

Interim Operational Plan Congressional Report

**Wetland Hydrology
and Estuarine Salinity
Related to SFWMM Scenarios**

(Models Version 1.1)

prepared for

Everglades National Park

January 2004

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This Project has been performed under AGREEMENT to The Cadmus Group, Inc. It was funded with Federal funds from the U.S. Dept. of the Interior under a Federal Supply Service contract number GS-10F-0105J. The content of this publication does not necessarily reflect the views or policies of the U.S. Dept. of the Interior nor does mention of trade names, commercial products or organizations imply endorsement by the U.S. Government.

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APPENDIX: Report of Meeting with Eric Swain (USGS), 14 August 2003

1 INTRODUCTION

Everglades National Park is reviewing the impacts of the Interim Operational Plan (IOP) on natural resources in the Park. The IOP guides operation of the Central and Southern Florida Project to achieve hydrological goals established in the Fish and Wildlife Service Final Amended Biological Opinion of March 28, 2002. In particular, the IOP is designed to influence the timing and allocation of surface water flowing into the Park across Tamiami Trail from the north and through the L31W and C111 canals from the east.

The IOP review weighs the impacts of these water management operations on the ecology of the coastal mangroves in the southeast portion of Everglades Park and adjacent estuarine areas. The estuarine areas include the basins of Long Sound, Joe Bay, Little Madeira Bay and Terrapin Bay and the northeast and central regions of Florida Bay. It is anticipated that the impacts of the IOP on resources in these areas occurs primarily through the effect of altered hydrology in the mangrove wetlands and on variation in salinity in the estuarine areas.

This report investigates the applicability of existing wetland hydrology and estuarine salinity models to the task of evaluating the impacts of the IOP on surface water in the wetlands and estuarine salinity in the southeast portion of Everglades Park. These models are under development by the Park for this general purpose. Nuttle and Teed (2002) report on the formulation, calibration and verification of Version 1.0 of these models. The initial verification, while generally encouraging, documents sources of error that could compromise the application of these models to the analysis of IOP impacts. The work reported here corrects some of these deficiencies and documents the remaining uncertainty in salinity predictions. The refined models are applied to analyze four water management scenarios based on the South Florida Water Management Model.

1.1 Objectives

The work described here generally addresses the following goals and objectives of the Park's IOP review:

- Assess the impacts of the IOP structural and operational features on water quality in Everglades National Park.
- Recommend a monitoring program to assess the long-term impacts of the IOP structural and operational features.

Within these broad goals and objectives, this report addresses the following specific objectives established for this project:

1. Complete model improvements.
2. Verify model.
3. Estimate model uncertainty.
4. Apply model to Base runs and IOP runs.
5. Interpret model results (possible BACI analysis) and compare to observed data analysis and other model results.

The accomplishment of objectives four and five depends on the results obtained from refining the models and documenting the uncertainties in the model predictions of estuarine salinity.

1.2 Approach

The work proceeded in three phases. The first phase consisted of consultations with hydrologists at Everglades National Park and the US Geological Survey, Miami District Office, on representation of the wetland water budget in the mass balance models. Dr. Sherry Mitchell (ENP) provided comments based on her review of the implementation report for the Version 1.0 models (Nuttle and Teed 2002). Dr. Eric Swain (USGS) provided comments and supplemental information in an interview by Dr. Nuttle on 14 August 2003; a summary of this meeting is attached as an appendix to this report. These consultations identified likely sources of error in the wetland water budget.

The second phase of work implemented refinements to the wetland hydrology and estuarine salinity models that address the issues identified by the consultations in the first phase of work. This work assembled data, performed analyses to evaluate the relative magnitude of errors, and refined the models to decrease the major sources of error. Finally, work in the second phase calibrated the refined models and evaluated the errors remaining in the hydrology and wetland models applied with historical water budget data. The refined and recalibrated wetland hydrology and estuarine salinity models constitute Version 1.1 of these models, to distinguish them from the initial implementation.

The third phase of work applied the refined wetland hydrology and estuarine salinity models to project the salinity response to be expected in connection with various regional water management scenarios based on the South Florida Water Management Model (SFWMM). Efforts to evaluate the errors in salinity predictions with the Version 1.1 models applied with input from the SFWMM were inconclusive with respect to their expected magnitude, but consistent results were obtained across all basins. Therefore, salinity projections based on wetland inflows from the SFWMM can only be used to compare the relative effects of one SFWMM scenario with another rather than to predict the mean salinity that might occur. With this caveat in mind, the results produce clear differences for the Base 1995 scenario compared to the IOP, ISOP, and NSM scenarios.

2 RECOGNIZED SOURCES OF ERROR

This section describes recognized sources of error in Version 1.0 of the wetland hydrology and estuarine basin salinity models. Nuttle and Teed (2002) provide details on the formulation, calibration and verification of these models. Subsequent sections of this report describe refinements to the models to correct recognized sources of error, the results of recalibration and verification of the refined models, and application of the models to analyze the local effects of regional hydrologic simulations.

Both the wetland hydrology and the estuarine salinity models employ a mass-balance approach. This means that predictions of freshwater discharge, for the wetland models, and salinity, for the estuarine models, are based on an accounting of fluxes and changes in storage of water and salt, respectively. This approach provides the rigor of being physically based, in contrast to purely empirical, statistical models. But the models lack the numerical complexity of more articulate models based on solving coupled equations for the conservation of fluid mass, conservation of momentum, and transport of substances in the water column. The relative simplicity of the mass balance models comes at the cost of sacrificing resolution of small-scale variation in time and space.

The wetland hydrology models account flows and storage of surface water in three wetland basins in the Taylor Slough/C111 area of Everglades National Park, Figure 2.1. Major surface inflows are measured at Taylor Slough Bridge, the S175 structure in the L31W canal, and as the difference between flows measured in the C111 canal at S18C and S197. Rainfall is estimated from selected rain gauges, and changes in water storage are estimated based on data from water level monitoring stations in these basins. Evapotranspiration is estimated based on survey results and analog measures. Surface water discharge into the mangrove estuarine zone is calculated from estimated water depth in the basin based on hydraulic principles.

2.1 Wetland Hydrology Models

The most serious deficiency in the wetland hydrology models relates to the deficit in mean wetland discharge calculated by the models as compared with the long-term average of the estimated estuarine creek discharge at the USGS monitoring stations, Table 2.1. The figure for estuarine creek discharge is the total for all stations, both gaged and ungaged (Hittle et al. 2001). The bias in mean flow amounts to about 25 percent of the long-term average predicted by the wetland hydrology models.

In addition to the bias in mean discharge, the measured creek discharge values (as weekly totals) exhibit periodic (~2 weeks) reversals in flow direction. These are the result of the local effects of wind on the exchange of water between various ponds and estuarine basins that line the coast and Florida Bay. Creek flow direction can shift direction many times in a day during periods of lower flow (C. Hittle, pers. com.). The wetland water balance models capture the low-frequency variations in flow associated with seasonal variation within years and year-to-year variations, but they are unable to account for these higher frequency fluctuations associated with hydrodynamically driven processes.

Figure 2.1: Wetland hydrology basins showing surface inflows included in water balance calculations (black) and locations of measured creek flow used for verification (yellow).

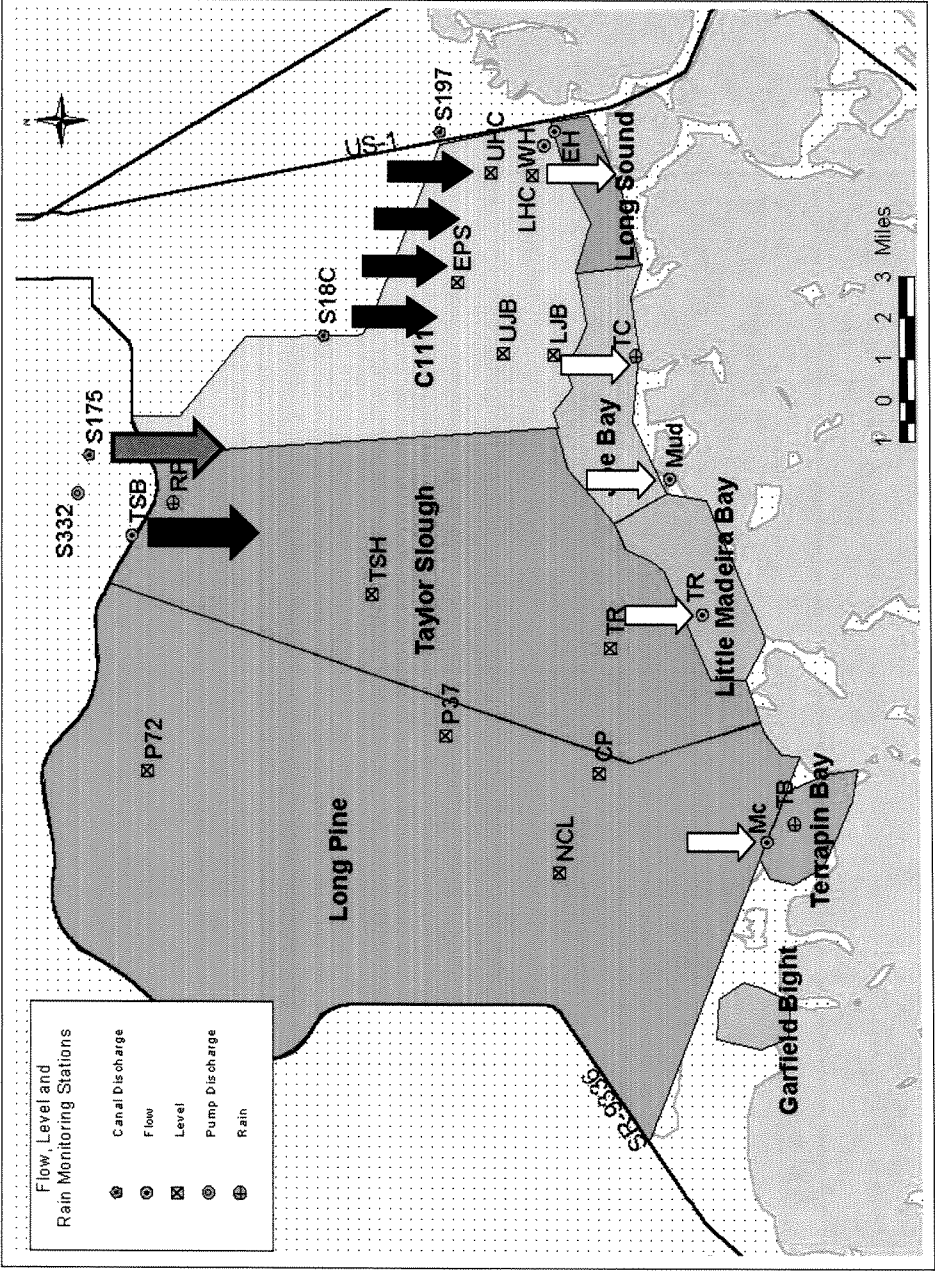


Table 2.1: Average of measured and modeled surface flows for wetland hydrology basins for the period March 1996 to September 2001 (units in millions cubic feet per week)

TSB	58	
C111	111	
	169	Surface Inflow
CP Model	53	
EPSW Model	95	
	148	Modeled Discharge to Estuaries
USGS Gaged	197	
USGS Ungaged	47	
	244	Measured Estuarine Creek Discharge
Residual Surface Flow	96	Error (Measured discharge – Modeled discharge)
Long Pine Basin	320	
Taylor Slough Basin	171	
C111 Basin	104	
	595	Wetland Rainfall
Long Pine Basin	354	
Taylor Slough Basin	190	
C111 Basin	115	
	659	Wetland Evapotranspiration
	(?)	Net Groundwater Discharge to Surface

The refinements to the wetland hydrology models reported here are all directed at reducing the bias component of model error. In particular, the following sources for this error are investigated:

- Unaccounted inflow from S175
- Unknown discharge from Long Pine basin
- Groundwater contribution to surface water discharge
- Uncertainty in calculation of rainfall excess over evapotranspiration

2.1.1 Inflow from S175

Discharge through the S175 was not included as an inflow in compiling the water budget for Version 1.0 of the wetland models. Advice from Park hydrologists and results obtained in the study by Genereux and Slater (1999) suggested that the C111 canal above the S18C structure recaptures surface water discharged from the S175 before it reaches the coastal mangroves. Therefore, including this discharge in a wetland water budget that also includes discharge from the C111 canal below the S18C structure would amount to a double accounting of this water source. However, new information on flow paths in surface flow generated by the USGS Southern Inland and Coastal Systems (SICS) model suggests that a significant portion of the S175 discharge finds its way into Taylor Slough.

2.1.2 Discharge from Long Pine basin

This discharge was neglected in compiling the water budget for Version 1.0 of the wetland models based on lack of information on the water budget and surface water flow paths in this region. Although excess rainfall over evapotranspiration in this large area represents a possibly large source of surface water; an unknown portion of this water exits north and west across the Park road to Flamingo. Representation of surface flows in this area is also problematic for the SICS model; however, model results show that rainfall in this basin contributes flow into the lakes area east of Flamingo and into Garfield Bight through Alligator Creek and into Terrapin Bay through McCormick Creek. Including discharge from these creeks in the comparison between measured and models wetland flows would contribute to the apparent error estimated for outflow from the Taylor Slough and C111 basins.

2.1.3 Groundwater

In Version 1.0, the wetland models do not account for any contribution of groundwater to the surface water budget and subsequent discharge through the coastal mangroves. Previously, we examined published estimates of groundwater discharge to surface water in the Taylor Slough/C111. These estimates vary widely, and the mixed results from field studies provide little guidance on how groundwater might be incorporated into the models or the consequences of leaving it out of the water budget. Different methods produce estimates of groundwater discharge that are either small in magnitude, or the range brackets zero – implying a smaller average value. Interpretation of patterns of chloride concentrations in surface water suggests that the apparent discharge of groundwater seen in the upper reaches of Taylor Slough, below the Park road, may in fact be the effect of lateral inflow of surface water contributed from the Long Pine basin. Problems with accounting for the water budget in the Long Pine basin have already been mentioned.

Some of the variation in groundwater discharge (recharge) estimates apparently reflects seasonality in the surface water hydrology (Sutula et al. 2001). Groundwater discharge is expected to vary also with location on the landscape, generally increasing toward the coast due to the effect of the intrusion of denser, saline water into the aquifer forcing the discharge of freshwater to the surface. Near the coast, discharge most likely occurs during the dry season (Price 2001, Sutula et al. 2001). The higher values of groundwater discharge are short-lived, and thus their effect on the surface water budget was judged to be within the range of error already associated with the uncertainty in rainfall and evapotranspiration (Price, pers. com.).

2.1.4 Rainfall excess over evapotranspiration

Rainfall and evapotranspiration are major fluxes in the wetland water budget. The difference of rainfall in excess of evapotranspiration could contribute a large component of the discharge through the coastal mangroves. Estimates of rainfall excess are highly sensitive to errors in estimating the regional weekly fluxes of rainfall and evapotranspiration for input into the wetland hydrology models. Of these, uncertainty in evapotranspiration is the greater potential source of error. Both the mass balance model and the SICS model rely on evapotranspiration measurements by German (2000). But where Version 1.0 of the wetland models uses the median value of all of German's sites to scale a seasonal distribution, the SICS model calculates daily value of evapotranspiration based on water depth. This has the effect of suppressing evapotranspiration when the surface of the wetland goes dry. A twenty percent reduction from the median value appears possible when the presence or absence of surface water is factored into estimates of evapotranspiration, based on German's (2000) figure 16.

2.1.5 Other sources of error

Other possible sources of error in the wetland hydrology models are recognized (Nuttall and Teed 2002), but these were not investigated as part of this work. These include possible errors associated with not taking into account spatial patterns in rainfall and the exchange of surface water between basins. In particular, the possible inflow of surface water into the Taylor Slough basin from the Long Pine base might prove to be significant.

2.2 Estuarine Salinity Models

As with the wetland hydrology models, development of Version 1.0 of the estuarine salinity models left unresolved a number of deficiencies that contribute to errors in the model predictions. These include questions about the allocation of wetland discharge among the estuarine basins, the possible effects of changes in basin volume related to fluctuations in sea level, the influence of direct rainfall and evaporation, and the role of groundwater flow in delivering fresh water to the basins.

The work reported here does not address any of these issues directly. Instead, it is expected that reducing the errors in the prediction of wetland discharge will also reduce errors in the salinity predictions.

3 MODEL REFINEMENTS

3.1 Wetland Hydrology Models

Refinements in the wetland models correct errors in inflow from the S175 and account for the effects of rainfall and surface dryness on evapotranspiration. Analysis of results obtained by the USGS SICS model suggest that the net, long-term contribution from groundwater to surface water budgets cannot account for a large component of the error in calculated wetland discharge, Table 2.1. Not enough is known about the patterns and magnitude of the surface flows in the Long Pine Basin to model the wetland water budget in this area with any confidence.

3.1.1 Contribution of S175 and other surface inflow

Surface water inflow to the Taylor Slough/C111 area occurs principally at three locations, Figure 2.1, Taylor Slough Bridge (TSB), the S175 structure, and discharge from the C111 canal. Water passing the S18C structure, and not discharged through the S197 structure during flood control operations, discharges as sheet flow into the wetlands south of the C111 canal and into Joe Bay and Long Sound. The difference in measured flow at S18C minus S197 is used to estimate this inflow, C111.

Weekly total discharge data for water control structures exhibit a bimodal seasonal distribution with one peak corresponding to the onset of the wet season, in June, and a larger peak in October, Table 3.1. Recent water management operations reduce flow through the S175 to zero; however the flows recorded at this structure have been significant at times during the period used for calibration and verification of the models, Figure 3.1. On average, flows through the S175 have been about half of that estimated for the Taylor Slough Bridge for the period 1994 through 2001.

The refined Version 1.1 wetland hydrology models include a proportion of S175 flow as surface water inflow into the Taylor Slough and the C111 wetland basins. The proportion of S175 flow to apply to each basin is a parameter that is determined by calibration (see below). The result of calibration indicates that about 95 percent of the measured S175 flows contributes as inflow to the wetland hydrology models, and this is evenly split between the two wetland basins. Presumably the remaining portion is recaptured by the C111 canal and discharges into the C111 basin below the S18C structure – as was previously assumed for the entire S175 flow.

Table 3.1: Surface Inflow Summary Statistics; monthly average, annual statistics and proportion of variation explained by monthly means (units are cubic feet per second)

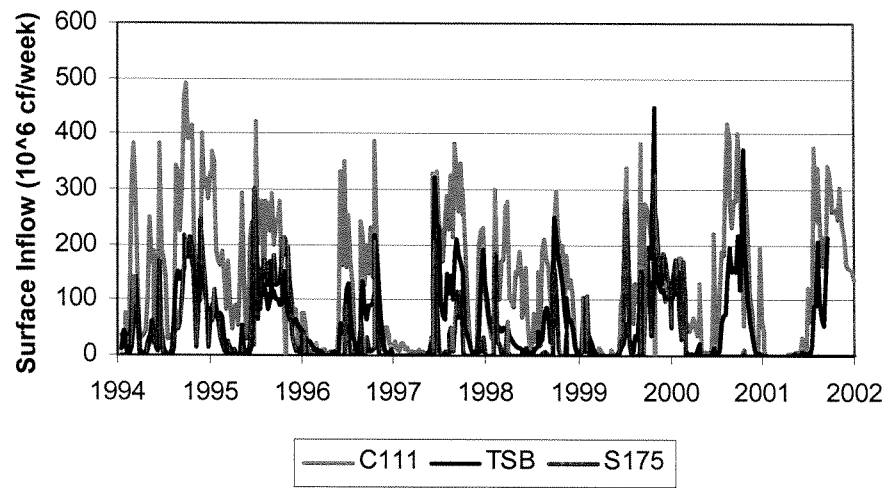
	TSB	S175	S18C	S197
n (weeks)	402	417	417	417
Monthly avg.				
Jan	76	57	136	0
Feb	50	46	146	0
Mar	24	9	97	0
Apr	10	3	89	0
May	16	8	101	0
Jun	81	96	414	143
Jul	93	42	291	36
Aug	174	67	401	22
Sep	227	115	550	117
Oct	269	126	578	263
Nov	110	85	239	48
Dec	93	37	172	0
All weeks				
avg.	100	57	269	53
s.d.	114	107	290	211
seasonal r^2	0.47	0.14	0.34	0.14

3.1.2 Long Pine basin

Little is known about the magnitude and pattern for surface water discharge in the Long Pine basin. Some evidence indicates that water flows out of the basin, across the Park road, during periods of high water. Clearly, the basin contributes to the relatively small amount of fresh water that discharges into the Central region of Florida Bay through the fresh water lakes drained by McCormick Creek and Alligator Creek. However water from the Taylor Slough basin may contribute to these flows during wet years when surface water backs up behind the Buttonwood embankment. And it is also possible that surface water from the Long Pine basin contributes to surface flow in Taylor Slough.

In face of continuing uncertainty about the how to formulate the water budget in Long Pine basin, this basin is removed as a component of the wetland hydrology model in Version 1.1. To be consistent, the comparison of the calculated wetland discharge with the USGS monitoring data for flows in estuarine creek will exclude data for Alligator Creek and McCormick Creek, as discharge from Long Pine basin most likely supports these flows.

Figure 3.1: Magnitude and timing of inflow through S175 compared with other gaged inflows



3.1.3 Groundwater

It appears that the total groundwater discharge to the surface on an annual basis for the entire SICS model domain is on the order of magnitude of only one cubic meter per second. This is small enough that its contribution and it can be ignored. This estimate is based on analysis of the average net groundwater discharge calculated for each node of the SICS model within the Taylor Slough and C111 wetland basins. Net figures for groundwater exchange in the period 1995 through 1999 show patterns of upwelling to the surface in the upper reaches of Taylor Slough, north of Old Ingram Highway, Figure 3.2. Moving from north to south, this region of upwelling is followed by a net loss of from surface water into groundwater, probably as a result of surface water ponding north of the Buttonwood ridge and then again by upwelling groundwater discharging into the estuarine basins and near shore regions of Florida Bay.

3.1.4 Evapotranspiration

In the Version 1.0 wetland hydrology models, monthly evapotranspiration rates are estimated as the median of evapotranspiration measured at nine sites throughout South Florida (German 2000). Comparison of these values with German's measurements at the Old Ingram Highway site, in the Long Pine basin, and with values calculated by the SFWMM for sites along the T23 transect suggest that the median of German's stations tends to overestimate evapotranspiration in these basins, Figure 3.3. This would translate into an underestimation of wetland discharge, and it might account for the large bias error in calculated discharge documented for the Version 1.0 models, Table 2.1. German's (2000) results suggest that the lower evapotranspiration rates measured at the Old Ingram Highway site reflect the relatively drier surface water conditions at this site and the suppression of evapotranspiration when the wetland surface is dry.

This work develops an empirical model for evapotranspiration, based on German's measurements at the Old Ingram Highway site. The model captures the effect of surface flooding and drying but does not require additional data not presently used by the wetland hydrology models. The form of the model is based on the established concept of representing actual evapotranspiration as the sum of a potential rate e_P and a deviation rate e_Δ ; $e = e_\Delta + e_P$.

The potential evapotranspiration rate reflects the largely seasonal influence of regional factors that drive evapotranspiration, such as solar radiation and humidity. The deviation rate reflects the influence of local effects, such as soil moisture and weather conditions at a particular site.

Using German's (2000) measured evapotranspiration, aggregated to weekly values, both weekly rainfall p and water depth h correlate with the deviation rate, Table 3.2. Here the seasonal pattern of evaporation for Florida Bay (Nuttle et al. 2001) is taken as the potential evapotranspiration rate and the deviation rate is calculated by subtracting the evapotranspiration measured at the Old Ingram Highway site. Surface water elevation and rainfall data are also from German's (2000) measurements at this site. The correlation with weekly rainfall probably reflects the effect of clouds suppressing evapotranspiration by reducing the amount of solar radiation.

Figure 3.2: Net groundwater exchange with surface water calculated by the USGS SICS model for the period 1995 through 1999 for the sub domain shown in the inset. Values are cumulative from the northern boundary of the model domain, and negative values indicate net groundwater discharge to the surface over the upstream reach.

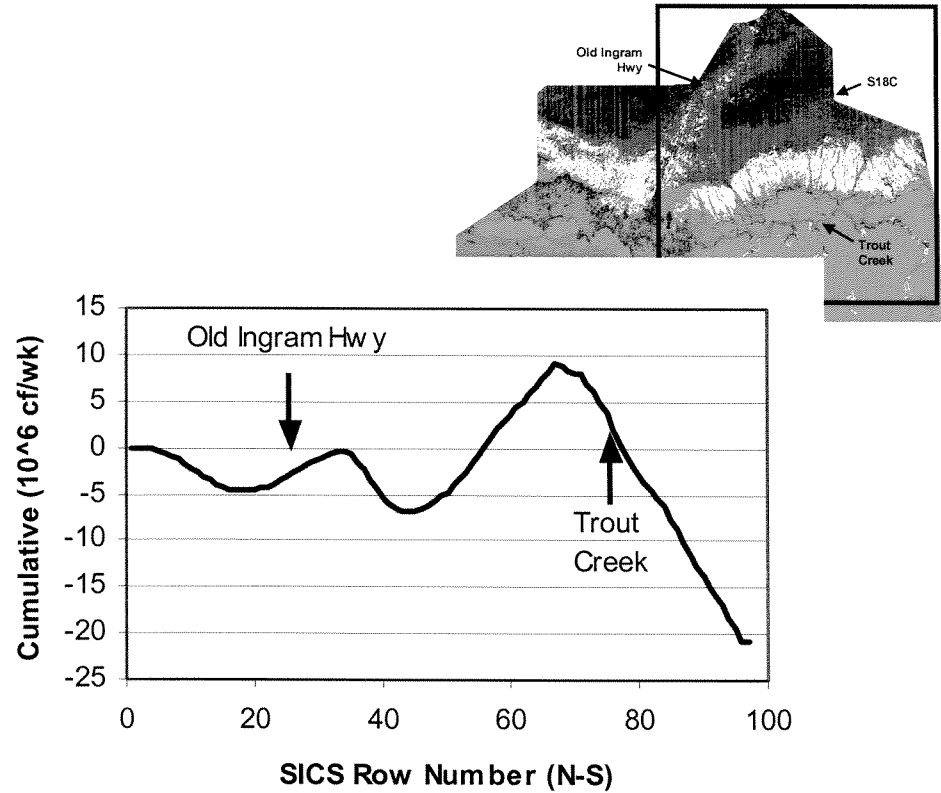


Figure 3.3: Mean monthly values for evapotranspiration measured or calculated for sites in or adjacent to the domain of the wetland hydrology models.

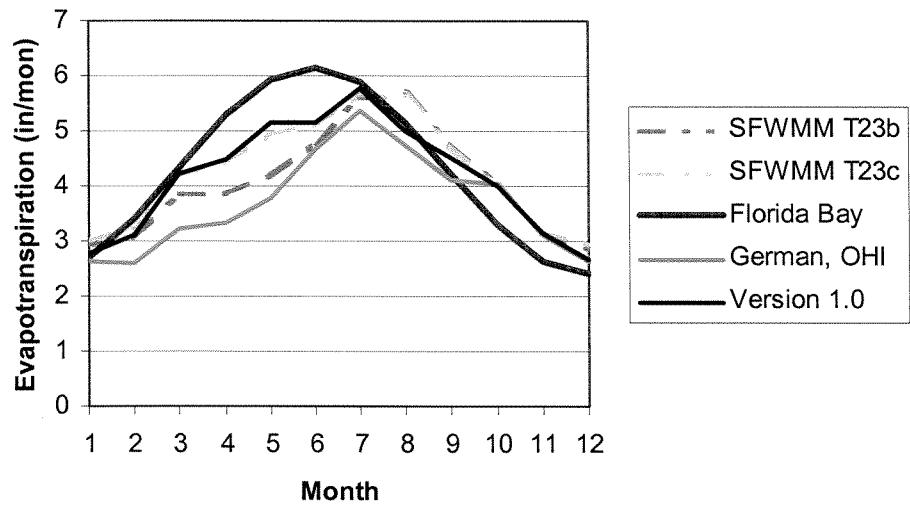


Figure 3.4: Evaporation model calibrated to German's (2000) measured weekly evapotranspiration for the site at Old Ingram Highway

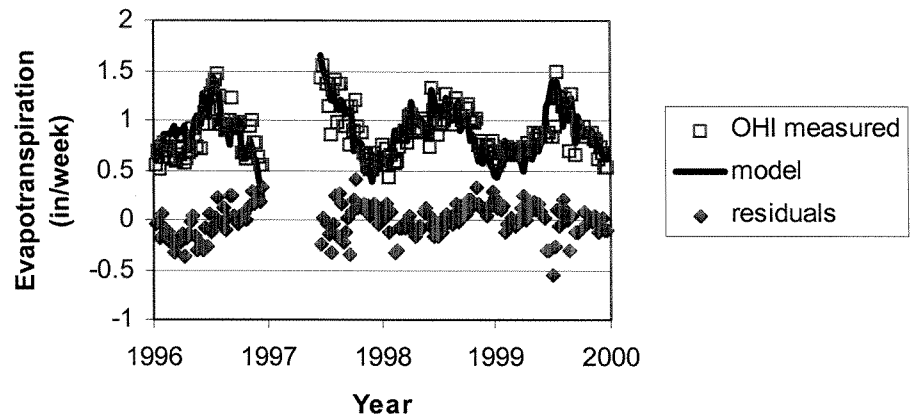


Table 3.2: Correlation matrix for evaporation and factors affecting weekly evaporation based on measurements at Old Ingram Highway (USGS, pers. com.)

	<i>h</i>	<i>p</i>	<i>e</i>	<i>e_A</i>
<i>h</i>	1			
<i>p</i>	0.233	1		
<i>e</i>	0.235	0.128	1	
<i>e_A</i>	0.710	-0.143	0.253	1

Multiple linear regression was used to estimate a model for the deviation rate of evapotranspiration from the data for the Old Ingram Highway site, Figure 3.4;

$$e_A = \text{Constant} + 0.412h - 0.059p$$

The model has an r-squared of 0.61. The refined Version 1.1 wetland hydrology models use this equation with the coefficients for water depth and rainfall determined from the Old Ingram Highway data to estimate weekly water loss due to evapotranspiration. The constant in the equation reflects site-specific conditions, such as the extent of surface flooding associated with a given water depth, and this is estimated for each basin as part of the calibration of the Version 1.1 wetland models.

3.1.5 Other water balance data

For other components of the water balance not described in the preceding sections, calibration of the Version 1.1 models relies on the data assembled for calibration and verification of the Version 1.0 models (Nuttle and Teed 2002). The description of these data from the earlier report is reproduced here for sake of convenience.

All of the water balance data cover the period generally 1994 through 2001, Table 3.3. Data were obtained from the originating agency, screened and stored in a relational database. The hydrology and salinity models employ a weekly time step, and the data series are aggregated to this level from the original, daily values with one exception; Florida Bay salinity values are monthly samples. Data used for calibration and verification are a sub-sample of all the data received for the selected monitoring locations. The monitoring stations represented in this compilation, Table 3.3 and Figure 2.1, were selected after reviewing data quality and coverage from a larger, initial set of monitoring stations.

Table 3.3: Summary of Data Sources for Water Balance Data

Code	Station Name	Data Type	Units	Agency	Begin	End
MC	McCormick Creek	flow	cfs	USGS	27-Oct-95	31-Dec-01
Mud	Mud Creek	flow	cfs	USGS	16-Oct-95	31-Dec-01
TC	Trout Creek	flow	cfs	USGS	1-Feb-96	31-Dec-01
TR	Taylor River	flow	cfs	USGS	8-Oct-95	31-Dec-01
TSB	Taylor Slough Bridge	flow	cfs	ENP	1-Jan-93	15-Sep-01
WH	West Highway Creek	flow	cfs	USGS	1-Mar-96	31-Dec-01
S175	S175	flow (canal)	cfs	SFWMD	1-Jan-93	31-Dec-01
S18C	S18C	flow (canal)	cfs	SFWMD	1-Jan-93	31-Dec-01
S197	S197	flow (canal)	cfs	SFWMD	1-Jan-93	31-Dec-01
CP	Craighead Pond	level	feet	ENP	1-Jan-94	31-Dec-01
EPSW	EPSW	level	feet	ENP	1-Jan-93	8-Jan-01
NCL	NCL	level	feet	ENP	14-Mar-96	31-Dec-01
P37	P37	level	feet	ENP	1-Jan-93	31-Dec-01
NP72	P72	level	feet	ENP	1-Jan-93	25-Apr-01
TS2	Taylor Slough Bridge	level	feet	ENP	20-May-99	31-Jul-01
TSH	Taylor Slough Hilton	level	feet	ENP	12-Mar-94	31-Dec-01
CP	Craighead Pond	rain	inches	ENP	21-May-94	31-Dec-01
JBTS	Joe Bay met. station	rain	inches	SFWMD	1-Jan-93	31-Dec-01
P37	P37	rain	inches	ENP	1-Jan-93	31-Dec-99
RPL	Royal Palm	rain	inches	ENP	1-Jan-93	31-Dec-99
S18C	S18C	rain	inches	SFWMD	1-Jan-93	31-Dec-01
TB	Terrapin Basin	rain	inches	ENP	9-Aug-93	21-Nov-01
TC	Trout Creek	rain	inches	ENP	29-Jul-93	31-Dec-01
TR	Taylor River	rain	inches	ENP	19-May-93	31-Dec-01

3.1.5.1 Rainfall

This study applies a spatially averaged rainfall rate (inches per week) to each of the wetland hydrology basins, Figure 3.5. This rate is calculated as the average for each week across the rainfall monitoring locations identified in Table 3.3 and Figure 2.1. Missing values in the rainfall records for each station were estimated from a regression relating observed station values with the average of observations at all stations. Average annual rainfall is 47.8 inches.

Weekly average rainfall data exhibit a bimodal seasonal distribution with one peak corresponding to the onset of the wet season, in June, and a larger peak in October, Table 3.4. Average rainfall increases generally from south, coastal, to north, inland, sites. Locations near the C111 canal (EPSW and S18C) have highest seasonal (monthly average) rainfall in June. At locations nearer the coast, the highest rainfall occurs in the fall.

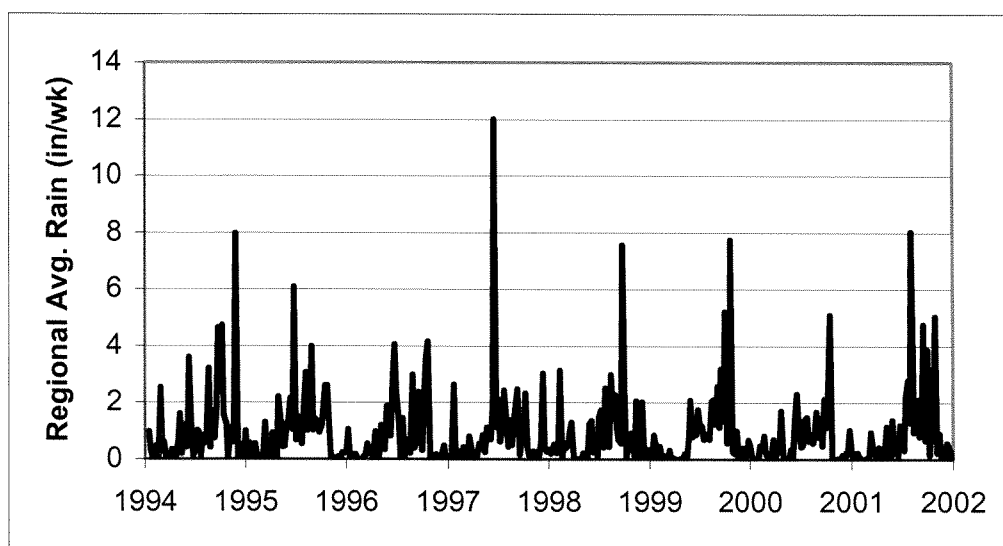
Table 3.4: Rainfall Summary Statistics; monthly average, annual statistics and proportion of variation explained by monthly means (units are inches per day)

	CP	JBTS	P37	RPL	S18C	TB	TC	TR
n (weeks)	346	371	344	339	404	375	386	372
Monthly avg.								
Jan	0.04	0.04	0.05	0.06	0.05	0.02	0.05	0.07
Feb	0.04	0.06	0.06	0.06	0.06	0.03	0.05	0.05
Mar	0.05	0.02	0.06	0.06	0.07	0.01	0.05	0.03
Apr	0.04	0.03	0.07	0.11	0.08	0.05	0.06	0.07
May	0.13	0.05	0.18	0.18	0.12	0.09	0.10	0.12
Jun	0.23	0.19	0.37	0.31	0.35	0.24	0.20	0.19
Jul	0.23	0.11	0.20	0.16	0.27	0.19	0.14	0.15
Aug	0.20	0.18	0.24	0.27	0.25	0.23	0.19	0.24
Sep	0.30	0.22	0.36	0.34	0.28	0.26	0.24	0.29
Oct	0.16	0.16	0.21	0.21	0.26	0.19	0.19	0.18
Nov	0.08	0.08	0.11	0.13	0.09	0.09	0.06	0.08
Dec	0.05	0.03	0.06	0.06	0.05	0.01	0.04	0.04
All weeks								
avg.	0.13	0.10	0.17	0.16	0.16	0.12	0.12	0.12
s.d.	0.23	0.17	0.26	0.25	0.27	0.24	0.21	0.20
seasonal r^2	0.14	0.14	0.17	0.14	0.15	0.15	0.11	0.16

Table 3.5: Correlation matrix for weekly rainfall data

	CP	JBTS	P37	RPL	S18C	TB	TC	TR
CP	1.000							
JBTS	0.710	1.000						
P37	0.828	0.724	1.000					
RPL	0.660	0.643	0.806	1.000				
S18C	0.604	0.626	0.736	0.685	1.000			
TB	0.732	0.614	0.807	0.679	0.646	1.000		
TC	0.461	0.647	0.644	0.642	0.563	0.563	1.000	
TR	0.660	0.653	0.575	0.498	0.385	0.526	0.280	1.000

Figure 3.5: Regional average rainfall is applied uniformly across the wetland hydrology basins



3.1.5.2 Wetland water level

The hydrology model for the Long Pine/Taylor Slough basin is calibrated to match water levels measured at Craighead Pond (CP). Water from Taylor Slough ponds behind the Buttonwood Embankment in the area adjacent to this monitoring location. The hydrology model for the C111 basin is calibrated to match water levels measured at EPSW. Other water level stations in the C111 basin have significantly shorter periods of record; therefore, they are less attractive for the purpose of model calibration.

Weekly average water levels vary seasonally with peak levels occurring in either September or October, Table 3.6. Average water levels and the range of seasonal fluctuations increase from east to west and with topography from south to north.

Water level fluctuations at all sites exhibit strong cross correlation, Table 3.7; however differences are apparent between basins and between inland sites and sites close to the coast. For example, compare the magnitude of fluctuation indicated by the standard deviation at EPSW to other locations and inland sites NP72 and fluctuations at TSB2 compared to other stations in the Long Pine/Taylor Slough basin.

Comment:

Table 3.6: Water Level Summary Statistics; monthly average, annual statistics and proportion of variation explained by monthly means (units in feet relative to ngvd 1929)

	CP	EPSW	P37	NP72	TSH	TSB2
n (weeks)	419	316	419	334	406	314
Monthly avg.						
Jan	1.3	1.6	1.6	2.5	2.2	3.8
Feb	1.2	1.5	1.5	2.1	2.0	3.6
Mar	0.9	1.4	1.3	2.3	1.8	3.1
Apr	0.7	1.1	0.9	1.6	1.5	2.6
May	0.4	1.1	0.8	2.3	1.4	3.0
Jun	0.8	1.5	1.5	3.9	2.0	3.9
Jul	1.3	1.5	1.6	3.8	2.2	3.8
Aug	1.6	1.7	1.8	4.0	2.4	4.3
Sep	1.8	1.9	2.0	4.2	2.6	4.7
Oct	1.9	2.0	2.2	4.3	2.7	4.8
Nov	1.7	1.7	1.9	3.7	2.4	4.2
Dec	1.5	1.6	1.7	3.4	2.3	4.2
All weeks						
avg.	1.3	1.6	1.6	3.1	2.1	3.8
s.d.	0.6	0.3	0.5	1.2	0.5	0.9
seasonal r^2	0.53	0.56	0.62	0.55	0.52	0.46

Table 3.7: Correlation matrix for water level data

	CP	EPSW	P37	NP72	TSH	TSB2
CP	1.000					
EPSW	0.893	1.000				
P37	0.944	0.905	1.000			
NP72	0.802	0.796	0.875	1.000		
TSH	0.905	0.927	0.963	0.881	1.000	
TSB2	0.831	0.882	0.860	0.857	0.902	1.000

3.1.5.3 Estuarine creek flow

This study uses the estimated creek discharge data compiled for five locations, Figure 2.1, McCormick Creek (MC), Mud Creek (MUD), Taylor River (TR), Trout Creek (TC) and West Highway Creek (WH). The additional flow in four ungaged creeks is estimated from gaged flows using regression equations established by Hittle et al. (2001). Three of these creeks, Stillwater Creek, Oregon Creek, and East Highway Creek, discharge into Long Sound, and the remaining ungaged creek, East Creek, discharges into Little Madeira Bay.

Discharge in estuarine creeks reflects the net inflow of freshwater from the wetland basins in the Taylor Slough/C111 area of Everglades Park. Other processes also drive the creek flows, in both directions, on periods of a month or less. These include tides, which are largely wind-driven, changes in mean sea level, and the balance between local rainfall and evaporation. As a result, the creek flows exhibit a large component of variation that cannot be related directly to the wetland discharge. However, it can be expected that these influences will have a negligible effect on net flows measured seasonally and over a period of years.

Weekly total surface flow in estuarine creeks exhibits a bimodal seasonal distribution with one peak corresponding to the onset of the wet season, in June, and a larger peak in October, Table 3.8. The largest flow occurs in Trout Creek, which connects Joe Bay with Florida Bay.

Table 3.8: Estuarine Creek Flow Summary Statistics; monthly average, annual statistics and proportion of variation explained by monthly means (units are cubic feet per second)

	MC	Mud	TC	TR	WH
n (weeks)	323	324	310	325	305
Monthly Avg.					
Jan	-8	10	84	23	26
Feb	-7	5	68	16	21
Mar	-14	0	23	8	18
Apr	-38	-14	-80	-6	4
May	-46	-11	-46	-6	6
Jun	33	37	313	33	62
Jul	10	27	166	36	45
Aug	26	49	307	60	84
Sep	69	80	576	87	120
Oct	124	109	765	104	135
Nov	25	45	315	55	64
Dec	1	18	157	32	43
All weeks					
avg.	15	30	223	38	53
s.d.	76	54	376	48	63
seasonal r^2	0.34	0.34	0.41	0.49	0.42

3.1.6 Calibration: revised water budget

Calibration of the revised wetland models follows the approach described by Nuttle and Teed (2002) with the following differences:

- the area of the Taylor Slough basin is set to the measured area for the region delineated in Figure 2.1 (Long Pine is no longer included);
- calibration determines the proportion of S175 flow to allocated as inflow into each basin; and
- calibration determines the constant in the evaporation model for each basin.

The method of calibration minimizes the sum of squared deviations between modeled and observed water levels at CP, for the Long Pine/Taylor Slough basin, and at EPSW, for the C111 basin model. Optimization was performed using the solver routine in Microsoft Excel. In general, the basin hydrology models succeed in fitting the fluctuations in water levels (comparison with water levels not shown). The calibrated parameters related to flow and storage in the revised models are comparable in magnitude to the values determined for the Version 1.0 models and the r-squared and the mean squared error are slightly improved in the revised models, Table 3.9. Figures 3.6 – 3.9 show the seasonal and year-to-year variation in calibrated water levels and calculated wetland discharge through the calibration and verification period.

Table 3.9: Calibrated parameter values and statistics for fit to water level data

	Taylor Slough	C111
α	424	723
h^*	1.18	1.24
A^1 (million ft ²)	2300	1400
wet fraction	0.60	1.00
S175 fraction	0.49	0.46
Evap const.	-0.65	-0.75
r^2	0.86	0.83
mse (ft ²)	0.047	0.016

¹ Set to measured basin area

3.1.7 Verification

Verification of the revised wetland hydrology models follows the approach describe by Nuttle and Teed (2002) with the difference that measured discharge for McCormick Creek, which drains the Long Pine basin, is not included in the comparison of calculated and measured values of discharge. The comparison of calculated and measured weekly values of discharge is summarized in Figures 3.10, 3.11 and 3.12 and in the water budget compilation in Table 3.10. The residual error obtained by the revised models is reduced by about 70% compared to the Version 1.0 models, Table 2.1. The residuals exhibit a seasonal pattern, Figure 3.12 that reflects the tendency for estuarine creek flows to reverse in the late winter and spring months. This phenomenon is related to the combination of seasonally low wetland discharge with regional wind forcing.

Table 3.10: REVISED average of measured and modeled surface flows for wetland hydrology basins for the period March 1996 to September 2001 (units in millions cubic feet per week)

TSB	58	
C111	111	
S175	24	
	193	Surface Inflow
CP Model	80	
EPSW Model	130	
	210	Modeled Discharge to Estuaries
USGS Gauged	190	w/o McCormick
USGS Ungauged	47	
	237	Measured Estuarine Creek Discharge
Residual Surface Flow	27	Error (Measured discharge – Modeled discharge)
Long Pine Basin	na	
Taylor Slough Basin	171	
C111 Basin	104	
	275	Wetland Rainfall
Long Pine Basin	na	
Taylor Slough Basin	152	
C111 Basin	95	
	247	Wetland Evapotranspiration
	<5	Net Groundwater Discharge to Surface

Figure 3.6: Calibrated water level for the Taylor Slough basin, station CP.

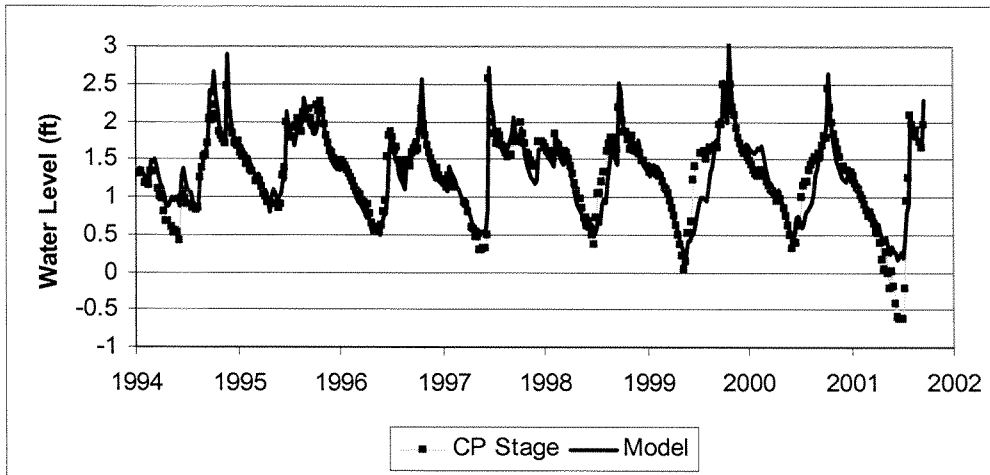


Figure 3.7: Calculated wetland discharge from the Taylor Slough basin.

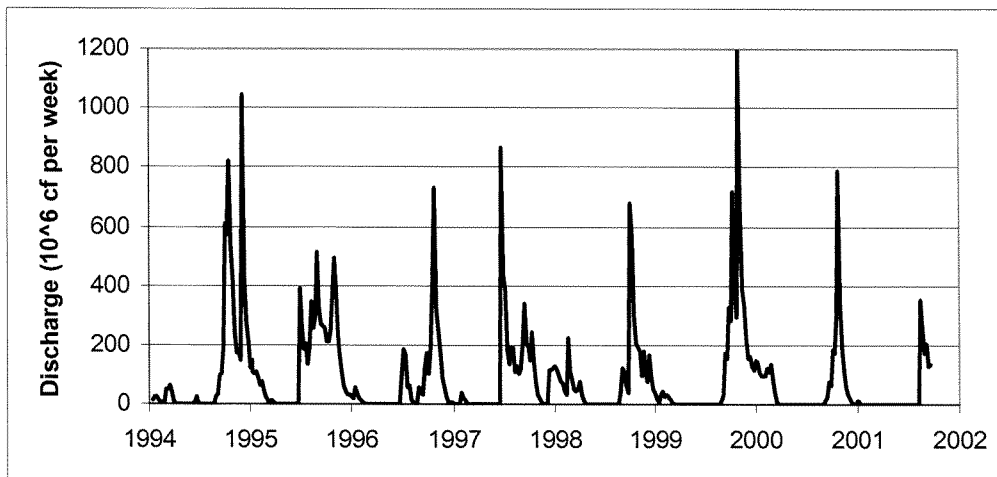


Figure 3.8: Calibrated water level for the C111 basin, station EPSW.

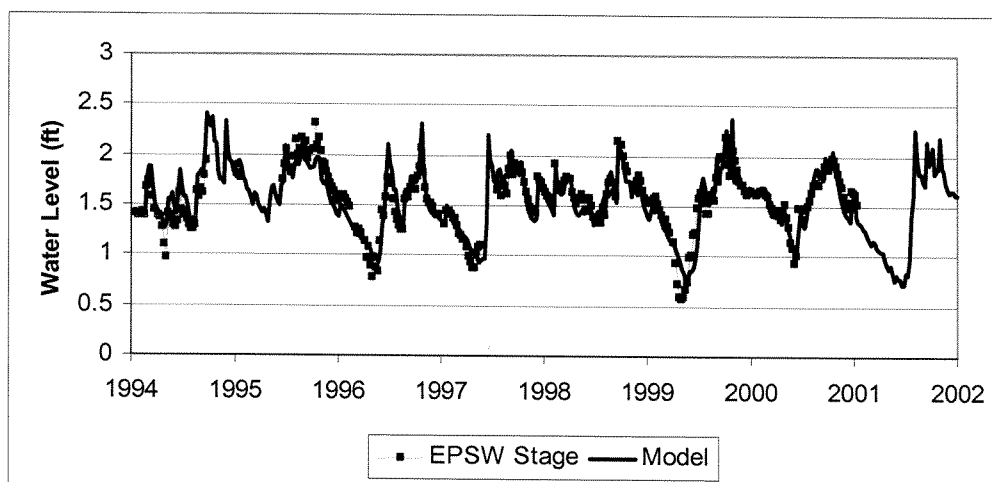


Figure 3.9: Calculated wetland discharge from the C111 basin.

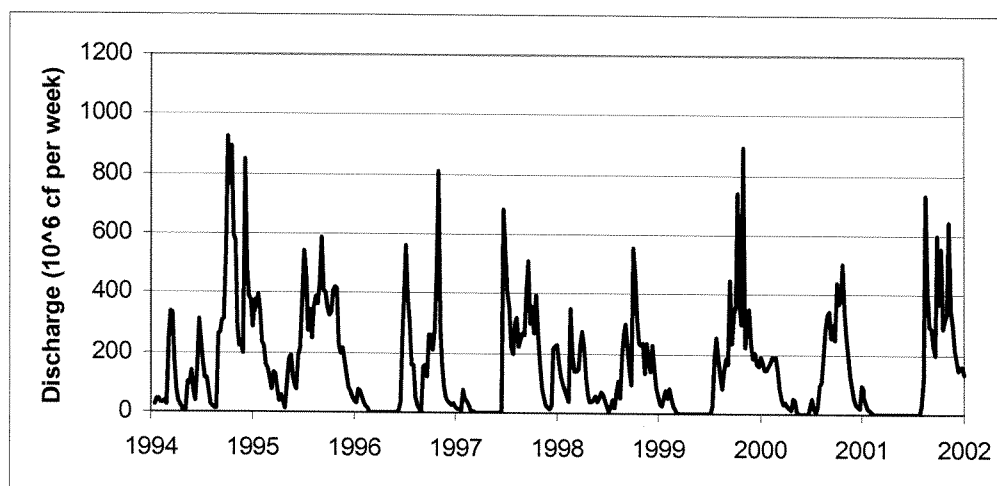


Figure 3.10: Verification of wetland hydrology models against independent USGS creek flow data

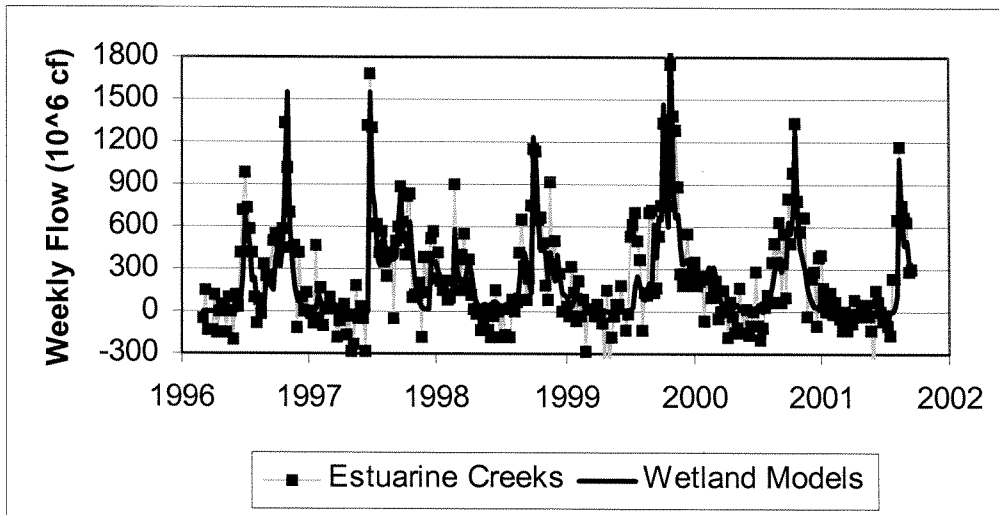


Figure 3.11: Residual creek discharge in excess of calculated wetland discharges; the seasonal model is the average of the residuals by month of the year (see Figure 3.x).

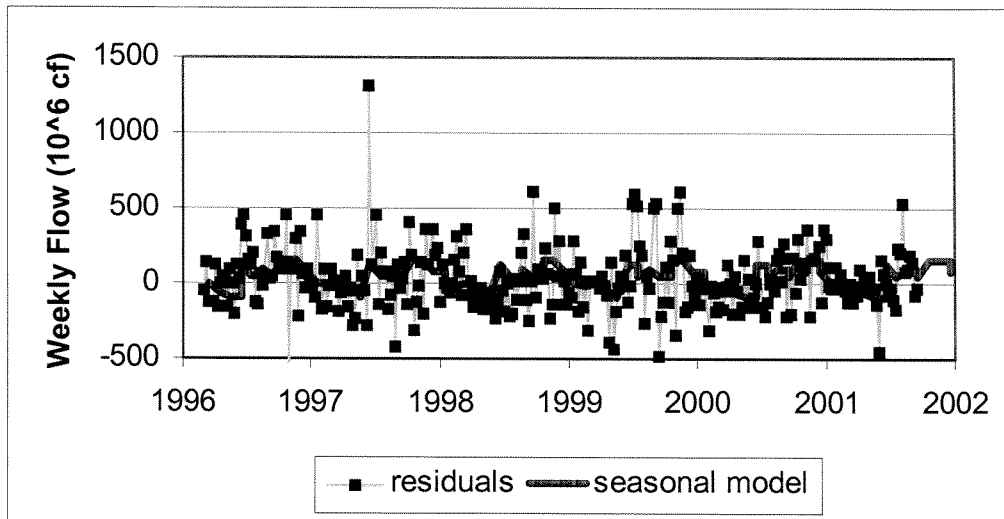
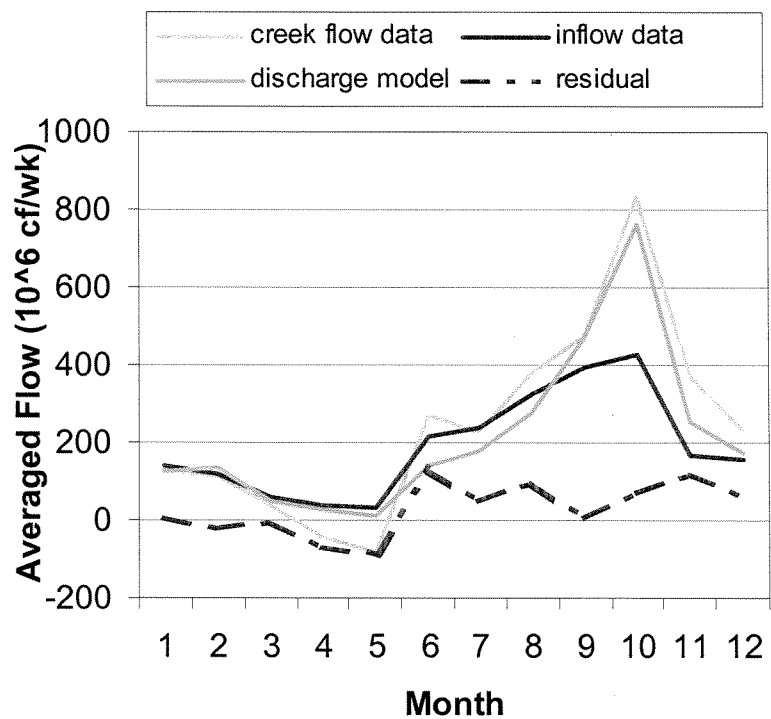


Figure 3.12: Monthly summary over 6 years of water balance results for the entire Taylor Slough/C111 area compares the total surface inflow with the sum of estimated discharge in the tidal creeks and the sum of the wetland basin hydrology model discharges.



3.2 Estuarine Salinity Models

Calibration and verification of estuarine basin salinity models uses information on salinity in estuarine basins and in the adjacent areas of Florida Bay. The monthly values of salinity in Florida Bay collected by Jones and Boyer (2001) provide the salinity information needed to calculate the effect of dispersive exchange between the estuarine basins and Florida Bay. Nuttle et al. (2001) aggregate the Florida Bay salinity data to produce time series of month-end values for four regions, Figure 3.13. Salinity in region 1 is the weighted average of salinity values measured monthly at Jones and Boyer (2001) stations 11, 22, 23, and 24, with weights calculated based on Thiessen polygons. Long Sound, Joe Bay and Little Madeira Bay exchange water with region 1.

Salinity data for the estuarine basins are from continuously monitored platforms in or near each of the basins. The salinity values used in this study are daily averages of the continuous data, sampled on the last day of each week. Data for the period 1994 through 2001 exhibit a gradient of generally increasing salinity values from east to west, Table 3.11.

Table 3.11: Summary statistics for salinity measured in the estuarine basins

	LS	JBTS	LM
Mean	14.4	12.5	19.8
Standard Deviation	8.8	10.2	6.0
Minimum	0	0	10.1
Maximum	36.5	37.2	32.4
Count	401	349	336

The structure of the estuarine salinity models remains as described by Nuttle and Teed (2002) with the exception that the Version 1.1 models do not include a salinity model for Terrapin Bay. This change is a direct consequence of redefining the domain of the wetland hydrology models to exclude the Long Pine basin. This alters slightly the allocation of wetland discharge as inflow into the estuarine basins, Table 3.12.

Calibration and verification of the estuarine salinity models follows the approach described by Nuttle and Teed (2002). The calibration procedure minimizes the sum of squared differences between observed and calculated salinity at week-end. Calibration was performed on the first half of the data period 1994 through 2001. Comparison of model prediction with measured salinity values in the second half of this period served as a verification of the model. The solver routine in Microsoft Excel was used to perform the calibration and estimate the single parameter value, the weekly exchange volume, for each estuarine basin.

Figure 3.13: Florida Bay can be divided into four regions based on observed patterns in water quality (Boyer et al 1997, Nuttle et al. 2000). Estuarine basin salinity models use time series of aggregated salinity values for region 1.

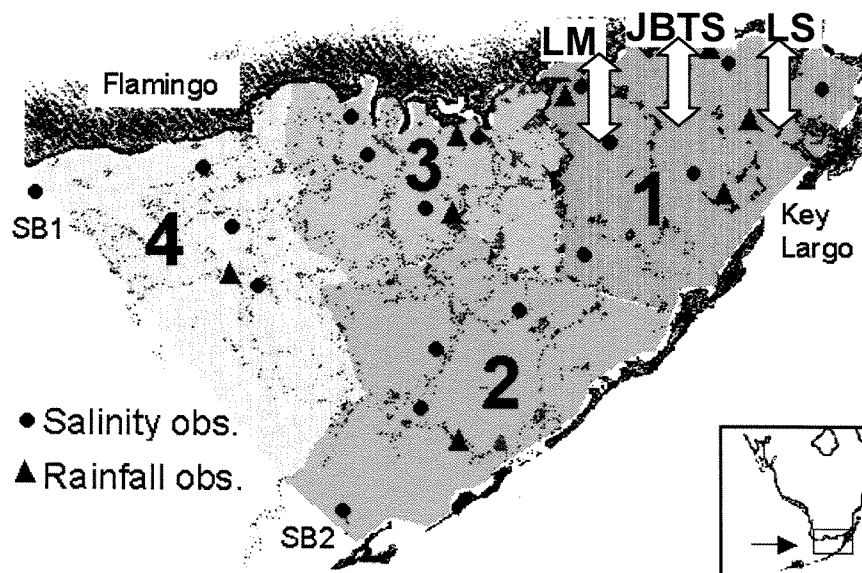


Table 3.12: Proportion of modeled discharge allocated as inflow for each estuarine basin salinity model and the corresponding creek discharge monitoring location

Estuarine Basin	Wetland Hydrology Model		Measured Creek Discharge	
	CP model	EPSW model	% of Total	
Terrapin Bay	0.00		0.02	McCormick
(none)	0.16		0.07	Mud Creek
Joe Bay	0.42	0.58	0.51	Trout Creek
Little Madeira Bay	0.39		0.14	Taylor River, East Creek
Long Sound		0.42	0.27	West Highway Creek, Stillwater Creek, Oregon Creek, East Highway Creek

The estuarine basin salinity models succeed in fitting the lower frequency seasonal and inter-annual variations in salinity during the calibration period, Figures 3.14, 3.15 and 3.16. Values of exchange volume determined by recalibration are essentially unchanged from Version 1.0 (Nuttall and Teed 2002). The models do not reproduce higher frequency salinity fluctuations (~0.5 per week) and some of the rapid decreases observed in the data. These appear to be related to rapid exchange associated with wind-driven storm tides.

The simulated values of salinity are less variable, i.e. lower variance, than the observed values because the salinity models do not account for all of the sources of variation present in the data. The salinity models only account for that portion of the variation in salinity that is caused by variation in freshwater inflow on time scales represented by weekly averaged values. Additional sources of variation present in the observed data, and not accounted for by the models, include variations in freshwater flow that occur on time scales less than a week and variations caused by discrete wind-driven exchanges of water between the estuarine basins and Florida Bay.

The salinity models explain over 50 percent of the variation in measured values of salinity, based on the r^2 values, Table 3.13. Model predictions in the second half of the data period continue to track seasonal and interannual patterns in salinity. Standard error is similar for both the calibration and verification periods, except in Joe Bay. The 95% confidence intervals, based on the standard error in the verification period, are also shown. These apply to the prediction of salinity observed at week-end.

The salinity in Joe Bay appears to be inherently more variable than in adjacent Long Sound. Large fluctuations occur especially in 1998 and 1999. These fluctuations appear different in character, i.e. more spiked, to those in other years. The winter of 1997-98 coincided with a strong El Nino event, and the entire southeast US was subject to extreme weather during this period. Later in 1998 and again in the fall of 1999, Florida Bay was affected by several hurricanes and large tropical storms. This suggests that the lower predictive power of the Joe Bay model during this period might be the result of a series of storm tides that enhanced exchange between Joe Bay and Florida Bay.

Figure 3.14: Calibration and verification of Joe Bay basin salinity model; inputs to model are predicted discharge from Taylor Slough and C111 hydrology and Florida Bay salinity (in red)

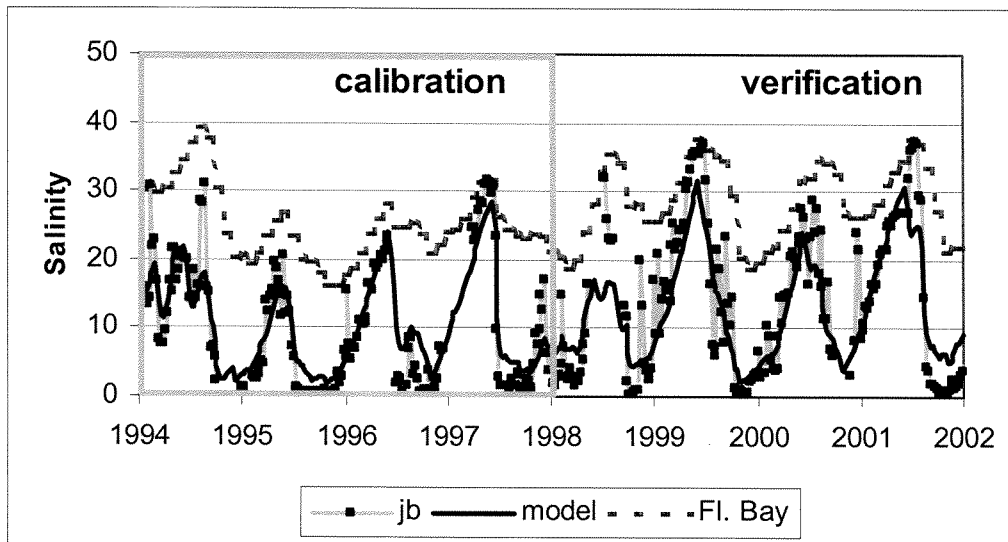


Figure 3.15: Calibration and verification of Long Sound basin salinity model; inputs to model are predicted discharge from C111 hydrology and Florida Bay salinity (in red).

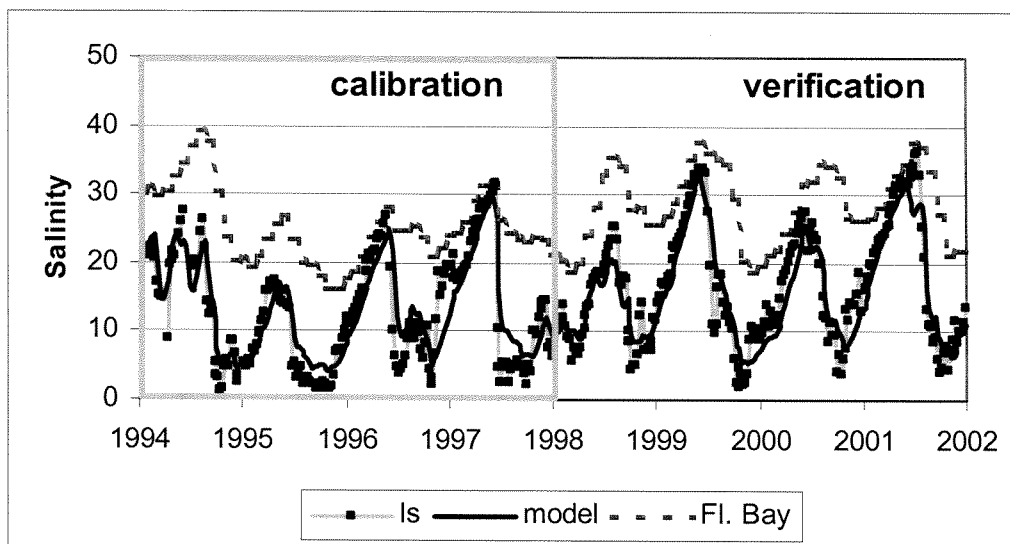


Figure 3.16: Calibration and verification of Little Madeira basin salinity model; inputs to model are predicted discharge from Taylor Slough and Florida Bay salinity (in red).

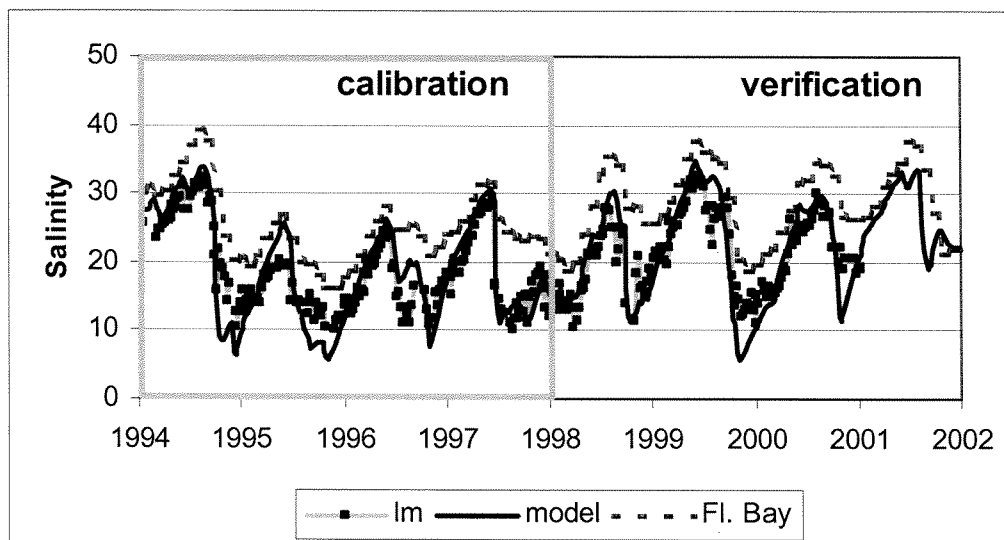


Table 3.13: Parameter values (exchange volume) and goodness-of-fit statistics for calibration and verification of estuarine basin salinity models (calibrated exchange volumes measured in millions cubic feet per week)

	Long Sound	Joe Bay	Little Madeira Bay
Exchange volume	58	60	75
Calibration Statistics:			
R-square	0.79	0.83	0.63
Bias (mean error)	0.52	0.70	0.49
Standard error	3.7	3.7	3.6
Verification Statistics:			
R-square	0.87	0.77	0.57
Bias (mean error)	-0.54	-0.71	0.25
Standard error	3.2	5.2	3.8
95% confidence interval (+/-)*	6.3	10.2	7.3

*based on assumed normal distribution

4 SFWMM SCENARIOS

This section describes the application of the refined wetland hydrology and estuarine salinity models, Version 1.1, with input from the SFWMM. Applied thus the wetland and estuarine models extend the results of the SFWMM scenarios into the coastal mangroves and provide a quantitative basis for evaluating differences among these scenarios based on their influence on coastal ecosystems. This evaluation depends on the differences in projected freshwater flows and salinities and on the uncertainties related to these projections. Therefore, characterization of these uncertainties forms an important part of this work.

The results reported here correspond to the application of the Version 1.1 wetland hydrology and estuarine salinity with five scenarios of the SFWMM, Table 4.1. These results do not include the analysis of single yearlong time series of surface flows generated for analysis of “marsh ops” with the MODBRANCH model.

Table 4.1: Summary of SFWMM scenarios examined in this report

Scenario	Description
Version 3.5 (V 3.5)	Reconstruction of actual hydrologic conditions for the period 1979 through 1995
Base 95 (V 4.4r13 95bm4)	Regional hydrology under operating rules as they existed in 1995 based on climate inputs from 1965 through 1995
Natural System Model (NSM V 4.5)	Regional hydrology under predevelopment conditions based on climate inputs from 1965 through 1995
ISOP (V 4.4r13 Altcur)	Regional hydrology under ISOP operations based on climate inputs from 1965 through 1995
IOP (V 4.4r13 IOP Alt7R)	Regional hydrology under IOP operations based on climate inputs from 1965 through 1995

Surface water flows calculated by the SFWMM substitute for inputs to the wetland hydrology models for the measured surface water inputs. Flow values calculated for the T23b transect substitute for the inflow measured at Taylor Slough Bridge plus the proportion of the S175 flow allocated to the Taylor Slough basin. Flow values calculated for the T23c transect substitute for the inflow measured as the difference of the S18C and S197 canal flows plus the proportion of the S175 flow allocated to the C111 basin. The wetland models also use the rainfall and evaporation amounts applied by the SFWMM in the vicinity of these transects.

The calculated values of discharge from the wetland models provide input into the calculation of estuarine salinity values related to the SFWMM scenarios. Calculation of salinity values in the central and northeast regions of Florida Bay, as a boundary condition on the calculation of salinity values in the coastal basins, requires additional rainfall and evaporation data over the Bay corresponding to the period of climate data used to drive the SFWMM. Generally, this period will be 1965 through 1995 for older versions of the SFWMM and 1965 through 2000 for the more recent versions. The rainfall data assembled by Nuttle et al. 2000 and the evaporation

estimated by Nuttle et al. 2001 serve this purpose. Salinity values are set to 35 psu at the western edge of Florida Bay, roughly corresponding to the Everglades National Park boundary.

4.1 SFWMM V3.5 Calibration/Verification

Application of the wetland hydrology and estuarine basin salinity models with the SFWMM introduces new sources of error on top of those documented in the preceding section. In order to estimate these errors, we analyze the results obtained from the application with the calibration/verification run SFWMM V3.5. The other SFWMM scenarios analyzed for IOP rely on the calibration/verification documented in Version 3.5.

Unfortunately, the period of climate data used in the calibration/verification of SFWMM V3.5, 1979 through 1995, overlaps by only two years with the period of data assembled for the calibration and verification of the wetland hydrology and estuarine salinity models. This complicates the effort to estimate the overall prediction error of the combined models. The water budget data assembled by Nuttle et al. 2000 are used to extend the inflow data set assembled by Nuttle and Teed 2002 to cover the entire period 1979 through 1995, but assessment of the error in salinity is restricted to comparisons in the two-year period.

The wetland inflow values calculated in the SFWMM V3.5 are compared with inflow data for the entire period 1979 through 1995, Table 4.2, and for the period 1994 through 1995, Table 4.3. No wetland discharge data exist prior to 1996 for comparison with the calculated discharge based on the SFWMM V3.5 scenario, but a comparison can be made between these calculated outflow values and values calculated from observed inflows, Table 4.4. The calculated salinity values based on the SFWMM V3.5 can only be compared with assembled salinity data for the period 1994 through 1995, Table 4.5; also shown for comparison are salinity values calculated based on observed wetland inflow.

Absent other guidance, the comparisons between model results and observation and between scenarios reference the mean surface water discharge from the two wetland basins, Taylor Slough and C111, Tables 4.2, 4.3 and 4.4. Similarly, comparison of salinity values in the three estuarine basins, Long Sound, Joe Bay and Little Madeira Bay, and in the northeast and central regions of Florida Bay reference the mean and standard deviation, Table 4.5.

The discrepancy between observed surface inflows and inflows estimated based on SFWMM V3.5 is much larger for the shorter period (22%, Table 4.3), 1994 through 1995 than for the period 1979 through 1995 (8%, Table 4.2). This translates into a large discrepancy in wetland outflows for the shorter period (49%, Table 4.4) and in calculated salinity values, Table 4.5. These results are inconclusive with respect to the expected magnitude of errors associated with predicting wetland outflows and salinity values based on the SFWMM for the period of climate data 1965 through 1995; however these errors are likely not as large as suggested by comparison for the shorter period of 1994 through 1995.

Table 4.2: Comparison of mean surface inflows into wetland basins for period 1979 through 1995 from SFWMM V3.5 and measurements (cfs)

	T23b	T23c	T23b+T23c
SFWMM V3.5	93	169	263
Data:			
TSB	43		
S175*	31	30	
C111 – S197		181	
			285
Percent error**			8

* Proportion of S175 flow counted as inflow to wetland models

** Error in inflow based on SFWMM V3.5

Table 4.3: Comparison of mean surface inflows into wetland basins for period 1994 through 1995 from SFWMM V3.5 and measurements (cfs)

	T23b	T23c	T23b+T23c
SFWMM V3.5	153	218	372
Data:			
TSB	115		
S175*	32	32	
S18C – S197		298	
			477
Percent error**			22

* Proportion of S175 flow counted as inflow to wetland models

** Error in inflow based on SFWMM V3.5

Table 4.4: Comparison of mean outflow for the period 1994 through 1995 calculated by the wetland hydrology models from inflow data provided by SFWMM V3.5 and from inflow data provided by measured inflow at Taylor Slough Bridge, S175 and the C111 canal (cfs)

	Taylor	C111	Total
SFWMM V3.5	129	182	311
Data	217	387	604
percent error*			49

* Error as based on SFWMM V3.5 input compared to calibration run

Table 4.5: Comparison of monthly salinity values, calculated based on input to the wetland basins from the SFWMM V3.5 and from measured inflows, with measured salinity for the period 1994 through 1995.

	Little Madeira	Joe Bay	Long Sound
SFWMM V3.5:			
mean	28.7	22.5	25.7
standard dev.	7.8	7.1	7.3
rms error*	10.2	14.3	15.6
Measured inflow:			
mean	19.3	9.6	12.5
standard dev.	7.6	6.4	7.2
rms error*	3.0	4.3	3.0
Measured salinity:			
average	19.7	10.1	10.8
standard dev.	6.7	8.4	7.7

* root mean square error in calculated salinity

The deviation between calculated and observed salinity values is consistent among the different coastal basins, and the range of variation for salinity in a basin (i.e. standard deviation) is preserved. This is consistent with the discrepancy in the SFWMM V3.5 flows being a major factor contributing to this deviation. These results suggest that salinity values calculated based on SFWMM scenarios can be used to assess the effects of one scenario relative to another as long as reference to absolute values of salinity are avoided.

The results reported above rely on **monthly averaged** inflow data from the SFWMM. This introduces another source of error because the wetland hydrology and estuarine salinity models are calibrated and validated with weekly data on water balance fluxes. The sensitivity of the wetland discharge and estuarine salinity calculations to using monthly averaged inflows was evaluated by comparing discharge and salinity calculations based on weekly hydrologic data and on a six-week running average of these same data. The results of this sensitivity analysis suggest that the errors in calculated mean flows and salinities are generally less than 3% for the calibration and verification period 1996 through 2000. These results suggest that the difference between weekly and monthly aggregation of the water budget data cannot account for errors of the magnitude discussed above.

4.2 Comparison of SFWMM Scenarios

This section compares the four SFWMM scenarios based on the 1965 through 1995 climate period, Table 4.1, in terms of the flows in the wetland models, Table 4.6, and the estuarine salinity values calculated from these flows, Tables 4.7 and 4.8. Clear differences are seen between the Base 95 scenario compared to the IOP, ISOP and NSM scenarios, in terms of mean flow and mean salinity values, with the Base 95 scenario providing more inflow into the wetlands and producing lower mean salinity values in the estuaries. There is comparatively little difference among the IOP, ISOP and NSM scenarios in terms of mean inflow and mean values of estuarine salinity. In contrast to results for mean salinity values, differences among the SFWMM scenarios in terms of the standard deviation of calculated salinity values are small.

Table 4.6: Comparison of wetland basin inflow and calculated discharge to estuaries based on SFWMM and climate inputs for the period 1965 through 1995 (cfs)

Scenario	Inflow from SFWMM			Calculated Wetland Discharge		
	T23b	T23c	T23b + T23c	Taylor Slough	C111	Total
SFWMM V3.5*	93.5*	169.8*	263.3*	66.3*	130.6*	196.9*
B1995 V4.4	247.4	132.6	379.9	287.5	255.9	543.5
IOP	95.3	57.8	153.1	101.6	49.8	151.4
ISOP	91.1	58.8	149.9	97.9	50.3	148.2
NSM V4.5	108.0	70.3	178.3	113.7	64.1	177.8

* covers only the period 1979 through 1995

Table 4.7: Summary of salinity values at various locations calculated based on input from SFWMM scenarios; reported as estimated means and associated uncertainty (as standard error)

Scenario	North-east*	Central*	Little Madeira	Long Sound	Joe Bay
B1995 V4.4	31.0	36.5	27.2	24.4	20.9
	(0.6)	(0.4)	(0.3)	(0.3)	(0.3)
IOP	41.8	41.6	37.5	33.4	28.8
	(0.6)	(0.4)	(0.3)	(0.3)	(0.3)
ISOP	41.8	41.6	37.5	33.6	28.8
	(0.6)	(0.4)	(0.3)	(0.3)	(0.3)
NSM V4.5	40.9	41.2	36.6	32.6	28.2
	(0.6)	(0.4)	(0.3)	(0.3)	(0.3)

* regions within Florida Bay

Table 4.8: Summary of salinity values at various locations calculated based on input from SFWMM scenarios; reported as estimated standard deviations

Scenario	North-east*	Central*	Little Madeira	Long Sound	Joe Bay
B1995 V4.4	10.7	7.5	11.3	10.3	10.1
IOP	11.4	8.1	12.3	11.6	11.7
ISOP	11.0	7.9	11.9	11.3	11.5
NSM V4.5	12.4	8.3	13.1	12.2	12.2

* regions within Florida Bay

The cause of the higher surface flow values in the Base95 scenario, compared with the other SFWMM scenarios examined, lies either with how these alternative water management scenarios are defined or with how they have been implemented within the SFWMM. Surface flows from the SFWMM supply boundary conditions to the wetland hydrology and estuarine salinity models, and the flow time series are taken directly from the SFWMM output supplied for these scenarios. This discrepancy in surface flows, and the resulting effect on projected estuarine salinity values is also evident in the application of the Version 1.0 wetland hydrology and salinity models to the analysis of SFWMM scenarios reported in the appendix to Nuttle and Teed (2002).

The discrepancy in surface flow into Florida Bay between Base95 and other SFWMM scenarios also caught the attention of a review committee of the National Research Council (NRC 2002, page 10). The committee explains this difference as follows:

From Figure 3 [in NRC (2002)] it can be seen that more water flows into the Eastern Panhandle under the 1995 Base or “current condition” relative to the NSM simulation. This is reduced under alternative D13R4 (a scenario based on D13R that would capture additional water “lost” to tide). The surplus ($119,000 - 50,000 = 69,000$ acre-ft per year (8.5×10^7 cubic meters per year)) would be redirected upstream into Shark River Slough and downstream to a very small degree into Craighead Basin and Taylor Slough, in an effort to replicate NSM flows (although CERP flow targets may differ from NSM estimates). Hence, simulated fresh surface water flows to Florida Bay through Craighead Basin and Taylor Slough increase only minutely from $32,000 + 94,000 = 126,000$ acre-ft per year (15.5×10^7 cubic meters per year) under the 1995 Base scenario to $45,000 + 82,000 = 127,000$ acre-ft per year (15.6 cubic meters per year) under the D13R4 scenario. The Taylor Slough flow under the D13R4 scenario would be close to the NSM-estimated flow shown in Figure 3 [in NRC (2002)].

5 CONCLUSIONS AND RECOMMENDATIONS

Progress can be reported in two areas. First, refinements to the wetland hydrology and estuarine salinity models described by Nuttle and Teed (2002) have addressed several recognized sources of error. Second, the models have been applied to extend the results of SFWMM scenarios into the mangrove wetlands and estuarine salinity.

The refined Version 1.1 wetland hydrology models are improved in their accounting of surface inflow, based on observations, and estimation of evaporation. A large bias in the predicted wetland discharge has been reduced, and salinity predictions are moderately improved. Results from the USGS Southern Inland Coastal Salinity (SICS) model reinforce the earlier assessment based on results of field investigations that groundwater flow does not contribute significantly to the long term surface water budget in these wetlands. At present, not enough is known about the water budget and patterns and magnitude of surface flow in the Long Pine basin to predict freshwater discharge from this area.

Efforts to estimate the total prediction error for estuarine salinity based on values of wetland inflow from the SFWMM proved to be inconclusive. Largely this is due to the fact that the SFWMM output that was anticipated to be available during the planning stages of this work could not be acquired in a timely manner. And the period of climate data for calibration/verification scenario that was available and applicable, SFWMM V3.5, overlapped by only two years with the salinity data that had been assembled for the project. Compared to the rest of the calibration/verification period it appears that the inflows calculated by the SFWMM for these two years are anomalously low relative to observed inflows. For this reason the resulting error in the calculated mean values of discharge and salinity should not be taken as indicative of the mean prediction error.

In spite of these difficulties, the comparison of predicted discharge and salinity for the four SFWMM scenarios applicable to the IOP analysis indicate that the Base 95 scenario provides significantly more surface flow into the Taylor Slough and C111 wetland than the IOP, ISOP and NSM scenarios. As a result, the calculated mean salinity values are significantly lower for the Base 95 scenario compared to the other scenarios. These results are consistent across all of the estuarine locations analyzed. There is relative little difference among these scenarios in terms of the range of variation of calculated salinity values around the mean.

5.1 Recommendations for data collection

A monitoring program should be undertaken to measure evapotranspiration in the mangrove wetlands in the southeast portion of Everglades Park. Evapotranspiration is potentially the largest single flux of freshwater in the wetland water budgets. The evapotranspiration model developed in this work relies on evaporation measurements in other vegetative communities in South Florida. Analysis of these data by German (2000) demonstrate that evapotranspiration is sensitive to local characteristics of the vegetation and of patterns of surface flooding.

A coordinated effort is needed to construct and validate a water budget for the Long Pine basin, with special attention to estimating discharge into the central region of Florida Bay. The series

of salinity maps compiled by NOAA and by USGS with coverage in this region could be analyzed to estimate ungaged freshwater discharge from this region.

5.2 Recommendation for model application

The steps taken in this report to apply the Version 1.1 wetland hydrology and estuarine salinity models with input from the SFWMM should be repeated with output from scenarios based on the recent recalibration of the SFWMM when these become available. The effort to estimate the composite error for predictions of wetland discharge and estuarine salinity should be repeated.

6 REFERENCES

- Genereux, D. and E. Slater, 1999. Water exchange between canals and surrounding aquifer and wetlands in the Southern Everglades, USA. *Journal of Hydrology* 219:153-168.
- German, E.R., 2000. Regional Evaluation of Evapotranspiration in the Everglades. Water-Resources Investigations Report 00-4217. U.S. Geological Survey, Tallahassee, FL.
- Hittle, C., E. Patino, and M. Zucker, 2001. Freshwater Flow from Estuarine Creeks into Northeastern Florida Bay. Water-Resources Investigations Reports 01-4164, US Geological Survey, Tallahassee, Florida.
- Nuttle, W.K. and S. Teed, 2002. Estuarine Salinity Models in the Taylor Slough/C111 Area. Progress report submitted to Everglades National Park on GSA Order Number D5284020058. December 2002.
- Nuttle, W.K., J.W. Fourqurean, B.J. Cosby, J.C. Zieman, and M.B. Robblee, 2000. The influence of net freshwater supply on salinity in Florida Bay. *Water Resources Research* 36:1805-1822.
- Nuttle, W.K., R. Price, and P.K. Swart, 2001. Estimating evaporation from Florida Bay. page 102 in Conference Abstracts, 16th Biennial Conference of the Estuarine Research Federation, November 2001, St. Pete Beach, Florida.
- Price, R. 2001. Geochemical determinations of groundwater flow in Everglades National Park, Ph.D. dissertation, University of Miami, Coral Gables, FL, 307pp.
- Sutula, M., J.W. Day, J. Cable, and D. Rudnick, 2001, Hydrological and nutrient budgets of freshwater and estuarine wetlands of Taylor Slough in Southern Everglades, Florida (U.S.A), *Biogeochemistry*, 56, pp. 287-310.

Application of Wetland Hydrology and Salinity Models to IOP Review

Report of Meeting with Eric Swain, 14 August 2003

Purpose: to compare notes on reconstruction of the wetland water budget in the Taylor Slough/C111 area of Everglades National Park used in the mass-balance modeling approach and in the USGS SICS model.

Our discussions focused on identifying the likely sources of the residual error in modeled wetland discharge through the coastal mangroves compared to the aggregate estuarine stream flow measured at the USGS gauging stations. The report on version 1.0 of the mass balance models documents this residual flow (Nuttle and Teed 2002). Below, I summarize these discussions and the proposed follow-up analysis on each of the likely sources of error considered.

Discharge from the L31W canal through structure S175 – This discharge is neglected in the current compilation of the water budget based on advice from Park hydrologists and the study by Genereux and Slater (1999) that suggest that surface water discharged from the S175 is recaptured by the C111 canal above the S18C structure before it reaches the coastal mangroves. Therefore, including this discharge in a wetland water budget that also includes discharge from the C111 canal below the S18C structure amount to a double accounting of this water source. Flow paths generated by the USGS SICS suggest that a significant portion of the S175 discharge finds its way into Taylor Slough.

Follow-up analysis – Examine discharge data for the S175 structure in comparison to other sources of surface water in the wetland models. If S175 appears to be a significant source, then include as a factor in the recalibration of the wetland hydrology models.

Discharge from Long Pine basin – This discharge is neglected in the current compilation of water budget based on lack of information on the water budget and surface water flow paths in this region. Although excess rainfall over evapotranspiration in this large area represents a possibly large source of surface water; an unknown portion of this water exits north and west across the Park road to Flamingo. Representation of surface flows in this area is also problematic for the SICS model; however, model results show that rainfall in this basin contributes flow into the lakes area east of Flamingo and into Garfield Bight through Alligator Creek and into Terrapin Bay through McCormick Creek. Including discharge from these creeks in the comparison between measured and models wetland flows would contribute to the apparent error in total outflow from the Taylor Slough and C111 basins.

Follow-up analysis – Remove discharge data for Alligator Creek and McCormick Creek from comparison with modeled wetland flows. Review basis for modeling salinity in Terrapin Bay if freshwater discharge depends on unknown water budget in the Long Pine basin.

Groundwater surface water exchange – The current version of the mass-balance models do not account for any contribution of groundwater to the surface water budget and subsequent discharge through the coastal mangroves. We examined summary output for groundwater discharge to the surface from a SICS model run for the period 1995 through 1999. It appears

that the total groundwater discharge to the surface on an annual basis for the entire SICS model domain is on the order of one cubic meter per second. This is small relative to measured creek flow and other components of the surface water budget.

Follow-up analysis – Review the preliminary analysis of these SICS model results in light of comments and data by Dr. Rene Price, reported by Nuttle and Teed (2002) and hydrologic measurements reported by Sutula et al. (2001).

Rainfall excess over evapotranspiration – Rainfall and evapotranspiration dominate the wetland water budget. The difference of rainfall in excess of evapotranspiration is a major factor contributing to discharge through the coastal mangroves. In turn, rainfall excess is highly sensitive to errors in estimating the regional weekly fluxes of rainfall and evapotranspiration for input into the wetland hydrology models. Of these, uncertainty in evapotranspiration is the greater potential source of error. Both the mass balance model and the SICS model rely on evapotranspiration measurements by German (2000). But where the mass balance models use the median value of all of German's sites to scale a seasonal distribution, the SICS model calculates daily value of evapotranspiration based on water depth. This has the effect of suppressing evapotranspiration when the surface of the wetland goes dry. A twenty percent reduction from the median value appears possible, based on German's (2000) figure 16.

Follow-up analysis – Review alternative approaches to estimating weekly evapotranspiration in the mass balance models in light of the results reported by German (2000) and other studies on evapotranspiration in South Florida that have recently become available. Formulate and test alternative approaches by performing sensitivity analyses with wetland discharge. Also review approach to estimating weekly amounts of rainfall.

References

- Genereux, D. and E. Slater, 1999. Water exchange between canals and surrounding aquifer and wetlands in the Southern Everglades, USA. *Journal of Hydrology* 219:153-168.
- German, E.R., 2000. Regional Evaluation of Evapotranspiration in the Everglades. Water-Resources Investigations Report 00-4217. U.S. Geological Survey, Tallahassee, FL.
- Nuttle, W.K. and R.S. Teed. 2002. Version 1: wetland hydrology and estuarine salinity models for the Taylor Slough/C111 area. Report prepared for the Everglades National Park. The Cadmus Group, Inc. Watertown, MA 02472. 44 p. (+ appendix).
- Sutula, M., J.W. Day, J. Cable, and D. Rudnick, 2001, Hydrological and nutrient budgets of freshwater and estuarine wetlands of Taylor Slough in Southern Everglades, Florida (U.S.A), *Biogeochemistry*, 56, pp. 287-310.