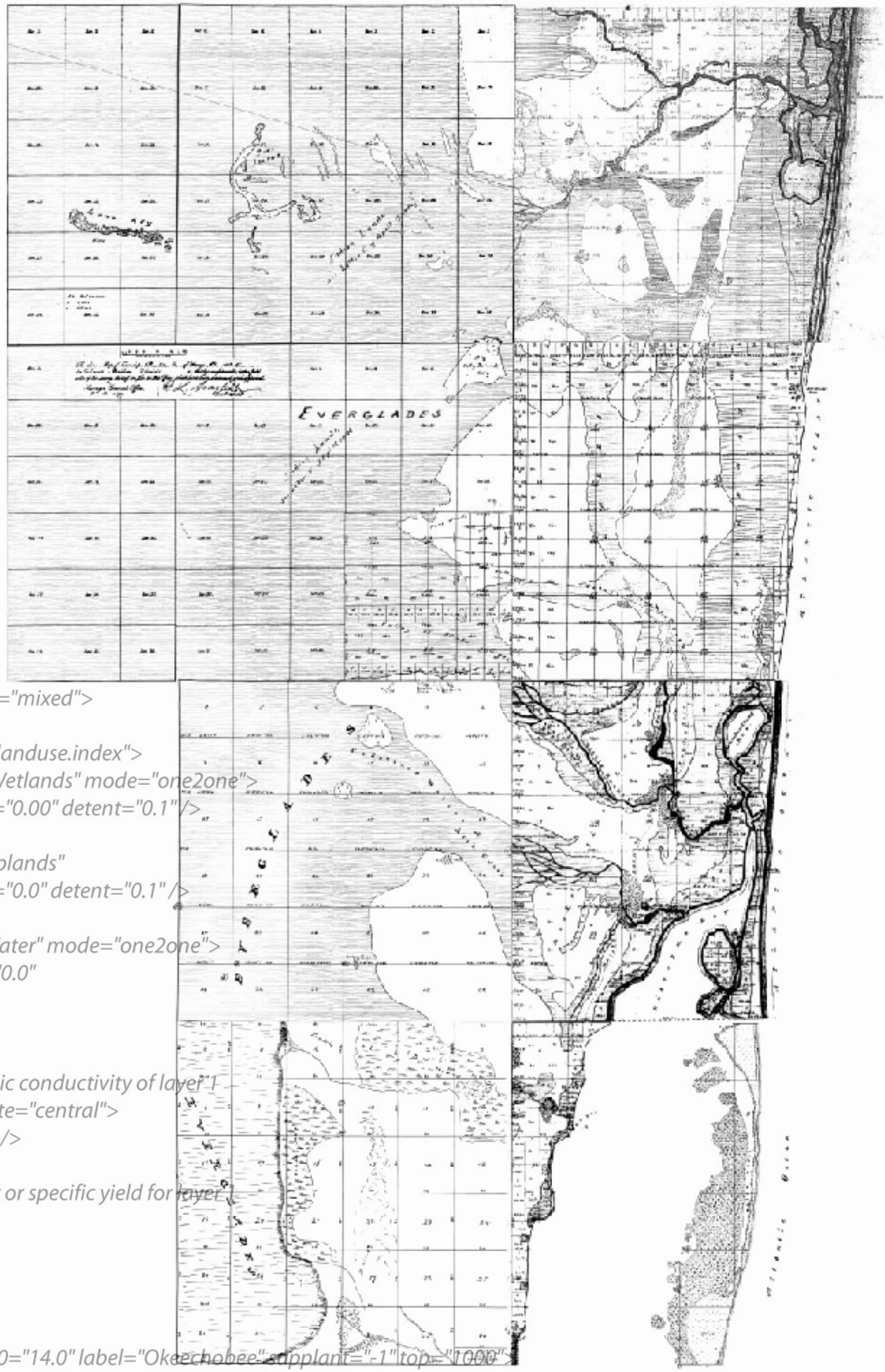
NSRSM



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NATURAL SYSTEM REGIONAL SIMULATION MODEL (NSRSM) V2.0 IMPLEMENTATION REPORT

PREPARED BY:

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Chapter 1 Executive Summary

Recent technological advances in hydrologic modeling at the SFWMD have resulted in the development of the "next generation" Regional Simulation Model (RSM). RSM is a finite-volume based computer model that simulates multi-dimensional and fully integrated groundwater and surface water flow. This report documents RSM application to the Natural System Regional Simulation Model (NSRSM).

The NSRSM simulates the historical hydrology (ca. 1850) for approximately 12,000 mi^2 (7.7 million acres) of pre-drainage south Florida including 5,000 mi^2 (3 million acres) of Everglades wetlands. The RSM hydrologic simulation engine (HSE) has been proven highly effective in modeling the processes that influenced pre-drainage hydrology in south Florida; slow overland flow through flat but micro topographically varied landscapes, prolonged recession associated with storage, and a system primarily driven by rainfall and evapotranspiration tuned to south Florida's characteristic annual wet and dry cycling with seasonally fluctuating water levels.

Model input was painstakingly assembled from the best information available with which to characterize pre-drainage system conditions. NSRSM input data development is thoroughly documented in this report (e.g. topography, reference evapotranspiration, landcover, river network development, etc…) with the intention of exposing it to critical review.

Although standard calibration procedures cannot be applied to NSRSM, an evaluation was conducted to provide information for application and interpretation of results. Model performance was evaluated for correspondence to reference ranges compiled from published and peer reviewed literature.

Results were evaluated at the landscape level for long term average performance (1966-2000), as well as average, wet and dry year simulated conditions. Performance measures include inundation duration (hydroperiod), and seasonal water depths. Regional system simulation results were evaluated for long term average annual and seasonal (wet/dry) performance. Surface water flows are calculated for selected transects, and water budgets were designed for ease of comparison to existing models.

Model performance relative to inundation duration and water levels had good correspondence to reference ranges, particularly in the Everglades Basin. Simulated overland and river flows are comparable to observed natural system distribution, directionality and volumes.

A scientific peer review will provide expert opinion on model implementation and the validity of model performance. It is expected that the panel report will provide modelers, stakeholders, and management with information benefiting NSRSM application.

Chapter 2--Introduction

For over a century, the South Florida ecosystem has been affected by canal drainage, the channelization of its natural rivers, and other associated development. Over time, the cumulative effects of altered quantity, quality, timing and distribution of water have resulted in significant habitat deterioration and loss throughout the natural system. In an effort to reverse this trend and ultimately affect sustainable habitat while balancing the needs of a rapidly developing state, two decisive acts of Congress were passed in the 1990s that set the stage for hydrologic restoration initiatives: the authorization of the Kissimmee River Restoration Project designed to restore 43 miles of meandering river channel and 27,000 acres of wetlands, and the reauthorization of the Central and South Florida (C&SF) Project for Flood Control and Other Purposes, resulting in the implementation of the Comprehensive Everglades Restoration Plan (CERP) designed to restore the Everglades ecosystem while maintaining adequate flood protection and water supply for south Florida.

Restoration strategies require an understanding of regional system hydrology prior to drainage and development. Natural system modeling has been used, in combination with other adaptive management tools, in restoration plan formulation and target setting. For this purpose, a regional scale two-dimensional coupled surface/ground water Natural System Model (NSM) for south Florida was implemented to establish "…a tool which mimics natural and, *eventually*, pre-drainage hydrology, within the limitations of recorded history… to provide insight in evaluating alternatives for future restoration initiatives" (Fennema *et al*, 1994). The NSM uses the same climatic input, computational methods, and model parameters calibrated and verified by the managed system model (SFWMM) in order to simulate the hydrologic response of the natural system to current hydrologic input. Intensive applications of this tool during the C&SF Project Restudy, CERP, and several Water Supply Planning efforts made it a significant component of the planning process.

Recent technological advances and improved knowledge of natural system features has resulted in the implementation of the "next generation" NSM. Using Regional Simulation Model (RSM) governing equations, numerical methods, and object oriented software design developed at the SFWMD, the Natural System Regional Simulation Model (NSRSM), documented in this report, has been implemented concurrently with its counterpart, the managed system RSM. RSM is a finite-volume based computer model that simulates multi-dimensional and fully integrated groundwater and surface water flow. The RSM hydrologic simulation engine (HSE) is extremely applicable to the unique hydrologic processes and geologic features in pre-drainage south Florida, such as storage and flows through a flat but microtopologically varied ridge and slough landscape.

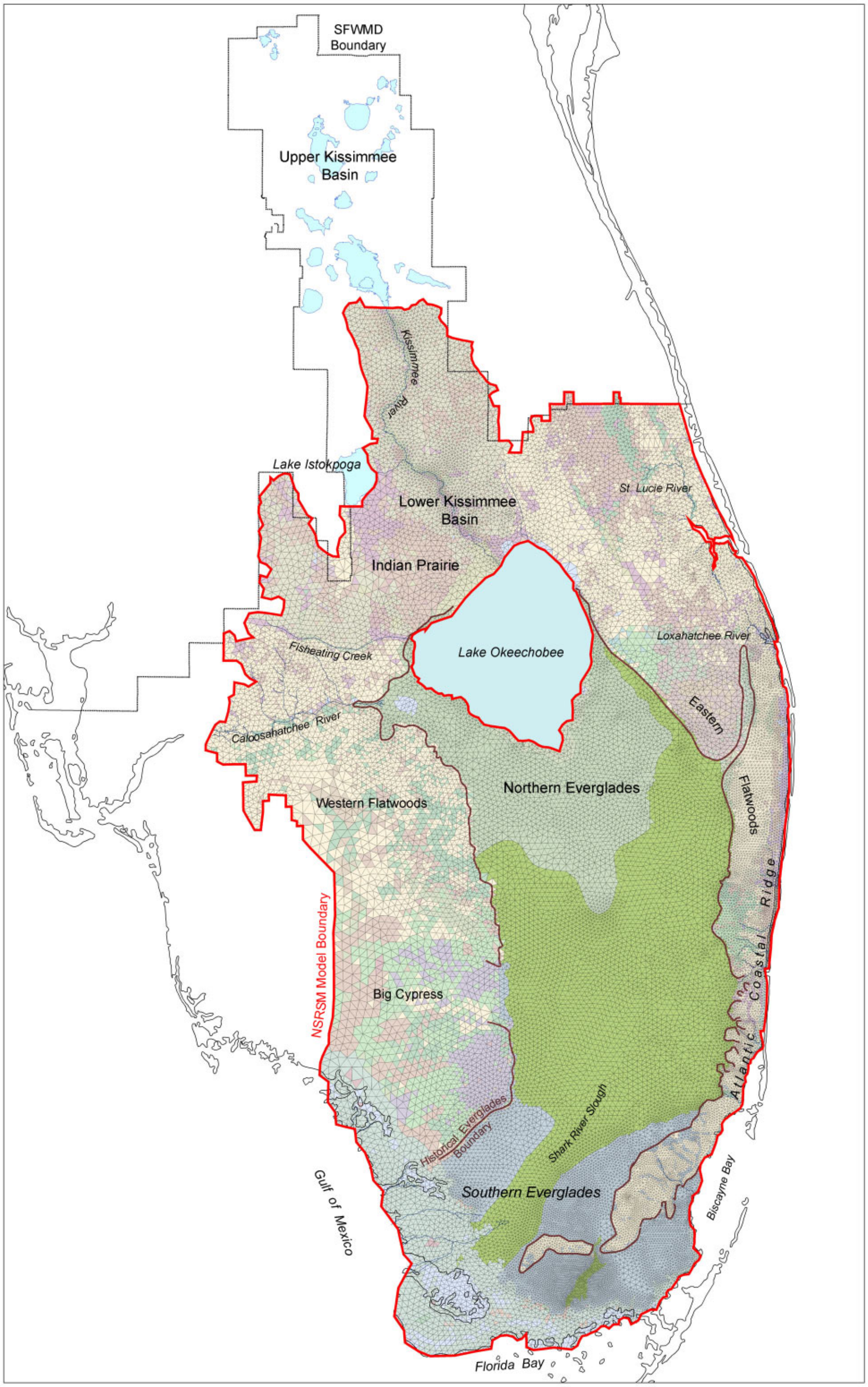
The NSRSM, like its predecessor the NSM, simulates the natural system hydrology of south Florida prior to canal drainage and compartmentalization. However, the availability of long-term climatic data and refined parameter input (e.g. topography) in combination with the model's improved HSE has resulted in simulations that reasonably represent *pre-drainage* (ca. 1850) hydrology in south Florida.

This report summarizes natural system hydrology (Chapter 3 and Appendix A), describes the development of input data and RSM application to the natural system (Chapter 4 and Appendices), and presents model results for the Base Condition (Chapter 5).

The base simulation uses the same climatic input (rainfall, PET) as the managed system models allowing for comparison of results. Physical parameters, including the natural system river network, landcover, and topography, are based on pre-drainage conditions. Model parameters such as soil storage and ET coefficients were developed based on reasonable values from literature with reference to south Florida ecosystems where possible. Calibrated parameters from current system models were not used in order to avoid introducing artifacts of drainage.

In order to provide insight on the long term hydrologic effects of climate fluctuations and cyclic patterns, an Extended Period of Record (EPOR [1895-2005]) simulation is in preparation. In addition to the pre-drainage physical parameters, this simulation will use rainfall and PET input generated from assimilated climate models including the Parameter-Elevation Regressions on Independent Slopes Model (PRISM). While a PET dataset has not yet been finalized for the extended period of record, a rainfall time series from 1895-2005 has been prepared. Historical weather data from PRISM was used for developing a long-term (1895-2005) rainfall database. This data was used to calculate reference periods of wet, dry and average conditions for evaluation of base condition results (**Appendix C.3**).

Although standard calibration procedures cannot be applied to NSRSM, verification was conducted to provide information for application and interpretation of model results. Model performance was evaluated for correspondence with reference ranges compiled from published and peer reviewed literature. Performance measures include inundation duration (hydroperiod), water depth range, flow transects, and water budgets.



1
2 **Figure 1.** Physiographic regions within the NSRSM domain

Chapter 3- Natural System Hydrology

The NSRSM simulates the historical hydrology for approximately 12,000 mi^2 (7.7 million acres) of pre-drainage south Florida (**Figure 1**) including 5,000 mi^2 (3 million acres) of Everglades wetlands (twice the current extent). The Everglades were part of the much larger (11,000 mi^2) Kissimmee-Okeechobee-Everglades (KOE) system extending 310 mi north to south, and 62 mi east to west (Light and Dineen, 1994). The KOE includes the Kissimmee River, Lake Okeechobee basin, Lake Okeechobee, and the Everglades basin.

Physiographic regions flanking the KOE include the Western Flatwoods (including the Caloosahatchee River), and Big Cypress basins to the west, and to the east -the St. Lucie River and Loxahatchee River watersheds, and the Eastern Flatwoods/Atlantic Coastal Ridge system (**Figure 1**).

In the natural system, rainfall run-off from the Okeechobee basin was delivered to Lake Okeechobee, a large (730 mi^2) but relatively shallow water body, via the Kissimmee River. The Okeechobee Basin contains distinct watersheds (**Table 1**), which are associated with major surface flow features (Figure 2). Distinct upper and lower sections exist within the Kissimmee River watershed. The upper section is part of the Lake Region of central Florida and is characterized by a high degree of natural detention in numerous lakes, which overflow across wide shallow marshes into lower lakes during the normally wet summer months and during periods of heavy rainfall (Parker, 1955). The lower section (within the NSRSM domain) includes the Kissimmee River, which begins at the outlet of Lake Kissimmee.

Table 1. Watersheds in the Okeechobee Basin

Basin	Area ($miles^2$)
Upper Kissimmee River Basin	1596.15
Lower Kissimmee River	727.1
Upper Lake Istokpoga Basin	601.0
Lower Istokpoga Basin	552.9
Fisheating Creek	550.0
NE Peripheral Basins	216.2
Lake Okeechobee Basin Total	4243.7

In its natural state, the Kissimmee River meandered through a nearly flat valley. At low water levels, water flowed through a clearly defined channel and under wetter conditions the entire flood plain was inundated. In contrast to the upper section, there are fewer lakes in the lower Kissimmee section.

The Istokpoga watershed can also be divided into two sections. The upper section is drained by Arbuckle Creek and Josephine Creek which discharge directly into Lake Istokpoga. The lower section is located between Lake Istokpoga and Lake Okeechobee, and is commonly referred to as Indian Prairie. Prior to drainage activity in the Indian

Prairie, Lake Istokpoga would seasonally overflow its southeastern banks, and water would move towards Lake Okeechobee as overland flow. The Okeechobee Basin also includes watersheds drained by Fisheating Creek, and peripheral creeks and sloughs north and northeast of Lake Okeechobee, including Taylor Creek and Nubbin Slough. (Okeechobee Basin description adapted from NSM documentation, VanZee, 2000).

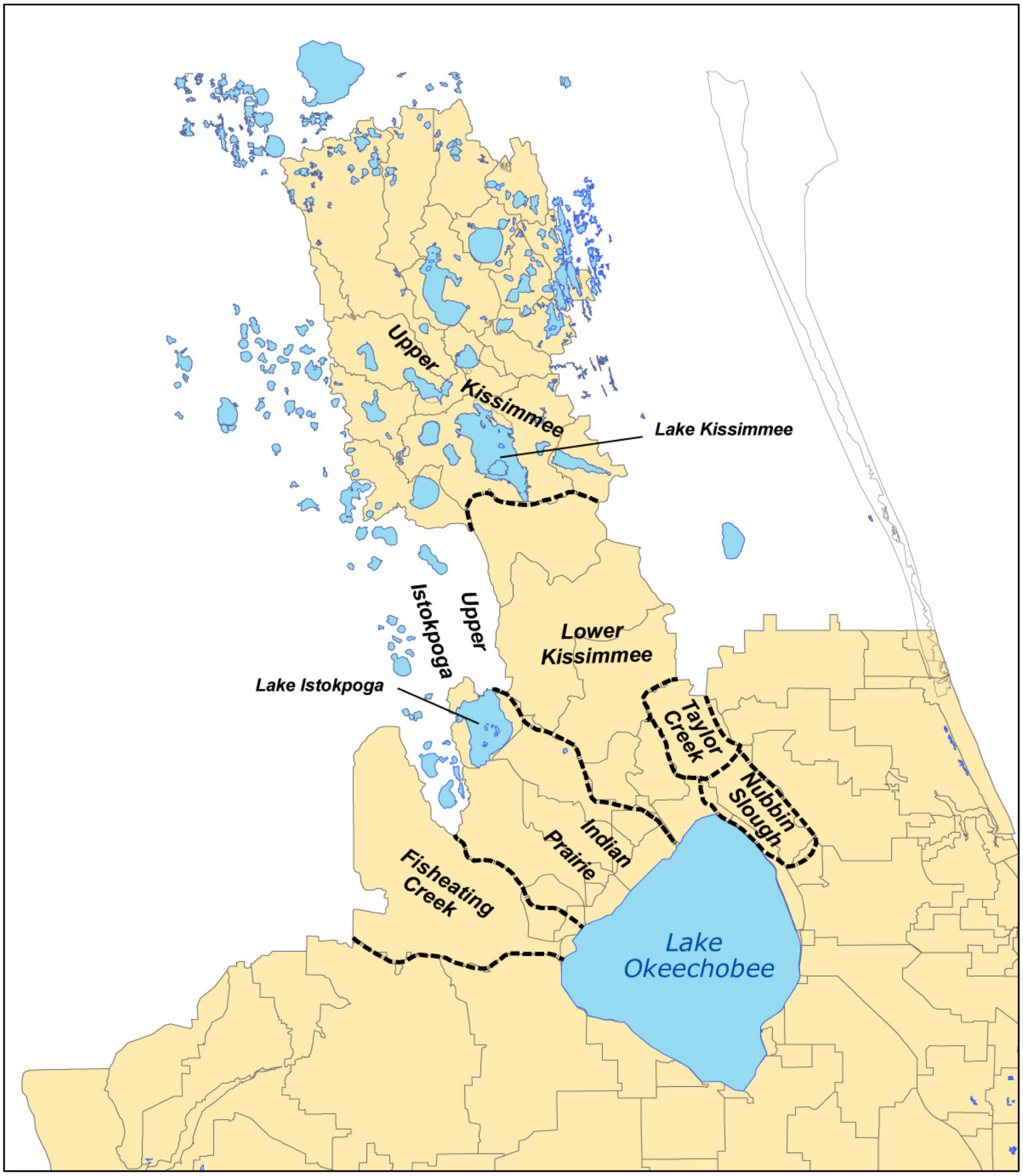


Figure 2. Lake Okeechobee Basin

Lake Okeechobee functioned as the “heart” of the Everglades keeping it inundated most of the year. When inflows less evaporative losses exceeded lake storage, water overtopped the southern shores providing an almost continuous pulse of overland flow downstream through the Everglades where distinctive landscape features were oriented (and still are in more pristine parts of the remnant system) in the direction of two main outflows; southeast through rivers and glades that breached the Atlantic Coastal Ridge, and southwest primarily through Shark River Slough to the mangrove forest that fringes the southern coast (**Figure 3**). When Lake Okeechobee stages were high, the Caloosahatchee River watershed also received overland flow through sawgrass marshes on the lake's western shore.

The Everglades system was interconnected through the regional hydrology, with its unifying surface and subsurface freshwater transport system. The primary characteristics of the pre-drainage wetland ecosystem in the Everglades included slow overland flow, a prolonged recession associated with storage, and seasonally fluctuating water levels.

West of the Everglades, the Big Cypress region is an expansive (2450 mi^2 [1,568,000 acres] wetland/upland mosaic in south western Florida of which 900 mi^2 is national preserve (Duever et al, 1986). The entire region is not included in the NSRSM domain, only the area east of what is now state highway 27. Most of the watershed is less inundated than the adjacent and slightly lower-lying Everglades. Predominate flow direction is southwest through numerous cypress strands to the coastal mangrove fringe. However, as indicated in **Figure 4**, the central Everglades basin historically received inflows from northeastern Big Cypress.

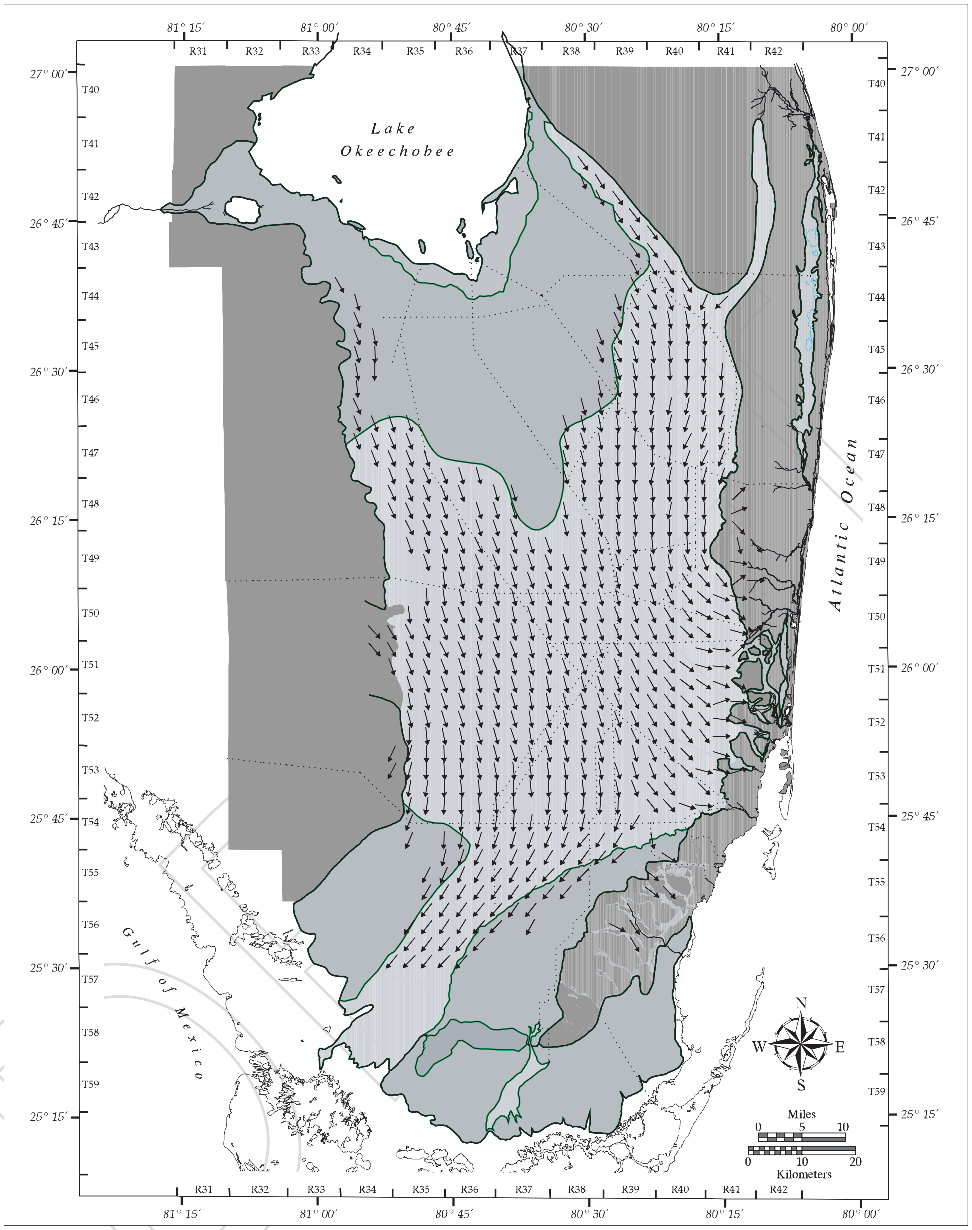


Figure 3. Estimated flow directions in the historical Everglades. Source: Parker 1955

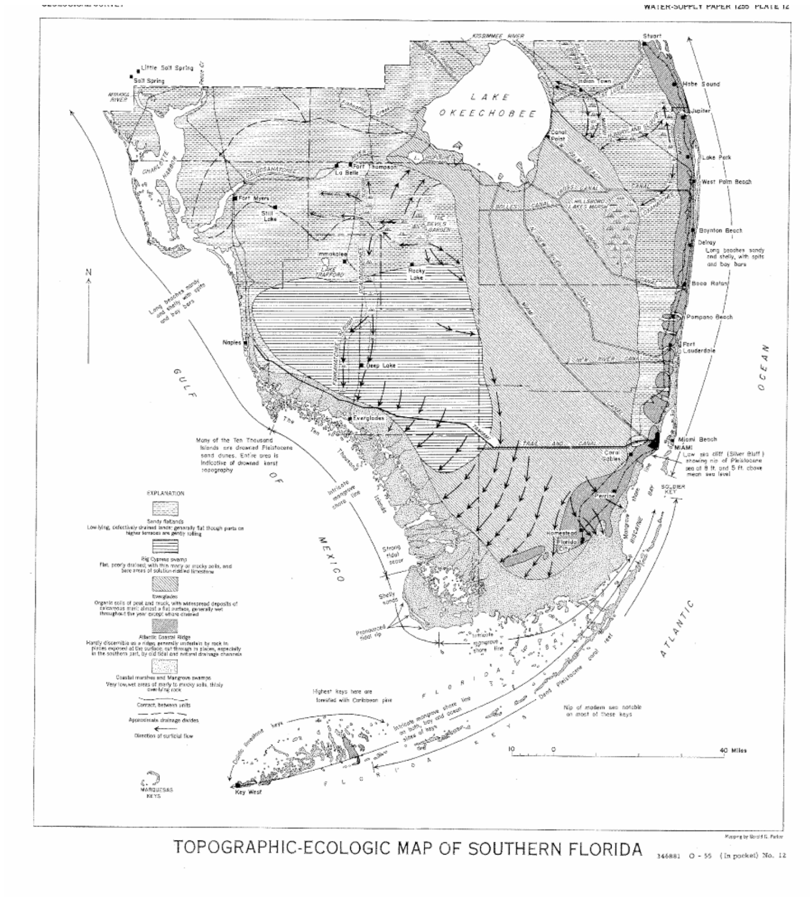


Figure 4. Natural system flows in southwestern Florida. Source: Parker, 1955

Natural system hydrology was, and continues to be, primarily driven by rainfall and evapotranspiration tuned to south Florida's characteristic annual cycling of wet and dry seasons. Convective and tropical storms contribute to wet season (May – October) rainfall while dry season (November – April) rainfall comes primarily from frontal systems (Sculler, 1986). Evapotranspiration is a major component of the water budget. On the average, 80% of rainfall in the wetlands is lost to evapotranspiration with the greatest losses in the wet season (Duever, 1994). As observed by Marjory Stoneman Douglas (1947), "it is the subtle ratio between rainfall and evaporation that is the final secret of water in the Glades."

Three major aquifer systems underlying south Florida are the result of vast marine carbonate sedimentation: the Floridan, intermediate, and surficial. Rainfall recharges the surficial aquifer under what are now Miami-Dade, Broward and eastern Palm Beach Counties. Historically, this provided a source of groundwater to the Everglades. The highly transmissive Biscayne aquifer is a component of the surficial system. It is thickest in the east then thins out as it extends westward under the central Everglades. Hydraulic conductivity is relatively high in the east and correspondingly lower in the west (Harvey et al., 2005).

Additional and more detailed descriptions of natural system hydrology are included in **Appendix** A.

Chapter 4--RSM Implementation of Natural System Hydrology

This chapter summarizes the NSRSM implementation process; beginning with an evaluation of mesh computational health followed by descriptions of data input and parameter refinement. Extensible Markup Language (XML) examples of model input are provided for selected components. The complete NSRSM v2.0 XML is available in **Appendix I.**

MODEL DOMAIN AND MESH

NSRSM model domain includes the Kissimmee-Okeechobee-Everglades system from Lake Kissimmee to the north and south to Florida Bay, eastern portions of the Big Cypress and Caloosahatchee basins east to the Atlantic Coastal Ridge system (**Figure 5**). The upper Kissimmee basin is characterized separately and is represented in the model by boundary conditions.

The model domain consists of a flexible mesh covering 11,858 square miles with 48,602 cells. Triangular cell sizes range from a minimum resolution of 0.14 miles per side along the eastern coastal ridge to a maximum of 2.4 miles per side in the prairies northwest of Lake Okeechobee. **Table 2** summarizes basic statistics of mesh cell geometry.

Table 2: Mesh cell geometry statistics

Number of cells	48,602
Max. cell size (acres)	1,582
Avg. cell size (acres)	156
Min. cell size (acres)	4.5
Std. Deviation (acres)	123

Model elevations are based on the 1929 National Geodetic Vertical Datum (NGVD29) and the horizontal spatial data are referenced to the 1983 North American Datum (NAD83). NSRSM mesh framework incorporates watershed boundaries comparable to those defined in the managed system RSMs to allow for meaningful comparison of results.

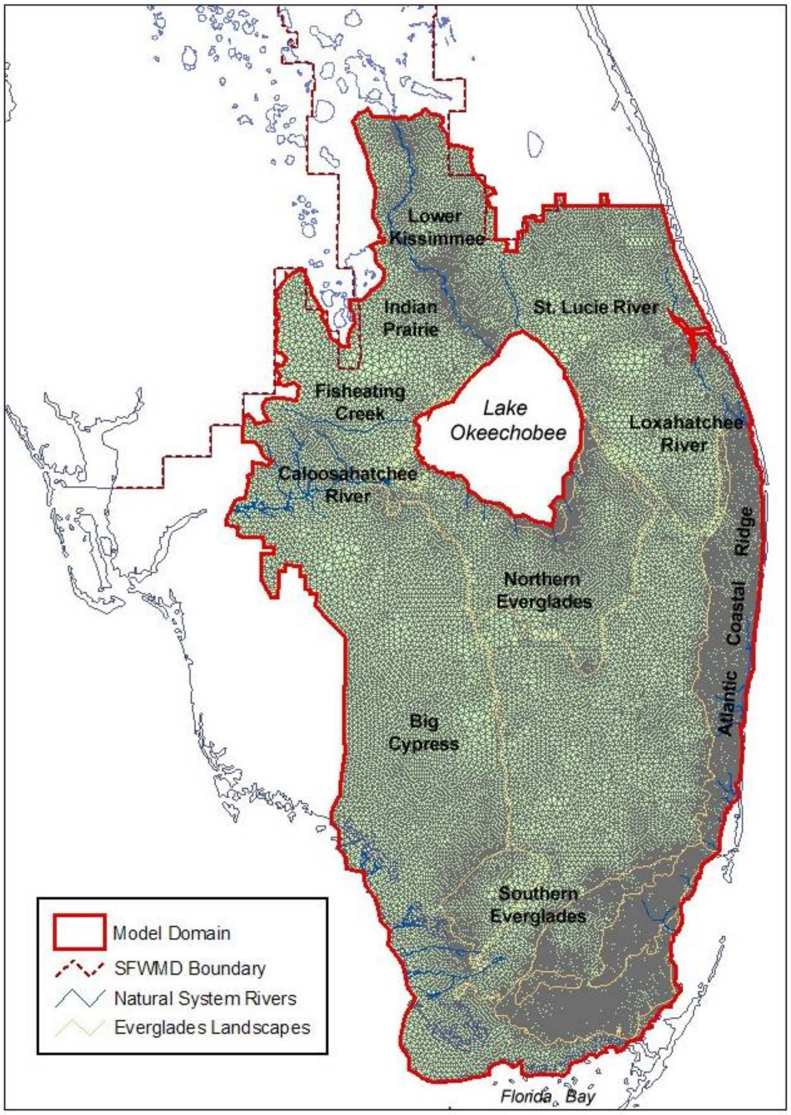


Figure 5. NSRSM domain

Mesh Evaluation

Numerical errors are introduced when the solution to the governing partial differential equations is represented by discrete values in a numerical model, and when these discrete values are used in numerical computations in the finite difference method. Numerical error can be managed or controlled by selecting proper spatial and temporal discretizations. For this purpose, the user has to design the model grid with a sufficiently fine discretization, which depends on the specific intended use of the model. On the other hand, the user also has to limit the number of computational points to make sure that the model does not become exceedingly slow (i.e., very small spatial grid resolution). The purpose of this section is to assess the upper bounds of the total numerical error present in NSRSM mesh (i.e., spatial resolution) and ensure that the users are aware of the presence of numerical error and its upper bounds. These bounds have been calculated and verified not to exceed known limits, because the maximum error is not present at all places and at all times.

Stresses and errors due to conditions common in South Florida such as variable water levels and variable rainfall are analyzed separately. The results of these analyses can be used in a wide variety of practical problems to determine numerical error. An application of the model spatial discretization method is presented here to demonstrate the evaluation of an overland flow model and a groundwater flow model for South Florida. Numerical errors introduced in the representation of data and during computations are discussed in two additional separate reports entitled "RSM Guidelines for Managing Numerical Error" and "Natural System Regional Simulation Model Sensitivity and Uncertainty Analysis."

Numerical models inherently show errors under different stress conditions. Numerical errors in a dynamic model are the result of transient stress (e.g., rainfall events, other inflows and outflows), initial conditions and prescribed boundary conditions. Numerical errors are found only under conditions of stress. These errors will last as long as the stress lasts. If there is no stress, the solution is flat and there is no error. However, numerical error introduced during a rainstorm event will be present until the rainfall event is dissipated. For an initial condition stress (e.g., water surface elevation), numerical errors are transient, and after a few time steps (depending on the problem/model simulation type), these numerical errors disappear (the model in a sense "forgot" what the initial values were and the associated errors with these initial values; also known as "spin-up" or "warm-up" time period). Similarly, prescribed boundary conditions for any modeling application will introduce numerical error, which also will dissipate or disappear, after several time steps. The amount of persistence of error that is accumulated during a model run is referred to as the "evolution" and is measured using fT where f= frequency of the disturbance and T= time of evolution of the solution (Lal, 2000). For most practical applications, fT=1 is a reasonable estimate. Numerical error due to prescribed boundary conditions may also propagate inward in the model domain. This type of error can be determined a prior (i.e., RSM Guidelines for Managing Numerical Error).

Mesh cell size evaluation criteria include susceptibility of the model to numerical instability and numerical error. The potential for the introduction of numerical error into the NSRSM mesh construction due to discretization was determined through the use of ArcGIS. Analyses were necessary to ensure adequate cell size and good computational health. Transient stresses such as rainfall (input) and ponding (output) from the Natural System Model (NSM v4.6) were used to conduct this initial mesh evaluation with the intention of repeating the analysis using NSRSM results mesh at a later time (i.e., RSM Guidelines for Managing Numerical Error report).

Two types of tests were performed. The purpose of the first test was to investigate and optimize mesh cell size, i.e., lambda test, and the purpose of the second test was to determine the health of the numerical computation on the selected grid, referred to as the "Badness Test"(B_{pd}; Lal, 2000).

Lambda, or maximum cell-side length, was calculated to determine the smallest spatial scale needed to capture a disturbance in groundwater, which is the most restrictive and controlling value. The "worst case" groundwater scenario used the driest day of the rainfall time series (i.e., April 27, 1990). The groundwater values used in the lambda test calculations are shown below as follow:

$$\lambda = \sqrt{\frac{2\pi TP}{s_c}} \tag{1}$$

where:

T = transmissivity for groundwater (ft^2/day); It should be noted that transmissivity is defined differently for surface water and groundwater

P = period of 5.7 days for 5% error limit

s_c = storage coefficient (dimensionless).

For groundwater, transmissivity can be expressed as:

$$T = k(h - x) \tag{2}$$

where:

k = hydraulic conductivity

(h – x) = saturated thickness, where h = head and x = bottom of aquifer

Groundwater storage coefficient (s_c) values, used in his analysis, were obtained from the NSM.

Cells with sides a fraction of the calculated length are necessary and needed to capture the spatial signature of a disturbance and lambda may be divided by five or six for adequate spatial discretization. Transmissivity is defined differently for surface water and groundwater.

Figure 6 illustrates the results of this analysis using equation 1 above. The lambda values, as calculated by Equation 1, serve as a guide for determining the maximum cell sizes needed in a mesh to "capture" a disturbance (i.e., maximum cell-side length). The lambda value is then divided by the number of cells that can represent and capture the spatial signature of a disturbance; typically lambda value calculated using Equation 1 is divided by five or six for adequate discretization. The groundwater lambda values, selected for this analysis, were conservative, ranging from about 100 feet to greater than 5 miles. Our analysis indicates that the eastern part of the model requires the most detail (small cell sizes) and that the sawgrass and marsh landscapes can be modeled with larger sized cells.

Mesh Computational Health

The effects of discretization on computational health can be determined by the formula below (Lal, 2000), or the "Badness Test." This calculation was performed on both surface and groundwater parameters for the new NSRSM mesh because transmissivity is defined differently for both surface and groundwater flow. The formula for "badness" B_{pd} assumes diffusion flow and is defined as follow:

$$B_{pd} = \frac{T\Delta t}{s_c A_c}\left(\frac{W}{d}\right) \tag{3}$$

where:

T = transmissivity or conveyance

ΔT = time step (one day)

s_c = storage coefficient

A_c = cell area

W/d = aspect ratio, defined as the ratio of the length of the longest wall to the shortest distance between cell circumcenters (center of an outside circle where all triangle verticies lies on the circumference of the circle), assumed to be 1.0 for these analyses.

For surface water, conveyance was calculated using:

$$T = \frac{h^{5/3}}{n_b\sqrt{S_n}} \text{ (Metric units, m}^2\text{/sec)} \qquad T = (1.49)\frac{h^{5/3}}{n_b\sqrt{S_n}} \text{ (English units, ft}^2\text{/sec)} \tag{4}$$

where:

T = conveyance for surface water (ft^2/day) in which h = water depth

n_b = Manning's roughness

S_n = slope of water surface, which was the smallest possible value of $1x10^{-8}$, to prevent conveyance values from reaching infinity.

The most demanding case for surface water is the wettest day of the rainfall time series, currently October 21, 1995. Water depth, h, was based on the ponding depth of each NSM 2x2 cell on this day. Manning's roughness was calculated using the coefficient A, exponent B, and the ponding depth in Equation 5:

$$n = Ah^B \quad (5)$$

The A and B values were based on predetermined estimates corresponding to the designated land use of each 2 x 2 mile model grid cell from the existing NSM. The grid cell areas were calculated from the ArcGIS database file that corresponds to the existing NSRSM mesh. A multiplier of 86,400 sec/day was used to convert conveyance from $ft^2\ sec^{-1}$ to $ft^2\ day^{-1}$ for use in Equation 3 where the time, Δt, is in days. Storage coefficients (s_c) are assumed to be 1.0 for surface water.

The objective of selecting a proper discretization is to ensure that the mesh accurately represent and capture the simulated transient stresses, with the least amount of computational and data collection effort. Results of the error analyses, B_{pd}, indicate a few areas requiring larger cells in the NSRSM mesh to accommodate surface water. For surface water, the badness test results ranged from less than 500, indicating very good computational health, to greater than 6,000. The highest values indicate that the cells may be too small relative to their volume of water and may become "unstable". The average surface water B_{pd} was about 2500, falling well below the upper badness test limit of 10,000. Error analysis results based on surface water are illustrated in **Figure 7**.

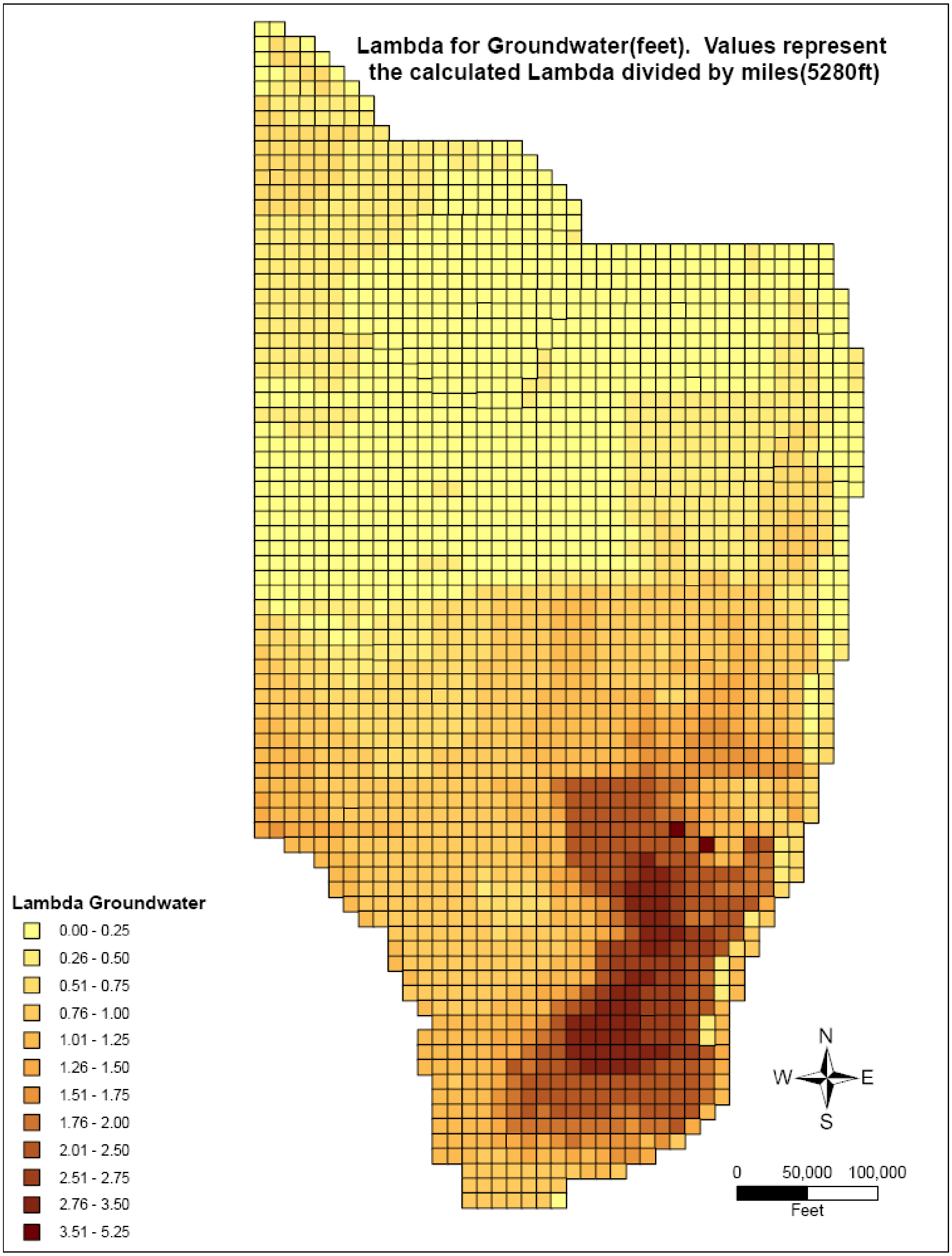


Figure 6. Lambda analysis results (Equation 1) for groundwater plotted using the NSM 2x2 mile grid.

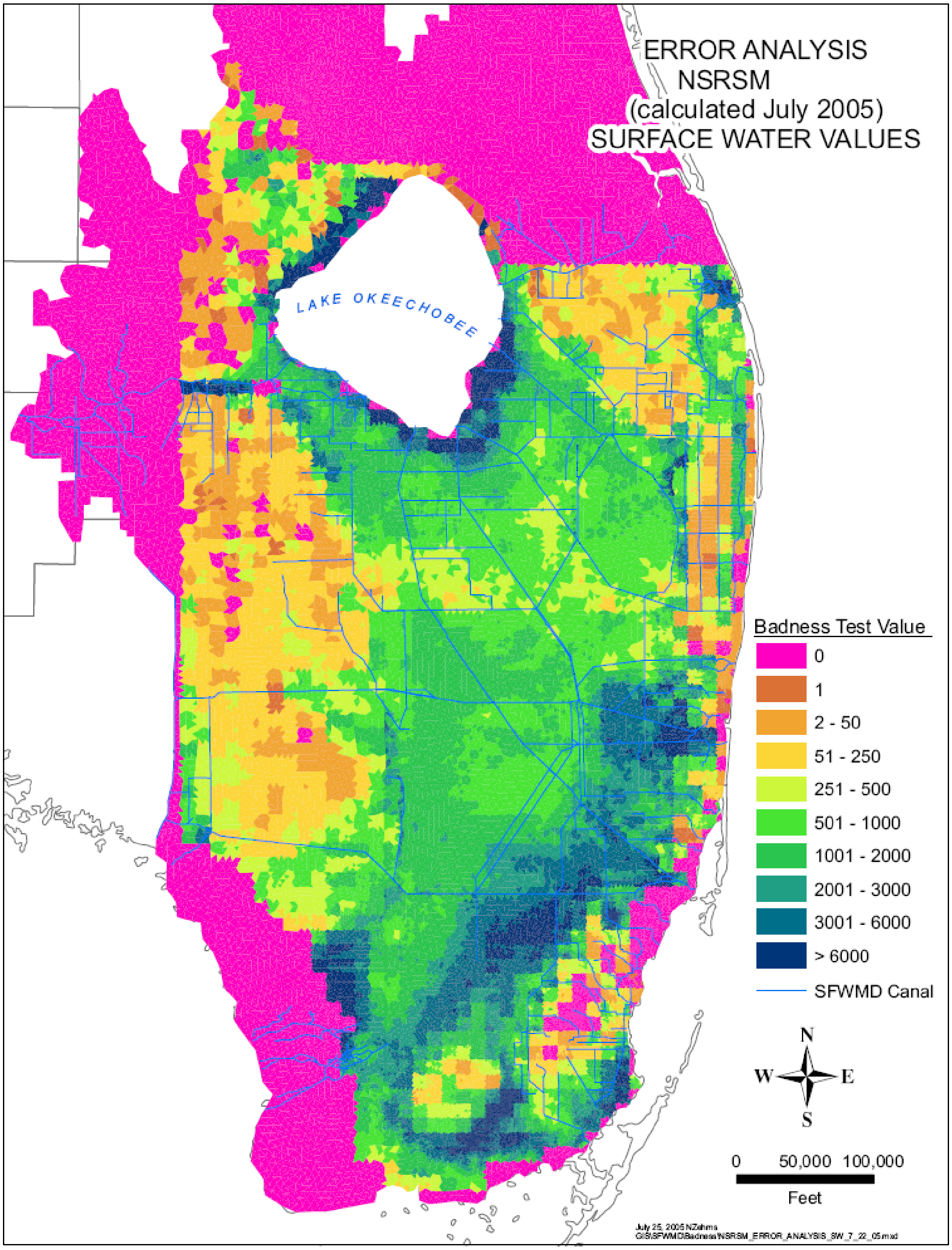
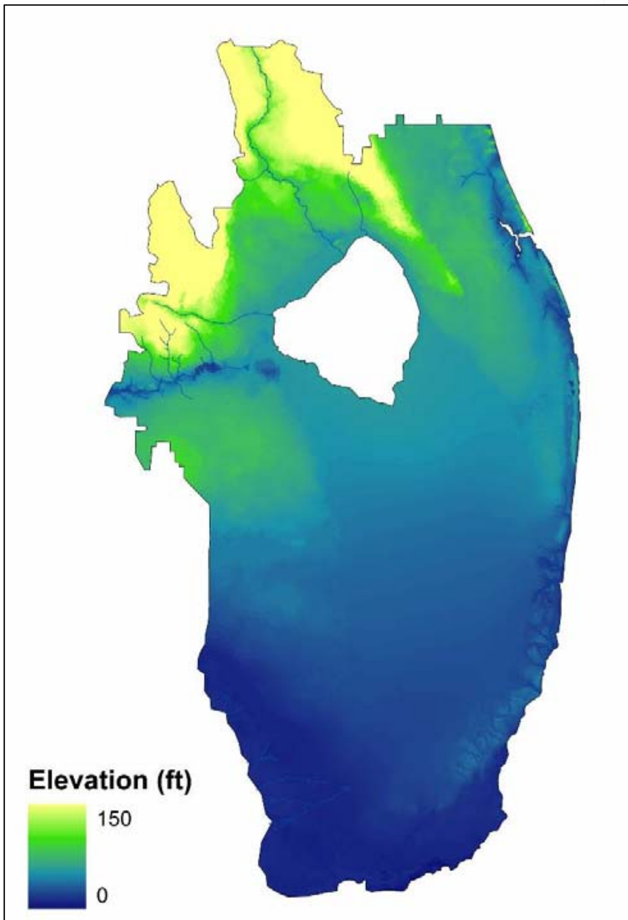


Figure 7. NSRSM mesh error analysis results using NSM ponding values.

Results from the recent error analysis conducted using NSRSM v2.0 input are in preparation and will be included in a separate document (RSM Guidelines for Managing Numerical Error).

TOPOGRAPHY

Land surface elevations within the NSRSM model domain range from ~150 feet in the northern highlands to near sea level in the south (**Figure 8**). Elevations were derived from multiple sources (**Figure 9**). Sub-regional elevation grids (100ft x 100ft) developed for the South Florida Regional Simulation Model (SFRSM) were used as base grids for NSRSM topographical input in all areas where the SFRSM and NSRSM model domains overlap except for the Everglades basin. SFRSM topographical data set development is documented in **Appendix B.1**.



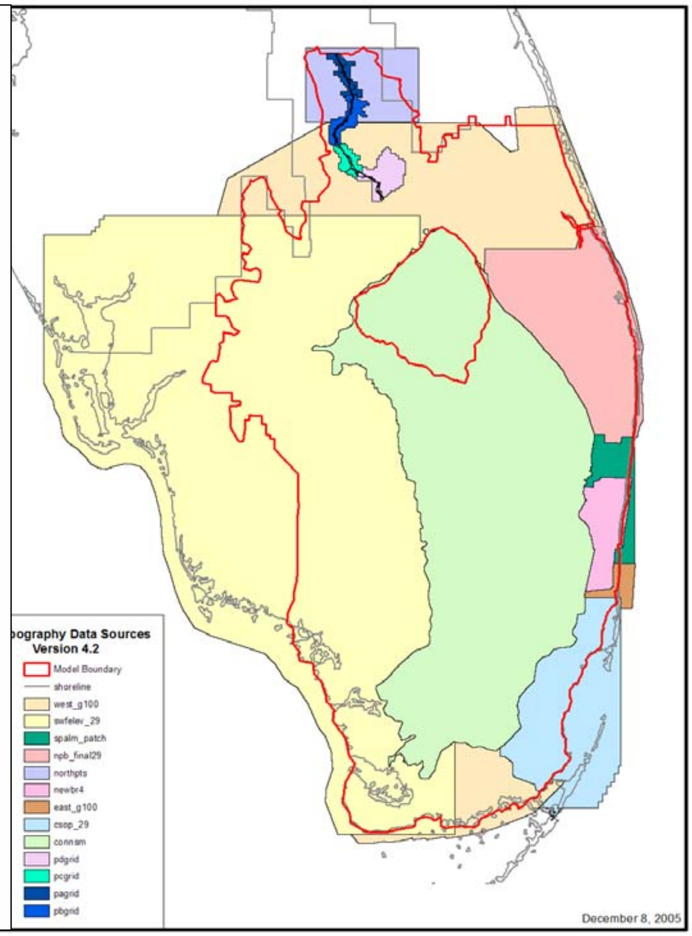


Figure 8 . NSRSM Landsurface Elevations
Figure 9. Topographic data sources included in NSRSM base grid.

While upland elevations are assumed to have not changed substantially over the last 100 years (except in areas of intense disturbance), organic soils within the Kissimmee-Okeechobee-Everglades watershed have subsided to varying degrees, resulting in somewhat lowered to substantially lowered current elevations compared to the pre-development land surface. To account for subsidence in the Everglades basin, estimated historical elevation contours (connsm in **Figure 9**) developed by an interagency team for NSM v4.6.2 Sensitivity Run 4 were included as a base grid. Documentation of this data set is provided in **Appendix B.2**. A comparison of NSM and NSRSM contours in the Everglades basin can be seen in **Figures 10 and 11**.

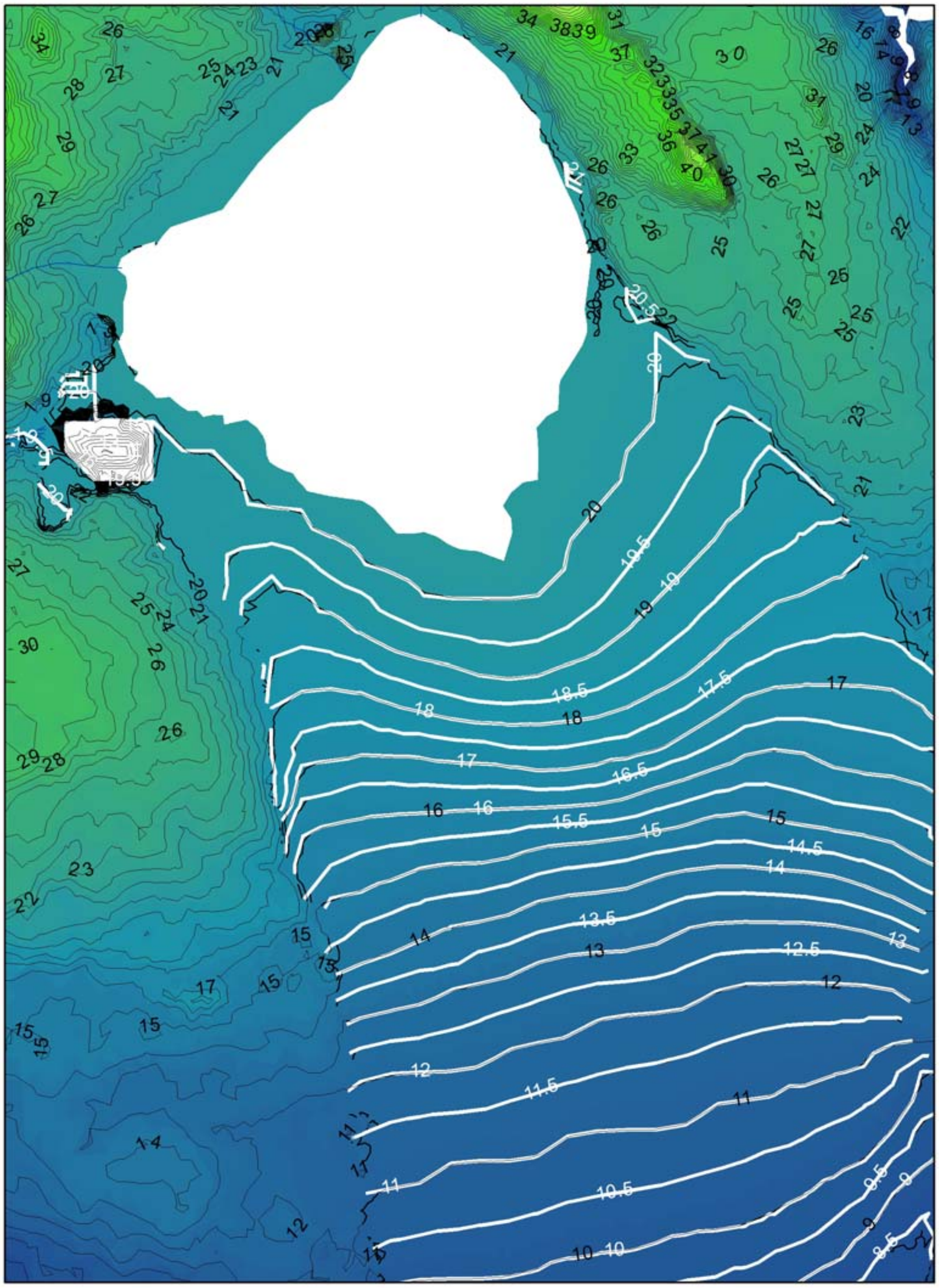


Figure 10. NSRSM Topography (black contours) compared to NSM v4.6.2 Sens 4 (white contours) within the historical Everglades Basin.

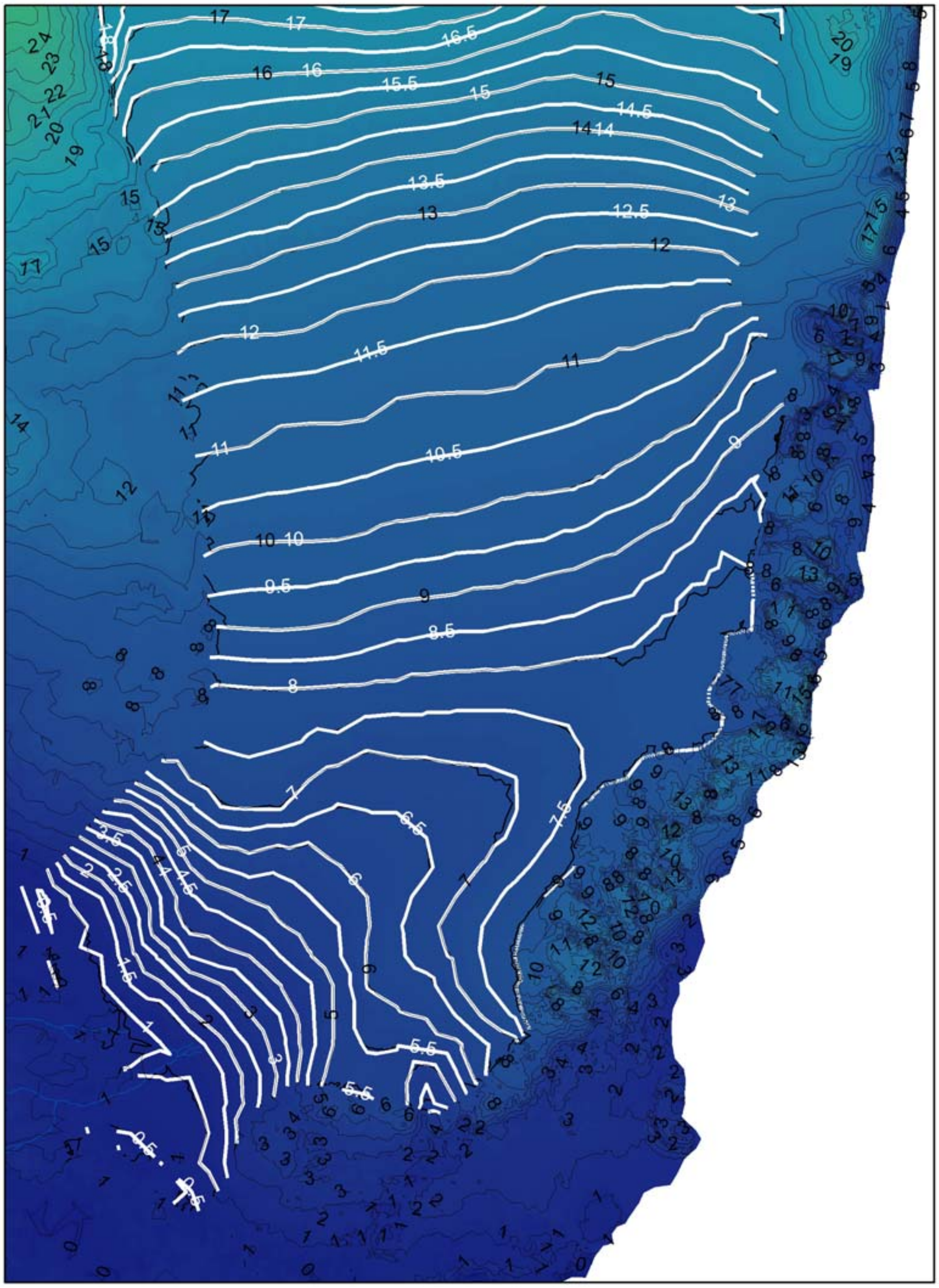


Figure 11. NSRSM Topography (black contours) compared to NSM v4.6.2 Sens 4 (white contours) within the historical Everglades Basin.

NSRSM Landsurface elevations north and northwest of Lake Okeechobee were based on Kissimmee River flood plain (pool A, B, C and D) grids developed in support of the Kissimmee Restoration Project (**Appendix B.3)**, and points reselected from the U. S. Geological Survey 24K Quad data (north and west points) documented in **Appendix B.1**. Elevations were compared to pre-development landcover and determined to reasonably represent natural landscape positions.

Gridded elevation data from several surveys developed for the SFWMD Southwest Florida Feasibility Study was applied to the western model domain. Documentation for this data is provided in **Appendix B.4**. A datum adjustment was performed to convert from vertical datum 88 to NGVD 29.

South Palm Beach County topography used in SFRSM was determined to have processing artifacts so was not used for the NSRSM base grid. To create a topo patch for this area, a grid was constructed (south palm patch) using a border of point elevations from adjacent grids, and interior values corresponding to pre-drainage natural system landcover features and early surveys (Zahina et al., 2006; USCOE, 1960). USGS 24K Quad Series elevation data points were compared to the resulting grid. It was determined that the south palm patch elevation values were within a reasonable range of historical elevations.

Broward County and North Palm Beach County base grids were processed to remove gross artifacts of development (e.g. tall structure signatures). All other adjustments to source data elevations were made in the mesh environment.

Regional Topography GRID to Mesh

A regional elevation grid for the model domain was created using ArcGis mean mosaic option to combine the 13 base grids from the data sources described above.

To populate the NSRSM mesh with land surface elevation grid data, the NSRSM mesh was converted to a 100’ cell GRID, Zonal statistics were used to create a database that was joined to the mesh in the geodatabase. Once joined, elevation data was calculated to the mean.

Mesh Modification

The modifications described below were made to land surface elevations in the NSRSM mesh to account for subsidence in organic soils impacted by development outside the Everglades basin, to incorporate historical data not included in previous datasets, and as needed to provide edge matching between datasets. Areas where modifications were made are shown in **Figure 12** and described below.

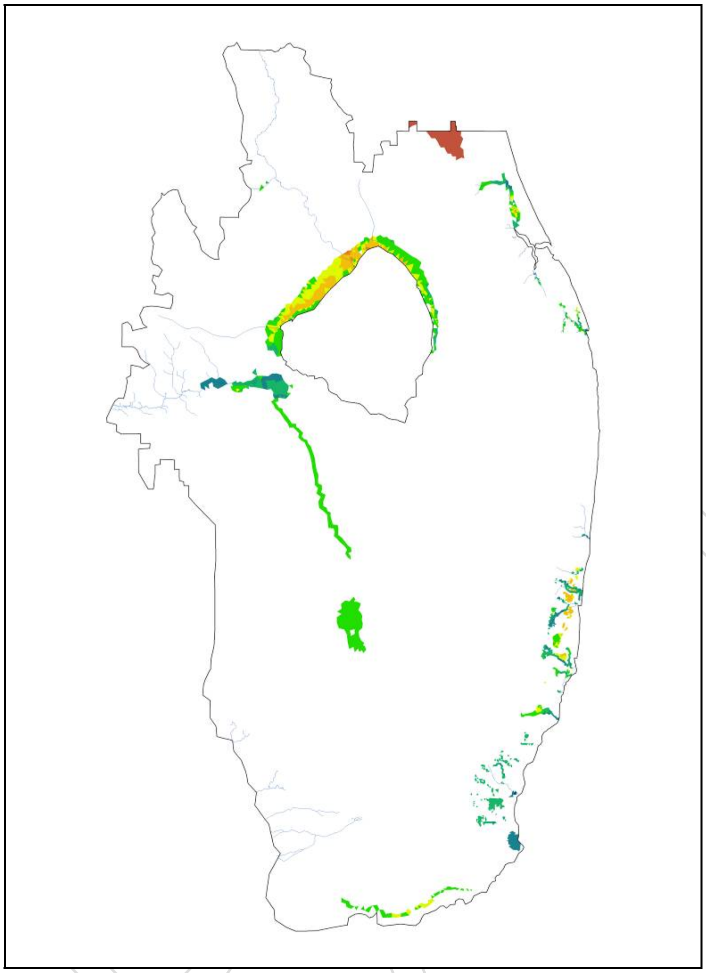


Figure 12. NSRSM mesh modifications (mesh not shown)

Lake Flirt/Lake Hicpochee

Surveys conducted by the Corps of Engineers in March, April and May of 1879 (Miegs, 1879) were used to adjust elevations in this area (**Figure 13**). Lake Flirt bottom elevations were modified to range from 4.5 to 6 feet msl where the center of mesh cell lies within the Lake Flirt polygon. Adjustments were made in the Lake Hicpochee area so that bottom elevations range from 8.9 to 14.6 msl where the center of mesh cell lies within the Lake Hicpochee polygon. The area between Lake Hicpochee and the Caloosahatchee River was adjusted to better represent surveyed data.

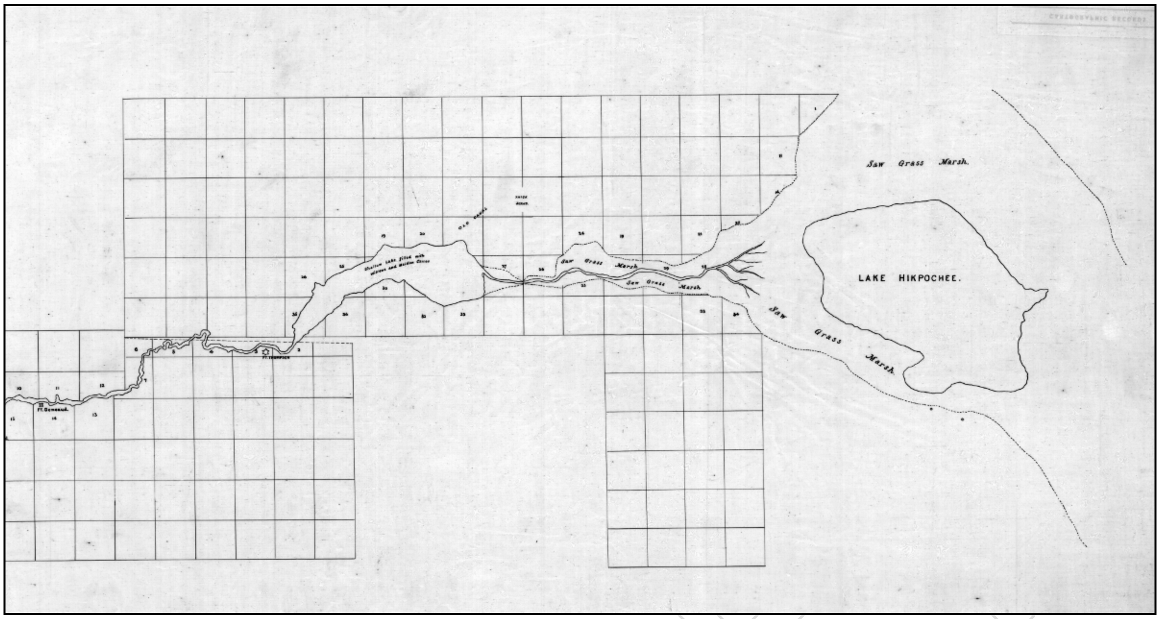


Figure 13. Section of Map from Report of the Chief of Engineers (Meigs, 1879). Elevations are referenced above mean low tide at Fort Meyers.

Big Cypress/Everglades Basin Interface

Marsh landscapes adjacent to the western Everglades in the Big Cypress region were considered to have been impacted (pers. comm. Mike Duever) by drainage activities. Before adjusting the mesh for subsidence in this area, an artificial “ledge” was apparent between the area currently known as WCA-3A and Mullet Slough in the Big Cypress region. Base grid elevations were at least a foot higher on the Everglades side of the bordering landscapes. This gradient was not considered representative of pre-development conditions in this area. Adjustments were made to the mesh to raise elevations (accounting for subsidence) in cells where vegetation communities reselected from the Southwest Florida Feasibility Study Pre-development Vegetation GIS database (Duever, 2000) were classified as organic soils. Post modification model results match historical flow patterns in this area (Parker 1955). Additional adjustments were made to the Immokalee Rise adjacent to the northwestern border of the Everglades.

Buttonwood Embankment (Southern Everglades)

The buttonwood embankment is a naturally occurring “coastal levee” that historically impounded freshwater water in the southern Everglades (Craighead 1964; Holmes et al. 1999); It is characterized by a series of embankments of varying lengths, averaging 1.5 ft in height, that follow the coastline (just inland from the mangrove fringe) from the southeastern corner of what is now Everglades National Park (ENP), to the periphery of the Shark River outflow, then resurfaces somewhat inland throughout the western ENP river network (**Figure 14**). Sections of the embankment remain intact (aerial inspection, W. Said 1999), however, this feature was considered to have been more continuous pre-development. Mesh cells were adjusted along the southern border of the model to represent the historical condition of the embankment.

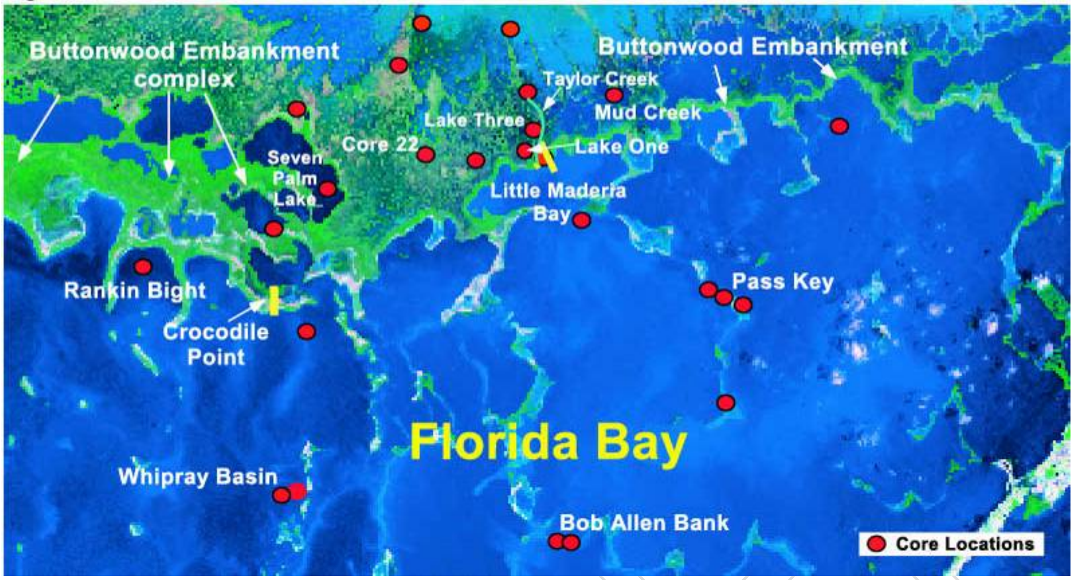


Figure 14. Location of Buttonwood Embankment from Holmes et al. (1999)

Northeastern to Northwestern Shore Lake Okeechobee

Land surface elevations were modified to account for changes resulting from water management in the area. Values were adjusted to correspond to earliest available contour information in combination with pre-development landscape positions. Source data included topographic surveys (US Army COE 1909; Florida Everglades Engineering Commission,1913) and Government Land Office (GLO) surveys conducted by J .Jackson and J. Tannehill (**Figure 15**).

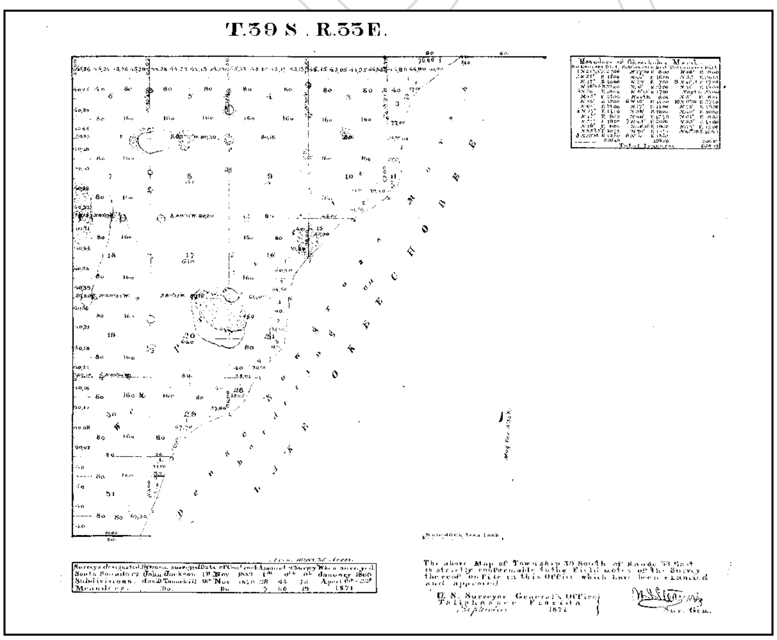


Figure 15. GLO Survey conducted in 1860 and 1871 by John Jackson and Jas. Tannehill respectively. Lake Okeechobee transitioned into a dense sawgrass marsh in this region southwest of the mouth of the Kissimmee River.

East Coast Rivers

Modifications were made to cells adjacent to river channels where artifacts of development in the base grids were inconsistent with pre-development landscape positions. River channels were adjusted to correspond with the NSRSM river network described later on in this chapter. Source materials included historical observations and surveys compiled by McVoy et al. (2005), GLO and US Coast and Geodetic Surveys.

Marl Transverse Glades

Modifications were made to cells adjacent to river channels where artifacts of development in the base grids were inconsistent with pre-development landscape positions (Figure 16). River channels were adjusted to correspond with the NSRSM river network. Source materials included recorded observations (McVoy et al., 2005), GLO and US Coast and Geodetic Surveys.

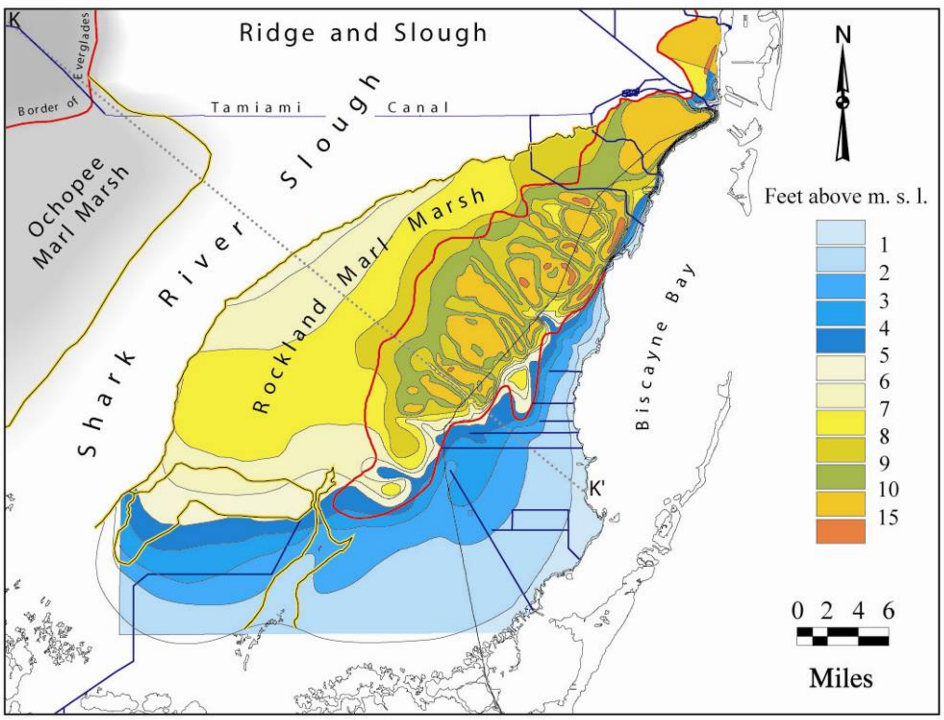


Figure 16. Plate 16 from Pre-drainage Everglades Landscapes and Hydrology (McVoy et al., 2005) showing elevations of the pre-development Miami Rock Ridge and marl transverse glades.

RAINFALL

Rainfall, the primary source of water for the natural system, varies temporally and spatially throughout the system. Wet and dry seasons alternate annually within a framework of decadal oscillation. Rainfall also varies spatially, ranging from an average of 43 inches/yr north of Lake Okeechobee up to more than 62 inches/yr over parts of the Atlantic Coastal Ridge. (**Figure 17**).

The NSRSM base condition (1965-2000) uses a rainfall database developed for SFWMD Regional Modeling (Rainfall v2.1 Global). Daily time series data processed from over 860 rainfall stations within the model domain resulted in temporal and spatial distribution of rainfall representative of the simulated period of record (1965-2000). The general procedure for the development of the Version 2.1 rainfall data set used in the NSRSM can be described as follows: data collection, quality screening of rainfall station data, and transformation of rainfall point data into grid based (grid_io) data. Details of the rainfall dataset development are available in **Appendix C**.

An example XML of <rain> is provided below in **Table 3.** Rainfall data for the NSRSM is stored in a binary "Grid (2 mile x 2 mile) io" format with an x and y origin of 237027, 286611. The time step is one day (1440 minutes) and the multiplier converts inches to feet.

Table 3. Example XML for rain element.

```
<rain>
<gridio file="/nw/oom/nsrsm/data/rain/rain_v2.1_global_tin.bin"
  xorig="237027" yorig="286611" mult=".0833" dbintl="1440">
</gridio>
<rain>
```

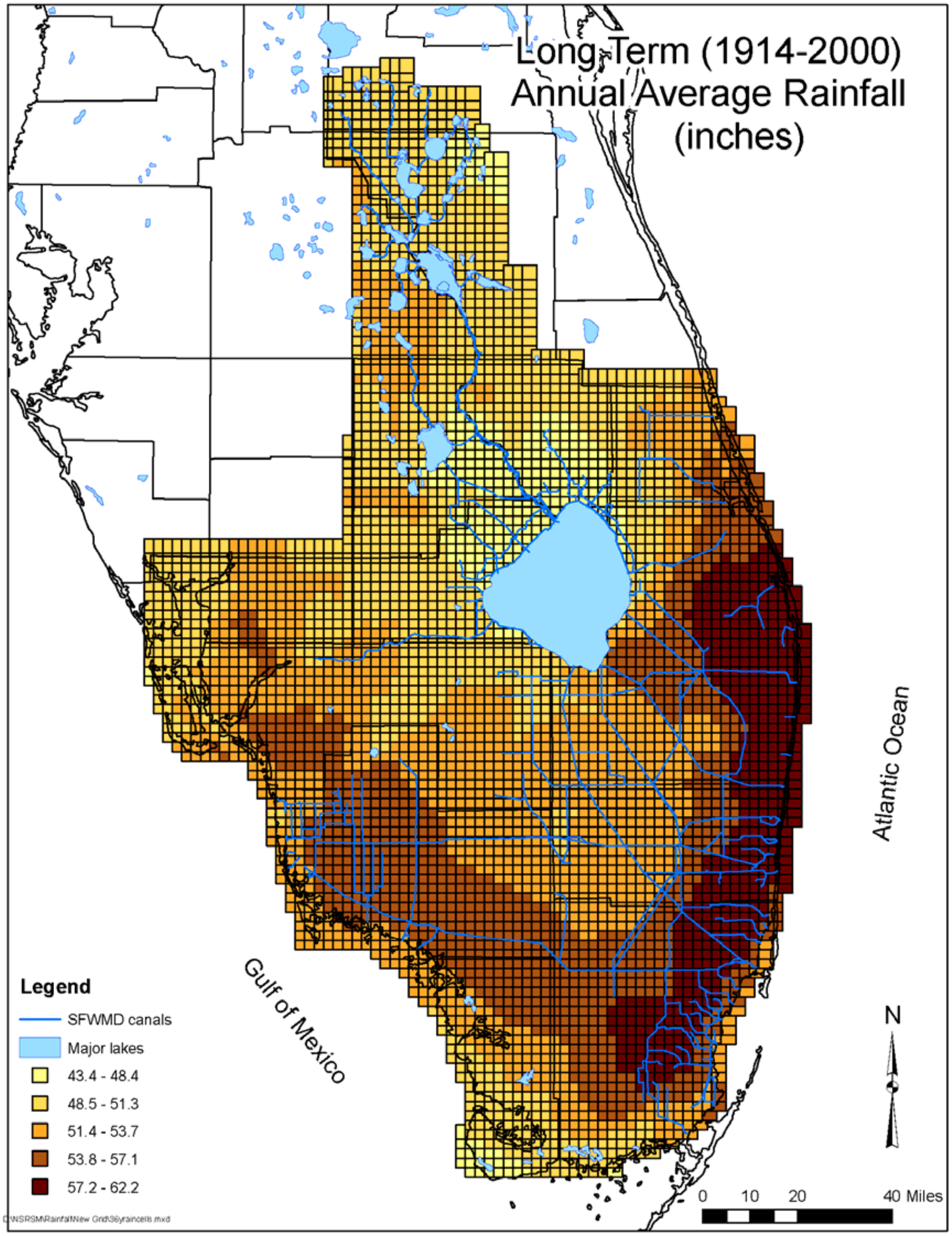


Figure 17. Long term annual average rainfall (in/yr) from NSRSM Grid_io input (Rainfall version 2.1).

REFERENCE EVAPOTRANSPIRATION

ET is a major part of the hydrologic cycle in south Florida where the water table is near or above the land surface for much of the year. The calculation of evapotranspiration (ET) in the NSRSM is based on reference crop potential ET (ETp) , which is adjusted according to crop type, available soil moisture content, and location of the water table. Reference ET ranges from an average of 55 in/yr to 64 in/yr in an average annual spatial pattern displayed in **Figure 18**. Development of a regional reference ET for hydrologic modeling in south Florida is documented in **Appendix D**.

Computed ET is calculated as the remaining PET after evaporation from interception storage times a PET correction coefficient (Kc). The value of Kc depends on the location of the water table in relative to the ponding depth, land surface (Z), rooting depth (Rd) and ET extinction depth (Xd). Kveg is the reference vegetation PET correction coefficient for a specified landuse type. Kw is the PET correction coefficient for a ponded condition. Values for these parameters are discussed in the Hydrologic Process Module (HPM) section of this report.

For Lake Okeechobee and Istokpoga, evapotranspiration depends on the surface area of the lake and the depth of the water in addition to the <refet> values assigned to the waterbody. The method used to calculate ET from lakes is addressed in Waterbodies—Lakes and Ponds.

An example XML using the <refet> element is provided in **Table 4.** Potential evapotranspiration data for the NSRSM is stored in the SFWMD binary “Grid io” format with an x and y origin of 237027, 286611. The time step is one day (1440 minutes) and the multiplier converts inches to feet.

Table 4. Example XML for reference ET.

```
<refet>
 <gridio file="/nw/oom/sfrsm/data/common/rain+et/ETp_recomputed_tin.bin"
   xorig="237027" yorig="286611" mult=".0833" dbintl="1440">
 </gridio>
</refet>
```

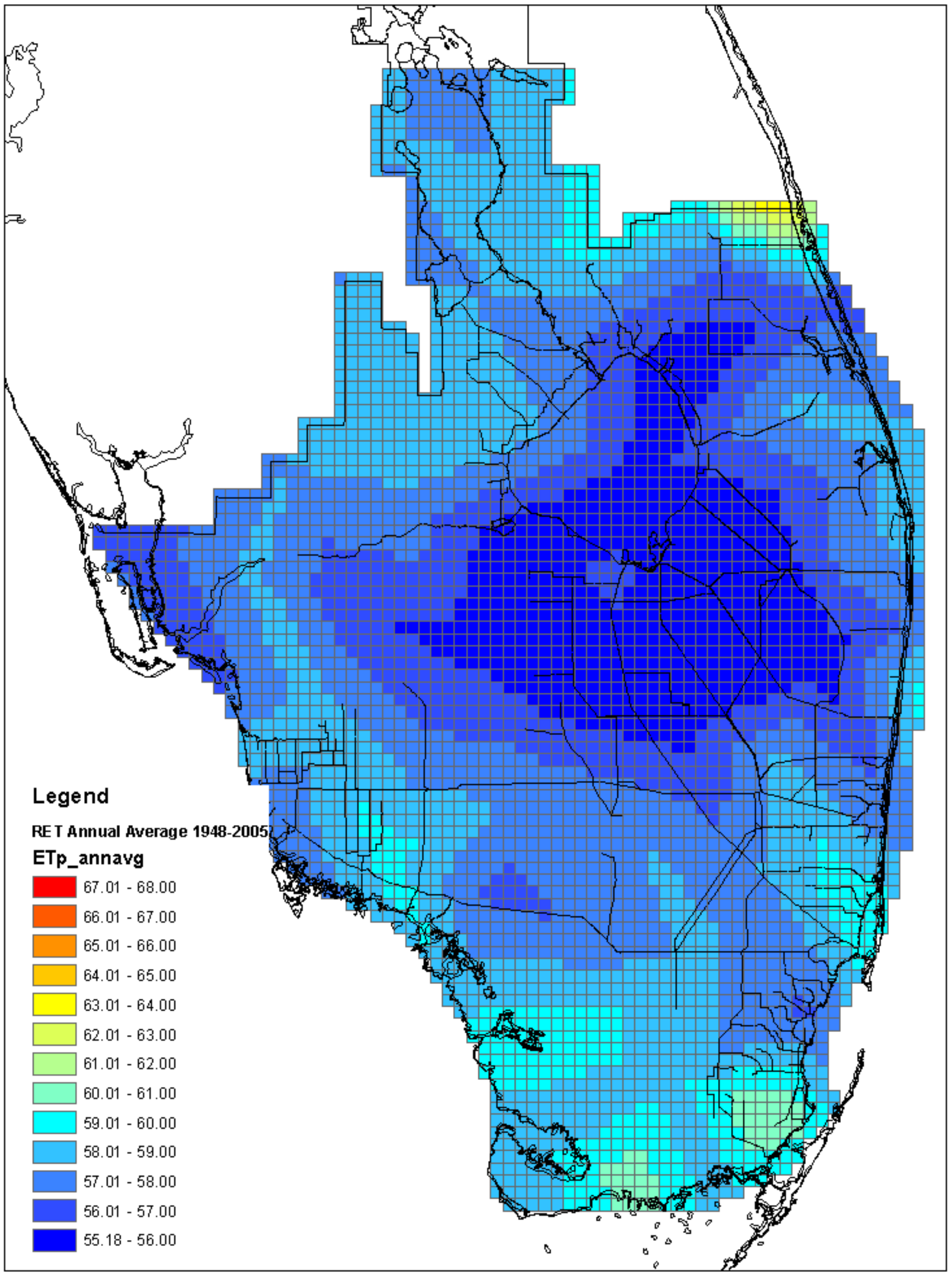


Figure 18. Long-term Average (1948-2005) Annual Reference ET (inches/year)

LANDCOVER

Prior to drainage, south Florida functioned as a mosaic of wetland, upland, estuarine and marine ecosystems with distinct hydrologic regimes that supported a range of vegetation communities (**Figure 19**). A District-wide pre-development vegetation database was assembled by the SFWMD (Zahina et al., 2006) using an ecological community approach to classify vegetation for use in hydrologic modeling. Twenty-seven hydrologically distinct classes were identified and mapped (**Table 5, Appendix E**). This database was used for NSRSM landcover input although not all vegetation types occurred within the model domain.

Table 5. Pre-Development Landcover Vegetation Classes

Vegetation Type	Description	NSRSM Landcover Code
Water	Permanently inundated site; includes freshwater, estuary and marine systems.	100
Intra-tidal Wetland	Tidally inundated sites; vegetation community is influenced by magnitude of daily flooding regime and saltwater exposure	200
Beach	Consolidated substrate (e.g., rock) or unconsolidated deposits (e.g., sands) on shorelines influenced by moving water	300
Forested Freshwater Wetland	Forested freshwater wetlands (swamps)	400
Cypress Swamp	Freshwater swamp dominated by cypress	410
Hardwood Swamp	Freshwater swamp dominated by broadleaf trees	420
Non-Forested Freshwater Wetland	Freshwater wetland dominated by herbaceous vegetation; non-forested	500
Long-hydroperiod Marsh	Freshwater marsh with hydroperiods extending from 11-12 months on average	510
Ridge and Slough Marsh	Everglades-specific community mosaic of alternating open water sloughs and sawgrass ridges interspersed with tree islands	511
Sawgrass Plain	Northern Everglades-specific community consisting of a generally unbroken expanse of sawgrass across a large spatial extent	512
Medium-hydroperiod Marsh	Freshwater marsh with hydroperiods extending from 6-10 months on average	520
Marsh with Scattered Cypress	Freshwater marsh with hydroperiods (6-10 months on average) that contain scattered stunted cypress	521
Everglades Marl Marsh	Everglades-specific community consisting of a medium-hydroperiod marsh with marl soils derived from calcareous algae; most extensive in the southern Everglades	522
Wet Prairie	Short-hydroperiod treeless wetlands that have hydric soils, hydroperiods extending from 2-6 months, and inundation to 1 foot on average	530

Table 5. Pre-Development Landcover Vegetation Classes (Continued).

Vegetation Type	Description	NSRSM Landcover Code
Wet Prairie with Scattered Trees	Wet prairie with scattered trees, including pine, cypress and bay	531
Wet Prairie with Cypress	Wet prairie with scattered cypress	532
Hydric Upland	Moist woodlands on non-hydric soils in level, low landscapes than may have some short-duration flooding each year. Fire frequency is the primary factor in shaping dominant vegetation type.	600
Hydric Flatwood	Hydric flatwoods typically are dominated by slash pine	610
Hydric Hammock	Hydric hammocks typically are dominated by hardwood species	620
Mesic Upland	Mesic communities are found on upland (non-hydric) soils; short-duration flooding may occur only during high-rainfall events. Fire frequency is the primary factor shaping dominant vegetation type.	700
Dry Prairie	Non-forested upland community composed primarily of grasses and palms; high fire frequency.	710
Mesic Pine Flatwood	Forested upland community composed primarily of pines; moderate fire frequency.	720
Mesic Hammock	Forested upland community composed primarily of broadleaf trees; low fire frequency.	730
Xeric Upland	Xeric communities are found on highest elevation sites with the water table well below (more than 3 feet) the soil surface all year. Xeric plant communities are dominated by species that have special adaptations for survival in dry conditions. Fire frequency is the primary factor shaping dominant vegetation type.	800
High Pine (Sandhill)	Dry pine communities on undulating sandy soils that are dominated by longleaf pines and wiregrass; these communities are typically found in central Florida.	810
Scrub	Scrub communities are dominated by sand pine or oak scrub species and are typically found on pure, deep sands of relic dune systems	820
Coastal Strand	Coastal strand communities are typically found on excessively drained elevated sites, such as coastal dunes, ridges, rocky outcrops or shell mounds. Vegetation species are primarily of tropical and Caribbean origin.	830

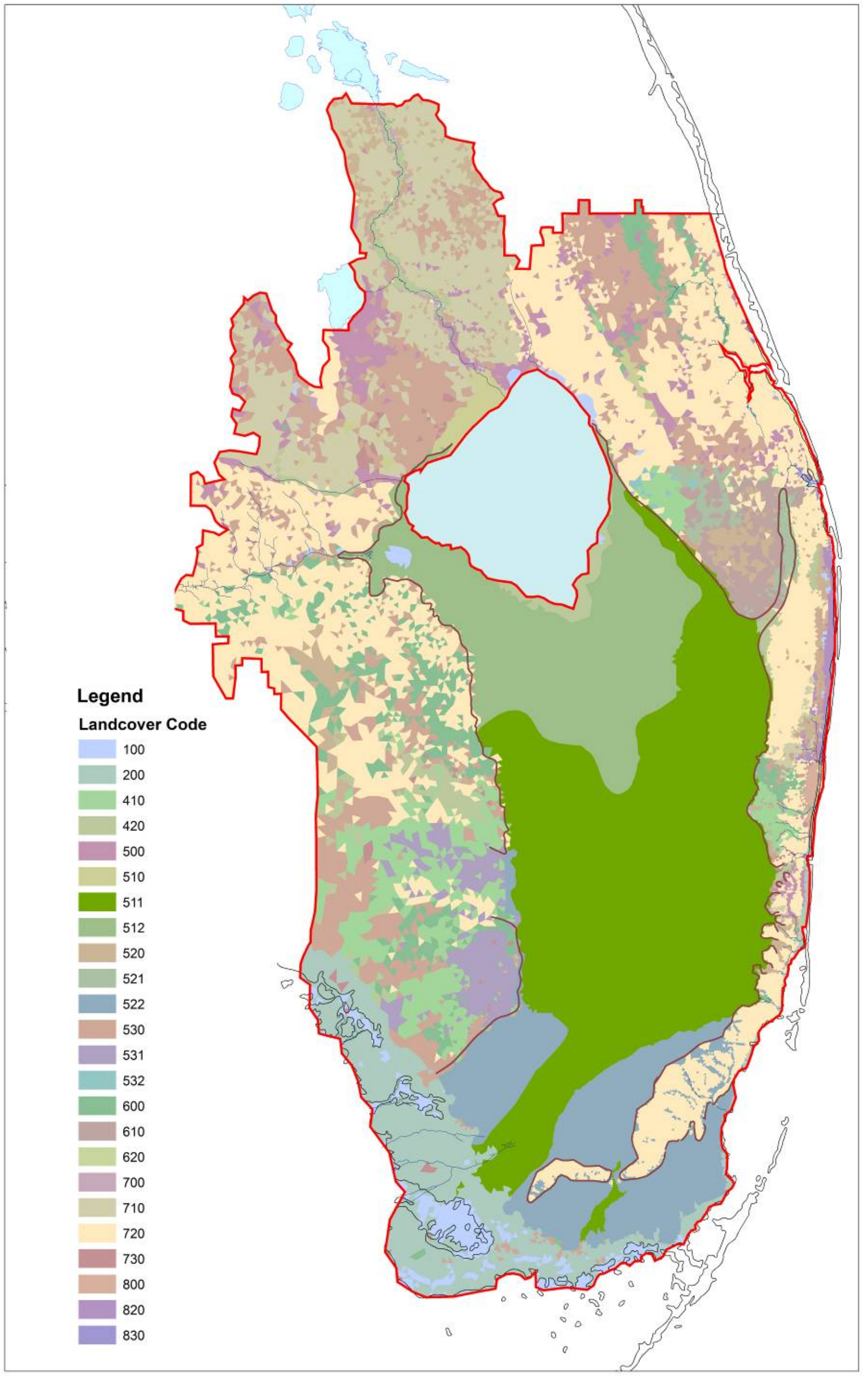


Figure 19. NSRSM Landcover

WATERMOVERS

Movement of water between water bodies in the model can take place only through watermovers. Watermover objects contain functions to compute the flow of water from one waterbody to another. Watermovers fall into three general categories.

1. Default watermovers are automatically created when the mesh and canal network are set up. Overland flow and groundwater flow watermovers between adjacent cells in the mesh, and canal flow between adjacent canal segments are examples of default watermovers that are created automatically based on the 2-D mesh or canal network geometry files.
2. User defined watermovers including
    a. Concept watermovers in which water flow is computed using generic equations that can be used to represent actual structures in a limited way. Lookup tables, time series, and power functions are examples of concept watermovers. These are intended to provide flexibility for the user to represent movement of water with methods that are not included in the other categories.
    b. Physical structure watermovers are designed to represent man-made structures such as weirs, culverts, and orifices.

The most common user defined watermover utilized by the NSRSM is the shunt, described in the following section.

Shunts

The Natural System conceptual model (Appendix A.1), describes the edges of Lake Okeechobee and Lake Istokpoga as not well defined resulting in a flow that transitions gradually from lake flow to overland flow. The NSRSM uses shunt watermovers to simulate flow between the lake and the adjacent cells. The shunt moves water between water bodies (from waterbody 1 to waterbody 2) according to the equation $Q = K(H_1 - H_2)$ with no flow below a user defined elevation. Water can move in either direction from higher to lower head and the flow rate depends only on the relative heads and a user defined constant, K. The values of K are set to large values proportional to the length of the wall separating the lake from the cell. The effect of this approach is that the water level in the lake acts as a variable head boundary condition, as the water level in a cell quickly approaches that in the lake. An excerpt of XML defining a shunt is shown in **Table 6**. The upstream waterbody is “id1” and the downstream waterbody is “id2”. No flow occurs when the head in the waterbody is less than 20.5 feet, the elevation of the “bottom” attribute. The “sconst” attribute defines the conveyance of the shunt (K in the flow equation) in ft^2 per second. The conveyance for the model was computed by multiplying 10.0 by the length of the cell wall adjacent to the lake. This will allow for a very high conveyance that best describes flow from the Lake to adjacent cells.

Shunts were added to the north and south rim of Lake Okeechobee. The stage below which there is no flow over the rim is 20.5 feet. Lake Istokpoga has shunts to the east and southeast. The stage below which there is no flow is 40.0 feet.

Table 6. Example XML for shunt watermover.

```
<shunt wmID="122" id1="400001" id2="5860" bottom="20.5" sconst="17740.40"> </shunt> <!--
South Rim -->
```

Lake Seepage Watermover

In addition to overland flow between the lake and the adjacent cells, there is seepage through the aquifer. This flow is simulated in the NSRSM model by the lake seepage watermover. Flow is computed as:

$$Q = LCD(H_u - H_d) \tag{6}$$

where:

L = length of the shore line in contact with the cell

C = user defined transmissivity

H_u and H_d are the higher and lower heads in the lake and the cell, and

D = the depth of water in the lake if the head in the lake is higher or (H_{cell}-$H_{lakebottom}$) if the head in the cell is higher.

This allows for flow in either direction between the cell and the lake depending on which head is higher.

An example from the NSRSM XML is shown below. For watermover number 400, the length of the shoreline in contact with the cell is 1845.975 feet and the conveyance is 0.000369/second (C in the equation above) into waterbody number 13992. There are <lakeseepage> elements for the shorelines of Lake Okeechobee and Lake Istokpoga in the NSRSM XML. Hydraulic conductivity was used for the conveyance term.

Lake seepage watermovers were also added to the shoreline of other waterbodies modeled using the lake package. The extent of each lake model for estuaries and lagoons were derived from the 1884 Coast and Geodetic Survey maps. **Table 7** summarizes the water bodies modeled using the lake package.

Table 7. Waterbodies modeled using the Lake package.

LakeID	Waterbody	Description
400001	Lake Okeechobee	N/A
400002	Lake Istokpoga	N/A
400003	St. Lucie Estuary	N/A
400004	Caloosahatchee Lagoon	Used to collect flow from Caloosahatchee River
400005	Loxahatchee Estuary	N/A
400006	Hillsboro Lagoon	Used to collect flow from Hillsboro River
400007	Three rivers Lagoon	Used to collect flow from Cypress Creek, Middle River, and New River
400008	Snake Lagoon	Used to collect flow from Snake Creek

An excerpt of XML defining a lake seepage watermover is shown in **Table 8**.

Table 8. Example XML for lake seepage watermover.

```
<watermovers>
<!-- Lake Okeechobee -->
<lakeseepage wmID="400" lakeID ="400001" wbID="13992" length="1845.975"
conveyance="0.000369"> </lakeseepage>
<lakeseepage wmID="401" lakeID ="400001" wbID="13993" length="8183.593"
conveyance="0.000257"> </lakeseepage>
<lakeseepage wmID="402" lakeID ="400001" wbID="17218" length="3168.649"
conveyance="0.000116"> </lakeseepage>
```

Lake Source Watermover

Lake Istokpoga receives inflow from Arbuckle and Josephine creeks in addition to direct runoff from overland flow during rainfall events. The inflow is computed from rainfall within basin boundaries using the Sealink model described in the boundary conditions section of this chapter. This inflow is defined in the model by use of a <lakesource> watermover in the lake boundary condition. The <lakesource> watermover simply adds water to Lake Istokpoga according to the time series of flows designated in the DSS file. An excerpt of XML defining a lake source watermover is shown in **Table 9**.

Table 9. Example XML for lake source watermover.

```
<lake_bc>
 <!-- Istokpoga -->
 <lakesource lakeID="400002">
 <dss file="./input/LakeIstoInflow.dss" pn="/ISTOKPOGA/INFLOW/FLOW/01JAN1965-
31DEC2000/1DAY//"
     mult="1.0" units="CFS"> </dss>
 </lakesource>
</lake_bc>
```

WATERBODIES - LAKE AND PONDS

Lakes and ponds are simulated as independent water bodies in the model. They do not act as cells in the regional solution and their only interaction with cells in the mesh is through seepage in either direction or through other user created watermovers. There are no default watermovers for lakes. The amount of water in a reservoir is calculated using the equation of mass balance:

$$A_s \frac{dH}{dt} = \sum Q_{in} - \sum Q_{out} \; A_s \qquad (7)$$

where:

A_s = the surface area of the lake,

H = the head in the lake, and

$\sum Q_{in}$ and $\sum Q_{out}$ = rainfall, evaporation, seepage into and out of the lake/pond and the flows in any user created watermovers.

Once the storage is calculated, the water level and surface area are estimated using 1-D lookup tables or from a calculation assuming a cylindrical or parabolic shape for the lake as selected by the user. Neither lakes nor ponds are discretized in the model. Lakes are larger water bodies, and the mesh cell discretization can surround the lake with cell walls in contact with the lake boundary. Ponds are smaller water bodies, and occupy a small space inside a triangular model mesh cell. Ponds situated within a single cell are considered to be sufficiently small that they do not disrupt the 2-D flow although they do decrease the area of the cell by the area of the pond. Whether a waterbody is treated as a lake or a pond is specified by the user. **Figure 20** shows a definition sketch of a reservoir, to which water is fed from an upstream river. **Figure 21** shows the discretization around a lake and the placement of a pond entirely within a cell.

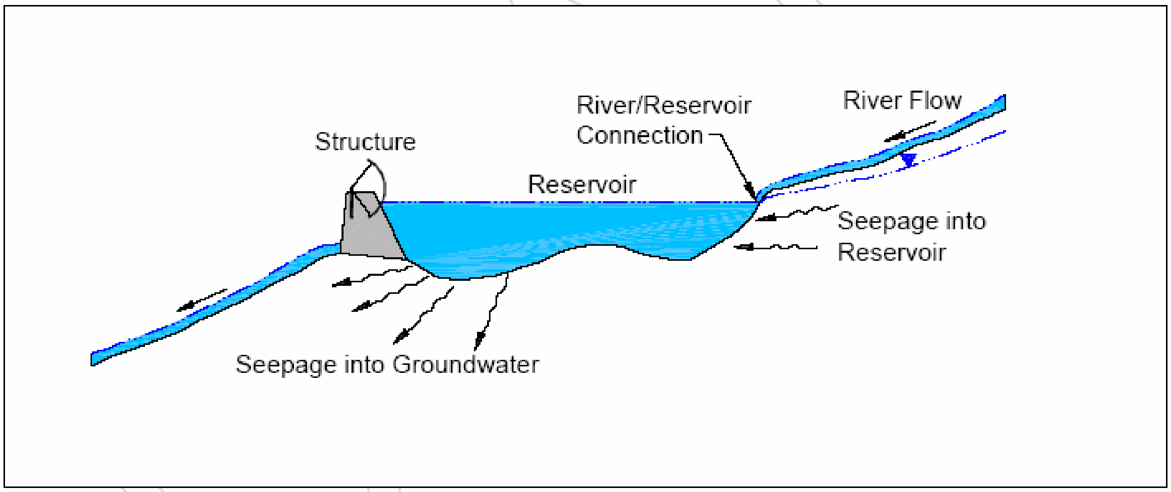


Figure 20. Schematic diagram of a reservoir formed in a river.

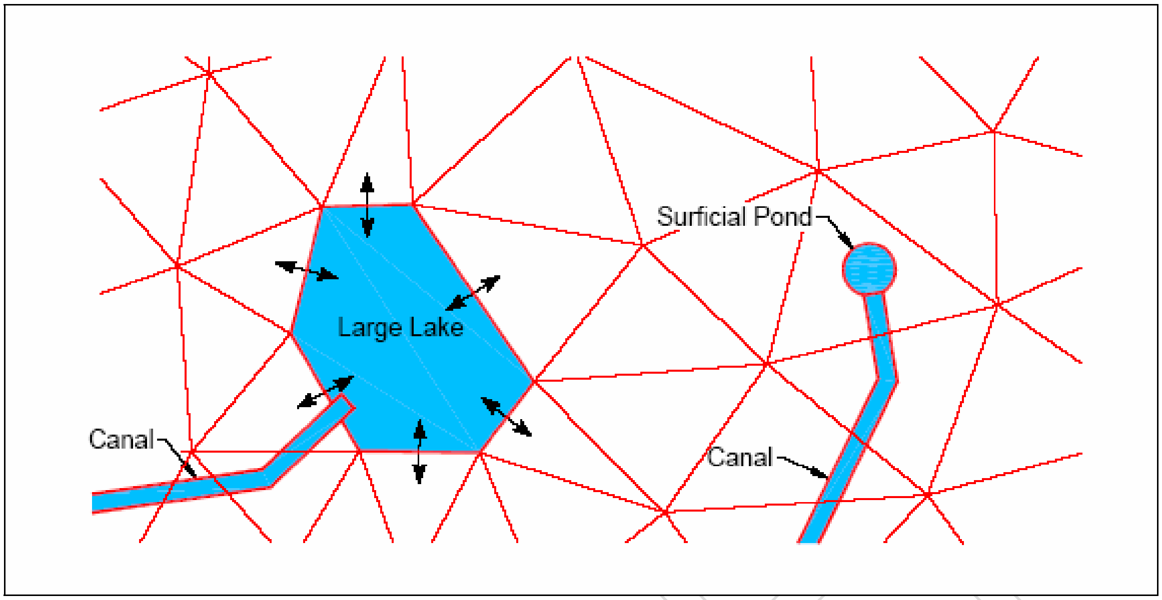


Figure 21. Discretization around a lake and a pond.

Rainfall and ET on Lakes

Two major components of the water budget of a lake or pond are precipitation and evapotranspiration. While the contribution of precipitation is straightforward, evapotranspiration depends on the surface area of the lake and the depth of the water in addition to the potential evapotranspiration (RefET) values assigned to the waterbody. In order to account for the different rates of evapotranspiration over shallow and deep water, the total ET over the lake is calculated as:

$$ET\_Volume = \left[swcoeff * \left(DryArea + ShallowArea\right) + owcoef * DeepArea * REFET\right] \tag{8}$$

where:

DryArea = the area of the lake that is not inundated,

ShallowArea = the area of the lake that is shallow,

DeepArea = the area of the lake that is deep.

The reference ET coefficients for shallow and deep water and the dividing depth between deep and shallow water are specified under <EvapRainStressors> as described in **Table 10**.

Table 10. Elements and attributes used to define <EvapRainStressors>.

<Element> or Attribute	Definition
<litZoneET>	Lake ET parameters are specified
lakeID	ID of the lake
owcoef	Open Water coefficient for RefET
swcoef	Shallow water coefficient for RefET
swdepth	Depth that divides shallow and deep water

An excerpt from the NSRSM XML is shown below in **Table 11** for Lake Okeechobee (400001) and Lake Istokpoga (400002).

Table 11. Example XML for EvapRainStressors.

```
 <EvapRainStressors>
 <litZoneET lakeID="400001" owcoef="1.0" swcoef=".92" swdepth="5.0"></litZoneET>
 <litZoneET lakeID="400002" owcoef="1.0" swcoef=".92" swdepth="5.0"></litZoneET>
</EvapRainStressors>
```

Precipitation and potential evapotranspiration for Lake Okeechobee and Istokpoga is supplied by averages of the daily rainfall and RefET input grid_io cells that fall within the boundary of each lake An example of the use of the DSS files for both potential evapotranspiration and rainfall is presented in the next **Table 12**.

Table 12. Example XML for rainfall and RefET.

```
<lake id="400001" head0 = "20.5" label="Okeechobee">
  <rain> <dss file="./input/LakeOkeeRain.dss" pn="/OKEECHOBEE/AVG/RAINFALL/1DAY//"
mult="0.0833" dbintl="1440"> </dss> </rain>
  <refet> <dss file="./input/LakeOkeeET.dss" pn="/NSRSMPET/LOK/PET/1DAY//"
mult="0.0833" dbintl="1440"> </dss> </refet>
```

NSRSM Lakes

The two major lakes modeled in the NSRSM are Lake Okeechobee and Lake Istokpoga. Other features modeled using the <lake> element includes estuaries and areas where rivers discharge (“lagoons”). There are several lagoons along the east coast that have substantial releases to the ocean during high flow events. These are sometimes referred to as blowouts (creating a channel through shoaled outlets). The RSM has the ability to simulate this phenomenon using the lake package coupled with a stage-discharge relationship.

All lakes require a stage-area and stage-volume relationship. Since historic bathymetric data do not exist for the smaller lagoons, a simplistic approach was used. The extent of each lagoon was determined from historic drawings from the Government Land Office or U.S. Coast and

Geodetic Survey. The extent was projected vertically, without any side slope, to obtain the appropriate volumes. This procedure was used in four <lake> elements shown below in **Table 13**. Note that Three Rivers Lagoon refers to discharges from Cypress Creek, Middle River and New River. The Hillsboro River and Snake River discharge to their respective lagoon.

Table 13. Elevation ranges and sizes of lagoons.

Name	Elevation Range	Area	Source
Loxahatchee Estuary	-8.0 to 6.0	105,266,531.1	Coast and Geodetic Survey
Hillsboro Lagoon	-6.0 to 6.0	16,142,667.5	GLO
Three Rivers Lagoon	-15.0 to 5.0	74,295,744.9	GLO
Snake Lagoon	-8.0 to 5.0	19,446,914.2	GLO

A stage-discharge relationship is used to simulate flow to the ocean. A look-up table is generated with the appropriate flow rate for a given elevation. The elevation at which discharge to the ocean begins is based on the bottom elevation of the river that discharges to the lagoon and is typically only a few feet. Once the water level is above the target elevation, the discharge begins, and is stopped once the water level is below the target elevation. **Table 14** provides flows and target elevations for the lagoons.

Table 14. Discharge and target elevations of estuaries and lagoons.

Name	Discharge, cfs	Target Elevation, NGVD (ft)
St Lucie Estuary	3000.0	8.5
Caloosahatchee Estuary	2000.0	4.0
Loxahatchee Estuary	2000.0	-0.5
Hillsboro River Lagoon	600.0	-1.5
Three Rivers Lagoon	2500.0	-1.5
Snake River Lagoon	1000.0	-1.5

The stage-discharge of the lagoons is simulated with a boundary condition applied to the shunt using the <hq_relation> element where the flow into or out of the waterbody is determined by a 1D stage-discharge lookup table. The <hq_relation> element allows them to maintain a constant elevation. An example from the St Lucie Estuary XML is shown below in **Table 15**. The first column under <hq> is stage (feet) and the second column is discharge (cubic feet per second). The discharge is tracked by the water budget in the model.

Table 15. Example XML for watermover with 1D lookup table, St Lucie Estuary.

```
<hq_relation wmID="50" id="400003" mult="1.0" label="StLucieEsturary">
  <hq>
   -22.0   0.0
   -1.5   0.0
   -1.6  -10.0
   15.0 -3000.0
  </hq>
</hq_relation> >
```

Lake Okeechobee

Lake Okeechobee is modeled using the lake package. The required inputs are stage area and stage volume relationships. Three feature classes were used to construct the surface and are listed below.

Bounding polygon is the 1913 boundary of Lake Okeechobee, **Figure 22**. The data source is from the Office of Chief Drainage Engineer. The map was scanned and rectified. Lake bathymetry was obtained from a 1925 U.S. Coast and Geodetic Survey. Surveys H04473 and H04474 contained images of the original drawings and coordinates for each sounding location. The surveys were obtained from the web site http://map.ngdc.noaa.gov/website/mgg/nos_hydro/viewer.htm. The soundings were converted from mean low water Punta Rassa to NGVD 1929. In order to produce a more historic representation, all artifacts of dredging were removed.

Contours surrounding the lake are SFWMD District-wide USGS topographic 5-foot contours based on original contour work on 7.5 minute quads (1:24K) by the USGS. The sources mentioned above were used to construct a Triangular Irregular Network (TIN). In an effort to construct a more historic representation, 30 years of sedimentation were removed. Lake Okeechobee has an average of 1 cm / decade of sedimentation (Brezonik and Engstrom, 1998) or 3 cm for a 30 year historic period. GRID math was used to uniformly subtract the historic sedimentation buildup of 3 cm (0.0984 ft) from the bathymetric surface to create new contours.

Comparisons were made with the 1913 survey for the Office of Chief Drainage Engineer. The soundings, when corrected for datum, are comparable. A comparison was also made with the 1989 SFWMD bathymetric surface adjusted for 100 years of sedimentation. When corrected for datum, elevation differences are also comparable.

The stage volume and stage area relationships for the model were created from the historic bathymetric elevation GRID. The stage area and stage volume table are shown graphically in **Figure 23**.

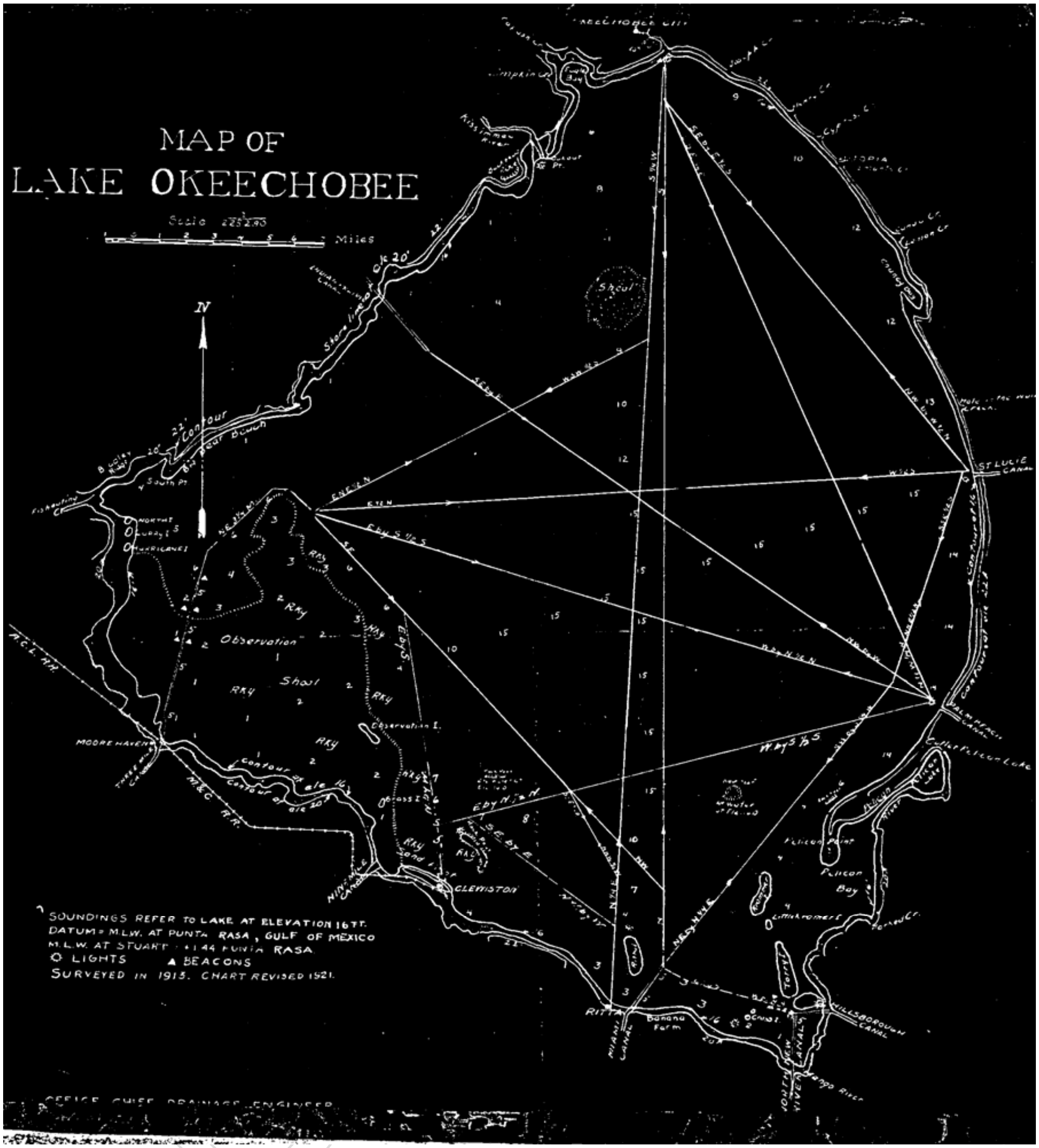


Figure 22. 1913 Lake Okeechobee boundary.

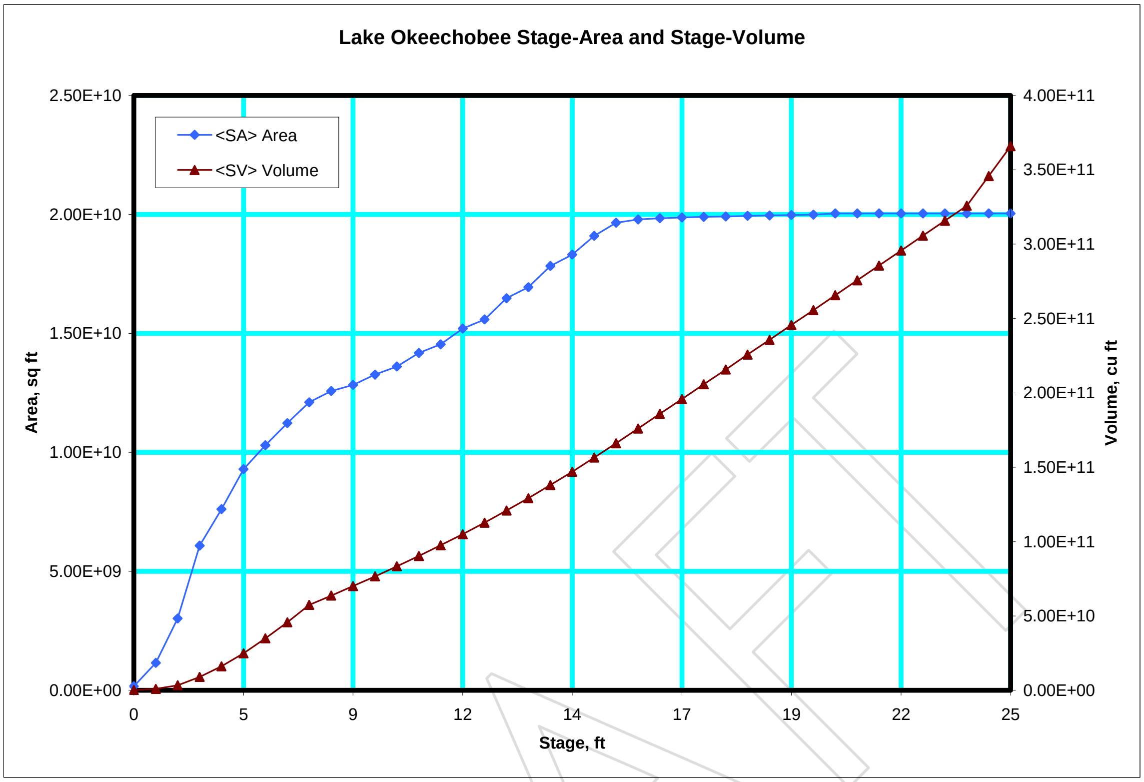


Figure 23. Graph of Lake Okeechobee stage area and stage volume table.

Lake Istokpoga

Lake Istokpoga is located just outside the northwest boundary of the model domain. The Istokpoga watershed is drained by Arbuckle and Josephine Creeks which discharge directly into Lake Istokpoga. The discharge into the lake was also modeled from a separate rainfall-runoff simulation using Sealink described in the Model Boundaries section. The XML in **Table 16** defines Lake Istokpoga's inflow during the 1965 to 2000 period of record as a boundary condition.

Table 16. Example XML for inflow into Lake Istokpoga.

```
<lake_bc>
 <!-- Istokpoga -->
 <lakesource lakeID="400002">
 <dss file="./input/LakeIstoInflow.dss" pn="/ISTOKPOGA/INFLOW/FLOW/01JAN1965-
31DEC2000/1DAY//" mult="1.0"> </dss>
   </lakesource>
</lake_bc>
```

Lake Istokpoga is modeled using the lake package. The required inputs are stage area and stage volume relationships. These were developed from bathymetric inputs from the SFWMD GIS Data Catalog. The data was provided by ReMetrix, LLC, Carmel, Indiana, in 2003. A known limitation of this dataset is that sedimentation was not taken into account. The dataset has a NGVD 1929 vertical datum. The XML defining Lake Istokpoga is presented in **Table 17**. The rainfall and evapotranspiration data provided by the DSS file were obtained from a point near the geographical center of the lake. The stage area and stage volume table are omitted from the text below but are shown graphically in **Figure 24**.

Table 17. Example XML for Lake Istokpoga.

```
<lake id="400002" head0 = "37.0" label="Istokpoga">
  <rain> <dss file="./input/LakeIstoRain.dss" pn="/ISTOKPOGA/AVG/RAINFALL/01JAN1965-
31DEC2000/1DAY//" mult="0.0833" dbintl="1440"> </dss> </rain>
  <refet> <dss file="./input/LakeIstoET.dss" pn="/NSRSMPET/LI/PET/01JAN1965-
31DEC2000/1DAY//" mult="0.0833" dbintl="1440"> </dss> </refet>
```

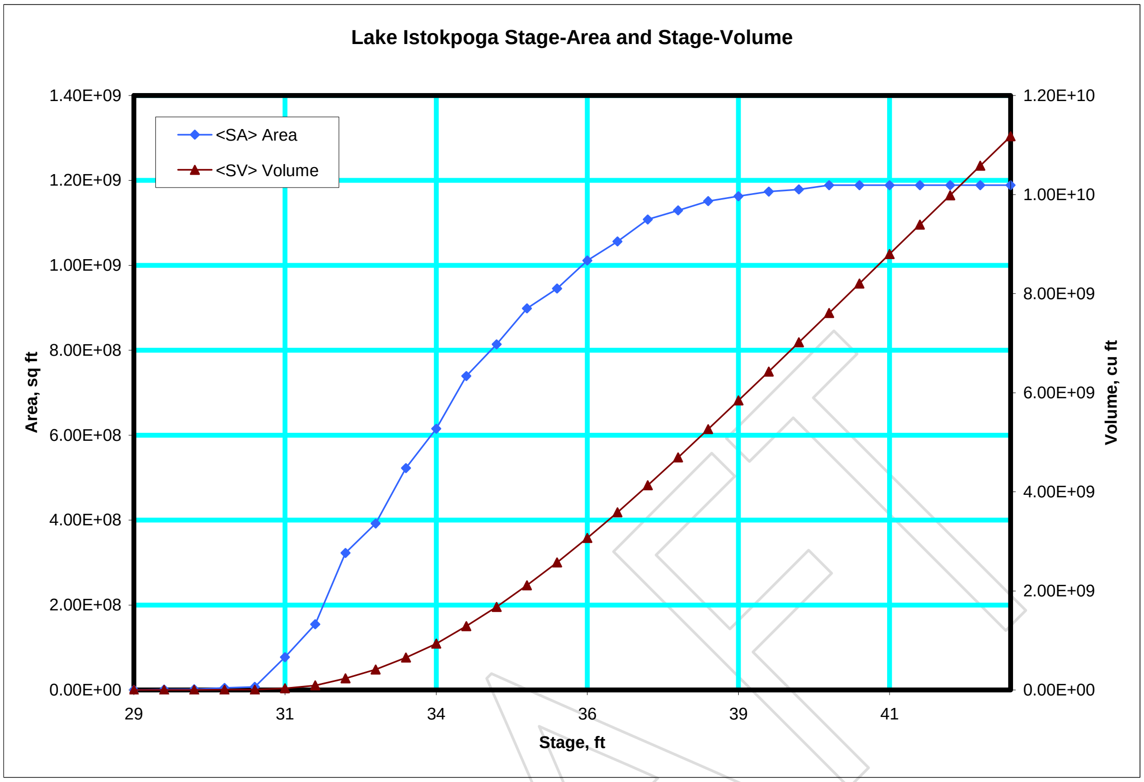


Figure 24. Graph of Lake Istokpoga stage area and stage volume table.

Three Rivers Lagoon

The Three Rivers Lagoon handles the volume of water draining through from Cypress Creek, the Middle River and New River located in the eastern portion of the model. The lagoon is modeled using a cylindrical shape as its area remains constant. Appropriate stages for the stage-area and stage-volume relationship were based on the lowest bottom elevation of the rivers emptying into the lagoon and professional judgment was used to determine the maximum elevation.

The XML defining the three river discharge is shown in **Table 18.** The stage area and stage volume table are omitted from the text below but are shown graphically in **Figure 25** below.

Table 18. Example XML for the three river discharge lagoon.

```
<lake id="400007" head0 = "1.8" label="ThreeRiverLagoon">
  <rain> <dss file="./input/LakeRain.dss" pn="/THREERIVER/AVG/RAINFALL/01JAN1965-
31DEC2000/1DAY//" mult="0.0833" dbintl="1440" units="INCHES"> </dss> </rain>
  <refet> <dss file="./input/LakeET.dss" pn="/NSRSMPET/THREERIVER/PET/01JAN1965-
31DEC2000/1DAY//" mult="0.0833" dbintl="1440" units="INCHES"> </dss> </refet>
```

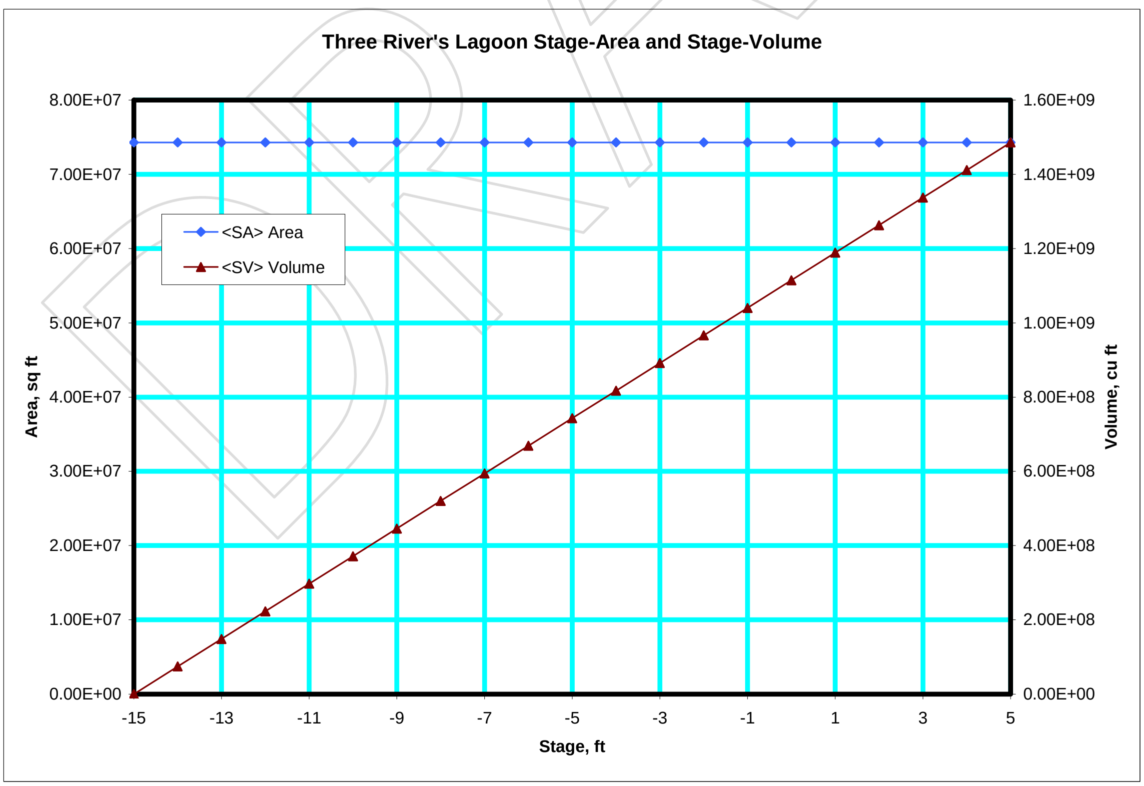


Figure 25. Graph of the Three Rivers Lagoon stage area and stage volume.

St. Lucie Estuary

The St Lucie estuary is being implicitly modeled using the lake package. The inputs were developed from bathymetric input from the U.S. Coast and Geodetic Survey in 1883. The datum used in the map represented mean low water 1883. To convert to NGVD 1929, the sea level rise was estimated at National Ocean Service station 8722371, Sewall Point St Lucie River, FL. The rise in mean sea level was compared at current and previous epochs. The difference was 0.20 feet, for a 22 year period, this is a 0.0087 ft/year rise in mean sea level. The current mean low water is at 0.15 feet NGVD 29, therefore the mean low water 100 years ago would have been at about -0.72 feet NGVD 29 in 1884.

Since the soundings on the 1883 map represent depth below mean low water, the sounding value was subtracted from -0.72, i.e. -0.72 – 20 = -20.72 NGVD 29. The points and bounding polygon are stored in a GIS database. A TIN was constructed from the data. Results from surface analysis were used to generate the stage area / stage volume tables. A known issue is that sedimentation was not taken into account. Bathymetry is illustrated in **Figure 26**.

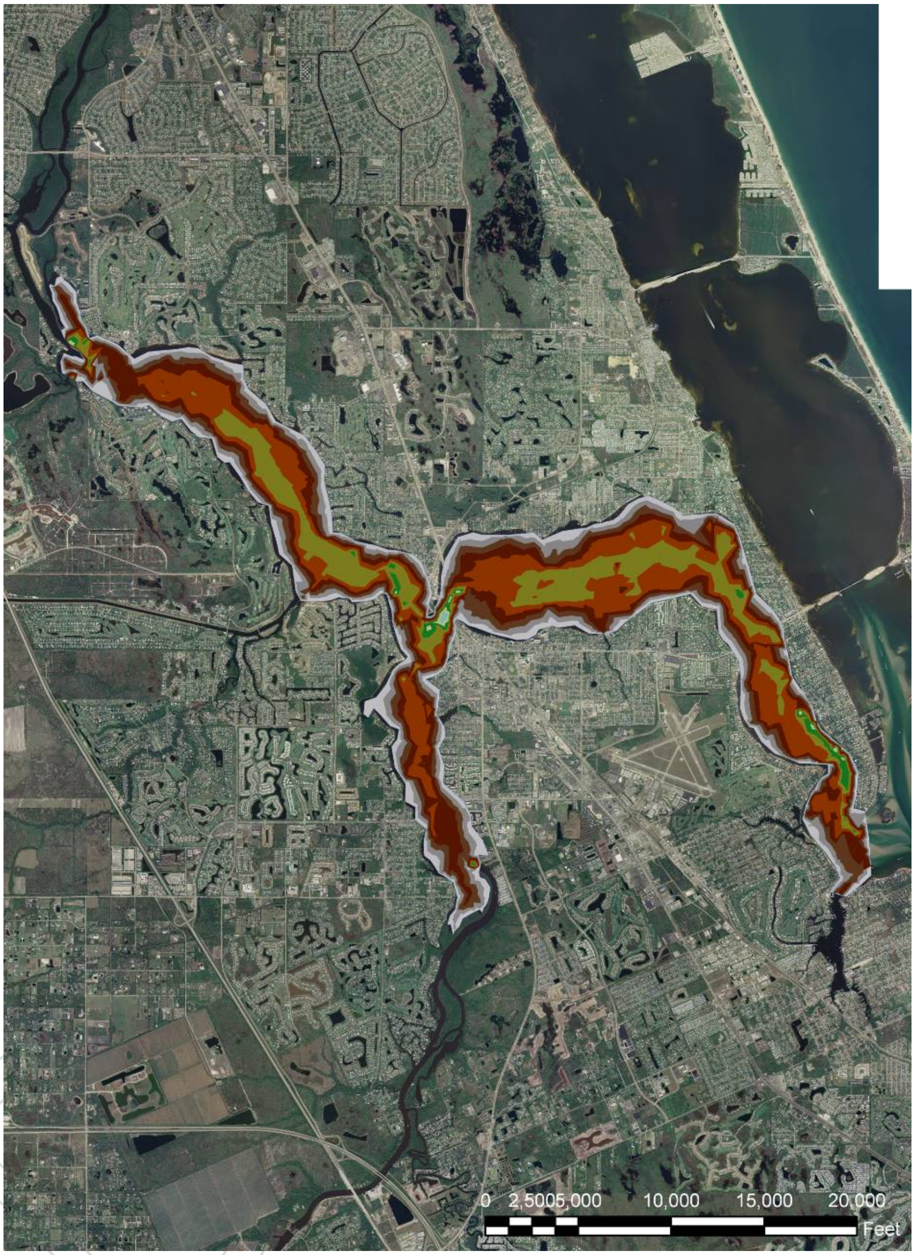


Figure 26. St. Lucie estuary bathymetry.

The XML defining the St. Lucie estuary is presented in **Table 19**. The stage area and stage volume table are omitted from the text below but are shown graphically in **Figure 27**.

Table 19. Example XML for St. Lucie estuary.

```
<lake id="400003" head0 = "3.5" label="StLucieEsturary">
  <rain> <dss file="./input/LakeRain.dss" pn="/STLUCIE/AVG/RAINFALL/01JAN1965-
31DEC2000/1DAY//" mult="0.0833" dbintl="1440" units="INCHES"> </dss> </rain>
  <refet> <dss file="./input/LakeET.dss" pn="/NSRSMPET/STLUCIE/PET/01JAN1965-
31DEC2000/1DAY//" mult="0.0833" dbintl="1440" units="INCHES"> </dss> </refet>
```

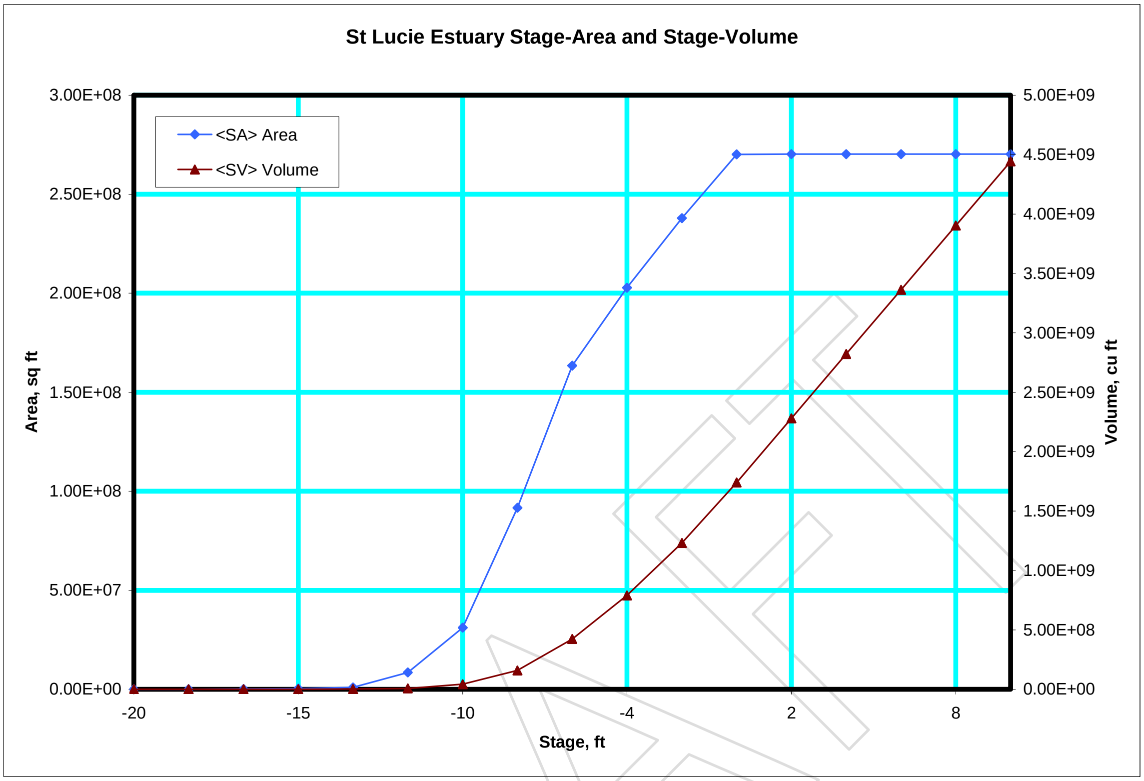


Figure 27. Graph of the St. Lucie estuary stage area and stage volume.

Loxahatchee Estuary

The lake element was necessary to simulate releases to the ocean from the Loxahatchee estuary located in the northeastern portion of the model.

The XML defining the Loxahatchee estuary is presented in **Table 20**. The stage area and stage volume table are omitted from the text below but are shown graphically in **Figure 28**. The estuary is modeled using a cylindrical shape as its area remains constant. Appropriate stages were based on soundings from the 1884 Coast and Geodetic Survey. The Datum is mean low water. To convert this to NVGD 29, the mean low water at Loxahatchee River, FL station 8722481 is 0.15 feet. It is assumed that the sea level rise is about 0.87 feet in 100 years (measured at the St Lucie station). Therefore, mean low water in 1884 is about -0.72 feet NGVD 29. Professional judgment was used to determine the maximum stage. The stage range used in the stage-area and stage-volume relationship is -8.0 to 6.0, which is within the range to the 1884 survey.

Table 20. Example XML for Loxahatchee estuary.

```
<lake id="400005" head0 = "4.1" label="LoxEsturary">
  <rain> <dss file="./input/LakeRain.dss" pn="/LOXAHATCHEE/AVG/RAINFALL/01JAN1965-
31DEC2000/1DAY//" mult="0.0833" dbintl="1440" units="INCHES"> </dss> </rain>
  <refet> <dss file="./input/LakeET.dss" pn="/NSRSMPET/LOXAHATCHEE/PET/01JAN1965-
31DEC2000/1DAY//" mult="0.0833" dbintl="1440" units="INCHES"> </dss> </refet>
```

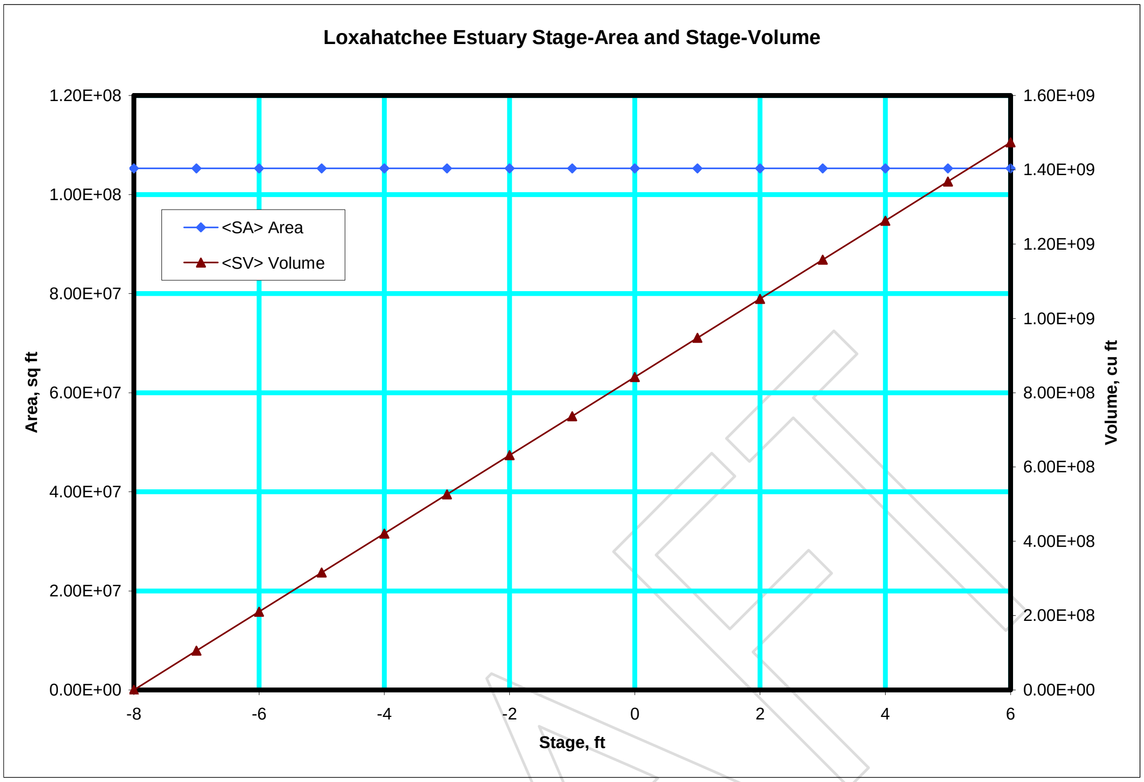


Figure 28. Graph of the Loxahatchee estuary stage area and stage volume.

Hillsboro River Lagoon

The Hillsboro River lagoon requires the lake element to simulate releases to the ocean. The reservoir has a cylindrical shape as its area remains constant. Appropriate stages for the stage-area and stage-volume relationship were based on the lowest bottom elevation of the rivers emptying into the lagoon and professional judgment was used to determine the maximum elevation. The XML defining the Hillsboro River Lagoon is presented in **Table 21.** The stage area and stage volume table are omitted from the text below but are shown graphically in **Figure 29**.

Table 21. Example XML for the Hillsboro Lagoon discharge.

```
<lake id="400006" head0 = "0.2" label="HillsboroLagoon">
  <rain> <dss file="./input/LakeRain.dss" pn="/HILLSBORO/AVG/RAINFALL/01JAN1965-
31DEC2000/1DAY//" mult="0.0833" dbintl="1440" units="INCHES"> </dss> </rain>
  <refet> <dss file="./input/LakeET.dss" pn="/NSRSMPET/HILLSBORO/PET/01JAN1965-
31DEC2000/1DAY//" mult="0.0833" dbintl="1440" units="INCHES"> </dss> </refet>
```

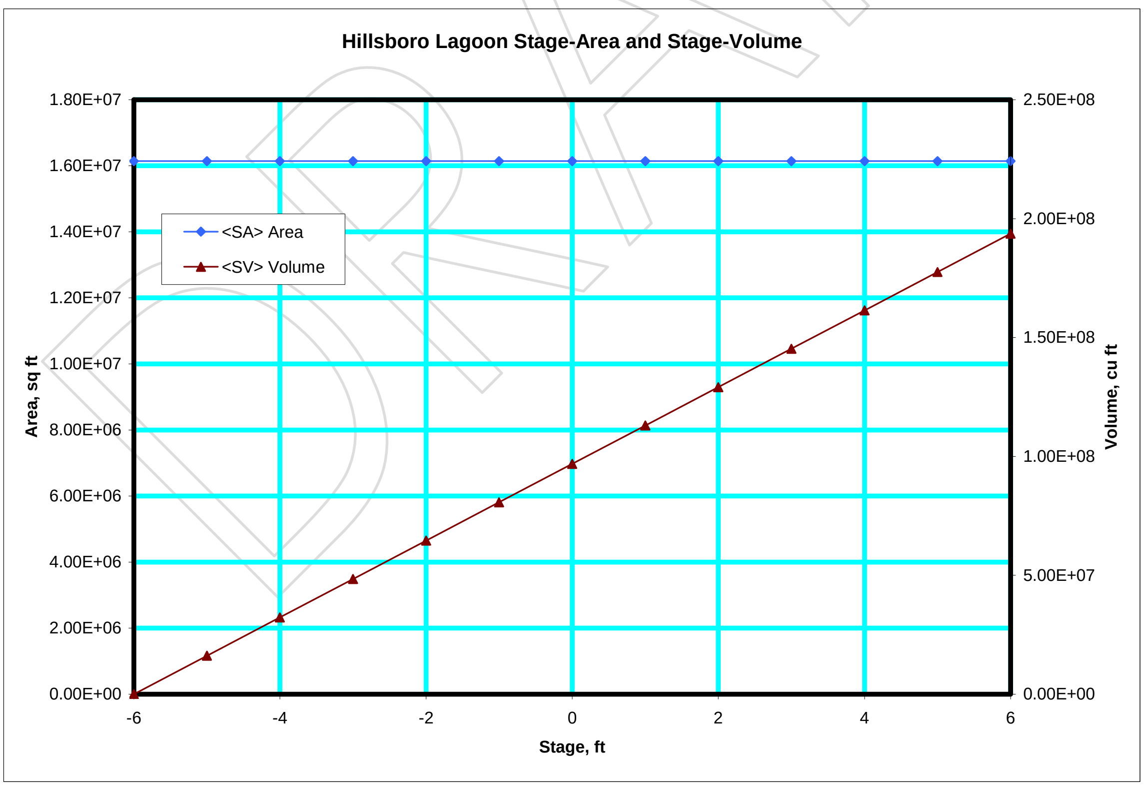


Figure 29. Graph of the Hillsboro Lagoon stage area and stage volume.

Snake River Lagoon

The discharge of the Snake River requires the lake element to simulate releases to the ocean. The reservoir has a cylindrical shape as its area remains constant. The river connects with Dumfundling Bay which is represented with the lake package.

The XML defining the Snake River Lagoon is presented in **Table 22.** The stage area and stage volume table are omitted from the text below but are shown graphically in **Figure 30**. The stages are based on soundings from the 1884 U.S. Coast and Geodetic Survey map. The datum is mean low water. Present mean low water in Dumfoundling Bay is 0.14 feet NGVD 29, station 8723044. With an assumed sea level rise of 0.87 feet for 100 years, the mean low water datum in 1884 would be -0.73 feet NGVD 29. The stage range used in the stage-area and stage-volume relationship is -8.0 to 5.0, which is within the range to the 1884 survey.

Table 22. Example XML for the Snake River Lagoon discharge.

```
<lake id="400008" head0 = "2.8" label="SnakeLagoon">
  <rain> <dss file="./input/LakeRain.dss" pn="/SNAKE/AVG/RAINFALL/01JAN1965-
31DEC2000/1DAY//" mult="0.0833" dbintl="1440" units="INCHES"> </dss> </rain>
  <refet> <dss file="./input/LakeET.dss" pn="/NSRSMPET/SNAKE/PET/01JAN1965-
31DEC2000/1DAY//" mult="0.0833" dbintl="1440" units="INCHES"> </dss> </refet>
```

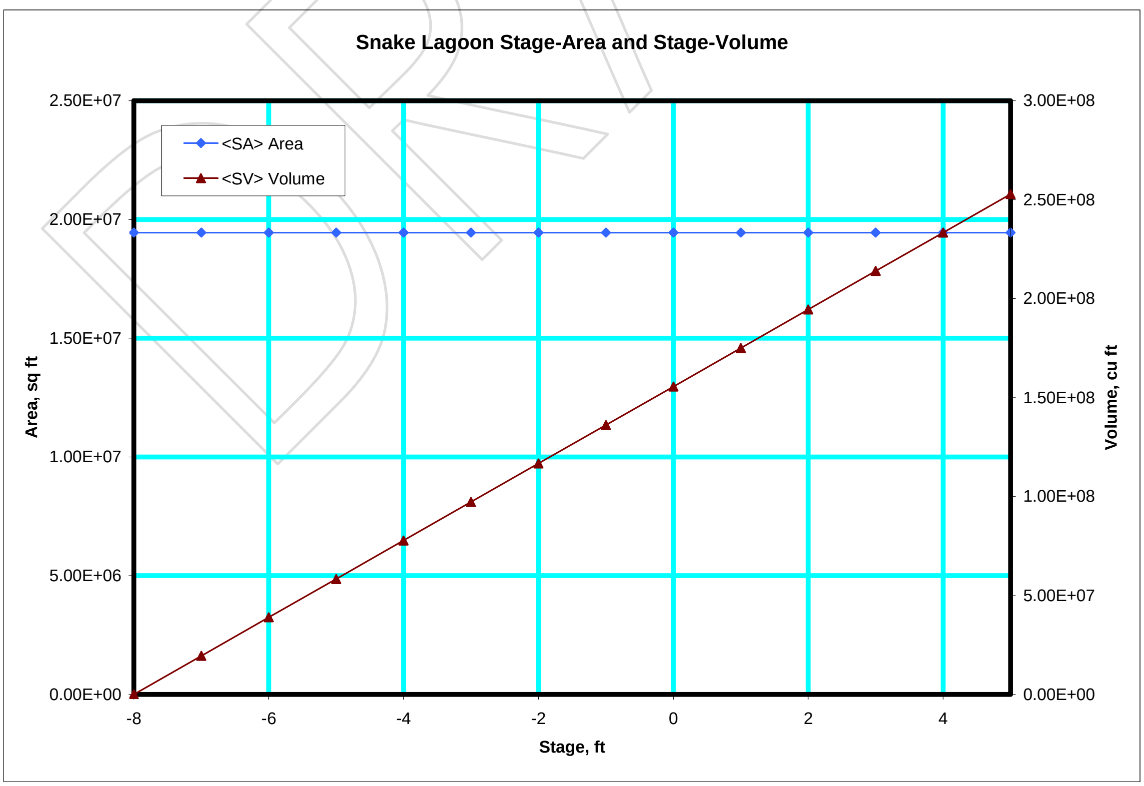


Figure 30. Graph of the Snake Lagoon stage area and stage volume table.

Caloosahatchee Estuary

The Caloosahatchee estuary is modeled using the lake package. The required inputs are stage area and stage volume relationships. These were developed from bathymetric input from the U.S. Coast and Geodetic Survey in 1927. The points and bounding polygon are stored in a GIS database. A TIN was constructed from the data. Results from surface analysis were used to generate the stage area / stage volume tables. A known issue is that sedimentation was not taken into account. Bathymetry is illustrated in **Figure 31**.

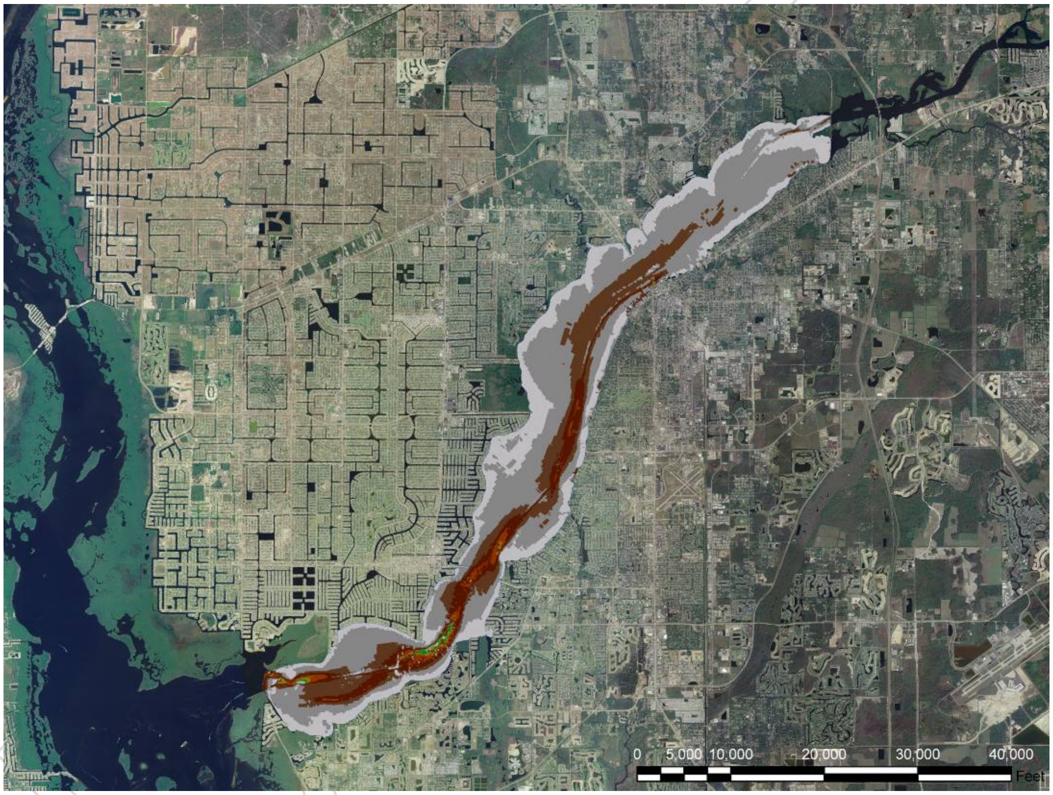


Figure 31. Bathymetric map of Caloosahatchee Estuary.

Estuary bathymetry was obtained from a 1927 U.S. Coast and Geodetic Survey. Surveys H04690 and H04691 contained images of the original drawings and coordinates for each sounding location. The surveys were obtained from the web site http://map.ngdc.noaa.gov/website/mgg/nos_hydro/viewer.htm. The soundings were converted from mean low water Fort Myers, Caloosahatchee River to NGVD 1929.

Present mean low water in the Fort Myers, Caloosahatchee River datum is 0.12 feet NGVD 29, station 8725520. With an assumed sea level rise of 0.75 feet for 100 years, the mean low water datum for pre-development conditions would be -0.63 feet NGVD 29.

The XML defining the Caloosahatchee Estuary storage is presented in **Table 23**. The stage area and stage volume table are omitted from the text below but are shown graphically in **Figure 32**.

Table 23. Example XML for the Caloosahatchee River storage.

```
<lake id="400004" head0 = "0.5" label="CaloosahatcheeEstuary">
  <rain> <dss file="./input/LakeRain.dss" pn="/CALOO/AVG/RAINFALL/01JAN1965-
31DEC2000/1DAY//" mult="0.0833" dbintl="1440" units="INCHES"> </dss> </rain>
  <refet> <dss file="./input/LakeET.dss" pn="/NSRSMPET/CALOO/PET/01JAN1965-
31DEC2000/1DAY//" mult="0.0833" dbintl="1440" units="INCHES"> </dss> </refet>
```

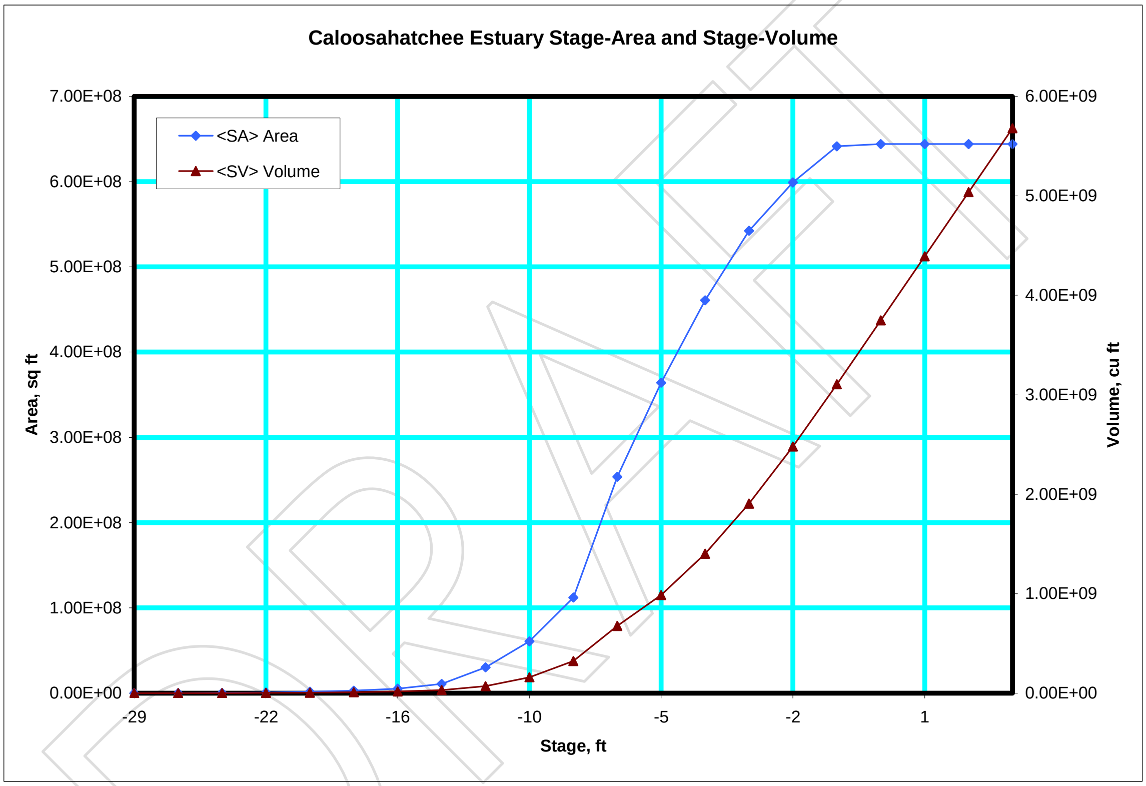


Figure 32. Graph of the Caloosahatchee Lagoon stage area and stage volume table.

OVERLAND FLOW

The model uses the <conveyance> element to describe overland flow. Data is entered in the mesh environment using either Manning's or Kadlec equation options to calculate flow. Manning's n (A and B) and Kadlec (K) values are assigned in the model according to landcover classification; Kadlec's equation is applied to Sawgrass Plains, Ridge and Slough, and Everglades Marl Prairie landscapes. All other conveyance is modeled with Manning's coefficients. The difference between the two equations is described below.

Overland Flow Options

Manning's

$$Q = \frac{1.49}{n} L d^{5/3} \sqrt{S} \tag{9}$$

where:

Q = flow in cfs

L = length of the flow face perpendicular to the flow direction (ft),

n = Manning's coefficient (sec/ft$^{1/3}$),

$$n = A d^{B}$$

where:

A and B = empirical constants.

d = water depth (ft), and

S = water surface slope.

Kadlec (Kadlec and Knight, 1996)

$$Q = L a d^{\beta} S^{\alpha} \tag{10}$$

where:

Q = volume flow rate (ft^3/sec),

L = width of flow (ft),

d = flow depth (ft), and

a, α and β = empirical constants.

This modification to Manning's equation is recommended for wetland flow. Manning's $\sqrt{S}$ term is replaced by S^{α} where α is a user-defined exponent.

An excerpt from the NSRSM conveyance XML using Manning's and Kadlec's equation is presented in **Table 24**. Conveyance will be zero when depth, d, is less than the detent attribute value. In this example Manning's n is dependent of depth when Manning's exponent b in is -0.77. A summary of conveyance parameters for other land cover designation is provided in **Table 25**.

Table 24. Example XML for conveyance.

```

<entry id="500" label="Non-forested Freshwater Wetlands">
 <mannings a="0.3" b="-0.77" detent="0.1"> </mannings>
</entry>

<entry id="510" label="Long hydroperiod Marsh">
 <mannings a="0.6" b="-0.77" detent="0.1"> </mannings>
</entry>

<entry id="511" label="Ridge and Slough">
 <kadlec K="1800.0" alpha="1.0" beta="3.0" detent="0.1"> </kadlec>
</entry>

<entry id="512" label="Sawgrass Plains">
 <kadlec K="1500.0" alpha="1.0" beta="3.0" detent="0.1"> </kadlec>
</entry>

```

Table 25. NSRSM cell conveyance parameters

Landcover	ID	Overland Flow Conveyance Parameter		
		Manning's A	**Manning's B**	**Detention**
Water	100	1.0	0.0	0.1
Intra-tidal wetlands	200	0.1	-0.77	0.1
Beaches	300	0.1	-0.77	0.1
Forested Freshwater Wetlands	400	0.4	-0.77	0.1
Cypress Swamp	410	0.4	-0.77	0.1
Hardwood Swamp	420	0.4	-0.77	0.1
Non-forested Freshwater Wetlands	500	0.3	-0.77	0.1
Long hydroperiod Marsh	510	0.6	-0.77	0.1
Medium Hydroperiod Marsh	520	0.3	-0.77	0.1
Marsh with Scattered Cypress	521	0.3	-0.77	0.1
Wet Prairie	530	0.3	-0.77	0.1
Wet Prairie with Scattered Trees	531	0.3	-0.77	0.1

Wet Prairie with Cypress	532	0.2	-0.77	0.1
Hydric Uplands	600	0.3	0.0	0.1
Hydric Flatwood	610	0.3	0.0	0.1
Hydric Hammock	620	0.4	0.0	0.1
Mesic Uplands	700	0.2	0.0	0.1
Dry Prairie	710	0.2	0.0	0.1
Mesic Pine Flatwood	720	0.2	0.0	0.1
Landcover	**ID**	**Max Kadlec Coeff**	**Alpha**	**Beta**
Ridge and Slough	511	1800.0	1.0	3.0
Sawgrass Plains	512	1500.0	1.0	3.0
Everglades Marl Marsh	522	1750.0	1.0	3.0

A conveyance lookup table for Sawgrass Plains and Ridge and Slough landscapes based on Kadlec's formulation was prepared using the computation below.

$$Conveyance = Kd^{\beta}$$

where:

K = Kadlec coefficient

d = flow depth (ft), and

β = empirical constants.

The peat layer varies from 2 ft to 14 ft throughout the Sawgrass Plains and Ridge and Slough landscapes. Peat is assumed to have a hydraulic conductivity of 0.84 ft/d (Harvy et.al., 2002). The conveyance lookup table for peat assuming a uniform hydraulic conductivity is:

Table 26. NSRSM cell conveyance parameters

Depth (ft)	Conveyance (sq ft/d)
1.0	0.84
2.0	1.68
3.0	2.52
4.0	3.36
5.0	4.20
6.0	5.04
7.0	5.88
8.0	6.72
9.0	7.56
10.0	8.40
11.0	9.24
12.0	10.08
13.0	10.92
14.0	11.76

Table 27. Lookup Table for Sawgrass Plains

Kadlec Coeff	Alpha	Beta	Depth	Conveyance
1500	1	3	0.00	0.00
1500	1	3	0.25	23.44
1500	1	3	0.50	187.50
1500	1	3	0.75	632.81
1500	1	3	1.00	1500.00

Table 28 Lookup Table for Ridge and Slough

Kadlec Coeff	Alpha	Beta	Depth	Conveyance
1800	1	3	0.00	0.00
1800	1	3	0.25	28.13
1800	1	3	0.50	225.00
1800	1	3	0.75	759.38
1800	1	3	1.00	1800.00

Hydraulic conductivity in the Everglades Marl Marsh was estimated to be twice (1.68 ft/d) the value for the Sawgrass Plains.

Table 29 Lookup Table for Everglades Marl Marsh

Kadlec Coeff	Alpha	Beta	Depth	Conveyance
1750	1	3	0.00	0.00
1750	1	3	0.25	27.34
1750	1	3	0.50	218.75
1750	1	3	0.75	738.28
1750	1	3	1.00	1750.00

Stage Volume Converter

Although the South Florida landscape is relatively flat, hydrological characteristics (e.g. water storage volume per unit change in head and ET rate) may change significantly within the range of elevations close to the average ground elevation. Stage-volume converters <svconverter> have been developed to allow a more accurate representation of the volume of water stored at different water levels. Depending on the area under water, wetlands can store variable amounts of water at various depths.

A flat ground with a designated storage coefficient below ground level and the assumption of open water above ground level is generally a poor representation of wetland storage conditions. However, this has been the standard method used to conceptualize water storage above and below ground. This section describes NSRSM elevation-storage relationships that better represent cell micro-topography in the ridge and slough landscape. **Figure 33** shows a section of a cell with an undulating ground surface. In the XML representation, the stage-storage conversion behavior is defined in the <mesh> environment using the element <svconverter>. A single <scvonverter> can be defined for the entire model, or the cells can be indexed to use different converters in different areas.

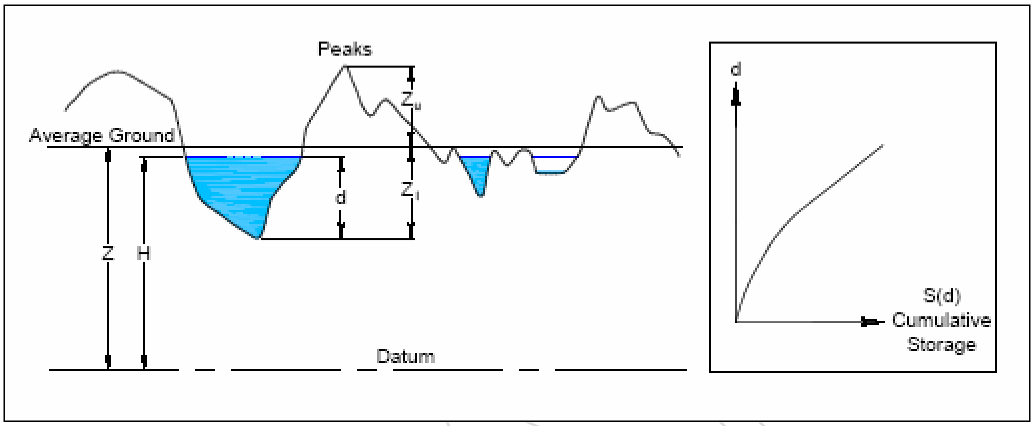


Figure 33. Stage-storage characteristics in micro-topography.

Application to NSRSM Landscapes

Figure 34 below illustrates a conceptual model describing a typical Ridge and Slough cell and **Table 30** has the percentages of each elevation used.

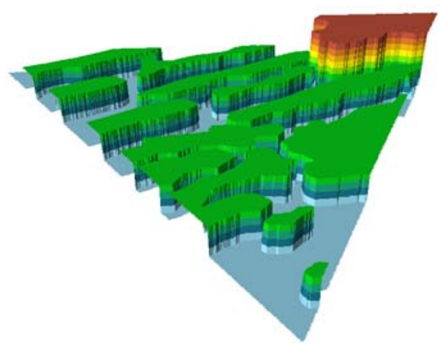


Figure 34. Model of ridge and slough mesh cell

Table 30. Elevations and percentages used in Ridge and Slough landscape.

Location	Elevation	Percentage
Slough	0.0	49.7%
Ridge	1.5	41.5%
Tree Island	3.5	8.8%

The Sv converter for the Sawgrass Plains and Ridge and Slough landscapes accounts for storage in the micro topography and groundwater. The volume of water stored in the micro topography is computed by adding the volume of open water and the volume of water available in the landscape. Land surface is defined as the bottom of the slough.

Table 31. Volume of water stored in ridge and slough at each elevation.

Elevation	Volume Available
0.00	2,237,587.6
0.25	2,424,840.7
0.50	2,425,448.8
0.75	2,430,555.0
1.00	2,427,913.8
1.25	2,435,371.8
1.50	2,438,557.5
1.75	2,601,865.7
2.00	2,594,205.1
2.25	2,594,701.5
2.50	2,594,769.0
2.75	2,594,836.9
3.00	2,594,913.8
3.25	2,595,008.5
3.50	2,595,121.4

The volume of water below land surface is computed from the porosity and the thickness of the Peat layer. The porosity varies as shown in **Table 32** below. The volume of water below land surface is computed by multiplying the porosity by the thickness of each horizontal slice.

Table 32. Porosity used in the Peat layer.

Layer	Porosity
Land surface to Bottom 1 ft thickness of Peat	0.85
Bottom 1 ft thickness of Peat	0.50
Beneath Peat Layer	0.20

The topographic surface used in the NSRSM for the Ridge and Slough cells represent a composite elevation. This composite elevation accounts for the elevation of a typical slough, ridge, and tree island. For a typical Ridge and Slough cell, it was determined that the average elevation above land surface is 2.25 feet. Similarly, the composite elevation for a typical Sawgrass Plains cell is an average 1.5 feet above land surface. Therefore, the elevations for the stage-volume lookup table need to be adjusted for the composite elevations. In the example lookup table below, the composite Ridge and Slough elevation is 2.25 ft above land surface and the bottom of the Peat layer is 3.25 ft below land surface.

Table 33 Sv Lookup Table

D	Sv
-3.25	0.000
-3.00	0.125
-2.75	0.250
-2.50	0.375
-2.25	0.588
-2.00	0.800
-1.75	1.013
-1.50	1.225
-1.25	1.438
-1.00	1.668
-0.75	1.898
-0.50	2.129
-0.25	2.360
0.00	2.591
0.25	2.822
0.50	3.069
0.75	3.316
1.00	3.562
1.25	3.809
1.50	4.055
1.75	4.302
2.00	4.548
2.25	4.794

HYDROGEOLOGY

High ground water flows occur in areas with the largest hydraulic gradients. Consequently, given the low gradient conditions in the Everglades Basin, ground water flow is very small in comparison to surface water flow.

The largest ground water flows occur across the Miami Rock Ridge and Atlantic Coastal Strip, which form a divide between the Everglades and the Atlantic Ocean. Other basins contain topographic gradients that are sufficient in magnitude to induce ground water flow, including the Western Flatwoods, Big Cypress and the areas north of Lake Okeechobee.

Hydrostratigraphy

The base of the surficial aquifer is the bottom of the single layer NSRSM. Where model domains overlap (hatched area **Figure 35**), the same hydrostatigraphic input prepared for the South Florida Regional Simulation Model (SFRSM) is applied in the NSRSM (**Appendix F.1**).

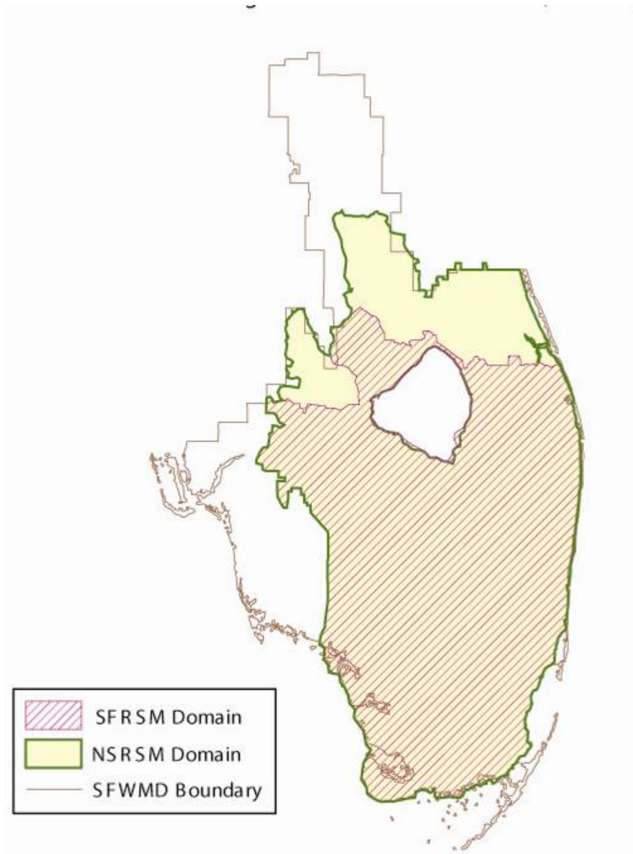


Figure 35. Comparison of model domains.

NSRSM regions outside of the SFRSM domain include the Lower Kissimmee River Basin, Fisheating Creek and St. Lucie River watersheds. Base elevations for the surficial aquifer in this area were obtained from SFWMD DBHydro well data. Data development is described in **Appendix F**.

Transmissivity and Conductivity

Transmissivity is the product of aquifer thickness and aquifer conductivity:

$$Q = LkdS \tag{14}$$

where:

L = width of the aquifer (ft),

d = the aquifer thickness (ft),

k = average hydraulic conductivity (ft/sec), and

S = head gradient (i.e., hydraulic gradient) in the direction of flow.

Surficial aquifer properties are defined by aquifer transmissivity and soil storage coefficient values. Surficial aquifer properties in the NSRSM are consistent with those developed for the SFRSM. In the areas north of the SFRSM model domain, transmissivity values were interpolated. SFRSM Hydraulic conductivity values were used in this region to calculate NSRSM transmissivity resulting in values that range from 0.24 Kft^2/day to 1,050.31 Kft^2/day. The average is 151.31 Kft^2/day and the median is 7.72 Kft^2/day. Soil storage coefficient values were set to 0.2.

The NSRSM uses a uniform bottom elevation of -155.0 NGVD29. This is the lowest elevation in a GRID representing the bottom elevation of the surficial aquifer. The uniform elevation gives the model a greater global aquifer thickness resulting in no mass violation errors. The hydraulic conductivity was scaled to the transmissivity.

The model requires a top, bottom, and hydraulic conductivity values unique to each cell. The hydraulic conductivity was computed for each cell by dividing the thickness (computed by subtracting the uniform bottom elevation from the top elevation) into the transmissivity (computed by multiplying the hydraulic conductivity by the difference between the top elevation and variable bottom elevation). The resultant transmissivity is the same if either a variable or uniform bottom elevation is used.

In the example below, the transmissivity for cell 29824 was calculated by multiplying the thickness (ft) and hydraulic conductivity (fps). The hydraulic conductivity for cell ***29824'*** was computed by dividing the thickness (195.6) into the transmissivity (0.2805). Therefore, cell ***29824'*** has the same effective hydraulic conductivity as cell 29824. This methodology was applied throughout the entire model.

Table 34. Transmissivity Calculations for NSRSM Mesh

Cell	Top Elevation	Bottom Elevation	Thickness	Hydraulic Cond	Transmissivity
29824	40.6	-65.9	106.5	0.002634	0.2805
29824'	40.6	-155.0	195.6	***0.001435***	

HYDROLOGIC PROCESS MODULES

The Hydrologic Process Modules (HPMs) were developed to simulate the small-scale, local hydrology and vertical processes for the RSM. The primary function of HPMs is to provide the surface boundary condition for the regional solution; HPMs are used to process rainfall and potential evapotranspiration (PET) and provide net recharge to the mesh cells of the HSE. Structurally, the foot print for the HPMs matches the cell boundaries of the irregular triangular

2D mesh. The HPMs are solved explicitly at the beginning of each model time step and the results are provided as known flows to the upper boundary condition of the regional implicit finite-volume flow model.

Two types of natural system HPMs are used by NSRSM: “layer1nsm” and “unsat”. Layer1nsm is used to simulate natural hydrology by calculating a simple water budget for the soil with a water table that is defined by the water level in the mesh cell. The unsaturated soil HPM is similar to layer1nsm except that it considers water in the unsaturated soil above the water table. Using “unsat” can be useful when the water table may be below ground for a significant portion of the year.

The HPMs are designed to simulate local hydrology in natural areas that can be classified as wetlands and uplands. The principal distinction in terms of hydrologic processes is the interaction with the surficial aquifer. In wetlands and other areas where the water table is in the root zone for most of the year, the local hydrology is largely controlled by the depth to the water table. In upland areas there is substantial water storage in the unsaturated zone above the water table but below the root zone. Water will drain from saturated soil over extended periods contributing to surface water and regional groundwater. Natural areas differ from developed areas in that the hydrology is controlled by the native landscape features, and water moves relatively slowly through the landscape. In developed areas, man-made features move water quickly to maintain and manage water levels. The natural systems HPMs are briefly described below:

- The natural wetland system <layer1nsm> HPM is used to represent the local hydrology of wetlands and high water table soils where the water table is in the root zone for extended periods every year. The available soil water for evapotranspiration is determined by the location of the water table. When the water table is below the root zone the simple algorithm used in this HPM will not accurately describe evapotranspiration and the water budget will not be accurately simulated.
- The unsaturated soil HPM <unsat> an extension of the <layer1nsm> HPM type. Whereas the <layer1nsm> HPM assumes that there is no unsaturated soil and all of the water for evapotranspiration is extracted from the water table, <unsat> maintains moisture accounting in the unsaturated zone as well as tracking the water table. The available moisture in the unsaturated zone is extracted for evapotranspiration demand before water is removed from the water table.

Table 35. HPM parameters

Landuse Code	Name	Kw	Rd	Xd	Pd	Kveg
100	Water	0.9	0	5	3	1
200	Intra-tidal wetlands	0.9	0	4.5	5	-0.08
300	Beaches	0.9	0	4.5	5	0.5
400	Forested Freshwater Wetlands	0.9	0	8	5	-0.08
410	Cypress Swamp	0.9	0	8	5	-0.08
420	Hardwood Swamp	0.9	0	8	5	-0.08
500	Non-forested Freshwater Wetlands	0.9	0	4.4	4.5	-0.08
510	Long Hydroperiod Marsh	0.9	0	3	5	-0.08

511	Ridge and Slough	0.9	0	2.5	5	-0.08
512	Sawgrass Plains	0.9	0	2.75	5	-0.08
520	Medium Hydroperiod Marsh	0.9	0	3	5	-0.08
521	Marsh with Scattered Cypress	0.9	0	3	5	-0.08
522	Everglades Marl Marsh	0.9	0	2	4.5	-0.08
530	Wet Prairie	0.9	0	3	4.5	-0.08
531	Wet Prairie with Scattered Trees	0.9	0	8	5	-0.08
532	Wet Prairie with Cypress	0.9	0	8	5	-0.08
600	Hydric Uplands	0.9	0	8	5	-0.08
610	Hydric Flatwood	0.9	0	8	5	-0.08
620	Hydric Hammock	0.9	0	8	5	-0.08

Kw = Maximum crop coefficient for water
Rd = Shallow root zone depth
Xd = Extinction depth below which no ET occurs
Pd = Open water ponding depth
Kveg = Vegetation crop coefficient. When Kveg = -0.08, a seasonal amplitude table is used.

Table 36 Monthly vegetation coefficients for each landuse code in NSRSM.

	Landuse Code																
Date	***200***	***400***	***410***	***420***	***500***	***510***	***511***	***512***	***520***	***521***	***522***	***530***	***531***	***532***	***600***	***610***	***620***
Jan-1	0.68	0.68	0.68	0.68	0.76	0.76	0.74	0.81	0.76	0.76	0.76	0.76	0.76	0.76	0.68	0.68	0.68
Jan-31	0.68	0.68	0.68	0.68	0.76	0.76	0.74	0.81	0.76	0.76	0.76	0.76	0.76	0.76	0.68	0.68	0.68
Feb-1	0.65	0.65	0.65	0.65	0.73	0.73	0.72	0.78	0.73	0.73	0.73	0.73	0.73	0.73	0.65	0.65	0.65
Feb-28	0.65	0.65	0.65	0.65	0.73	0.73	0.72	0.78	0.73	0.73	0.73	0.73	0.73	0.73	0.65	0.65	0.65
Mar-1	0.69	0.69	0.69	0.69	0.78	0.78	0.75	0.82	0.77	0.77	0.77	0.77	0.77	0.77	0.69	0.69	0.69
Mar-31	0.69	0.69	0.69	0.69	0.78	0.78	0.75	0.82	0.77	0.77	0.77	0.77	0.77	0.77	0.69	0.69	0.69
Apr-1	0.7	0.7	0.7	0.7	0.81	0.81	0.77	0.85	0.8	0.8	0.8	0.78	0.78	0.78	0.7	0.7	0.7
Apr-30	0.7	0.7	0.7	0.7	0.81	0.81	0.77	0.85	0.8	0.8	0.8	0.78	0.78	0.78	0.7	0.7	0.7
May-1	0.74	0.74	0.74	0.74	0.85	0.85	0.81	0.89	0.85	0.85	0.85	0.81	0.81	0.81	0.74	0.74	0.74
May-31	0.74	0.74	0.74	0.74	0.85	0.85	0.81	0.89	0.85	0.85	0.85	0.81	0.81	0.81	0.74	0.74	0.74
Jun-1	0.75	0.75	0.75	0.75	0.9	0.9	0.85	0.9	0.89	0.89	0.89	0.83	0.83	0.83	0.75	0.75	0.75
Jun-30	0.75	0.75	0.75	0.75	0.9	0.9	0.85	0.9	0.89	0.89	0.89	0.83	0.83	0.83	0.75	0.75	0.75
Jul-1	0.77	0.77	0.77	0.77	0.94	0.94	0.92	0.91	0.96	0.96	0.96	0.85	0.85	0.85	0.77	0.77	0.77
Jul-31	0.77	0.77	0.77	0.77	0.94	0.94	0.92	0.91	0.96	0.96	0.96	0.85	0.85	0.85	0.77	0.77	0.77
Aug-1	0.78	0.78	0.78	0.78	0.97	0.97	0.98	0.96	0.98	0.98	0.96	0.88	0.88	0.88	0.78	0.78	0.78
Aug-31	0.78	0.78	0.78	0.78	0.97	0.97	0.98	0.96	0.96	0.96	0.96	0.88	0.88	0.88	0.78	0.78	0.78
Sep-1	0.78	0.78	0.78	0.78	0.97	0.97	0.98	0.96	0.96	0.96	0.96	0.88	0.88	0.88	0.78	0.78	0.78
Sep-30	0.78	0.78	0.78	0.78	0.97	0.97	0.98	0.96	0.96	0.95	0.95	0.88	0.88	0.88	0.78	0.78	0.78
Oct-1	0.76	0.76	0.76	0.76	0.9	0.9	0.91	0.88	0.88	0.9	0.95	0.84	0.84	0.84	0.76	0.76	0.76
Oct-31	0.76	0.76	0.76	0.76	0.9	0.9	0.91	0.88	0.88	0.88	0.95	0.84	0.84	0.84	0.76	0.76	0.76
Nov-1	0.73	0.73	0.73	0.73	0.84	0.84	0.81	0.86	0.86	0.86	0.86	0.81	0.81	0.81	0.73	0.73	0.73

	Landuse Code																
Date	***200***	***400***	***410***	***420***	***500***	***510***	***511***	***512***	***520***	***521***	***522***	***530***	***531***	***532***	***600***	***610***	***620***
Nov-30	0.71	0.71	0.71	0.71	0.82	0.82	0.79	0.84	0.84	0.84	0.84	0.79	0.79	0.79	0.71	0.71	0.71
Dec-1	0.69	0.69	0.69	0.69	0.78	0.78	0.75	0.82	0.78	0.78	0.78	0.77	0.77	0.77	0.69	0.69	0.69
Dec-31	0.69	0.69	0.69	0.69	0.78	0.78	0.75	0.82	0.78	0.78	0.78	0.77	0.77	0.77	0.69	0.69	0.69

Table 37 NSRSM “unsat” HPM’s

Index	Name	Ew	Kw	Rd	Xthresh	Pthresh	Pd	Wilt	Kveg
700	Mesic Uplands	0.6	0.9	2	0.3	0.7	2	0.1	0.61
710	Dry Prairie	0.6	0.9	2	0.3	0.7	2	0.1	0.75
720	Mesic Pine Flatwoods	0.6	0.9	2	0.3	0.7	2	0.1	0.61
730	Mesic Hammock	0.6	0.9	2	0.3	0.7	2	0.1	0.61
800	Xeric Upland	0.6	0.9	2	0.3	0.7	2	0.1	0.61
810	High Pine	0.6	0.9	2	0.3	0.7	2	0.1	0.61
820	Scrub	0.6	0.9	2	0.3	0.7	2	0.1	0.61
830	Coastal Strand	0.6	0.9	2	0.3	0.7	2	0.1	0.61

RIVER NETWORK

Rivers in the NSRSM consist of a series of connected segments. The network is defined by the input of data that describe:

The geometry that defines the location and cross sectional shapes of the river segments.

Flow and interactions with the mesh. These include Manning's n and coefficients for overland flow, seepage into and out of the bottom of the river, and seepage through levees adjacent to rivers. (See **Figure 37**)

The initial conditions (water levels) in the river segments.

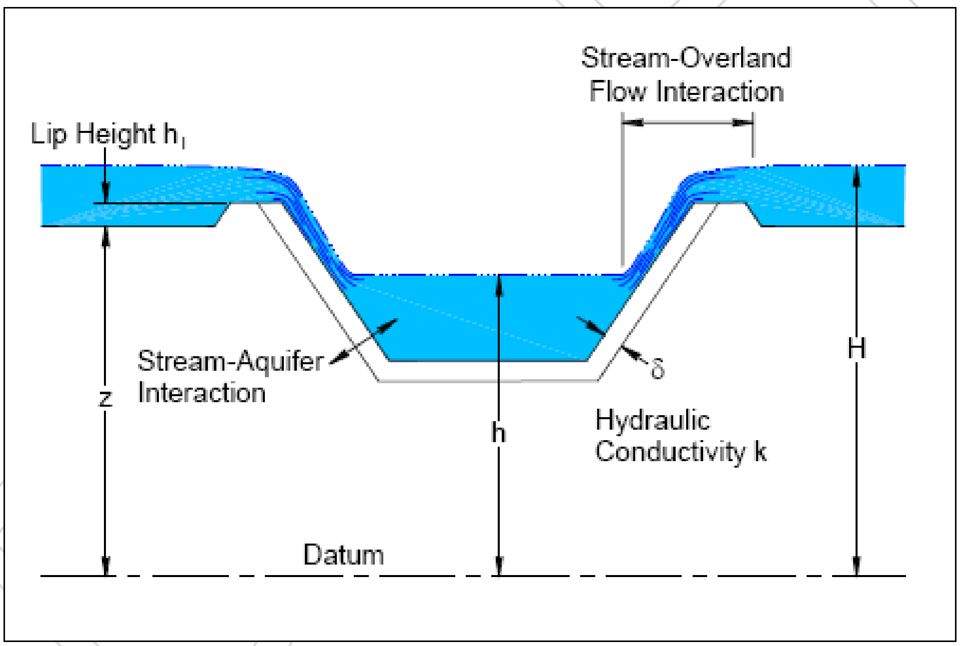


Figure 36. Flow interaction with the river.

The first step in setting up the network was GIS discretization of the rivers. After the discretization, the nodal connectivity, nodal coordinates, segment properties and segment connectivity were defined under the <network> element in the XML. The XML defining the river network is listed in **Table 38**. Geometry, cross section, and parameter data were described using the GMS. The initial condition file lists the heads in each canal segment at the start of the simulation. The <arcs> environment is set and data on each segment cross section and the values of parameters required to compute flow is provided in the XML. The interaction between the river and the surrounding cells is also addressed.

Table 38. Example XML defining a river network.

```
<network>
  <geometry file="./input/nsriv_2_13.map"> </geometry>
  <initial file="./input/nsriv_2_13.init"> </initial>
  <arcs>
   <indexed file="./input/nsriv_2_13a.index">
    <xsentry id="1">
     <!-- <arcflow n="0.035"></arcflow> -->
     <arcseepage leakage_coeff="0.000186"></arcseepage>
     <arcoverbank bank_height="0.1" bank_coeff="0.05"> </arcoverbank>
    </xsentry>
   </indexed>
  </arcs>
 &nsmriv_bc;
</network>
```

The values of parameters for calculating the seepage and overland flow between a river segment and the neighboring cell(s) are also specified in the ARC environment). The token *leakage_coeff* is used to represent k/d from which flow between the aquifer and the canal is computed as:

$$q = \frac{k}{\delta} p(H - h) \tag{15}$$

where q = seepage flow per unit length of the canal,

k = hydraulic conductivity of bottom sediment,

d = thickness of the sediment layer,

p = wetted perimeter of the canal,

h = water level in the canal segment,

H = water level in the cell.

Water may flow in either direction.

Lal (2001) described critical values of k/d below which the interaction is insignificant, and above which the interaction is full. There is not a single value of k/d that separates the two regions, rather k/d is a function of dimensionless parameters and depends on the details of the aquifer and the river segment.

The RSM requires a vertical hydraulic conductivity for the stream aquifer interaction. A rule of thumb states the vertical can be 1/10 of the horizontal hydraulic conductivity (Anderson and

Woessner, 1992). For all rivers within the model domain, the horizontal hydraulic conductivity ranged from 14.7 ft/day to 8,265.6 ft/day. The mean was 953.5 ft/day and the median value was 160.9 ft/day. Assuming the vertical is 1/10 of the horizontal, the mean is 95.3 ft/day and the median value would be 16.1 ft/day.

Overland flow between a river segment and a cell is modeled as weir flow over a "lip" along the edge of the segment. The flow is shown schematically in **Figure 38**. The lip height is specified after the *bank_height* token and the weir coefficient, C, after the *bank_coeff* token in the river geometry file. Flow is computed as:

$$Q = CL\sqrt{g}h^{1.5} \tag{16}$$

where

C = weir coefficient,

L = length of overlap between the segment and the cell, and

h = H - (Z + h_l), defined in 4.#1

A tailwater correction of:

$$Q = Q + \left[1 - \left(\frac{h_{tw}}{h}\right)^{1.5}\right]^{0.385} \tag{17}$$

is applied, where h_{tw} = height of downstream head above the "lip." When the head in the river is greater than the head in the cell, flow from the river to the cell is computed using the same equation with the heads in the river and in the cell reversed. This streambank type water mover is created only if the bank height is greater than or equal to zero.

The river simulation also requires boundary conditions. The <segmentsource> boundary condition is often used at the upstream end of a river or canal. The user may specify an inflow or outflow from a canal segment according to the following equation.

$$Qi = QB(t) \tag{18}$$

Where i represents the segment ID and QB(t) = a constant, rating curve, or time series flow. The XML input below in **Table 39** specifies a flow into segment 300414 defined by a time series.

Table 39. Segmentsource boundary condition used for upper Kissimmee.

```
<network_bc>
 <!-- Kissimmee River -->
 <segmentsource id="300414" label="Kissimmee">
   <dss file="./input/KissimmeeInflow.dss" pn="/UPPER KISSIMMEE/BASIN/RUNOFF/01JAN1965-
31DEC2000/1DAY/SIMULATEDWITHNEWET/"
     mult="1.0" units="CFS"> </dss>
 </segmentsource>
</network_bc>
```

The <segmenthead> boundary condition type can be used to specify the water level in a river segment at the model domain boundary. An example would be as an upstream boundary condition for a river or canal that drains water from a large lake. The head in the canal segment is specified as shown in Equation 19:

$$Hi = HB(t) \tag{19}$$

where HB(t) can be a time series, a constant, or a rating curve. This boundary condition type modifies the solution matrix by setting all entries in the row corresponding to the segment number equal to 0.0 except for the diagonal term which is set equal to 1.0. The corresponding entry in the source vector is set equal to the difference between specified and existing head in the segment. This allows water to flow into or out of the segment subject to the head boundary condition without changing the volume of water in the segment.

River Boundary Condition Types

The NSRSM river boundary conditions are prescribed or dictated by the tide elevations at the coasts. There are 3 types of river boundary conditions, described in **Table 40** below.

From these options, it has been decided to use a third-type boundary condition for all upstream segments. The topography allows water to flow into these river/stream reaches through seepage or overland flow. The Kissimmee River has the only upstream specified flow (second-type) boundary condition.

Table 40. Types of River Boundary Conditions

Type	Component	Mathematical Solution
1st	Head	Dirichlet
2nd	Flux	Neumann
3rd	Transfer	Cauchy

A third-type boundary condition is also used downstream. The Kissimmee River, Fisheating Creek, and Taylor Creek are allowed to transfer water to Lake Okeechobee using a third-type boundary condition. Istokpoga Creek has an upstream (Lake Istokpoga) and downstream (Kissimmee River) third-type boundary condition. The Caloosahatchee River, north and south forks of the St Lucie estuary, Loxahatchee River, Hillsboro River, Cypress Creek, Middle River, New River, and Snake River allowed to freely transfer water to a lagoon, a third-type boundary condition. The lagoons are modeled using the lake element. Once the water has reached a specified level in the lagoon, the water exits the lagoon. In reality, water is discharged into the lagoon. Once the water level reaches a critical elevation, the weakest portion fails and water discharges to the ocean. See **Table 41** below for the location and a description of each river segment's boundary condition.

Table 41. River segment boundary condition

River Name	Location	BC Type
St Lucie North Fork	Downstream	Third Type
St Lucie North Fork - Trib2a	Downstream	Third Type
St Lucie North Fork - Trib2b	Downstream	Third Type
St Lucie - Trib1	Downstream	Third Type
St Lucie - Trib2	Downstream	Third Type
St Lucie South Fork	Downstream	Third Type
Jupiter River	Downstream	Third Type
Jupiter River - South	Downstream	Third Type
Hillsboro River	Downstream	Third Type
Cypress Creek	Downstream	Third Type
Middle River	Downstream	Third Type
New River	Downstream	Third Type
Snake River	Downstream	Third Type
Arch Creek	Downstream	Third Type
Little River	Downstream	Third Type
Black Creek	Downstream	Third Type
Miami River	Downstream	Third Type
Lostman's River	Downstream	Third Type
Harney River	Downstream	Third Type
Shark River	Downstream	Third Type
Huston River	Downstream	Third Type
Chatam River	Downstream	Third Type
Broad River	Downstream	Third Type
Fisheating Creek	Downstream	Third Type
Kissimmee River	Downstream	Third Type
Taylor Creek	Downstream	Third Type
Istokpoga Creek	Upstream	Third Type
Kissimmee River	Upstream	Second Type
Caloosahatchee River	Downstream	Third Type

Input Data

Prior to drainage, natural breaks in the Atlantic Coastal Ridge allowed southeastern overland flow from the Everglades to coalesce into a series of short coastal rivers that ultimately discharged to the Atlantic Ocean. These rivers extended north to south from what is now the Hillsboro River Canal to the Miami River (now the Miami Canal) (**Figure 37)**.

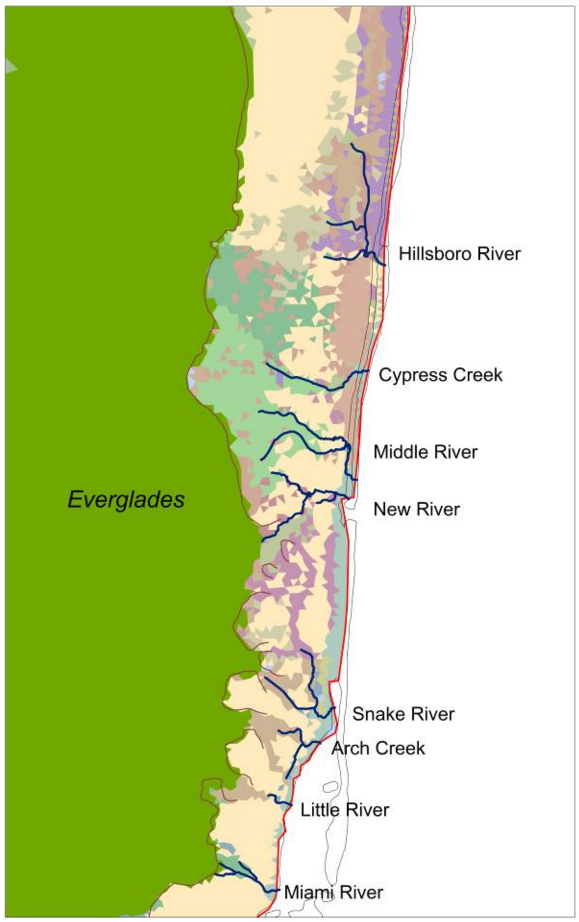


Figure 37. Southeastern Rivers

Southeastern river dimensions were estimated from several sources (**Appendix G.1**); U.S. Government Land Office (GLO) surveys conducted in the late 1800's and early 1900's, Florida state Everglades Drainage District (EDD) maps, Central and Southern Florida State maps and historical observations compiled by McVoy (unpublished).

Southwest coast rivers (**Figure 38**) discharged waters collected from Big Cypress and Everglades basin into the Gulf of Mexico. Unlike the east coast rivers, these channels have not significantly altered due to drainage improvements. Dimensions were assigned based on early U.S Geodetic Survey data and current aerial photography (**Appendix** G.2).

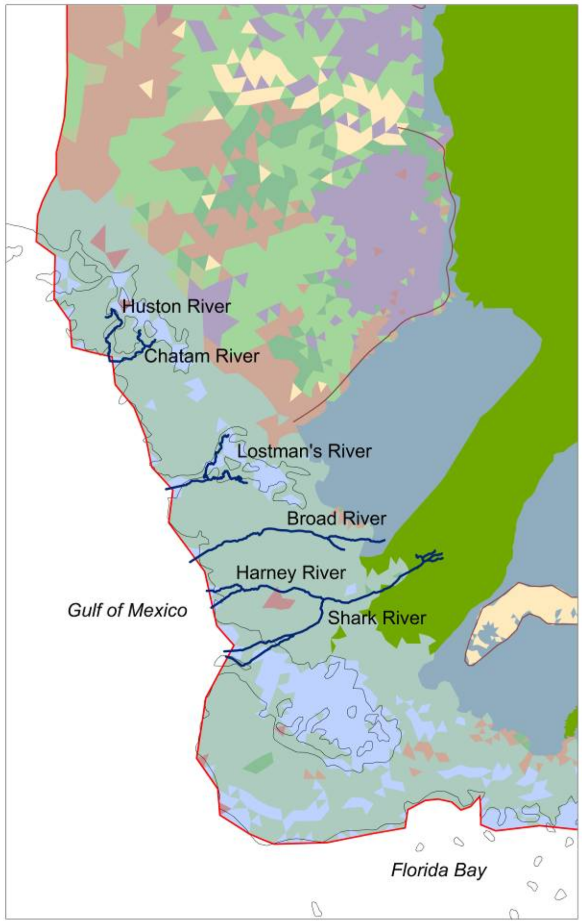


Figure 38. Southwest Coast Rivers

A considerable amount of qualitative and, in some cases quantitative, information is available from historical sources to allow for the development of reasonable estimates for natural system river geometry and mesh interactions. Dataset development for the southeast and southwest coastal rivers, the Caloosahatchee, Kissimmee, and Loxahatchee Rivers, is described in **Appendix** G.

BOUNDARY CONDITIONS

Water levels in the NSRSM domain fluctuate in response to forcing functions including transient boundary conditions, which are imposed on certain cells. Boundary conditions cause water to be added or removed from the model domain. Model boundaries are generally located along physiographic boundaries where no-flow conditions can be assumed, or areas where inflows can be estimated and applied as boundary conditions.

The NSRSM uses a wall type general head boundary along the coast with the head set equal to tide elevations at simulated stations. Predicted tide data from the National Oceanic and Atmospheric Administration / National Ocean Service (NOAA/NOS) were selected to create the tidal data set for the NSRSM. (**Figure 39** – Tidal Stations)

A wall type uniform flow boundary condition is used for the remainder for the NSRSM boundary. This type of boundary assumes that there is uniform overland flow that discharges water through the boundary wall. A flat slope, 0.00001, along the boundary was specified. (**Figure 39** – WallUF)

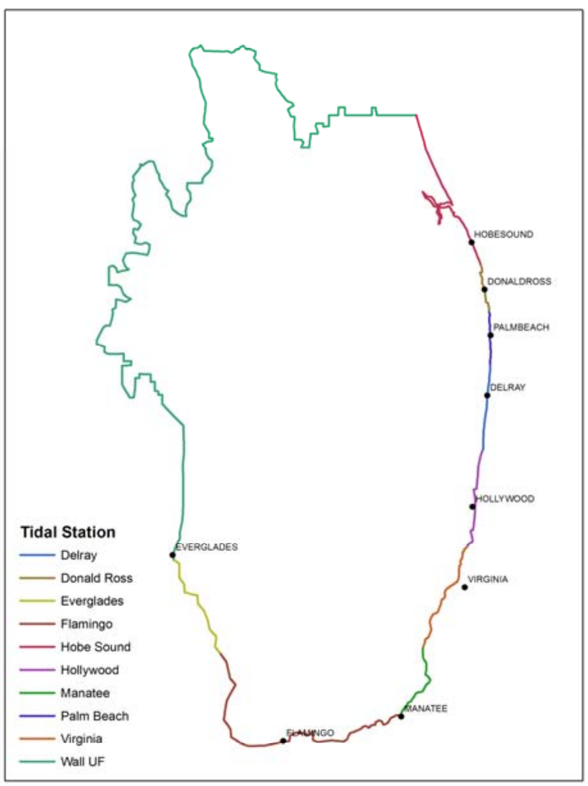


Figure 39. NSRSM wall boundary assignments: General Head (Tidal Stations) and Uniform Flow

Tidal

The NSRSM uses a wall type general head boundary along the coast. Water will flow through the wall if the head in the adjacent cell is not equal to the specified head. The flow rate (*wallghb)* is controlled by a user defined coefficient; for this application, a value of 10.0. The *nodelist* defines the series of line segments along which the tidal elevations will be applied. The tide elevations are retrieved from a DSS file and applied uniformly along the coastal segment. A sample tidal boundary is below.

Table 42. Example XML for wall general head boundary condition.

```
  <wallghb  value="10.00" label = "Hobe Sound tide record" >
    <nodelist> 3094 2954 2805 2806 2807 2649 2500 2359 2360 2230 2101 1979
1853 1728 1613 1505 1400 1298 1202 1109 1023 </nodelist>
    <!--  Use  Tidal stage record from   -->
    <uniform> <dss file="./input/RSM_TIDES_2006.dss"
     pn="/NSRSM/HOBESOUND/TIDE/01JAN1965/1DAY/SIMULATED/"
units="FT"> </dss>
```

Data from Hobe Sound, Donald Ross, Palm Beach, Delray, Hollywood, Virginia, Manatee, Flamingo, and Everglades tidal stations was applied to the boundary **(Figure 41)**. Daily stage data was uniformly applied to a series of nodes within proximity of each tidal station.

The following steps were taken to develop the necessary tidal data: (1) Download hourly historical data available for the chosen primary stations, Naples and Virginia Key, from the NOAA/NOS website; (2) use NOAA/NOS Products and Services Division coefficients to simulate tidal data for secondary stations; (3) transform NOAA/NOS historical hourly values to mean daily values and (4) convert from Mean Lowest Low Water (MLLW) datum to the NGVD 1929 datum. Thirty six years (1965 to 2000) of daily data for each station were utilized in the base condition model. (**Appendix H.1**)

Lower Kissimmee Basin Boundary Conditions

The XML that defines the Kissimmee River flow as a canal network boundary condition is presented in **Table 43**. The <segmentsource> element is used to specify the inflow to the segment as a time series. Flows calculated with the Sealink model (**Appendix H.2**) are then input through a DSS file.

Table 43. Example XML for segment source element.

```
<network_bc>
  <!-- Kissimmee River -->
  <segmentsource id="300414" label="Kissimmee">
    <dss file="./input/KissimmeeInflow.dss" pn="/UPPER KISSIMMEE/BASIN/RUNOFF/01JAN1965-
31DEC2000/1DAY/SIMULATEDWITHNEWET/"
     mult="1.0" units="CUBICFEET"> </dss>
```

Daily inflow along the northern boundary is defined by a series of inflow points into Lake Istokpoga and Lake Okeechobee. These flows represent the "natural" inflow which would have occurred under pre-drainage conditions. The upper Lake Istokpoga and Fisheating Creek watersheds rainfall-runoff relationship is assumed to be comparable to pre-drainage conditions and natural inflows from these watersheds are approximated by observed flows at Arbuckle Creek, Josephine Creek, and ungaged local inflow at Lake lstokpoga, and Fisheating Creek.

The Kissimmee River watershed has been affected by a number of water management projects, including the connection and regulation of lakes in the upper section, and canalization of the Kissimmee River in the lower section. Natural inflow from the Kissimmee River watershed is estimated using the Sealink model developed by the SFWMD.

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