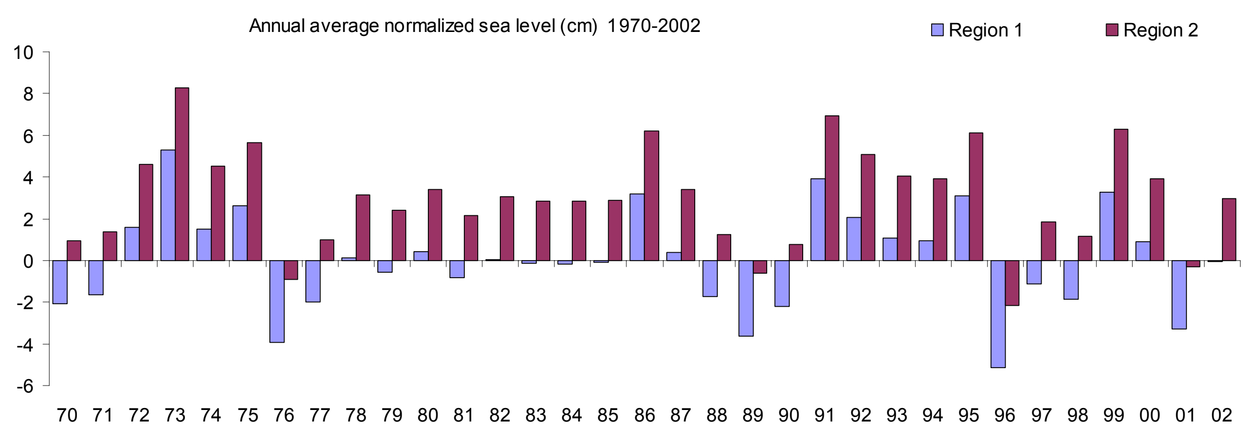
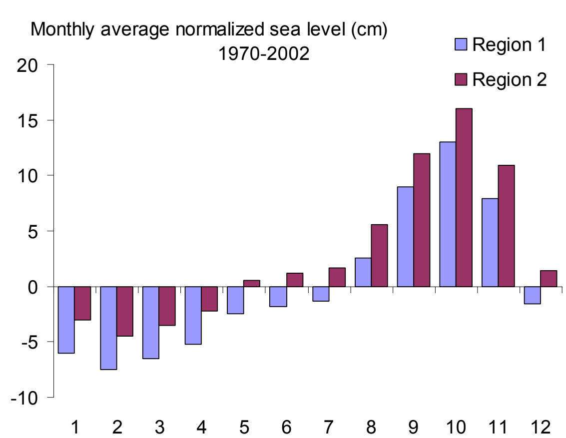


Figure 4.9: Time series of sea level input into FATHOM.







4.2 Estimated Parameter Values

4.2.1 Tides

Tides drive exchange and mixing within the Bay and across its boundaries. The complex pattern of water level forcing over the course of a simulation was represented by adding the repeated sequence of hourly tides to monthly values of sea level. The sequence of hourly tide levels describes water level fluctuations within a month; different sequences are specified for each of ten input regions (Figures 4.10 and 4.11). These reproduced the general characteristics of tide predictions for each input region based on tides measurements at three primary NOAA tide stations Key West, Naples and the Miami Harbor entrance.

Figure 4.10: Ten boundary tide regions used for FATHOM.

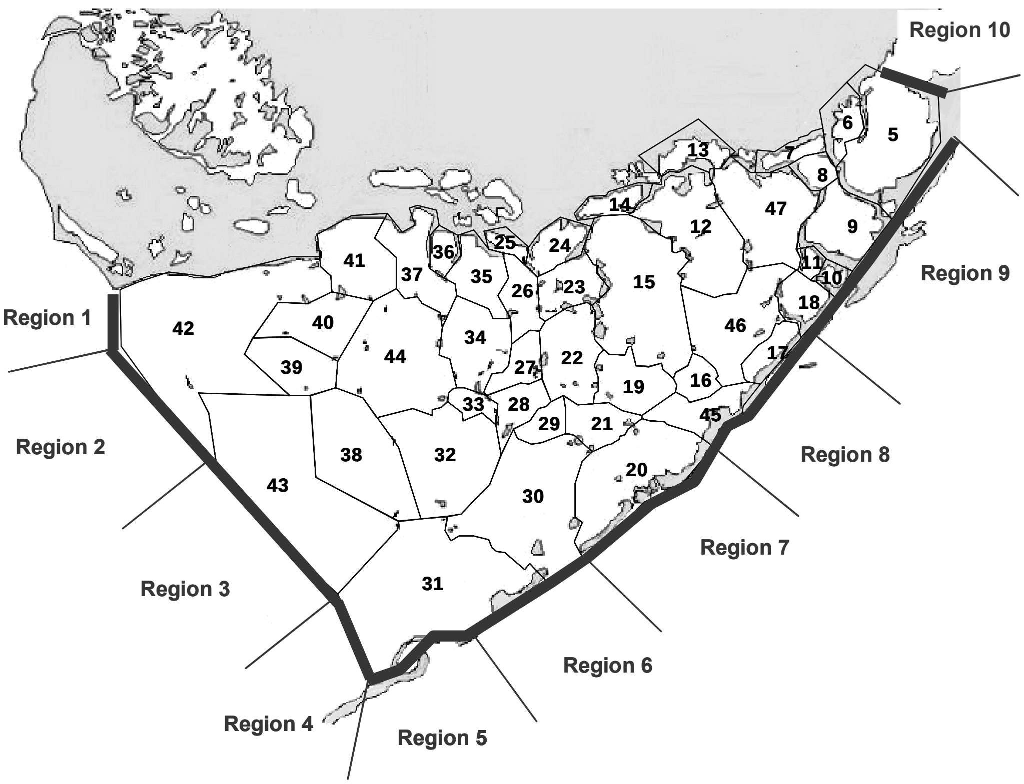


Figure 4.11: Semi-diurnal tidal patterns for boundary tide regions used for FATHOM. Data referenced by day of the month, and the same pattern was repeated each month of the simulation.

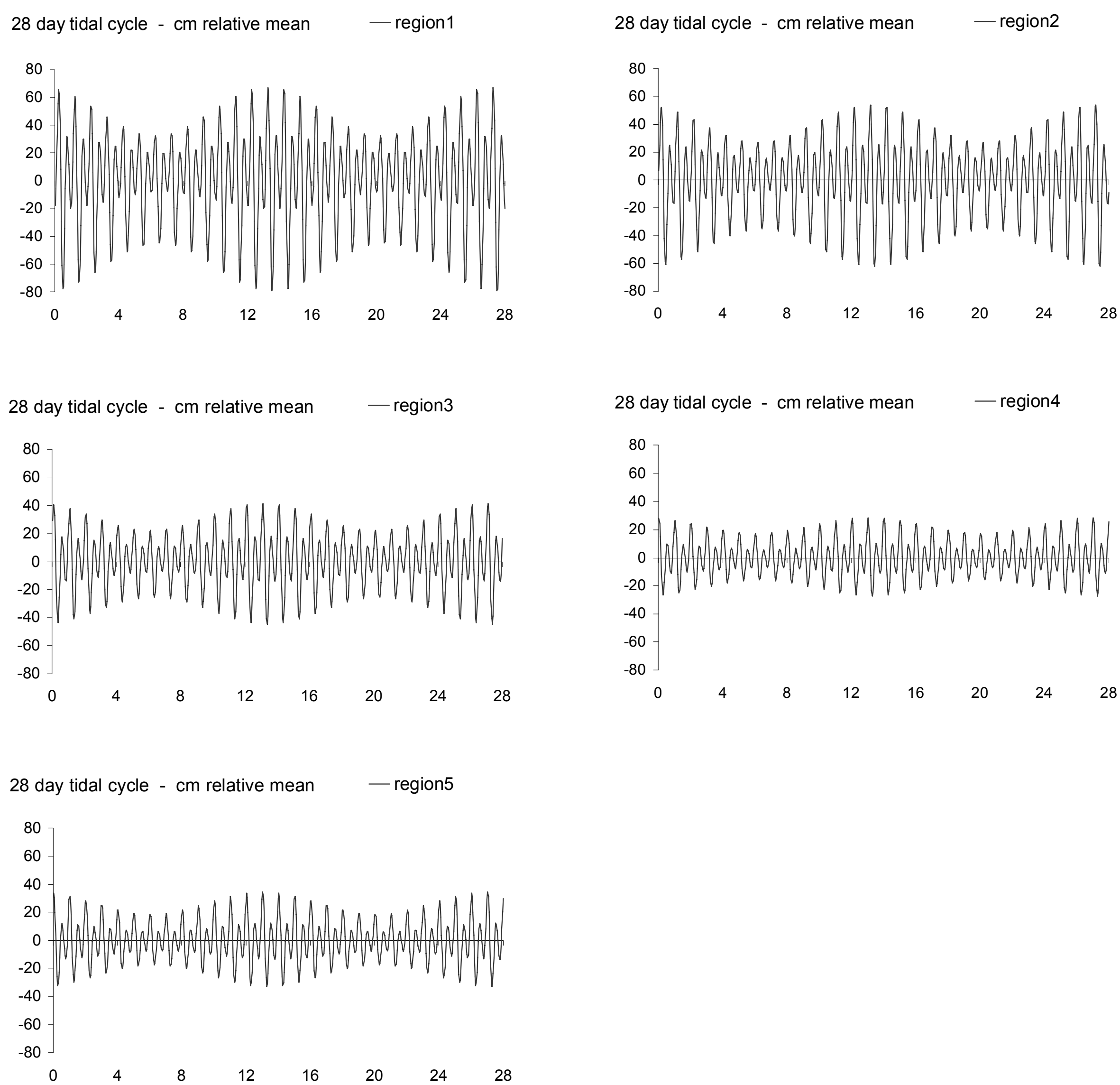
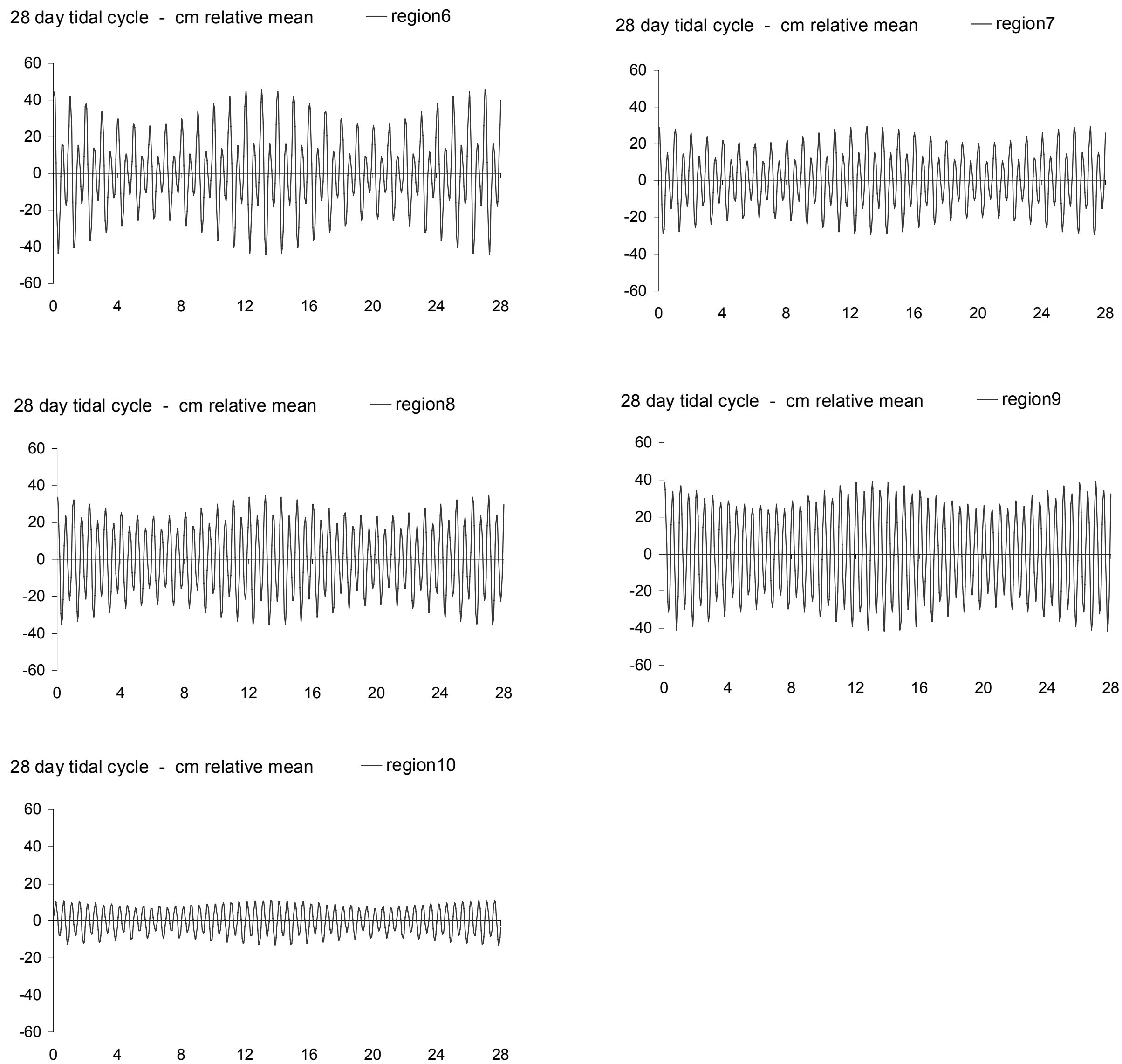


Figure 4.11 (continued): Semi-diurnal tidal patterns for boundary tide regions used for FATHOM. Data referenced by day of the month, and the same pattern was repeated each month of the simulation.



4.2.2 Bathymetry

The bathymetry of Florida Bay was represented in FATHOM by two sets of parameters. The first is the proportion of area by FATHOM basin in each depth class; this defines the hypsometry of each basin. The second is the proportion of length by FATHOM bank segment in each depth class that provides information on hydraulic radius used in the calculation of flow across the banks between basins. Section 2.1 provides a detailed description of how these parameter values were determined for the MFL bathymetry produced by this project.

4.2.3 Bottom Friction Parameter

The MFL base case specified a uniform value for Manning's n of 0.1 for the calculation of exchange flows between basins and at the tidal boundaries. The use of this value for hydraulic calculations over the shallow banks was supported by results of hydraulic modeling of measured estuarine creek flow at the USGS gauging stations (Swain et al. 2004) and of direct experimental measurement of flow over banks in Florida Bay (Fourqurean and Childers, pers. comm.). The sensitivity analysis investigated model performance with alternative values of the bottom friction parameter selected within the range measured by Swain et al. (2004).

4.3 Results of Salinity Calculations

This section reports summary results of salinity calculations based on the MFL base case input data and model parameters. Results are reported here for the SFWMD areas of interest with complete results contained in the appendices. Results are summarized as time series plots, (Figure 4.12); box and whisker summaries of salinity distributions calculated for each location, (Figure 4.13); and frequency of occurrence within salinity ranges, (Figure 4.14). Detailed output for the base case salinity simulations are presented in Appendix A and E.

The frequency of occurrence of extreme values of salinity is closely linked to ecological response. This statistic was examined for the base case by calculating the frequency (% of months) for which the monthly average salinity fell into one of six different salinity ranges. The ranges chosen listed below likely have ecological significance (practical salinity scale or pss):

extreme hyperhaline	> 50,
hyperhaline	41-50,
euhaline	31-40,
polyhaline	19-30,
mesohaline	6-18, and
oligohaline	0-5.

Figure 4.12: Time series plots of simulated salinity (pss) for the MFL base case.

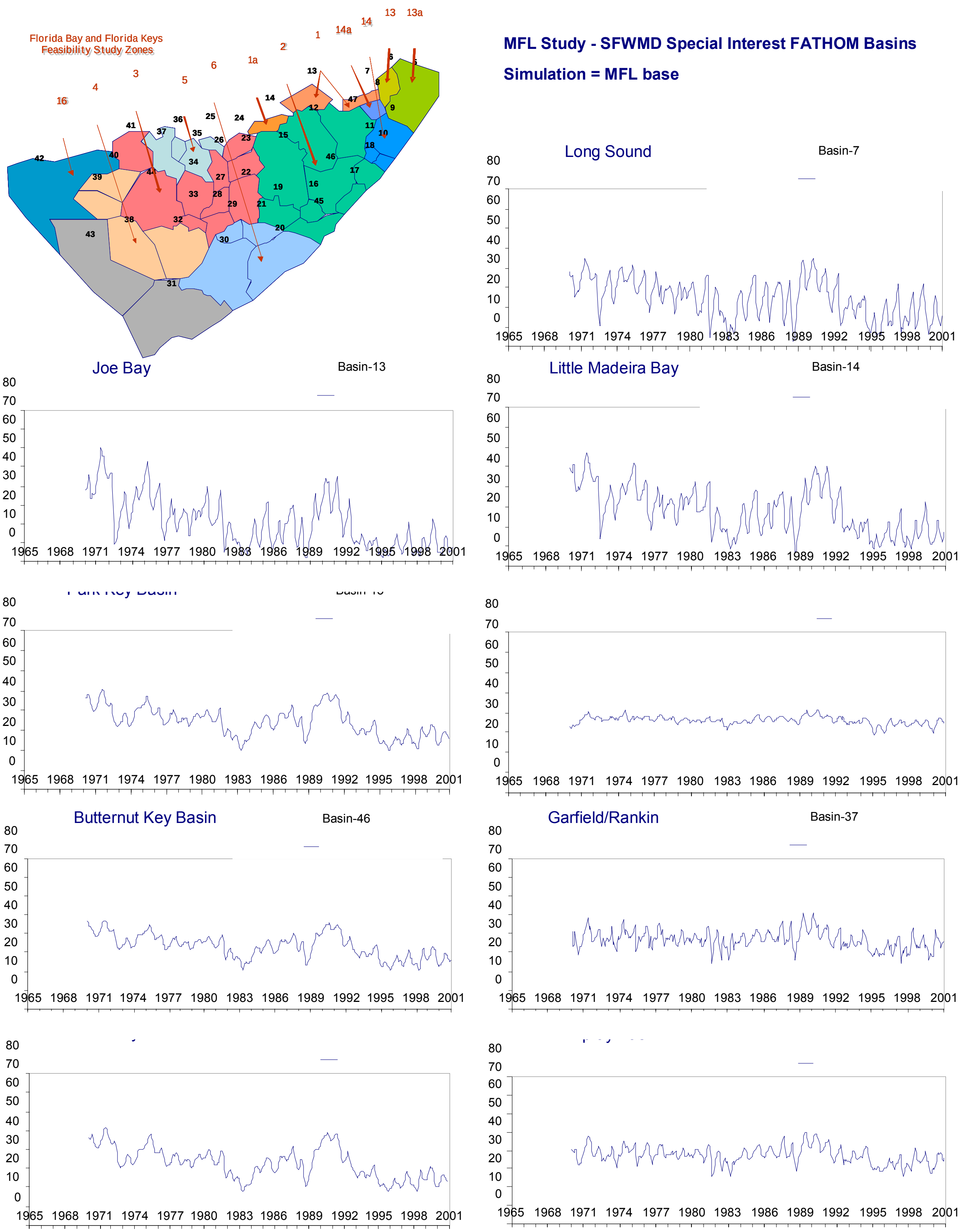
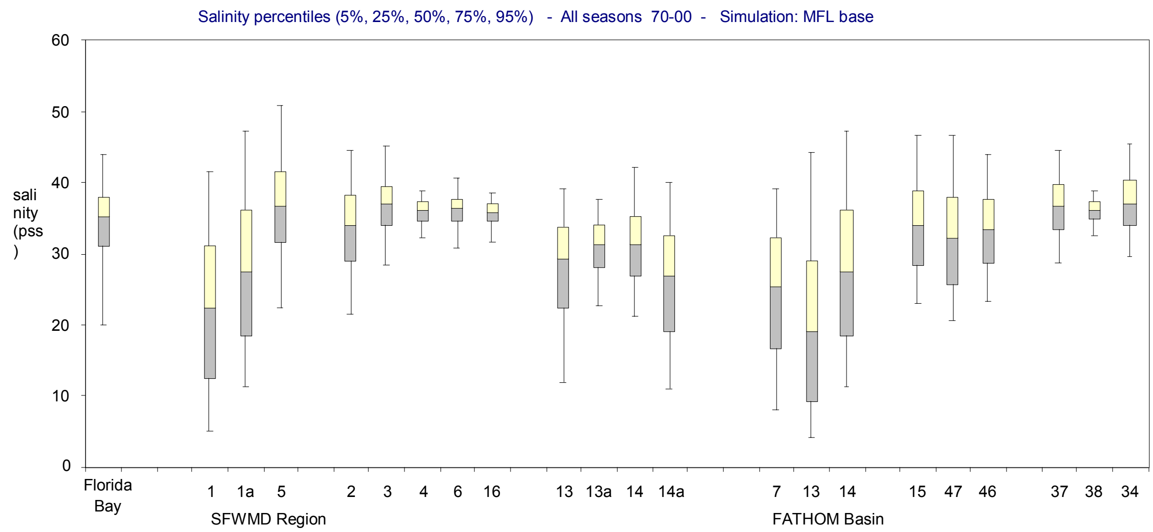
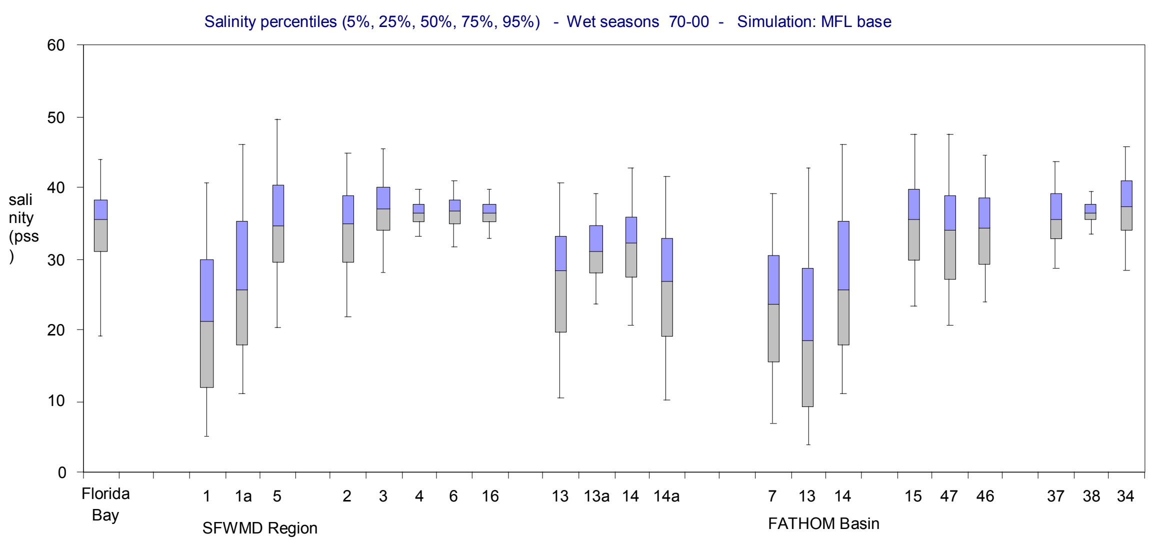


Figure 4.13: Overall summary of salinity distributions obtained for MFL base case.





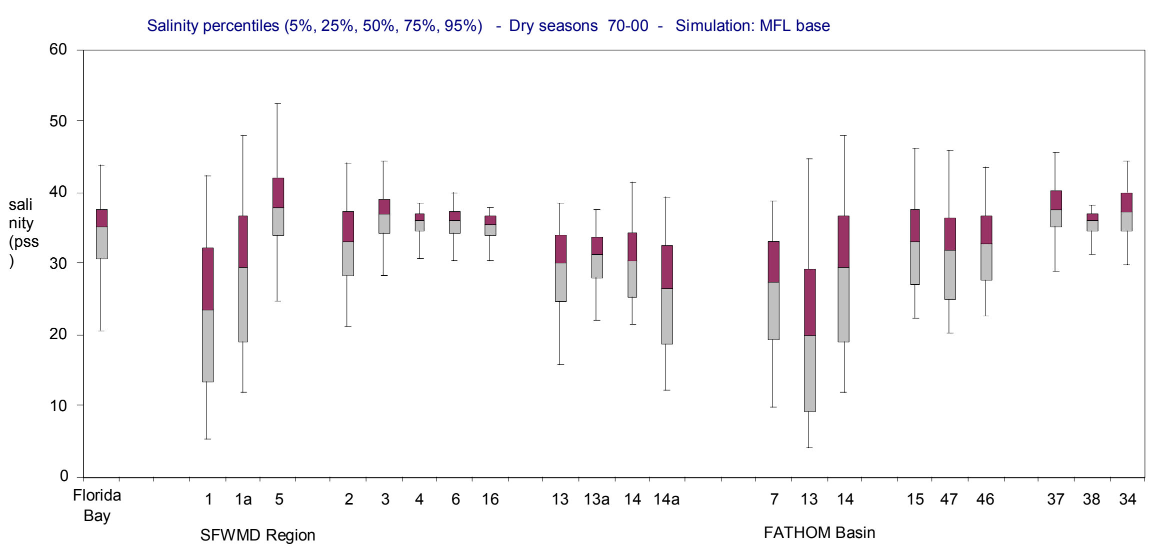


Figure 4.14: Frequency of occurrence within salinity classes for the MFL base case.

4.4 Results of Residence Time Calculations

Residence time calculations were performed using two accepted estimates – turnover time and decay half-life. Calculated residence time in Florida Bay sub-basins ranges from a few days up to almost six months (Table 4.4). Basins in the central and northeast regions have longer residence times than basins in the west and south regions of the Bay (Figure 4.15). Detailed output for residence time calculations can be found in Appendices B and F.

The turnover time (Figures 4.16-4.18) and decay half-life (Figures 4.19-4.21) calculations yielded almost identical results. Turnover time for a single input single output CSTR (continuously stirred reactor) is conceptually the same thing as the decay half-life. For example, a pulse of dye added to a CSTR would produce a concentration curve that has an exponential decline, and the characteristic time constant (defined as V/Q, i.e. the Turnover Time) would be the same as that determined by the numerical procedure for finding the decay half-life.

Casual inspection of the residence time results and the results of the salinity calculations in the previous section suggested that periods of rapid increase in salinity coincide with periods of high residence times in the Bay. Basins with long residence times were more susceptible to the effect of evaporation in excess of rainfall leading to the development of hypersaline conditions. Residence time was also more variable in these basins.

Table 4.4: Residence time values for the SFWMD areas of interest calculated from the FATHOM MFL base simulation for the period 1970 – 2002.

SFWMD Basin	Decay Half-life (days)			Turnover Time (days)		
	median	max	min	median	max	min
Long Sound	19	30	10	19	34	11
Joe Bay	63	30	16	63	171	21
Little Madeira Bay	34	88	14	39	82	18
Duck Key	57	130	31	63	128	36
Butternut Key	17	28	11	16	32	10
Park Key	55	124	29	58	129	31
Whipray Basin	19	38	10	19	42	9
Rankin Lake	7	14	5	9	17	4
Rabbit Key	6	8	5	6	10	4

Figure 4.15: Distribution of FATHOM basis with median residence time (decay half-life) longer than ten days (show as darker shade).

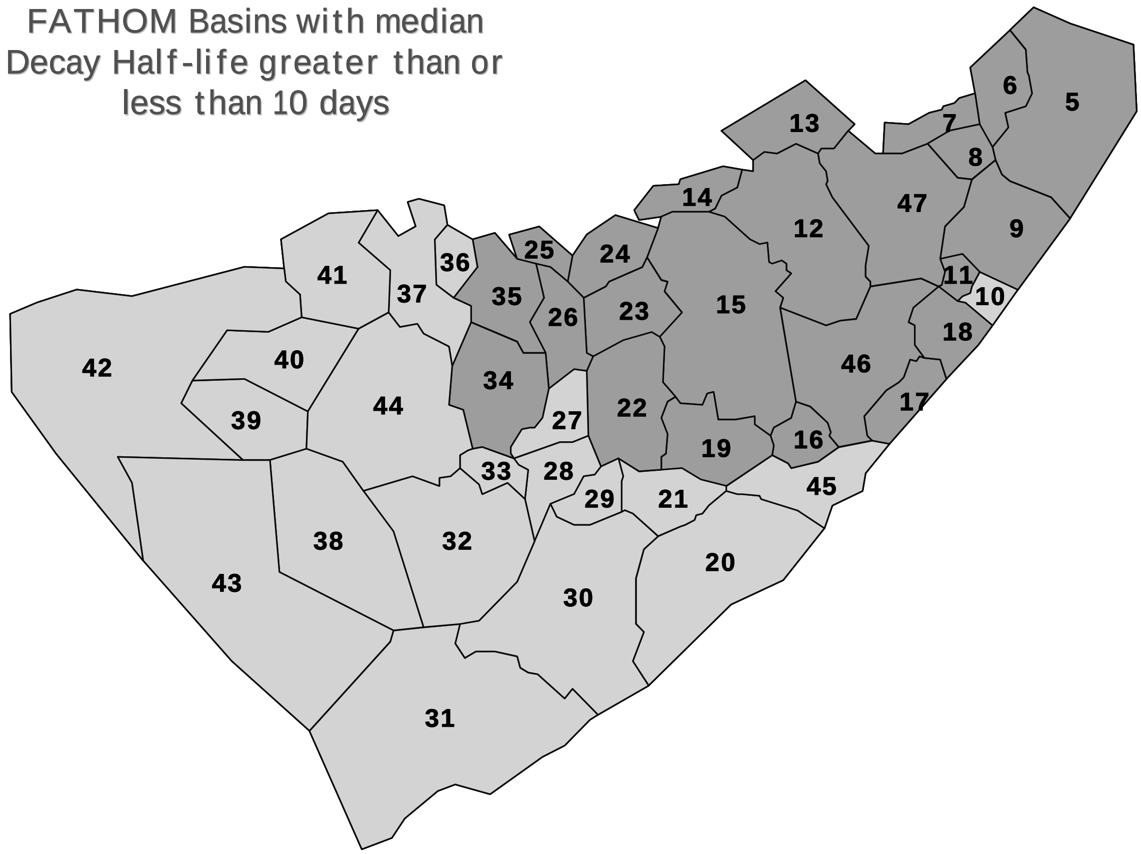


Figure 4.16: Time series of monthly values of simulated Turnover Time (days) for nine selected FATHOM basins. The map at upper left shows the location of the FATHOM basins and the Feasibility Study regions.

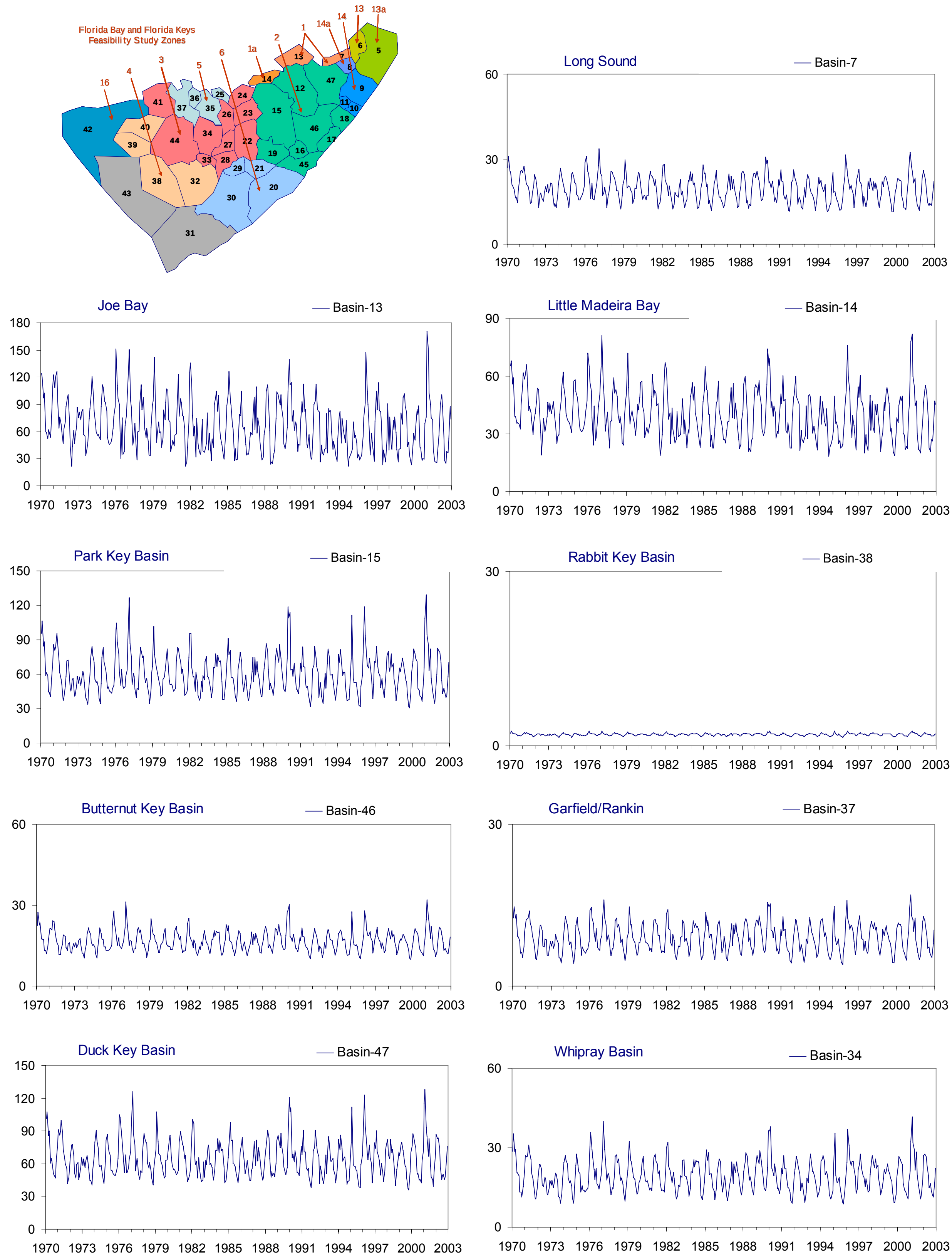


Figure 4.17: Bar and whisker diagrams showing the percentiles (5% 25%, 50%, 75%, 95%) of simulated Turnover Time (days). The percentiles are displayed for all seasons (upper panel), wet seasons (middle panel) and dry seasons (lower panel).

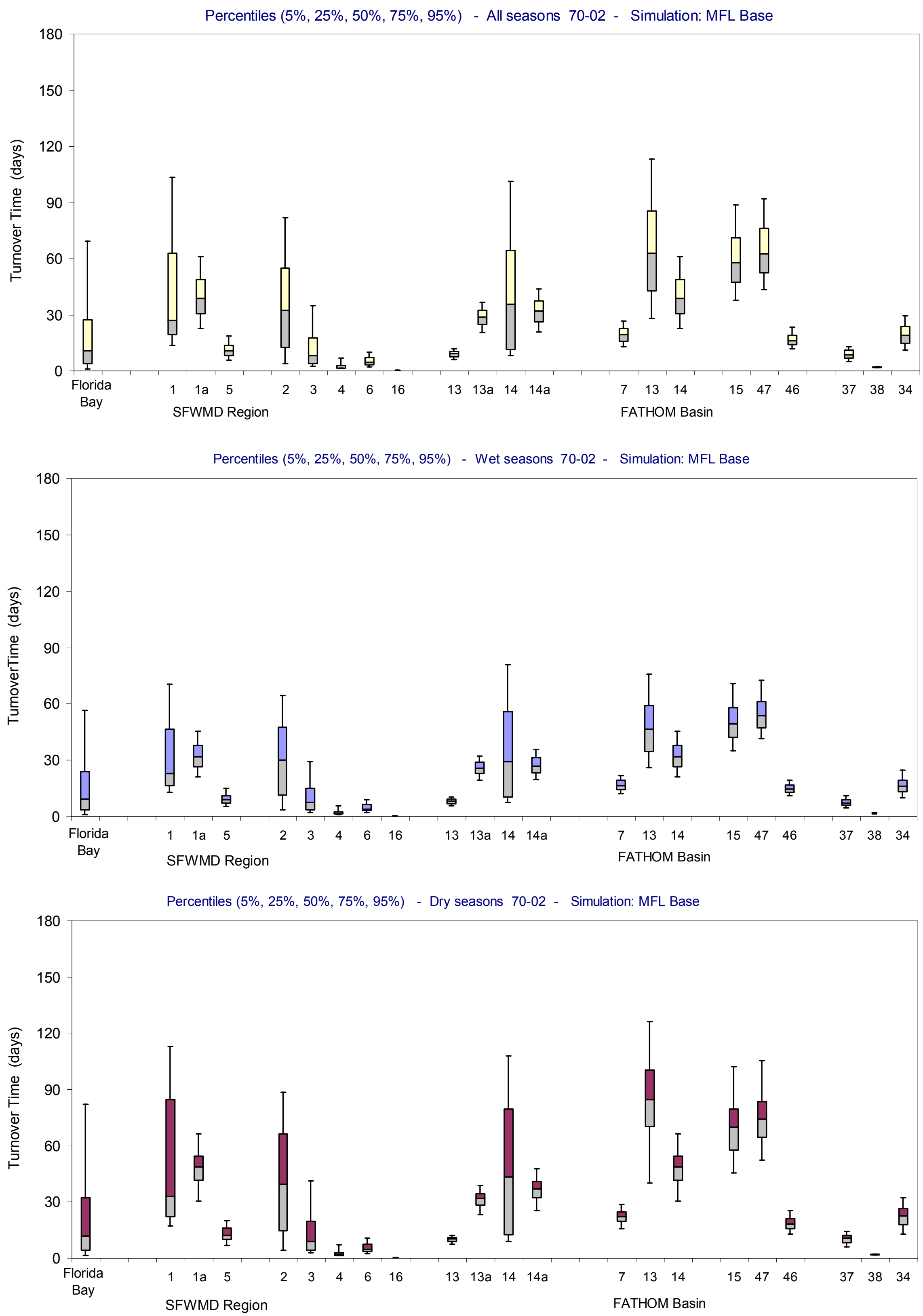


Figure 4.18: Frequency (% of months) with which Turnover Time (days) was simulated in different ranges. From top to bottom panels: > 120 days; 61-120 days; 31-60 days; 15-30 days; 8-14 days; and 0-7 days. Frequencies were calculated for all seasons and for the wet and dry seasons separately.

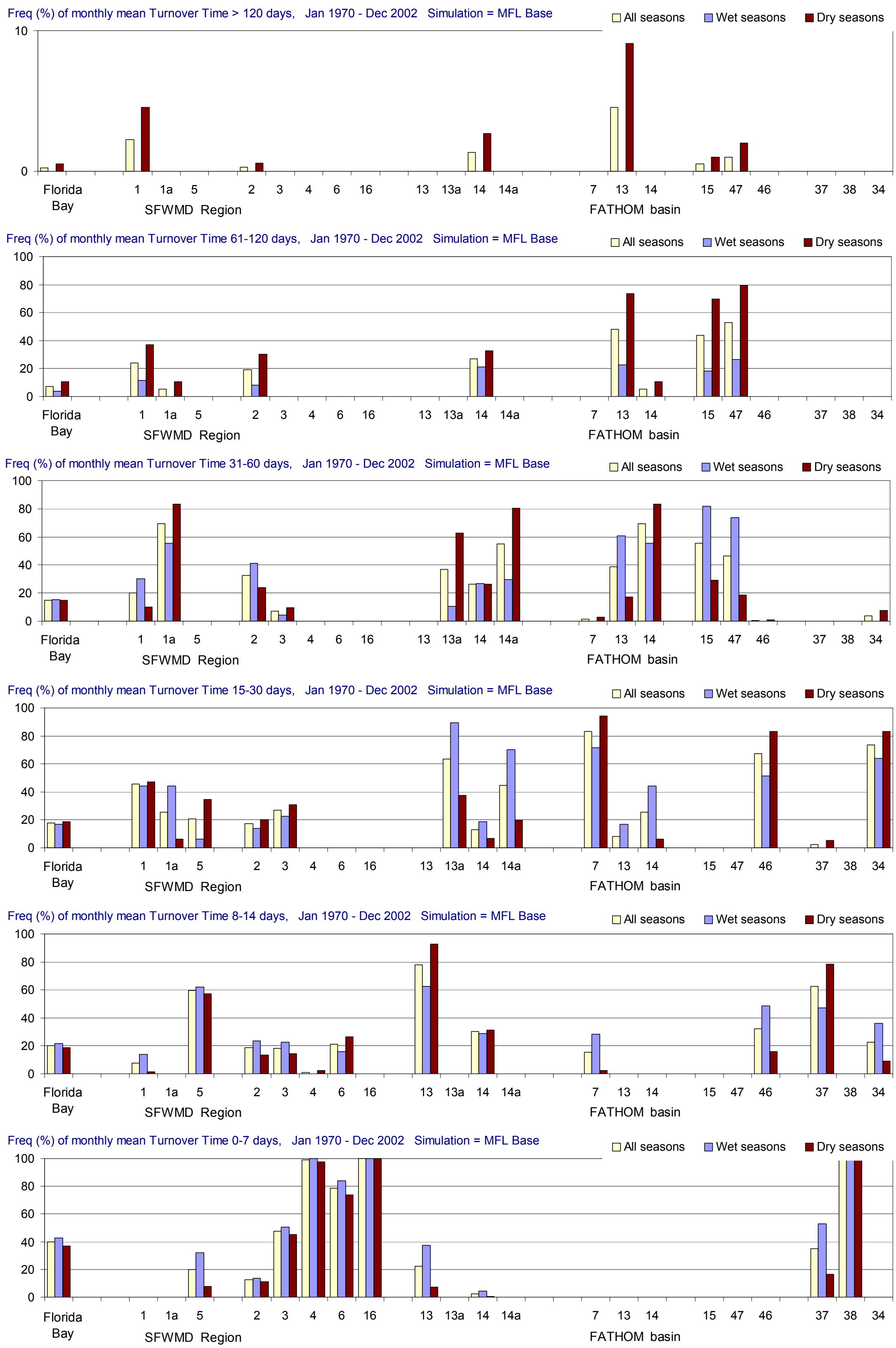


Figure 4.19: Time series of monthly values of simulated Decay Half-life (days) for nine selected FATHOM basins. The map at upper left shows the location of the FATHOM basins and the Feasibility Study regions.

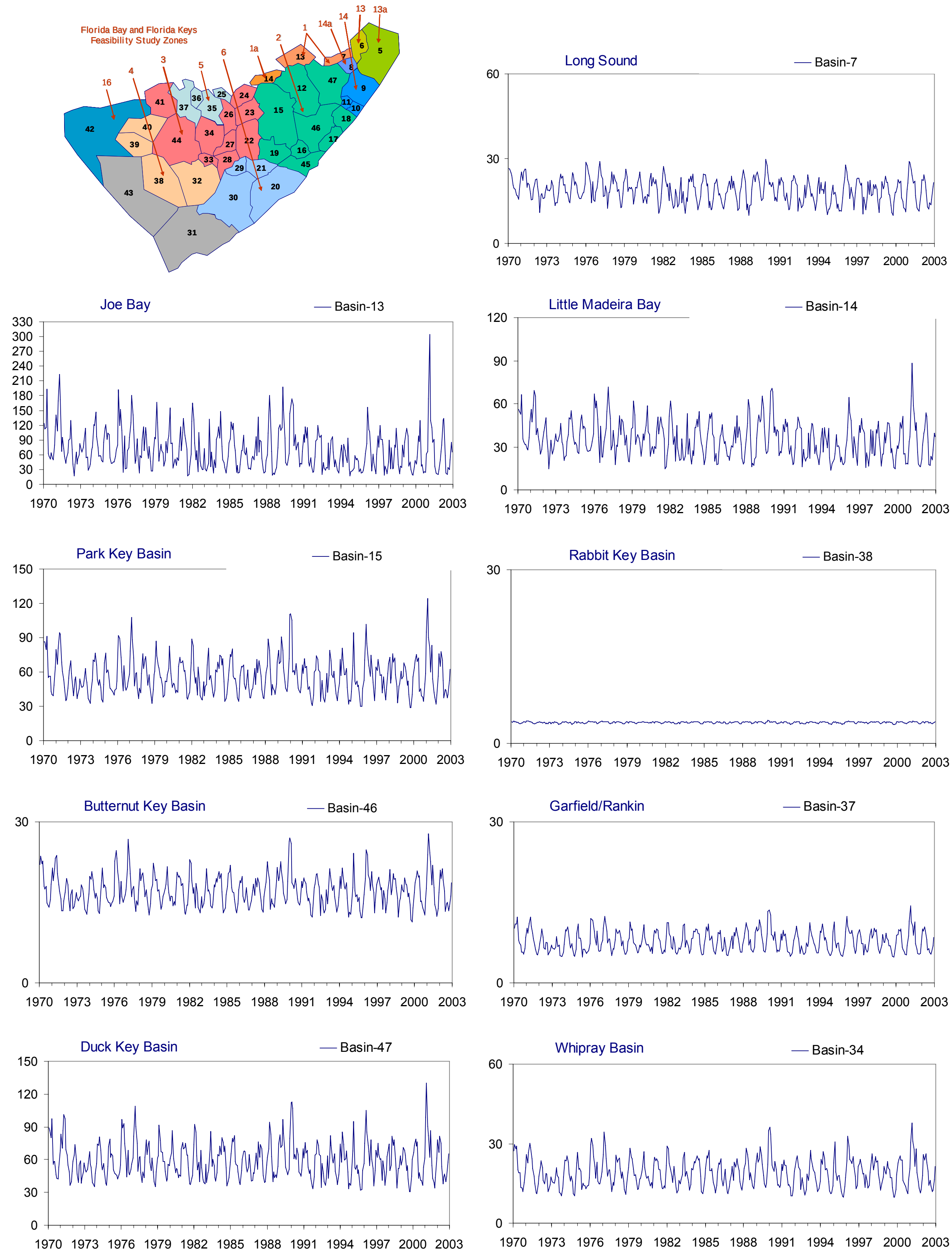


Figure 4.20: Bar and whisker diagrams showing the percentiles (5% 25%, 50%, 75%, 95%) of simulated Decay Half-life (days). The percentiles are displayed for all seasons (upper panel), wet seasons (middle panel) and dry seasons (lower panel).

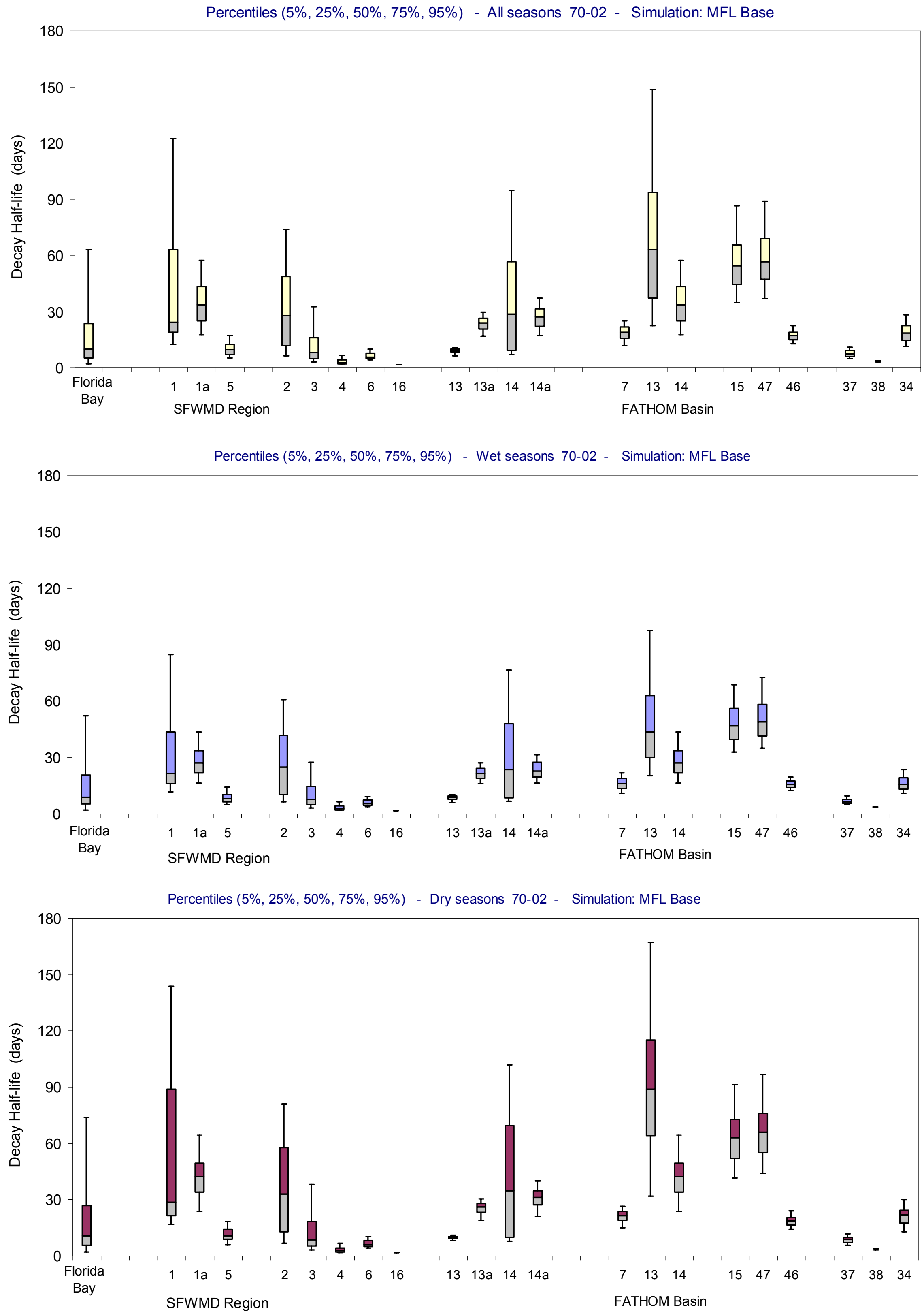
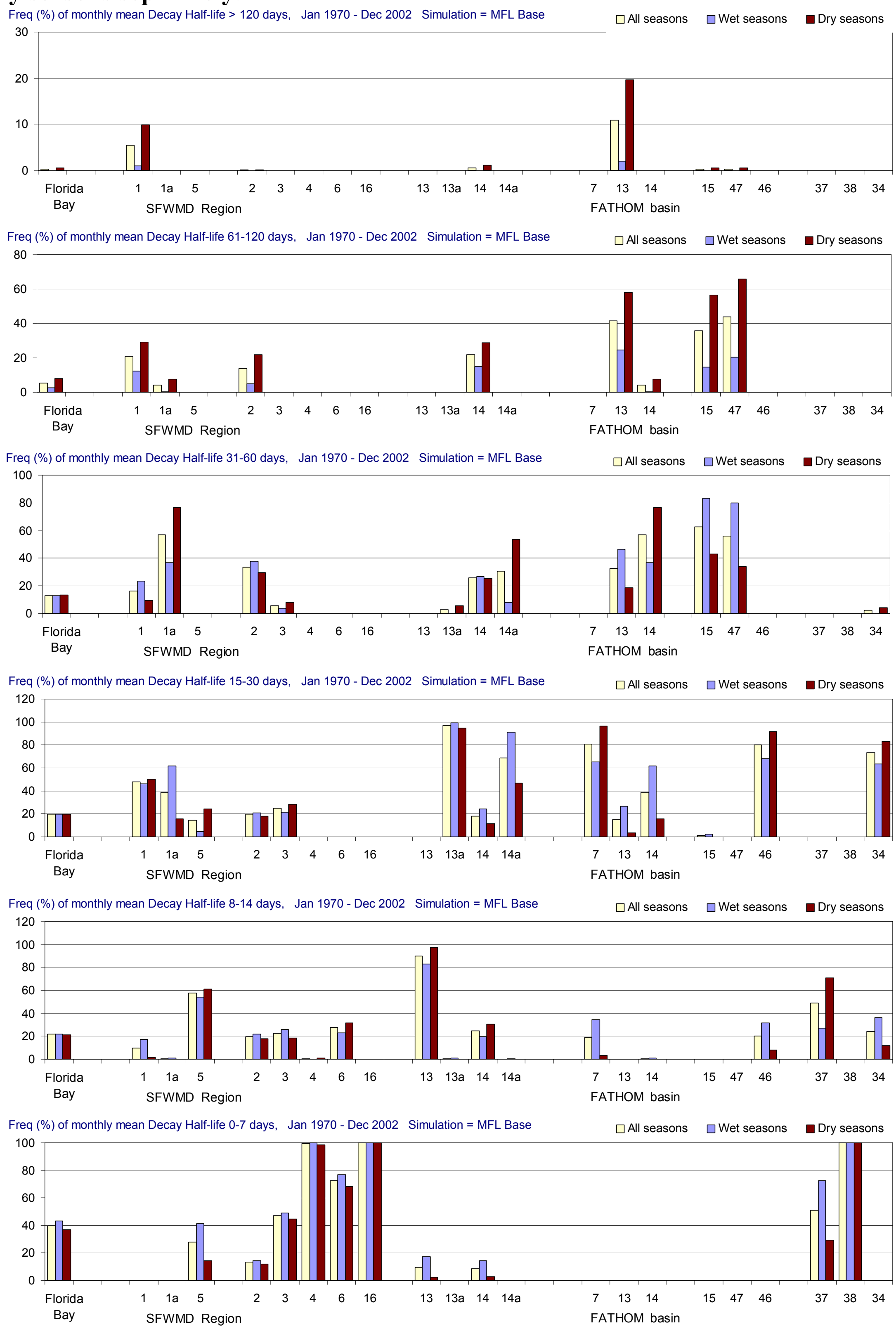


Figure 4.21: Frequency (% of months) with which Decay Half-life (days) was simulated in different ranges. From top to bottom panels: > 120 days; 61-120 days; 31-60 days; 15-30 days; 8-14 days; and 0-7 days. Frequencies were calculated for all seasons and for the wet and dry seasons separately.



5 Error, Sensitivity and Uncertainty

This section describes the evaluation of errors in salinity calculations by the FATHOM model with input data defined by the MFL base case, and examines the sensitivity of these errors to alternative choices of input data and model parameters. The error indicates the level of uncertainty inherent in applying the MFL base case inputs and FATHOM to predict salinity in Florida Bay under scenarios where Everglades hydrology differs from historical conditions. This uncertainty derives from a number of sources, including model error, errors in the estimated input data and boundary conditions, and variability in salinity not completely measured by the available data. The sensitivity analysis provides a test and validation of the selection of the input data and parameter values that comprise the MFL base case.

The analysis combined information from calculations and data compiled over three periods of time (Table 5.1). The MFL base case input data supported calculation of salinity fluctuations over the period 1970 through 2002. Estimates of error in the MFL base case simulation were based on differences between calculated values and monthly salinity measurements. With one exception, the sensitivity analysis was based on comparing errors calculated over the period for which salinity measurements were available, 1991 through 2002. The exception compared errors for the MFL base case with those for salinity calculations based on directly measured inflow from the Everglades wetlands into Florida Bay. These inflow data were available for this study only for the period 1996 through 2000.

In these comparisons, errors in the salinity calculations were defined by comparing the 30-day averaged salinity values calculated by FATHOM with salinity measurements collected by the SERC monitoring program. The SERC monitoring program has measured salinity once a month at 25 locations within Florida Bay since 1991 (Jones and Boyer 2001) (Figure 1.5). These data provided the most comprehensive and consistent picture of salinity variation in the bay over this time period that can be obtained from a single source.

Table 5.1: Time periods relevant to the calculation of salinity, error and sensitivity to alternative input data.

1970-2002	Florida Bay salinity calculated based on MFL Base Case and alternative input data sets – wetland inflow estimated from regional hydrology data.
1991-2002	Florida Bay salinity measurements available for comparison with calculated salinity values.
1996-2000	Wetland inflow measurements available as input into salinity calculations.

5.1 Errors in the Base Case Simulation – 1991 through 2002

Error and uncertainty were evaluated based on the set of residual errors, *R*. The residual errors were calculated as the differences between measured and calculated salinity values that corresponded to the same location in time and space. In this analysis, the residual errors were calculated as the difference between the basin-wide average salinity calculated by FATHOM, based on monthly-averaged input data, and salinity measured on one day each month at one location within the basin. Residual error represents combined effects of model error (i.e. salinity variations due to processes not accounted for in the model calculations), and noise within the data (i.e. variations not adequately characterized by the available data).

5.1.1 Error Statistics

This analysis characterized the error in calculated salinity at three scales: for Florida Bay overall, for the sub-regions within the bay identified for the Florida Bay and Florida Keys Feasibility study, and for the areas of interest to the District for MFL criteria (Figure 1.5).

Five error statistics are reported:

- average error (avg e),
- root mean squared error (rmse),
- average absolute error (abs e),
- coefficient of determination (r-sq), and
- model efficiency (eff).

The average error, the average of *R*, measures bias between simulated and observed values; a mean error of zero means no bias. Even if the average error is zero there can still be significant differences between simulated and observed values; these differences may simply cancel out in the calculation of the average error.

The root mean squared error (rmse) and the average absolute error are measures of residual deviation between simulated and observed values, reported in the units of the simulated variable. The root mean squared error is calculated as the square root of the mean of the squared residuals MSE. The average absolute error is calculated as the mean of the absolute values of the *R* values. These measures better reflect the expected magnitude of the difference between calculated and measured salinity at a particular location and time.

Model efficiency is similar to the coefficient of determination expressed as R-squared or R^2. The coefficient of determination measures the fraction of the variance in the observations that can be explained by a linear transformation of the simulated salinity values. Therefore, the definition of the coefficient of determination is based on the correlation between the simulated and observed values. In contrast, model efficiency is calculated from the mean square error normalized by the variance of the observed salinity;

$$eff = 100 * (1 - MSE / Var(obs)) \qquad 5.1$$

where MSE is the mean of the squared residual errors and Var(obs) is the variance of the observed salinity data. This statistical measure of model fidelity is also known as the Nash-Sutcliffe efficiency, c.f. Nash and Sutcliffe (1970) and Weglarczyk (1998).

In this analysis, model efficiency proved to be the most sensitive and versatile measure of the fidelity of calculated to measured salinity. Model efficiency can be interpreted broadly as the percentage of the variance in the data that is accounted for directly by the model. A model efficiency of zero indicates that the model accounts for no more of the variation than does the mean of the data. An efficiency of 100 indicates that the model accounts for all of the variation in the data. However, model efficiency can take on negative values if, for example, the model produces a biased estimate of the data.

5.1.2 Results

The salinity calculations based on the MFL base case inputs scored a model efficiency of 81 percent throughout Florida Bay (Table 5.2). Values of model efficiency in the feasibility study regions and in areas of interest ranged between 42 percent and 78 percent. Model efficiency evaluated for specific regions within the bay were expected to be lower than efficiency values obtained for the bay as a whole. This is because the variance of the salinity data for the whole bay, which appears in the denominator of Equation 5.1, was higher than the variance of salinity for any sub-region within the bay.

Values for the coefficient of determination (R^2) were acceptable being greater than 0.68 at all locations and equal to 0.9 overall. Largely, this reflected the ability of the MFL base case calculations to capture the seasonal cycles that dominate salinity variations (Figure 5.1).

The overall average error of –0.1 indicates that calculations based on the MFL base case inputs matched the overall the mean salinity in Florida Bay; however bias in the calculated salinity values evident at the scale of sub-regions and basins contributed to the errors measured by the root mean square error and average absolute error. Values of the root mean squared error and the average absolute error were generally consistent with each other throughout Florida Bay.

Joe Bay and Garfield/Rankin (Feasibility Study Region 5) stand out as locations of interest where the performance of the model was lower than elsewhere. These are locations were fresh water enters the bay from the adjacent wetlands. The poorer performance of the model here might reflect errors in the amount, timing and spatial distribution of inflow as described by the MFL base case input data. Also, limitations in the model calculations, such as lack of wind-driven circulation, and the assumption that each basin was well-mixed, likely had a large influence potentially causing error.

The model efficiency was low also for Feasibility Study Region 13. This region is isolated from Florida Bay by the U.S. Route 1 causeway, and the poor performance of the model here was likely due to poorly described boundary conditions in southern Biscayne Bay.

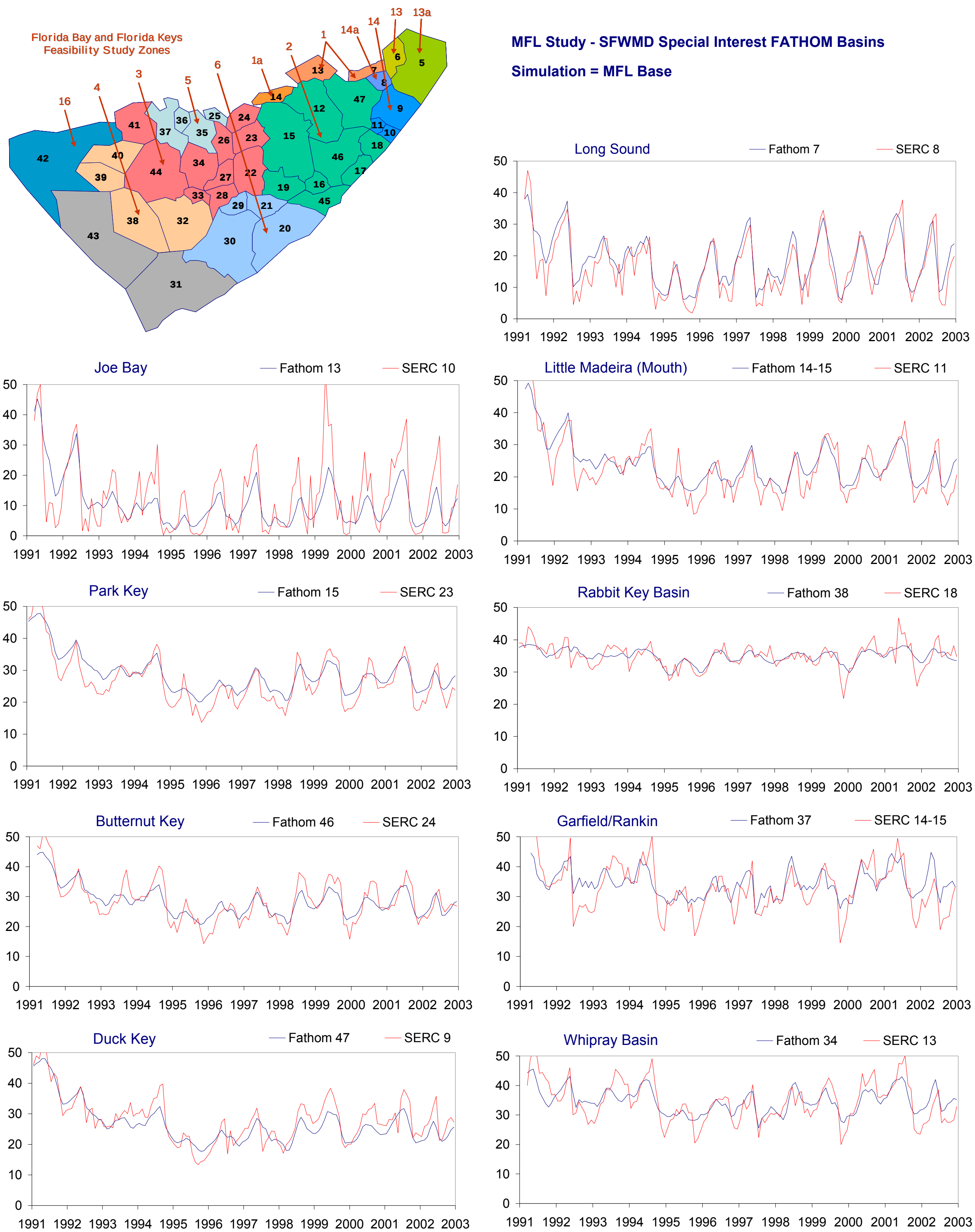
The error values reported in Tables 5.2 are not true measures of the error in calculated salinity, but these are a conservative estimate of the model error. This distinction arises from a fundamental difference between the salinity that was calculated and the salinity that was measured. Because of the temporal averaging inherent in the FATHOM calculations and in the input data provided to drive the model, calculated salinity values should be interpreted as estimates of time-averaged salinity values. The averaging period was about one month.

By contrast, the salinity observations were collected as grab samples at one point in time each month, and the variation in these data included the influence of short-term and day-to-day variability in salinity that was not present in the FATHOM calculations. This short-term variability accounted for some portion of the residuals *R* and the measures of model performance. Consequently, the bay-wide value of model efficiency of 81 percent indicated a deficiency of 19 percent in the ability of the model to explain the variation in the grab sample results. Removing the influence of short-term variation from the data, for example, by comparison of model predictions to time averaged salinity measurements, could have resultd in a somewhat higher value for model efficiency and better assessment of model performance.

Table 5.2: Errors estimated by comparing salinity predictions for the MFL base case with monthly measurements over the period 1991 through 2002. The statistics used to characterize the errors were model efficiency (eff), root mean squared error (rmse), average error (avg e), average absolute error (abs e), and the coefficient of determination (r-sq).

Location		eff	rmse	avg e	abs e	r-sq
All Florida Bay		81	4.1	-0.1	3.1	0.9
SFWMD Regions						
Feasibility Study Region	1	65	6.3	0.0	4.5	0.8
Feasibility Study Region	1a	76	4.2	1.3	3.3	0.9
Feasibility Study Region	5	43	5.9	1.5	4.5	0.7
Feasibility Study Region	2	78	3.5	-0.2	2.9	0.9
Feasibility Study Region	3	58	5.1	1.0	4.1	0.8
Feasibility Study Region	4	51	2.8	-0.2	2.1	0.7
Feasibility Study Region	16	47	3.0	0.4	2.1	0.7
Feasibility Study Region	6	59	2.9	-0.5	2.3	0.9
Feasibility Study Region	13	42	4.7	-1.3	3.3	0.8
Feasibility Study Region	13a	74	2.8	-0.1	2.2	0.9
Feasibility Study Region	14	67	3.6	-1.9	2.8	0.9
Feasibility Study Region	14a	76	4.1	-1.1	3.2	0.9
FATHOM basins						
Long Sound	7	77	4.3	1.9	3.4	0.9
Joe Bay	13	56	7.7	-1.9	5.6	0.8
Little Madeira (Mouth)	14	76	4.2	1.3	3.3	0.9
Park Key	15	77	3.7	2.0	3.1	0.9
Duck Key	47	76	3.7	-1.6	3.0	0.9
Butternut Key	46	76	3.5	-0.2	2.8	0.9
Garfield/Rankin	37	43	5.9	1.5	4.5	0.7
Whipray Basin	34	58	4.5	0.2	3.6	0.8
Rabbit Key Basin	38	51	2.6	0.0	1.9	0.7

Figure 5.2: Results for the MFL Base simulation (Jan 1991 - Dec 2002). Time series showing monthly average values of both simulated (FATHOM, blue) and observed (SERC, red) salinity values (pss). The time series are presented for nine selected FATHOM basins.



5.2 Sensitivity Analysis of Alternative Inputs – 1992 through 2002

Sensitivity analysis compares the performance of the salinity simulations for the MFL base case with the performance obtained with alternative choices of input data and model parameters. The sensitivity analysis addressed the question of whether the MFL base case was the best choice of input data sets and model parameter values among the alternatives considered. The sensitivity analysis also provided information about how different assumptions made in assembling the input data influenced the predicted salinity values.

5.2.1 Alternative Inputs and Parameter Values

This section describes the alternative input data and parameter values used in the sensitivity analysis. Differences among the alternative input data and model parameter values spanned the range of uncertainty inherent in selecting the corresponding component for the MFL base case. Alternatives were examined for each input and parameter except sea level and tides.

Sea level was excluded from the sensitivity analysis because fluctuations in sea level occurred regionally and the Key West data adequately characterized these fluctuations within Florida Bay. The alternatives considered for bathymetry also accounted for uncertainty in the position of the mean sea level datum. Tides were excluded because, the idealized representation of tides within FATHOM was regarded as a feature of the representation of mixing and exchange within the model rather than an input into the calculations. Tidal fluctuations in water levels occurred on a time scale smaller than the time scales resolved by the input data and on which predictions of the model were considered valid (i.e. monthly).

5.2.1.1 Rainfall

The MFL base rainfall input data weare estimated regional values based on data from the three NCDC rainfall stations at Flamingo, Royal Palm and Tavernier (Table 5.3). Rainfall Alternative 1 was based on data from the same three stations, but at greater spatial resolution of the distribution of rainfall. Rainfall Alternative 2 applied rainfall estimated by the NCDC Florida Division 7 dataset, which included data from Tavernier and other adjacent monitoring stations, uniformly over the bay. The Division 7 region included Florida Bay and the Keys but not the Everglades or the southeast mainland coast.

Table 5.3: MFL base case and alternative rainfall input data.

Data Set	Description
MFL Base Rainfall	Monthly rainfall amount was derived for five FATHOM regions within the bay from long-term observations of precipitation at three locations: Flamingo, Royal Palm and Tavernier. The monthly precipitation measured at the three locations around the bay was applied to the five FATHOM regions within the bay using Thiessen polygons. The bay-wide average annual rainfall is 120 cm/yr.
Alternate 1 (RF-1)	Monthly rainfall amount was estimated for five FATHOM regions within the bay using regressions of monthly rainfall observed within the bay (at the fourteen ENP marine monitoring stations) on monthly rainfall observed around the bay (at Flamingo, Royal Palm, and Tavernier) for the period 1993-2002. The monthly rainfall estimates derived from the regressions for the fourteen stations within the bay were applied to the five FATHOM regions within the bay using Thiessen polygons. The bay-wide average annual rainfall is 109 cm/yr.
Alternate 2 (RF-2)	Monthly rainfall amount was derived for five FATHOM regions within the bay from the observed NCDC Division 7 precipitation data. The monthly Division 7 rainfall amounts were applied uniformly over the bay by assigning the same monthly values to all five FATHOM regions within the bay. The bay-wide annual rainfall is 107 cm/yr.

5.2.1.2 Evaporation

The MFL base evaporation input data were estimated based on a Dalton Law (wind speed) formula. This approach resulted in an average rate of 135 cm/year (Table 5.4).

Evaporation Alternative 1 is a radiation-based approach to estimating evaporation. It resulted in an average rate of 137 cm/year. In the radiation approach, evaporation was calculated as a fraction (53 percent) of estimated total solar radiation by the method described by Abtew (1996) for South Florida. Total solar radiation was estimated from radiation incident at the top of the atmosphere for given time of year, reduced by an amount to account for attenuation by moisture in the air. The attenuation factor was estimated using the method employed by the SFWMD (2003) based on the daily temperature range interpolated over the bay from temperatures measured at Flamingo, Royal Palm, and Tavernier.

Evaporation Alternative 2 applied the Thornthwaite formula (Thornthwaite and Holzman 1939), based on temperature indices. This approach resulted in an average rate of 147 cm/year.

Evaporation Alternative 3 applied the same approach as the MFL base evaporation rescaled so that the average rate was 147 cm/year.

Table 5.4: MFL base case and alternative evaporation input data.

Data Set	Description
MFL Base Evaporation	Monthly evaporation amount was calculated for five FATHOM regions within the bay from Dalton's Law using air temperature, surface water temperature, wind speed and relative humidity. Monthly mean air temperature was derived from long-term observations at three locations: Flamingo, Royal Palm and Tavernier. Monthly mean surface water temperature was estimated for fourteen locations within the bay using regressions of monthly average water temperature (observed at the 14 ENP marine monitoring stations) on monthly average air temperature (observed at 3 sites - Flamingo, Royal Palm, and Tavernier) for the period 1995-2002. Monthly mean wind speed and relative humidity were estimated using seasonal patterns based on average monthly observations at Joe Bay tower for 1991-2002. The wind function was adjusted to set bay-wide average annual evaporation to 135 cm/yr. The monthly evaporation estimates at the fourteen stations within the bay were applied to the five FATHOM regions within the bay using Thiessen polygons.
Alternate 1 (EV-1)	Monthly evaporation amount was calculated for five FATHOM regions within the bay from the SFWMD Simple Method using solar radiation at the water surface, the latent heat of evaporation, and a coefficient characteristic of the surface. The coefficient value selected was the SFWMD recommended value for mixed marsh, shallow lakes and open water. Radiation at the water surface was estimated from the solar constant, the latitude of the bay, and atmospheric transmissivity over the bay. Estimates of atmospheric transmissivity were obtained for three sites around the bay based on long-term observations of average daily max/min air temperatures at Flamingo, Royal Palm and Tavernier. Estimated average annual bay-wide evaporation given the selected surface characteristic coefficient was 137 cm/yr. The monthly evaporation estimates derived from the three transmissivity estimates were applied to the five FATHOM regions within the bay using Thiessen polygons.
Alternate 2 (EV-2)	Monthly evaporation amount was calculated for five FATHOM regions within the bay using the Thornthwaite method based on observed mean monthly air temperatures from the NCDC Division 7 data set. The Thornthwaite method does not involve the selection of a scalar or coefficient value. Calculated average annual bay-wide evaporation given the Division 7 air temperature data was 147 cm/yr. The calculated evaporation amounts were applied uniformly over the bay by assigning the same monthly values to all five FATHOM regions within the bay.
Alternate 3 (EV-3)	Same as base simulation except the wind function was adjusted to give a bay-wide average annual evaporation of 147 cm/yr.

5.2.1.3 Boundary Salinity

The boundary salinity for the MFL base case and the two alternatives (Table 5.5) differed in their representation of the temporal variability around the same long-term mean value. The MFL base boundary salinity input data were estimated from a regression with the S12T structure flows and the P33 water level data (Table 2.1). Boundary Salinity Alternative 1 estimated the boundary salinity as the pattern of averages by month of the observed boundary salinity values for the period 1992 through 2002. Boundary Salinity Alternative 2 estimated the boundary salinity as the average on each boundary for the period 1992 through 2002.

Table 5.5: MFL base case and alternative boundary salinity input data.

Data Set	Description
MFL Base Boundary Salinity	Monthly values of boundary salinity were estimated for three FATHOM boundary regions. Monthly salinity along the Gulf of Mexico and Card Sound boundaries were estimated from multivariate regressions of observed monthly salinity values (SERC monitoring data) on monthly discharges at the S12T structures and monthly water levels in the P33 well, for the period 1992-2002 (lag 2 for the Gulf boundary, lag 0 for the Card Sound boundary). Monthly salinity values for the Atlantic boundaries were set to the long-term average of observed data from monitoring in the Florida Keys National Marine Sanctuary for the period 1995-2002.
Alternate 1 (BS-1)	Monthly values of boundary salinity along the Gulf and Card Sound boundaries were estimated as the seasonal pattern of observed mean monthly salinity values (SERC monitoring data) for the period 1992-2002. (The average seasonal pattern was repeated every year). Salinity at the Atlantic boundary was the same as in the base simulation.
Alternate 2 (BS-2)	Monthly values of boundary salinity along the Gulf and Card Sound boundaries were estimated as the long-term annual mean value of all sites along each boundary (SERC monitoring data) for the period 1992-2002. (There was no variation with time or location the along boundaries). Salinity at the Atlantic boundary is the same as in the base simulation.

5.2.1.4 Freshwater Inflow from Wetlands

The base case and alternative input data for freshwater inflow from wetlands are described in section 3.3.

5.2.1.5 Bottom Friction Parameter

The value of Manning's n chosen for the MFL base case was an estimate derived from measurements of flow over shallow, grass-covered shoals at two locations in the West region of Florida Bay (Fourqurean and Childers, unpub. data). The values of Manning's n chosen for the Friction Parameter Alternate 1 and Friction Parameter Alternate 2, Table 5.6, spanned the range of estimates of Manning's n at the USGS estuarine creek monitoring stations (Swain et al. 2004).

Table 5.6: MFL base case and alternative bottom friction parameter.

Data Set	Description
MFL Base Friction Coefficient	Manning's n (the friction coefficient), used in the hydraulic calculation of flows over the banks, was assumed to be constant over time and space. A value of 0.1 (mks systems) was used everywhere. The value, 0.1, was based on calculations from flume studies on a western bank and also agrees well with calculations based on observed USGS discharges in creeks flowing into the northeast of the bay.
Alternate 1 (FR-1)	Manning's n set equal to 0.2 for hydraulic calculation of flow over the banks, assumed to be constant over time and space.
Alternate 2 (FR-2)	Manning's n set equal to 0.05 for hydraulic calculation of flow over the banks, assumed to be constant over time and space.

5.2.1.6 Bathymetry

The parameters that established the bathymetry of Florida Bay in FATHOM consisted of the information on percent coverage by 1-foot depth class for each basin and for each line segment that marked the banks between the basins. Section 2.1 describes how bathymetric information was assembled from several sources and applied to estimate the parameter values that comprise the MFL bathymetry in FATHOM. The alternative bathymetry parameter sets (Table 5.7) increase the depth by 60 percent, first only in the mean depth of the basins in Bathymetry Alternate 1, and second in the mean depth of both the basins and the banks in Bathymetry Alternate 2.

Table 5.7: MFL base and alternative bathymetry parameterization.

Data Set	Description
MFL Base Bathymetry	*(see description of the MFL bathymetry in section 2.1)*
Alternate 1 (BT-1)	*Basins* – All depths in all basins increased by 60% (depths multiplied by 1.6) *Banks* – same as in base simulation
Alternate 2 (BT-2)	*Basins* – All depths in all basins increased by 60% (depths multiplied by 1.6) *Banks* – All depths along all banks increased by 60% (depths multiplied by 1.6)

5.2.2 Results

Measures of model performance are reported for the MFL base case in Tables 5.8 through 5.13. Results are reported for Florida Bay as a whole, for each of the feasibility study regions, and for the areas of interest to the District for MFL criteria. Each of the columns to the right of the results for the base case reports the results of an alternative salinity simulation. In the alternative simulations, the indicated input data or model parameter substituted for the corresponding input data or model parameter in the MFL base case. Substitutions were made one at a time.

None of the alternatives examined performed generally better than the MFL base case. Values in Table 5.8 are highlighted where the model efficiency of an alternative exceeded the model efficiency for the MFL base case. Where model efficiencies were higher for an alternative, the difference is generally less that five percent higher, and these are balanced by much larger decreases in model efficiency for the same alternative at other locations (Table 5.13). The other measures of model performance (Tables 5.9 through 5.12) show results that are consistence with those for model efficiency.

The results provide some insight into how uncertainty in the input data and model parameters affected the salinity calculations. Overall, the largest effect is seen for boundary salinity, bottom friction parameter, and bathymetry (Table 5.14). Model performance was much less sensitive to the other alternatives investigated, and response was less coherent spatially. Areas affected by choice of boundary salinity were in the West Region, adjacent to the Florida Shelf, and in the far eastern portion of the model domain where Florida Bay joins Biscayne Bay. (The eastern-most regions were effectively isolated from the rest of Florida Bay by a shallow bank and the U.S. Route 1 causeway.) The same areas affected by choice of the bottom friction parameter were generally also affected by bathymetry alternatives, but these do not include the West Region.

The areas affected by the bottom friction parameter and bathymetry were in the Northeast and Central Regions. In these areas, bottom friction and basin volume affected the degree of flushing by exchange with the other parts of the bay and the Florida Shelf. Generally, a higher degree of flushing, lower residence time, suppressed the ability of water loss by evaporation to generate high salinity peaks and the ability of rainfall events and seasonal inflow of freshwater to generate low salinity minima. Lower flushing, higher residence time, had the opposite effect.

Feasibility regions 13, 14, and 14a were also sensitive to the application of the PHAST model to describe inflow (RN5). These regions were in the far eastern portion of the model domain where simulations were also affected by uncertainty in the boundary conditions with lower Biscayne Bay.

Table 5.8: Values of MODEL EFFICIENCY computed for the period 1991 through 2002 from the difference between simulated monthly average salinity and salinity measured in water samples taken once every month (n=144). Higher values are highlighted.

Location		Base-case	Rainfall RF1	Rainfall RF2	Evaporation EV1	Evaporation EV2	Evaporation EV3	Wetland Inflow RN1	Wetland Inflow RN2	Wetland Inflow RN3	Wetland Inflow RN4	Wetland Inflow RN5	Bnd Salinity BS1	Bnd Salinity BS2	Manning n FR1	Manning n FR2	Bathymetry BT1	Bathymetry BT2
All Florida Bay		81	79	79	80	79	80	80	80	81	79	78	78	73	64	49	76	63
SFWMD Regions																		
Feasibility Study Region 1	1	65	**67**	**66**	**68**	63	65	62	62	65	65	60	65	56	12	2	53	6
Feasibility Study Region 1a	1a	76	61	59	72	59	67	**77**	64	**77**	74	**82**	75	75	-9	-10	68	-12
Feasibility Study Region 5	5	43	37	39	38	43	40	43	43	**45**	30	31	38	26	34	38	**46**	37
Feasibility Study Region 2	2	78	70	68	73	68	75	74	75	77	77	**82**	75	76	43	-25	66	41
Feasibility Study Region 3	3	58	50	52	55	55	54	**59**	57	**61**	45	50	52	47	41	**69**	57	41
Feasibility Study Region 4	4	51	51	51	50	**53**	**52**	51	51	51	51	51	30	7	49	**55**	51	48
Feasibility Study Region 16	16	47	47	47	47	47	47	47	47	47	47	47	30	0	47	47	47	47
Feasibility Study Region 6	6	59	**60**	58	57	**61**	**61**	59	59	59	58	**60**	46	31	50	**67**	56	48
Feasibility Study Region 13	13	42	**46**	**48**	40	**47**	**43**	36	**46**	42	42	21	39	10	**53**	-28	**54**	**58**
Feasibility Study Region 13a	13a	74	74	**75**	72	**75**	**75**	74	74	74	74	**75**	54	-27	66	**78**	**75**	67
Feasibility Study Region 14	14	67	**73**	**72**	**69**	**71**	**75**	61	**71**	67	67	41	56	67	**74**	-11	51	**69**
Feasibility Study Region 14a	14a	76	**77**	76	**79**	74	**78**	72	**77**	76	76	45	73	76	52	-39	54	56
FATHOM basins																		
Long Sound	7	77	73	74	76	71	75	**81**	68	77	77	**82**	74	50	14	60	74	10
Joe Bay	13	56	**61**	**59**	**62**	56	**58**	48	56	55	56	44	**57**	**58**	6	-40	38	-1
Little Madeira (Mouth)	14	76	61	59	72	59	67	**77**	64	**77**	74	**82**	75	75	-9	-10	68	-12
Park Key	15	77	52	49	70	50	62	**83**	65	80	74	**84**	77	76	16	4	62	13
Duck Key	47	76	**79**	**79**	72	75	**80**	63	**80**	75	**77**	76	74	**77**	54	-103	64	52
Butternut Key	46	76	70	68	69	69	75	72	73	75	76	**83**	72	72	33	-27	66	32
Garfield/Rankin	37	43	37	39	38	43	40	43	43	**45**	30	31	38	26	34	38	**46**	37
Whipray Basin	34	58	53	53	56	**59**	57	58	57	57	51	53	51	44	44	**65**	56	44
Rabbit Key Basin	38	51	51	51	51	**52**	**52**	**52**	51	**52**	51	51	28	6	50	**54**	51	50

Notes:

62 efficiency is higher than MFL base case

62 efficency is higher than MFL base case by > **5%**

62 efficency is higher than MFL base case by > **10%**

Table 5.9: Values of RMSE (root mean squared error) computed for the period 1991 through 2002 from the difference between simulated monthly average salinity and salinity measured in water samples taken once every month (n=144).

Location		Base-case	Rainfall		Evaporation			Wetland Inflow					Bnd Salinity		Manning n		Bathymetry	
			RF1	RF2	EV1	EV2	EV3	RN1	RN2	RN3	RN4	RN5	BS1	BS2	FR1	FR2	BT1	BT2
All Florida Bay		4.1	4.3	4.3	4.2	4.3	4.2	4.2	4.2	4.1	4.3	4.4	4.4	4.9	5.7	6.7	4.6	5.7
SFWMD Regions																		
Feasibility Study Region 1	1	6.3	6.1	6.2	6.0	6.4	6.2	6.5	6.5	6.3	6.2	6.7	6.3	7.0	10.0	10.5	7.2	10.3
Feasibility Study Region 1a	1a	4.2	5.3	5.4	4.5	5.4	4.8	4.0	5.0	4.1	4.3	3.6	4.2	4.2	8.8	8.9	4.8	8.9
Feasibility Study Region 5	5	5.9	6.2	6.1	6.1	5.9	6.0	5.9	5.9	5.8	6.5	6.5	6.2	6.7	6.4	6.1	5.7	6.2
Feasibility Study Region 2	2	3.5	4.1	4.2	3.9	4.2	3.7	3.8	3.7	3.6	3.6	3.2	3.7	3.7	5.7	8.4	4.4	5.8
Feasibility Study Region 3	3	5.1	5.6	5.5	5.3	5.2	5.3	5.0	5.1	4.9	5.8	5.5	5.5	5.7	6.0	4.4	5.2	6.0
Feasibility Study Region 4	4	2.8	2.8	2.8	2.8	2.7	2.8	2.8	2.8	2.8	2.8	2.8	3.3	3.8	2.8	2.7	2.8	2.9
Feasibility Study Region 16	16	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.5	4.2	3.0	3.0	3.0	3.0
Feasibility Study Region 6	6	2.9	2.9	3.0	3.0	2.9	2.8	2.9	2.9	2.9	3.0	2.9	3.4	3.8	3.2	2.6	3.0	3.3
Feasibility Study Region 13	13	4.7	4.5	4.5	4.8	4.5	4.6	4.9	4.5	4.7	4.7	5.5	4.8	5.8	4.2	7.0	4.2	4.0
Feasibility Study Region 13a	13a	2.8	2.8	2.8	2.9	2.8	2.8	2.8	2.8	2.8	2.8	2.8	3.8	6.2	3.3	2.6	2.8	3.2
Feasibility Study Region 14	14	3.6	3.2	3.3	3.5	3.3	3.1	3.9	3.3	3.6	3.6	4.7	4.1	3.5	3.2	6.5	4.4	3.4
Feasibility Study Region 14a	14a	4.1	4.0	4.1	3.9	4.2	3.9	4.4	4.0	4.1	4.1	6.2	4.3	4.1	5.8	9.9	5.7	5.5
FATHOM basins																		
Long Sound	7	4.3	4.7	4.6	4.5	4.9	4.6	3.9	5.1	4.3	4.4	3.8	4.7	6.4	8.5	5.8	4.7	8.6
Joe Bay	13	7.7	7.2	7.4	7.1	7.7	7.5	8.3	7.7	7.8	7.7	8.6	7.6	7.5	11.2	13.7	9.1	11.7
Little Madeira (Mouth)	14	4.2	5.3	5.4	4.5	5.4	4.8	4.0	5.0	4.1	4.3	3.6	4.2	4.2	8.8	8.9	4.8	8.9
Park Key	15	3.7	5.4	5.5	4.3	5.5	4.8	3.2	4.6	3.5	3.9	3.1	3.8	3.8	7.1	7.6	4.8	7.3
Duck Key	47	3.7	3.5	3.5	4.0	3.8	3.3	4.6	3.3	3.8	3.6	3.7	3.9	3.6	5.1	10.8	4.5	5.2
Butternut Key	46	3.5	3.9	4.0	3.9	3.9	3.5	3.8	3.6	3.5	3.5	2.9	3.7	3.7	5.8	7.9	4.1	5.8
Garfield/Rankin	37	5.9	6.2	6.1	6.1	5.9	6.0	5.9	5.9	5.8	6.5	6.5	6.2	6.7	6.4	6.1	5.7	6.2
Whipray Basin	34	4.5	4.7	4.7	4.5	4.4	4.5	4.4	4.5	4.5	4.8	4.7	4.8	5.1	5.1	4.1	4.5	5.1
Rabbit Key Basin	38	2.6	2.6	2.6	2.6	2.5	2.5	2.6	2.6	2.5	2.6	2.6	3.1	3.6	2.6	2.5	2.6	2.6

Table 5.10: Values of MEAN ERROR computed for the period 1991 through 2002 from the difference between simulated monthly average salinity and salinity measured in water samples taken once every month (n=144).

Location		Base-	Rainfall		Evaporation			Wetland Inflow					Bnd Salinity		Manning n		Bathymetry	
		case	RF1	RF2	EV1	EV2	EV3	RN1	RN2	RN3	RN4	RN5	BS1	BS2	FR1	FR2	BT1	BT2
All Florida Bay		-0.1	0.8	0.9	0.2	0.8	0.7	-0.7	0.6	-0.4	0.2	-0.5	-0.3	0.8	2.3	-3.1	-0.2	2.2
SFWMD Regions																		
Feasibility Study Region 1	1	0.0	1.0	1.0	0.3	0.9	0.9	-1.6	1.9	0.0	0.0	-1.0	-0.2	1.5	8.2	-7.0	-0.6	8.3
Feasibility Study Region 1a	1a	1.3	3.2	3.5	1.7	3.4	2.9	-0.4	3.1	0.9	1.6	-0.4	1.0	1.2	7.1	-6.4	1.3	7.1
Feasibility Study Region 5	5	1.5	2.0	1.9	1.8	1.9	2.1	1.5	1.5	0.2	2.9	2.9	1.2	1.6	1.6	1.6	1.4	1.4
Feasibility Study Region 2	2	-0.2	1.7	2.0	0.2	1.8	1.4	-1.4	1.0	-0.5	0.1	-0.4	-0.4	-0.1	3.2	-5.5	-0.1	3.1
Feasibility Study Region 3	3	1.0	1.8	1.8	1.4	1.8	2.1	0.9	1.2	-0.3	2.5	2.2	0.7	1.0	1.3	0.1	0.8	1.1
Feasibility Study Region 4	4	-0.2	-0.1	-0.1	-0.2	-0.1	-0.1	-0.2	-0.2	-0.3	-0.2	-0.2	-0.5	-0.5	-0.2	-0.2	-0.2	-0.2
Feasibility Study Region 16	16	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.1	0.4	0.4	0.4	0.4	0.4
Feasibility Study Region 6	6	-0.5	-0.1	-0.1	-0.4	-0.1	-0.1	-0.7	-0.4	-0.7	-0.3	-0.4	-0.7	-0.9	-0.3	-1.1	-0.5	-0.3
Feasibility Study Region 13	13	-1.3	-0.6	-0.8	-1.0	-0.8	-0.8	-1.9	-0.8	-1.4	-1.3	-3.0	-1.5	2.5	1.3	-4.4	-1.7	1.5
Feasibility Study Region 13a	13a	-0.1	0.4	0.3	0.1	0.3	0.2	-0.2	0.1	-0.1	-0.1	-0.5	0.0	4.6	0.6	-1.0	-0.2	0.6
Feasibility Study Region 14	14	-1.9	-0.5	-0.9	-1.7	-0.8	-1.0	-2.5	-1.3	-1.9	-1.9	-3.7	-2.1	1.3	0.7	-5.1	-1.8	0.2
Feasibility Study Region 14a	14a	-1.1	-0.1	-0.4	-0.7	-0.4	-0.4	-2.2	0.0	-1.1	-1.2	-4.7	-1.4	2.1	4.1	-8.1	-1.7	3.5
FATHOM basins																		
Long Sound	7	1.9	2.6	2.4	2.3	2.4	2.5	0.7	3.2	1.9	1.9	-1.5	1.7	4.9	7.1	-4.2	1.3	7.2
Joe Bay	13	-1.9	-0.7	-0.5	-1.6	-0.6	-0.7	-3.8	0.7	-2.0	-1.8	-0.6	-2.1	-1.9	9.3	-9.8	-2.4	9.3
Little Madeira (Mouth)	14	1.3	3.2	3.5	1.7	3.4	2.9	-0.4	3.1	0.9	1.6	-0.4	1.0	1.2	7.1	-6.4	1.3	7.1
Park Key	15	2.0	4.1	4.4	2.3	4.2	3.8	0.7	3.3	1.5	2.4	1.4	1.7	1.9	5.4	-3.2	2.1	5.4
Duck Key	47	-1.6	0.7	1.0	-1.2	0.8	0.3	-3.1	0.0	-1.8	-1.4	-1.6	-1.9	-1.2	2.8	-8.2	-1.4	2.6
Butternut Key	46	-0.2	1.6	1.8	0.2	1.6	1.2	-1.4	1.0	-0.4	0.0	-0.3	-0.4	0.0	3.5	-6.2	-0.1	3.4
Garfield/Rankin	37	1.5	2.0	1.9	1.8	1.9	2.1	1.5	1.5	0.2	2.9	2.9	1.2	1.6	1.6	1.6	1.4	1.4
Whipray Basin	34	0.2	0.9	0.9	0.5	0.8	1.1	0.1	0.3	-0.9	1.3	1.1	-0.1	0.1	0.3	-0.2	0.0	0.1
Rabbit Key Basin	38	0.0	0.0	0.0	0.0	0.1	0.0	-0.1	0.0	-0.1	0.0	0.0	-0.4	-0.4	-0.1	0.0	-0.1	0.0

Table 5.11: Values of AVERAGE ABSOLUTE ERROR computed for the period 1991 through 2002 from the difference between simulated monthly average salinity and salinity measured in water samples taken once every month (n=144).

Location		Base-	Rainfall		Evaporation			Wetland Inflow					Bnd Salinity		Manning n		Bathymetry	
		case	RF1	RF2	EV1	EV2	EV3	RN1	RN2	RN3	RN4	RN5	BS1	BS2	FR1	FR2	BT1	BT2
All Florida Bay		3.1	3.2	3.3	3.2	3.2	3.1	3.1	3.2	3.0	3.2	3.3	3.3	3.8	4.3	4.9	3.4	4.3
SFWMD Regions																		
Feasibility Study Region 1	1	4.5	4.6	4.6	4.4	4.8	4.6	4.5	5.0	4.5	4.5	4.7	4.6	5.6	8.9	7.4	5.2	9.1
Feasibility Study Region 1a	1a	3.3	4.4	4.5	3.7	4.4	3.9	3.2	4.1	3.2	3.4	2.7	3.3	3.4	7.9	7.6	3.9	8.0
Feasibility Study Region 5	5	4.5	4.7	4.7	4.9	4.4	4.7	4.5	4.5	4.5	5.1	5.0	4.7	5.4	4.7	5.0	4.3	4.6
Feasibility Study Region 2	2	2.9	3.4	3.5	3.1	3.5	3.1	3.0	3.1	2.9	2.9	2.6	3.0	3.0	4.8	7.3	3.6	4.8
Feasibility Study Region 3	3	4.1	4.5	4.4	4.3	4.2	4.3	4.1	4.2	3.9	4.8	4.5	4.4	4.7	4.9	3.5	4.2	4.9
Feasibility Study Region 4	4	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.5	3.0	2.2	2.0	2.1	2.2
Feasibility Study Region 16	16	2.1	2.2	2.1	2.2	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.6	3.1	2.1	2.1	2.1	2.1
Feasibility Study Region 6	6	2.3	2.3	2.4	2.4	2.3	2.3	2.3	2.3	2.3	2.4	2.3	2.7	3.1	2.5	2.1	2.4	2.6
Feasibility Study Region 13	13	3.3	3.2	3.1	3.5	3.1	3.3	3.5	3.2	3.3	3.2	4.1	3.3	5.0	3.3	5.5	3.0	3.1
Feasibility Study Region 13a	13a	2.2	2.2	2.2	2.3	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.8	5.5	2.6	2.1	2.2	2.5
Feasibility Study Region 14	14	2.8	2.5	2.6	2.7	2.6	2.4	3.1	2.6	2.8	2.8	4.1	3.2	2.8	2.5	5.6	3.5	2.7
Feasibility Study Region 14a	14a	3.2	3.1	3.2	3.0	3.4	3.0	3.6	3.1	3.2	3.2	5.5	3.4	3.2	4.8	8.7	4.7	4.4
FATHOM basins																		
Long Sound	7	3.4	3.8	3.7	3.6	3.9	3.7	3.0	4.2	3.4	3.4	2.9	3.6	5.7	7.7	4.7	3.6	7.8
Joe Bay	13	5.6	5.4	5.5	5.2	5.7	5.5	6.0	5.8	5.6	5.6	6.4	5.6	5.5	10.2	10.2	6.8	10.4
Little Madeira (Mouth)	14	3.3	4.4	4.5	3.7	4.4	3.9	3.2	4.1	3.2	3.4	2.7	3.3	3.4	7.9	7.6	3.9	8.0
Park Key	15	3.1	4.7	4.9	3.6	4.7	4.2	2.6	4.0	2.9	3.4	2.5	3.2	3.2	6.3	6.6	4.1	6.4
Duck Key	47	3.0	2.7	2.8	3.1	2.9	2.7	3.8	2.7	3.1	3.0	3.0	3.2	2.9	4.2	9.7	3.8	4.2
Butternut Key	46	2.8	3.3	3.4	3.2	3.3	2.9	2.9	3.0	2.8	2.8	2.3	2.9	2.9	5.0	7.0	3.4	5.0
Garfield/Rankin	37	4.5	4.7	4.7	4.9	4.4	4.7	4.5	4.5	4.5	5.1	5.0	4.7	5.4	4.7	5.0	4.3	4.6
Whipray Basin	34	3.6	3.8	3.8	3.7	3.5	3.6	3.6	3.6	3.6	3.9	3.8	3.8	4.2	4.1	3.3	3.8	4.1
Rabbit Key Basin	38	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2.2	2.7	1.9	1.8	1.9	1.9

Table 5.12: Values of R-SQUARED computed for the period 1991 through 2002 from the difference between simulated monthly average salinity and salinity measured in water samples taken once every month (n=144).

Location		Base-case	Rainfall RF1	RF2	Evaporation EV1	EV2	EV3	Wetland Inflow RN1	RN2	RN3	RN4	RN5	Bnd Salinity BS1	BS2	Manning n FR1	FR2	Bathymetry BT1	BT2
All Florida Bay		0.90	0.89	0.89	0.89	0.89	0.90	0.90	0.90	0.90	0.89	0.89	0.88	0.86	0.88	0.86	0.87	0.88
SFWMD Regions																		
Feasibility Study Region 1	1	0.81	0.82	0.82	0.83	0.80	0.81	0.80	0.81	0.81	0.81	0.78	0.80	0.77	0.87	0.68	0.73	0.86
Feasibility Study Region 1a	1a	0.89	0.88	0.88	0.88	0.87	0.89	0.89	0.89	0.89	0.89	0.91	0.89	0.89	0.83	0.77	0.84	0.87
Feasibility Study Region 5	5	0.69	0.67	0.68	0.66	0.72	0.69	0.69	0.69	0.67	0.69	0.69	0.65	0.55	0.68	0.71	0.72	0.72
Feasibility Study Region 2	2	0.89	0.89	0.88	0.87	0.87	0.89	0.89	0.89	0.89	0.89	0.91	0.89	0.90	0.87	0.77	0.82	0.90
Feasibility Study Region 3	3	0.80	0.76	0.78	0.77	0.82	0.80	0.80	0.80	0.79	0.78	0.79	0.77	0.72	0.75	0.84	0.82	0.79
Feasibility Study Region 4	4	0.75	0.74	0.75	0.74	0.76	0.75	0.75	0.75	0.75	0.75	0.75	0.60	0.35	0.73	0.77	0.75	0.73
Feasibility Study Region 16	16	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.55	0.19	0.70	0.70	0.70	0.70
Feasibility Study Region 6	6	0.87	0.87	0.87	0.85	0.89	0.87	0.87	0.87	0.87	0.87	0.88	0.85	0.73	0.84	0.87	0.87	0.85
Feasibility Study Region 13	13	0.79	0.79	0.80	0.79	0.80	0.79	0.79	0.79	0.79	0.79	0.81	0.73	0.70	0.77	0.82	0.83	0.80
Feasibility Study Region 13a	13a	0.87	0.87	0.87	0.85	0.88	0.87	0.87	0.87	0.87	0.87	0.87	0.77	0.73	0.83	0.90	0.89	0.85
Feasibility Study Region 14	14	0.88	0.87	0.87	0.89	0.86	0.88	0.88	0.88	0.88	0.88	0.89	0.91	0.92	0.92	0.78	0.77	0.89
Feasibility Study Region 14a	14a	0.89	0.88	0.87	0.89	0.87	0.89	0.89	0.88	0.89	0.89	0.88	0.90	0.91	0.91	0.75	0.76	0.89
FATHOM basins																		
Long Sound	7	0.90	0.90	0.90	0.91	0.89	0.90	0.91	0.90	0.90	0.90	0.92	0.89	0.89	0.87	0.90	0.88	0.88
Joe Bay	13	0.77	0.79	0.77	0.81	0.75	0.76	0.78	0.75	0.76	0.77	0.67	0.78	0.78	0.86	0.58	0.65	0.85
Little Madeira (Mouth)	14	0.89	0.88	0.88	0.88	0.87	0.89	0.89	0.89	0.89	0.89	0.91	0.89	0.89	0.83	0.77	0.84	0.87
Park Key	15	0.93	0.91	0.92	0.92	0.90	0.93	0.93	0.93	0.93	0.93	0.94	0.94	0.94	0.91	0.77	0.84	0.94
Duck Key	47	0.90	0.90	0.90	0.87	0.87	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.88	0.77	0.82	0.92
Butternut Key	46	0.89	0.90	0.89	0.85	0.88	0.89	0.88	0.89	0.89	0.89	0.92	0.89	0.89	0.85	0.80	0.83	0.90
Garfield/Rankin	37	0.69	0.67	0.68	0.66	0.72	0.69	0.69	0.69	0.67	0.69	0.69	0.65	0.55	0.68	0.71	0.72	0.72
Whipray Basin	34	0.78	0.75	0.76	0.76	0.81	0.78	0.78	0.78	0.77	0.77	0.78	0.76	0.68	0.74	0.81	0.80	0.78
Rabbit Key Basin	38	0.73	0.73	0.73	0.73	0.74	0.74	0.74	0.73	0.74	0.73	0.73	0.56	0.32	0.72	0.75	0.74	0.72

Table 5.13: Values of MODEL EFFICIENCY computed for the period 1991 through 2002 from the difference between simulated monthly average salinity and salinity measured in water samples taken once every month (n=144). Low values are highlighted. Otherwise contents are identical to Table 5.7.

Location		Base-case	Rainfall RF1	Rainfall RF2	Evaporation EV1	Evaporation EV2	Evaporation EV3	Wetland Inflow RN1	Wetland Inflow RN2	Wetland Inflow RN3	Wetland Inflow RN4	Wetland Inflow RN5	Bnd Salinity BS1	Bnd Salinity BS2	Manning n FR1	Manning n FR2	Bathymetry BT1	Bathymetry BT2
All Florida Bay		81	79	79	80	79	80	80	80	81	79	78	78	73	**64**	**49**	76	**63**
SFWMD Regions																		
Feasibility Study Region 1	1	65	67	66	68	63	65	62	62	65	65	60	65	56	**12**	**2**	53	**6**
Feasibility Study Region 1a	1a	76	61	**59**	72	**59**	67	77	64	77	74	82	75	75	**-9**	**-10**	68	**-12**
Feasibility Study Region 5	5	43	37	39	38	43	40	43	43	45	**30**	31	38	**26**	34	38	46	37
Feasibility Study Region 2	2	78	70	68	73	68	75	74	75	77	77	82	75	76	**43**	**-25**	66	**41**
Feasibility Study Region 3	3	58	50	52	55	55	54	59	57	61	**45**	50	52	47	**41**	69	57	**41**
Feasibility Study Region 4	4	51	51	51	50	53	52	51	51	51	51	51	**30**	**7**	49	55	51	48
Feasibility Study Region 16	16	47	47	47	47	47	47	47	47	47	47	47	**30**	**0**	47	47	47	47
Feasibility Study Region 6	6	59	60	58	57	61	61	59	59	59	58	60	**46**	**31**	50	67	56	48
Feasibility Study Region 13	13	42	46	48	40	47	43	36	46	42	42	**21**	39	**10**	53	**-28**	54	58
Feasibility Study Region 13a	13a	74	74	75	72	75	75	74	74	74	74	75	**54**	**-27**	66	78	75	67
Feasibility Study Region 14	14	67	73	72	69	71	75	61	71	67	67	**41**	56	67	74	**-11**	**51**	69
Feasibility Study Region 14a	14a	76	77	76	79	74	78	72	77	76	76	**45**	73	76	**52**	**-39**	**54**	**56**
FATHOM basins																		
Long Sound	7	77	73	74	76	71	75	81	68	77	77	82	74	**50**	**14**	**60**	74	**10**
Joe Bay	13	56	61	59	62	56	58	48	56	55	56	**44**	57	58	**6**	**-40**	**38**	**-1**
Little Madeira (Mouth)	14	76	61	**59**	72	59	67	77	64	77	74	82	75	75	**-9**	**-10**	68	**-12**
Park Key	15	77	**52**	**49**	70	**50**	**62**	83	**65**	80	74	84	77	76	**16**	**4**	**62**	**13**
Duck Key	47	76	79	79	72	75	80	63	80	75	77	76	74	77	**54**	**-103**	64	**52**
Butternut Key	46	76	70	68	69	69	75	72	73	75	76	83	72	72	**33**	**-27**	66	**32**
Garfield/Rankin	37	43	37	39	38	43	40	43	43	45	**30**	**31**	38	**26**	34	38	46	37
Whipray Basin	34	58	53	53	56	59	57	58	57	57	51	53	51	**44**	**44**	65	56	**44**
Rabbit Key Basin	38	51	51	51	51	52	52	52	51	52	51	51	**28**	**6**	50	54	51	50

Notes:

30 efficency is lower than MFL base case by > **20%**

30 efficency is lower than MFL base case by > **40%**

5.3 Comparison of Base Case and Measured Inflow – 1996 through 2000

In addition to the analysis using the input alternatives described above, salinity calculations were made using the data that directly measured the inputs required by FATHOM. These data included rainfall measured at the Everglades Park marine monitoring stations, boundary salinity based on the SERC monitoring data, and the USGS measured inflows from the Taylor Slough C111 wetland basin. Salinity calculations based on the direct data span the period February 1996 through October 2000, which was the period of record for the USGS flow data available to this project. Details of the compilation of these data are presented in Progress Report 1 (Mark I run).

A comparison of model performance over this period using the MFL base case inputs with the FATHOM simulation using inputs based on direct local measurements provided information on the error in the calculated salinity that arose from using input data estimated from regional indices instead of direct measurements of the inputs. The results of this comparison (Table 5.14) show that there was no overall degradation in model performance related to using the estimated input data. Bay-wide efficiency was 80 percent for the MFL base case compared to 78 percent for input data based on locally observed data.

The reason for this can be seen from the detailed results by region within the Bay (Appendices D and H). The local observed data provided a better description of the boundary salinity, and this was reflected in higher model efficiencies in the West Region of the Bay using observed data. However, the local observed inflow, based on the measured USGS creek flow was a biased estimate of the actual inflow because ungauged flows were not included. By including an estimate of ungauged inflow to the Central Region, the MFL base case improved model performance in the Central Region of the Bay.

The use of this comparison of model performance must remain in context. The model efficiencies in Table 5.12 and in Appendices D and H using the observed data were based on model input data and observed salinity in the sub-basins for the period 1996-2000. The model efficiencies for the use of the indirect regional data for the MFL base case model were computed using observed salinity values for the period 1991-2000, even though the base case model produced salinity estimates for 1970-2000. Even so, it appears that the use of indirect regional data to estimate FATHOM input data when observed values were not available produced a reasonable estimate of salinity over the longer time periods.

Table 5.14: Values of MODEL EFFICIENCY computed for the period February 1996 through October 2000 from the difference between simulated monthly average salinity and salinity measured in water samples taken once every month (n=56).

Location		base case	observed inputs
All Florida Bay		80	78
SFWMD Regions			
Feasibility Study Region 1	1	57	53
Feasibility Study Region 1a	1a	64	**52**
Feasibility Study Region 5	5	45	**20**
Feasibility Study Region 2	2	68	71
Feasibility Study Region 3	3	57	**26**
Feasibility Study Region 4	4	53	**77**
Feasibility Study Region 16	16	47	**74**
Feasibility Study Region 6	6	62	66
Feasibility Study Region 13	13	36	41
Feasibility Study Region 13a	13a	76	86
Feasibility Study Region 14	14	21	21
Feasibility Study Region 14a	14a	67	**54**
FATHOM basins			
Long Sound	7	81	**65**
Joe Bay	13	44	46
Little Madeira (Mouth)	14	64	**52**
Park Key	15	65	**39**
Duck Key	47	51	**74**
Butternut Key	46	66	74
Garfield/Rankin	37	45	**20**
Whipray Basin	34	60	**46**
Rabbit Key Basin	38	52	**77**

Notes:

62 efficiency is lower than MFL base case by > **10%**

62 efficency is higher than MFL base case by > **10%**

6 DEVELOPMENT AND DESCRIPTION OF A WATER BUDGET - 1970-2000

Input data assembled for the MFL base case provided the best estimates for components of the freshwater budget in Florida Bay as estimated from FATHOM salinity estimates. This section summarizes key aspects of the water budget for the period 1970 through 2000, including the influence of water management activities, and it presents results of an analysis to identify where in the Bay salinity wais sensitive to changes in inflow from the Taylor Slough C111 wetland basin.

Water management activities since 1970 have altered surface flows in the Taylor Slough C111 wetland sub-basin. In particular, the completion around 1980 of the first phase of the South Dade Conveyance System markedly increased surface water discharge into the wetlands directly upstream from Florida Bay. Comparing the inflow component of the annual average freshwater budget for the Bay pre-1980 and post-1980 revealed the effect of this change.

The summary of the water budget is presented in two parts. In the first part, average values of component fluxes by month illustrate their relative magnitude and seasonal variation. The second part compares components of the water budget for dry, wet, and average years to characterize the range of year-to-year variations.   In this analysis, the water year provided the basis for compiling the water budget. The water year synchronized with the seasonal variation in rainfall – the 1990 water year begins 1 November 1989 and ends on 31 October 1990.

The analysis to identify areas where inflow from the wetlands affected salinity was based on the maximum salinity in a calendar year. The calendar year synchronized with the seasonal variation of salinity in Florida Bay. The sensitivity of maximum annual salinity is of interest because the purpose for setting an MFL criterion is to help protect Florida Bay from ecological harm during some periods of water shortage. Over the Bay as a whole, inflow from the wetlands made a small contribution to the water budget compared to the amount of freshwater contributed by rainfall. However in nearshore areas, close to the estuarine creeks where inflow enters the Bay, inflow from wetlands and rainfall were comparable in magnitude. Analysis of the MFL base case simulation identified locations where year-to-year changes in the volume of inflow from wetlands explained a significant portion of the year-to-year variation in maximum salinity separate from the effect of rainfall inputs.

6.1 Changes to Water Management Operations 1960-2000

Water management activities that currently have the most direct effect on the supply of fresh water to Florida Bay began with the completion of the Central and Southern Florida Project in the early 1960's. The completion of the Tamiami Trail levee and the S12 flow control structures in 1962 and the C111 Canal in 1968 allowed water managers for the first time to fully regulate the flow of surface water into Everglades National Park and adjacent estuarine areas, including Florida Bay. Prior efforts since the late 1800s to drain the main body of the original Everglades had already irreversibly altered hydrological conditions throughout South Florida. These works interrupted the flow of water southward out of Lake Okeechobee into the Everglades and increased the volume of water draining toward the east and west coasts.

By the early 1970s, there was sufficient concern over the consequences of water management on Everglades National Park and in Florida Bay to motivate a series of actions intended to mitigate the effects drainage. Modifications to the water management system and operations continued over the next 30 years (Table 6.1). Beginning in the late 1970's, a program of minimum prescribed water deliveries set monthly targets for the quantity of water to be supplied to Shark River Slough, across Tamiami Trail, to Florida Bay through the C111 Canal, and for discharge into the headwaters of Taylor Slough. Then the Experimental Water Deliveries program replaced the minimum monthly delivery targets, but the objective of increasing water deliveries to Florida Bay was not met.

Changes to water management activities that occurred around 1981 stand out as significant for the water budget of Florida Bay. Beginning in the early 1970s and continuing until about the mid-1980s, the completion of the South Dade Conveyance System (SDCS) project enhanced flood protection in southern Miami-Dade County and further altered the hydrology in the region east of the headwaters of Taylor Slough, near the main entrance to Everglades National Park. The records of surface water discharge at Taylor Slough bridge (TSB) and at the S175 and S18C structures document that a large increase in surface flow into the Taylor Slough - C111 Canal sub-basin occurred around 1980 and has continued (Figure 3.2).

The net effect of these more recent changes has not been as large as the increase in flow that occurred around 1981. In the early 1980's, flooding concerns in Miami-Dade County prompted additional operational changes to the SDCS in an attempt to alleviate flooding and also provide additional freshwater to Everglades National Park. Additional operational modifications were made in the 1990's in an attempt to restore flows and water levels in Taylor Slough. Structural changes were also planned and made to implement a more even distribution of flows from the C-111 Canal across the mangrove wetlands.

Table 6.1: Water management activities affecting Florida Bay, 1960 through 2000.

Period	Water Management Activities
1960 - 1969	• Construction of the levee and S12 control structures completed in 1962. This blocks free flow of surface water into Everglades Park from wetland areas north of Tamiami Trail. Initially, there are no outlets through this dike to supply water into northeast Shark Slough and the headwaters of Taylor Slough. • Construction begins on C111 and associated canals that will alter the hydrology in south Miami-Dade County, adjacent to the headwaters for Taylor Slough and north of the freshwater wetlands and mangrove transition in the southwest portion of the Park. Initially the S173 structure limits the amount of flow that can occur from the wetlands north of Tamiami Trail into southern Miami-Dade county and Florida Bay. • Drainage of south Miami-Dade agricultural lands decreases water flow to the mangrove transition zone through the finger glades. • C111 canal and its control structures are completed in 1968. The C111 canal establishes a hydrologically significant new breach for flow through the coastal ridge, parallel to Taylor Slough. An earthen plug is installed at present location of S197 structure to prevent salt-water intrusion by maintaining water levels above sea level in the lower reaches of the C111 canal.
1970 - 1979	• Congressionally mandated Minimum Schedule Water Deliveries (MSWD) into Everglades Park begins in 1970 in response to concerns that not enough water is reaching Taylor Slough and other areas of the Park. • Work begins on the South Dade Conveyance System (SDCS) that is needed to implement the MSWD to Taylor Slough. The first phase of work is completed in 1980 with installation of the S332 pump to deliver water to Taylor Slough.
1980 - 1989	• High water levels and flooding in Miami-Dade County during 1981-1983 prompt changes in the SDCS. The plug at S197 is removed several times to allow free discharge of flood waters through the C111 canal; this eventually leads to construction (in 1992) of the present, gated control structure. The S133 pump is installed to increase the capacity to move water from wetlands north of Tamiami Trail into southern Miami-Dade County through the C111 and L31N canals. • Increased flows in C111 canal initially discharge into wetlands and Florida Bay through Long Sound, flowing along the eastern boundary of the Park formed by US Route 1. In 1987, discharge from the C111 canal accounts for 90% of surface water delivered to the wetlands north of Florida Bay. Changes in water management operations supply more water to Taylor Slough over the next five years. • Beginning in 1983, the Experimental Water Deliveries program establishes operational goals for water deliveries to Everglades Park; this effectively replaces the MSWD goals. This program will institute a succession of changes in water management operations over the next 15 years.
1990 - 2000	• Marked changes in the ecology of Florida Bay motivate actions to further increase water deliveries to Florida Bay through Taylor Slough and redistribute discharge from the C111 canal west, into Joe Bay and away from Long Sound. • Capacity of the S332 pumps feeding water into Taylor Slough is increased in 1993 and again in 1994. Impediments to surface flow within Taylor Slough are decreased by removing a portion of the Old Ingram Highway and by widening the bridge where the main Park road crosses the slough (completed in 2000). • In 1992, the Modified Water Deliveries General Design Memorandum establishes a strategy for restoring flow and water levels in the portion of Everglades Park that feeds the headwater of Taylor Slough: implementation of this plan has been delayed. • In 1997, removal of the spoil mound along the C111 canal, south of S18C, allows a more even east-west distribution of discharge into the wetlands north of Florida Bay.

6.2 Summary of Water Budget for Florida Bay

For analysis of seasonal variation the water budget components by month were summarized four ways – for two reporting periods, 1970 through 2000 and 1996 through 2000, and for two regions, the entire Bay and the Central and Northeast Regions combined. The period 1996 through 2000 corresponded to the period in which inflow from the wetlands was best known, because data were available from the USGS estuarine creek monitoring stations (Figure 1.4). Rainfall during this period was more moderate compared to the longer historical period. All of the freshwater inflow from wetlands entered the Bay through the central and northeast regions of Florida Bay. Therefore, inflow from wetlands was a more important source of freshwater for these regions than for Florida Bay as a whole. The compilation of the water budget separately for the Central and Northeast Regions and for the whole Bay reflected this difference.

Rainfall and evaporation dominated the freshwater budget (Figures 6.1 and 6.2). The fluxes (plotted in figures below) were calculated from the MFL base case input data. The results obtained here were similar to results obtained previously by Nuttle et al. (2000). The magnitude of inflow was typically about ten percent of magnitude of rainfall over the whole Bay. The relative importance of inflow doubled in the water budget for just the central and northeast regions. Changes in salinity were driven by the net supply of freshwater, that is rainfall plus inflow minus evaporation. Changing the amount and timing of freshwater inflow from wetlands affected the net supply of freshwater, and thus salinity, but would require large changes in inflow from the wetlands.

For analysis of year-to-year variation, components of the water budget were compared for "typical" wet, dry and normal years. Variation in regional rainfall determined the overall pattern of wet, dry and normal hydrologic conditions. However, for a given year, rainfall in Florida Bay may have reflected normal or wet conditions at the same time that conditions in the upstream Everglades were generally dry (1976 in Table 6.2 and Figure 6.3). For this analysis, water year rainfall amounts typical for the Everglades (Shark Slough and the Water Conservation Areas) were taken from the Florida Climate Division 5 rainfall. Florida Climate Division 5 rainfall is a data product compiled by the National Climatic Data Center - NOAA. Rainfall in Florida Bay had the more immediate effect on salinity as the largest source of freshwater, but water management decisions for inflow from the wetlands are made based on regional rainfall conditions over the Everglades.

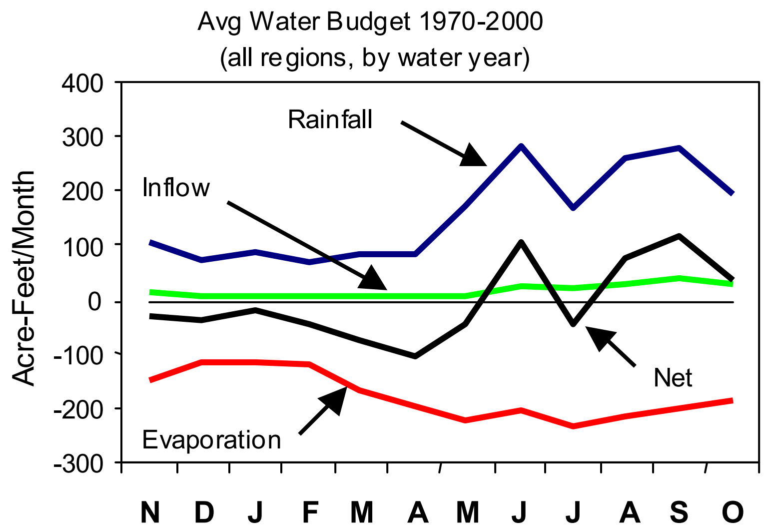
For consistency with respect to both conditions affecting Florida Bay and rainfall conditions most relevant to water management operations, the years 1970 – 2000 were ranked based on rainfall for the Bay (MFL base case) and for the Everglades (NCDC Division 5) separately, (Table 6.2). The NCDC Division 5 rainfall data were the long-term data for the region that included most of south and southwest Florida and the Everglades, but did not include the east coast of south Florida or the Florida Keys. Wet, normal, and dry years were selected as years ranking near the 10%, 50%, and 90% exceedance level on both ranked lists. Years in which rainfall in Florida Bay and over the Everglades differed markedly were excluded from the selection of wet, normal and dry years.

As discussed in Section 6.1, water management activities increased surface water discharge into the Taylor Slough - C111 wetland sub-basin around 1980. Surface flows increased by about a factor of four relative to rainfall at this time. This was perhaps the most significant change that occurred in Florida Bay's freshwater budget during the period 1970 through 2000. To account for this change, normal and dry years were defined in both the pre-1980 and post-1980 periods for comparison. It was judged that the pre-1980 period did not include a 90% exceedance wet year for the available data.

The summary water budget fluxes for Florida Bay and the adjacent wetland basin are reported in Table 6.3 for the wet, normal, and dry years; pre-1980 and post-1980. The wetland water budget fluxes followed the naming conventions as defined in Figure 6.4. These can be compared to the flux estimates compiled for the upstream wetland basins from local direct measurements in 1996 through 2000 in Figure 3.5. Significantly, the additional inflow to the wetland basins in the post-1980 period was comparable to the difference between wet year and normal year rainfall and between normal year and dry year rainfall (Table 6.3).

Figure 6.1: Monthly average fluxes in the freshwater budget of Florida Bay for the period 1970 through 2000; A) budget for entire Bay, B) budget for Central and Northeast regions only.

A



B

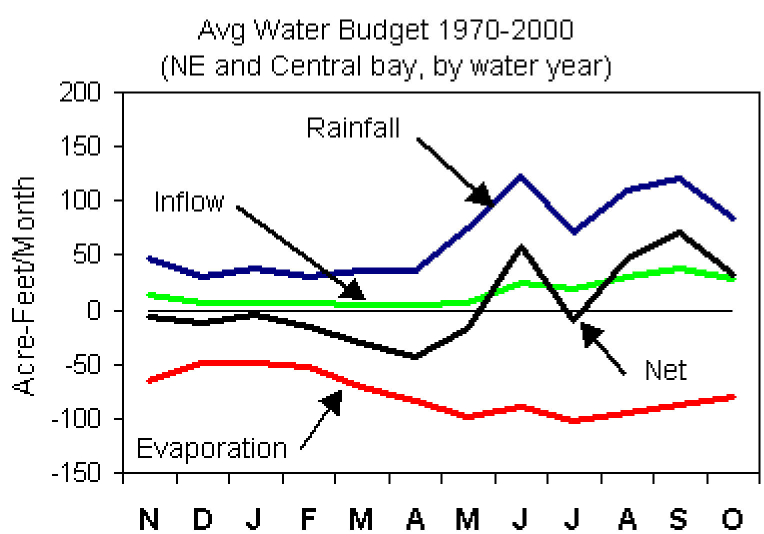
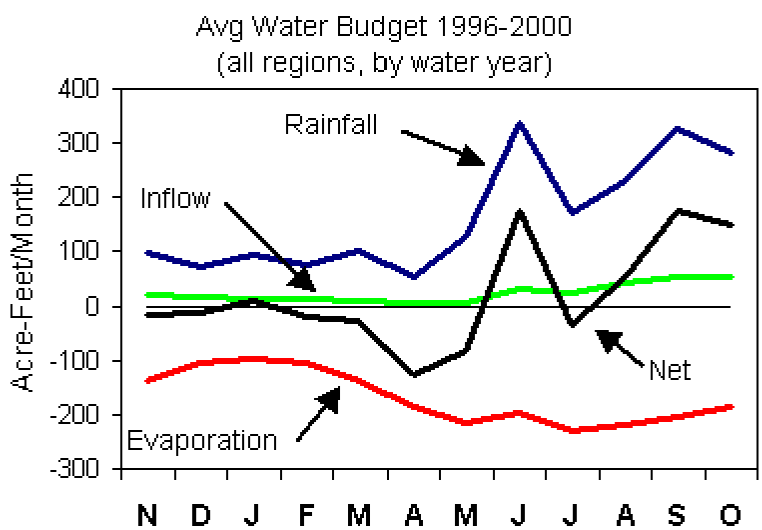


Figure 6.2: Monthly average fluxes in the freshwater budget of Florida Bay for the period 1996 through 2000; A) budget for entire Bay, B) budget for Central and Northeast regions only.

A



B

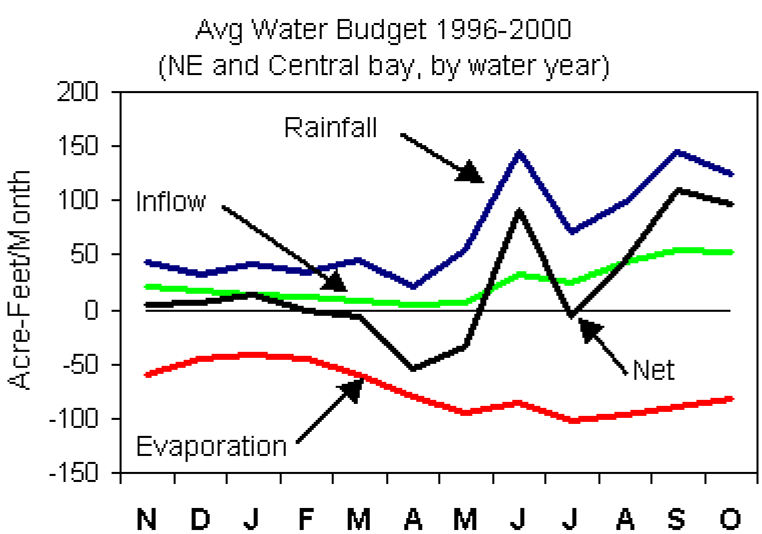


Table 6.2: Selection of Wet, Dry and Normal water years in the pre-1980 and post-1980 periods. Annual rainfall was reported in inches both for Florida Bay (MFL base case) and for Everglades (NCDC region 5) regional rainfall. Regional differences resulted in individual years ranking differently based on total annual rainfall. The selection of specific Wet, Dry and Normal years preserved continuity between the two regions.

Water Year	Fl. Bay Rainfall	Water Year	Div. 5 Rainfall	
1989	31.7	1976	41.4	
1971	34.7	1971	42.72	
1986	35.7	1985	44.02	
1974	36.2	2000	44.45	Dry
1985	40.9	1990	44.71	
1990	41.4	1981	44.81	
2000	43.4	1977	45.55	
1980	43.5	1972	46.53	
1984	43.6	1989	46.55	
1977	45.4	1988	46.91	
1970	45.9	1980	47.03	
1994	46.3	1996	47.38	
1979	49.2	1974	47.85	
1992	49.5	1975	48.62	Normal
1987	49.6	1997	48.97	
1996	50.4	1987	49.78	
1975	51.4	1986	50.5	
1991	52.4	1984	50.91	
1976	54.0	1973	51.09	
1993	54.9	1992	52.31	
1998	55.0	1994	53.6	
1978	55.6	1979	53.69	
1972	55.7	1993	55.15	
1997	57.5	1978	55.67	
1973	60.8	1970	57.46	
1982	61.3	1991	57.53	
1988	63.6	1998	57.56	
1981	63.8	1983	59.8	
1999	67.3	1982	60.41	Wet
1983	71.7	1999	63.22	
1995	72.4	1995	78.2	

Figure 6.3: Annual rainfall (water year basis) for period 1970 through 2000 showing selected Wet, Dry and Normal years.

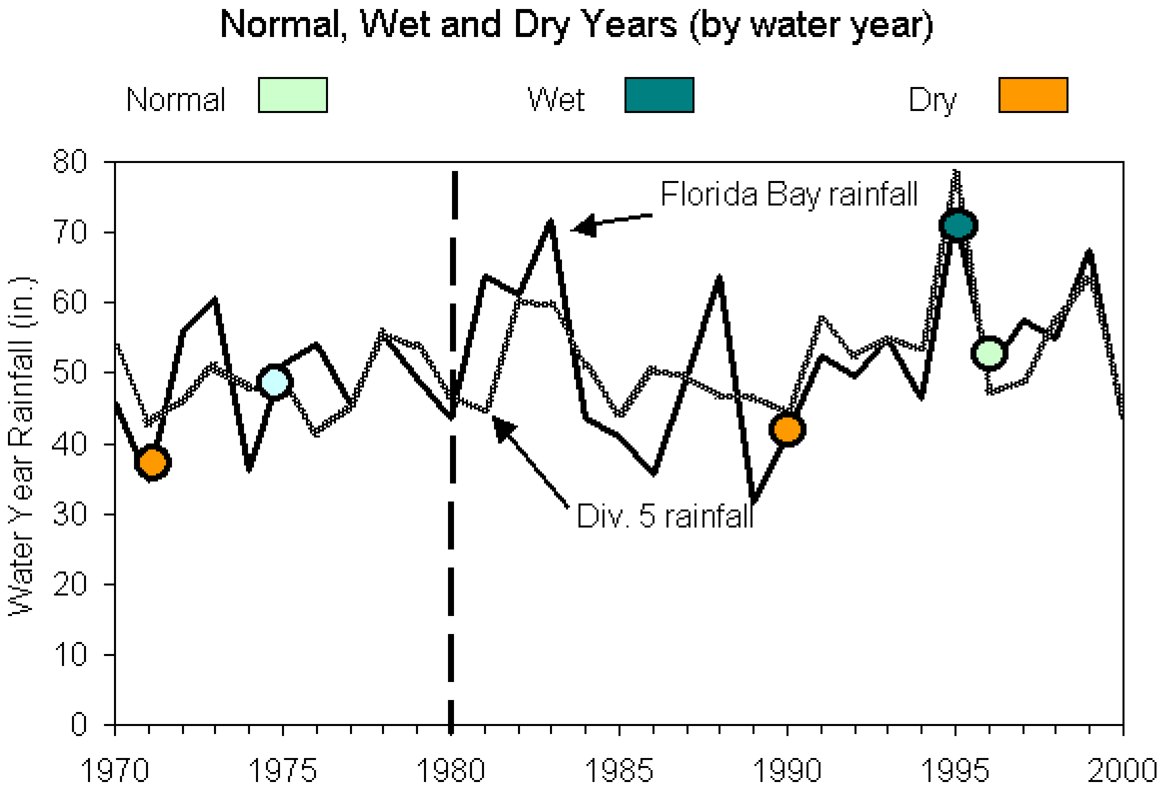


Figure 6.4: Wetland sub basins used to estimate freshwater inflow from the wetlands in the Taylor Slough C111 wetland basin. The locations of the MFLx flow transects are shown superimposed on the SFWMM grid (see Table 6.3).

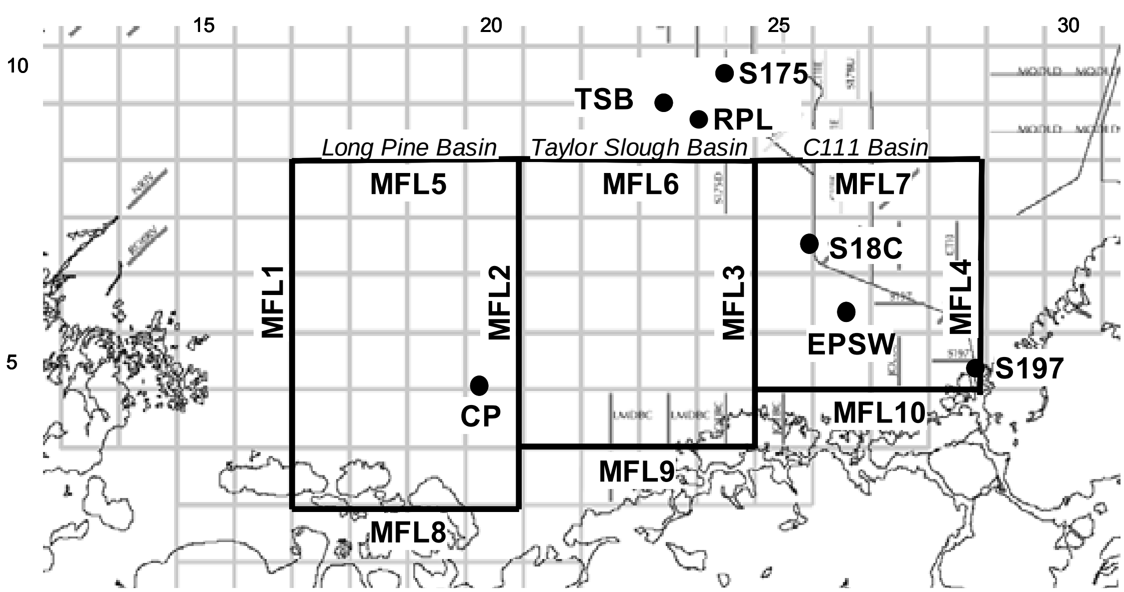


Table 6.3: Summary of water budget components for Florida Bay and the Taylor Slough C111 wetland basin (See Figure 6.4 for reference map).

Simplified Water Budget for NE and Central

(flows in 10^3 ac-ft/yr reported for water year; water year 1995 = Nov 1994 thru Oct 1995)

Source of Freshwater Inputs	Pre-1980						Post-1980								
	Dry Year - 1971			Normal Year - 1975			Dry Year - 1990			Normal Year - 1996			Wet Year - 1995		
	Wet Season	Dry Season	Total	Wet Season	Dry Season	Total	Wet Season	Dry Season	Total	Wet Season	Dry Season	Total	Wet Season	Dry Season	Total
Direct Freshwater Inputs															
1. Rainfall	452	78	530	472	306	778	395	245	640	576	218	794	688	447	1135
2. Evaporation	-428	-445	-873	-420	-477	-896	-503	-536	-1039	-377	-380	-757	-400	-463	-863
Net from Atmosphere	23	-367	-344	52	-171	-119	-108	-291	-399	199	-162	37	288	-15	273
Inflow from wetlands															
Budget for Taylor Slough subbasin:															
3. MFL6 - Taylor Slough bridge and S-175	1	0	1	7	0	7	18	0	18	56	31	87	124	70	195
4. MFL2 - flow from Long Pine basin	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
5. MFL9 - inflow to Madeira, Little Madeira	2	0	2	7	1	8	9	2	11	19	7	26	25	22	47
Budget for C-111 subbasin:															
6. MFL7 - S18c flow	2	1	3	23	0	23	57	10	67	115	32	147	197	154	351
7. MFL3 - flow from Taylor Slough basin	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
8. MFL4 - outflow via S197 to Manatee Bay	0	0	0	0	0	0	0	0	0	27	0	27	93	20	114
9. MFL10 - inflow to Joe Bay and Long Sound	14	1	15	48	7	54	66	11	77	133	51	184	174	155	329
Budget for Long Pine subbasin:															
10. MFL5 - flow across Park road	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
11. MFL1 - flow across Park road	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
12. MFL2 - flow to Taylor Slough	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
13. MFL8 - inflow to McCormick Creek and central region	2	0	2	7	1	8	10	2	12	21	8	29	27	24	51
14. Freshwater Inputs from All Sources (1+5+9+13)	470	79	549	534	315	848	480	260	740	749	284	1033	915	648	1563
15. Freshwater Inputs from Mangrove Transition Zone (5+9+13)	18	1	19	62	9	71	85	15	100	173	66	239	226	201	428

nd - no data available

6.3 Locations Where Salinity was Sensitive to Inflow from Wetlands

As this work progressed, it became apparent that two questions were relevant to the use of salinity in setting minimum flows and levels targets for water management. First, where in Florida Bay is salinity sensitive to changes in the inflow of freshwater from the Everglades at the monthly level? Second, do water management activities exert sufficient influence on this inflow to be detected against a background of the salinity variation driven by climate? The following analysis of the 31-year water budget, wetland water levels, and estimated salinity began to answer the first question. The results of salinity projections for different water management scenarios, presented in the following section, addresses the second question.

The approach to evaluating the sensitivity to inflow assumed that a linear relationship existed between rainfall and inflow, as independent variables, and rainfall and inflow were definitive characteristics of salinity as the dependent variable. The coefficients in the linear relationship provided a measure of the sensitivity of salinity to each of the independent variables. Standard statistical tests for the strength of the relationship between the dependent and independent variables and for the significance of the coefficients served as objective measures of whether a significant relationship existed between any one of the independent variables and salinity. A map of areas of significant effect for each independent variable was constructed by fitting the model to salinity at a number of locations in the Bay, treated independently (Figure 6.4).

The maximum salinity value in each year, calculated with FATHOM for the MFL base case, served as the summary statistic in this application. This analysis was conducted on the basis of a calendar year. Evaluating sensitivity to inflow based on maximum salinity was consistent with the application of these results to setting minimum flows and levels in order to mitigate the effects of hypersalinity in Florida Bay. The difference between annual maximum salinity $\boldsymbol{S}_{\max}$ and the average salinity at the boundary with the Gulf of Mexico $\boldsymbol{S}_{\mathrm{b}}$ was assumed to be a linear function of the depth of rainfall $\boldsymbol{R}$ and the volume of inflow from the mangrove transition zone $\boldsymbol{Q}$ both in the current year and in the preceding year (Equation 6.1).

$$[\boldsymbol{S}_{\max} - \boldsymbol{S}_b]_i = \boldsymbol{f}(\boldsymbol{R}_i, \boldsymbol{R}_{i-1}, \boldsymbol{Q}_i, \boldsymbol{Q}_{i-1}) + \varepsilon_i \qquad 6.1$$

Taking the difference with the average boundary salinity removed the influences of year-to-year fluctuations in boundary salinity that were affected by either rainfall or inflow from the wetlands. The dependence of salinity in Equation 6.1 on rainfall and inflow in the preceding year helped to account for the effect of antecedent salinity conditions, recognizing that residence times were high in some parts of Florida Bay.

For purposes of establishing operating rules for water management, it may be more desirable to establish goals with reference to water levels that are easily monitored in wetlands adjacent to the mangrove transition zone rather than using the volume of inflow into Florida Bay. This raises the question of where are salinity values sensitive to changes in wetland water levels. The approach to addressing this question paralleled that described for inflow, based on an assumed linear relationship between annual maximum salinity S_{max} and rainfall and water levels, Equation 6.2:

$$[S_{max} - S_b]_i = f(R_i, R_{i-1}, (H_{CP})_i, (H_{EPSW})_i) + \varepsilon_i \qquad 6.2$$

Here H_{CP} and H_{EPSW} refer to annual average water levels at the Craighead Pond (CP) and EPSW monitoring locations used in the calibration of the PHAST wetland hydrology model, (Figure 3.1).

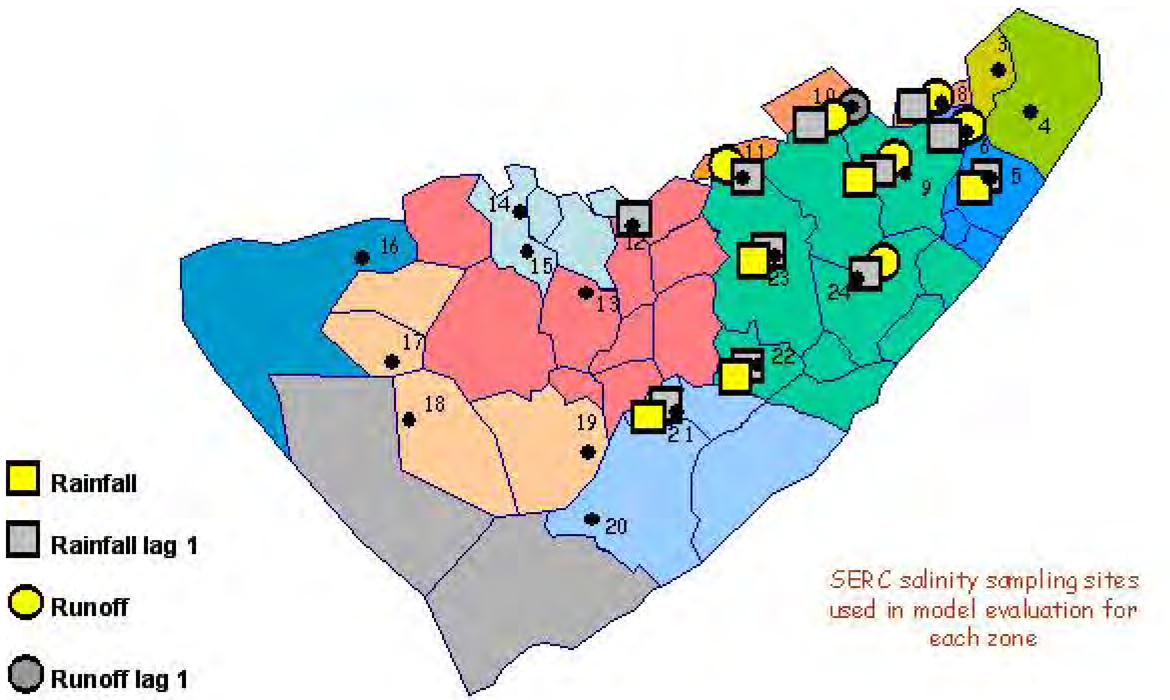
Models based on Equations 6.1 and 6.2 were constructed for calculated salinity values in each basin containing a salinity-monitoring site, as shown in Figure 6.4. Maximum annual salinity was judged to be sensitive to rainfall, inflow or water level if the corresponding coefficient in the linear model tests were significantly different from zero at the p = 0.05 level. The 31 years of salinity data produced by the FATHOM model using the "best" model input parameters, i.e. the MFL base case, were used at each location.

Results of this analysis are shown as maps indicating locations where each rainfall, inflow, and water level variable were significant (Figure 6.4). Generally, basins in which annual maximum salinity has been sensitive to year-to-year changes in inflow or wetland water level were clustered in the Northeast and the South Regions of the Bay. Models for locations in the west and western portion of the south region explained little of the variation in maximum annual salinity. Presumably, this is because maximum annual salinity values here followed the variation in salinity on the open western boundary of the Bay. Part of this was due to changes in freshwater discharge from Shark Slough, but oceanographic processes in the Gulf of Mexico also contributed to this variability.

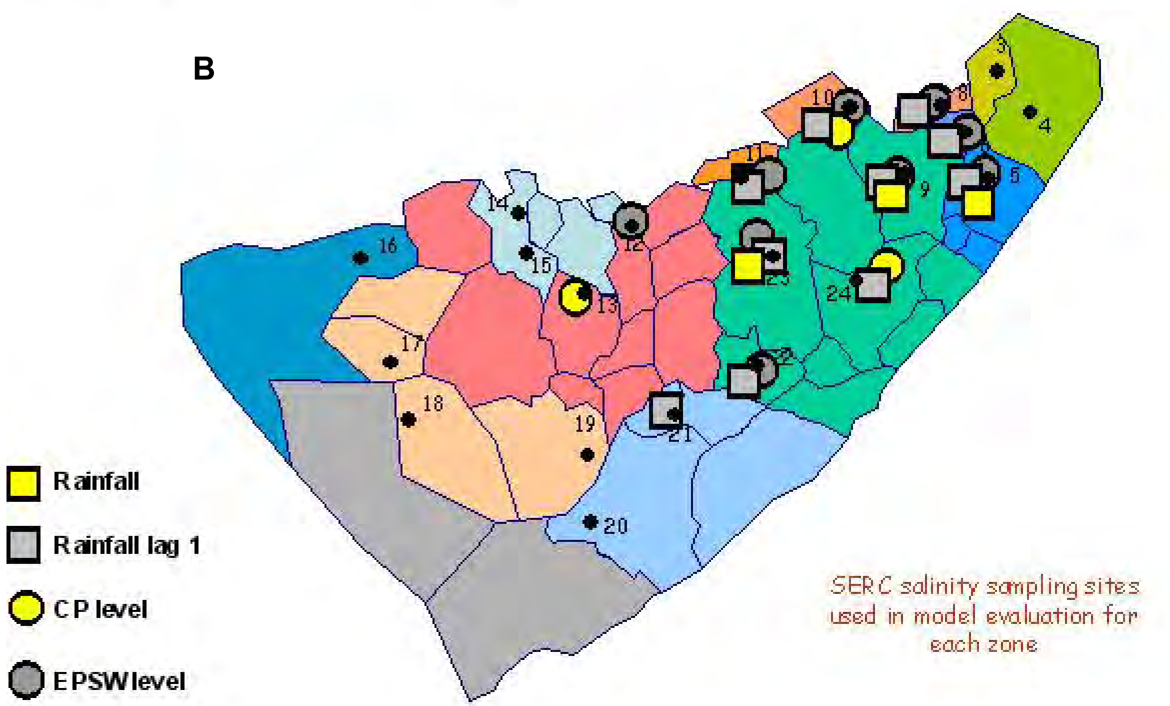
The apparent lack of influence of inflow and water level on annual maximum salinity in the Central Region, according to this analysis, may simply reflect the fact that very little or no inflow reached the Central Region during dry years. Therefore, annual maximum salinity values here were not affected by changes in inflow when inflow was essentially zero. Even so, the response of model efficiency in the Central Region to inflow alternatives provideed evidence of the general sensitivity of salinity to inflow in the Central Region (Table 5.11).

Figure 6.4: Areas of Florida Bay where annual maximum salinity (calendar year basis) was sensitive to annual rainfall in addition to A) annual inflow and B) annual average wetland water levels at either the Craighead Pond (CP) or EPSW monitoring location.

A



B



7 APPLICATION: PROJECTED EFFECTS OF WATER MANAGEMENT ALTERNATIVES

This section presents results of applying the FATHOM salinity model (MFL base case) to compare salinity conditions in Florida Bay that could occur under four regional water management scenarios: the base 2000 scenario (B2000), the base 2050 scenario (B2050), the current preferred CERP restoration alternative (CERP1), and the current version of the natural system model (NSM 4.6.2). Output from the SFWMM provided regional hydrological conditions projected for each water management alternative as if these alternatives had been in operation during the period 1965 through 2000. These alternative realizations of regional hydrology facilitated an evaluation of the benefits and impacts to water supply, flood control and wetland ecosystems of each water management alternative. FATHOM extended these projected conditions to include salinity conditions in Florida Bay, making it possible to also evaluate benefits and impacts on Florida Bay.

7.1 Coupling SFWMM Output to FATHOM

Regional hydrologic conditions simulated with the SFWMM provided the data necessary to estimate inflow from the wetlands and boundary salinity values along the western boundary of Florida Bay (Table 7.1). Other base case input data and model parameters remained the same as described for the MFL base case, with the exception that the rainfall and evaporation time series were extended to cover the period 1965 through 2000.

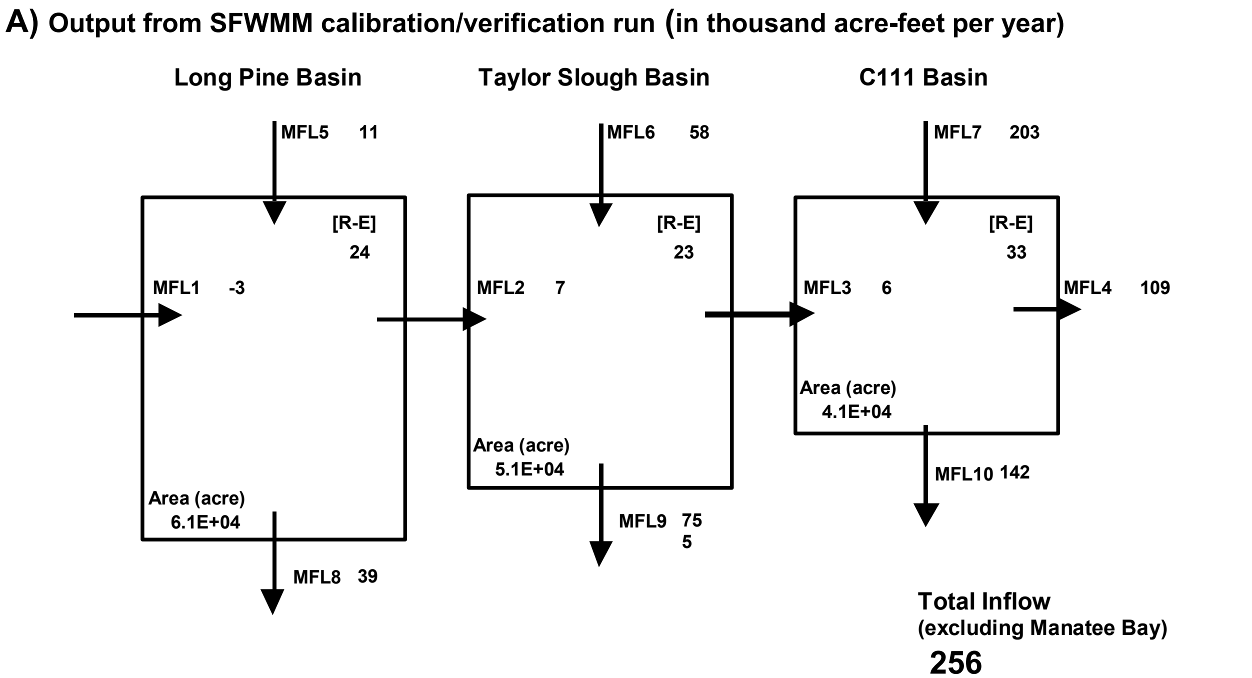
Coupling the SFWMM to FATHOM employed calculated wetland flows across the wetland basin boundaries, MFL8, MFL9 and MFL10 (Figure 3.1) and the total discharge across the T21 transect in Shark Slough (Figure 2.3). Small negative (northward) flows occured occasionally in the SFWMM output, so these were set to zero flow in preparing the input into FATHOM. The total monthly discharge across each transect was allocated into adjacent FATHOM basins in the proportions described for the inflow regions (Figure 3.10). Output from the SFWMM completely specified the inflow from wetlands. No ungauged flow was added to the output from the SFWMM.

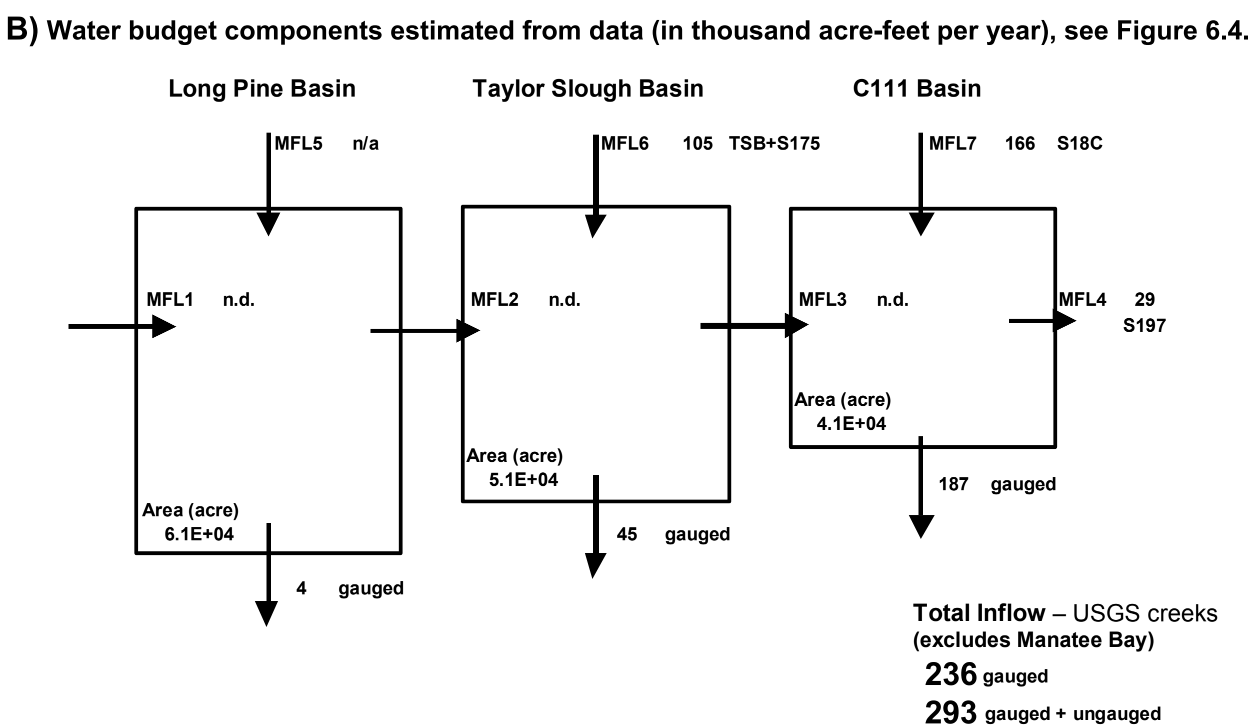
This approach for coupling the SFWMM and FATHOM was developed after an analysis of output for the calibration and verification run of the SFWMM. Output from the calibration and verification run simulated regional hydrologic conditions that occurred historically in the period 1981 through 2000. The components of the wetland water budget calculated by the SFWMM for the period February 1996 through September 2000 compared well with estimates compiled from that data (Figure 7.1). This was interpreted as verification of the wetland inflow calculations by the SFWMM and led to the direct application of the SFWMM flows as the mangrove inflows into FATHOM. The apparent discrepancy in the sub-basin water budgets based on SFWMM output can be explained by the contribution of groundwater, which was not accounted in the MFLx fluxes.

Table 7.1: Sources of input data to FATHOM applied to examine water management scenarios. Data were assembled for the calendar period 1965 through 2000.

FATHOM Input	Data Source
Rainfall	Flamingo, Royal Palm, Tavernier (same as MFL base case)
Evaporation	Air temperature (mean and range) from Flamingo, Royal Palm and Tavernier, relative humidity and wind speed (seasonal pattern) from Joe Bay (same as MFL base case)
Boundary salinity	SFWMM output for flow across T21 transect for corresponding SFWMM scenario (B2000, B2050, CERP1, NSM)
Inflow	SFWMM output for flow across MFL4, MFL8, MFL9 and MFL10 transects for corresponding SFWMM scenario (B2000, B2050, CERP1, NSM)
Sea level	Key West sea level

Figure 7.1: Comparison of wetland water budget components for the period February 1996 through September 2000: A) calculated by the SFWMM (calibration and verification run) and B) directly from data. Fluxes are in units of thousands of acre-feet per year. [R-E] is volume of rainfall in excess of evaporation. (Refer to Figure 6.4 for the location of the wetland basins shown).





The wetland surface flow predicted by the SFWMM for the T21 transect served as the basis for estimating the variation in western boundary salinity. The T21 simulated flows served the same role as the total flow through the S12 structures and levels at P33 that were used to estimate boundary salinity values in the MFL base case (section 2.2). Regression models were calibrated using the T21 transect flows from the calibration and verification runs and data from the SERC boundary salinity stations (SERC stations 25, 26, 27 and 28) for the period 1991 through 2000. The selected models incorporated a lagged response of salinity to variations in Shark Slough hydrology. Lags up to three months were investigated. The models achieved adjusted r-square values of between 0.41 and 0.65, with the highest r-squared associated with the model for the station closest to the mouth of Shark River, station 25, (Table 7.2). These were similar to the r-square values obtained in the regression based on the S12T flows and P33 levels.

Table 7.2: Summary of regression models used to estimate salinity on western boundary and at Card Sound (SERC station 1) for the application with the SFWMM scenarios.

SERC Station	Lag (months)	T21 Flow Transect	Intercept	R^2
25	2	-3.59E-05	36.60	0.66
26	2	-3.08E-05	36.70	0.64
27	2	-2.65E-05	36.71	0.55
28	2	-2.1E-05	36.52	0.42
1	0	-4.31E-05	32.60	0.56

7.2 SFWMM Scenarios

The SFWMM scenarios differed mainly in the wetland inflow input data. Average annual inflow to the northeast portion of Florida Bay for the NSM scenario, which was the lowest inflow, was 42 percent less than average annual inflow for the B2000 scenario to the Northeast Bay, the highest inflow (Table 7.3). However, the NSM scenario had significantly higher inflow directed into the Central Region than the other three scenarios. Average annual inflow for the B2000 scenario was comparable to the average annual inflow for the MFL base case.

The overall mean value for salinity imposed along the western boundary for the B2000 scenario was also comparable to that for the MFL base case (Table 7.4). Variation among the SFWMM scenarios in mean boundary salinity was small, and occurs in direct proportion to the amount of flow in Shark Slough for each scenario. The NSM scenario supported the highest flows, and water levels in Shark Slough. This had the effect of lowering salinity along the western boundary (Table 7.4). But it also supported greater inflow from the wetlands directly into the center region of Florida Bay. This latter effect might have the greater influence on salinity in the center region of the Bay.

7.3 Salinity Calculations

Results of salinity calculations are presented for each SFWMM scenario in the format used previously for the MFL base case (Figures 7.2 through 7.13). There are three figures for each scenario. The first figure presents time series plots of simulated salinity at the FATHOM basins of interest. The second figure compares the distribution of salinity values across sites for the entire record, during the wet season (June through October), and during the dry season (November through May). The third figure summarizes the frequency (% of months) with which the monthly average salinity falls into one of the six different salinity ranges presented previously.

Table 7.3: Summary of freshwater inflow defined by each of the SFWMM scenarios. Units are 1000 acre-feet per year, averaged over the period 1965 through 2000. Summary of the MFL base case inflow for the period 1970 through 2000 are provided for reference.

	Florida Bay Region		
Scenario	Central	Northeast	Total
B2000	30	200	230
B2050	31	179	210
CERP1	34	152	186
NSM	61	117	178
MFL Base (1970 - 2000)	28	204	232

Table 7.4: Summary statistics for boundary salinity calculated from the SFWMM T21 transect flows for each of the water management scenarios compared to the MFL base case.

Scenario	Average	St. Dev.
B2000	35.2	1.86
B2050	34.8	2.01
CERP1	34.2	2.28
NSM	33.4	2.87
MFL base	35.8	2.12

Figure 7.2: Time series plots of simulated salinity (pss) forthe B2000 scenario.

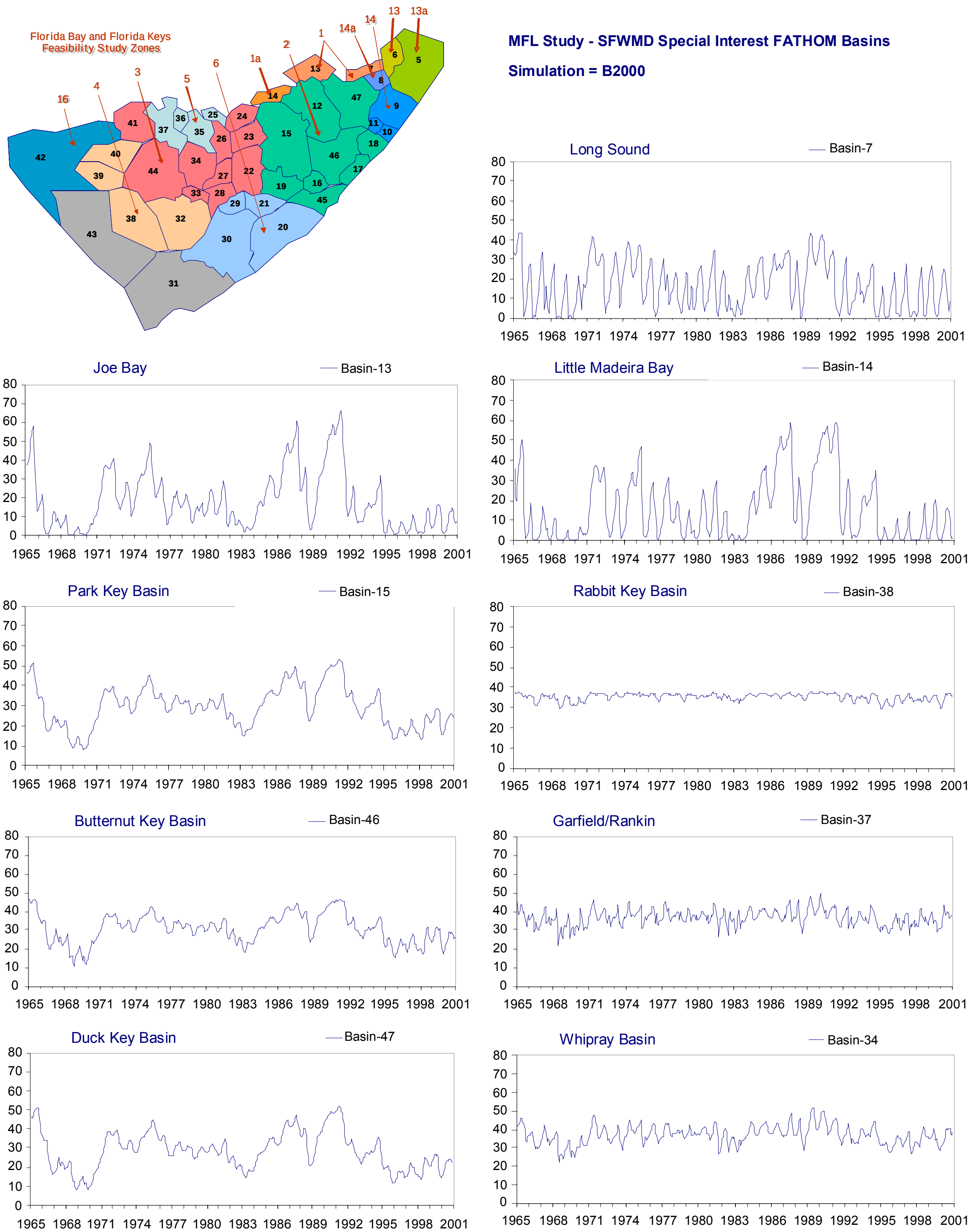
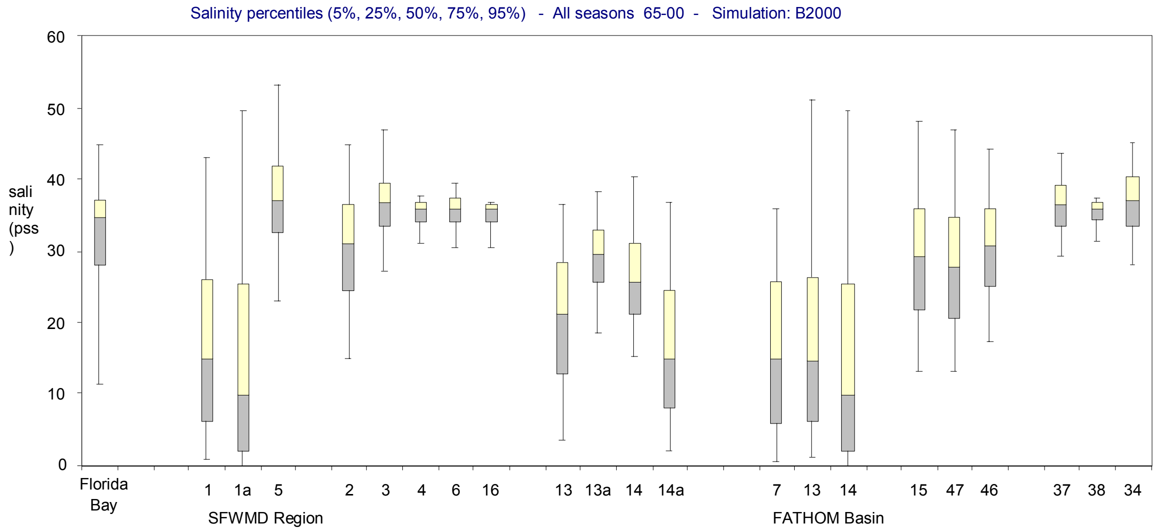
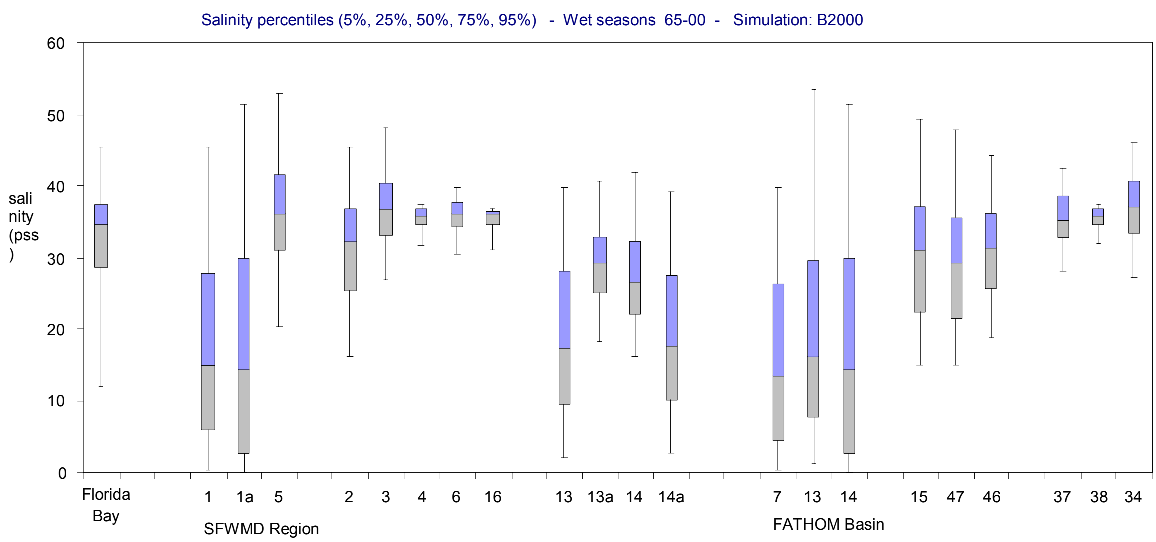


Figure 7.3: Overall summary of salinity distributions obtained for the B2000 scenario.





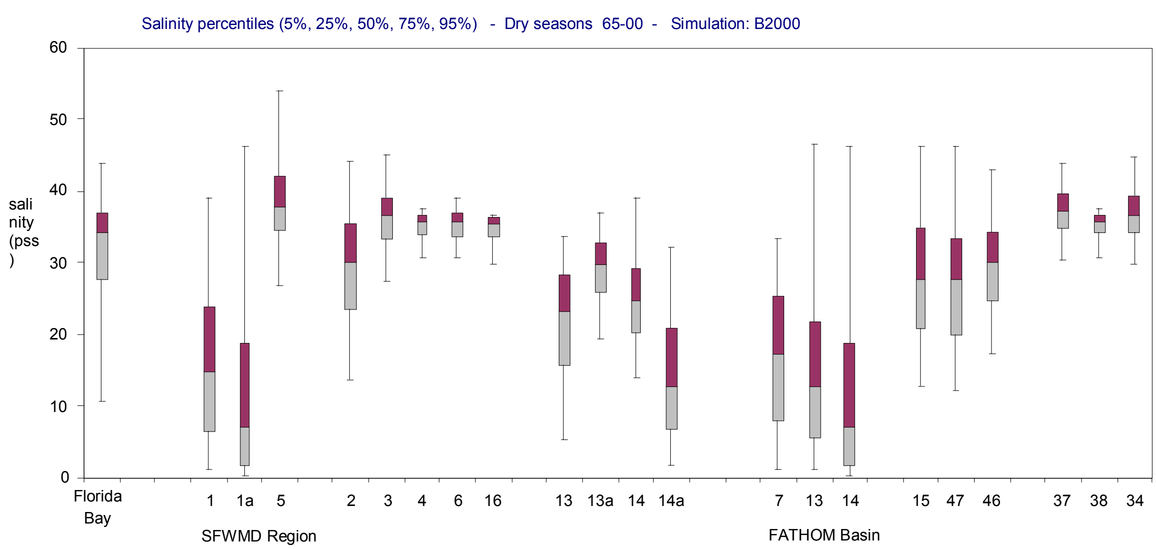


Figure 7.4: Frequency of occurrence within salinity classes for the B2000 scenario.

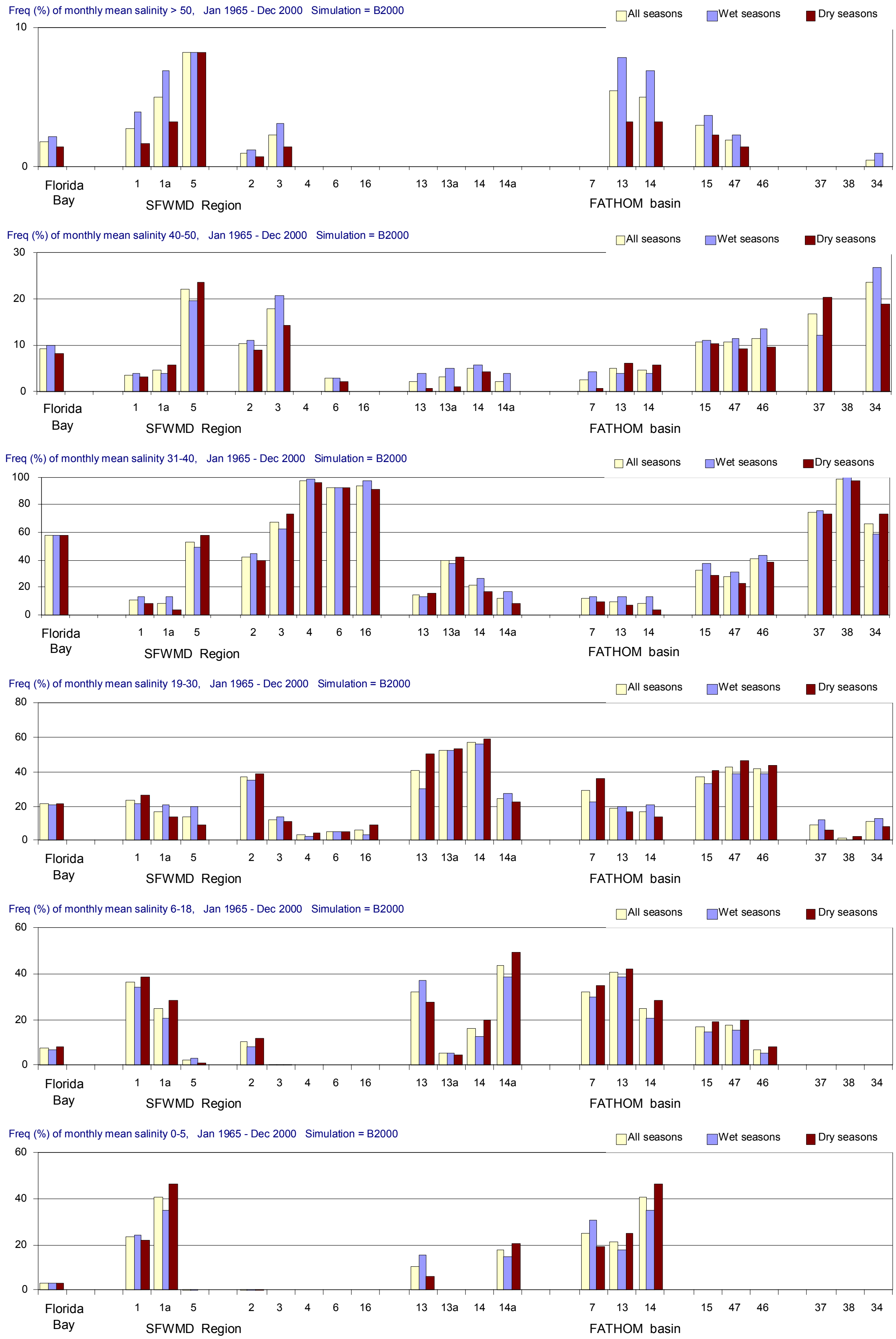


Figure 7.5: Time series plots of simulated salinity (pss) for the B2050 scenario.

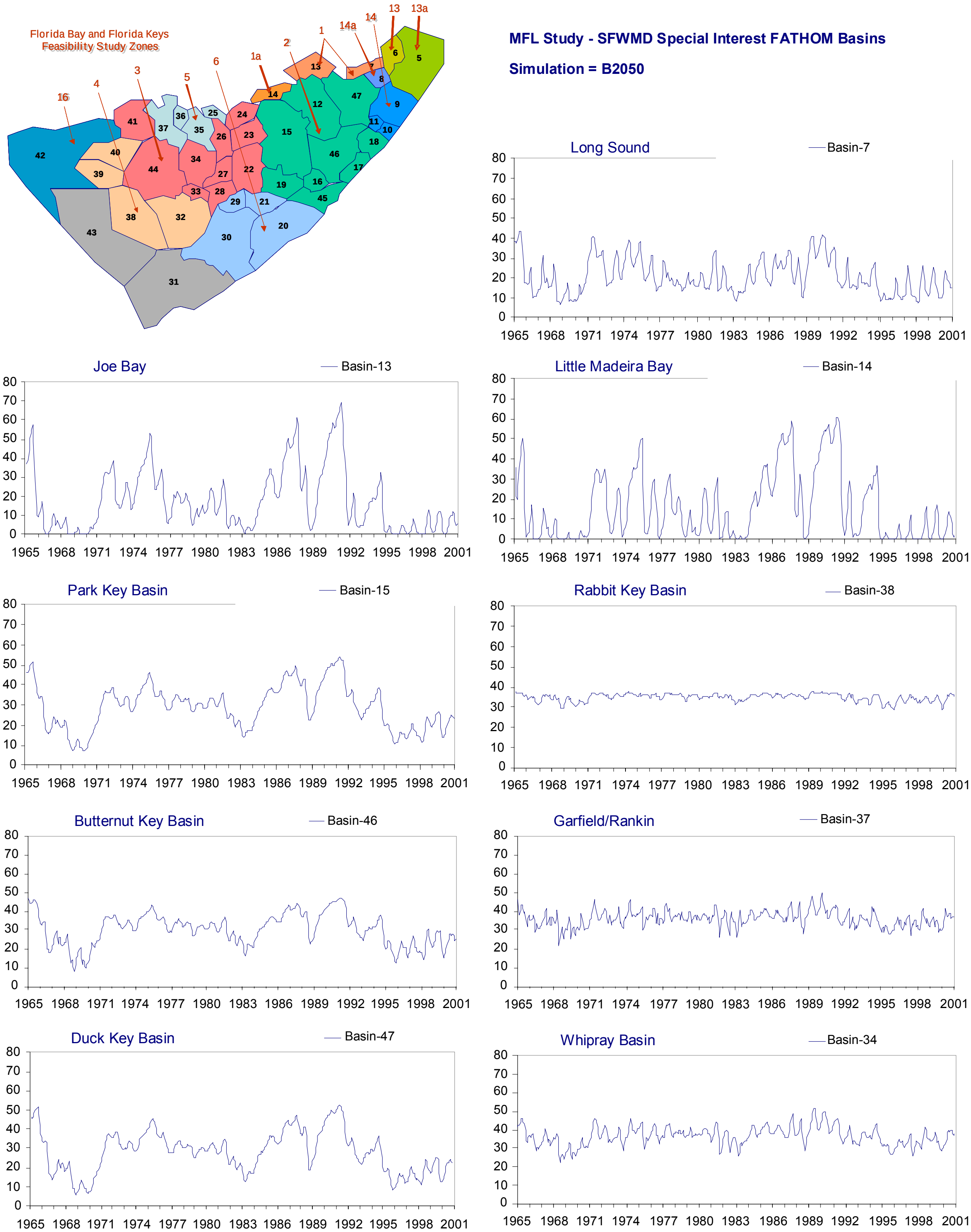


Figure 7.6: Overall summary of salinity distributions obtained for the B2050 scenario.

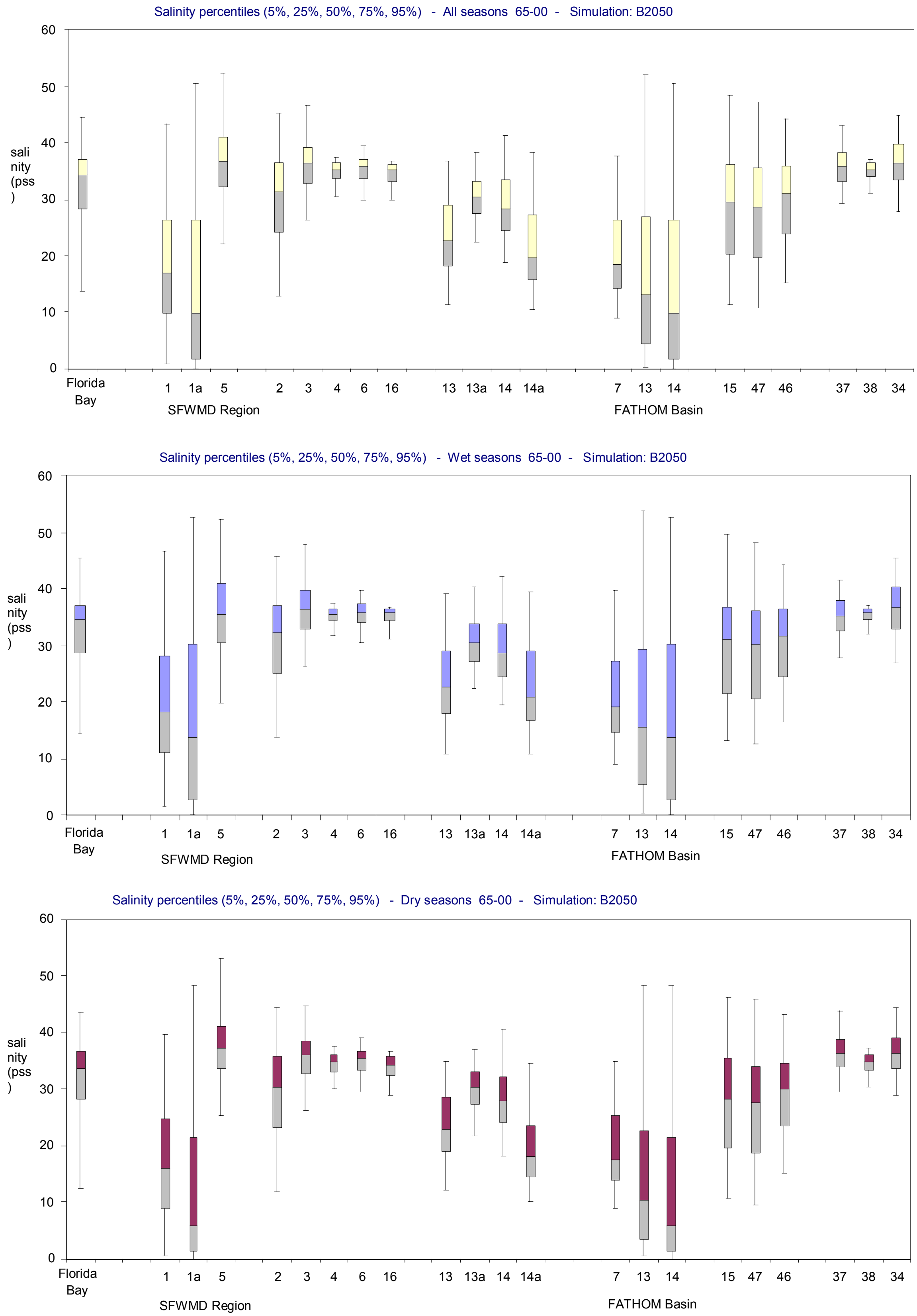


Figure 7.7: Frequency of occurrence within salinity classes for the the B2050 scenario.

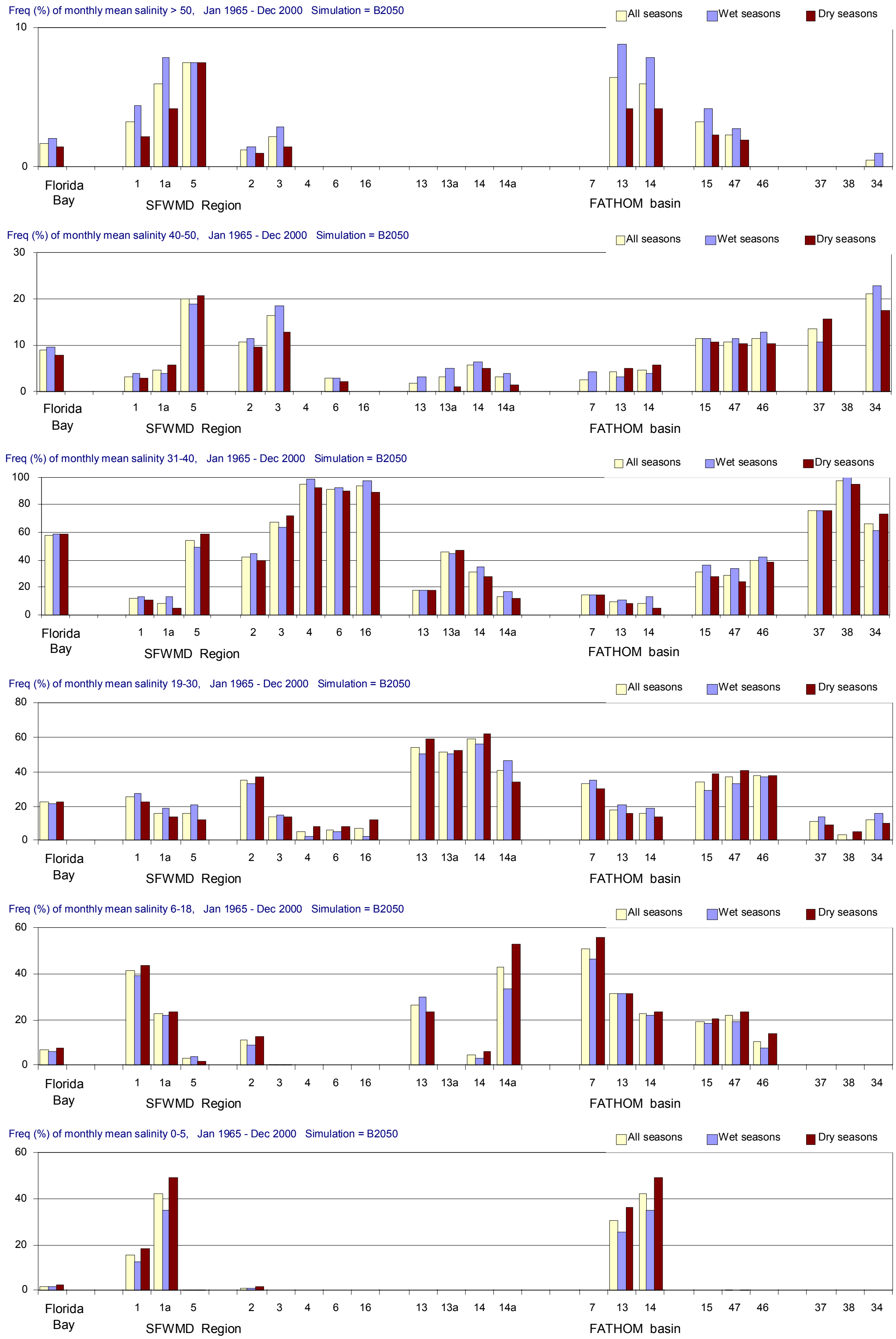


Figure 7.8: Time series plots of simulated salinity (pss) for the CERP1 scenario.

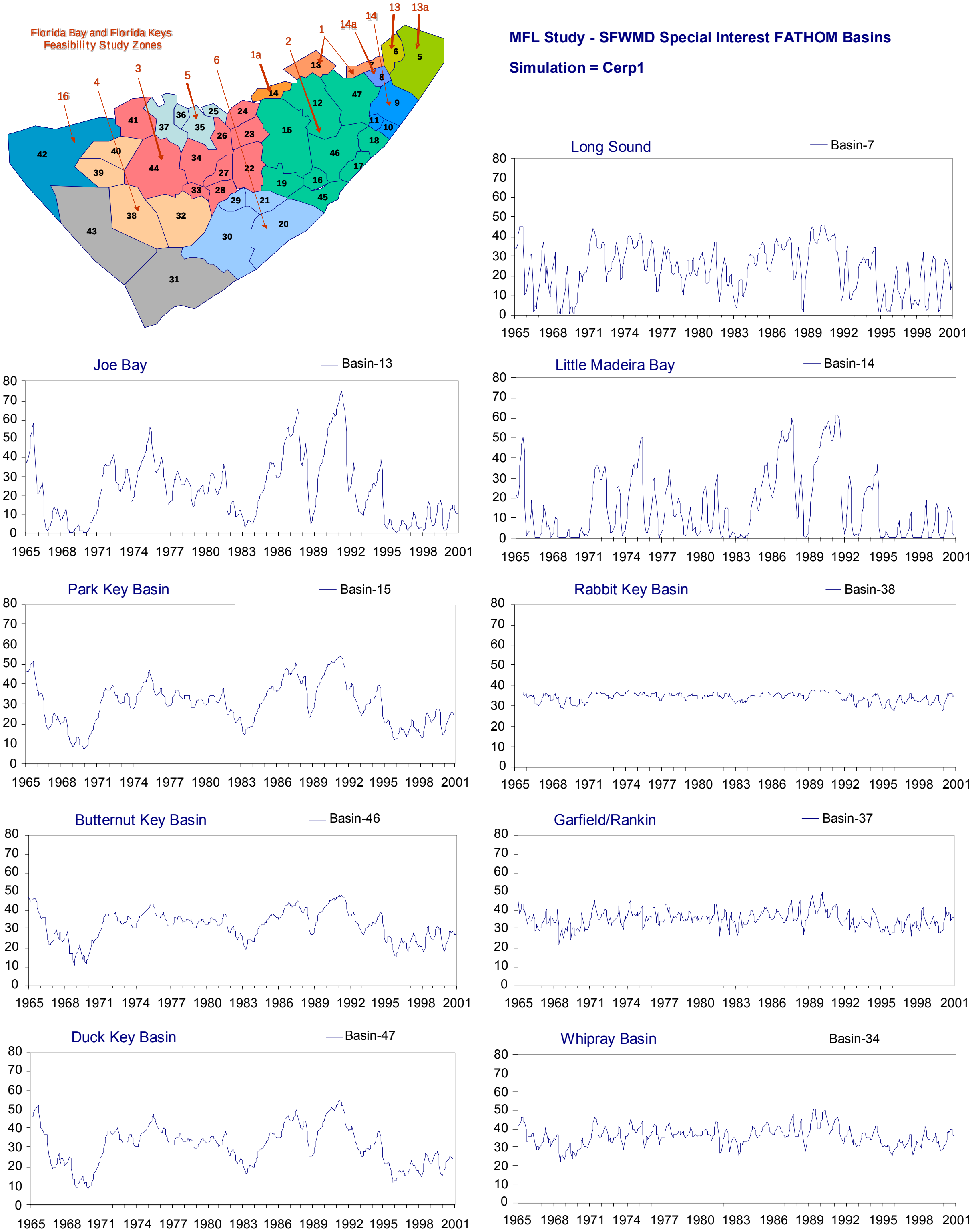
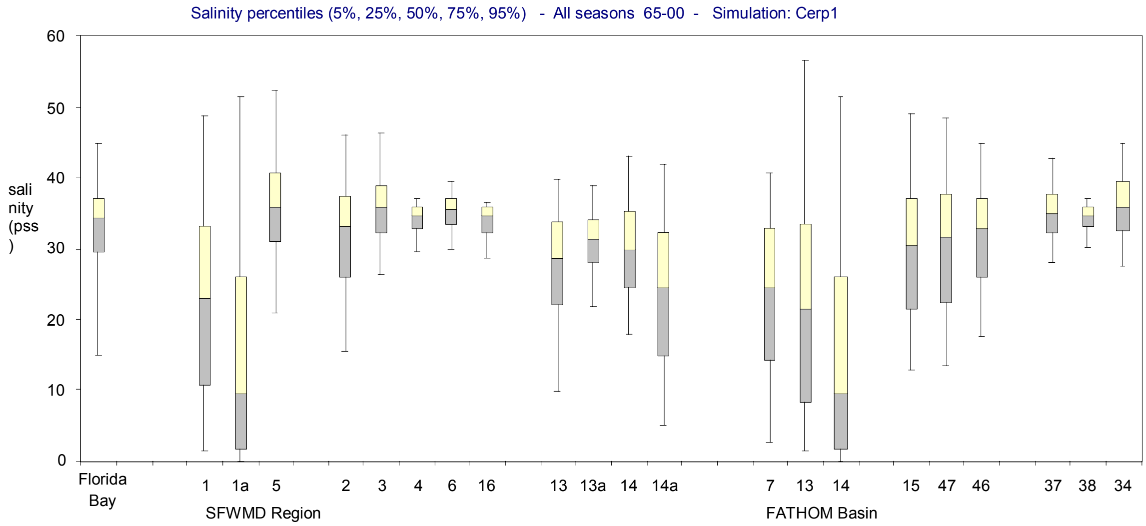
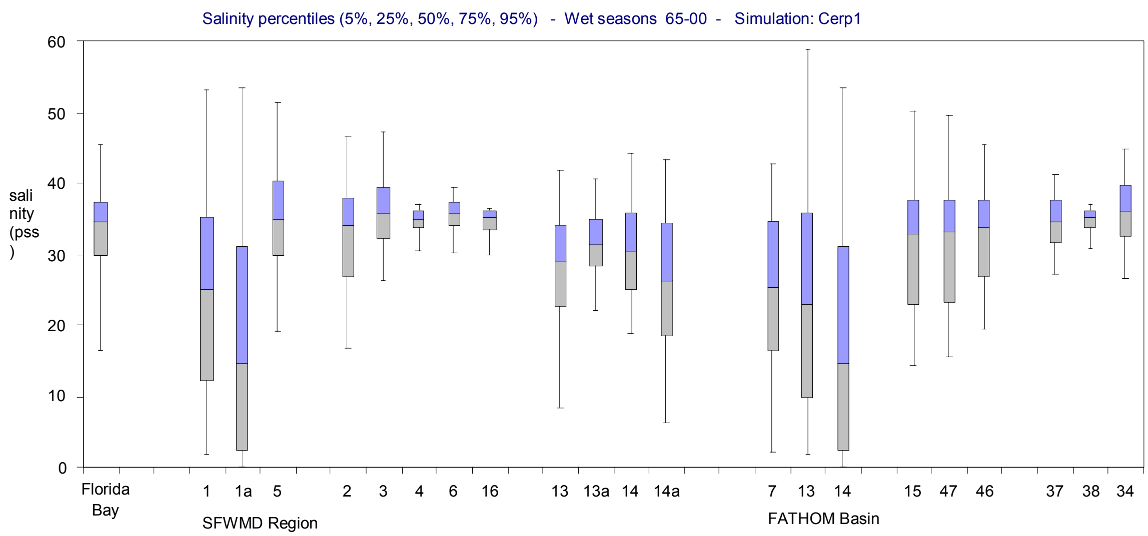


Figure 7.9: Overall summary of salinity distributions obtained for the CERP1 scenario.





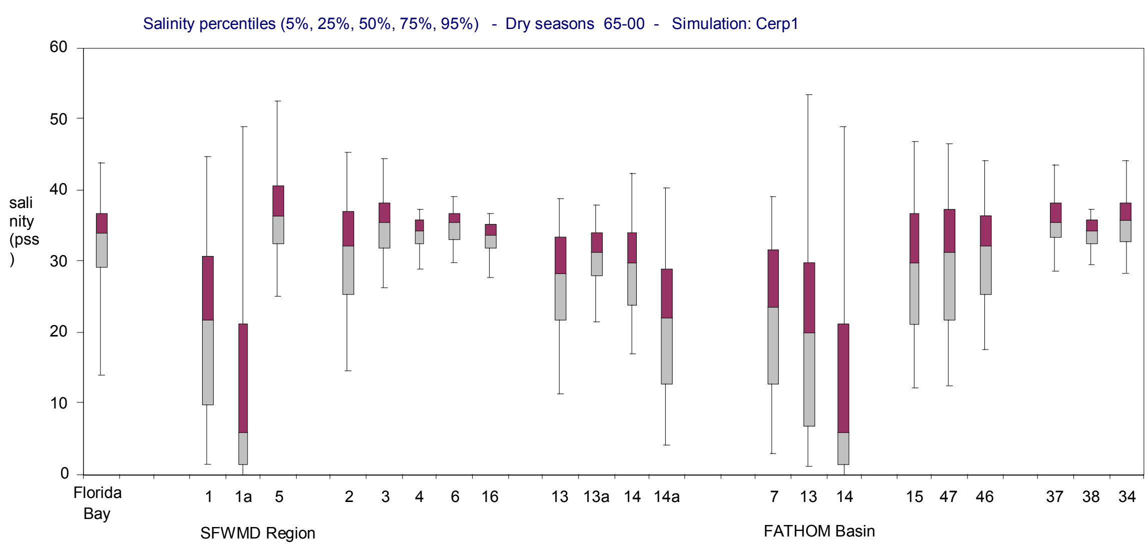


Figure 7.10: Frequency of occurrence within salinity classes for the CERP1 scenario.

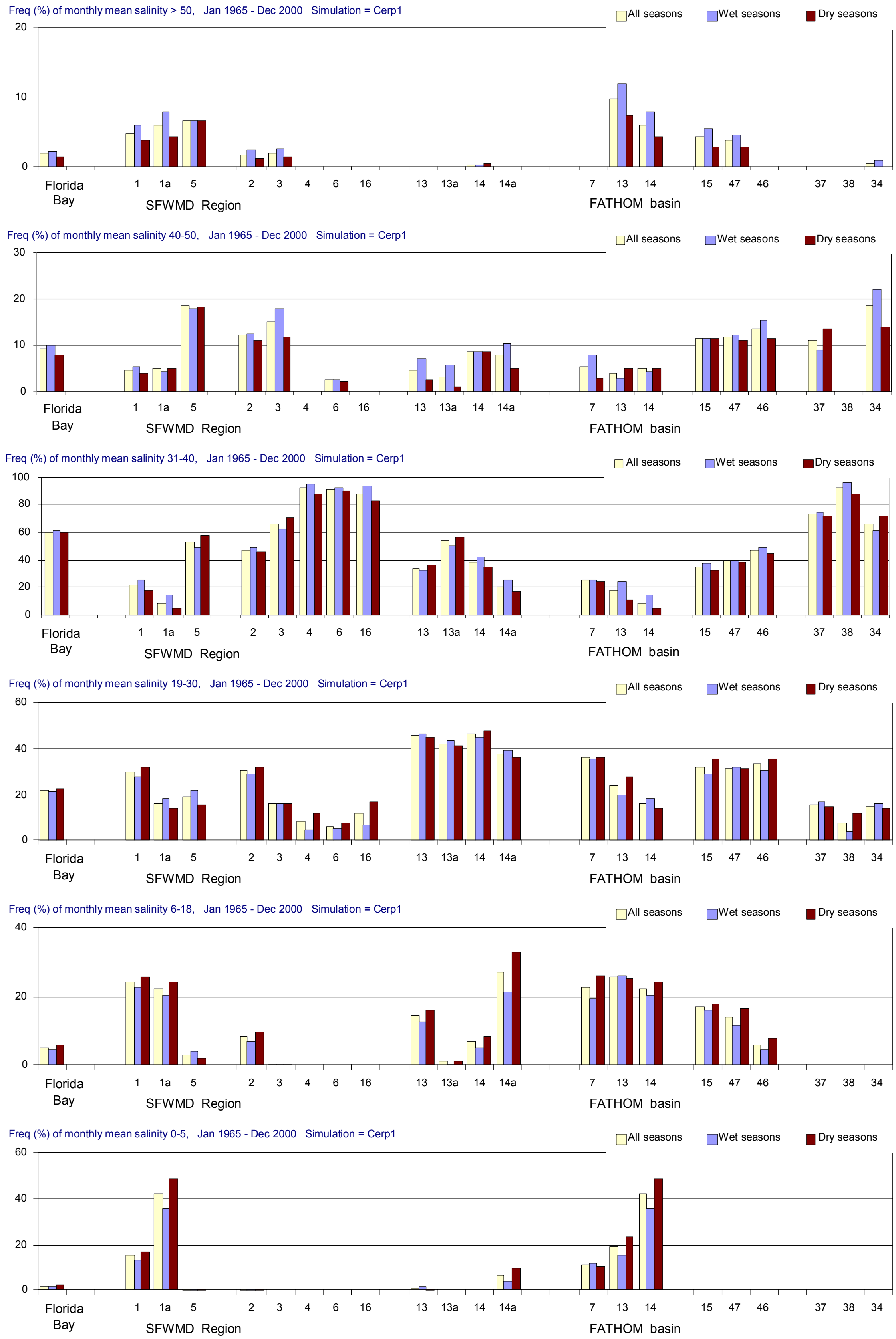


Figure 7.11: Time series plots of simulated salinity (pss) for the NSM scenario.

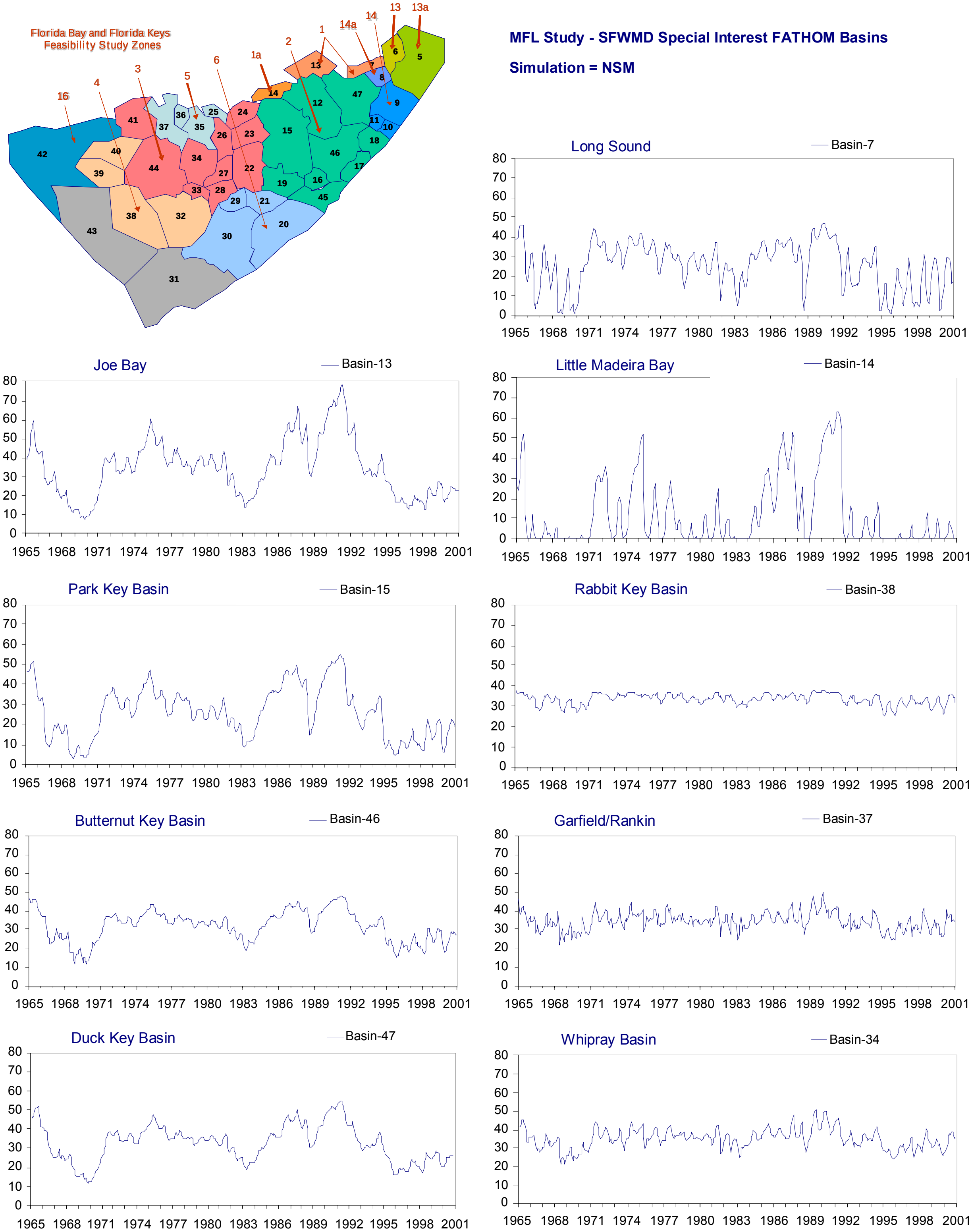


Figure 7.12: Overall summary of salinity distributions obtained for the NSM scenario.

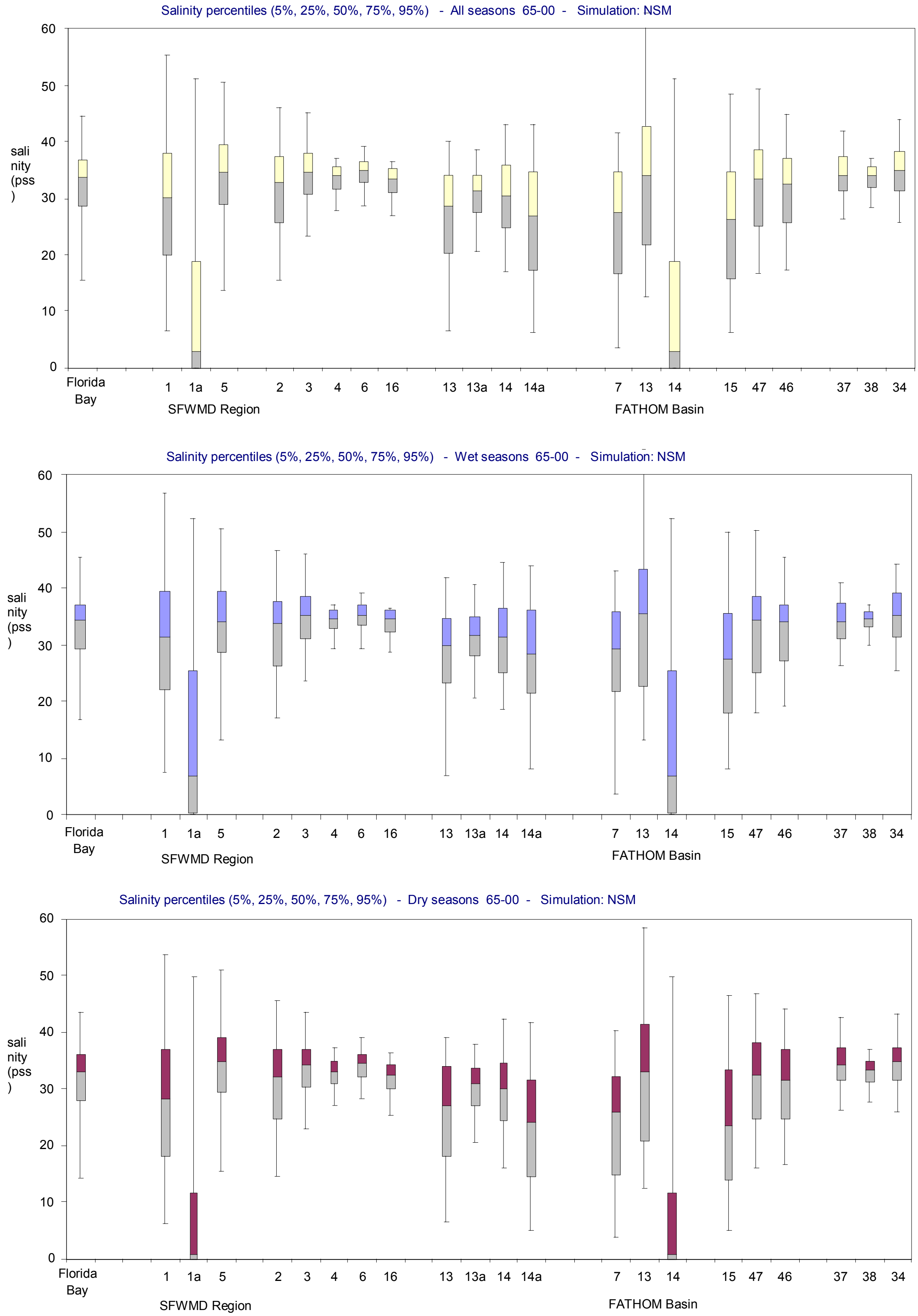
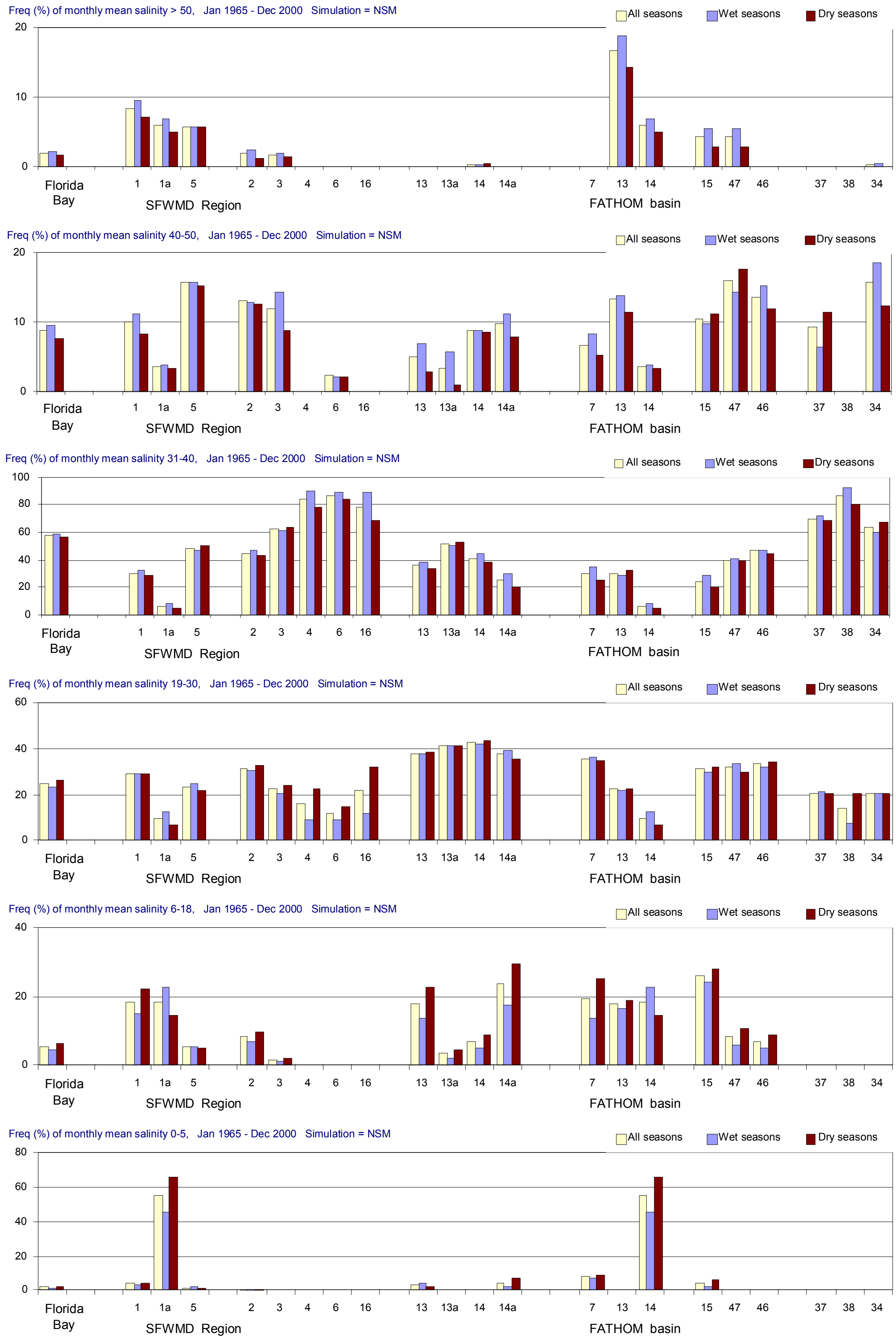


Figure 7.13: Frequency of occurrence within salinity classes for the NSM scenario.



7.4 Comparison of Results

Overall, all of the SFWMM scenarios produced similar frequency distributions of salinity when compared by FATHOM group (Table 7.5). In part this result may be an artifact of grouping basins in which salinity was sensitive to changes in wetland inflow together in FATHOM group C with basins in which the salinity was less sensitive to changes in wetland inflow. Differences were seen between scenarios when comparisons were made at the basin level (Figures 7.14 through 7.22), and when attention was paid to the extreme values that were not well represented in the regional summaries. Basins where evident differences occured among SFWMM scenarios corresponded to the basins identified as sensitive to wetland inflow in the analysis reported in the preceding section (Figure 6.4). The higher inflow into the Central Basin provided by the NSM scenario resulted in a depression of low values of salinity in Whipray Basin and Park Key Basin (Figures 7.17 and 7.18); however, this did not occur during periods of higher salinity (i.e. the dry years when minimum flows and levels management targets would come into play).

Table 7.5: Distribution of monthly salinity values relative to the ecologically defined salinity ranges for each SFWMM scenario. Values are percent of months in each range for each FATHOM grouping of basins (Figure 1.6). The distribution obtained for the MFL base case is shown for reference.

Fathom Group A

salinity category	1970-2000 (31 years) MFL base	1965 - 2000 (36 years) B2000	B2050	CERP	NSM
> 50	0	0	0	0	0
40-50	6	4	4	7	7
31-40	43	22	28	37	39
19-30	44	48	54	44	41
6-18	7	22	14	10	11
0-5	0	5	0	1	1

Fathom Group B

salinity category	1970-2000 (31 years) MFL base	1965 - 2000 (36 years) B2000	B2050	CERP	NSM
> 50	4	6	6	6	7
40-50	16	14	13	13	12
31-40	38	35	35	37	37
19-30	25	17	19	22	23
6-18	15	15	17	12	11
0-5	2	12	11	11	10

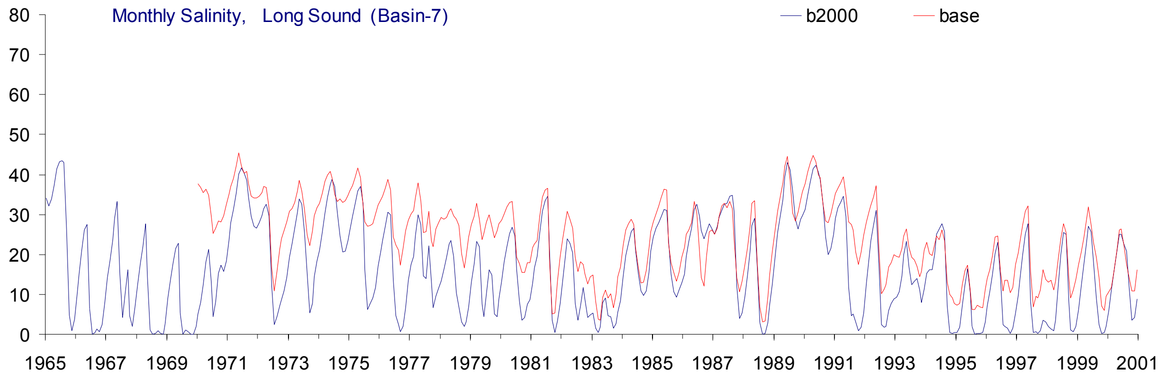
Fathom Group C

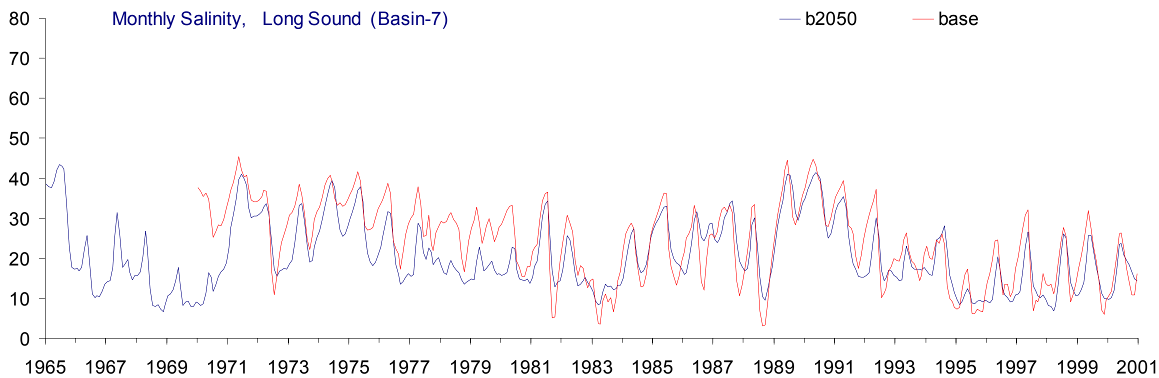
salinity category	1970-2000 (31 years) MFL base	1965 - 2000 (36 years) B2000	B2050	CERP	NSM
> 50	1	2	2	2	2
40-50	17	14	14	14	12
31-40	62	55	55	57	54
19-30	20	24	24	23	27
6-18	1	5	5	4	5
0-5	0	0	1	0	0

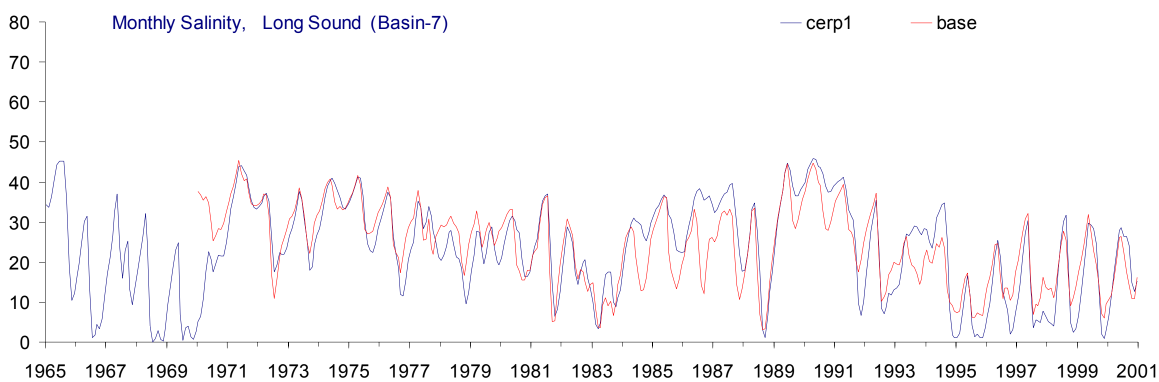
Fathom Group D

salinity category	1970-2000 (31 years) MFL base	1965 - 2000 (36 years) B2000	B2050	CERP	NSM
> 50	0	0	0	0	0
40-50	3	1	1	1	1
31-40	94	95	94	92	85
19-30	3	4	5	7	14
6-18	0	0	0	0	0
0-5	0	0	0	0	0

Figure 7.14: Comparison of salinity time series for the four SFWMM scenarios at Long Sound (Basin 7). The salinity time series obtained for the MFL base case is shown on all plots for reference (red).







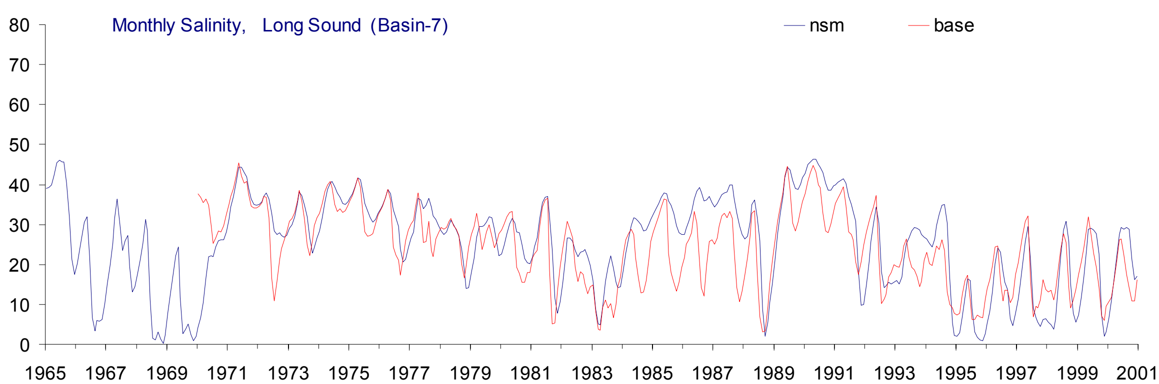


Figure 7.15: Comparison of salinity time series for the four SFWMM scenarios at Joe Bay (Basin 13). The salinity time series obtained for the MFL base case is shown on all plots for reference (red).

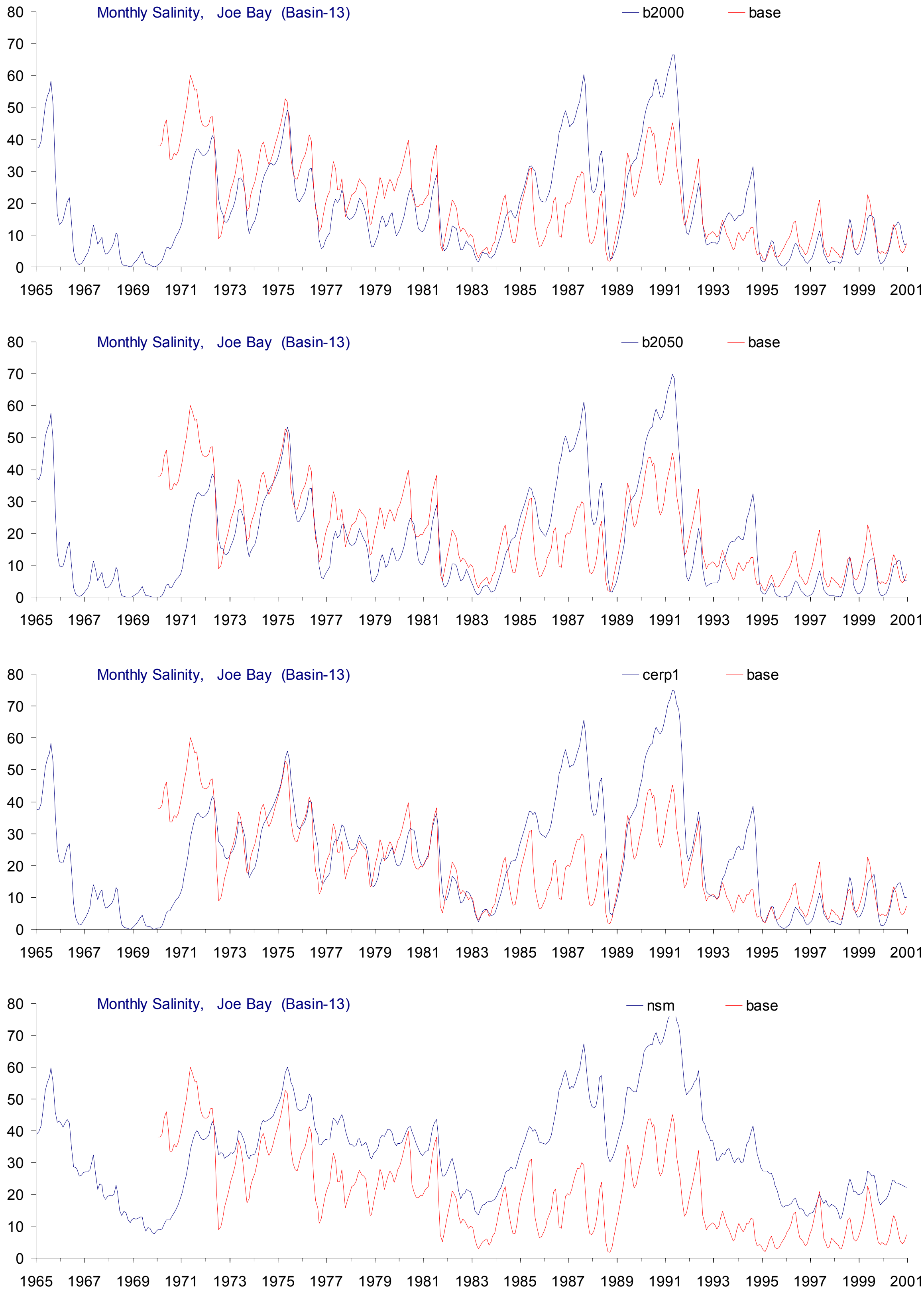


Figure 7.16: Comparison of salinity time series for the four SFWMM scenarios at Little Madeira Bay (Basin 14). The salinity time series obtained for the MFL base case is shown on all plots for reference (red).

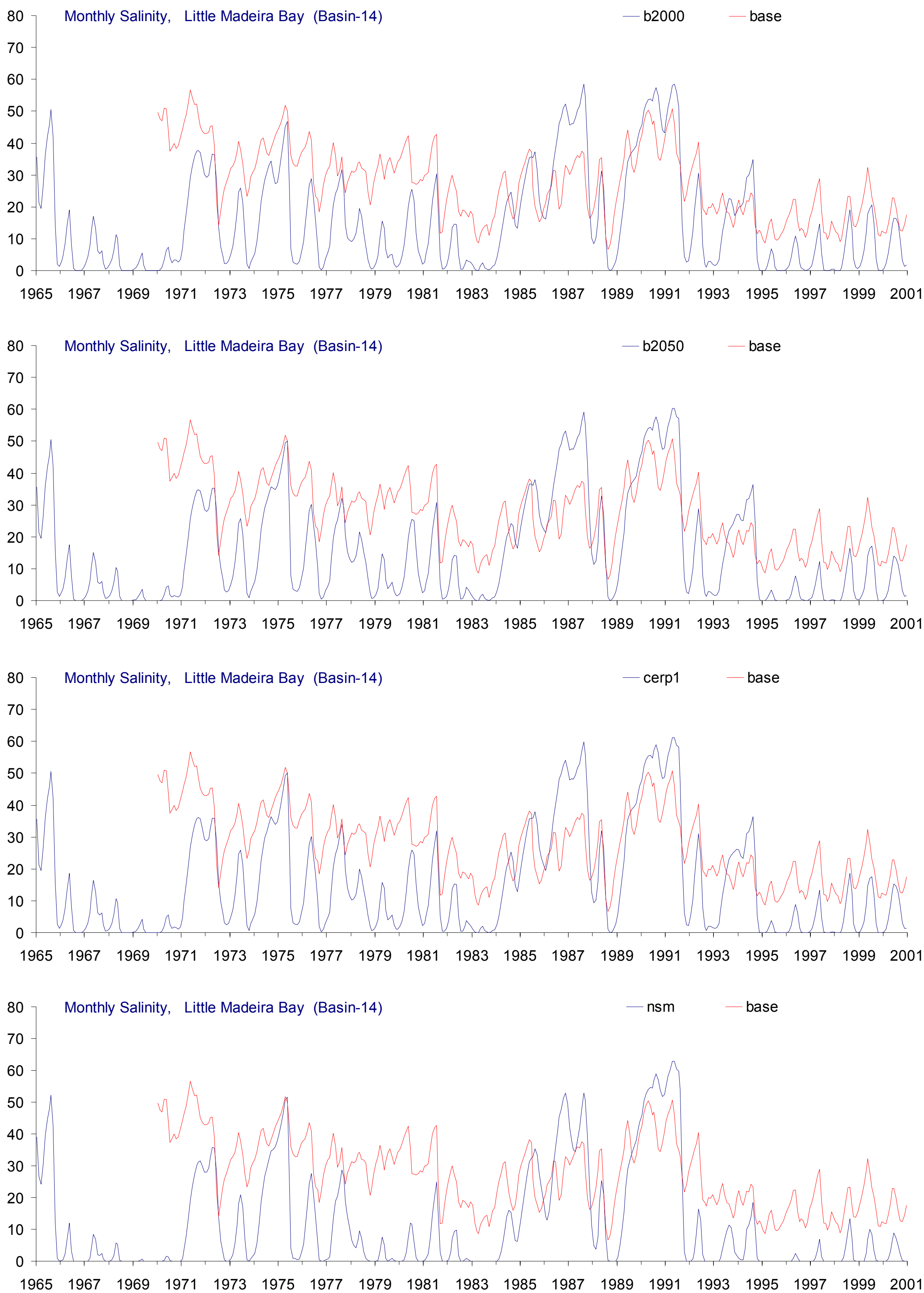


Figure 7.17: Comparison of salinity time series for the four SFWMM scenarios at Park Key (Basin 15). The salinity time series obtained for the MFL base case is shown on all plots for reference (red).

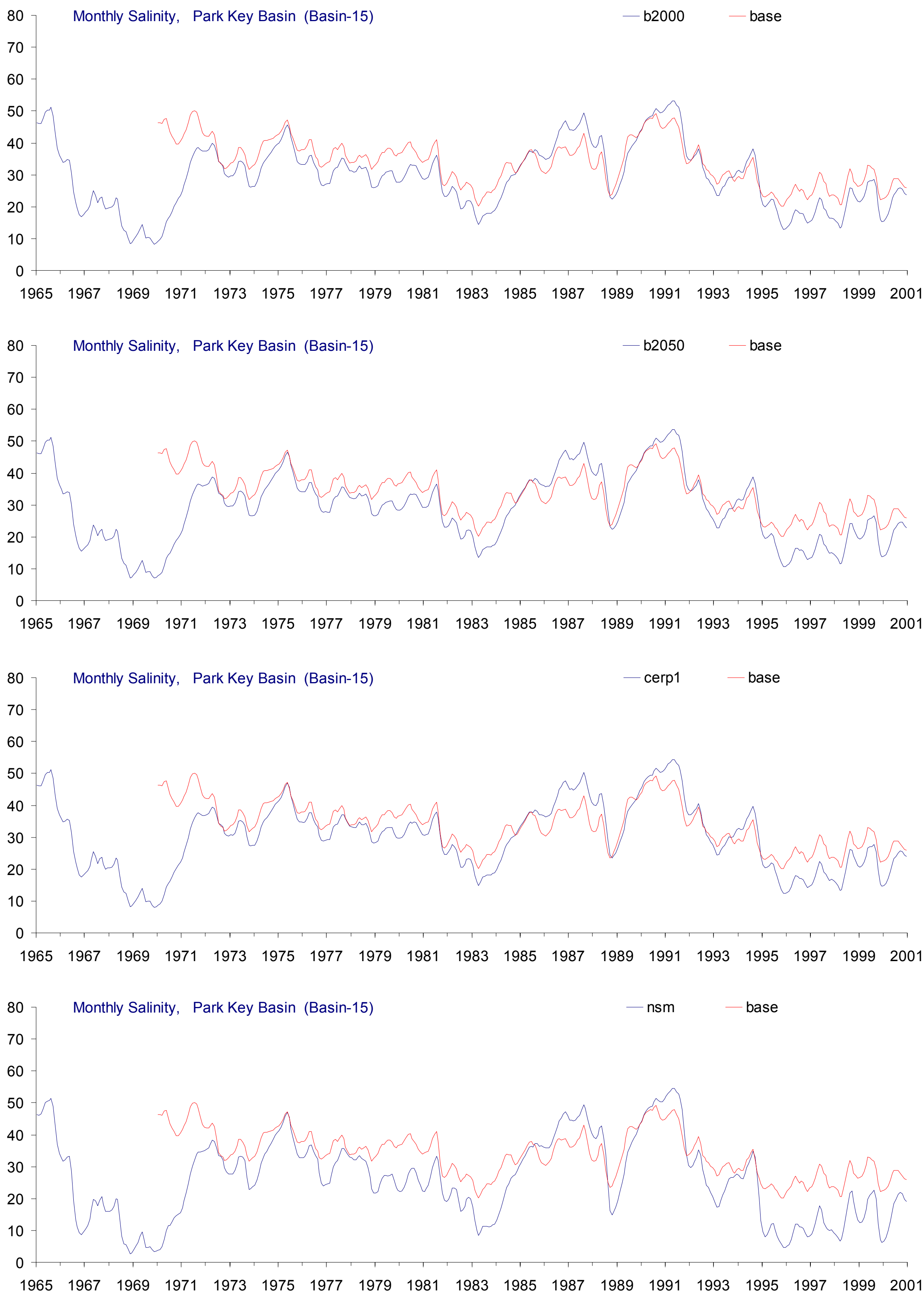
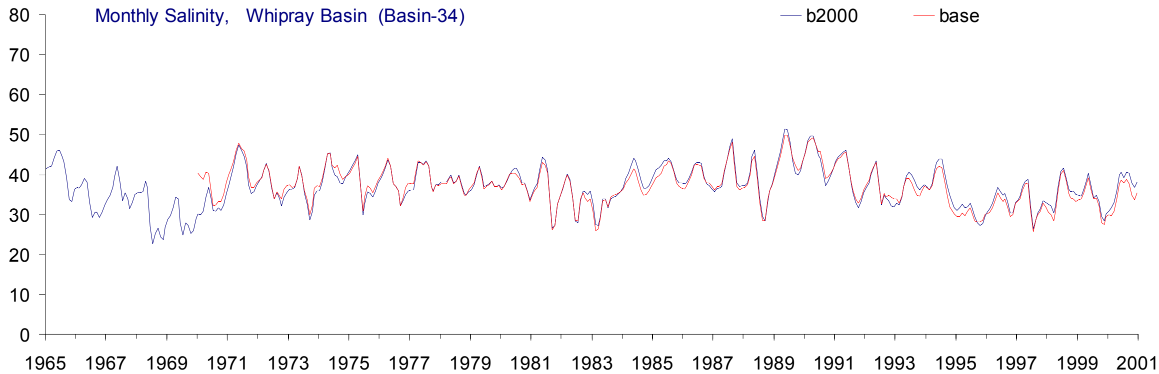
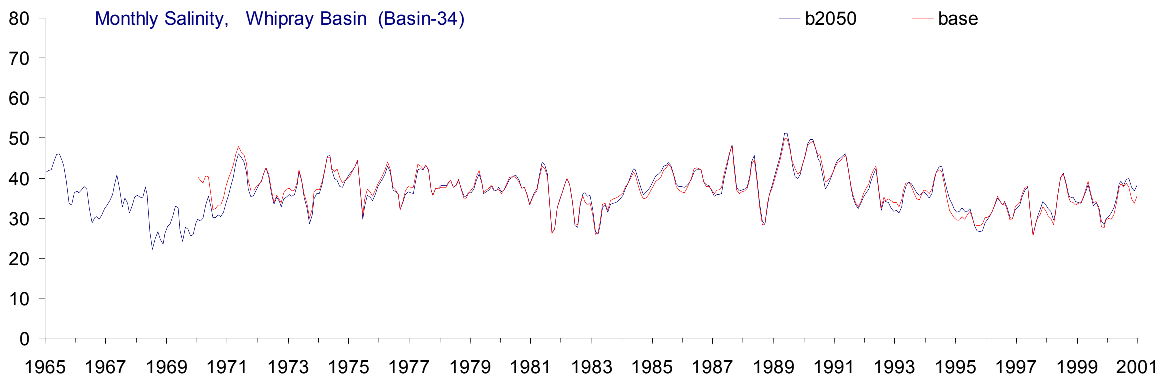
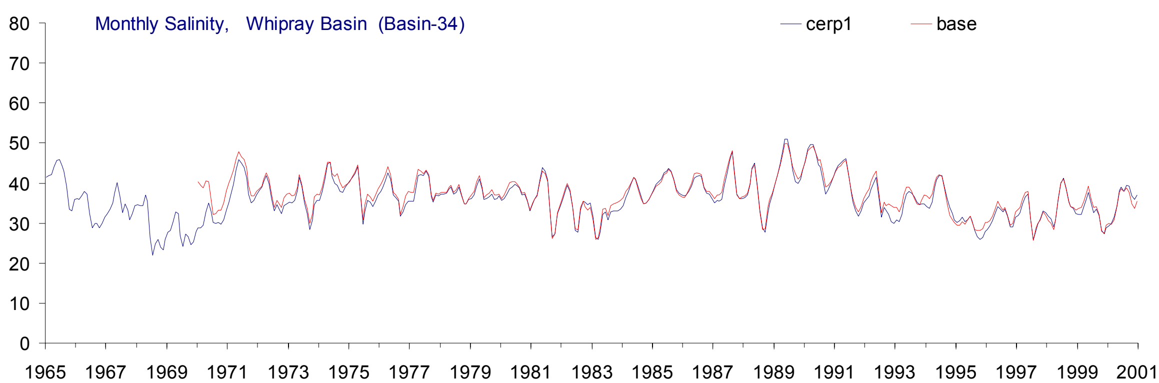


Figure 7.18: Comparison of salinity time series for the four SFWMM scenarios at Whipray Basin (Basin 34). The salinity time series obtained for the MFL base case is shown on all plots for reference (red).







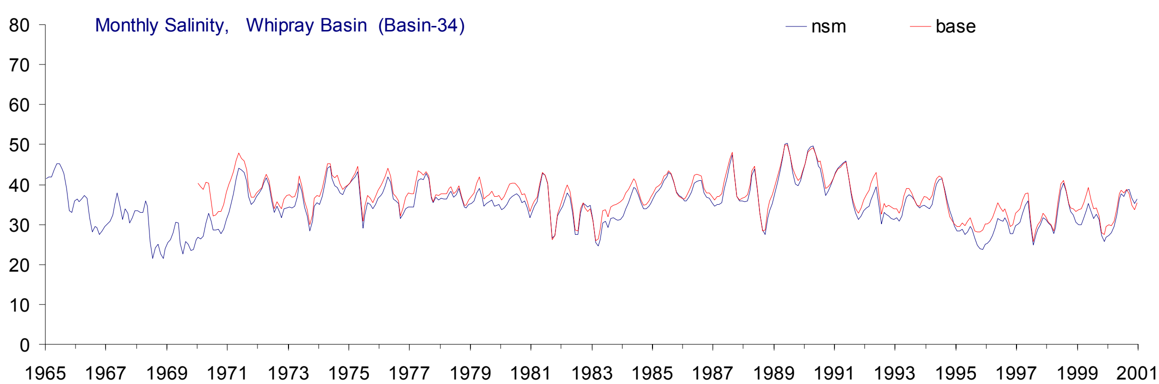


Figure 7.19: Comparison of salinity time series for the four SFWMM scenarios at Garfield/Rankin (Basin 37). The salinity time series obtained for the MFL base case is shown on all plots for reference (red).

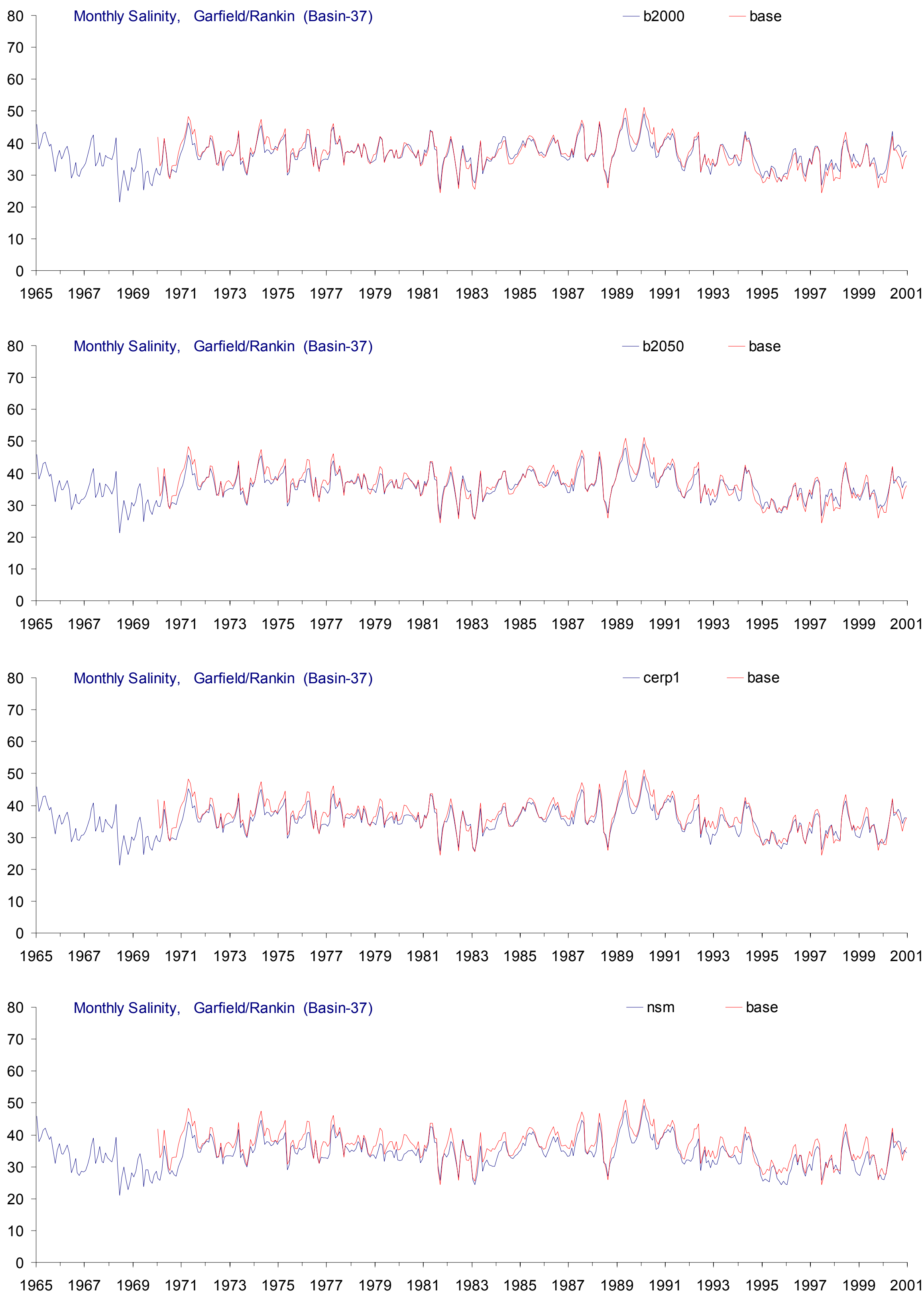


Figure 7.20: Comparison of salinity time series for the four SFWMM scenarios at Rabbit Key (Basin 38). The salinity time series obtained for the MFL base case is shown on all plots for reference (red).

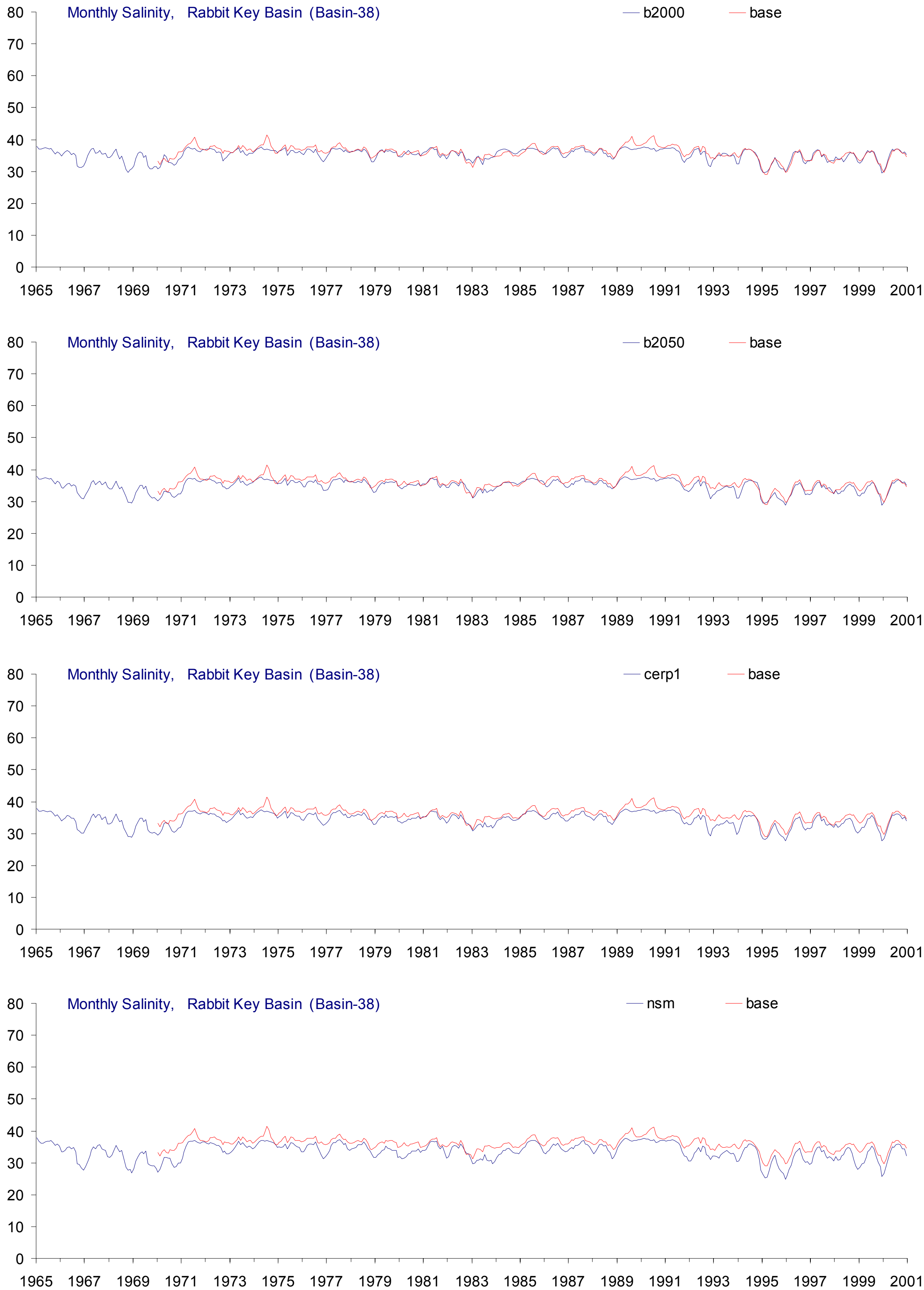
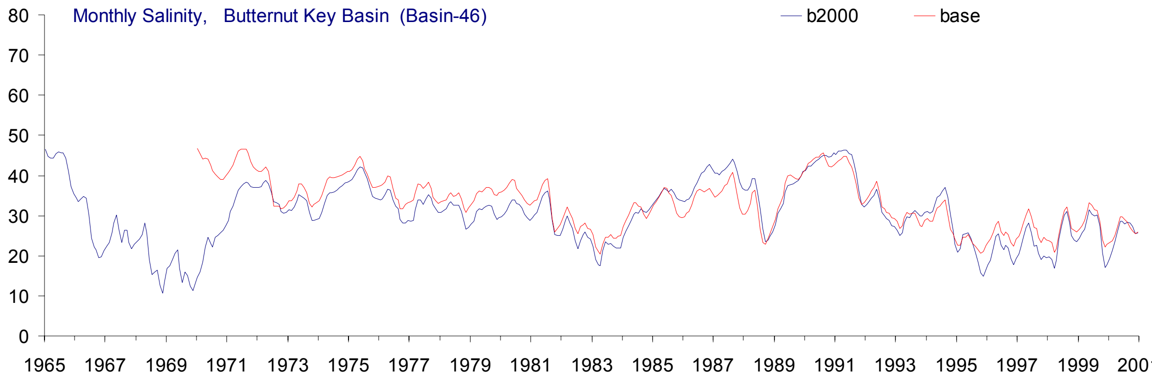
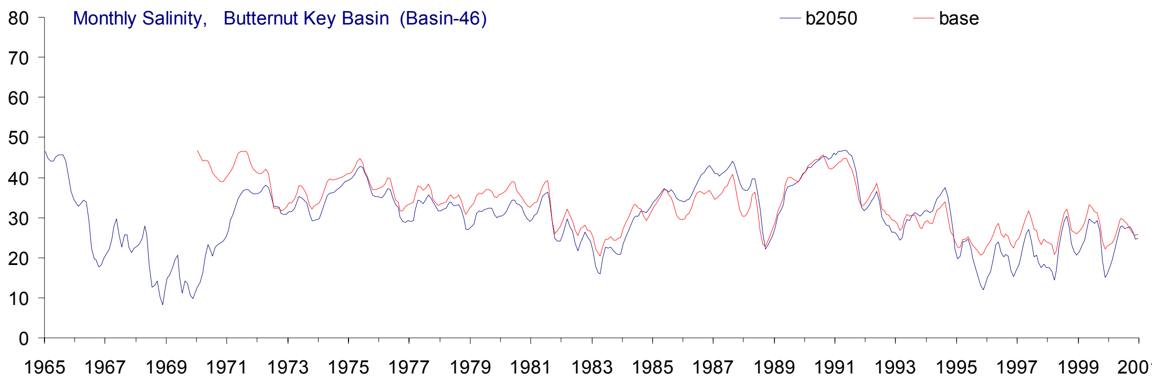
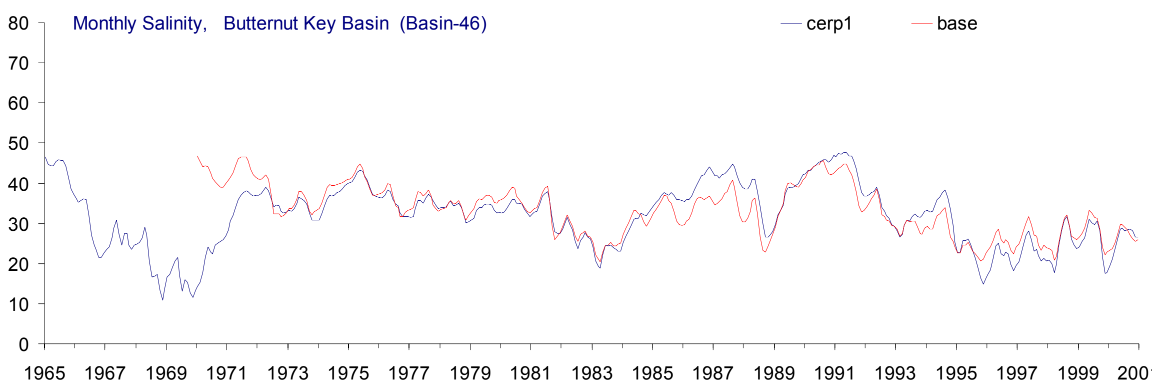


Figure 7.21: Comparison of salinity time series for the four SFWMM scenarios at Butternut Key (Basin 46). The salinity time series obtained for the MFL base case is shown on all plots for reference (red).







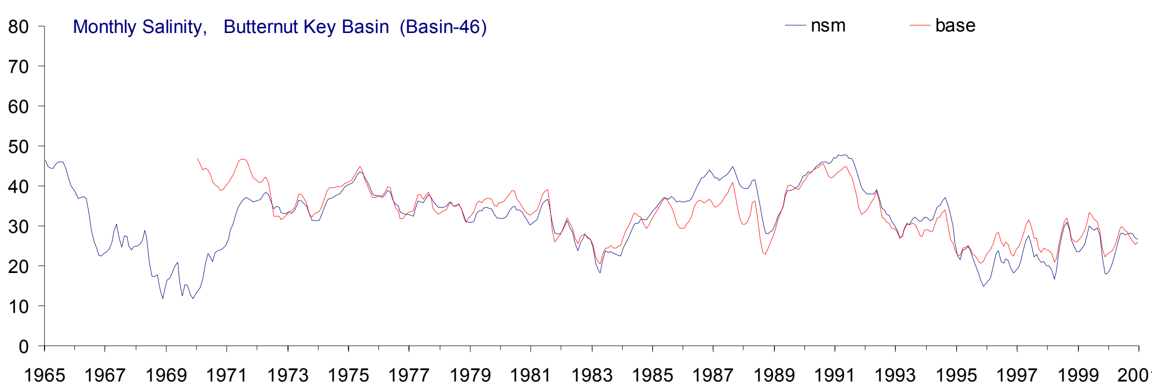
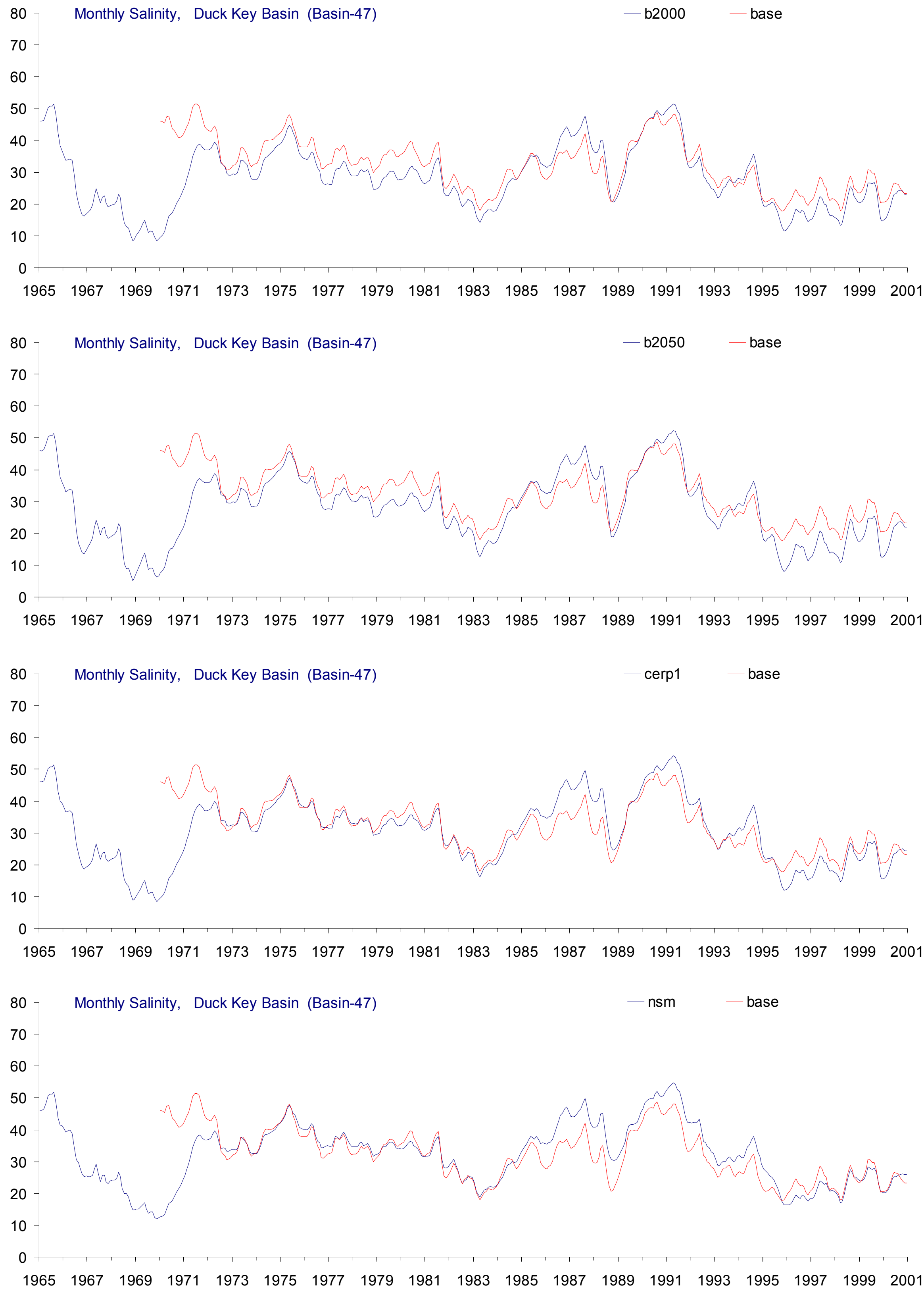


Figure 7.22: Comparison of salinity time series for the four SFWMM scenarios at Duck Key (Basin 47). The salinity time series obtained for the MFL base case is shown on all plots for reference (red).



8 SUMMARY AND RECOMMENDATIONS

8.1 Summary

This significant effort has produced a basic salinity modeling tool needed to establish minimum freshwater flows and levels based on Florida Bay salinity. As described in the approved Final Work Plan, an existing mass-balance model of Florida Bay (FATHOM) has been adapted for MFL use, and the wetland hydrology model (PHAST) has been updated by adding the Long Pine Basin and re-calibrated. Along the way, a better understanding has been gained of the role that freshwater inflow plays in the complex salinity regime of Florida Bay. This knowledge is important for meaningful goals such as establishing MFLs.

The project began by examining the original FATHOM input data, model parameters, and boundary conditions using the available data. However, the period for which existing model input data were directly available was short (1996 – present) and represented a moderately wet period. Initial alternative runs (Mark I) indicated that FATHOM was sensitive to inflow and rainfall inputs, and also to the bathymetry. The Progress Report 1 describes those results in detail.

At the onset of the project it was thought that the updated bathymetry would be available for use at the start of the project, but it was not. The upgrading of the bathymetry as part of this project was one of the most important accomplishments.

Other input data were assembled for the extended period of analysis (1970 through 2000) using a variety of indirect data that were regional indicators of important climatologic and hydrologic conditions. Regional data that were available for the extended period were used to create regression relationships with the existing data so that the period of analysis could be extended and salinity variation over a broader range of conditions could be examined. The primary results from the Mark II model run activities, as reported in Progress Report 2 were assembled from 31-year input data sets, an updated assessment of which combination of alternative input data provided the best reconstruction of the water budget, and an evaluation of alternative model input parameters using the 31-year period.

At the onset of the project it was assumed that an updated bathymetry data set would be available for all of the tasks after the Mark I runs, but it was not completed until later in the project, after the Mark II runs were completed. It was a cooperative task between the District and ECT. The updated bathymetry was incorporated into the Mark III runs (Progress Report 3).

The “best” input parameters from the Mark II and III analyses (Progress Reports 2 and 3) were chosen to be the MFL base case. When the uncertainty statistics were computed over the entire Bay, the FATHOM MFL base case model was capable of explaining about 81% of the monthly salinity variability. However, for some of the basins, particularly in the Northeast and Central Regions, model fidelity showed improvement through the use of rainfall and inflow alternatives other than the base case parameters. This suggests that FATHOM may be able to be improved further through the use of area specific model parameters in some basins.

The 31-year MFL simulations were used to develop the water budget for the 31-year period. A statistical modeling technique was also used to determine that high salinity values in the northeast and south parts of Florida Bay were sensitive to inflows and water levels in addition to direct precipitation. It was also noted that the central area also reacted in a limited manner to fresh water inflows as hypersalinity conditions are known to form when fresh water inputs are very low or non-existing, sometimes for several years.

The 31-year input data set was modified for use with SFWMM produced flow data and the runs were extended to 36 years. Four salinity simulations were then produced for the B2000, B2050, CERP1, and NSM 4.6.2 water management scenarios.

8.2 Recommendations

8.2.1 Application of Models to MFL

Based on the findings presented in the summary above, the following findings are made relative to the use of FATHOM for MFL purposes:

- The updated FATHOM model is recommended for use as the basic modeling tool for setting MFLs for Florida Bay with the input data and parameter values specified by the MFL base case as described in Section 4.
- The enhanced PHAST model can provide an estimate of inflow from the Taylor Slough C111 wetland basin, though it is biased towards lower salinity estimates. Instead. the wetland inflow data derived by the mass accounting method using regional data and regression equations described in Section 3.3 are the preferred estimate of wetland inflow.
- The method of applying results of regional hydrologic simulations with the SFWMM as input to FATHOM described in Section 7 appears to be satisfactory for extending the analysis of water management alternatives to include an evaluation of the expected effect of the CERP water management alternatives on Florida Bay salinity.
- A relationship needs to be developed between freshwater inflows and water levels in the Everglades that can be used to assist in operational management once a minimum flow regime is determined that protects against significant harm in Florida Bay.
- An analysis of the timing of flows into Florida Bay indicated that minimum flows and levels management may need to be invoked at the end of a normal wet season during some years (in addition to dry periods) to protect the Florida Bay ecology against significant harm.

8.2.2 Possible Further Refinements

Specific locations where improvements to model fidelity may be possible include the following:

- Manatee Bay
- Joe Bay
- Terrapin Bay
- Whipray Basin
- Group D (all).

The Joe Bay and Manatee Bay situations may be influenced by the changes in flow direction that are thought to occur when S197 is open and discharging into Manatee Bay. Although the model takes into account the opening and closing of S197, Manatee Bay salinity is also influenced heavily by the boundary salinity condition nearby at the Card Sound Road bridge. Joe Bay may also be influenced by a change the hydraulic gradient pattern in the Everglades panhandle that nay be caused by the opening of S197. Recent observations by the USGS indicate that Joe Bay salinity can vary spatially, and the spatial variation may be relatively large (Hittle and Zucker, 2004, personal communication). Wind effects appear to be responsible for trapping saltwater in Joe Bay at times and density differences can keep adequate mixing from taking place. It is difficult for a grab sample or for a stationary platform measurement to characterize these spatial differences, and model performance in this basin may have been compromised by these conditions.

Terrapin Bay and Whipray Basin model fidelity may be affected by the assignment of fresh water flows into the central area of Florida Bay as defined in the base case. There are several site-specific ways to address this should it be necessary. In addition, the FATHOM Group D salinity may be affected by the proximity of these basins to the western boundary salinity conditions. Model fidelity may also be compromised by inadequate freshwater flows into the central basin that in turn may affect the Group D salinity results.

Based on the findings presented above, the following recommendations are made:

- Use the MFL base case FATHOM model to establish MFLs for Florida Bay.
- Evaluate further the use of site-specific model parameters in the basins that showed the potential for additional improvement when alternative inputs were used in the MFL runs, for example Whipray Basin and the Group D basins.
- Investigate the effect of the opening of the S197 structure on the hydraulic gradient in the northeastern portion of the Bay and the areas upstream of Joe Bay, Little Madeira Bay, Terrapin Bay, and Manatee Bay.
- Evaluate the data available on the spatial variability of salinity in Joe Bay and communicate with the USGS on their findings in this regard.
- Investigate the effect of the boundary salinity conditions in the proximity of Manatee Bay on the salinity in that basin.

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