Hydrologic Simulation of the Predrainage Greater Everglades Using the Natural System Regional Simulation Model v3.5.2

By Winifred Park Said and M. Clay Brown

South Florida Water Management District
Water Resources Division
Water Supply Bureau
Hydrologic and Environmental Systems Modeling Section
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Acknowledgments

South Florida Water Management District

Melissa L. Meeker, Executive Director

Robert M. Brown, Assistant Executive Director

Water Resources Division

Terrie A. Bates, Division Director

Water Supply Bureau

Dean S. Powell, Bureau Chief

Hydrologic and Environmental Systems Modeling Section

Akintunde O. Owosina, Section Administrator

Project Management

Winifred Park Said

M. Clay Brown

Technical Direction

M. Clay Brown, Lead

Wasantha Lal

Randy VanZee

Jayantha Obeysekera

Eric Flaig

David Welter

Editing

Joel VanArman

Pattie Fulton

Sheri Jordan

Victor Mullen

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Acronyms and Abbreviations

AMO	Atlantic Multidecadal Oscillation
APT	Aquifer pumping test
BC	Boundary condition
BCB	Big Cypress Basin
C&SF Project	Central and Southern Florida Project for Flood Control and Other Purposes
C&SF Restudy	Central and Southern Florida Project Comprehensive Review Study
CERP	Comprehensive Everglades Restoration Plan
CSOP	Combined Structure and Operational Plan
DBHYDRO	The South Florida Water Management District's hydrometeorologic database, water quality, and hydrogeologic data retrieval system
DEM	Digital Elevation Model
District	South Florida Water Management District
DOQQ	Digital Orthophoto Quarter Quads (digital images produced by the U.S. Geological Survey)
EAA	Everglades Agricultural Area
EDD	Everglades Drainage District
EMC	National Center of Environmental Prediction Environmental Modeling Center
ENP	Everglades National Park
ENSO	El Niño-Southern Oscillation
EST	Eastern Standart Time
ET	Evapotranspiration
GIS	Geographic information system
GMT	Greenwich Mean Time
GLO	General Land Office
GOH	Glades-Okeechobee-Highlands
GRIB	Gridded Binary
HAEDC	High Accuracy Elevation Data Collection
HESM	Hydrologic and Environmental Systems Modeling

HPM	Hydrologic Process Module
HRAN	High Accuracy Range Network
HSE	Hydrologic Simulation Engine
Hydro51	The U.S. Hydrological Reanalysis by the Noah Land Data Assimilation System (NLDAS Reanalysis) is code named Hydro51 by the SFWMD.
ISWAB	Interactive Water Balance Model
KOE	Kissimmee-Okeechobee-Everglades
KRR	Kissimmee River Restoration
KRREP	Kissimmee River Restoration Evaluation Program
Kveg	A coefficient of crop transpiration
LEC	Lower East Coast
LECR	Lower East Coast Regional
LIDAR	Light Detection and Ranging
LKB	Lower Kissimmee Basin
Mannings n	A roughness coefficient
MLLW	Mean lower low water
MLW	Mean low water
MSE	Management Simulation Engine
NARA	National Archives and Records Administration
NARR	North America Regional Reanalysis
NCEP-NCAR	National Center for EnvironmentalPrediction–National Center for Atmospheric Research
NLDAS	NOAH Land Data Assimilation System
NOAA/NOS	National Oceanic and Atmospheric Administration / National Ocean Service
NOAH	Consolidated data from a consortium which includes the National Centers for Environmental Prediction; Oregon State University, Department of Atmospheric Sciences; United States Air Force Weather Agency and U.S. Air Force Research Laboratory (formerly Air Force Geophysics Laboratory and Philips Laboratory); and Office of Hydrologic Development (formerly Hydrologic Research Lab – National Weather Service)
NRCS	Natural Resources Conservation Service

NSM	Natural System Model
NSRSM	Natural System Regional Simulation Model
PDLD	Pre-Development Landscape Database
PDV	Pre-Development Vegetation
PEST	Parameter Estimation by Sequential Testing
PET	Potential evapotranspiration (also abbreviated as ETp)
POR	Period of record
PRISM	Parameter Elevation Regressions Independent Slopes Model
QA/QC	Quality Assurance/Quality Control
RSM	Regional Simulation Model
SAS	Surficial aquifer system
SFWMD	South Florida Water Management District
SFWMM	South Florida Water Management Model
SRTM	Shuttle Radar Topography Mission
SSURGO	Soil Survey Geographic Database
SWFFS	Southwest Florida Feasibility Study
TIN	Triangular Irregular Network
Topo	Topography
UCAR	University Corporation for Atmospheric Research
UKB	Upper Kissimmee Basin
USACE/COE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WCA	Water Conservation Area
WL	Water level

Table 1. Conversion Factors and Datums.

Multiply	By	To Obtain
Length		
inch (in)	2.54	centimeter (cm)
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square foot (ft^2)	0.0929	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	640.0	acre
Volume		
cubic foot (ft^3)	0.2832	cubic meter (m^3)
acre-foot	1233.48	cubic meter (m^3)
Flow rate		
acre-foot per year (acre-ft/yr)	1233.046	cubic meter per year (m^3/yr)
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per day (ft^3/d)	0.2832	cubic meter per day (m^3/d)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
Hydraulic conductivity		
foot per day (ft/d)	0.3048	meter per day (m/d)
Transmissivity		
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
Velocity		
inch per second (in/s)	25.4	millimeter per second (mm/s)
inch per day (in/d)	2.54	centimeter per day (cm/d)
inch per year (in/yr)	2.54	centimeter per year (cm/yr)
Datums		
Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD29).		
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83) - High Accuracy Range Network (HARN).		
Altitude, as used in this report, refers to distance above the vertical datum.		
North American Vertical Datum 1988 (NAVD88)		

Executive Summary

Technological advances in hydrologic modeling at the South Florida Water Management District (SFWMD or District) resulted in the development of the Regional Simulation Model (RSM). The RSM is a finite-volume based computer model that simulates multidimensional and fully integrated groundwater and surface water flow. The RSM Hydrologic Simulation Engine (HSE) has proven to be highly effective in modeling the processes influencing natural system hydrology in south Florida: a rainfall driven system characterized by slow overland flow through flat but microtopographically varied landscapes, prolonged recession associated with storage, and seasonally fluctuating water levels defined by south Florida's subtropical climate. Application of the RSM to south Florida's Kissimmee-Okeechobee-Everglades and adjacent Big Cypress pre-drainage watersheds is referred to as the Natural System Regional Simulation Model (NSRSM).

The NSRSM v3.5.2 simulates the hydrology of approximately 12,000 mi^2 (7.7 million acres) of south Florida, including 5,000 mi^2 (3 million acres) of Everglades wetlands, as they existed before drainage (ca. 1850). Scenarios have been generated using recent climatic input (1965–2005), as well as historical rainfall (1895–1935). Model conceptualization, as described in this report, was based on information from critically reviewed sources.

Although standard calibration procedures cannot be applied to the 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 (1966–2005), as well as average, wet and dry year simulated conditions. Performance measures include inundation duration (hydroperiod) and seasonal water depths for distinct landscapes. Regional system simulation results were evaluated for long-term average annual and seasonal (wet/dry) performance, surface water flows calculated for selected transects, and water budgets designed for ease of comparison to existing models.

Model performance relative to computed evapotranspiration (ET), hydroperiod, and water level correspond well to reference ranges, particularly in the Everglades basin. Simulated overland and river flows are comparable to observed natural system distribution, directionality, and volumes.

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Chapter 1
Introduction

Canal drainage, the channelization of natural rivers, and other associated development have impacted the south Florida ecosystem for over one hundred years (McVoy *et al.,* 2011). Over time, the cumulative effects of altered quantity, quality, timing and distribution of water resulted in significant habitat deterioration and loss throughout the natural system. To reverse this trend and ultimately affect sustainable habitat while balancing the needs of the state's growing population, two decisive acts passed by Congress in the 1990s set the stage for hydrologic restoration initiatives, including the Kissimmee River Restoration Project and the Central and Southern Florida Project Comprehensive Review Study (C&SF Restudy) for Flood Control, the precursor to the Comprehensive Everglades Restoration Plan (CERP). Now in its implementation phase, the CERP is expected to restore the Everglades ecosystem while maintaining adequate flood protection and water supply for south Florida.

Restoration strategies require an understanding of how the regional system hydrology interacts with topography, soils and plant communities. The existing landscape and hydrology represent altered/degraded systems that formed in response to multiple stressors resulting from extensive changes that occurred in south Florida during the past century. To understand how the south Florida ecosystem existed in an apparent dynamic equilibrium with natural hydrologic conditions, studies were undertaken to develop a *Natural System Model* that represents how the south Florida hydrology and ecology functioned prior to drainage and development. Natural system modeling is designed and intended to be used, in combination with other adaptive management tools, to assist in restoration plan formulation and implementation.

BACKGROUND

For application to Everglades restoration alternative evaluation, 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*, predrainage hydrology, within the limitations of recorded history…" (Fennema *et al.,* 1994). The NSM uses the same climatic input, computational methods, and model parameters calibrated and verified by the managed system model, the South Florida Water Management Model (SFWMM), to simulate the hydrologic response of the natural system to current hydrologic input. Intensive applications of this tool during the C&SF Project Restudy, the

CERP, and several water supply planning efforts made it a significant component of the planning process.

Technical advancement coupled with an improved knowledge of the historical Kissimmee-Okeechobee-Everglades (KOE) System, based on critically reviewed sources, resulted in the next generation NSM referred to as the Natural System Regional Simulation Model (NSRSM). The NSRSM is the predrainage implementation of the Regional Simulation Model (RSM). The RSM is a finite-volume based computer model that simulates multidimensional and fully integrated groundwater and surface water flow using a variable mesh. The RSM Hydrologic Simulation Engine (HSE) has proven effective, modeling the unique hydrologic processes and geologic features of south Florida, such as flow through a flat, but microtopographically varied, ridge and slough landscape.

The NSRSM, like its predecessor the NSM, simulates the natural system hydrology of south Florida. The availability of long-term climatic data and refined parameter input (e.g. topography), combined with the model's improved HSE, enables NSRSM simulations to reasonably represent predrainage (ca. 1850) hydrology in south Florida.

RECENT REVISIONS

The NSRSM version 2.0 was completed in 2005 and the initial report was peer reviewed in 2006. The peer review panel was generally impressed by the model performance, although several improvements were suggested. Since then, the South Florida Water Management District (SFWMD or District) staff made changes to improve the model's performance, and the issues raised by the peer review panel were addressed, resulting in the release of NSRSM v3.5.2. Significant improvements made to the previous model version are detailed below.

Technical Improvements

- Improved mesh design for a more stable and robust model.
- Updated topographic data. The NSRSM v3.5.2 utilizes the U.S. Army Corps of Engineers (USACE) South Florida Composite Elevation data model which replaces the previous patchwork grids from various efforts. All artificial features (e.g., roads, landfills) were removed.
- Improved boundary conditions.
- Simplification of lake/cell watermovers. The NSRSM v3.5.2 exclusively uses lake/cell watermovers. The NSRSM v2.0 used lake/cell watermovers and direct connection (shunt) watermovers.
- Improved overland flow conveyance lookup tables.
- Improved and simplified stage-volume lookup tables for microtopography.

- Updated rainfall including additional stations.
- Improved post-processing methods applied to the current version of the model to generate tabular and graphic output that better represents information.

Improvements to Documentation and Interpretation of Results

- Documentation was revised to better describe model performance, conceptualization, calibration/validation, sensitivity and uncertainty, and other concerns mentioned by the peer review panel.
- Performance reference ranges were fine-tuned with significant emphasis on conclusions from McVoy *et al.* (2011).
- Evaluation methodology was improved to better consider a range of scales at which model output can be interpreted. Results from individual cells were aggregated to consider performance within cells, zones, subregions and landscape level characteristics.
- Sensitivity of the model was tested against variations of key parameters. Additionally, several alternative methods for evaluation of uncertainty were developed and tested.

MODEL DOMAIN

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

The KOE includes the Kissimmee River, Lake Okeechobee, and the Everglades watersheds. The upper Kissimmee watershed is outside the NSRSM boundary and is modeled separately with output provided to the NSRSM as boundary conditions. Physiographic regions flanking the KOE within the NSRSM domain include the western flatwoods, Caloosahatchee River Watershed, and Big Cypress Basin to the west. Eastern features within the NSRSM include the coastal river systems, eastern flatwoods, and Atlantic Coastal Ridge uplands.

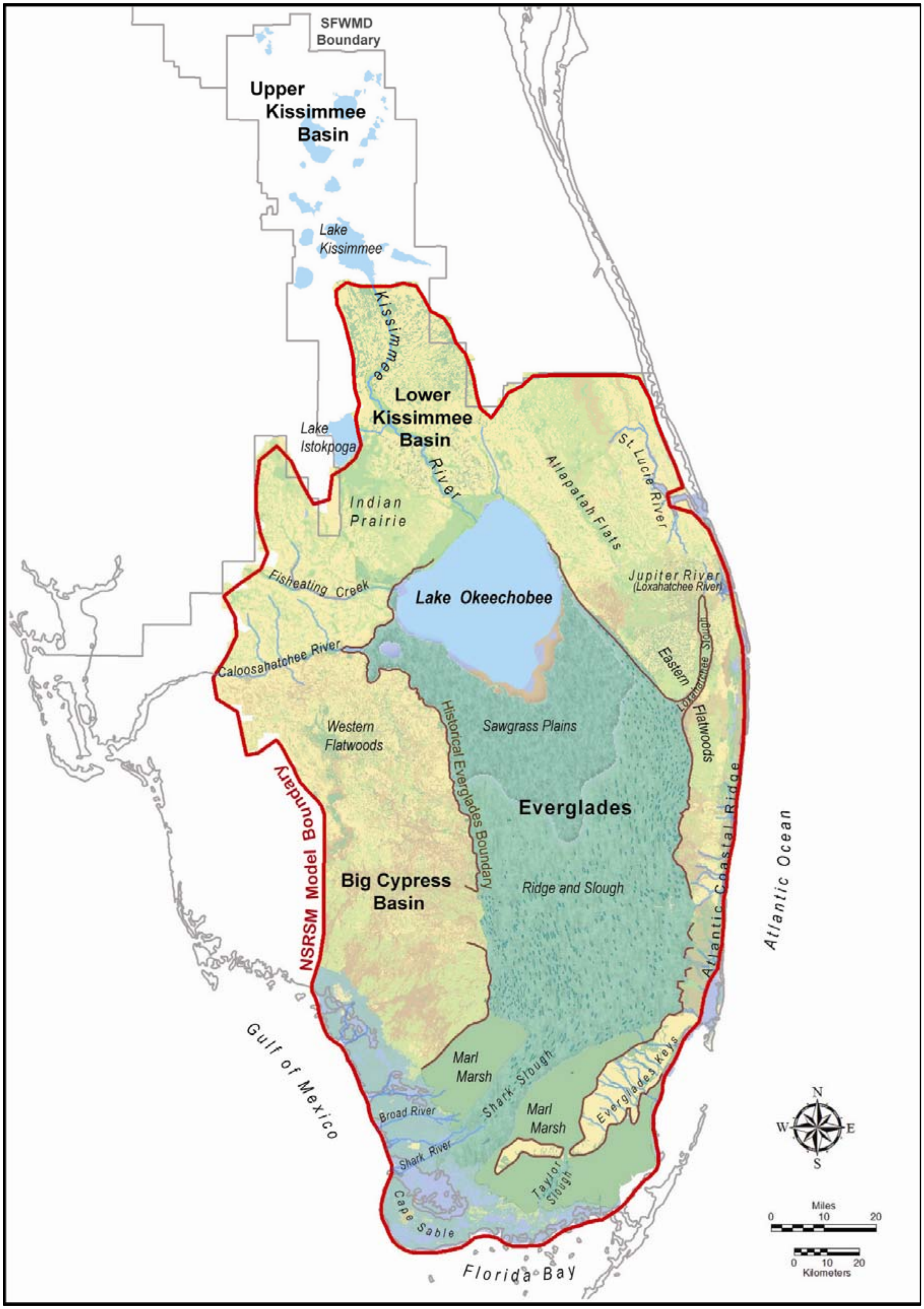

Figure 1. Extent of the Natural System Regional Simulation Model (NSRSM) Model Domain.

PREVIEW

The opening chapters of this report provide an overview of natural system hydrology, a description of the RSM application to the natural system (model conceptualization), calibration results, and a performance evaluation for the Base Condition. The Base Condition simulation uses the same climatic input (rainfall, potential evapotranspiration [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 predrainage conditions. Calibrated parameters from current system models, such as hydraulic conductivity and canal conductance, were not used to avoid introducing artifacts of drainage. Parameter uncertainty and sensitivity, and a discussion of model use, are addressed in the closing chapters. The report concludes with a chapter summarizing conclusions and recommendations.

This report is accompanied by a series of appendices, which provide supporting material related to model development and conceptualization.

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Chapter 2
Predrainage KOE Hydrologic System (ca. 1850)

KISSIMMEE RIVER AND LAKE OKEECHOBEE BASIN

Historically, the KOE was a rainfall driven system. Rainfall runoff 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, which were associated with major surface flow features (**Table 2, Figure 2**). Distinct upper and lower basins exist within the Kissimmee River watershed. The upper basin was characterized by a high degree of natural detention in numerous lakes which overflow across wide shallow marshes and creeks into lower lakes during the normally wet summer months and during periods of heavy rainfall (Parker *et al.,* 1955). The lower basin (within the NSRSM domain) includes the Kissimmee River, which begins at the outlet of Lake Kissimmee.

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. The Okeechobee Basin description was adapted from previous NSM documentation (VanZee, 2000).

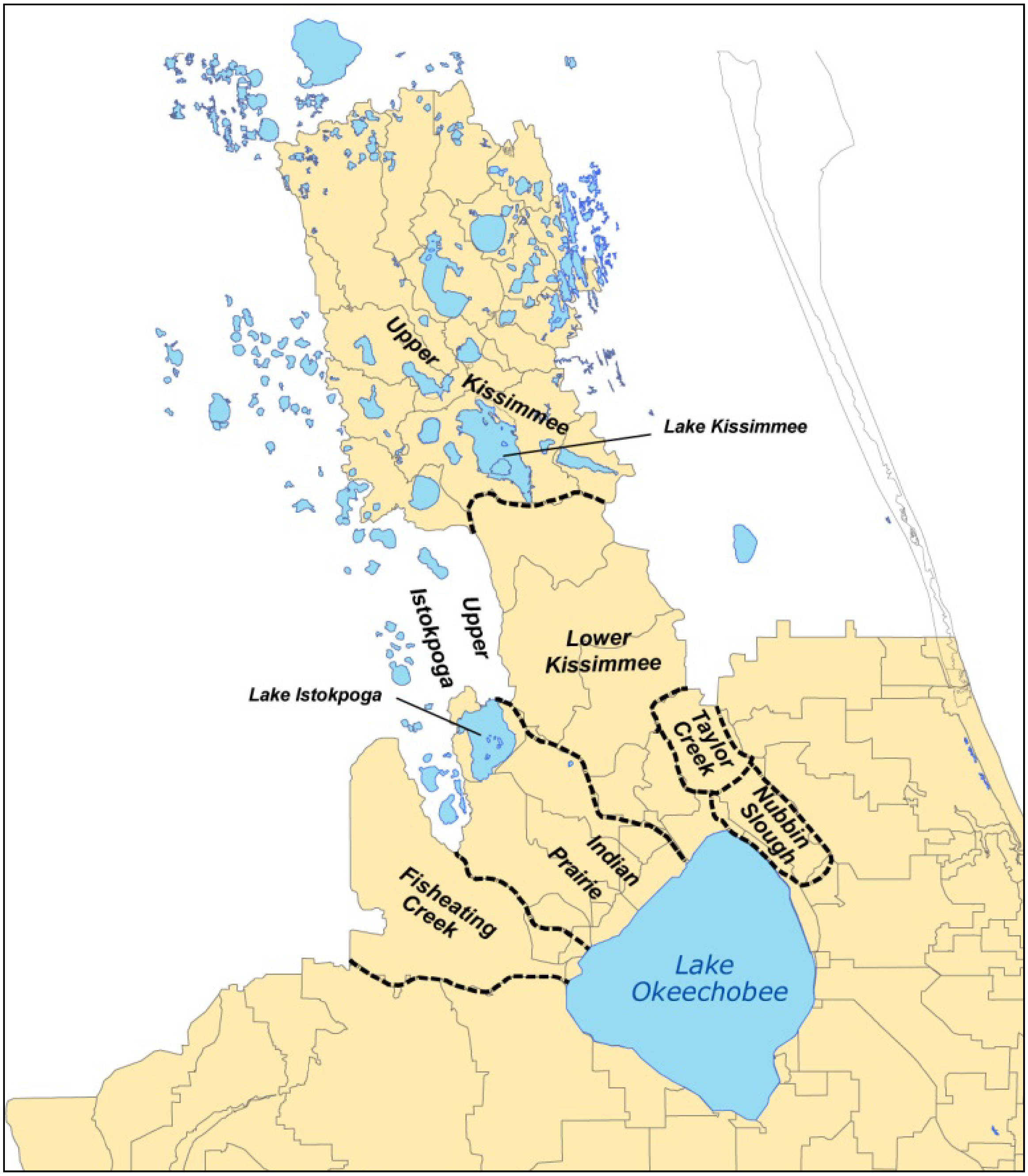

Figure 2. Lake Okeechobee Basin.

Table 2. Okeechobee Basin watersheds.

Basin	Area (miles^2)
Upper Kissimmee River Basin	1,596
Lower Kissimmee River	727
Upper Lake Istokpoga Basin	601
Lower Istokpoga Basin	552
Fisheating Creek	550
NE Peripheral Basins	216
Lake Okeechobee Basin Total	4,242

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 floodplain was inundated (Anderson & Chamberlain, 2005). In contrast to the upper basin, there are fewer lakes in the lower Kissimmee basin.

Lake Okeechobee provides a significant volume of water to the Everglades when its stage exceeds the minimum ground surface elevation along the southern shore. Distinctive landscape features were oriented 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**). The flow pattern is still true in more pristine parts of the remnant system. When Lake Okeechobee stages were high, the Caloosahatchee River Watershed also received overland flow through sawgrass marshes on the lake's western shore.

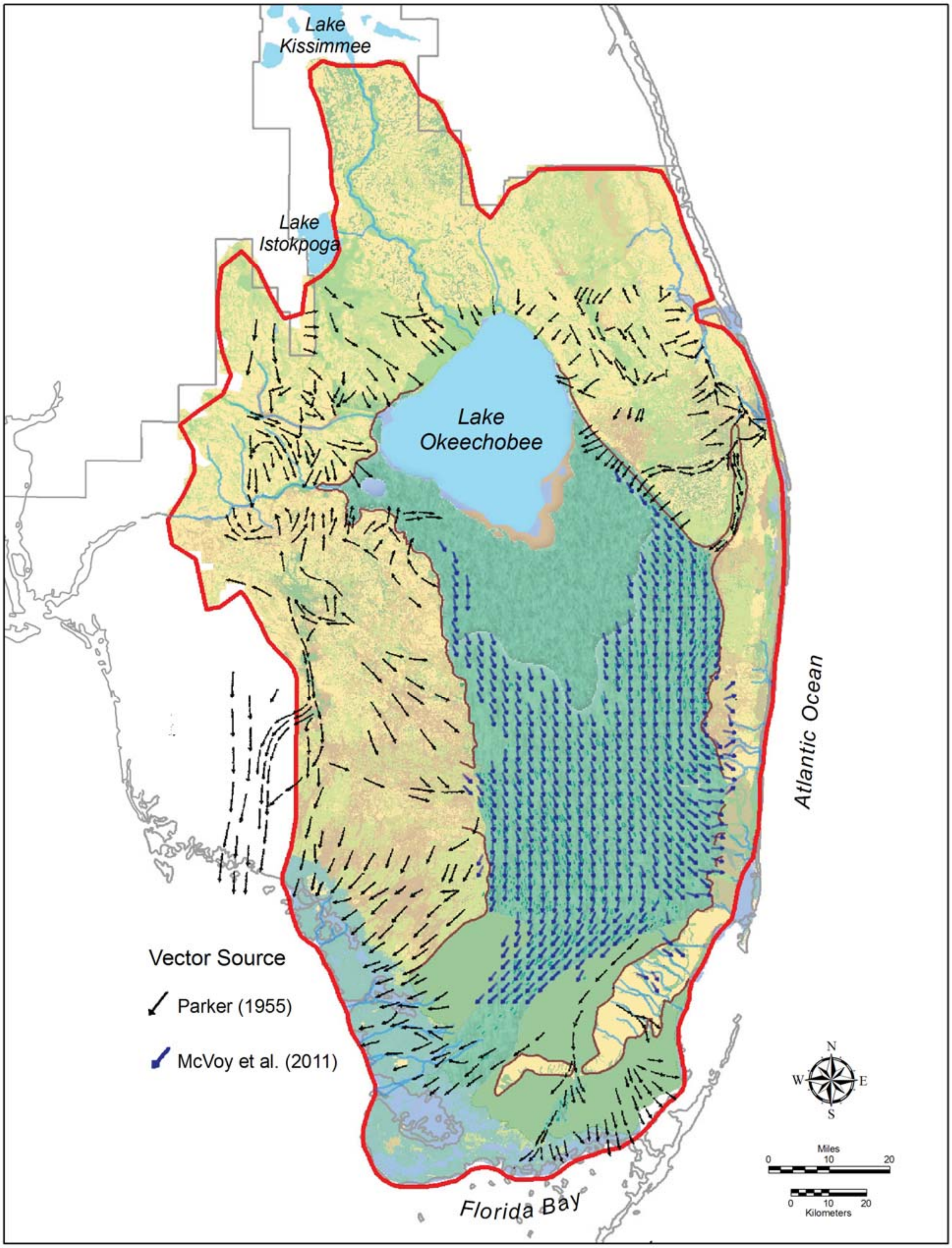

Figure 3. Estimated flow directions in the historical Everglades.

EVERGLADES

The following excerpt is from "Landscape and Hydrology of the Predrainage Everglades" (McVoy *et al.,* 2011). A majority of the input data for the NSRSM were derived from this study:

> The Predrainage Everglades was hydrologically unique because of its particular combination of geometry and climate. The basin topography allowed the accumulation of an enormous body of peat soil, which in turn allowed the formation of a vast and exceedingly flat ground surface. The slight slope of the basin kept the accumulating peat surface slightly tipped from horizontal; three inches to the mile (5 cm/km). This slope and the balance between the energy of the flows and the structural coherence of the peat prevented formation of either a central drainage channel or a dendritic drainage pattern. These flows were sufficient to create and/or maintain systematic microtopographic relief, making a large portion of the Everglades a patterned peatland, and creating a multicomponent landscape with sustained elevation differences. The stable elevation differences between sloughs, sawgrass ridges and tree islands created thousands of semi-terrestrial areas surrounded by persistent wetlands. The absence of a central or dendritic drainage pattern meant that water flow was distributed evenly among hundreds of similarly sized sloughs, spreading the flow field across the full 40 mile (60 km) width of the landscape.
>
> The slope and flow meant that the Everglades was likely never in hydrologic equilibrium, but instead continually draining. The strongly seasonal rainfall distribution made the Everglades a seasonally pulsed system, with rainfall exceeding drainage during the wet season, each year reversing the declining water depths of the dry season. The balance between rates of inflow and rates of outflow was such that each year's rainy season typically arrived just before the system had completely dried out. Thus, water depths within sloughs throughout the Ridge and Slough landscape typically rose and fell each year from a low of about one foot (30 cm) to a high of about three feet (90 cm); an environment that could support long-lived aquatic organisms. Sawgrass ridges were just high enough to be semi-aquatic and without surface water during part of each typical year. The annual cycle of wetting and drying on ridges may have been chemically and biologically important, releasing a nutrient pulse as the soil reflooded during the wet season, and concentrating populations of small aquatic fauna into sloughs during the dry season. Tree island peat surfaces were high enough to provide habitat for woody vegetation, and low enough to derive dry season water from surrounding sloughs.

In contrast to the ridge and slough landscape, a portion of the flanking Marl Marshes typically dried below ground surface each year, perhaps leading to a more diverse flora. Survival of longer-lived fauna must have been supported by the aquatic refugia within the extremely irregular and porous limestone bedrock combined with recolonization from waters from Shark Slough.

Altogether, the unique combination of climate, geometry, peat and vegetation of the Everglades created a ‘region of mystery’…where the water was ‘pure and limpid and almost imperceptibly moves, not in partial currents, but, as it seems, in a mass, silently and slowly to the southward,’ and where it annually rose and fell to create a “region that [was] not exactly land, and not exactly water.” (Dix and MacGonigle 1905)….

BIG CYPRESS

West of the Everglades, the Big Cypress region is an expansive 2,450 mi^2 (1,568,000 acres) wetland/upland mosaic in southwestern Florida. Currently, 900 mi^2 is designated as a national preserve (Duever *et al.,* 1986). The only area of this region included in the NSRSM domain is the area east of what is now State Highway 29. Most of the watershed is less inundated than the adjacent and slightly lower-lying Everglades. Predominant flow direction is southwest through numerous cypress strands to the coastal mangrove fringe. However, as indicated in **Figure 3**, the central Everglades basin historically received inflows from northeastern Big Cypress.

RAINFALL AND EVAPOTRANSPIRATION

Natural system hydrology is driven primarily 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 originates primarily from frontal systems (Sculley, 1986).

Rainfall in central and south Florida is heavily influenced by the Atlantic Multidecadal Oscillation (AMO). The AMO is a mode of variability occurring in the North Atlantic Ocean based on the sea surface temperature. Rainfall increases when the Atlantic Ocean is in its warm phase, whereas droughts are more frequent in its cool phase. Variations in the AMO cycle can affect inflows to Lake Okeechobee. **Figure 4** below compares annual rainfall and AMO.

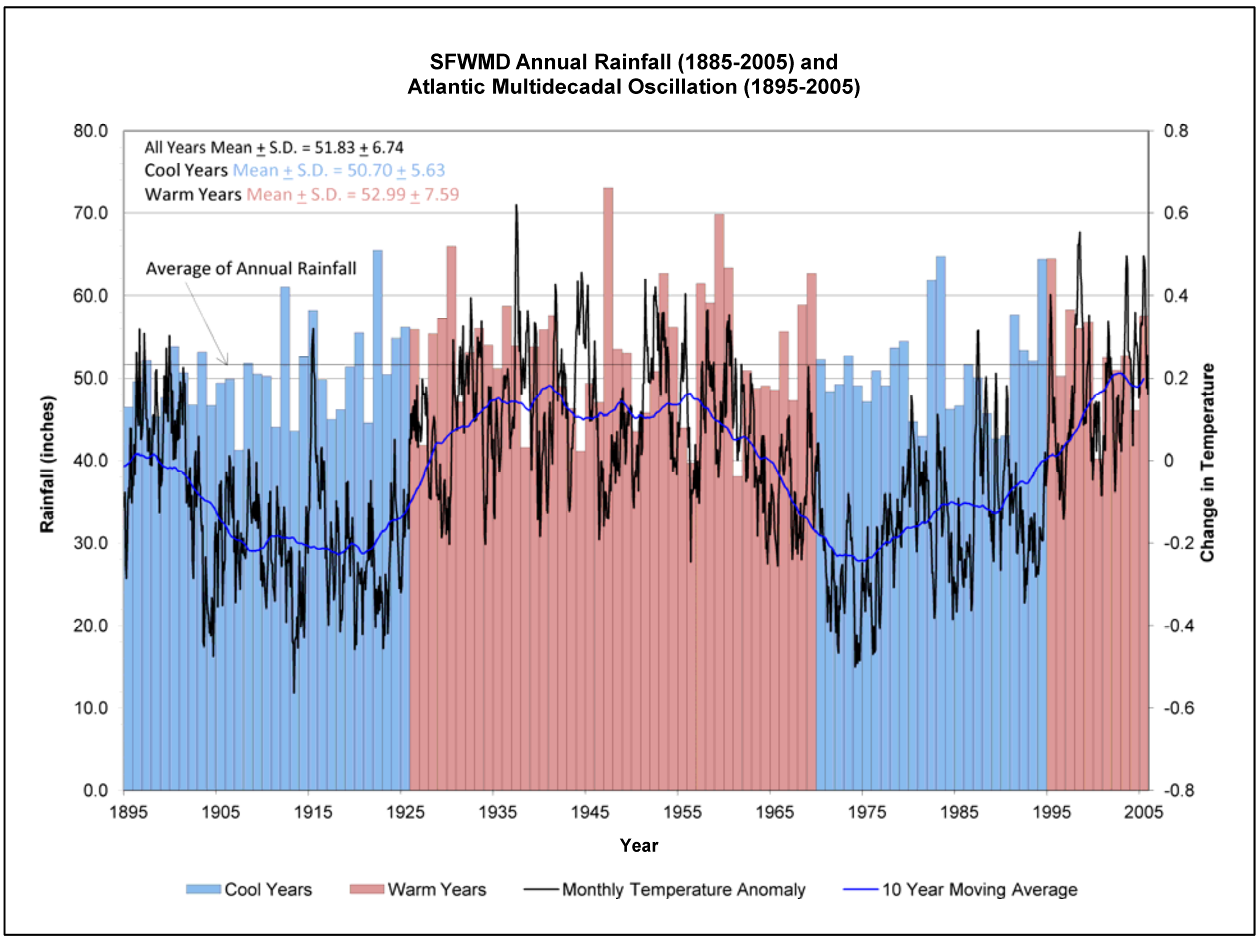

Figure 4. District rainfall (inches) and Atlantic Multidecadal Oscillation (AMO) (1895–2005).

South Florida rainfall is also strongly influenced by the El Niño-Southern Oscillation (ENSO) in the Pacific Ocean. The normally persistent easterly trade winds near the west coast of South America allow cooler water to upwell from beneath the ocean surface, resulting in cool sea surface temperatures in the eastern equatorial Pacific Ocean. When the easterly trade winds become stronger, upwelling of cold water is increased, resulting in even colder sea surface temperatures. This state of ENSO is known as La Niña. When the trade winds weaken or reverse, upwelling is impeded and sea surface temperatures become warmer than normal. This state of ENSO is known as El Niño. In the winter dry season, Florida is typically wetter than normal during El Niño events and drier than normal during La Niña events.

Evapotranspiration (ET) is a major component of the water budget. Based on data prior to the mid 1970's, 70 to 90 percent of rainfall in undisturbed wetlands in south Florida is lost to ET with the greatest losses in the wet season (Duever *et al.,* 1994). In 1947, Marjory Stoneman Douglas observed:

> It is the subtle ratio between rainfall and evaporation that is the final secret of water in the Glades. (Douglas, 1947)

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

Chapter 3
Assumptions and Governing Equations

The NSRSM is a specific implementation of the RSM. The RSM features in this section pertain only to the NSRSM implementation. For example, the RSM has the capability to simulate levees and water control structures, but since neither is utilized by the NSRSM, these features are not included in the discussion.

The RSM consists of the Hydrologic Simulation Engine (HSE) and the Management Simulation Engine (MSE); the latter is not used by the NSRSM. The HSE simulates the physical processes in the hydrologic system by coupling control volumes (waterbodies) with different types of flow between them (watermovers) based on control volume properties.

ASSUMPTIONS

Generalized assumptions are as follows:

- Topography and landscape (vegetation) are assumed to be constant during the period of simulation. A constant relationship may be valid for a short period. However, it is well known that a dynamic relationship exists between hydrology, topography, and vegetation. For example, a prolonged period of lower water levels leads to a change in vegetation and potentially microtopography. A modification to the RSM that dynamically changes the topography and vegetation would enhance the RSM for long-term simulations, and is under consideration by RSM developers.
- The effects of fire on microtopography are not simulated.
- There is no vertical gradient between the surface water and groundwater domain; there is only one head value for each cell. This assumption also implies that surface water and groundwater flow in the same direction (isotropic). Investigations suggest a water exchange flux exists between the surface water and surficial aquifer in the central Everglades (Harvey *et al.,* 2002; Harvey *et al.,* 2004).
- For wetland areas, there is no unsaturated soil; evapotranspiration is determined by the depth of the water table and also assumes that the water level does not fall below the root zone.
- The base of the surficial aquifer is assumed to be impermeable.

- Current climatic input (1965–2005) is used in the base condition.

GOVERNING EQUATIONS

Hydrologic Simulation Engine

The HSE uses a finite volume method to simulate the hydrologic system using conservation of mass and conservation of momentum governing equations (SFWMD, 2005a). The equation for mass balance of overland flow is described by the Saint Venant equation.

$$\frac{\partial h}{\partial t}+\frac{\partial (hu)}{\partial x}+\frac{\partial (hv)}{\partial y}-S=0$$

in which u and v are the velocities in the x and y directions; h = water depth; S summation of rainfall and evapotranspiration. Neglecting inertia terms, the momentum equation can be written as

$$S_c\frac{\partial H}{\partial t}=\frac{\partial}{\partial x}\left(K\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(K\frac{\partial H}{\partial y}\right)+S$$

in which K can be computed as for overland flow using a general form of the Manning equation (Kadlec and Knight, 1966) and for groundwater flow, K = transmissivity; S_c = storage coefficient when the water level is below ground; S_c = 1 at all other times.

A finite volume formulation is used to describe the mass balance condition of 2-D cells for overland and groundwater flow, can be given by

$$\Delta\mathrm{A}\cdot\frac{\mathrm{dH}}{\mathrm{dt}}=\mathrm{Q(H)}+\mathrm{S}$$

in which H = $[H_1, H_2, \ldots H_m \ldots H_{nc}]^T$ is a vector containing the average heads in all cells; $\Delta\mathrm{A}$ = a diagonal matrix whose element $\Delta\mathrm{A}(m,m)$ is equal to the cell area $\Delta\mathrm{A_m}$ for cell *m*; Q and S are the nre inflows and source terms to cells.

Stage-Volume Relationships

Control volumes are referred to as waterbodies. The calculation of a change in mass of the waterbody is performed by using a stage-volume relationship. This describes the relationship between the volume of water in a waterbody and the water head. Stage-volume relationships can be used for a flat ground representation or complex local topography. A flat ground representation for a cell with a single layer aquifer is given by:

$$V=A_0 s_c(H-z_b)\text{ for }H<z$$

$$V=A_0 s_c(z-z_b)+A_0(H-z)\text{ for }H\ \geq z$$

where V = the volume of water in the waterbody (ft^3), A_0 = the cell area (ft^2), s_c = the storage coefficient, H = the head (ft), z_b = the elevation of the bottom of the aquifer (ft), and z = the ground surface elevation (ft). Complex local topography is represented using a lookup table and is given by:

$$V = \sum A_o \, \alpha_A(H) + A_o(1 - \alpha_A(H))s_c(H)$$

where $\alpha_A(H)$ = fraction of open water area at water level H and $s_c(H)$ = soil storage coefficient.

Overland Flow

Overland and groundwater flows in the HSE can be separated. Overland flow is commonly characterized as conveyance and is modeled in the NSRSM using Manning's equation and a lookup table formulation. The equation for computing overland flow using Manning's formulation is given by:

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

where Q = flow (ft^3/sec), L = length of the flow face perpendicular to the flow direction (ft), n = Manning's coefficient, d = water depth (ft), and S = water surface slope. The lookup table formulation of conveyance is given by:

$$Q = LC(d)S^{\alpha}$$

where L = width of flow (ft), $C(d)$ = a lookup table function of conveyance versus depth, S = slope, and α = empirical constant. The empirical constant α is determined from field experiments and assigned a value of 1.0.

Groundwater Flow

The groundwater flow calculation is simulated in the NSRSM using the following formulation:

$$Q = LkdS$$

where Q = flow (ft^3/sec), L = width of the aquifer (ft), k = average hydraulic conductivity (ft/sec), d = the aquifer thickness (ft), and S = head gradient (i.e., hydraulic gradient) in the direction of flow.

Lake Module

Lakes are simulated as independent waterbodies 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. The model cells are discretized around lakes. Lakes are described using a mass balance equation. The volume of water in a lake is defined as:

$$A_s \frac{dH}{dt} = \sum Q_{in} - \sum Q_{out}$$

where A_s = the surface area of the lake (ft^2), $\frac{dH}{dt}$ = the head with respect to time step in the lake (ft/day), and $\sum Q_{in}$ = rainfall, river flow, lake seepage, and overland flow (ft^3/day) and $\sum Q_{out}$ = evapotranspiration, lake seepage, and overland flow (ft^3/day). Once the volume is calculated, the water level and surface area are estimated using a stage-area and stage-volume relationship defined by a 1-D lookup table.

Flow between a lake and a cell is represented by a lakeseepage watermover. The flow is computed as:

$$q = LCD(H_u - H_d)$$

where q = seepage (ft^3/sec), L = length of lake shoreline adjacent to cell (ft), C = conveyance of interface between lake and cell (sec-1), D = depth of water in lake (ft), and H_u and H_d are the higher and lower heads in the lake and cell (ft).

River Network

The effects of a river system are simulated by diffusion flow in the HSE. The river system can be a single network with loops, trees, joints, and completely disconnected segments with the proper boundary conditions. River flow between segments is calculated by:

$$q = \frac{A_m}{l_m \sqrt{S_n} n_b} \left(\frac{A_m}{P_m}\right)^{\frac{5}{3}} \frac{H_m - H_n}{\Delta d_{mn}}$$

where q = flow between river segments (ft^3/sec), A_m= average canal cross-sectional area of segment m (ft^2), l_m= length of a canal segment (ft), S_n= slope of segment n, n_b= average Manning roughness coefficient, P_m= average wetted perimeter (ft), $H_m$and H_n are water levels in river segments m and n (ft), and Δd_{mn}= distance between segment midpoints (ft).

Flow between the river system and the model cell are represented by two types of river-cell watermovers. Seepage between the river segment and the cell is described using a river seepage watermover, where the seepage is derived using Darcy's equation as:

$$q_l = \frac{k_m p}{\delta}(H_i - H_m)$$

where q_l = seepage rate per unit length of river (ft^3/sec), k_m = sediment layer conductivity (ft/sec), p = perimeter of the river subjected to seepage (ft), δ = sediment thickness (ft), and $H_i - H_m$ = head drop across the sediment layer (ft). The sediment layer conductivity is derived using a 10:1 ratio of the aquifer hydraulic conductivity adjacent to the river segment.

Overland flow between the river segment and the cell is simulated as weir flow over a bank along the edge of the canal segment. The flow over the bank of a river segment is computed as:

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

where Q = flow (ft^3/sec), C = weir coefficient, L = length of overlap between the river segment and the cell (ft), g = the gravitational acceleration constant (32.2 ft^2/sec), h = the difference of the stage in the river and cell ground elevation subtracted from the computed head in the cell (ft).

The interaction of a river network and a lake can be simulated by using a shunt watermover. The flow of water from a river to a lake is simulated as:

$$Q = K(H_1 - H_2)$$

where Q = flow (ft^3/sec), K = conductance (ft^2/sec), and H_1 and H_2 = the heads in the two waterbodies.

Boundary Conditions

Boundary conditions for overland flow, groundwater flow, rivers, and lakes are necessary for a proper implementation and solution of the HSE. The HSE has the ability to utilize time dependent boundary conditions.

Overland and groundwater flow boundary conditions are implemented in the NSRSM by using no-flow and wallhead type boundary conditions on model cells. A no-flow boundary condition prevents overland or groundwater flow watermovers from becoming effective. It typically specifies a no-flow region, such a physiographic groundwater or surface water divide. The equation for a no-flow boundary is specified as:

$$Q_i = 0$$

where Q_i = flow through the cell wall (ft^3/sec). A wallhead type boundary condition specifies a time series or constant value of head. This boundary condition typically specifies a shoreline. Flow may enter or exit the cell depending on the value of the boundary condition with repect to the cell's water level. The equation for a wallhead type boundary condition is specified as:

$$H_i = H_B(t)$$

where H_i = head in the cell (ft.)and $H_B(t)$ = constant value or specified value of head for a given time (ft).

The river system implemented by the NSRSM uses junction head, segment source, and uniform flow type boundary conditions. The junction head boundary condition specifies a time series or constant value of head; it typically specifies the head at the end of a river. The equation is the same as for a wallhead type boundary condition. A segment source boundary condition specifies a time series or constant value of flow. This type of boundary condition is typically used at the upstream segment of a river. The equation is specified as:

$$Q_i = Q_B(t)$$

where Q_i = flow (ft^3/sec) and $Q_B(t)$ = constant value or specified value of head for a given time (ft^3/sec). A uniform flow boundary condition is defined by assuming that there is a uniform flow that discharges through the river boundary. This is typically used in the absence of data. The equation is specified as:

$$Q_B = K_i S_B$$

where Q_B = flow through the boundary (ft^3/sec), K_i = cell conveyance (ft^3/sec), and S_B = slope.

Lake implementation in the NSRSM uses lakesource and open water evaporation boundary conditions. The lakesource boundary condition specifies a time series or constant value of flow. It typically specifies flows entering the lake. The equation is the same as for a segment source boundary condition. The open water evaporation boundary condition removes water from a lake based on the input reference evaporation. The equation is specified as:

$$Q_i = Area(H_i)RefET(t)$$

where Q_i = evaporation from the lake i, H_i = water level in the lake i, $Area(H_i)$ = lake surface area interpolated from a lookup table, and $RefET(t)$ = potential evaporation defined as a time series.

Hydrologic Process Module Formulation

The Hydrologic Process Module (HPM) was developed to simulate the effects of local hydrology for the RSM. Rainfall and evapotranspiration are processed providing net recharge to the mesh cells. The governing equation for the HPM is the conservation of mass. Mass is conserved for each time step and model cell. For the NSRSM, the HPM uses the following equation:

$$\Delta S = P - ET$$

where ΔS = change in storage in the HPM (ft^3), P = precipitation (ft^3) and ET = computed evapotranspiration (ft^3).

The NSRSM uses only the natural wetland and unsaturated soil HPM types. In simplistic terms, the lyer1nsm HPM provides recharge to model cell computed from the rainfall and evapotranspiration (Figure 5**)**. The natural wetland HPM represents 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. The natural wetland HPM assumes that there is no unsaturated soil and all water for evapotranspiration is extracted from the water table up to the extinction depth (Xd), when it becomes 0.

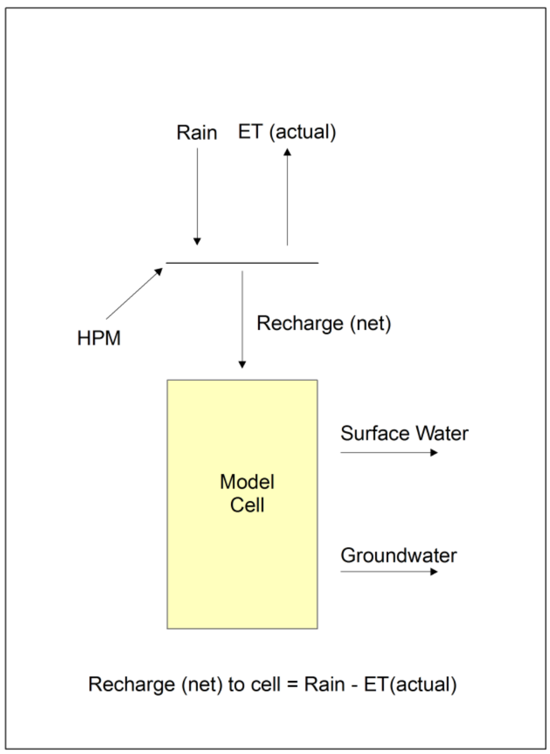

Figure 5. Conceptualization of a layer1nsm HPM.

The evapotranspiration rate is determined by a PET vegetation correction coefficient (Kc). Kc is a coefficient that converts reference evapotranspriation to landscape specific evapotranspiration. As illustrated in **Figure 6**, the value of Kc depends on the location of the water table (H) relative to the ponding depth (Pd), land surface (Z), rooting depth (Rd), and ET extinction depth (Xd). Kveg is the reference vegetation PET correction coefficient for a specified landuse type. Kveg varies monthly for landuse types in the Everglades and is a uniform value in other areas. When Kveg varies monthly, a parameter is used to offset the values. Kw is the PET correction coefficient for a ponded condition. Ponding depth (Pd) or ponding is the water level depth above land surface. The rooting depth (Rd) is the depth of soil that contains the root system and extinction depth (Xd) is depth at which evapotranspiration ceases. The PET correction coefficient for a natural wetland HPM is determined as follows:

$$\mathrm{Kc} = \begin{cases} \mathrm{Kw} & \mathrm{H} \geq \mathrm{Z} + \mathrm{Pd} \\ (\mathrm{Kw} - \mathrm{Kveg})\frac{\mathrm{H}-\mathrm{Z}}{\mathrm{Pd}} + \mathrm{Kveg} & \mathrm{Z} \leq \mathrm{H} < Z + Pd \\ \mathrm{Kveg} & \mathrm{Z} - \mathrm{Rd} \leq \mathrm{H} < Z \\ \mathrm{Kveg}\frac{\mathrm{Xd}-(\mathrm{Z}-\mathrm{H})}{\mathrm{Xd}-\mathrm{Rd}} & \mathrm{Z} - \mathrm{Xd} \leq \mathrm{H} < Z - Rd \\ 0 & \mathrm{H} < Z - Xd \end{cases}$$

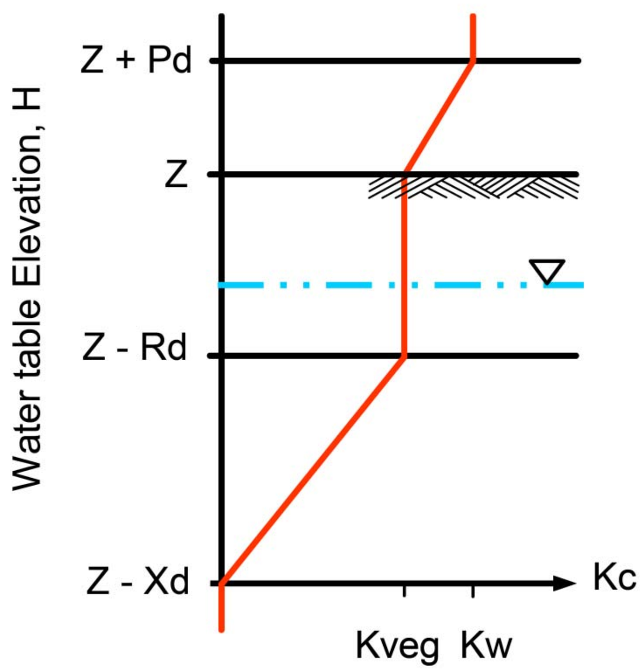

Figure 6. Variation of the PET correction coefficient Kc with the water depth.

The unsaturated soil HPM is an extension of the natural wetland HPM type. It accounts for moisture in the unsaturated zone above the water table as well as tracking the water table. In simplistic terms, the unsat HPM provides recharge to model cell computed from the soil moisture, rainfall and evapotranspiration (Figure 7). Since the water balance accounts for the water content of the unsaturated zone, this type of HPM is utilized in areas where the water table is below the land surface for a significant portion of the year. Evapotranspiration depends on the depth of the water table (wtdepth) and water content in the unsaturated zone (Θ). When the wtdepth is less than the surface elevation (Z) or greater than the rooting depth (Rd), the PET correction coefficient is a function of the water table depth. When the wtdepth is less than Rd, Kc is a function of the water content of the soil in the unsaturated root zone.

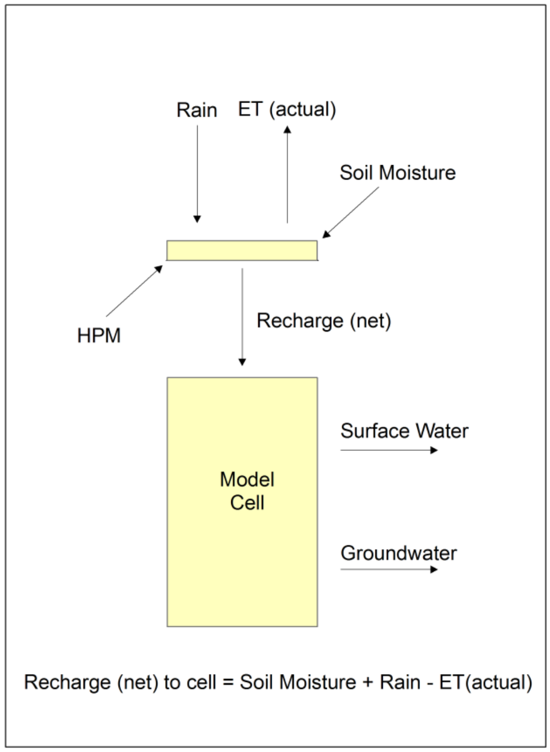

Figure 7. Conceptualization of an unsat HPM.

Where ϴ is greater than a threshold value (Pthres), a calibrated parameter which is typically equal to one half of extractable water content, Kc equals Kveg. Once ϴ drops below Pthres, ET decreases linearly until the wilting point (Xthres) below which ET ceases. The PET correction coefficient for an unsaturated soil HPM is determined as follows:

$$\mathrm{Kc} = \begin{cases} \mathrm{Kw} & \mathrm{wtdepth} < 0 \\ (\mathrm{Kw} - \mathrm{Kveg})\dfrac{\mathrm{H} - \mathrm{Z}}{\mathrm{Pd}} + \mathrm{Kveg} & 0 > wtdepth > Pd \\ \mathrm{Kveg} & \theta > \mathrm{Pthres} \quad (\mathrm{wtdepth} < Rd) \\ \mathrm{Kveg}\dfrac{\theta - \mathrm{Xthres}}{\mathrm{Pthres} - \mathrm{Xthres}} & \mathrm{Xthres} < \theta < \mathrm{Pthres} \quad (\mathrm{wtdepth} < Rd) \\ 0 & \theta < \mathrm{Xthres} \quad (\mathrm{wtdepth} < Rd) \\ 0 & \mathrm{wtdepth} > Rd \end{cases}$$

For a detailed description and formulation of all HPM types, including layer1nsm and unsat, it is recommended to review Flaig *et al.* (2005).

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Chapter 4
Conceptual Model

OVERVIEW

Hydrologic simulation in south Florida requires the development of a conceptual model that integrates hydrology, topography, landscapes, soils, and geology. In order to conceptualize a model, the hydrologic processes were first defined in terms of external and internal geometry (hydrologic and geologic framework), material and fluid properties (groundwater and overland flow), and character and physical extent of the boundaries. The information that characterizes the hydrologic processes was then converted into mathematical terms in the numerical model.

A generalized description of the hydrologic processes along a north-south section of the NSRSM is shown in **Figure 8**. The upper boundary is defined by the water level surface which can reside above or below land surface and does not extend below the base of the surficial aquifer. Water above land surface, unless constrained, tends to move down gradient toward lakes, rivers, low lands, or the coastline. Other discharges from the land surface and surficial aquifer occur as evapotranspiration and downward leakage through the upper confining unit. In areas where the potentiometric surface of the underlying aquifer is higher than the water level in the surficial aquifer, there is the possibility for upward recharge to the surficial aquifer.

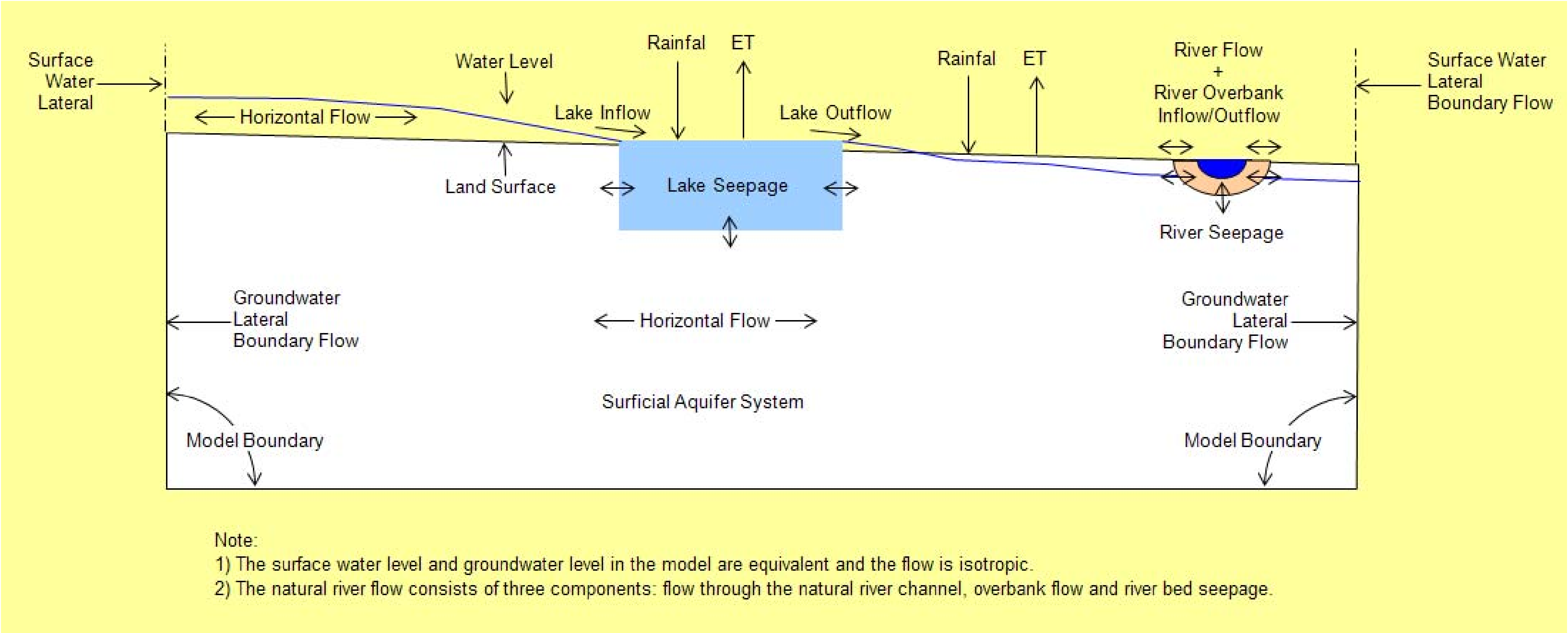


Figure 8. Generalized KOE natural system hydrology.

MESH DESIGN

The model consists of a variable mesh covering 11,840 square miles with 7,438 cells. Triangular cell sizes range from a minimum resolution of 0.77 miles per side in the Everglades to a maximum of 6.4 miles per side in the prairies northwest of Lake Okeechobee. The size of the mesh was dictitated by the area of interest, such as the Everglades, so that a comparative analysis may be performed with other models. In areas outside of the Everglades, the mesh size is larger in areas with large topographic differences over short distances; the larger cells promote model stability. **Table 3** summarizes basic statistics of mesh cell geometry.

Table 3. Mesh cell geometry statistics for the NSRSM.

Number of cells: 7,438	Acres	Square MIles
Maximum cell size	8,821	13.8
Average cell size	1,019	1.6
Minimum cell size	241	0.4
Standard Deviation	957	1.5

MODEL PARAMETERS

Since there is little to no measured field data for the predrainage model parameters, an inverse modeling technique known as Tikhonov regularization was used to facilitate the generation of model parameters. Tikhonov regularization incorporates expert knowledge associated with ranges of preferred parameter values and the system response of the Everglades in order to derive calibrated model parameters. This type of calibration process can be viewed as conditioning expert knowledge. The following model parameters used this technique: vegetation coefficients, overland conveyance and lake ET coefficients.

LANDSCAPE

The NSRSM simulates the landscape as it existed before drainage (ca. 1850). 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 9, left**). A District-wide predrainage vegetation database was assembled by the SFWMD (Zahina *et al.*, 2007) using an ecological community approach to classify vegetation for use in hydrologic modeling. Twenty-seven hydrologically distinct classes were identified and mapped (Table 1, Zahina *et al.*, 2007). This database was aggregated by classification code (**Table 4)** and mapped into the NSRSM mesh cells using a GIS statistical operation called majority. The majority statistical operation computes the area of each predrainage vegetation database polygon that resides within each NSRSM mesh cell. The area of the majority or largest landscape type is assigned to the NSRSM mesh cell (**Figure 9, right**). The NSRSM vegetation is modeled with three components: local surface hydrology, overland flow, and microtopography.

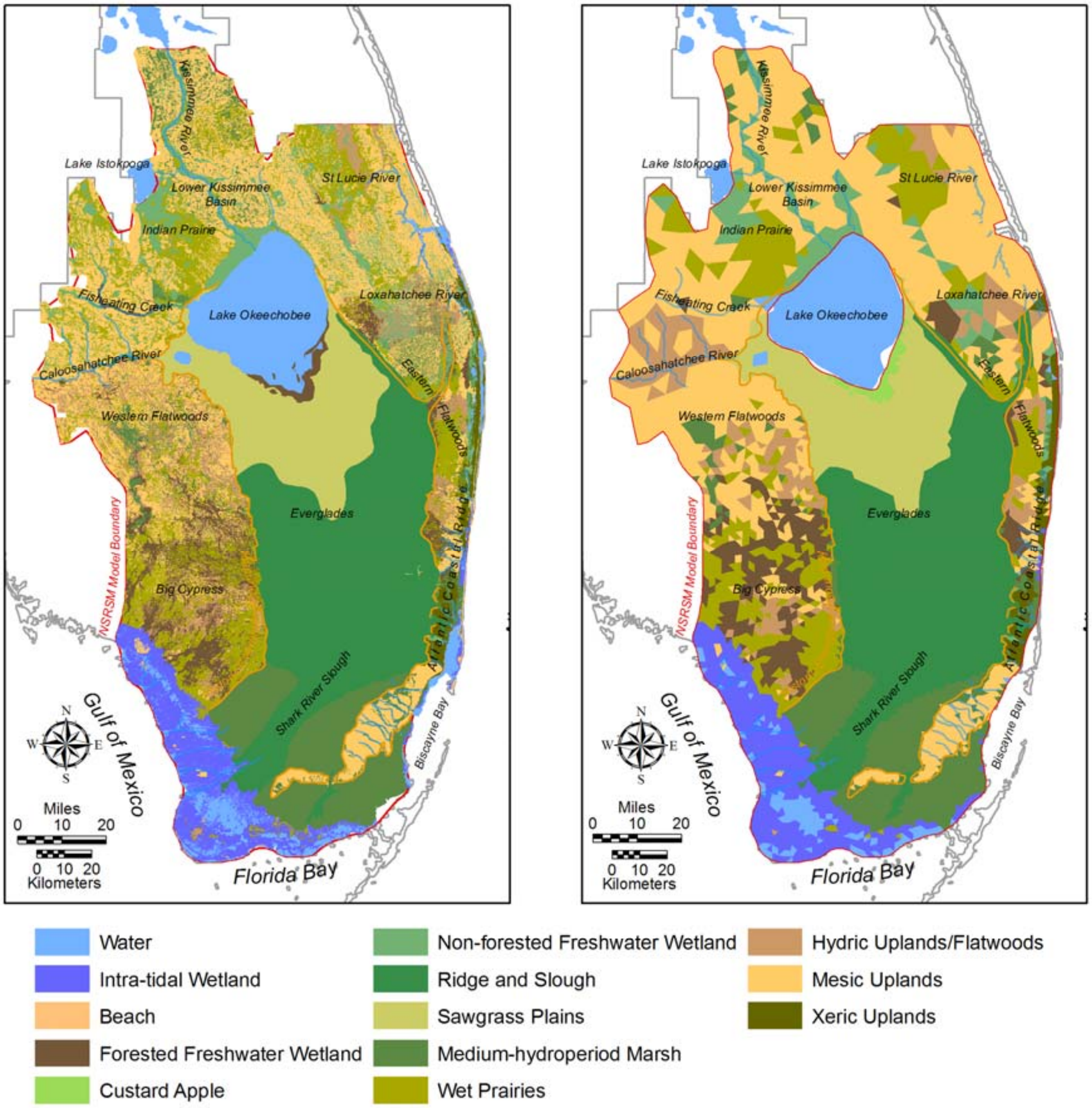


Figure 9. Predrainage vegetation database (left) and NSRSM landscape types (right).

Table 4. Cross walk between predrainage vegetation database and NSRSM landscape types.

No.	Classification Code	Pre-development Vegetation Database	NSRSM Landscape Types
1	1	Water	Water
2	2	Inter-tidal Wetland	Intra-tidal Wetland
3	3	Beach (Shore)	Beach (Shore)
4	4	Forested Freshwater Wetland	Forested Freshwater Wetland
5	4.1	Cypress Swamp	
6	4.2	Hardwood Swamp	
*	4.21	Custard Apple	Custard Apple
7	5	Non-Forested Freshwater Wetland	Non-Forested Freshwater Wetland
8	5.1	Long-hydroperiod Marsh	
9	5.11	Ridge and Slough	Ridge and Slough
10	5.12	Sawgrass Plain	Sawgrass Plain
11	5.2	Medium-hydroperiod Marsh	Medium-hydroperiod Marsh
12	5.21	Marsh with Scattered Cypress	
13	5.22	Everglades Marl Marsh	
14	5.3	Wet Prairie	Wet Prairie
15	5.31	Wet Prairie with Scattered Trees	
16	5.32	Wet Prairie with Cypress	
17	6	Hydric Upland/Flatwood	Hydric Upland/Flatwood
18	6.1	Hydric Flatwood	
19	6.2	Hydric Hammock	
20	7	Mesic Upland	Mesic Upland
21	7.1	Dry Prairie	
22	7.2	Mesic Pine Flatwood	
23	7.3	Mesic Hammock	
24	8	Xeric Upland	Xeric Upland
25	81	High Pine (Sandhill)	
26	8.2	Scrub	
27	8.3	Coastal Strand	

Note: * is a subclassification of Hardwood Swamp

Local Surface Hydrology

Local surface hydrology is defined in this context in combination with the surficial aquifer. This interaction is controlled by the evapotranspiration of the vegetative landscape. The Hydrologic Process Modules (HPMs) were developed to simulate the small-scale, local hydrology and vertical processes for the RSM. The NSRSM only uses two types of HPMs: wetland and unsaturated soil.

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 these areas, the natural wetland HPM is implemented where it is simulated 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 natural wetland HPM is a reasonable simplification that assumes there is no water available above the water table and all of the water for evapotranspiration is extracted from the water table. The RSM parameters for the natural wetland HPMs were adapted from the NSM and adjusted as shown in **Table 5** (South Florida Water Management District and Interagency Modeling Center, 2005). The variables in **Table 5** are defined as:

- Kw = Maximum vegetation coefficient for water
- Rd = Shallow root zone depth
- Xd = Extinction depth below which no ET occurs
- Pd = Open water ponding depth
- Kveg = Vegetation coefficient for uniform values or a lookup table (LUT) for monthly vegetation coefficients are detailed in Chapter 3 of HPM formulation. **Table 6** illustrates the Kveg values used by the model.

Table 5. NSRSM parameters for the natural wetland HPM.

Vegetation Type	Kw	Rd(ft.)	Xd(ft.)	Pd(ft.)	Kveg
Water	0.9	0	5.0	3.0	1.00
Inter-tidal wetlands	0.9	0	4.5	5.0	LUT
Beaches	0.9	0	7.5	5.0	0.50
Forested Freshwater Wetlands	0.9	0	8.0	5.0	LUT
Cypress Swamp	0.9	0	8.0	5.0	LUT
Hardwood Swamp	0.9	0	8.0	5.0	LUT
Custard Apple	0.9	0	4.5	5.0	LUT
Non-forested Freshwater Wetlands	0.9	0	1.2	4.5	LUT
Long Hydroperiod Marsh	0.9	0	2.0	5.0	LUT
Ridge and Slough	0.9	0	1.5	5.0	LUT
Ridge and Slough South Everglades	0.9	0	1.5	5.0	LUT
Sawgrass Plains	0.9	0	4.5	5.0	LUT
Medium Hydroperiod Marsh	0.9	0	2.0	5.0	LUT
Marsh with Scattered Cypress	0.9	0	2.0	5.0	LUT
Everglades Marl Marsh	0.9	0	6.5	4.5	LUT
Wet Prairie	0.9	0	2.0	4.5	LUT
Wet Prairie with Scattered Trees	0.9	0	2.0	5.0	LUT
Wet Prairie with Cypress	0.9	0	2.0	5.0	LUT
Hydric Uplands	0.9	0	8.0	5.0	LUT
Hydric Flatwood	0.9	0	8.0	5.0	LUT
Hydric Hammock	0.9	0	8.0	5.0	LUT

Table 6. Monthly vegetation coefficients used for the natural wetland HPM.

Vegetation Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Inter-tidal Wetlands	0.60	0.61	0.62	0.63	0.66	0.67	0.69	0.70	0.70	0.68	0.65	0.61
Forested Freshwater Wetlands	0.60	0.61	0.62	0.63	0.66	0.67	0.69	0.70	0.70	0.68	0.65	0.61
Cypress Swamp	0.60	0.61	0.62	0.63	0.66	0.67	0.69	0.70	0.70	0.68	0.65	0.61
Hardwood Swamp	0.60	0.61	0.62	0.63	0.66	0.67	0.69	0.70	0.70	0.68	0.65	0.61
Custard Apple	0.67	0.64	0.68	0.71	0.75	0.76	0.77	0.82	0.77	0.74	0.72	0.68
Non-forested Freshwater Wetlands	0.67	0.64	0.69	0.72	0.76	0.81	0.85	0.88	0.85	0.81	0.75	0.69
Long Hydroperiod Marsh	0.67	0.64	0.69	0.72	0.76	0.81	0.85	0.88	0.85	0.81	0.75	0.69
Ridge and Slough	0.61	0.60	0.61	0.63	0.66	0.70	0.77	0.82	0.77	0.74	0.66	0.62
Ridge and Slough South Everglades	0.61	0.60	0.61	0.63	0.66	0.70	0.77	0.82	0.77	0.74	0.66	0.62
Sawgrass Plains	0.70	0.68	0.70	0.72	0.74	0.75	0.76	0.80	0.80	0.73	0.72	0.71
Medium Hydroperiod Marsh	0.69	0.66	0.70	0.73	0.78	0.82	0.89	0.91	0.89	0.81	0.79	0.71
Marsh with Scattered Cypress	0.69	0.66	0.70	0.73	0.78	0.82	0.89	0.91	0.89	0.81	0.79	0.71
Everglades Marl Marsh	0.61	0.60	0.61	0.62	0.65	0.69	0.76	0.76	0.76	0.75	0.66	0.62
Wet Prairie	0.69	0.66	0.70	0.71	0.74	0.76	0.78	0.81	0.81	0.77	0.74	0.70
Wet Prairie with Scattered Trees	0.69	0.66	0.70	0.71	0.74	0.76	0.78	0.81	0.81	0.77	0.74	0.70
Wet Prairie with Cypress	0.69	0.66	0.70	0.71	0.74	0.76	0.78	0.81	0.81	0.77	0.74	0.70
Hydric Uplands	0.61	0.60	0.62	0.63	0.66	0.67	0.69	0.70	0.70	0.68	0.65	0.62
Hydric Flatwood	0.61	0.60	0.62	0.63	0.66	0.67	0.69	0.70	0.70	0.68	0.65	0.62
Hydric Hammock	0.61	0.60	0.62	0.63	0.66	0.67	0.69	0.70	0.70	0.68	0.65	0.62

Substantial water storage is available in upland areas 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. In these areas, the unsaturated soil HPM is implemented. The unsaturated soil HPM is similar to the natural wetland HPM except that it considers water in the unsaturated soil above the water table. Application of the unsaturated soil HPM can be useful when the water table is below ground for a significant portion of the year. The RSM parameters for the unsaturated soil HPMs were adapted from the NSM and adjusted as shown in **Table 7**. Variables in **Table 7** are defined as:

- Ew = Extractable water
- Kw = Maximum vegetation coefficient for water
- Rd = Shallow root zone depth
- Xthresh = Soil water content when ET ceases
- Pthresh = Soil water content when Kc begins to decrease from Kveg to 0.0
- Pd = Open water ponding depth
- Wilt = Soil water content at wilting point
- Kveg = Vegetation coefficient

Table 7. NSRSM parameters for the unsaturated soil HPM.

Vegetation Type	Ew	Kw	Rd	Xthresh	Pthresh	Pd	Wilt	Kveg
Mesic Uplands	0.6	0.9	8.0	0.3	0.7	2.0	0.1	0.61
Dry Prairie	0.6	0.9	8.0	0.3	0.7	2.0	0.1	0.61
Mesic Pine Flatwoods	0.6	0.9	8.0	0.3	0.7	2.0	0.1	0.61
Mesic Hammock	0.6	0.9	8.0	0.3	0.7	2.0	0.1	0.61
Xeric Upland	0.6	0.9	8.0	0.3	0.7	2.0	0.1	0.61
High Pine	0.6	0.9	8.0	0.3	0.7	2.0	0.1	0.61
Scrub	0.6	0.9	8.0	0.3	0.7	2.0	0.1	0.61
Coastal Strand	0.6	0.9	8.0	0.3	0.7	2.0	0.1	0.61

The natural wetland HPM (layer1nsm) is used in all wetland areas and the unsaturated soil HPM (unsat) is used in the remaining areas, as shown in **Table 8**.

Table 8. Natural wetland (Layer1nsm) and unsaturated soil (Unsat) HPMs used for each vegetation type.

Vegetation Type	HPM Type
Water	Layer1nsm
Inter-tidal Wetland	Layer1nsm
Beach	Layer1nsm
Forested Freshwater Wetland	Layer1nsm
Cypress Swamp	Layer1nsm
Hardwood Swamp	Layer1nsm
Non-Forested Freshwater Wetland	Layer1nsm
Long-hydroperiod Marsh	Layer1nsm
Ridge and Slough	Layer1nsm
Sawgrass Plain	Layer1nsm
Medium-hydroperiod Marsh	Layer1nsm
Marsh with Scattered Cypress	Layer1nsm
Everglades Marl Marsh	Layer1nsm
Wet Prairie	Layer1nsm
Wet Prairie with Scattered Trees	Layer1nsm
Wet Prairie with Cypress	Layer1nsm
Hydric Upland	Layer1nsm
Hydric Flatwood	Layer1nsm
Hydric Hammock	Layer1nsm
Mesic Upland	Unsat
Dry Prairie	Unsat
Mesic Pine Flatwood	Unsat
Mesic Hammock	Unsat
Xeric Upland	Unsat
High Pine (Sandhill)	Unsat
Scrub	Unsat
Coastal Strand	Unsat

HYDROGEOLOGY

The hydrogeologic component of the NSRSM includes the surficial aquifer system (SAS) shown in **Figure 10**. The largest groundwater flows occur in the Biscayne aquifer across the Miami Rock Ridge and Atlantic Coastal Ridge, which form a divide between the Everglades and the Atlantic Ocean. Other basins contain topographic gradients that are sufficient in magnitude to induce groundwater flow, including the Western Flatwoods, Big Cypress, and the areas north of Lake Okeechobee.

Surficial Aquifer System (SAS)

Three major aquifer systems underlying south Florida are the result of vast marine carbonate sedimentation: the Floridan aquifer, intermediate aquifer system, and SAS. Rainfall recharges the surficial aquifer under what are now Miami-Dade, Broward and eastern Palm Beach counties. Historically, this aquifer provided a source of groundwater to the Everglades. The highly transmissive Biscayne aquifer is a component of the SAS (**Figure 10**). It is thickest in the east, then thins out as it extends westward under the central Everglades. Hydraulic conductivity values are relatively high in the east and correspondingly lower in the west.

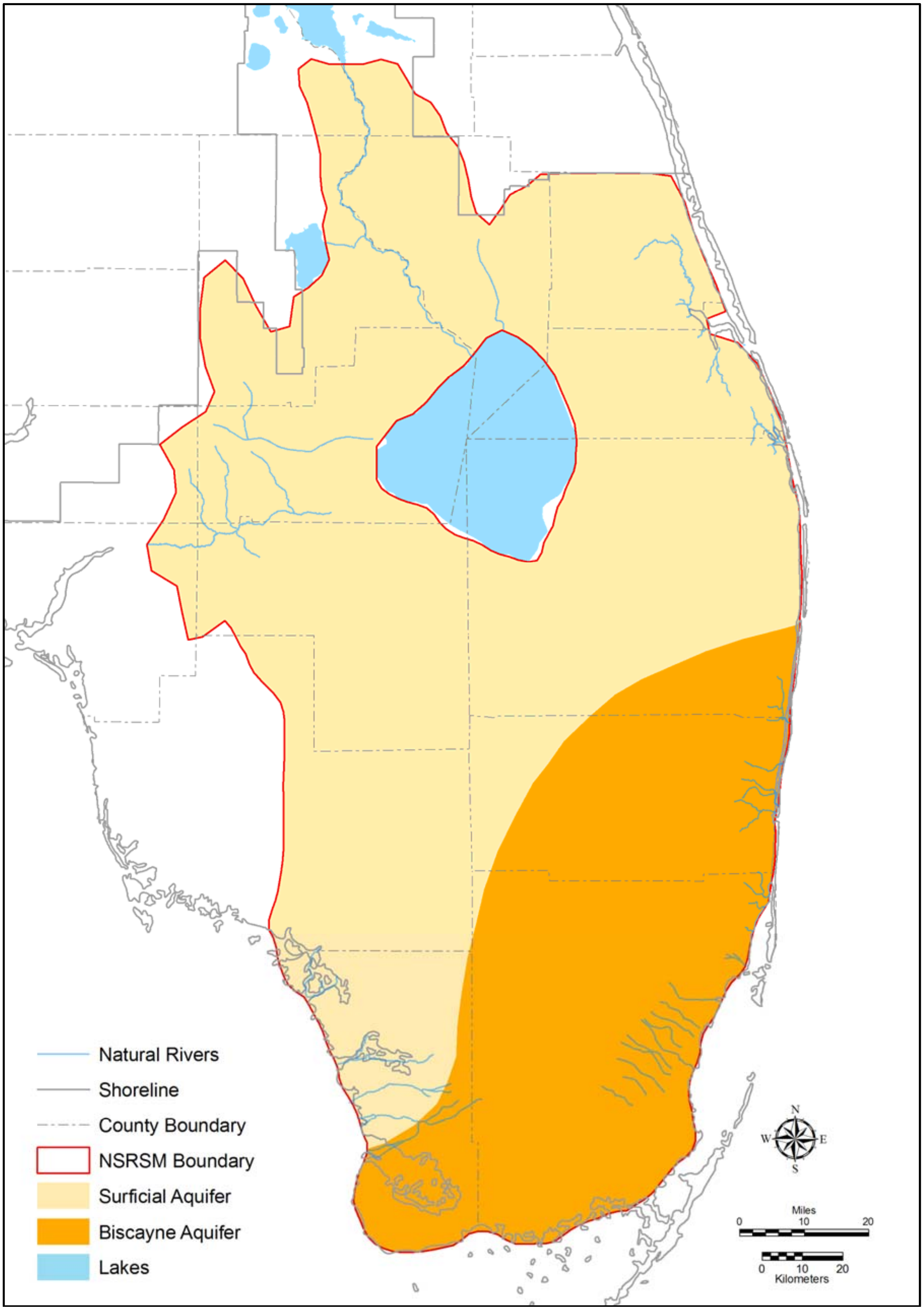


Figure 10. Biscayne and surficial aquifer systems.

The NSRSM groundwater flows are modeled in the surficial aquifer system and the Biscayne aquifer. The surficial aquifer system includes any aquifer present at the land surface. The Biscayne aquifer is also present at land surface and is laterally connected to the surficial aquifer system. However, the United States Geological Survey (USGS) separates it from the surficial aquifer system because of its importance as a water source (USGS, 1990). **Figure 10** illustrates both aquifers within the NSRSM domain.

Beneath the surficial aquifer system is a multiaquifer system separated by low permeable confining units. The geologic framework of the NSRSM includes the surficial aquifer system and Biscayne aquifer. It assumes the base of the aquifer to be impermeable. Other models, such as the NSM, use this assumption. However, geochemical studies suggest that Hawthorn formation groundwater, located beneath the surficial aquifer, has the potential to recharge the surficial aquifer (Price, 2006). This potential of additional recharge is not reflected in the NSRSM.

The SAS consists of a complex interbedding of unconsolidated sand, shelly sand, and shell. Highly permeable limestone beds are locally present in southwestern Florida. The SAS can be divided into two or three aquifers in some places; however, the system is mostly undivided. The Biscayne aquifer consists of sand, sandstone, and highly permeable limestone. The entire sequence is not present at any one location and most formations are thin lenses.

The Biscayne aquifer also thickens coastward and ranges in thickness from a few feet near its western limit to about 240 feet near the coast (USGS, 1990). Transmissivity typically varies from 1,000 ft^2 to 10,000 ft^2 per day. In some places, values of 25,000 ft^2 to 50,000 ft^2 per day have been reported. The larger values typically represent beds of shell or limestone (USGS, 1990).

Ground water levels in the SAS are unconfined at most locations. Thin clay beds can create a local semiconfined or confined condition. Most of the water that enters the system moves quickly and discharges as baseflow to streams. Evapotranspiration returns a large percentage of groundwater to the atmosphere. Water that does not run off or evapotranspires moves downward and lateral through the surficial aquifer system until it discharges to a surface water body or to the ocean. In places, the confining unit separating the surficial aquifer and the Floridan aquifer is thin clay, allowing water to leak into the Floridan aquifer. In locations where the hydraulic head in the surficial aquifer is lower than the head in the Floridan aquifer, upward leakage occurs.

Generally, the water table follows the topography of land surface. Steep gradients occur between hills and streams, and gentle gradients occur in broad, flat areas. The general direction of groundwater movement is toward the Atlantic Ocean, the Gulf of Mexico, or major rivers. The complexity of the water table is reflected by the movement of water in the surficial aquifer to the nearest surface water body. Within short distances, the movement of groundwater can noticeably change.

A direct hydraulic connection exists between the Biscayne aquifer and the natural rivers that cross it. Water passes freely to and from the natural rivers into the aquifer. The water table level changes almost immediately with the water level in a natural river and vice versa.

Implementation of Aquifer Properties

The NSRSM requires aquifer thickness and aquifer conductivity data. Aquifer thickness is measured from the base of the surficial aquifer system to the lesser of either the water level or topographic elevation. The properties of the surficial aquifer system are consistent with those developed for regional modeling. In the areas north of the model domain, aquifer conductivity values were extrapolated from the northern model extent. Supporting information on aquifer properties is provided in **Appendix E**.

OVERLAND FLOW

Characteristics of overland flow are assigned attributes representative of each landscape type. The attributes are based on the roughness of each landscape type; microtopography is simulated by the stage-volume converter which is discussed in a later section. Within the Everglades, the Sawgrass Plains, Ridge and Slough, and Marl Marsh landscapes use a lookup table formulation to compute overland flow. The inverse modeling technique using Tikhonov regularization was used to generate the lookup tables. The lookup table allows for a more realistic representation of hydrology by specifying varying degrees of roughness at different depths (**Figure 11**).

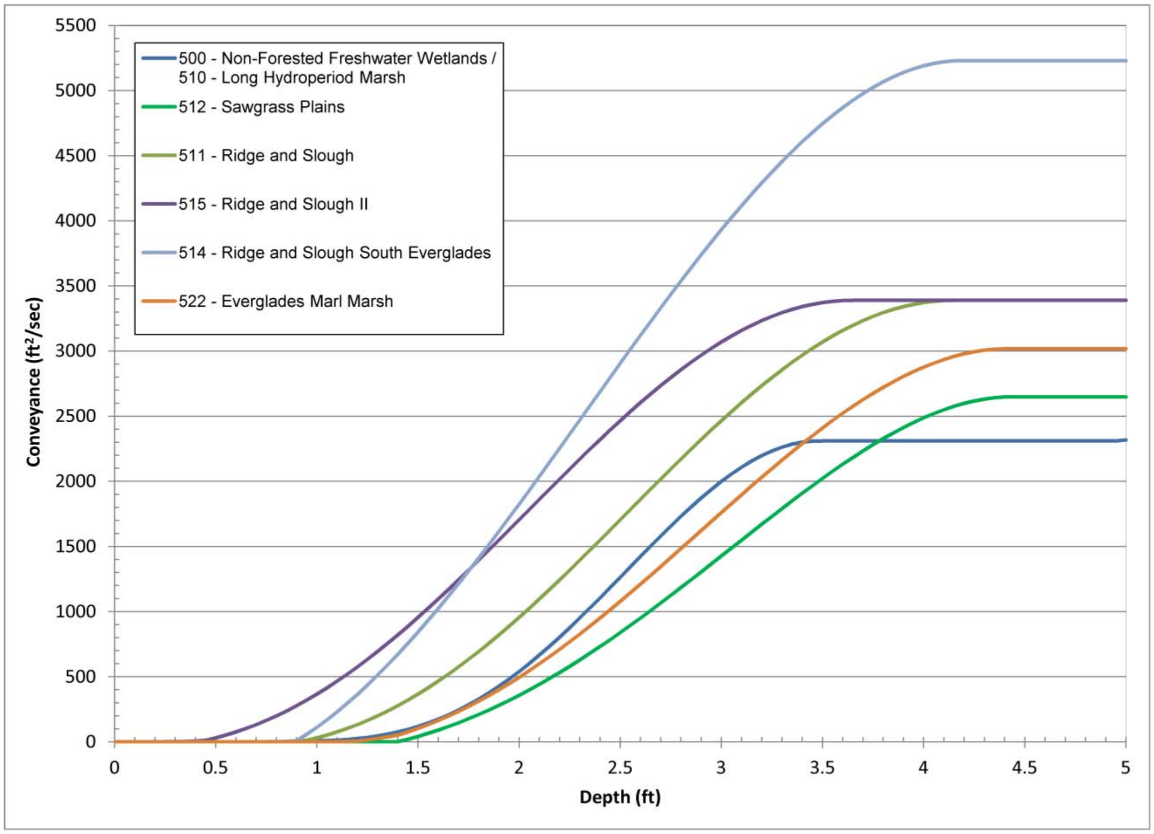


Figure 11. Depth and conveyance relationship for Long Hydroperiod Marsh, Sawgrass, Ridge and Slough, and Marl Marsh landscapes.

In all other areas, overland flow is computed using a Manning's formulation. A summary of conveyance parameters for these landcover designations are provided in **Table 9**. The RSM parameters for the Manning's coefficients were adapted from the NSM and adjusted as shown in **Table 9** (South Florida Water Management District and Interagency Modeling Center, 2005).

Table 9. Manning's overland conveyance factors used in the NSRSM.

Vegetation Type	Overland Flow Conveyance Parameter	
	Manning's η	Detention Depth
Water	0.10	0.1
Inter-tidal wetlands	0.10	0.1
Beaches	0.10	0.1
Forested Freshwater Wetlands	0.30	0.1
Cypress Swamp	0.30	0.1
Hardwood Swamp	0.40	0.1
Custard Apple	0.10	0.1
Medium Hydroperiod Marsh	0.70	0.5
Marsh with Scattered Cypress	0.70	0.5
Wet Prairie	0.70	0.5
Wet Prairie with Scattered Trees	0.70	0.5
Wet Prairie with Cypress	0.70	0.5
Hydric Uplands	0.85	0.1
Hydric Flatwood	0.85	0.1
Hydric Hammock	0.85	0.1
Mesic Uplands	0.85	0.1
Dry Prairie	0.85	0.1
Mesic Pine Flatwood	0.85	0.1
Mesic Hammock	0.85	0.1

Note: Computed overland flow is also a function of the topographic elevation of each adjacent cell. This is addressed in the upcoming Topography section.

TOPOGRAPHY

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) High Accuracy Range Network (HARN). The horizontal and vertical datums are independent and not used by the HSE code. The datums are spatial reference planes for model input data (i.e., topographic elevations, hydraulic conductivity, etc.) which are stored and managed by a geographical information system (GIS). A GIS requires specific horizontal and vertical datums.

Topographic elevation is an important input parameter relative to overland flow. The NSRSM requires a representative topographic elevation for each model cell. Due to the variation of cell sizes and topographic features, each cell can represent a small (e.g. flat areas such as the Everglades) or large (e.g. upland areas) range of topographic elevations. The NSRSM requires a single topographic elevation for each model cell which is assigned by spatial interpolation.

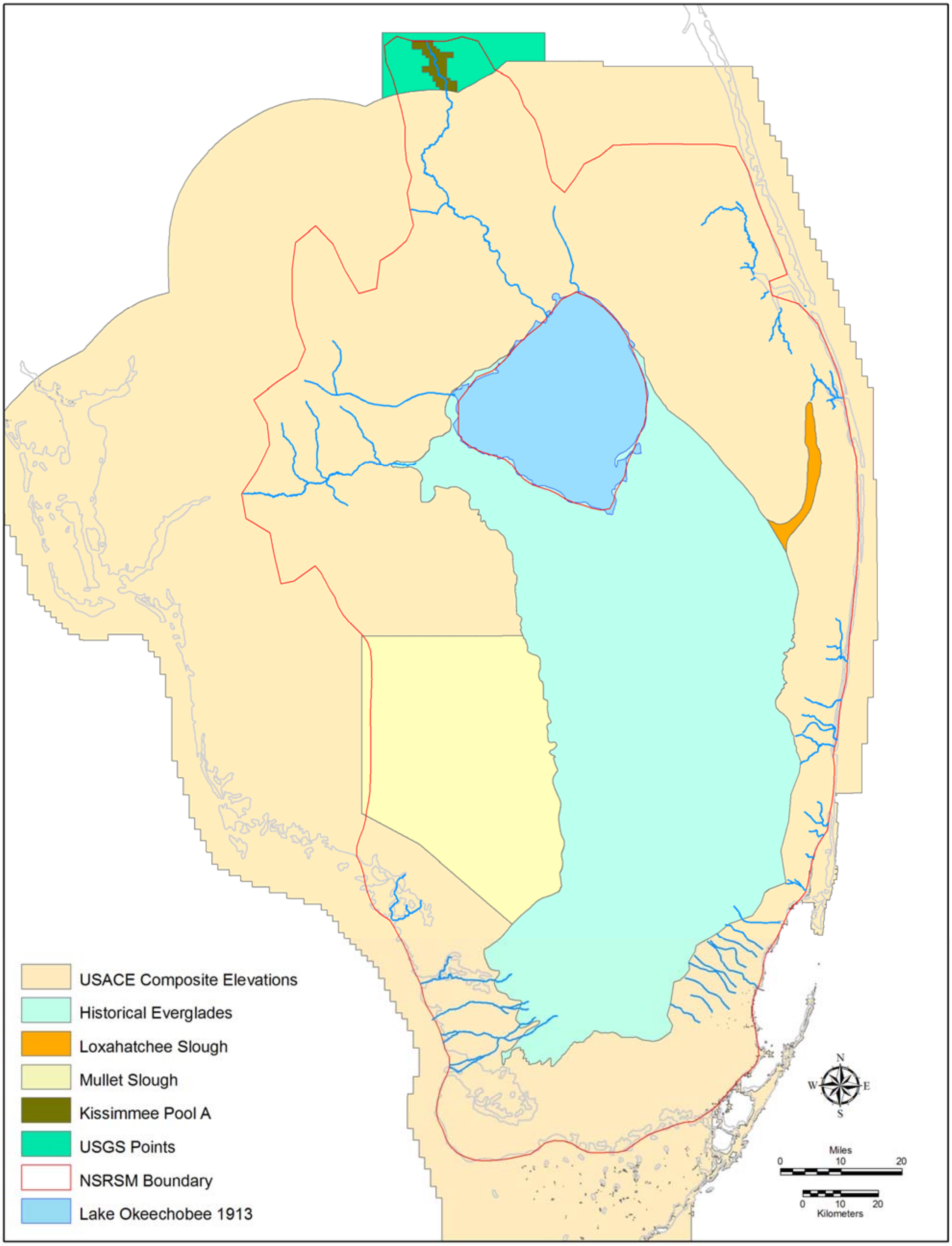


Figure 12. NSRSM topographic data sources.

Elevation Sources

Topographic elevations for the NSRSM were derived from multiple sources (**Figure 12**) and detailed in **Appendix B**. A majority of the region outside of the historical Everglades was assigned values from a composite elevation map of south Florida developed by the U.S. Army Corps of Engineers (USACE). Artifacts of development were removed from this source and areas adjacent to the Everglades were adjusted (edge-matched) for better representation of predrainage land surface elevations.

The NSRSM landsurface elevations north and northwest of Lake Okeechobee were based on the Kissimmee River flood plain topographic elevation model, developed in support of the Kissimmee Restoration Project (**Appendix B**), and data from the U.S. Geological Survey 24K Quadrangle data documented in **Appendix B**. Elevations were compared to pre-development landscape and determined to represent natural landscape positions.

While upland elevations are not assumed to have 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 lowered soil surface elevations today as compared to the pre-development land surface. To account for subsidence in the Everglades basin, estimated predrainage elevation contours developed by an interagency team for NSM v4.6.2 Sensitivity Run 4 were adapted for the NSRSM. Documentation of this dataset is provided in **Appendix B**.

Additional topographic enhancements include:

- Depressions added within present day Water Conservation Area 1 (WCA-1), based on spot elevations adapted from Richardson *et al.* (1990).
- Modification to eastern Big Cypress Basin elevations to account for subsidence in organic soils. Orgainc soils adjacent to the Everglades boundary were adjusted one foot for subsidence.
- Generalized edgematching along the Everglades boundary.

Data from all sources were combined to form a topographic elevation map representative of predrainage south Florida. Topographic elevations within the NSRSM model domain range from ~200 feet in the northern highlands to near sea level in the south (**Figure 13**).

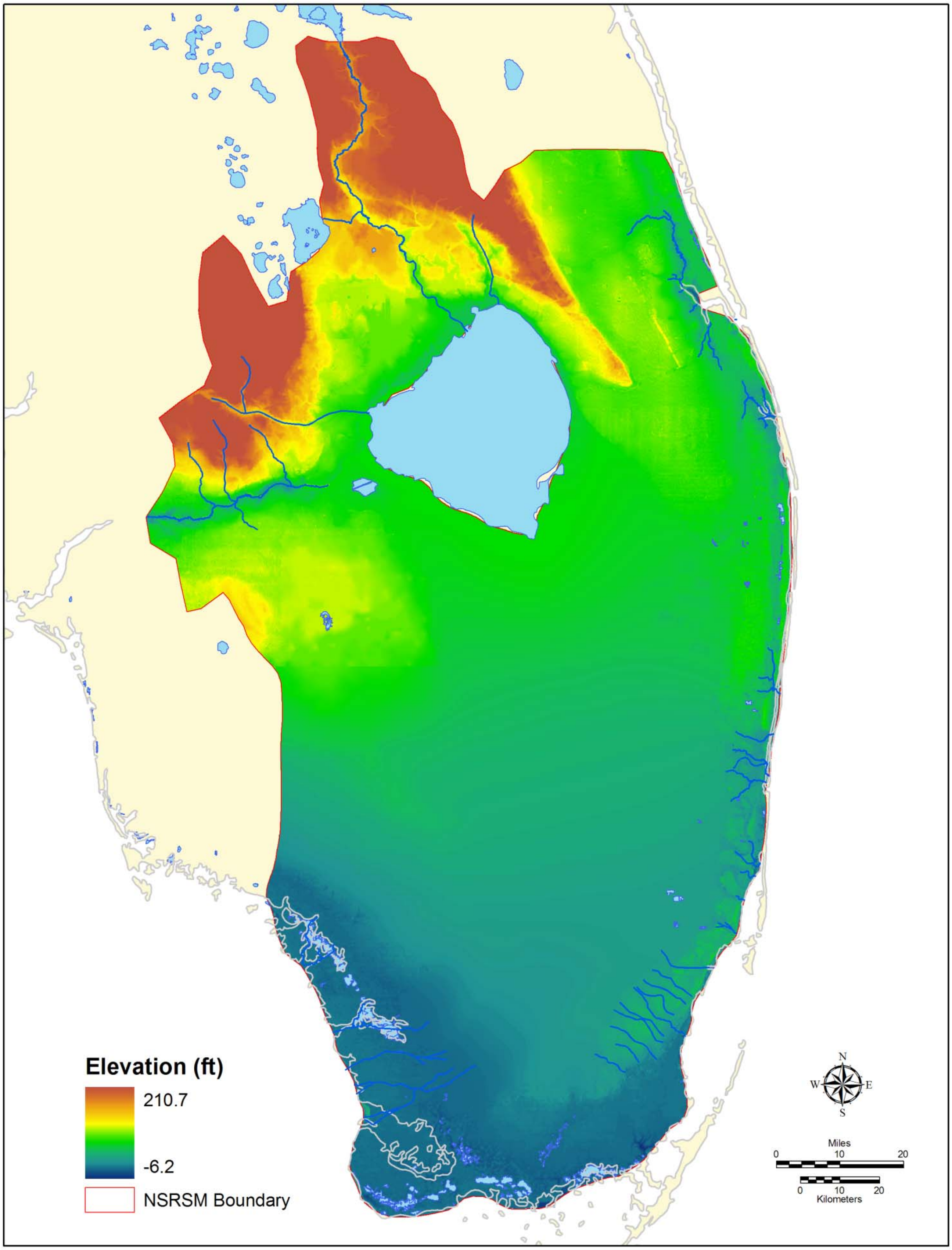


Figure 13. NSRSM topographic elevations (NGVD29).

MICROTOPOGRAPHY

Although the south Florida landscape is relatively flat, hydrologic characteristics (e.g., water storage volume per unit change in head, ET rate) may change significantly with even small (1 ft) changes in soil surface elevation. The NSRSM has one topographical elevation for each model cell that represents a composite, flat ground, elevation. However, microtopography within a model cell can be simulated using a stage-volume relationship. This is an important feature that simulates the ridge and tree island landscape where local elevations within a model cell can vary from 0 to 3.5 feet. The stage-volume relationship simulates the stage in a model cell as a function of its volume of water. The stage-volume relationship allows 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.

In order to develop a representative stage-volume relationship for the Ridge and Slough landscape, the spatial distribution and elevations relative to the slough bottom for each landscape were needed. Based on research conducted by the SFWMD Everglades Systems Assessment Section, the sloughs, ridges, bay head, and tree islands spatially account for 46 percent, 46 percent, 3 percent, and 5 percent of the historical Everglades, respectively (**Table 10**).

Table 10. Spatial extent and relative elevations of major Everglades landscape types.

Feature	Spatial Percentage	Elevation (relative to slough bottom - ft)
Slough Bottom	46	0.0
Ridge Top	46	1.5
Bay Head Top	3	3.5
Tree Island Top	5	3.5

The topographic elevation model discussed in the previous section represents a composite elevation within the Ridge and Slough landscape; therefore, the stage-volume relationship must be synchronized with model cell elevations. This synchronization is accomplished for each model cell within the Ridge and Slough landscape by subtracting the weighted average of the values in **Table 10** (0.97 ft.) from the composite elevation. In summary, the topographic surface within the Ridge and Slough landscape represents the bottom of the slough and surface feature elevations are represented using a stage-volume relationship. Caution must be used when comparing Everglades's water level depths with other models. Other models, such as the SFWMM and NSM, use a composite topographic elevation for computing water level depth. A comparison of the Ridge and Slough landscape topographic datum can be seen in **Figure 14**, as used by the NSRSM (**Figure 14, left**) and the SFWMM or NSM (**Figure 14, right**).

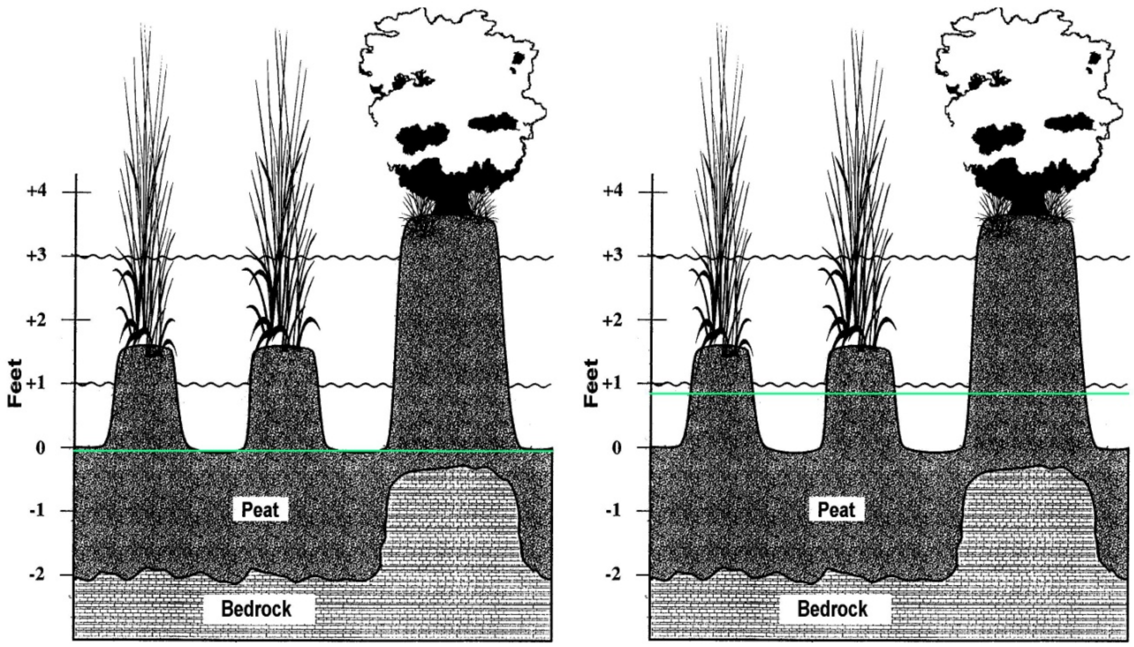


Figure 14. Ridge and slough landscape topographic datum (green line) used by NSRSM (left) and datum used by SFWMM or NSM (right).

Note: Horizontal spacing is greatly compressed and relief is exaggerated for clarity.
Source: (McVoy *et al.*, 2011)

The stage-volume relationship is also applied to the peat soil within the Everglades. The thickness of the peat soil layer varies; it is thicker in the north (south of Lake Okeechobee) and gradually becomes thinner towards Shark Slough in the south (**Figure 15**). The peat thickness was computed using the bedrock contours (Parker *et al.*, 1955) and the predrainage topographic elevation. However, since simulated predrainage water levels in the Ridge and Slough landscape remain above the slough bottom, the implementation of the peat soil layer was simplified to account for the surface/soil interface using a uniform three foot thickness.

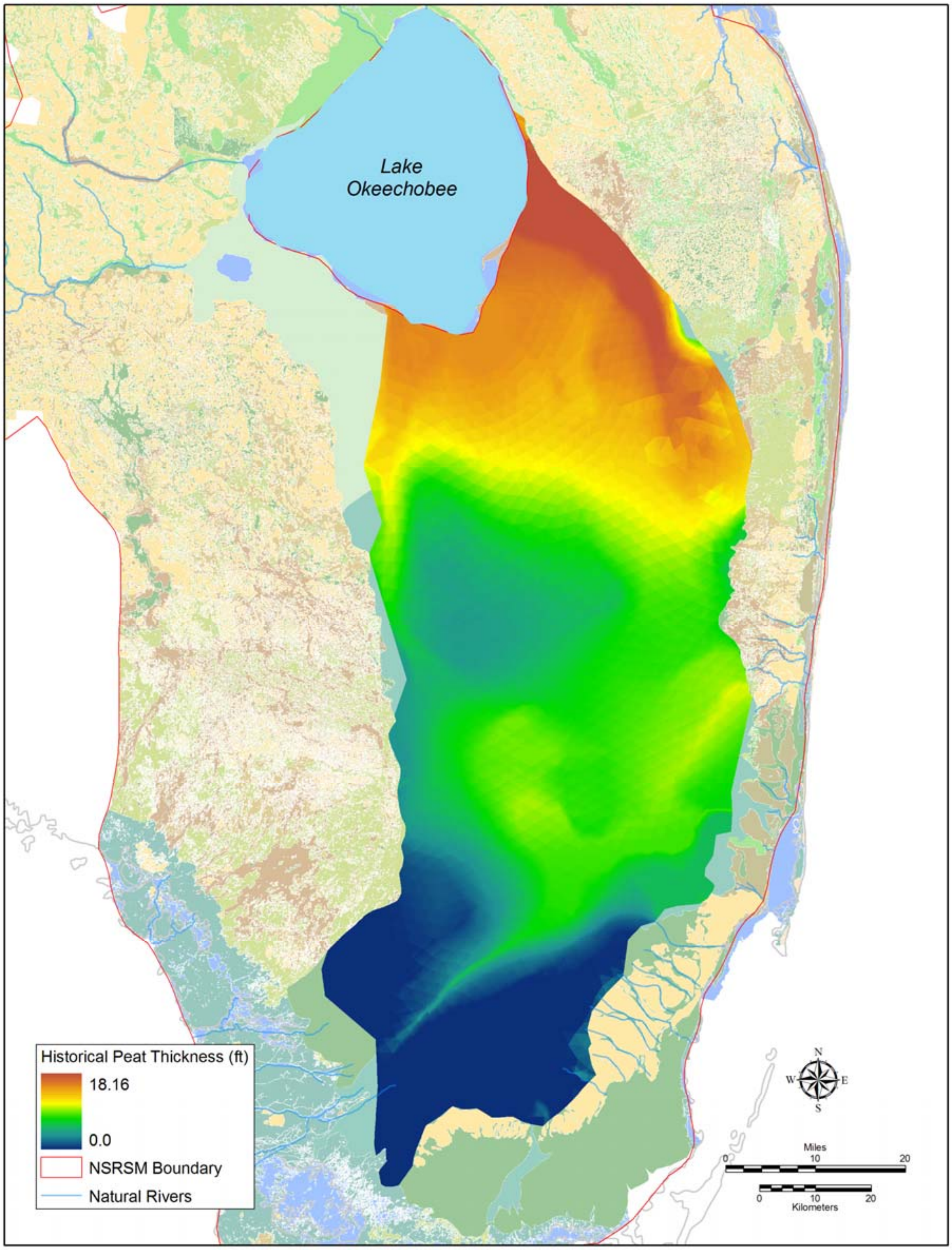


Figure 15. Estimated predrainage peat layer thickness.

The peat soil layer (3 ft.) and a vertical distribution of the slough, ridge, and tree island landscape (3.5 ft.) are used to develop a stage-volume relationship for microtopography and subsurface (6.5 ft.). The stage-volume relationship is normalized to the base of the peat soil layer. The volume available for water storage in the subsurface is computed using the porosity and the thickness of the peat soil layer. A porosity value of 0.90 is used for the peat soil layer (Harvey *et al*., 2004). The resultant table of normalized stage-storage volume is shown in **Table 11**.

Table 11. Volume of water (depth) available for storage in Ridge and Slough landscape.

Normalized Elevation (ft.)	Depth (ft.)	Component
0.00	0.000	Peat soil
0.50	0.450	Peat soil
1.00	0.900	Peat soil
1.50	1.350	Peat soil
2.00	1.800	Peat soil
2.50	2.250	Peat soil
3.00	2.700	Ridge/ Tree Island
3.50	3.174	Ridge/ Tree Island
4.00	3.649	Ridge/ Tree Island
4.50	4.124	Tree Island
5.00	4.620	Tree Island
5.50	5.116	Tree Island
6.00	5.611	Tree Island
6.50	6.107	Tree Island

This methodology, also assuming a peat thickness of three feet, was also used to create a stage-volume relationship for the Sawgrass Plains landscape with the assumption that it was a uniform, flat landscape (100% ridge).

LAKES

Lake Okeechobee inflows and outflows are simulated with the RSM lake module using the conservation of mass equation to calculate storage. All lakes require a stage-area and stage-volume relationship in order to compute storage. Overbank and river inflow/outflow are connected to Lake Okeechobee using watermovers. These watermovers allow water to move freely between cells or river segments and the lake. Rainfall and evapotranspiration time series are provided as data input to the lake module.

Two additional waterbodies simulated in the NSRSM are Lake Istokpoga and the St. Lucie Estuary. Lake Istokpoga is connected to cells using watermovers that overflow to the Indian Prairie (**Figure 16)**. The lake is connected to Istokpoga Creek using a watermover. Rainfall and evapotranspiration are simulated using input data files. This lake has an inflow boundary condition that was developed using an external model, described in **Appendix H**. The inflow boundary condition represents inflow from other streams and groundwater sources not simulated by the NSRSM.

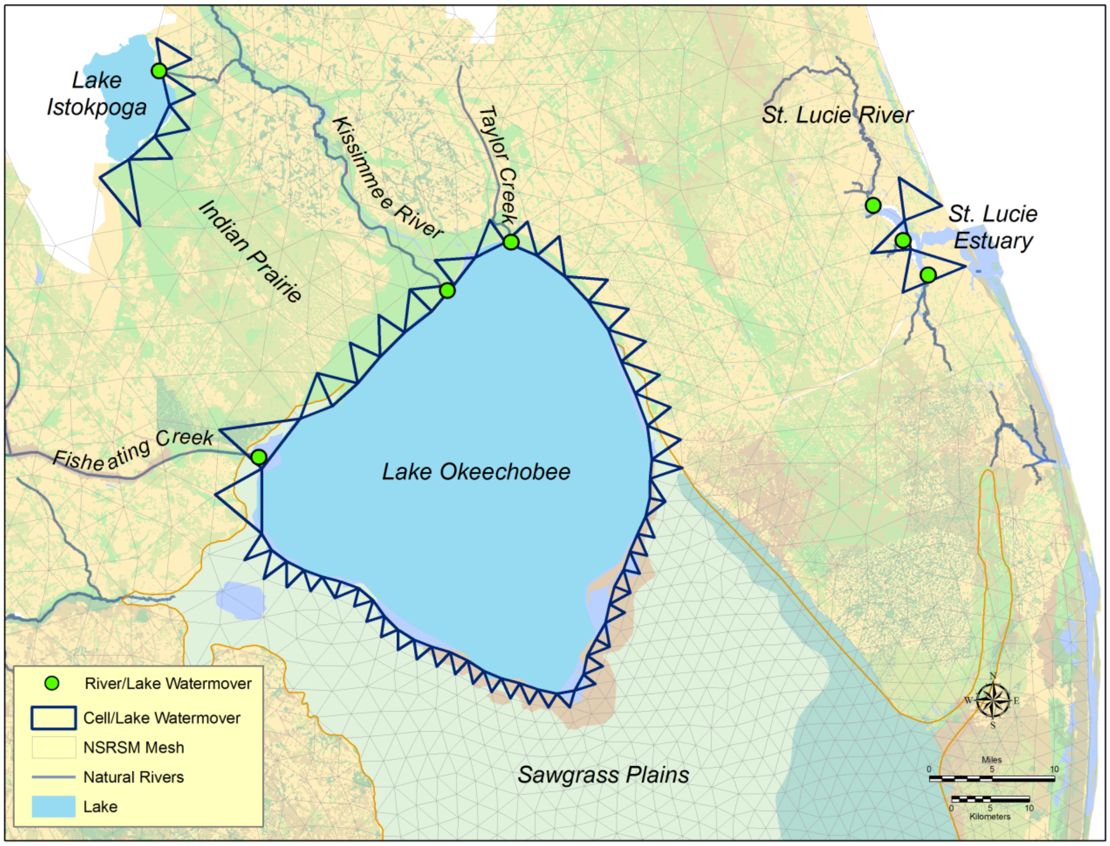


Figure 16. NSRSM lakes.

The St. Lucie Estuary is connected to cells using watermovers that provide inflow/outflow (**Figure 16**). The estuary is connected to the north and south forks of the St. Lucie River and Bessie Creek using a watermover. Rainfall and evapotranspiration are simulated using input data files. Utilizing these features of the RSM allows for a reasonable implementation of Lake Okeechobee, Lake Istokpoga, and the St. Lucie Estuary.

NATURAL SYSTEM RIVERS

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 Canal to the Miami River. Southeastern river dimensions were estimated from several sources (**Appendix F**); General Land Office (GLO) surveys conducted in the late 1800s and early 1900s (**USDOI, GLO survey data**), State of Florida's Everglades Drainage District (EDD) maps, Central and Southern Florida state maps, and historical observations (**McVoy, 2000**). Southwest coastal rivers discharged waters collected from Big Cypress and Everglades basins into the Gulf of Mexico. These rivers extend north to south from the Huston River to the Shark River (Figure 17). Unlike the east coast rivers, these channels were not significantly altered due to drainage improvements. Dimensions were assigned based on early U.S Geodetic Survey data and current aerial photography (**Appendix F**).

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 River, Fisheating Creek, Kissimmee River, Taylor Creek, St. Lucie River and Loxahatchee River, is described in **Appendix F**.

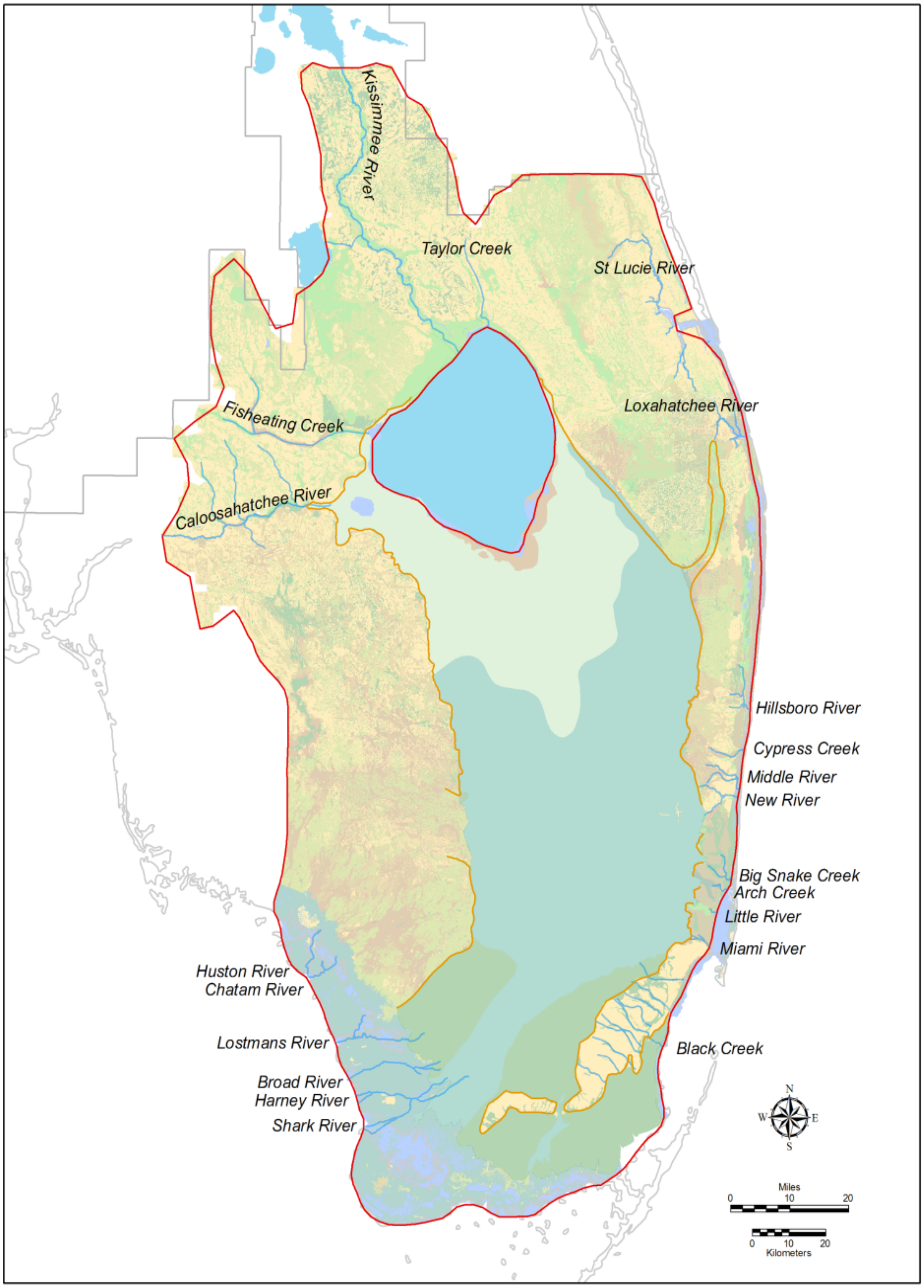


Figure 17. Rivers represented in the NSRSM.

BOUNDARY CONDITIONS

Water levels in the NSRSM domain fluctuate in response to forcing functions including transient boundary conditions, which are imposed on certain cells, river segments, or lakes. 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. In summary, model boundaries are assigned to approximate the actual flow system as accurately as possible.

Overland Flow Boundaries

The limits of the overland flow systems are based on watershed boundaries, physiographic boundaries, and coastline (**Figure 18**). The overland flow boundary conditions of the NSRSM use no-flow, time-varying specified head (tidal), and lake boundary conditions.

No-flow boundary conditions are used in five locations: (1) the Lake Wales Ridge, (2) the lower Kissimmee Basin, (3) the northern boundary of the St. Lucie Basin, (4) along the Atlantic Coastal Ridge, and (5) the western boundary of the Big Cypress Basin including the Caloosahatchee Basin.

A no-flow boundary condition was used along the east coast from the St. Lucie Basin to Biscayne Bay that follows the centerline of the Atlantic Coastal Ridge. The model domain does not include the Intracoastal Waterway.

The NSRSM's western no-flow boundary in Big Cypress Basin coincides with historical military routes from 1856 (**Figure 19**). These routes were typically along topographic highs which were not inundated for most of the year. This boundary intersects a network of military roads and paths. The map was registered as close as possible; however, due to the map making techniques or survey errors introduced at the time of publication an exact overlay is not possible.

The lake seepage boundary condition was used for Lake Istokpoga, Lake Okeechobee and the St. Lucie Estuary (**Figure 18**). This type of boundary condition allows water to flow from the lake into the overland and groundwater component of the mesh cell and vice versa.

Time-varying specified head or tidal boundary conditions are assigned to mesh cells adjacent to the coastline along Florida Bay and Ten Thousand Islands (**Figure 18**). Predicted tide data from the National Oceanic and Atmospheric Administration/ National Ocean Service (NOAA/NOS) were selected to create the tidal dataset for the NSRSM. NSRSM's tidal boundary conditions are a significant improvement when compared to the "repeating annual cycle" used by the NSM. **Appendix G** describes the process for creating the tidal datasets.

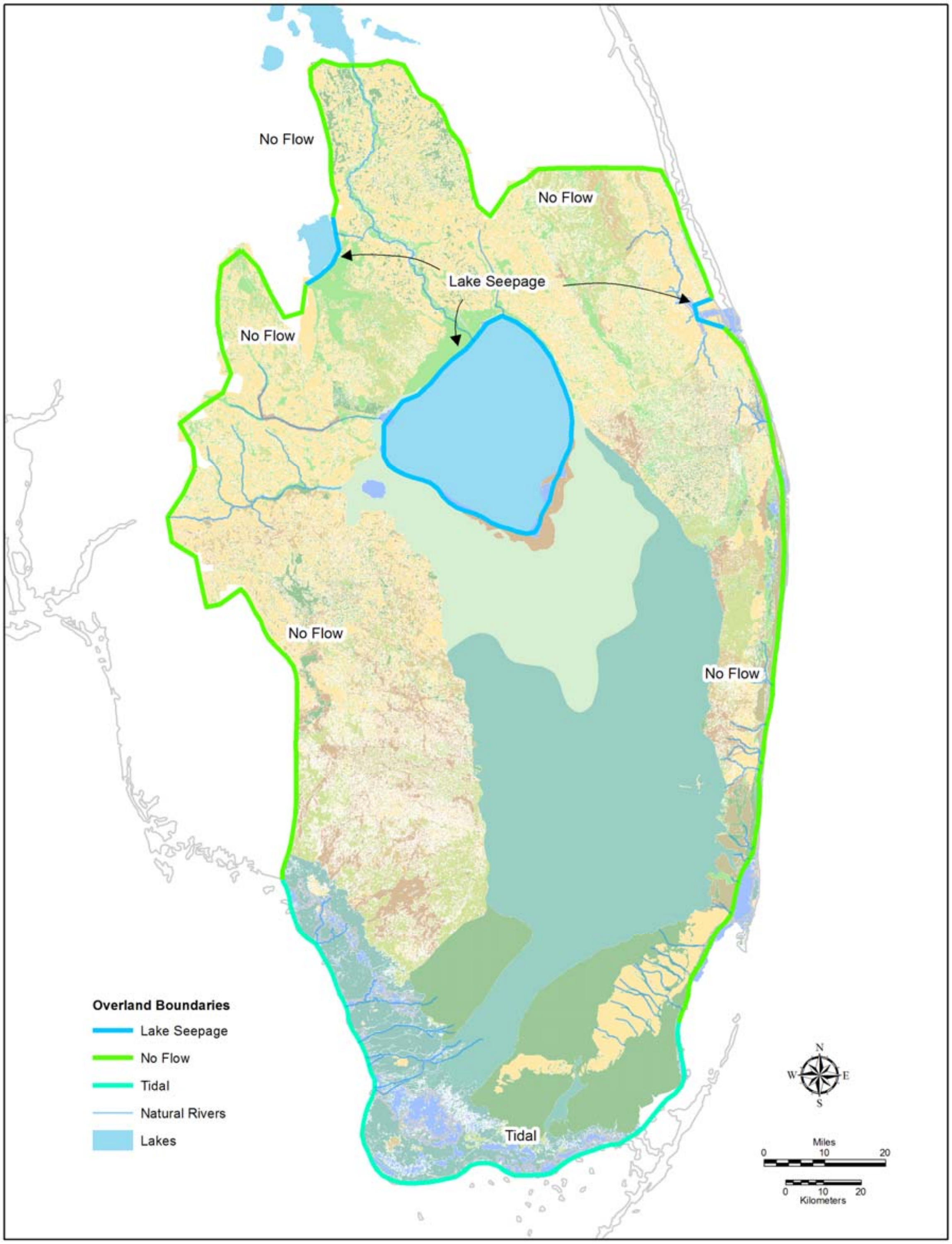


Figure 18. Overland flow boundary conditions for the NSRSM.

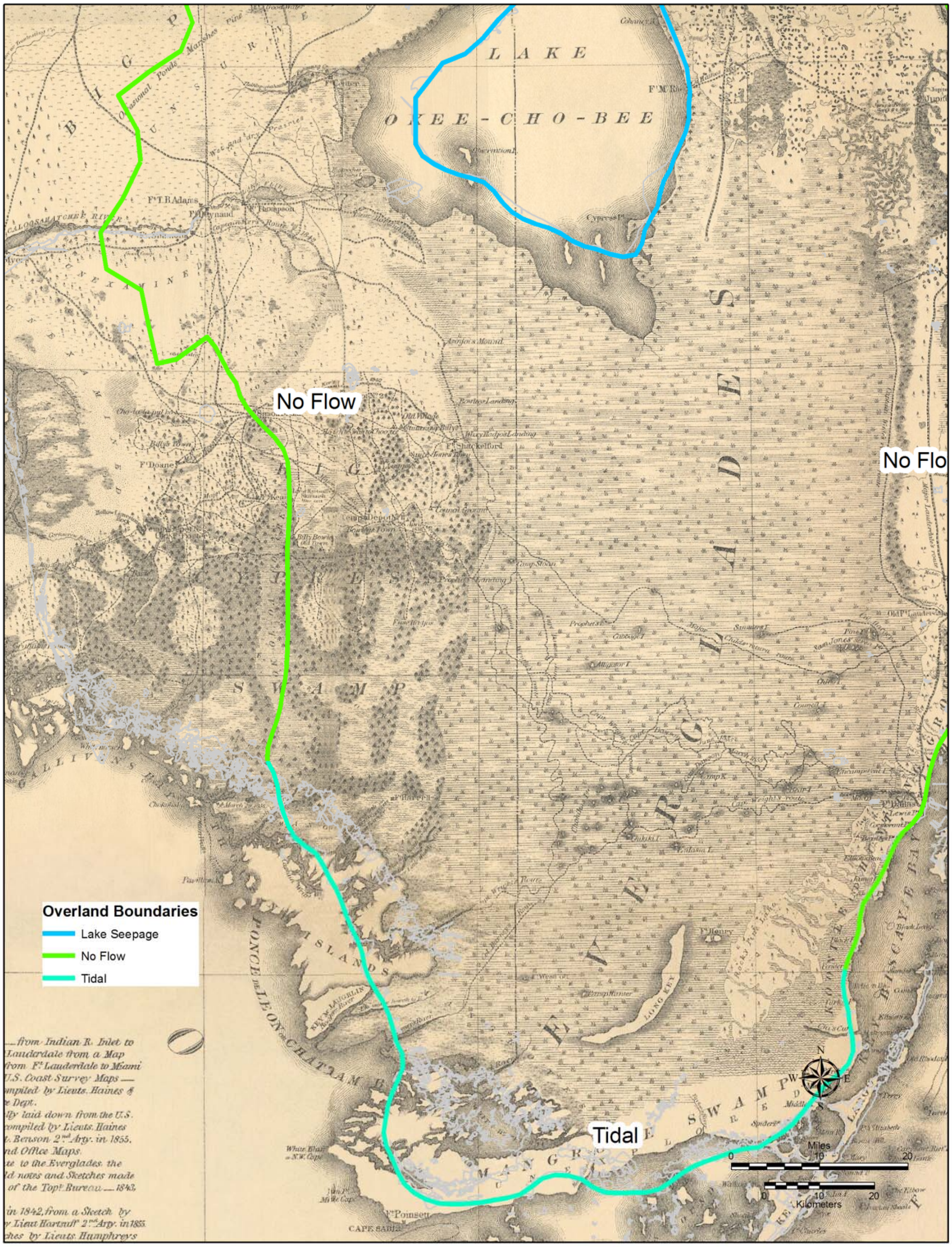


Figure 19. NSRSM western no-flow boundary overlain with Military Map (Ives, 1856).

A no flow boundary condition was used as an overland and groundwater boundary condition for the western boundary of the Caloosahatchee Basin (**Figure 19**). A no flow head boundary for overland and groundwater was implemented along the northwestern boundary of the Caloosahatchee Basin.

Groundwater Flow Boundaries

The groundwater boundary conditions of the NSRSM use time-varying specified head (tidal), no-flow, prescribed head, and lake seepage boundary conditions (Figure 20). The time-varying specified head or tidal boundary conditions are assigned to model cells adjacent to the coastline. The no-flow boundary condition was used along the western boundary of Big Cypress Basin and the Caloosahatchee Basin. No-flow boundaries were determined using a USGS groundwater level map (USGS, 1990) shown in **Figure 21**. Prescribed head boundary conditions are used along the boundary of the Indian Prairie Basin, lower Kissimmee Basin, and the St. Lucie Basin. The lake seepage boundary conditions are the same as described in the previous section for overland flow boundary conditions.

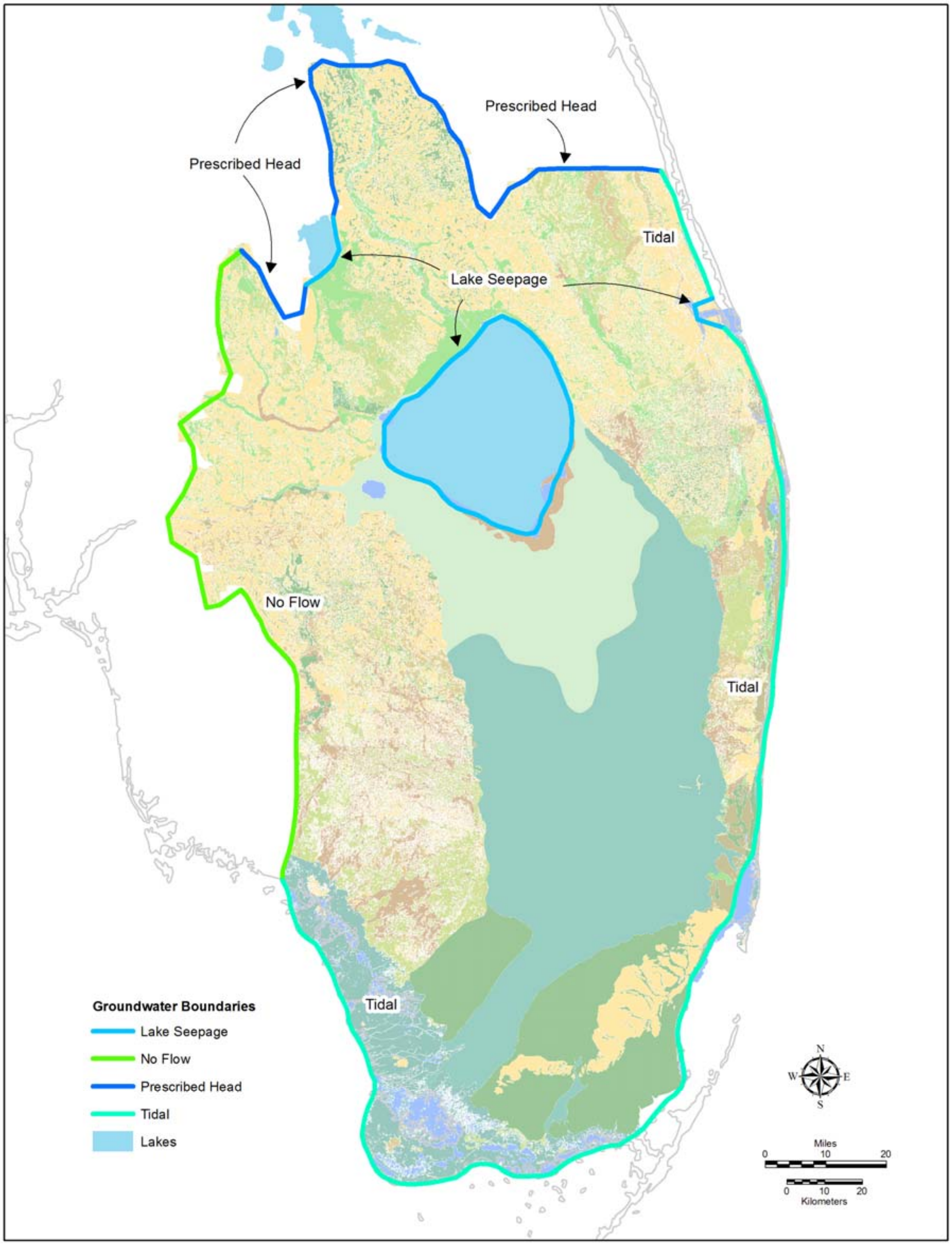


Figure 20. Groundwater flow boundary conditions for the NSRSM.

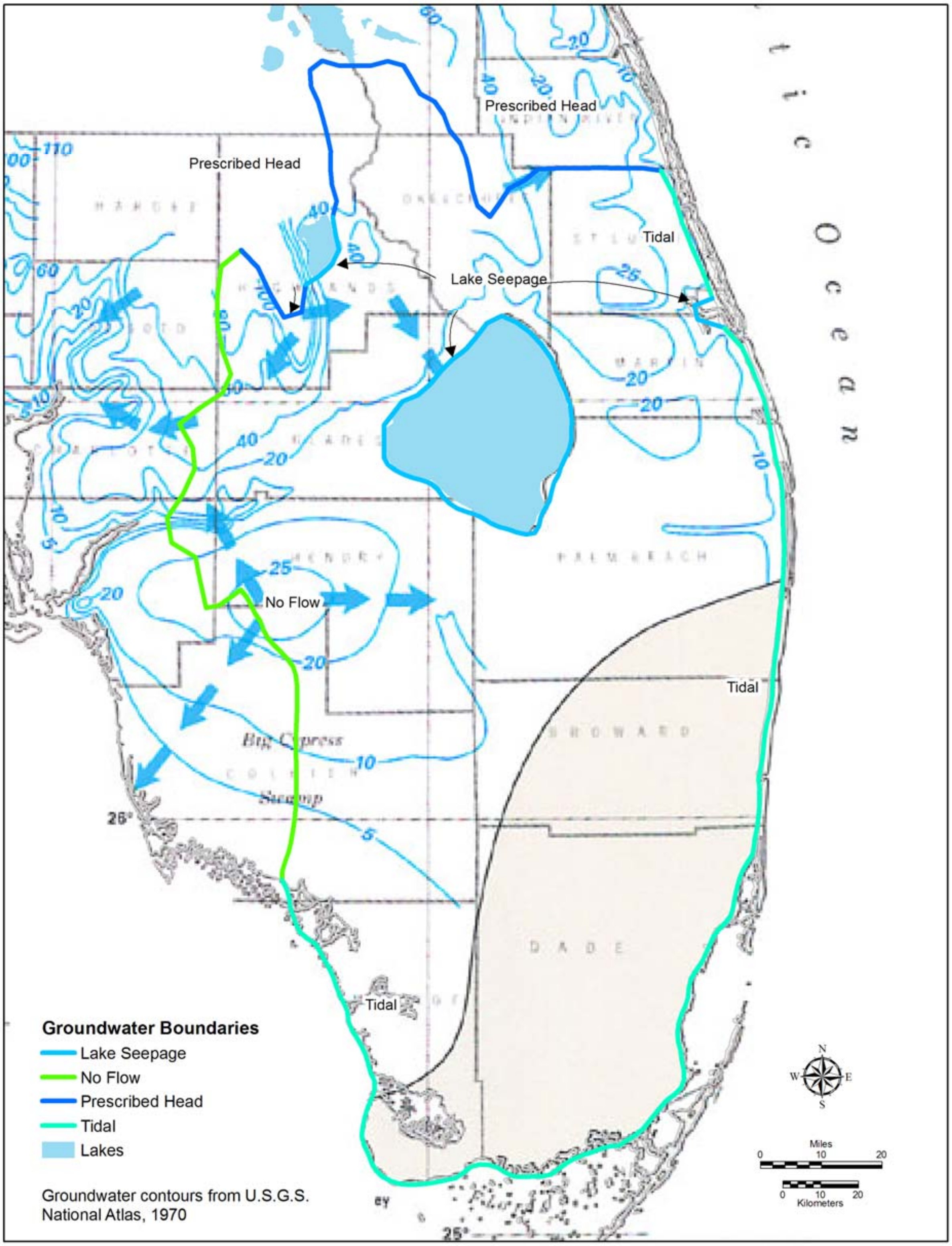


Figure 21. The USGS groundwater level map overlain with NSRSM boundary conditions.

Prescribed head boundary conditions were used in the western Indian Prairie, Lake Wales Ridge, Kissimmee Basin and northern St. Lucie Basin. The boundary condition for western Indian Prairie is described in the previous section. In the Lower Kissimmee Basin and the Lake Wales Ridge areas, USGS groundwater models (Yobbi, 1996) and District models (SFWMD, 2000) use prescribed head boundaries. No monitor wells with long-term observations were found in the Lake Wales Ridge area. The USGS estimates the water level to be at depths five ft. or more in the ridge areas (Yobbi, 1996). Therefore, the assumption decision was made to implement a prescribed head boundary condition 5.0 ft. below land surface. For the Lower Kissimmee Basin, the USGS Ground Water Atlas (USGS, 1990) states that the groundwater level in the surficial aquifer system follows that of the surface elevations. Historical water level data were obtained from DBHydro, the District's hydrometeorologic, water quality, and hydrogeologic data retrieval system, at five locations shown in **Figure 22** (DBHydro). The data from each well exhibit uniform water level elevations as shown in **Figure 23**. The average water level depths for all wells were determined to be about 2.2 ft. below land surface; therefore, the model cells bordering the lower Kissimmee and northern St. Lucie Basin were assigned a prescribed head value of 1.2 ft. below land surface in order to account for development stresses.

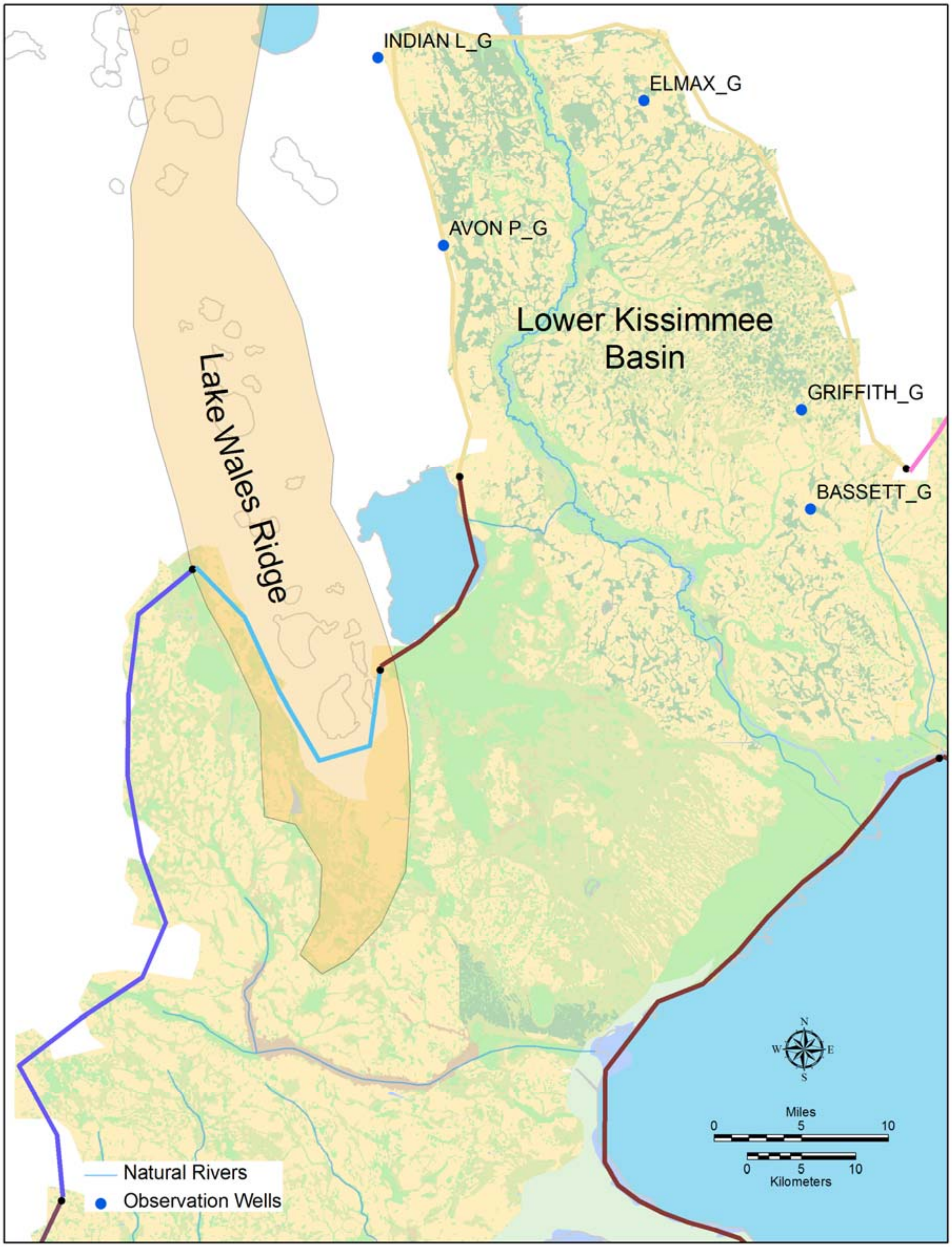


Figure 22. Locations and names of observation wells in the surficial aquifer system for defining prescribed head boundary conditions.

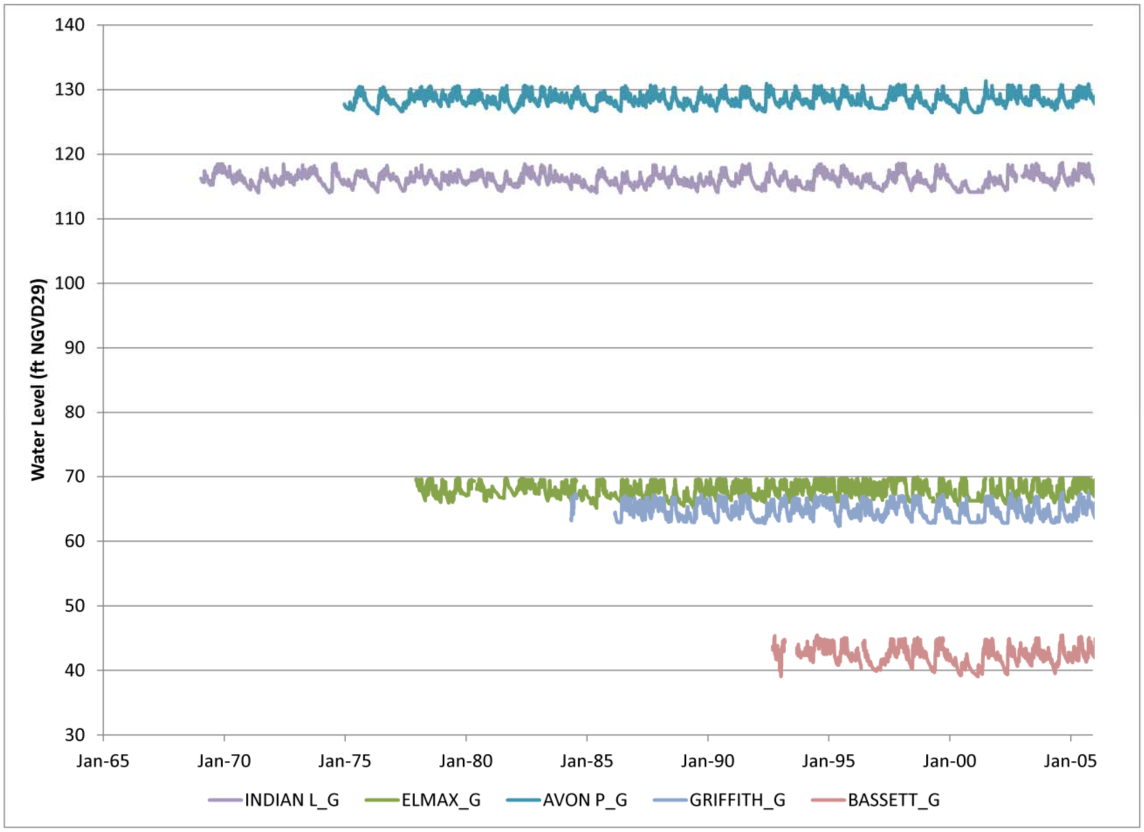


Figure 23. Groundwater levels in Lower Kissimmee valley.

River Boundaries

River boundary conditions of the NSRSM use the following types: time-varying specified head (tidal), time-varying specified flow, no-flow, river segment to lake, and river segment to cell. The time-varying specified flow boundary condition uses the same equation as described in the previous section, except that flow is used instead of head.

The river segment to the lake-boundary connection is a direct connection that transfers water from the river segment to the lake. The movement of water from the river segment to the lake occurs when the stage of the river reaches a user-specified stage. The cell to river segment is a direct connection that moves water from the cell to the river segment when the water level of the cell reaches a target water level. A target water level is defined as the topographic elevation of the model cell.

The upstream boundary condition for the Caloosahatchee River and its tributaries uses a direct cell to river segment connection, because it is the most applicable boundary condition that describes the transition from overland flow to river flow. A time-varying specified head boundary condition is used downstream.

Fisheating Creek uses a direct cell to river segment connection for its upstream boundary conditions. A river segment to a lake boundary is used for the downstream boundary condition (**Figure 24**).

Daily inflow into Lake Istokpoga is defined using a time-varying specified flow boundary condition. These flows represent the natural inflow which would have occurred under predrainage conditions. The rainfall-runoff relationship in the upper Lake Istokpoga and Fisheating Creek watersheds is assumed to be comparable to predrainage conditions, and natural inflows from these watersheds are approximated by observed flows at Arbuckle Creek and Josephine Creek into Lake lstokpoga and Fisheating Creek. Outflows from Lake Istokpoga occur as overland flow using the lake to cell connections and through Istokpoga Creek using a lake to river segment connection.

The upstream boundary condition for the Kissimmee River is also estimated using a rainfall-runoff relationship. Natural inflow from the Kissimmee River Watershed is estimated using the Sealink model developed by the SFWMD (**Appendix G**).

Taylor Creek uses a direct cell to river segment connection as its upstream boundary. A river segment to a lake boundary condition is used for the downstream boundary. **Figure 25** shows the locations of boundary conditions for Lake Istokpoga, Istokpoga Creek, Kissimmee River, and Taylor Creek.

The St. Lucie Estuary uses a cell to river segment connection for the upstream boundary for its tributaries (**Figure 26**). The downstream boundary condition is a river segment to lake connection. The outflow of the St. Lucie Estuary uses a time-varying specified head or tidal boundary condition.

The Jupiter River uses a cell to river segment connection for the upstream boundary for its tributaries. The downstream boundary condition is a time-varying specified head or tidal boundary condition. **Figure 26** shows the spatial location of boundary conditions for the St. Lucie Estuary and its tributaries and the Jupiter River.

The Lower East Coast rivers use the cell to river segment connection for the upstream boundary conditions. The downstream boundary condition is a time-varying specified head or tidal boundary condition. **Figure 27** shows the spatial location of boundary conditions for the Lower East Coast rivers.

The transverse glades use the cell to river segment connection for the upstream and downstream boundary conditions. For Black Creek, the downstream boundary condition is a time-varying specified head or tidal boundary condition. **Figure 28** shows the spatial location of boundary conditions of the transverse glades and Black Creek.

The Lower West Coast rivers use the cell to river segment connection for the upstream boundary conditions. The downstream boundary condition is a time-varying specified head or tidal boundary condition. **Figure 29** shows the spatial location of boundary conditions of the Lower West Coast rivers.

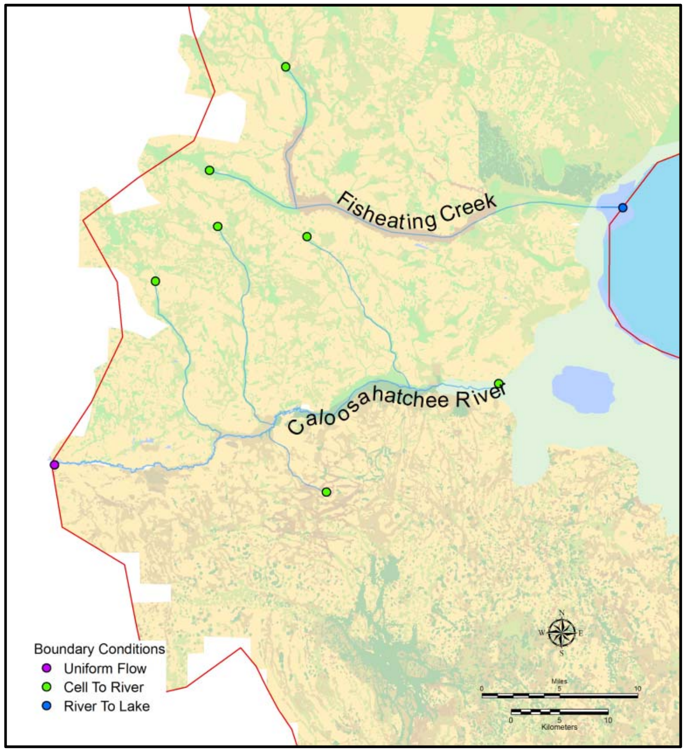


Figure 24. Caloosahatchee River and Fisheating Creek boundary conditions.

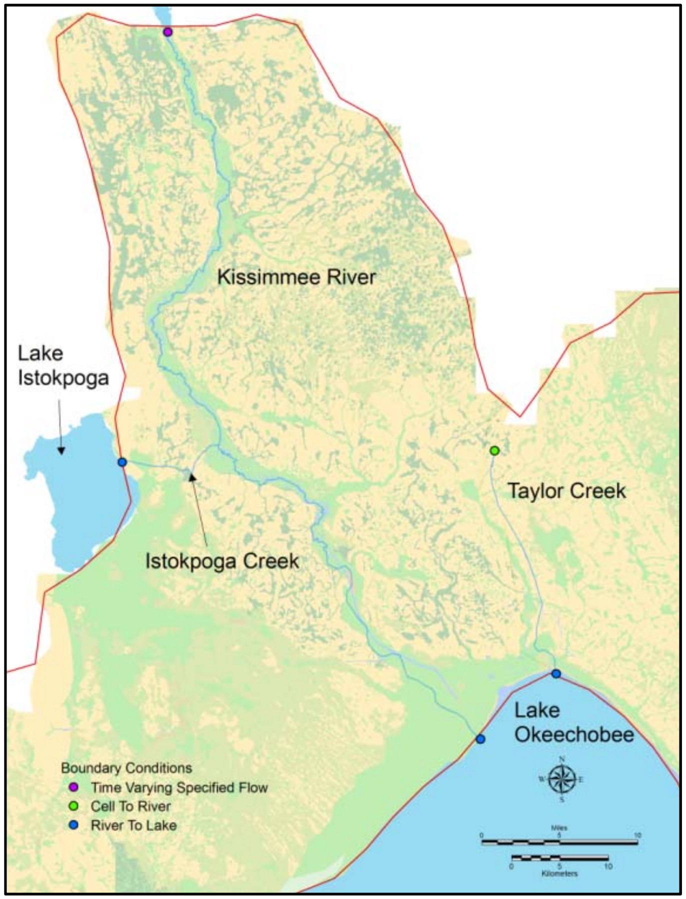


Figure 25. Istokpoga Creek, Kissimmee River, and Taylor Creek boundary conditions.

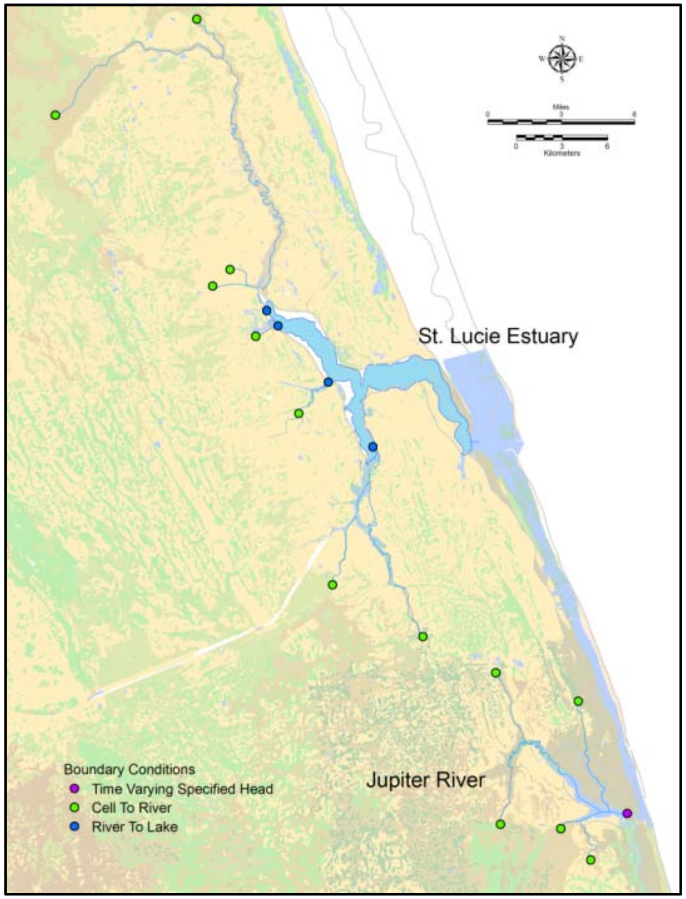


Figure 26. St. Lucie Estuary and Jupiter River boundary conditions.

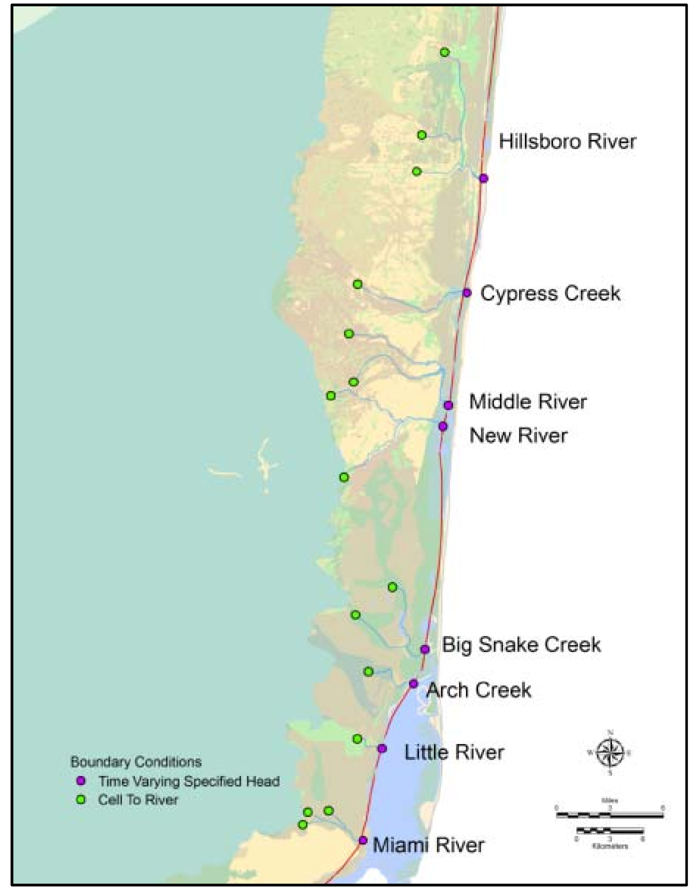


Figure 27. Lower East Coast rivers boundary conditions.

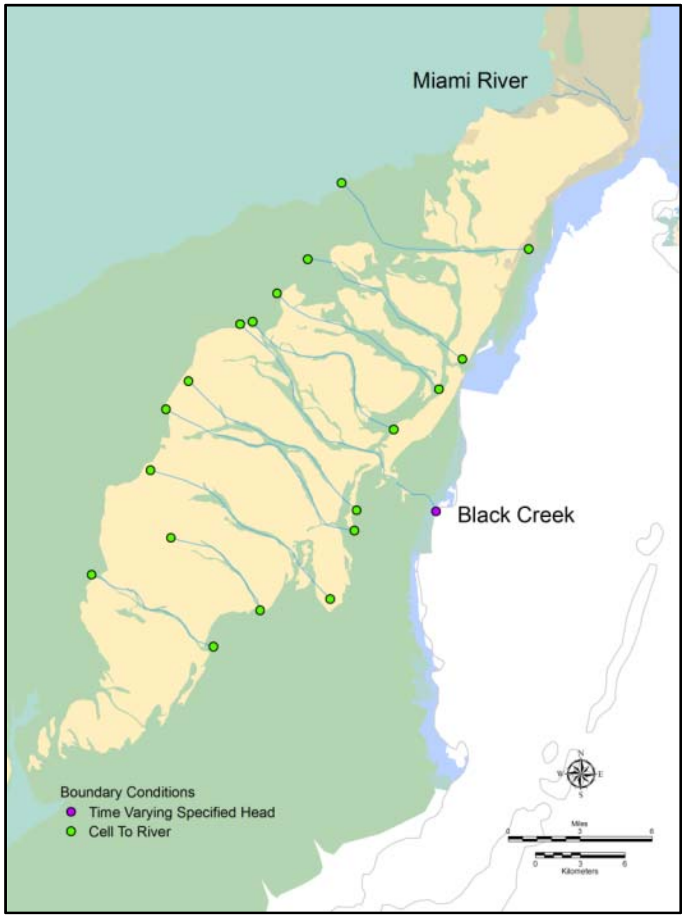


Figure 28. Transverse Glades and Black Creek boundary conditions.

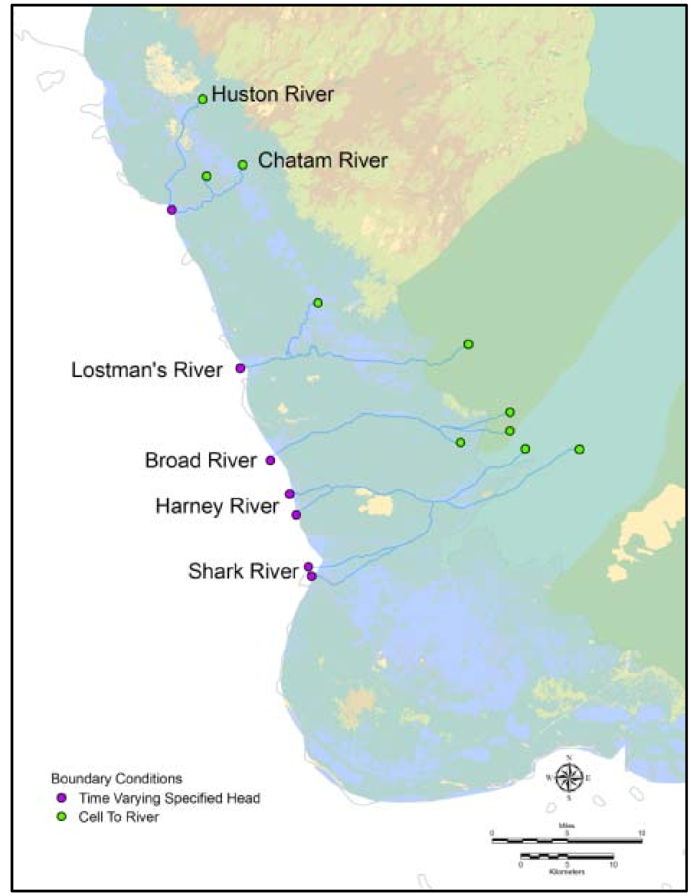


Figure 29. Lower West Coast rivers boundary conditions.

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 in/yr north of Lake Okeechobee, to more than 62 in/yr over parts of the Atlantic Coastal Ridge for the NSRSM base condition (1965-2005).

The NSRSM base condition uses a rainfall database developed for SFWMD Regional Modeling. 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 (1965–2005). The general procedure for the development of the rainfall dataset used in the NSRSM can be described as follows: data collection, quality screening of rainfall station data, and transformation of rainfall point data into a format compatible with the NSRSM. Details of the rainfall dataset development are available in **Appendix C**. It is important to note that the NSRSM uses current climatic input with a landscape mosaic from the 1850's.

The NSRSM base condition was implemented as the simulation period of record (1965-2005) for comparative purposes with the SFWMM and other models as well as data availability. The PRISM Climate Group of Oregon State University has monthly precipitation products dating to 1895. Based on this historical data, a long-term (1895-1935) average annual rainfall shows a shift in rainfall, concentrating more rainfall in the Everglades, possible due to anthropogenic changes (PRISM, 2006). A comparison of 1895-1935 PRISM dataset and 1965-2005 NSRSM base condition dataset are shown in **Figure 30**. In order to determine the impact of the rainfall pattern, historical rainfall and evapotranspiration (ET) patterns were investigated in a sensitivity run.

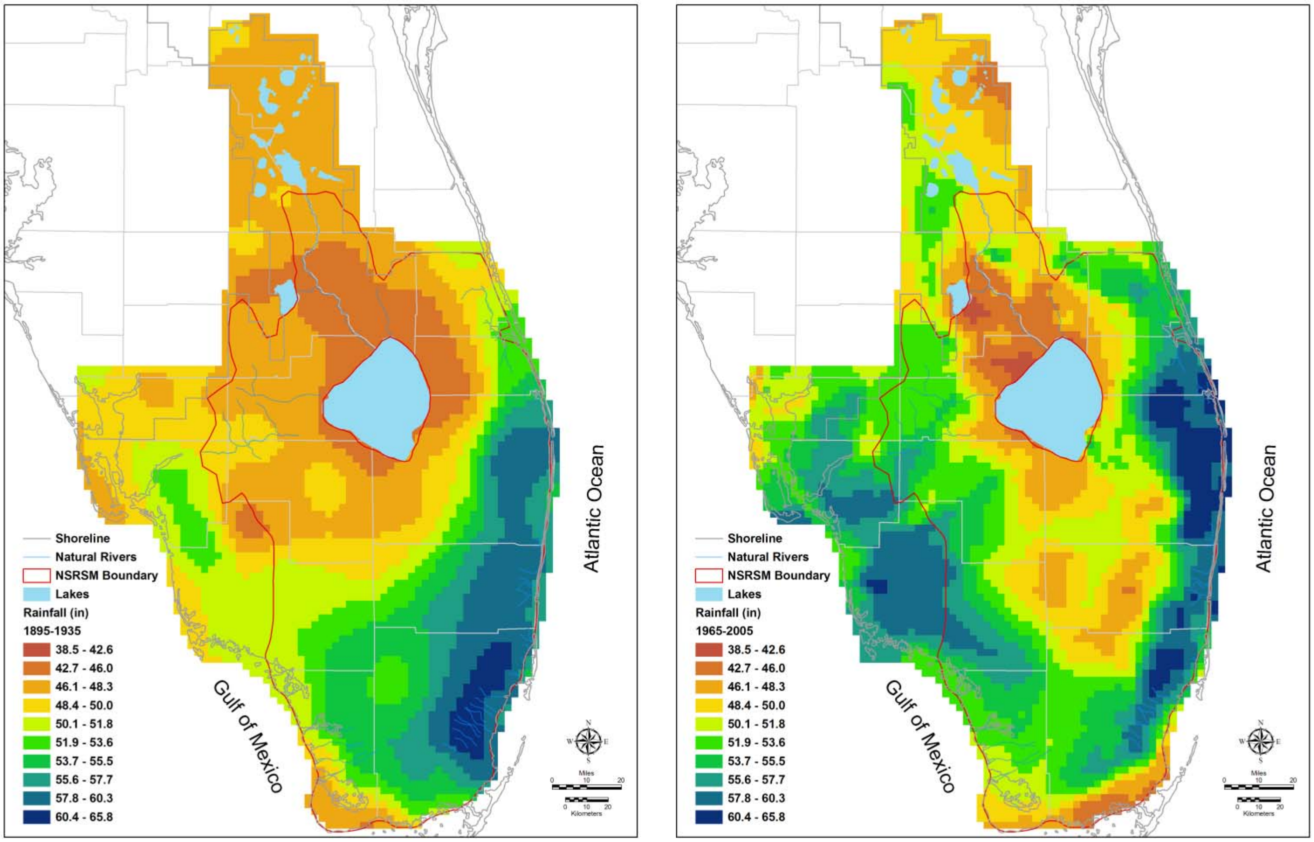


Figure 30. Long-term average annual rainfall (in/yr) for 1895-1935 (left) and 1965–2005 (right).

REFERENCE EVAPOTRANSPIRATION

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 ET in the NSRSM is based on reference potential ET (ETp), which is adjusted according to vegetation 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 31**.

Computed ET (ETc) is calculated as that remaining after evaporation from interception storage multiplied by an ETp correction coefficient (Kc). The value of Kc depends on the location of the water table relative to the ponding depth, land surface (Z), rooting depth (Rd) and ET extinction depth (Xd). The reference vegetation ETp correction coefficient for a specified landuse type (Kveg) and the ETp correction coefficient for a ponded condition (Kw) are discussed in the Local Surface Hydrology section of this report. For Lake Okeechobee and Lake Istokpoga, evapotranspiration depends on the surface area of the lake and the depth of the water in addition to the assigned ET coefficients. The method for calculating ET from lakes is addressed in the Lakes section of this report. Development of a regional reference ET for hydrologic modeling in south Florida is documented in **Appendix D**.

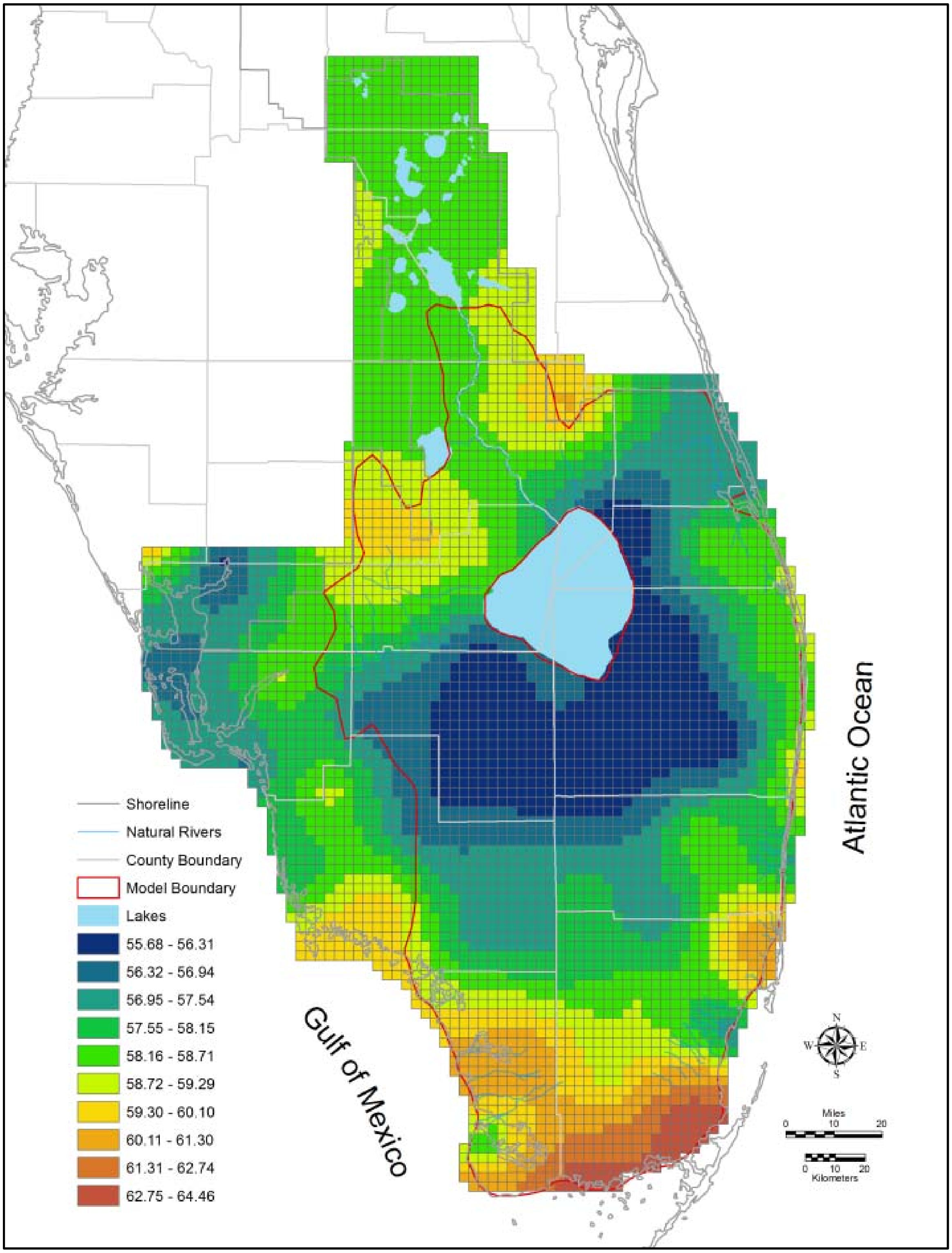


Figure 31. Long-term (1965–2005) average annual reference ET (in/yr).

INITIAL CONDITIONS

The NSRSM initial conditions represent an average aquifer head, river and lake stage for January 1, 1965 and are implemented in a two step process:

1. A rainfall analysis identifies a similar antecedent condition. The 1974 year represents the closest annual total rainfall when compared to the antecedent year 1964. December 1974 has the closest monthly rainfall when compared to the antecedent month December 1964, as shown in **Table 12**.

2. The NSRSM was executed from January 1, 1965 to December 31, 1974 using the following initial conditions: a) the aquifer head was equal to the topographic elevation, b) the stage in all rivers was initialized to 5.0 ft. above the bottom elevation of the river bed, and c) stages in Lake Okeechobee, Lake Istokpoga and the St. Lucie Estuary were estimated from annual averages. Once the execution was complete, the resultant aquifer head, river and lake stages from December 31, 1974 were used for initial conditions.

Table 12. Rainfall data used to determine antecedent conditions in the NSRSM.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1964	2.159	3.154	1.727	2.786	3.387	7.382	6.067	8.092	6.230	5.289	1.098	1.700	49.071
1965	0.817	3.508	2.279	1.559	1.244	8.179	8.470	6.320	6.576	7.476	0.978	1.166	48.571
1966	4.223	3.092	1.147	2.621	4.859	12.807	7.228	6.913	7.071	4.368	0.493	0.800	55.623
1967	1.531	2.831	1.156	0.133	1.463	11.374	6.985	6.888	6.917	4.948	0.931	2.174	47.332
1968	0.741	2.422	1.106	0.602	9.111	14.769	7.855	6.136	7.204	6.518	2.200	0.249	58.914
1969	2.330	1.817	4.735	2.111	5.368	10.933	6.316	7.702	7.394	9.472	2.123	2.387	62.687
1970	3.640	2.589	9.726	0.300	5.634	7.235	7.088	5.422	6.010	3.927	0.267	0.406	52.242
1971	0.610	2.055	0.794	0.496	4.307	7.884	6.982	7.469	7.972	6.225	1.968	1.618	48.381
1972	1.233	3.049	3.151	2.903	5.828	9.194	5.454	6.694	3.658	2.225	4.052	1.809	49.249
1973	3.447	2.155	3.138	1.588	2.819	7.629	9.685	9.024	7.299	2.826	0.796	2.280	52.687
1974	1.265	0.680	0.712	1.144	4.110	12.647	10.026	7.465	5.854	1.622	2.020	1.529	49.073
1975	0.496	1.305	1.041	1.334	7.262	7.698	8.133	5.731	8.907	3.856	0.865	0.558	47.184
1976	0.533	2.106	1.110	1.998	9.529	8.650	5.491	7.937	7.348	1.813	2.180	2.160	50.855
1977	2.879	1.158	0.593	0.786	5.470	6.792	6.606	7.533	8.825	1.434	3.407	3.613	49.096
1978	2.627	3.075	3.193	1.738	4.828	8.326	8.814	6.377	5.374	3.564	2.042	3.753	53.710
1979	4.717	0.904	1.519	3.785	7.115	3.780	5.556	7.361	12.383	2.375	2.268	2.742	54.505
1980	2.985	1.824	2.263	4.063	4.399	3.982	6.788	6.681	4.909	1.985	3.923	0.986	44.785
1981	0.564	2.976	1.336	0.181	2.946	6.126	5.824	12.370	6.499	1.578	1.971	0.573	42.944
1982	0.911	2.074	5.423	4.488	7.375	12.708	7.318	6.464	7.611	3.654	2.819	1.009	61.854
1983	4.746	8.762	5.072	2.221	1.641	10.047	5.543	7.319	7.498	5.600	2.103	4.190	64.742
1984	0.644	2.680	4.126	2.283	6.724	5.103	8.217	5.211	6.529	1.197	3.108	0.426	46.248
1985	0.683	0.419	2.229	3.175	2.915	6.337	9.617	6.354	7.617	3.748	1.806	1.791	46.688
1986	2.657	1.378	4.878	0.543	2.323	11.869	5.941	7.705	4.291	4.319	1.638	4.129	51.672

1987	1.922	1.727	6.560	0.444	3.776	5.324	5.818	4.619	7.416	4.752	7.005	0.752	50.114
1988	2.340	1.920	3.044	1.580	3.444	6.241	8.803	9.692	3.355	1.305	3.124	0.845	45.694
1989	1.472	0.407	2.501	3.451	1.986	6.360	6.626	7.075	6.167	3.214	1.131	2.218	42.607
1990	0.795	2.390	1.468	2.148	4.486	6.091	7.154	8.484	5.028	3.425	0.861	0.669	43.001
1991	5.384	1.918	2.922	4.352	7.100	8.061	9.081	6.450	5.327	4.870	1.587	0.631	57.683
1992	1.542	3.436	2.150	3.495	1.229	15.720	4.030	9.779	5.504	1.887	3.989	0.633	53.394
1993	6.303	2.294	4.164	2.810	3.591	5.507	6.114	6.233	6.402	6.530	1.247	0.867	52.062
1994	3.298	3.158	2.259	3.771	3.394	8.210	6.471	7.866	9.895	4.978	5.814	5.271	64.386
1995	3.009	1.923	2.286	3.230	3.114	10.996	8.922	11.631	7.274	10.344	0.928	0.773	64.431
1996	2.396	0.794	4.679	1.933	7.005	9.458	4.223	6.690	4.966	6.016	0.866	1.172	50.199
1997	1.943	1.531	2.512	5.171	4.222	9.117	7.397	7.240	7.364	1.413	4.033	6.359	58.303
1998	2.903	6.307	5.394	1.131	2.801	3.322	7.326	7.898	9.320	2.260	6.116	1.239	56.015
1999	2.941	0.763	0.747	1.740	4.135	12.468	5.064	8.535	9.251	8.406	1.551	1.188	56.789
2000	1.112	0.620	1.912	3.150	1.414	6.187	7.340	5.647	7.143	4.173	0.569	0.959	40.225
2001	0.584	0.133	4.284	0.721	3.917	6.771	10.378	7.062	11.855	4.443	1.124	1.230	52.503
2002	1.280	2.697	0.972	1.558	3.106	11.577	7.445	6.620	5.817	2.042	3.164	4.662	50.940
2003	1.000	1.253	4.012	2.837	5.893	8.709	5.580	9.580	8.139	0.858	2.601	2.251	52.713
2004	2.316	2.927	0.483	2.249	1.419	5.938	7.092	9.653	9.975	2.154	0.716	1.166	46.087
2005	1.122	1.545	4.988	2.224	4.179	14.376	6.610	6.818	5.251	7.127	2.618	0.693	57.551

Chapter 5
Calibration

Subsequent to the peer review of NSRSM v2.0, improvements were made to the model that incorporated reviewer recommendations and improved input data for landsurface elevations. This version of the model (3.0) was then soft-calibrated using reference ranges from historical literature, resulting in the release of the NSRSM v3.5.2 base condition. The soft-calibration methodology, also called Tikhonov regularization, utilizes expert knowledge associated with ranges of preferred parameter values and the system response of the Everglades in order to derive calibrated model parameters.

This section presents model performance monitoring methodology and results for the NSRSM v3.5.2 base condition simulation. The base condition (1965–2005) period of record (POR) was selected for comparison to existing models and current availability of long-term datasets, (e.g., potential evapotranspiration). Results are compared to reference ranges developed from the best available estimates of predrainage hydrology (some of which are included in the appendices of this report). An evaluation of the degree to which model performance falls within the established reference ranges is provided as a starting point for discussion regarding the validity of the model as a representation of natural (predrainage) conditions.

Model output is evaluated at the landscape level using hydrologic performance measures including inundation duration (hydroperiod), seasonal water depth, and seasonal range of minimum and maximum water depths or amplitude. It is important to note that the NSRSM base simulation POR (1965–2005) has 25 years within the cool phase of the Atlantic Multidecadal Oscillation (AMO) resulting in below average rainfall for the years 1970-1994 (**Figure 32**). Because this climatic input was used for the base condition, model results are expected to fall within lower reference ranges values.

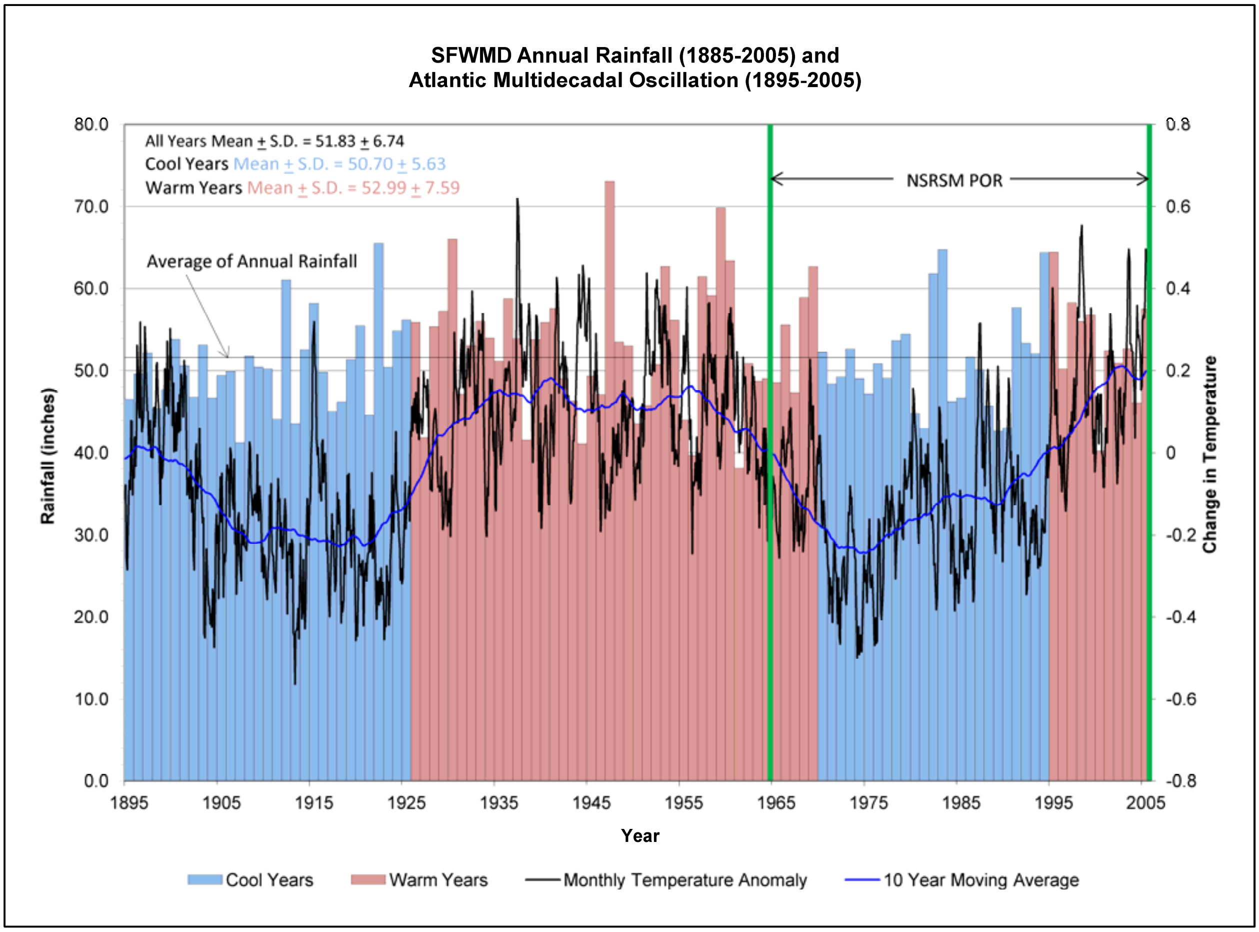


Figure 32. District rainfall (in) and Atlantic Multidecadal Oscillation (AMO) (1895-2005) with NSRSM period of record (POR) (1965-2005).

Studies pertaining to historical south Florida vegetation community composition and associated hydrologic requirements concluded that a significant amount of information is available to provide reference range estimates (McVoy *et al.,* 2011 and Fennema, 1994). Evaluation reference ranges represent the hydrologic conditions necessary for the sustainability of recorded predrainage vegetation communities existing at the time of the mid-1800 Government Land Office surveys (Zahina *et al.*, 2007), with the understanding that vegetation community composition is dynamic at multiple temporal scales due to hydrologic variables:

- **slow** - variable sea level rise
- **medium** - multidecadal climate oscillation
- **fast** - seasonal rainfall variability, hurricanes, severe droughts and fires (Gunderson, 1994)

Information relative to regional scale hydrologic performance (e.g. water budgets and overland flow rates/volumes across selected transects) is not available from the historical record due to technological limitations relating to data collection. It is assumed that model validation at the landscape level will translate systemically resulting in regional performance comparable (notwithstanding model and parameter uncertainty) to the best available estimates of south Florida predrainage hydrology.

PERFORMANCE MONITORING

Model performance monitoring sites within the NSRSM domain are displayed in **Figure 33.**

Zone monitors record hydroperiod, stage and evapotranspiration results. A monitoring zone is an aggregation of cells with homogeneous vegetation type and uniform landsurface elevations. Model output from these zones is used as an indicator of model performance for a specified landscape.

Junction monitors record flows at a point where two discretized river segments join (as opposed to natural river junctions).

Overland flow transects record surface flows for a linear transect. Transect locations were selected for comparison to existing models (i.e. SFWMM 2x2 and NSM 2x2).

RESULTS

In this section results are evaluated at the landscape level for the POR 1966–2005. The year 1965 is intentionally excluded to avoid start-up bias. Long-term average performance was used for comparison to reference ranges for model validation.

Regional system results are evaluated for long-term average annual and seasonal (wet/dry) performance (1966–2005). Surface water flows are calculated for selected transects and water budgets (Net Rainfall – ET, Inflows and Outflows) are presented for Lake Okeechobee and watershed basins. The watershed basins were selected for comparison to existing models.

A representative sample of performance results follows and was evaluated with respect to correspondence to reference ranges. A full suite of model results will be accessible in a performance viewer after uploading is finalized. Results showing stage, ponding depth, flow direction and inundation are in **Appendix K**.

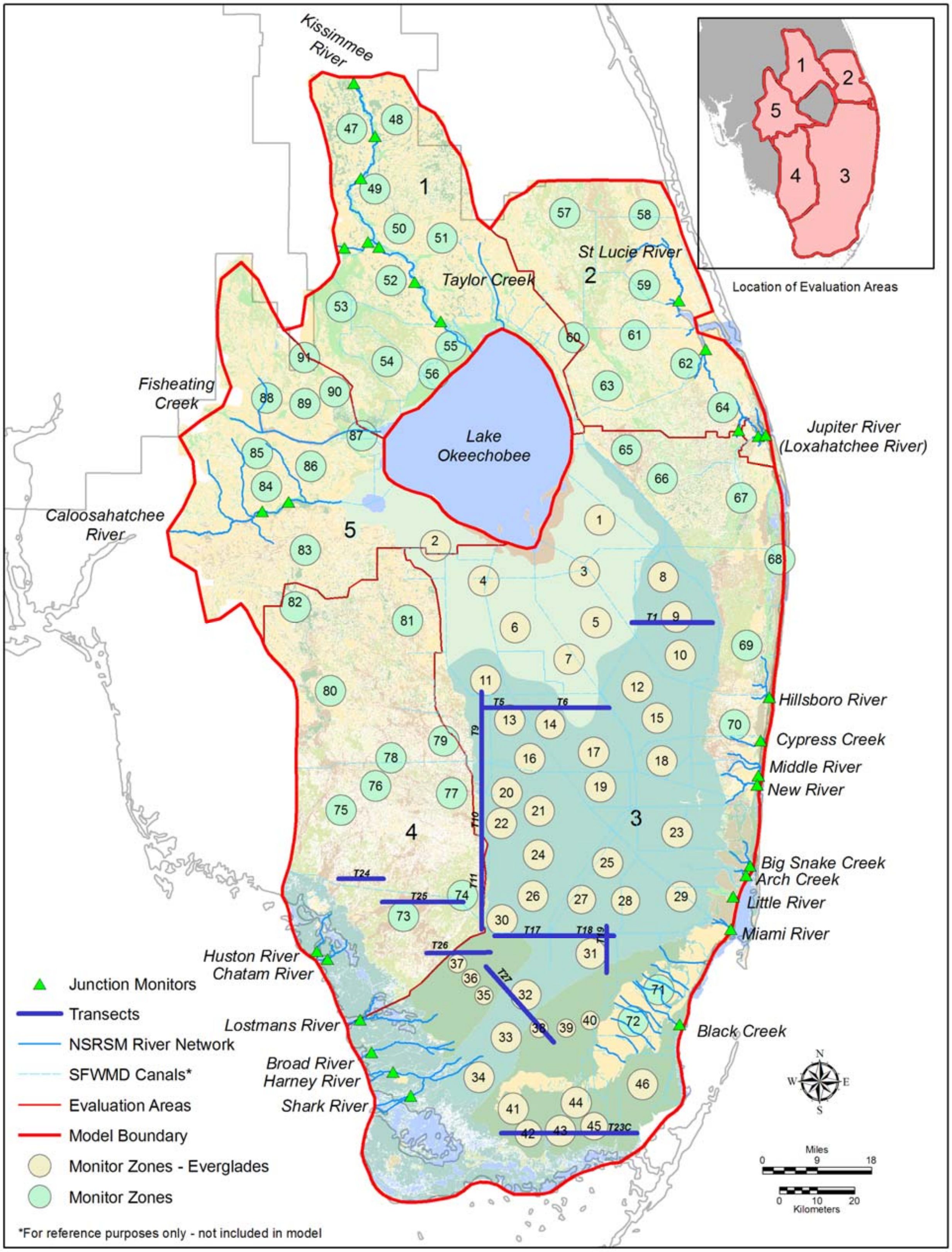


Figure 33. NSRSM v3.5.2 model stage and flow monitors.

Inundation Duration and Seasonal Water Level Results

Processed model output for each zone monitor includes inundation duration (percentage of time water levels were above ground) and long-term average minimum and maximum water levels relative to ground surface. The monitor zones are grouped into five evaluation areas that report results for a majority of the landscape types. Evaluation areas having landscape types represented by one monitor zone are only included in the summary for all evaluation areas. Monitor zone results for each evaluation area and summary for all evaluation areas are presented in the following sections. Details of reference range development are included in **Appendix A** (McVoy *et al.,* 2011; Zahina *et al.,* 2007; USDOI, GLO Surveys; Duever, 2004). A summary of reference ranges by landscape is provided in **Table 13**.

Table 13. Reference ranges for NSRSM landscapes.

Landscape	Hydroperiod (Months)	Seasonal Max.[1] (ft)	Seasonal Min.[1] (ft)
Intra-tidal Wetland	Tidal		
Beach	Variable		
Forested Freshwater Wetland	6-10	2.0	-1.0
Cypress Swamp	6-8	1.5	-1.5
Hardwood Swamp	8-10	2.0	-1.0
Non-forested Freshwater Wetland	6-12	2.5	-2.0
Long-hydroperiod Marsh	9-12	2.0	-0.5
Ridge and Slough Landscape	9.5-11	2.0	0.0
Ridge	9-10	1.5	-0.5
Slough	12	3	1
Sawgrass Plains	9-10	1.5	-0.5
Medium-hydroperiod Marsh	6-10	1.5	-0.5
Marsh with Scattered Cypress	6-10	1.5	-0.5
Everglades Marl Marsh	6-9	1.5	-1.0
Wet Prairie	2-6	1.0	-2.0
Wet Prairie with Scattered Trees	2-6	1.0	-2.0
Wet Prairie with Cypress	2-6	1.0	-2.0
Hydric Uplands	1-2	0.5	-2.5
Hydric Flatwoods	1-2	0.5	-2.5
Hydric Hammock	1-2	0.5	-2.5
Mesic Uplands	<1	0	
Dry Prairie	<1	0	
Mesic Pine Flatwoods	<1	0	
Mesic Hammock	<1	0	
Xeric Uplands	0	0	

Note: (1) Seasonal maximum and seasonal minimum are measured relative to ground surface.
Sources: Green Highlighted Rows: Duever, Appendix I; Yellow: McVoy *et al.*, 2011;
Blue: Zahina *et al.*, 2007.

Evaluation Area 3 Results

Evaluation Area 3 includes most of the Everglades Basin in addition to the eastern coastal landscapes (**Figure 34**). This evaluation area is the focus of this report.

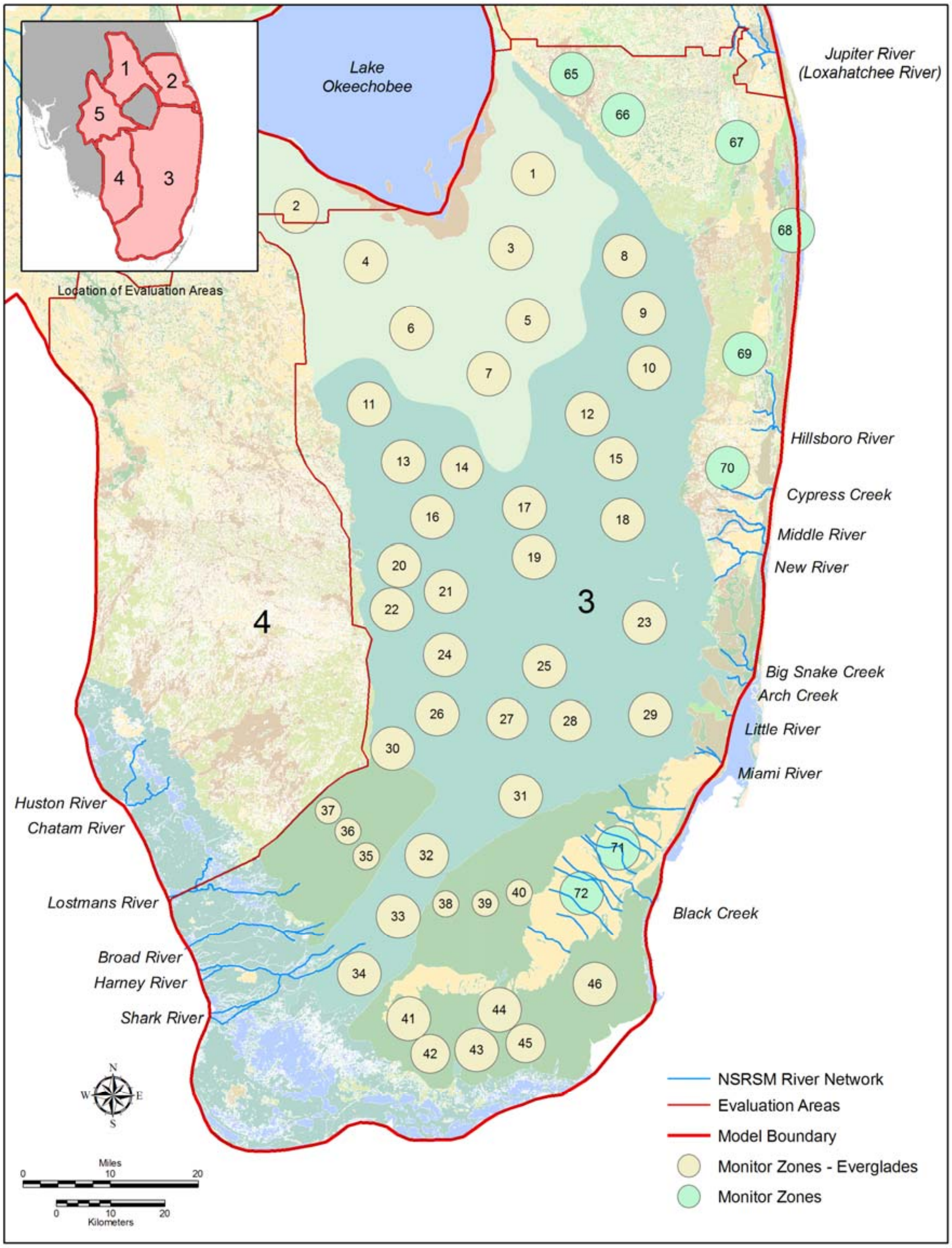


Figure 34. Monitor locations for Evaluation Area 3.

The reference range for long-term average seasonal water levels in the Ridge and Slough landscape, relative to slough bottom, is 1 foot minimum (dry season) and 3 foot maximum (wet season). Hydroperiods should be 12 months for sloughs and within the 9–10 month range for ridges. **Figure 35** illustrates the relationship between the landscape component elevations and minimum/maximum water levels.

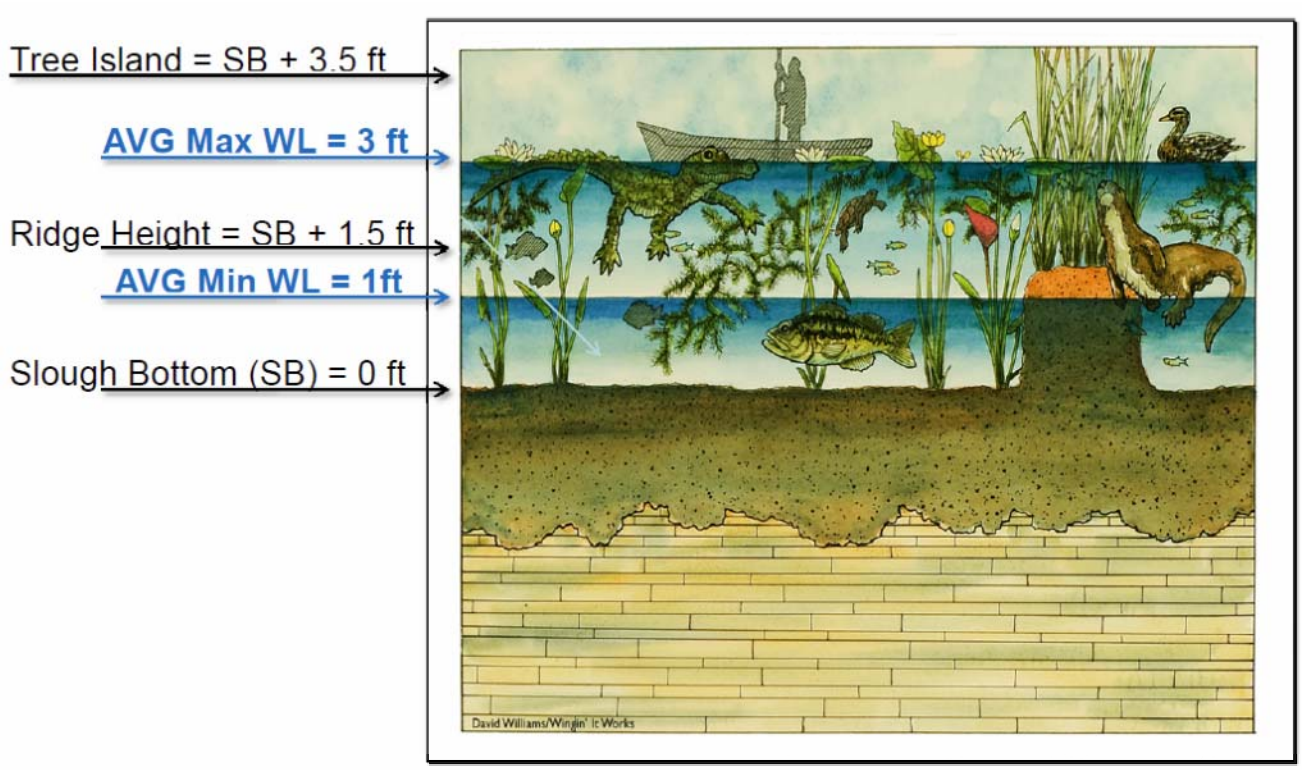


Figure 35. Relative water levels for Everglades landscape components.

Representation of annual seasonal water levels for the ridge and slough landscape was based on the long-term (1966–2005) annual maximum (95th percentile) and minimum (5th percentile) for all monitoring zones within the landscape. Model results are graphed in **Figure 36**. The reference ranges of the seasonal water levels relative to the slough bottom are indicated by the orange lines. The average annual minimum and maximum water levels for all zones are 0.6 ft and 2.5 ft, respectively (zones 8-34 in **Figure 36**). The below average water levels may be influenced by the below average rainfall caused by the cool phase of the AMO; the simulation POR used by the NSRSM has 25 years within the cool phase of the AMO.

Monitoring zone ponding hydrographs were produced for the base condition POR and reviewed for annual and interannual hydropatterns. A subset of these results for Evaluation Area 3 is presented in **Figures 37–45**.

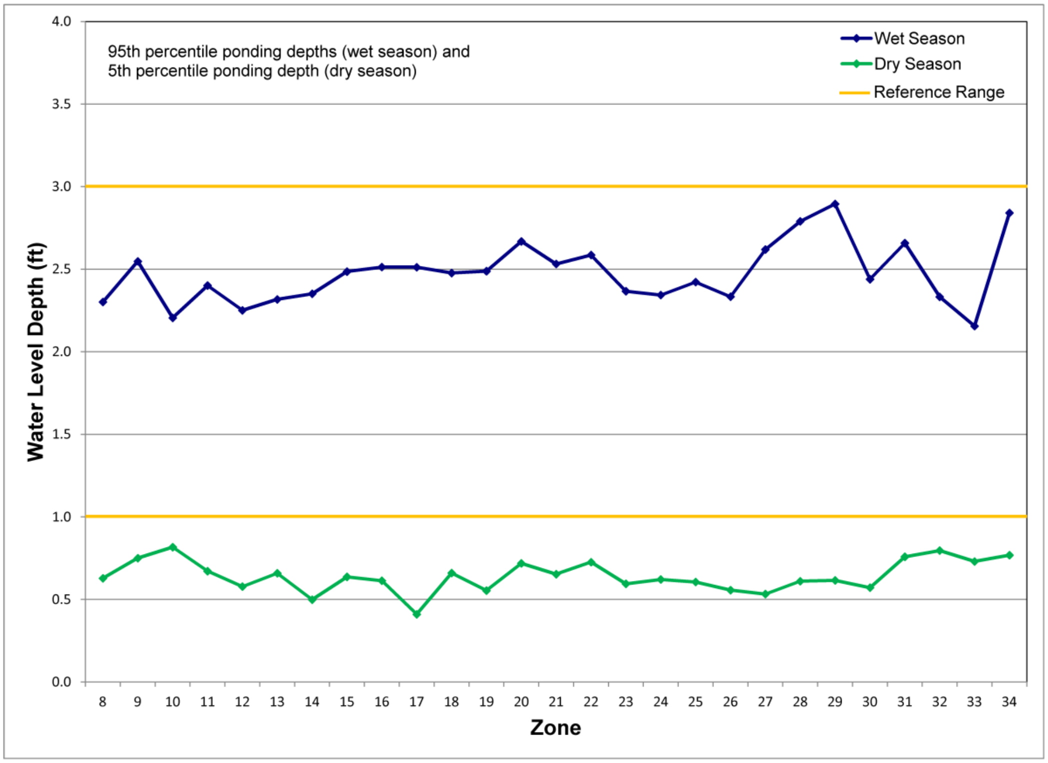


Figure 36. Simulated Ridge and Slough landscape annual average wet and dry season water levels (1966-2005).

Ridge and Slough

Simulated ponding depths for several Ridge and Slough monitoring zones are shown in **Figures 37–42**. Ponding depth is relative to the bottom of the slough (blue line at bottom of graph). The height of typical sawgrass ridges and tree islands are shown on the graph as green and brown horizontal lines, respectively. The reference range for ridge and slough long-term maximum and minimum water levels is indicated on the graph with dashed lines. Hydroperiod was calculated as the duration (in months) a landscape component was inundated. Computed hydroperiod and reference range values appear in the table preceding each graph. Results for all monitor zones in Ridge and Slough are shown in **Table 14**. The below average water levels may be influenced by the below average rainfall caused by the cool phase of the AMO.

Table 14. Evaluation results for Ridge and Slough (relative to slough landscape).

Zone Monitor	Landcover	Reference Hydroperiod (months)	Simulated Inundation Duration: Months	Simulated Inundation Duration: % POR	Reference Seasonal Water Level: Wet (ft)	Reference Seasonal Water Level: Dry (ft)	Simulated Long Term Water Levels: Avg Max (ft)	Simulated Long Term Water Levels: Avg Min (ft)
All	Ridge and Slough	10.5-11	11.9	99.8%	3.0	1.0	2.4	0.6

Location	Hydroperiod (months)	Average of Annual Maximum (ft)	Average of Annual Minimum (ft)
Zone 9 Central WCA-1	Ridge 7.8 Slough 12	2.5	0.7

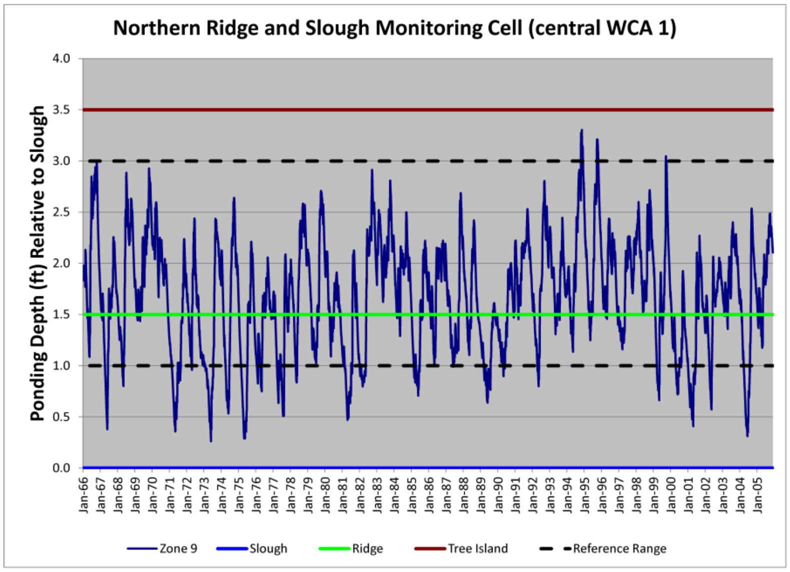


Figure 37. Northern Ridge and Slough monitoring cell (Zone 9/Central WCA-1).

Location	Hydroperiod (months)	Average of Annual Maximum (ft)	Average of Annual Minimum (ft)
Zone 15 Central WCA-2A	Ridge 7.1 Slough 12	2.5	0.6

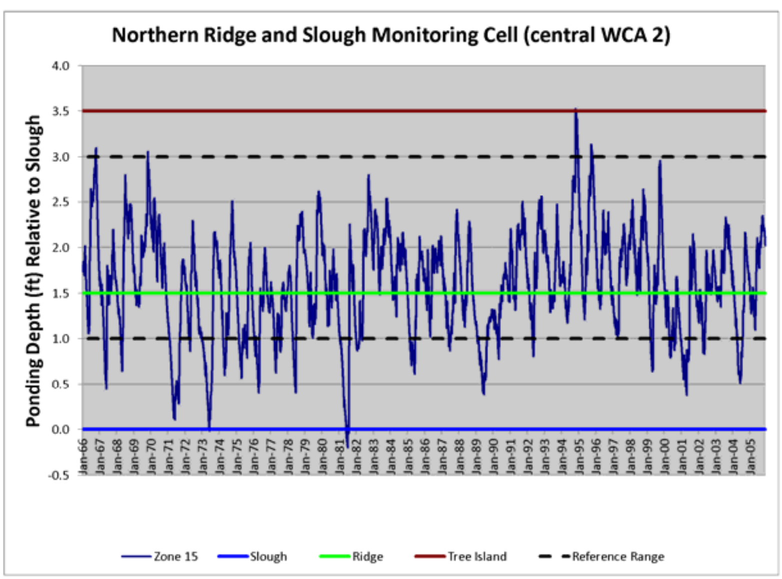


Figure 38. Northern Ridge and Slough monitoring cell (Zone 15/Central WCA-2A).

Location	Hydroperiod (months)	Average of Annual Maximum (ft)	Average of Annual Minimum (ft)
Zone 21 Central WCA-3A	Ridge 7.7 Slough 12	2.5	0.6

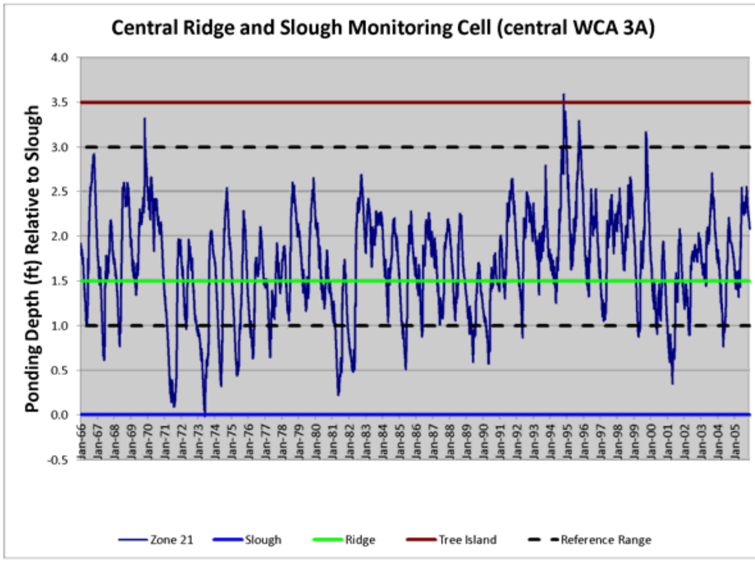


Figure 39. Central Ridge and Slough monitoring cell (Zone 21/Central WCA-3A).

Location	Hydroperiod (months)	Average of Annual Maximum (ft)	Average of Annual Minimum (ft)
Zone 27 Central WCA-3B	Ridge 6.9 Slough 12	2.6	0.5

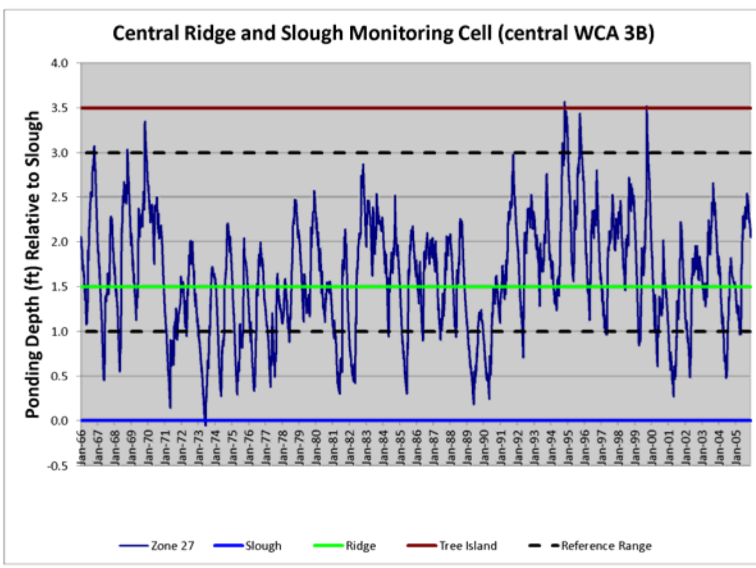


Figure 40. Central Ridge and Slough monitoring cell (Zone 27/Central WCA-3B).

Location	Hydroperiod (months)	Average of Annual Maximum (ft)	Average of Annual Minimum (ft)
Zone 31 NE Shark Slough	Ridge 8.1 Slough 12	2.7	0.8

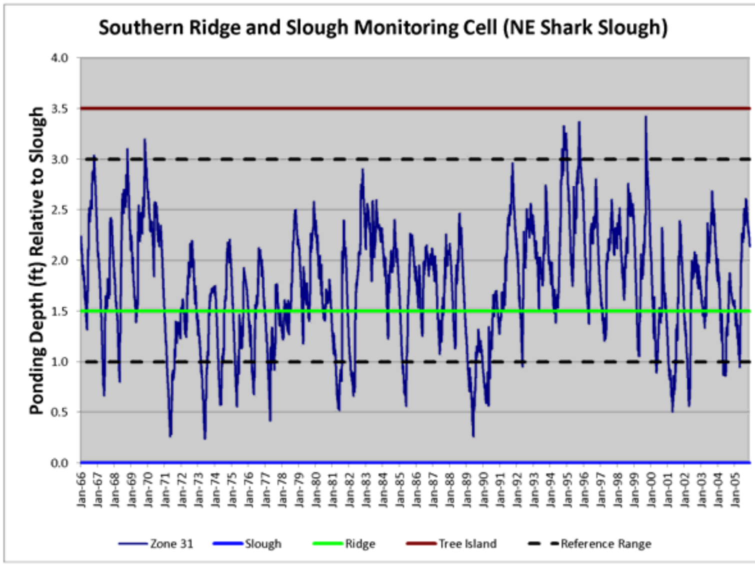


Figure 41. Southern Ridge and Slough monitoring cell (Zone 31/NE Shark Slough).

Location	Hydroperiod (months)	Average of Annual Maximum (ft)	Average of Annual Minimum (ft)
Zone 33 Shark Slough	Ridge 5.7 Slough 12	2.2	0.7

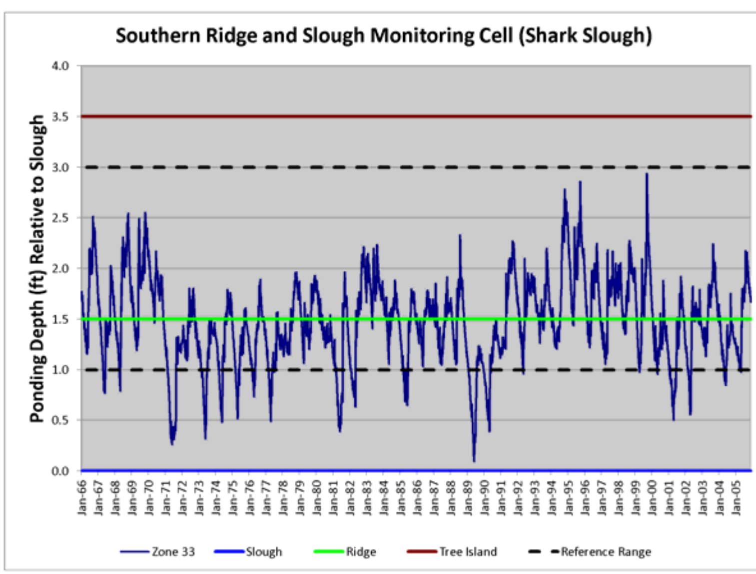


Figure 42. Southern Ridge and Slough monitoring cell (Zone 33/Shark Slough).

Sawgrass Plains

Sawgrass Plains are represented by monitoring zones 1-7 shown in **Figure 34**. The reference range of water levels for this landscape is -0.5 to 1.5 feet and the hydroperiod range is 9-10 months shown in **Table 15**. Simulated ponding depths for a representative Sawgrass Plains monitoring zone is shown in **Figure 43**. Results for all monitor zones in Sawgrass Plains are shown in **Table 15**.

Table 15. Evaluation results for Sawgrass Plains.

			Simulated Inundation Duration		Reference Seasonal Water Level		Simulated Long Term Water Levels	
Zone Monitor	Landcover	Reference Hydroperiod (months)	Months	% POR	Wet (ft)	Dry (ft)	Avg Max (ft)	Avg Min (ft)
All	Sawgrass Plains	9-10	10.8	89.7%	1.5	-0.5	1.4	-0.1

Location	Hydroperiod (months)	Average of Annual Maximum (ft)	Average of Annual Minimum (ft)
Zone 3 Sawgrass Plains	10.7	1.4	-0.1

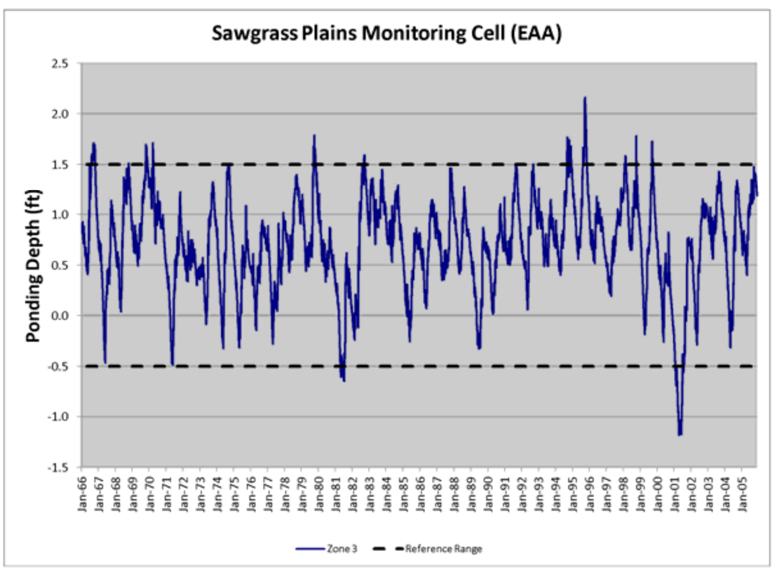


Figure 43. Sawgrass Plains monitoring cell (Zone 3/EAA).

Everglades Marl Marsh

Everglades Marl Marsh is represented by zones 35-42 and zones 45-46 shown in **Figure 33**. The reference range of water levels for this landscape is -1.0 to 1.5 feet and the hydroperiod range is 6-9 months in **Table 16.** Simulated ponding depth for representative Everglades Marl Marsh monitoring zones are shown in **Figures 44-45**. Results for all monitor zones are shown in **Table 16**.

Table 16. Evaluation results for Everglades Marl Marsh.

			Simulated Inundation Duration		Reference Seasonal Water Level		Simulated Long Term Water Levels	
Zone Monitor	Landcover	Reference Hydroperiod (months)	Months	% POR	Wet (ft)	Dry (ft)	Avg Max (ft)	Avg Min (ft)
All	Everglades Marl Marsh	6-9	7.1	58.9%	1.5	-1.0	0.7	-1.1

Location	Hydroperiod (months)	Average of Annual Maximum (ft)	Average of Annual Minimum (ft)
Zone 39 Everglades Marl (Rocky Glades)	4.5	0.5	-1.7

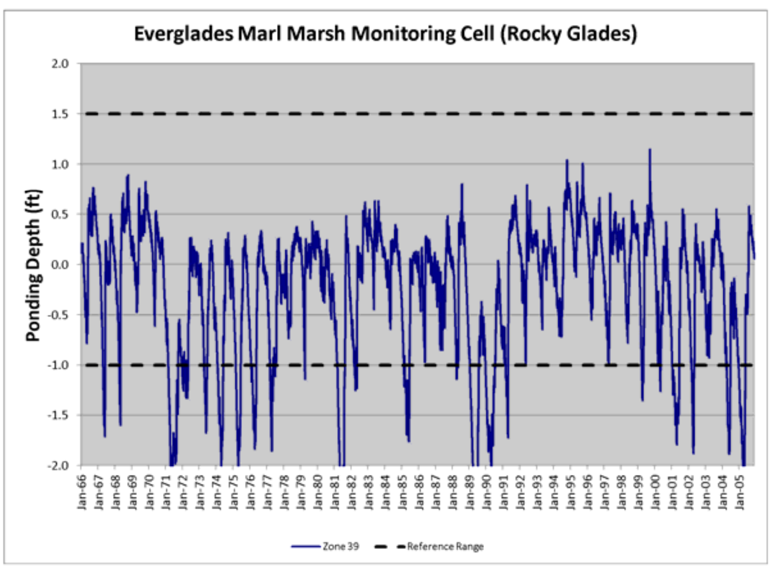


Figure 44. Everglades Marl Marsh monitoring cell (Zone 39/Rocky Glades).

Location	Hydroperiod (months)	Average of Annual Maximum (ft)	Average of Annual Minimum (ft)
Zone 46 Everglades Marl Marsh (C-111 Basin)	8.4	0.9	-1.0

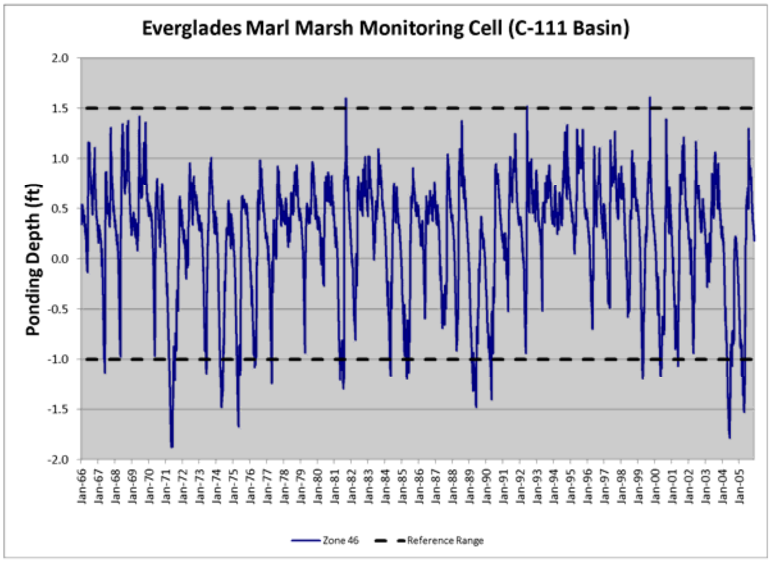


Figure 45. Everglades Marl Marsh monitoring cell (Zone 46/C-111 Basin).

Evaluation Area 1 Results

Evaluation Area 1 includes the lower Kissimmee River Basin and northern Okeechobee basins (**Figure 46**). It primarily consists of Dry Prairie and Long-hydroperiod Marsh landscape monitor zones. Reference ranges and model results are in green and blue columns, respectively shown in **Table 17**. The model results have been averaged by landscape type. The results for Dry Prairie are above the reference range; this may be influenced by adjacent cells with different landscape types having higher reference ranges.

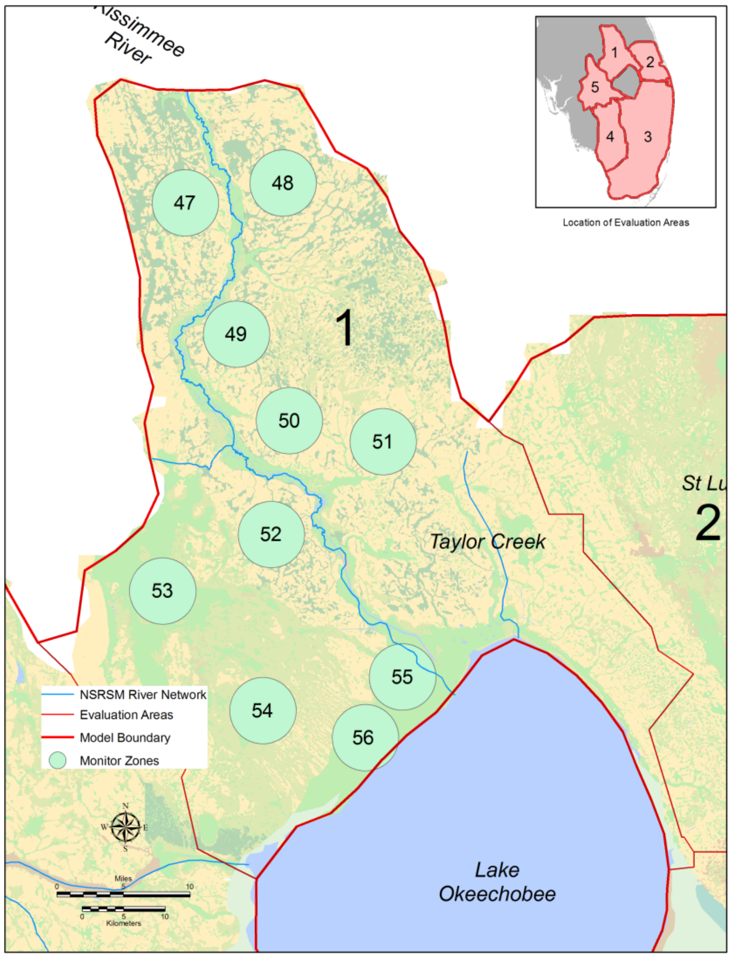


Figure 46. Monitor locations for Evaluation Area 1.

Table 17. Evaluation Area 1 results.

Landcover	Number of Zone Monitors	Reference Hydroperiod (months)	Simulated Inundation Duration Months	Simulated Inundation Duration % POR	Reference Seasonal Water Level Wet (ft)	Reference Seasonal Water Level Dry (ft)	Simulated Long Term Water Levels Avg Max (ft)	Simulated Long Term Water Levels Avg Min (ft)
Dry Prairie	6	<1	4.9	40.7%	<-2	-	0.3	-3.9
Long-hydroperiod Marsh	3	9-12	11.0	91.4%	2	-0.5	2.1	-0.1

Evaluation Area 2 Results

Evaluation Area 2 includes the St. Lucie River watershed east of Lake Okeechobee (**Figure 47**). It primarily consists of Mesic Pine Flatwood landscape monitor zones. The results are shown in **Table 18**. The model results have been averaged by landscape type. The results for Mesic Pine Flatwood are above the reference hydroperiod; this may be influenced by adjacent cells with different landscape types having higher reference ranges or the threshold at which indunation begins.

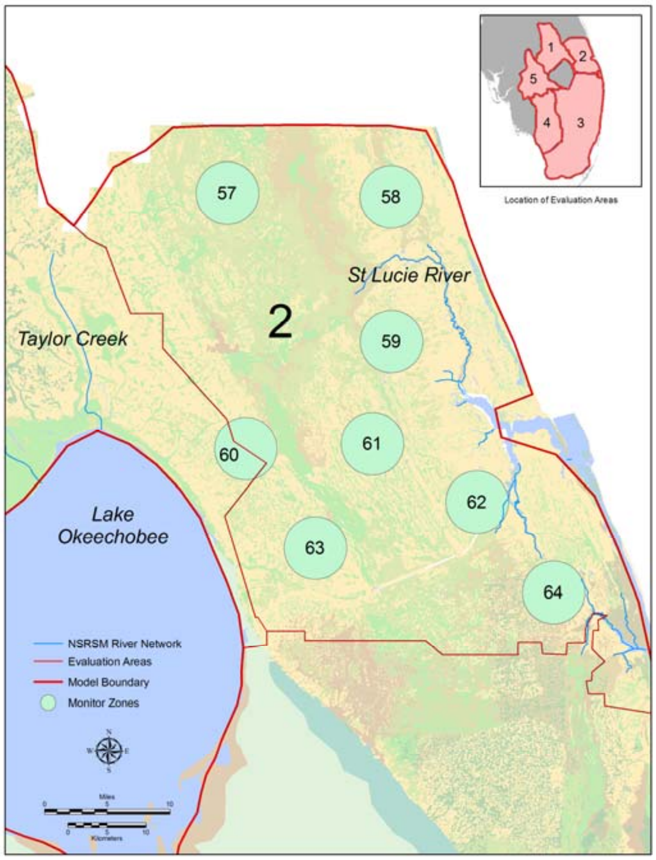


Figure 47. Monitor locations for Evaluation Area 2.

Table 18. Evaluation Area 2 results.

Landcover	Number of Zone Monitors	Reference Hydroperiod (months)	Simulated Inundation Duration		Reference Seasonal Water Level		Simulated Long Term Water Levels	
			Months	% POR	Wet (ft)	Dry (ft)	Avg Max (ft)	Avg Min (ft)
Mesic Pine Flatwood	7	<1	4.4	36.9	-	-	-0.5	-3.9

Evaluation Area 4 Results

Evaluation Area 4 includes Big Cypress Basin (**Figure 48**). It primarily consists of Cypress Swamp and Wet Prairie with Scattered Trees landscape monitor zones. Results for Evaluation Area 4 are shown in **Table 19**. The model results have been averaged by landscape type. The results for Cypress Swamp and Wet Prairie with Scattered Trees are above/below the reference hydroperiod; this may be influenced by adjacent cells with different landscape types having lower/higher reference ranges.

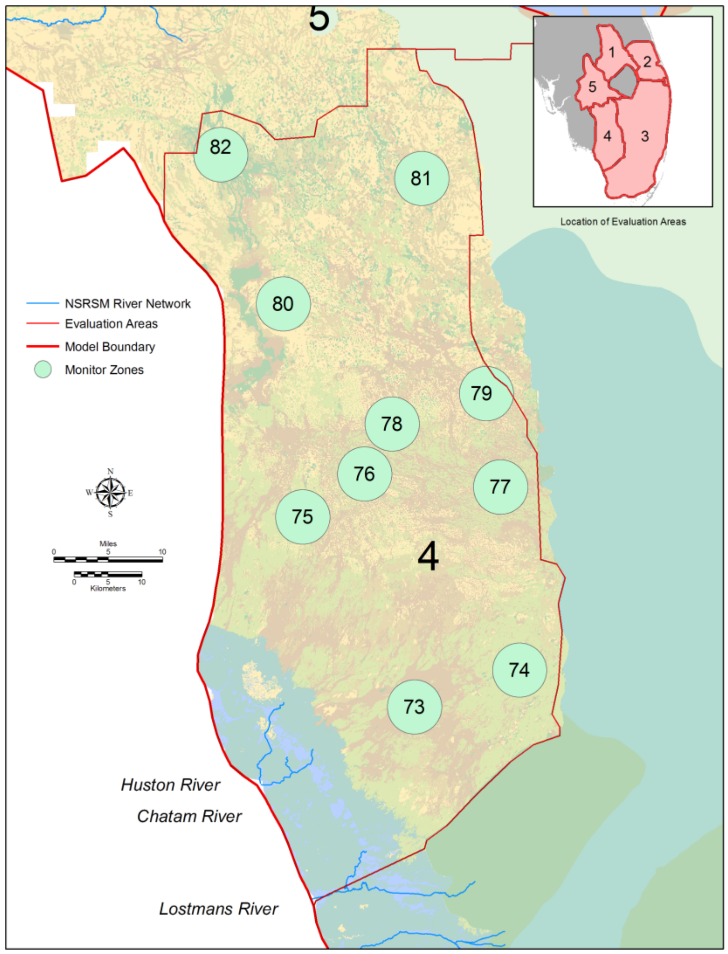


Figure 48. Monitor locations for Evaluation Area 4.

Table 19. Evaluation Area 4 results.

Landcover	Number of Zone Monitors	Reference Hydroperiod (months)	Simulated Inundation Duration		Reference Seasonal Water Level		Simulated Long Term Water Levels	
			Months	% POR	Wet (ft)	Dry (ft)	Avg Max (ft)	Avg Min (ft)
Cypress Swamp	3	5-9	6.9	57.4%	1.5	-1.5	0.5	-1.9
Wet Prairie w/ Scattered Trees	3	2-6	10.5	87.7%	1.0	-2.0	1.3	-0.6

Evaluation Area 5 Results

Evaluation Area 5 includes the Caloosahatchee Watershed (**Figure 49**). It primarily consists of Dry Prairie and Mesic Pine Flatwood landscape monitor zones. The zones in Evaluation Area 5 have below ground reference ranges since they represent Mesic Pine Flatwood and Dry Prairie (**Table 20**). The model results have been averaged by landscape type. The results for Dry Prairie and Mesic Pine Flatwood are above the reference ranges; this may be influenced by adjacent cells with different landscape types having higher reference ranges.

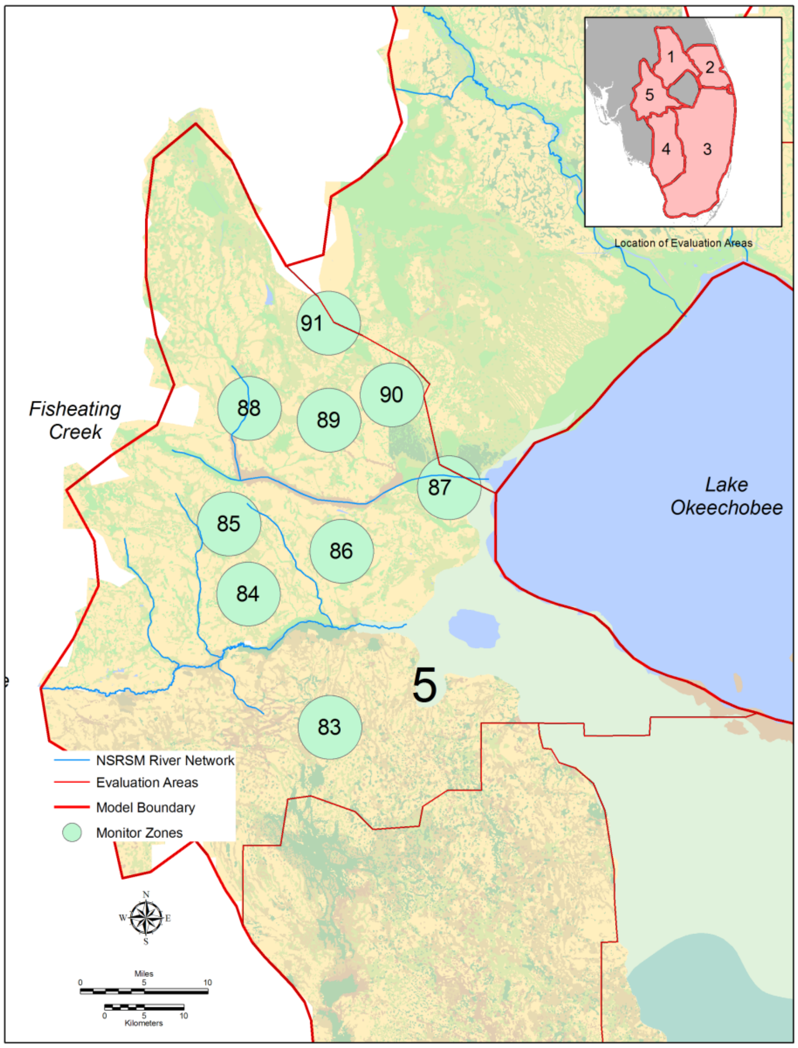


Figure 49. Monitor locations for Evaluation Area 5.

Table 20. Evaluation Area 5 results.

Landcover	Number of Zone Monitors	Reference Hydroperiod (months)	Simulated Inundation Duration		Reference Seasonal Water Level		Simulated Long Term Water Levels	
			Months	% POR	Wet (ft)	Dry (ft)	Avg Max (ft)	Avg Min (ft)
Dry Prairie	3	<1	2.6	21.8%	<-2	-	-0.4	-5.8
Mesic Pine Flatwood	5	<1	5.0	41.4%	<-2	-	0.6	-3.9

Evaluation Area Results Summary

The results for Evaluation Areas 1 through 5 have been summarized in **Table 21**. It is based on average results for each landscape type. The results may vary slightly when compare to the evaluation section since all monitor cells were used for each landscape type. For example, Mesic Pine Flatwood contains monitor cells in evaluation areas 2 and 5; the summary below reports the average for all Mesic Pine Flatwood monitor zones. Differences in the simulated results and reference ranges for each landscape type have been discussed in the preceeding sections for each evaluation area.

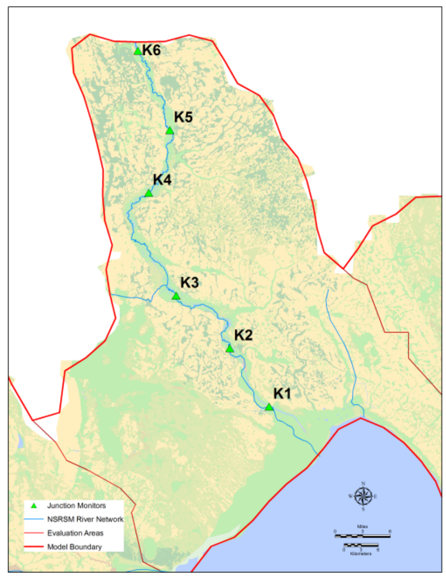
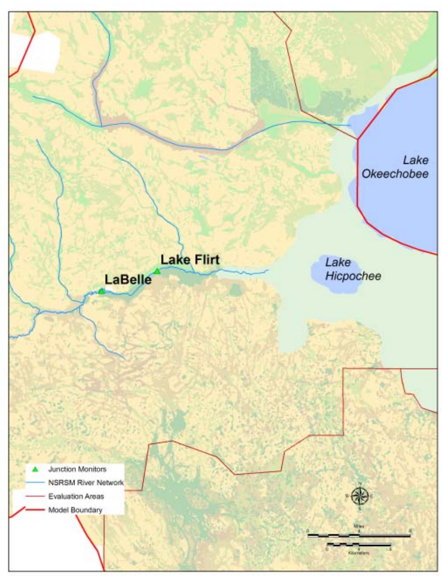
Table 21. Results summary for all Evaluation Areas.

Landcover	Number of Zone Monitors	Reference Hydroperiod (months)	Simulated Inundation Duration		Reference Seasonal Water Level		Simulated Long Term Water Levels	
			Months	% POR	Wet (ft)	Dry (ft)	Avg Max (ft)	Avg Min (ft)
Cypress Swamp	4	5 - 9	6.8	56.7%	1.5	-1.5	0.5	-1.9
Dry Prairie	9	<1	4.1	34.4%	<-2	-	0.1	-4.5
Everglades Marl Marsh	10	6 - 9	7.1	58.9%	1.5	-1	0.7	-1.1
Hardwood Swamp	1	6 - 10	7.5	62.4%	2	-1	0.6	-1.8
Hydric Upland	3	1 - 2	3.7	30.5%	0.5	-2.5	-0.4	-3.9
Long-hydroperiod Marsh	4	9 - 12	10.8	89.8%	2	-0.5	1.7	-0.2
Medium-hydroperiod Marsh	1	6 - 10	10.8	90.0%	1.5	-0.6	1.2	-0.4
Mesic Pine Flatwood	15	<1	4.2	35.3%	<-2	-	-0.3	-4.1
Ridge and Slough	30	10.5 - 11	11.9	99.8%	3.0	1.0	2.4	0.6
Sawgrass Plain	7	9 - 10	10.8	89.7%	1.5	-0.5	1.4	-0.1
Scrub	1	-	0.4	3.3%	-	-	-0.5	-9.5
Wet Prairie	3	2 - 6	10.2	85.4%	1	-2	1.2	-0.8
Wet Prairie with Scattered Trees	3	2 - 6	9.1	75.6%	1	-2	1.1	-1.0

Natural River Flows

Quantitative flow data for south Florida natural rivers prior to extensive channel modifications for drainage and navigation improvement is very limited. However, substantial survey information is available to define historical physical dimensions of the rivers (**Appendix F**). The NSRSM simulated long-term annual average flows are compared to historical reference ranges in **Table 22**.

Table 22. Natural system river flows.

Water Body	Reference Source Reference Range	Monitoring Location	NSRSM Simulated Flow (cfs)	Locator Map
Kissimmee River	Kissimmee River Restoration Studies (SFWMD 2005). Appendix A.3 800–2,000 cfs	K1 K2 K3 K4 K5 K6	1789 1706 1615 1360 1161 1033	
Caloosahatchee River	USGS, 1926 800 –1,000 cfs	Lake Flirt LaBelle	642 581	

<table>
<tr><th>Water Body</th><th>Reference Source Reference Range</th><th>Monitoring Location</th><th>NSRSM Flow AcFtYr (AFY)</th><th>Locator Map</th></tr>
<tr>
<td>East Coast rivers:

Hillsboro River
Cypress Creek
Middle River
New River
Snake Creek
Arch Creek
Little River
Miami River</td>
<td>SFWMD spreadsheet analysis (Appendix F)

Maximum discharge capacity for 8 East Coast rivers identified in left column = 3M AFY

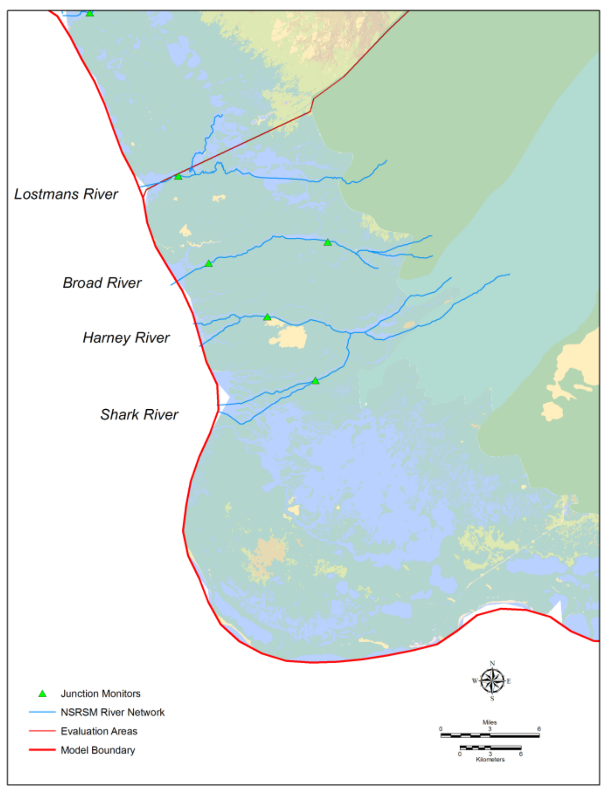
Uncertainty +/- 1M AFY</td>
<td>See map</td>
<td>Average Annual Discharge 1.5 M AFY

Maximum Annual Discharge 3.1 M AFY</td>
<td>
</td>
</tr>
<tr>
<td>Lower West Coast rivers:

Broad River
Harney River
Shark River</td>
<td>Observed (USGS Flow Monitoring Levesque 2004)

versus

simulated flow comparisons

presented in Figures 48-50.</td>
<td colspan="3">
</td>
</tr>
</table>

The date for the reference source of the Caloosahatachee River, USGS 1926, occurs after significant development of the river; therefore, the predrainage simulated flows are less than the reference source. The headwaters of the Caloosahatchee River are not directly connected to Lake Okeechobee. A topographic divide in the area allows the Caloosahatchee River to receive overflow from Lake Okeechobee when its stage exceeds the elevation of the divide. Figure 50 shows the headwaters of the Caloosahatchee River receive low or negligible flow during periods of lower stages in Lake Okeechobee (e.g. April 1981to June 1982).

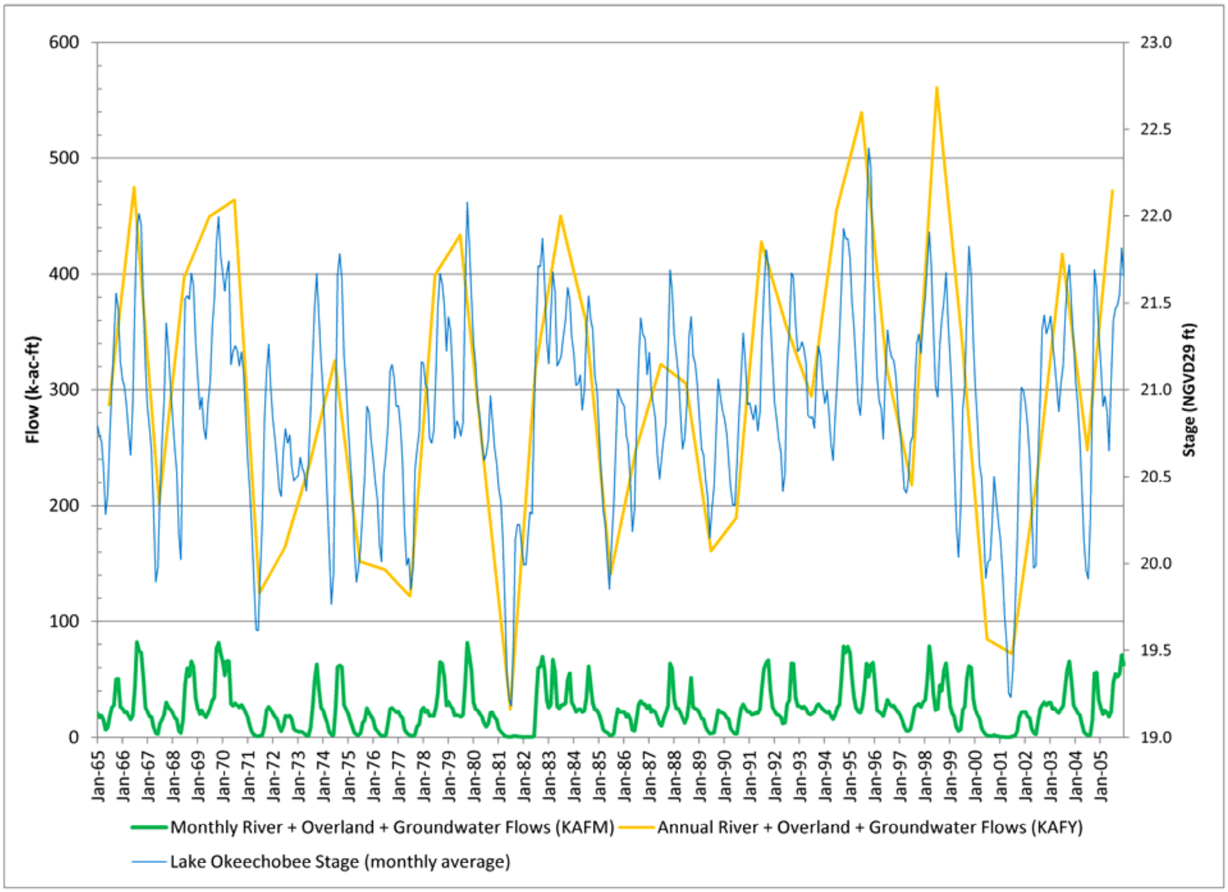


Figure 50. Caloosahatchee River headwater flow.

Lower West Coast rivers have not been significantly altered and therefore flows are compared to current monitoring data (Levesque, 2004) shown in **Figures 51-53**. It is important to note that although the rivers have not been significantly altered, the measured flows are from the post drainage system; therefore, the simulated flows are expected to be higher.

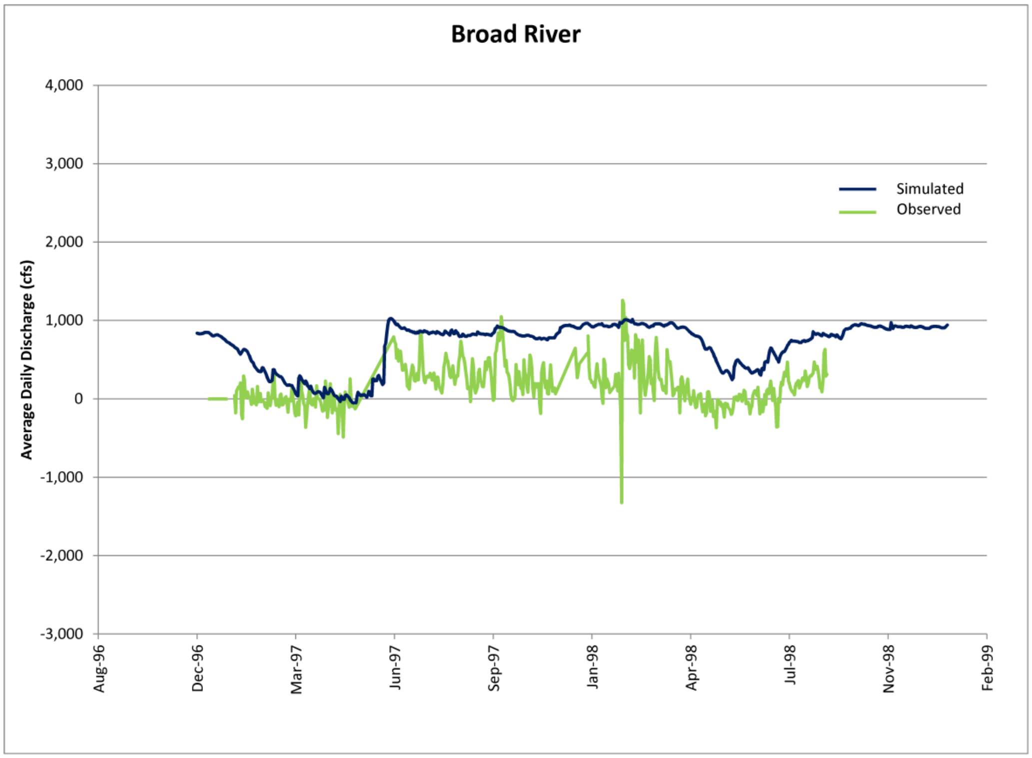


Figure 51. Broad River simulated and measured flows.

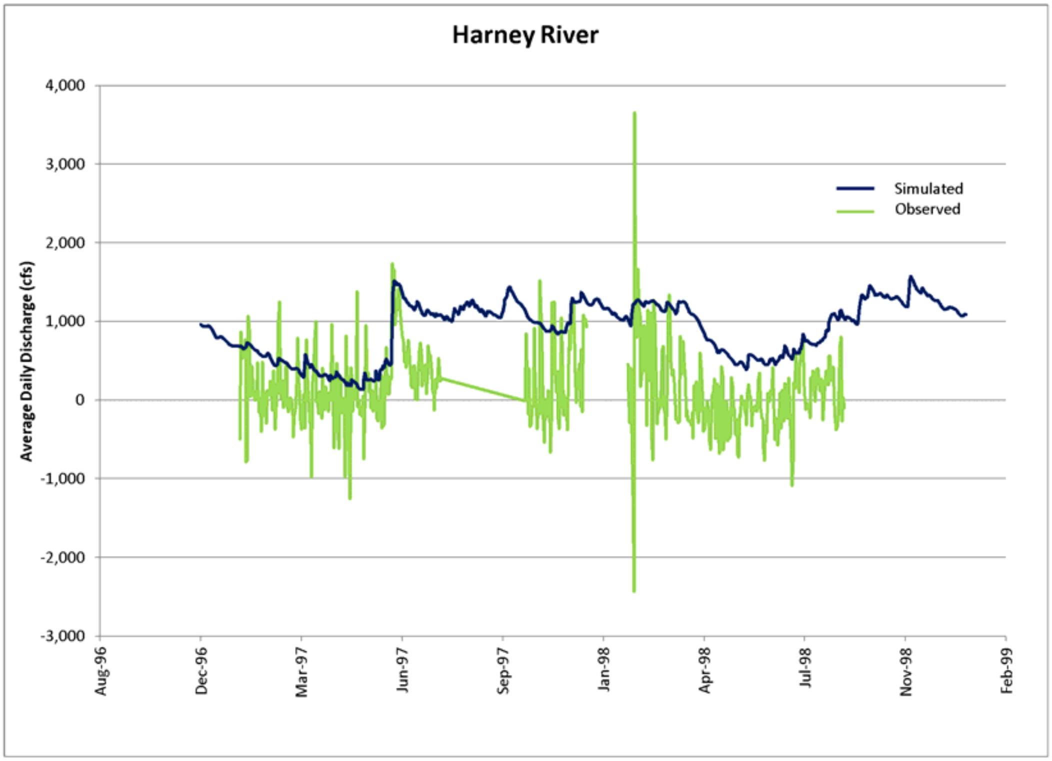


Figure 52. Harney River simulated and measured flows.

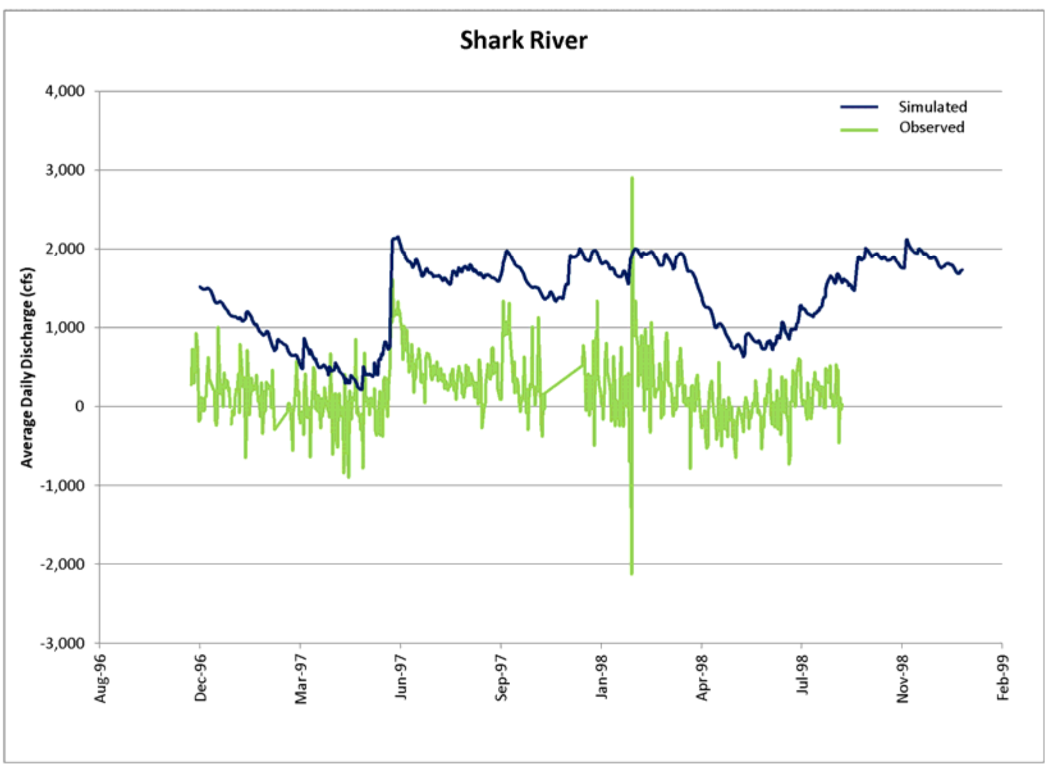


Figure 53. Shark River simulated and measured flows.

Monitor locations showing simulated water levels, monthly flow, and flow frequency are shown in Figure 54. The simulated water level for each river was measured at the river mid-point and the simulated flow was measured at the outlet. The results for the Caloosahatchee River, Kissimmee River, N. Fork St. Lucie River, Fisheating Creek, Taylor Creek, Loxahatchee River, and Shark River Slough are shown in Figure 55 - Figure 75.

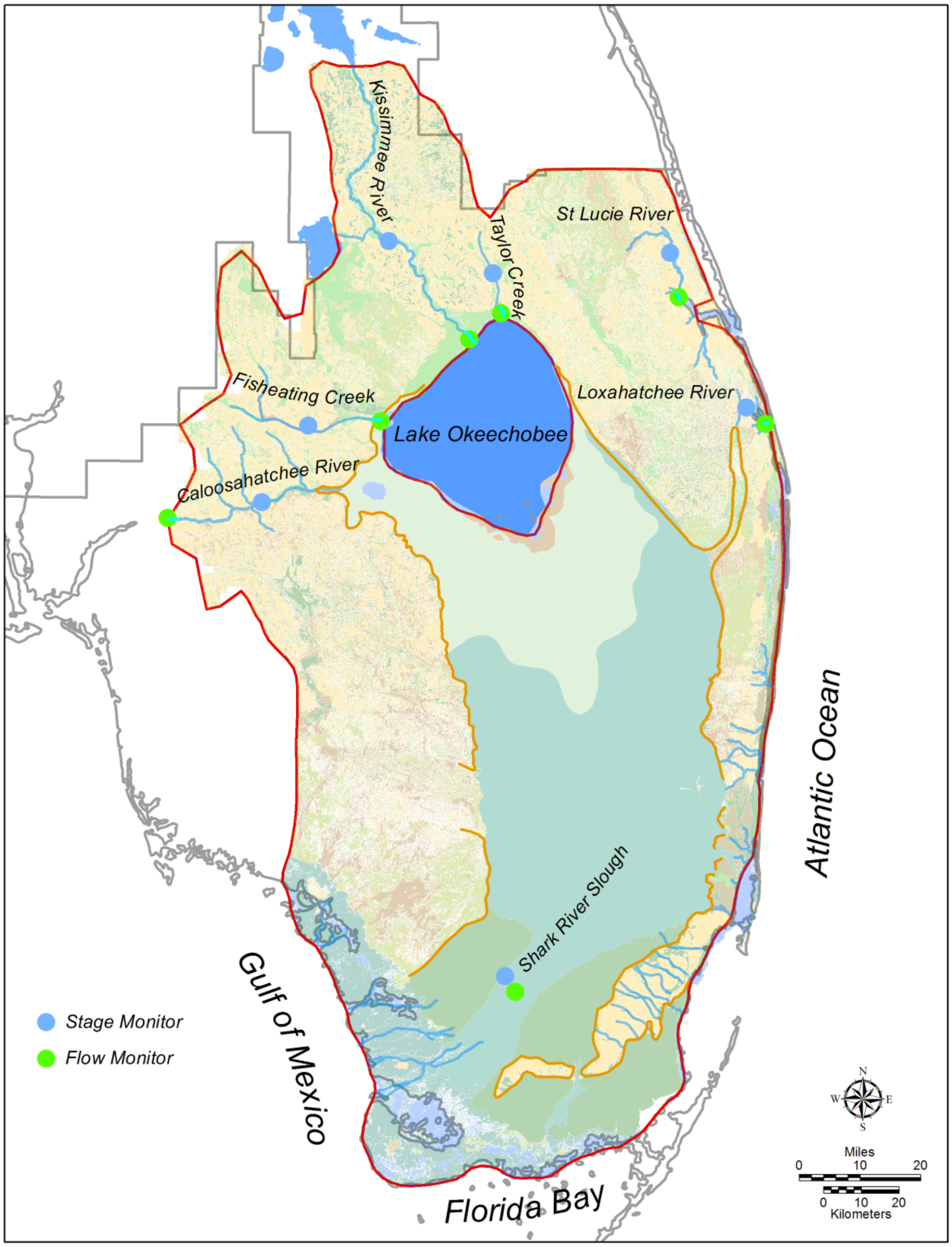


Figure 54. Water level and flow monitoring locations.

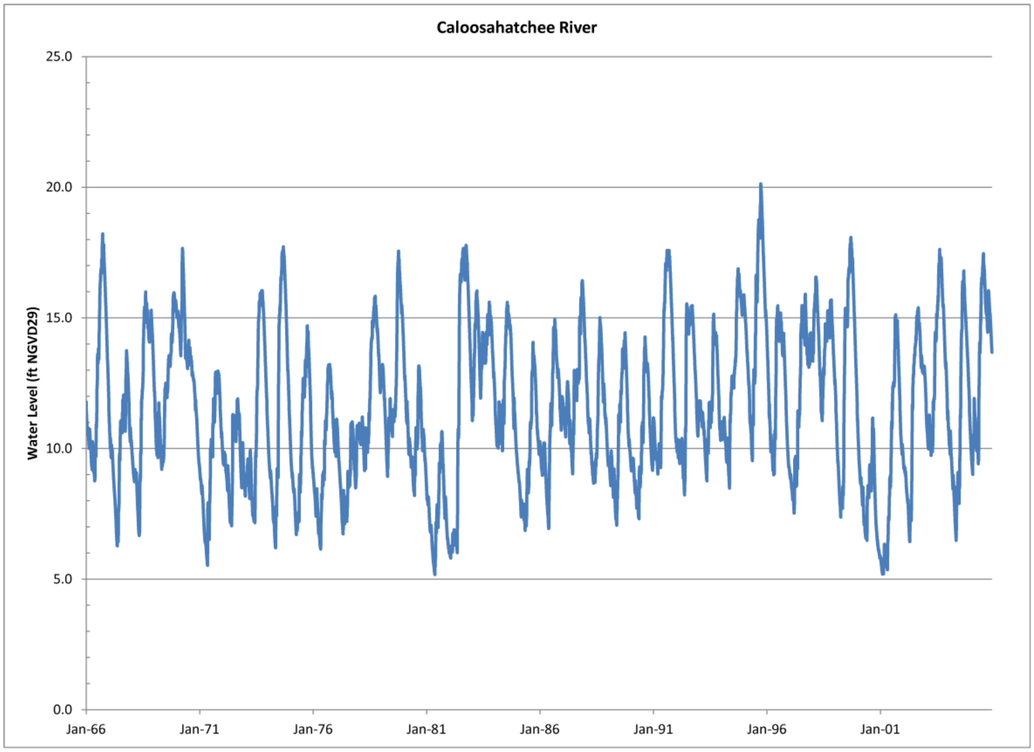


Figure 55. Simulated water level at the Caloosahatchee River.

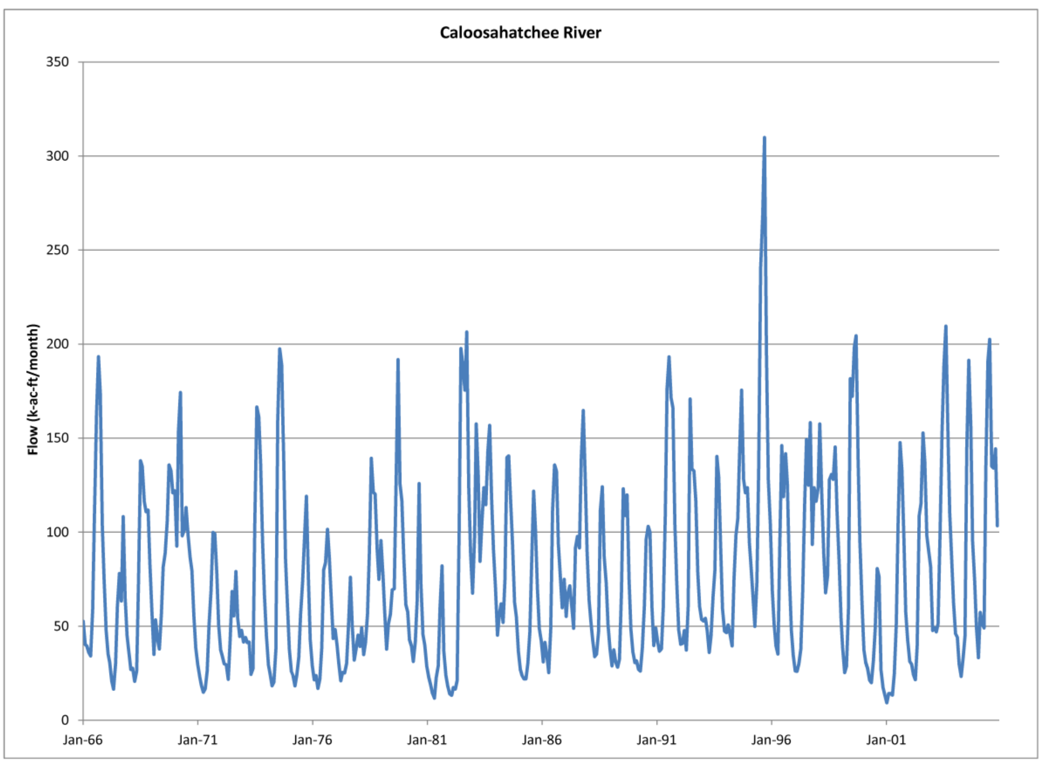


Figure 56. Simulated monthly flow at the Caloosahatchee River.

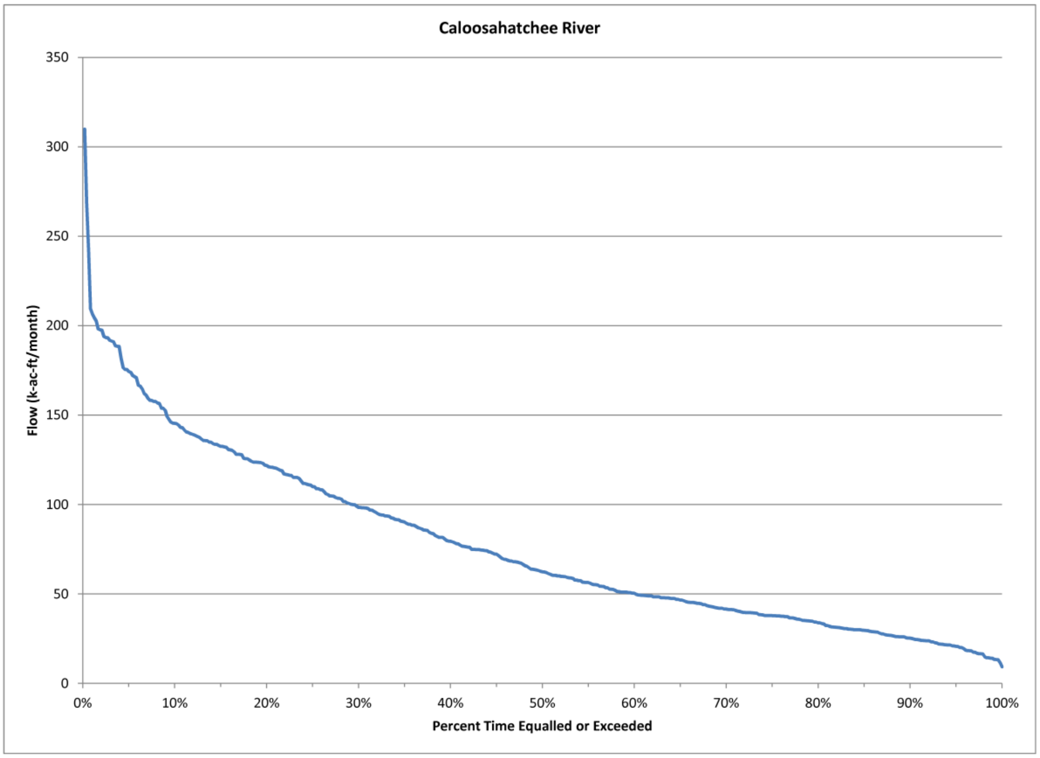


Figure 57. Simulated flow frequency at the Caloosahatchee River.

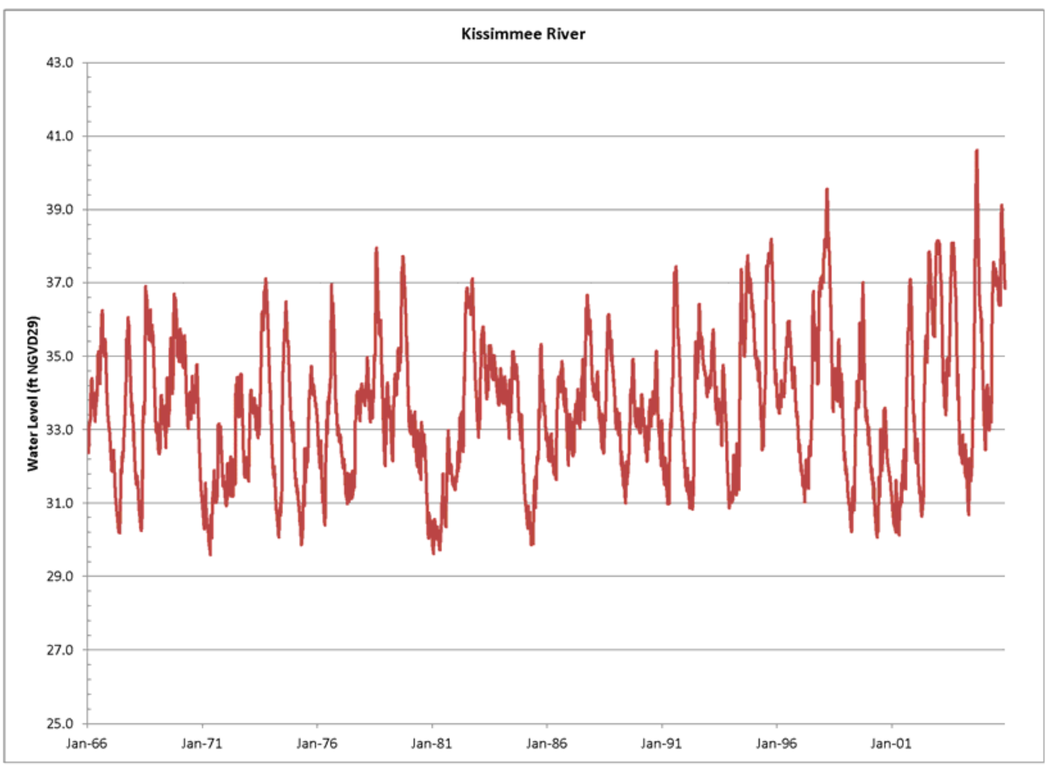


Figure 58. Simulated water level at the Kissimmee River.

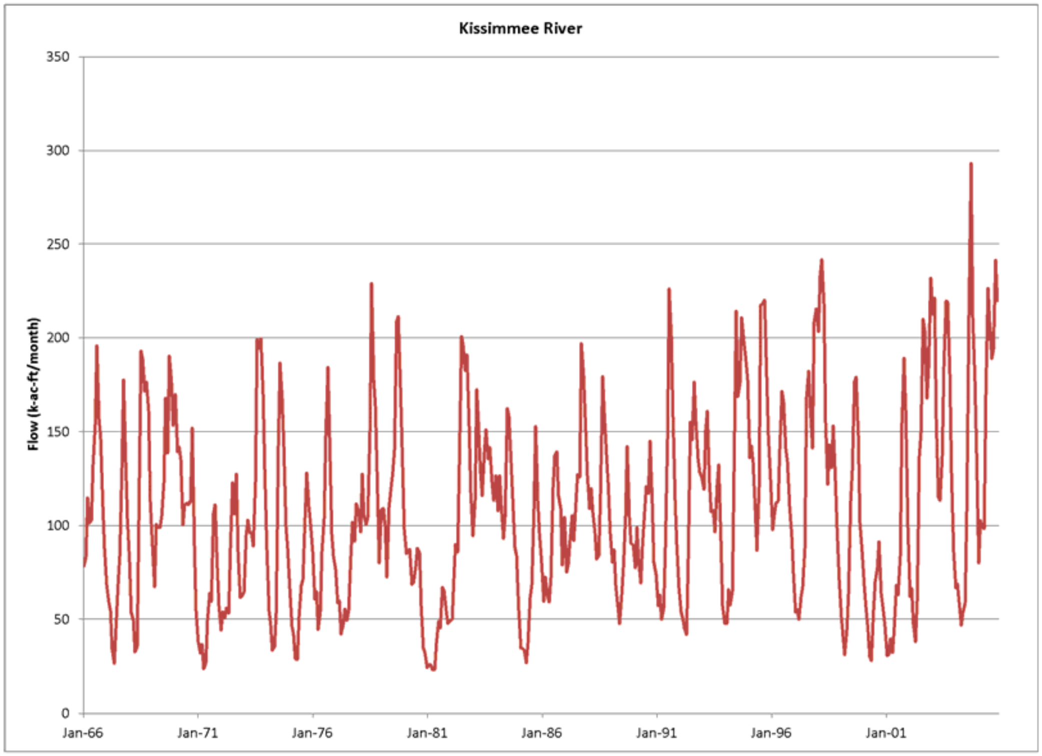


Figure 59. Simulated monthly flow at the Kissimmee River.

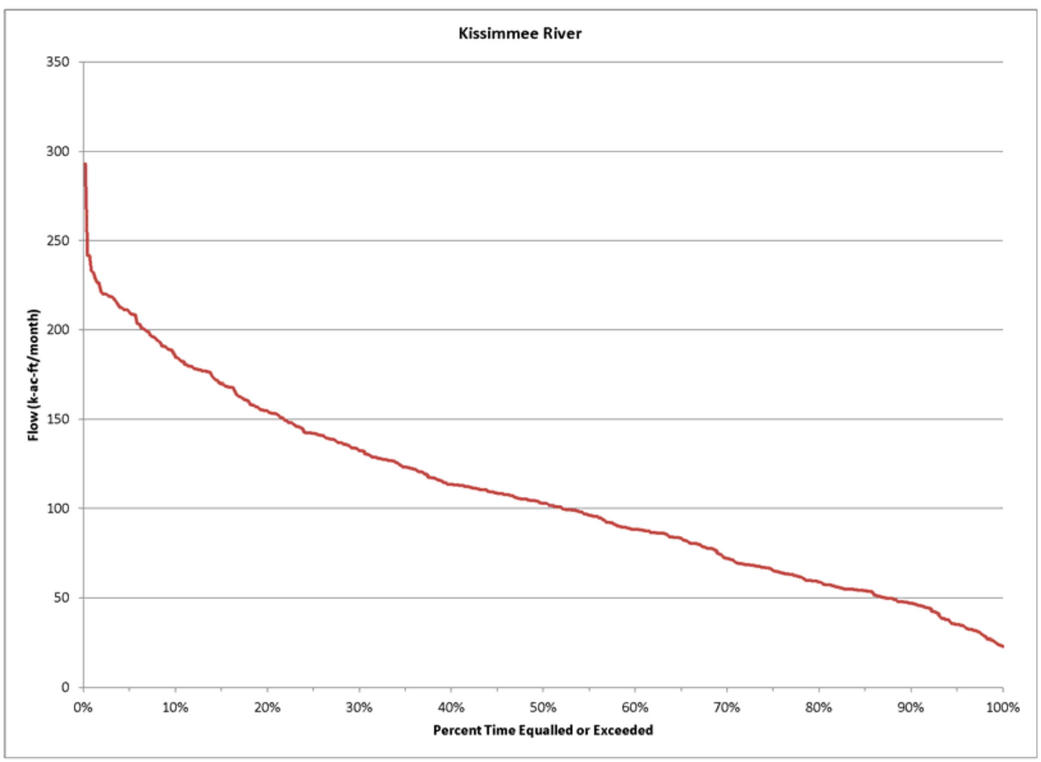


Figure 60. Simulated flow frequency at the Kissimmee River.

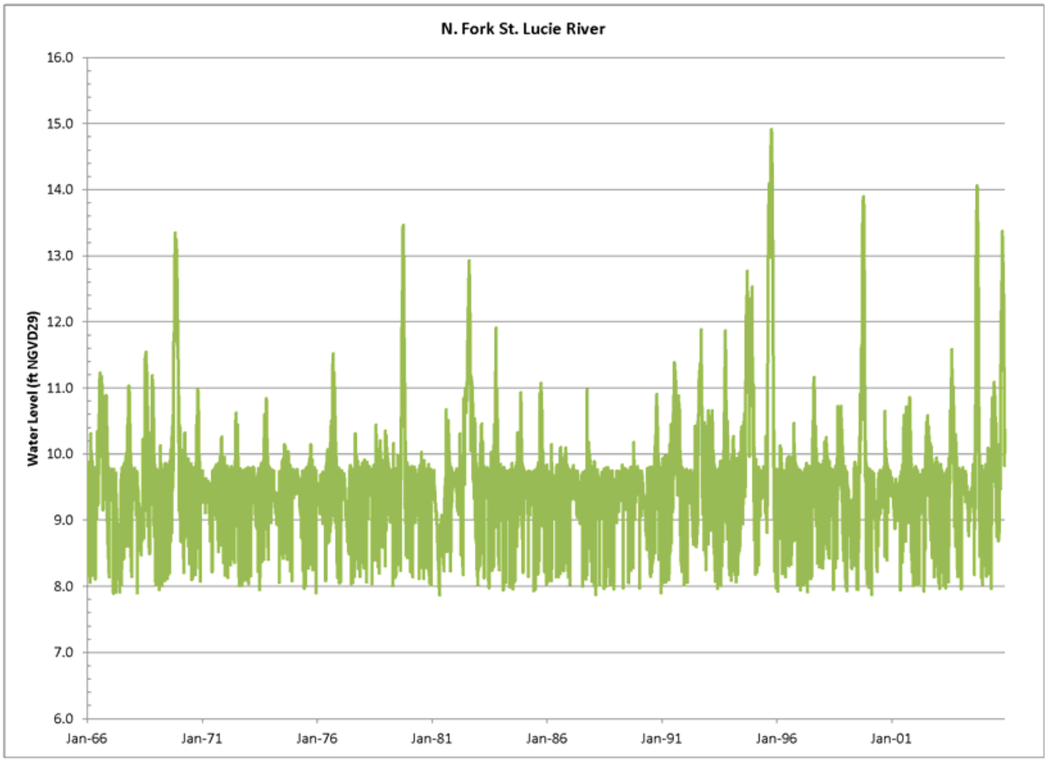


Figure 61. Simulated water level at the N. Fork St. Lucie River.

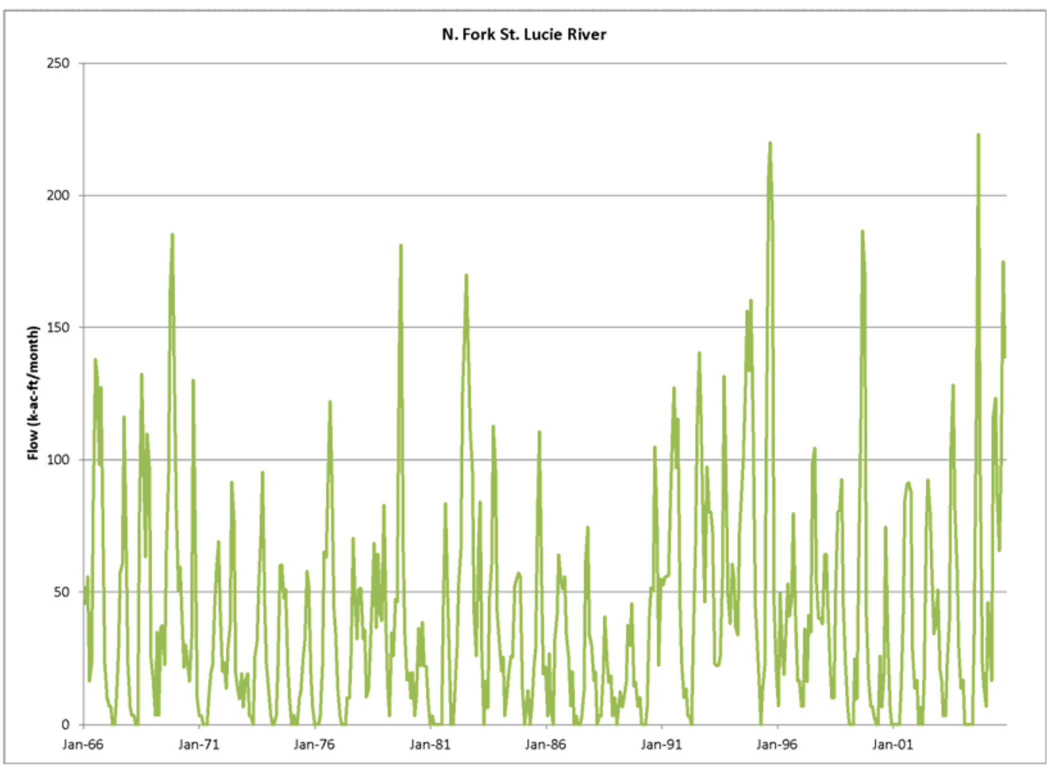


Figure 62. Simulated monthly flow at the N. Fork St. Lucie River.

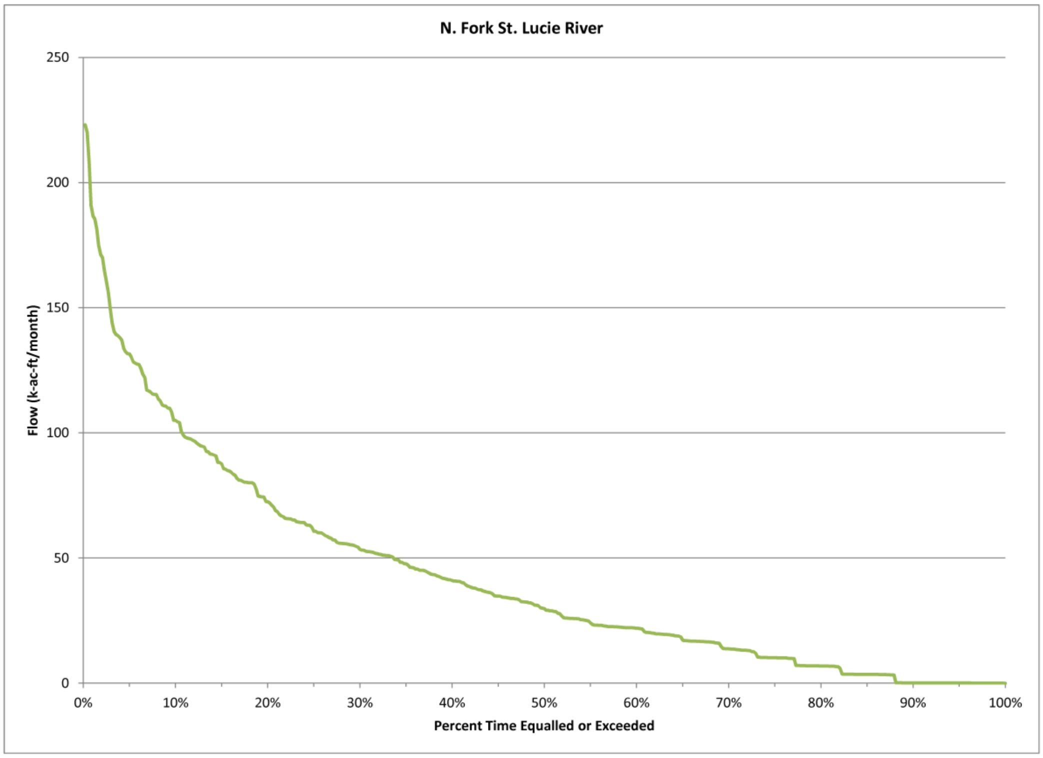


Figure 63. Simulated flow frequency at the N. Fork St. Lucie River.

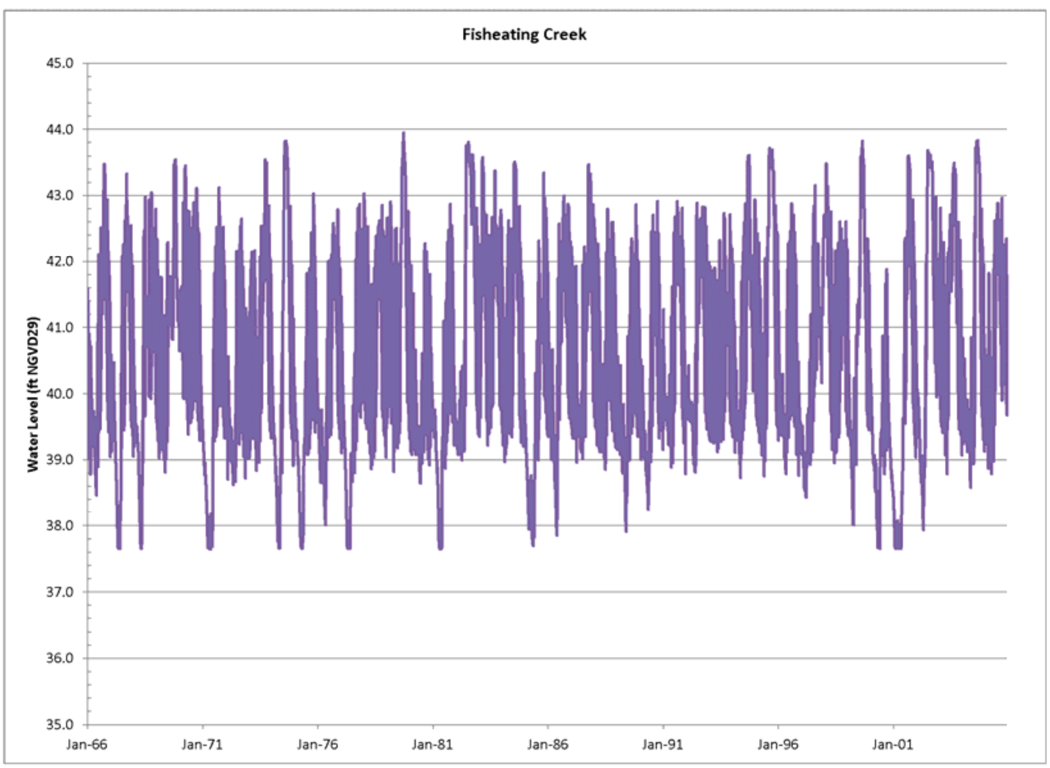


Figure 64. Simulated water level at the Fisheating Creek.

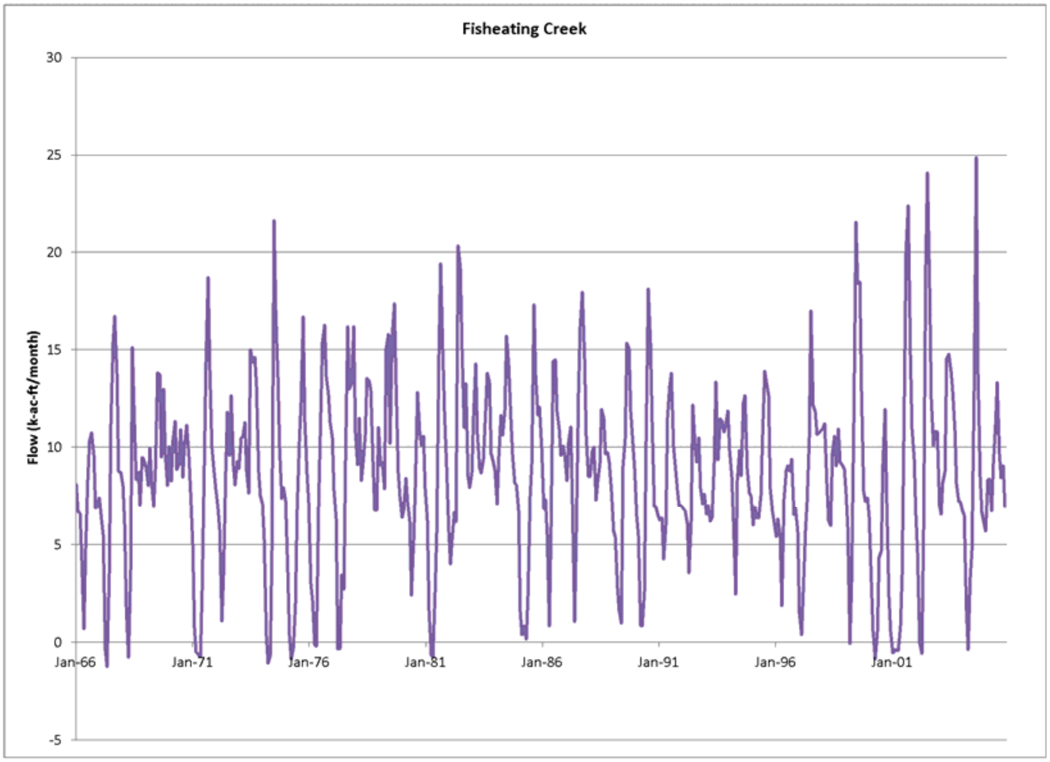


Figure 65. Simulated monthly flow at the Fisheating Creek.

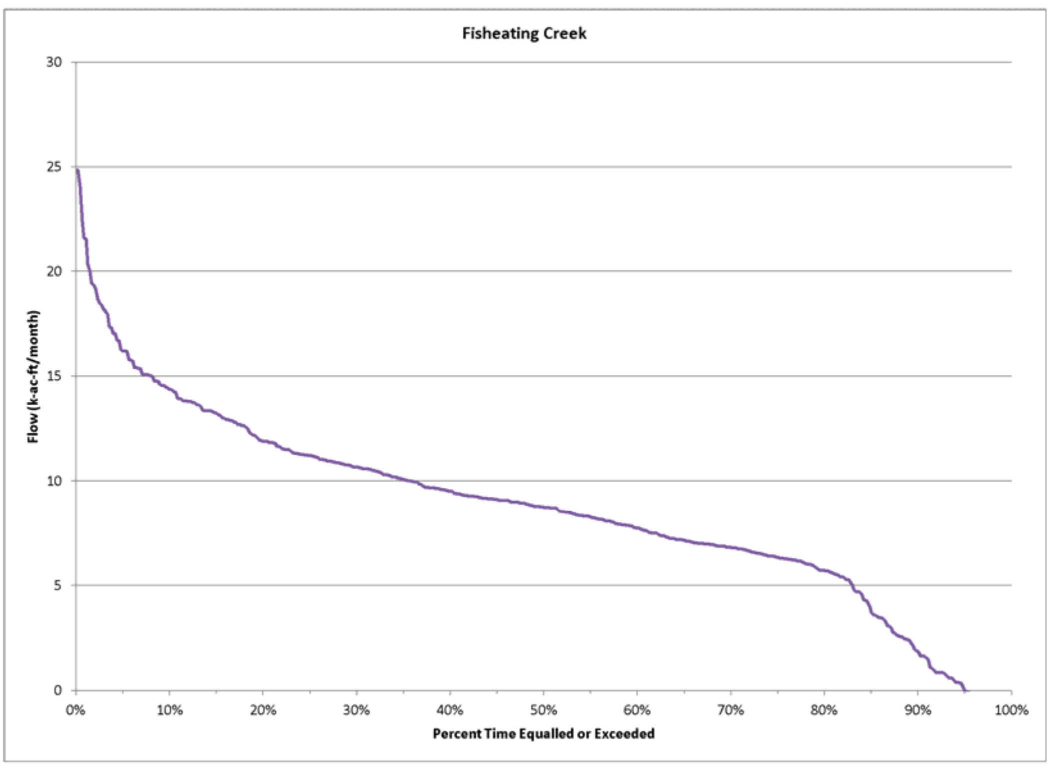


Figure 66. Simulated flow frequency at the Fisheating Creek.

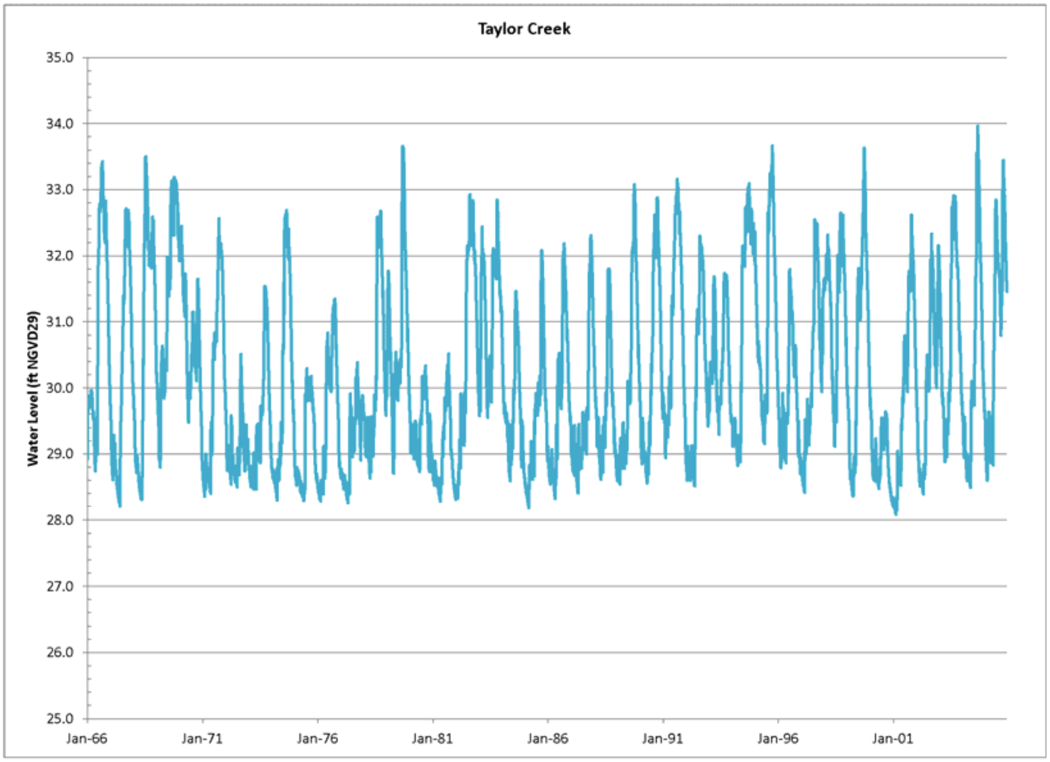


Figure 67. Simulated water level at the Taylor Creek.

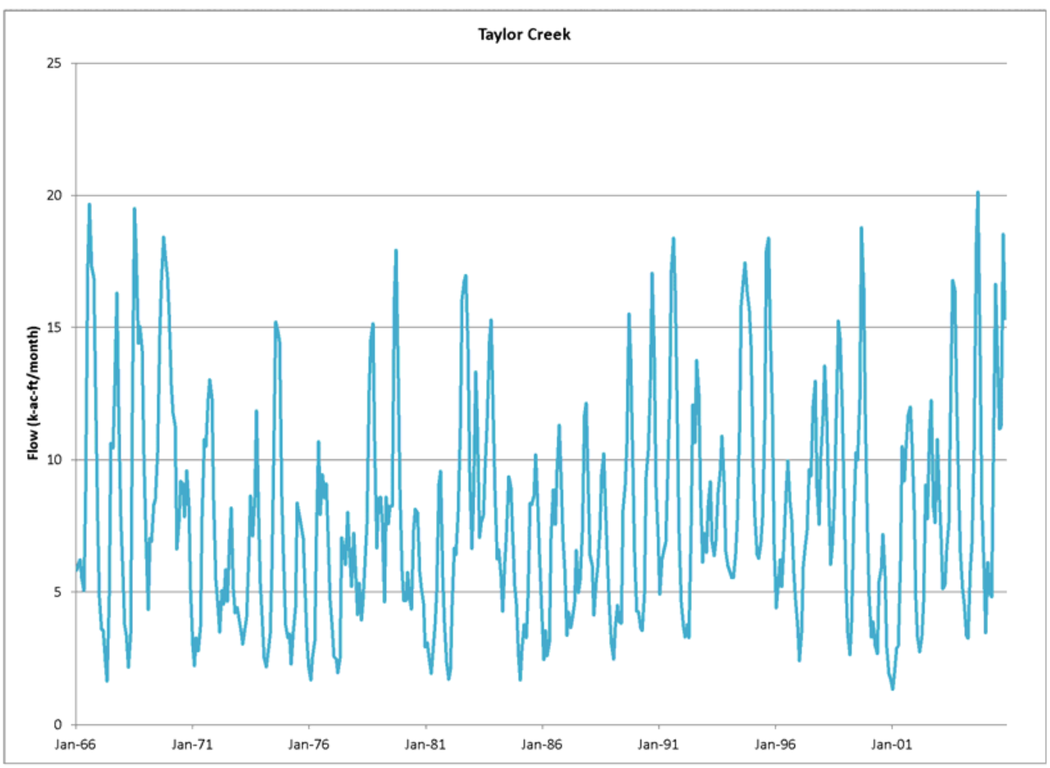


Figure 68. Simulated monthly flow at the Taylor Creek.

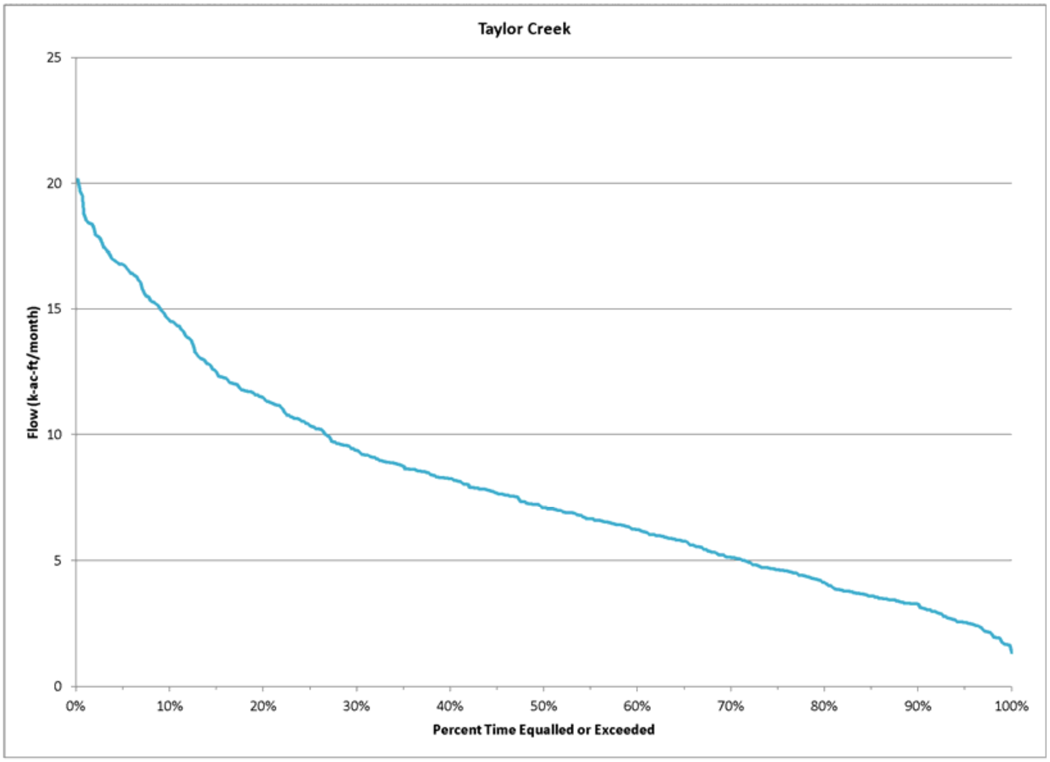


Figure 69. Simulated flow frequency at the Taylor Creek.

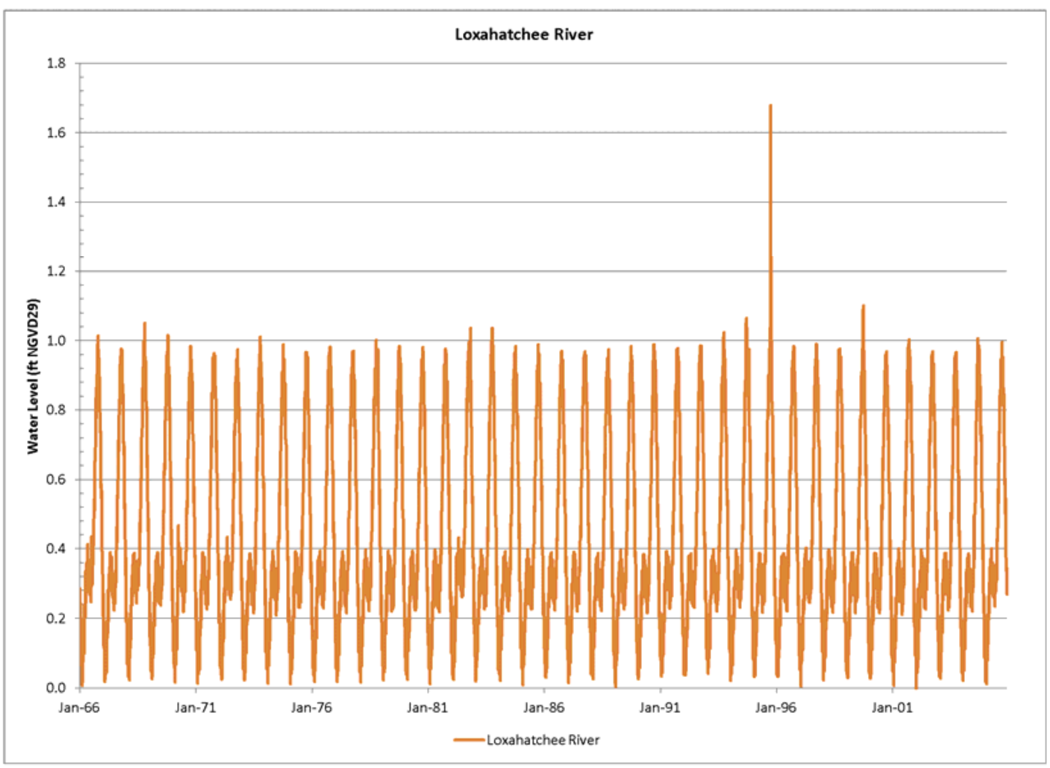


Figure 70. Simulated water level at the Loxahatchee River.

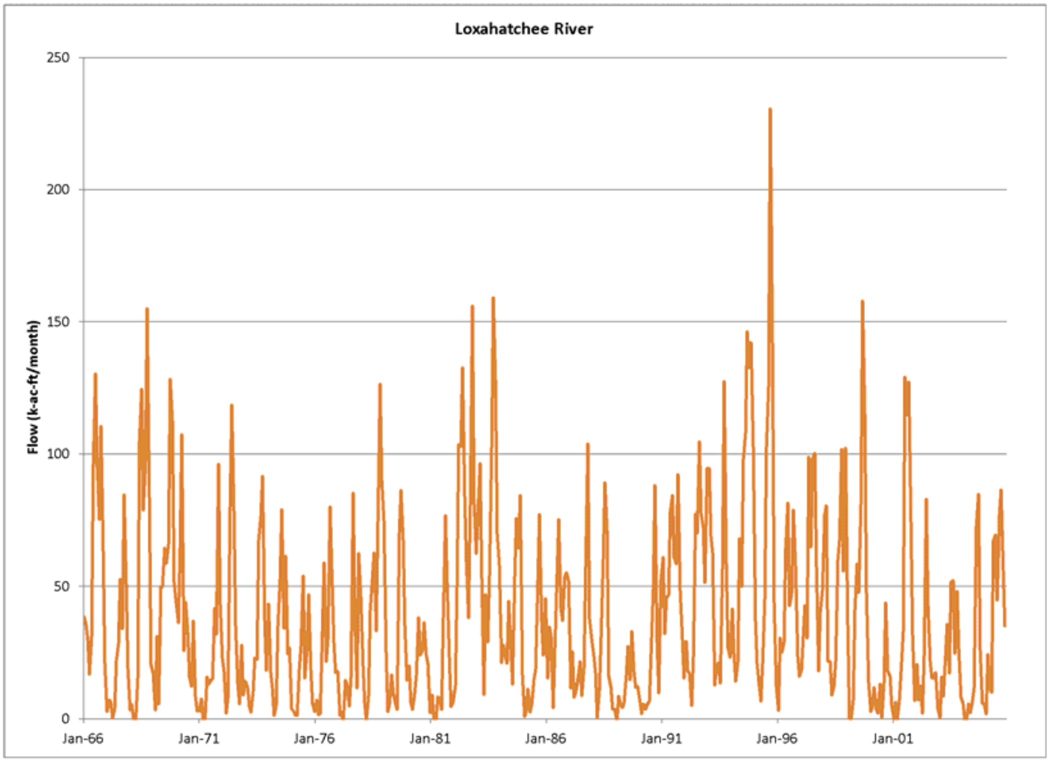


Figure 71. Simulated monthly flow at the Loxahatchee River.

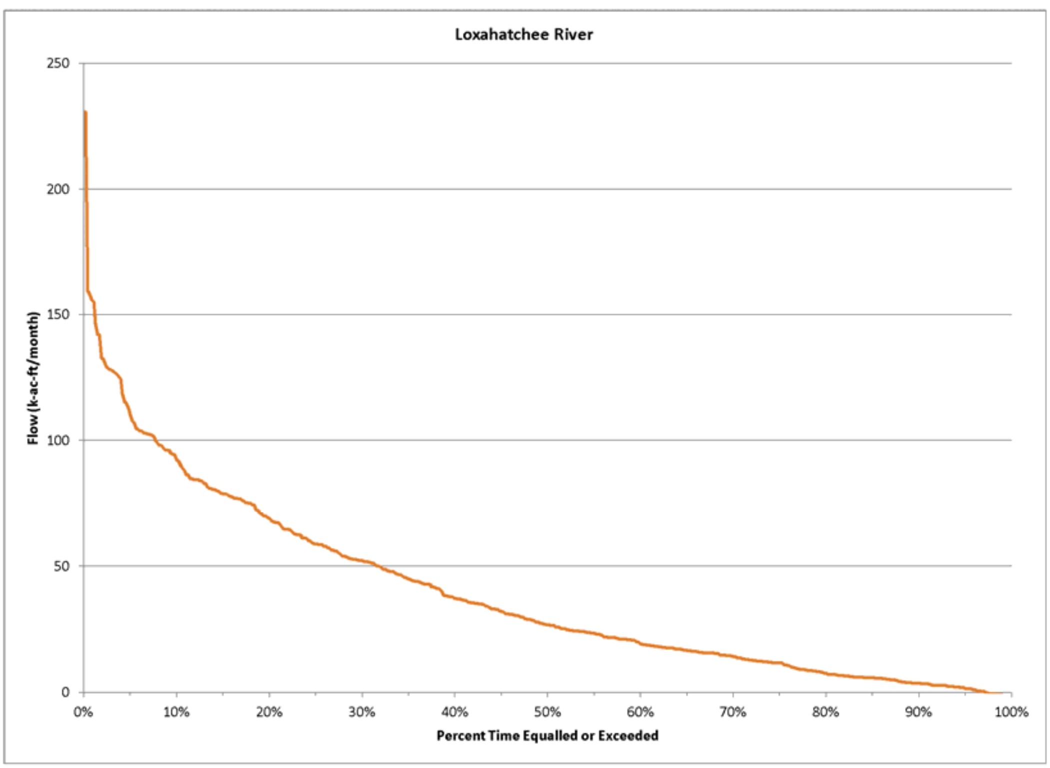


Figure 72. Simulated flow frequency at the Loxahatchee River.

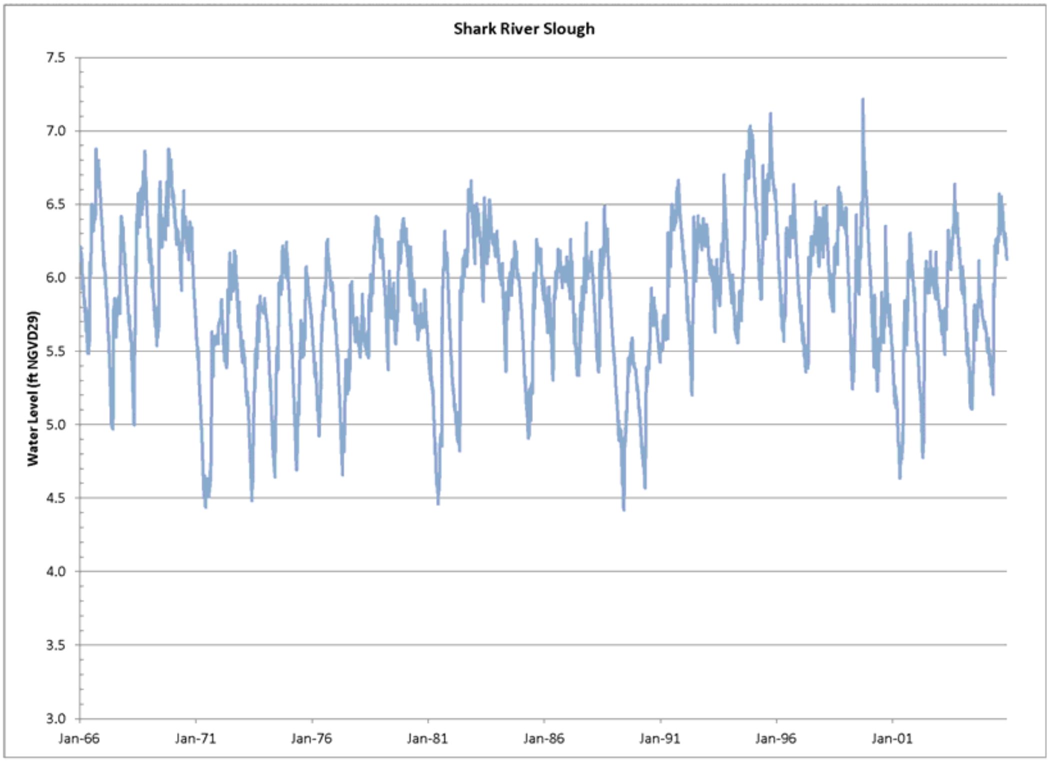


Figure 73. Simulated water level at the Shark River Slough.

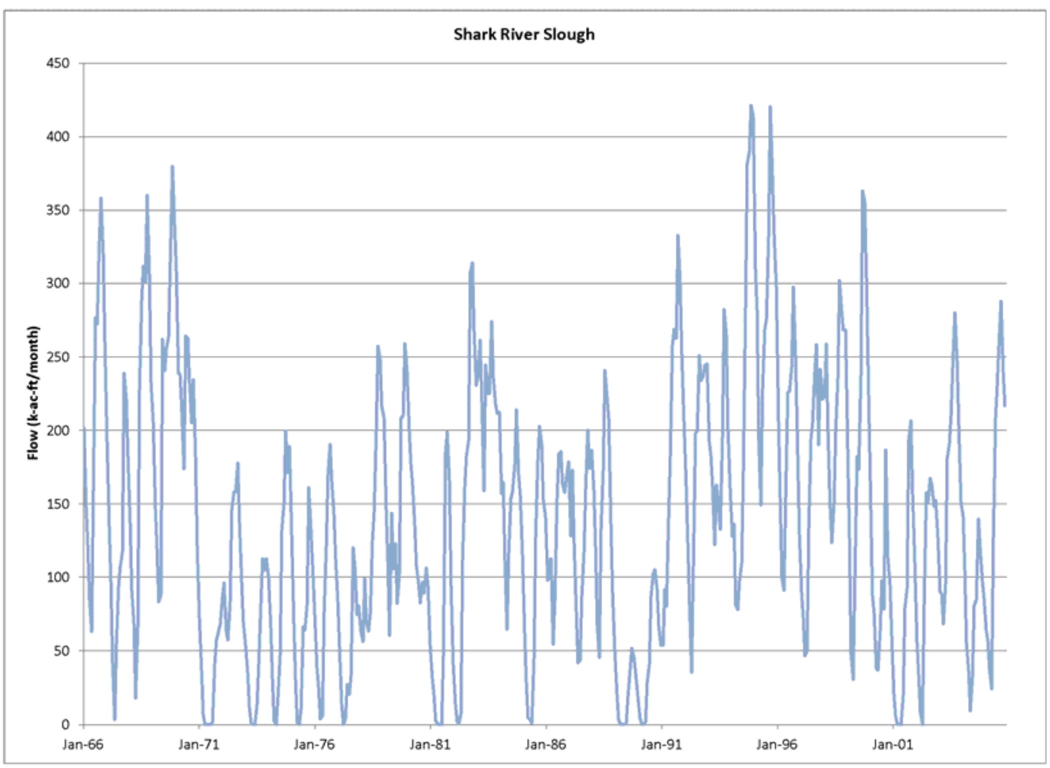


Figure 74. Simulated monthly flow at the Shark River Slough.

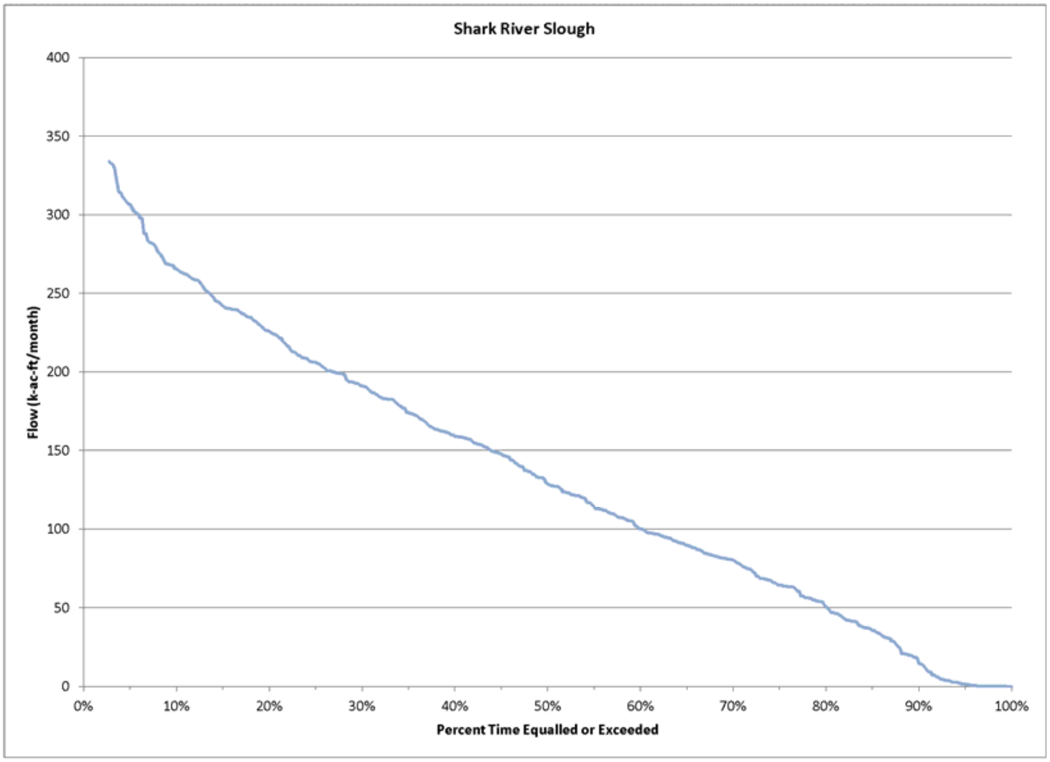


Figure 75. Simulated flow frequency at the Shark River Slough.

Everglades Viewing Windows

The supplemental evaluation tool, Everglades Viewing Windows or "Ever Views", utilizes a viewing window concept linking hydrology and ecology. It facilitates whole system viewing and is neither a performance measure nor target. The "Ever Views" transects are aligned with directionality (Figure 76). Five longitudinal transects are represented in profiles A through E and four transverse transects are represented in transects F through I. Water depth viewing windows are shown for each transect in Figure 77 through Figure 85.

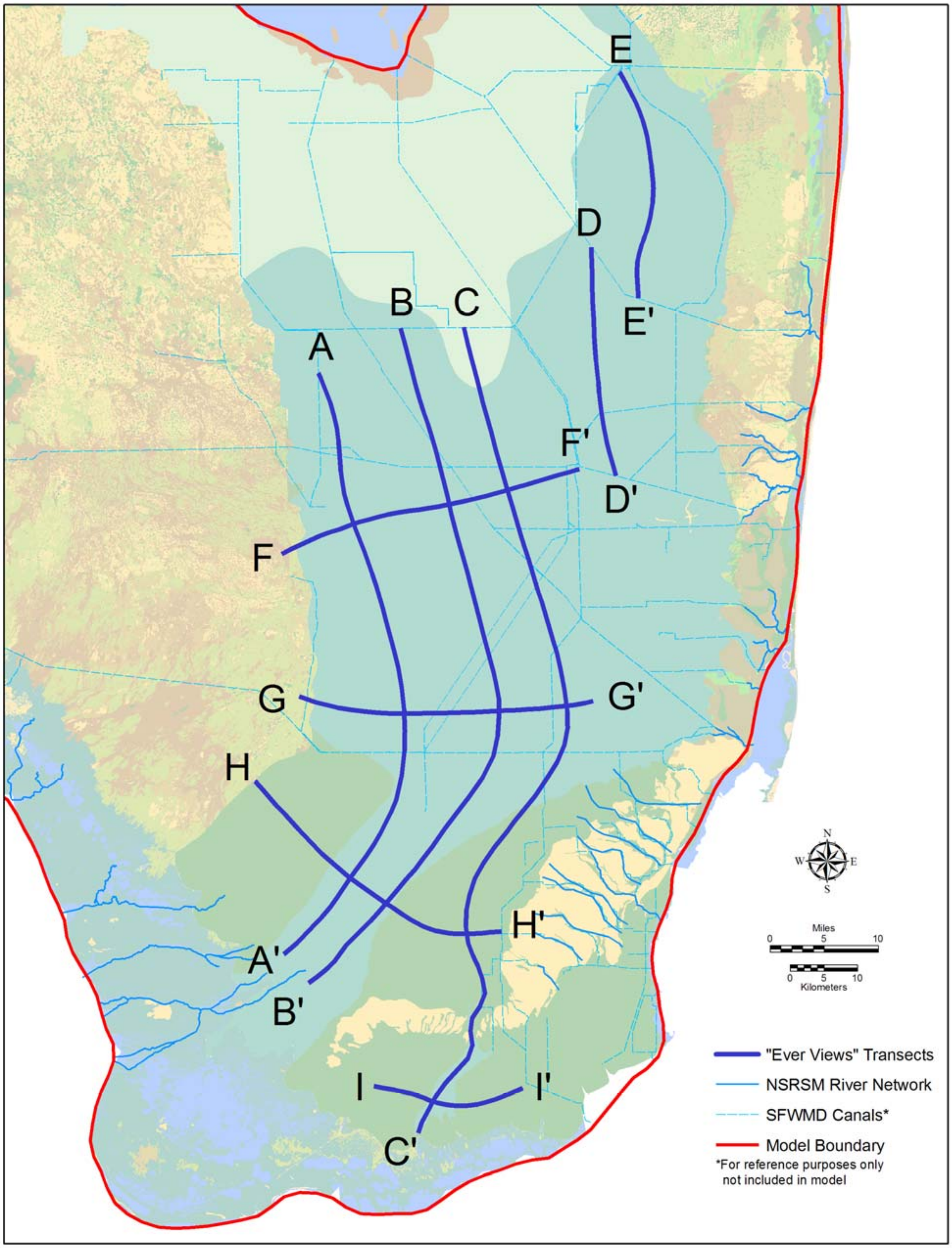


Figure 76. Everglades Viewing Window "Ever Views" transects.

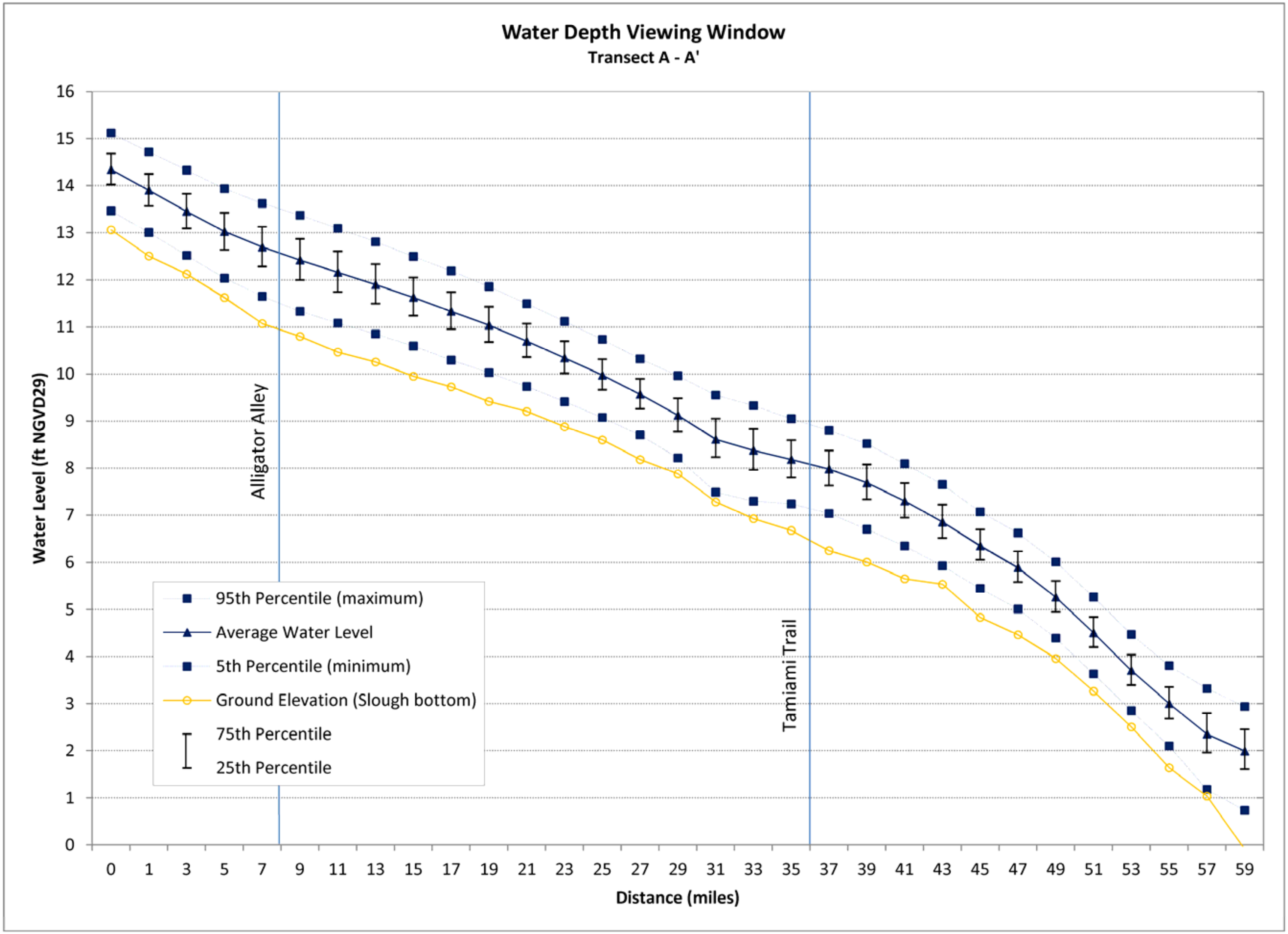


Figure 77. "Ever Views" water depth transect A – A'.

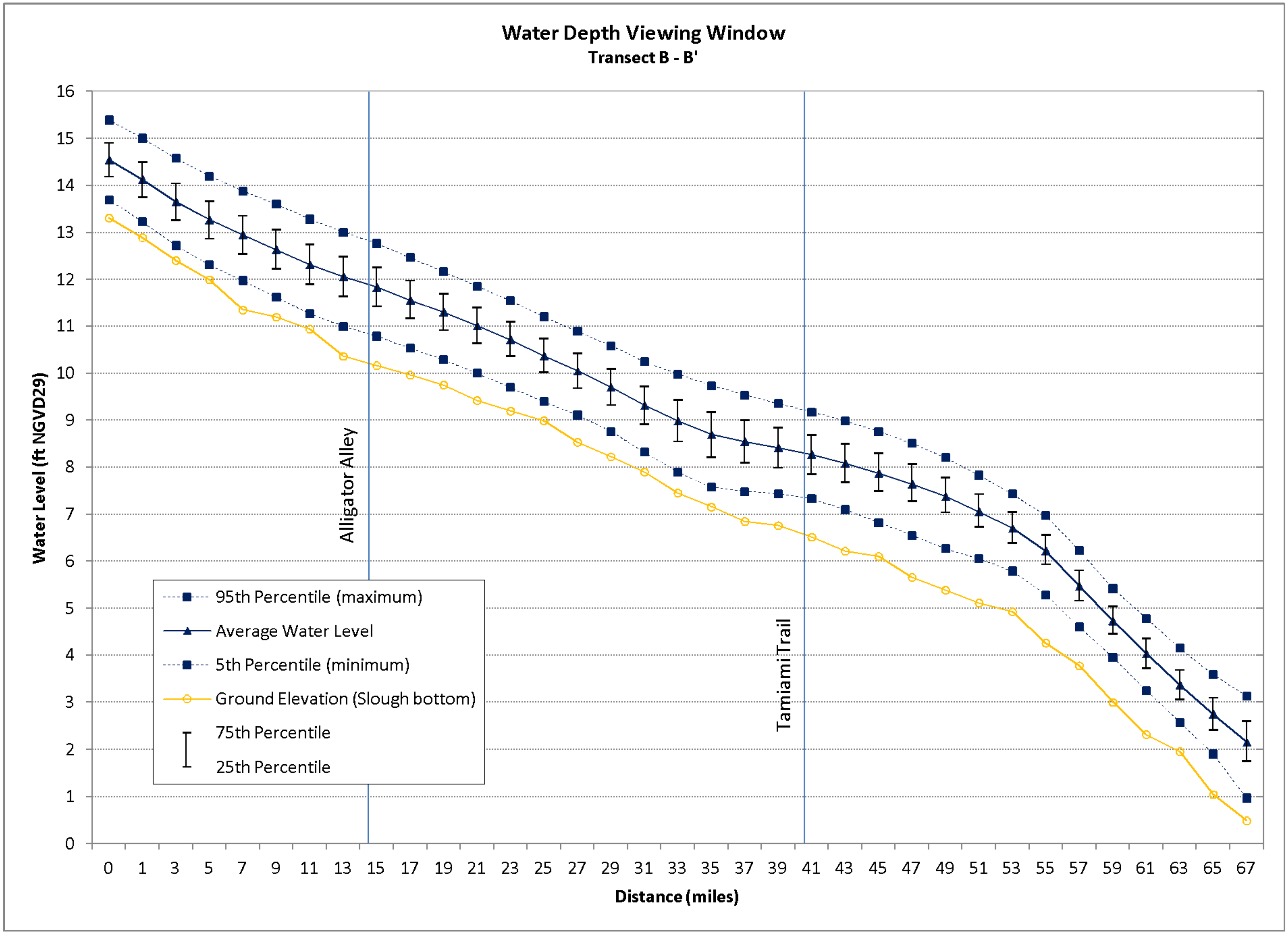


Figure 78. "Ever Views" water depth transect B - B'.

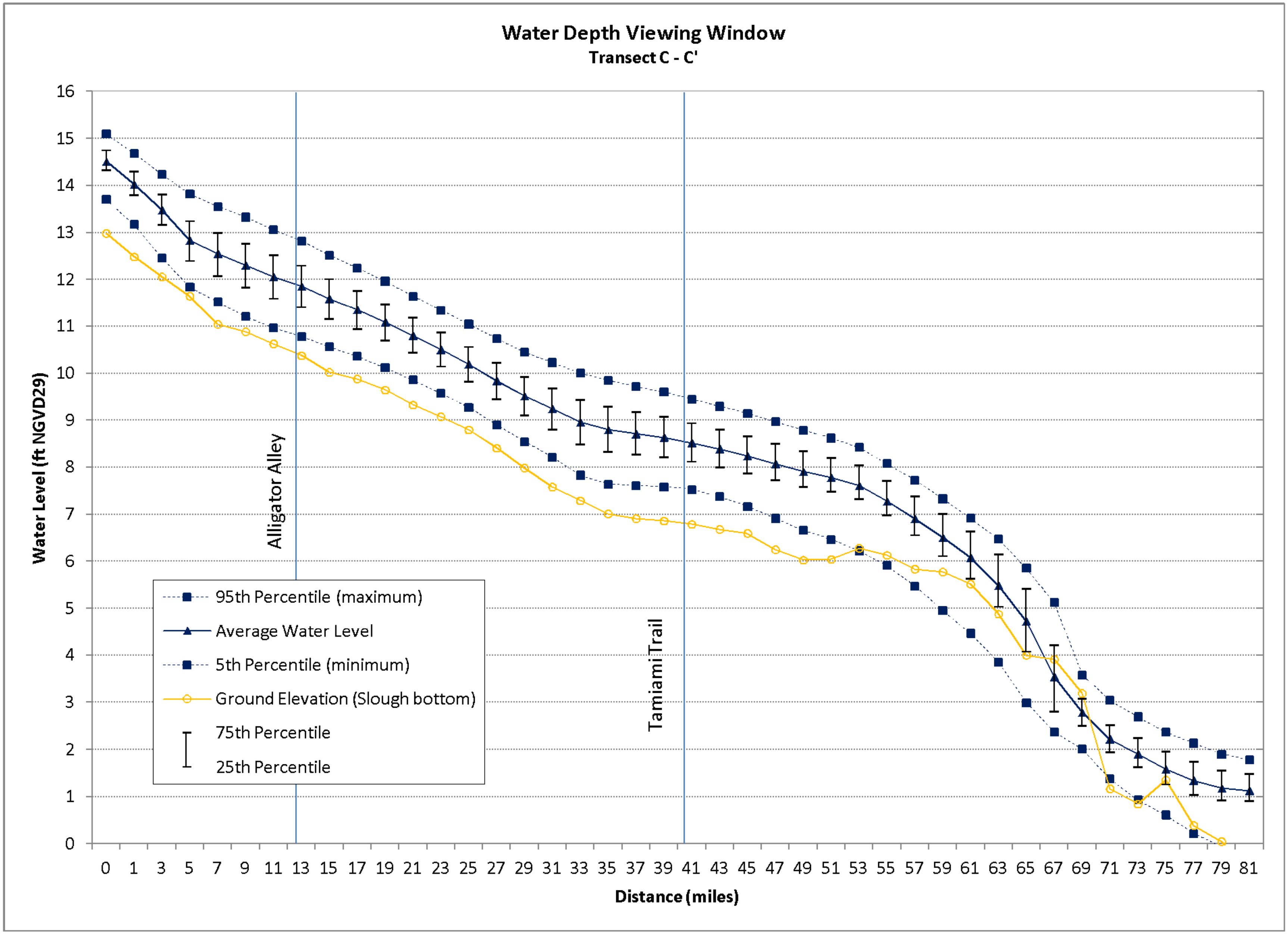


Figure 79. "Ever Views" water depth transect C - C'.

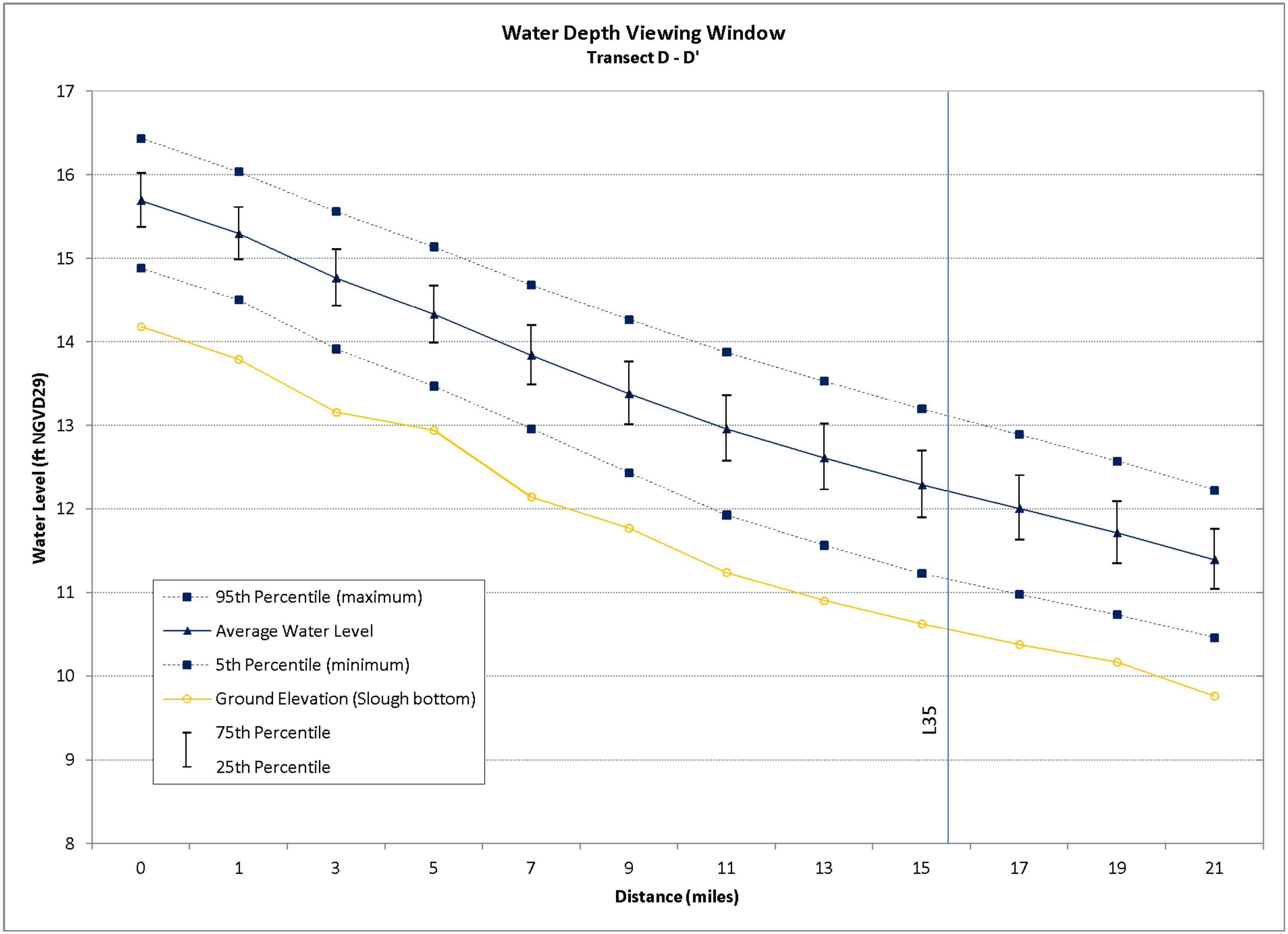


Figure 80. "Ever Views" water depth transect D - D'.

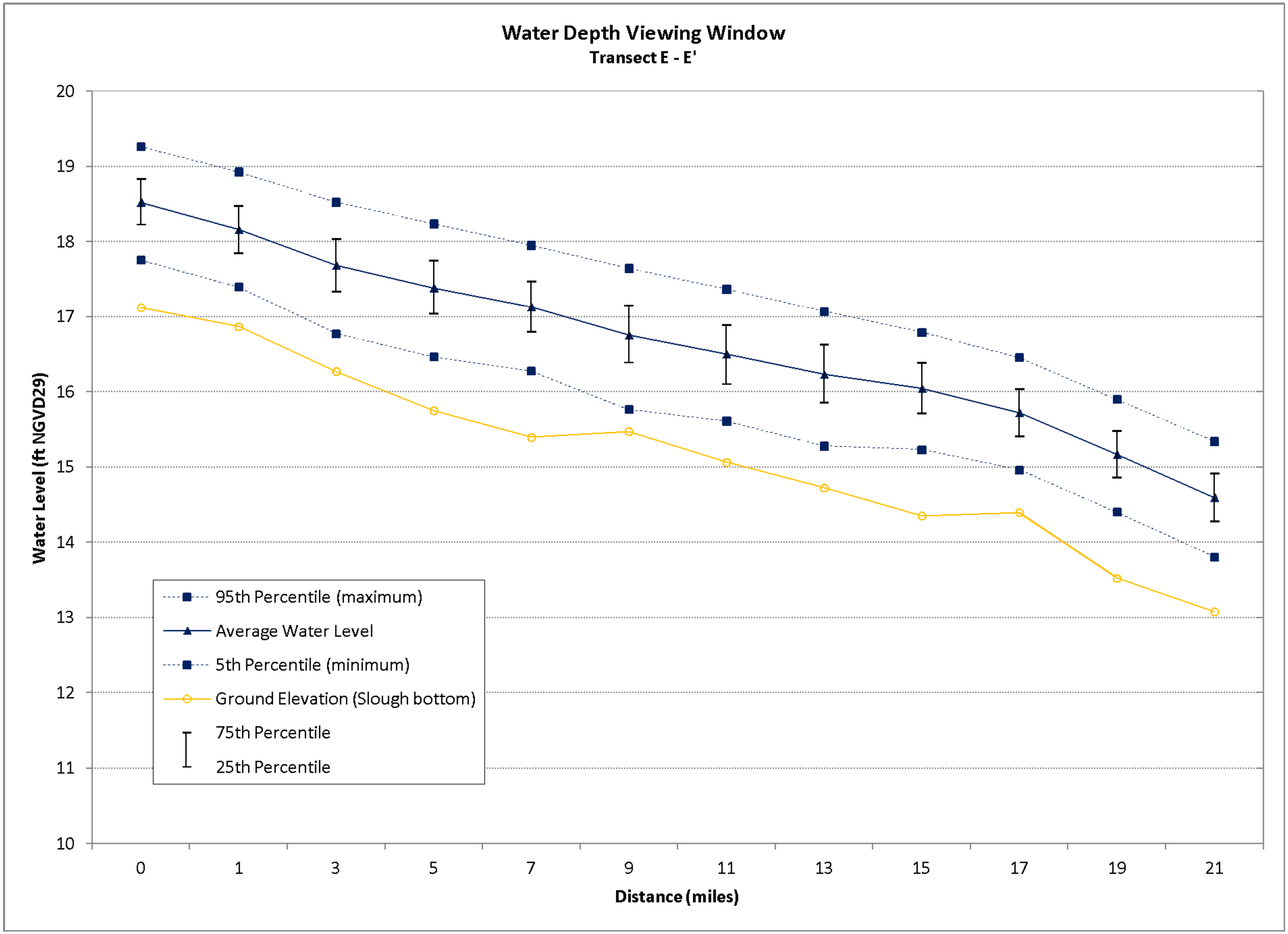


Figure 81. "Ever Views" water depth transect E - E'.

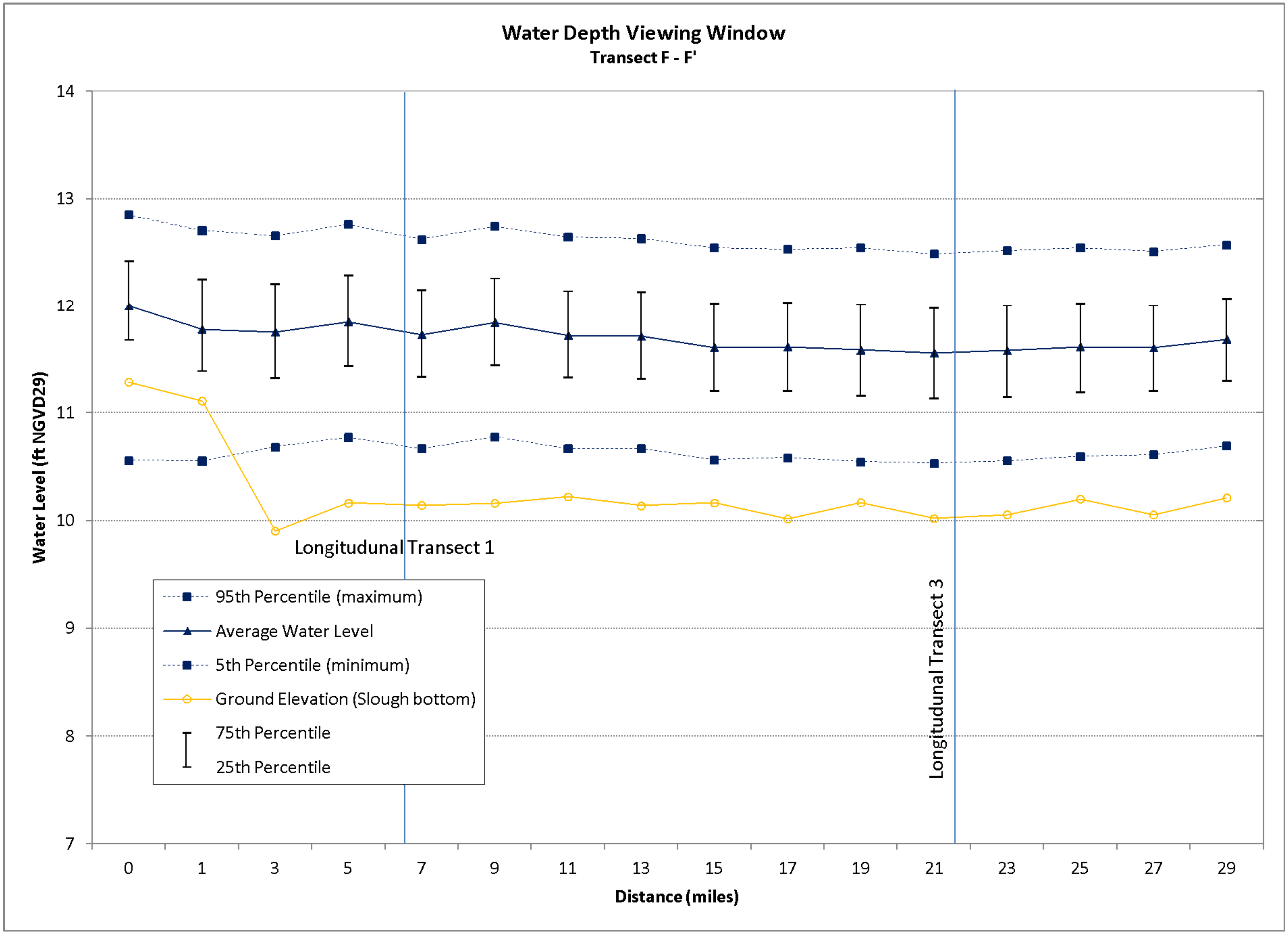


Figure 82. "Ever Views" water depth transect F - F'.

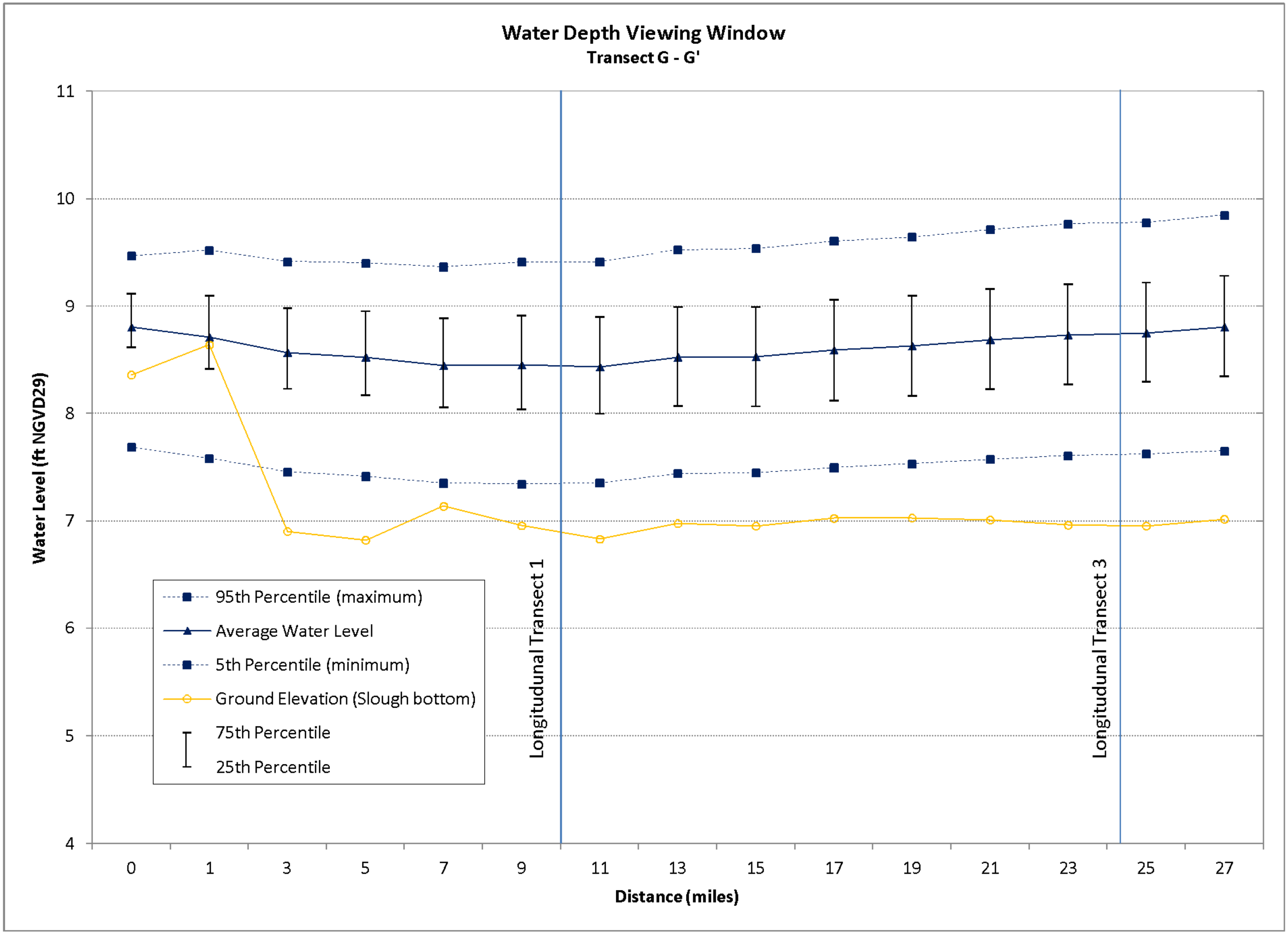


Figure 83. "Ever Views" water depth transect G - G'.

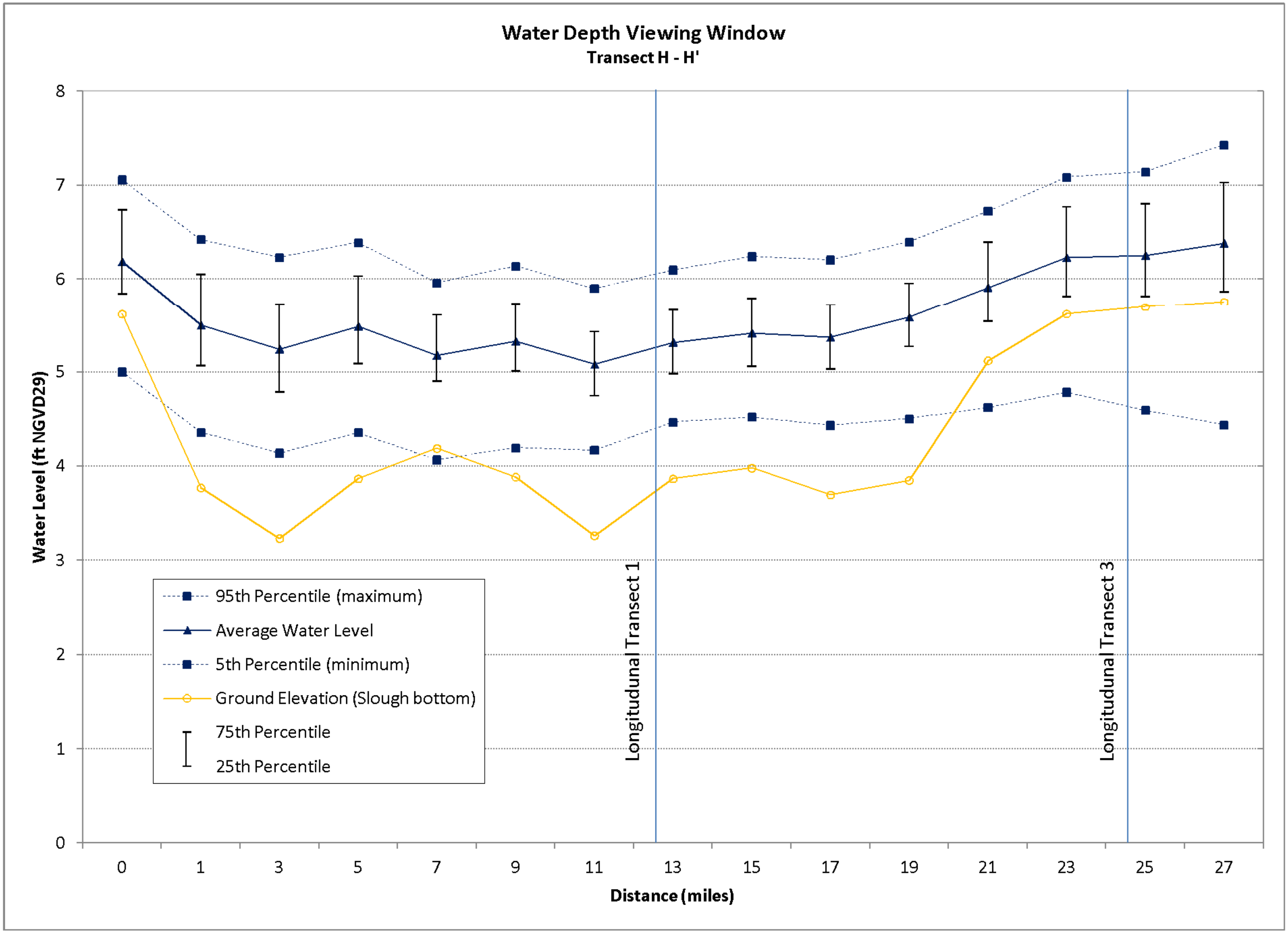


Figure 84. "Ever Views" water depth transect H - H'.

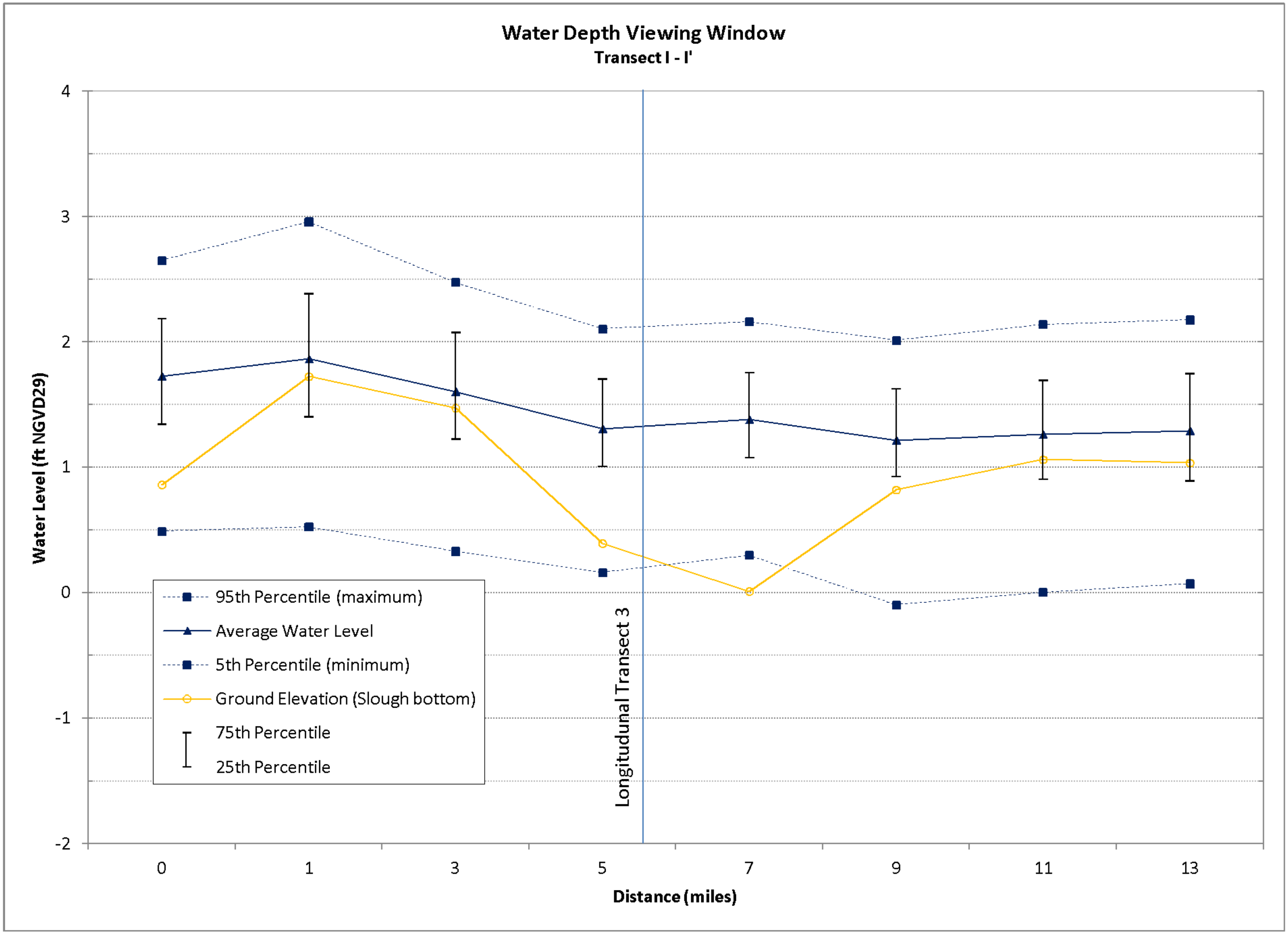


Figure 85. “Ever Views” water depth transect I - I’.

Computed Evapotranspiration (ETc)

Uncertainty for the computed ET (ETc) reference range is moderately high due to the scarcity of landscape specific long-term data for south Florida. Scientists agree that "despite the importance of ET in the Everglades water budget, our knowledge of ET is, at present, only semiquantitative" (German, 2000).

Model results for ETc are available for all monitoring cells. We compared a subset of ridge and slough monitoring cells with USGS data recorded at nine remnant ridge and slough landscape sites (German, 2000). The ETc of Ridge and Slough monitor cells is shown in **Figure 86**. Orange lines indicate the range of observed values considered representative of modeled landscape.

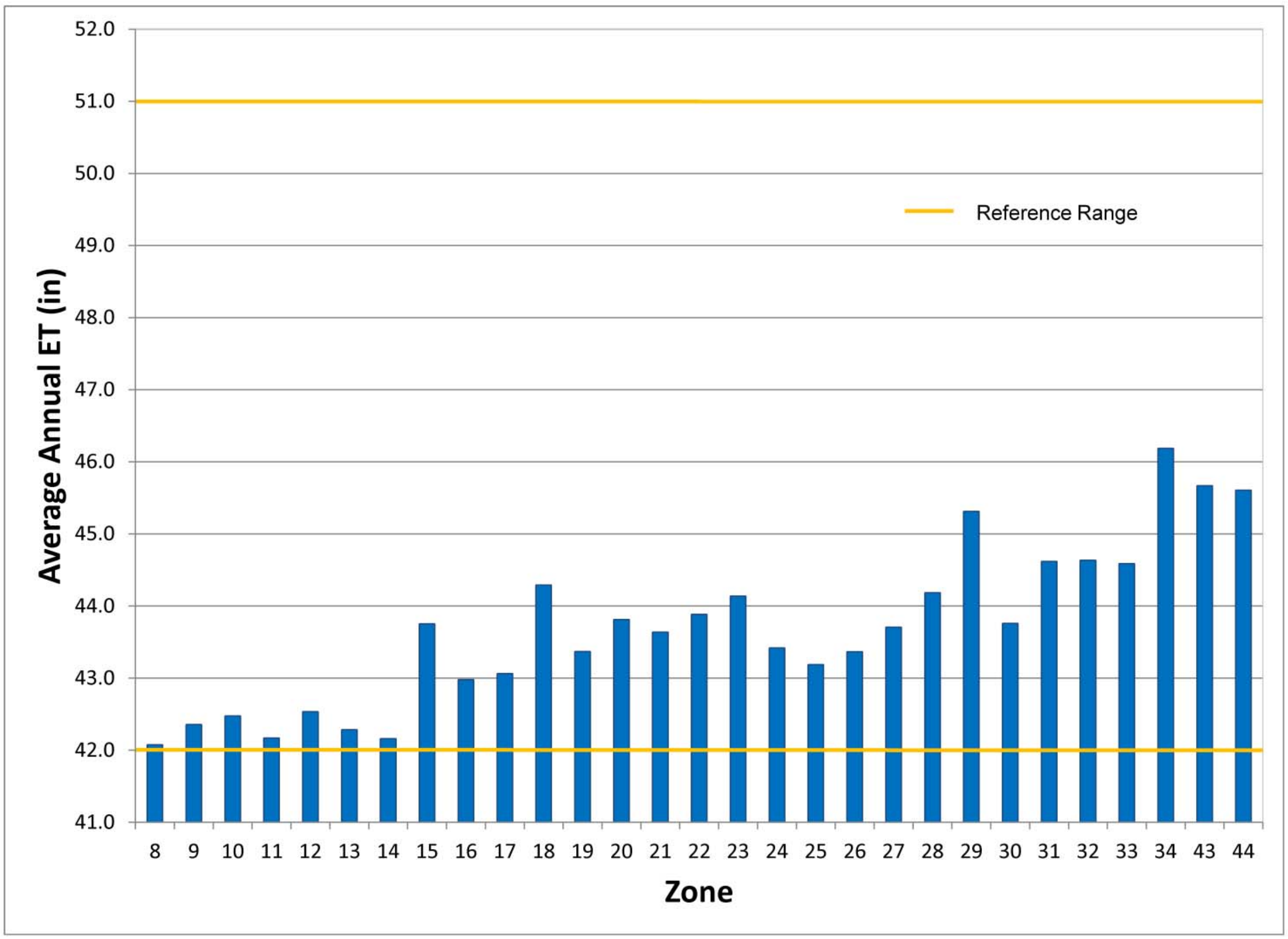


Figure 86. Computed ET (ETc) for Ridge and Slough monitoring cells.

Lake Okeechobee

The spatial extent of Lake Okeechobee has changed significantly from its predevelopment condition **Figure 87.** However, considerable historical information is available to reconstruct the hydrology of predrainage Lake Okeechobee (**Appendix A**).

Figure 87. Lake Okeechobee map issued in 1888: "New sectional map of the eastern and southeastern portion of the State of Florida".

Map Credit: Courtesy of the Special Collections Department, University of South Florida.

Lake stage performance is measured in the graph shown in **Figure 88**. The average annual stage is shown in yellow and is within the reference range (green lines).

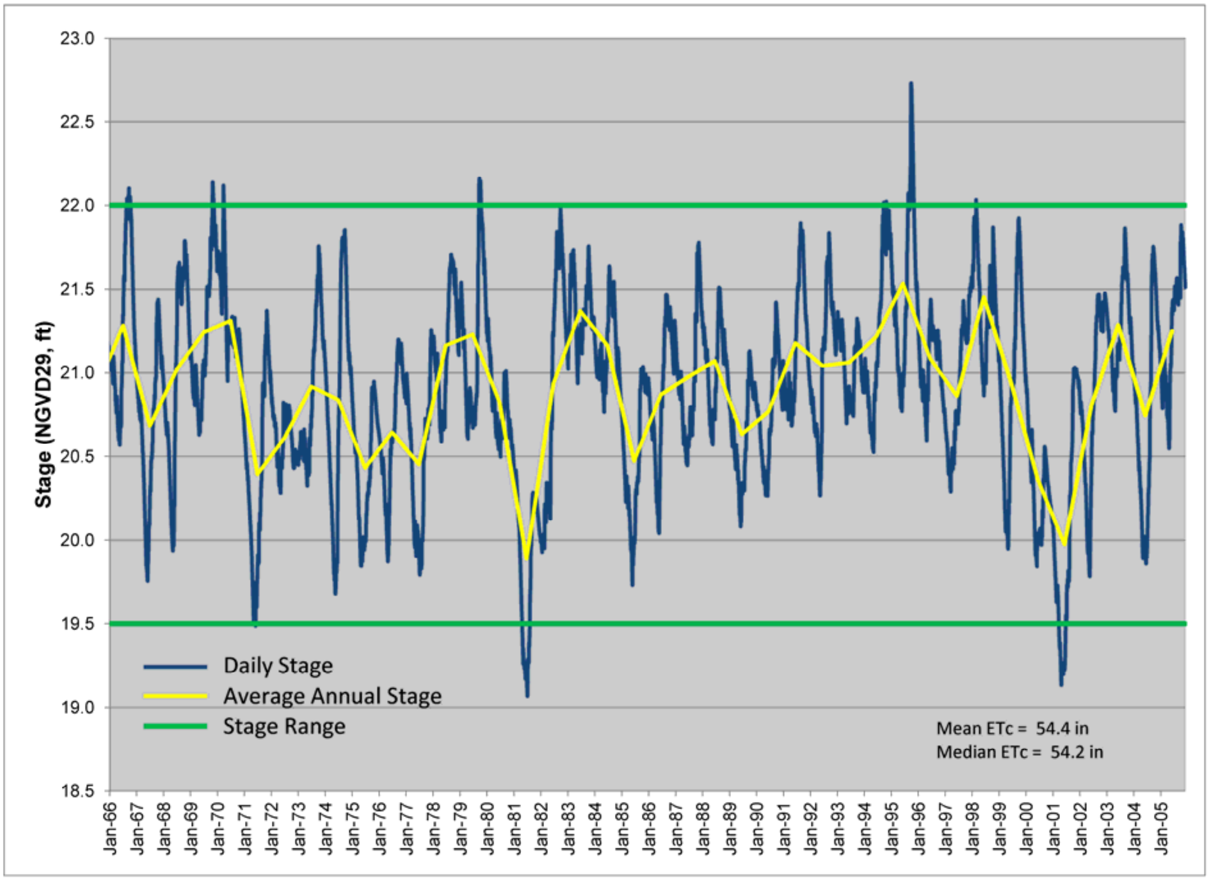


Figure 88. Lake Okeechobee stages.

Studies conclude that inflows from the northwest (Lake Istokpoga/Indian Prairie) rim and outflows from the south rim occurred annually and were substantial (**Appendix A**). Since no quantitative historical data exists for annual average inflows and outflows, no reference ranges are provided for the lake water budget. The simulated water budget is shown in **Figure 89**. The annual average reference ETc for Lake Okeechobee is 53 in. ± 1 in. (Abtew *et al.* 2003). The simulated average annual ETc of 54 in. is within the reference range. The monthly flow and flow frequency of water fom Lake Okeechobee to the Everglades is shown in Figure 90 and Figure 91.

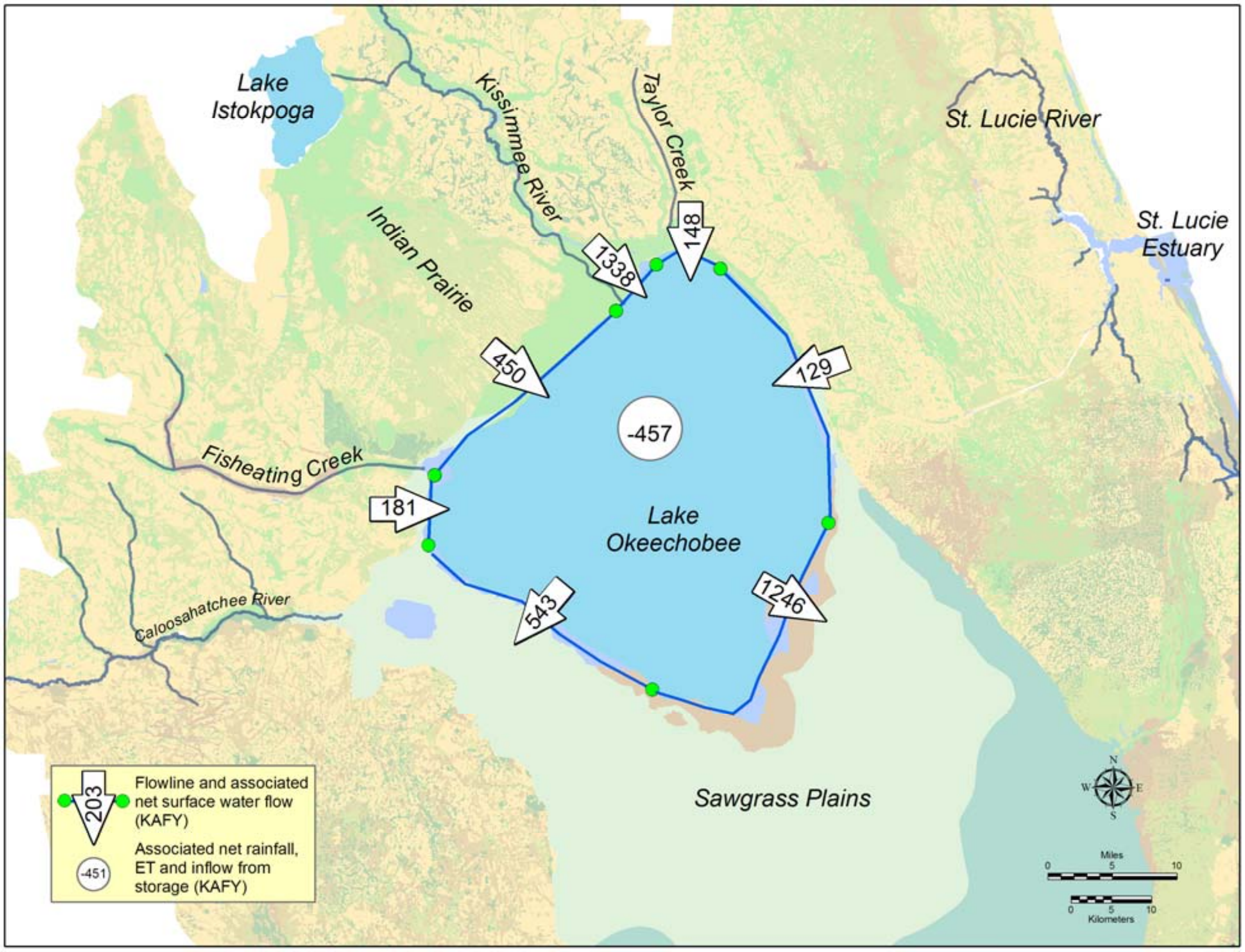


Figure 89. Simulated water budget for Lake Okeechobee.

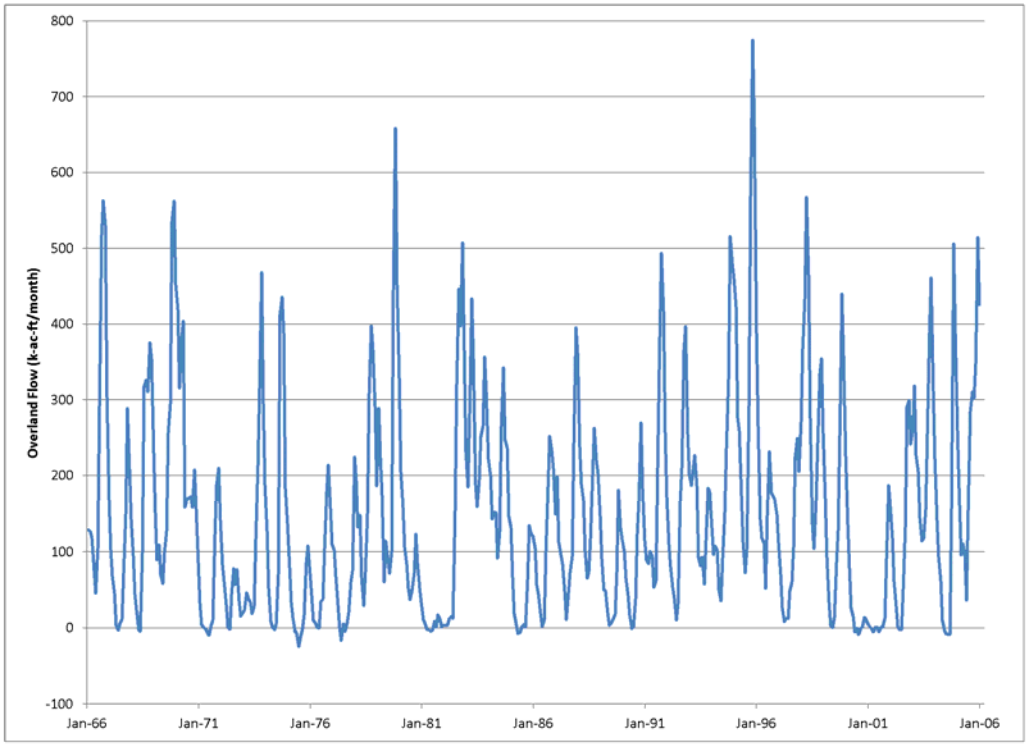


Figure 90. Simulated monthly flow for Lake Okeechobee to the Everglades.

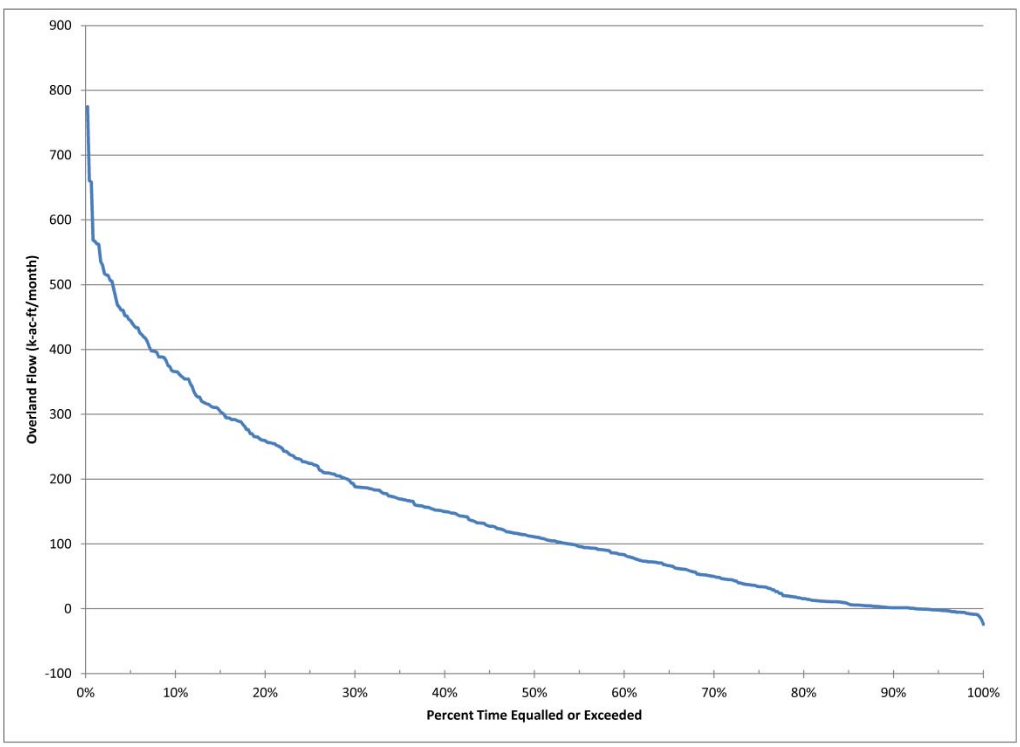


Figure 91. Simulated flow frequency for Lake Okeechobee to the Everglades.

Overland Flow Transects

Transect locations are shown in **Figure 92**. Note that reference values do not exist for transect flows. The graph, **Figure 93**, and associated table, **Table 23**, compares NSRSM v3.5.2 results to NSM v4.6.2 Sens 4 flow output.

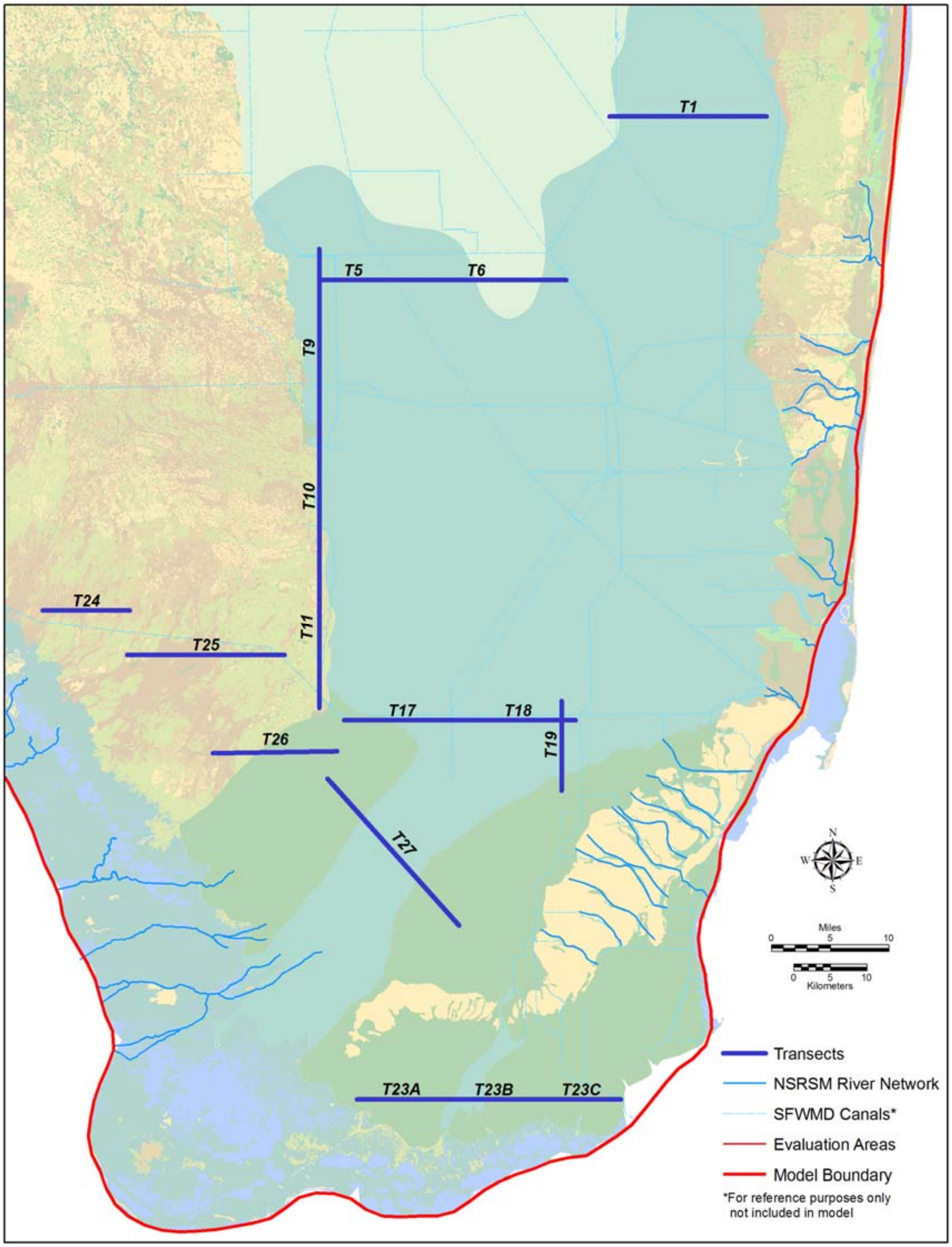


Figure 92. Transect locations.

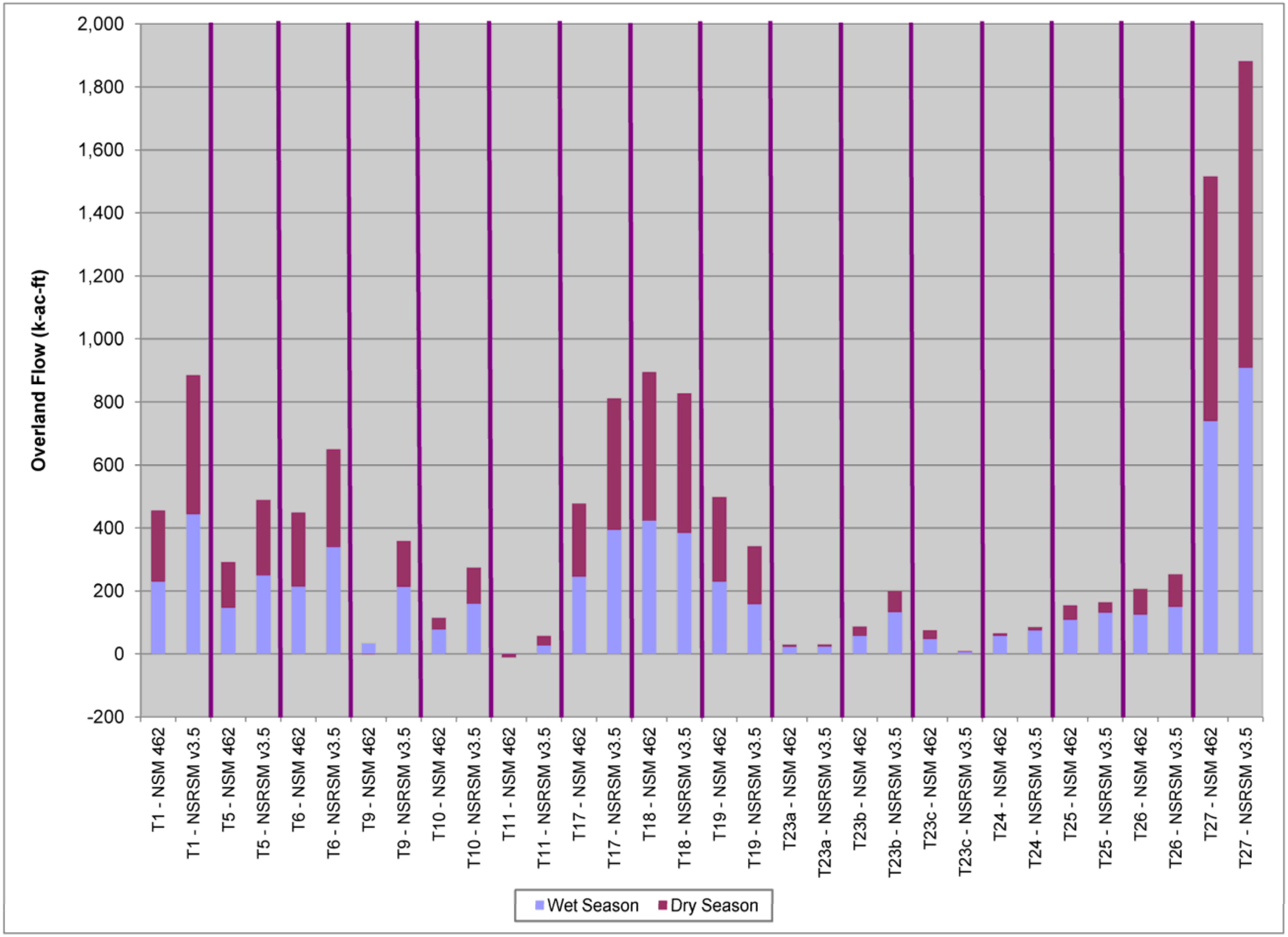


Figure 93. Simulated overland transect flow (1966-2005).

Table 23. Tabular overland flow values (k-ac-ft) corresponding to Figure 93.

	T1	T5	T6	T9	T10	T11	T17	T18	T19	T23a	T23b	T23c	T24	T25	T26	T27
NSRSM v3.5.2 (1966–2000) Wet Season	443	249	339	213	159	26	394	383	157	23	132	7	75	131	149	908
NSRSM v3.5.2 (1966–2000) Dry Season	442	239	310	145	115	31	418	444	185	7	68	2	11	33	103	973
NSMSENS4 (1965–2000) Wet Season	230	138	141	54	47	-14	244	311	188	18	47	40	60	167	158	641
NSMSENS4 (1965–2000) Dry Season	232	145	142	38	26	-17	213	300	183	6	22	25	10	96	110	603
NSM462 (1965–2000) Wet Season	229	146	214	33	78	2	245	423	229	22	57	47	57	108	124	739
NSM462 (1965–2000) Dry Season	227	146	235	-1	36	-11	232	472	269	7	30	29	9	46	83	777

Overland Flow Vectors

Quantative data for overland flow velocities were measured by the USGS in Shark River Slough and within present day Water Conservation Area 3 (Harvey *et al.,* 2009). A subset of Ridge and Slough monitoring cells were compared with USGS measured data and summarized in **Table 24**. The velocities of Ridge and Slough and Shark River Slough monitor cells are shown in **Figure 94**. Orange lines indicate the range of observed values considered representative of modeled landscape.

Table 24. Comparison of USGS flow velocity data and NSRSM simulation results.

Metric	USGS Data	NSRSM Data
Ridge and Slough - Mean Velocity	0.32 cm/s	0.35 cm/s
Ridge and Slough - Velocity Range	0.02 to 0.79 cm/s	0.00 to 0.73 cm/s
Shark Slough - Velocity Range	0.2 to 2.43 cm/s	0.0 to 1.97 cm/s

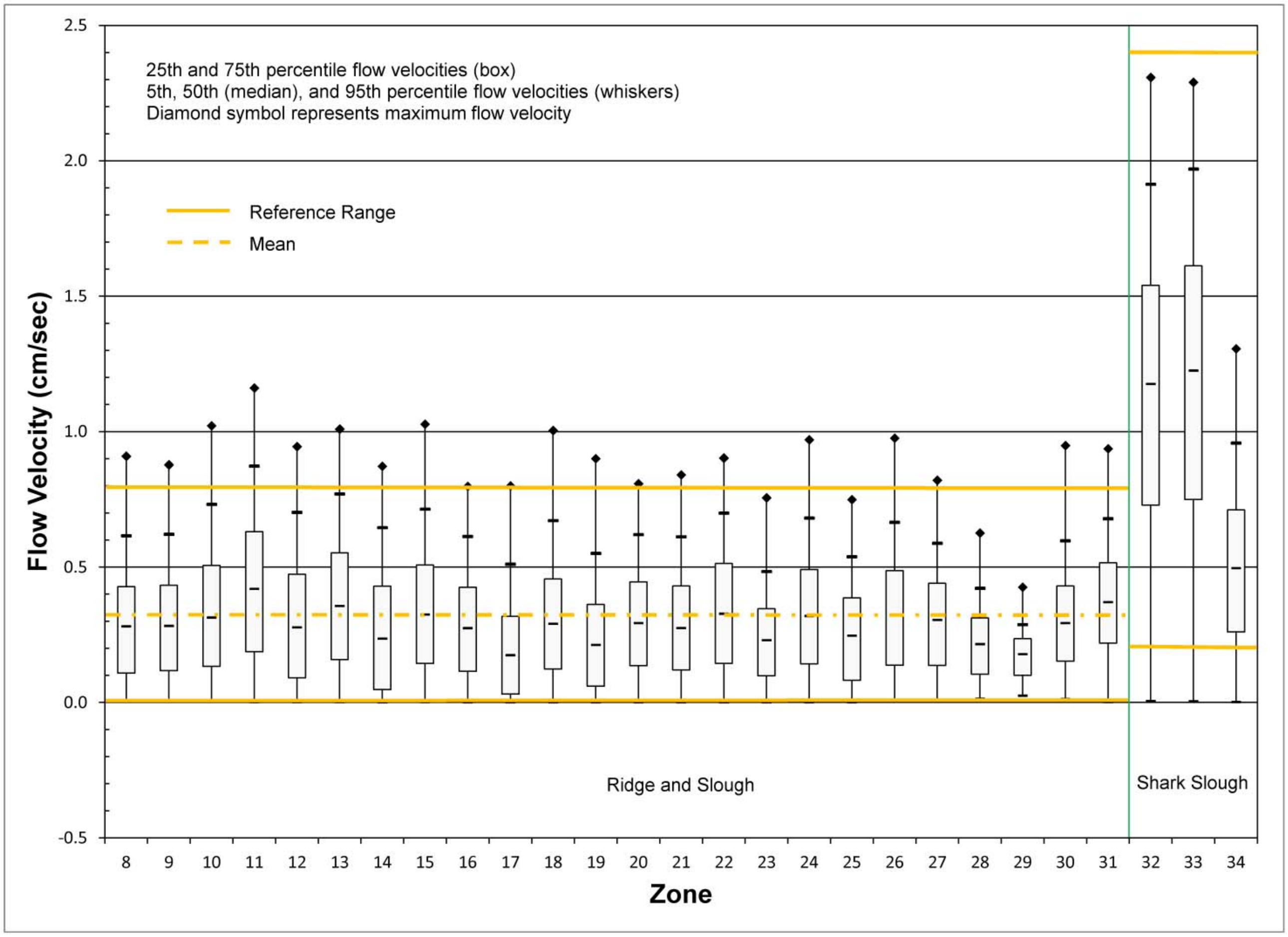


Figure 94. Computed flow velocities for Ridge and Slough monitor cells.

A comparison of seasonal long-term monthly averages of overland flow vectors is shown in **Figure 95**. The image on the left depicts the dry season (November–April), and the image on the right features the wet season (May–October).

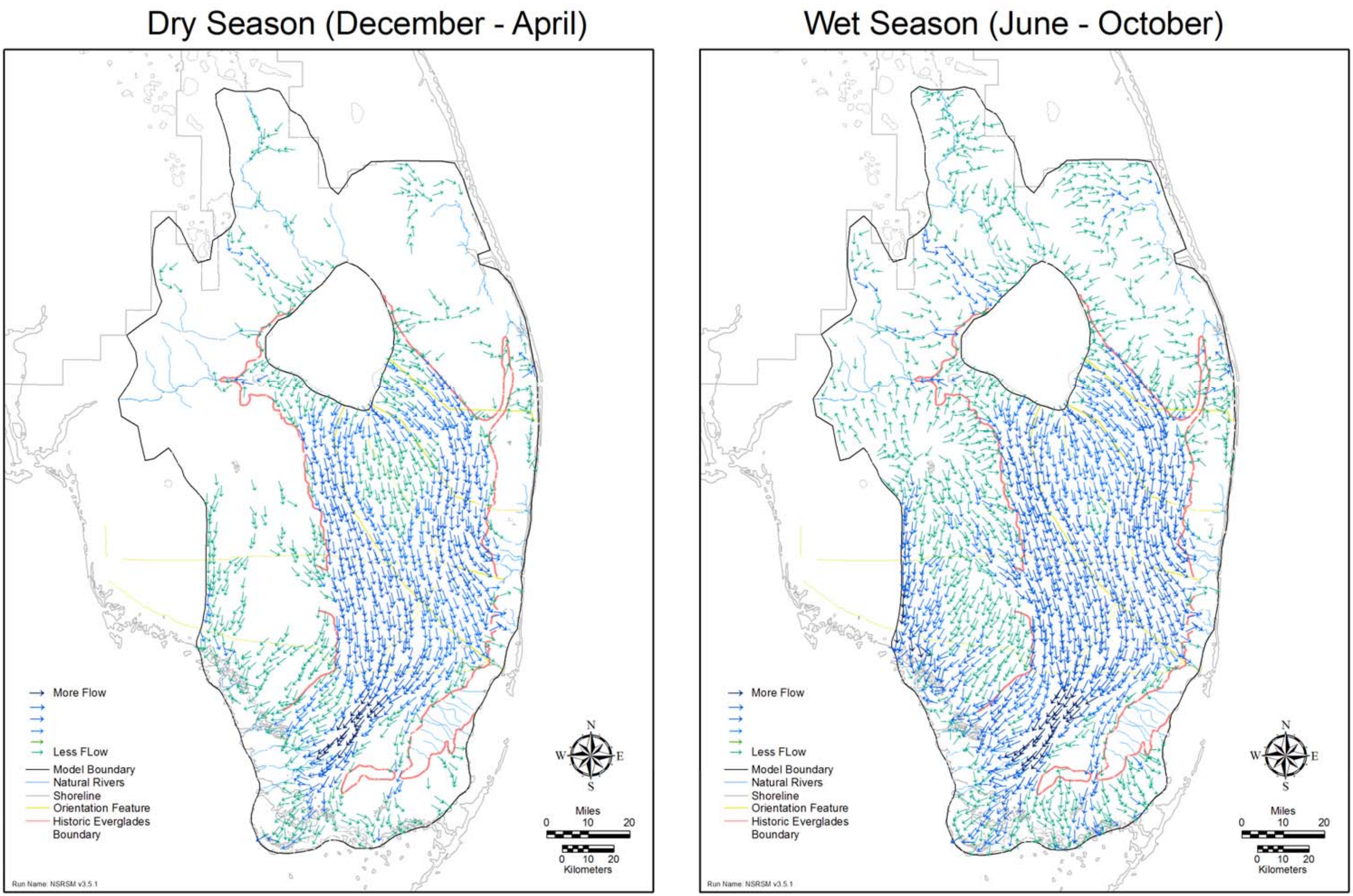


Figure 95. NSRSM v3.5.2 long-term (1966–2005) average of monthly flow vectors for the dry and wet seasons.

Simulated Water Budget

The volumetric budget for the model is computed from all inflows and outflows at the model boundaries. The simulated annual average (1966-2005) water budget (k-ac-ft) is shown in **Table 25**. The inflows are rainfall and flow boundary conditions (Source BC); the outflows for the model are ET and water level boundary conditions (Head BC). The residual is computed by the model and storage is the change in volume.

Table 25. Simulated water budget (k-ac-ft) for entire model.

Year	Rainfall	ET	Head BC	Source BC	Residual	Storage	Inflow-Outflow	Percent Discrepancy
1966	39018.8	-26637.1	-14028.4	1192.7	0.0	453.9	0.0	0.00%
1967	32278.0	-26160.7	-7006.4	812.8	0.0	76.4	0.1	0.00%
1968	39815.4	-26653.8	-13741.9	993.3	0.0	-412.1	0.8	0.00%
1969	42325.5	-26264.5	-14374.3	1159.1	0.0	-2845.0	0.9	0.00%
1970	34649.9	-29102.8	-11644.9	1046.3	0.0	5050.6	-1.0	0.00%
1971	32269.7	-26631.1	-4506.8	328.7	0.0	-1460.7	-0.1	0.00%
1972	32200.0	-27871.2	-6379.3	537.4	0.0	1513.4	0.1	0.00%
1973	34469.2	-26532.1	-7223.3	1151.6	0.0	-1866.7	-1.4	0.00%
1974	32370.8	-27118.9	-6492.9	898.7	0.0	344.4	2.1	0.01%
1975	31141.2	-27880.9	-5422.5	697.1	0.0	1465.3	0.2	0.00%
1976	33942.8	-26600.8	-7088.2	782.0	0.0	-1035.7	0.1	0.00%
1977	32440.5	-27903.8	-4213.4	629.0	0.0	-952.8	-0.4	0.00%
1978	36115.0	-27332.2	-8250.0	1195.4	0.0	-1728.7	-0.5	0.00%
1979	35322.1	-27496.1	-9124.1	1292.9	0.0	5.5	0.3	0.00%
1980	29846.0	-27699.7	-6218.7	528.1	0.0	3543.8	-0.6	0.00%
1981	28930.0	-26291.6	-4764.6	350.6	-0.1	1774.7	-1.0	0.00%
1982	40691.9	-26354.0	-11308.5	1237.8	0.0	-4268.6	-1.4	0.00%
1983	42342.5	-27260.1	-14701.9	1271.1	0.0	-1649.7	1.9	0.00%
1984	31108.6	-26921.3	-8158.4	979.3	0.0	2991.1	-0.6	0.00%
1985	31461.0	-26269.1	-5549.4	578.1	0.0	-220.0	0.7	0.00%
1986	34630.4	-26035.4	-7337.7	767.3	-0.1	-2024.1	0.4	0.00%
1987	32065.0	-26431.8	-6902.3	913.0	0.0	357.1	0.9	0.00%
1988	30205.2	-26439.6	-7750.7	1185.9	0.0	2799.2	0.0	0.00%
1989	27929.3	-25720.2	-3202.0	754.7	0.0	239.4	1.1	0.00%
1990	29185.3	-25938.7	-4142.1	884.8	0.0	12.9	2.1	0.01%
1991	39188.9	-26149.7	-11778.2	921.5	0.1	-2182.8	-0.2	0.00%
1992	35794.1	-26644.2	-9843.8	879.3	0.0	-185.0	0.4	0.00%
1993	35320.9	-27015.2	-9855.5	800.2	0.0	749.3	-0.2	0.00%

1994	44730.5	-26366.9	-13602.1	1082.8	0.0	-5843.1	1.2	0.00%
1995	42191.9	-26846.6	-20129.3	1345.7	0.1	3438.8	0.5	0.00%
1996	33530.8	-27012.9	-10858.1	1139.7	0.0	3199.4	-1.1	0.00%
1997	39160.7	-25966.7	-10198.0	825.0	-0.1	-3820.7	0.1	0.00%
1998	37685.5	-28442.4	-12201.3	1724.3	0.0	1234.6	0.7	0.00%
1999	39210.7	-27163.0	-13241.5	747.0	0.0	447.3	0.5	0.00%
2000	27099.9	-27060.4	-5123.1	547.9	0.0	4535.5	-0.2	0.00%
2001	34684.1	-25561.3	-7196.9	897.0	0.0	-2821.1	1.8	0.01%
2002	32852.8	-25694.7	-6455.5	1286.4	0.0	-1988.7	0.3	0.00%
2003	34040.4	-27271.1	-9557.9	1875.5	-0.1	914.5	1.2	0.00%
2004	30387.7	-27320.5	-5330.8	1320.4	0.0	943.9	0.6	0.00%
2005	37362.9	-27629.9	-9544.7	1680.3	-0.1	-1868.4	0.1	0.00%
Average	34749.9	-26842.3	-8861.2	981.0	0.0	-27.1	0.3	0.00%

Chapter 6
Parameter Analysis

SENSITIVITY ANALYSIS

A global sensitivity analysis (GSA) is performed to determine which parameters dominate model response. The GSA evaluates model output response in relation to change of input parameters through the entire range of the input parameter. This analysis is performed using the Method of Morris; a randomized approach that evaluates the impact to the model by changing one factor at a time (OAT). Model parameters that were evaluated in the GSA are listed in **Appendix J**. The model simulations for a GSA can be visualized as a treatment matrix. The first row of a treatment matrix uses the initial random selection of parameters with a column representing each parameter; each row differs by only one parameter from the previous row for a total of *n* parameters + 1. Each set of *n* parameters + 1 model simulations is know as a trajectory, providing one estimate of responses for each parameter (Morris, **1991**). Ten trajectories were used for the GSA resulting in 11,020 model simulations [(1,101 parameters + 1) x 10 trajectories].

The GSA provides a qualitative estimate of the relative importance of each model parameter. The results of the GSA can be interpreted by graphing the elementary effects (absolute mean error) and higher order effects (standard deviation). The absolute mean (μ^*) represents the overall impact of a parameter and the standard deviation (σ) represents non-linearities and parameter interactions (Morris, **1991**). The mean absolute error and standard deviation were computed for each parameter (Figure 96). The parameter grouping in the lower left corner of the graph characterizes parameters that have little effect irrespective of other parameters (Figure 96). 207 parameters, out of the 1,101 parameters used in the GSA, had no effect and were not graphed. The most sensitive parameters are shown in **Figure 97**.

The GSA revealed the Lake Okeechobee ET coefficient, topography, vegetation coefficients in the Sawgrass Plains, Ridge and Slough, Dry Prairie, and Mesic Pine Flatwoods are the most significant model parameters, shown in Figure 98**.** The parameters listed above were expected to be the most sensitive since each has the ability to impact the availability of water in the Everglades or Lake Okeechobee.

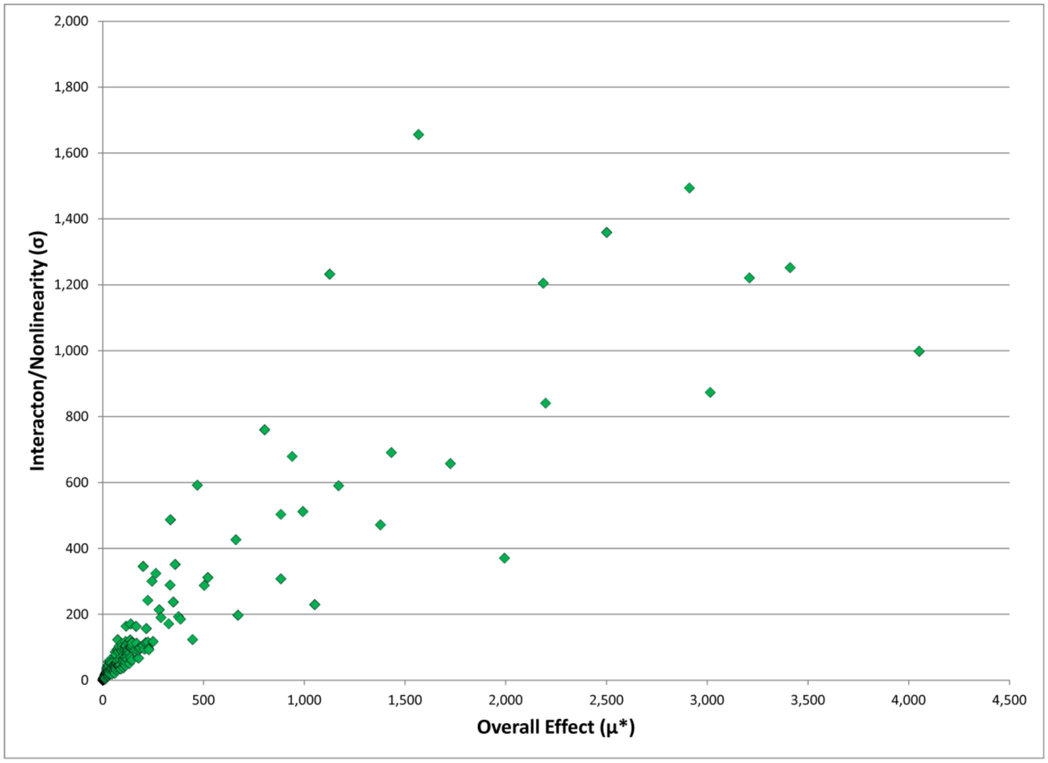


Figure 96. OAT sensitivity measures (μ* and σ) for all parameters.

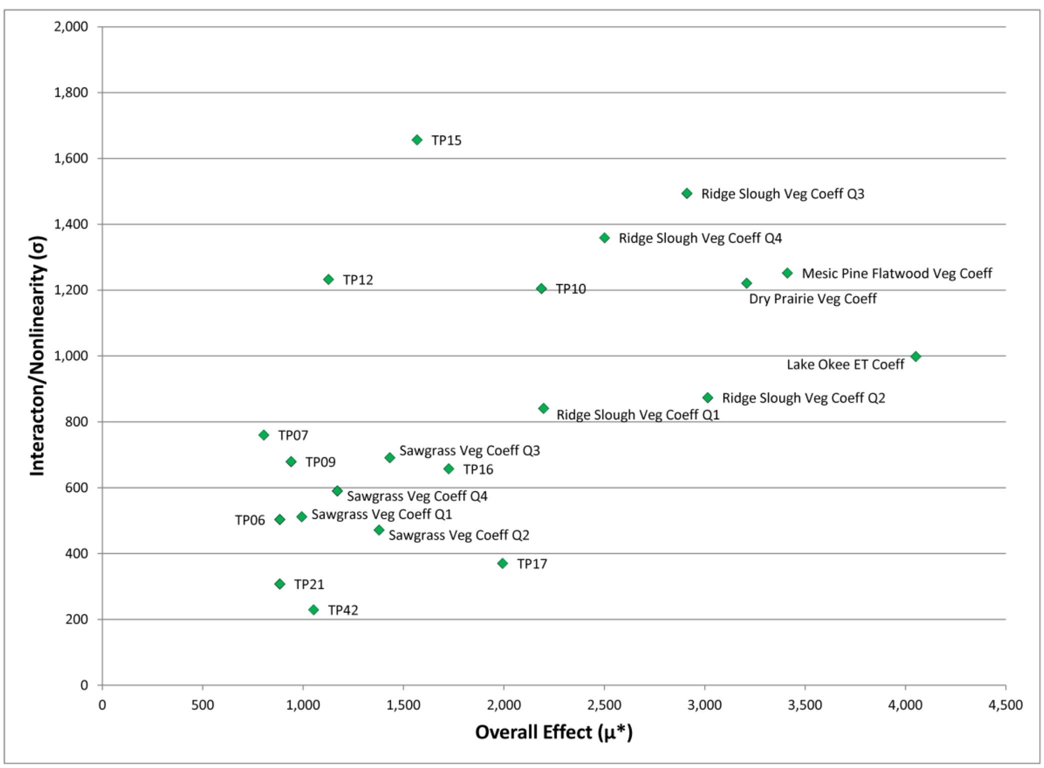


Figure 97. OAT sensitivity measures (μ* and σ) for the most significant parameters.

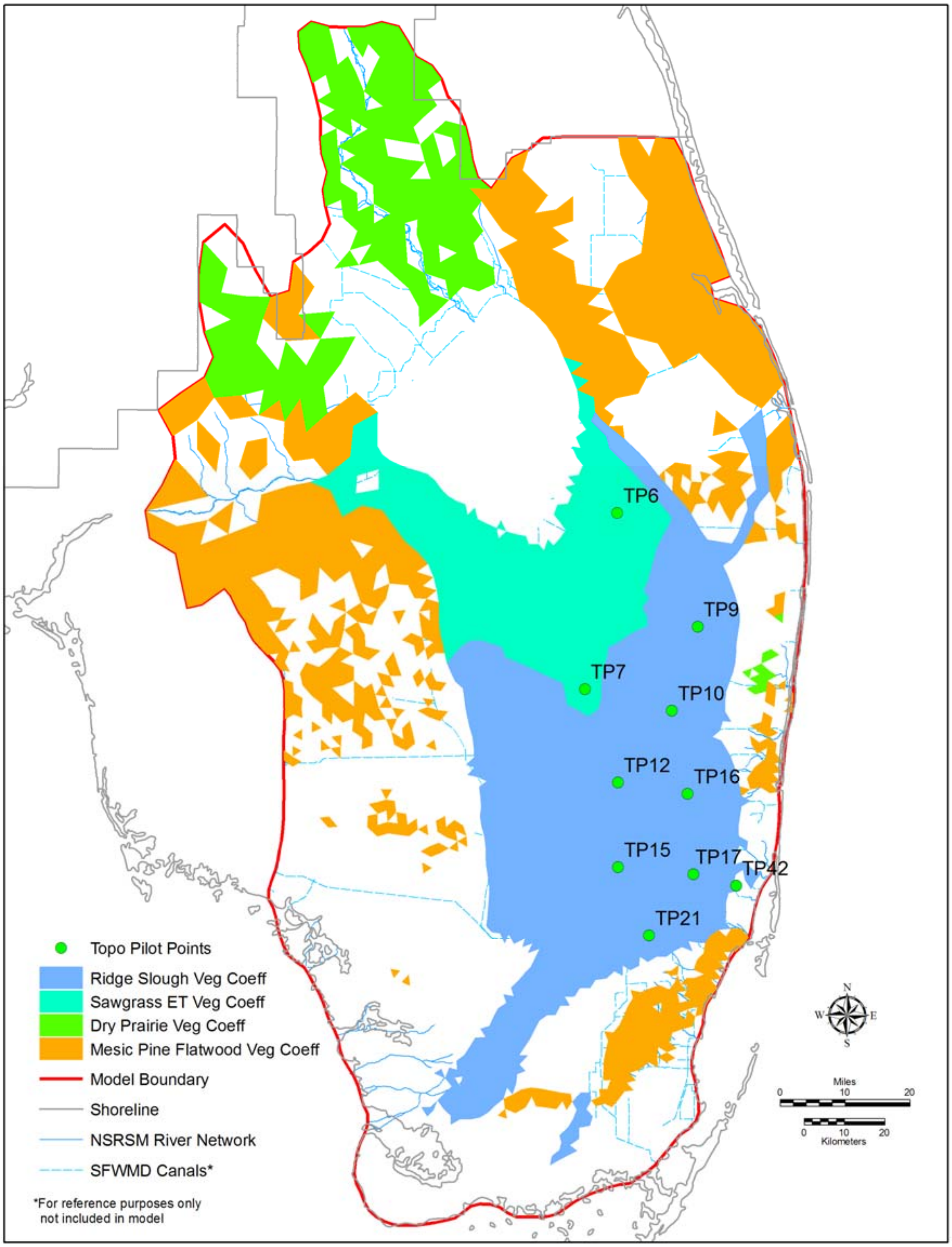


Figure 98. Location of the most significant model parameters determined by the global sensitivity analysis.

UNCERTAINTY ANALYSIS

Modeling cannot provide certainty where none exists. If used properly, it can minimize our potential for error when evaluating model performance by providing proper methodology for all available information. This information includes expert knowledge, point measurements of system properties, and historical measurements of system state. Modeling can then quantify the potential for error that remains after all information is assimilated. This quantification is essential to risk assessment which, in turn, is essential to good decision-making.

An uncertainty analysis is a formal approach to assess the value of selected model parameters. Model performance and calibration is typically achieved by a model whose parameterization is based on expert knowledge. Since the model performance and calibration can be expressed using a probability distribution, software such as Parameter Estimation by Sequential Testing (PEST) (Doherty, **2008**) can provide a probabilistic description of model performance given the expert knowledge about model input (Doherty, **2010**).

The uncertainty analysis used by the NSRSM v3.5.2 employs the null space Monte Carlo procedure. It's a method for examining the post-calibration parameter and predictive error. Another advantage of this methodology is that it can be adapted for a simulation with lengthy run times (Doherty, **2010**). The null space Monte Carlo is used to generate 1,000 to 5,000 varying data sets that calibrate the model. The data sets can then be used to determine parameter distributions.

The results from the uncertainty analysis will be included as an addendum once complete. Initial ranges for model parameters used in this analysis can be found in **Appendix J.** The methodology used to select parameter initial values with their lower and upper bounds is described in **Chapter 4, Conceptual Model, Model Parameters.**

Chapter 7
Summary

MODEL STATUS

NSRSM has evolved since the first peer review. NSRSM v2.0 was peer reviewed externally. Prof. Rafael L. Bras chaired the panel that reviewed the model and documentation. NSRSM v3.0 incorporated improvements based on the comments from the external peer review. The improvements were made to input parameters, mesh geometry and documentation. The simulation period of record was also extended from 2000 to 2005. NSRSM v3.5 included additional parameter refinement, sensitivity analysis and internal review. The documentation underwent extensive editing and reorganization during NSRSM v3.0 and NSRSM 3.5. It is anticipated that NSRSM v3.6 will be released in the Fall of 2014. The model will include additional improvements and a comparison of historical simulations (1895-1935) and present (1965-2005). **Figure 99** illustrates the evolution of NSRSM.

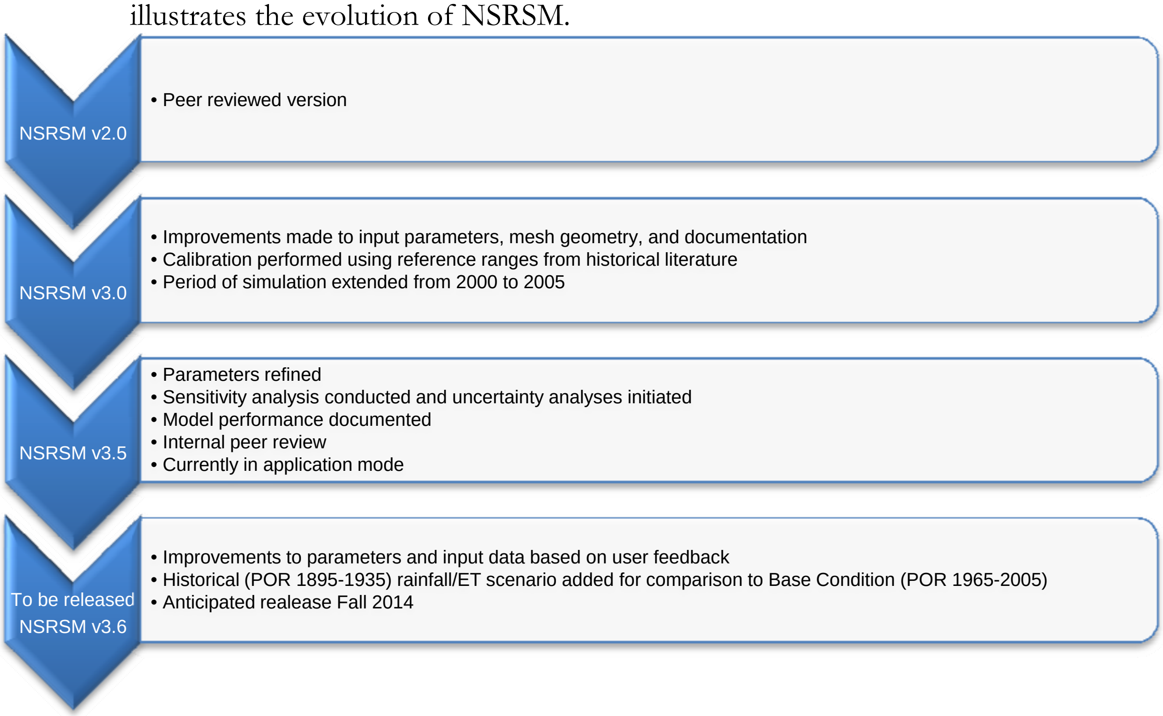


Figure 99. Recent evolution of NSRSM.

CONCLUSIONS

The NSRSM v3.5.2 effectively simulates predrainage hydrology for the natural system in south Florida.

- Regionally, water level and inundation duration results correspond well to reference ranges, particularly in the Everglades Basin.
- Natural river flows correspond well to available reference information. Performance graphic enhancement includes additional information regarding seasonal variability.
- Considerable effort went into preparing potential ET input for south Florida regional modeling (**Appendix D**). As indicated in **Figure 86**, computed ET values correspond well to reference ranges within Everglades wetlands where observed ET data is currently available.
- Lake Okeechobee performance is maintained within reference ranges. The Lake overflows its southern shore within reference levels and timing linked to the sustainability of the surrounding landscape. Lake ET is within observed values.
- Results from overland flow across Tamiami Trail show a noticeable shift in distribution of flows (westward) compared to previous model simulations by the natural system implementation of the South Florida Water Management Model (NSM v.4.6.2 and Sens4). Flows are more characteristically evenly distributed across the landscape. All other transects have reasonable flow performance.
- Simulated distribution and directionality of wet and dry season flows shown in the ponding and flow vector graphics are characteristic of the natural system.

During this phase of implementation, model evaluation focused on system wide performance with the understanding that a higher resolution evaluation will be conducted for local performance during application peer review. Future versions will include higher resolution evaluations for areas outside the Everglades.

The next phase of NSRSM (v3.6) will continue to optimize performance as well as incorporate historical rainfall and reference ET spatial distributions. The NSRSM uses current climatic input with a landscape from the 1850's; this implies that the current climatic input is comparable to the 1850's period. To address this concern, an extended period of record (EPOR) simulation (1895-2005) will be incorporated as a future version. During the dataset development for this simulation, differences between methodologies, data (including comparision with USGS reference ET estimates) and recommended subsets of the period of record (wet, day, and mixed periods) will be examined.

RECOMMENDATIONS

Monitoring zone output will continue to be improved to optimize indicator performance for areas that are hydrologically distinct. Future performance will be measured to provide more feedback on temporal variability.

Careful consideration should be exercised when applying model output. It is recommended that output be used in conjunction with other models, studies and information, to suggest how depths, flows and hydroperiod patterns may have changed. The changes in depths, flows or hydroperiod patterns should be reported as a range of values, not as a single value.

INTENDED USE

The NSRSM is not designed or intended to be used in isolation to make future water management decisions. The model is primarily designed for use within an adaptive management framework, to help understand the conditions and factors that gave rise to predrainage soils and plant communities; as a guide to restoration planning and a means to help predict outcomes of restoration activities.

The Peer Review Panel indicated that one of the most useful applications of the NSRSM is as a tool to help guide future inquiries about the Everglades system. This would occur when model results do not mesh with an evaluator's preconceived notions of the condition(s), thus stimulating investigation. The NSRSM should be used in an adaptive management framework to help guide management experiments aimed at restoring hydrologic regimes, and ecological function.

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Chapter 8
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Appendices

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Appendix A
Descriptions of Natural System Hydrology from Project Documentation

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A.1: LAKE OKEECHOBEE

Evidence for Historical Lake Okeechobee Water Levels and Outflows

Excerpt from *Predrainage Everglades Landscape and Hydrology* (McVoy *et al.,* 2011):

> Estimates of the predrainage depths and hydroperiods in this landscape were based on the characteristics of the vegetation (buttressed, enlarged bases of the custard apple trees), and the repeated identification of the area as a "swamp" suggesting that surface water was present much of the time.
>
> The most detailed information on the width of the landscape is available from the field notes of State township surveys carried out in 1915 and 1916, mostly by Otis Hardin. These surveys mapped not only the township lines, but more importantly, the subdivision lines, providing a network of transects, one mile apart, with vegetation described and transitions mapped to the nearest hundredth of a chain (ca. 0.5 foot).
>
> The mapping derived from the State surveys can be compared with the Kreamer (1892) map where they overlap in Townships 34 and 35. In Township 35, where the landscape is at about typical width, the combined width of the custard apple and willow/elder bands is very similar to the single band labeled "Willow & Custard Apple" by Kreamer. However, further west in Township 34, where the landscape narrowed down to zero, the State survey notes showed a much wider extent than Kreamer's (1892) map, presumably indicating substantial post-drainage expansion between 1892 and 1916.
>
> In December of 1855, U.S. Surveyor W. J. Reyes surveyed the subdivisions of Township 41 South, Range 37 East. This is the only township of the Custard Apple and Cypress Swamps to have been surveyed by U.S. Surveyors. All others were surveyed much later as State surveys, between 1912 and 1919, after the initial lowering of Lake Okeechobee.

```
"Run bet. secs. 2 and 11 West
40.00 chs set 1/4 sec post, no mound, water too deep.
48.00 chs across sawgrass to swamp.
75.97 to east bank of Lake Okeechobee ...
M.C. referenced by a cypress 9 ins. ... 12 ins.
3rd rate sawgrass and swamp / ...
Run bet. secs 10 and 15 West
3.66 chs to east bank of Lake Okeechobee
M.C. referenced by a cypress 14 ins. ... cypress 16 ins.
2nd rate low hammock / ...
```

```
Run bet. secs 14 and 23 West
30.00 chs across sawgrass to low hammock
40.00 chs set 1/4 sec post referenced by a Bay 4 ins ...
Bay 5 ins
73.21 chs to east bank of Lake Okeechobee
M.C. referenced by a Bay 4 ins ... cypress 10 ins
2nd rate low hammock and 3rd rate sawgrass / ...

Run bet secs 22 and 27 West
14.00 chs across sawgrass to low hammock
40.00 chs set 1/4 sec post referenced by an Ash 15 ins ...
Bay 9 ins
70.51 chs to east bank of Lake Okeechobee
M.C. referenced by a cypress 10 ins ... cypress 14 ins
2nd rate low hammock and sawgrass / ...

Run bet. secs. 33 and 4 West
40.00 chs set 1/4 sec post referenced by a papau 9 ins ...
bay 6 ins
45.75 chs to east bank of L. O.
M.C. referenced by a cypress 20 ins ... cypress 24 ins
2nd rate low hammock"
```

Source: Reyes 1855-T41 R37, pp.1-5.

The Times-Democrat expedition started their travels southward in November 1883 from the southern shores of Lake Okeechobee, first exploring a number of short rivers flowing out of the lake:

"Examining streams, or lagoons, flowing southerly from lake [Okeechobee], we found 8 streams from 1 to 2 miles apart, along south shore. These water courses extend only about one or two miles southerly from lake shore and are from 1 to 200 yards in width; depth of water 8 to 10 feet. Bottom soft mud, no rock. No perceptible current until we get 2 miles from lake, through custard apple swamp. The third stream west of the most easterly one we have selected from which to enter saw grass." (Hopkins 1884).

An 1892 survey and map of potential "sugar lands" along the southeast shore of Lake Okeechobee (Kreamer 1892) indicates a band of "Willow & Custard Apple Swamp" bordering the lake in Ranges 34 and 35. The band is about one mile wide, tapering to "Thickets" less than 1/8 mile wide further west. Given the rapidity of shrub encroachment after initial lowering of Lake Okeechobee levels in the early 1880s, it is likely that the narrow strip of "Thickets" is a post-drainage artifact.

Samuel Sanford, formerly a field geologist in South Florida for the Florida East Coast railroad does not discuss custard apple along the southern shore of Lake Okeechobee, but does give a detailed description of the relationship between the lake and the Everglades, and mentions the cypress swamp bordering the lake's eastern side. Sanford's work was published in a U.S. Geological Survey Water Supply paper in 1913, and reflects observations made approximately from 1905 to 1913:

"...water...escapes from Lake Okeechobee through a canal connecting with the Caloosahatchee and through the saw grass. The short streams around the southern edge of the lake, shown on most maps of Florida, do not flow into the lake but from it. They close up within a few miles and the thick growth of saw grass makes the movement of water in any given direction very slow. Some of the water entering the lake reaches the Gulf and some the Atlantic, the water moving as a mass slowly southward. When the lake rises to about 22 feet above mean sea level it is said to overflow into the Everglades along its whole southern border."

"Arms [of the Everglades] extend farther north, but much of the eastern and most of the northern shore of the lake is bordered by cypress swamps, some of these containing the tallest and cleanest cypress to be found in Florida." (Sanford, in Matson and Sanford 1913, p.54).

A 20 mile portion of the Sawgrass Plains landscape bordered directly on the lake and was subject to regular outflow (Plate 13; Meigs 1879; Heilprin 1887; Kreamer 1892; TIIF 1902; see also Figure 4.14)

The fact that the Sawgrass Plains bordered Lake Okeechobee directly is highly significant hydrologically. The presence of sawgrass abutting the lake suggests a peat surface that was level with the lake surface; i.e., the absence of any sort of rim. If an elevated rim had been present, it would have been colonized by woody species.

The presence of deep, sawgrass peats (Meigs 1879; Menge in Stewart 1907; Kreamer 1892; and Jones *et al.* 1948) suggests that lake levels, in fact, remained high enough to regularly inundate the sawgrass, thus supporting a continuous sawgrass presence. We estimate seasonal water levels in this landscape to range from 0.5 feet below land surface at the end of the dry season to 1.5 feet above land surface at the end of the wet season, with a hydroperiod of 9 to 10 months.

The portion of the lakeshore that overflowed—70 miles along the southern shore, from Fisheating Creek on the west to Pelican Bay on the east — was formed by the accumulation of organic soils. These soils, as much as 10 or 12 feet thick prior to drainage (Kraemer 1892; Wright 1911), provided the "plug" that allowed the waters of Lake Okeechobee to accumulate. Two different Everglades landscapes contributed to the formation of the soil: the Sawgrass Plains bordering the southwestern shoreline and the Custard Apple Swamp bordering the southern and southeastern shoreline

"The men waded the swamp [south of Lake Hicpochee] and continued the [survey] line in the direction of Lake Okeechobee until a point was reached where there was no slope in the surface of the water for several miles. This condition extended to the open water of Lake Okeechobee." (Wright 1911, p. 153).
"The overflow from Lake Okeechobee floods the Everglades except in the dry season of the year." (Wright 1911, p. 159).

Similar accounts from two other drainage engineers— George Hills "literally crawled on … hands and knees" for many miles of the survey for the West Palm Beach Canal; Ben Herr was chief drainage engineer for the Okeechobee Flood Control District:

"Under those natural conditions the normal elevation of Lake Okeechobee was approximately that of the surface of the muck lands along its shores. Any increase in height of the lake resulting from floods in its tributaries resulted in the discharge of such flood waters upon the muck lands of the Everglades ... Under such conditions it is apparent that the muck lands of the Everglades were continuously saturated and constantly subject to inundation by waters of outside origin." (Hills 1931, p. 3).

"The excess of water from rainfall and inflow over evaporation spilled over the low southern shore into the Everglades. This water together with the rainfall kept the Everglades flooded most of the year." (Herr 1943, p.12-13).

We estimated that the elevation of the Lake Okeechobee shoreline, from a few miles south of Fisheating Creek to approximately Bacom (Cypress) Point, was 20.5 feet above NGVD 1929 (about 22 feet above the Punta Rassa datum typically used for Lake Okeechobee prior to the 1920's), based on observations from Meigs (1879), Sackett (1888), Kraemer (1892) and Slattery (1913).

A.2: ST. LUCIE WATERSHED

Introduction

This report (McVoy, 2001) was researched and written in response to a request for information from Dan Haunert, Upper East Coast Division, South Florida Water Management District. The objective of this time-limited study was to develop a sense of predrainage hydrology of the St. Lucie River Watershed, based on understanding the area's predrainage landscape ecology. Source materials included satellite imagery (**Figure A-1**), General Land Office (GLO) township surveys from the 1850s (**USDOI, GLO survey data**), field notes from the same township surveys, knowledge of drainage history, maps of the present drainage system, U.S. Geological Survey (USGS) topographical maps, maps from the 1940s of vegetation and soils, and knowledge of remaining areas categorized as natural. Contour maps of elevation at 1-foot resolution were not available. The approach is deductive, using multiple sources of landscape information to piece together a predrainage picture consistent with all available information.

The following questions were to be addressed:

- What spatial patterns were present within the watershed?
- What directions might water have drained under natural conditions?
- What were the relative contributions of the North and South Forks of the St. Lucie River?

Ideally, these questions would be answered from direct observations of predrainage hydrology, e.g., water depths during the course of the year, durations of above ground water, observed flow directions, and so on. As it was recognized that such direct observations were unlikely to be available, at least in numbers sufficient to cover the whole watershed, indirect approaches based on landscape ecological knowledge were encouraged. Predrainage vegetation and soils, when known, can be useful indicators of predrainage hydrology, particularly if additional topographical information is available to position the vegetation types and soils within the landscape.

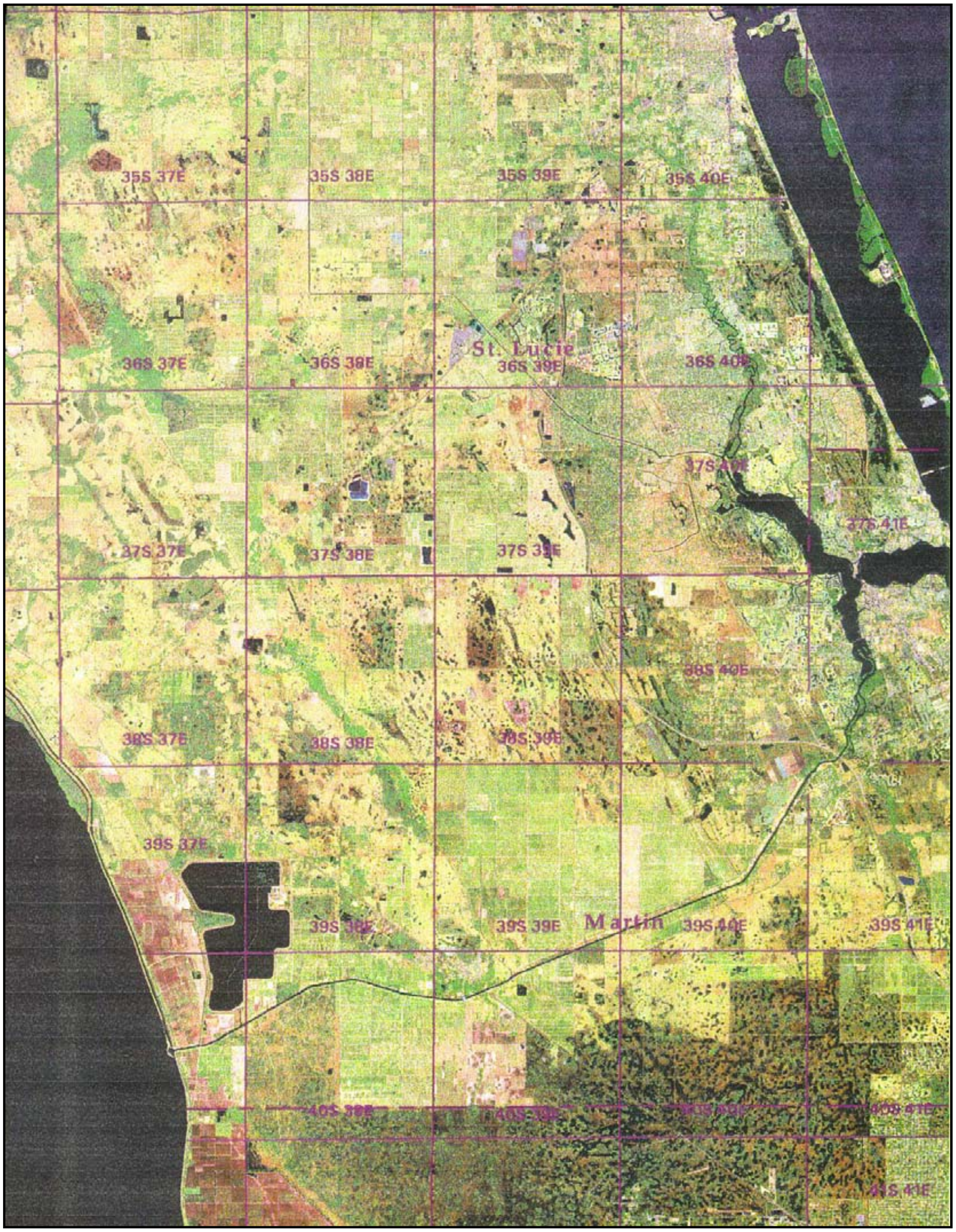

Figure A-1. Satellite image of majority of the St. Lucie River Watershed, overlain with township range grid.

[Note: Notice relation of land use to township range grid.]

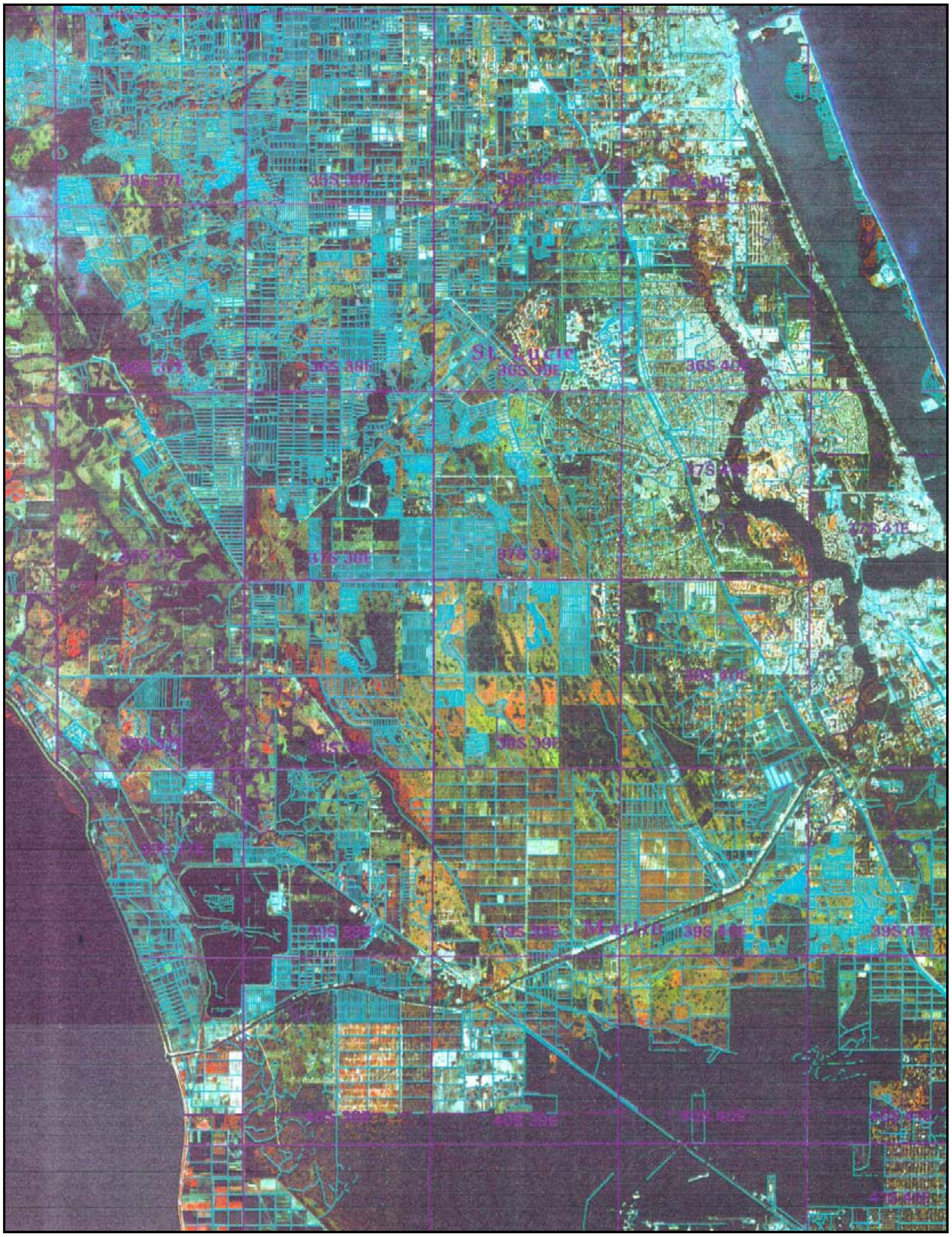

Figure A-2. Satellite image of majority of the St. Lucie River Watershed, overlain with current canal system and township range grid.

It is important to recognize from the outset that, by all indications, the St. Lucie Watershed has been extensively and intensively influenced by drainage. Almost every square mile is traversed by numerous drainage canals and ditches (**Figure A-2**). It is also important to recognize that historical information (e.g., Randolph *et al.* 1919), as well as the accessibility of the landscape suggest that significant drainage was in place well before the 1940s. Substantial and significant landscape change almost certainly accompanied this drainage. Peat soils in this area originally accumulated in low spots in the underlying sand, due to prevention of oxidation by standing water present during much of the year. Once drainage had lowered water tables below the land surface, complete loss of the peat could easily have occurred within a few decades (Stephens and Johnson 1951), as these soils were generally not more than a few feet deep.

The ephemeral nature of shallow peat soils in south Florida, once drainage is initiated, has important implications for understanding predrainage landscape ecology and hydrology. The flatness of the area, combined with the quantities and timing of rainfall that originally kept the water table close to ground surface, means that variations of only a few feet create the difference between upland pine or oak-cabbage hammock areas on a sand or loamy sand substrate, and wetland swamps or sawgrass ponds on a peat substrate. If drainage causes the low-lying peat soils to completely oxidize away, the newly exposed underlying sand can come to resemble the sandy substrate of the original (predrainage) upland areas. Wetland and upland areas, once easily distinguishable, can blur, with upland vegetation starting to appear throughout. This is not surprising; in a sense it is the intended objective of drainage, to transform swampland into habitable or cultivatable uplands.

The significance of the ephemeral nature of organic (peat) soils after drainage for correctly understanding predrainage ecology and hydrology is that soil mapping carried out after drainage cannot be assumed to reliably indicate the presence of predrainage wetlands. At best, post-drainage maps will underestimate the area of wetlands; at worst they can misleadingly indicate complete absence of wetlands if all peat has been lost.

Therefore, vegetation maps from the 1940s (e.g. Davis, 1943), soil maps from the 1940s (Jones *et al.* 1948), present day soil maps, and present day satellite images all are inherently unreliable indicators of the predrainage landscape patterns within the St. Lucie Watershed. While these sources can provide very useful leads and suggestions of predrainage conditions, the information must be carefully interpreted, using predrainage information that includes spatial detail.

Cursory inspection of a number of GLO (**USDOI, GLO survey data**) township survey maps (**Figure A-3**) from within the watershed indicated that most of the area originally formed a mosaic, with multiple elements present within a square mile. Current topographic maps (**Figure A-4**), satellite imagery and the 1943 Davis vegetation map (**Figure A-5**) tended to confirm presence of a mosaic. In light of this information, the original questions were necessarily modified as follows:

- What were the main two or three elements composing the predrainage mosaic?
- Was the mosaic random in orientation, or did elements form an organized pattern?
- Was the mosaic different in different parts of the watershed?

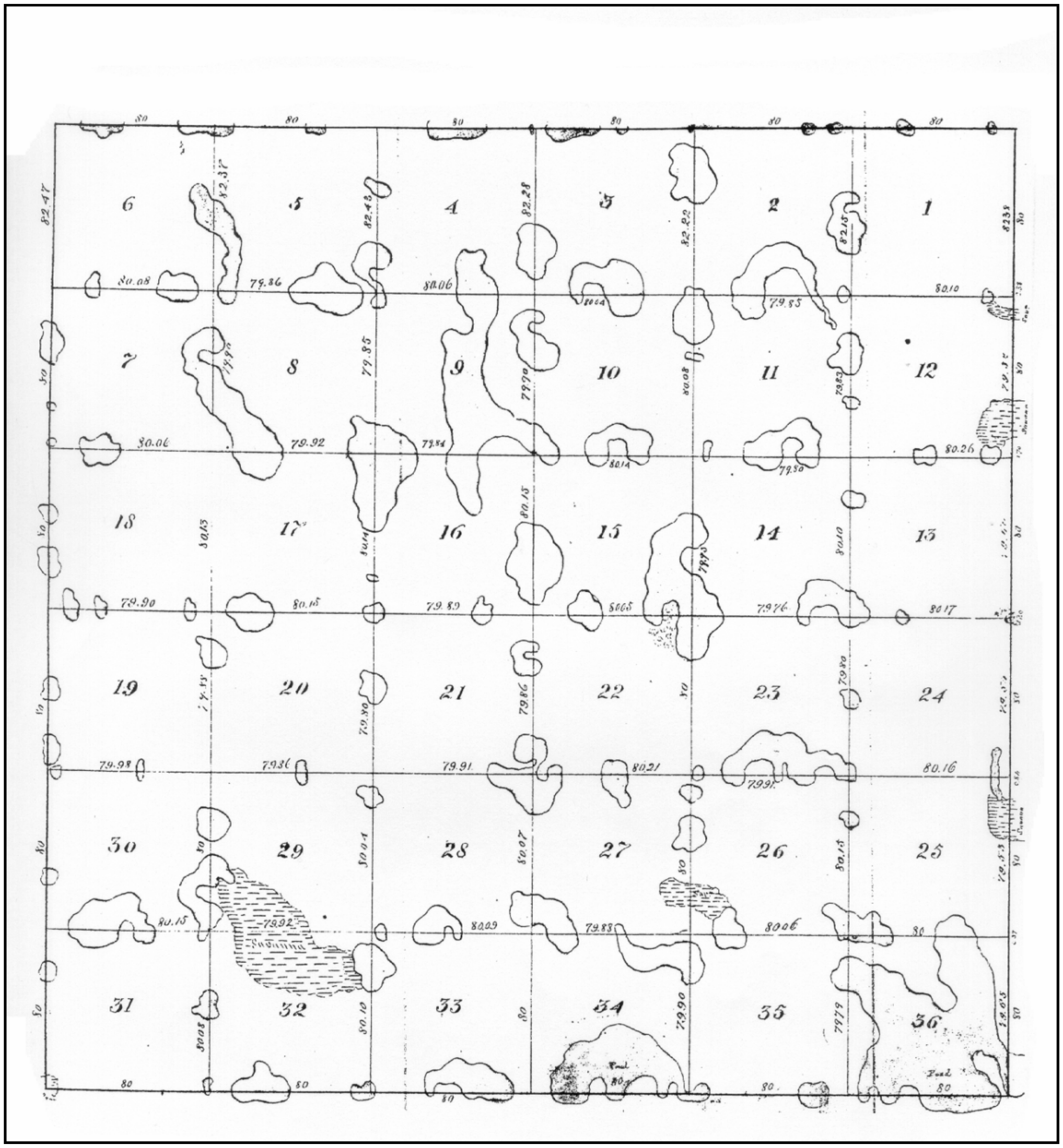

Figure A-3. Sample Township Plat Map of Township 38 S., Range 39 E., Surveyed by M. A. Williams in May & June of 1853.

[Note: Open polygons are "Ponds," probably open water ponds, in a few cases labeled in the field notes as "Saw Grass Ponds."]

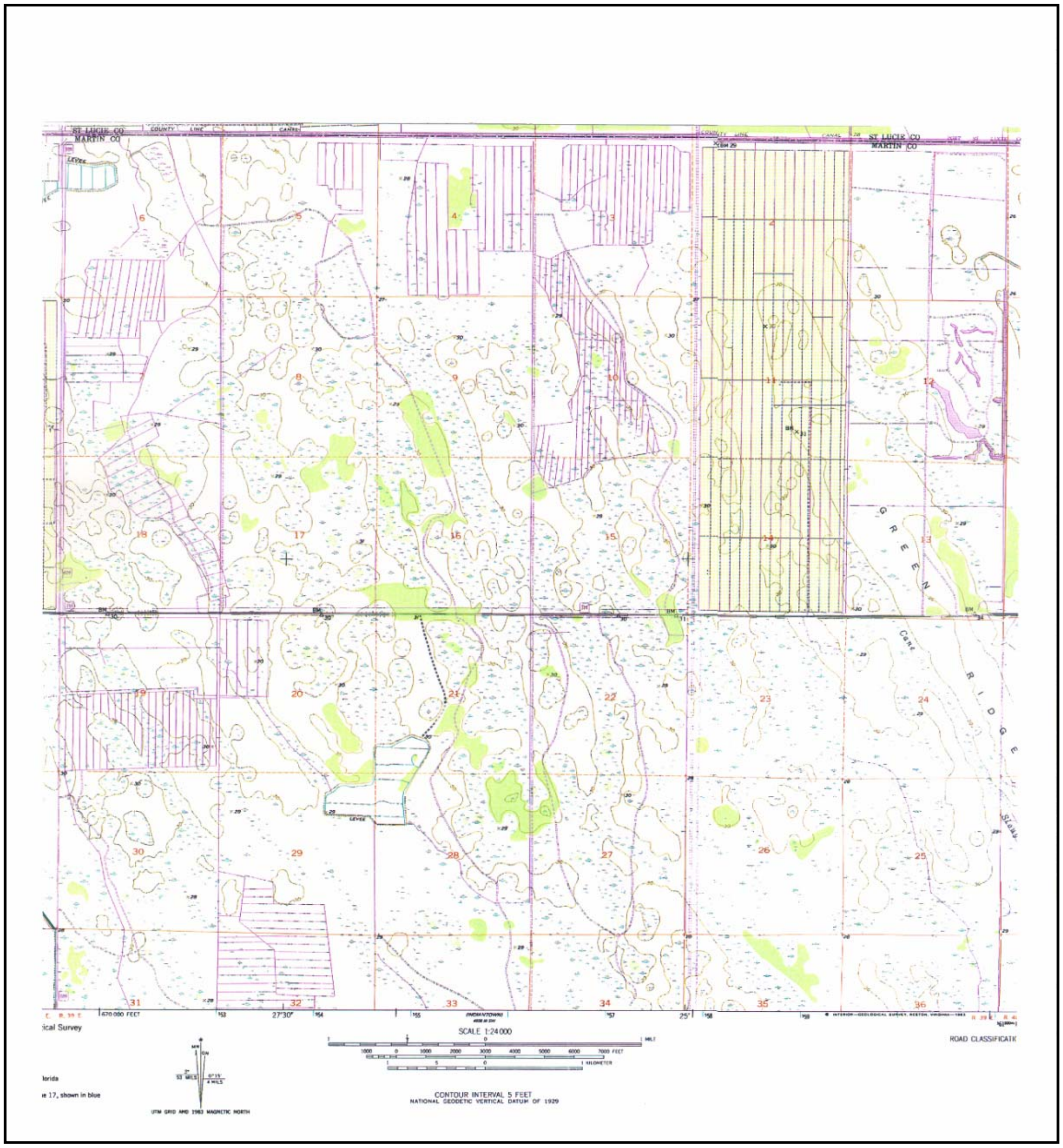

Figure A-4. U.S. Geological Survey Topographical Map of Township 38 S., Range 39 E, photo revised in 1983.

The presence of wetlands matches those drawn 130 years earlier on township plat (**Figure A-3**) along the surveyed Section lines. However, the topographical map shows additional wetland extent within Section interiors, as well as wetland orientation, NW-SE. Note coincidence of drainage ditch network in Sections 29 and 32 with area marked "Savanna" on Township plat (**Figure A-3**).

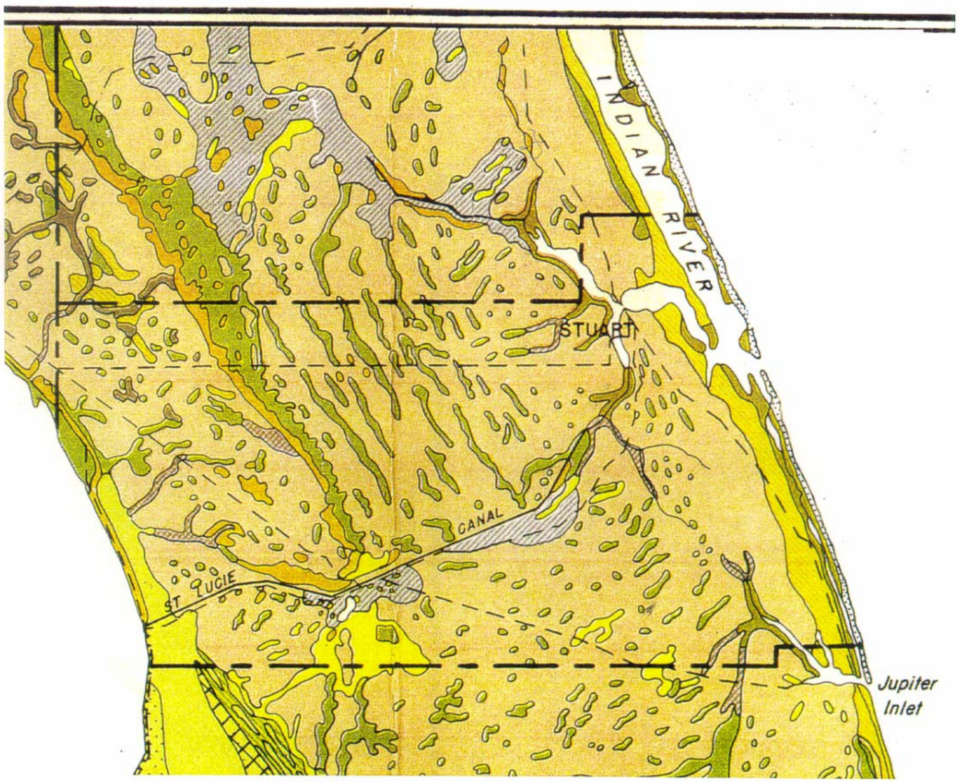

Figure A-5. St. Lucie Watershed portion of "Vegetation Map of Southern Florida".
(Davis 1943)

Methods

This brief reconnaissance study was initiated by examination of a satellite image overlain with a township range grid (**Figure A-1**). By inspection, four townships ranging from north to south within the watershed were selected, based on the remaining presence of original mosaic pattern (townships outlined in red on **Figure A-1**). The four townships were also selected for their alignment with the prevailing NW-SE pattern, possibly related to relict sand dunes. It was necessary to include an additional southern township (Township 40 Range 38), as field notes were not available on site for T40 R40.

Each of these five 36-square-mile townships were sectioned (walked along the boundaries of each square mile), with vegetation and presence of water bodies measured and described, between 1853 and 1855. Three different Deputy Surveyors were involved, all under the same State Surveyor General, John Westcott. Five plat maps (scale 2 inches = 1 mile) were reviewed and used the section boundaries to compare them with current USGS topographical quadrangle maps (scale 2 5/8 inches = 1 mile). For example, compare **Figure A-3** and **Figure A-4**.

The field notes available for four of the five townships were then read (84 linear miles for each township) and compared with the plats to develop a sense of the mosaic elements present within each township. Three aspects associated with mile were examined: (1) the transitions between different elements (e.g., "33.00 [chains] exit Pine, enter Saw Grass Pond"), (2) the species of witness trees noted to locate the section and quarter section marker posts, and (3) the overall description included at the end of each mile (e.g., "3rd Rate Pine[, Saw] Palm[etto] & Ponds") (Craighead, 1964). Given the time limitation, the examinations of the field notes were necessarily qualitative, rather than quantitative.

A separate second effort examined township plats located in the "Allapattah Flats" area along the eastern foot of the NW-SE ridge forming the western boundary of the watershed. This area was originally called "Halpatta Swamp" (Williams 1853) and "Alpatiokee Swamp" (Fla. S.G.O. 1853). Comparison of township maps with satellite imagery (**Figure A-1**) and with the 1943 Davis vegetation map (**Figure A-5**) suggested that much of the original extent and character of the Halpatta Swamp area had already been lost or altered prior to 1943, leading to an underestimate of this area.

A third effort compared township plat maps in the headwater areas for the North and South Forks of the St. Lucie River.

Written records of the area presently known to the author were examined. Considerably more narrative material is almost certainly available, but was not researched within the present timeframe.

Results

General

A rough map (Fla. S.G.O., 1853) compiled by the Surveyor General's Office in St. Augustine shows both the south and north forks of the St Lucie River draining from an approximately 400-square-mile area labeled the "Alpatiokee Swamp" (**Figure A-6**). Plat maps and field notes for several of the townships mention a "Halpatta Swamp" and an "Alpatiokee Swamp." Further research is needed to determine if these were alternate names for the same natural feature, or two separate features. As has often been the case in post-drainage south Florida, place names have changed as the landscape becomes drier under drainage. The current label "Allapattah Flats" is a post-drainage name certainly derived from Halpatta or Alpatiokee Swamp, but the area is no longer wet enough to be referred to as a swamp; much of it is now cultivated as citrus groves.

A map compiled in 1913 by the Florida Geological Survey on a base map by the U.S. Geological Survey (Matson and Sanford, 1913) labels the South Fork of the St Lucie River as "Halpatiokee R.," suggesting a link with a Halpatta or Alpatiokee Swamp(s).

In a letter to Dr. V.M. Conway, Surveyor General of Florida, George MacKay, a U.S. Deputy Surveyor of many townships in southern Florida, wrote the following regarding what appears to be the St. Lucie River Watershed:

> "The country is generally poor land. Immediately on the Indian River Lagoon, it is low oak scrub & on my west line, it is open pine prairie, and saw grass savanna. Small pine scrubs. The savannas are the best land, tho' in the rainy season of the year they are covered with water. The --?-- --?-- entirely dry, and present a pleasing view. (MacKay, 1846)."

Mackay mentions the "sawgrass savannas" as the "best land" probably to contrast them from the common "3rd Rate Pine Lands" of Florida, found on sand with little native fertility. "Best" very likely refers to the presence of a top layer of organic peat soil, accumulated from wetland sawgrass growth. If this is the case, it would indicate that hydroperiods were probably 8 months to 10 months of the year, such that the rate of organic matter accumulation slightly exceeded the rate of oxidative loss during the few months when standing water was absent. These also appear to be the optimal conditions for sawgrass; presence of peat soil, and water throughout most, but not all of the year.

In 1882, the Trustees of the Internal Improvement Fund, State of Florida, employed Silas L. Niblack as an Agent to examine:

> "The lands granted to the State of Florida as Swamp [and Overflowed] lands under the Act of September 28th, 1850" … [such examination being] "for the purpose of ascertaining the general character of the Swamp lands … with respect to their ability to overflow … and what proportion of said lands are already high and dry enough for cultivation… (State of Florida Report, 1882)."

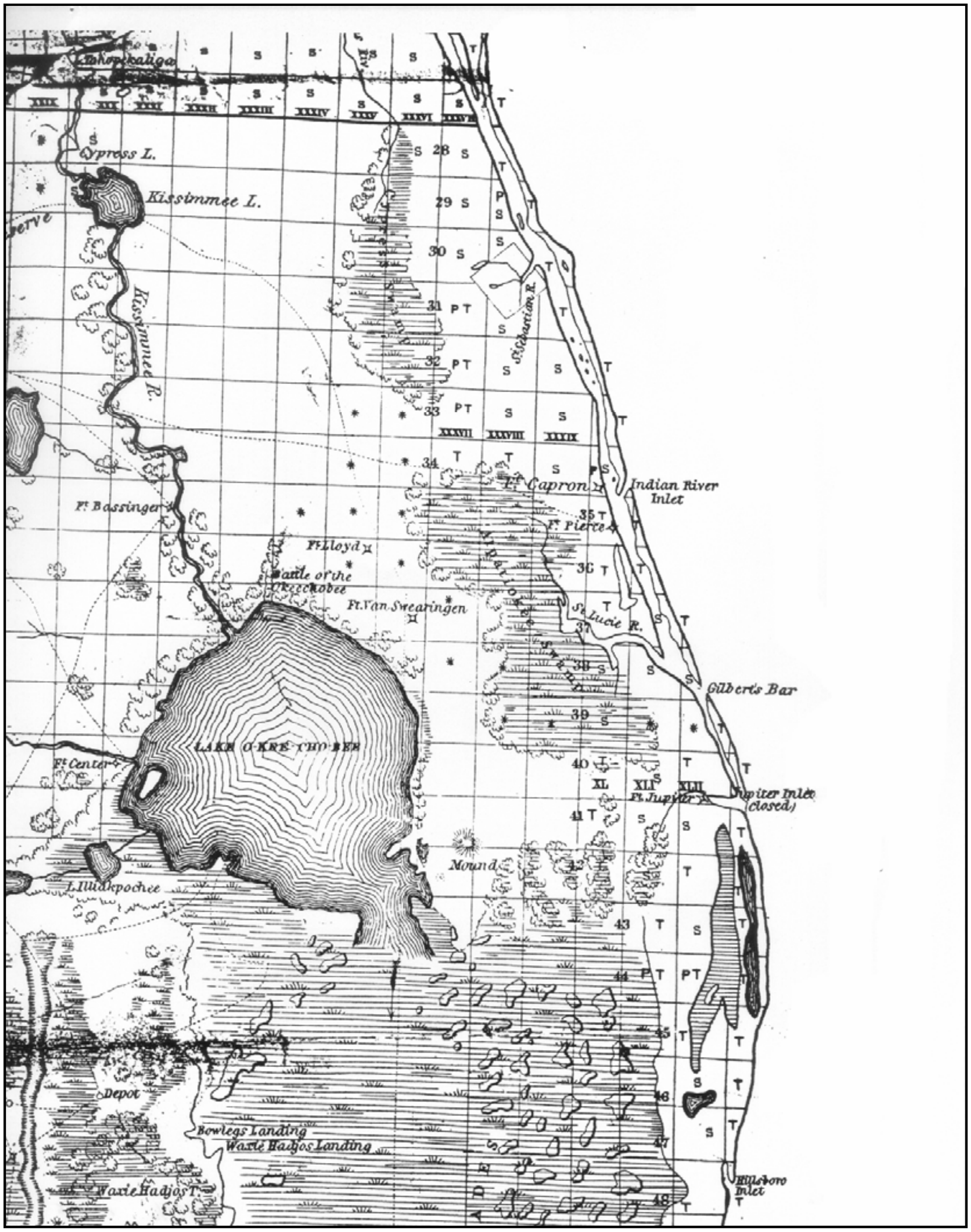

Figure A-6. Alpatiokee Swamp as headwaters of north and south forks of St. Lucie River.

Source: U.S. Bureau of Topographical Engineers Map of Southern Florida, 1853.

Niblack's report of June 1882 states that "the balance of the land in Dade County would come within the terms of your drainage contract." (Niblack 1882). Niblack is stating that the whole St. Lucie Watershed was in fact subject to overflow; Dade County at that time extended much farther north than at present. "Balance" refers to all of Dade County except the high ground near the New River and Miami River.

Even in adjoining, higher elevation pine lands, dry ground was the exception to the rule:

> "Within this limit there is in the neighborhood of Fort Drum [T 34 R 35] a pine ridge about five miles in length and 1/2 to 3/4 mile in width, that might be, with light drainage cultivated; there is also near Taylor Creek a small ridge of Pine land that during a dry season might be cultivated, but subject to overflow in a wet season (Niblack 1882)."

Niblack concluded by writing:

> "I give it as my opinion and views resulting from examination and information received, [that] it is not advisable to have a … survey made of the State lands within said limits and a list prepared designating those not subject to overflow… [because] … I am satisfied the quantity of land <u>not</u> now subject to overflow, would be so small it would not pay the State the expense of examination and survey (italics added; Niblack 1882)."

In 1919, two engineering firms, Isham Randolph & Co, Consulting Engineers, and Cunningham and Hallowes, Chief Engineers, issued a report and Plan of Reclamation for the North St. Lucie River Drainage District (Randolph *et al.* **1919**). This drainage district (Townships 35 and 36, Ranges 38, 39, and 40) lies in the NE portion of the St. Lucie Watershed (**Figure A-1**). We quote extensively from their report, as it gives a good sense of the landscape and landscape elements mapped by the township surveyors. Note, however, that inspection of township maps from throughout the St. Lucie Watershed indicate that the North St. Lucie Drainage District portion included a higher proportion of "Prairie" landscape than the rest of the watershed:

> "The lands within the District may generally be described as flat, although elevations vary from fourteen to twenty-four feet above sea level. The highest lands are the pine woods which lie principally in the eastern half of the District. The prairie lands which are located mainly in the western portion of the district are flat, but there is a general slope from all portions of the District to Ten Mile Creek and Five Mile Creek and to the North Fork of the St. Lucie River, which is formed by the confluence of the first two named streams. These streams together afford the existing natural drainage outlets for the lands within the District as well as for a large body of prairie land lying further west. (Randolph *et al.* 1919)."

The pine woods referred to on high ground in the eastern portion were probably associated with the Atlantic Coastal Ridge. This is in contrast to much of the rest of the St. Lucie Watershed, where pines formed part of a mosaic landscape of "3rd Rate Pine and Ponds." The statement that Ten and Five Mile Creeks are the natural drainage outlets for the North district and even for the prairie lands further west is no doubt true. However, further research would be required to determine whether water reached the creeks primarily as surface water or as (shallow) ground water flow. Three points suggest an important contribution of groundwater: (1) A later statement by Randolph *et al.* (**1919**) concerning the "lack of natural drainage" in the prairies; (2) apparent absence, at least in some areas, of a clear pattern of directionally connected surface wetlands; and (3) the presence of a soil layer of lower hydraulic conductivity several feet below the upper, more conductive sand horizon:

> "SOIL AND VEGETATION: ... The soil of the District consists of Hammock, Muck, Prairie and Pine lands. Approximately ninety percent of the lands are underlaid with a marl or clay subsoil, at a depth of from one to four feet. Probably three percent of the lands are underlaid with hardpan, and the balance has a subsoil of sand. (Randolph *et al.* 1919)."

Modern soil surveys should be consulted to confirm the widespread presence of a marl or clay subsoil. If present, such subsoil would provide high water holding capacity as well as a restriction to rapid downward drainage of water, tending to create consistent baseflow from the watershed, rather than the more transient, "spikier" groundwater discharges associated with a completely sandy profile.

> "PRAIRIE: The District includes 40,418 [out of 75,000] acres of prairie land. These are lands, usually very level, which through lack of natural drainage in the past have been so wet as to prevent the growth of trees. The existing vegetation is confined to native grasses, which make a luxuriant growth where water does not stand for too long a period. These lands have a general top soil of heavy sandy loam, underlaid with clay or marl. They respond readily to drainage, and private operations on limited tracts have indicated them as well adapted for groves or general crop production. The fact that no clearing [of trees] is required in developing these lands is a consideration in determining their present and future value. (Randolph *et al.* 1919)."

As sawgrass is not specifically mentioned, it is not clear to what extent this corresponds to the "saw grass savannas" mentioned by MacKay (1846), or to more of a wet prairie environment of some combination of spike rush (*Eleocharis*), beak rush (*Rhynchospora*), Maiden cane (*Panicum hemitomon*). "Luxuriant growth" is suggestive (but not conclusive) of saw grass. Reference to absence of vegetation where water "stands for too long a period" probably refers to the open water ponds depicted on all township plat maps examined within the St. Lucie Watershed.

In some parts of the prairie landscape, depressions were apparently deep enough to allow accumulation of significant peat soil deposits:

> "In isolated tracts where local depressions in the prairie lands have brought about conditions favorable to a rank growth of [water] lilies, Maiden cane and other water grasses, a cover of well rotted muck varying from a few inches to six feet in depth is found. As at least the upper portion of the muck is ordinarily dry for a considerable part of each year, oxidation and decomposition of the vegetable matter has proceeded to an advanced degree, and the result is a soil which may be made highly producive by proper handling. (Randolph *et al.* 1919)."

The description of open ponds (10 percent of the North St. Lucie River Drainage District) suggests sand-bottomed areas with sparse vegetation, perhaps 8 months to 10 months of standing water, and maximum depths of 1 foot to 2 feet of water:

> "OPEN PONDS: 7,270 [out of 75,000] acres of land in the District consists of open ponds. These lands similar in general nature to the prairie lands, but which are of such elevation as to be covered with a shallow depth of water for the greater portion of the year. For this reason the growth of vegetation in the past has been light and the top soil is of correspondingly poorer nature. These ponds are all of such elevation as to permit complete drainage under the Proposed Plan of Recommendation. (Randolph *et al.* 1919)."

Absence of ponds on satellite imagery in areas where they had originally been shown on township maps suggests that Randolph *et al.* (**1919**) predicted correctly; sufficient man-made drainage was achieved to lower the water table below even the bottom of the pond elevations. Water tables were apparently lowered enough that both higher ground and former ponds could be farmed equally. (Note: there is little doubt that most predrainage ponds have disappeared, but land leveling, not just drainage alone, may have been partially responsible for this; [personal communication. K. Konyha, 21 Nov., 2000].)

Township Maps

The following section focuses on detailed examination of a series of five townships extending NW to SE through the St. Lucie Watershed. All township plats examined showed evidence of the mosaic nature of this region, mostly "ponds" within a matrix of less wet vegetation. Some plat maps also showed regional features, such as the Halpatta Swamp (Allapattah Flats), consisting of "impracticable" sawgrass and bordering "Bay Galls," "Swamp," or "Savanna". Interestingly, the ponds were usually drawn as features about one-eighth to one-quarter of a mile across, and curiously lined up in north-south and east-west rows. Probability aside, the satellite imagery and the topographic maps clearly indicate that these neat rows do not accurately depict the original landscape. Detailed comparison of individual square mile sections between the township plats and the topographical quads shows that the township surveyors tended to draw disconnected, circular ponds centered on the section lines (**Figure A-3**; see for example Section 7 and Section 8), whereas in actuality the ponds had more complex shapes (**Figure A-4**). Actual ponds often extend, and presumably extended NW to SE, and crossed two or more section lines. As the surveyors only walked the borders of the mile square sections, and did not have the benefit of aerial views of the landscape, they often incorrectly drew larger, rambling ponds as a series of circular, independent ponds, not realizing that they were in fact connected. Based on this information, It was determined that the township plats are not a reliable way to estimate the fraction of the mosaic occupied by ponds.

Evaluation of the landscape fraction occupied, prior to drainage, by ponds is best done using the topographical maps and the satellite imagery. (Comparison of two different satellite images, taken at different times, suggested that the size of these ponds can change significantly as water levels rise and fall.)

No water depths or mentions of duration of standing water (hydroperiod) were found in the field notes for these townships. One mention of stream flow direction was found. An important limitation of this analysis of the watershed and these township survey results is the author's lack of having explored the area on foot.

Although streams were generally drawn on township maps, only one was found connecting between ponds within the St. Lucie Watershed. (However, many streams connecting ponds are shown on township plats from within the high ridge area to the west of the watershed.) The shape of the ponds, when examined jointly on topographical maps as well as the township plats, generally did not suggest strong inter-pond connections, although this varied somewhat between townships. Overall, the impression was one of a landscape drained more by slow groundwater flow than by surface runoff. Ten Mile Creek, contrary to expectations, did not extend much farther on the plat maps than it currently does on topographical maps.

Township 36 Range 37

The southwestern corner of this township bordered the western ridge, and included what appeared to be a northern portion of the Halpatta Swamp (Allapattah Flats) area. This portion of the Hallapata Swamp included three separate areas of "Hammock" in a NW-SE line, as well as some "Swamp," "Bay Swamp," and "Low Prairie" area. Interestingly, this same western area now appears to have become wetter (possibly used as a local detention basin); the topographical maps currently show it as cypress swamp, rather than as hammocks. The majority of the Township was labeled "Prairie." It is not clear what "Prairie" represents, but it appears to include some pine, saw palmetto, and Cabbage Palm. On some early township survey maps, pits and mounds were used to mark some Section corners, apparently because no witness trees were available. Sawgrass ponds were scattered throughout the Prairie area. The Jones Hammock and North of Bluefield (Okeechobee 1 SE) USGS topographical quads show a considerable number of isolated wetlands (possible former sawgrass ponds), as well as a number of networks of drainage ditches. Elevations in the township ranged from 25 ft. to 30 ft. above sea level. Landscape categories reported in the GLO field notes for Township 36 Range 37 (**USDOI, GLO survey data**) are presented in **Table A-1**.

Table A-1. Landscape categories reported in the GLO Field Notes for Township 36 Range 37.

Surveyor's Name	Witness Trees	Comments
"3rd Rate Prairie", "3rd Rate Pine & Palm[etto] Prairie"	Pits, Cabbage [Palm], Pine	Matrix over most of Twp. Includes: Sawgrass Ponds, Pine Islands
"Saw Grass Ponds"		More scattered wetlands (ponds?) shown on USGS topo than on twp plat – significant?
"Pine Islands," "Pine Lands"	Pine	Considered as distinct inclusions within "Prairie"; Match well w/ forested areas on topo
"1st Rate Hammock"	Oaks, Cabbage Palms, Ash (1)	Occurred as northern extension of Hallapata Swamp, NW-SE; Probably rich soils
"Swamp"	Cypress	Two smaller areas; W side of Twp
"Bay Swamp," "Bay Gall"	Bay	Small; W side; w/ Low Prairie, Swamp
"Saw Grass Marsh"		One small area only

Surveyed by C. F. Hopkins in July 1853.

Township 37 Range 38

Western half of township was all "Saw Grass" and "Savanna" – part of the Hallapata Swamp feature. Eastern half was matrix of "3rd Rate Pine" with inclusions of numerous "Ponds." As one pond was specifically labeled "Saw Grass Pond," I assume that the numerous others labeled only "Pond" were either too deep for sawgrass or too shallow to accumulate enough peat for sawgrass. Appears to be more Pine than in T 36 R 37, and fewer Cabbage Palms. Less developed parts of township show wetlands throughout on USGS topographical quads Bluefield (Okeechobee 4 NE) and North of Bluefield (Okeechobee 1 SE); topo quads give wetter impression than the survey notes. The large Sawgrass area in Secs 31, 32, 30, 29, 19 (Hallapata Swamp/Allapattah Flats) is visible on topo quad; includes some forested area. Elevations in eastern half of Township (Pine Land) were 25 feet to 28 feet above sea level, mostly around 26 feet. Three "Flowing Wells" marked in eastern half. Landscape categories reported in the GLO field notes for Township 37 Range 38 (**USDOI, GLO survey data**) are presented in **Table A-2**.

Table A-2. Landscape categories reported in GLO Field Notes for Township 37 Range 38.

Surveyor's Name	Witness Trees	Comments
"3rd Rate Pine & Ponds", "3rd Rate Pine & Rough Palm[etto]" (1)	Many Pines, A few Cabbage Palms	Matrix over East 1/2 of Twp. Includes: Ponds
"Ponds" "Saw Grass Pond" (1 only)	--	Vegetation unclear but either too deep for sawgrass; or too little peat for sawgrass
"Saw Grass"	--	17 sq miles; Hallapata Swamp
"1st Rate Hammock"	--	A few small hammocks within Sawgrass
"Savanna," "Wet Savanna"	A few Pines, 1 Cabbage Palm, 1 Myrtle	Along E side of Sawgrass; Intermediate between Sawgrass and Pineland??
"Bay Swamp," "Bay Gall"	Bay	Small; W side; w/ Low Prairie, Swamp

Surveyed by M. A. Williams in June 1853.

Township 38 Range 39

With the exception of one or two townships on the southern border of the watershed, T 38 R 39 appears to be the least developed (**Figure A-1**), lending itself to comparisons between present day topographical maps and the township plat map, which is 130 years older. Regional drainage almost certainly affects the township, but local ditch systems seem to be less developed here than elsewhere in the watershed (**Figure A-2**). The survey notes are repetitively consistent, all "3rd Rate Pine & Ponds" with Pines as witness trees. Comparison of the township plat map (**Figure A-3**) with the USGS Indiantown NW topographical quad (**Figure A-4**) suggests a close match in wetland delineation. The hammock found on the Section 15-22 border appears to still be present (benchmark elevation is 31 ft. above sea level). Elevations seem to indicate a very flat landscape, ranging from 29 ft.to 31 ft., with the 30-foot contour line often being the coincident with the edge of the wetlands. The topographical map also suggests that many of the wetlands are elongated and interconnected in the NW-SE direction. Green Ridge, reaching 35 ft., runs with the same NW-SE orientation through Sections 11, 13, and 24. A single note in the township survey, "18.00 [chains] to Pond Running Water E S E" (N boundary Sec 11 Course W), suggests that drainage from this location east of Green Ridge might proceed toward the South Fork of the St. Lucie River. Elongated, interconnected wetlands oriented NW-SE could be consistent with this, but no other flow information is available from the 1853 notes. Landscape categories reported in the GLO field notes for Township 38 Range 39 (**USDOI, GLO survey data**) are presented in **Table A-3**.

Table A-3. Landscape categories reported in GLO Field Notes for Township 38 Range 39.

Surveyor's Name	Witness Trees	Comments
All "3rd Rate Pine & Ponds"	All Pines	Matrix. Includes: Ponds
"Ponds" "Saw Grass Pond" (1 only)	1 Bay, probably on edge	Vegetation unclear but probably deeper than Sawgrass; or too little peat for sawgrass
"Hammock"	--	One small hammock
"Savanna"	1 Pine, might have been outside	A few small areas

Surveyed by M. A. Williams in May & June 1853.

Township 40 Range 40

This township was chosen because approximately two-thirds of the township is undrained natural area, and therefore might provide a model for the predrainage condition of the more developed townships farther north in the St. Lucie Watershed. The West of Rood (West Palm Beach 2 NE) orthophotomap suggests that there might be an important difference from townships farther north in the watershed as the wetlands in T 40 R 40 generally appear more circular, less directional, and the regional pattern less oriented than was the case in T 38 R 39.

Although field notes were not available for this township (but should be obtainable from Tallahassee), comparison of the plat map with the USGS orthophotomap confirmed that the plat map underestimates the large quantity of wetlands (which appear to be ponds with areas of cypress), showing only those crossed by the section lines. Comparison of Section 35 suggests a good match for those shown. Elevations range from 20 ft. to 25 ft. above sea level, with lower elevations to the NE.

Township 40 Range 38

This township was examined as a proxy for T 40 R 40, due to the local unavailability of field notes for the latter. Information from two different surveyors is available for this Township: M. A. Williams surveyed the north boundary in August 1853 and September 1853 and W.J. Reyes surveyed the whole township in February 1855. Elevations are between 24 ft. and 26 ft. above sea level, with one isolated spot in the NE corner at an elevation of 30 ft. As for other townships, the topographical maps (Port Mayaca and Barley Barber Swamp [Okeechobee 4 SE]), indicated many more wetlands than those shown on the township plat. The field notes indicate numerous wetlands, generally either "ponds" or "cypress swamps." This could be underestimated, because this township appears significantly affected by drainage. Landscape categories reported in the GLO field notes for Township 40 Range 38 (**USDOI, GLO survey data**) are presented in **Table A-4** and **Table A-5**.

Table A-4. Landscape categories reported in GLO Field Notes for Township 40 Range 38 (North boundary only).

Surveyor's Name	Witness Trees	Comments
"3rd Rate Pine", "3rd Rate Pine & Ponds"	Pines	Includes Ponds
"2nd Rate Hammock"	Cabbage Palm	"Cabbage Hammock"
2nd Rate Pine & Cabbage & Hammocks & Sawgrass Ponds"	Pine, Cabbage	Includes: Sawgrass Ponds, Hammocks; Cabbage appears to be mixed with pine
"1st Rate Hammock"	--	
"Savanna"	Cabbage Palms, Pines	

Surveyed by M. A. Williams in Aug. & Sept. 1853.

Table A-5. Landscape categories reported in GLO field notes for Township 40 Range 38.

Surveyor's Name	Witness Trees	Comments
"3rd Rate Cypress (Swamp), Pine & Palmetto		Inclusions: "Cypress Swamp", "Pine [Land]", "Ponds" (many; several per mile), "Sawgrass & Cypress (Pond)"
"Cypress Swamp"	Cypress, Pine, Cabbage, Bay, Myrtle	Many; probably as frequent as "Ponds"
"Pine [Land]"	Pine, Cabbage	
"3rd Rate (flat) Pine & Palmetto (land)", "3rd Rate Sawgrass Pine & Palmetto"	Pines, Cabbage	Inclusions: "Ponds" (many; several per mile), "Shallow Pond" (1), "Sawgrass"
"2nd Rate Pine & Cabbage"	Pines	Inclusions: "Ponds" (many; several per mile), "Willow Swamp" (1)
"Prairie"	Myrtle, Maple, Cabbage	Not much, but distinguished from "Sawgrass"
"Hammock"		Not many

Surveyed by W. J. Reyes in Feb. 1855.

Cross-Township Landscape Features

Figure A-7 shows a portion of the Halpatta Swamp (Allapattah Flats) that extended NW-SE across five townships. This area of "impracticably" dense and boggy sawgrass would originally have included peat soils and may have in part drained overland, along the NW-SE axis.

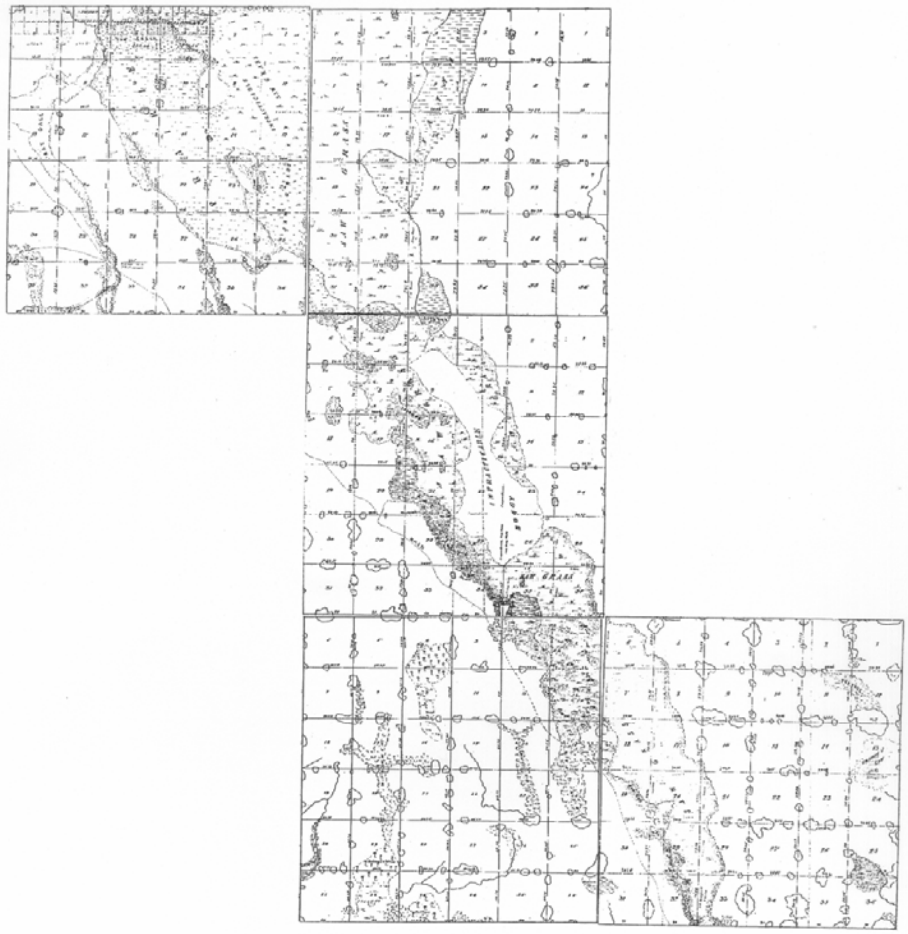

Figure A-7. Mosaic of Five Township Plats from Townships 37 to 39 S.

Ranges 37 to 39 E., Showing Extensive Sawgrass Marsh, Too Dense and Wet, Hence "Impractible" to Survey. Surrounding swamp, and perhaps sawgrass area as well, referred to as "Halpatta Swamp," Later Called the "Allapattah Flats." Much of original extent has disappeared under drainage and cultivation.

Headwaters of the St. Lucie River

Figure A-8 is a township plat map that includes the South Fork of the headwaters of the St. Lucie River. It appears similar to the township plats mapping the North Fork (not shown; Townships 35 and 36, Ranges 39 and 40). It is tempting to assume that all of the "Prairie and Ponds" physiographic region present within the northern part of the watershed contributed surface runoff to the North Fork of the St. Lucie River, and therefore the flow through the North Fork was much greater than through the South Fork. While the North Fork likely passed more water than the South Fork, it is important to note that no actual evidence was found within the township survey plats or field notes documenting surface runoff. The difference between the two forks may be less than expected. There is some indication that the Halpatta Swamp / Allapattah Flats area may have been connected to the South Fork, but this certainly bears additional investigation.

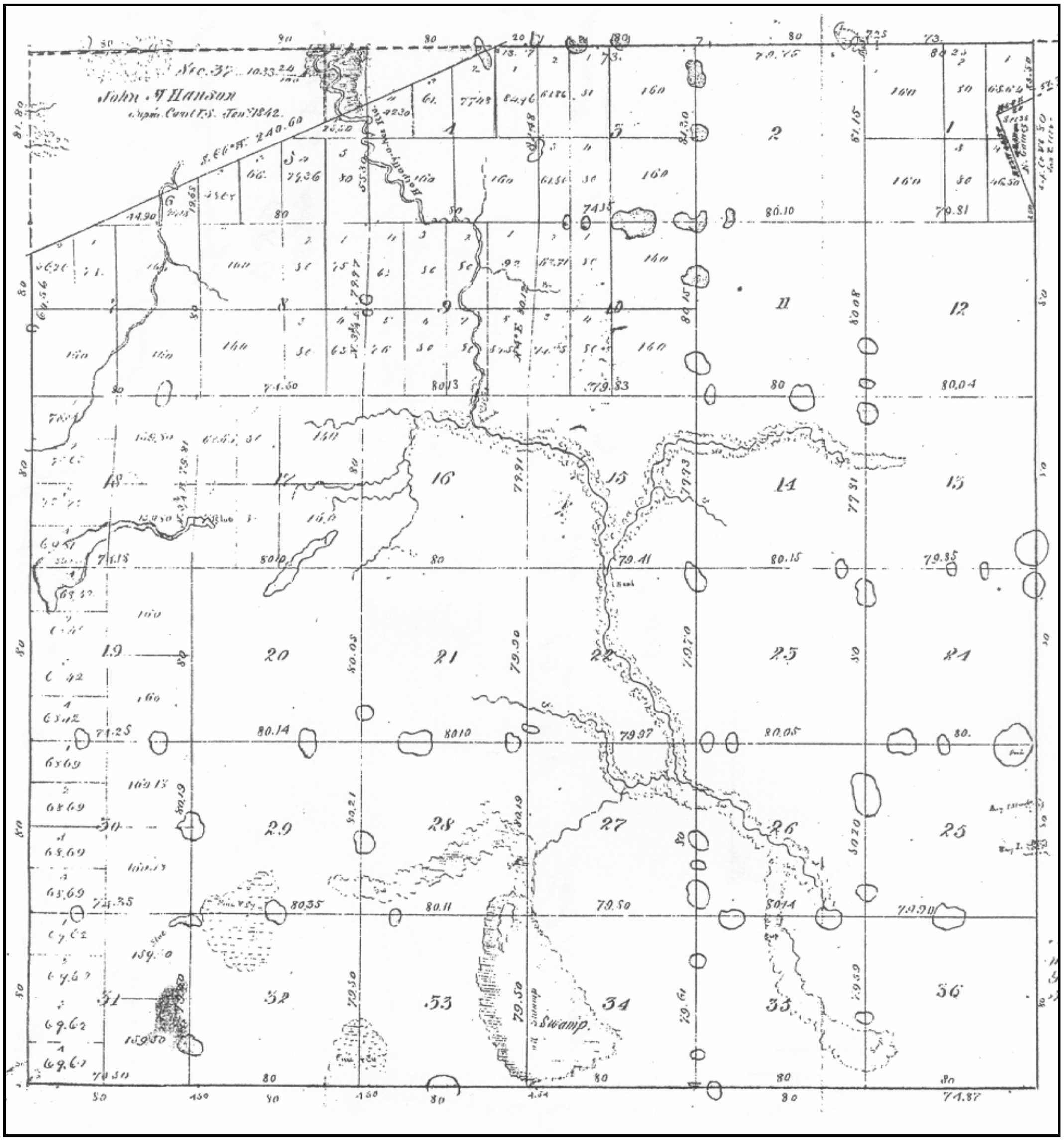

Figure A-8. Township 39 S., Range 41 E., showing several branches of south fork of the St. Lucie River.

Surveyed by M. A. Williams in June 1853.

Conclusions

The conclusions presented in this document are based on examination of field notes and plat maps, as described herein, for five of approximately thirty townships which comprise the watershed. Plat maps for a number of additional townships were examined briefly. The author has not visited the watershed for in-person exploration.

Three main physiographic regions appear to have been present in the predrainage watershed: an area of Pine & Ponds mosaic, an area of Prairie & Ponds mosaic, and an area referred to as the Halpatta Swamp, later as the "Allapattah Flats." Ponds, whether of sawgrass, open water or "grassy species," appear to have been very common throughout the Pine and the Prairie areas. The difference in the non-pond "matrix" found in the Prairie compared to that found in the Pine areas is not clear, but the Prairie matrix appears to have been covered by standing water for longer periods each year, which resulted in a reduced density (or complete absence in some places) of pine trees.

All three physiographic regions appear to have been very flat, with the elevation difference between pineland and pond probably often as little as two feet. It is likely that the depths of the depressions varied, with the shallower depressions forming either open water or wet prairie-type ponds, and the deeper depressions accumulating peat deposits and supporting sawgrass vegetation. Once the deeper depressions had accumulated peat, the elevation difference between peat surface and surrounding pine land surface may have been similar to the elevation difference between pine land and the bottom elevation of the open-water, sand-based ponds.

The Prairie mosaic was described primarily in the northern portion of the St. Lucie Watershed. The sawgrass marshes and bordering forested wetlands (Bay Galls and Cypress Swamps) that formed the Halpatta Swamp were present along the western edge of the watershed, along the eastern foot of the high NW-SE trending ridge. Cypress occurring in pond-like patches seems confined to the southernmost townships of the watershed.

Although there appears to have been variation in spatial pattern and apparent interconnection between the ponds present in the watershed, in general, a strong suggestion of extensive connection and extensive surface runoff does not appear. The most important contribution of the watershed to the St. Lucie River may be more through groundwater contribution to baseflow than through surface runoff. The long duration of standing water in ponds and even longer duration in the sawgrass marshes may be of assistance in estimating duration of the baseflow recession during each year's dry season.

The presence of extensive surface water throughout the watershed, the probably limited degree of surface runoff, and examination of townships surrounding the headwaters of the north and south forks of the St. Lucie River, tentatively suggest that the difference in discharge between the two forks may be smaller than might at first appear.

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Appendix B
NSRSM Topography Sources

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B.1: SOUTH FLORIDA COMPOSITE ELEVATION DATA

Digital elevation data is a requirement for many types of spatial, hydrologic and ecosystem analysis. Many agencies have collected elevation data over parts of south Florida, and most of this data is available in digital form.

Overview

The Central and Southern Florida Review Study approved in 1999 and authorized in the Water Resources and Development Act of 2000, contains an explicit requirement for system-wide planning, analysis and evaluation of results. Nevertheless, due to fragmentation of funding and authority, elevation data continues to be collected piecemeal. The implicit strategy seems to be that these disparate collections can somehow be combined into a coherent and consistent Digital Elevation Model (DEM) of sufficient accuracy and resolution to support the required analyses.

Proceeding with this assumption, an inventory was made of elevation datasets in south Florida. These were collected, reduced to their original points wherever possible, converted to NAVD88 where necessary, compared in areas of overlap (and occasionally adjusted), and interpolated over the entire area to produce a 100-foot ArcInfo grid. As additional datasets become available, this grid will be updated and refined.

Versioning

The metadata for the previous version was referred to as, "Version 2". Since this dataset received little review outside the development team, we are reverting to a "Release Candidate" naming scheme. Under this scheme, "Version 2" is now "sftopo_rc3".

Brief revision history

- **sftopo_rc1** A quick compilation of existing raster DEMs.
- **sftopo_rc2** The point at which datasets that comprised the source of the existing DEMs were analyzed and combined, and a single interpolation routine was employed throughout. Exceptions to this are the SGGE LIDAR and SWFFS which were retained in their original raster form. Significant water bodies were masked and coded as NODATA.
- **sftopo_rc3** Lake Okeechobee and the FPL reservoir were "filled-in" using existing data sources. This version was released to REMER as well as the SFWMD OoM, and the SFWMD CERP Topo Project.
- **sftopo_rc4** Additional data sources were sought to further fill in water features coded as NODATA. These were principally the

Caloosahatchee/C-43 Basin and waterway, the St. Lucie/C-44 waterway and estuary, the AICWW from St. Lucie to Biscayne Bay, the Estero Bay/Ten Thousand Islands/Whitewater Bay area, and Florida Bay.

- **sftopo_rc5** In response to several comments, EAA was updated with data from the Shuttle Radar Topography Mission (SRTM - 2000). It was suggested that EAA elevations based on USGS 1970 plane table surveys may not adequately represent the current ground surface in the area. The SRTM required some processing before use in the final DEM. Efforts are ongoing to document the process for incorporating this data. We are also undertaking a vertical accuracy assessment to validate its use.

Note from NSRSM Team

The data file is located on the SFWMD GIS server at the following location: \\gisdata1\raster\landform\hypsography\usace_lfhyp_grid_comp_100ft.

The dataset was modified by the NSRSM Team. Anthropogenic features were removed along the east coast and other areas. The buttonwood embankment was added to the dataset (Holmes *et al,* 1999)..

B.2: NATURAL SYSTEM MODEL V4.6.2

This section serves as a reference for the development of the predrainage topographic data.

Primary sources used for this effort:

1. *Estimation of Predrainage Topographic Coverage for the NSM*, Jose Otero, Walter Wilcox, and Cary White, South Florida Water Management District April 21, 2005

2. Report for RECOVER. Based on *Contour Development*, Christopher McVoy, Everglades Division, South Florida Water Management District, October 8, 2004.

Phase 1: Contour Development

Approach:

Contours for the area within the Predrainage Everglades boundary were hand-drawn by applying the following rules:

Elevations within the [predrainage] peat soil portions of the Everglades must be related logically to the directly adjacent upland elevations, specifically: (Everglades) ≤ (Uplands) and (Uplands) – (Everglades) ≤ 2 feet.

Contours should be perpendicular to the predrainage directions of flow.

Contours should cross "Big Four" (muck) canals at the 1913 canal survey elevations (FEEC 1914) along the unsubsided majority of canal length.

Contours should not follow 1913 canal survey elevations along subsided portions; near Lake Okeechobee and near the coastal ridge.

Contours should follow subsidence-corrected 1913 canal elevations along the subsided portions.

Southern Lake Okeechobee shoreline, from about Fisheating Creek to Port Myakka (Bacom Point), should be level at 20.5 ft. above mean sea level.

Contours should reflect the generally smooth, continuous surface expected from peat accumulation processes.

Few minor, and no serious, conflicts were found between the rules enumerated in the previous list. It was possible to draw contours that satisfied all of the rules with only minor exceptions. Surprisingly, this set of rules generally constituted a strong set of constraints, that is, they defined the allowable set of contours quite closely. It is important to note that within the Ridge and Slough landscape, the contours represent an average elevation corresponding conceptually to a spatially-weighted average of actual slough, ridge and tree island elevations.

There is an area of uncertainty in the vicinity of the 7-foot and 8-foot contours near the current location of Tamiami Trial (see **Figure B-1**). In this case, the central tendency of the various interpretations was used in contour development for the NSM.

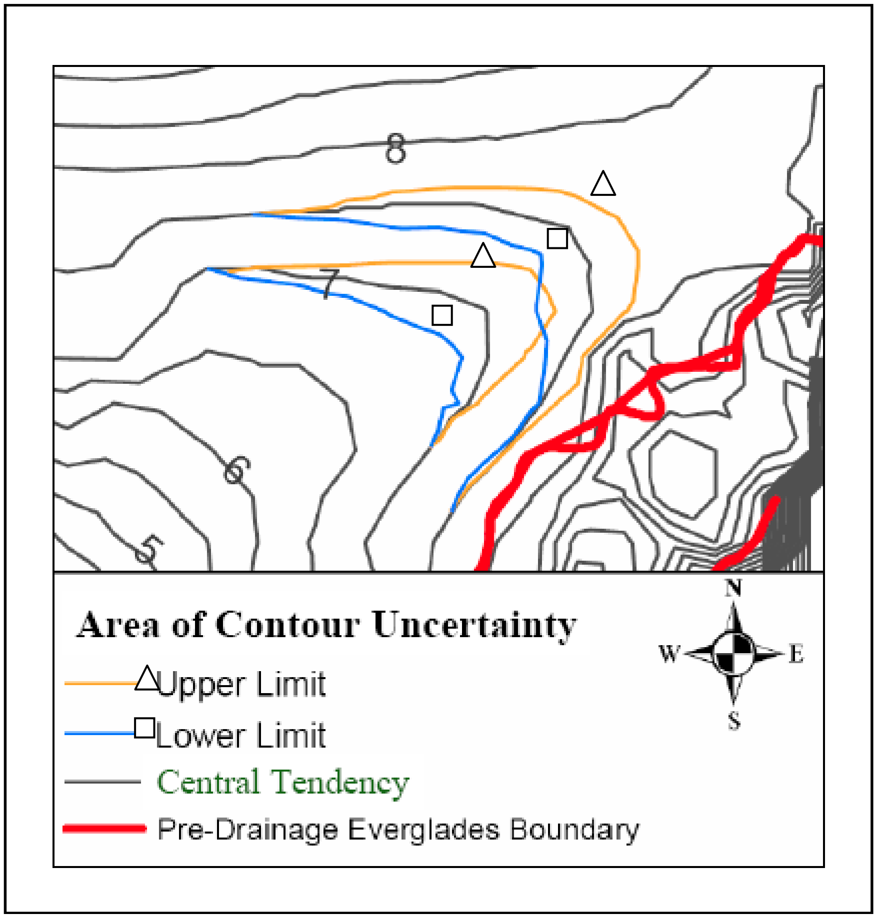

Figure B-1. Contour uncertainty near current Tamiami Trail area.

Sources referenced in C. McVoy Memo October 8 2004:

Upland elevations:

1. High Accuracy Elevation Data Collection (HAEDC) from U.S. Geological Survey as of October 2001 for current elevations below elevation 8 ft.
2. 1-foot contours generated from NSM 4.6.2 grid cell values.
3. 1-foot contours generated from SFWMM v. 4.5.
4. U.S. Army Corps of Engineers (1960b) map of 1-ft contours.

Elevation along eastern edge of Everglades:
1. Bache (1850).
2. MacGonigle (1896).
3. Rose (1898).
4. Senate Document 89 (1911).
5. U.S. Army Corps of Engineers (1960a).
6. Gaby (1993).

Landscape directionality (proxy for predrainage flow directions):
1. Board of Commissioners (1935).
2. USDA-SCS (1940).
3. McVoy et al. (**2011**).

1913 canal survey elevations:
1. FEEC (1914); Elevation profiles digitized from same.
2. King (1917).
3. Wilson (1918).
4. Crabtree (1921).

1913 canal survey subsidence corrections:
1. Jennings (1907).
2. Anonymous (1907).
3. Wright (1910).
4. Senate Doc 89 (1911).
5. McVoy et al. (**2011**).

Predrainage elevation of Lake Okeechobee:
1. Meigs (1879).
2. Sackett (1888).
3. Kraemer (1892).
4. Slattery (1913).

Additional sources and use of Information to supplement C. McVoy Memo October 8, 2004:

W. Said and R. VanZee, (personal communication), Office of Modeling, South Florida Water Management District.

Alignment of 8-foot contour south of Miami, on west edge of coastal ridge:
1. Combined Structure and Operational Plan (CSOP) for MWD and C-111 LIDAR (**2003**) Surveys Digital Elevation Model.

Sources used to estimate 7-foot contour south of Tamiami Trail include:
1. Board of Commissioners (1935).
2. Parker (1955).
3. FEEC (1914).

Phase 2: Grid Development

Approach:

Develop grid data based on the contours developed in Phase 1. Account for known topographic features not exhibited in the contours developed in Phase 1.

The processing steps are:

1. Develop preliminary grid data using Arc's TopoGrid.

2. Develop output contours from the preliminary grid data.

3. Compare input contours from Phase 1 with output contours from Phase 2.

4. Iterate steps 1 through 3 as necessary.

Actions:

The following actions are an attempt to bring the output contours in line with the intent and criteria used for the input contours, and accounting for known topographic features not exhibited in the input contours. Most of these actions were identified in the workshop of February 22, 2005.

Individual features

Lake Hicpochee and Mullet Slough were reinstated as they existed in NSM 4.6.2, as they were not present in the Phase 1 contours.

Edge matching

Correct contours in areas near the predrainage boundary so that the areas outside of the predrainage boundary are consistent with current elevations.

The areas corrected were:

1. Area near just northeast of historical Everglades (L-8 area).

2. Area near LEC boundary, starting near North New River and to the south.

3. Area near Lostman's Slough close to the predrainage boundary.

4. Area near the headwaters of the Caloosahatchee River.

No-Accretion Criteria

Only subsidence, no accretion, was assumed to have occurred in areas covered by High Accuracy Elevation Data (HAED). Ground elevations from the predrainage period compared to current elevations should stay the same or subside. Preliminary grid values were compared to current ground elevations. Where preliminary grid values were lower than NSM 4.6.2 elevations, the NSM 4.6.2 elevations were used.

Product:

The end result of the approaches outlined in Phase 1 and Phase 2 was used in the creation of the NSM 4.6.2 Sens 4 run. Final contours are illustrated in **Figure B-2**.

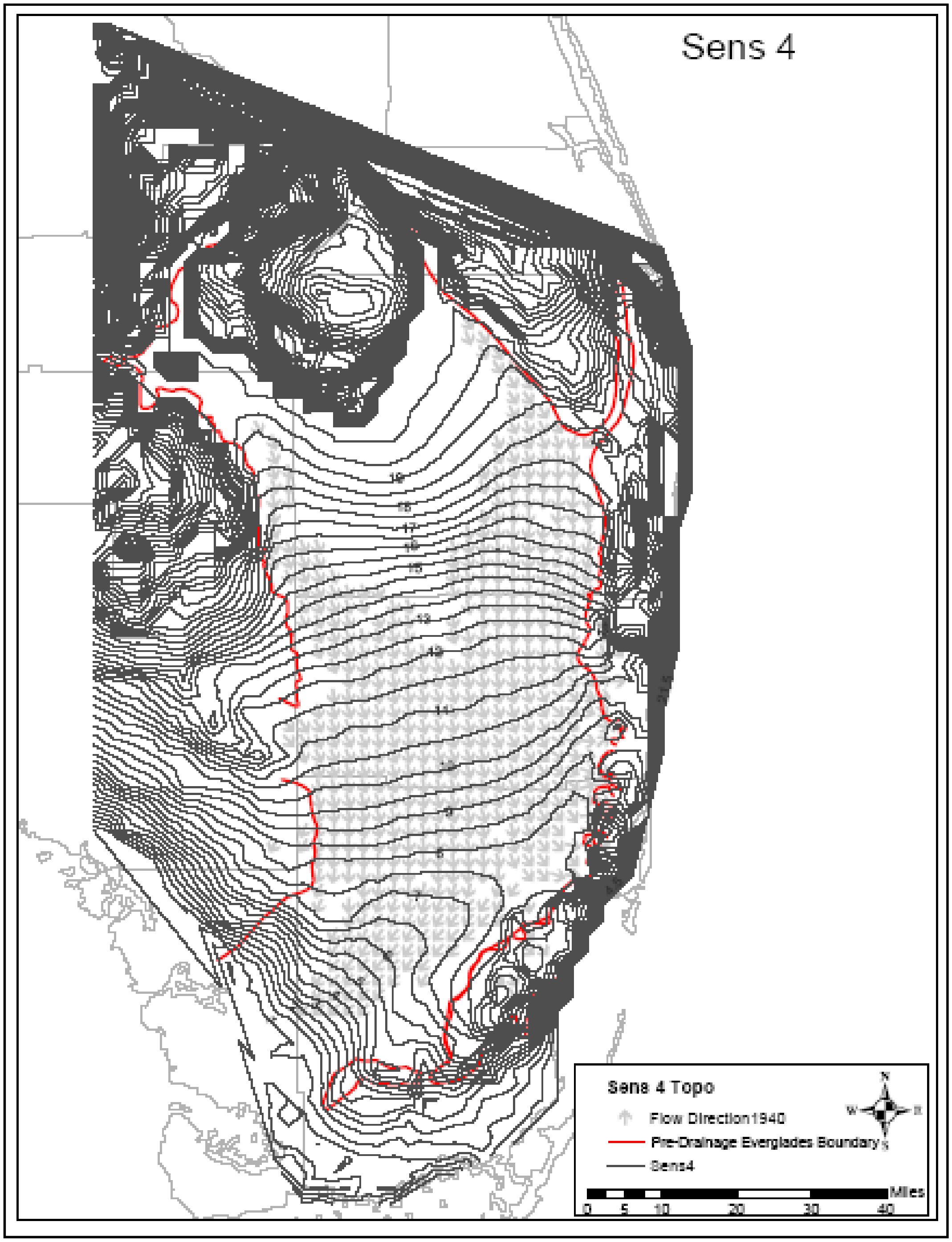

Figure B-2. NSM v4.6.2 Sens4 derived as a result of Phase 1 and Phase 2.

Note from NSRSM Team

The topographic model was corrected for depressions in WCA-1 (Richardson *et al.*, **1990**). Depressions are based on data from surveyed points in Water Conservation Area 1, (January 1987).

Data path:
\\gisdata1\gislib\vector\project\wca1\landform\landform_hypsography\spot_elevation_point\1987.

Data was also modified within the historical Loxahatchee Slough.

B.3: KISSIMMEE RIVER

Kissimmee River Floodplain Landsurface Elevation Data

Excerpted from Kissimmee Department Spatial Data Documentation: \\Ha1-fs1\fa_bus\krrep\Metadata\Spatial-Data-Doc.doc

All spatial data are stored in the Stateplane Coordinate System, Florida East zone, U.S. survey feet, horizontal datum NAD83, and vertical datum NGVD29. The data are stored in a file system located on an infrastructure server at the South Florida Water Management District's headquarters in West Palm Beach, Florida.

This dataset was developed during the years 1993 and 1994 by private architectural and engineering contractors for the U.S. Army Corps of Engineers (USACE), Jacksonville District, in support of the Kissimmee River Restoration (KRR) Project. The data are suitable for applications requiring elevation and high resolution aerial orthoimagery. Some examples of applications include inundated area mapping, land use determination, and existence of structures, roads, and drainage features. The data was collected and processed for government use for a specific USACE activity. The Jacksonville District makes no representation as to the suitability or accuracy of these data for any other purpose and disclaims any liability for errors that the data may contain. The data are only valid for their intended use within their content, time, and accuracy specification. Appropriate and professional judgment should be exercised in their use and interpretation.

The dataset describes the baseline topographic condition of the Kissimmee River floodplain prior to restoration and serves as the base map for the Kissimmee River Restoration Evaluation Program (KRREP) spatial database. The dataset consists of geodetic control, orthoimagery, contours, spot elevations, breaklines, cross sections, bathymetry, and digital terrain models (both GRIDS and TINS). The entire dataset was developed relative to the same geodetic control network to ensure good absolute and relative accuracy between thematic data. The control network was designed to support the development of 1:6,000 scale digital orthophotographs and 1-foot contours. It was derived from the Florida High Accuracy Reference Network (HARN). The entire dataset meets national map accuracy standards at a scale of 1" = 100'. This means that the horizontal position of features described in these datasets are within +/- 2.5 ft.of their absolute location on the ground, contours are within +/- 1 foot, and spot elevations are within +/- 0.5 ft.

The dataset is organized by theme and geographic area. Each geographic area is subdivided into blocks which break the files for each pool into manageable units. The digital orthophotographs are further divided into sheets where multiple sheets make up a block.

The themes within the dataset are Bline, Control, Grid, Index, Ortho, Spot, Tin, and Topo:

- **Bline** contains breaklines derived through stereocompilation and represent abrupt changes in elevation.
- **Control** contains locations and descriptions for the monuments that comprise the KRR third order geodetic control network.
- **Grid** contains ARC/INFO floating point Grids derived from the breakline and spot elevation data. These use a 60-foot cell size and are stored as a single grids per pool.
- **Index** describes the boundaries of the KRR project area and contains the Pool, Block, and Sheet layout for the project area.
- **Ortho** contains the digital orthophotography for 1994. The orthoimages are 8-bit greyscale TIFF files. The pixel size is 1-foot x 1-foot. Individual images are 3,000 pixels x 2,500 pixels. Image quality varies between pools. A project to tonally balance, resample, and compress the images is underway. The new image files will be added to this directory to allow end users to choose images appropriate for their uses.
- **Spot** contains spot elevations derived through stereocompilation at 60-foot intervals throughout the project area; ground survey cross sections run perpendicular to the C-38 canal and spaced at 1,000-foot intervals across the floodplain and 250-foot intervals across spoil mounds; and bathymetry for remnant river channel and the C-38 canal. Stereocompiled elevations are good in areas where the ground is not obscured by shadows, tall grasses, and slopes. In areas with dense marsh vegetation, spot elevations do not correspond well with the ground survey cross section elevations. These areas are identifiable in contour, DEM, and lattice datasets which were derived from the spot data. The data in these locations tend to bias towards the cross section data and show a strong linear correlation to the cross section course.
- **Tin** contains lattices derived from the grid data.
- **Topo** contains contours derived from the breakline and spot elevation data. Index contours occur at five-foot intervals with supplemental contours at one-foot intervals. The contour data for Pool D remain under evaluation. Errors have been found within these files.

Each thematic area is further subdivided into geographic area directories. The geographic areas are Pool A, Pool B, Pool C, and Pool D. These geographic descriptors refer to areas within the Kissimmee River Floodplain.

Note from NSRSM Team

Only data from Pool A was used in the topographic model. Anthropogenic features, such as spoil mounds, were removed from the dataset. The primary data source, RSM topo 2009, had data gaps in this area. The remaining data gap in this area was filled in using data from USGS spot surveys.

B.4: MULLET SLOUGH

Mullet Slough is an important part of the historical system that provided water to the Everglades. The coverage \\modserv\hsm_data2\everhist\nsmval\dadecon60 was used as a guide for implementing the historical contours of Mullet Slough.

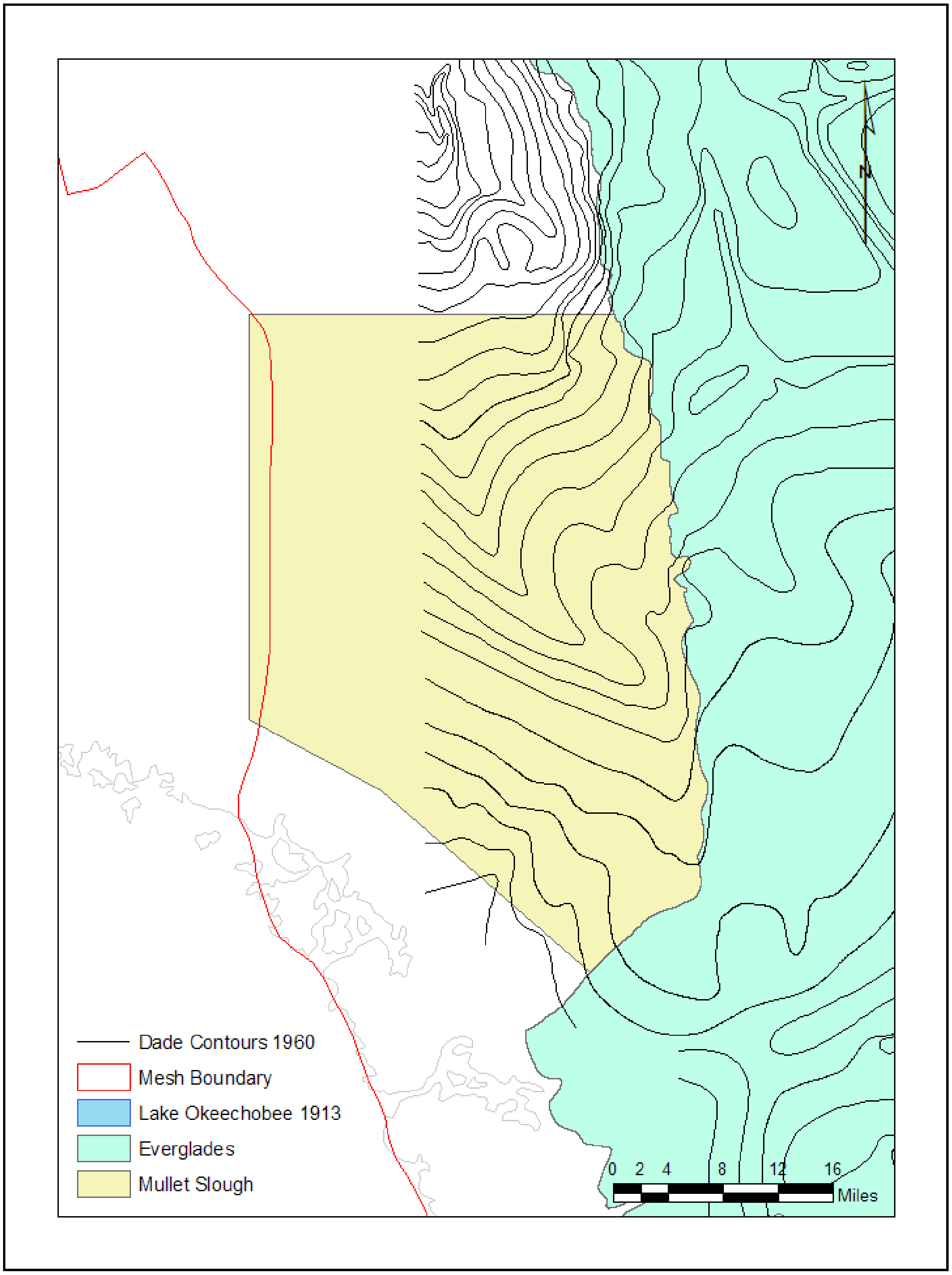

Figure B-3. Mullet Slough contour map.

B.5: USGS POINT

The USGS five-foot point data using 1:24,000 scale quadrangles were utilized in the data gaps for the northern portion of the model. The file is located on the SFWMD GIS data catalog at:

\\gisdata1\gislib\vector\other\usgs\q24k\topo\point\north\north_points

B.6: WATER CONSERVATION AREA 1 ELEVATION DATA

Historically, Water Conservation Area 1 (WCA1) was known as Hillsborough Lakes. The elevation data within the historical Everglades topographic model was modified in the area. WCA1 was surveyed in 1987 (Richardson *et al.*, 1990) and showed several depressions that are not related to anthropogenic alterations. The file is located on the SFWMD GIS data catalog at:

\\gisdata1\gislib\vector\project\wca1\landform\landform_hypsography\spot_elevation_point\1987.

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Appendix C
Generation of Rainfall Dataset

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[Appendix C reproduces, "Rainfall Version 3.0", an internal South Florida Water Management District document, authored by Alaa Ali in 2010.]

C.1 RAINFALL V3.0

Rainfall Binary File: Quality Assurance/Quality Control (QA/QC), assembling, and updates up to V3.0

Rainfall is the driving force in the hydrology of south Florida, and hence is the main input hydrologic data for hydrologic models in this region. In all South Florida Water Management Model (SFWMM) runs, rainfall is assumed to have the same temporal and spatial distribution as that which occurred historically over the period of simulation. Rainfall's prominent role in the region's hydrology makes it well-suited as a control variable for evaluating alternative ways of managing the system as a whole.

For the distributed mesh portion of the SFWMM, a daily time series of rainfall depths for each grid cell is used. For Lake Okeechobee and other lumped hydrologic systems a single daily time series of rainfall depths is input and assumed to apply over the spatial extent of the basin. Because of the temporal and spatial influence of rainfall on the system hydrology, the rainfall input file received a great deal of preparation, scrutiny, and continuous improvements and updates to assure proper model input for hydrologic representation. The general procedure for the development of the rainfall dataset in the SFWMM can be described as follows: data collection and associated quality assurance/quality control (QA/QC) or screening of rainfall station data; and transformation of rainfall point data into grid-based data.

For preparation of rainfall data the period of record 1914–2000 was considered to create a rainfall database. This period of record is used for all of the models maintained by the South Florida Water Management District (SFWMD) Hydrologic and Environmental Systems Modeling (HESM) section. Allowances for flexibility in the period of records, and opportunity for studies such as frequency and trend analysis benefitting the use of the hydrologic models (e.g., SFWMM, Glades-LECSA, C-111) were taken into account as part of this process.

The primary purpose of this effort was improving the rainfall input binary file of the SFWMM. This effort has evolved over the years from versions V1.2 through V3.0. Version V1.2 represents the first dataset that covers the period of record 1965-1995, and the original coverage, (**Figure C-1**). Version V1.3, an expanded version of V1.2, includes a longer period of record (1914-2000). In V1.4, the rainfall interpolation method of V1.3 was modified from the Thiessen method using the nearest neighbor approach to the Triangular Irregular Network (TIN), coupled with the local averaging approach, TIN10 method. Version V2.0, an expanded version of V1.4, includes more spatial coverage (C-43 Basin and C-44 Basin). In the V2.1 release, the coverage was expanded north to include the Upper Kissimmee forming what is known now as the super grid. The spatial extent of the super grid was determined to be larger than that of the computational grid for the SFWMM in order to allow for determination of rainfall in the Natural System Model (NSM) as well as to provide rainfall information for the lumped portions of the SFWMM. The main changes in V3.0 are the extension of the period of record to 2005 and the addition of 225 new rainfall stations. Rainfall binary file temporal and spatial extent is larger than the current coverage of the Hydrologic and Environmental Systems Modeling (HESM) Department's existing models. The primary reason for creating a rainfall data file with a greater period of record than required by the modeling period of simulation (1965 to 2000) was to support identification of monthly and annual data trends.

In this section, rainfall preparation methodology and results are presented for rainfall binary file V1.4. An overview of the results is also presented for subsequent versions of the rainfall input data.

Rainfall Binary file version V1.4

Due to data availability issues, the rainfall data for the period from 1914 to 1998 were processed separately from the period of 1999 to 2000; however, the identical procedure was used for both time periods. For the period from 1914 to 1998, there were 860 rainfall stations covering 11 counties (Broward, Highlands, Martin, Palm Beach, Collier, Glades, Monroe, Miami-Dade, Hendry, St. Lucie, and Okeechobee). For the period 1999 to 2000, rainfall data at 964 stations covering the same counties were available.

Preparation of the rainfall binary file from the aforementioned rainfall stations was carried out using the following five phases with a number of methodical steps for completing each phase:

1. Identification and quality classification of extreme values in daily data.
2. Testing and elimination of some extreme daily values.
3. Screening of data with zero monthly rainfall.
4. Screening of rainfall data having extreme low annual values and high monthly values.
5. Data screening through visualization.

The first two phases were designed to identify and remove highly questionable daily values according to a prescribed classification scheme. The third and fourth phases were designed to identify and remove data associated with stations not consistent with monthly and annual trends. The fifth phase provides final QA/QC through data visualization through the grid IO application on the binary file.

A summary of the process is provided in the next section.

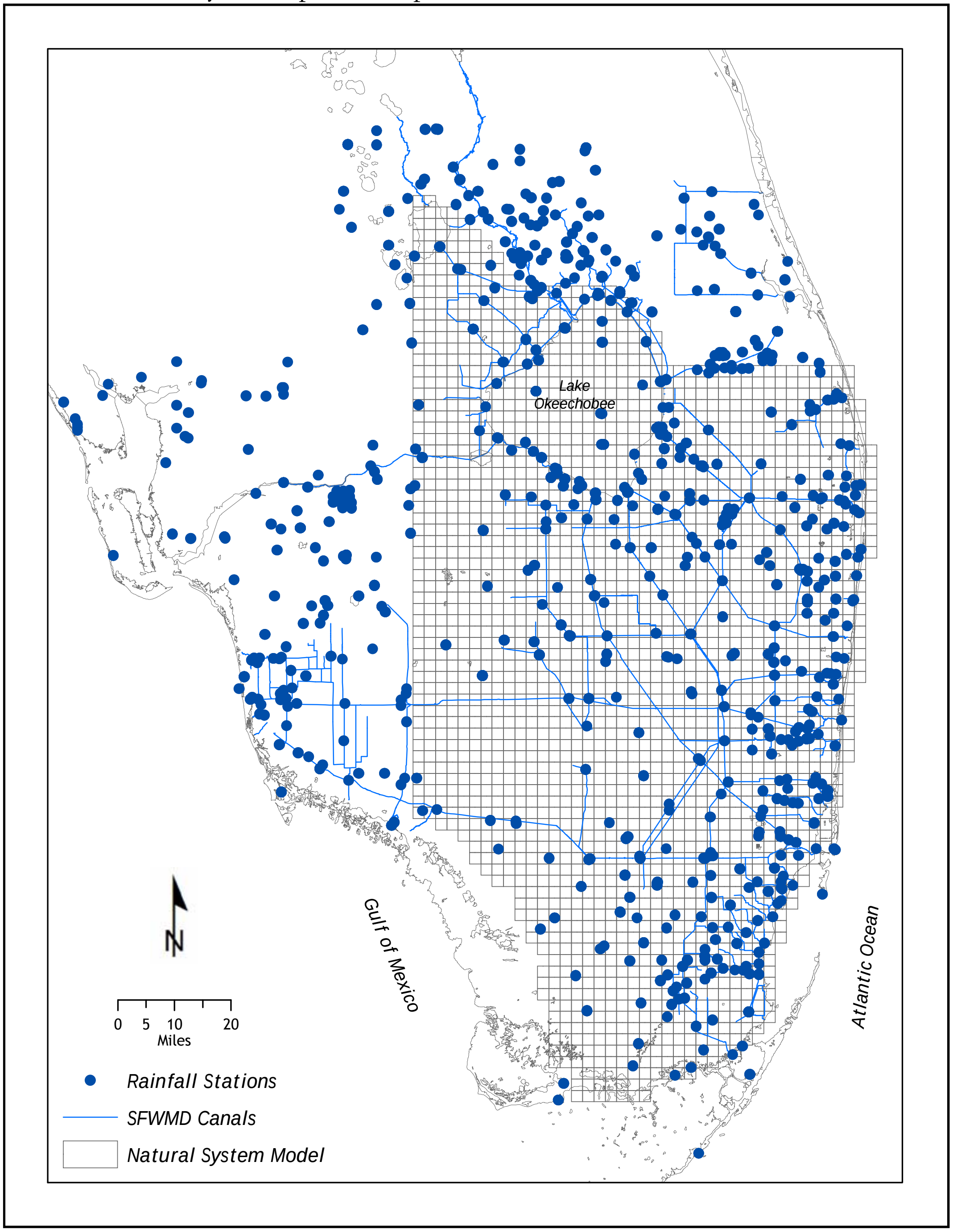

Figure C-1. Rainfall stations and grid coverage for rainfall binary file V1.2-V1.4.

Phase I: Identification and quality classification of extreme daily rainfall values

In Phase I daily rainfall values greater than 16 in. were flagged as questionable. Additionally, daily rainfall values less than 16 in. but higher than 5.5 in. in Miami-Dade, Broward, and Palm Beach counties, were flagged as questionable. Daily rainfall values less than 16 in. but higher than 5 in. in the other counties of the District area (Highlands, Martin, Collier, Glades, Monroe, Hendry, St. Lucie, and Okeechobee) were also flagged as questionable.

The lower threshold values for questionable data represent approximately the 99.9 percentile in each respective county. For each day when at least one questionable data point was identified, values from the nearest six stations where extracted into a dataset. For each of the resulting 1,973 datasets a classification scheme (Ali and Cadavid, **2001**), consisting of seven classes based on distance and value difference, was used to automatically accept or mark values for further review. After automatic acceptance of two of the classes, and marking the remaining five classes as questionable, the rainfall binary file was recreated and reviewed using grid summaries and viewing programs.

Phase II: Screening of extreme daily rainfall data

During Phase II rainfall data values identified as questionable in Phase I, were further analyzed for either acceptance or rejection. A manual examination of the questionable rainfall data values was conducted using the nearest six rainfall stations to each site value. The manual examination included consideration for: distance, direction, difference in values, number of neighbors with high values, time of year, frequency of re-occurrence in the period of record, and known tropical storm events. Following Phase II, 711 data points were eliminated (about 35 percent of the initial 1,973 questionable values) and 1,262 points were accepted.

Phase III: Screening of daily data corresponding to zero monthly rainfall

In Phase III efforts focused on identification and verification of rainfall data for calendar months with zero rainfall. The objective in this phase was to reject or accept such data based on prescribed criteria (Ali., et. al. 2001).

For each county, calendar months with zero rainfall data were extracted into a file. Excluding the site under investigation, average rainfall was calculated and compared to the site in question. A monthly value of zero rainfall during dry seasons was not considered unreasonable. However, zero monthly rainfall values during the wet season where nearby stations averaged $\geq$ 5 in., were considered highly suspect. A total of 1,797 questionable monthly rainfall values were identified and manually reviewed. Considerations for acceptance or rejection of data included:

- Nearby averages.
- Historical monthly average tables which included surrounding areas.
- The repetition of zero values from other sites for the same month.
- Seasonality.
- The number of consecutive zero values at a given site.
- Whether or not the nearby site average was below the long-term monthly average.

A final evaluation was made for stations with zero rainfall for three or more consecutive months by examining the quality of the daily rainfall.

Of the 1,797 monthly rainfall data points identified in this analysis, 165 sets of monthly data were rejected. The majority of rejected data points were from the period of record between 1966 through 1998. Almost no rejection was assigned to a month belonging to a drought period. There is no particular month where rejection was assigned to all counties. **Table C-1** provides the number of rejections for each county.

After elimination of the data (**Table C-1**), the rainfall binary file was updated, the statistical summary was analyzed, and the monthly rainfall values were reviewed. Zero monthly rainfall appeared only on the dry season months. All but a small portion of the SFWMM domain was covered with zero rainfall in the following months:

- December 1932.
- January 1933.
- February 1933.
- February 1944.
- January 1949.
- January 1960.
- January 1961.
- April 1967.
- December 1968.
- April 1970.

Extended periods in which zero monthly rainfall values were found over significant areas (that vary in location and size for more than one month) were:

- November 1948 to March 1949.
- November 1970 to April 1971.
- December 1984 to February 1985.

No zero rainfall values were observed over the same area for an extended period.

Table C-1. Zero monthly rainfall occurrences excluded from creation of the Rainfall Binary File.

County	Number of rejections of monthly records of zero rainfall
Broward	19
Collier	62
Miami-Dade	16
Glades	3
Hendry	5
Highlands	10
Lee	1
Martin	1
Okeechobee	8
Palm Beach	40
Monroe	0

Phase IV: Examination of annual rainfall below 30 inches and monthly rainfall above 20 inches

Visual examination of the binary file showed annual rainfall below 30 in. in some areas. Similarly, monthly rainfall was greater than 20 in. in some areas. The examination of data was carried out in three steps:

1. Investigation of the corresponding data.

2. Comparison with rainfall local statistics.

3. Visual inspection of annual snapshots extracted from the revised rainfall binary file.

The investigation of the corresponding data consisted of a visual review of the daily data for records not meeting the criteria. Of the 364 cases in which annual rainfall was below 30 in., 22 years of daily data which were determined poor quality (a combination of unrealistically low and missing values) were consequently removed. Of the 362 cases in which monthly rainfall was greater than 20 in., one month of rainfall (January 1992) was rejected because rainfall of 31.06 in. was recorded in an area of 0.65 average rainfall; the remaining cases were accepted.

There were 98 cases in which annual rainfall was below 30 in. and a maximum of two months of data were missing. For those cases, the following annual statistics were generated: the average, the standard deviation, the annual rainfall excluding the missing months, and the annual rainfall after counting for the missing month, using the following approximation:

Adjusted Value = Value * 12 / (12 – number of missing months)

If the number of stations used to compute the statistics was two or less, discretion (based on a visual evaluation) was used to either reject or accept the daily dataset for the year. In cases where the number of stations used to compute the statistics was more than two, the daily records for a given year were rejected if the associated adjusted value was:

1. Below 20 in.

2. Less than 1/2 of the average rainfall (for the given county and given year based on all locations except the one of interest) or less than (AVG-2.5*STD) where STD is the standard deviation of annual rainfall within that county and that year.

Of the 98 cases identified, 53 daily datasets were rejected.

Phase V: Final QA/QC through data visualization

Phase V involved performing a visual examination of daily, monthly, and annual snapshots of the rainfall binary file. Since some areas of very low rainfall still existed, associated stations were identified and a visual inspection of the daily values was performed. At some stations, daily data were of poor quality as indicated by an overwhelmingly large number of missing data for a given year.

As a result of this evaluation, six records were rejected for at least one year and one record was rejected for two years. Additionally, two stations were dropped for the entire period of record.

Evaluation of rainfall data for 1999-2000

As mentioned earlier, the data for the 1999 to 2000 period was evaluated separately due to data availability issues. However, the same methodologies that were applied to the 1914 through 1998 period of record data were also applied to the dataset for 1999 to 2000. The results of this effort were as follows:

1. A total of 484 data points were identified as extreme values and needed further evaluation which resulted in the rejection of 254 data points.

2. There were 9 monthly records for June 1999 with low rainfall which were inconsistent with the high rainfall recorded for that month. Data for that period were rejected.

3. Thirteen rainfall stations with annual rainfall below 30 (with maximum of two months of missing data) were rejected.

4. One station was eliminated for unrealistically high values and one station was eliminated for missing data throughout the period of record (with zero data at the end and beginning of each month).

Rainfall interpolation to the grid cells (change from nearest neighbor to TIN10).

Once the rainfall data QA/QC was completed, a Triangular Irregular Network (TIN) approximation method was performed to assign a representative rainfall depth for each day and grid cell. This was necessary because rainfall gauging stations do not normally coincide with the centroid of the grid cells and most grid cells do not contain rainfall gauging stations.

The normal TIN approximation involves using the centroid of the grid cell as a reference point for determining which three rainfall stations are used for estimating the daily rainfall value. If rainfall stations are fairly sparse, model grid cells are small, or rain events are spatially large, then TIN is a suitable application. However, in south Florida, the rainfall stations are not sparsely located, the model grid cells are large (4-square-miles each), and heavy rainfall events can be localized. Therefore, a variation of the normal TIN approximation method was developed for this application.

The new method involved dividing each model grid cell into 100 subcells. Because each cell was equally divided horizontally and vertically by 10, the methodology is referred to as TIN-10. A triangular pattern of rainfall stations with stations at each apex (**Figure C-2**) was overlaid the subcells. For subcells contained within a single triangle, a daily rainfall value was calculated based on the rainfall stations at each apex. The calculated values were the weighted average of the three nearest stations (based on distance from each station to each subcell centroid). Once the daily rainfall for each subcell was determined, the values were averaged to compute the grid cell daily rainfall value used by the model.

From **Figure C-2**, the normal TIN approximation method would apply the rainfall at stations B, C, and D, to the centroid of the grid cell (despite only 38 percent of the subcells falling within the triangle). Consequently, the influence of two other rainfall stations would not be considered for the remaining 42 percent of sub-cells. For the TIN-10 method, the influences of the other two stations would be included in the approximation.

A comparison between the two methods revealed only small differences in annual averages with the TIN-10 method being slightly lower. The monthly average differences were generally less than 0.2 in. with the TIN-10 method having consistently lower maxima. However, the differences between the two methods were more evident during the wet season months. The TIN-10 method tends to decrease the dominance of any one station, thus minimizing the effect of a localized rain event on a grid cell.

Average annual results of the generation of the rainfall dataset by the process for data collection, QA/QC, and transformation to grid, are provided in **Figure C-3**. The seasonal variability of the end product is shown in **Figure C-4**.

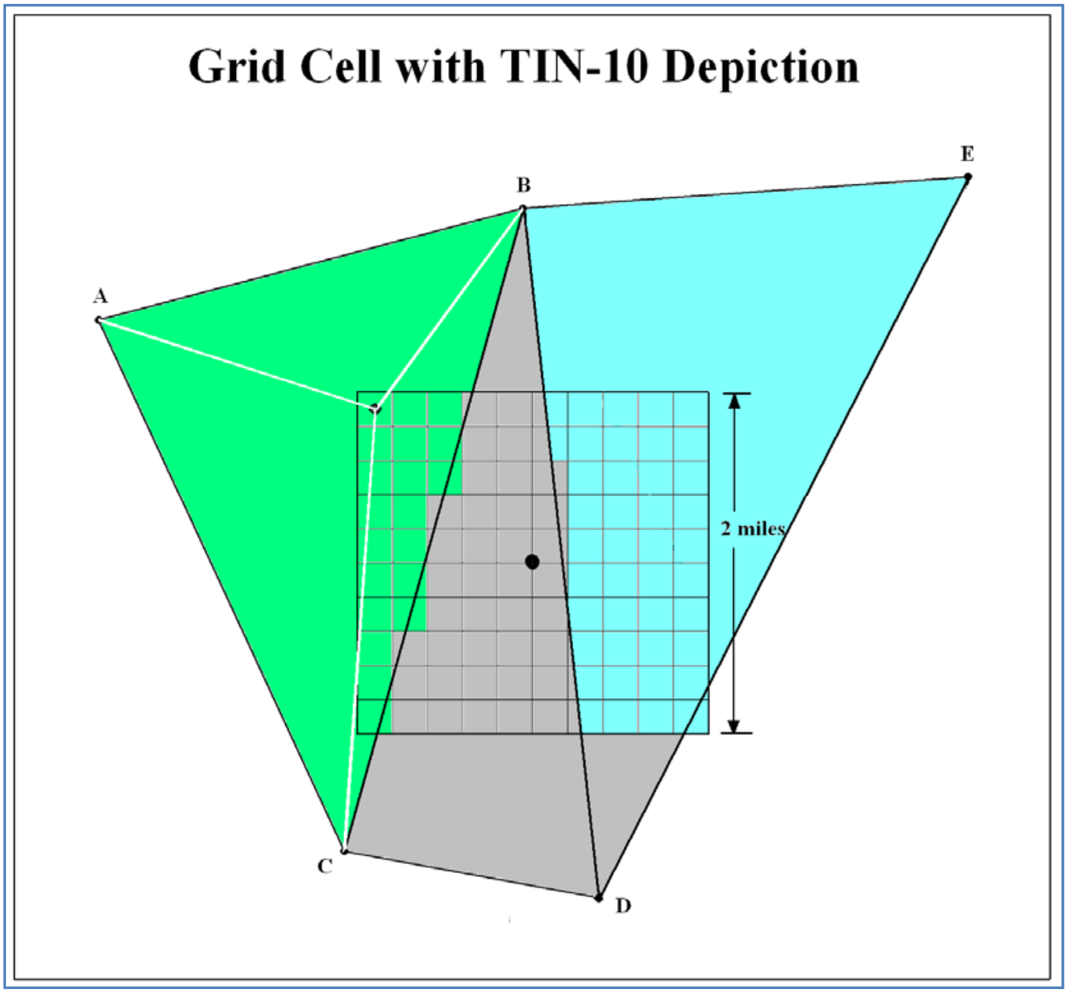

Figure C-2. Example of TIN-10 Estimation for Model Grid Cell.

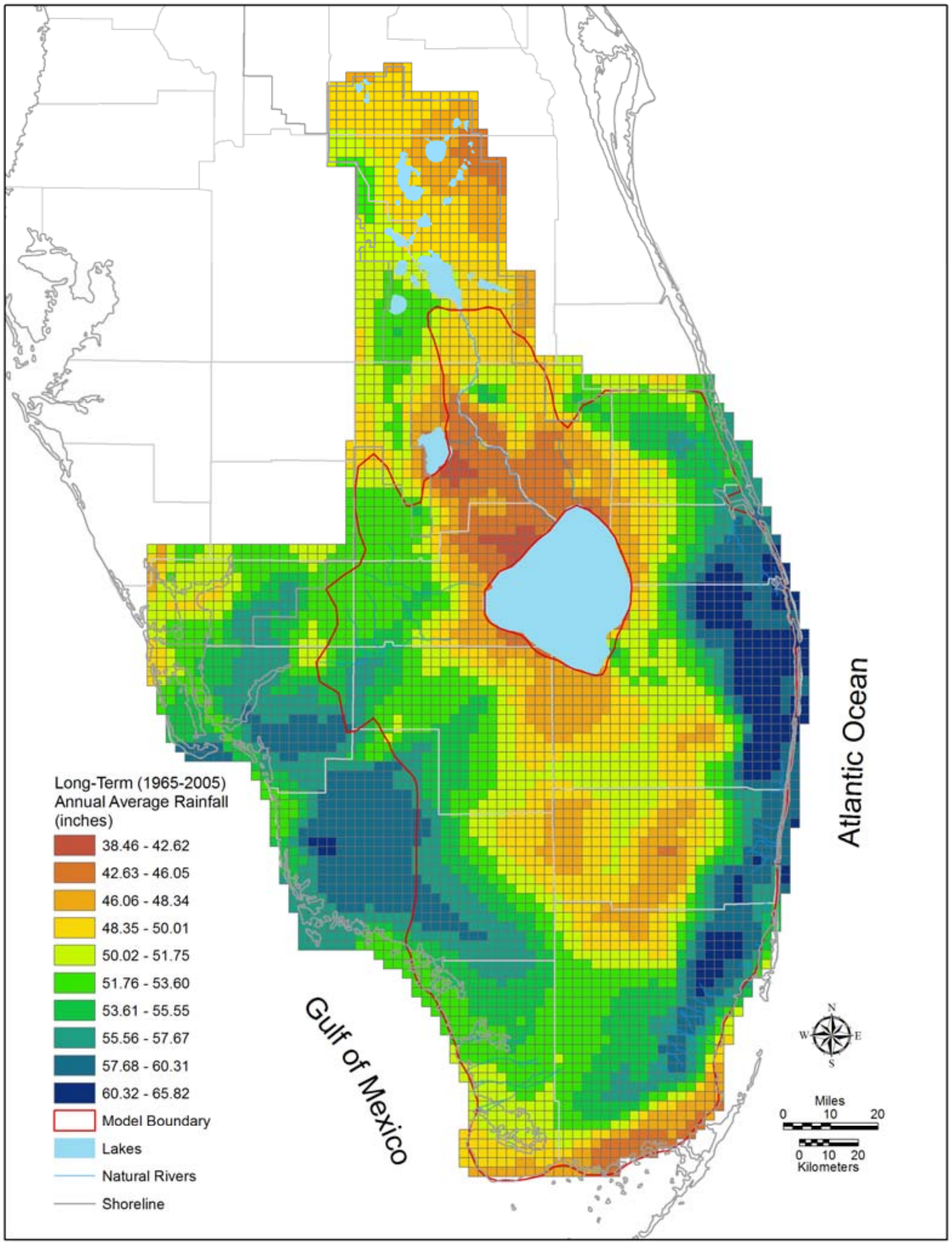

Figure C-3. Grid values of annual average rainfall.

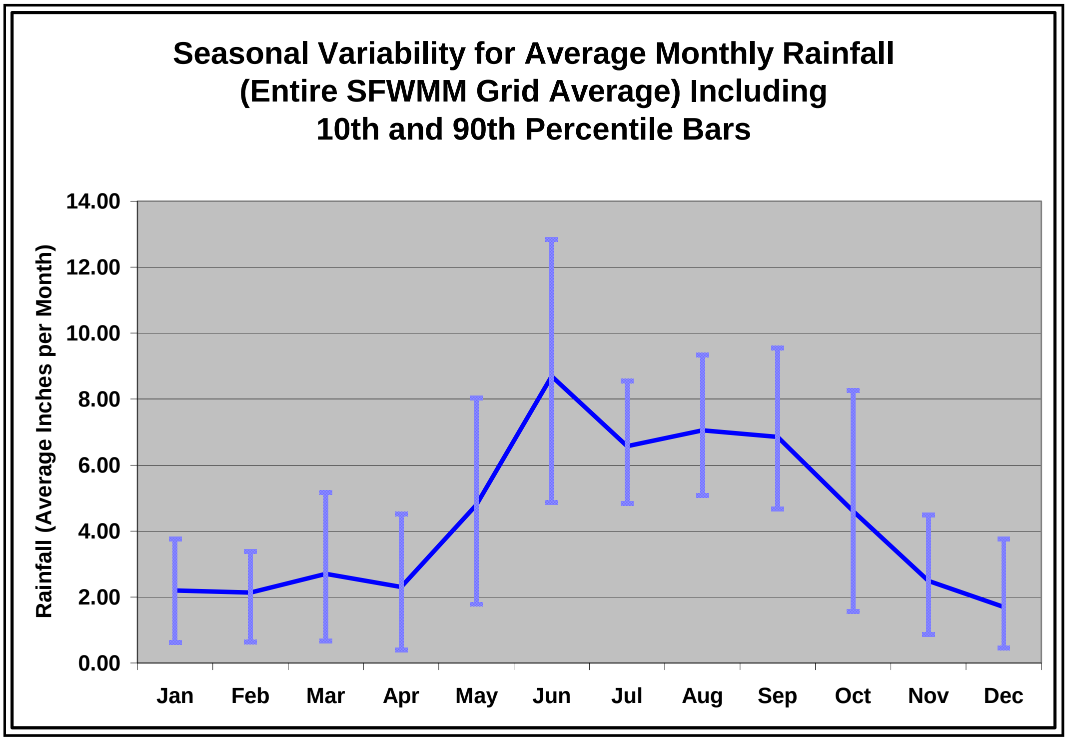

Figure C-4. Monthly mean with 10th and 90th percentile bars for rainfall.

Comparisons of Rainfall Distribution Estimation Methods

A new version of the rainfall binary file, V1.3, was created to reflect the changes made as a result of the quality assurance efforts described in this appendix. In V1.3, rainfall was estimated at the center of the SFWMM grid cell centroid by selecting the nearest neighbor as an approximation to the Thiessen polygon method.

As mentioned earlier, V1.4, was created where rainfall is estimated using TIN. In this version, TIN estimates are obtained at the centroids of 10x10 subcells within the SFWMM cell and averaged over that cell. The set of figures in **Figure C-5** present the results of the rainfall statistics for the estimation methods for the entire model region. The years are grouped into two periods (1965 to 1995 and 1996 to 2000) to allow for comparisons to the previous rainfall binary file, V1.2, which was used in earlier versions of the SFWMM.

The differences of monthly rainfall between V1.4 (TIN) and V1.3 (nearest neighbor), reflecting the estimation method effect for rainfall distribution, are depicted in **Figure C-5**. **Figure C-5** shows all but two (May and June) of the monthly rainfall differences range within ± 0.2 in., with the average (the solid line) close to zero and the difference magnitude higher between 1983 and 1995 (very wet years). The larger differences occur mainly in the wet season months (May through October).

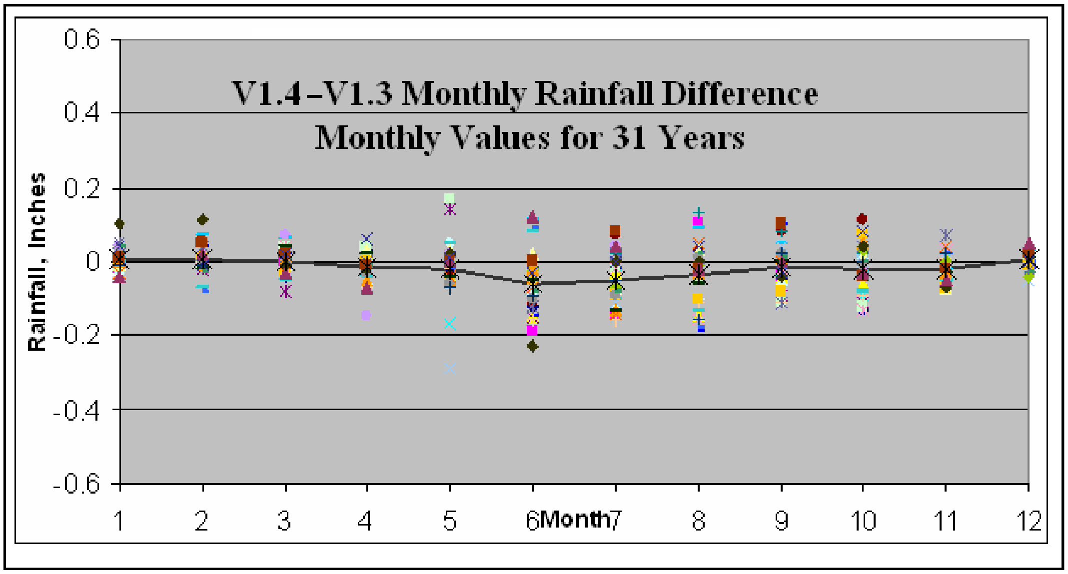

Figure C-5. Monthly average rainfall differences for V1.4 and V1.3 (1965-1995).

Figure C-6 depicts maximum monthly rainfall for each month. For the period 1965 to 1995 and compared to V1.2, V1.3 monthly rainfall maxima decrease in February by four in. and change slightly in May, August, September, and December. Compared to V1.3, V1.4 maxima are lower in general. For the period 1996 to 2000 (V1.3 and V1.4), monthly rainfall maxima are consistently lower due to the "averaging" nature of the TIN estimator.

The monthly average rainfall (**Figure C-7**), the monthly standard deviation (**Figure C-8**), and the annual rainfall (**Figure C-9**) show only minor differences between the distribution methods and the earlier version (V1.2) of the rainfall binary file. The annual rainfall for the three versions, as depicted in **Figure C-9**, are almost identical in most of the years with less than a one-inch difference in years 1977, 1983, 1985, 1992, and 1993.

The differences between the distribution methods were further explored by evaluation of subregional or basin rainfall within Lake Okeechobee, the Everglades Agricultural Area (EAA), and the Everglades National Park (ENP). No significant differences were noted within these regions.

A final evaluation of the distribution methods was conducted by creating performance measure (PM) graphic sets from the different versions of the rainfall binary files. In general, the results based on the PM graphs, exhibit slight variations. For example, observed changes in water budgets ranged from about -4 percent to +4 percent with the majority very close to zero for all basins. No specific location or specific performance measures can be characterized by a unique pattern of variations. Furthermore, no systematic difference or trend was observed. The rainfall binary file V1.4 was used as the standard set for the SFWMM v5.5.

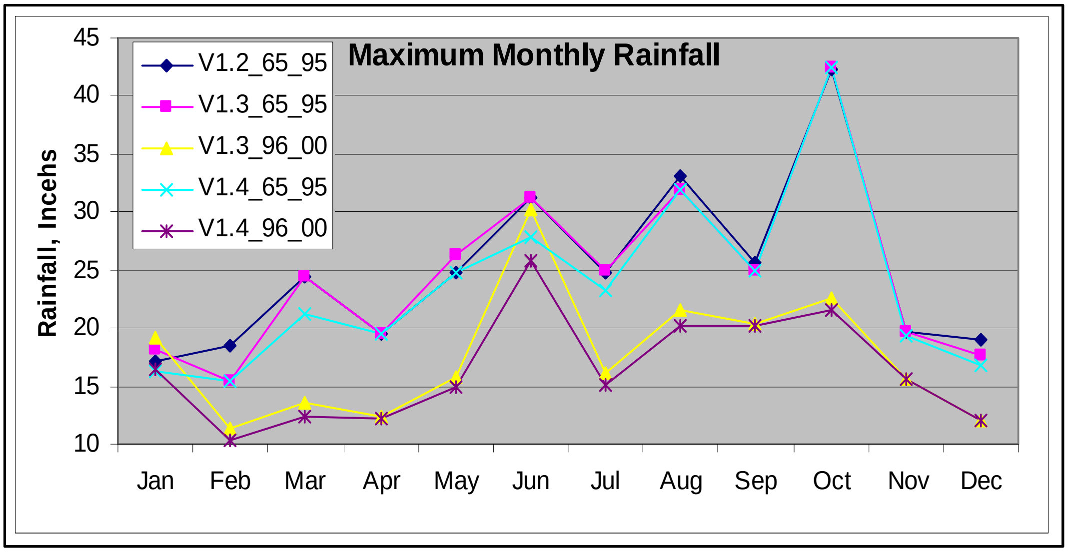

Figure C-6. Maximum monthly rainfall for the entire model domain.

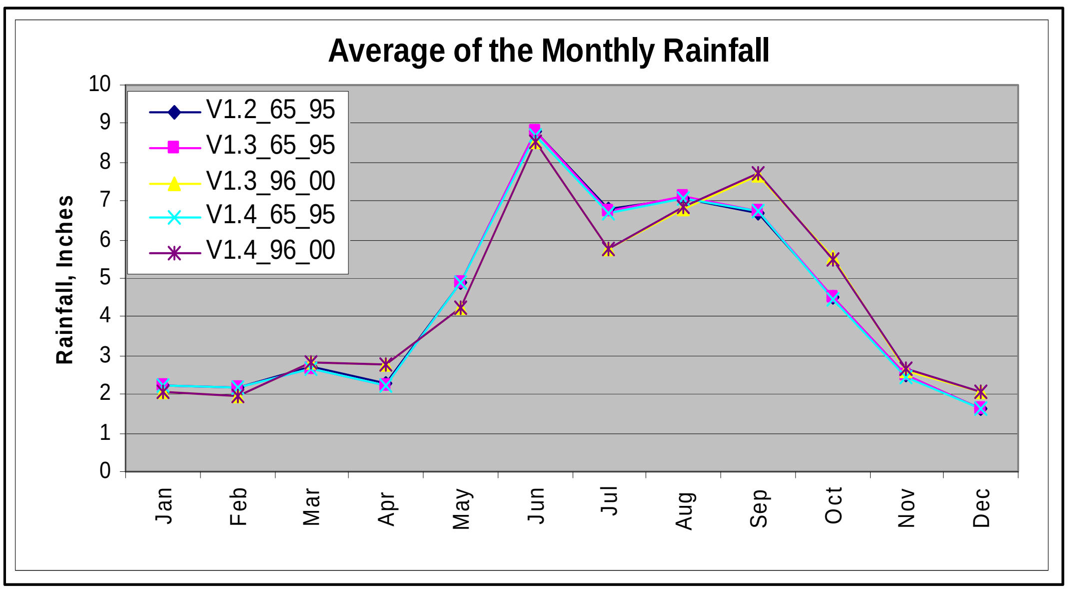

Figure C-7. Average monthly rainfall.

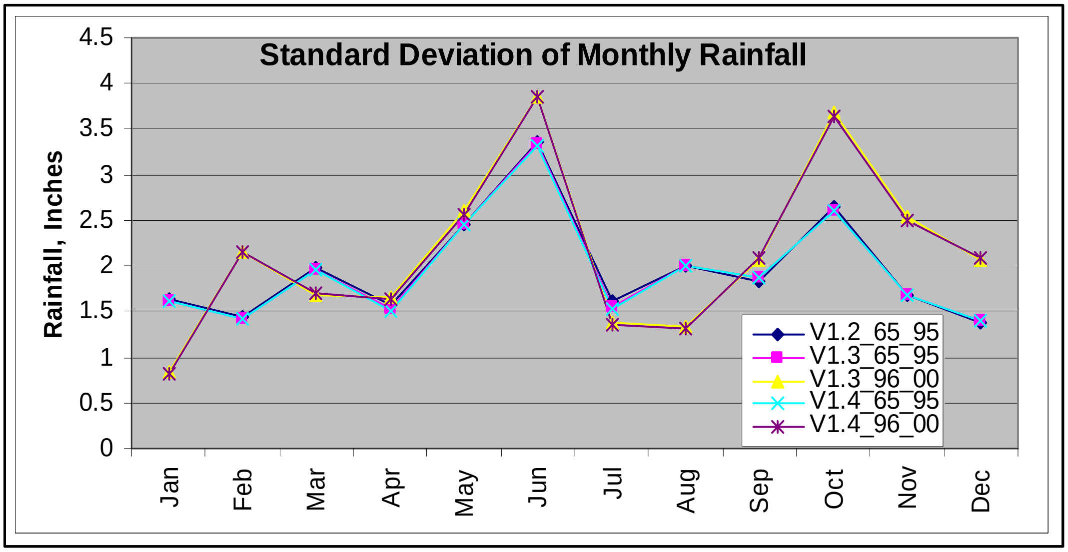

Figure C-8. Standard deviation of monthly rainfall.

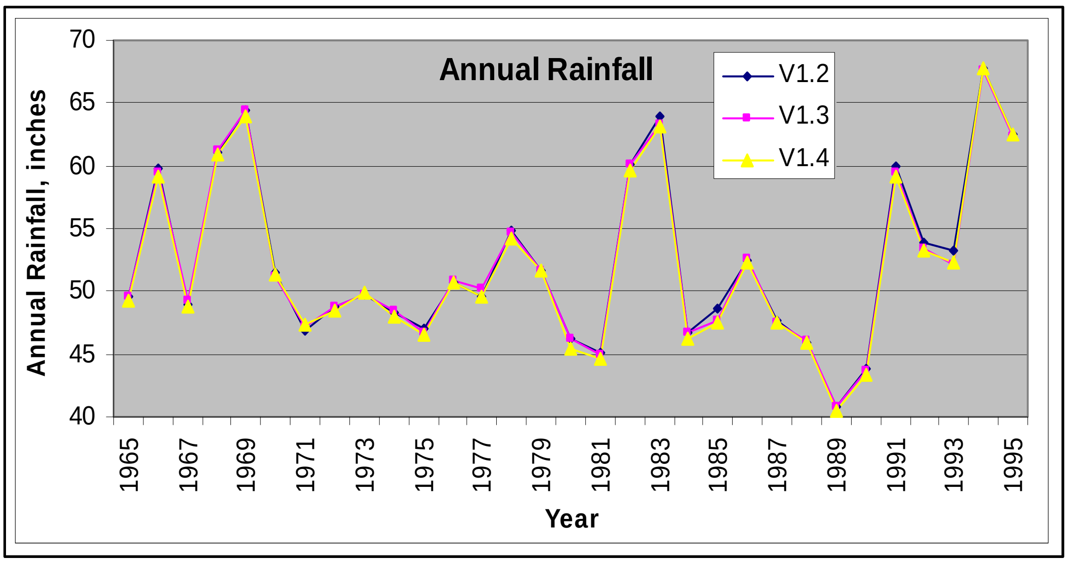

Figure C-9. Annual rainfall for the period 1965-1995.

Rainfall Binary file version 2.0

In the binary file version 2.0, portions of the rainfall grid are expanded 29 columns to the west to accommodate western counties such as Charlotte and Lee counties. Rainfall data from those counties, as well as from St Lucie County, were acquired and added to the database. The same methodologies were applied to these data. The results of this effort were as follows:

1. A total of 50 stations were acquired.

2. A total of 133 data points were identified as extreme values and needed further evaluation which resulted in rejecting 69 data points.

3. A total of 55 monthly records of low rainfall (zero- or close to zero-inch) were rejected for inconsistency with local monthly rainfall in the respective months.

4. A total of 5 annual records of rainfall below 30 in. (with maximum of two months of missing data) were rejected for inconsistency with local annual rainfall in the respective years.

5. There were 2 monthly records accepted for rainfall greater than 20 inches.

Rainfall Binary file version 2.1

In the binary file version v2.1, the rainfall grid is expanded to include the northern portion of the SFWMD area (Upper and Lower Kissimmee basins). The size of the new grid is 70 columns by 118 rows. Rainfall data from seven counties: Osceola, Orange, Lake, Highland, Hardee, DeSoto, and Polk, were acquired and added to the database. The same QA/QC methodologies were applied to these data. The results of this effort were as follows:

Table C-2. Rainfall stations used to expand the rainfall grid in the northern portion of the SFWMD area.

County	# stations
Osceola	56
Orange	40
Lake	56
Highland	41
Hardee	14
DeSoto	12
Polk	44
Total	263

A total of 263 stations were acquired covering the following counties: DeSoto, Hardee, Lake, Polk, Osceola, Orange, and Highland. Forty two stations were dropped and 221 stations were retained.

1. A total of 1,653 data points were identified as extreme values (more than 4 in.) and needed further evaluation which resulted in rejecting 704 data points.

2. No "very low" monthly data were rejected.

3. No "less than 30-inch" annual rainfall was rejected.

4. No "greater than 20-inch" monthly rainfall was rejected.

Rainfall Binary file version 3.0

In the binary file version v3.0, the rainfall data period of record was extended to 2005. In addition to existing stations, new rainfall stations from Broward, Miami-Dade, Charlotte, Collier, DeSoto, Glades, Hardee, Hendry, Highlands, Lake, Lee, Okeechobee, Orange, Osceola, Palm, Polk, Martin, and St. Lucie, were acquired. The same QA/QC methodologies were applied to these data. The results of this effort were as follows:

Table C-3. Rainfall stations added to expand the rainfall grid period of record from 2000 to 2005.

County	# stations
Broward	10
Miami-Dade	15
Charlotte	5
Collier	22
DeSoto	14
Glades	5
Hardee	9
Hendry	9
Highlands	19
Lake	7
Lee	1
Okeechobee	10
Orange	7
Osceola	12
Palm	15
Polk	54
Martin	9
St. Lucie	2
Total	225

1. A total of 225 stations were acquired covering the following counties: Broward, Miami-Dade, Charlotte, Collier, DeSoto, Glades, Hardee, Hendry, Highlands, Lake, Lee, Okeechobee, Orange, Osceola, Palm, Polk, Martin, and St. Lucie.

2. A total of 1,415 data points were identified as extreme values (more than 4 in.) and needed further evaluation which resulted in rejecting 173 data points.

3. No "very low" monthly data was rejected.

4. No "less than 30-inch" annual rainfall was rejected.

5. No "greater than 20-inch" monthly rainfall was rejected.

REFERENCES

Ali, A. 2010. Rainfall version 3.0. Internal memorandum, HESM, SFWMD, West Palm Beach, FL. 2010.

Ali, A. and L. Cadavid, 2001. "Preparation of the Regional Models' Rainfall Binary File (1914-2000)", Internal memorandum, HSM, SFWMD, West Palm Beach, FL. 2001.

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Appendix D
Generation of the Expanded Coverage Reference Evapotranspiration Dataset for Hydrologic Modeling

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[Appendix D is a 2008 report by ARCADIS, "Generation of the Expanded Coverage Reference Evapotranspiration Dataset for Hydrologic Modeling". The report was produced for the South Florida Water Management District by an external contractor.]

D.1: DOCUMENTATION

Introduction

The objective of this project was to provide an expanded coverage dataset of long-term (1948-2005), daily reference evapotranspiration (ETo) that included the northern Kissimmee area. This "expanded" dataset may be used as input to the hydrologic models of south Florida. It is based on the research and methods described in the South Florida Water Management District (SFWMD) document, Estimation of Long-Term Reference Evapotranspiration for Hydrologic Modeling (Said *et al.* 2008). In these models, actual evapotranspiration is calculated by spatial interpolation of the reference or potential evapotranspiration between the sites, and by the application of landscape-specific vegetation coefficients, which are a function of water depth.

The standardized method selected by the SFWMD calculates reference grass evapotranspiration (ETo), the potential evapotranspiration for a pre-defined reference grass with certain pre-defined physical characteristics (FAO: Smith 1991). This method closely tracks the recommended ASCE Penman-Monteith standardized reference equation (Irmak *et al.* 2005; Itenfisu *et al.* 2003)

For this project, data from two major weather model datasets were utilized to calculate regional ETo: (1) U.S. Hydrological Reanalysis by the NOAH Land Data Assimilation System (Hydro51) and (2) North America Regional Reanalysis (NARR). All data are stored in a bit-oriented data exchange format called GRIB (GRIdded Binary) and in Greenwich Mean Time.

Hydro51 Data

The U.S. Hydrological Reanalysis by the Noah Land Data Assimilation System (NLDAS Reanalysis) is code named Hydro51 by the SFWMD. The NLDAS Reanalysis is a 51-year (1948-1998) set of hourly land surface meteorological forcing used to execute the Noah Land Surface Model, all on the 1/8th degree (approximately 12 km) grid of the NLDAS. The surface forcing includes air temperature, air humidity, surface pressure, wind speed, and surface downward shortwave and long-wave radiation, all derived from the National Center for Environmental Prediction–National Center for Atmospheric Research (NCEP-NCAR) Global Reanalysis (2.5° or 265 km in south Florida).

New Hydro51 forcing data was provided by Chi-Fan Shih of the Data Support Section / Scientific Computing Division of the National Center for Atmospheric Research (NCAR) in Spring 2008 (http://dss.ucar.edu/). These data were based on the same weather model as the previously obtained Hydro51 forcing data. The new data extends from 25.063 degrees latitude, -83.063 degrees longitude, to 29.32 degrees latitude, -79.813 degrees longitude, covering a much larger spatial extent to the north. The data points occur every one-eighth degree, resulting in a total of 945 coordinates, but only 497 of the points are associated with land and have data values (**Figure D-1**). The dataset has all variables necessary for the Penman-Monteith calculation of ETo. A Perl script was written to convert the binary GRIB files into separate text files for each variable.

Table D-1. Hydro51 forcing variables.

Variable	Description
APCP	Convective precipitation [kg/m^2] at surface
DLWRF	Downward long-wave radiation flux [W/m^2] at surface
DSWRF	Downward shortwave radiation flux [W/m^2] at surface
PRES	Pressure [Pa] at surface
SPFH	Specific humidity at 2m
TMP	Temperature [K] at 2m
UGRD	u wind [m/s] at 10m
VGRD	v wind [m/s] at 10m

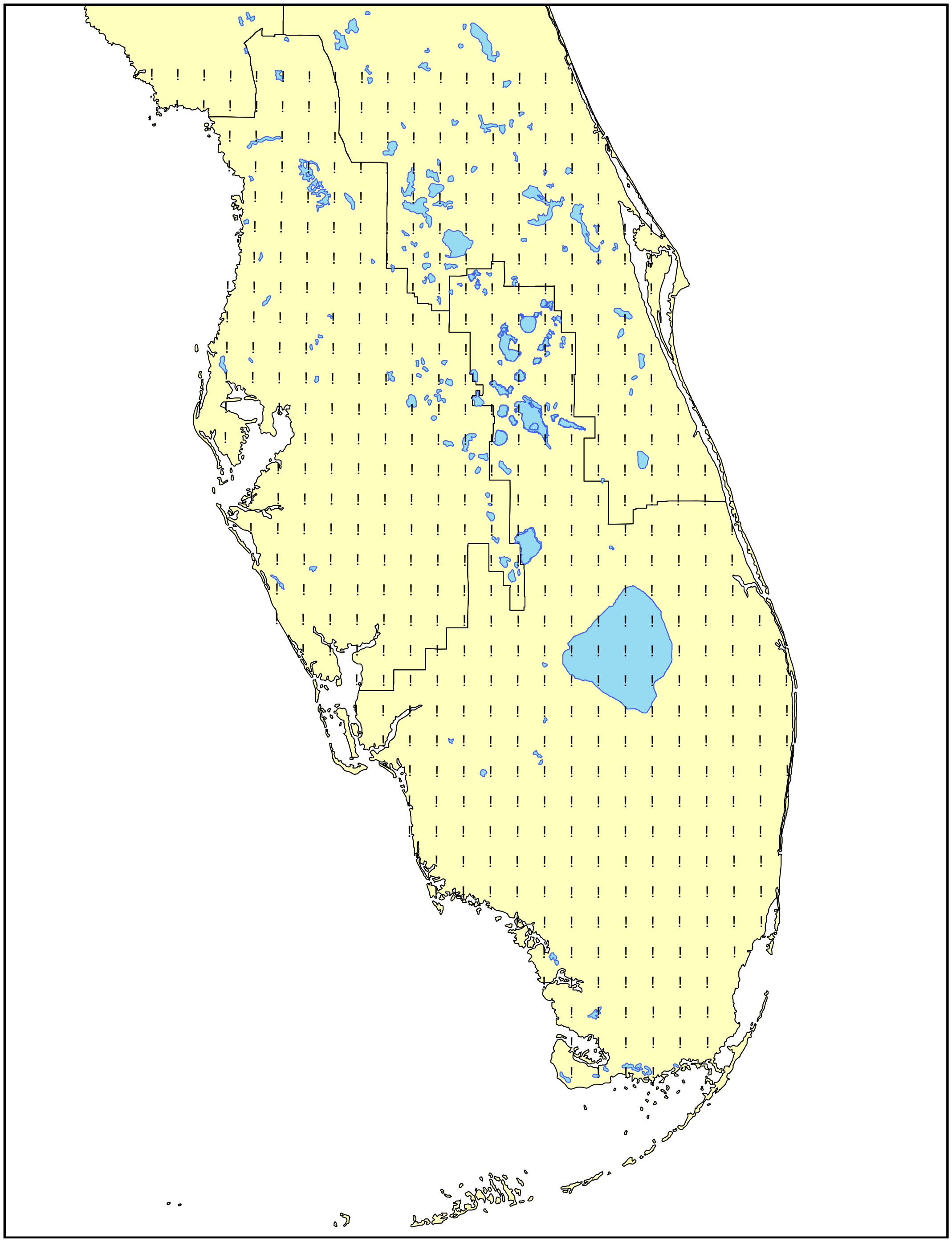

Figure D-1. Illustration of the coverage provided by the 497 Hydro51 data points.

North America Regional Reanalysis (NARR)

The North American Regional Reanalysis (NARR) dataset is a long-term homogenous mesoscale regional analysis performed with a frozen model and data assimilation system (NARR; Mesinger *et al.* 2005). NARR assimilated data is produced with the application of a state-of-the-art dynamically and physically based coupled atmospheric/hydrologic model from the National Center of Environmental Prediction Environmental Modeling Center (EMC) and a complete set of directly and remotely sensed data sources. It has spatial resolution of approximately 32 km and 210 points that provide coverage of southern Florida. The model includes 45 layers in the vertical and has a time step of 3 hours.

This is a novel, versatile methodology for estimating spatial hydrologic and atmospheric variables at regional resolution. The estimation of these variables is accomplished by integrating observational data with the underlying dynamic principles governing the system under observation. The process makes efficient, accurate, and realistic estimations possible (**Figure D-2**).

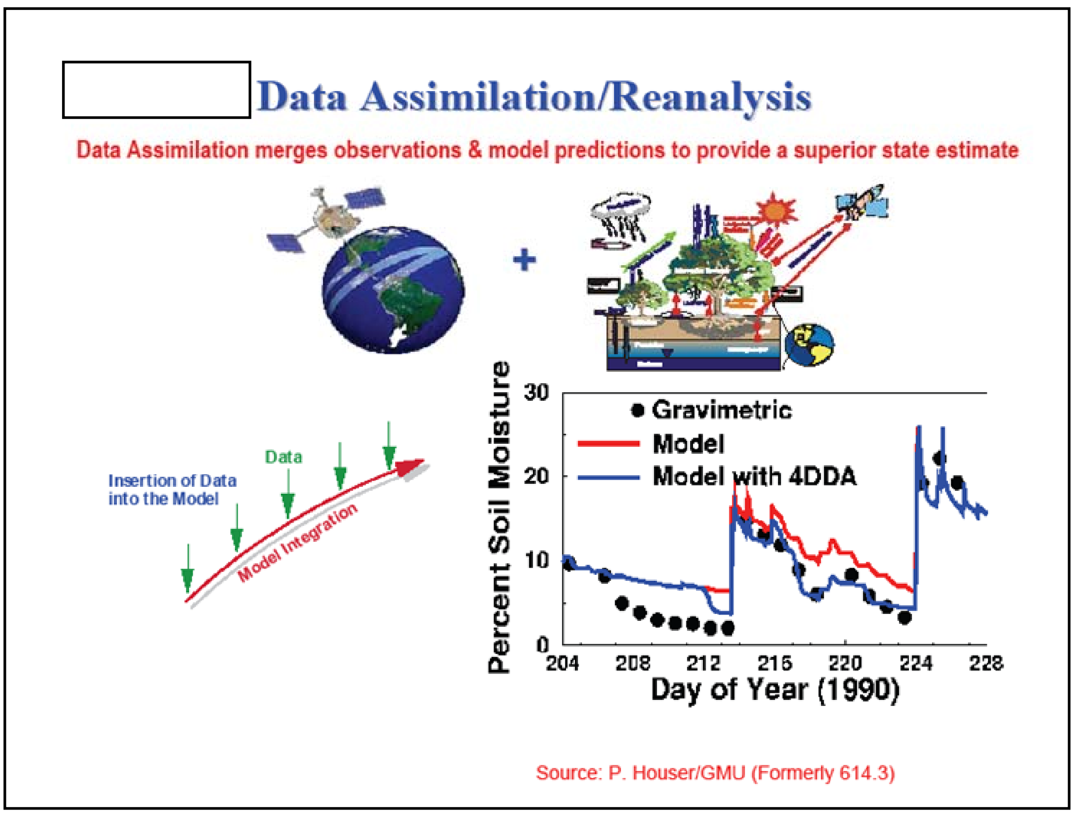

Figure D-2. NARR Data Assimilation/Reanalysis.

The NARR models North America and its adjacent oceans from January 1, 1979, to December 31, 2005. A subset of data for south Florida was obtained from the NCAR with the variables necessary to calculate Penman-Monteith ETo, including relative humidity. The NARR data was processed during an earlier project and the resulting files were ready to be used in the generation of the expanded reference ET dataset. **Table D-2** lists the variables provided from the NCAR NARR data. **Figure D-3** shows the processed 210-point NARR grid with the points renumbered from the original grid.

Table D-2. Selected Variables from NCAR NARR Data.

Variable	Description
DLWRF	Downward long-wave radiation flux [W/m^2] surface
DSWRF	Downward shortwave radiation flux [W/m^2] surface
PRES	Pressure [Pa] sfc
RH	Relative humidity [%] 2m
TMP	Temperature [K] 2m
UGRD	u wind [m/s] 10m
VGRD	v wind [m/s] 10m

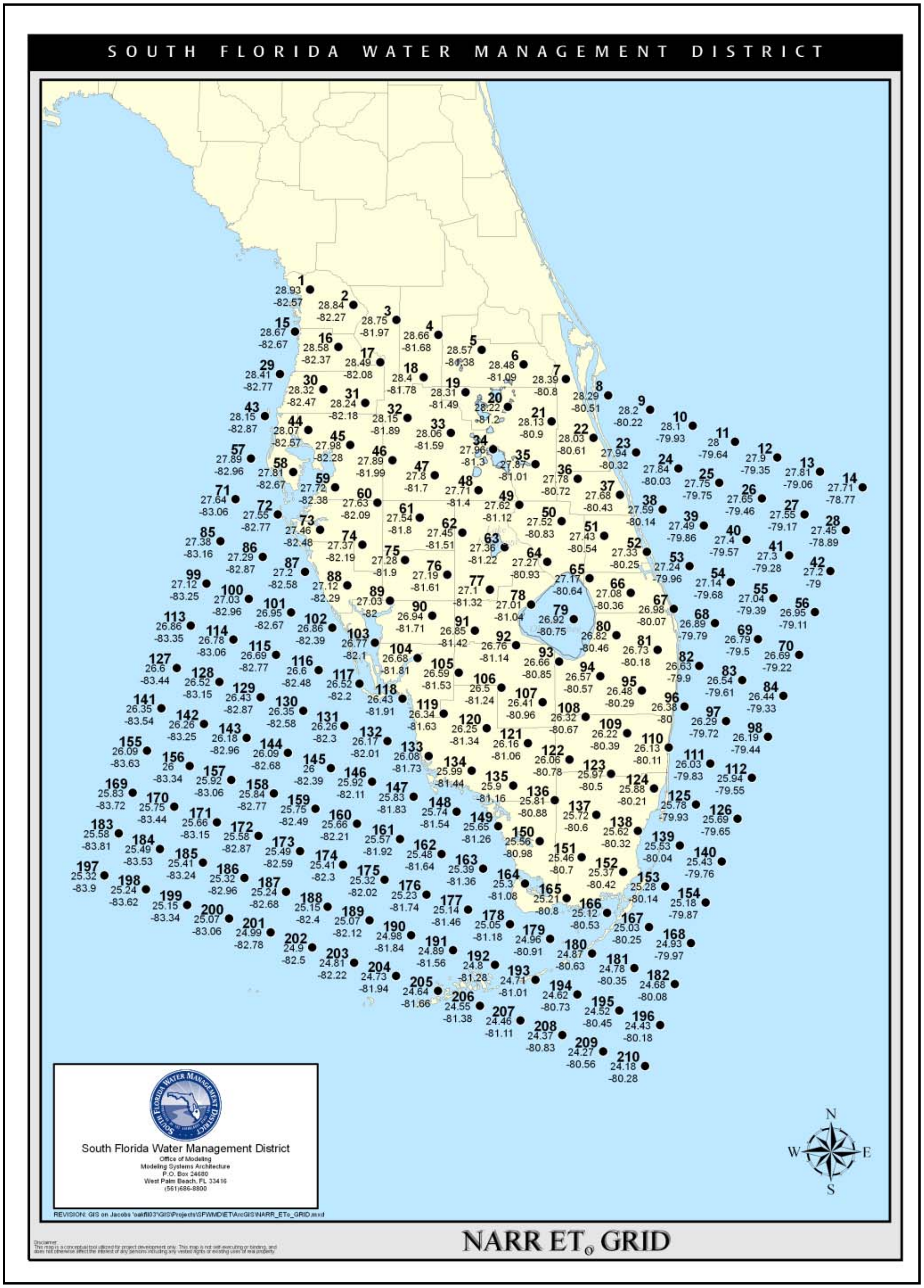

Figure D-3. South Florida NARR grid based on GRIB and renumbered by data processing.

Data Processing

The new Hydro51 dataset was downloaded, reformatted, and processed in March 2008. These procedures are summarized in **Figure D-4**. Hourly variable files were converted to local time (EST), compatible units, and daily average values with a Python script written by Beheen Trimble, (SFWMD). Calculations included minimum and maximum relative humidity, vapor pressure deficit, wind speed, and minimum and maximum temperature. It is important to note that the processing changed the geographic origin from the lower left of the GRIB format to the upper left.

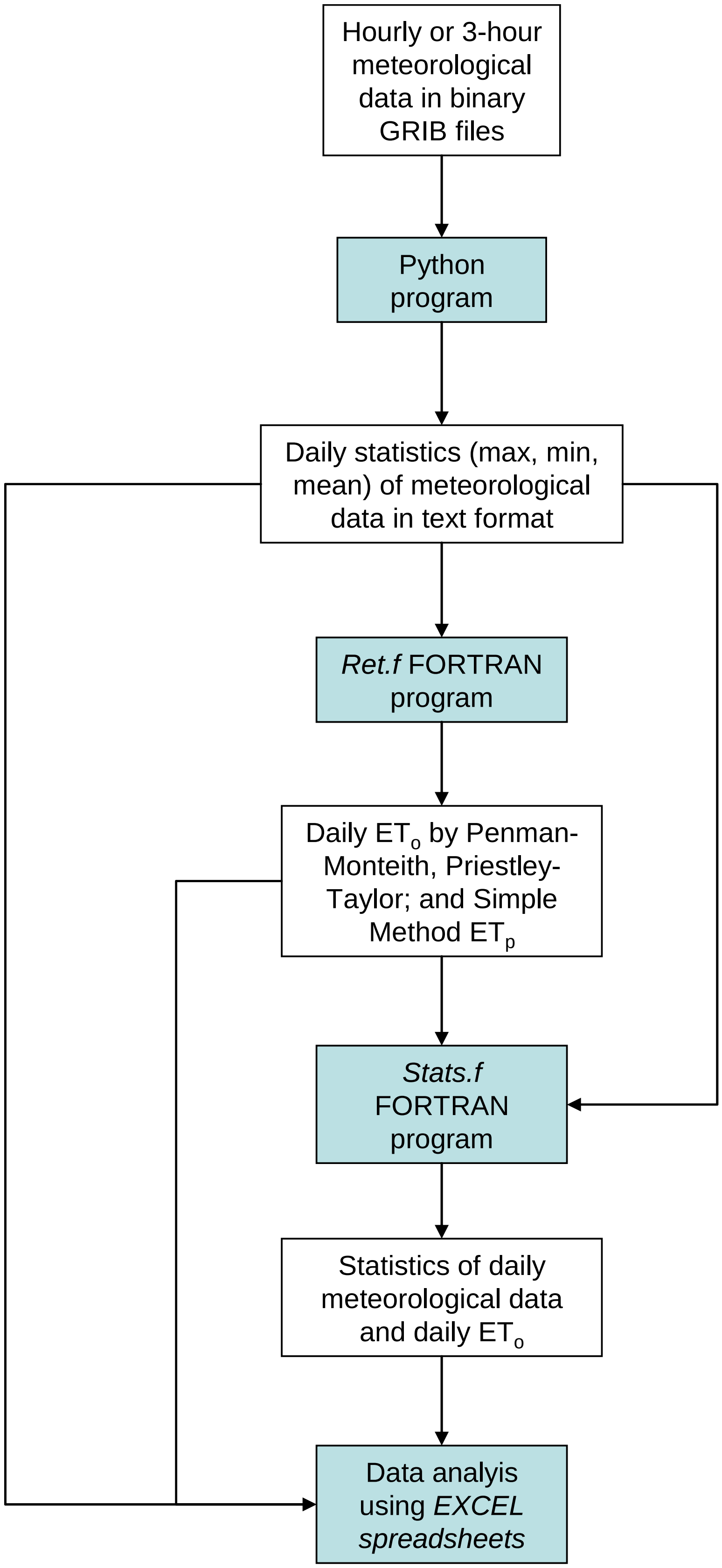

Figure D-4. Data processing and analysis.

Data was then processed through two FORTRAN programs (Michelle Irizarry, SFWMD, Appendix A) to calculate ETo and statistics. The first, *Ret.f*, reads the files created by Trimble's Python script and calculates ETo by three methods: Penman-Monteith as defined by FAO Irrigation and Drainage Paper 56 (FAO-56, Smith 1991); Priestly-Taylor; and the District's "Simple" Method (Abtew, 1996). Options included capping the maximum and minimum relative humidity input values at 100 percent and using daily-average vapor deficit instead of relative humidity to compute ETo. Only the Penman-Monteith results were utilized in the generation of the expanded coverage ET dataset. The option to cap relative humidity at 100 percent was chosen for both the NARR and Hydro51 data.

The second program, called *Stats.f*, calculated several useful statistics from the files generated by the Python script. **Table D-3** lists the *Stats.f* program's output.

Table D-3. Files generated by the Stats.f program.

File Name	Description
ave_clim.txt	Daily average by month.
adev_clim.txt	Daily absolute deviation by month.
sdev_clim.txt	Daily standard deviation by month.
var_clim.txt	Daily variance by month.
skew_clim.txt	Daily skewness by month.
kurtexc_clim.txt	Daily kurtosis excess by month.
cv_clim.txt	Daily coefficient of variation by month.
annual_totals.txt	Annual sums by year.
annual_ave.txt	Annual Average by year.
annual_stats.txt	Statistics of data in annual_totals.txt including average, standard deviation, and coefficient of variation of annual totals.

Producing the Expanded Long-Term Reference Evapotranspiration Dataset

The expanded dataset was to be constructed identically to the existing ETo dataset so that the only variation would occur near the new points that were added in the northern portion of the expanded grid. An adjusted Hydro51 dataset from 1948 to 1978 was combined with the NARR data for the period from 1979 to 2005. The methodology for producing the expanded area, long-term (1948–2005) regional ETo dataset is described in the following sections and is summarized in **Figure D-5** and **Figure D-6**.

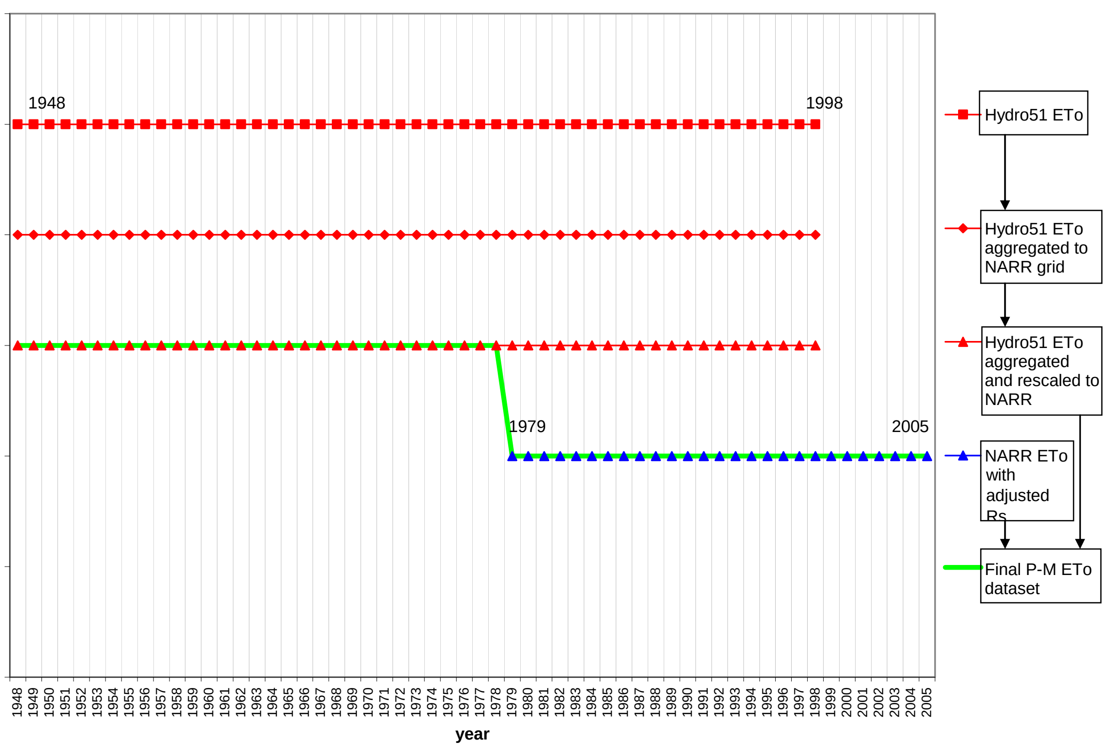

Figure D-5. Producing the long-term (1948-2005) regional ETo dataset for south Florida from the NARR and Hydro51 ETo datasets.

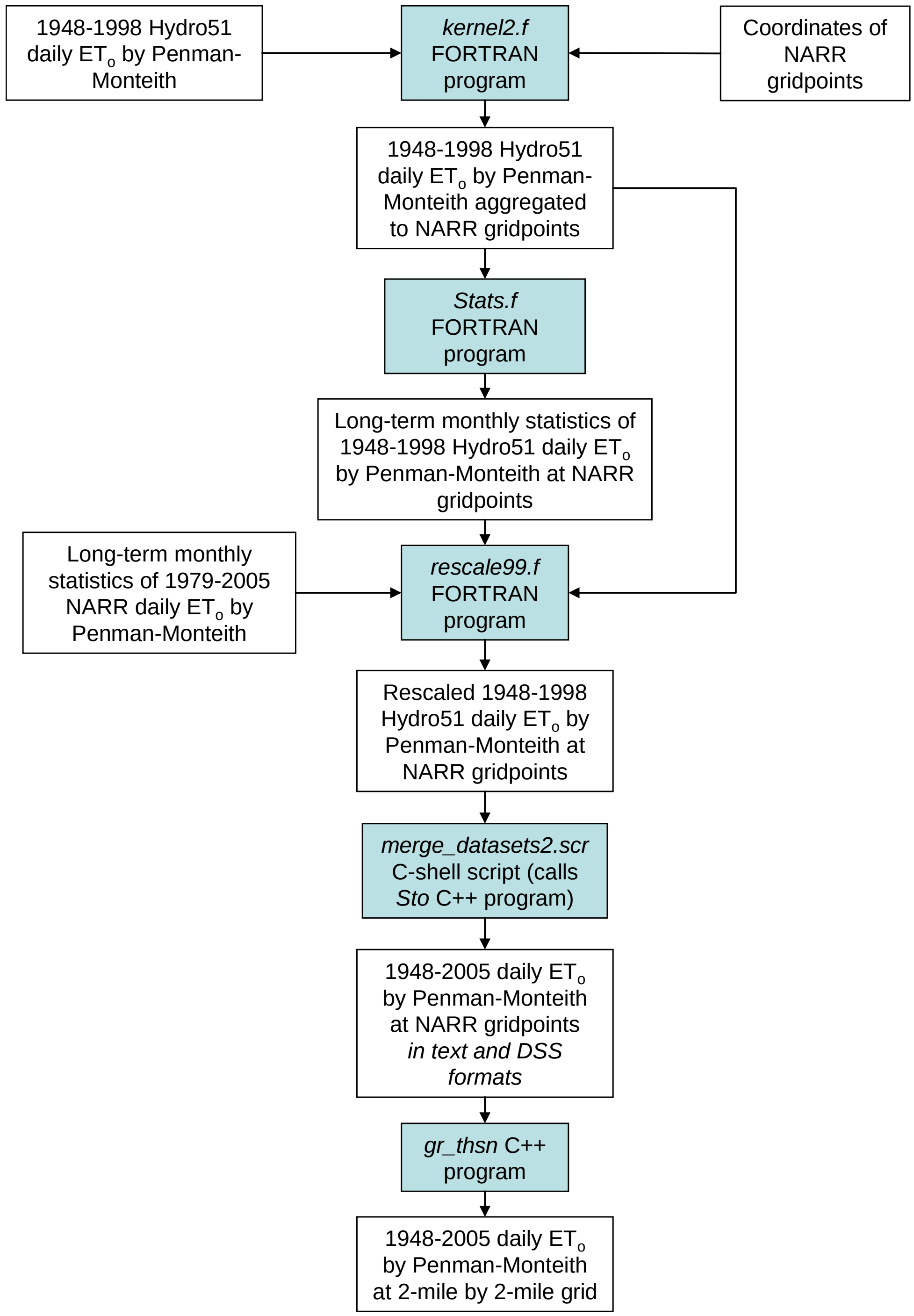

Figure D-6. Methodology for producing the long-term (1948-2005) regional ETo dataset for south Florida.

Adjusting NARR Reference Evapotranspiration based on results from sensitivity analysis

The sensitivity analysis performed by the District on the NARR dataset as described in *Estimation of Long-Term Reference Evapotranspiration for Hydrologic Modeling* (Said *et al.* 2008) showed that ETo would be overestimated all across south Florida by approximately 6.8 percent (3.7 in./year) on average. A significant region-wide positive bias was only observed for solar radiation (7.5 percent on average). This observed bias in solar radiation is supported by other studies (Betts *et al.* 1997) which have found solar radiation to be overestimated from 10 percent to 20 percent. Therefore, the SFWMD has decided to correct the NARR dataset only for biases in solar radiation. The NARR solar radiation was lowered by 7.5 percent for the entire region. The NARR downward solar radiation was reduced with a modification to the *Ret.f* program where the NARR based reference ET was calculated.

Hydro51 Aggregation and Rescaling

The Hydro51 ETo was rescaled to match the mean and standard deviation on a long-term daily basis by month according to the following relationship:

$$H' = \frac{(H - \overline{H})}{\sigma_H}\sigma_N + \overline{N}$$

Where

H' = Rescaled Hydro51 ETo

H = Daily Hydro51 ETo

$\overline{H}$ = Long-term daily average of Hydro51 ETo by month

σ_H = Long-term daily standard deviation of Hydro51 ETo by month

$\overline{N}$ = Long-term daily average of NARR ETo by month that was calculated with solar radiation reduced by 7.5%

σ_N = Long-term daily standard deviation of NARR ETo by month that was calculated with solar radiation reduced by 7.5%

A FORTRAN program called *rescale08.f*, printed in **Appendix D.2**, was used to perform the rescaling at the 109 selected NARR locations shown in **Figure D-8**.

Before performing this rescaling, a spatial aggregation of the 497 12-km Hydro51 grid points into the 109 point 32-km resolution NARR grid was conducted using a FORTRAN program called *kernel08.f* (A. Ali, SFWMD); see **Appendix A**. The program is a bivariate kernel estimator with an ad-hoc selection of its bandwidth.

The Hydro51 ETo at each NARR location was computed based on a simple weighted-average scheme.

$$H_{NARR} = \frac{\sum_{j=1}^{19}\left[w(j) * H_j\right]}{\sum_{j=1}^{19}\left[w(j)\right]}$$

Where

H_{NARR} = Estimated Hydro51 ETo at a NARR location

w(j) = a reduced form of Kernel estimator function estimated at point j

= weight contribution of data point j to the estimate at NARR location

j = 1…19 = index for one of closest 19 Hydro51 points (19 was approximately the square root of the total number of the original 321 data points)

H_j = Hydro51 ETo data point at jth location

The weights were assigned based on the distance from the NARR point to its closest 19 Hydro51 points as defined by the following relationship:

$$w(j) = \left[1 - \left(\frac{r(j)}{r(19)}\right)^2\right]^2$$

Where

w(j) = weight associated with point j

r(j) = distance from NARR point (point of estimate) to jth closest Hydro51 point

r(19) = rmax = ad-hoc kernel bandwidth

= distance from NARR point (point of estimate) to 19th closest Hydro51 point

Figure D-7 shows the relative weights (i.e. w(j)/w(19)) assigned to the closest 19 Hydro51 points as a function of their relative distance from the 19th closest point (rmax=r(19)).

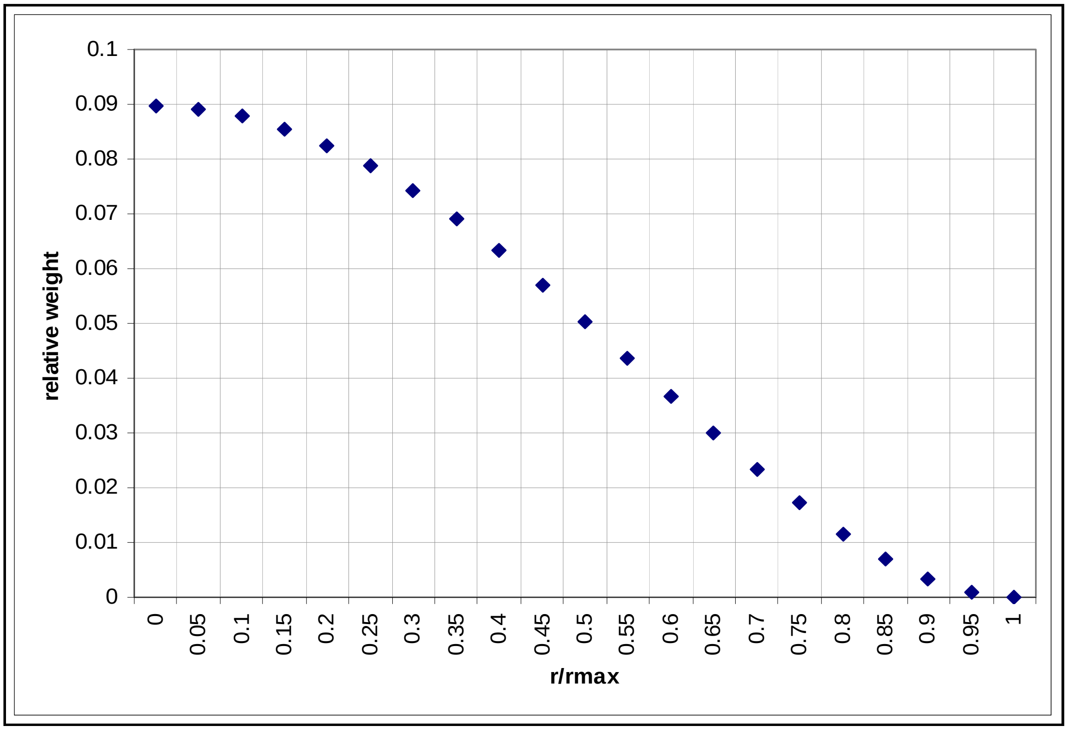

Figure D-7. Relative weights assigned to Hydro51 points for aggregation into NARR grid.

Creating the Composite Reference Evapotranspiration Dataset

Once the Hydro51 ETo dataset for 1948–1978 was rescaled, it was merged with the NARR ETo dataset for 1979-2005 to create a single ETo dataset encompassing the period 1948–2005. A C-shell script (*merge_datasets3.scr*) was written to merge the two datasets as shown in **Appendix A**. Only 109 points were selected and a DSS file of the daily ETo at each point was created by using the *Sto* C++ program which is called *merge_datasets3.scr*.

The District's review of the initial 109 NARR points resulted in the elimination of 24 of them. The ocean points were replaced with control points at deliberately chosen locations on the coasts to ensure that extrapolated potential evapotranspiration (PET) values along the shore remained reasonable. The NARR renumbered grid points 36 and 37 (near Vero Beach) were removed due to erroneous values of temperature and wind speed encouraging an overestimation of ETo. The final input file for the multiquadric *gr_thsn* C++ program contained 85 data points at the NARR locations and 25 control points. The *gr_thsn* program is described in the next section of this report.

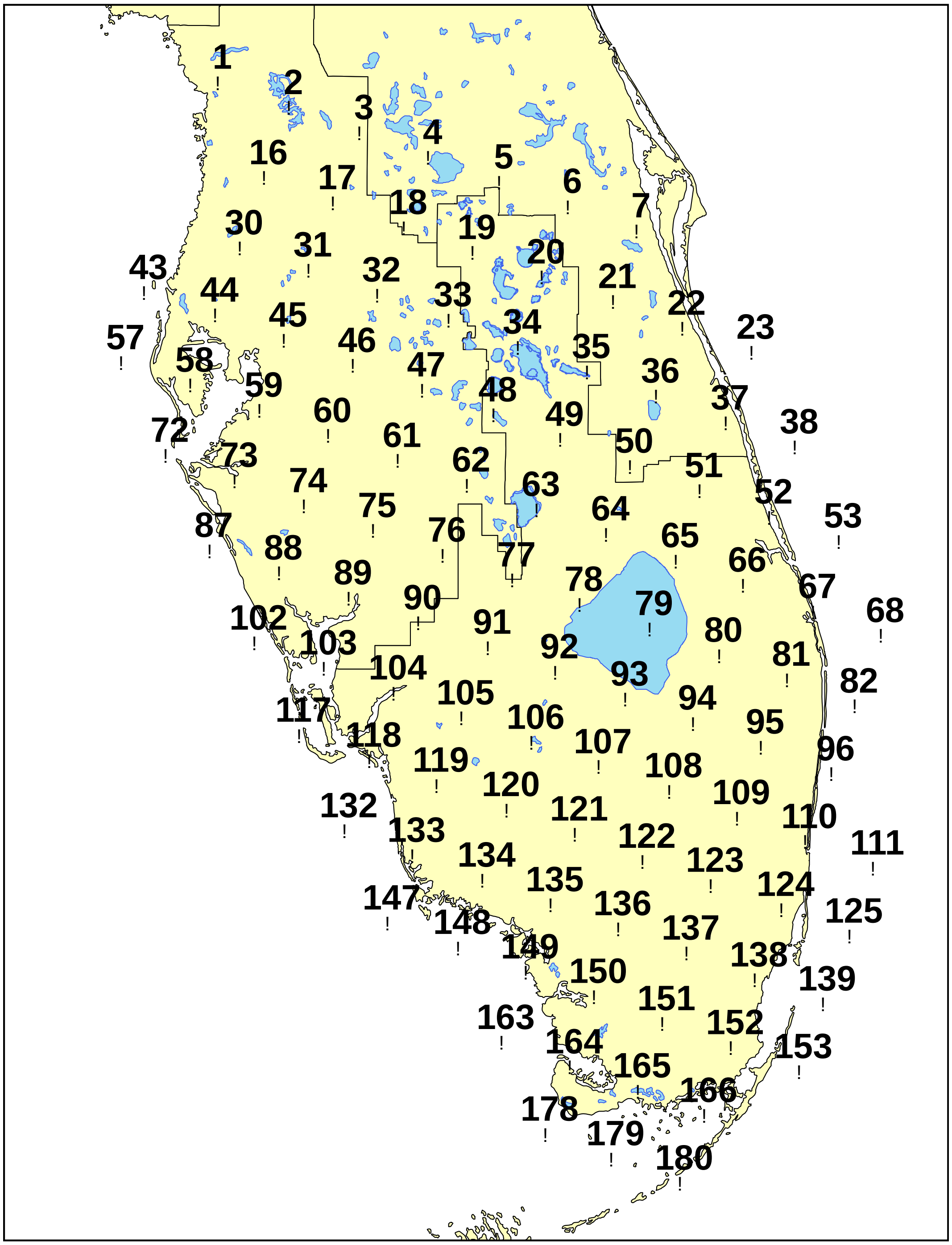

Figure D-8. The NARR points selected for the long-term (1948-2005) ETo dataset.

The 25 control points were strategically placed along the coasts to aid in the interpolation of ETo to the final 2-mile by 2-mile grid. The control points are populated with data from a nearby land-based NARR location. **Figure D-9** shows the locations of the control points while **Table D-4** provides the land based NARR grid points on which they are based.

Table D-4. Control Points and NARR data.

Original Control Point ID	Data from NARR Point (renumbered grid)	Control Point ID as in DSS file
1	52	CAL1001
2	67	CAL1002
3	81	CAL1003
4	96	CAL1004
5	110	CAL1005
6	124	CAL1006
7	138	CAL1007
8	152	CAL1008
9	165	CAL1009
11	164	CAL1011
12	150	CAL1012
13	149	CAL1013
15	134	CAL1015
16	133	CAL1016
18	118	CAL1018
19	118	CAL1019
20	103	CAL1020
21	51	CAL1021
22	87	CAL1022
23	87	CAL1023
24	43	CAL1024
25	30	CAL1025
26	1	CAL1026
27	22	CAL1027
28	22	CAL1028

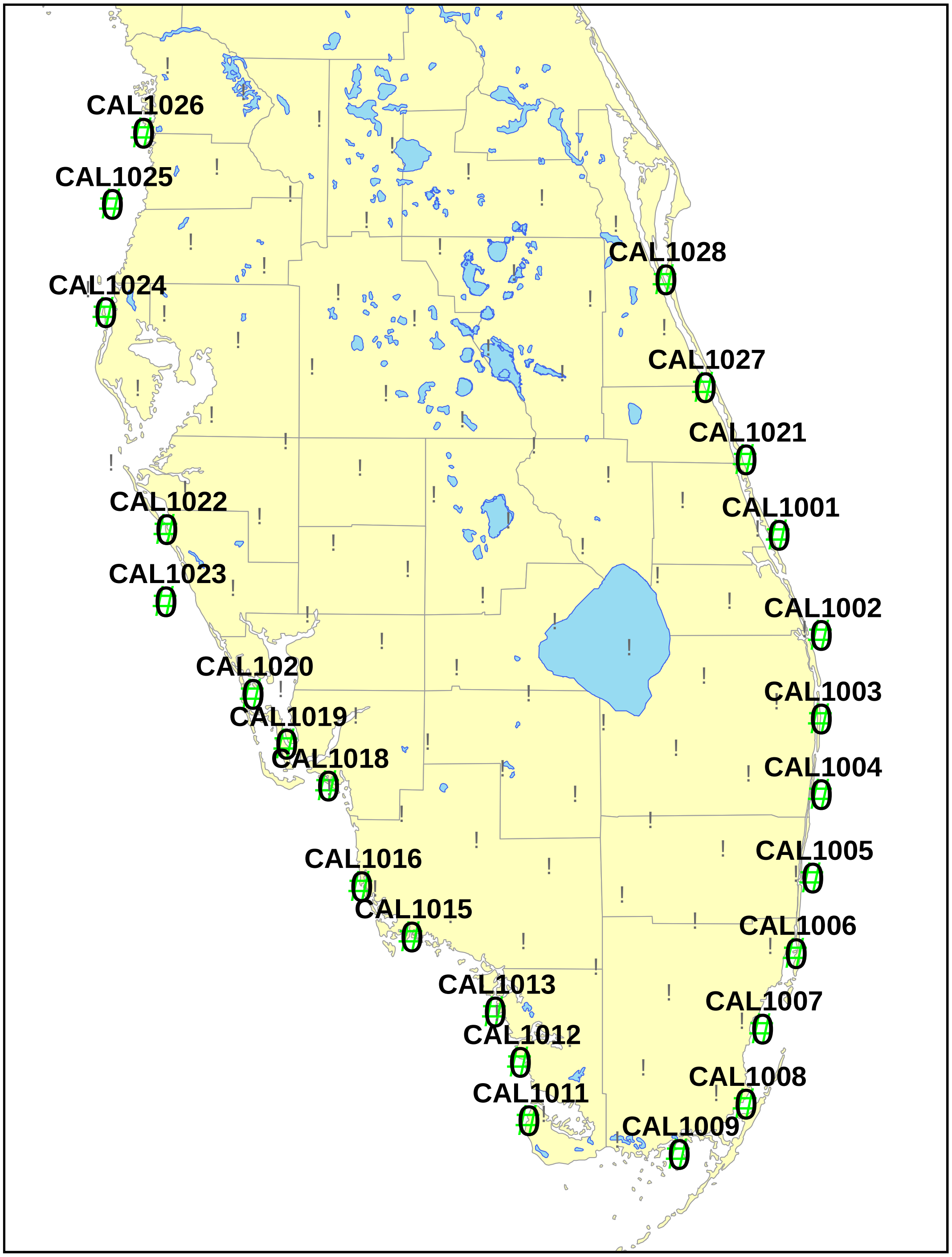

Figure D-9. Control point locations with DSS file ID numbers.

Spatial Interpolation to a 2-Mile by 2-Mile Grid

The final step in the process was to interpolate the long-term (1948-2005) regional ETo dataset to an expanded 119-row 2-mile by 2-mile grid coincident that was slightly larger than the 118-row grid used by the Natural System Regional Simulation Model (NSRSM). The 2-mile by 2-mile grid is fine enough to capture regional ETo patterns and therefore may be used by other models without further interpolation.

A multiquadric method was selected to interpolate the NARR data points into the 2-mile by 2-mile super-grid covering most of south Florida (**Figure D-10**). The multiquadric method was chosen based on a comparison of interpolation techniques described in *Spatial Analysis for Monthly Rainfall in South Florida* (Abtew *et al*. 1993). A C++ program called *gr_thsn* was modified to include an option for multiquadric interpolation and then used to generate the binary reference ET data file for use as model input. The *gr_thsn* program spatially interpolates time series data from the data points to the grid cells defined by the grid_io input file. Any size grid can be defined by the input file, thus the interpolated dataset is not limited to this particular grid shape. A copy of the input file, *gr_48_05_nad83_119row_MULTIQUAD.in*, is provided in Appendix A.

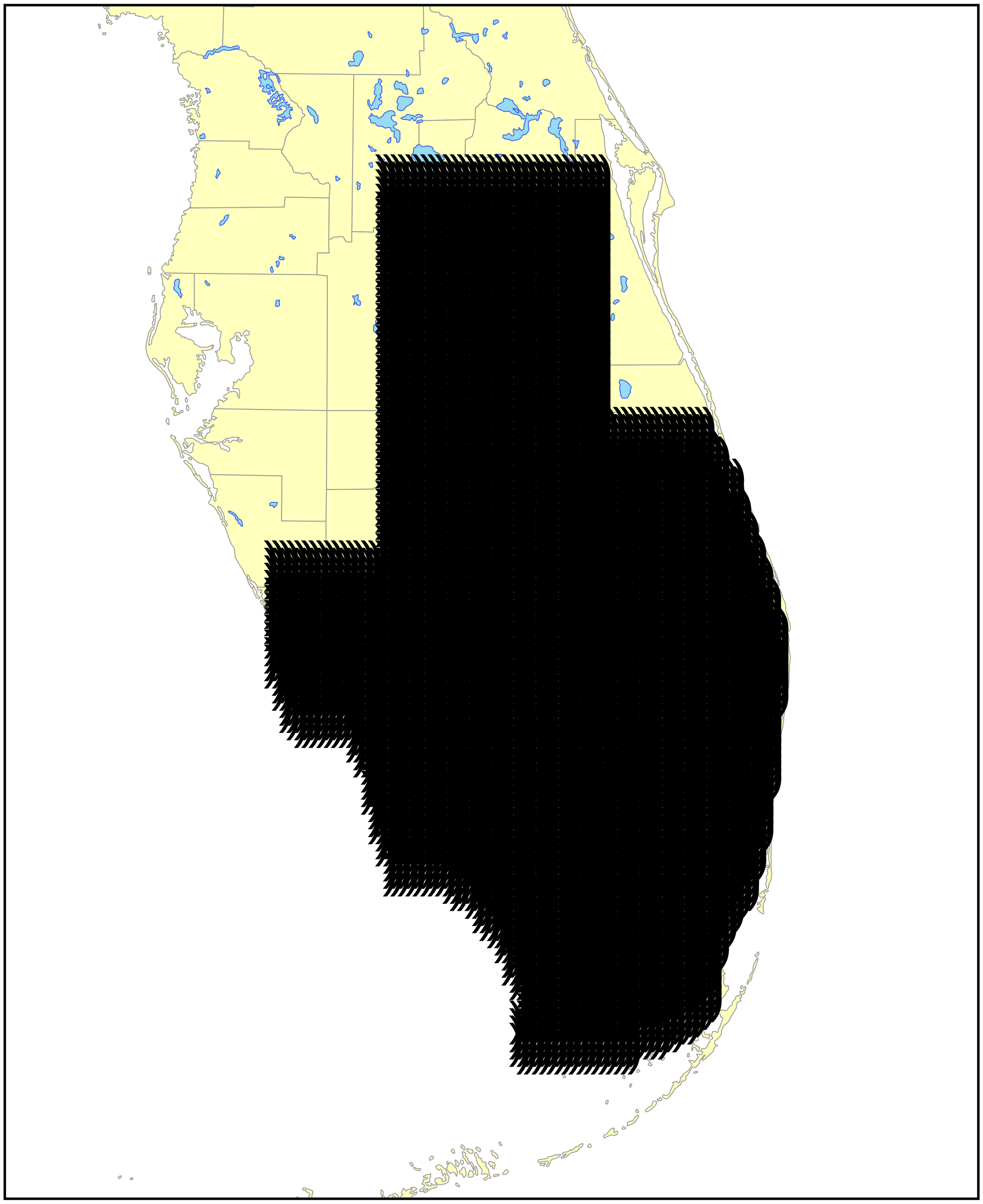

Figure D-10. The 2x2 mile grid over which ETo at the NARR points will be interpolated to create the long-term (1948-2005) ETo dataset.

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D.2: PROGRAMS

sorthydroVARSFL3.pl

This program extracts the climate variable data from the binary GRIB files provided by University Corporation for Atmospheric Research (UCAR). The program generates hourly text files for each variable. These text files contain data for every point in the grid. The 51 years of data resulted in over 3.5 million files.

```
#!/usr/bin/perl -w

# For compilation warrning checking ==> perl -w x.pl
# use strict;
use Switch;

# File name: sort hydro
# Author: Beheen Trimble modified by newton
# Date: 03/19/08
# Revision: 0.0
# Running:
# Description:
#This is to separate variables on NLDAS ONLY!!


# ================= Main ================

@DIM = qw(NULL 31 29 31 30 31 30 31 31 30 31 30 31);

@LPYR = qw(1948 1952 1956 1960 1964 1968 1972 1976 1980
1984 1988 1992 1996 2000
 2004 2008 2012 2016 2020);

@CYCLE = qw(00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15
16 17 18 19 20 21 22 23);
$DTG1 = "19471231";
$DTG2 = "19990101";


$this_dtg = $DTG1;
$YYYY = int(substr($this_dtg,0,4));
$MM   = int(substr($this_dtg,4,2));
$DD   = int(substr($this_dtg,6,2));
$iterations = 0;
$flag = 1;

while ( $this_dtg le $DTG2 )
{

  # Increment DTG
  $leapyear = scalar grep(/$YYYY/,@LPYR);
  if( $DD > $DIM[$MM] )
    { $DD=1; $MM++; $flag = 1;}

  if( ($leapyear==0) && ($MM == 2) && ($DD == 29) )
    { $DD=1; $MM=3; $flag = 1; }
```

```
  if( $MM > 12 )
    { $YYYY++; $MM=1; $DD=1;  $flag = 1; }

  $this_dtg = sprintf("%04d%02d%02d",$YYYY,$MM,$DD);
  printf("-- DTG --> ${this_dtg}\n");

  $YYYYMM = substr($this_dtg,0,6);

  $YYYYMMDD = substr($this_dtg,0,8);

  for $j (0 .. $#CYCLE) {
    $c = $CYCLE[$j];

    $file_name = "${YYYYMMDD}${c}\.lsmforce_ldas.FL3";
    print "$file_name\n";

    $florida = "${YYYYMMDD}${c}";

    $cmd = "./grib_read -s -ncep_rean -4yr ${file_name} >
inventory";
    system($cmd);

    $var1 = "1";    # record 1: TMP
    $out = "${florida}\.dat";
    $cmd = "./grib_read -i $file_name -d $var1 -text -o
${florida}\_h.TMP.dat < inventory";
    print "$cmd\n";
    system($cmd);

    $var2 = "2";    # record 2: PRESS
    $out = "${florida}\.dat";
    $cmd = "./grib_read -i $file_name -d $var2 -text -o
${florida}\_h.PRES.dat < inventory";
    print "$cmd\n";
    system($cmd);

    $var3 = "3";    # record 3: DLWRF
    $out = "${florida}\.dat";
    $cmd = "./grib_read -i $file_name -d $var3 -text -o
${florida}\_h.DLWRF.dat < inventory";
    print "$cmd\n";
    system($cmd);

    $var4 = "4";    # record 4: SPFH
    $out = "${florida}\.dat";
    $cmd = "./grib_read -i $file_name -d $var4 -text -o
${florida}\_h.SPFH.dat < inventory";
    print "$cmd\n";
    system($cmd);

    $var5 = "5";    # record 5: UGRD
    $out = "${florida}\.dat";
    $cmd = "./grib_read -i $file_name -d $var5 -text -o
${florida}\_h.UGRD.dat < inventory";
    print "$cmd\n";
    system($cmd);
```

```
    $var6 = "6";    # record 6: VGRD
    $out = "${florida}\.dat";
    $cmd = "./grib_read -i $file_name -d $var6 -text -o
${florida}\_h.VGRD.dat < inventory";
    print "$cmd\n";
    system($cmd);

    $var7 = "7";    # record 7: DSWRF
    $out = "${florida}\.dat";
    $cmd = "./grib_read -i $file_name -d $var7 -text -o
${florida}\_h.DSWRF.dat < inventory";
    print "$cmd\n";
    system($cmd);

    $var8 = "8";    # record 8: APCP
    $out = "${florida}\.dat";
    $cmd = "./grib_read -i $file_name -d $var8 -text -o
${florida}\_h.APCP.dat < inventory";
    print "$cmd\n";
    system($cmd);


    $cmd = "rm -f ${file_name}";
    print"$cmd\n";
    system($cmd);
    $cmd = "rm -f ${file_name}";
    print"$cmd\n";
    system($cmd);
  }
  $DD++;

  # Infinite loop - Force break
  if( $iterations > 10000000 )
  {
     $this_dtg = "9999999999"; $DTG2 = "";
     print STDOUT "!!!!! Potential infinate loop
broken!\n";
  }
  $iterations++;
}
exit(0);
```

Ret.f program

This program calculates ETo by three methods: Penman-Monteith as defined by FAO Irrigation and Drainage Paper 56 (Smith, **1991**), Priestly-Taylor, and the District's "Simple" Method (Abtew, 1996). The NARR solar radiation was reduced by multiplying the rs() variable by 0.925, resulting in the 7.5 percent reduction used in this process.

```
Program usage: Ret.exe eaflag rhflag gflag nproc

           eaflag=[1|2|3|4]
           Method for computing ea (actual vapor press.):
           eaflag = 1  Based on Tdew
           eaflag = 2  Assuming Tdew=Tmin
           eaflag = 3  Based on RHmax, RHmin, Tmax, Tmin
           eaflag = 4  Input daily-average VPD (es-ea)

           rhflag=[0|1]
           Flag to cap relative humidity to 100%
           Only applies if eaflag = 3
           rhflag = 0  Do not cap RH
           rhflag = 1  Cap RH

           gflag=[0|1]
           Method for computing G (ground heat flux):
           gflag = 0  Neglected
           gflag = 1  Based on daily air temp. change

           nproc>=1
           Number of stations to process
```

```
      PROGRAM REFET
*
***********************************************************
*****
*       Program to compute Daily Reference Grass ET (ETo)
based on
*         1 - PENMAN MONTEITH METHOD as defined by FAO
Irrigation and
*             Drainage Paper 56 (FAO-56)
*         2 - PRIESTLEY-TAYLOR METHOD with monthly-varying
alpha coef.
*
*       Wet marsh potential ET (PET) by the Simple Method
is also
*           computed
*
***********************************************************
*****
*       Input requirements:
*            rs  = downward solar radiation (MJ/m^2/day)
*           tmax = daily maximum temperature (C)
*           tmin = daily minimum temperature (C)
*
```

```
*             dew = daily average dew point temperature (C)
OR
*              [rhmax = daily maximum relative humidity (%)
AND
*               rhmin = daily minimum relative humidity (%)]
OR
*                 vpd = vapor pressure deficit (kPa)
*                             See eaflag below
*
*              uz = daily average wind speed (m/s)
*               p = daily average barometric pressure (kPa)
*              zm = wind measurement height (m)
*              zh = temperature/humidity measurement height
(m)
*            glat = station latitude (deg)
*            elev = station elevation (m)
*              alphac = monthly alpha coefficients for
Priestley-Taylor
*
*       Output:
*             etopm = ETo by Penman-Monteith (in/day)
*             etopt = ETo by Priestley-Taylor (in/day)
*
*           petsmpl = PET by Simple Method (in/day)
*
***********************************************************
*****
*
*
***********************DEFINITIONS***********************
*****
        integer     nsta,nproc
      parameter   (nsta=400)

        integer     date,i,icount,iyear,imon,iday,ista,j,l

        real        pi
        parameter   (pi=3.141592654)

        real        acoeff
        real        alphac(12)

        real
hc,rl,alpha,cs,ds,gsc,as,bs,zcoeff,ac,bc,
     a              al,bl,vk

        real
tmax_min,ra,rc,es,ea,delta,lambda,gamma,
     a              gammod,rho,g

        real
dr,del,phi,ws,rad,rns,rso,fcl,epsi,rnl,rn

        real        zm,zh
        real        glat(nsta),elev(nsta)
        real
rs(nsta),tmax(nsta),tmin(nsta),dew(nsta),
```

```
     a
rhmax(nsta),rhmin(nsta),vpd(nsta),uz(nsta),
     a              p(nsta)
        real
t(nsta),tn(nsta),etrad(nsta),etaero(nsta),
     a              etopm(nsta),etopt(nsta),petsmpl(nsta)

        data        icount /0/

      character*50 cdum, ndum

        character*1 eaflag,rhflag,gflag

*
************************PARAMETERS************************
*****

c       Reference crop height (m)
hc = 0.12

c       Stomatal resistance of a single leaf (s/m)
      rl = 100.0

c       Albedo of reference crop
      alpha=0.23

c       Soil heat capacity (MJ/m^3/C)
      cs = 2.1

c       Effective soil depth (m) for daily temp.
fluctuations
      ds = 0.18

c       Solar constant (MJ/m^2/min)
        gsc = 0.0820

c       Angstrom values (as recommended by Doorenbos &
Pruitt, 1977)
c          if no calibrated values are available
      as = 0.25
      bs = 0.50

c       Elevation coefficient for clear-sky solar rad.
(zcoeff, 1/m)
        zcoeff = 2E-5

c       Coefficients to compute cloudiness factor
      ac = 1.35
      bc = -0.35

c       Coefficients to compute net emissivity
      al = 0.34
      bl = -0.14

c       Von Karman's constant
        vk = 0.41
```

```
*
***********************************************************
*****

c       Check number of arguments passed to program
        if (iargc().lt.4) then
           write (*,*) ''
           write (*,*) 'Only', iargc(), ' arguments have
been entered'
           write (*,*) ''
           write (*,*) 'Program usage:'
           write (*,*) 'Ret.exe eaflag rhflag gflag nproc'
           write (*,*) ''
           write (*,*) 'eaflag=[1|2|3|4]'
           write (*,*) 'Method for computing ea (actual
vapor press.):'
           write (*,*) 'eaflag = 1  Based on Tdew'
           write (*,*) 'eaflag = 2  Assuming Tdew=Tmin'
           write (*,*) 'eaflag = 3  Based on RHmax, RHmin,
Tmax, Tmin'
           write (*,*) 'eaflag = 4  Input computed VPD (es-
ea)'
           write (*,*) ''
           write (*,*) 'rhflag=[0|1]'
           write (*,*) 'Flag to cap relative humidity to
100%'
           write (*,*) 'Only applies if eaflag = 3'
           write (*,*) 'rhflag = 0  Do not cap RH'
           write (*,*) 'rhflag = 1  Cap RH'
           write (*,*) ''
           write (*,*) 'gflag=[0|1]'
           write (*,*) 'Method for computing G (ground heat
flux):'
           write (*,*) 'gflag = 0  Neglected'
           write (*,*) 'gflag = 1  Based on daily air temp.
change'
           write (*,*) ''
           write (*,*) 'nproc>=1'
           write (*,*) 'Number of stations to process'
           write (*,*) ''
           stop
        endif

        call getarg(1,eaflag)
        call getarg(2,rhflag)
        call getarg(3,gflag)
        call getarg(4,ndum)

        read (unit=ndum,fmt='(i5)') nproc
        if (nproc.lt.1) then
           write (*,*) 'Number of stations to process must
be >= 1'
           stop
        endif

        if (nproc.gt.nsta) then
           write (*,*) 'Number of stations to process:',
nproc
```

```
           write (*,*) 'is larger than array dimensions:',
nsta
           write (*,*) ''
           write (*,*) 'Modify parameter nsta in program '
           write (*,*) 'to increase array size'
           stop
        endif

*
***********************************************************
*****

c       Open files
        open (1, file = 'alpha_coeff_PT.dat', access
='sequential',
     a      form ='formatted',status ='old')

      open (2, file = 'dswrf.txt', access ='sequential',
     a      form ='formatted',status ='old')

      open (3, file = 'tmax.txt', access ='sequential',
     a      form ='formatted',status ='old')

      open (4, file = 'tmin.txt', access ='sequential',
     a      form ='formatted',status ='old')

        if (eaflag.eq.'1') then
         open (5, file = 'tdew.txt', access ='sequential',
     a                  form ='formatted',status ='old')
        else if (eaflag.eq.'3') then
         open (5, file = 'rhmax.txt', access ='sequential',
     a                  form ='formatted',status ='old')

         open (6, file = 'rhmin.txt', access ='sequential',
     a                  form ='formatted',status ='old')
       else if (eaflag.eq.'4') then
         open (5, file = 'vpd.txt', access ='sequential',
     a                  form ='formatted',status ='old')
       endif

      open (7, file = 'wind.txt', access ='sequential',
     a      form ='formatted',status ='old')

      open (8, file = 'pres.txt', access ='sequential',
     a      form ='formatted',status ='old')

      open (9, file = 'dataset_metadata.txt', access
='sequential',
     a      form ='formatted',status ='old')

      open (10, file = 'station_metadata.txt', access
='sequential',
     a      form ='formatted',status ='old')

      open (21, file = 'etopm.txt', access ='sequential',
     a      form ='formatted',status ='unknown')

      open (22, file = 'etopt.txt', access ='sequential',
```

```
     a      form ='formatted',status ='unknown')

      open (23, file = 'petsmpl.txt', access ='sequential',
     a      form ='formatted',status ='unknown')

*
***********************************************************
*****

c       Read in alpha coefficients for Priestley-Taylor
        read (1,*) cdum

 100    continue
           read (1, *, end=200) imon, acoeff
           alphac(imon) = acoeff
           go to 100
 200    continue

c       Read in dataset metadata (zm, zh)
      read (9, *) zm, zh

c       Read in station metadata (glat, elev)
        ista = 1
 150    continue
         read (10, *, end=250) glat(ista), elev(ista)
           ista = ista + 1
           go to 150
 250    continue
        if (ista-1.lt.nproc) then
           write (*,*) 'Missing station metadata'
           write (*,*) 'data for',nproc,' stations
expected'
           write (*,*) 'data only found for',ista-1,'
stations'
           stop
        endif

c       Read in date, rs, tmax, tmin, rhmax, rhmin, uz, p
 300    continue
           read (2, *, end=400) date, (rs(i),i=1,nproc)
c           write (*,*) date, ' rs', rs(1)
           read (3, *, end=400) date, (tmax(i),i=1,nproc)
c           write (*,*) date, 'tmax', tmax(1)
           read (4, *, end=400) date, (tmin(i),i=1,nproc)
c           write (*,*) date, 'tmin', tmin(1)

           if (eaflag.eq.'1') then
              read (5, *, end=400) date, (dew(i),i=1,nproc)
c              write (*,*) date, 'dew', dew(1)
           else if (eaflag.eq.'3') then
              read (5, *, end=400) date,
(rhmax(i),i=1,nproc)
c              write (*,*) date, 'rhmax', rhmax(1)
              read (6, *, end=400) date,
(rhmin(i),i=1,nproc)
c              write (*,*) date, 'rhmin', rhmin(1)
           else if (eaflag.eq.'4') then
              read (5, *, end=400) date, (vpd(i),i=1,nproc)
```

```
c              write (*,*) date, 'vpd', vpd(1)
            endif

            read (7, *, end=400) date, (uz(i),i=1,nproc)
c            write (*,*) date, 'uz', uz(1)
            read (8, *, end=400) date, (p(i),i=1,nproc)
c            write (*,*) date, 'p', p(1)

c           Increment icount
            icount = icount+1

c           Extract year, month, day from date
            iyear = date/10000
            imon = (date - iyear*10000)/100
            iday = (date - iyear*10000) - imon*100

c           Determine whether year is a leap year
c              Years divisible by 400 are leap years
            if (mod(iyear,400).eq.0) then
               l = 1
c              Other centuries are not leap years
            else if (mod(iyear,100).eq.0) then
               l = 0
c              Otherwise, every fourth year is a leap year
            else if (mod(iyear,4).eq.0) then
               l = 1
c              Other years are not leap years
            else
               l = 0
            endif

c           Compute julian day (Annex 2 FAO-56)
          j = int(275.0*float(imon)/9.0-30.0+float(iday))-2

          if (float(imon).lt.3.0) then
                  j = j+2
          else if ((l.eq.1) .and. (float(imon).gt.2.0)) then
                  j = j+1
          endif
            write (*,*) 'Processing ',iyear,imon,iday,'
(',j,' )'

c           Loop through all stations
            do 350 ista = 1,nproc

c              Compute daily average temp. and temp. range
             t(ista) = (tmax(ista)+tmin(ista))/2.
c               write (*,*) 't', t(ista)
               tmax_min = tmax(ista)-tmin(ista)

c              Compute aerodynamic resistance (ra, s/m)
             call aerores(vk,zm,hc,zh,uz(ista),ra)
c               write (*,*) 'ra', ra

c              Compute bulk canopy resistance (rc, s/m)
             call cropres(rl,hc,rc)
c               write (*,*) 'rc', rc
```

```
c             Compute saturated vapor pressure (es, kPa)
            call satvap(tmax(ista),tmin(ista),es)
c              write (*,*) 'es', es

c             Compute vapor pressure deficit
c             Method for computing ea:
c                eaflag = '1'  Based on Tdew,
c                eaflag = '2'  Assuming Tdew=Tmin
c                eaflag = '3'  Based on RHmax, RHmin, Tmax,
Tmin
c                eaflag = '4'  Input computed VPD (es-ea)
              if (eaflag.ne.'4') then
c               Compute actual vapor pressure (ea, kPa)
              call
actvap(eaflag,rhflag,tmax(ista),tmin(ista),
     a
dew(ista),rhmax(ista),rhmin(ista),ea)
c                write (*,*) 'ea', ea

c               Compute vapor pressure deficit (vpd, kPa)
              call vpdef(es,ea,vpd(ista))
c                write (*,*) 'vpd', vpd(ista)
              else
c               Estimate actual vapor pressure (ea, kPa)
                ea = es - vpd(ista)
c                write (*,*) 'ea', ea
c                write (*,*) 'vpd', vpd(ista)
              endif

c             Compute slope of sat. vapor press. curve
(delta, kPa/C)
            call slope(es,t(ista),delta)
c              write (*,*) 'delta', delta

c             Compute latent heat of vaporization (lambda,
MJ/kg)
            call latheat(t(ista),lambda)
c              write (*,*) 'lambda', lambda

c             Compute psychrometric constant (gamma, kPa/C)
            call psyconst(p(ista),lambda,gamma)
c              write (*,*) 'gamma', gamma

c             Compute modified psychrometric constant
(gammod, kPa/C)
            call modpsyconst(gamma,rc,ra,gammod)
c              write (*,*) 'gammod', gammod

c             Compute mean air density (rho, kg/m^3)
            call dense(p(ista),ea,t(ista),rho)
c              write (*,*) 'rho', rho

c             Compute soil heat flux (g, MJ/m^2/day)
c             Method for computing g:
c                gflag = '0'  Neglected
c                gflag = '1'  Based on daily air
temperature change
              if (gflag.eq.'0') then
```

```
c             Soil heat flux is neglected
                 g = 0.0
              else
                 if (icount.eq.1) tn(ista)=t(ista)
               call gterm(cs,ds,t(ista),tn(ista),g)
              endif
c              write (*,*), 'g', g

c             Compute inverse distance Earth-Sun (dr)
            dr = 1.0+0.033*cos(2*pi/365*j)
c              write (*,*) 'dr', dr

c             Compute solar declination (del, rad)
            del = 0.409*sin(2*pi/365*j - 1.39)
c              write (*,*) 'del', del

c             Compute station latitude (phi, rad)
            phi = glat(ista)*pi/180.
c              write (*,*) 'phi', phi

c             Compute sunset hour angle (ws, rad)
            ws = acos(-tan(phi)*tan(del))
c              write (*,*) 'ws', ws

c             Compute extraterrestrial solar radiation
c             (rad, MJ/m^2/day)
            rad = 24*60/pi*gsc*dr*(ws*sin(phi)*sin(del)+
     a                   cos(phi)*cos(del)*sin(ws))
c              write (*,*) 'rad', rad

c             Compute net solar radiation (rns, MJ/m^2/day)
            rns = (1.0-alpha)*rs(ista)
c              write (*,*) 'rns', rns

c             Compute clear-sky solar radiation (rso,
MJ/m^2/day)
            rso = (as+bs+zcoeff*elev(ista))*rad
c              write (*,*) 'rso', rso, ' elev', elev(ista),
as, bs,
c     a                       zcoeff, elev(ista)

c             Compute cloudiness factor (fcl)
            fcl = max(0.0,ac*min(1.0,(rs(ista)/rso)) + bc)
c              write (*,*) 'fcl', fcl

c             Compute net emissivity (epsi)
            epsi = (al + bl*sqrt(ea))
c              write (*,*) 'epsi', epsi

c             Compute net longwave radiation (rnl,
MJ/m^2/day)
            rnl = 4.903e-9*(0.5*((tmax(ista)+273.16)**4+
     a               (tmin(ista)+273.16)**4))*epsi*fcl
c              write (*,*) 'rnl', rnl

c             Compute net radiation (rn, MJ/m^2/day)
            rn = rns - rnl
c              write (*,*) 'rn', rn
```

```
c             Compute radiation component of ETo by Penman-
Monteith
c             (etrad, mm/day)
            etrad(ista) = delta*(rn-
g)/((delta+gammod)*lambda)
c              write (*,*) 'etrad', etrad(ista)

c             Compute aerodynamic component of ETo by
Penman-Monteith
c             (etaero, mm/day)
            etaero(ista) = 86.4*rho*622.
     a
*gamma*vpd(ista)/((delta+gammod)*ra*p(ista))
c              write (*,*) 'etaero', etaero(ista)

c             Compute ETo by Penman-Monteith (etopm,
in/day)
c             25.4 is conversion from mm/day to in/day
            etopm(ista)  = (etrad(ista)+etaero(ista))/25.4
c              write (*,*) 'etopm', etopm(ista)

c             Compute ETo by Priestley-Taylor (etopt,
in/day)
c             25.4 is conversion from mm/day to in/day
              etopt(ista) = alphac(float(imon))*delta*(rn-
g)
     a                 /((delta+gamma)*lambda)/25.4
c              write (*,*) 'etopt', etopt(ista)

c             Compute wet marsh PET by Simple Method
(petsmpl, in/day)
c             25.4 is conversion from mm/day to in/day
              petsmpl(ista) = 0.53*rs(ista)/lambda/25.4
c              write (*,*) 'petsmpl', petsmpl(ista)

c             Save previous timestep temperature
              tn(ista) = t(ista)

 350       continue

c          Write out results
           write (21,50)
iyear,imon,iday,j,(etopm(i),i=1,nproc)
           write (22,50)
iyear,imon,iday,j,(etopt(i),i=1,nproc)
           write (23,50)
iyear,imon,iday,j,(petsmpl(i),i=1,nproc)
 50        format (i4,3(2x,i3),2x,400(f7.5,2x))
           go to 300

 400    continue

      close (1)
      close (2)
      close (3)
      close (4)
      close (5)
```

```
      close (6)
      close (7)
      close (8)
      close (9)
      close (21)
      close (23)
      close (23)

        stop
      end


*
************************SUBROUTINES***********************
*****

c       Compute aerodynamic resistance (ra, s/m)
      subroutine aerores(vk,zm,hc,zh,uz,ra)

        ra = log((zm-0.66*hc)/(0.123*hc))*log((zh-
0.66*hc)/(0.0123*hc))
     a            /(vk**2*uz)
c       ra = log((zm-0.08)/(0.015))*log((zh-0.08)/(0.0015))
c     a           /(vk**2*uz)
c          write (*,*) 'inside ra',zm,hc,zh,vk,uz
      end

c       Compute bulk canopy resistance (rc, s/m)
      subroutine cropres(rl,hc,rc)

         ail = 24*hc

         rc = rl/(0.5*ail)
      end

c       Compute saturated vapor pressure (es, kPa)
      subroutine satvap(tmax,tmin,es)

         call vappr(tmax,estmax)
         call vappr(tmin,estmin)
         es = (estmax+estmin)/2.
      end

c       Compute actual vapor pressure (ea, kPa)
      subroutine
actvap(eaflag,rhflag,tmax,tmin,dew,rhmax,rhmin,ea)
          character*1 eaflag,rhflag
         if (eaflag.eq.'1') then
            call vappr(dew,ea)
          else if (eaflag.eq.'2') then
             call vappr(tmin,ea)
         else if (eaflag.eq.'3') then
             call vappr(tmax,estmax)
             call vappr(tmin,estmin)
             if (rhflag.eq.'1') then
                rhmax=min(100.0,rhmax)
                rhmin=min(100.0,rhmin)
             endif
```

```
           ea = 0.5*(estmin*rhmax/100.+estmax*rhmin/100.)
         endif
       end

c        Compute vapor pressure (e, kPa)
       subroutine vappr(temp,e)

          e = 0.611*exp(17.27*temp/(temp+237.3))
       end

c        Compute vapor pressure deficit (vpd, kPa)
       subroutine vpdef(es,ea,vpd)

          vpd = es - ea
       end

c        Compute slope of saturation vapor pressure curve
(delta, kPa/C)
       subroutine slope(es,t,delta)

          delta = 4098.0*es/(t+237.3)**2
       end

c        Compute latent heat of vaporization (lambda, MJ/kg)
       subroutine latheat(t,lambda)

            real lambda
          lambda = 2.501 - (0.002361*t)
c            write (*,*) 'inside lambda', t, lambda
       end

c        Compute psychrometric constant (gamma, kPa/C)
       subroutine psyconst(p,lambda,gamma)

            real lambda
          gamma = 0.00163*p/lambda
       end

c        Compute modified psychrometric constant (gammamod,
kPa/C)
       subroutine modpsyconst(gamma,rc,ra,gammod)

          gammod = gamma*(1.0+rc/ra)
       end

c        Compute mean air density (rho, kg/m^3)
       subroutine dense(p,ea,t,rho)

          rho = 3.486*p*(1.-0.378*ea/p)/(t+273.16)
       end

c        Compute soil heat flux (g, MJ/m^2/day)
       subroutine gterm(cs,ds,t,tn,g)

          g = cs*ds*((t-tn)/1)
       end
```

Stats.f

This program computes statistics and allows output of annual totals (sums) or annual averages. Set aveflag=0 for the three PET datasets from the Ret.f output files (to get in./year), but =1 for all the other variables (to get m/s or % or MJ/m^2/day or kPa or C). Input file should be called data.txt.

```
            Program usage: Stats.exe aveflag fmt nproc

            aveflag=[0|1]
            Flag for annual statistics
            aveflag = 0:  Compute annual total statistics
             aveflag = 1:  Compute annual average
statistics

            fmt=[1|2]
            Data format:
            fmt = 1:  yyyymmdd, data1, data2, ...
            fmt = 2:  yyyy, mm, dd, jjj, data1, data2, ...

Use fmt = 1 to get statistics of meteorological data
produced by Python program.
Use fmt = 2 to get statistics of RET and PET computed by
FORTRAN Ret program.

             nproc>=1
            Number of stations to process


      PROGRAM STATS
*
***********************************************************
*****
*       Program to compute mean ave, average deviation
adev,
*         standard deviation sdev, variance var, skewness
skew,
*         kurtosis kurt, and coefficient of variation cv.
*
***********************************************************
*****

*
***********************DEFINITIONS************************
*****
        integer      nsta,nm,nproc,ny,nydata
      parameter    (nsta=500,nm=12,ny=200)

        integer
date,i,icount,iyear,imon,iday,iyrprev,ista,j,l
        integer      ctm(nm),cty(ny)
        integer      years(ny)

        real         avecty
        real         s(nm,nsta),p(nm,nsta)
```

```
        real
dat(nsta),ave(nm,nsta),adev(nm,nsta),sdev(nm,nsta),
     a
var(nm,nsta),skew(nm,nsta),kurt(nm,nsta),
     a                cv(nm,nsta)
        real          sy(ny,nsta)
        real
sa(nsta),avea(nsta),sdeva(nsta),cva(nsta)

        data          icount/0/,iyrprev/0/,nydata/0/
        data          ctm/nm*0/,cty/ny*0/
        data
sa/nsta*0.0/,avea/nsta*0.0/,sdeva/nsta*0.0/,
     a                cva/nsta*0.0/
        character*1  aveflag,fmt
      character*50 ndum
*
***********************************************************
*****

c       Check number of arguments passed to program
        if (iargc().lt.3) then
           write (*,*) ''
           write (*,*) 'Only', iargc(), ' arguments have
been entered'
           write (*,*) ''
           write (*,*) 'Program usage: Stats.exe aveflag
fmt nproc'
           write (*,*) ''
           write (*,*) 'aveflag=[0|1]'
           write (*,*) 'Flag for annual statistics'
           write (*,*) 'aveflag = 0:  Compute annual total
statistics'
           write (*,*) 'aveflag = 1:  Compute annual
average statistics'
           write (*,*) ''
           write (*,*) 'fmt=[1|2]'
           write (*,*) 'Data format:'
           write (*,*) 'fmt = 1:  yyyymmdd, data1, data2,
...'
           write (*,*) 'fmt = 2:  yyyy, mm, dd, jjj, data1,
data2, ...'
           write (*,*) ''
           write (*,*) 'nproc>=1'
           write (*,*) 'Number of stations to process'
           write (*,*) ''
           stop
        endif

        call getarg(1,aveflag)
        call getarg(2,fmt)
        call getarg(3,ndum)

        read (unit=ndum,fmt='(i5)') nproc
        if (nproc.lt.1) then
           write (*,*) 'Number of stations to process must
be >= 1'
           stop
```

```
        endif

        if (nproc.gt.nsta) then
           write (*,*) 'Number of stations to process:',
nproc
           write (*,*) 'is larger than array dimensions:',
nsta
           write (*,*) ''
           write (*,*) 'Modify parameter nsta in program '
           write (*,*) 'to increase array size'
           stop
        endif

*
***********************************************************
*****

c       Open files
      open (1, file = 'data.txt', access ='sequential',
     a      form ='formatted',status ='old')

c       Climatology files
        open (11, file = 'ave_clim.txt', access
='sequential',
     a  form ='formatted',status ='unknown')

        open (12, file = 'adev_clim.txt', access
='sequential',
     a  form ='formatted',status ='unknown')

        open (13, file = 'sdev_clim.txt', access
='sequential',
     a  form ='formatted',status ='unknown')

        open (14, file = 'var_clim.txt', access
='sequential',
     a  form ='formatted',status ='unknown')

        open (15, file = 'skew_clim.txt', access
='sequential',
     a  form ='formatted',status ='unknown')

        open (16, file = 'kurtexc_clim.txt', access
='sequential',
     a  form ='formatted',status ='unknown')

        open (17, file = 'cv_clim.txt', access
='sequential',
     a  form ='formatted',status ='unknown')

c       Files with annual statistics
        if (aveflag.eq.'0') then
           open (18, file = 'annual_totals.txt', access
='sequential',
     a     form ='formatted',status ='unknown')
        else
           open (18, file = 'annual_ave.txt', access
='sequential',
```

```
     a     form ='formatted',status ='unknown')
        endif

        open (19, file = 'annual_stats.txt', access
='sequential',
     a  form ='formatted',status ='unknown')
*
***********************************************************
*****

c       Initialize variabes
        do imon=1,nm
          do ista=1,nproc
            s(imon,ista)=0.0
            p(imon,ista)=0.0
            ave(imon,ista)=0.0
            adev(imon,ista)=0.0
            sdev(imon,ista)=0.0
            var(imon,ista)=0.0
            skew(imon,ista)=0.0
            kurt(imon,ista)=0.0
            cv(imon,ista)=0.0
          end do
        end do

        do iyear=1,ny
          do ista=1,nproc
            sy(iyear,ista)=0.0
          end do
        end do

c       Read-in data to compute means
 300    continue
        if (fmt.eq.'1') then

           read (1, *, end=400) date,(dat(i),i=1,nproc)

c          Extract year, month, day from date
           iyear = date/10000
           imon = (date - iyear*10000)/100
           iday = (date - iyear*10000) - imon*100

c          Determine whether year is a leap year
c             Years divisible by 400 are leap years
           if (mod(iyear,400).eq.0) then
              l = 1
c             Other centuries are not leap years
           else if (mod(iyear,100).eq.0) then
              l = 0
c             Otherwise, every fourth year is a leap year
           else if (mod(iyear,4).eq.0) then
              l = 1
c             Other years are not leap years
           else
              l = 0
           endif

c          Compute julian day (Annex 2 FAO-56)
```

```
          j = int(275.0*float(imon)/9.0-30.0+float(iday))-2

          if (float(imon).lt.3.0) then
                  j = j+2
          else if ((l.eq.1) .and. (float(imon).gt.2.0)) then
                  j = j+1
          endif

        else

           read (1, *, end=400)
iyear,imon,iday,j,(dat(i),i=1,nproc)

        endif

c       Increment icount
        icount = icount+1

c       Set beginning year for data
        if (icount.eq.1) ibegyr=iyear

c       Check if this is a new year
        if (iyear.ne.iyrprev) then
          nydata=nydata+1
          years(nydata)=iyear
        endif

        iyrprev=iyear

c       Count data for each month
        ctm(imon)=ctm(imon)+1
        cty(nydata)=cty(nydata)+1
c        write(*,*) iyear,nydata,cty(nydata)

c       Loop through all stations accumulating data
        do 350 ista = 1,nproc
          s(imon,ista)=s(imon,ista)+dat(ista)
          sy(nydata,ista)=sy(nydata,ista)+dat(ista)
          sa(ista)=sa(ista)+dat(ista)
 350    continue

        go to 300
 400    continue

c       Loop through all months/stations computing means
        do imon=1,nm
          do ista=1,nproc
            if (ctm(imon).le.1) then
              write(*,*) 'Need at least 2 data points for
month ', imon
              stop
            endif
            ave(imon,ista)=s(imon,ista)/ctm(imon)
          end do
        end do

c       Loop through all stations/years computing average
annual
```

```
c       and year-to-year stdevs
        do ista=1,nproc
          avea(ista)=sa(ista)/nydata
          do iyear=1,nydata
            sdeva(ista)=sdeva(ista)
     a                    +(sy(iyear,ista)-avea(ista))**2
          end do
          if (nydata.le.1) then
            sdeva(ista)=-999.0
            cva(ista)=-999.0
          else
            sdeva(ista)=sqrt(sdeva(ista)/(nydata-1))
            cva(ista)=sdeva(ista)/avea(ista)
          endif
        end do

c       Read-in data again to compute other stats
        rewind 1
 301    continue
        if (fmt.eq.'1') then

           read (1, *, end=401) date,(dat(i),i=1,nproc)

c          Extract year, month, day from date
           iyear = date/10000
           imon = (date - iyear*10000)/100
           iday = (date - iyear*10000) - imon*100

c          Determine whether year is a leap year
c             Years divisible by 400 are leap years
           if (mod(iyear,400).eq.0) then
              l = 1
c             Other centuries are not leap years
           else if (mod(iyear,100).eq.0) then
              l = 0
c             Otherwise, every fourth year is a leap year
           else if (mod(iyear,4).eq.0) then
              l = 1
c             Other years are not leap years
           else
              l = 0
           endif

c          Compute julian day (Annex 2 FAO-56)
         j = int(275.0*float(imon)/9.0-30.0+float(iday))-2

         if (float(imon).lt.3.0) then
                 j = j+2
         else if ((l.eq.1) .and. (float(imon).gt.2.0)) then
                 j = j+1
         endif

        else
           read (1, *, end=401)
iyear,imon,iday,j,(dat(i),i=1,nproc)
        endif
```

```
        write (*,*) 'Processing ',iyear,imon,iday,' (',j,'
)'

c       Loop through all stations accumulating data
        do 351 ista = 1,nproc
          s(imon,ista)=dat(ista)-ave(imon,ista)
          adev(imon,ista)=adev(imon,ista)+abs(s(imon,ista))
          p(imon,ista)=s(imon,ista)**2
          var(imon,ista)=var(imon,ista)+p(imon,ista)
          p(imon,ista)=s(imon,ista)**3
        skew(imon,ista)=skew(imon,ista)+p(imon,ista)
        p(imon,ista)=s(imon,ista)**4
        kurt(imon,ista)=kurt(imon,ista)+p(imon,ista)
 351    continue

        go to 301
 401    continue

c       Loop through all months/stations computing stats
        do imon=1,nm
          do ista=1,nproc
            if (ctm(imon).le.1) then
              write(*,*) 'Need at least 2 data points for
month ', imon
              stop
            endif
            adev(imon,ista)=adev(imon,ista)/ctm(imon)
            var(imon,ista)=var(imon,ista)/(ctm(imon)-1)
            sdev(imon,ista)=sqrt(var(imon,ista))
            if (var(imon,ista).ne.0.0) then
              skew(imon,ista)=
     a
skew(imon,ista)/(ctm(imon)*sdev(imon,ista)**3)
              kurt(imon,ista)=
     a
kurt(imon,ista)/(ctm(imon)*var(imon,ista)**2)-3.0
            else
c             No skew or kurtosis when zero variance
              skew(imon,ista)=-999.0
              kurt(imon,ista)=-999.0
            endif
            if (ave(imon,ista).ne.0.0) then
              cv(imon,ista)=sdev(imon,ista)/ave(imon,ista)
            else
              cv(imon,ista)=-999.0
           endif
          end do
        end do

c       Output stats for all stations, months
        do ista = 1,nproc
           write (11,50) (ave(imon,ista),imon=1,nm)
           write (12,50) (adev(imon,ista),imon=1,nm)
           write (13,50) (sdev(imon,ista),imon=1,nm)
           write (14,50) (var(imon,ista),imon=1,nm)
           write (15,50) (skew(imon,ista),imon=1,nm)
           write (16,50) (kurt(imon,ista),imon=1,nm)
           write (17,50) (cv(imon,ista),imon=1,nm)
```

```
 50       format (12(f15.5,2x))
        end do

c       Output annual data for all stations, years
        write (18,60) (years(iyear),iyear=1,nydata)
 60     format (200(4x,I4,2x,2x))
        do ista = 1,nproc
           if (aveflag.eq.'0') then
              write (18,70) (sy(iyear,ista),iyear=1,nydata)
           else
              write (18,70)
(sy(iyear,ista)/cty(iyear),iyear=1,nydata)
           endif
 70        format (200(f15.5,2x))
        end do

c       Compute average number of days per year for period
of record
        do iyear = 1,nydata
           avecty = avecty + cty(iyear)
        end do
        avecty = avecty / nydata
c       write (*,*) avecty, nydata

c       Output annual stats for all stations
        write (19,80) 'Ave','Sdev','Cv'
 80     format (3(4x,A4,2x,2x))
        do ista = 1,nproc
           if (aveflag.eq.'0') then
              write (19,90)
avea(ista),sdeva(ista),cva(ista)
           else
              write (19,90)
avea(ista)/avecty,sdeva(ista)/avecty,
     a                       cva(ista)
           endif
 90        format (3(f15.5,2x))
        end do

      close (1)
        close (11)
        close (12)
        close (13)
        close (14)
        close (15)
        close (16)
        close (17)
        close (18)
        close (19)

        stop
      end
```

kernel08.f

This program is a bivariate kernel estimator with an ad-hoc selection of its bandwidth. It was used for the spatial aggregation of the 12km Hydro51 data into the 32km resolution NARR grid.

```
Input files:
etopm.txt - Hydro51 based Penman-Monteith reference ET
file, produced by RET.f with relative humidity variables
capped at 100%.
hydro51_497_xy.csv - Comma separated file of x-y
coordinates of the 497 Hydro51 points.
NARR_xy_08.csv - Comma separated file of x-y coordinates of
the selected 109 NARR points.
etopt.txt - Hydro51 based Preistley-Taylor reference ET
file, produced by RET.f with relative humidity variables
capped at 100%. Only the dates are read from this file.

      Output file:
Agg_hydro_at_NARR_locs.out


        integer index(19)
       real xn(109),yn(109),xh(497),yh(497)
         real eth(18628,497),w(19),eth_N(18628,211)

        open (unit=1,file='etopm.txt',status='old')
        open(unit=2,file='hydro51_497_xy.csv',status='old')
        open(unit=3,file='NARR_xy_08.csv',status='old')
        open
(unit=4,file='Agg_hydro_at_NARR_locs.out',status='unknown')

c  read NARR x, y
        read(3,*)
        read(3,*)
        do i=1,109
           read(3,*) xn(i),yn(i)
      enddo

c  read hydro51 x, y
        read(2,*)
        read(2,*)
        do i=1,497
           read(2,*) xh(i),yh(i)
      enddo
        close(2)
        nn=19
        do i=1,18628
                read(1,*)iy,im,id,idd,(eth(i,j),j=1,497)
        enddo
        close(1)

        do ip =1,109
                write(*,*)'now processing location ',ip
```

```
          x1=xn(ip)
          y1=yn(ip)

        open(unit=2,file='hydro51_497_xy.csv',status='old')
        read(2,*)
        read(2,*)
        do i=1,497
           read(2,*) xh(i),yh(i)
      enddo
        close(2)
          call xkernel(nn,x1,y1,xh,yh,b,index,w)
          sum=0.
          do i =1,nn
          sum=sum+w(i)
          enddo
 102    format(f8.5,1x,i4,1x,f8.5)
          do i=1,18628
            ee=0.
            do j=1,nn
                ee=ee+w(j)*eth(i,index(j))
            enddo
                eth_N(i,ip)=ee/sum
          enddo
        enddo
        open (unit=1,file='etopt.txt',status='old')
           write(4,201)(xn(ip),ip=1,109)
           write(4,201)(yn(ip),ip=1,109)
        do i=1,18628
        write(*,*)'now writing ',i
           read(1,*)iy,im,id,idd,(eth(i,j),j=1,497)
           write(4,200)iy,im,id,idd,(eth_N(i,ip),ip=1,109)
        enddo
201      format('x coordinates       ',109(f9.1,1x))
202      format('y coordinates       ',109(f9.1,1x))
200     format(i4,1x,i4,1x,i4,1x,i4,1x,109(f9.5,1x))
100     format(i4,1x,i3,1x,2(f10.2,1x),f8.5)
        stop
        end



        subroutine xkernel(nn,x1,y1,xh1,yh1,b,index,w)
         integer index(19)
       real xh1(497),yh1(497),dr(497),w(19)
         do i =1,497
                index(i)=i
                dx=x1-xh1(i)
                dy=y1-yh1(i)
                dr(i)=sqrt(dx*dx+dy*dy)
         enddo


        do i=1,nn
             do j=i+1,497
                if(dr(j).lt.dr(i)) then
                        temp = dr(i)
                        dr(i)=dr(j)
                        dr(j)=temp
```

```
                        itemp=index(i)
                        index(i)=index(j)
                        index(j)=itemp
                endif
             enddo
        enddo
        b=dr(nn)
        do i=1,nn
             dd=dr(i)/b
             w(i)=(1-dd*dd)*(1-dd*dd)

write(18,101)b,index(i),w(i),xh1(index(i)),yh1(index(i))
        enddo
101     format(f10.2,1x,i4,1x,f8.5,1x,2(f10.2,1x))
        return
        end
```

rescale08.f

This program rescales Hydro51-based reference ET to match the long-term mean and standard deviation of the NARR based reference ET.

```
Input files:
NARR_ave_clim109.txt - Long term NARR daily average
reference ET by month for the selected 109 grid points.
This is an output file from the Stats.f program that used
the ET computation with solar radiation reduced by 7.5%.
NARR_sdev_clim109.txt - Long term NARR daily standard
deviation reference ET by month for the selected 109 grid
points. This is an output file from the Stats.f program
that used the ET computation with solar radiation reduced
by 7.5%.
ave_clim109.txt - Long term spatially aggregated HYDRO51
daily average reference ET by month, output file from
Stats.f program.
sdev_clim109.txt - Long term spatially aggregated HYDRO51
daily standard deviation reference ET by month, output file
from Stats.f program.
Agg_hydro_at_NARR_locs.out - Daily, spatially aggregated
HYDRO51 based reference ET, output file from kernel08.f
program.


Output file:
HYDRO51_PRIME.dat

c     Program: rescale.f
c          By: Tim Newton
c        Date: 25-Jul-2006,updated April 2008
c              Modified May 11 by T. Newton,ARCADIS
c Description: This program rescales Hydro51 forcing PET
1948-98
c
c     Compile: g77 -o rescale08.exe rescale08.f
c
c===========================================================
=============
c Dimension variables
c===========================================================
=============
c HP=H', pet=etopm_rhcap value, HA=average H,sdh=std dev H,
sdn=std dev NARR
c NA= Average NARR
      real
HP(325),HA(325,13),sdh(325,13),NA(325,13),sdn(325,13)
      real pet(325)
      integer ct, j, k, n
      integer mo,da,yr,jda
c===========================================================
=============
c Open files to read and write
c===========================================================
=============
```

```
c-----Hydro51 PM Eto
      open(10,file='ave_clim109.txt',status='old')
        do 15 ct = 1, 109
c-----------Read variables into array
            read(10,*) (HA(ct,n),n=1,12)
  15        continue

c-----Hydro51 PM Eto
      open(20,file='sdev_clim109.txt',status='old')
        do 20 j = 1, 109
c-----------Read variables into array
             read(20,*) (sdh(j,n),n=1,12)
  20        continue

      open(30,file='NARR_ave_clim109.txt',status='old')
        do 30 ct = 1, 109
c-----------Read variables into array
             read(30,*) (NA(ct,n),n=1,12)
  30        continue

      open(40,file='NARR_sdev_clim109.txt',status='old')
        do 40 j = 1, 109
c-----------Read variables into array
             read(40,*) (sdn(j,n),n=1,12)
  40        continue

      open(50,file='HYDRO51_PRIME.dat',status='unknown')


open(60,file='Agg_hydro_at_NARR_locs.out',status='old')

c===========================================================
=============
c Begin BIG loop
c From 1948 to 1998, 51 years
c===========================================================
=============

        do 50 ct = 1, 18628

c-----------Read variables into array
              read(60,*) yr,mo,da,jda,(pet(n),n=1,109)
              do 60 k = 1, 109
      HP(k)=((pet(k)-
HA(k,mo))/sdh(k,mo))*sdn(k,mo)+NA(k,mo)

 60         continue

            write(50,1025) yr,mo,da,jda,(HP(n),n=1,109)

 50         continue

            close(50)


c===========================================================
=============
```

```
c Format statements
c==========================================================
=============
 1025 format (i4," ",i2," ",i2," ",i3," ",109(f6.4,2x))

c==========================================================
=============
c End program
c==========================================================
=============
      stop
      end
```

merge_datasets3.scr

This script merges the 1948 to 1978 Hydro51-based reference ET with the 1979 to 2005 NARR-based reference ET and saves the combined data to DSS using the grid_io STO command.

Input files:
NARR_xy_109.prn – List of point IDs, NARR IDs, and x-y coordinates of the 109 NARR points.
HYDRO51_PRIME.dat – Rescaled HYDRO51 reference ET data. This is the output file from the rescale program.
etopm_SWR75.txt – NARR daily reference ET that with the solar radiation component reduced by 7.5%.

Output file:
Hydro51P_NARR_PMETo_RHcap.dss

```
#!/bin/csh -f

set dssfilename = Hydro51P_NARR_PMETo_RHcap.dss

set HPbegyr = 1948
set NARRbegyr = 1979
set NARRendyr = 2005

echo $dssfilename >! temp1.$$

gawk '{if(NR>1){print $2}}' ./NARR_xy_109.prn >
NARR_active_ids

gawk '{if($1<cutyear)print $1,$2,$3}' cutyear=$NARRbegyr
./HYDRO51_PRIME.dat > dates.txt

gawk '{print $1,$2,$3}' ./etopm_SWR75.txt >> dates.txt

@ i = 0
foreach id (`cat NARR_active_ids`)
  @ i++
  echo id $id $i

  set colH = `expr $i + 4`
  gawk '{if($1<cutyear)print $col}' cutyear=$NARRbegyr
col=$colH ./HYDRO51_PRIME.dat > temp1.txt

  set colN = `expr $id + 4`
  gawk '{print $col}' col=$colN ./etopm_SWR75.txt >>
temp1.txt

  paste dates.txt temp1.txt > temp2.txt

  set row = `expr $i + 1`
  gawk 'BEGIN{print "TIME WINDOW 01JAN1948
31DEC2005\n"};{if(NR==row){printf "STATION \"%s\"\nXCOORD
%s\nYCOORD %s\nDBKEY \"CALC-%s\"\nBASIN
\"outdomain\"\nLOCATION \"%s\"\nPARAMETER
\"PM_ETo\"\nINTERVAL \"DA\"\nDESCRIPTOR \"%s\"\nALT_ID
```

```
\"\"\nAGENCY \"SFWMD\"\nUNITS
\"INCHES\"\nDSSFILE\"Hydro51P_NARR_PMETo_RHcap\"\nQUALFLAGS
\nEND\n\n",$2,$5,$6,$2,$2,$2}};END{print "DATA"}' row=$row
./NARR_xy_109.prn > header.txt

  cat header.txt temp2.txt > temp3.txt
  cat temp3.txt > fordss.${i}.txt

  ./Sto fordss.${i}.txt

end

/bin/rm temp*.txt temp*.$$ header.txt
```

gr_48_05_nad83_MULTIQUAD.in

This is the input file for the multiquadric version of the *gr_thsn* C++ program. The final output grid is defined by the origin, spacing, and beginning and ending columns. All units are in feet. The numbers following RIGHT_EXT are the right-most column numbers in order of rows, starting with row 1 at the origin and moving up (north). The numbers following LEFT_EXT are the beginning columns, listed in the same order of the right-most column numbers. Time series data is loaded from the DSS files listed at the end of the code. Each DSS file has an associated grid coordinate that was assigned in an earlier process with the C++ *Sto* function.

gr_48_05_nad83_119row_MULTIQUAD.in - Input file that defines input data points in the DSS file and the output grid.
PET_48_05_EXTEND_119ROW_MULTIQUAD.bin - Binary reference ET output file in grid_io format that serves as the input file for RSM models

```
# Input file for gr_thsn program UPDATED JUNE08 FOR wider
119 row Grid
# Provides input specifications to compute daily cell by
cell PET
# for the Natural Systems Model

TITLE    "SF PET - V1.0_beta"

# DSS message level specification
MLEVEL   2

METHOD MULTIQUAD

# time window specifications ..
TIME WINDOW       01JAN1948   31DEC2005

# grid specifications ....

GRID
      XORIGIN   237027
      YORIGIN   286611

      NROWS    119
      NCOLS    70

SPACING  10560

      RIGHT_EXT
          50 50 54 56 58 59 60 61 61 61
          61 61 61 61 62 62 62 63 63 64
          64 65 66 66 66 66 67 67 67 67
          68 68 68 68 68 68 68 69 69 69
          69 69 69 69 69 69 69 69 70 70
          70 70 70 70 70 70 70 70 69 69
          69 69 68 68 68 67 67 67 66 66
```

```
            66 65 65 65 64 64 64 64 62 62
            62 61 60 60 60 46 46 46 46 46
            46 46 46 46 46 46 46 46 46 46
            46 46 46 46 46 46 46 46 46 46
            46 46 46 46 46 46 46 46 46
        END

        LEFT_EXT
            35 34 34 34 34 35 35 35 35 35
            34 34 33 33 33 32 32 31 30 29
            29 28 26 25 17 17 17 17 16 16
            16 15 15 15 15 14 14 14 14 14
            13 13 12 12  5  4  3  3  3  2
             2  2  1  1  1  1  1  1  1  1
             1  1  1  1  1  1  1 16 16 16
            16 16 16 16 16 16 16 16 16 16
            16 16 16 16 16 16 16 16 16 16
            16 16 16 16 16 16 16 16 16 16
            16 16 16 16 16 16 16 16 16 16
            16 16 16 16 16 16 16 16 16
        END
END
DSSFILE "Hydro51P_NARR_PMETo_RHcap.dss"
STATION "1"
pathname    "/OUTDOMAIN/1/PM_ETO//1DAY/CALC-1-1/"
END
STATION "2"
pathname    "/OUTDOMAIN/2/PM_ETO//1DAY/CALC-2-2/"
END
STATION "3"
pathname    "/OUTDOMAIN/3/PM_ETO//1DAY/CALC-3-3/"
END
STATION "4"
pathname    "/OUTDOMAIN/4/PM_ETO//1DAY/CALC-4-4/"
END
STATION "5"
pathname    "/OUTDOMAIN/5/PM_ETO//1DAY/CALC-5-5/"
END
STATION "6"
pathname    "/OUTDOMAIN/6/PM_ETO//1DAY/CALC-6-6/"
END
STATION "7"
pathname    "/OUTDOMAIN/7/PM_ETO//1DAY/CALC-7-7/"
END
STATION "16"
pathname    "/OUTDOMAIN/16/PM_ETO//1DAY/CALC-16-16/"
END
STATION "17"
pathname    "/OUTDOMAIN/17/PM_ETO//1DAY/CALC-17-17/"
END
STATION "18"
pathname    "/OUTDOMAIN/18/PM_ETO//1DAY/CALC-18-18/"
END
STATION "19"
pathname    "/OUTDOMAIN/19/PM_ETO//1DAY/CALC-19-19/"
END
STATION "20"
pathname    "/OUTDOMAIN/20/PM_ETO//1DAY/CALC-20-20/"
```

```
END
STATION "21"
pathname    "/OUTDOMAIN/21/PM_ETO//1DAY/CALC-21-21/"
END
STATION "22"
pathname    "/OUTDOMAIN/22/PM_ETO//1DAY/CALC-22-22/"
END
STATION "30"
pathname    "/OUTDOMAIN/30/PM_ETO//1DAY/CALC-30-30/"
END
STATION "31"
pathname    "/OUTDOMAIN/31/PM_ETO//1DAY/CALC-31-31/"
END
STATION "32"
pathname    "/OUTDOMAIN/32/PM_ETO//1DAY/CALC-32-32/"
END
STATION "33"
pathname    "/OUTDOMAIN/33/PM_ETO//1DAY/CALC-33-33/"
END
STATION "34"
pathname    "/OUTDOMAIN/34/PM_ETO//1DAY/CALC-34-34/"
END
STATION "35"
pathname    "/OUTDOMAIN/35/PM_ETO//1DAY/CALC-35-35/"
END
STATION "43"
pathname    "/OUTDOMAIN/43/PM_ETO//1DAY/CALC-43-43/"
END
STATION "44"
pathname    "/OUTDOMAIN/44/PM_ETO//1DAY/CALC-44-44/"
END
STATION "45"
pathname    "/OUTDOMAIN/45/PM_ETO//1DAY/CALC-45-45/"
END
STATION "46"
pathname    "/OUTDOMAIN/46/PM_ETO//1DAY/CALC-46-46/"
END
STATION "47"
pathname    "/OUTDOMAIN/47/PM_ETO//1DAY/CALC-47-47/"
END
STATION "48"
pathname    "/OUTDOMAIN/48/PM_ETO//1DAY/CALC-48-48/"
END
STATION "49"
pathname    "/OUTDOMAIN/49/PM_ETO//1DAY/CALC-49-49/"
END
STATION "50"
pathname    "/OUTDOMAIN/50/PM_ETO//1DAY/CALC-50-50/"
END
STATION "51"
pathname    "/OUTDOMAIN/51/PM_ETO//1DAY/CALC-51-51/"
END
STATION "52"
pathname    "/OUTDOMAIN/52/PM_ETO//1DAY/CALC-52-52/"
END
STATION "58"
pathname    "/OUTDOMAIN/58/PM_ETO//1DAY/CALC-58-58/"
END
```

```
STATION "59"
pathname    "/OUTDOMAIN/59/PM_ETO//1DAY/CALC-59-59/"
END
STATION "60"
pathname    "/OUTDOMAIN/60/PM_ETO//1DAY/CALC-60-60/"
END
STATION "61"
pathname    "/OUTDOMAIN/61/PM_ETO//1DAY/CALC-61-61/"
END
STATION "62"
pathname    "/OUTDOMAIN/62/PM_ETO//1DAY/CALC-62-62/"
END
STATION "63"
pathname    "/OUTDOMAIN/63/PM_ETO//1DAY/CALC-63-63/"
END
STATION "64"
pathname    "/OUTDOMAIN/64/PM_ETO//1DAY/CALC-64-64/"
END
STATION "65"
pathname    "/OUTDOMAIN/65/PM_ETO//1DAY/CALC-65-65/"
END
STATION "66"
pathname    "/OUTDOMAIN/66/PM_ETO//1DAY/CALC-66-66/"
END
STATION "67"
pathname    "/OUTDOMAIN/67/PM_ETO//1DAY/CALC-67-67/"
END
STATION "72"
pathname    "/OUTDOMAIN/72/PM_ETO//1DAY/CALC-72-72/"
END
STATION "73"
pathname    "/OUTDOMAIN/73/PM_ETO//1DAY/CALC-73-73/"
END
STATION "74"
pathname    "/OUTDOMAIN/74/PM_ETO//1DAY/CALC-74-74/"
END
STATION "75"
pathname    "/OUTDOMAIN/75/PM_ETO//1DAY/CALC-75-75/"
END
STATION "76"
pathname    "/OUTDOMAIN/76/PM_ETO//1DAY/CALC-76-76/"
END
STATION "77"
pathname    "/OUTDOMAIN/77/PM_ETO//1DAY/CALC-77-77/"
END
STATION "78"
pathname    "/OUTDOMAIN/78/PM_ETO//1DAY/CALC-78-78/"
END
STATION "79"
pathname    "/OUTDOMAIN/79/PM_ETO//1DAY/CALC-79-79/"
END
STATION "80"
pathname    "/OUTDOMAIN/80/PM_ETO//1DAY/CALC-80-80/"
END
STATION "81"
pathname    "/OUTDOMAIN/81/PM_ETO//1DAY/CALC-81-81/"
END
STATION "88"
```

```
pathname    "/OUTDOMAIN/88/PM_ETO//1DAY/CALC-88-88/"
END
STATION "89"
pathname    "/OUTDOMAIN/89/PM_ETO//1DAY/CALC-89-89/"
END
STATION "90"
pathname    "/OUTDOMAIN/90/PM_ETO//1DAY/CALC-90-90/"
END
STATION "91"
pathname    "/OUTDOMAIN/91/PM_ETO//1DAY/CALC-91-91/"
END
STATION "92"
pathname    "/OUTDOMAIN/92/PM_ETO//1DAY/CALC-92-92/"
END
STATION "93"
pathname    "/OUTDOMAIN/93/PM_ETO//1DAY/CALC-93-93/"
END
STATION "94"
pathname    "/OUTDOMAIN/94/PM_ETO//1DAY/CALC-94-94/"
END
STATION "95"
pathname    "/OUTDOMAIN/95/PM_ETO//1DAY/CALC-95-95/"
END
STATION "103"
pathname    "/OUTDOMAIN/103/PM_ETO//1DAY/CALC-103-103/"
END
STATION "104"
pathname    "/OUTDOMAIN/104/PM_ETO//1DAY/CALC-104-104/"
END
STATION "105"
pathname    "/OUTDOMAIN/105/PM_ETO//1DAY/CALC-105-105/"
END
STATION "106"
pathname    "/OUTDOMAIN/106/PM_ETO//1DAY/CALC-106-106/"
END
STATION "107"
pathname    "/OUTDOMAIN/107/PM_ETO//1DAY/CALC-107-107/"
END
STATION "108"
pathname    "/OUTDOMAIN/108/PM_ETO//1DAY/CALC-108-108/"
END
STATION "109"
pathname    "/OUTDOMAIN/109/PM_ETO//1DAY/CALC-109-109/"
END
STATION "110"
pathname    "/OUTDOMAIN/110/PM_ETO//1DAY/CALC-110-110/"
END
STATION "118"
pathname    "/OUTDOMAIN/118/PM_ETO//1DAY/CALC-118-118/"
END
STATION "119"
pathname    "/OUTDOMAIN/119/PM_ETO//1DAY/CALC-119-119/"
END
STATION "120"
pathname    "/OUTDOMAIN/120/PM_ETO//1DAY/CALC-120-120/"
END
STATION "121"
pathname    "/OUTDOMAIN/121/PM_ETO//1DAY/CALC-121-121/"
```

```
END
STATION "122"
pathname    "/OUTDOMAIN/122/PM_ETO//1DAY/CALC-122-122/"
END
STATION "123"
pathname    "/OUTDOMAIN/123/PM_ETO//1DAY/CALC-123-123/"
END
STATION "124"
pathname    "/OUTDOMAIN/124/PM_ETO//1DAY/CALC-124-124/"
END
STATION "133"
pathname    "/OUTDOMAIN/133/PM_ETO//1DAY/CALC-133-133/"
END
STATION "134"
pathname    "/OUTDOMAIN/134/PM_ETO//1DAY/CALC-134-134/"
END
STATION "135"
pathname    "/OUTDOMAIN/135/PM_ETO//1DAY/CALC-135-135/"
END
STATION "136"
pathname    "/OUTDOMAIN/136/PM_ETO//1DAY/CALC-136-136/"
END
STATION "137"
pathname    "/OUTDOMAIN/137/PM_ETO//1DAY/CALC-137-137/"
END
STATION "138"
pathname    "/OUTDOMAIN/138/PM_ETO//1DAY/CALC-138-138/"
END
STATION "149"
pathname    "/OUTDOMAIN/149/PM_ETO//1DAY/CALC-149-149/"
END
STATION "150"
pathname    "/OUTDOMAIN/150/PM_ETO//1DAY/CALC-150-150/"
END
STATION "151"
pathname    "/OUTDOMAIN/151/PM_ETO//1DAY/CALC-151-151/"
END
STATION "152"
pathname    "/OUTDOMAIN/152/PM_ETO//1DAY/CALC-152-152/"
END
STATION "164"
pathname    "/OUTDOMAIN/164/PM_ETO//1DAY/CALC-164-164/"
END
STATION "165"
pathname    "/OUTDOMAIN/165/PM_ETO//1DAY/CALC-165-165/"
END
STATION "CAL1001"
pathname "/OUTDOMAIN/1001/PM_ETO//1DAY/CALC-1001-1001/"
END
STATION "CAL1002"
pathname "/OUTDOMAIN/1002/PM_ETO//1DAY/CALC-1002-1002/"
END
STATION "CAL1003"
pathname "/OUTDOMAIN/1003/PM_ETO//1DAY/CALC-1003-1003/"
END
STATION "CAL1004"
pathname "/OUTDOMAIN/1004/PM_ETO//1DAY/CALC-1004-1004/"
END
```

```
STATION "CAL1005"
pathname "/OUTDOMAIN/1005/PM_ETO//1DAY/CALC-1005-1005/"
END
STATION "CAL1006"
pathname "/OUTDOMAIN/1006/PM_ETO//1DAY/CALC-1006-1006/"
END
STATION "CAL1007"
pathname "/OUTDOMAIN/1007/PM_ETO//1DAY/CALC-1007-1007/"
END
STATION "CAL1008"
pathname "/OUTDOMAIN/1008/PM_ETO//1DAY/CALC-1008-1008/"
END
STATION "CAL1009"
pathname "/OUTDOMAIN/1009/PM_ETO//1DAY/CALC-1009-1009/"
END
STATION "CAL1011"
pathname "/OUTDOMAIN/1011/PM_ETO//1DAY/CALC-1011-1011/"
END
STATION "CAL1012"
pathname "/OUTDOMAIN/1012/PM_ETO//1DAY/CALC-1012-1012/"
END
STATION "CAL1013"
pathname "/OUTDOMAIN/1013/PM_ETO//1DAY/CALC-1013-1013/"
END
STATION "CAL1015"
pathname "/OUTDOMAIN/1015/PM_ETO//1DAY/CALC-1015-1015/"
END
STATION "CAL1016"
pathname "/OUTDOMAIN/1016/PM_ETO//1DAY/CALC-1016-1016/"
END
STATION "CAL1018"
pathname "/OUTDOMAIN/1018/PM_ETO//1DAY/CALC-1018-1018/"
END
STATION "CAL1019"
pathname "/OUTDOMAIN/1019/PM_ETO//1DAY/CALC-1019-1019/"
END
STATION "CAL1020"
pathname "/OUTDOMAIN/1020/PM_ETO//1DAY/CALC-1020-1020/"
END
STATION "CAL1021"
pathname "/OUTDOMAIN/1021/PM_ETO//1DAY/CALC-1021-1021/"
END
STATION "CAL1022"
pathname "/OUTDOMAIN/1022/PM_ETO//1DAY/CALC-1022-1022/"
END
STATION "CAL1023"
pathname "/OUTDOMAIN/1023/PM_ETO//1DAY/CALC-1023-1023/"
END
STATION "CAL1024"
pathname "/OUTDOMAIN/1024/PM_ETO//1DAY/CALC-1024-1024/"
END
STATION "CAL1025"
pathname "/OUTDOMAIN/1025/PM_ETO//1DAY/CALC-1025-1025/"
END
STATION "CAL1026"
pathname "/OUTDOMAIN/1026/PM_ETO//1DAY/CALC-1026-1026/"
END
STATION "CAL1027"
```

```
pathname "/OUTDOMAIN/1027/PM_ETO//1DAY/CALC-1027-1027/"
END
STATION "CAL1028"
pathname "/OUTDOMAIN/1028/PM_ETO//1DAY/CALC-1028-1028/"
END
OUTFILE         "PET_48_05_EXTEND_119ROW_MULTIQUAD.bin
```

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Appendix E
Hydrogeology

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E.1 HYDROSTRATIGRAPHY FOR THE REGIONAL SIMULATION MODEL

The elevation of the base of the aquifer to be simulated in the Natural System Regional Simulation Model (NSRSM) was generated from a combination of data sources (**Figure E-1**).

In southeast Florida, in Miami-Dade, Broward, and southern Palm Beach counties, the elevation was based on hydrostratigraphic picks for the top of the Tamiami confining unit from select wells used in development of the Lower East Coast Regional (LECsR) model. The top of the Tamiami confining unit corresponds to layers one and two of the LECsR.

In southwest Florida, in Hendry, Lee, and Collier counties, the base NSRSM model is the base of the Water Table aquifer. This is the hydrostratigraphic equivalent of the top of the Tamiami confining unit. The dataset for this region was compiled from various historical South Florida Water Management District (SFWMD or District) reports, as well as data previously compiled by consultants for District modeling efforts in Lee and Collier counties.

The hydrostratigraphy for the rest of the NSRSM area: northern Palm Beach, southern Martin, and parts of Okeechobee, Highlands, and Glades counties, was interpolated from a well distributed sampling of points extracted from other District models. In the east, this data was extracted from the base of layer 2 of the LECsR model. In the northwest, it was extracted from the base of layer 1 of the Glades-Okeechobee-Highlands (GOH) model (SFWMD, **2000**).

Where the GOH model data meets the well data from the Lower West Coast, there is an inconsistency of which the users of this dataset should be aware. The GOH model used the top of the intermediate confining unit as the base of its first layer. Where the lower Tamiami aquifer is unconfined, this is equivalent to the base of the Water Table aquifer. It is likely, however, that some confinement for the lower Tamiami exists in the southeastern portion of Glades County. In which case, the unit mapped as the base of the NSRSM in Glades County, and the unit mapped in adjacent Hendry County will not be hydrostratigraphically equivalent. The rapid depth change visible in the elevation surface for this area is likely due to this discrepancy (**Figure E-2**). Unfortunately, data to support a more refined discretization of the surficial aquifer system in Glades County is not currently available.

The location of the well data, and extracted model data points, along with the elevation used for the base of the NSRSM surface, and source of that information are documented. This information is available in a separate document: **rsm_hydrostratpoints.csv** (SFWMD, **2012a**).

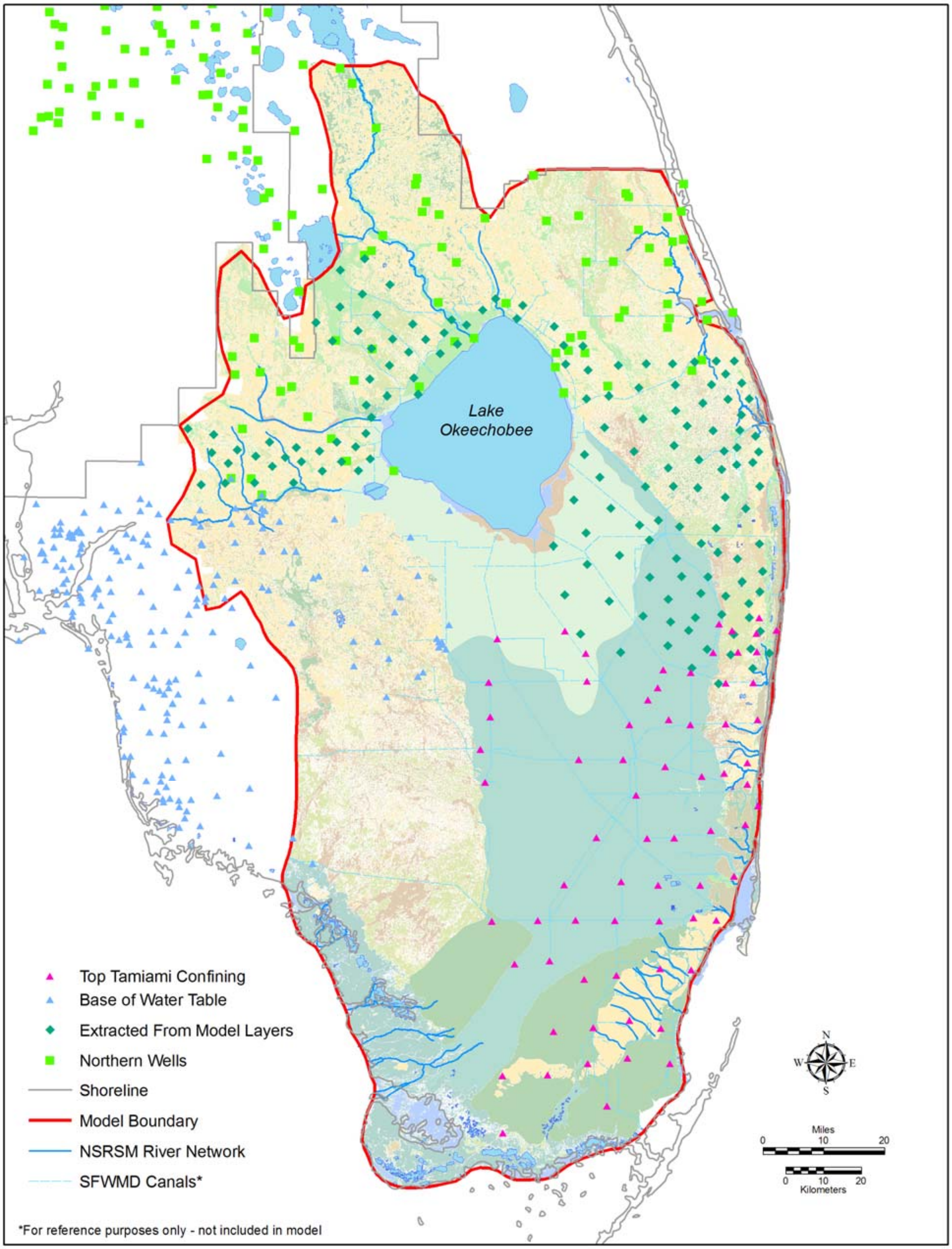

Figure E-1. Data points used to generate the elevation surface for the base of the NSRSM.

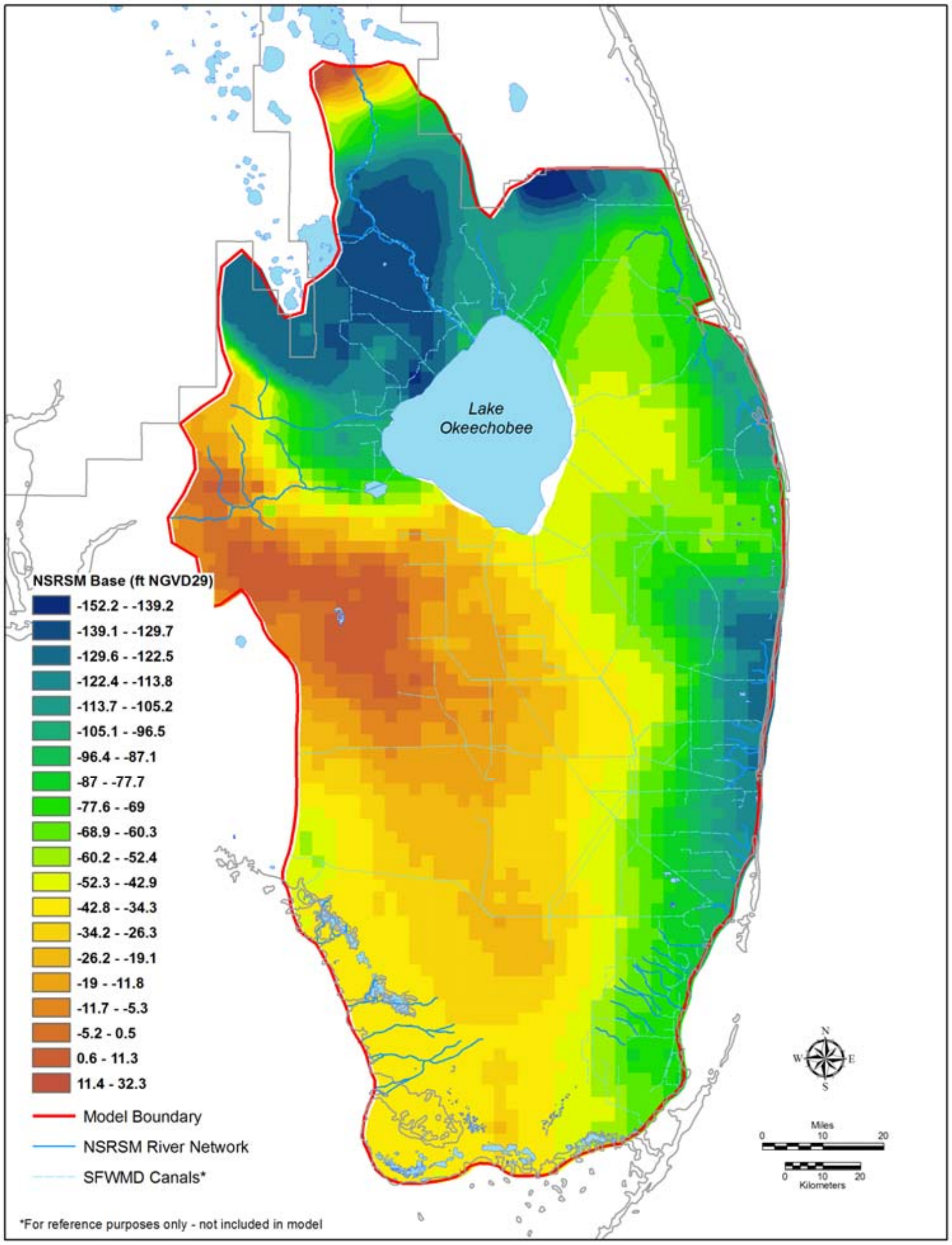

Figure E-2. Elevation [FT NGVD29] of the base of the NSRSM.

The elevation surface pictured in **Figure E-2** was generated by inverse distance weighted (IDW) interpolation using Viewlog software. Output is provided in ASCII format for easy importation to GIS. A relatively coarse surface (2 mile x 2 mile) was used for interpolation, with the objective of covering the entire model area at a scale commensurate with the separation of the data points.

For areas in the Lower Kissimmee River Basin, a surface was initially generated from the well data through interpolation using the inverse distance weighted (IDW) method of kriging. A composite surface was created and mesh values were assigned using GIS techniques to smooth the transition within the NSRSM domain.

Northern NSRSM Data Verification

In areas in the Lower Kissimmee River Basin domain, elevations were verified using hydrostratigraphic layers and cross-section subsets of data from Reese and Richardson (**2008**).

Figure E-3 is a base map of cross-section locations for maps of the extent and thickness of the hydrostratigraphic units existing in the basins north of Lake Okeechobee. **Figure E-4** through **Figure E-6** correspond to the lines in the base map.

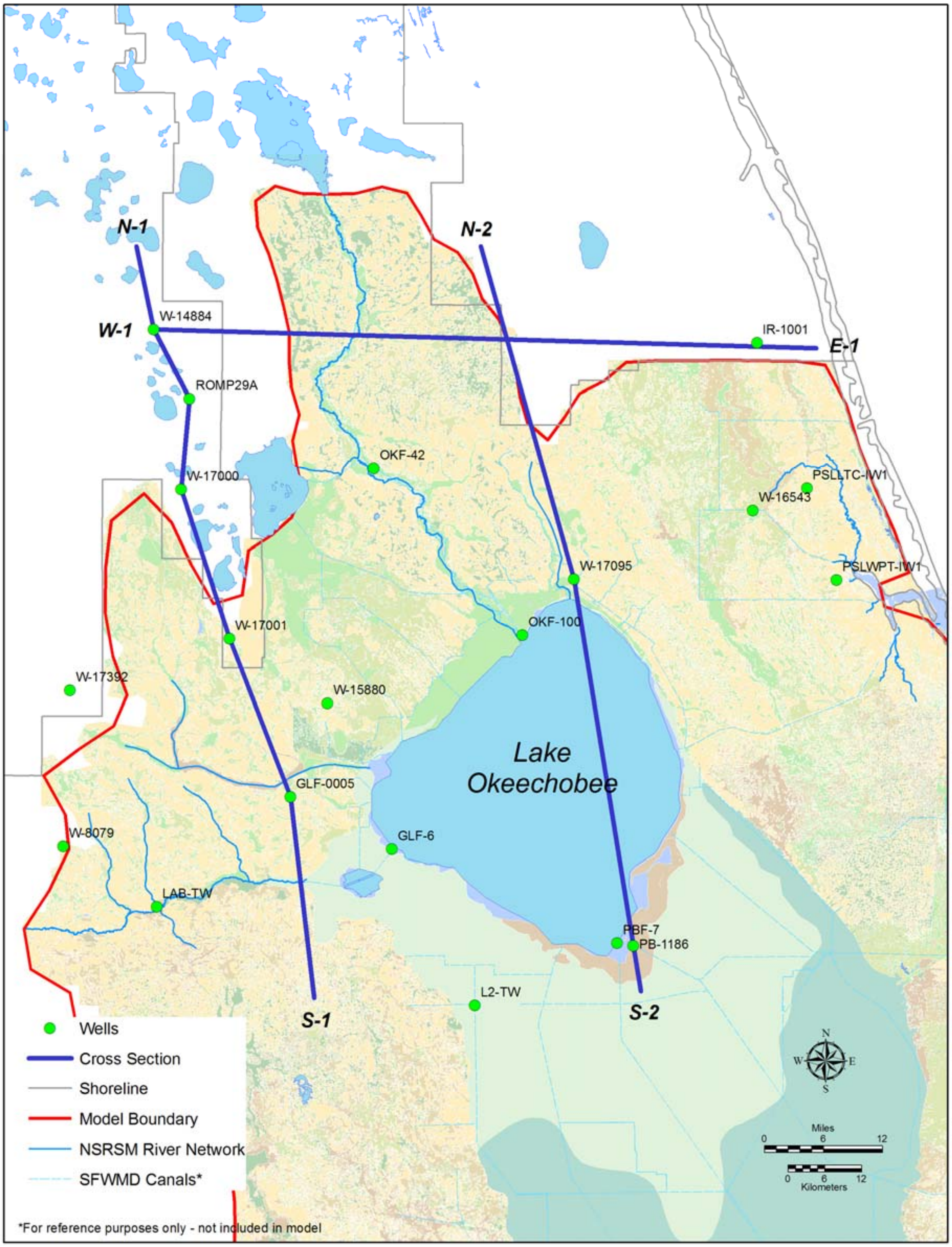

Figure E-3. Hydrostratigraphic Units Base Map.

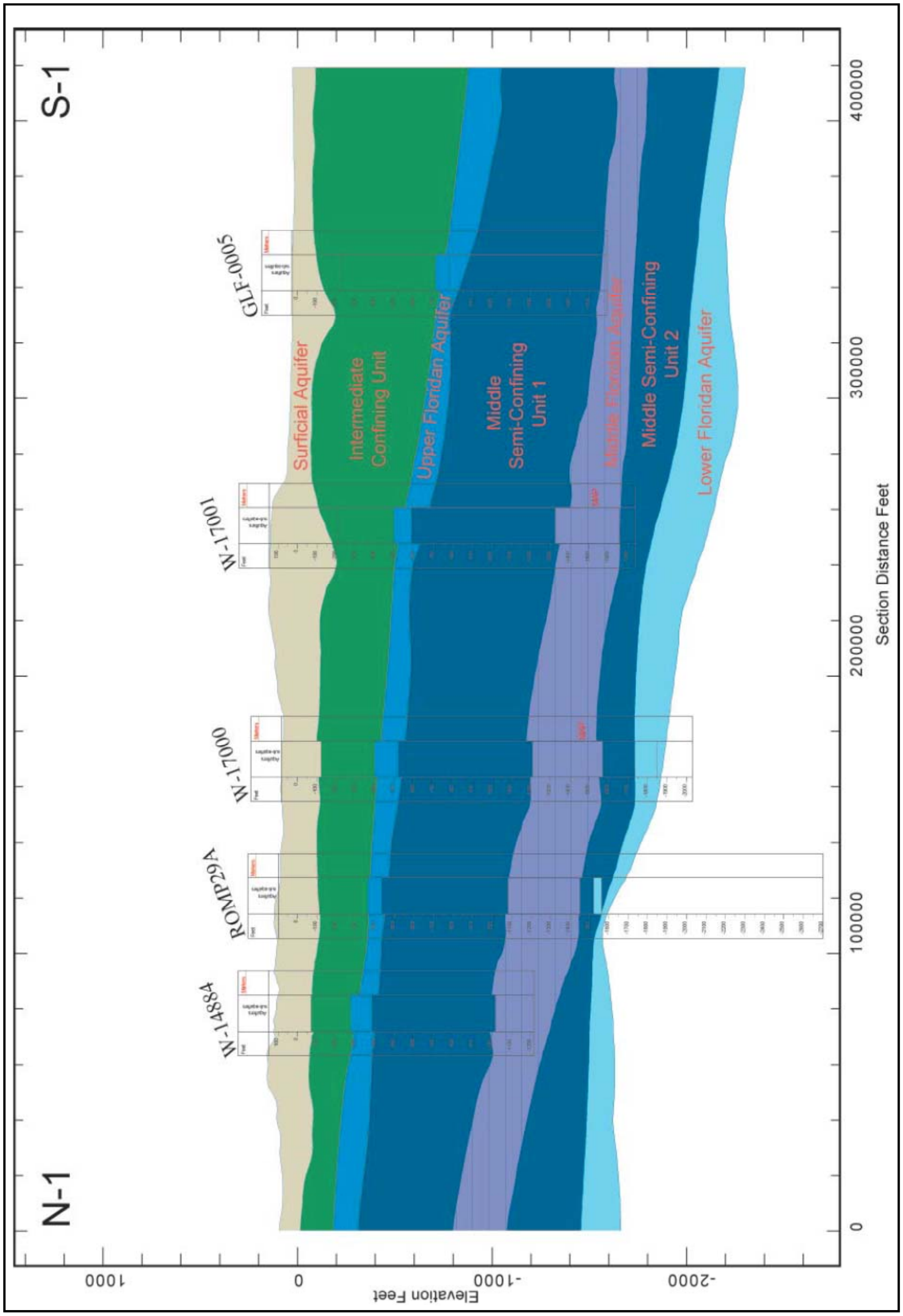

Figure E-4. Geologic and hydrologic layers and thicknesses, N-1 to S-1 transect.

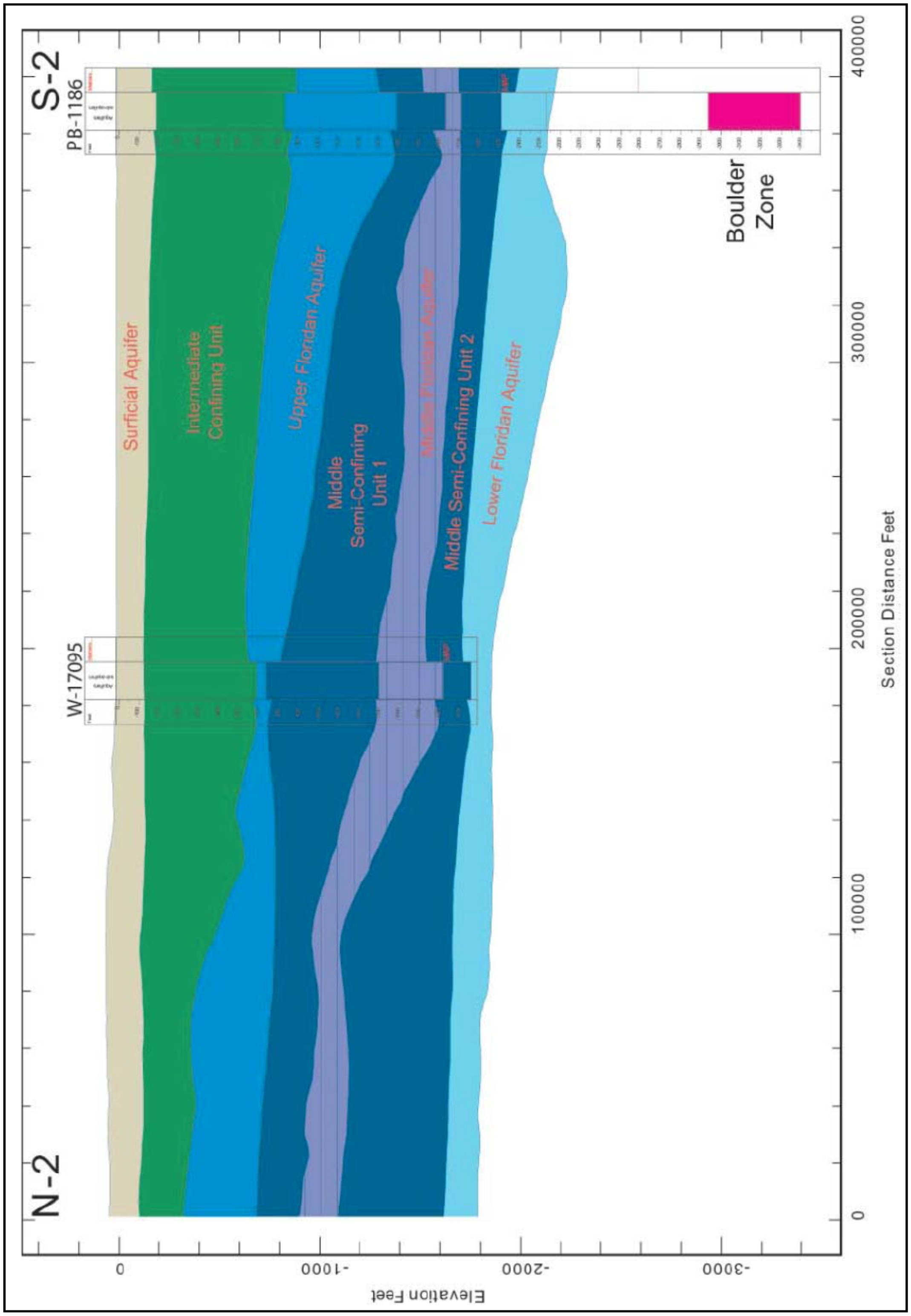

Figure E-5. Geologic and hydrologic layers and thicknesses, N-2 to S-2 transect.

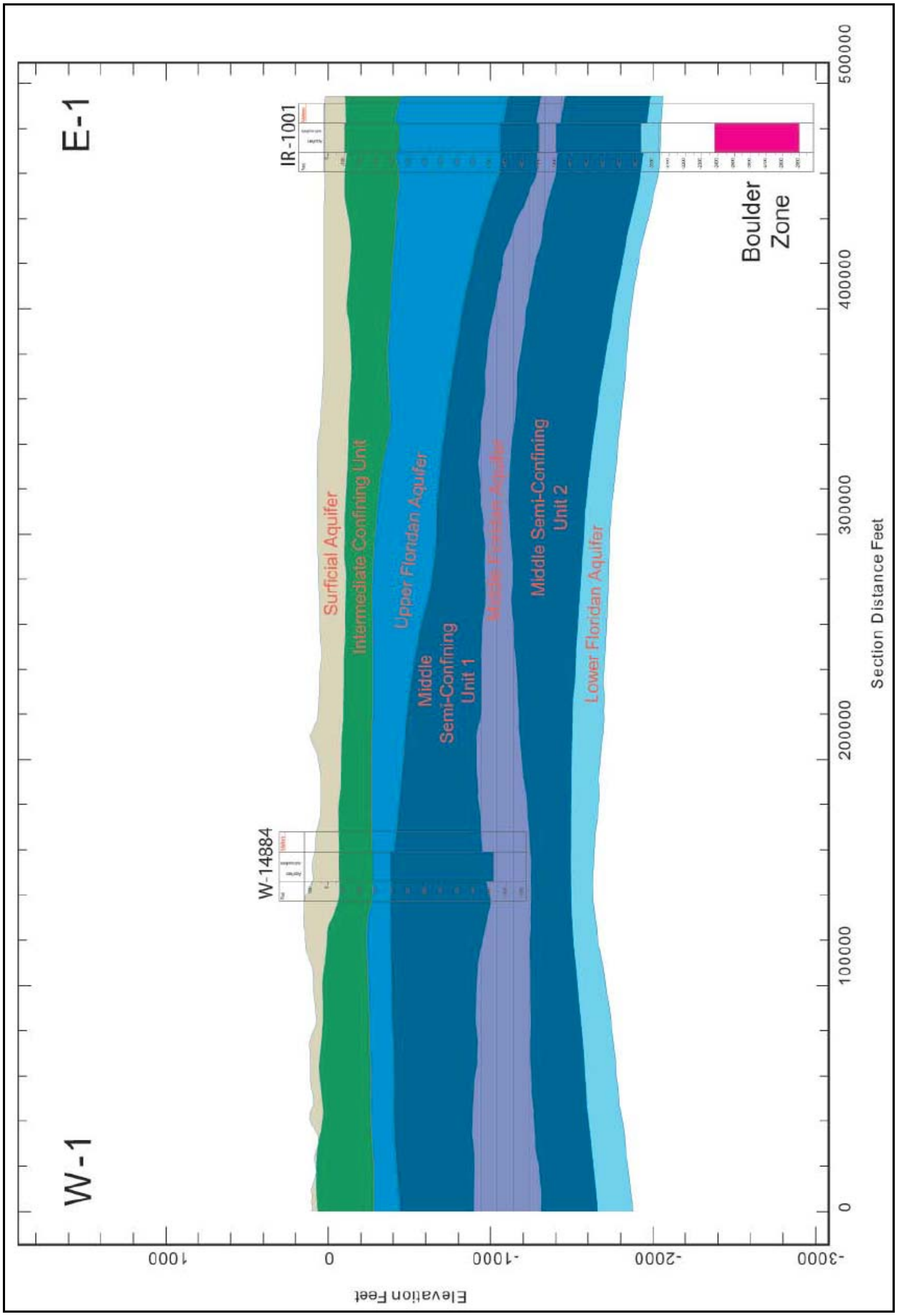

Figure E-6. Geologic and hydrologic layers and thicknesses, W-1 to E-1 transect.

E.2 TRANSMISSIVITY VALUES FOR THE NATURAL SYSTEM REGIONAL SIMULATION MODEL

A combination of data sources was used to create the transmissivity surface for the NSRSM area, including transmissivity values from DBHYDRO, hydraulic conductivity values extracted from the Lower East Coast Regional (LECsR) and Glades-Okeechobee-Highlands (GOH) models, and hydraulic conductivity values from a 1988 U.S. Geological Survey report (Fish, **1988**). The transmissivity surface map is shown in **Figure E-7**.

Sources used to determine transmissivity such as aquifer pumping tests or hydraulic conductivity require acquifer thickness. The hydrostratigraphic surface for the base of the aquifer, recently completed by Emily Richardson, was used to determine the thickness of the NSRSM. The NSRSM thickness map is shown in **Figure E-8**.

DBHYDRO transmissivity

DBHYDRO was queried to gather acceptable transmissivity values from aquifer pumping tests (APTs). Acceptable DBHYDRO transmissivity values were determined using the following methodology:

- Data from DBHYDRO was queried to give back any APTs that fell within the lateral NSRSM boundaries. This yielded 238 APTs shown in **Figure E-9**.
- This data was further reduced to only include APTs in which any part of the tested interval was above the base of the NSRSM. This yielded 107 APTs shown in **Figure E-10**.
- Ideally, the tested interval of the APT would have tested 100 percent of the NSRSM thickness and it would not have gone below the confining unit at the base of the NSRSM. However, there was not a single APT that met these criteria. Different criteria for choosing acceptable APT transmissivity results were weighed to balance the need to get the most lateral coverage and still maintain the integrity of the APT transmissivity data. After manipulating the data, the final criteria to choose acceptable values were determined: APTs that tested at least 30 percent of the NSRSM thickness and APTs that did not exceed the base of the NSRSM by more than 40 percent of the NSRSM thickness. Using these criteria 45 acceptable APTs were found within the NSRSM boundaries. These 45 APTs are shown in **Figure E-11**.

LECsR and GOH hydraulic conductivity

Other transmissivity values were derived using the hydraulic conductivity values from the LECsR and GOH models and multiplying the values by the NSRSM thickness. This was helpful near Lake Okeechobee where shallow APT data are sparse. The locations of these points are shown on **Figure E-12**.

Hydraulic conductivity values from USGS report

Despite the two aforementioned transmissivity datasets there was still a big gap in the western portions of Broward and Miami-Dade counties and the eastern portions of Collier and Monroe counties. Transmissivity values for this area were calculated by using the hydraulic conductivity values for silty-sand from Fish's USGS report (**1988**).

In this area the Biscayne aquifer to the east pinches out and the gray limestone to the west plunges under this area. Because of the higher hydraulic conductivities to the east and west of this area Viewlog assigned artificially high transmissivity values here. Eight points were chosen to create transmissivity values for this area using the hydraulic conductivity values from the USGS report and the NSRSM thickness in this area. The location of these eight points are shown in **Figure E-13**.

Viewlog Transmissivity Grid

The three sets of transmissivity values were combined to create the transmissivity grid in Viewlog, shown in **Figure E-7**. The transmissivity grid was generated by third order linear quick kriging using Viewlog. Output is available in ASCII format for easy importation to GIS in the file **RSM_WTT_042505.AGR** (SFWMD, **2012b**). A relatively coarse grid (2 mile x 2 mile) was used for the interpolation, with the objective of covering the entire model area at a scale commensurate with the separation of the data points.

All the transmissivity values used to create the grid, as well as the hydraulic conductivity points from the LECsR and GOH models, are available in a separate document: **RSM_TransData_June_2005.xls** (SFWMD, **2012c**).

Hydraulic conductivity in the Lower Kissimmee River Basin, Fisheating Creek Watershed, and a portion of the St. Lucie River Basin were estimated based on averaged values of nearby data. Estimates were within data ranges reported in literature (SFWMD, **2002;** Bradner**, 1994**).

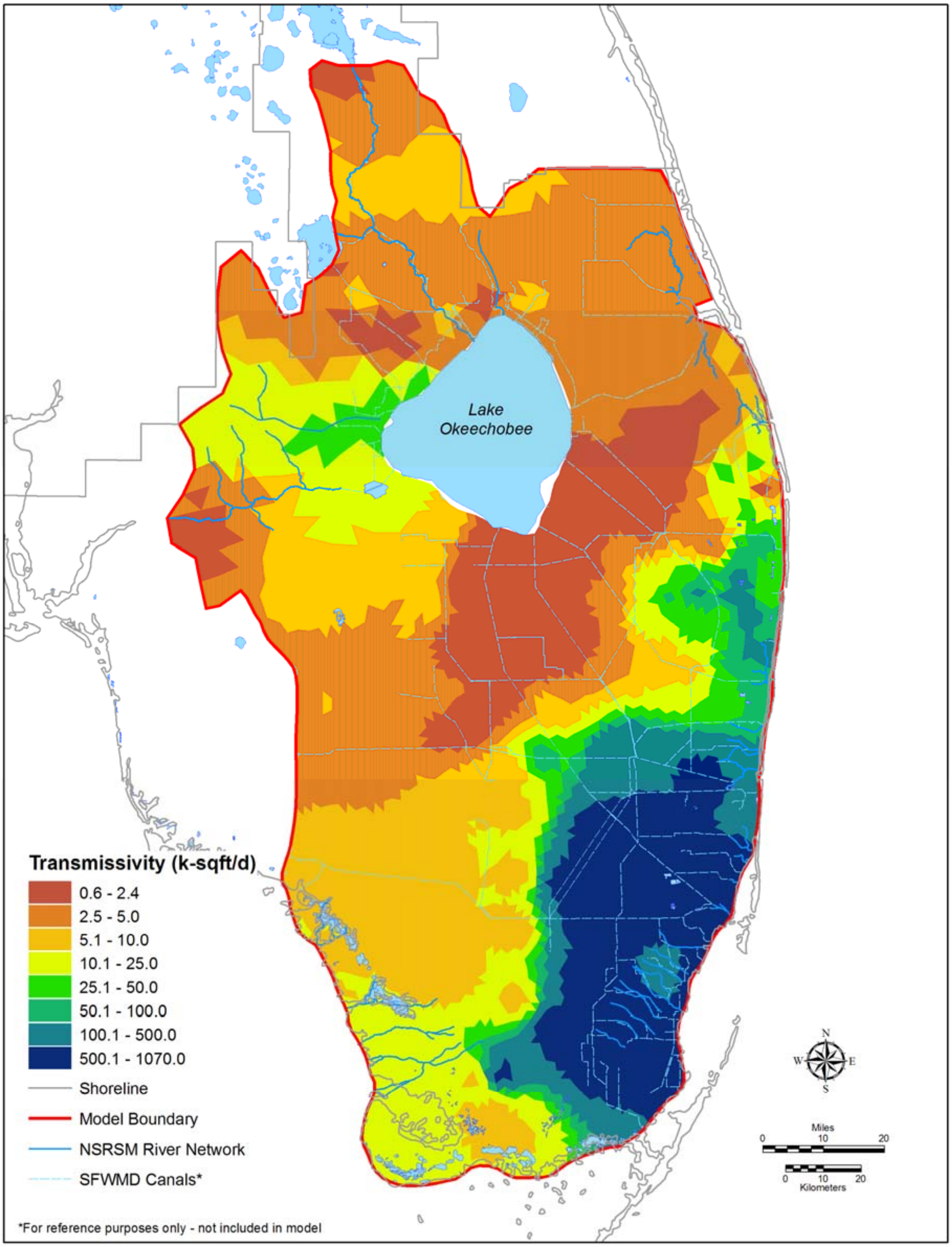

Figure E-7. Transmissivity values of the NSRSM.

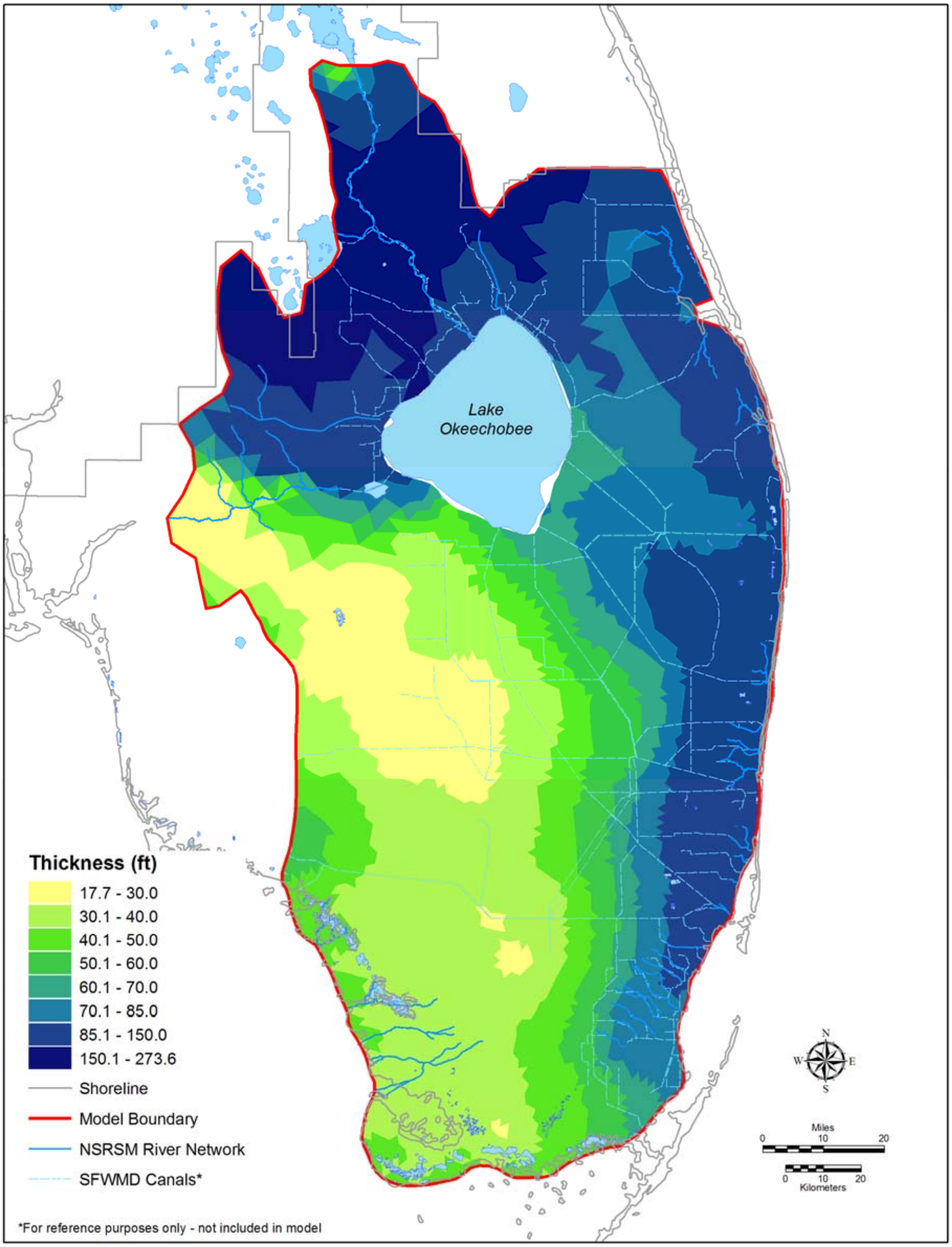

Figure E-8. Thickness of the NSRSM.

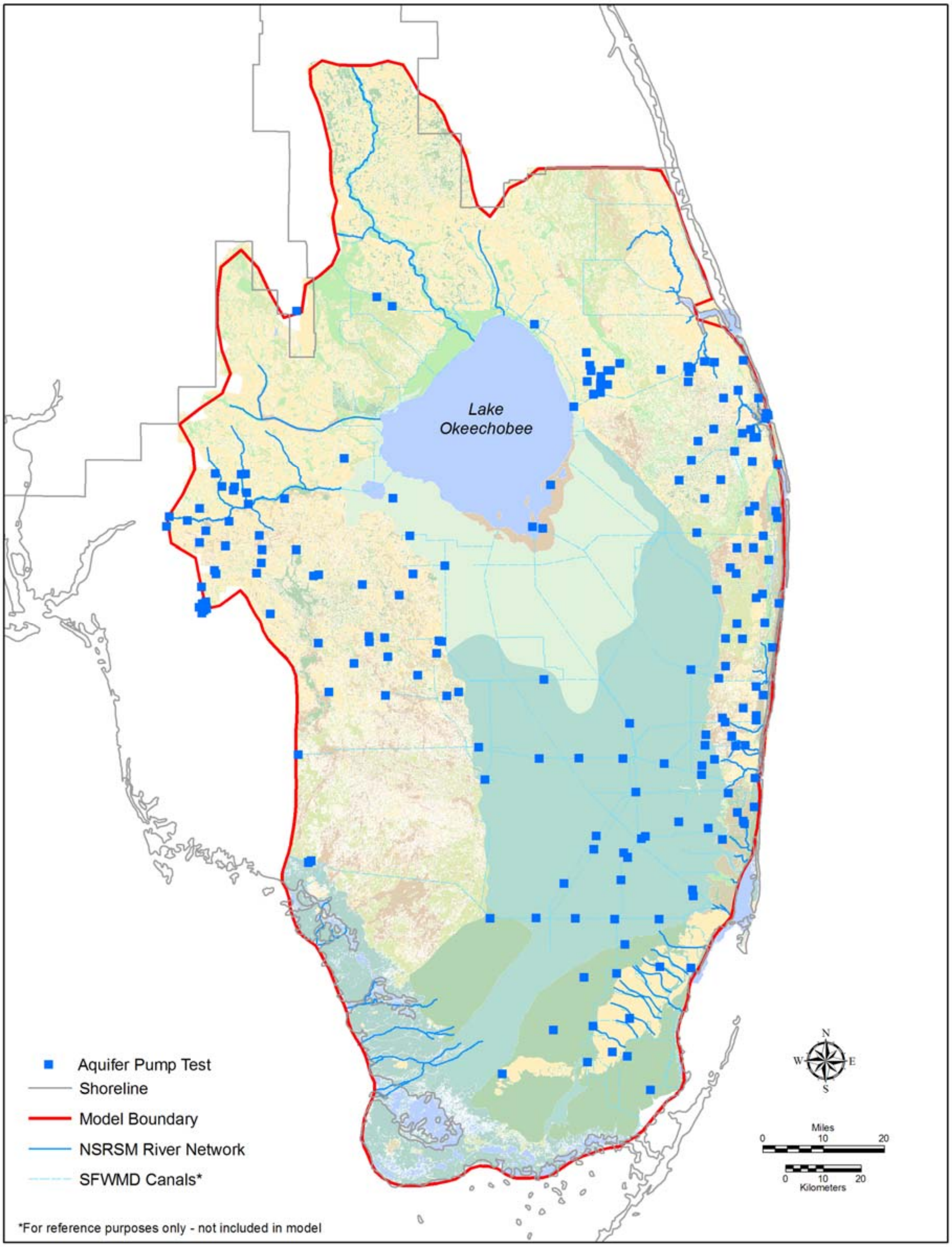

Figure E-9. DBHYDRO APTs that fit within the NSRSM.

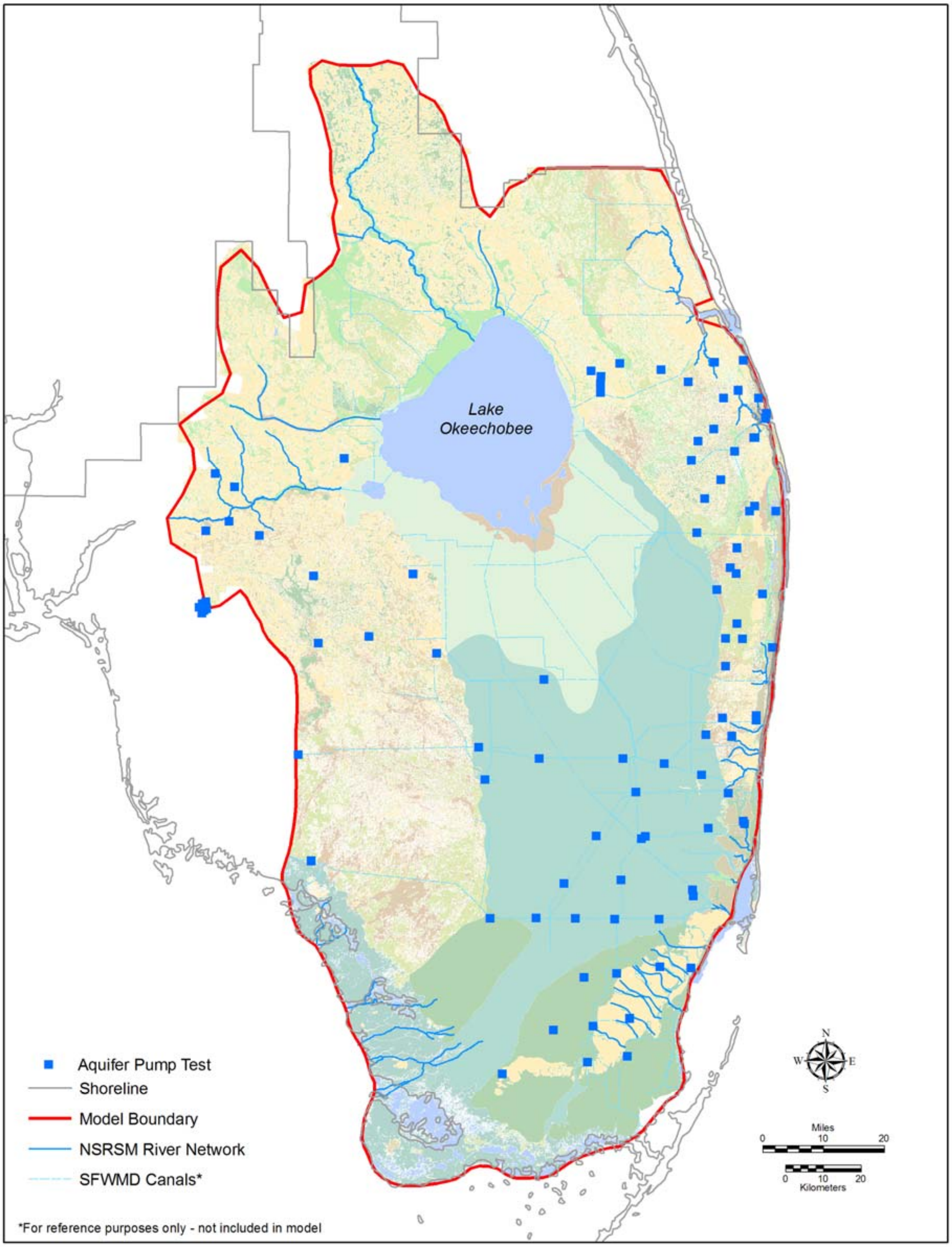

Figure E-10. DBHYDRO APTs in which any part of the tested interval was above the NSRSM base.

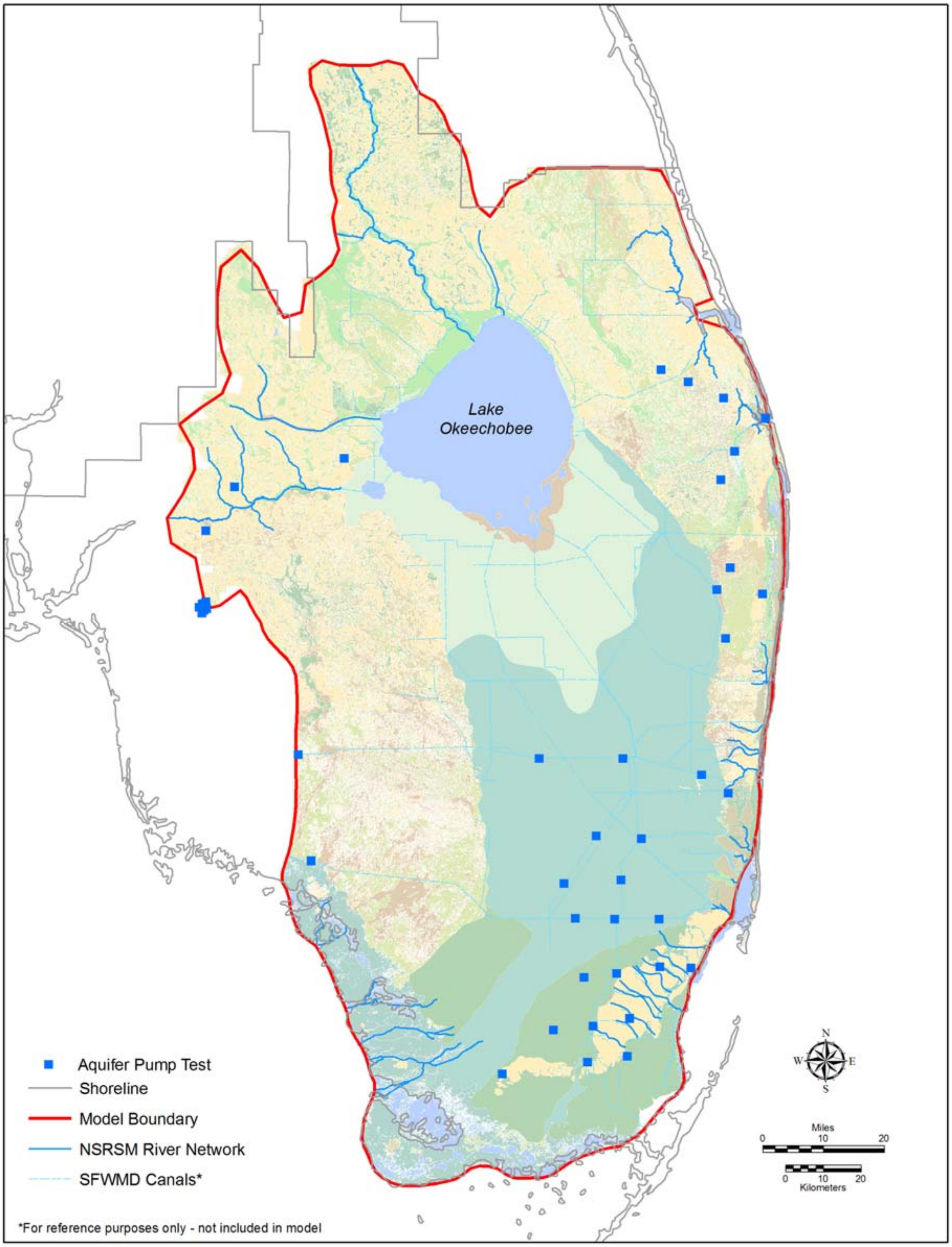

Figure E-11. DBHYDRO APTs which tested within 30–40 percent NSRSM thickness range.

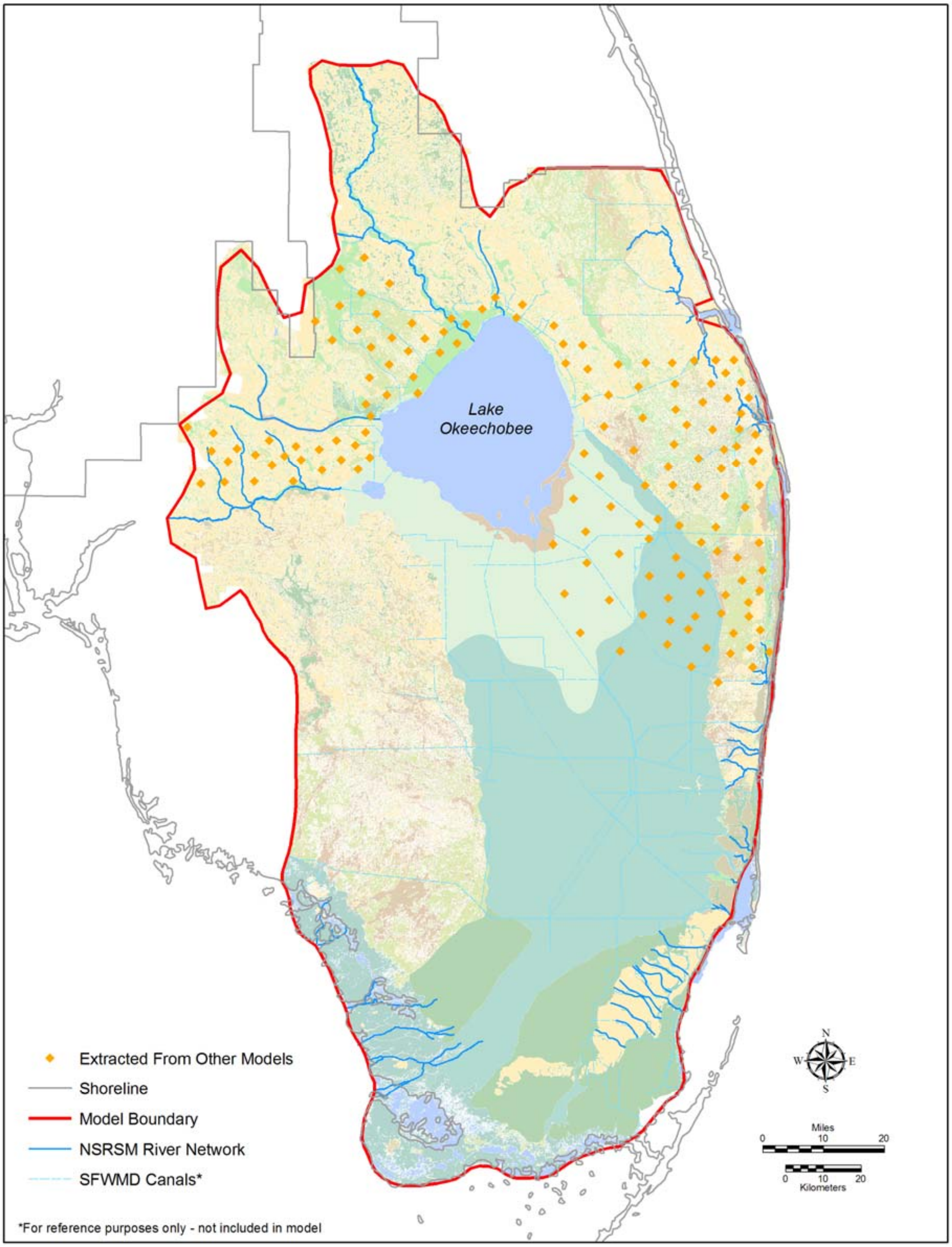

Figure E-12. Hydraulic conductivity points from the LECsR and GOH models.

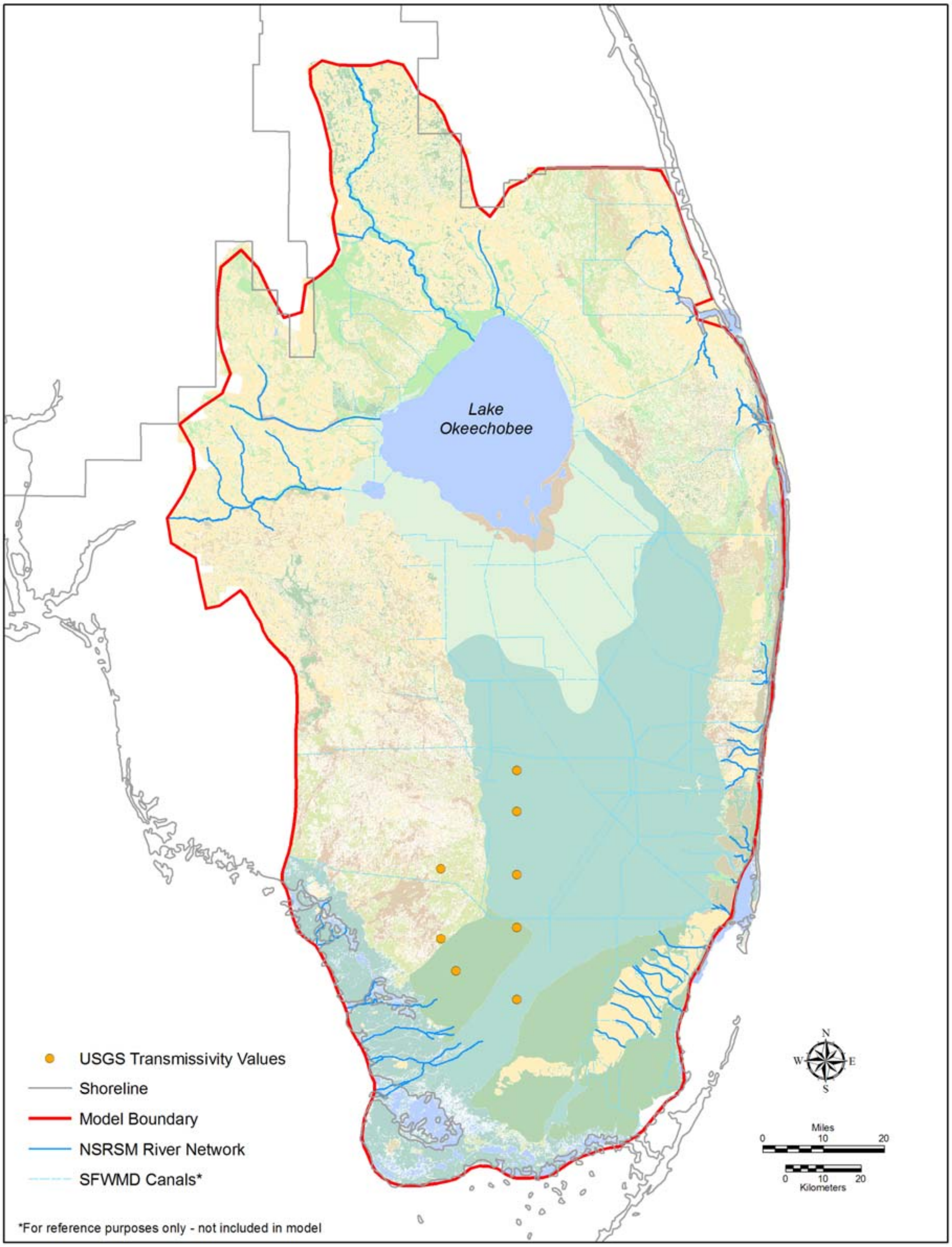

Figure E-13. Eight points chosen to create transmissivity values using USGS hydraulic conductivity values (Fish, 1988).

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Bradner, L. A., 1994, Groundwater resources of Okeechobee County, Florida: U.S. Geological Survey Water Resources Investigations Report 92-4166, 41p.

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Reese, R.S., and E. Richardson, 2008, *Synthesis of the Hydrogeologic Framework of the Floridan Aquifer System and Delineation of a Major Avon Park Permeable Zone in Central and Southern Florida*. U.S. Geological Survey Scientific Investigations Report 2007-5207, 60 p., 4 pls., plus apps (on CD).

South Florida Water Management District. 2000. *Kissimmee Basin Water Supply Plan,Appendix G Glades, Okeechobee and Highlands Model*. SFWMD, West Palm Beach, FL.

South Florida Water Management District, 2002. *Kissimmee River Groundwater Seepage Study, Phase I and II Final Report.* South Florida Water Management District, West Palm Beach, FL.

*South Florida Water Management District, 2012a. **rsm_hydrostratpoints.csv** file on internal data server

*South Florida Water Management District, 2012b. **RSM_WTT_042505.AGR** file on internal data server

*South Florida Water Management District, 2012c. **RSM_TransData_June_2005.xls** file on internal data server

*These Geology files are available on request.

Appendix F
NSRSM River Network Development

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F.1 LOWER EAST COAST RIVERS

Introduction

Historical data from surveys dating to the 1880s were used for the vertical elevation datum of the NSRSM river network (**USDOI, GLO survey data**). Most of the historical data references soundings (depth) measured with respect to mean low water (MLW). A conversion is needed between the historical data and the vertical datum National Geodetic Vertical Datum of 1929 (NGVD29) used by the NSRSM river network. National Oceanic and Atmospheric Administration (**NOAA website**) tidal stations were used to provide the 100-year linear mean sea level (MSL) trend. Using information from the NOAA tidal station, mean low water (MLW) and the NGVD29 reference, a conversion is computed.

The following rules, summarized in **Table F-1**., are used to assign the 100-year mean sea level rise to each river in the network:

- All rivers on the Lower East Coast use the Miami NOAA Station.
- All rivers on the Lower West Coast use the average of the Vaca Key and Naples NOAA stations, 0.77' for the 100-year mean sea level rise.
- The Caloosahatchee River and Lake Okeechobee 100-year mean sea level rise, 0.75', is based on personal communication (email) from James Hubbard (**2002**).

Table F-1. The 100 year linear mean sea level trend.

NSRSM Rivers	NOAA Station (NOAA, cite) or Remarks	Mean Sea Level Rise/ 100 years
Lower East Coast	Miami	0.78'
-	Vaca Key	0.85'
-	Naples	0.68'
Lower West Coast	Average of Vaca Key and Naples	0.77'
Caloosahatchee River and Lake Okeechobee	Personal communication (**Hubbard, 2002**)	0.75'

Hillsboro River

The Hillsboro River is spatially adjusted to 1940s aerial photography (**Smith et al, 1940**). The bottom elevation of the river's mouth is compared to the 1884 U.S. Coast and Geodetic Survey (**USCGS, 1884**). The datum used for sounding data from the 1884 U.S. Coast and Geodetic Survey is mean low water. To convert the data to National Geodetic Vertical Datum of 1929 (NGVD29):

NOAA Station 8722859
NGVD29 = 0.66′
MLW = 0.15′
100 yr Sea level rise = 0.78

MLW_{100} = 0.15′ – 0.78′ = -0.63′
$MLW_{NGVD29\ 100}$ = -0.63′ – 0.66′ = -1.29′
$NGVD29_{100}$ = -1.29′ – sounding

The NGVD29 for the 1884 map would be -1.29 ft. The 1884 map indicates a sounding of 5 ½ ft., or a bottom elevation of -6.79 ft. NGVD29. An additional 2.0 ft were subtracted to adjust for river network conceptualization; the adjustment was needed to account for the coarse mesh spacing along the Atlantic Coastal Ridge.

Table F-2. Hillsboro River data.

NsRiv ID	Location	Depth[1]	Bottom Elev	Bottom Width[4]	Top Width[5]
300839	Hillsboro River - Trib1	5.0	-2.66[2]	80.0	100.0
300840	Hillsboro River - Trib1	5.0	-3.63[2]	80.0	100.0
300838	Hillsboro River - Trib1	5.0	-4.65[2]	80.0	100.0
300850	Hillsboro River - Trib2	5.0	-1.0[2]	80.0	100.0
300849	Hillsboro River - Trib2	5.0	-1.98[2]	80.0	100.0
300847	Hillsboro River - Trib2	5.0	-2.97[2]	80.0	100.0
300868	Hillsboro River	5.0	2.09[2]	110.0	130.0
300867	Hillsboro River	5.0	1.37[2]	110.0	130.0
300865	Hillsboro River	5.0	0.4[2]	110.0	130.0
300863	Hillsboro River	5.0	-0.77[2]	110.0	130.0
300861	Hillsboro River	5.0	-1.87[2]	110.0	130.0
300859	Hillsboro River	5.0	-2.92[2]	110.0	130.0
300858	Hillsboro River	5.0	-3.9[2]	110.0	130.0
300857	Hillsboro River	5.0	-4.76[2]	110.0	130.0
300331	Hillsboro River	5.0	-5.76[2]	150.0	170.0
300330	Hillsboro River	5.0	-8.79[3]	150.0	170.0

Endnote 2. An average depth of 5 ft.is used. [1]
Relied on best professional judgment. [2]
Value from 1884 U.S. Coast and Geodetic Survey was used. [3]
Calculated from depth, assumed side slope of 2.0 and top width.[4]
Estimated using Digital Orthophoto Quarter Quads (DOQQ) width ranges. [5]

Cypress Creek

The Cypress Creek is spatially adjusted to the 1940s aerial photographs (**Smith et al, 194**). There was no data from the U.S. Coast and Geodetic Survey. A bottom elevation at the downstream segment was assumed to be -7.3 NGVD29.

Table F-3. Cypress Creek data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[3]	Top Width[4]
300809	Cypress Creek	3.5	-5.68	151.0	165.0
300810	Cypress Creek	3.5	-5.93	151.0	165.0
300808	Cypress Creek	3.5	-6.18	151.0	165.0
300806	Cypress Creek	3.5	-6.45	151.0	165.0
300272	Cypress Creek	3.5	-6.73	151.0	165.0
300271	Cypress Creek	3.5	-7.0	151.0	165.0
300270	Cypress Creek	3.5	-7.3	151.0	165.0

Endnote 7. Depth estimated at 3 ft.to 4 ft., using mean of 3.5 ft. [1]
Relied on best professional judgment. [2]
Calculated from depth, assumed side slope of 2.0 and top width. [3]
Endnote 6. Surveyed widths range from 132 ft. and 198 ft., using mean of 165 ft. [4]

Middle River

The north and south forks of the Middle River uses width and general location from the GLO (**USDOI, GLO survey data**) and is spatially adjusted to the Digital Orthophoto Quarter Quads (DOQQ; USGS, **DOQQs**). The main river uses data, bottom and width, from the 1884 U.S. Coast and Geodetic Survey (**USCGS, 1884**). This portion is also spatially adjusted to the DOQQ. The datum used for sounding data from the 1884 U.S. Coast and Geodetic Survey is mean low water. To convert the data to vertical datum NGVD29:

NOAA Station 8722859
NGVD29 = 0.69′
MLW = 0.16′
100 yr Sea level rise = 0.78′

MLW_{100} = 0.16′ – 0.78′ = -0.62′
$MLW_{NGVD29\ 100}$ = -0.62′ – 0.69′ = -1.31′
$NGVD29_{100}$ = -1.31′ – sounding

The NGVD29 for the 1884 map would be -1.31 ft. The 1884 map indicates a sounding of 10 ft., or a bottom elevation of -11.31 ft. NGVD29. An additional 1.0 foot was subtracted to adjust for river network conceptualization. The north fork and south fork bottom elevation were obtained from the upstream reach of the main channel. U.S. Coast and Geodetic Survey depth information is only available for main segment of river.

Table F-4. Middle River data.

NsRiv ID	Location	Depth	Bottom Elev	Bottom Width[7]	Top Width
300789	Middle River – North Fork	4.0[1]	-5.22[3]	44.0	60.0[4]
300790	Middle River – North Fork	4.0[1]	-6.0[3]	64.0	80.0[4]
300791	Middle River – North Fork	4.0[1]	-6.8[3]	84.0	100.0[4]
300792	Middle River – North Fork	4.0[1]	-7.53[3]	84.0	100.0[5]
300259	Middle River – North Fork	4.0[1]	-8.33[3]	184.0	200.0[5]
300260	Middle River – North Fork	4.0[1]	-9.15[3]	224.0	240.0[5]
300261	Middle River – North Fork	4.0[1]	-9.87[3]	224.0	240.0[5]
300797	Middle River – South Fork	4.0[1]	-5.17[3]	44.0	60.0[4]
300798	Middle River – South Fork	4.0[1]	-5.89[3]	64.0	80.0[4]
300795	Middle River – South Fork	4.0[1]	-6.62[3]	84.0	100.0[4]
300796	Middle River – South Fork	4.0[1]	-7.33[3]	144.0	160.0[5]
300263	Middle River – South Fork	4.0[1]	-8.1[3]	144.0	160.0[5]
300264	Middle River – South Fork	4.0[1]	-8.89[3]	144.0	160.0[5]
300265	Middle River – South Fork	4.0[1]	-9.74[3]	144.0	160.0[5]
300266	Middle River	6.0[2]	-10.69[2]	126.0	150.0[6]
300267	Middle River	8.0[2]	-11.53[2]	268.0	300.0[6]
300268	Middle River	10.0[2]	-12.31[2]	460.0	500.0[6]

Endnote 12. An estimated depth of 4 ft.is used. [1]
1884 U.S. Coast and Geodetic Survey. Depths are within range specified in Endnote 11. [2]
Relied on best professional judgment. [3]
Widths were tapered according to U.S. Coast and Geodetic Survey. [4]
Endnote 11, 158 ft.width for south fork. There were 2 surveyed widths of the north fork 243 ft. and 194 ft. A composite width of north fork, south fork, and GLO were used. [5]
Composite value of 1884 U.S. Coast and Geodetic survey and Endnote 11. [6]
Calculated from depth, assumed side slope of 2.0 and top width. [7]

New River

The north and south forks of the New River uses width and general location from the GLO (USDOI, **GLO survey data**) and is spatially adjusted to the DOQQ (USGS, **DOQQs**). Two segments from the New River have sounding data from the 1884 U.S. Coast and Geodetic Survey (USCGS, **1884**). The datum used for sounding data from the 1884 U.S. Coast and Geodetic Survey is mean low water. To convert the data to vertical datum NGVD29:

NOAA Station 8722859
NGVD29 = 0.69′
MLW = 0.16′
100 yr Sea level rise = 0.78′

MLW_{100} = 0.16′ – 0.78′ = -0.62′
$MLW_{NGVD29\ 100}$ = -0.62′ – 0.69′ = -1.31′
$NGVD29_{100}$ = -1.31′ – sounding

Table F-5. New River data.

NsRiv ID	Location	Depth	Bottom Elev	Bottom Width[8]	Top Width
301004	New River - North Fork	10.0[1]	-6.76[3]	90.0	130.0[4]
300254	New River - North Fork	10.0[1]	-8.26[3]	110.0	150.0[4]
300253	New River - North Fork	10.0[1]	-8.54[3]	160.0	200.0[4]
300252	New River - North Fork	10.0[1]	-9.09[3]	150.0	190.0[4]
300251	New River - North Fork	10.0[1]	-9.67[3]	200.0	240.0[4]
300250	New River - South Fork	10.0[1]	-6.17[3]	100.0	140.0[5]
300249	New River - South Fork	10.0[1]	-8.15[3]	240.0	280.0[5]
300248	New River - South Fork	10.0[1]	-8.67[3]	240.0	280.0[5]
300247	New River - South Fork	10.0[1]	-9.15[3]	240.0	280.0[5]
300246	New River - South Fork	10.0[1]	-9.73[3]	250.0	290.0[5]
300374	New River	10.0[2]	-10.31[3]	250.0	290.0[6]
300375	New River	10.0[2]	-10.77[3]	250.0	290.0[6]
300823	New River	10.0[2]	-11.05[3]	300.0	340.0[7]
300824	New River	10.0[2]	-11.31[2]	300.0	340.0[7]

Endnote 17. South Fork having a depth varying from 3 ft.to 20 ft. This depth was also applied to the north fork. [1]
Average sounding depths from 1884 U.S. Coast and Geodetic Survey used for the main river segment. [2]
Relied on best professional judgment. [3]
Endnote 16. North Fork widths range from 66 ft.to 350 ft. Values used are a composite from Endnote 16, estimated using DOQQ, and Williams 1870 T50 R42. [4]
Endnote 16. South Fork widths range from 150 ft.to 450 ft. Values used are a composite from C.M. McVoy (Endnote 16), DOQQ, and Williams 1870 T50 R42. [5]
Endnote 16. Within range of widths (Williams 1870 T50 R42). [6]
Within range of widths from DOQQ, and U.S. Coast and Geodetic Survey. [7]
Calculated from depth, assumed side slope of 2.0 and top width. [8]

Snake Creek

The north and south forks of Snake Creek uses width and general location from the GLO (USDOI, **GLO survey data**) and is spatially adjusted to the DOQQ (USGS, **DOQQs**). Two segments from Snake Creek have sounding data from the 1884 U.S. Coast and Geodetic Survey. Remaining depths were adjusted from the 1884 soundings. The datum used for sounding data from the 1884 U.S. Coast and Geodetic Survey (USCGS, **1884**) is mean low water. To convert the data to vertical datum NGVD29:

NOAA Station 8723044
NGVD29 = 0.34′
MLW = 0.14′
100 yr Sea level rise = 0.78′

MLW_{100} = 0.14′ – 0.78′ = -0.64′
$MLW_{NGVD29\ 100}$ = -0.64′ – 0.34′ = -0.98′
$NGVD29_{100}$ = -0.98′ – sounding

NGVD29 for the 1884 map would be -0.98 ft. The 1884 map indicates a sounding of 6 ft., or a bottom elevation of -6.98 ft. NGVD29. An additional 4.0 ft. was subtracted to adjust for river network conceptualization.

Table F-6. Snake Creek data.

NsRiv ID	Location	Depth	Bottom Elev	Bottom Width[6]	Top Width
300240	Big Snake Creek	5.0[1]	-6.5[3]	40.0	60.0[4]
300239	Big Snake Creek	5.0[1]	-6.6[3]	40.0	60.0[4]
300238	Big Snake Creek	5.0[1]	-6.7[3]	40.0	60.0[4]
300237	Big Snake Creek	5.0[1]	-6.8[3]	80.0	100.0[4]
300672	Big Snake Creek	5.0[1]	-10.9[3]	160.0	180.0[4]
300245	Little Snake Creek	5.0[1]	-6.5[3]	80.0	100.0[5]
300244	Little Snake Creek	5.0[1]	-6.6[3]	130.0	150.0[5]
300243	Little Snake Creek	5.0[1]	-6.7[3]	180.0	200.0[5]
300242	Little Snake Creek	5.0[1]	-6.8[3]	180.0	200.0[5]
300241	Little Snake Creek	5.0[1]	-6.9[3]	180.0	200.0[5]
300235	Snake Creek	6.0[2]	-10.98[2]	200.0	224.0[2]
300234	Snake Creek	6.0[2]	-10.98[2]	200.0	224.0[2]

Endnote 21. Depth of 5 ft.was used. [1]
Within range of 1884 U.S. Coast and Geodetic Survey. [2]
Relied on best professional judgment. [3]
Endnote 20. Big Snake Creek width was 66 ft. and 176 ft. Values used are composite of Endnote 20 and estimated using DOQQ. [4]
Endnote 20, Little Snake Creek width was 132 ft. along. Values used are composite of Endnote 20 and average widths estimated using DOQQ. [5]
Calculated from depth, assumed side slope of 2.0 and top width. [6]

Arch Creek

The Arch Creek, including the south fork, uses width and general location from the GLO (USDOI, **GLO survey data**). It could not be spatially adjusted to the DOQQ (USGS, **DOQQs**) due to development. The datum used for sounding data from the 1884 U.S. Coast and Geodetic Survey (USCGS, **1884**) is mean low water. To convert the data to vertical datum NGVD29:

NOAA Station 8723089
NGVD29 = 0.55′
MLW = 0.13′
100 yr Sea level rise = 0.78′

MLW_{100} = 0.13′ – 0.78′ = -0.65′
$MLW_{NGVD29\ 100}$ = -0.65′ – 0.55′ = -1.20′
$NGVD29_{100}$ = -1.20′ – sounding

The NGVD29 for the 1884 map would be -1.20 ft. A nearby sounding at the mouth of Arch Creek from the 1884 U.S. Coast and Geodetic Survey has a depth of 5 ft. or -6.20 ft. NGVD29. An additional 6.0 ft. was subtracted to adjust for river network conceptualization.

Table F-7. Arch Creek data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[3]	Top Width[4]
300233	Arch Creek	10.0	-6.3	350.0	390.0[5]
300232	Arch Creek	10.0	-7.35	350.0	390.0[5]
300231	Arch Creek	10.0	-8.45	100.0	140.0[4]
300773	Arch Creek	10.0	-10.73	100.0	140.0[4]
300774	Arch Creek	10.0	-12.0	100.0	140.0[4]

Endnote 25. Estimated depth of 20 ft., but should not be considered the average. A depth of 10 ft.is based on best professional judgment. [1]
Relied on best professional judgment based on U.S. Coast and Geodetic Survey point 6.20 ft. NGVD29 at segment 300774. [2]
Calculated from depth, assumed side slope of 2.0 and top width. [3]
The surveyed widths of the 2 forks ranged from 99 ft.to 132 ft.
Values used are composite of Endnote 24 and GLO. [4]
Estimated width. [5]

Little River

The Little River uses width and general location from the GLO (USDOI, **GLO survey data**) and is spatially adjusted to the DOQQ (USGS, **DOQQs**). The datum used for sounding data from the 1876 U.S. Coast and Geodetic Survey (USCGS, **1876**) is mean low water. To convert the data to vertical datum NGVD29:

```
NOAA Station 8723165
NGVD29 = 0.74'
MLW = 0.14'
100 yr Sea level rise = 0.78'
```

MLW_{100} = 0.14′ – 0.78′ = -0.64′
$MLW_{NGVD29\ 100}$ = -0.64′ – 0.74′ = -1.38′
$NGVD29_{100}$ = -1.38′ – sounding

The NGVD29 for the 1876 map would be -1.38 ft. The 1876 U.S. Coast and Geodetic Survey has one sounding at the mouth of the river of 1.5 ft. or -2.88 ft. NGVD29. An additional 2.0 ft. was subtracted to adjust for river network conceptualization.

Table F-8. Little River data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[3]	Top Width[4]
300329	Little River	4.0	-4.7	50.0	66.0
300328	Little River	4.0	-4.88	50.0	66.0

Endnote 30. Depths ranged from 2 ft.to 6 ft; used an average of 4 ft. [1]
Relied on best professional judgment. [2]
Calculated from depth, assumed side slope of 2.0 and top width. [3]
Endnote 29. Predrainage measurements are 66 ft. [4]

Miami River

The Miami River uses width and general location from the GLO (USDOI**, GLO survey data**) and is spatially adjusted to the DOQQ (USGS, **DOQQs**). An 1876 U.S. Coast and Geodetic Survey (USCGS, **1876**) has one sounding at the mouth of the river of 6.75 ft. or -8.3 ft. NGVD29. The datum used for sounding data from the 1876 U.S. Coast and Geodetic Survey is mean low water. To convert the data to vertical datum NGVD29:

```
NOAA Station 8723165
NGVD29 = 0.74′
MLW = 0.14′
100 yr Sea level rise = 0.78′
```

MLW_{100} = 0.14′ – 0.78′ = -0.64′
$MLW_{NGVD29\ 100}$ = -0.64′ – 0.74′ = -1.38′
$NGVD29_{100}$ = -1.38′ – sounding

The NGVD29 for the 1876 map would be -1.38 ft. The 1876 U.S. Coast and Geodetic Survey has one sounding at the mouth of the river of 6.75 ft. or -8.3 ft. NGVD29. An additional 2.4 ft. was subtracted to adjust for river network conceptualization.

Table F-9. Miami River data.

NsRiv ID	Location	Depth[1]	Bottom Elev[1]	Bottom Width[3]	Top Width[4]
301143	Miami River - North Fork	2.0	7.3	1.0	9.0
301144	Miami River - North Fork	4.0	7.1	10.0	26.0
301145	Miami River - North Fork	4.0	6.9	15.0	31.0
301146	Miami River - North Fork	4.0	6.7	35.0	51.0
301147	Miami River - North Fork	4.0	6.5	72.0	88.0
301148	Miami River - North Fork	4.0	6.3	72.0	88.0
301149	Miami River - North Fork	4.0	6.1	84.0	100.0
301150	Miami River - North Fork	4.0	5.9	84.0	100.0
301151	Miami River - North Fork	4.0	5.7	84.0	100.0
301152	Miami River - North Fork	4.0	5.5	84.0	100.0
301153	Miami River - North Fork	4.0	5.3	84.0	100.0
301154	Miami River - North Fork	4.0	5.1	104.0	120.0
301100	Miami River - North Fork	4.0	4.9	104.0	120.0
301155	Miami River - North Fork	4.0	4.7	104.0	120.0
301157	Miami River - South Fork	2.0	6.5	1.0	9.0
301158	Miami River - South Fork	2.0	6.3	10.0	26.0
301159	Miami River - South Fork	4.0	6.1	25.0	41.0
301160	Miami River - South Fork	4.0	5.9	50.0	66.0
301161	Miami River - South Fork	4.0	5.7	112.0	128.0

301162	Miami River – South Fork	4.0	5.5	112.0	128.0
301163	Miami River – South Fork	4.0	5.3	112.0	128.0
301164	Miami River – South Fork	4.0	5.1	112.0	128.0
301166	Miami River – South Fork	4.0	4.9	112.0	128.0
301167	Miami River – South Fork	4.0	4.7	112.0	128.0
301124	Miami River – Tributary	2.0	4.3	1.0	9.0
301125	Miami River – Tributary	4.0	4.1	10.0	26.0
301126	Miami River – Tributary	4.0	3.9	25.0	41.0
301127	Miami River – Tributary	4.0	3.7	50.0	66.0
301128	Miami River – Tributary	4.0	3.5	104.0	120.0
301129	Miami River – Tributary	4.0	3.3	104.0	120.0
301130	Miami River – Tributary	4.0	3.1	104.0	120.0
301131	Miami River – Tributary	4.0	2.9	104.0	120.0
301102	Miami River – Tributary	4.0	2.7	104.0	120.0
301132	Miami River – Tributary	4.0	2.5	104.0	120.0
301133	Miami River	6.0	-6.5	176.0	200.0
301134	Miami River	6.0	-6.7	176.0	200.0
301135	Miami River	6.0	-6.9	176.0	200.0
301136	Miami River	6.0	-7.1	176.0	200.0
301137	Miami River	6.0	-7.3	176.0	200.0
301138	Miami River	6.0	-7.5	176.0	200.0
301139	Miami River	6.0	-7.7	176.0	200.0
301140	Miami River	6.0	-7.9	176.0	200.0
301141	Miami River	6.0	-8.1	176.0	200.0
301101	Miami River	6.0	-8.3	176.0	200.0
301142	Miami River	6.0	-8.5	176.0	200.0
301114	Miami River	6.0	-8.7	176.0	200.0
301115	Miami River	6.0	-8.9	176.0	200.0
301116	Miami River	6.0	-9.1	176.0	200.0
301117	Miami River	6.0	-9.3	176.0	200.0
301118	Miami River	6.0	-9.5	176.0	200.0
301119	Miami River	6.0	-9.7	176.0	200.0
301120	Miami River	6.0	-9.9	176.0	200.0
301121	Miami River	6.0	-10.1	176.0	200.0
301122	Miami River	6.0	-10.3	176.0	200.0
301103	Miami River	6.0	-10.5	176.0	200.0
301123	Miami River	6.75[2]	-10.7[2]	173.0	200.0

Width based on best professional judgment. [1]
Value from 1876 U.S. Coast and Geodetic Survey. For bottom elevation, an additional 2.3 ft.was subtracted to adjust for river network conceptualization. [2]
Calculated from depth, assumed side slope of 2.0 and top width. [3]
Endnote 34. Below confluence width of 198 ft., length varies from 200 ft.to 300 ft., and at locations narrow as 130 ft. Fork widths from 0 ft.to 150 ft. (GLO). Values used are composite of GLO and Endnote 34. [4]

Black Creek

The Black Creek uses width and spatial location from the DOQQ (USGS**, DOQQs**). No data was available from the GLO (USDOI**, GLO survey data**). An 1852 U.S. Coast and Geodetic Survey (USCGS**, 1852**) have one sounding at the mouth of the river of 3.0 ft. or -4.08 ft. NVGD. The datum used for sounding data from the 1852 U.S. Coast and Geodetic Survey is mean low water. To convert the data to vertical datum NGVD29:

NOAA Station 8723423
NGVD29 = 0.42′
MLW = 0.12′
100 yr Sea level rise = 0.78′

MLW_{100} = 0.12′ – 0.78′ = -0.66′
$MLW_{NGVD29\ 100}$ = -0.66′ – 0.42′ = -1.08′
$NGVD29_{100}$ = -1.08′ – sounding

Table F-10. Black Creek data.

NsRiv ID	Location	Depth	Bottom Elev	Bottom Width[4]	Top Width[5]
300354	Black Creek	3.0[1]	-1.5[3]	88.0	100.0
300355	Black Creek	3.0[1]	-1.75[3]	88.0	100.0
300356	Black Creek	3.0[1]	-2.0[3]	88.0	100.0
300357	Black Creek	3.0[1]	-2.25[3]	88.0	100.0
300358	Black Creek	3.0[1]	-2.5[3]	88.0	100.0
300359	Black Creek	3.0[1]	-2.75[3]	88.0	100.0
300360	Black Creek	3.0[1]	-3.0[3]	88.0	100.0
300370	Black Creek	3.0[1]	-3.25[3]	88.0	100.0
300371	Black Creek	3.0[1]	-3.5[3]	88.0	100.0
300372	Black Creek	3.0[1]	-3.75[3]	88.0	100.0
300373	Black Creek	3.0[2]	-4.08[2]	88.0	100.0

Endnote 7, for Cypress Creek, uses depth estimates of 3 ft.to 4 ft. The smaller depth is used since it corresponds to estimates from U.S. Coast and Geodetic Survey. [1]
Values used from 1852 U.S. Coast and Geodetic Survey. [2]
Relied on best professional judgment. [3]
Calculated from depth, assumed side slope of 2.0 and top width[4]
Values estimated using DOQQ. [5]

Endnotes from Predrainage Surface Hydrology of the Eastern Everglades, Coastal Ridge, and the Coastal Rivers

C. McVoy, 2000 (unpublished)

Endnotes

[1] Hillsboro River width shown on plat map (Williams 1870-T48 R43) appears similar to the New River (Williams 1870-T50 R42), so estimate based on New River width. Surveyed widths from field notes for plat would be a better source, but field notes for this township were not presently available.

[2] Hillsboro River depth (average for river) estimated from description of 6 feet deep at the mouth (Williams 1837) and from Cooley's 1851 description of the Boca Ratones River (a branch of the Hillsboro) having "an average on this section of 5 feet in depth" (Knetsch 1989). In addition, the presence of multiple upstream branches suggested deeper rather than shallower.

[3] Hillsboro River headwater elevation estimated from USGS (1983a-Boca) (7-12 feet), using pre-drainage estimates of location of headwaters (Williams 1870-T47 R43; Austin *et al.* 1977), and assumption of 2-3 feet of peat subsidence. Peat subsidence estimated from soil types and vegetation present in 1940s (Jones et al. 1948). For comparison, Austin *et al.* (1977) reported pine flatwoods in the area at 17 feet and the swamp system at 14-15 ft.

[4] Hillsboro River length is less clear than for other rivers as multiple branches intergraded with an extensive network of cypress swamps, which in turned drained from the Everglades (Vignoles 1823; Williams 1837; Austin *et al.* 1977). A northward running fork was the longest, about 11 miles long (Williams 1870-T47 R43, Williams 1870-T48 R43). The several westward branches appear to have been about 6-7 miles long from head to river mouth (Williams 1870-T47 R43, Williams 1870-T48 R43).

[5] Hillsboro River slope: "...the rush of water through this narrow channel [one of branches of the Hillsboro River] is very great, the current driving with a velocity capable of giving motion to the largest [water] wheels, and upon it several saw-mills might work with advantage, should the Florida pitch pine which is abundantly supplied by the adjacent woods, ever become in sufficient demand as lumber." (Vignoles 1823, p. 49).

[6] Cypress Creek width based on plat maps (Williams 1870-T49 R42; Williams 1870-T49 R43), and on surveyed widths of 132 and 198 feet near the headwaters in Section 11, Township 49 Range 42 (Williams 1870-T49 R42). Current width of the apparently least altered portions is 150-200 feet (USGS 1986-Pompano).

[7] Cypress Creek depth - no pre-drainage measurements found. Depth estimated at 3-4 feet based on assumption (from general reading of historical literature) that Cypress Creek was somewhat smaller than other rivers. Current depth in Section 6, Township 49, Range 43 is about 6 feet (USGS 1986).

[8] Cypress Creek headwater elevation based on headwater location in Section 11, T 49 R 42 (Williams 1870-T49 R42), on current elevations there of 6-7 feet (USGS (1969; 1986), and assumption of 0-1 feet of post-drainage peat subsidence. Subsidence assumed from soil types and cypress vegetation present in 1940s (Jones *et al.* 1948).

[9] Cypress Creek length from plat maps (Williams 1870-T49 R42; Williams 1870-T49 R43; Williams 1870-T50 R42). After running east from the cypress swamps, creek ran mostly south, parallel to coast, and discharged into the New River Inlet. North-south portion dredged in the 1890s to become part of the Intracoastal Waterway.

[10] Cypress Creek slope – if one assumes that the last five miles of the New River (the "Inlet"), running parallel to the coast, was at or very close to sea level, then the slope for Cypress Creek would be 9 inches per mile.

[11] Middle River width based on two surveyed widths of 147 and 308 feet below confluence of the two forks (MacKay 1845-T50 R42 and Williams 1870-T49 R42; different locations), and on one surveyed width of the south fork (158 feet) and two surveyed widths of the north fork (243 and 194 feet) (all from Williams 1870-T49 R42). Current width of the apparently least altered portions below confluence of forks is 250-300 feet (USGS 1983b-Ft Laud So).

[12] Middle River depth – no pre-drainage measurements found. Shallow four feet depth estimate based on assumption that Middle River was somewhat smaller than other rivers. Current depth below confluence of forks is about 6 feet (USGS 1986).

[13] Middle River headwater elevation based on headwater locations in Sections 17 and 21, Township 49 Range 42 (Williams 1870-T49 R42), on current elevations there of 6-8 feet (USGS 1969), and 1-2 feet of peat subsidence assumed. Estimates may be somewhat lower than expected (e.g., in comparison with New River) because Middle River did not extend all the way west to the Everglades. There likely was an elevation drop within the intervening 4-6 miles of cypress swamp.

[14] Middle River length from plat maps (Williams 1870-T49 R42 and Williams 1870-T50 R42).

[15] New River included two major forks (Cooley 1851 in Knetsch 1989 noted a total of four forks).

[16] New River width based on sum of widths of North and South Forks, and on width in main section, that is, above confluence with Middle River and Cypress Creek, and below confluence of North and South Forks of New River (Sections 10 and 11, T 50 R42). Surveyed main width was 185 feet (Williams 1870-T50 R42). Surveyed widths for the North Fork are 66 feet (MacKay 1845-T50 R42), and 132, and 132+ feet (Williams 1870-T50 R42). Surveyed widths for the South Fork were 231 feet (MacKay 1845-T50 R42), and 207 feet (Williams 1870-T50 R42). Henshall in 1883 described the South Fork as having "about an average width of fifty yards (150 feet) (Reiger 1971). Williams (1870)-T50 R42 also surveyed a width of 20 feet for one of the 6 to 8 prongs at the very top of the South Fork. Current width of the apparently least altered portions in the main section is ca. 200 feet (USGS 1983b-Ft Laud So).

[17] New River depths based on accounts such as Gifford (1911): "generally deep, but very deep in places, one spot having a depth of eighty-five feet," and Pierce, who grew up in So. Florida in the 1880s: "A rather narrow but very deep stream, it is said to have a depth of more than sixty feet in places." Pierce (1970). Henshall 1883, in Reiger (1971), describes the South Fork as having "a varying depth of from three to twenty feet." A Report of the Joint Committee of the Florida Legislature for the year 1907, on the drainage of the Everglades states: "We found the depth of water in New River to be on an average of about 20 feet." (Senate Doc. 89 (1911). Cooley, 1851 in Knetsch (1989) notes: "we there [from Section 12, T 50 R 42] ascended New River about 8 miles to the Everglades this section is good steam navigation." Note that this eight mile distance would indeed have extended close to the headwaters at the edge of the Everglades (Williams 1870-T50 R42). USGS (1983b-Ft Laud So) notes depths of 7, 8, 13,and 37 feet in the main section of the New River (see width endnote for location).

[18] New River headwater elevation estimated from pre-drainage location of headwaters of North Fork (Section 31 T49 R42) and South Fork, (Section 19 T50 R42), post peat-subsidence elevations, and estimates of original peat thickness. Estimates for the North and South Fork elevations were averaged (N was about 1 foot higher). Headwater locations from plat maps (Williams 1870-T49 R42 and Williams 1870-T50 R42). Post peat-subsidence elevation for North Fork was about 8 feet (USGS 1969), for South Fork about 6.5 feet; (USGS 1983b-Ft. Laud So). Post peat-subsidence elevations were assumed to include essentially no peat (Stephens and Johnson 1951). Estimates of original peat thickness in the South Fork area were 3-5 feet (Anonymous 1907); 3-6 feet, John Newman in Senate Doc. 89 (1911); 3-4 feet (Baldwin and Hawker 1915); 3 feet (west of South Fork, and after 16 years of subsidence, Mitchell *et al.* 1928b); and 4 feet (Stephens and Johnson 1951). In the North Fork area, pre-drainage peat thicknesses may have been somewhat less.

[19] New River length from Williams (1870)-T50 R42 and from (USGS 1969; 1983b-Ft. Laud So). Note also endnote on depth.

[20] Snake Creek width based on sum of surveyed widths for Little and Big Snake Creeks and on width below confluence. Surveyed width for Little Snake Creek was 132 feet (Williams 1870-T52 R42), and for Big Snake Creek was 66 feet (Mackay 1845-T52 R42), and 66 and 176 feet (Williams 1870-T52 R42). Below confluence width was 264 feet (Williams 1870-T52 R42). Current width of the apparently least altered portions in the below confluence section is ca. 200 feet USGS (1988b-No Miami).

[21] Snake Creek depth estimated from measured depth of 5 feet on Big Snake Creek (Mackay 1845-T52 R42, and regular use of Snake Creek as an Indian (R. Carr, pers. comm., 2000) and early settler (Pierce 1970) navigation route from Biscayne Bay to the Everglades.

[22] Snake Creek headwater elevation estimated from USGS (1988)-No Miami, using Williams (1870)-T51 R42, Newman (1908)-T52 R41, and Williams (1870)-T52 R42 for location. 1-2 feet of peat subsidence assumed, based on soil mapping (Jones *et al.* 1948).

[23] Snake Creek length an average of Little and Big Snake Creeks (similar), based on plat maps (Williams 1870-T51 R42; Williams 1870-T52 R42).

[24] Arch Creek width based on sum of surveyed widths for the two forks, 99 and 132 feet (Williams 1870-T52 R42). Width seems to have varied considerably along length of creek, with circa 50 feet on north fork at natural bridge (Parks 1977) and 99 feet below the arch (Williams 1870-T52 R42). At point where width was 99 feet, the depth was 20 feet , suggesting that this was a narrow point in the north fork.

[25] Arch Creek depth estimated from measured depth of 20 feet (Williams 1870-T52 R42), which would certainly not be applicable as average depth, but does give a sense of river volume, and from photographs (Parks 1977).

[26] Arch Creek headwater elevation estimated from USGS (1988b-No Miami), using Williams (1870)-T52 R41, and Williams (1870)-T52 R42 for location.

[27] Arch Creek length average of north and south forks, based on plat map (Williams 1870-T52 R42).
[28] Arch Creek slope. The current in pre-drainage Arch Creek was apparently sufficient for two partners to spend one year (1858) endeavoring to set up a water mill for coontie processing at the Natural Arch (Dietrich 1987).
[29] Little River width as drawn on plat map (Williams 1870-T53 R42) appears to have been fairly constant along length. The two available pre-drainage measurements (from same point) are both 66 feet: MacKay (1845)-T53 R42 and Williams (1870)-T53 R42. Post-drainage estimate is about 100 feet (USGS 1988a-Miami).
[30] Little River depth estimated from 2.5 feet depth measured in April at river mile 1, circa 0.5 mile from headwaters (MacKay 1845-T53 R42), from 2-6 depth given by Depuis (1954) for closer to river mouth, and recorded boat travel. Prior to construction of the muck canals, Gov. Broward and his party "went up Little River to the Everglades" in the "little yacht Linnet" (Anonymous 1905), during the dry season (Feb 16, 1905).
[31] Little River headwater elevation may be somewhat lower than regional Everglades levels due to elevation drop within relatively long (4 miles) transverse glade (c.f. plat map, MacKay 1845-T53 R41).
[32] Little River length is estimated from MacKay (1845)-T53 R42 (field notes) and Williams (1870)-T53 R42 (plat).
[33] Little River slope. MacKay (1845)-T53 R42 reports a race way for a coontie (starch) mill near the Little River.
[34] Miami River width estimated from surveyed withs of the forks of 83 and 39 feet, and below confluence width of 198 feet (all MacKay 1845-T53 R41). The width varied along the length, with sections 200 to 300 feet wide, points as narrow as 130 feet. See Gaby (1993), p. 4-5.
[35] Miami River depth estimated from boat navigation and from Gaby (1993). Note that tour boats ("well over 40 feet" Gaby 1993) made regular excursions right up to the bottom of the rapids in the north fork prior to drainage: the tour boat *Leo* of Rev. William Phipps starting about 1902, and the tour boat *Sallie* of Captain Burch starting about 1903 (Gaby 1993): "From the earliest times, boats drawing as much as four feet could go as far as Ferguson's Creek" (i.e., to the base of the rapids in the north fork).
[36] Miami River headwaters elevation estimated from pre-drainage surveys in 1849 and 1898. The first survey was done at request of the U.S. Secretary of the Treasury by the U.S. Coast Survey (Bache 1850). This survey found that "the level of the water in the glades was 6 feet 2.5 inches above low tide in the gulf," but noted also that "when the levelings were made, the level of the water in the glades was stated to be lower, and the tide in the gulf higher than ordinary," so this would constitute a low estimate of typical headwater elevation. The 1898 survey found that , "The *Mean* of three surveys, 6 ft 11 inches, can be safely taken as the amount of fall from the head of the Rapids of the Miami River to tide water in Biscayne Bay..." (Rose 1898).
[37] Miami River length surveyed as 3 and 3/4 miles (Bache 1850) This is consistent with the plat maps (MacKay 1845-T53 R41 and MacKay 1845-T54 R42).
[38] Miami River slope was described in a Report of the Superintendent of the Coast Survey for 1849 as: "The average fall per mile thus ascertained by Mr. Gerdes is nineteen inches and eighty-seven hundredths." (Bache 1850). The same report noted that at the time of the survey, "the level of the water in the glades was stated to be lower, and the tide in the gulf higher than ordinary," so the slope estimate was recognized as a likely underestimate (Bache 1850). Current in the South Fork: "Brewer with his pole in the stern, and myself with the Canadian paddle in the bow, made rapid headway against the current, which was getting stronger and stronger. ... Very soon we saw large white objects ahead, which proved to be balls of foam hurrying down with the current. With a quick turn to the left, after about three miles of paddling, we struck the South Fork, the water becoming swifter and swifter, and the cotton-like balls larger and more numerous. We were on the falls, and how the water did run! I could hear Brewer panting behind me, but I never turned my head or gave any signal that we were conquered, but started in on my old-time stroke, inch by inch crawling up that water, dodging the rocks. After about three-quarters of an hour of the hardest paddling I think I have ever done, the water slowed up a little, and we could get some speed on the canoe. The trees opened up more, the stream becoming narrower and narrower, until we came to an opening where everything was clear ahead.
This was the edge of the Everglades... The stream here loses itself among the lily-pads and before you lies a sea of apparently pathless grass. On closer observation shallow water-courses are seen running through the grass, cutting in all directions..." (Willoughby 1898, p.39-40). Gaby (1993) notes that the North Fork of the Miami River was narrower than the South Fork described by Willoughby (1898), apparently passed a greater volume of water; and was generally used as the return route to Miami by Indians and explorers of the Everglades.

F.2 SOUTHWEST COAST RIVERS

Introduction

The historical vertical elevations of the southwest coast rivers are obtained from the 1890 U.S. Coast and Geodetic Survey inshore hydrographic map (**USCGS, 1890**). The officer in charge of this survey was Lieutenant J.F. Moser, USN. The 1890 survey provided data along the coast and did not travel into the rivers. All lower east coast rivers are spatially (horizontally) adjusted to the 1930 U.S. Coast and Geodetic Survey map (USCGS, **1930**).

Huston River

The datum used for Huston River sounding data is mean low water. To convert the data to vertical datum NGVD29:

NOAA Station 8724919
NGVD29 = 0.87′
MLW = 0.37′
100 yr Sea level rise = 0.77′

MLW_{100} = 0.37′ – 0.77′ = -0.40′
$MLW_{NGVD29\ 100}$ = -0.40′ – 0.87′ = -1.27′
$NGVD29_{100}$ = -1.27′ – sounding

Table F-11. Huston River data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[4]	Top Width[3]
300904	Huston River	5.0	-3.20[5]	130.0	150.0
300905	Huston River	5.0	-3.30[5]	980.0	1000.0
300906	Huston River	5.0	-3.40[5]	2980.0	3000.0
300426	Huston River	5.0	-3.51	1180.0	1200.0
300425	Huston River	5.0	-3.93	1980.0	2000.0
300424	Huston River	5.0	-8.17	780.0	800.0
300423	Huston River	5.0	-8.10	980.0	1000.0
300422	Huston River	5.0	-7.38	980.0	1000.0
300421	Huston River	5.0	-6.32	1180.0	1200.0

Average of all soundings in Huston River from 1930 U.S. Coast and Geodetic Survey map. [1]
Average of all soundings for each reach in Huston River from 1930 U.S. Coast and Geodetic Survey map. [2]
Estimated using DOQQ. [3]
Calculated from depth, assumed side slope of 2.0 and top width. [4]
Relied on best professional judgment. [5]

Chatam River

The datum used for Chatam River sounding data is mean low water. To convert the data to vertical datum NGVD29:

```
NOAA Station 8724919
NGVD29 = 0.87'
MLW = 0.37'
100 yr Sea level rise = 0.77'
```

MLW_{100} = 0.37' – 0.77' = -0.40'
$MLW_{NGVD29\ 100}$ = -0.40' – 0.87' = -1.27'
$NGVD29_{100}$ = -1.27' – sounding

Table F-12. Chatam River data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[4]	Top Width[3]
300898	Chatam River	5.0	-5.70[5]	280.0	300.0
300899	Chatam River	5.0	-5.60[5]	330.0	350.0
300427	Chatam River	5.0	-6.54	580.0	600.0
300428	Chatam River	5.0	-6.22	430.0	450.0
300308	Chatam River	5.0	-5.71	480.0	500.0
300307	Chatam River	5.0	-6.25	780.0	800.0
300429	Chatam River	5.0	-7.48	680.0	700.0
300430	Chatam River	5.0	-8.00	780.0	800.0
300431	Chatam River	5.0	-4.92	1980.0	2000.0

Average of all soundings in Chatam River from 1930 U.S. Coast and Geodetic Survey map. [1]
Average of all soundings for each reach in Chatam River from 1930 U.S. Coast and Geodetic Survey map. [2]
Estimated using DOQQ. [3]
Calculated from depth, assumed side slope of 2.0 and top width. [4]
Relied on best professional judgment. [5]

Lostman’s River

The datum used for Lostman’s River sounding data is mean low water. To convert the data to vertical datum NGVD29:

NOAA Station 8724919
NGVD29 = 0.87′
MLW = 0.37′
100 yr Sea level rise = 0.77′

MLW_{100} = 0.37′ – 0.77′ = -0.40′
$MLW_{NGVD29\ 100}$ = -0.40′ – 0.87′ = -1.27′
$NGVD29_{100}$ = -1.27′ – sounding

Table F-13. Lostman’s River data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[4]	Top Width[3]
300875	Lostman’s River	5.0	-4.30[5]	30.0	50.0
300876	Lostman’s River	5.0	-4.35[5]	55.0	75.0
300877	Lostman’s River	5.0	-4.40[5]	180.0	200.0
300878	Lostman’s River	5.0	-4.45[5]	80.0	100.0
300879	Lostman’s River	5.0	-4.50[5]	130.0	150.0
300880	Lostman’s River	5.0	-4.55[5]	380.0	400.0
300881	Lostman’s River	5.0	-4.60[5]	1980.0	2000.0
300882	Lostman’s River	5.0	-4.65[5]	1980.0	2000.0
300883	Lostman’s River	5.0	-4.70[5]	1980.0	2000.0
300438	Lostman’s River	5.0	-5.64	2480.0	2500.0
300439	Lostman’s River	5.0	-5.65	1480.0	1500.0
300440	Lostman’s River	5.0	-5.41	1180.0	1200.0
300441	Lostman’s River	5.0	-7.17	1480.0	1500.0
300442	Lostman’s River	5.0	-6.02	2480.0	2500.0
300443	Lostman’s River	5.0	-8.29	1480.0	1500.0
300437	Lostman’s River	5.0	-4.74	1480.0	1500.0
300436	Lostman’s River	5.0	-6.36	680.0	700.0
300435	Lostman’s River	5.0	-4.44	580.0	600.0
300434	Lostman’s River	5.0	-2.51	80.0	100.0
300433	Lostman’s River	5.0	-4.72	130.0	150.0
300432	Lostman’s River	5.0	-6.93	180.0	200.0
300310	Lostman’s River	5.0	-10.30	730.0	750.0
300309	Lostman’s River	5.0	-6.20	1980.0	2000.0

Average of all soundings in Lostman’s River from 1930 U.S. Coast and Geodetic Survey map. [1]
Average of all soundings for each reach in Lostman’s River from 1930 U.S. Coast and Geodetic Survey map. [2]
Estimated using DOQQ. [3]
Calculated from depth, assumed side slope of 2.0 and top width. [4]
Relied on best professional judgment. [5]

Broad River

The datum used for Broad River sounding data is mean low water. To convert the data to vertical datum NGVD29:

```
NOAA Station 8724919
NGVD29 = 0.87′
MLW = 0.37′
100 yr Sea level rise = 0.77′
```

MLW_{100} = 0.37′ – 0.77′ = -0.40′
$MLW_{NGVD29\ 100}$ = -0.40′ – 0.87′ = -1.27′
$NGVD29_{100}$ = -1.27′ – sounding

Table F-14. Broad River data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[4]	Top Width[3]
300871	Broad River	5.0	-5.90[5]	80.0	100.0
300872	Broad River	5.0	-6.00[5]	130.0	150.0
300873	Broad River	5.0	-6.10[5]	130.0	150.0
300874	Broad River	5.0	-6.20[5]	280.0	300.0
300455	Broad River	5.0	-4.27[5]	30.0	50.0
300456	Broad River	5.0	-4.27[5]	30.0	50.0
300457	Broad River	5.0	-4.27[5]	280.0	300.0
300458	Broad River	5.0	-5.21	480.0	500.0
300459	Broad River	5.0	-6.29	430.0	450.0
300460	Broad River	5.0	-5.31	380.0	400.0
300461	Broad River	5.0	-5.88	280.0	300.0
300454	Broad River	5.0	-7.41	180.0	200.0
300453	Broad River	5.0	-6.53	280.0	300.0
300452	Broad River	5.0	-5.96	730.0	750.0
300451	Broad River	5.0	-5.75	1180.0	1200.0
300450	Broad River	5.0	-6.31	980.0	1000.0
300449	Broad River	5.0	-9.03	380.0	400.0
300448	Broad River	5.0	-9.05	230.0	250.0
300447	Broad River	5.0	-9.74	230.0	250.0
300446	Broad River	5.0	-9.47	230.0	250.0
300445	Broad River	5.0	-9.57	380.0	300.0
300444	Broad River	5.0	-6.11	580.0	600.0

Average of all soundings in Broad River from 1930 U.S. Coast and Geodetic Survey map. [1]
Average of all soundings for each reach in Broad River from 1930 U.S. Coast and Geodetic Survey map. [2]
Estimated using DOQQ. [3]
Calculated from depth, assumed side slope of 2.0 and top width. [4]
Relied on best professional judgment. [5]

Shark River

The datum used for Shark River sounding data is mean low water. To convert the data to vertical datum NGVD29:

NOAA Station 8724919
NGVD29 = 0.87′
MLW = 0.37′
100 yr Sea level rise = 0.77′

$MLW_{100} = 0.37' - 0.77' = -0.40'$
$MLW_{NGVD29\ 100} = -0.40' - 0.87' = -1.27'$
$NGVD29_{100} = -1.27' - \text{sounding}$

Table F-15. Shark River data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[4]	Top Width[3]
300314	Shark River	6.5	-5.0[5]	24.0	50.0
300315	Shark River	6.5	-4.9[5]	24.0	50.0
300318	Shark River	6.5	-5.1[5]	124.0	150.0
300462	Shark River	6.5	-5.2[5]	174.0	200.0
300463	Shark River	6.5	-5.3[5]	174.0	200.0
300464	Shark River	6.5	-5.4[5]	174.0	200.0
300465	Shark River	6.5	-5.5[5]	154.0	180.0
300466	Shark River	6.5	-5.6[5]	124.0	150.0
300467	Shark River	6.5	-5.7[5]	74.0	100.0
300468	Shark River	6.5	-5.8[5]	174.0	200.0
300469	Shark River	6.5	-5.9[5]	974.0	1000.0
300470	Shark River	6.5	-6.05	574.0	1200.0
300483	Shark River	6.5	-7.82	374.0	400.0
300484	Shark River	6.5	-7.38	324.0	350.0
300485	Shark River	6.5	-8.93	324.0	350.0
300486	Shark River	6.5	-8.6	374.0	400.0
300487	Shark River	6.5	-8.73	274.0	350.0
300324	Shark River	6.5	-9.32	374.0	400.0
300323	Shark River	6.5	-9.9	274.0	300.0
300322	Shark River	6.5	-9.03	324.0	350.0
300327	Shark River	6.5	-9.49	224.0	250.0
300326	Shark River	6.5	-9.39	374.0	400.0
300325	Shark River	6.5	-9.21	624.0	650.0

Average of all soundings in Shark River from 1930 U.S. Coast and Geodetic Survey map. [1]
Average of all soundings for each reach in Shark River from 1930 U.S. Coast and Geodetic Survey map. [2]
Estimated using DOQQ. [3]
Calculated from depth, assumed side slope of 2.0 and top width. [4]
Relied on best professional judgment. [5]

Harney River

The datum used for Harney River sounding data is mean low water. To convert the data to vertical datum NGVD29:

NOAA Station 8724919
NGVD29 = 0.87′
MLW = 0.37′
100 yr Sea level rise = 0.77′

MLW_{100} = 0.37′ – 0.77′ = -0.40′
$MLW_{NGVD29\ 100}$ = -0.40′ – 0.87′ = -1.27′
$NGVD29_{100}$ = -1.27′ – sounding

Table F-16. Harney River data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[4]	Top Width[3]
300886	Harney River	6.5	-7.20[5]	49.0	75.0
300888	Harney River	6.5	-7.25[5]	49.0	75.0
300890	Harney River	6.5	-7.30[5]	174.0	200.0
300892	Harney River	6.5	-7.35[5]	274.0	300.0
300894	Harney River	6.5	-7.40[5]	674.0	700.0
300896	Harney River	6.5	-7.45[5]	974.0	1000.0
300897	Harney River	6.5	-7.50[5]	874.0	500.0
300479	Harney River	6.5	-7.55	398.0	424.0
300478	Harney River	6.5	-7.73	274.0	300.0
300477	Harney River	6.5	-7.04	274.0	300.0
300476	Harney River	6.5	-7.51	324.0	350.0
300475	Harney River	6.5	-6.93	324.0	350.0
300474	Harney River	6.5	-7.55	474.0	500.0
300473	Harney River	6.5	-8.07	274.0	300.0
300472	Harney River	6.5	-8.34	324.0	350.0
300482	Harney River	6.5	-8.22	224.0	250.0
300481	Harney River	6.5	-7.93	374.0	400.0
300480	Harney River	6.5	-5.73	424.0	450.0
300321	Harney River	6.5	-9.08	324.0	350.0
300320	Harney River	6.5	-7.64	424.0	450.0

Average of all soundings in Harney River from 1930 U.S. Coast and Geodetic Survey map. [1]
Average of all soundings for each reach in Harney River from 1930 U.S. Coast and Geodetic Survey map. [2]
Estimated using DOQQ. [3]
Calculated from depth, assumed side slope of 2.0 and top width. [4]
Relied on best professional judgment. [5]

F.3 ST. LUCIE RIVER

North Fork – Northern Tributaries

Data sources used to construct the tributaries were from DOQQs (USGS, **DOQQs**). The spatial extent of tributary was refined using the DOQQs. The bottom elevations were estimated from the USGS 5-foot contour lines. Spatial locations were compared, where available, with the GLOs (USDOI, **GLO survey data; Figure F-1**). Four segments (300685, 300760, 300716, 300717) were in the general area of the GLOs; it is assumed that the DOQQs provide a more realistic representation of spatial location.

Table F-17. St. Lucie River North Fork – Northern Tributaries data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[3]	Top Width[4]
300718	St Lucie North Fork – Trib 1a	5.0	10.0	30.0	50.0
300719	St Lucie North Fork – Trib 1a	5.0	8.0	30.0	50.0
300720	St Lucie North Fork – Trib 1b	5.0	10.0	10.0	30.0
300721	St Lucie North Fork – Trib 1b	5.0	8.0	10.0	30.0
300699	St Lucie North Fork – Trib 1	5.0	-2.0	60.0	80.0
300698	St Lucie North Fork – Trib 1	5.0	-4.1	60.0	80.0
300696	St Lucie North Fork – Trib 1	5.0	-4.2	60.0	80.0
300685	St Lucie North Fork – Trib 1	5.0	-4.3	60.0	80.0
300760	St Lucie North Fork – Trib 1	5.0	-4.5	60.0	80.0
300716	St Lucie North Fork – Trib 1c	5.0	0.0	30.0	50.0
300717	St Lucie North Fork – Trib 1c	5.0	-4.0	30.0	50.0

Relied on best professional judgment. [1]
USGS Contours. [2]
Calculated from depth, assumed side slope of 2.0 and top width. [3]
Estimated using DOQQ. [4]

North Fork

Dimensions for the North Fork of the St. Lucie River were derived from DOQQ (USGS, **DOQQs**) and bathymetric data. The data were averaged along each model river reach. The spatial extent of tributary was refined using the DOQQ. A * denotes a shunt connection with the estuary, modeled using the lake package. Spatial location was compared with the GLOs (USDOI, **GLO survey data**) and it is assumed that the DOQQs provide a more realistic representation of spatial location.

Table F-18. St. Lucie River North Fork data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[3]	Top Width[4]
301028	St Lucie North Fork	8.0	4.5	200.0	232.0
301029	St Lucie North Fork	8.0	4.5	200.0	232.0
300761	St Lucie North Fork	8.0	7.9	118.0	150.0
300628	St Lucie North Fork	8.0	7.9	168.0	200.0
300629	St Lucie North Fork	8.0	7.91	168.0	200.0
300630	St Lucie North Fork	8.0	5.75	168.0	200.0
300631	St Lucie North Fork	8.0	6.0	168.0	200.0
300632	St Lucie North Fork	8.0	4.8	168.0	200.0
300633	St Lucie North Fork	8.0	2.05	168.0	200.0
300634	St Lucie North Fork	8.0	4.27	168.0	200.0
300635	St Lucie North Fork	8.0	4.58	168.0	200.0
300636	St Lucie North Fork	8.0	4.74	218.0	250.0
300637*	St Lucie North Fork	8.0	4.5	268.0	300.0

Relied on best professional judgment. [1]
Bathymetry adjusted for coarse mesh cells. [2]
Calculated from depth, assumed side slope of 2.0 and top width. [3]
Within range of 1845 GLO survey. [4]

North Fork – Southern Tributaries

The North Fork tributaries were derived from DOQQs (USGS, **DOQQs**). The spatial extent of tributary was refined using the DOQQ. The bottom elevations were estimated from the USGS 5 foot contour lines. A * denotes a shunt connection with the estuary, modeled using the lake package. Spatial location was compared with the GLOs (USDOI, **GLO survey data**) and it is assumed that the DOQQs provide a more realistic representation of spatial location.

Table F-19. St. Lucie River North Fork – Southern Tributaries data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[3]	Top Width[4]
300714	St Lucie North Fork – Trib 2b	8.0	11.3	68.0	100.0
300715	St Lucie North Fork – Trib 2b	8.0	6.2	68.0	100.0
300712	St Lucie North Fork – Trib 2a	8.0	12.2	100.0	132.0
300713	St Lucie North Fork – Trib 2a	8.0	6.1	100.0	132.0
300775	St Lucie North Fork – Trib 2a	8.0	6.0	100.0	132.0
300776*	St Lucie North Fork – Trib 2a	8.0	5.0	100.0	132.0

Relied on best professional judgment. [1]
USGS Contours adjusted for coarse mesh cells. [2]
Calculated from depth, assumed side slope of 2.0 and top width. [3]
Within range of 1845 GLO survey. [4]

St. Lucie – Tributary 1

The tributaries used DOQQ data (USGS, **DOQQs**). The spatial extent of tributary was refined using the DOQQ. The bottom elevations were estimated from the USGS 5-foot contour lines. A * denotes a shunt connection with the estuary, modeled using the lake package. Spatial location was compared with the GLOs (USDOI, **GLO survey data**) and it is assumed that the DOQQs provide a more realistic representation of spatial location. To convert this to the vertical datum NGVD29:

```
NOAA Station 8722371
NGVD29 = 0.15′
MLW = 0.12′
100 yr Sea level rise = 0.78′
```

MLW_{100} = 0.12′ – 0.78′ = -0.66′
$MLW_{NGVD29\ 100}$ = -0.66′ – 0.15′ = -0.81′
$NGVD29_{100}$ = -0.81′ – sounding

Table F-20. St. Lucie River-Tributary 1 data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[3]	Top Width[4]
300764	St Lucie - Trib 1	8.0	5.0	100.0	132.0
301057*	St Lucie - Trib 1	8.0	5.0	100.0	132.0

Relied on best professional judgment. [1]
Based on USGS elevations. [2]
Calculated from depth, assumed side slope of 2.0 and top width. [3]
Within range of 1845 GLO survey. [4]

St. Lucie – Bessie Creek

The tributaries used DOQQ data (USGS, **DOQQs**). The spatial extent of tributary was refined using the DOQQ. The bottom elevations were estimated from the USGS 5-foot contour lines. A * denotes a shunt connection with the estuary, modeled using the lake package. Spatial location was compared with the GLOs (USDOI, **GLO survey data**) and it is assumed that the DOQQs provide a more realistic representation of spatial location. To convert this to the vertical datum NGVD29:

NOAA Station 8722371
NGVD29 = 0.15′
MLW = 0.12′
100 yr Sea level rise = 0.78′

MLW_{100} = 0.12′ – 0.78′ = -0.66′
$MLW_{NGVD29\ 100}$ = -0.66′ – 0.15′ = -0.81′
$NGVD29_{100}$ = -0.81′ – sounding

Table F-21. St. Lucie River – Bessie Creek Tributaries data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[3]	Top Width[4]
300709	St Lucie - Trib 2	8.01	9.12	118.0	150.0
300707*	St Lucie - Trib 2	8.01	5.92	114.0	150.0

Relied on best professional judgment. [1]
Based on USGS elevations. [2]
Calculated from depth, assumed side slope of 2.0 and top width. [3]
Within range of 1845 GLO survey. [4]

South Fork

Spatial location was derived from GLO (USDOI, **GLO survey data**) plat maps. The bottom elevations were estimated from the USGS 5-foot contour lines (USGS, **DOQQs**). A * denotes a shunt connection with the estuary, modeled using the lake package.

Table F-22. St. Lucie River South Fork Tributaries data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[3]	Top Width[4]
301058	St Lucie South Fork – Trib1	2.0	7.0	40.0	48.0
301059	St Lucie South Fork – Trib1	2.0	6.0	40.0	48.0
301090	St Lucie South Fork – Trib1	2.0	5.0	40.0	48.0
301061	St Lucie South Fork – Trib1	2.0	4.0	40.0	48.0
301062	St Lucie South Fork – Trib1	2.0	3.0	40.0	48.0
300639	St Lucie South Fork	5.0	11.5	80.0	100.0
300640	St Lucie South Fork	5.0	11.0	80.0	100.0
300641	St Lucie South Fork	5.0	10.5	80.0	100.0
300642	St Lucie South Fork	5.0	10.0	80.0	100.0
300765	St Lucie South Fork	5.0	7.0	80.0	100.0
300766	St Lucie South Fork	5.0	6.0	80.0	100.0
300771	St Lucie South Fork	5.0	5.0	80.0	100.0
300772	St Lucie South Fork	5.0	4.0	80.0	100.0
300770	St Lucie South Fork	5.0	3.0	80.0	100.0
301064	St Lucie South Fork	5.0	3.0	80.0	100.0
300768	St Lucie South Fork	5.0	2.5	80.0	100.0
301063*	St Lucie South Fork	5.0	2.5	80.0	100.0

Relied on best professional judgment. [1]
Based on USGS elevations. [2]
Calculated from depth, assumed side slope of 2.0 and top width. [3]
Within range of 1845 GLO survey. [4]

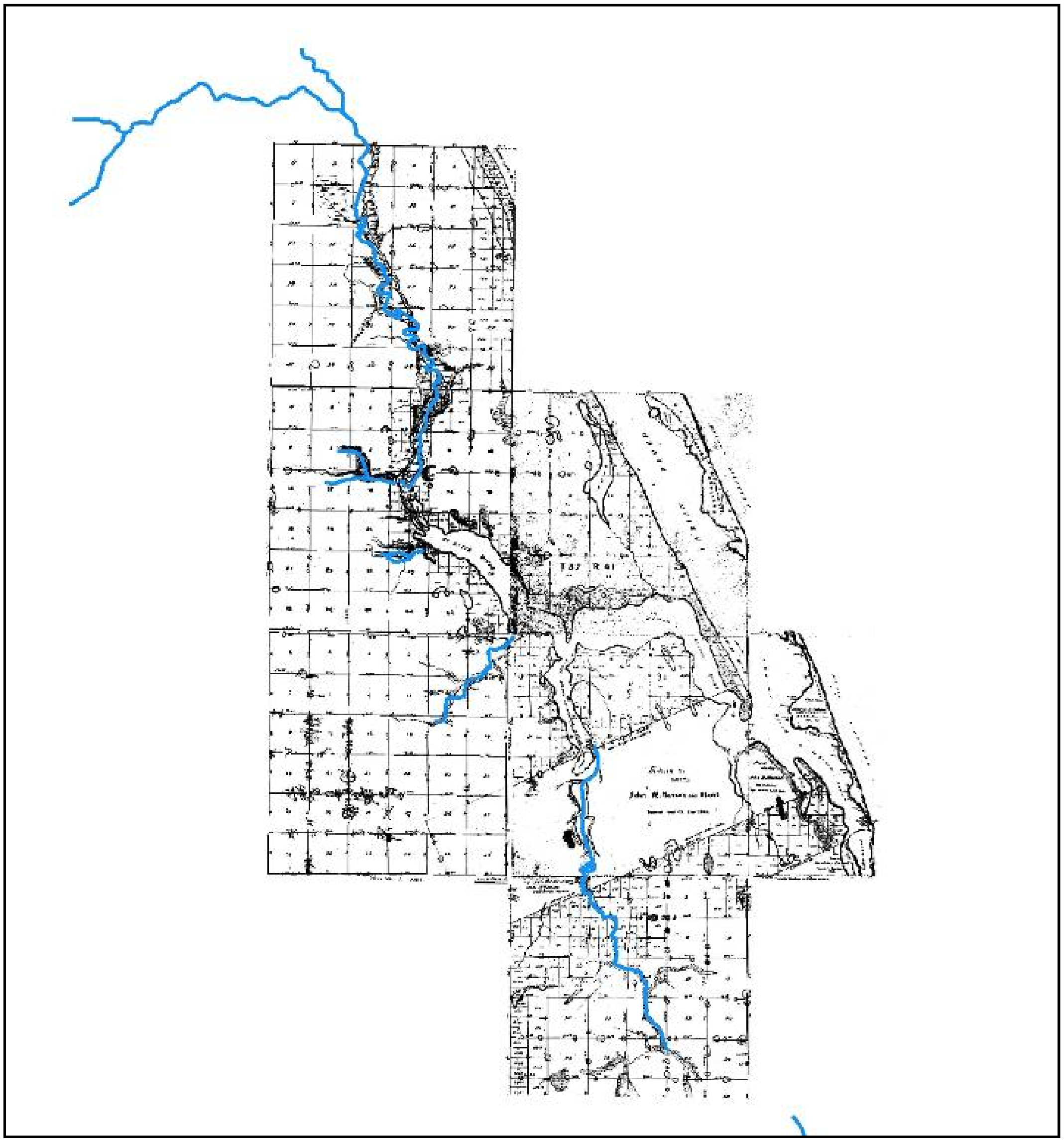

Figure F-1. Government Land Office maps of the St. Lucie Basin (**USDOI, GLO survey data**).

F.4 CALOOSAHATCHEE RIVER

The Caloosahatchee River feature class is a composite dataset from 1879 and 1887 surveys conducted by the U.S. Army (**US Army, 1879 and 1887**). Copies of reports and maps were obtained from National Archives and Records Administration (**NARA website**). The 1887 survey is much more detailed, but reflects improvements made in the early 1880s. The improvements were in the eastern sections of the river connecting it to Lake Okeechobee. The 1879 surveys were used for the eastern sections of the Caloosahatchee River. Both surveys provided detailed information on the width, depth, location and vertical datum.

Elevations from the survey of 1879 are referenced above mean low tide at Fort Meyers. Elevations from the survey of 1887 are referenced to mean low water of the Gulf of Mexico. Since the 1887 survey was closed on the benchmark at Fort Myers from the 1879 survey, it is assumed that the reference to mean low of Gulf of Mexico refers to the mean low water at Fort Meyers. To convert 1879 datum to the NGVD29 used by the NSRSM:

NOAA Station 8725520
NGVD29 = -0.13′
MLW = 0.15′
100 yr Sea level rise = 0.75′

MLW_{100} = 0.15′ – 0.75′ = -0.60′
$MLW_{NGVD29\ 100}$ = -0.60′ – -0.13′ = -0.47′
$NGVD29_{100}$ = MLW_{1879} - 0.47′

Table F-23. Historical dimensions of the Caloosahatchee River.

Location	Sounding 1879	Width 1879	Bottom Elev 1887[1]	Width 1887
1.5 miles east of Sugar Berry Hummock (SBH)	10” to 20”	NA		
SBH	5’ to 8’	15’		12’
2 miles west of SBH (boundary separating section 25 and 30)	5’ to 7’		10.36	21.76
Thence for 2 miles to boundary separating section 26 and 27	7’	40’	8.98	36’
Thence for 1 mile to boundary separating section 27 and 28	2’ to 7’	40’	6.53	36’
Section 28	4’ to 6’	5280’	-0.47	6155’
Thence to ½ mile	10” to 20”	70’ to 80’	4.83	1129’
Thence 1000’		30’	4.83	27’
Thence 1¼ miles	2’ to 5’	250’	5.13	225’
Thence 1 mile	2.5’ to 4’	½ to 3/4 mi	4.53	2970’
Thence 1.5 miles	2.5’ to 5’	800’	0.9	550’
Ft. Thompson Rapids to 4800’. There is a 2.5’ fall for this length	4.5’ to 8.5’	35’ to 105’	-1.57	58’
Thence to west bound of range 29	6.9’	50’ to 85’	-5.01	
Thence to west bound of range 28	8.8’	85’ to 130’	-10.22	
Thence to west bound of range 27	11.1’	120’ to 250’	-10.79	
Thence to west bound of range 26	12.7’	200’ to 400’	-12.93	

Calculated from the average depth and adjusted to NGVD29. [1]

Table F-24. Caloosahatchee River Tributary data from 1879 data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[3]	Top Width[4]
300057	Caloosahatchee Tributary	1.25	16.81	5.0	10.0
300063	Caloosahatchee Tributary	1.25	16.81	5.0	10.0
300067	Caloosahatchee Tributary	1.25	16.81	5.0	10.0
300068	Caloosahatchee Tributary	1.25	17.13	5.0	10.0
300077	Caloosahatchee Tributary	1.25	17.03	5.0	10.0
300078	Caloosahatchee Tributary	1.25	17.03	5.0	10.0
300079	Caloosahatchee Tributary	1.25	16.68	5.0	10.0
300084	Caloosahatchee Tributary	1.25	17.03	5.0	10.0
300086	Caloosahatchee Tributary	1.25	17.03	5.0	10.0
300087	Caloosahatchee Tributary	1.25	17.03	5.0	10.0
300056	Caloosahatchee	1.25	16.81	5.0	10.0
300061	Caloosahatchee	1.25	16.81	5.0	10.0
300064	Caloosahatchee	1.25	17.13	5.0	10.0
300066	Caloosahatchee	1.25	16.80	5.0	10.0
300076	Caloosahatchee	1.25	16.68	5.0	10.0
300080	Caloosahatchee	6.50	11.06	-11.0	15.0
300081	Caloosahatchee	6.00	11.56	-4.0	20.0
300074	Caloosahatchee	6.00	11.27	-4.0	20.0
300082	Caloosahatchee	7.00	9.70	12.0	40.0
300083	Caloosahatchee	7.00	8.46	12.0	40.0
300175	Caloosahatchee	4.50	1.42	22.0	40.0
300075	Lake Flirt	5.00	-0.50	5260.0	5280.0
300065	Lake Flirt	1.25	3.19	70.0	75.0
300062	Lake Flirt	2.00	2.44	22.0	30.0
300172	Lake Flirt	3.50	0.94	236.0	250.0
300173	Lake Flirt	3.25	1.63	3287.0	3300.0
300085	Lake Flirt	3.25	1.63	3287.0	3300.0
300095	Lake Flirt	3.75	1.34	785.0	800.0
300096	Lake Flirt	3.75	6.76	785.0	800.0
300102	Ft. Thompson Rapids	3.75	6.76	785.0	800.0
300100	Caloosahatchee	7.50	4.47	40.0	70.0
300099	Caloosahatchee	6.90	6.59	39.9	67.5
300094	Caloosahatchee	6.90	5.53	39.9	67.5

300097	Caloosahatchee	6.90	5.53	39.9	67.5
300101	Caloosahatchee	6.90	3.93	39.9	67.5
300176	Caloosahatchee	6.90	3.93	39.9	67.5
300177	Caloosahatchee	6.90	3.93	39.9	67.5
300181	Caloosahatchee	6.90	4.65	39.9	67.5
300182	Caloosahatchee	6.90	5.26	39.9	67.5
300120	Caloosahatchee	8.80	3.36	72.3	107.5
300122	Caloosahatchee	8.80	3.99	72.3	107.5
300121	Caloosahatchee	8.80	3.84	72.3	107.5
300187	Caloosahatchee	8.80	3.84	72.3	107.5
300188	Caloosahatchee	8.80	4.35	72.3	107.5
300131	Caloosahatchee	8.80	4.35	72.3	107.5
300139	Caloosahatchee	8.80	3.67	72.3	107.5
300184	Caloosahatchee	8.80	3.67	72.3	107.5
300185	Caloosahatchee	8.80	6.55	72.3	107.5
300147	Caloosahatchee	8.80	3.79	72.3	107.5
300149	Caloosahatchee	8.80	2.06	72.3	107.5
300153	Caloosahatchee	11.10	-0.79	140.6	185.0
300145	Caloosahatchee	11.10	-3.43	140.6	185.0
300192	Caloosahatchee	11.10	-3.43	140.6	185.0
300193	Caloosahatchee	11.10	-2.99	140.6	185.0
300155	Caloosahatchee	11.10	-2.34	140.6	185.0
300148	Caloosahatchee	11.10	-2.52	140.6	185.0
300198	Caloosahatchee	11.10	-5.69	140.6	185.0
300194	Caloosahatchee	11.10	-5.69	140.6	185.0
300201	Caloosahatchee	11.10	-5.98	140.6	185.0
300217	Caloosahatchee	11.10	-5.98	140.6	185.0
300200	Caloosahatchee	11.10	-5.98	140.6	185.0
300196	Caloosahatchee	11.10	-2.51	140.6	185.0
300197	Caloosahatchee	12.70	-4.11	249.2	300.0
300203	Caloosahatchee	12.70	-3.26	249.2	300.0
300220	Caloosahatchee	12.70	-4.94	249.2	300.0
300219	Caloosahatchee	12.70	-4.94	249.2	300.0
300202	Caloosahatchee	12.70	-2.69	249.2	300.0
300680	Caloosahatchee	12.70	-1.36	249.2	300.0

Sounding from 1879 survey. [1]
Subtracted 1879 sounding from historical topography and adjusted for mesh cell discretization. [2]
Calculated from depth, assumed side slope of 2.0 and top width. [3]
Based on 1879 Survey. [4]

Caloosahatchee Tributaries

Caloosahatchee River tributaries were spatially derived from the U.S. Army Corps of Engineers (US Army, **1879 and 1887**) and Flood Control District Maps.

Table F-25. Caloosahatchee River Tributary data, converted from 1879 data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[3]
300040	Caloosahatchee Tributary	5.0	56.0	20.0
300041	Caloosahatchee Tributary	5.0	55.0	20.0
300042	Caloosahatchee Tributary	5.0	45.0	20.0
300043	Caloosahatchee Tributary	5.0	44.0	20.0
300044	Caloosahatchee Tributary	5.0	42.0	20.0
300045	Caloosahatchee Tributary	5.0	41.0	20.0
300046	Caloosahatchee Tributary	5.0	40.0	20.0
300047	Caloosahatchee Tributary	5.0	33.0	20.0
300048	Caloosahatchee Tributary	5.0	31.0	20.0
300049	Caloosahatchee Tributary	5.0	30.0	20.0
300050	Caloosahatchee Tributary	5.0	25.5	20.0
300051	Caloosahatchee Tributary	5.0	25.0	20.0
300052	Caloosahatchee Tributary	5.0	18.0	20.0
300053	Caloosahatchee Tributary	5.0	14.0	20.0
300054	Caloosahatchee Tributary	5.0	13.5	20.0
300055	Caloosahatchee Tributary	5.0	13.2	20.0
300056	Caloosahatchee Tributary	5.0	13.1	20.0
300004	Caloosahatchee Tributary	5.0	62.92	10.5
300005	Caloosahatchee Tributary	5.0	57.34	10.5
300013	Caloosahatchee Tributary	5.0	56.7	10.5
300014	Caloosahatchee Tributary	5.0	56.58	10.5
300020	Caloosahatchee Tributary	5.0	55.5	10.5
300021	Caloosahatchee Tributary	5.0	52.37	10.5
300025	Caloosahatchee Tributary	5.0	50.63	10.5
300030	Caloosahatchee Tributary	5.0	44.08	10.5
300206	Caloosahatchee Tributary	5.0	40.41	10.5
300038	Caloosahatchee Tributary	5.0	39.92	10.5
300058	Caloosahatchee Tributary	5.0	29.08	10.5
300059	Caloosahatchee Tributary	5.0	28.63	10.5
300089	Caloosahatchee Tributary	5.0	28.22	10.5
300090	Caloosahatchee Tributary	5.0	28.22	10.5
300092	Caloosahatchee Tributary	5.0	27.05	10.5
300105	Caloosahatchee Tributary	5.0	26.4	10.5
300107	Caloosahatchee Tributary	5.0	26.4	10.5

300110	Caloosahatchee Tributary	5.0	22.05	10.5
300180	Caloosahatchee Tributary	5.0	16.55	10.5
300123	Caloosahatchee Tributary	5.0	8.08	10.5
300125	Caloosahatchee Tributary	5.0	11.08	10.5
300166	Caloosahatchee Tributary	5.0	18.35	10.5
300167	Caloosahatchee Tributary	5.0	19.2	10.5
300168	Caloosahatchee Tributary	5.0	16.47	10.5
300169	Caloosahatchee Tributary	5.0	14.33	10.5
300170	Caloosahatchee Tributary	5.0	20.46	10.5
300183	Caloosahatchee Tributary	5.0	6.08	10.5
300015	Jack's Branch	5.0	48.27	10.5
300022	Jack's Branch	5.0	47.85	10.5
300032	Jack's Branch	5.0	35.15	10.5
300033	Jack's Branch	5.0	32.15	10.5
300034	Jack's Branch	5.0	31.69	10.5
300043	Jack's Branch	5.0	30.79	10.5
300044	Jack's Branch	5.0	30.79	10.5
300071	Jack's Branch	5.0	28.13	10.5
300072	Jack's Branch	5.0	24.36	10.5
300103	Jack's Branch	5.0	22.22	10.5
300104	Jack's Branch	5.0	18.54	10.5
300111	Jack's Branch	5.0	18.16	10.5
300114	Jack's Branch	5.0	11.13	10.5
300191	Jack's Branch	5.0	11.13	10.5
300190	Jack's Branch	5.0	9.64	10.5

Assumed depth of 5.0’. [1]
Subtracted depth from historical topography and adjusted for mesh cell discretization. [2]
Assumed bottom width. [3]

F.5 LOWER KISSIMMEE

Kissimmee River

Kissimmee River segments from Lake Kissimmee to Pool D were spatially derived from pre-channelization vegetation developed by the Kissimmee River Division using the open water classification (Milleson *et al,* **1980**). The centerline below pool D was digitized from 1909–1911 surveys (USACE, **1909**). Depths were derived from grids developed from LIDAR data and verified against observed depths recorded in early 1900s surveys of the Kissimmee River conducted in "compliance with the provisions of the river and harbor act" (USHR, **1902**).

Table F-26. Kissimmee River data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[3]	Top Width[4]
300520	Kissimmee River	10.0	44.22	160.0	200.0
300414	Kissimmee River	10.0	43.53	160.0	200.0
300415	Kissimmee River	10.0	43.53	160.0	200.0
300416	Kissimmee River	10.0	43.53	160.0	200.0
300518	Kissimmee River	10.0	43.20	160.0	200.0
300519	Kissimmee River	10.0	43.20	160.0	200.0
300521	Kissimmee River	10.0	42.95	160.0	200.0
300522	Kissimmee River	10.0	42.95	160.0	200.0
300523	Kissimmee River	10.0	42.95	160.0	200.0
300417	Kissimmee River	10.0	42.62	160.0	200.0
300418	Kissimmee River	10.0	42.62	160.0	200.0
300419	Kissimmee River	10.0	42.62	160.0	200.0
300420	Kissimmee River	10.0	42.62	160.0	200.0
300517	Kissimmee River	10.0	42.62	160.0	200.0
300524	Kissimmee River	10.0	41.59	160.0	200.0
300525	Kissimmee River	10.0	41.59	160.0	200.0
300530	Kissimmee River	10.0	40.42	160.0	200.0
300531	Kissimmee River	10.0	40.42	160.0	200.0
300526	Kissimmee River	10.0	39.43	160.0	200.0
300527	Kissimmee River	10.0	39.43	160.0	200.0
300528	Kissimmee River	10.0	39.43	160.0	200.0
300529	Kissimmee River	10.0	39.43	160.0	200.0
300532	Kissimmee River	10.0	38.26	160.0	200.0
300533	Kissimmee River	10.0	38.26	160.0	200.0
300534	Kissimmee River	10.0	38.26	160.0	200.0

300536	Kissimmee River	10.0	37.02	160.0	200.0
300537	Kissimmee River	10.0	37.02	160.0	200.0
300535	Kissimmee River	10.0	37.02	160.0	200.0
300538	Kissimmee River	10.0	36.18	160.0	200.0
300539	Kissimmee River	10.0	36.18	160.0	200.0
300540	Kissimmee River	10.0	36.18	160.0	200.0
300541	Kissimmee River	10.0	35.34	160.0	200.0
300542	Kissimmee River	10.0	32.31	160.0	200.0
300543	Kissimmee River	10.0	32.31	160.0	200.0
300544	Kissimmee River	10.0	32.31	160.0	200.0
300545	Kissimmee River	10.0	32.31	160.0	200.0
300546	Kissimmee River	10.0	32.31	160.0	200.0
300547	Kissimmee River	10.0	28.64	160.0	200.0
300548	Kissimmee River	10.0	28.64	160.0	200.0
300549	Kissimmee River	10.0	28.64	160.0	200.0
300555	Kissimmee River	10.0	27.14	180.0	220.0
300556	Kissimmee River	10.0	27.14	180.0	220.0
300557	Kissimmee River	10.0	27.14	180.0	220.0
300554	Kissimmee River	10.0	27.14	180.0	220.0
300558	Kissimmee River	10.0	26.11	180.0	220.0
300559	Kissimmee River	10.0	26.11	180.0	220.0
300560	Kissimmee River	10.0	26.11	180.0	220.0
300551	Kissimmee River	10.0	25.33	180.0	220.0
300552	Kissimmee River	10.0	25.33	180.0	220.0
300550	Kissimmee River	10.0	25.33	160.0	200.0
300553	Kissimmee River	10.0	25.33	180.0	220.0
300563	Kissimmee River	10.0	22.05	180.0	220.0
300564	Kissimmee River	10.0	22.05	180.0	220.0
300565	Kissimmee River	10.0	21.68	180.0	220.0
300566	Kissimmee River	10.0	21.61	180.0	220.0
300567	Kissimmee River	10.0	21.61	180.0	220.0
300568	Kissimmee River	10.0	21.61	180.0	220.0
300561	Kissimmee River	10.0	21.38	180.0	220.0
300562	Kissimmee River	10.0	21.38	180.0	220.0
300569	Kissimmee River	10.0	17.24	180.0	220.0
300570	Kissimmee River	10.0	17.24	180.0	220.0
300571	Kissimmee River	10.0	17.24	180.0	220.0
300572	Kissimmee River	10.0	17.24	180.0	220.0
300573	Kissimmee River	10.0	16.03	180.0	220.0
300574	Kissimmee River	10.0	16.03	180.0	220.0
300575	Kissimmee River	10.0	16.03	180.0	220.0
300576	Kissimmee River	10.0	11.30	180.0	220.0

300577	Kissimmee River	10.0	11.30	180.0	220.0
300578	Kissimmee River	10.0	11.30	190.0	230.0
300579	Kissimmee River	10.0	9.21	200.0	240.0
300580	Kissimmee River	10.0	8.02	210.0	250.0
300581	Kissimmee River	10.0	8.02	220.0	260.0
300582	Kissimmee River	10.0	6.27	230.0	270.0
300583	Kissimmee River	10.0	6.27	240.0	280.0
300584	Kissimmee River	10.0	6.27	250.0	290.0

Relied on best professional judgment using LIDAR from Pools A-D and adjusted for mesh cell discretization. [1]
LIDAR adjusted for dredging and spoil mounds. [2]
Calculated from depth, assumed side slope of 2.0 and top width. [3]
Relied on best professional judgment. [4]

Taylor Creek

The centerline for Taylor Creek was digitized from a USACE drainage map (USACE, **1909**).

Table F-27. Taylor Creek data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[1]	Top Width[3,4]
300648	Taylor Creek	4.0	36.77	59.0	75.0
300649	Taylor Creek	4.0	35.47	59.0	75.0
300650	Taylor Creek	4.0	34.16	59.0	75.0
300651	Taylor Creek	4.0	32.86	59.0	75.0
300652	Taylor Creek	4.0	31.55	59.0	75.0
300653	Taylor Creek	4.0	30.25	59.0	75.0
300654	Taylor Creek	4.0	28.3	59.0	75.0
300655	Taylor Creek	4.0	27.64	59.0	75.0
300656	Taylor Creek	4.0	26.33	59.0	75.0
300657	Taylor Creek	4.0	25.03	59.0	75.0
300658	Taylor Creek	4.0	23.72	59.0	75.0
300659	Taylor Creek	4.0	22.42	59.0	75.0
300660	Taylor Creek	4.0	21.1	59.0	75.0
300661	Taylor Creek	4.0	17.6	59.0	75.0
300622	Taylor Creek	4.0	17.4	59.0	75.0
300663	Taylor Creek	4.0	17.2	59.0	75.0

Relied on best professional judgment. [1]
Estimated from topography. [2]
Calculated from depth, assumed side slope of 2.0 and bottom width. [3]
Within range of 1859 GLO survey. [4]

F.6 INDIAN PRAIRIE WATERSHED AREA

Istokpoga Creek

The centerline for Istokpoga Creek was spatially derived from 1859 surveys (USDOI, **GLO survey data**).

Table F-28. Istokpoga Creek data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[1]	Top Width[3,4]
300735	Istokpoga Creek	2.0	30.48	40.0	48.8
300734	Istokpoga Creek	2.0	31.38	40.0	48.8
300732	Istokpoga Creek	2.0	32.35	40.0	48.8
300731	Istokpoga Creek	2.0	33.49	40.0	48.8
300730	Istokpoga Creek	2.0	33.97	40.0	48.8
300728	Istokpoga Creek	2.0	35.39	40.0	48.8

Relied on best professional judgment. [1]
Based on topographic elevation. [2]
Calculated from depth, assumed side slope of 2.0 and bottom width. [3]
Within range of 1859 GLO survey. [4]

Fisheating Creek

The centerline of Fisheating Creek was spatially derived from 1859 GLO surveys (USDOI, **GLO survey data**).

Table F-29. Fisheating Creek data.

NsRiv ID	Location	Depth[1]	Bottom Elev[2]	Bottom Width[1]	Top Width[3,4]
301067	Fisheating - North Trib	3.0	59.00	65.0	77.0
301069	Fisheating - North Trib	3.0	58.00	65.0	77.0
301070	Fisheating - North Trib	3.0	57.00	65.0	77.0
301071	Fisheating - North Trib	3.0	56.00	65.0	77.0
301072	Fisheating - North Trib	3.0	55.00	65.0	77.0
301074	Fisheating - North Trib	3.0	54.00	65.0	77.0
301075	Fisheating - North Trib	3.0	53.00	65.0	77.0
301076	Fisheating - North Trib	3.0	50.00	65.0	77.0
301077	Fisheating - North Trib	3.0	40.00	65.0	77.0
301078	Fisheating - North Trib	3.0	38.50	65.0	77.0
300387	Fisheating	3.0	44.71	40.0	52.0
300388	Fisheating	3.0	42.92	40.0	52.0
300389	Fisheating	3.0	42.06	40.0	52.0
300390	Fisheating	3.0	41.22	40.0	52.0
300391	Fisheating	3.0	40.34	40.0	52.0
300392	Fisheating	3.0	38.93	40.0	52.0
300393	Fisheating	3.0	38.05	85.0	97.0
300394	Fisheating	3.0	37.45	85.0	97.0
300395	Fisheating	3.0	36.75	85.0	97.0
300396	Fisheating	3.0	36.29	85.0	97.0
300397	Fisheating	3.0	35.39	85.0	97.0
300398	Fisheating	3.0	34.09	85.0	97.0
300399	Fisheating	3.0	31.64	85.0	97.0
300400	Fisheating	3.0	30.23	85.0	97.0
300401	Fisheating	3.0	28.75	85.0	97.0
300402	Fisheating	3.0	23.25	85.0	97.0
300403	Fisheating	3.0	22.25	85.0	97.0
300404	Fisheating	3.0	20.10	85.0	97.0
300405	Fisheating	3.0	18.43	85.0	97.0

300406	Fisheating	3.0	16.75	85.0	97.0
300407	Fisheating	3.0	15.10	85.0	97.0
300408	Fisheating	3.0	14.55	85.0	97.0
300409	Fisheating	3.0	13.74	85.0	97.0
300410	Fisheating	3.0	13.29	85.0	97.0
300411	Fisheating	3.0	12.75	95.0	107.0
300412	Fisheating	3.0	10.50	105.0	117.0
300413	Fisheating	3.0	9.38	115.0	127.0

Relied on best professional judgment. [1]
Estimated from topography. [2]
Calculated from depth, assumed side slope of 2.0 and bottom width. [3]
Within range of 1859 GLO survey. [4]

F.7 LOXAHATCHEE RIVER

Loxahatchee River (also known as Jupiter River)

Recent survey and bathymetric data verified against historical survey data, where available, was used for Loxahatchee River network development. (SFWMD and FDEP, **2009**; USGS, **DOQQs**; USCGS, **1884**).

Survey data from the SFWMD survey crews recorded primarily during 2003 was used for Northwest Fork river bed elevations (**Figure F-2**, **Table F-30**). To account for dredging, 2 ft.were added to the bottom elevation of each transect. Transects T8 and T10 are taken from Kitching Creek and the North Fork, respectively. It is assumed that there is no dredging at this part of the river. For both transects, the survey was stopped at the edge of water, therefore the bottom of the river may be slightly deeper.

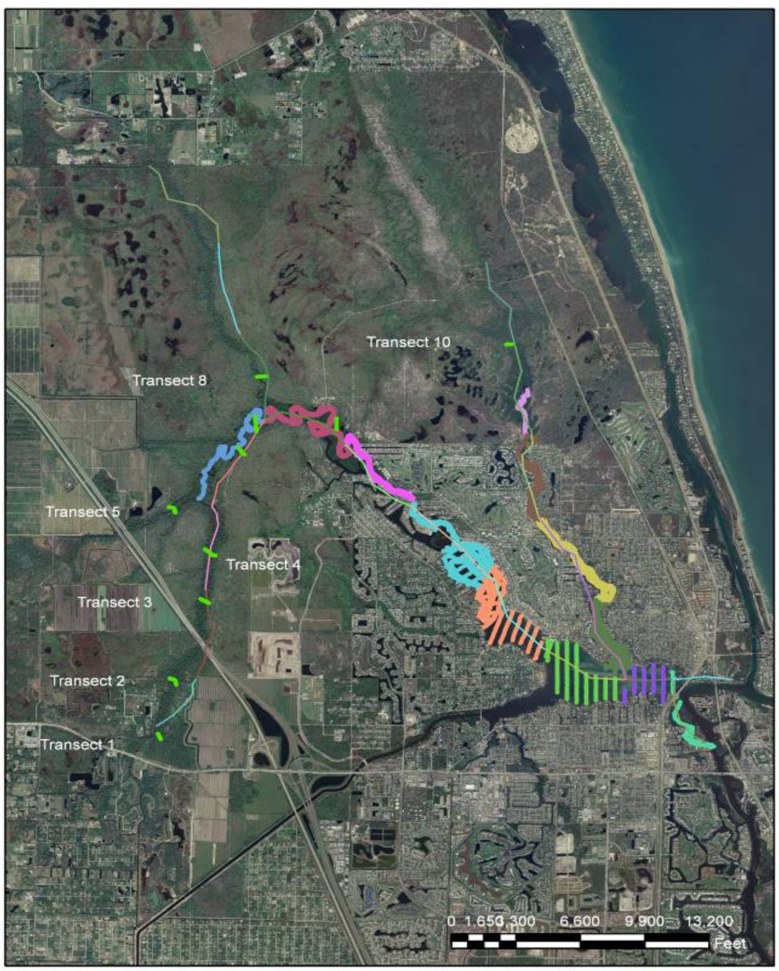

Figure F-2. SFWMD 2003 Loxahatchee River survey transects.

Bathymetric data was provided by the SFWMD (SFWMD and FDEP, **2009**). The data was used for river bed elevations in the Loxahatchee River (Jupiter River). To obtain a representative elevation of each network river segment, the data points were grouped spatially for each segment. An average bottom elevation was used for each spatial group and 2 ft.were added to the elevation to account for dredging.

Table F-30. Adjusted elevations for transects of Loxahatchee River Northwest Fork.

Transect	Bottom Elev	Adjusted Bottom Elev	Notes
T1	5.44	7.44	Assume 2' dredging
T2	3.07	5.07	Assume 2' dredging
T3	-9.87	-7.87	Assume 2' dredging
T4	-2.45	-0.45	Assume 2' dredging
T5	3.56	5.56	Assume 2' dredging
T8	0.77	0.77	Survey taken to edge of water
T10	5.97	5.97	Survey taken to edge of water

1884 U.S. Coast and Geodetic Survey

The river bottom elevations in the network were compared with historical soundings from an 1884 U.S. Coast and Geodetic Survey map (USCGS, **1884**; **Figure F-3**).

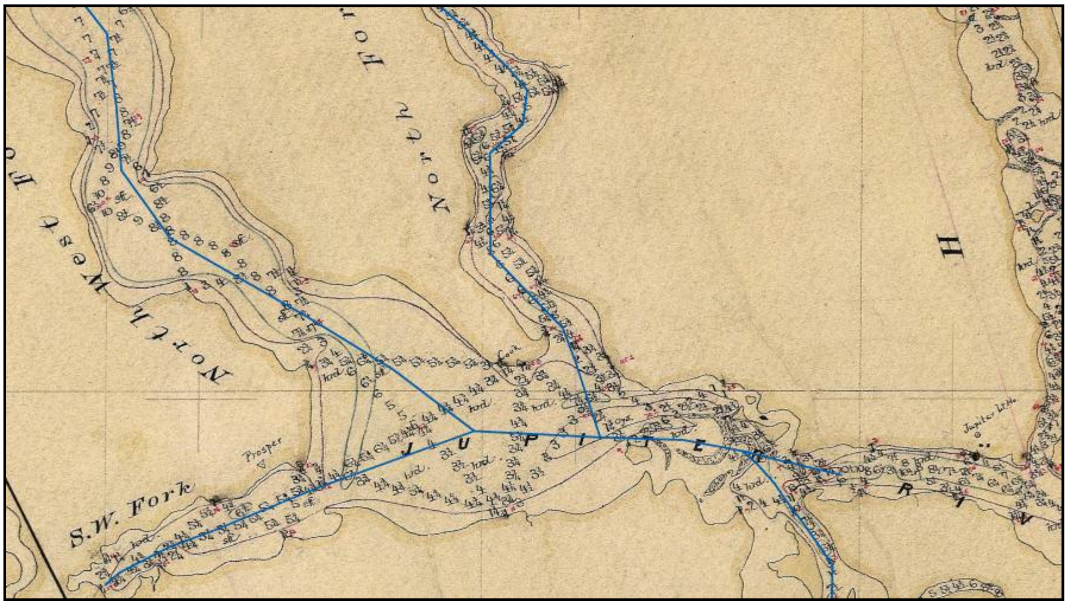

Figure F-3. 1884 U.S. Coast and Geodetic Survey of Loxahatchee (Jupiter) River.

The datum used for sounding data from the 1884 U.S. Coast and Geodetic Survey is mean low water. To convert the data to vertical datum NGVD29:

```
NOAA Station 8722481
NGVD29 = 0.58′
MLW = 0.15′
100 yr Sea level rise = 0.78′
```

$MLW_{100} = 0.15' - 0.78' = -0.63'$

$MLW_{NGVD29\ 100} = -0.63' - 0.58' = -1.21'$

$NGVD29_{100} = -1.21' - \text{sounding}$

Composite Dataset

A composite dataset was used for the Loxahatchee River consisting of transect data and bathymetry (SFWMD and FDEP, **2009**), DOQQ (USGS, **DOQQs)** and the 1884 U.S. Coast and Geodetic Survey (USCGS, **1884**).

Table F-31. Loxahatchee River composite dataset.

NsRiv ID	Location	Depth	Bottom Elev	Bottom Width[11]	Top Width
301023	Jupiter River	8.0[6]	-9.64[6]	400.0	432.0[6]
301005	Jupiter River	4.5[6]	-10.63[6]	1300.0	1318.0[6]
301025	Jupiter River	5.0[6]	-10.78[6]	1100.0	1120.0[6]
301012	Jupiter River - Kitching Creek	5.0[1]	-6.73[7]	100.0	120.0[7]
301011	Jupiter River - Kitching Creek	5.0[1]	-6.98[7]	100.0	120.0[7]
301010	Jupiter River - Kitching Creek	5.0[1]	-7.23[8]	100.0	120.0[8]
301017	Jupiter River - North Fork	2.0[1]	-7.80[4]	75.0	83.0[4]
301016	Jupiter River - North Fork	5.0[1]	-7.90[9]	160.0	180.0[9]
301015	Jupiter River - North Fork	5.0[1]	-8.00[4]	300.0	320.0[4]
301014	Jupiter River - North Fork	5.0[1]	-8.47[4]	400.0	420.0[4]
301013	Jupiter River - North Fork	5.0[1]	-9.22[4]	500.0	520.0[4]
301021	Jupiter River - Northwest Fork	5.0[1]	-0.75[2]	100.0	120.0[2]
301020	Jupiter River - Northwest Fork	5.0[1]	-2.00[4]	100.0	120.0[4]
301019	Jupiter River - Northwest Fork	5.0[1]	-7.92[3]	100.0	120.0[3]
301009	Jupiter River - Northwest Fork	5.0[1]	-8.23[4]	150.0	170.0[4]
301018	Jupiter River - Northwest Fork	5.0[1]	-8.27[4]	100.0	120.0[4]
301008	Jupiter River - Northwest Fork	7.25[6]	-10.04[6]	300.0	329.0[6]
301024	Jupiter River - Northwest Fork	5.25[6]	-10.21[6]	1000.0	1021.0[6]
301006	Jupiter River - Northwest Fork	7.5[6]	-10.76[6]	800.0	830.0[6]
301007	Jupiter River - Northwest Fork	6.0[6]	-10.87[6]	500.0	524.0[6]
301031	South West Fork - Jupiter River	5.0[1]	-8.51[1]	100.0	120.0[10]
301032	South West Fork - Jupiter River	5.0[1]	-8.52[1]	150.0	170.0[10]

301030	South West Fork - Jupiter River	5.5[6]	-8.53[6]	600.0	622.0[6]
301026	South West Fork - Jupiter River	5.0[6]	-8.53[6]	400.0	420.0[6]
301033	South West Fork - Tributary	5.0[1]	-8.47[1]	100.0	120.0[10]
301034	South West Fork - Tributary	5.0[1]	-8.48[1]	100.0	120.0[10]
301035	South West Fork - Tributary	5.0[1]	-8.49[1]	100.0	120.0[10]
301036	South West Fork - Tributary	5.0[1]	-8.50[1]	100.0	120.0[10]
301037	South West Fork - Tributary	5.0[1]	-8.51[1]	100.0	120.0[10]
301038	South West Fork - Tributary	5.0[1]	-8.52[1]	100.0	120.0[10]

Relied on best professional judgment. [1]
Average of transects T1 and T2. [2]
Average of transects T3 and T4. [3]
Best estimate using T10. [4]
Best estimate using T3 and T4. [5]
1884 U.S. Coast and Geodetic Survey map; includes adjustments for mesh discretization. [6]
Best estimate using T8. [7]
Transect T8; includes adjustments for mesh discretization. [8]
Transect T10; includes adjustments for mesh discretization. [9]
Estimated using DOQQ. [10]
Calculated using depth, side slope of 2 and top width. [11]

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*This file "McVoy_2000_Unpublished.pdf" is available on request.

Appendix G
Tidal and Flow Boundary Conditions

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G.1 TIDAL BOUNDARY CONDITIONS

Twelve NOAA tidal stations used to define coastal boundary conditions for the NSRSM are shown in **Figure G-1**. Tidal data were obtained from the NOAA website (NOAA **website**). **Table G-1** is used to calculate high and low water lag times for secondary stations based on recorded times for two primary stations, Naples and Virginia Key.

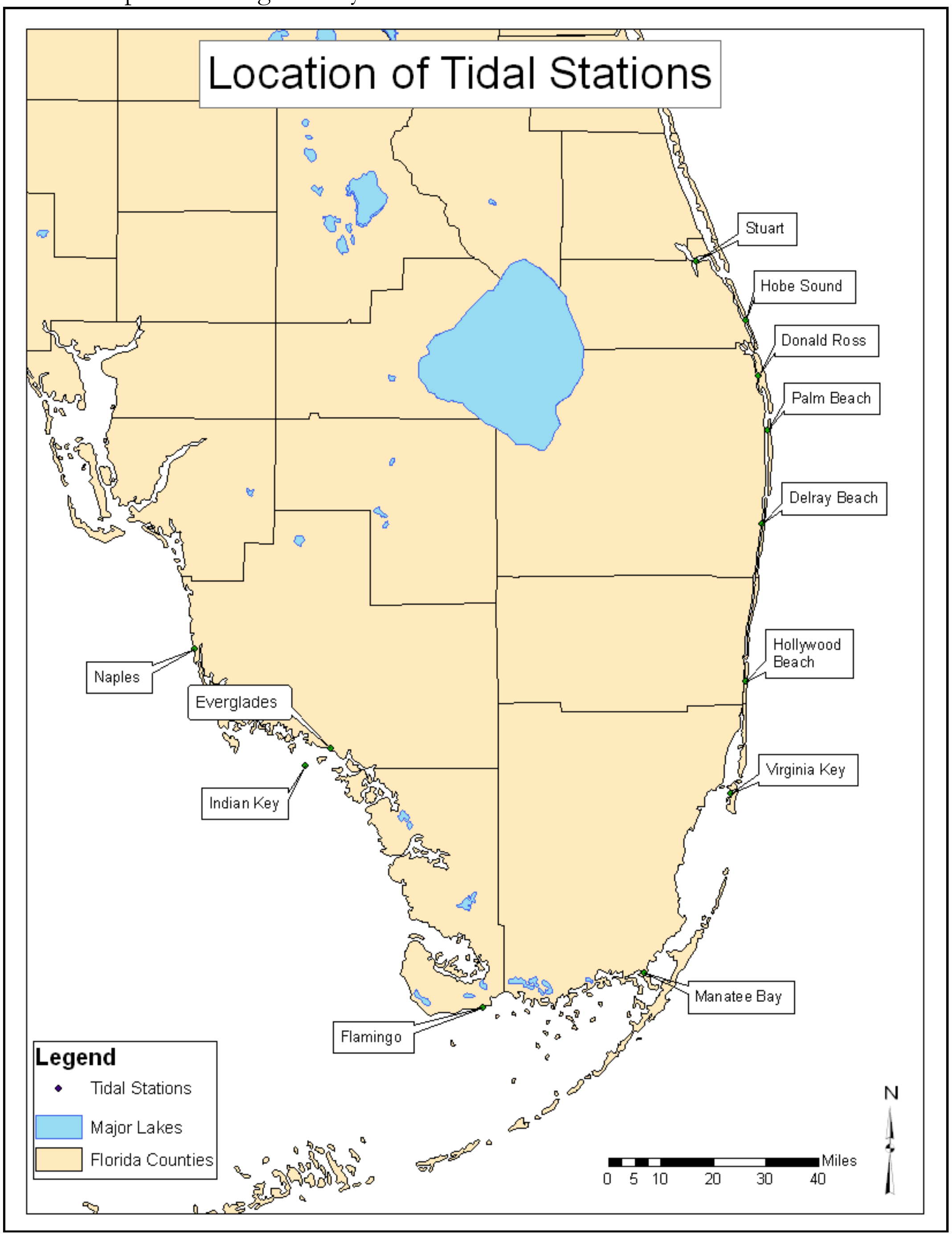

Figure G-1. Tidal stations used to define coastal boundary conditions for the NSRSM.

Table G-1. National Oceanic Service Products and Services Division constants used to compute water level for secondary stations.

Tidal Station	Time: High Water	Time: Low Water	Constant
Naples Primary Station			
Manatee Bay, FL	1 hr 14 min	2 hr 3 min	0.163
Flamingo Bay, FL	3 hr 5 min	4 hr 28 min	0.837
Indian Key, FL	47 min	1 hr 2 min	1.486
Everglades City, FL	2 hr 23 min	3 hr 25 min	0.983
Virginia Key Primary Station			
Stuart	1 hr 44 min	2 hr 41 min	0.483
Hobe Sound	59 min	1 hr 35 min	0.778
Donald Ross	-8 min[1]	1 min	1.148
Palm Beach	-41 min[1]	-35 min[1]	1.365
Delray Beach	53 min	1 hr 16 min	1.243
Hollywood Beach	8 min	15 min	1.017

[1]The negative time represents the lag time for high and low water measurements. The lag time is used to adjust tidal measurements for the secondary tidal station based on the primary station. Note that the NSRSM tidal boundary conditions use 2 primary tidal stations: Naples, FL and Virginia Key, FL.

Datum conversion from MLLW to NGVD29

Figures G-2 and G-3 and the following formula describe the conversion process from Mean Lower Low Water (MLLW) to National Geodetic Vertical Datum of 1929 (NGVD29) via The North American Vertical Datum of 1988 (NAVD88) when the difference between MLLW and NGVD29 is unknown and the shift values from MLLW to NAVD88 and NAVD88 to NGVD29 are known.

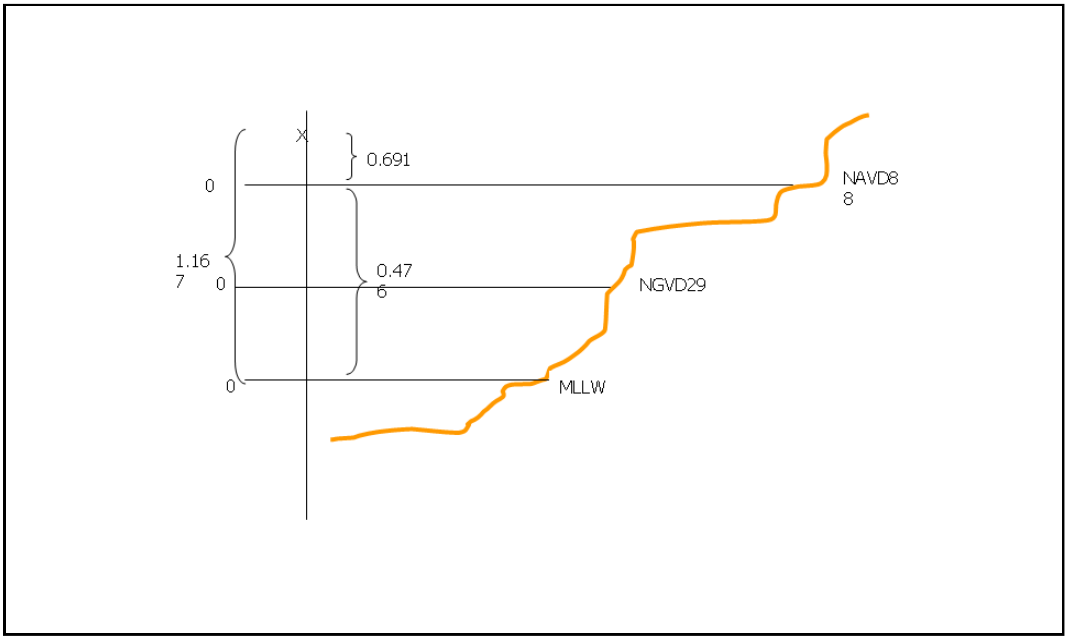

Figure G-2. Case 1 - Conversion process from MLLW to NGVD29 via NAVD88.

For this particular case:

NGVD29 = NAVD 88 + [Δ NAVD88 and NGVD29] (**4.1**)

NAVD88 = NGVD29 – [Δ NAVD88 and NGVD29] (**4.2**)

MLLW = NAVD88 + [Δ MLLW and NAVD88] (**4.3**)

NAVD88 = MLLW – [Δ MLLW and NAVD88] (**4.4**)

By replacing the value of NAVD88 from **Equation 4.4** in **Equation 4.1**, we have:

NGVD29 = (MLLW – [ΔMLLW and NAVD88]) + [ΔNAVD88 and NGVD29] (**4.5**)

(ΔMLLW and NAVD88) is a given value for the reference stations in National Oceanic and Atmospheric Administration National Ocean Service (NOAA/NOS) website, (ΔNAVD88 and NGVD29) can be computed with VERTCON (NOAA **VERTCON website**), and raw data are already referenced to the MLLW datum. VERTCON is a North American vertical datum conversion utility provided by the National Geodetic Survey.

Example:

For Virginia Key (ΔMLLW and NAVD88) is 0.608 m and datum shift from NAVD88 to NGVD29 or (ΔNAVD88 and NGVD29) computed with VERTCON is (-0.476).

To convert a water level referenced in MLLW for Virginia Key to NGVD29 we can replace the value referenced in MLLW in **Equation 4.5**, by using the datum shift value from NAVD88 to NGVD29 and (ΔMLLW and NAVD88) for Virginia Key.

For a water level = -0.037m referenced in MLLW datum we have:

NGVD29 = -0.037 -0.608+0.476 ⇒ NGVD29 = -0.169m

VERTCON output for Virginia Key.

Latitude: 25 43.9

Longitude: 80 09.7

NGVD29 Height: 1.008

Datum shift (NAVD88 minus NGVD 29): -0.476 meters

Converted to NAVD88 height: 0.532 meters

Latitude: 25 43.9

Longitude: 80 09.7

NAVD88 Height: 1.008

Datum shift (NAVD88 minus NGVD 29): -0.476 meters

Converted to NGVD29 height: 1.484 meters

Table G-2. Calculation of tides for the coastal NSRSM boundary conditions.

Tidal station	NOAA constant	Δ(MLLW and NAVD88)	Δ(NAVD88 and NGVD29	Δ(MLLW and NGVD29)
Naples	1	-	-	0.305
Equation	NGVD29 ft.=(Naples MLLW-0.305)*3.28083 PID AD5731			
Virginia Key	1	0.608	0.476	-
Equation	NGVD29 ft.=(Virginia MLLW-0.608+0.476)*3.28083 PID AC2154			
Secondary Stations using Naples Coast as reference				
Manatee Bay	0.163	-	-	0.07
Equation	NGVD29 ft.=(0.163*Naples MLLW+0.07)*3.28083 PID AC3299			
Flamingo Bay	0.837	0.64	0.447	-
Equation	NGVD29 ft.=(0.837*Naples MLLW-0.64+0.447)*3.28083			
Indian Key	1.486	-	-	0.216
Equation	NGVD29 ft.=(1.486*Naples MLLW-0.216)*3.28 PID AC0625			
Everglades City	0.983	0.632	0.419	-
Equation	NGVD29 ft.=(0.983*Naples MLLW-0.632+0.419)*3.28083 PID AC0625			
Secondary Stations using Virginia Key as reference				
Stuart	0.483	0.418	0.445	-
Equation	NGVD29 ft.=(0.483*Virginia MLLW-0.418+0.445)*3.28083 PID AF3145			
Hobe Sound	0.778	0.592	0.455	-
Equation	NGVD29 ft.=(0.778*Virginia MLLW-0.592+0.455)*3.28083 PID AF6989			
Donald Ross	1.148	0.722	0.460	
Equation	NGVD29 ft.=(1.148*Virginia MLLW-0.722+0.460)*3.28083 PID AD2897 and PID AD6273			
Palm Beach	1.365	0.805	0.465	-
Equation	NGVD29 ft.=(1.365*Virginia MLLW-0.805+0.465)*3.28083 PID AD0670			
Delray Beach	1.243	0.691	0.469	
Equation	NGVD29 ft.=(1.243*Virginia MLLW-0.691+0.469)*3.28083 PID AD5817			
Hollywood Beach	1.017	-	-	0.152
Equation	NGVD29 ft.=(1.017* Virginia MLLW-0.152)*3.28083 PID AD5895			

Tidal benchmarks (PID) on which the adjustments are based are listed in red.

The shift value remains the same from NAVD88 to NGVD29 or from NGVD29 to NAVD88 for the same coordinates or the same tidal station. The calculations of tides at the secondary stations are provided in **Table G-2**. In some cases, the shift value from MLLW to NGVD29 is known and a direct conversion can be made.

Processing diagram

An overview of the process from tidal raw data collection to the final dataset is given in the diagram shown below.

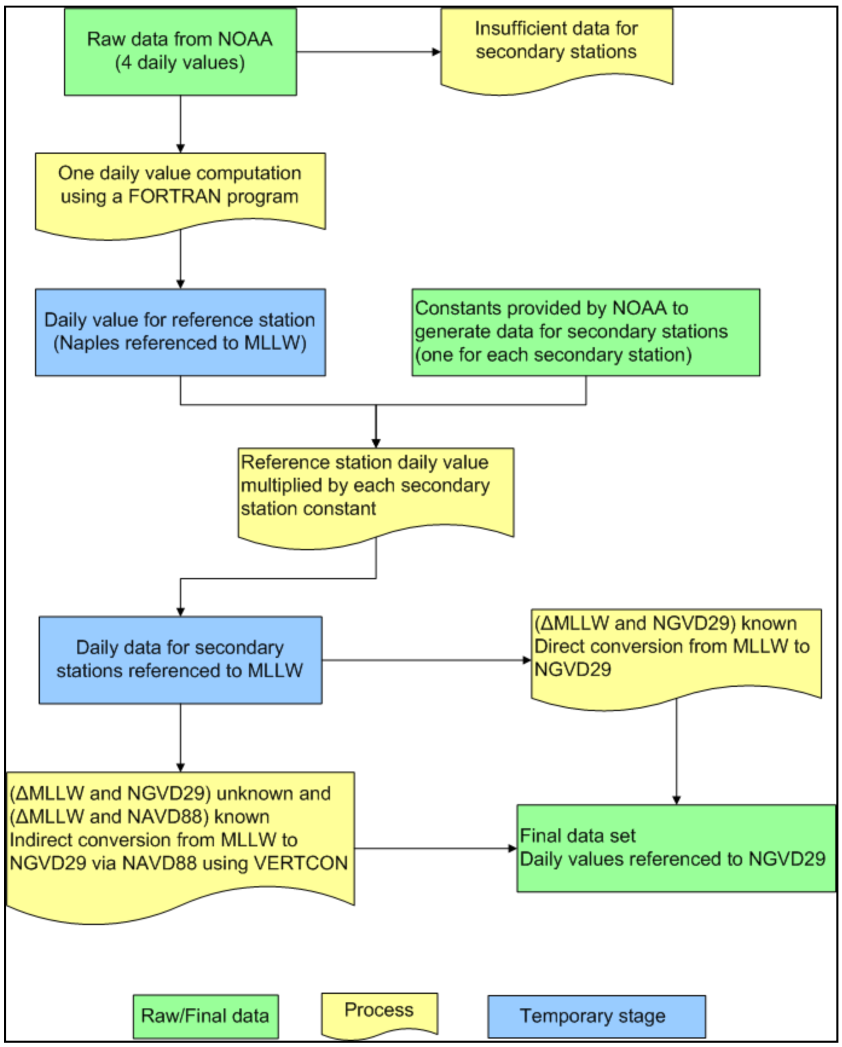

Figure G-3. Process diagram.

G.2 SEALINK MODEL

The upper extent of the Kissimmee River provides the NSRSM with flows from outside the model domain. Under predrainage conditions all overland flow from the Upper Kissimmee Basin (UKB) are assumed to collect in Lake Kissimmee and flow naturally into the Kissimmee River and into the Lower Kissimmee Basin (LKB).

The Sealink model (VanZee, **1994**) was used to simulate the runoff from the UKB that is assumed to drain through Lake Kissimmee and into the LKB. This flow input boundary condition was used for the NSRSM northern most boundary into the Kissimmee River and the LKB. The period of record for which Sealink was calibrated for the UKB was 1965 to 2000. This calibration was done using both Kissimmee basins and using historical flows from structures S-65E and S-65 where available. Only the UKB portion of this calibrated model is being used in the NSRSM.

Sealink was designed to simulate the movement of water within basins that are nearly level, poorly drained, and subject to frequent flooding. It is a field scale, root zone model using a daily time step. Sealink models the rainfall-runoff, infiltration, evapotranspiration (ET), irrigation, and seepage processes. It uses a variation of the Interactive Water Balance Model (ISWAB) developed at the SFWMD (Obeysekera, **198**-) to simulate regional movement of water. The ISWAB conceptualizes a basin as an array of storage tanks. Each column of tanks represents a subbasin. Within a subbasin, water moves vertically between a column of three tanks: surface storage, soil storage and groundwater storage. The vertical movement of water represents infiltration, ET and deep percolation processes of the hydrologic cycle. Flow between columns represents surface runoff, ground water flow, and base flow between subbasins. Equations with calibrated coefficients act as valves to control flow between storage tanks.

Although the concepts from the ISWAB model are used, Sealink replaces the soil storage tank in the ISWAB model with a series of field scale root zone models. Each "land use" within a subbasin is represented by a root zone similar to those in the CREAMS-WT model (Heatwole *et al.* **1984**). The root zone model uses daily rainfall, pan evaporation, soil and land use parameters, to simulate runoff, ET, seepage, base flow, soil water content and water table depth for each land use in each subbasin. The volume of runoff and base flow simulated by each root zone model is added to the respective subbasin surface storage. Similarly the volume of deep seepage is added to the respective subbasin groundwater storage.

Wetland areas can be designated within a subbasin. Sealink maintains water table levels in a wetland using base flow contributions from the other land use areas in the subbasin. The quantity of flow between the wetland and other land uses is a function of a hydraulic conductivity coefficient.

In addition to the NSRSM base condition simulation (1965 to 2005), a run was conducted for a 100-year boundary condition input to the NSRSM which has a period of record of 1885 to 1993. For this, 100-year period of record, the model was not calibrated. The runoff output from Sealink was compared to flow data at S-65 which exists from 1933 forward. The computed Sealink flows did approximate the measured flows observed at S-65 reasonably well for the period 1933 to 1993. It should be noted that from 1965 to 1993 the flows do not match as well as actual measured flows begin to exhibit operational management trends and not the natural flow regime (**Figure G-4)**.

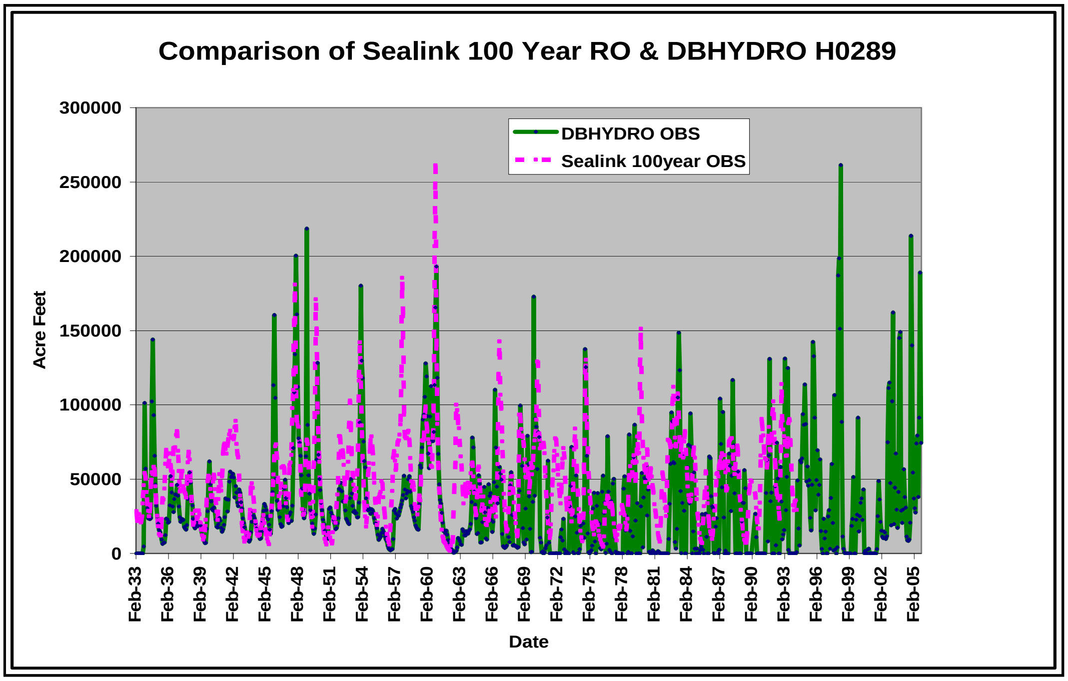

Figure G-4. Comparison of Sealink data.

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Appendix H
Lake Support Data

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H.1 LAKE OKEECHOBEE

Lake Okeechobee is modeled using the RSM lake package (SFWMD, **2005**). The required inputs are stage-area and stage-volume relationships. Three feature classes were used to construct the surface and are listed below.

The bounding polygon is the 1913 boundary of Lake Okeechobee, shown in **Figure H-1 (**US Army, **1913)**. The map was scanned and rectified. Lake bathymetry was obtained from a 1925 U.S. Coast and Geodetic Survey (USCGS, **1925**). Survey H04473 and Survey H04474 contained images of the original drawings and coordinates for each sounding location. The soundings were converted from mean low water Punta Rassa to National Geodetic Vertical Datum of 1929 (NGVD 1929). In order to produce a more historical representation, all artifacts of dredging were removed.

Contours surrounding the lake are the South Florida Water Management District District-wide U.S. Geological Survey topographic 5-foot contours based on original contour work on 7.5 minute quads (1:24K) by the USGS (USGS, **DOQQs**). These sources were used to construct a Triangular Irregular Network (TIN). In an effort to construct a more historical representation, 30 years of sedimentation were removed. Lake Okeechobee has an average of 1 centimeter per decade of sedimentation (Brezonik and Engstrom, **1998**) or 3 centimeters for a 30-year historical period. A GRID math was used to uniformly subtract the historical sedimentation buildup of 3 centimeters (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 historical bathymetric elevation GRID. The stage-area and stage-volume table are shown graphically in **Figure H-2**.

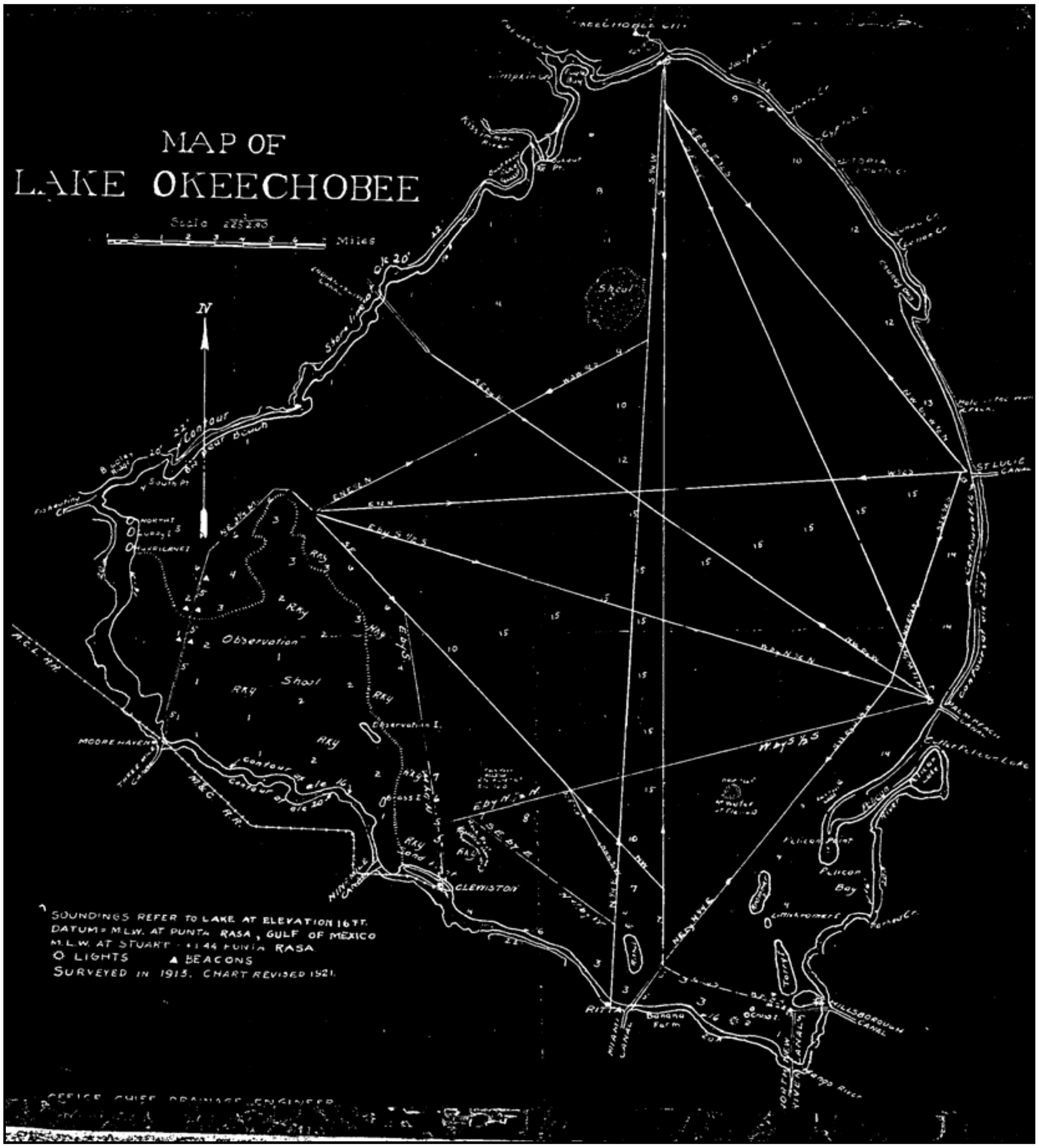

Figure H-1. 1913 Lake Okeechobee boundary.

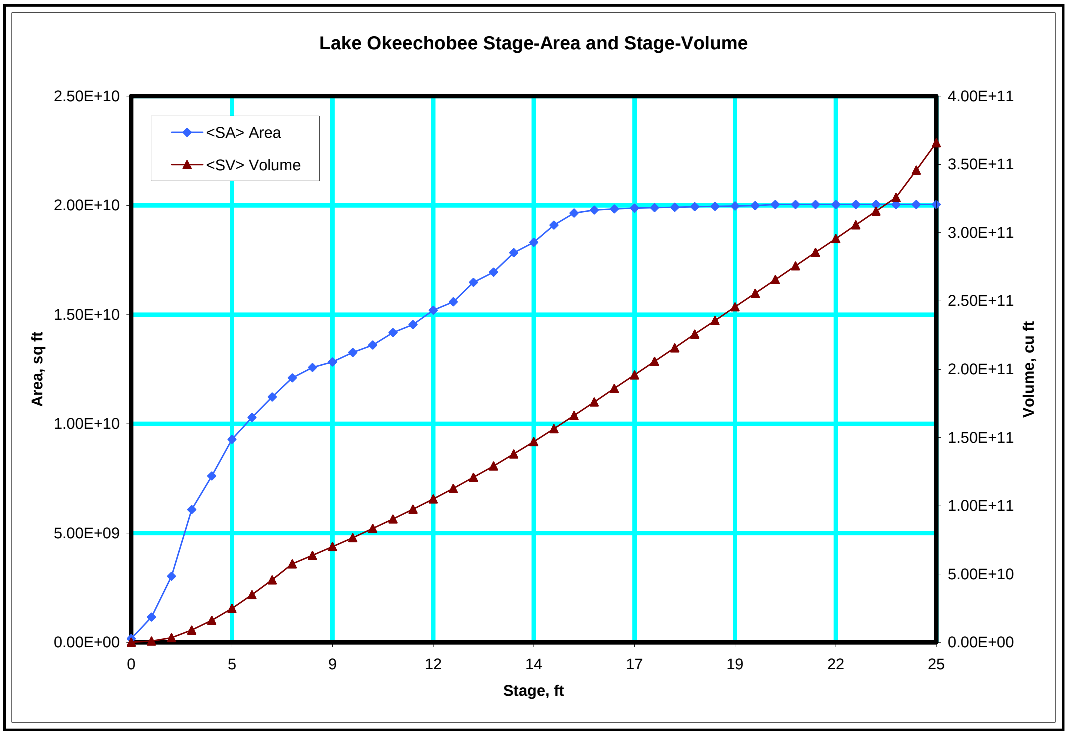

Figure H-2. Graph of Lake Okeechobee stage-area and stage-volume table.

H.2 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 H-1** defines Lake Istokpoga's inflow during the 1965 to 2000 period of record as a boundary condition.

Table H-1. 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 (SFWMD, **2003**). 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 H-2**. 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 H-3**.

Table H-2. 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>
```

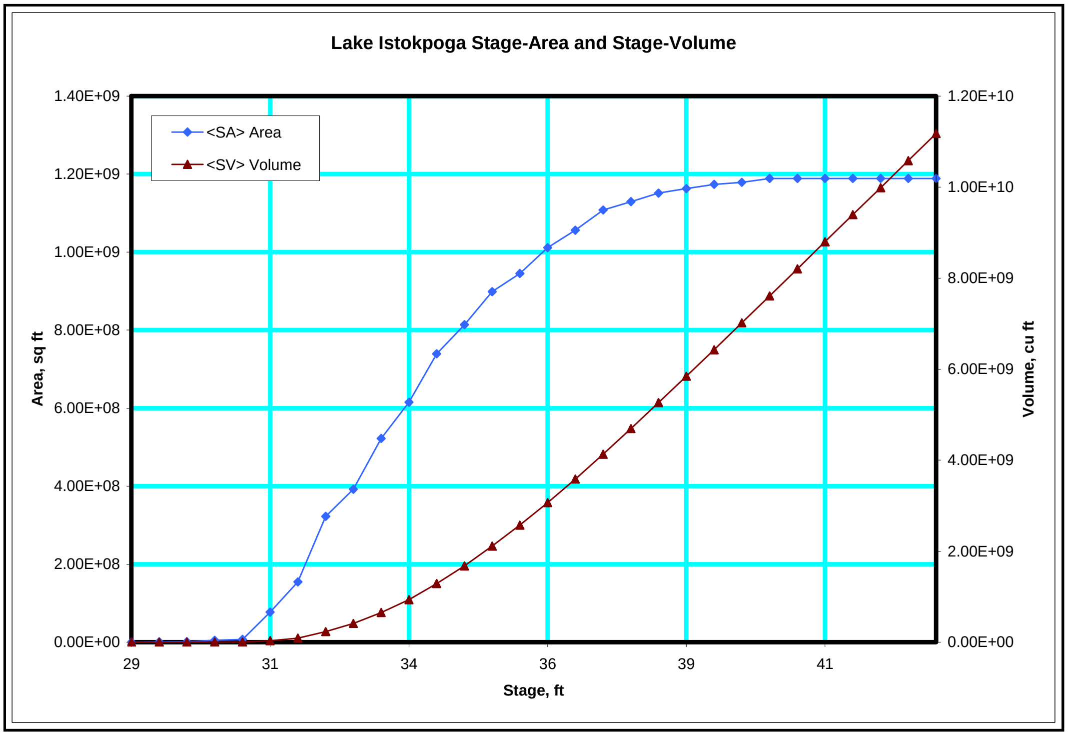

Figure H-3. Graph of Lake Istokpoga stage-area and stage-volume table.

H.3 ST. LUCIE ESTUARY

The St. Lucie Estuary is implicitly modeled using the RSM lake package (SFWMD, **2005**). The inputs were developed from bathymetric input from the U.S. Coast and Geodetic Survey in 1883 (USCGS, **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, Florida. The rise in mean sea level was compared at current and previous epochs. The difference was 0.20 ft., 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 ft. NGVD 29, therefore the mean low water 100 years ago is estimated at -0.72 ft. NGVD 29 in 1884.

Since the soundings on the 1883 map represent depth below mean low water, the sounding value needs to be converted to NGVD 29:

NOAA Station 8722371
NGVD29 = 0.15′
MLW = 0.12′
100 yr Sea level rise = 0.78′

MLW_{100} = 0.12′ – 0.78′ = -0.66′
$MLW_{NGVD29\ 100}$ = -0.66′ – 0.15′ = -0.81′
$NGVD29_{100}$ = -0.81′ – sounding

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 H-4**.

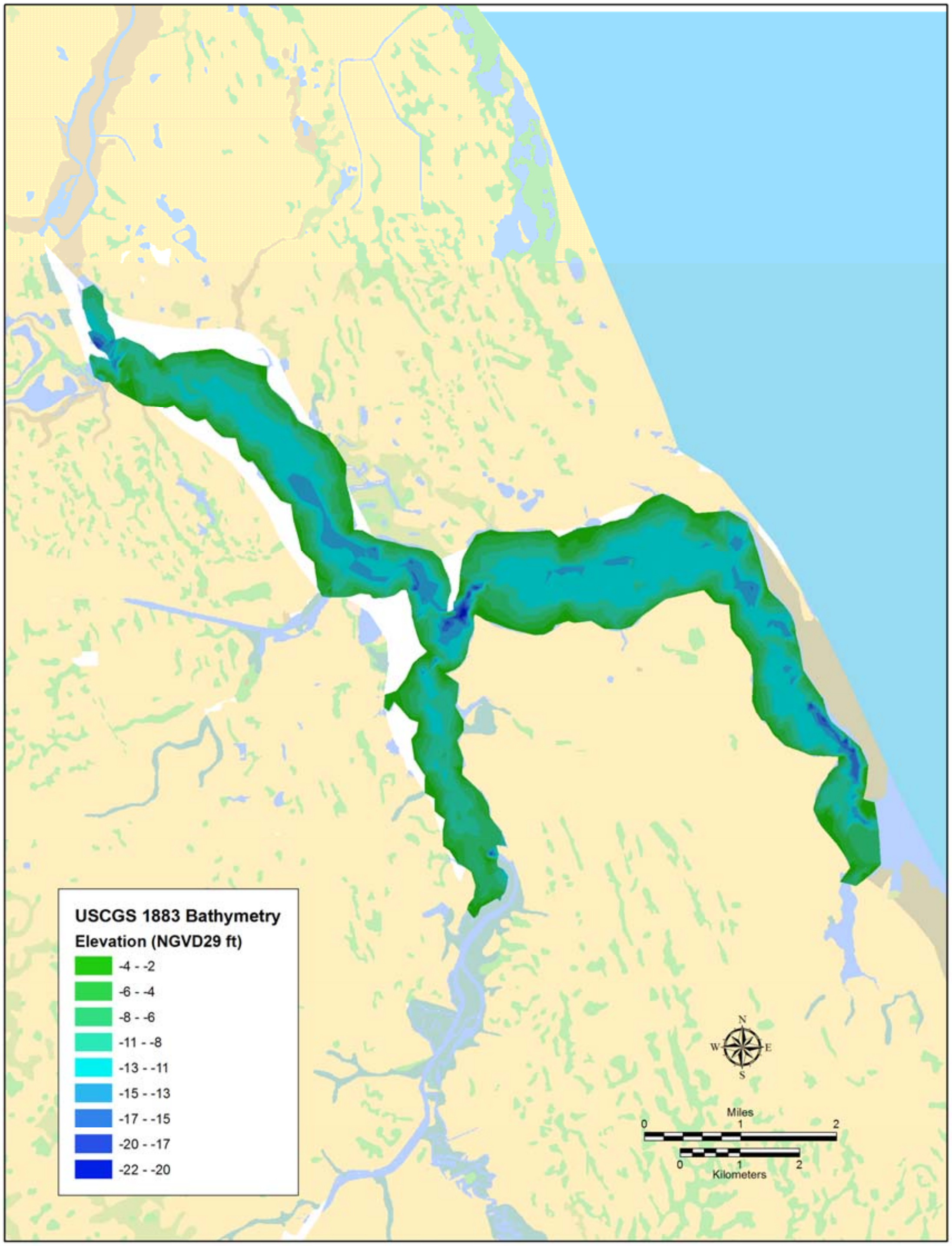

Figure H-4. St. Lucie Estuary bathymetry.

The XML defining the St. Lucie Estuary is presented in **Table H-3**. The stage-area and stage-volume table are omitted from the text below but are shown graphically in **Figure H-5**.

Table H-3. 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>
```

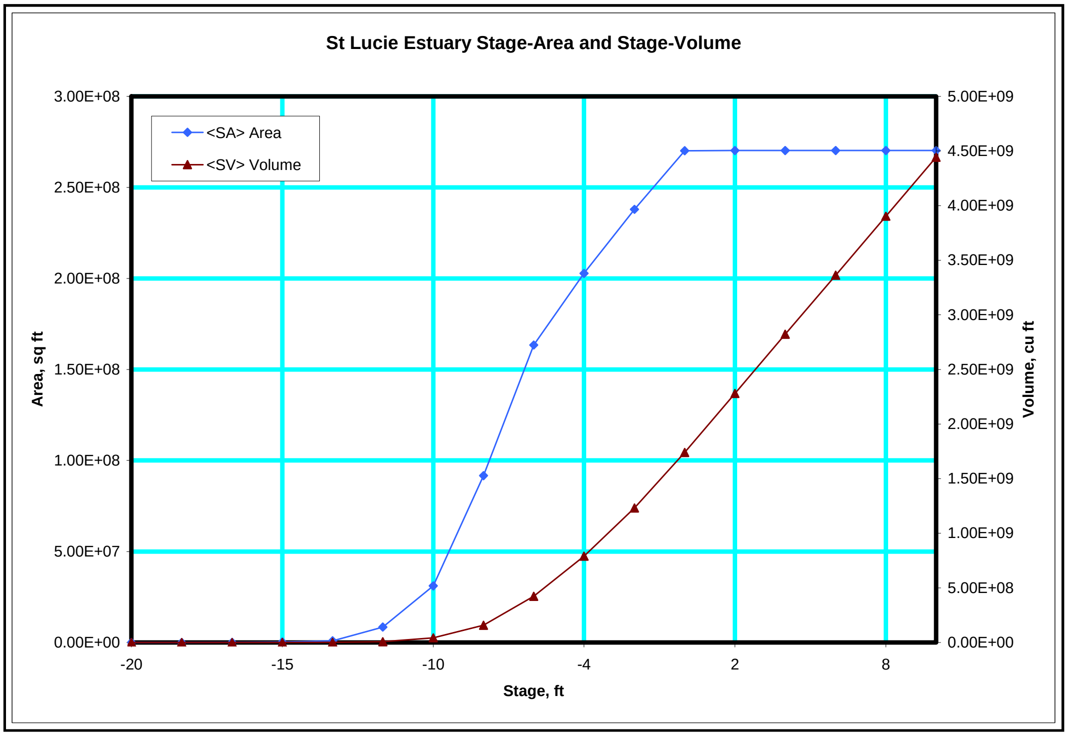

Figure H-5. Graph of the St. Lucie Estuary stage-area and stage-volume.

REFERENCES

Brezonik, P. L., and D. R. Engstrom. 1998, Modern and historic accumulation rates of phosphorus in Lake Okeechobee, Florida. *Journal of Paleolimnology*., 20: 31-46.

South Florida Water Management District, 2003. GIS Data Catalog Bathymetry Data for Lake Istokpoga. IT Bureau, Enterprise Application Section. West Palm Beach, FL

South Florida Water Management District, 2005. Regional Simulation Model—Hydrologic Simulation Engine (HSE) User Manual. SFWMD, West Palm Beach, FL.

U.S. Army, 1913. Office of Chief Drainage Engineer, Map of Lake Okeechobee.

U.S. Coast and Geodetic Survey, 1883. (available at http://maps.ngdc.noaa.gov/viewers/nos_hydro/).

U.S. Coast and Geodetic Survey, 1925. Surveys H04473 and H04474 (available at http://maps.ngdc.noaa.gov/viewers/nos_hydro/).

U.S. Geological Survey. 2004-2005 Digital Ortho Quarter Quads (DOQQs) 1-Meter Natural Color Aerial Photography.

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Appendix I
Model Stability

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I.1 STABILITY REPORT

Report of Standard RSM Model Checks/Tests for NSRSM v3.5.2

The Hydrologic and Environmental Systems Modeling (HESM) Application/Implementation teams need to analyze all aspects of model output in order to become comfortable and confident with the results. Three types of analyses are considered standard modeling practices and are conducted as standard HESM practice.

In this report, the three types of analyses are applied to the current version of the Natural System Regional Simulation Model (NSRSM). The first analysis examines the entire output and consists of two checks. A check of mass violation is reported for each time step and is performed during model execution (**Lal, 2000**). Once the model has successfully executed, a water budget is developed for lakes, cells, and rivers. A water budget will ensure a proper model conceptualization. The next analysis inspects the model for instabilities. This is accomplished by examining the minimum water level, maximum water level, and maximum time step change of water levels. A close examination of the maximum time step of water levels may be able to identify any oscillations. The last analysis is to calibrate and verify the model. This is addressed in the NSRSM by comparing select data with historical observations.

An additional guideline that examines the amplification ratio is in the development phase and is currently not in use. The NSRSM team is providing support to the developers for this development effort.

Mass Violation and Water Budget

A check for mass violation is reported for each model time step. The NSRSM exhibits no mass violation at any time step during the entire simulation period of record (January 1, 1965 to December 31, 2005). All water budgets presented herein represent an average annual flow (k-ac-ft) from January 1, 1966 to December 31, 2005.

Lake Okeechobee

The water budget for Lake Okeechobee balances with a negligible 0.2% error. **Table I-1** represents the average annual water budget for the period of record (POR) from 1966 through 2005. Average annual rainfall and computed evapotranspiration (ETc) for the POR are 42.6 in. and 54.4 in., respectively. This is well within the reference range for open water ET. The lake inflow/outflow is the net overland and groundwater flow into the lake. The river inflow/outflow represents the net inflows from Fisheating Creek, Kissimmee River, and Taylor Creek. The value -974.8 k-ac-ft represents the net water flowing out of the lake.

A more detailed description of lake outflow is presented in the model results (Appendix K).

Table I-1. Average annual water budget for the period of record from 1966-2005.

Lake Component	Flow (k-ac-ft)
Rainfall	1,634.5
Computed ET	-2,086.4
Lake Inflow/Outflow	-974.8
River Inflow/Outflow	1,431.9
Residual	0.0
WBDelta	5.2
WBError	0.0
Percent Error	0.2%

Caloosahatchee River

The water budget for the Caloosahatchee River balances with a percent error of 0.3 percent. A majority of the water flow entering the river network is from seepage. The next significant inflow into the river network is from a direct connect of the cells to river segments ("Cell To Riv" component). The outflow of -925.9 k-ac-ft occurs through a time-varying specified head boundary condition at the location of present day S-65.

Table I-2. Caloosahatchee River water budget.

River Component	Flow (k-ac-ft)
Seepage	694.5
Outflow	-925.9
Cell To Riv	225.9
Residual	0.0
WBDelta	0.1
WBError	-5.7
Percent Error	0.3%

Fisheating Creek

The water budget for Fisheating Creek balances with a percent error of 0.0 percent. A majority of the flow entering the river network is due to seepage. The outflow component of -92.2 k-ac-ft is from the direct river to cell connection. Nearly 50% of the water that enters Fisheating Creek is discharged to Lake Okeechobee.

Table I-3. Fisheating Creek water budget.

River Component	Flow (k-ac-ft)
Seepage	185.3
Outflow to LOK	-95.9
Cell To Riv	-92.2
Residual	0.0
WBDelta	0.0
WBError	-2.8
Percent Error	0.0%

Kissimmee River

The water budget for the Kissimmee River balances with a percent error of 0.0 percent. A majority of the flow enters the river network from the upstream boundary condition ("Lower Kissimmee BC" component). The next significant inflow source is from Istokpoga Creek and seepage. The entire outflow is discharged to Lake Okeechobee.

Table I-4. Kissimmee River water budget.

River Component	Flow (k-ac-ft)
Seepage	325.6
Lower Kissimmee BC	740.0
Inflow - Istok Creek	56.7
Outflow to LOK	-1218.2
Cell To Riv	96.0
Residual	0.0
WBDelta	0.2
WBError	0.0
Percent Error	0.0%

Taylor Creek

The water budget for Taylor Creek balances with a percent error of 0.0 percent. A majority of the flow enters the river network from seepage. Most of the outflow is discharged to Lake Okeechobee.

Table I-5. Taylor Creek water budget.

River Component	Flow (k-ac-ft)
Seepage	90.7
Outflow to LOK	-117.9
Cell To Riv	27.1
Residual	0.0
WBDelta	0.0
WBError	-0.1
Percent Error	0.0%

St. Lucie River System

The water budget for the St. Lucie River system balances with a percent error of 0.0 percent. A majority of the flow enters the river network from seepage. The outflow is discharged to the St. Lucie Estuary.

Table I-6. St. Lucie River system water budget.

River Component	Flow (k-ac-ft)
Seepage	653.9
Flow to STL Estuary	-772.3
Cell To Riv	118.3
Residual	0.0
WBDelta	0.0
WBError	-0.2
Percent Error	0.0%

Jupiter River System

The water budget for the Jupiter River system balances with a percent error of 0.0 percent. A majority of the flow enters the river network from seepage. A small component enters the system from the cells ("Cell to Riv" component). The outflow is discharged to the Atlantic Ocean.

Table I-7. Jupiter River system water budget.

River Component	Flow (k-ac-ft)
Seepage	468.9
Outflow to Ocean	-470.2
Cell to Riv	1.2
Residual	0.0
WBDelta	0.0
WBError	0.0
Error	0.0%

Lower East Coast River System

The water budget for the Lower East Coast river system balances with a percent error of 0.0 percent. A majority of the flow enters the river network from seepage. A small component enters the system from the cells ("Cell to Riv" component). The outflow is discharged to the Atlantic Ocean.

Table I-8. Lower East Coast river system water budget.

River Component	Flow (k-ac-ft)
Seepage	1671.8
Outflow to Ocean	-1723.0
Cell to Riv	-46.2
Residual	0.0
WBDelta	0.0
WBError	-0.5
Percent Error	0.0

Lower West Coast River System

The water budget for the Lower West Coast river system balances with a percent error of 0.0 percent. A majority of the flow enters the river network from seepage and from the cells ("Cell to Riv" component). The outflow is discharged to the Gulf of Mexico.

Table I-9. Lower West Coast river system water budget.

River Component	Flow (k-ac-ft)
Seepage	1533.4
Outflow to Ocean	-3032.1
Cell to Riv	1498.7
Residual	0.0
WBDelta	0.0
WBError	0.0
Percent Error	0.0%

Water Budgets

The water budgets for each zone are delineated using the present day watershed (**Figure I-1**). For each zone, groundwater and overland flow occurs between two open circles and is identified by direction in an accompanying table as "SE", "South", "West", and so on. Most of the descriptors are self explanatory: "ETc" for computed evapotranspiration, "GW" for groundwater flow, "OL" for overland flow, "Seepage" for groundwater connection to the river, "Cell To Riv" for an open connection to/from the cell to the river segment, and "Del Sto" represents the change in storage. The descriptor "Borrow" represents the amount of water transferred from the cell to the river segment in order to computationally conserve the volume of water within the Hydrologic Simulation Engine (HSE) code.

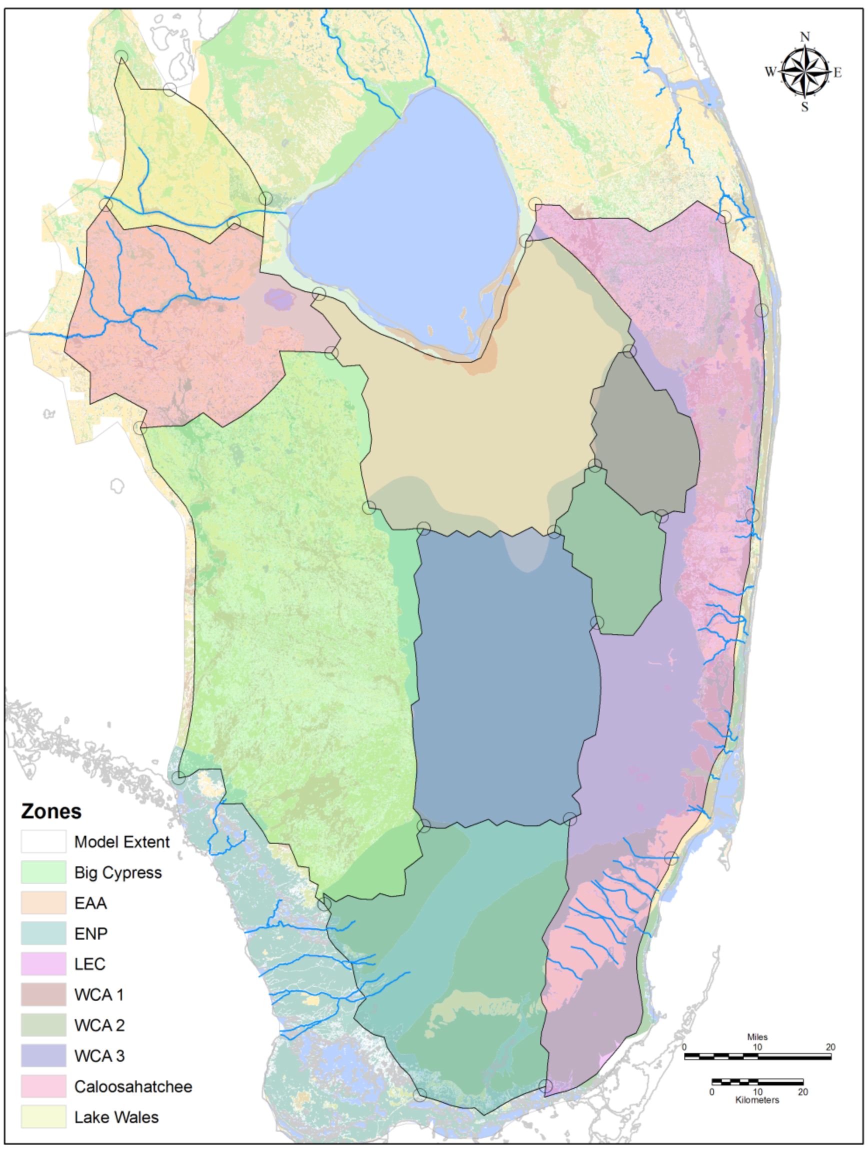
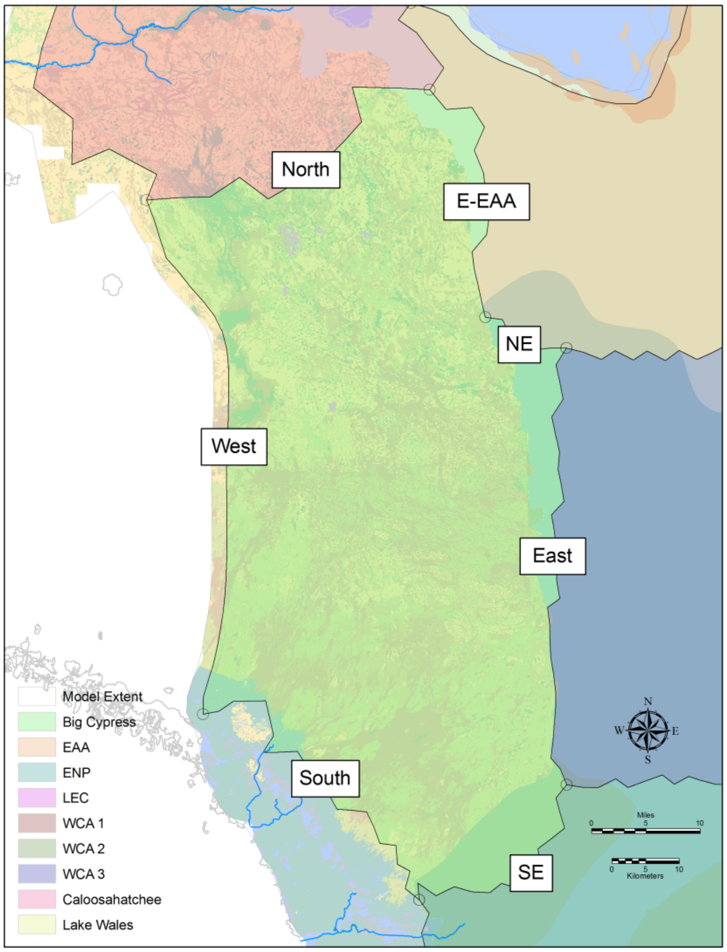


Figure I-1. NSRSM v.3.5.2 Water Budget Zones.

Big Cypress Basin

The water budget for the Big Cypress Basin is balanced (**Figure I-2)**. Most of the flow in this zone enters as rainfall and the northeast from the area presently known as the Everglades Agricultural Area (EAA). A majority of the flow exits through computed ET and the south and east boundaries as overland flow. A significant amount of water is carries out of this zone by the Huston and Chatam rivers as show in the "Cell To Riv" component in the budget.

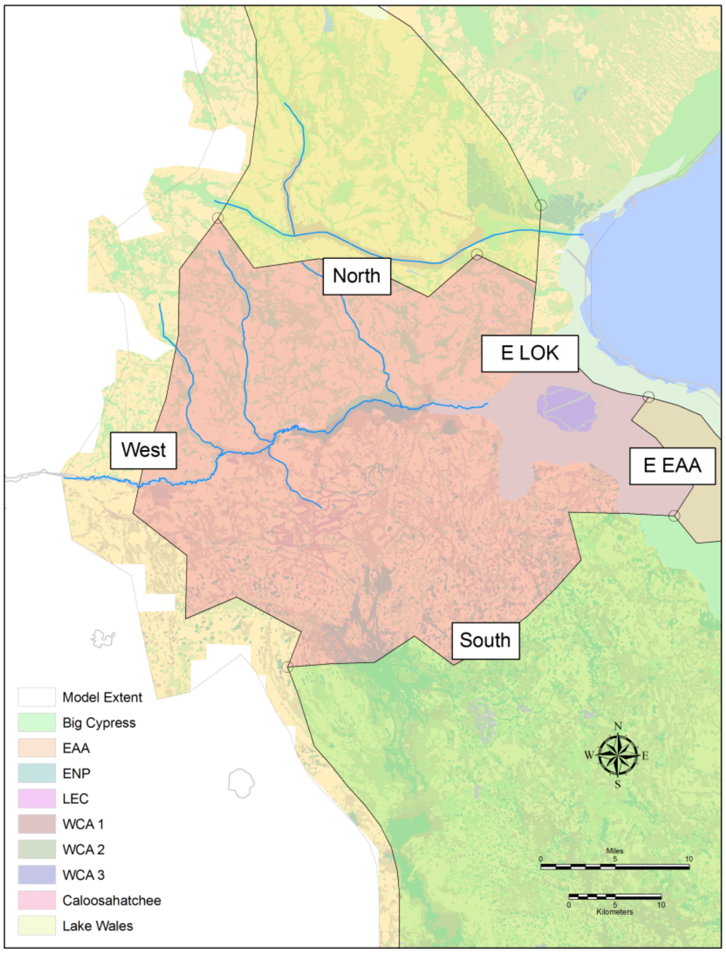


Big Cypress	k ac-ft/yr
Rain	5290.4
ETc	-3809.4
SE GW	0.0
SE OL	-149.9
South GW	0.0
South OL	-796.0
West GW	-0.2
West OL	-32.0
North GW	-0.8
North OL	1.9
E-EAA GW	0.0
E-EAA OL	-148.7
NE GW	0.0
NE OL	474.1
E GW	0.0
E OL	-614.2
Seepage	-166.0
Cell To Riv	-47.6
Del Sto	1.5
Error	0.0%

Figure I-2. NSRSM v.3.5.2 Water Budget Zones - Big Cypress Basin.

Caloosahatchee Basin

The water budget for the Caloosahatchee Basin is balanced (**Figure I-3**). Water in this zone originates from rainfall and flow from Lake Okeechobee. Most of the water exits west and through computed ET and the Caloosahatchee River ("Cell To Riv" and "Seepage" components). In this zone, the "Borrow" component represents less than 0.10 percent of the water budget.

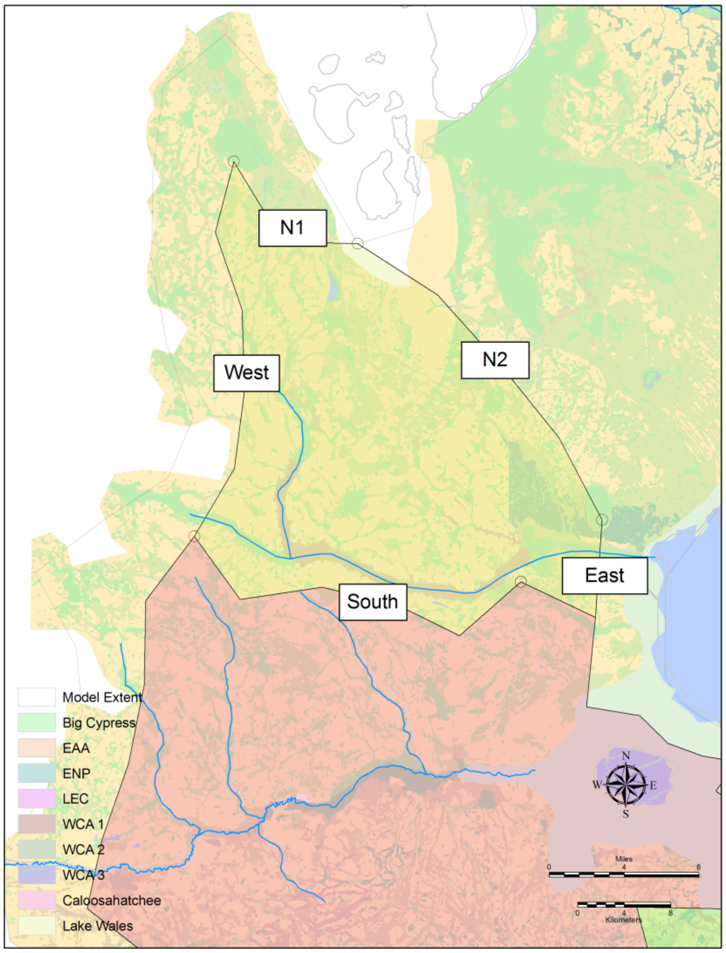


Caloo	k ac-ft/yr
Rain	1984.9
ETc	-1233.8
S GW	0.8
S OL	-1.9
W GW	-0.8
W OL	55.2
N GW	-1.9
N OL	18.9
E LOK GW	-0.3
E LOK OL	162.8
E EAA GW	0.0
E EAA OL	14.4
Seepage	-770.1
Cell To Riv	-222.0
Del Sto	1.9
Borrow	-4.3
Error	0.0%

Figure I-3. NSRSM v.3.5.2 Water Budget Zones - Caloosahatchee River Basin.

Lake Wales Basin

The water budget for the Lake Wales Basin is balanced (**Figure I-4**)**.** Most of the water enters this zone from rainfall and the west resulting from the imposed boundary conditions. Water predominately exits though computed ET and river seepage. In this zone, the "Borrow" component represents less than 0.13 percent of the water budget.

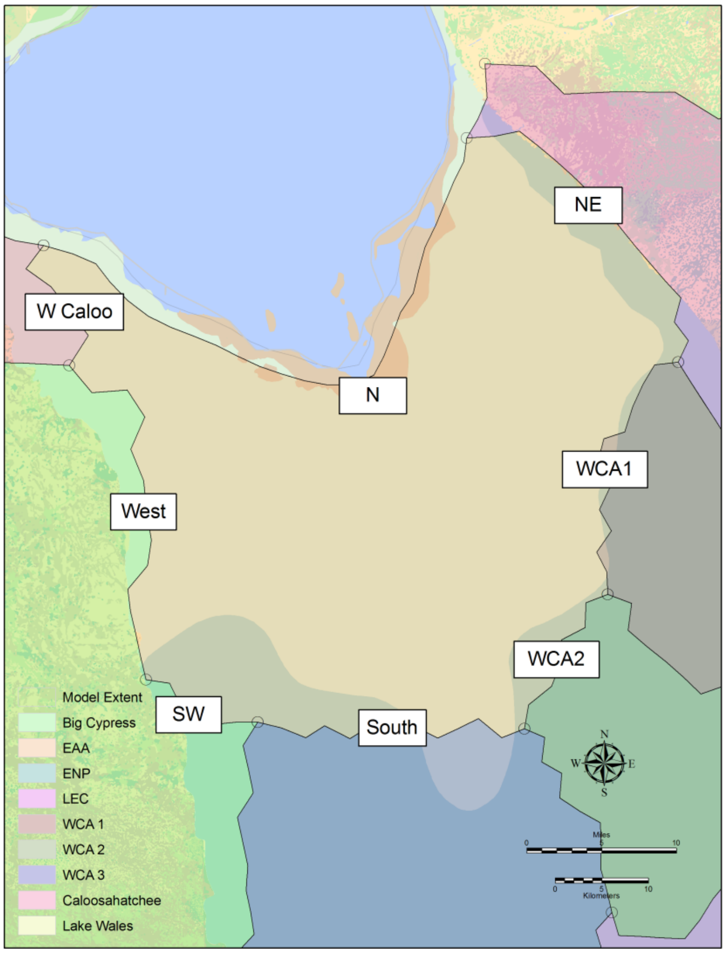


Lake Wales	k ac-ft/yr
Rain	860.5
ETc	-607.4
S GW	1.9
S OL	-18.9
W GW	1.5
W OL	64.4
N1 GW	0.9
N1 OL	10.1
N2 GW	-3.6
N2 OL	-13.5
E GW	-0.1
E OL	-241.1
Seepage	-153.1
Cell to Riv	101.8
Del Sto	0.7
Borrow	-2.7
Error	0.0%

Figure I-4. NSRSM v.3.5.2 Water Budget Zones – Lake Wales Basin.

Everglades Agricultural Area (EAA) Basin

The water budget for the EAA Basin is balanced (**Figure I-5**). A majority of the water originates from rainfall and Lake Okeechobee. Water exits the zone primarily as computed ET, as overland flow in the south and the area presently known as Water Conservation Area 1 (WCA-1).

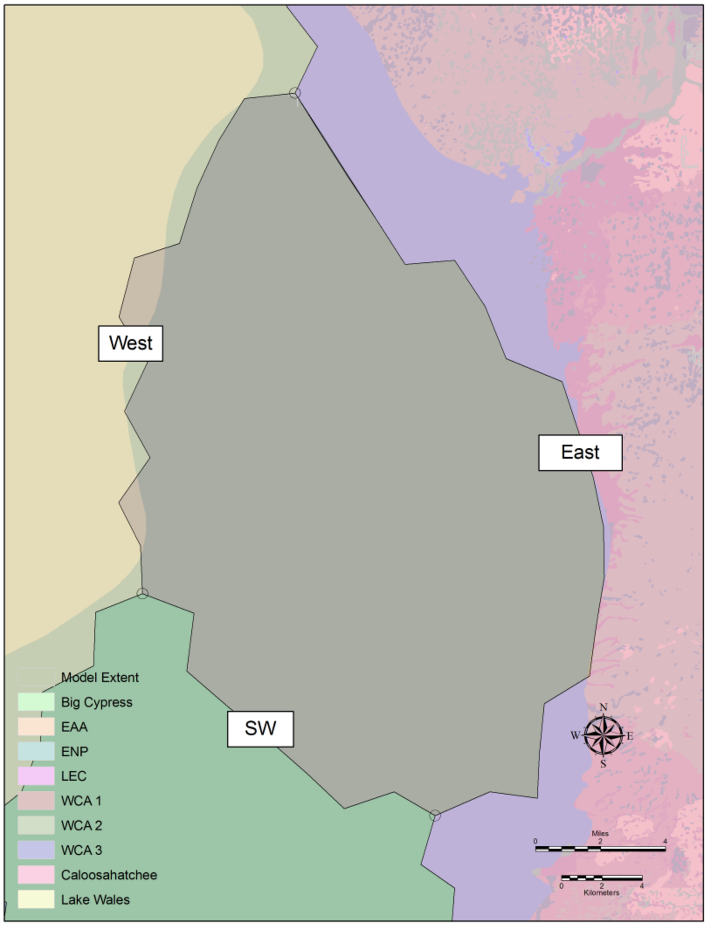


EAA	k ac-ft/yr
Rain	2454.8
ETc	-2161.2
S GW	-0.1
S OL	-785.0
SW GW	0.0
SW OL	-474.1
W GW	0.0
W OL	148.7
W Caloo GW	0.0
W Caloo OL	-14.4
N GW	0.1
N OL	1632.3
NE GW	0.0
NE OL	13.3
WCA1 GW	-0.2
WCA1 OL	-564.1
WCA2 GW	-0.1
WCA2 OL	-245.6
Del Sto	4.6
Error	0.0%

Figure I-5. NSRSM v.3.5.2 Water Budget Zones – EAA Basin.

WCA-1

The water budget for the WCA-1 is balanced (**Figure I-6**). Most of the water enters from rainfall and the area presently known as the EAA. Water exits the zone to the area presently known as WCA-2 and as computed ET.

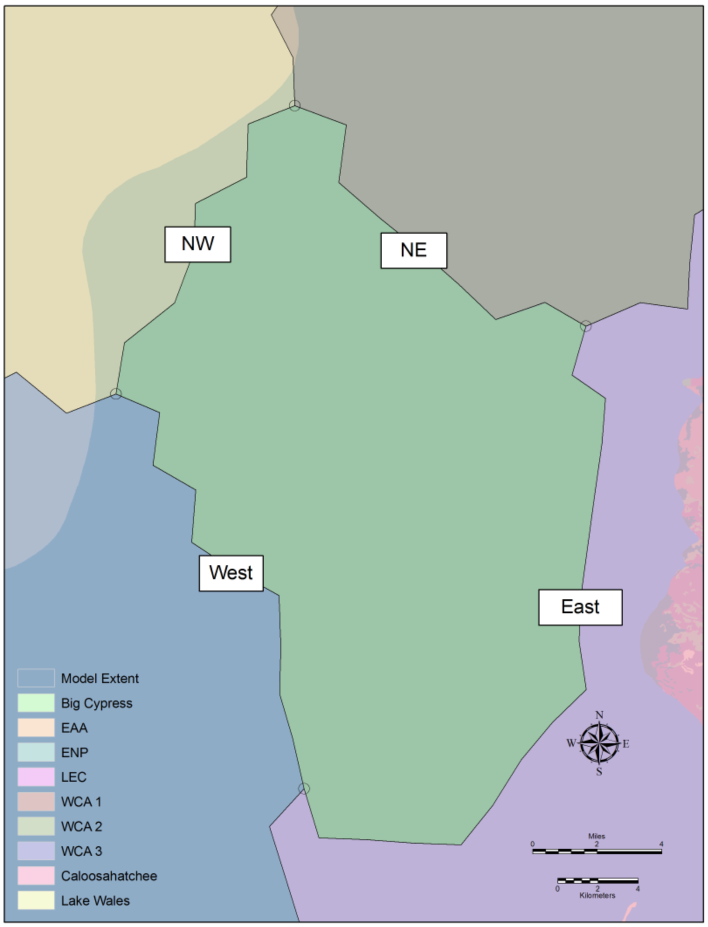


WCA1	k ac-ft/yr
Rain	609.0
ETc	-503.6
East GW	1.5
East OL	97.5
SW GW	-0.2
SW OL	-767.6
West GW	0.2
West OL	564.1
Del Sto	0.8
Error	0.0%

Figure I-6. NSRSM v.3.5.2 Water Budget Zones - WCA-1.

WCA-2

The water budget for the WCA-2 is balanced (**Figure I-7**)**.** Most of the water enters as rainfall and from the area presently know as WCA-1. A majority of the water exits the zone to the Lower East Coast and as computed ET.

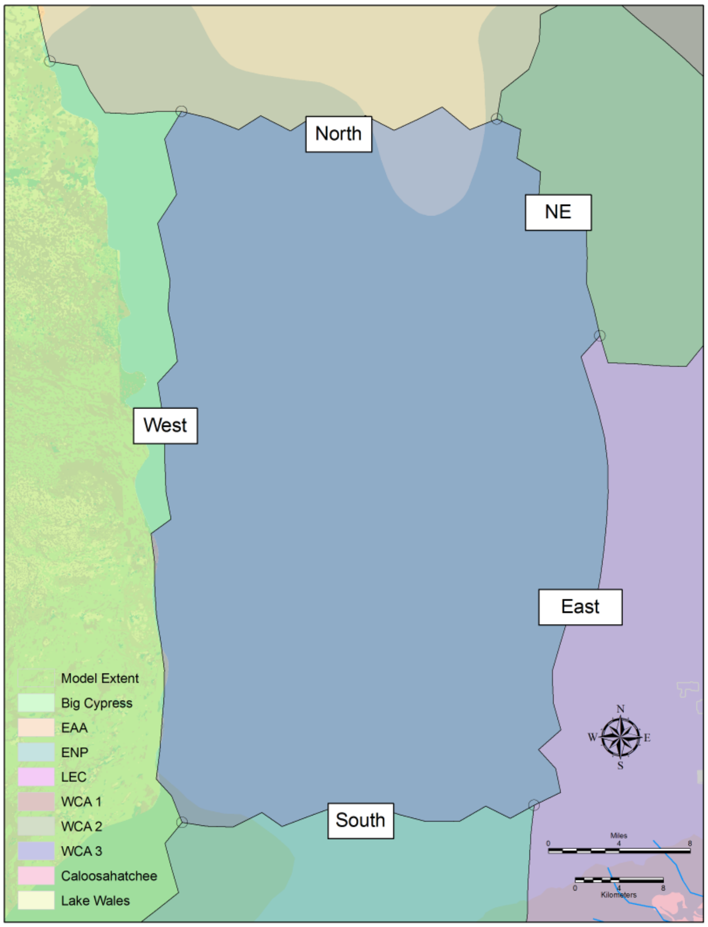


WCA2	k ac-ft/yr
Rain	552.8
ETc	-481.4
NE GW	0.2
NE OL	767.6
East GW	-4.2
East OL	-808.6
West GW	-0.3
West OL	-271.1
NW GW	0.1
NW OL	245.6
Del Sto	0.7
Error	0.0%

Figure I-7. NSRSM v.3.5.2 Water Budget Zones - WCA-2.

WCA-3

The water budget for the WCA-3 is balanced (**Figure I-8**). Most of the water enters as rainfall and from the north in the area presently known as the EAA. Most of the water exits as computed ET and to area presently know as Everglades National Park (ENP) and to the east to the Lower East Coast.

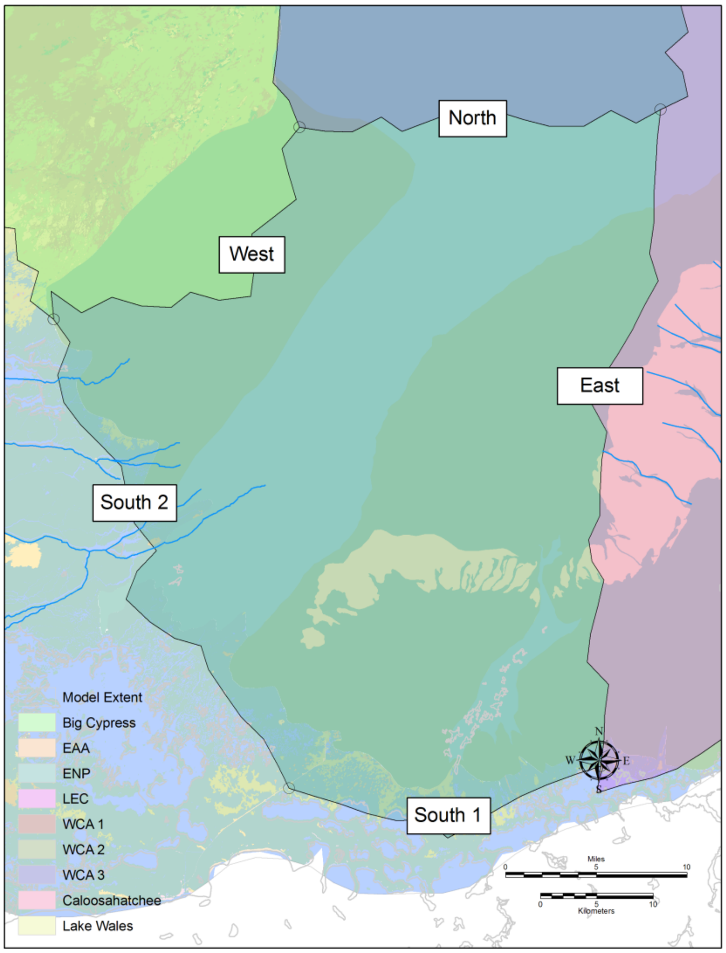


WCA3	k ac-ft/yr
Rain	2398.7
ETc	-2109.7
NE GW	0.3
NE OL	271.1
East GW	-7.5
East OL	-359.5
South GW	-4.5
South OL	-1586.1
West GW	0.0
West OL	614.2
North GW	0.1
North OL	785.0
Del Sto	2.1
Error	0.0%

Figure I-8. NSRSM v.3.5.2 Water Budget Zones - WCA-3.

Everglades National Park (ENP)

The water budget for the ENP is balanced (**Figure I-9**). Most of the water enters as rainfall and the area presently known as WCA-3. A majority of the water exits as computed ET, to Florida Bay and to the rivers through a direct connection with the cells.

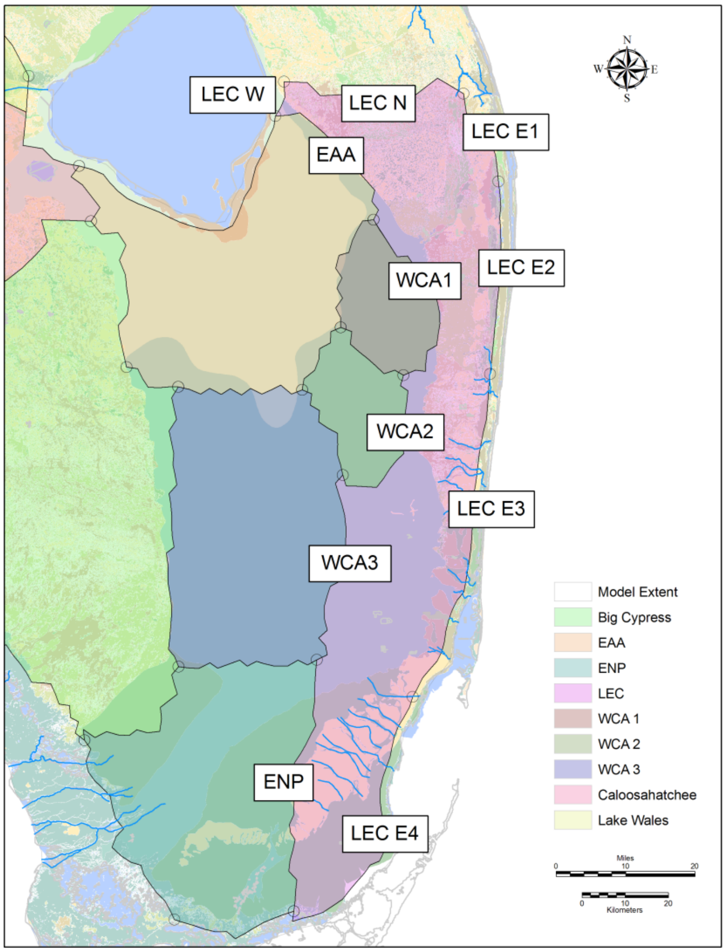


ENP	k ac-ft/yr
Rain	2524.4
ETc	-2092.8
East GW	-11.0
East OL	330.3
South1 GW	-0.9
South1 OL	-287.7
South2 GW	-0.1
South2 OL	-1194.7
West GW	0.0
West OL	149.9
North GW	4.5
North OL	1586.1
Seepage	-217.3
Cell To Riv	-791.8
Del Sto	-1.1
Error	0.0%

Figure I-9. NSRSM v.3.5.2 Water Budget Zones - ENP.

Lower East Coast (LEC)

The water budget for the LEC is balanced (**Figure I-10**). A majority of water enters this zone through rainfall and from areas presently known as WCA-2 and WCA-3. Most of the water exists the zone as computed ET and though the Lower East Coast rivers ("Seepage" component). The "Borrow" component only comprises 0.09 percent of the entire budget.



LEC	k ac-ft/yr
Rain	5353.9
ETc	-3585.4
ENP GW	11.0
ENP OL	-330.3
WCA3 GW	7.5
WCA3 OL	359.5
WCA2 GW	4.2
WCA2 OL	808.6
WCA1 GW	-1.5
WCA1 OL	-97.5
EAA GW	0.0
EAA OL	-13.3
LEC W GW	-0.1
LEC W OL	17.1
LEC N GW	-0.1
LEC N OL	44.1
LEC E1 GW	-2.2
LEC E1 OL	-189.5
LEC E2 GW	-25.5
LEC E2 OL	-60.2
LEC E3 GW	-171.2
LEC E3 OL	-16.2
LEC E4 GW	-145.9
LEC E4 OL	-176.2
Seepage	-1723.0
Cell To Riv	-55.5
Del Sto	0.1
Borrow	-12.2
Error	0.0%

Figure I-10. NSRSM v.3.5.2 Water Budget Zones – LEC.

Isolate and Manage Instabilities

In order to manage and isolate instabilities, the water level elevations and changes are analyzed for cells and river segments. The minimum and maximum water depths are examined and compared with historical data. Numerical oscillations are checked by finding the maximum time step difference.

Minimum water levels and select maximum water levels are checked for each area.

Caloosahatchee Area. **Table I-10** indicates that the difference between the minimum water level in the cell and the river segment is 4.36 ft. The maximum water level in the area is representative of a local depression based on the elevation of the surrounding cells.

Table I-10. Cell and segment statistics for the Caloosahatchee Area.

Caloosahatchee Area			
Minimum water levels		Maximum water levels	
Lowest simulated water level	Cell 234	Highest simulated water level	Cell 292
Elevation	31.88 ft NGVD29	Elevation	12.45 ft NGVD29
Minimum water level for POR	8.57 ft NGVD29	Maximum water level for POR	21.04 ft NGVD29
5th percentile for water level	11.07 ft NGVD29	95th percentile for water level	17.21 ft NGVD29
River segment	ID 300120	Elevation of surrounding cells	25.27 ft 22.09 ft 20.38 ft
Segment bottom elevation	1.23 ft NGVD29		
Cell-to-river segment minimum river depth	7.34 ft (8.57 ft - 1.23 ft)		
Minimum stage in segment	2.98 ft or 4.21 ft NGVD29 (4.21ft -1.23 ft)		
5th percentile for min stage	6.03 ft NGVD29		
Diff between cell and segment	4.36 ft (7.34 ft - 2.98 ft)		

Fisheating Creek Area. **Table I-11** indicates a relatively stable cell/segment interaction since the minimum water levels for the cell and river segment have difference of 0.56 ft. The maximum water levels are unremarkable.

Table I-11. Cell and segment statistics for the Fisheating Creek Area.

Fisheating Creek Area			
Minimum water levels		Maximum water levels	
Lowest simulated water level	Cell 57	Highest simulated water level	Cell 56
Elevation	79.37 ft NGVD29	Elevation	69.98 ft NGVD29
Minimum water level for POR	61.39 ft NGVD29	Maximum water level for POR	73.95 ft NGVD29
5th percentile for water level	62.07 ft NGVD29	95th percentile for water level	70.11 ft NGVD29
River segment	ID 301071		
Segment bottom elevation	56.0 ft NGVD29		
Cell-to-river segment minimum river depth	5.39 ft (61.39 ft – 56.0 ft)		
Minimum stage in segment	60.83 ft or 4.83 ft NGVD29 (60.83ft -56.0 ft)		
5th percentile for min stage	61.28 ft NGVD29		
Diff between cell and segment	0.56 ft (5.39 ft - 4.83 ft)		

Kissimmee Area. **Table I-12** indicates a relatively stable cell/segment interaction since the minimum water levels for the cell and river segment have difference of 0.39 ft. The maximum water levels are unremarkable.

Table I-12. Cell and segment statistics for the Kissimmee Area.

<table>
<tr><th colspan="4">Kissimmee Area</th></tr>
<tr><td colspan="2">Minimum water levels</td><td colspan="2">Maximum water levels</td></tr>
<tr><td>Lowest simulated water level</td><td>Cell 122</td><td>Highest simulated water level</td><td>Cell 127</td></tr>
<tr><td>Elevation</td><td>39.91 ft NGVD29</td><td>Elevation</td><td>34.33 ft NGVD29</td></tr>
<tr><td>Minimum water level for POR</td><td>24.75 ft NGVD29</td><td>Maximum water level for POR</td><td>42.56 ft NGVD29</td></tr>
<tr><td>5th percentile for water level</td><td>25.94 ft NGVD29</td><td>95th percentile for water level</td><td>38.86 ft NGVD29</td></tr>
<tr><td>River segment</td><td>ID 300564</td><td colspan="2" rowspan="6"></td></tr>
<tr><td>Segment bottom elevation</td><td>22.05 ft NGVD29</td></tr>
<tr><td>Cell-to-river segment minimum river depth</td><td>2.70 ft (24.75 ft – 22.05 ft)</td></tr>
<tr><td>Minimum stage in segment</td><td>4.83 ft or 24.36 ft NGVD29 (24.36 ft -22.05 ft)</td></tr>
<tr><td>5th percentile for min stage</td><td>25.75 ft NGVD29</td></tr>
<tr><td>Diff between cell and segment</td><td>0.39 ft (2.70 ft - 2.31 ft)</td></tr>
</table>

Taylor Creek Area. **Table I-13** indicates a relatively stable cell/segment interaction since the minimum water levels for the cell and river segment have difference of 0.10 ft.

Table I-13. Cell and segment statistics for the Taylor Creek Area.

Taylor Area	
Minimum water levels	
Lowest simulated water level	Cell 383
Elevation	51.82 ft NGVD29
Minimum water level for POR	35.71 ft NGVD29
5th percentile for water level	35.93 ft NGVD29
River segment	ID 300649
Segment bottom elevation	35.47 ft NGVD29
Cell-to-river segment minimum river depth	0.28 ft (35.75 ft – 35.47 ft)
Minimum stage in segment	0.18 ft or 35.65 ft NGVD29 (35.65 ft -35.47 ft)
5th percentile for min stage	35.75 ft NGVD29
Diff between cell and segment	0.10 ft (0.28 ft - 0.18 ft)

St. Lucie Area. **Table I-14** indicates that the minimum water level in the cell drops below the river segment. However, the minimum water levels for the cell and river segment have difference of 0.04 ft indicative of a stable cell/segment interaction. The maximum water levels are unremarkable.

Table I-14. Cell and segment statistics for the St. Lucie Area.

Kissimmee Area			
Minimum water levels		Maximum water levels	
Lowest simulated water level	Cell 1161	Highest simulated water level	Cell 1071
Elevation	17.55 ft NGVD29	Elevation	12.37 ft NGVD29
Minimum water level for POR	1.19 ft NGVD29	Maximum water level for POR	15.58 ft NGVD29
5^{th} percentile for water level	1.90 ft NGVD29	95^{th} percentile for water level	10.85 ft NGVD29
River segment	ID 301058		
Segment bottom elevation	7.0 ft NGVD29		
Cell-to-river segment minimum river depth	-5.81 ft (1.19 ft – 7.0 ft)		
Minimum stage in segment	-5.85 ft or 1.15 ft NGVD29 (1.15 ft -7.0 ft)		
5^{th} percentile for min stage	1.78 ft NGVD29		
Diff between cell and segment	0.04 ft (-5.81 ft -(-5.85 ft))		

Loxahatchee Area. Table I-15 indicates a relatively stable cell/segment interaction since the minimum water levels for the cell and river segment have difference of 0.29 ft.

Table I-15. Cell and segment statistics for the Loxahatchee Area.

Loxahatchee Area	
Minimum water levels	
Lowest simulated water level	Cell 1363
Elevation	16.46 ft NGVD29
Minimum water level for POR	0.19 ft NGVD29
5^{th} percentile for water level	0.52 ft NGVD29
River segment	ID 301020
Segment bottom elevation	-2.0 ft NGVD29
Cell-to-river segment minimum river depth	2.19 ft (0.19 ft – (-2.0ft))
Minimum stage in segment	1.9 ft or -0.1 ft NGVD29 (-0.1 ft –(-2.0 ft))
5^{th} percentile for min stage	0.12 ft NGVD29
Diff between cell and segment	0.29 ft (2.19 ft - 1.9 ft)

Hillsboro River Area. **Table I-16** indicates a relatively stable cell/segment interaction since the minimum water levels for the cell and river segment have difference of 0.09 ft.

Table I-16. Cell and segment statistics for the Hillsboro River Area.

Hillsboro River Area	
Minimum water levels	
Lowest simulated water level	Cell 4017
Elevation	14.96 ft NGVD29
Minimum water level for POR	0.40 ft NGVD29
5th percentile for water level	0.59 ft NGVD29
River segment	ID 300850
Segment bottom elevation	-1.0 ft NGVD29
Cell-to-river segment minimum river depth	1.40 ft (0.40 ft – (-1.0ft))
Minimum stage in segment	1.31 ft or 0.31 ft NGVD29 (0.31 ft –(-1.0 ft))
5th percentile for min stage	0.45 ft NGVD29
Diff between cell and segment	0.09 ft (1.41 ft - 1.31 ft)

Miami River Area. **Table I-17** indicates a relatively stable cell/segment interaction since the minimum water levels for the cell and river segment have difference of 0.02 ft.

Table I-17. Cell and segment statistics for the Miami River Area.

Miami River Area	
Minimum water levels	
Lowest simulated water level	Cell 6442
Elevation	10.67 ft NGVD29
Minimum water level for POR	0.24 ft NGVD29
5th percentile for water level	0.42 ft NGVD29
River segment	ID 301139
Segment bottom elevation	-7.7 ft NGVD29
Cell-to-river segment minimum river depth	7.94 ft (0.24 ft – (-7.7ft))
Minimum stage in segment	7.92 ft or 0.22 ft NGVD29 (0.22 ft –(-7.7 ft))
5th percentile for min stage	0.41 ft NGVD29
Diff between cell and segment	0.02 ft (7.94ft - 7.92 ft)

No oscillations occur with the cells of the NSRSM. This was determined by analyzing the maximum water level change for each time step. The three cells with the greatest change in water level occur within the lower Kissimmee Basin and the St. Lucie River Basin. Using the absolute value of the maximum water level change per time step, cells 1265, 455 and 226 have values of 7.96, 7.27 and 6.56, respectively. **Table I-18** reveals that these are one-time occurrences.

Table I-18. Statistics for water level change in lower Kissimmee and St. Lucie River Basin.

	Cell 1256	**Cell 455**	**Cell 226**
Maximum POR	7.96	7.27	6.56
1st Percentile	0.01	0.02	0.02
5th Percentile	0.01	0.01	0.02
50th Percentile	0.00	0.01	0.01
95th Percentile	0.09	0.06	0.06
99th Percentile	0.19	0.14	0.14

Overall, the natural system rivers exhibit reasonable low and high water levels. The maximum water level change for each time step was analyzed for the river network. Two river segments with the greatest change in water level occur within the Jupiter River and Fisheating Creek. Using the absolute value of the maximum water level change per time step, segments 301021 and 300402 have values of

3.50 and 4.26, respectively. **Table I-19** shows that this is a one-time occurrence and not an oscillation.

Table I-19. Statistics for water level change in the Jupiter River and Fisheating Creek.

	Jupiter River	Fisheating Creek
Maximum POR	3.50	4.26
1st Percentile	0.03	2.33
5th Percentile	0.02	2.01
50th Percentile	0.00	0.00
95th Percentile	0.03	2.18
99th Percentile	0.06	3.25

Oscillations do occur in Bessie Creek and a tributary of the St. Lucie Estuary, as shown in **Figure I-11** and **Figure I-12**. These are very small creeks and contribute 7.2 percent of the average monthly flow into the St. Lucie Estuary.

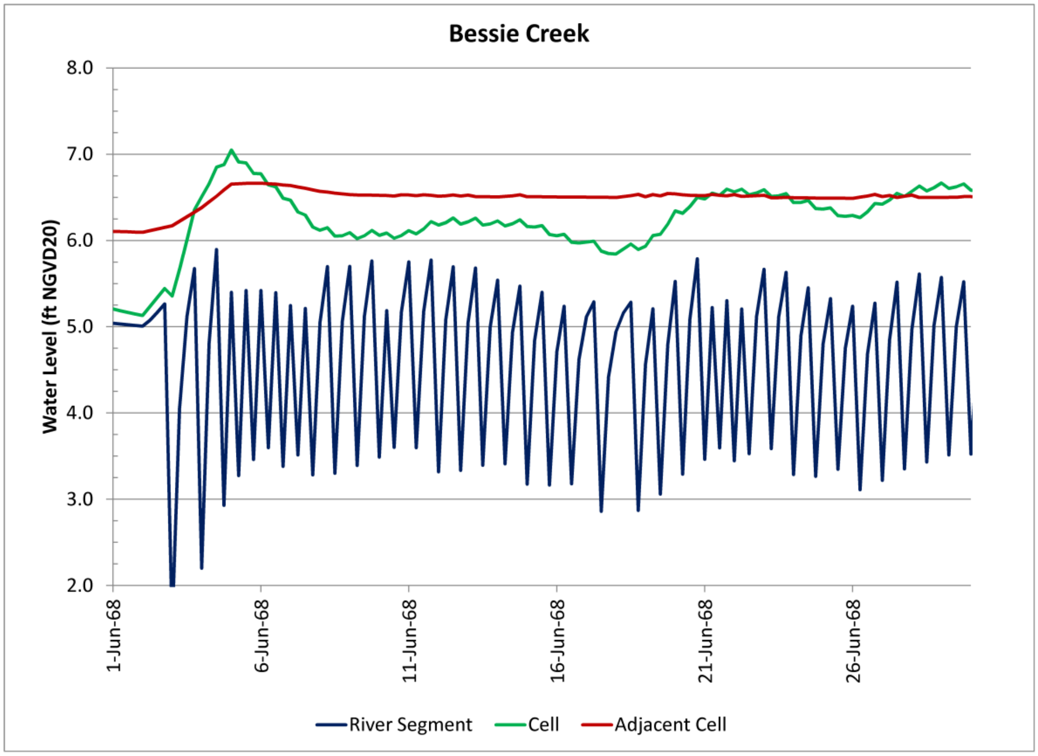


Figure I-11. Simulated water levels for Bessie Creek.

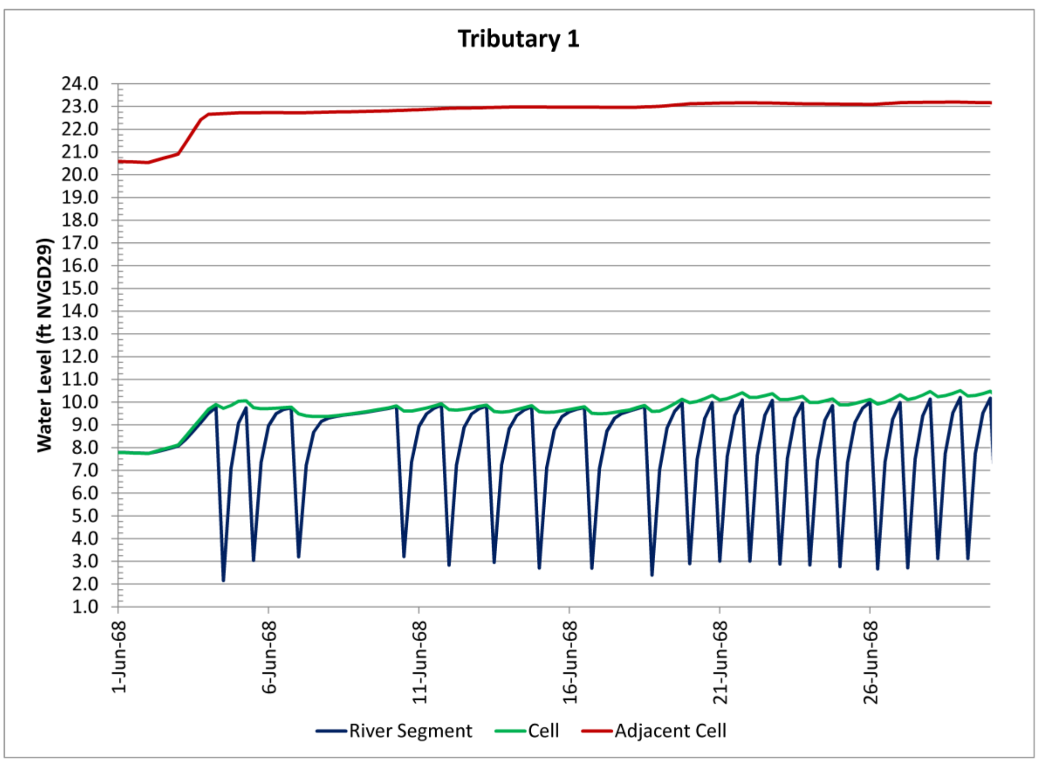


Figure I-12. Simulated water levels for St. Lucie Estuary—Tributary 1.

The oscillation does not propagate into the model. The cells that contain the river network were analyzed using the absolute value of the maximum water level change per time step. As the previous figures and **Table I-20** show, the cells exhibit minor oscillations with adjacent cells showing no oscillation, or any high one-time occurrences. This will be resolved in the next release.

Table I-20. Statistics describing water level change for cells adjacent to rivers with oscillations.

	Cell1066	Cell1165
Maximum POR	1.07	1.07
1st Percentile	0.33	0.13
5th Percentile	0.20	0.08
50th Percentile	0.00	0.01
95th Percentile	0.10	0.07
99th Percentile	0.19	0.16

Conclusion

No significant issues concerning model performance were identified for the NSRSM v3.5.2 using the approved tests described above.

REFERENCES

Lal, Wasantha, A. M. (2000) Numerical errors in groundwater and overland flow models. Water Resources Research, 36(5), pp 1237-1247.

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Appendix J
Model Sensitivity and Uncertainty

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J.1 INITIAL PARAMETERS

Model parameters varied in the uncertainty analysis include hydraulic conductivity, topography, lake evapotranspiration (lake ET), overland conveyance, evapotranspiration (ET), and storage coefficient. The initial value ranges for these model parameters are listed in **Tables J-1, J-2, J-3, J-4, J-5**, and **J-6**, respectively.

Table J-1. Initial ranges for hydraulic conductivity parameters used in initial optimization.

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Hydraulic Conductivity	hp01	log	13.87422	0.1409	1409.0
Hydraulic Conductivity	hp02	log	11.54617	0.1214	1214.0
Hydraulic Conductivity	hp03	log	193.3911	1.5634	15634.0
Hydraulic Conductivity	hp04	log	14.8375	0.1519	1519.0
Hydraulic Conductivity	hp05	log	172.4335	1.7611	17611.0
Hydraulic Conductivity	hp06	log	17.2072	0.1692	1692.0
Hydraulic Conductivity	hp07	log	28.0636	0.3	3000.0
Hydraulic Conductivity	hp08	log	196.0592	1.9351	19351.0
Hydraulic Conductivity	hp09	log	250.5622	2.3955	23955.0
Hydraulic Conductivity	hp10	log	212.9393	2.144	21440.0
Hydraulic Conductivity	hp11	log	174.538	1.8244	18244.0
Hydraulic Conductivity	hp12	log	17.74592	0.1747	1747.0
Hydraulic Conductivity	hp13	log	209.3346	2.2163	22163.0
Hydraulic Conductivity	hp14	log	31.7491	0.3	3000.0
Hydraulic Conductivity	hp15	log	77.54009	0.7462	7462.0
Hydraulic Conductivity	hp16	log	190.9787	1.8405	18405.0
Hydraulic Conductivity	hp17	log	30.56356	0.3	3000.0
Hydraulic Conductivity	hp18	log	26.92048	0.3	3000.0
Hydraulic Conductivity	hp19	log	166.1012	1.7114	17114.0
Hydraulic Conductivity	hp20	log	34.62788	0.3344	3344.0
Hydraulic Conductivity	hp21	log	31.57488	0.3	3000.0
Hydraulic Conductivity	hp22	log	113.0968	1.1103	11103.0
Hydraulic Conductivity	hp23	log	239.457	2.5023	25023.0
Hydraulic Conductivity	hp24	log	30.08282	0.3	3000.0
Hydraulic Conductivity	hp25	log	27.38783	0.3	3000.0
Hydraulic Conductivity	hp26	log	31.42948	0.3	3000.0
Hydraulic Conductivity	hp27	log	43.01931	0.4209	4209.0
Hydraulic Conductivity	hp28	log	31.25834	0.3	3000.0
Hydraulic Conductivity	hp29	log	235.9961	2.37	23700.0
Hydraulic Conductivity	hp30	log	115.3072	1.2036	12036.0
Hydraulic Conductivity	hp31	log	43.30942	0.4107	4107.0
Hydraulic Conductivity	hp32	log	30.10285	0.3	3000.0
Hydraulic Conductivity	hp33	log	25.49978	0.2681	2681.0
Hydraulic Conductivity	hp34	log	21.16146	0.2159	2159.0
Hydraulic Conductivity	hp35	log	41.30572	0.4261	4261.0
Hydraulic Conductivity	hp36	log	227.6251	2.3058	23058.0
Hydraulic Conductivity	hp37	log	77.25523	0.7717	7717.0
Hydraulic Conductivity	hp38	log	131.3838	1.294	12940.0
Hydraulic Conductivity	hp39	log	199.1291	2.0344	20344.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Hydraulic Conductivity	hp40	log	111.3634	1.127	11270.0
Hydraulic Conductivity	hp41	log	167.9943	1.6168	16168.0
Hydraulic Conductivity	hp42	log	17.31031	0.2021	2021.0
Hydraulic Conductivity	hp43	log	22.08137	0.2176	2176.0
Hydraulic Conductivity	hp44	log	18.13903	0.1943	1943.0
Hydraulic Conductivity	hp45	log	44.87949	0.4735	4735.0
Hydraulic Conductivity	hp46	log	20.26596	0.2244	2244.0
Hydraulic Conductivity	hp47	log	21.61781	0.2471	2471.0
Hydraulic Conductivity	hp48	log	37.29533	0.3784	3784.0
Hydraulic Conductivity	hp49	log	104.0521	1.0865	10865.0
Hydraulic Conductivity	hp50	log	27.6815	0.2609	2609.0
Hydraulic Conductivity	hp51	log	467.4538	4.8021	48021.0
Hydraulic Conductivity	hp52	log	125.5997	1.2298	12298.0
Hydraulic Conductivity	hp53	log	43.30403	0.4572	4572.0
Hydraulic Conductivity	hp54	log	341.8513	3.0405	30405.0
Hydraulic Conductivity	hp55	log	630.8224	6.3055	63055.0
Hydraulic Conductivity	hp56	log	239.6545	2.6196	26196.0
Hydraulic Conductivity	hp57	log	919.2782	9.1721	91721.0
Hydraulic Conductivity	hp58	log	147.6441	1.5499	15499.0
Hydraulic Conductivity	hp59	log	1305.278	13.3703	133703.0
Hydraulic Conductivity	hp60	log	784.5825	7.545	75450.0
Hydraulic Conductivity	hp61	log	8195	76.1216	761216.0
Hydraulic Conductivity	hp62	log	513.2618	5.4935	54935.0
Hydraulic Conductivity	hp63	log	183.8767	1.784	17840.0
Hydraulic Conductivity	hp64	log	309.8237	3.0046	30046.0
Hydraulic Conductivity	hp65	log	213.4093	2.149	21490.0
Hydraulic Conductivity	hp66	log	217.3861	2.2014	22014.0
Hydraulic Conductivity	hp67	log	210.7047	2.2634	22634.0
Hydraulic Conductivity	hp68	log	12780.63	142.428	1424280.0
Hydraulic Conductivity	hp69	log	7497.445	68.263	682630.0
Hydraulic Conductivity	hp70	log	5763.602	50.7246	507246.0
Hydraulic Conductivity	hp71	log	678.8766	6.6193	66193.0
Hydraulic Conductivity	hp72	log	216.1473	2.1245	21245.0
Hydraulic Conductivity	hp73	log	19362.18	189.873	1898730.0
Hydraulic Conductivity	hp74	log	17327.92	170.72	1707200.0
Hydraulic Conductivity	hp75	log	282.8306	2.7059	27059.0
Hydraulic Conductivity	hp76	log	616.2022	5.89	58900.0
Hydraulic Conductivity	hp77	log	3412.178	41.3798	413798.0
Hydraulic Conductivity	hp78	log	351.5671	3.8026	38026.0
Hydraulic Conductivity	hp79	log	18570.36	177.72	1777200.0
Hydraulic Conductivity	hp80	log	2551.159	68.2882	682882.0
Hydraulic Conductivity	hp81	log	4741.964	46.3122	463122.0
Hydraulic Conductivity	hp82	log	8583.966	117.243	1172430.0
Hydraulic Conductivity	hp83	log	411.4973	4.2887	42887.0
Hydraulic Conductivity	hp84	log	20360.84	196.631	1966310.0
Hydraulic Conductivity	hp85	log	17267.14	159.323	1593230.0
Hydraulic Conductivity	hp86	log	3236.655	68.9757	689757.0
Hydraulic Conductivity	hp87	log	12828.58	138.462	1384620.0
Hydraulic Conductivity	hp88	log	14139.25	146.227	1462270.0
Hydraulic Conductivity	hp89	log	2508.713	26.6014	266014.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Hydraulic Conductivity	hp90	log	297.4419	3.2203	32203.0
Hydraulic Conductivity	hp91	log	278.6634	2.8373	28373.0
Hydraulic Conductivity	hp92	log	9561.742	99.3969	993969.0
Hydraulic Conductivity	hp93	log	11537.86	128.81	1288100.0
Hydraulic Conductivity	hp94	log	322.5634	3.3655	33655.0
Hydraulic Conductivity	hp95	log	8294.342	77.3395	773395.0
Hydraulic Conductivity	hp96	log	264.973	2.6812	26812.0
Hydraulic Conductivity	hp97	log	1072.576	11.2276	112276.0

Table J-2. Initial ranges for topography parameters used in initial optimization.

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Topography	Tp01	None	14.61804	13.6169	15.6169
Topography	tp02	none	18.68417	17.692699	19.692699
Topography	tp03	none	16.53321	15.6228	17.6228
Topography	tp04	none	18.64857	17.644199	19.644199
Topography	tp05	none	15.81614	14.779999	16.779999
Topography	tp06	none	18.09137	17.091199	19.091199
Topography	tp07	none	12.67632	11.5794	13.5794
Topography	tp08	none	15.75495	14.791199	16.791199
Topography	tp09	none	14.44988	13.503199	15.503199
Topography	tp10	none	11.47158	10.420599	12.420599
Topography	tp11	none	11.37632	10.271599	12.271599
Topography	tp12	none	10.02393	8.933699	10.933699
Topography	tp13	none	9.55967	8.5488	10.5488
Topography	tp14	none	7.185198	6.324679	8.324679
Topography	tp15	none	8.370448	7.13891	9.13891
Topography	tp16	none	9.235003	8.158599	10.158599
Topography	tp17	none	7.298643	6.335289	8.335289
Topography	tp18	none	3.349966	2.339519	4.339519
Topography	tp19	none	3.889562	2.903749	4.903749
Topography	tp20	none	5.792613	4.774759	6.774759
Topography	tp21	none	7.105599	5.88421	7.88421
Topography	tp22	none	6.083755	5.01171	7.01171
Topography	tp23	none	-0.1760839	-1.194433	0.805567
Topography	tp24	none	1.346768	0.33041	2.33041
Topography	tp25	fixed	0.646835	-1.646835	1.646835
Topography	tp26	none	1.421943	0.41828	2.41828
Topography	tp27	none	-0.2908504	-1.343441	0.656559
Topography	tp28	none	1.081034	0.070829	2.070829
Topography	tp29	fixed	4.89271	3.89271	5.89271
Topography	tp30	fixed	7.56195	6.56195	8.56195
Topography	tp31	fixed	11.1113	10.1113	12.1113
Topography	tp32	fixed	12.8157	11.815699	13.815699
Topography	tp33	fixed	19.3088	18.308799	20.308799
Topography	tp34	fixed	21.2286	20.228599	22.228599
Topography	tp35	fixed	21.8261	20.826099	22.826099
Topography	tp36	fixed	21.0476	20.047599	22.047599

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Topography	tp37	fixed	22.5178	21.517799	23.517799
Topography	tp38	fixed	17.538	16.538	18.538
Topography	tp39	fixed	16.9357	15.935699	17.935699
Topography	tp40	fixed	12.3331	11.3331	13.3331
Topography	tp41	fixed	9.60478	8.60478	10.60478
Topography	tp42	fixed	10.6545	9.6545	11.6545
Topography	tp43	fixed	9.147399	8.147399	10.147399
Topography	tp44	fixed	8.90583	7.90583	9.90583
Topography	tp45	fixed	7.23045	6.23045	8.23045
Topography	tp46	fixed	5.11741	4.11741	6.11741
Topography	tp47	fixed	0.603291	-1.603291	1.603291
Topography	tp48	fixed	7.096899	6.096899	8.096899
Topography	tp49	fixed	8.41567	7.41567	9.41567
Topography	tp50	fixed	19	18	20
Topography	tp51	fixed	19	18	20
Topography	tp52	fixed	19	18	20
Topography	tp53	fixed	18.85	17.85	19.85
Topography	tp54	fixed	18.9717	17.9717	19.9717
Topography	tp55	fixed	2.23417	1.23417	3.23417
Topography	tp56	fixed	1.23022	0.23022	2.23022

Table J-3. Initial ranges for lake evapotranspiration (lake ET) parameters used in initial optimization.

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Lake ET	owcoeff1	none	1.38798	0.75	1.75
Lake ET	owcoeff2	none	1.037908	0.75	1.75
Lake ET	owcoeff3	none	1.005916	0.75	1.75

Table J-4. Initial ranges for overland conveyance parameters used in initial optimization.

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Overland Conveyance	nfw_01	log	0.5664596	1.00E-03	150.0
Overland Conveyance	nfw_02	log	0.5101218	1.00E-03	150.0
Overland Conveyance	nfw_03	log	1.139201	1.00E-03	150.0
Overland Conveyance	nfw_04	log	2.054695	1.00E-03	150.0
Overland Conveyance	nfw_05	log	3.99921	1.00E-03	150.0
Overland Conveyance	nfw_06	log	0.6189518	1.00E-03	150.0
Overland Conveyance	nfw_07	log	1.684246	1.00E-03	150.0
Overland Conveyance	nfw_08	log	2.88983	1.00E-03	150.0
Overland Conveyance	nfw_09	log	5.073765	1.00E-03	150.0
Overland Conveyance	nfw_10	log	6.746465	1.00E-03	150.0
Overland Conveyance	nfw_11	log	9.321219	1.00E-03	150.0
Overland Conveyance	nfw_12	log	11.08002	1.00E-03	150.0
Overland Conveyance	nfw_13	log	14.18835	1.00E-03	150.0
Overland Conveyance	nfw_14	log	16.95995	1.00E-03	150.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Overland Conveyance	nfw_15	log	19.71583	1.00E-03	150.0
Overland Conveyance	nfw_16	log	22.95865	1.00E-03	150.0
Overland Conveyance	nfw_17	log	26.6854	1.00E-03	150.0
Overland Conveyance	nfw_18	log	30.11689	1.00E-03	150.0
Overland Conveyance	nfw_19	log	30.10466	1.00E-03	150.0
Overland Conveyance	nfw_20	log	36.02724	1.00E-03	150.0
Overland Conveyance	nfw_21	log	37.13021	1.00E-03	150.0
Overland Conveyance	nfw_22	log	43.18441	1.00E-03	150.0
Overland Conveyance	nfw_23	log	48.79908	1.00E-03	150.0
Overland Conveyance	nfw_24	log	50.60329	1.00E-03	150.0
Overland Conveyance	nfw_25	log	57.38288	1.00E-03	150.0
Overland Conveyance	nfw_26	log	56.45916	1.00E-03	150.0
Overland Conveyance	nfw_27	log	62.66377	1.00E-03	150.0
Overland Conveyance	nfw_28	log	63.33276	1.00E-03	150.0
Overland Conveyance	nfw_29	log	65.77926	1.00E-03	150.0
Overland Conveyance	nfw_30	log	68.40941	1.00E-03	150.0
Overland Conveyance	nfw_31	log	71.43092	1.00E-03	150.0
Overland Conveyance	nfw_32	log	73.27886	1.00E-03	150.0
Overland Conveyance	nfw_33	log	76.29869	1.00E-03	150.0
Overland Conveyance	nfw_34	log	74.64619	1.00E-03	150.0
Overland Conveyance	nfw_35	log	70.33503	1.00E-03	150.0
Overland Conveyance	nfw_36	log	86.59131	1.00E-03	150.0
Overland Conveyance	nfw_37	log	68.55245	1.00E-03	150.0
Overland Conveyance	nfw_38	log	77.93785	1.00E-03	150.0
Overland Conveyance	nfw_39	log	74.60873	1.00E-03	150.0
Overland Conveyance	nfw_40	log	80.75261	1.00E-03	150.0
Overland Conveyance	nfw_41	log	68.86678	1.00E-03	150.0
Overland Conveyance	nfw_42	log	74.31174	1.00E-03	150.0
Overland Conveyance	nfw_43	log	78.62312	1.00E-03	150.0
Overland Conveyance	nfw_44	log	65.35637	1.00E-03	150.0
Overland Conveyance	nfw_45	log	64.81981	1.00E-03	150.0
Overland Conveyance	nfw_46	log	58.17791	1.00E-03	150.0
Overland Conveyance	nfw_47	log	64.21683	1.00E-03	150.0
Overland Conveyance	nfw_48	log	54.51337	1.00E-03	150.0
Overland Conveyance	nfw_49	log	45.94847	1.00E-03	150.0
Overland Conveyance	nfw_50	log	38.87109	1.00E-03	150.0
Overland Conveyance	nfw_51	log	35.00501	1.00E-03	150.0
Overland Conveyance	nfw_52	log	30.06847	1.00E-03	150.0
Overland Conveyance	nfw_53	log	22.47502	1.00E-03	150.0
Overland Conveyance	nfw_54	log	15.24607	1.00E-03	150.0
Overland Conveyance	nfw_55	log	8.113119	1.00E-03	150.0
Overland Conveyance	nfw_56	log	1.278224	1.00E-03	150.0
Overland Conveyance	nfw_57	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_58	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_59	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_60	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_61	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_62	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_63	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_64	log	1.00E-03	1.00E-03	150.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Overland Conveyance	nfw_65	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_66	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_67	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_68	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_69	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_70	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_71	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_72	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_73	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_74	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_75	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_76	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_77	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_78	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_79	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_80	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_81	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_82	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_83	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_84	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_85	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	nfw_86	log	7.768206	1.00E-03	150.0
Overland Conveyance	lhm_01	log	0.4951453	1.00E-03	150.0
Overland Conveyance	lhm_02	log	0.5794911	1.00E-03	150.0
Overland Conveyance	lhm_03	log	1.068782	1.00E-03	150.0
Overland Conveyance	lhm_04	log	1.794658	1.00E-03	150.0
Overland Conveyance	lhm_05	log	4.11679	1.00E-03	150.0
Overland Conveyance	lhm_06	log	0.6070049	1.00E-03	150.0
Overland Conveyance	lhm_07	log	1.964749	1.00E-03	150.0
Overland Conveyance	lhm_08	log	3.099273	1.00E-03	150.0
Overland Conveyance	lhm_09	log	4.902829	1.00E-03	150.0
Overland Conveyance	lhm_10	log	7.10215	1.00E-03	150.0
Overland Conveyance	lhm_11	log	9.02231	1.00E-03	150.0
Overland Conveyance	lhm_12	log	11.91642	1.00E-03	150.0
Overland Conveyance	lhm_13	log	13.05241	1.00E-03	150.0
Overland Conveyance	lhm_14	log	18.738	1.00E-03	150.0
Overland Conveyance	lhm_15	log	20.34169	1.00E-03	150.0
Overland Conveyance	lhm_16	log	21.22238	1.00E-03	150.0
Overland Conveyance	lhm_17	log	24.74733	1.00E-03	150.0
Overland Conveyance	lhm_18	log	31.96456	1.00E-03	150.0
Overland Conveyance	lhm_19	log	36.32591	1.00E-03	150.0
Overland Conveyance	lhm_20	log	36.57635	1.00E-03	150.0
Overland Conveyance	lhm_21	log	47.14509	1.00E-03	150.0
Overland Conveyance	lhm_22	log	37.5192	1.00E-03	150.0
Overland Conveyance	lhm_23	log	49.30224	1.00E-03	150.0
Overland Conveyance	lhm_24	log	50.89411	1.00E-03	150.0
Overland Conveyance	lhm_25	log	47.58273	1.00E-03	150.0
Overland Conveyance	lhm_26	log	56.01234	1.00E-03	150.0
Overland Conveyance	lhm_27	log	52.55653	1.00E-03	150.0
Overland Conveyance	lhm_28	log	62.59542	1.00E-03	150.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Overland Conveyance	lhm_29	log	64.29536	1.00E-03	150.0
Overland Conveyance	lhm_30	log	74.99799	1.00E-03	150.0
Overland Conveyance	lhm_31	log	72.78095	1.00E-03	150.0
Overland Conveyance	lhm_32	log	70.40858	1.00E-03	150.0
Overland Conveyance	lhm_33	log	71.40118	1.00E-03	150.0
Overland Conveyance	lhm_34	log	67.67818	1.00E-03	150.0
Overland Conveyance	lhm_35	log	76.88802	1.00E-03	150.0
Overland Conveyance	lhm_36	log	69.69322	1.00E-03	150.0
Overland Conveyance	lhm_37	log	78.19659	1.00E-03	150.0
Overland Conveyance	lhm_38	log	77.28411	1.00E-03	150.0
Overland Conveyance	lhm_39	log	79.99653	1.00E-03	150.0
Overland Conveyance	lhm_40	log	73.36856	1.00E-03	150.0
Overland Conveyance	lhm_41	log	72.31373	1.00E-03	150.0
Overland Conveyance	lhm_42	log	75.72306	1.00E-03	150.0
Overland Conveyance	lhm_43	log	64.0292	1.00E-03	150.0
Overland Conveyance	lhm_44	log	71.76391	1.00E-03	150.0
Overland Conveyance	lhm_45	log	59.3535	1.00E-03	150.0
Overland Conveyance	lhm_46	log	66.18226	1.00E-03	150.0
Overland Conveyance	lhm_47	log	60.82173	1.00E-03	150.0
Overland Conveyance	lhm_48	log	51.76302	1.00E-03	150.0
Overland Conveyance	lhm_49	log	47.08682	1.00E-03	150.0
Overland Conveyance	lhm_50	log	38.06166	1.00E-03	150.0
Overland Conveyance	lhm_51	log	34.0154	1.00E-03	150.0
Overland Conveyance	lhm_52	log	27.05163	1.00E-03	150.0
Overland Conveyance	lhm_53	log	25.78921	1.00E-03	150.0
Overland Conveyance	lhm_54	log	14.35577	1.00E-03	150.0
Overland Conveyance	lhm_55	log	7.96808	1.00E-03	150.0
Overland Conveyance	lhm_56	log	1.04947	1.00E-03	150.0
Overland Conveyance	lhm_57	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_58	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_59	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_60	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_61	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_62	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_63	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_64	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_65	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_66	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_67	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_68	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_69	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_70	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_71	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_72	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_73	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_74	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_75	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_76	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_77	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_78	log	1.00E-03	1.00E-03	150.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Overland Conveyance	lhm_79	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_80	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_81	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_82	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_83	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_84	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_85	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	lhm_86	log	7.336451	1.00E-03	150.0
Overland Conveyance	rs1_01	log	0.8879391	1.00E-03	150.0
Overland Conveyance	rs1_02	log	0.8581715	1.00E-03	150.0
Overland Conveyance	rs1_03	log	1.779283	1.00E-03	150.0
Overland Conveyance	rs1_04	log	2.714313	1.00E-03	150.0
Overland Conveyance	rs1_05	log	6.848676	1.00E-03	150.0
Overland Conveyance	rs1_06	log	16.78706	1.00E-03	150.0
Overland Conveyance	rs1_07	log	29.15556	1.00E-03	150.0
Overland Conveyance	rs1_08	log	25.53387	1.00E-03	150.0
Overland Conveyance	rs1_09	log	37.73925	1.00E-03	150.0
Overland Conveyance	rs1_10	log	29.27726	1.00E-03	150.0
Overland Conveyance	rs1_11	log	33.28368	1.00E-03	150.0
Overland Conveyance	rs1_12	log	45.35849	1.00E-03	150.0
Overland Conveyance	rs1_13	log	33.62757	1.00E-03	150.0
Overland Conveyance	rs1_14	log	49.1188	1.00E-03	150.0
Overland Conveyance	rs1_15	log	37.56985	1.00E-03	150.0
Overland Conveyance	rs1_16	log	42.0327	1.00E-03	150.0
Overland Conveyance	rs1_17	log	56.69458	1.00E-03	150.0
Overland Conveyance	rs1_18	log	52.2465	1.00E-03	150.0
Overland Conveyance	rs1_19	log	57.51926	1.00E-03	150.0
Overland Conveyance	rs1_20	log	51.07265	1.00E-03	150.0
Overland Conveyance	rs1_21	log	49.55634	1.00E-03	150.0
Overland Conveyance	rs1_22	log	42.52154	1.00E-03	150.0
Overland Conveyance	rs1_23	log	44.4417	1.00E-03	150.0
Overland Conveyance	rs1_24	log	45.44876	1.00E-03	150.0
Overland Conveyance	rs1_25	log	45.44202	1.00E-03	150.0
Overland Conveyance	rs1_26	log	45.7537	1.00E-03	150.0
Overland Conveyance	rs1_27	log	58.63013	1.00E-03	150.0
Overland Conveyance	rs1_28	log	61.96058	1.00E-03	150.0
Overland Conveyance	rs1_29	log	58.65866	1.00E-03	150.0
Overland Conveyance	rs1_30	log	56.96677	1.00E-03	150.0
Overland Conveyance	rs1_31	log	56.65364	1.00E-03	150.0
Overland Conveyance	rs1_32	log	59.29137	1.00E-03	150.0
Overland Conveyance	rs1_33	log	57.48804	1.00E-03	150.0
Overland Conveyance	rs1_34	log	69.49177	1.00E-03	150.0
Overland Conveyance	rs1_35	log	70.13864	1.00E-03	150.0
Overland Conveyance	rs1_36	log	82.36746	1.00E-03	150.0
Overland Conveyance	rs1_37	log	87.21386	1.00E-03	150.0
Overland Conveyance	rs1_38	log	73.37729	1.00E-03	150.0
Overland Conveyance	rs1_39	log	75.47189	1.00E-03	150.0
Overland Conveyance	rs1_40	log	84.63465	1.00E-03	150.0
Overland Conveyance	rs1_41	log	76.11183	1.00E-03	150.0
Overland Conveyance	rs1_42	log	61.86215	1.00E-03	150.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Overland Conveyance	rs1_43	log	69.0589	1.00E-03	150.0
Overland Conveyance	rs1_44	log	85.36053	1.00E-03	150.0
Overland Conveyance	rs1_45	log	77.37223	1.00E-03	150.0
Overland Conveyance	rs1_46	log	72.47798	1.00E-03	150.0
Overland Conveyance	rs1_47	log	77.06281	1.00E-03	150.0
Overland Conveyance	rs1_48	log	60.98103	1.00E-03	150.0
Overland Conveyance	rs1_49	log	80.69	1.00E-03	150.0
Overland Conveyance	rs1_50	log	89.10677	1.00E-03	150.0
Overland Conveyance	rs1_51	log	56.53128	1.00E-03	150.0
Overland Conveyance	rs1_52	log	56.53979	1.00E-03	150.0
Overland Conveyance	rs1_53	log	61.23764	1.00E-03	150.0
Overland Conveyance	rs1_54	log	54.15611	1.00E-03	150.0
Overland Conveyance	rs1_55	log	55.57786	1.00E-03	150.0
Overland Conveyance	rs1_56	log	49.52231	1.00E-03	150.0
Overland Conveyance	rs1_57	log	48.7521	1.00E-03	150.0
Overland Conveyance	rs1_58	log	42.30617	1.00E-03	150.0
Overland Conveyance	rs1_59	log	35.96721	1.00E-03	150.0
Overland Conveyance	rs1_60	log	32.44136	1.00E-03	150.0
Overland Conveyance	rs1_61	log	36.61676	1.00E-03	150.0
Overland Conveyance	rs1_62	log	27.6346	1.00E-03	150.0
Overland Conveyance	rs1_63	log	23.55112	1.00E-03	150.0
Overland Conveyance	rs1_64	log	21.70813	1.00E-03	150.0
Overland Conveyance	rs1_65	log	17.35321	1.00E-03	150.0
Overland Conveyance	rs1_66	log	14.05673	1.00E-03	150.0
Overland Conveyance	rs1_67	log	8.811635	1.00E-03	150.0
Overland Conveyance	rs1_68	log	5.004905	1.00E-03	150.0
Overland Conveyance	rs1_69	log	1.464788	1.00E-03	150.0
Overland Conveyance	rs1_70	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs1_71	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs1_72	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs1_73	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs1_74	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs1_75	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs1_76	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs1_77	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs1_78	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs1_79	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs1_80	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs1_81	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs1_82	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs1_83	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs1_84	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs1_85	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs1_86	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_01	log	0.7587599	1.00E-03	150.0
Overland Conveyance	rs2_02	log	0.8382686	1.00E-03	150.0
Overland Conveyance	rs2_03	log	1.815548	1.00E-03	150.0
Overland Conveyance	rs2_04	log	2.86003	1.00E-03	150.0
Overland Conveyance	rs2_05	log	5.487471	1.00E-03	150.0
Overland Conveyance	rs2_06	log	12.99569	1.00E-03	150.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Overland Conveyance	rs2_07	log	16.74821	1.00E-03	150.0
Overland Conveyance	rs2_08	log	19.04714	1.00E-03	150.0
Overland Conveyance	rs2_09	log	23.48266	1.00E-03	150.0
Overland Conveyance	rs2_10	log	34.2407	1.00E-03	150.0
Overland Conveyance	rs2_11	log	43.31675	1.00E-03	150.0
Overland Conveyance	rs2_12	log	44.42163	1.00E-03	150.0
Overland Conveyance	rs2_13	log	39.82242	1.00E-03	150.0
Overland Conveyance	rs2_14	log	48.04436	1.00E-03	150.0
Overland Conveyance	rs2_15	log	36.81173	1.00E-03	150.0
Overland Conveyance	rs2_16	log	45.32882	1.00E-03	150.0
Overland Conveyance	rs2_17	log	46.80204	1.00E-03	150.0
Overland Conveyance	rs2_18	log	50.92318	1.00E-03	150.0
Overland Conveyance	rs2_19	log	48.01452	1.00E-03	150.0
Overland Conveyance	rs2_20	log	45.04813	1.00E-03	150.0
Overland Conveyance	rs2_21	log	71.83988	1.00E-03	150.0
Overland Conveyance	rs2_22	log	63.91303	1.00E-03	150.0
Overland Conveyance	rs2_23	log	62.68305	1.00E-03	150.0
Overland Conveyance	rs2_24	log	69.70172	1.00E-03	150.0
Overland Conveyance	rs2_25	log	63.48591	1.00E-03	150.0
Overland Conveyance	rs2_26	log	73.27627	1.00E-03	150.0
Overland Conveyance	rs2_27	log	87.13338	1.00E-03	150.0
Overland Conveyance	rs2_28	log	88.26551	1.00E-03	150.0
Overland Conveyance	rs2_29	log	103.3948	1.00E-03	150.0
Overland Conveyance	rs2_30	log	80.43194	1.00E-03	150.0
Overland Conveyance	rs2_31	log	90.20815	1.00E-03	150.0
Overland Conveyance	rs2_32	log	99.81549	1.00E-03	150.0
Overland Conveyance	rs2_33	log	115.3201	1.00E-03	150.0
Overland Conveyance	rs2_34	log	91.9591	1.00E-03	150.0
Overland Conveyance	rs2_35	log	103.2768	1.00E-03	150.0
Overland Conveyance	rs2_36	log	101.2844	1.00E-03	150.0
Overland Conveyance	rs2_37	log	84.10158	1.00E-03	150.0
Overland Conveyance	rs2_38	log	87.97221	1.00E-03	150.0
Overland Conveyance	rs2_39	log	110.624	1.00E-03	150.0
Overland Conveyance	rs2_40	log	97.46951	1.00E-03	150.0
Overland Conveyance	rs2_41	log	90.50349	1.00E-03	150.0
Overland Conveyance	rs2_42	log	90.32216	1.00E-03	150.0
Overland Conveyance	rs2_43	log	101.9218	1.00E-03	150.0
Overland Conveyance	rs2_44	log	85.7841	1.00E-03	150.0
Overland Conveyance	rs2_45	log	72.06048	1.00E-03	150.0
Overland Conveyance	rs2_46	log	75.8077	1.00E-03	150.0
Overland Conveyance	rs2_47	log	86.41809	1.00E-03	150.0
Overland Conveyance	rs2_48	log	86.35001	1.00E-03	150.0
Overland Conveyance	rs2_49	log	68.85902	1.00E-03	150.0
Overland Conveyance	rs2_50	log	72.92444	1.00E-03	150.0
Overland Conveyance	rs2_51	log	58.08642	1.00E-03	150.0
Overland Conveyance	rs2_52	log	51.06886	1.00E-03	150.0
Overland Conveyance	rs2_53	log	63.15805	1.00E-03	150.0
Overland Conveyance	rs2_54	log	51.71274	1.00E-03	150.0
Overland Conveyance	rs2_55	log	51.88021	1.00E-03	150.0
Overland Conveyance	rs2_56	log	46.6648	1.00E-03	150.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Overland Conveyance	rs2_57	log	48.48278	1.00E-03	150.0
Overland Conveyance	rs2_58	log	40.18413	1.00E-03	150.0
Overland Conveyance	rs2_59	log	40.14981	1.00E-03	150.0
Overland Conveyance	rs2_60	log	35.62443	1.00E-03	150.0
Overland Conveyance	rs2_61	log	36.08649	1.00E-03	150.0
Overland Conveyance	rs2_62	log	28.69179	1.00E-03	150.0
Overland Conveyance	rs2_63	log	24.21402	1.00E-03	150.0
Overland Conveyance	rs2_64	log	22.27114	1.00E-03	150.0
Overland Conveyance	rs2_65	log	18.75652	1.00E-03	150.0
Overland Conveyance	rs2_66	log	12.19429	1.00E-03	150.0
Overland Conveyance	rs2_67	log	9.204098	1.00E-03	150.0
Overland Conveyance	rs2_68	log	5.582012	1.00E-03	150.0
Overland Conveyance	rs2_69	log	1.341772	1.00E-03	150.0
Overland Conveyance	rs2_70	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_71	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_72	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_73	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_74	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_75	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_76	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_77	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_78	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_79	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_80	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_81	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_82	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_83	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_84	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_85	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs2_86	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	sg_01	log	4.02E-03	1.00E-03	150.0
Overland Conveyance	sg_02	log	4.69E-03	1.00E-03	150.0
Overland Conveyance	sg_03	log	9.39E-03	1.00E-03	150.0
Overland Conveyance	sg_04	log	1.69E-02	1.00E-03	150.0
Overland Conveyance	sg_05	log	3.77E-02	1.00E-03	150.0
Overland Conveyance	sg_06	log	7.75E-02	1.00E-03	150.0
Overland Conveyance	sg_07	log	0.1443181	1.00E-03	150.0
Overland Conveyance	sg_08	log	0.2555182	1.00E-03	150.0
Overland Conveyance	sg_09	log	0.6164546	1.00E-03	150.0
Overland Conveyance	sg_10	log	18.80122	1.00E-03	150.0
Overland Conveyance	sg_11	log	19.93925	1.00E-03	150.0
Overland Conveyance	sg_12	log	27.71616	1.00E-03	150.0
Overland Conveyance	sg_13	log	25.85815	1.00E-03	150.0
Overland Conveyance	sg_14	log	24.03653	1.00E-03	150.0
Overland Conveyance	sg_15	log	29.21628	1.00E-03	150.0
Overland Conveyance	sg_16	log	30.90231	1.00E-03	150.0
Overland Conveyance	sg_17	log	36.36434	1.00E-03	150.0
Overland Conveyance	sg_18	log	38.50344	1.00E-03	150.0
Overland Conveyance	sg_19	log	39.59382	1.00E-03	150.0
Overland Conveyance	sg_20	log	43.54578	1.00E-03	150.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Overland Conveyance	sg_21	log	38.48062	1.00E-03	150.0
Overland Conveyance	sg_22	log	49.14094	1.00E-03	150.0
Overland Conveyance	sg_23	log	56.25164	1.00E-03	150.0
Overland Conveyance	sg_24	log	56.3729	1.00E-03	150.0
Overland Conveyance	sg_25	log	49.70397	1.00E-03	150.0
Overland Conveyance	sg_26	log	45.8807	1.00E-03	150.0
Overland Conveyance	sg_27	log	49.40993	1.00E-03	150.0
Overland Conveyance	sg_28	log	47.76677	1.00E-03	150.0
Overland Conveyance	sg_29	log	51.39945	1.00E-03	150.0
Overland Conveyance	sg_30	log	51.15053	1.00E-03	150.0
Overland Conveyance	sg_31	log	59.81054	1.00E-03	150.0
Overland Conveyance	sg_32	log	53.93858	1.00E-03	150.0
Overland Conveyance	sg_33	log	58.245	1.00E-03	150.0
Overland Conveyance	sg_34	log	59.15131	1.00E-03	150.0
Overland Conveyance	sg_35	log	60.34294	1.00E-03	150.0
Overland Conveyance	sg_36	log	70.10841	1.00E-03	150.0
Overland Conveyance	sg_37	log	59.34038	1.00E-03	150.0
Overland Conveyance	sg_38	log	57.32733	1.00E-03	150.0
Overland Conveyance	sg_39	log	57.21427	1.00E-03	150.0
Overland Conveyance	sg_40	log	69.3193	1.00E-03	150.0
Overland Conveyance	sg_41	log	54.2825	1.00E-03	150.0
Overland Conveyance	sg_42	log	62.35141	1.00E-03	150.0
Overland Conveyance	sg_43	log	56.03425	1.00E-03	150.0
Overland Conveyance	sg_44	log	59.42176	1.00E-03	150.0
Overland Conveyance	sg_45	log	61.89173	1.00E-03	150.0
Overland Conveyance	sg_46	log	59.84682	1.00E-03	150.0
Overland Conveyance	sg_47	log	57.6299	1.00E-03	150.0
Overland Conveyance	sg_48	log	59.0464	1.00E-03	150.0
Overland Conveyance	sg_49	log	57.30675	1.00E-03	150.0
Overland Conveyance	sg_50	log	61.61096	1.00E-03	150.0
Overland Conveyance	sg_51	log	52.54913	1.00E-03	150.0
Overland Conveyance	sg_52	log	52.82417	1.00E-03	150.0
Overland Conveyance	sg_53	log	49.16377	1.00E-03	150.0
Overland Conveyance	sg_54	log	57.00479	1.00E-03	150.0
Overland Conveyance	sg_55	log	44.89527	1.00E-03	150.0
Overland Conveyance	sg_56	log	52.77666	1.00E-03	150.0
Overland Conveyance	sg_57	log	45.80956	1.00E-03	150.0
Overland Conveyance	sg_58	log	46.11144	1.00E-03	150.0
Overland Conveyance	sg_59	log	38.26066	1.00E-03	150.0
Overland Conveyance	sg_60	log	41.81244	1.00E-03	150.0
Overland Conveyance	sg_61	log	33.80177	1.00E-03	150.0
Overland Conveyance	sg_62	log	31.63822	1.00E-03	150.0
Overland Conveyance	sg_63	log	28.69336	1.00E-03	150.0
Overland Conveyance	sg_64	log	22.73384	1.00E-03	150.0
Overland Conveyance	sg_65	log	22.11408	1.00E-03	150.0
Overland Conveyance	sg_66	log	16.66261	1.00E-03	150.0
Overland Conveyance	sg_67	log	16.22014	1.00E-03	150.0
Overland Conveyance	sg_68	log	9.630256	1.00E-03	150.0
Overland Conveyance	sg_69	log	5.125876	1.00E-03	150.0
Overland Conveyance	sg_70	log	0.7523062	1.00E-03	150.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Overland Conveyance	sg_71	log	9.97E-04	1.00E-03	150.0
Overland Conveyance	sg_72	log	9.97E-04	1.00E-03	150.0
Overland Conveyance	sg_73	log	9.97E-04	1.00E-03	150.0
Overland Conveyance	sg_74	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	sg_75	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	sg_76	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	sg_77	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	sg_78	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	sg_79	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	sg_80	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	sg_81	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	mm_01	log	0.3909151	1.00E-03	150.0
Overland Conveyance	mm_02	log	0.3836159	1.00E-03	150.0
Overland Conveyance	mm_03	log	0.8299257	1.00E-03	150.0
Overland Conveyance	mm_04	log	1.648123	1.00E-03	150.0
Overland Conveyance	mm_05	log	3.019857	1.00E-03	150.0
Overland Conveyance	mm_06	log	8.808243	1.00E-03	150.0
Overland Conveyance	mm_07	log	9.671051	1.00E-03	150.0
Overland Conveyance	mm_08	log	10.22219	1.00E-03	150.0
Overland Conveyance	mm_09	log	11.81268	1.00E-03	150.0
Overland Conveyance	mm_10	log	19.59169	1.00E-03	150.0
Overland Conveyance	mm_11	log	21.40687	1.00E-03	150.0
Overland Conveyance	mm_12	log	22.51674	1.00E-03	150.0
Overland Conveyance	mm_13	log	25.18775	1.00E-03	150.0
Overland Conveyance	mm_14	log	32.00417	1.00E-03	150.0
Overland Conveyance	mm_15	log	28.74449	1.00E-03	150.0
Overland Conveyance	mm_16	log	28.30635	1.00E-03	150.0
Overland Conveyance	mm_17	log	36.79385	1.00E-03	150.0
Overland Conveyance	mm_18	log	35.35551	1.00E-03	150.0
Overland Conveyance	mm_19	log	32.70854	1.00E-03	150.0
Overland Conveyance	mm_20	log	35.46431	1.00E-03	150.0
Overland Conveyance	mm_21	log	40.44346	1.00E-03	150.0
Overland Conveyance	mm_22	log	47.38237	1.00E-03	150.0
Overland Conveyance	mm_23	log	42.75189	1.00E-03	150.0
Overland Conveyance	mm_24	log	44.29283	1.00E-03	150.0
Overland Conveyance	mm_25	log	44.97812	1.00E-03	150.0
Overland Conveyance	mm_26	log	44.08117	1.00E-03	150.0
Overland Conveyance	mm_27	log	43.4501	1.00E-03	150.0
Overland Conveyance	mm_28	log	52.68781	1.00E-03	150.0
Overland Conveyance	mm_29	log	53.82198	1.00E-03	150.0
Overland Conveyance	mm_30	log	57.912	1.00E-03	150.0
Overland Conveyance	mm_31	log	65.58113	1.00E-03	150.0
Overland Conveyance	mm_32	log	60.97954	1.00E-03	150.0
Overland Conveyance	mm_33	log	60.14184	1.00E-03	150.0
Overland Conveyance	mm_34	log	59.0197	1.00E-03	150.0
Overland Conveyance	mm_35	log	55.26163	1.00E-03	150.0
Overland Conveyance	mm_36	log	53.90045	1.00E-03	150.0
Overland Conveyance	mm_37	log	72.1869	1.00E-03	150.0
Overland Conveyance	mm_38	log	67.66667	1.00E-03	150.0
Overland Conveyance	mm_39	log	63.20657	1.00E-03	150.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Overland Conveyance	mm_40	log	69.76352	1.00E-03	150.0
Overland Conveyance	mm_41	log	67.14189	1.00E-03	150.0
Overland Conveyance	mm_42	log	63.51161	1.00E-03	150.0
Overland Conveyance	mm_43	log	61.97726	1.00E-03	150.0
Overland Conveyance	mm_44	log	71.23647	1.00E-03	150.0
Overland Conveyance	mm_45	log	63.28194	1.00E-03	150.0
Overland Conveyance	mm_46	log	66.11538	1.00E-03	150.0
Overland Conveyance	mm_47	log	65.3731	1.00E-03	150.0
Overland Conveyance	mm_48	log	62.20732	1.00E-03	150.0
Overland Conveyance	mm_49	log	61.75389	1.00E-03	150.0
Overland Conveyance	mm_50	log	60.935	1.00E-03	150.0
Overland Conveyance	mm_51	log	59.267	1.00E-03	150.0
Overland Conveyance	mm_52	log	57.443	1.00E-03	150.0
Overland Conveyance	mm_53	log	55.465	1.00E-03	150.0
Overland Conveyance	mm_54	log	53.334	1.00E-03	150.0
Overland Conveyance	mm_55	log	51.046	1.00E-03	150.0
Overland Conveyance	mm_56	log	48.607	1.00E-03	150.0
Overland Conveyance	mm_57	log	46.013	1.00E-03	150.0
Overland Conveyance	mm_58	log	43.269	1.00E-03	150.0
Overland Conveyance	mm_59	log	40.373	1.00E-03	150.0
Overland Conveyance	mm_60	log	37.327	1.00E-03	150.0
Overland Conveyance	mm_61	log	34.133	1.00E-03	150.0
Overland Conveyance	mm_62	log	30.794	1.00E-03	150.0
Overland Conveyance	mm_63	log	27.309	1.00E-03	150.0
Overland Conveyance	mm_64	log	23.682	1.00E-03	150.0
Overland Conveyance	mm_65	log	19.915	1.00E-03	150.0
Overland Conveyance	mm_66	log	16.01	1.00E-03	150.0
Overland Conveyance	mm_67	log	11.97	1.00E-03	150.0
Overland Conveyance	mm_68	log	7.796	1.00E-03	150.0
Overland Conveyance	mm_69	log	3.495	1.00E-03	150.0
Overland Conveyance	mm_70	log	0.388	1.00E-03	150.0
Overland Conveyance	mm_71	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	mm_72	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	mm_73	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	mm_74	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	mm_75	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	mm_76	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	mm_77	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	mm_78	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	mm_79	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	mm_80	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	mm_81	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs3_01	log	1.042212	1.00E-03	150.0
Overland Conveyance	rs3_02	log	1.233532	1.00E-03	150.0
Overland Conveyance	rs3_03	log	2.040047	1.00E-03	150.0
Overland Conveyance	rs3_04	log	4.177658	1.00E-03	150.0
Overland Conveyance	rs3_05	log	67.75449	1.00E-03	150.0
Overland Conveyance	rs3_06	log	118.7371	1.00E-03	150.0
Overland Conveyance	rs3_07	log	102.4573	1.00E-03	150.0
Overland Conveyance	rs3_08	log	127.425	1.00E-03	150.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Overland Conveyance	rs3_09	log	116.2759	1.00E-03	150.0
Overland Conveyance	rs3_10	log	88.79966	1.00E-03	150.0
Overland Conveyance	rs3_11	log	87.47134	1.00E-03	150.0
Overland Conveyance	rs3_12	log	86.00182	1.00E-03	150.0
Overland Conveyance	rs3_13	log	74.99202	1.00E-03	150.0
Overland Conveyance	rs3_14	log	74.66147	1.00E-03	150.0
Overland Conveyance	rs3_15	log	73.18397	1.00E-03	150.0
Overland Conveyance	rs3_16	log	85.54505	1.00E-03	150.0
Overland Conveyance	rs3_17	log	91.54512	1.00E-03	150.0
Overland Conveyance	rs3_18	log	75.85005	1.00E-03	150.0
Overland Conveyance	rs3_19	log	83.83699	1.00E-03	150.0
Overland Conveyance	rs3_20	log	91.94544	1.00E-03	150.0
Overland Conveyance	rs3_21	log	92.55637	1.00E-03	150.0
Overland Conveyance	rs3_22	log	100.2104	1.00E-03	150.0
Overland Conveyance	rs3_23	log	101.4638	1.00E-03	150.0
Overland Conveyance	rs3_24	log	120.4773	1.00E-03	150.0
Overland Conveyance	rs3_25	log	112.2185	1.00E-03	150.0
Overland Conveyance	rs3_26	log	120.6432	1.00E-03	150.0
Overland Conveyance	rs3_27	log	111.7887	1.00E-03	150.0
Overland Conveyance	rs3_28	log	112.0244	1.00E-03	150.0
Overland Conveyance	rs3_29	log	129.7718	1.00E-03	150.0
Overland Conveyance	rs3_30	log	117.9139	1.00E-03	150.0
Overland Conveyance	rs3_31	log	128.5192	1.00E-03	150.0
Overland Conveyance	rs3_32	log	114.4421	1.00E-03	150.0
Overland Conveyance	rs3_33	log	127.8208	1.00E-03	150.0
Overland Conveyance	rs3_34	log	121.3485	1.00E-03	150.0
Overland Conveyance	rs3_35	log	114.8805	1.00E-03	150.0
Overland Conveyance	rs3_36	log	112.5248	1.00E-03	150.0
Overland Conveyance	rs3_37	log	97.27782	1.00E-03	150.0
Overland Conveyance	rs3_38	log	112.7078	1.00E-03	150.0
Overland Conveyance	rs3_39	log	91.02253	1.00E-03	150.0
Overland Conveyance	rs3_40	log	87.66583	1.00E-03	150.0
Overland Conveyance	rs3_41	log	106.5229	1.00E-03	150.0
Overland Conveyance	rs3_42	log	88.54722	1.00E-03	150.0
Overland Conveyance	rs3_43	log	110.3965	1.00E-03	150.0
Overland Conveyance	rs3_44	log	108.2127	1.00E-03	150.0
Overland Conveyance	rs3_45	log	93.83142	1.00E-03	150.0
Overland Conveyance	rs3_46	log	94.15128	1.00E-03	150.0
Overland Conveyance	rs3_47	log	82.71466	1.00E-03	150.0
Overland Conveyance	rs3_48	log	82.29156	1.00E-03	150.0
Overland Conveyance	rs3_49	log	93.31733	1.00E-03	150.0
Overland Conveyance	rs3_50	log	83.31126	1.00E-03	150.0
Overland Conveyance	rs3_51	log	78.771	1.00E-03	150.0
Overland Conveyance	rs3_52	log	78.903	1.00E-03	150.0
Overland Conveyance	rs3_53	log	78.88853	1.00E-03	150.0
Overland Conveyance	rs3_54	log	75.534	1.00E-03	150.0
Overland Conveyance	rs3_55	log	75.4819	1.00E-03	150.0
Overland Conveyance	rs3_56	log	67.30383	1.00E-03	150.0
Overland Conveyance	rs3_57	log	62.90119	1.00E-03	150.0
Overland Conveyance	rs3_58	log	60.12969	1.00E-03	150.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Overland Conveyance	rs3_59	log	56.39444	1.00E-03	150.0
Overland Conveyance	rs3_60	log	50.52708	1.00E-03	150.0
Overland Conveyance	rs3_61	log	46.6729	1.00E-03	150.0
Overland Conveyance	rs3_62	log	42.18175	1.00E-03	150.0
Overland Conveyance	rs3_63	log	38.18	1.00E-03	150.0
Overland Conveyance	rs3_64	log	33.37	1.00E-03	150.0
Overland Conveyance	rs3_65	log	28.39	1.00E-03	150.0
Overland Conveyance	rs3_66	log	23.26	1.00E-03	150.0
Overland Conveyance	rs3_67	log	17.95	1.00E-03	150.0
Overland Conveyance	rs3_68	log	12.5	1.00E-03	150.0
Overland Conveyance	rs3_69	log	6.88	1.00E-03	150.0
Overland Conveyance	rs3_70	log	1.09	1.00E-03	150.0
Overland Conveyance	rs3_71	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs3_72	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs3_73	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs3_74	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs3_75	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs3_76	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs3_77	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs3_78	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs3_79	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs3_80	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs3_81	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs3_82	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs3_83	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs3_84	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs3_85	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	rs3_86	log	1.00E-03	1.00E-03	150.0
Overland Conveyance	mann_100	none	0.197455	0.01	1.0
Overland Conveyance	mann_200	none	0.4088708	0.01	1.0
Overland Conveyance	mann_300	none	0.1	0.01	1.0
Overland Conveyance	mann_400	none	0.3	0.01	1.0
Overland Conveyance	mann_410	none	0.3072175	0.01	1.0
Overland Conveyance	mann_420	none	0.4367337	0.01	1.0
Overland Conveyance	mann_421	none	1.00E-02	0.01	1.0
Overland Conveyance	mann_520	none	0.6944851	0.01	1.0
Overland Conveyance	mann_521	none	0.6948172	0.01	1.0
Overland Conveyance	mann_530	none	0.6635814	0.01	1.0
Overland Conveyance	mann_531	none	0.8800607	0.01	1.0
Overland Conveyance	mann_532	none	0.6965524	0.01	1.0
Overland Conveyance	mann_600	none	0.8968345	0.01	1.0
Overland Conveyance	mann_610	none	0.8545183	0.01	1.0
Overland Conveyance	mann_620	none	0.85	0.01	1.0
Overland Conveyance	mann_700	none	0.85	0.01	1.0
Overland Conveyance	mann_710	none	0.8163955	0.01	1.0
Overland Conveyance	mann_720	none	0.8909708	0.01	1.0
Overland Conveyance	mann_730	none	0.8320276	0.01	1.0
Overland Conveyance	mann_800	none	0.8217393	0.01	1.0
Overland Conveyance	mann_810	none	0.85	0.01	1.0
Overland Conveyance	mann_820	none	0.8478003	0.01	1.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Overland Conveyance	mann_830	none	0.85	0.01	1.0

Table J-5. Initial ranges for evapotranspiration (ET) parameters used in initial optimization.

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
ET	kveg200q1	none	0.6026532	0.4	1.0
ET	kveg200q2	none	0.6110773	0.4	1.0
ET	kveg200q3	none	0.7089328	0.4	1.0
ET	kveg200q4	none	0.6837954	0.4	1.0
ET	kveg400q1	none	0.6	0.4	1.0
ET	kveg400q2	none	0.63	0.4	1.0
ET	kveg400q3	none	0.69	0.4	1.0
ET	kveg400q4	none	0.68	0.4	1.0
ET	kveg410q1	none	0.5323088	0.4	1.0
ET	kveg410q2	none	0.5608022	0.4	1.0
ET	kveg410q3	none	0.6408952	0.4	1.0
ET	kveg410q4	none	0.6859341	0.4	1.0
ET	kveg420q1	none	0.5186848	0.4	1.0
ET	kveg420q2	none	0.629685	0.4	1.0
ET	kveg420q3	none	0.7257502	0.4	1.0
ET	kveg420q4	none	0.5684865	0.4	1.0
ET	kveg421q1	none	0.6499637	0.4	1.0
ET	kveg421q2	none	0.6656784	0.4	1.0
ET	kveg421q3	none	0.7216446	0.4	1.0
ET	kveg421q4	none	0.6757785	0.4	1.0
ET	kveg500q1	none	0.6474037	0.4	1.0
ET	kveg500q2	none	0.6656725	0.4	1.0
ET	kveg500q3	none	0.7951549	0.4	1.0
ET	kveg500q4	none	0.8299541	0.4	1.0
ET	kveg510q1	none	0.7004195	0.4	1.0
ET	kveg510q2	none	0.6840531	0.4	1.0
ET	kveg510q3	none	0.8522017	0.4	1.0
ET	kveg510q4	none	0.8626732	0.4	1.0
ET	kveg511q1	none	0.4480781	0.4	1.0
ET	kveg511q2	none	0.5894921	0.4	1.0
ET	kveg511q3	none	0.8741382	0.4	1.0
ET	kveg511q4	none	0.5453348	0.4	1.0
ET	kveg514q1	none	0.61	0.4	1.0
ET	kveg514q2	none	0.63	0.4	1.0
ET	kveg514q3	none	0.77	0.4	1.0
ET	kveg514q4	none	0.74	0.4	1.0
ET	kveg512q1	none	0.9718769	0.4	1.0
ET	kveg512q2	none	0.9926202	0.4	1.0
ET	kveg512q3	none	0.8972419	0.4	1.0
ET	kveg512q4	none	0.659506	0.4	1.0
ET	kveg520q1	none	0.680813	0.4	1.0
ET	kveg520q2	none	0.7425886	0.4	1.0
ET	kveg520q3	none	0.8409396	0.4	1.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
ET	kveg520q4	none	0.8873398	0.4	1.0
ET	kveg521q1	none	0.6588594	0.4	1.0
ET	kveg521q2	none	0.735642	0.4	1.0
ET	kveg521q3	none	0.8804244	0.4	1.0
ET	kveg521q4	none	0.7767023	0.4	1.0
ET	kveg522q1	none	0.5587853	0.4	1.0
ET	kveg522q2	none	0.6204642	0.4	1.0
ET	kveg522q3	none	0.6802357	0.4	1.0
ET	kveg522q4	none	0.7155418	0.4	1.0
ET	kveg530q1	none	0.6953925	0.4	1.0
ET	kveg530q2	none	0.7420789	0.4	1.0
ET	kveg530q3	none	0.7429973	0.4	1.0
ET	kveg530q4	none	0.7963602	0.4	1.0
ET	kveg531q1	none	0.6149194	0.4	1.0
ET	kveg531q2	none	0.6468566	0.4	1.0
ET	kveg531q3	none	0.7570584	0.4	1.0
ET	kveg531q4	none	0.7043412	0.4	1.0
ET	kveg532q1	none	0.716325	0.4	1.0
ET	kveg532q2	none	0.7116005	0.4	1.0
ET	kveg532q3	none	0.7581215	0.4	1.0
ET	kveg532q4	none	0.737566	0.4	1.0
ET	kveg600q1	none	0.5143403	0.4	1.0
ET	kveg600q2	none	0.6134543	0.4	1.0
ET	kveg600q3	none	0.7064261	0.4	1.0
ET	kveg600q4	none	0.7316511	0.4	1.0
ET	kveg610q1	none	0.6109196	0.4	1.0
ET	kveg610q2	none	0.6266902	0.4	1.0
ET	kveg610q3	none	0.6800838	0.4	1.0
ET	kveg610q4	none	0.6567152	0.4	1.0
ET	kveg620q1	none	0.61	0.4	1.0
ET	kveg620q2	none	0.63	0.4	1.0
ET	kveg620q3	none	0.69	0.4	1.0
ET	kveg620q4	none	0.68	0.4	1.0

Table J-6. Initial ranges for storage coefficient parameters used in initial optimization.

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Storage Coefficient	nsm_100	none	0.9838213	0.01	1.2
Storage Coefficient	nsm_300	none	0.5	0.01	1.2
Storage Coefficient	unsat_700	none	0.61	0.01	1.2
Storage Coefficient	unsat_710	none	0.5076861	0.01	1.2
Storage Coefficient	unsat_720	none	0.3799289	0.01	1.2
Storage Coefficient	unsat_730	none	0.5640679	0.01	1.2
Storage Coefficient	unsat_800	none	0.4622916	0.01	1.2
Storage Coefficient	unsat_810	none	0.61	0.01	1.2
Storage Coefficient	unsat_820	none	0.6117898	0.01	1.2
Storage Coefficient	unsat_830	none	0.61	0.01	1.2
Storage Coefficient	sc_200	none	0.1974179	0.12	0.75

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Storage Coefficient	sc_300	none	0.2	0.12	0.75
Storage Coefficient	sc_400	none	0.2	0.12	0.75
Storage Coefficient	sc_410	none	0.2543344	0.12	0.75
Storage Coefficient	sc_420	none	0.1891461	0.12	0.75
Storage Coefficient	sc_421	none	0.1610943	0.12	0.75
Storage Coefficient	sc_500	none	0.15	0.12	0.75
Storage Coefficient	sc_510	none	0.2263255	0.12	0.75
Storage Coefficient	sc_520	none	0.1655921	0.12	0.75
Storage Coefficient	sc_521	none	0.3280396	0.12	0.75
Storage Coefficient	sc_530	none	0.15	0.12	0.75
Storage Coefficient	sc_531	none	0.2187303	0.12	0.75
Storage Coefficient	sc_532	none	0.2493494	0.12	0.75
Storage Coefficient	sc_600	none	0.2378434	0.12	0.75
Storage Coefficient	sc_610	none	0.15	0.12	0.75
Storage Coefficient	sc_620	none	0.2	0.12	0.75
Storage Coefficient	sc_700	none	0.2	0.12	0.75
Storage Coefficient	sc_710	none	0.15	0.12	0.75
Storage Coefficient	sc_720	none	0.2035131	0.12	0.75
Storage Coefficient	sc_730	none	0.15	0.12	0.75
Storage Coefficient	sc_800	none	0.2335009	0.12	0.75
Storage Coefficient	sc_810	none	0.2	0.12	0.75
Storage Coefficient	sc_820	none	0.15	0.12	0.75
Storage Coefficient	sc_830	none	0.2	0.12	0.75
Storage Coefficient	sv_mm_01	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_02	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_03	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_04	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_05	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_06	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_07	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_08	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_09	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_10	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_11	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_12	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_13	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_14	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_15	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_16	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_17	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_18	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_19	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_20	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_21	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_22	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_23	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_24	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_25	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_26	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_27	none	5.00E-02	0.001	5.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Storage Coefficient	sv_mm_28	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_29	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_30	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_31	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_32	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_33	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_34	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_35	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_36	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_37	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_38	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_39	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_40	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_41	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_42	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_43	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_44	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_mm_45	none	5.00E-02	0.001	5.0
Storage Coefficient	sv_sg_01	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_02	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_03	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_04	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_05	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_06	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_07	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_08	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_09	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_10	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_11	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_12	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_13	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_14	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_15	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_16	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_17	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_18	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_19	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_20	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_21	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_22	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_23	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_24	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_25	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_26	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_27	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_28	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_29	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_30	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_31	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_32	none	9.00E-02	0.001	5.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Storage Coefficient	sv_sg_33	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_34	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_35	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_36	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_37	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_38	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_39	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_40	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_41	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_42	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_43	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_44	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_sg_45	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs1_01	none	0.1754436	0.001	5.0
Storage Coefficient	sv_rs1_02	none	6.03E-02	0.001	5.0
Storage Coefficient	sv_rs1_03	none	6.03E-02	0.001	5.0
Storage Coefficient	sv_rs1_04	none	1.00E-03	0.001	5.0
Storage Coefficient	sv_rs1_05	none	1.00E-03	0.001	5.0
Storage Coefficient	sv_rs1_06	none	1.00E-03	0.001	5.0
Storage Coefficient	sv_rs1_07	none	1.00E-03	0.001	5.0
Storage Coefficient	sv_rs1_08	none	1.00E-03	0.001	5.0
Storage Coefficient	sv_rs1_09	none	0.2275634	0.001	5.0
Storage Coefficient	sv_rs1_10	none	0.2495706	0.001	5.0
Storage Coefficient	sv_rs1_11	none	5.16E-02	0.001	5.0
Storage Coefficient	sv_rs1_12	none	0.1028542	0.001	5.0
Storage Coefficient	sv_rs1_13	none	6.70E-02	0.001	5.0
Storage Coefficient	sv_rs1_14	none	0.1970796	0.001	5.0
Storage Coefficient	sv_rs1_15	none	0.187366	0.001	5.0
Storage Coefficient	sv_rs1_16	none	1.00E-03	0.001	5.0
Storage Coefficient	sv_rs1_17	none	1.00E-03	0.001	5.0
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Storage Coefficient	sv_rs1_19	none	0.1134557	0.001	5.0
Storage Coefficient	sv_rs1_20	none	0.1213344	0.001	5.0
Storage Coefficient	sv_rs1_21	none	0.2298419	0.001	5.0
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Storage Coefficient	sv_rs1_27	none	0.1330401	0.001	5.0
Storage Coefficient	sv_rs1_28	none	1.00E-03	0.001	5.0
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Storage Coefficient	sv_rs1_32	none	5.24E-02	0.001	5.0
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Storage Coefficient	sv_rs1_34	none	0.1827258	0.001	5.0
Storage Coefficient	sv_rs1_35	none	0.1827258	0.001	5.0
Storage Coefficient	sv_rs1_36	none	0.1827258	0.001	5.0
Storage Coefficient	sv_rs1_37	none	0.278513	0.001	5.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Storage Coefficient	sv_rs1_38	none	0.2646619	0.001	5.0
Storage Coefficient	sv_rs1_39	none	5.86E-03	0.001	5.0
Storage Coefficient	sv_rs1_40	none	5.86E-03	0.001	5.0
Storage Coefficient	sv_rs1_41	none	5.86E-03	0.001	5.0
Storage Coefficient	sv_rs1_42	none	5.86E-03	0.001	5.0
Storage Coefficient	sv_rs1_43	none	5.76E-02	0.001	5.0
Storage Coefficient	sv_rs1_44	none	0.1215842	0.001	5.0
Storage Coefficient	sv_rs1_45	none	0.1215842	0.001	5.0
Storage Coefficient	sv_rs1_46	none	0.124572	0.001	5.0
Storage Coefficient	sv_rs1_47	none	0.1818293	0.001	5.0
Storage Coefficient	sv_rs1_48	none	0.2964135	0.001	5.0
Storage Coefficient	sv_rs1_49	none	0.2963251	0.001	5.0
Storage Coefficient	sv_rs1_50	none	0.2088814	0.001	5.0
Storage Coefficient	sv_rs1_51	none	8.50E-03	0.001	5.0
Storage Coefficient	sv_rs1_52	none	0.1602193	0.001	5.0
Storage Coefficient	sv_rs1_53	none	0.1938461	0.001	5.0
Storage Coefficient	sv_rs1_54	none	0.2059033	0.001	5.0
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Storage Coefficient	sv_rs2_03	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_04	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_05	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_06	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_07	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_08	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_09	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_10	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_11	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_12	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_13	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_14	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_15	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_16	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_17	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_18	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_19	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_20	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_21	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_22	none	9.00E-02	0.001	5.0

Parameter	Name	Transformation	Initial Value	Lower Bound	Upper Bound
Storage Coefficient	sv_rs2_23	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_24	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_25	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_26	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_27	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_28	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_29	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_30	none	9.00E-02	0.001	5.0
Storage Coefficient	sv_rs2_31	none	9.50E-02	0.001	5.0
Storage Coefficient	sv_rs2_32	none	9.50E-02	0.001	5.0
Storage Coefficient	sv_rs2_33	none	9.50E-02	0.001	5.0
Storage Coefficient	sv_rs2_34	none	9.50E-02	0.001	5.0
Storage Coefficient	sv_rs2_35	none	9.50E-02	0.001	5.0
Storage Coefficient	sv_rs2_36	none	9.50E-02	0.001	5.0
Storage Coefficient	sv_rs2_37	none	9.50E-02	0.001	5.0
Storage Coefficient	sv_rs2_38	none	9.50E-02	0.001	5.0
Storage Coefficient	sv_rs2_39	none	9.50E-02	0.001	5.0
Storage Coefficient	sv_rs2_40	none	9.50E-02	0.001	5.0
Storage Coefficient	sv_rs2_41	none	9.50E-02	0.001	5.0
Storage Coefficient	sv_rs2_42	none	9.50E-02	0.001	5.0
Storage Coefficient	sv_rs2_43	none	9.50E-02	0.001	5.0
Storage Coefficient	sv_rs2_44	none	9.50E-02	0.001	5.0
Storage Coefficient	sv_rs2_45	none	9.50E-02	0.001	5.0
Storage Coefficient	sv_rs2_46	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_47	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_48	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_49	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_50	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_51	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_52	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_53	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_54	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_55	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_56	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_57	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_58	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_59	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_60	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_61	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_62	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_63	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_64	none	9.90E-02	0.001	5.0
Storage Coefficient	sv_rs2_65	none	9.90E-02	0.001	5.0

Appendix K
Model Results

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LIST OF FIGURES

K.1 STAGE

Figures K-1 through **K-40** display annual average stage values for the NSRSM model domain for 1966 through 2005, respectively. **Figure K-41** displays the average annual stage for the entire period of record, 1966-2005.

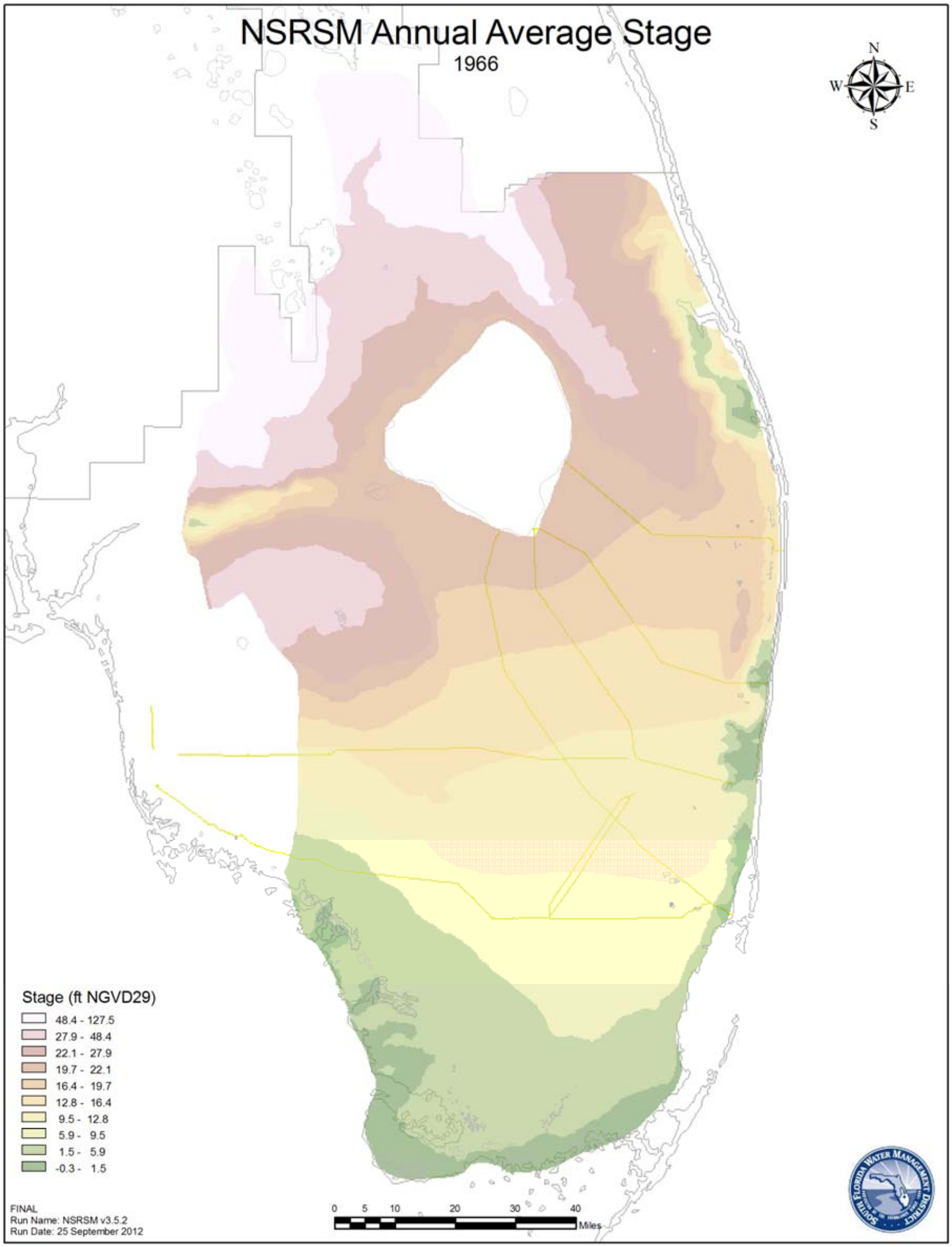

Figure K-1. Annual average stage values for the NSRSM model domain for 1966.

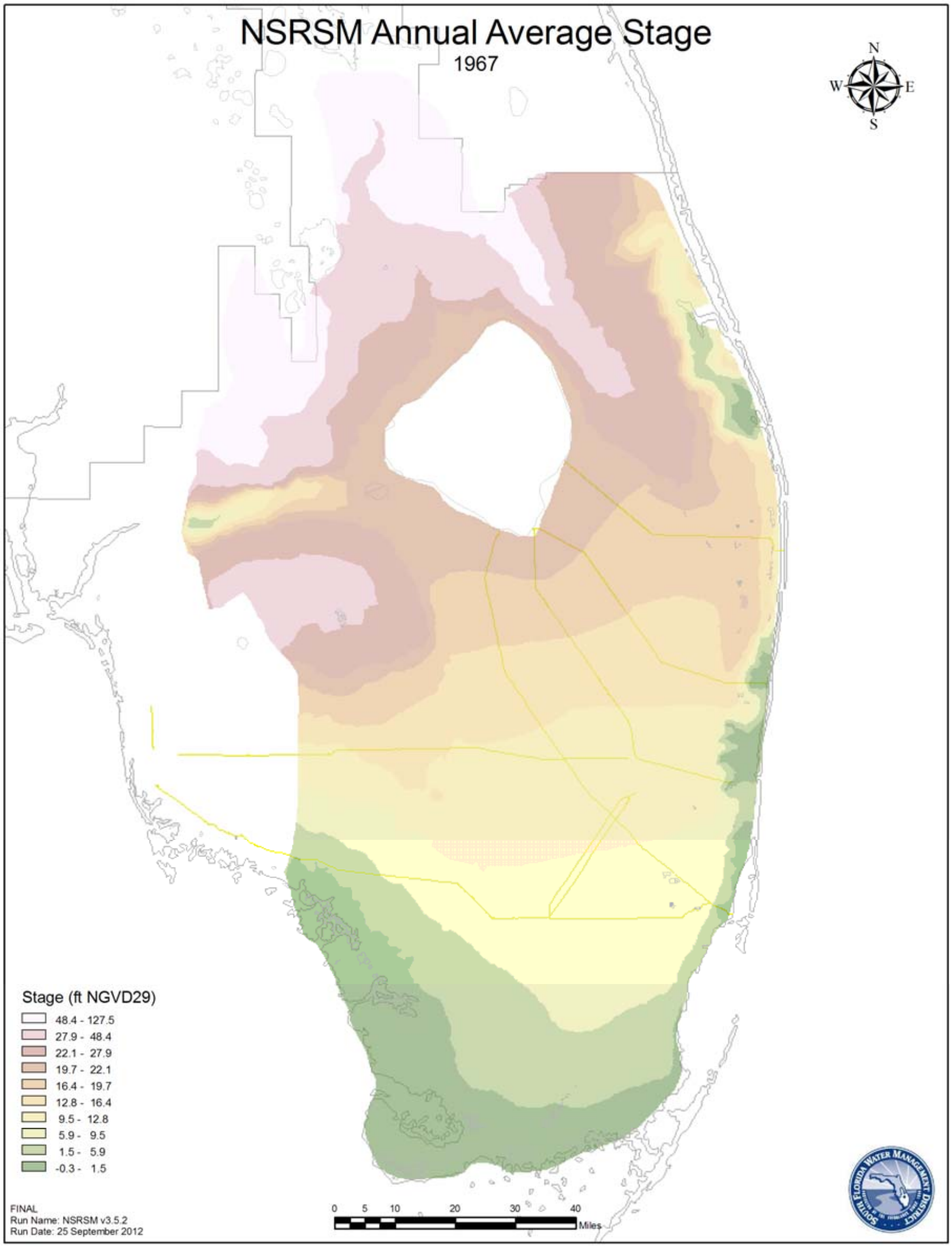

Figure K-2. Annual average stage values for the NSRSM model domain for 1967.

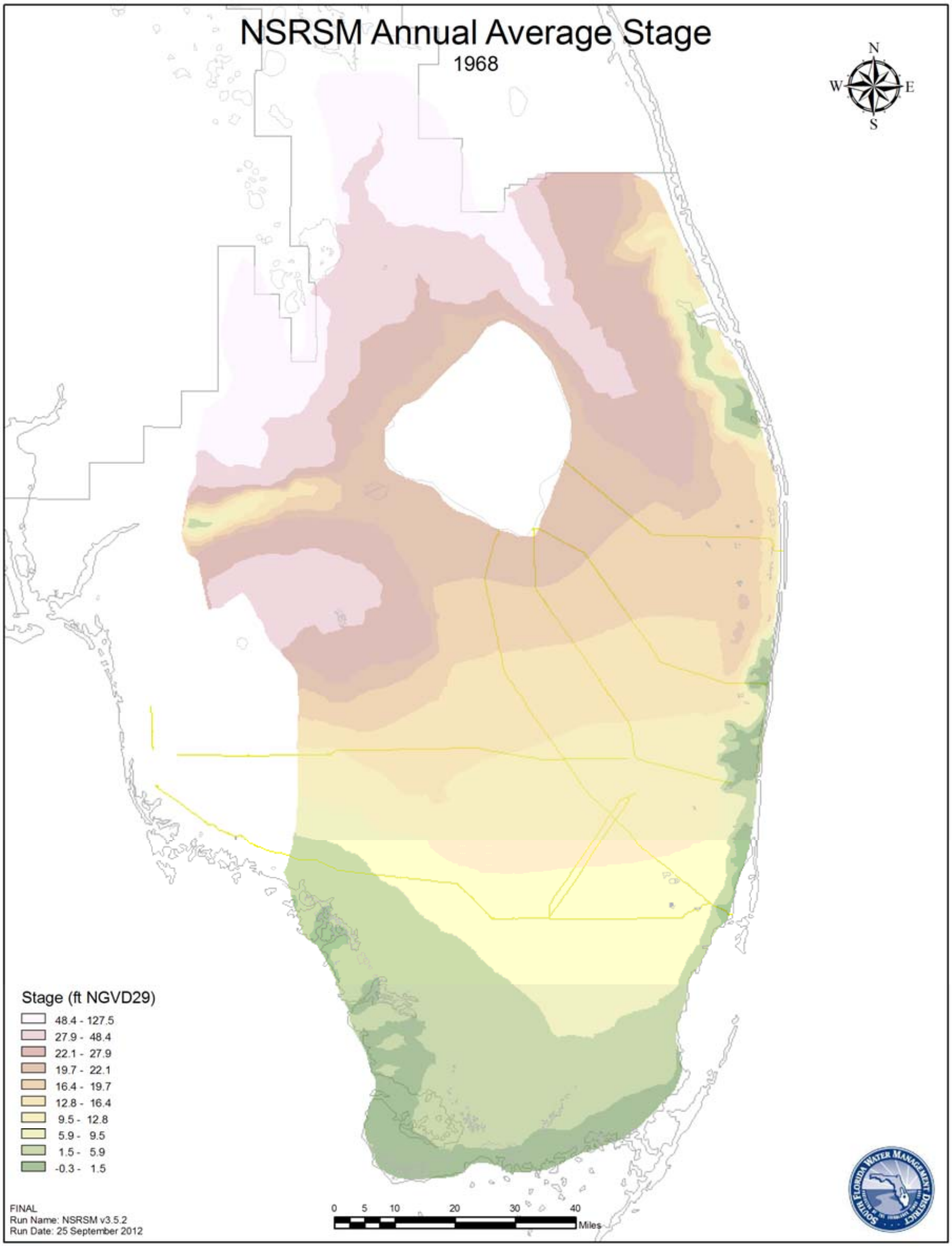

Figure K-3. Annual average stage values for the NSRSM model domain for 1968.

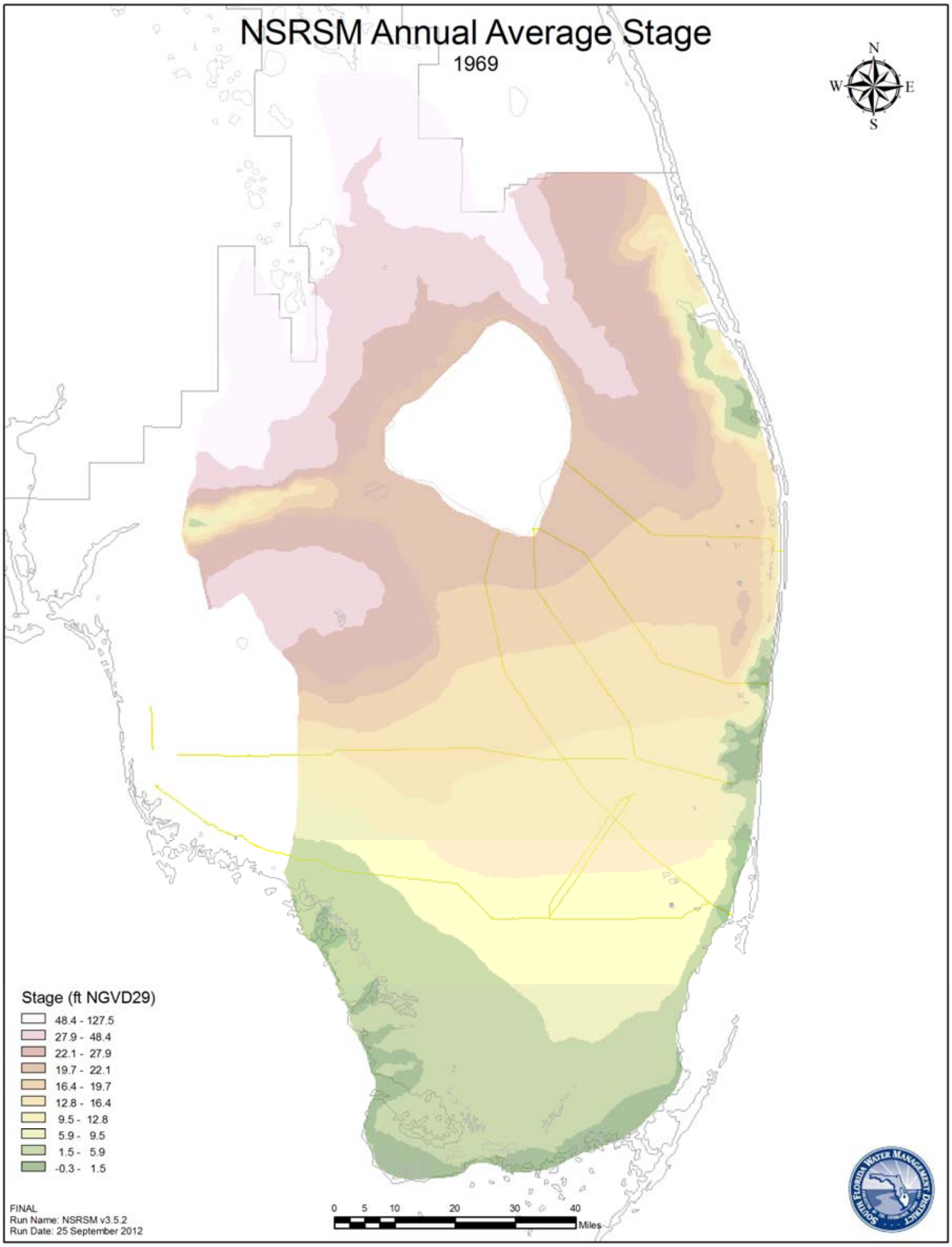

Figure K-4. Annual average stage values for the NSRSM model domain for 1969.

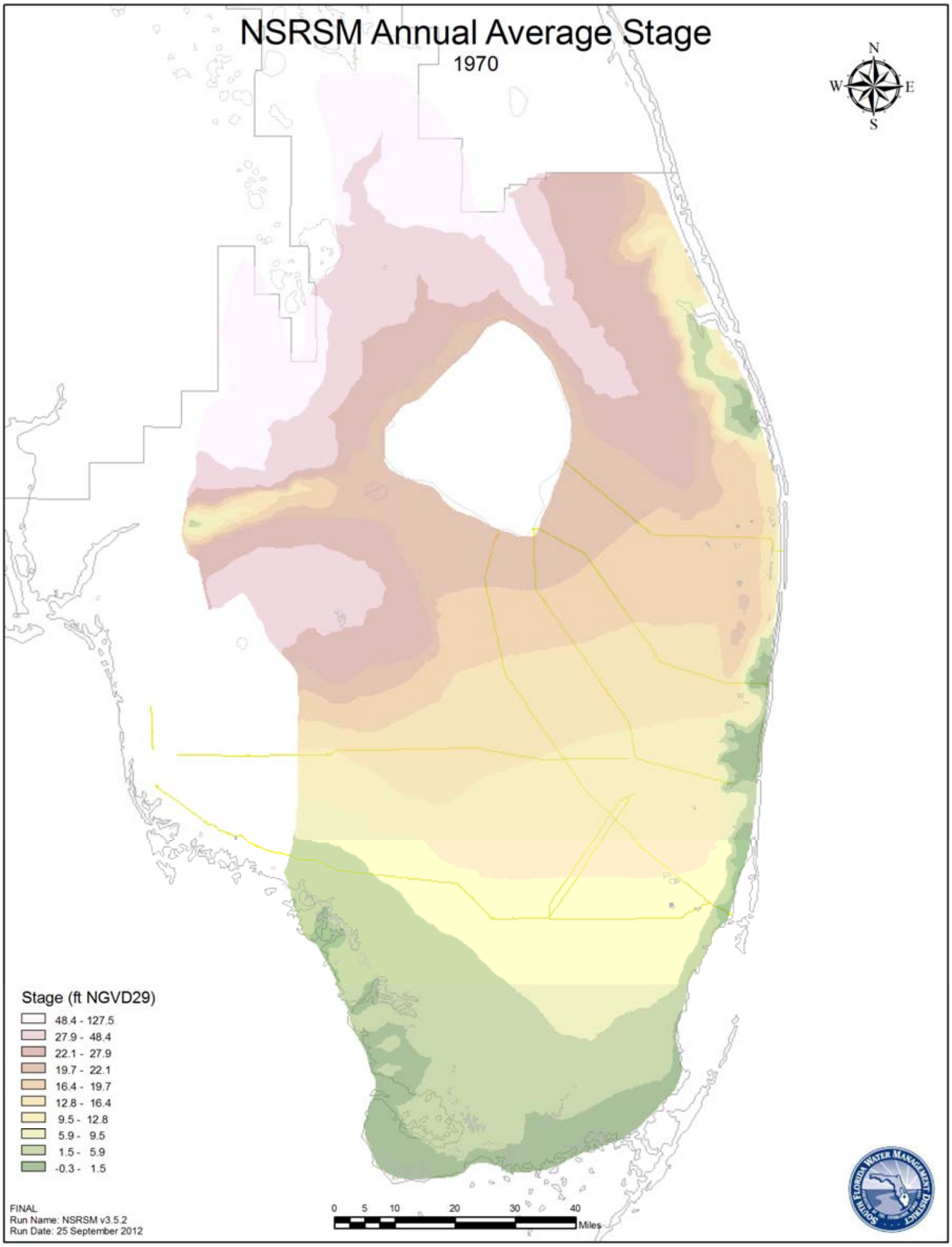

Figure K-5. Annual average stage values for the NSRSM model domain for 1970.

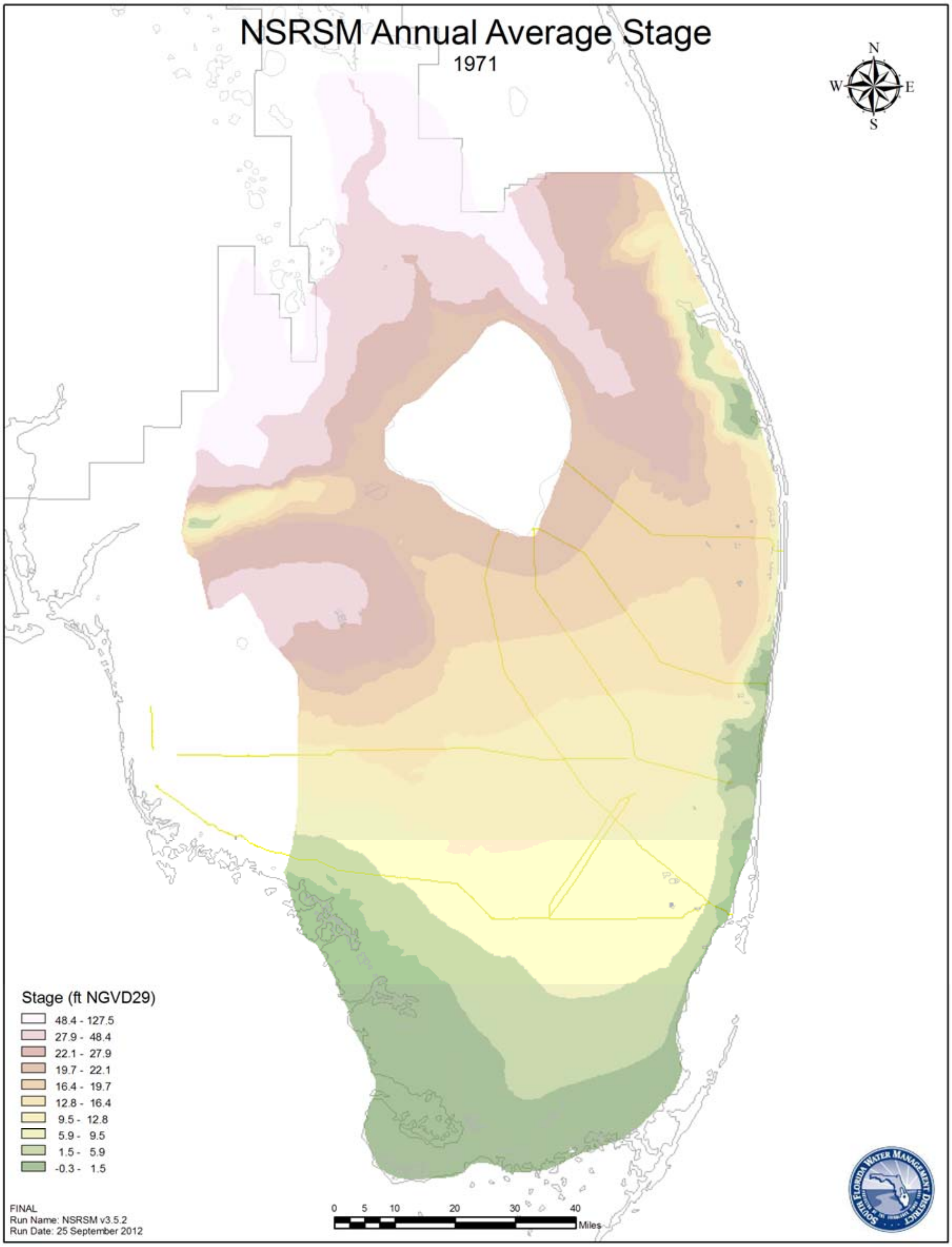

Figure K-6. Annual average stage values for the NSRSM model domain for 1971.

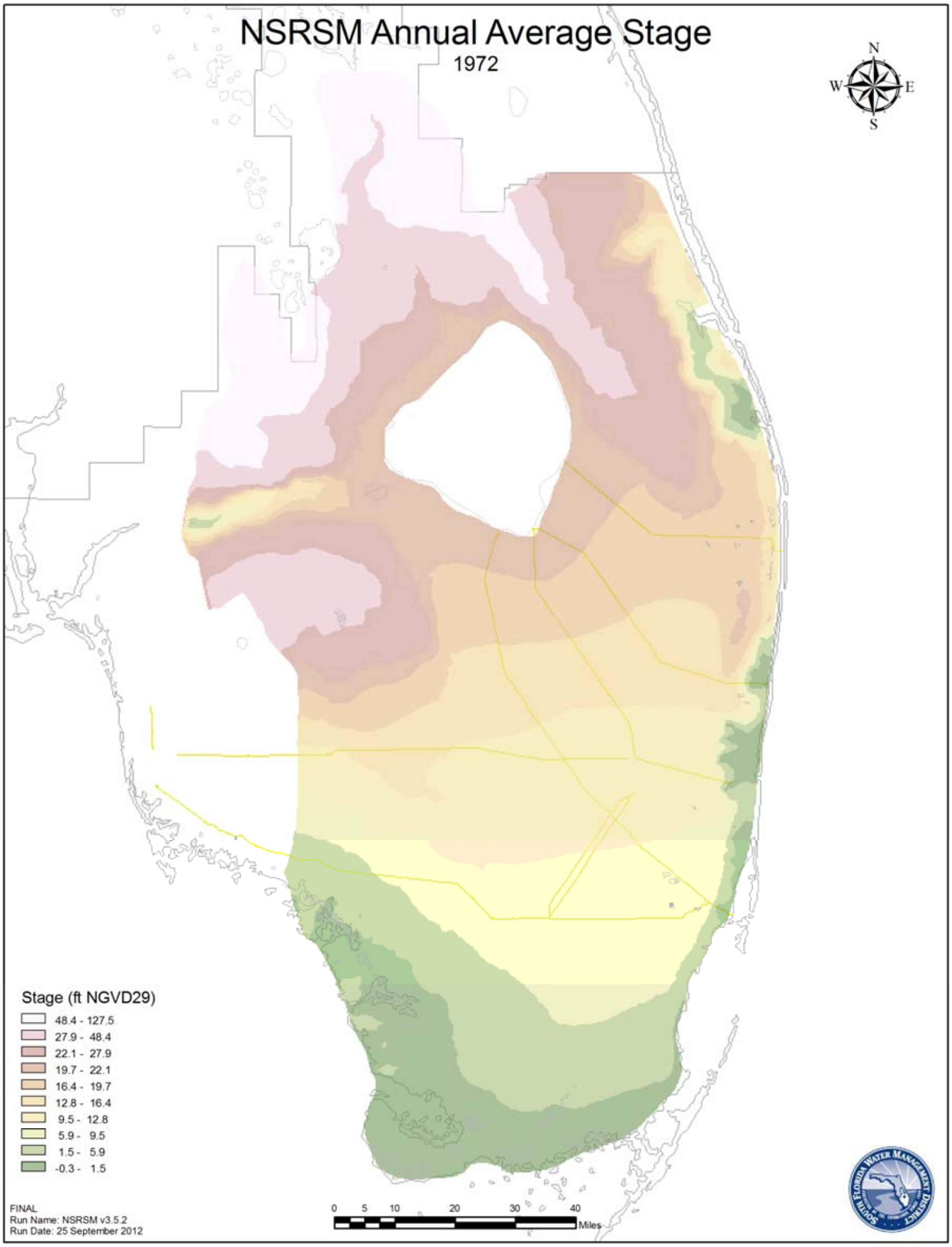

Figure K-7. Annual average stage values for the NSRSM model domain for 1972.

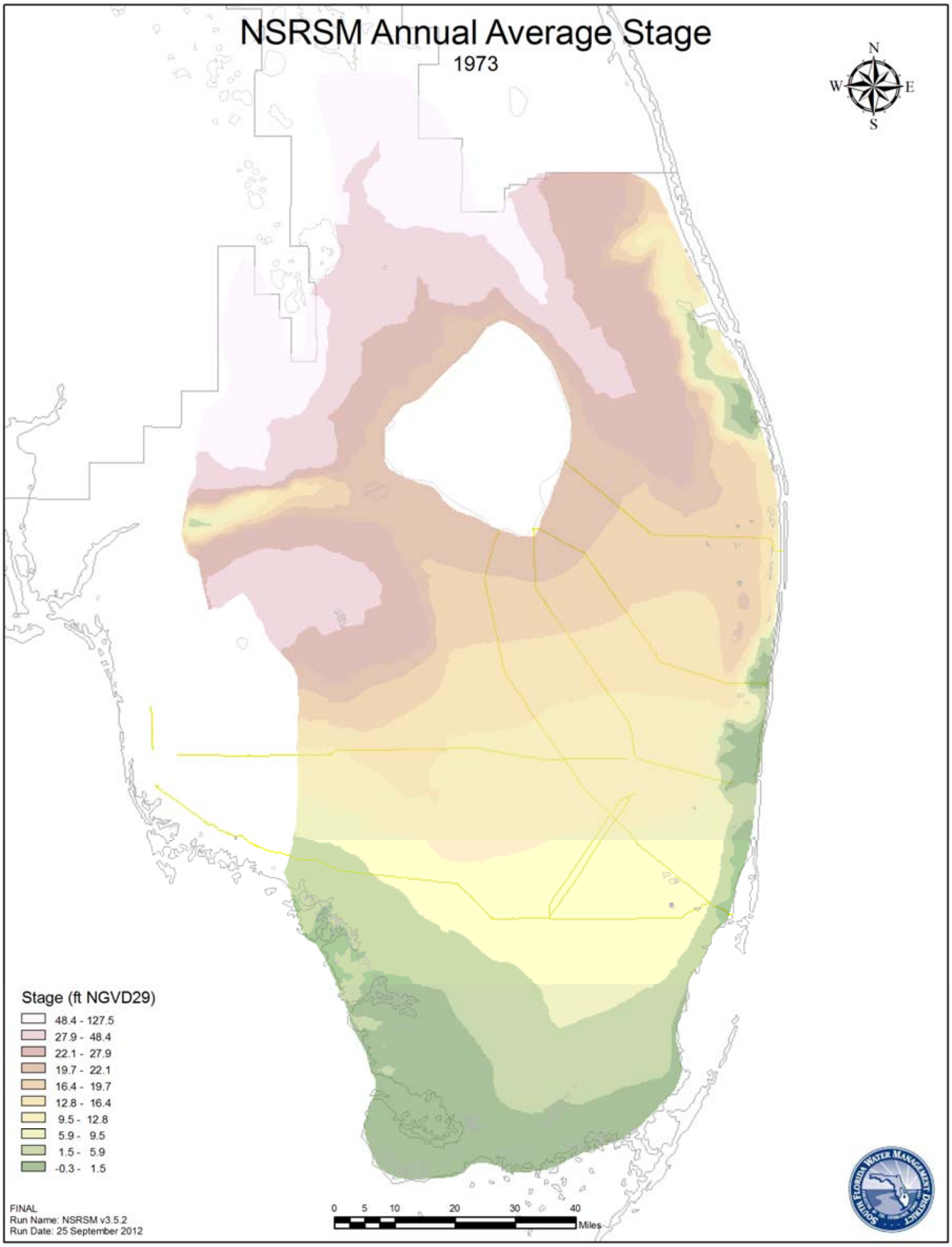

Figure K-8. Annual average stage values for the NSRSM model domain for 1973.

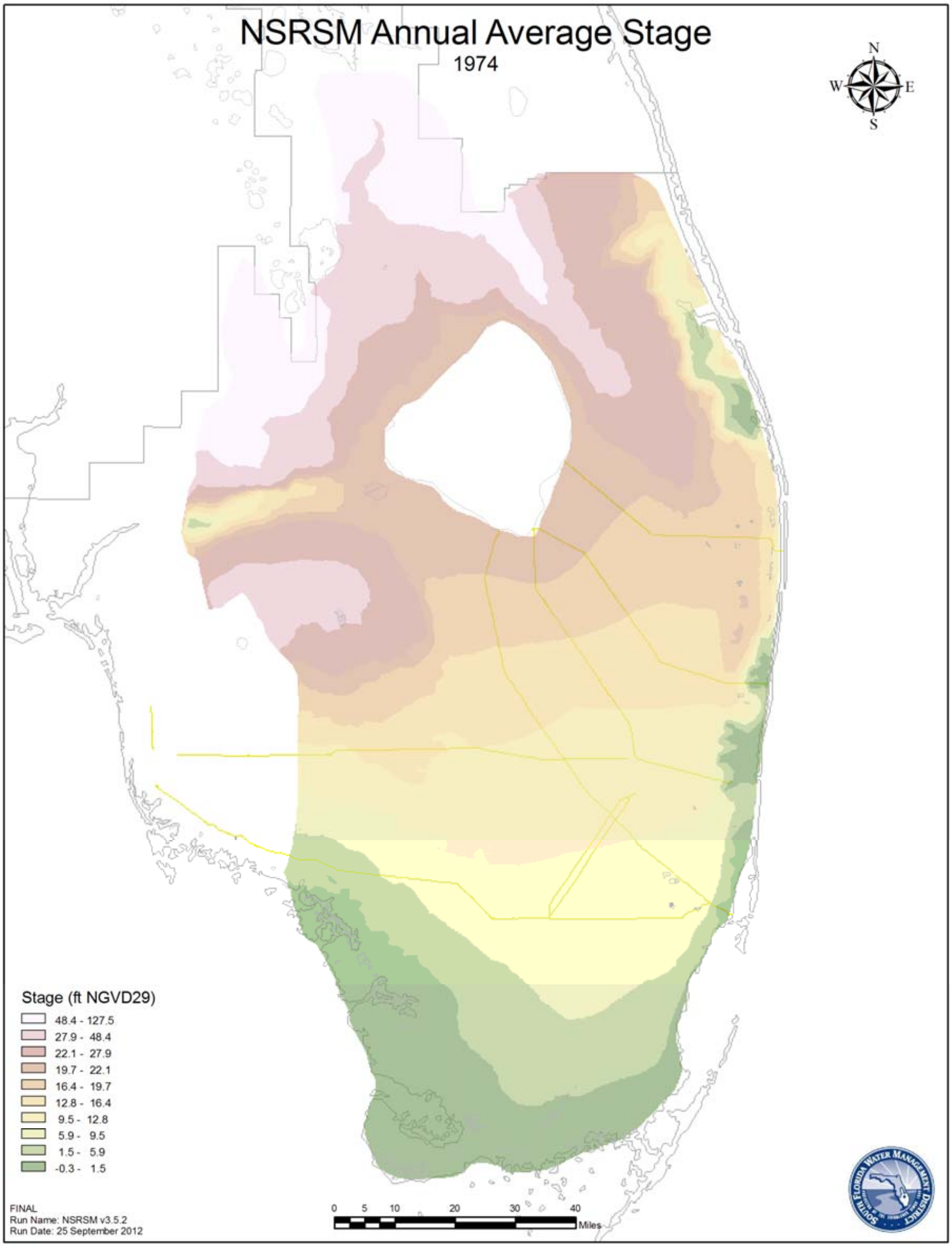

Figure K-9. Annual average stage values for the NSRSM model domain for 1974.

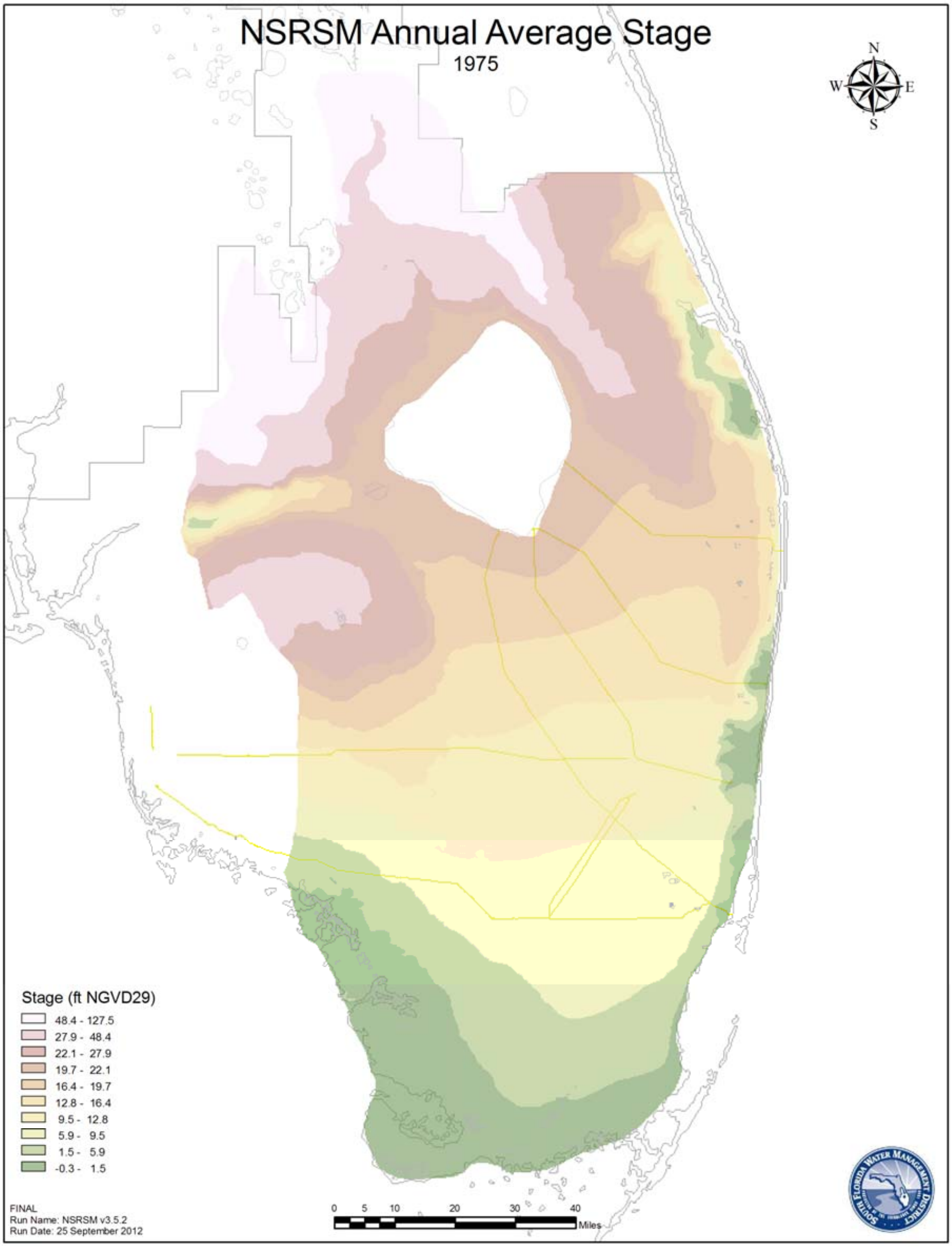

Figure K-10. Annual average stage values for the NSRSM model domain for 1975.

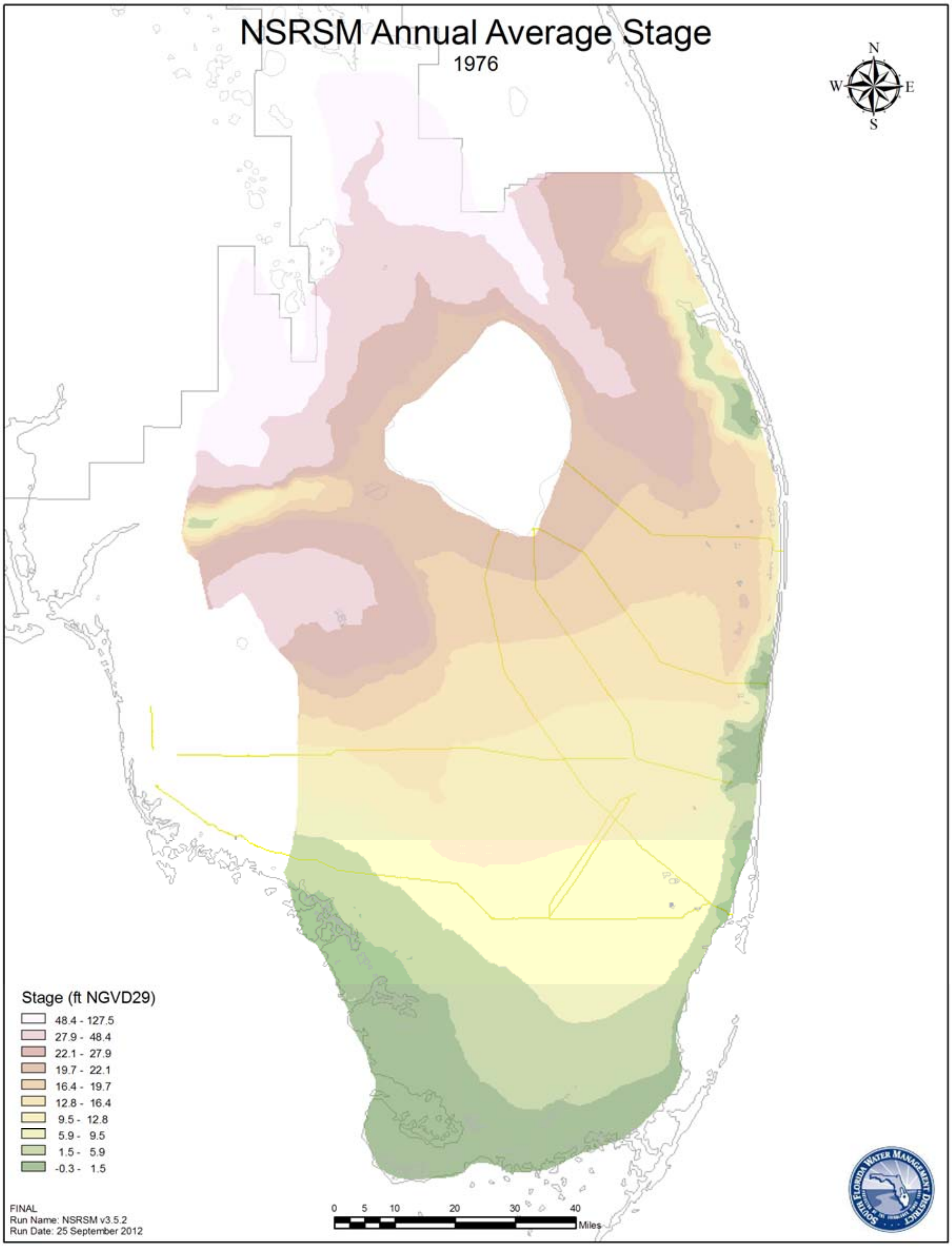

Figure K-11. Annual average stage values for the NSRSM model domain for 1976.

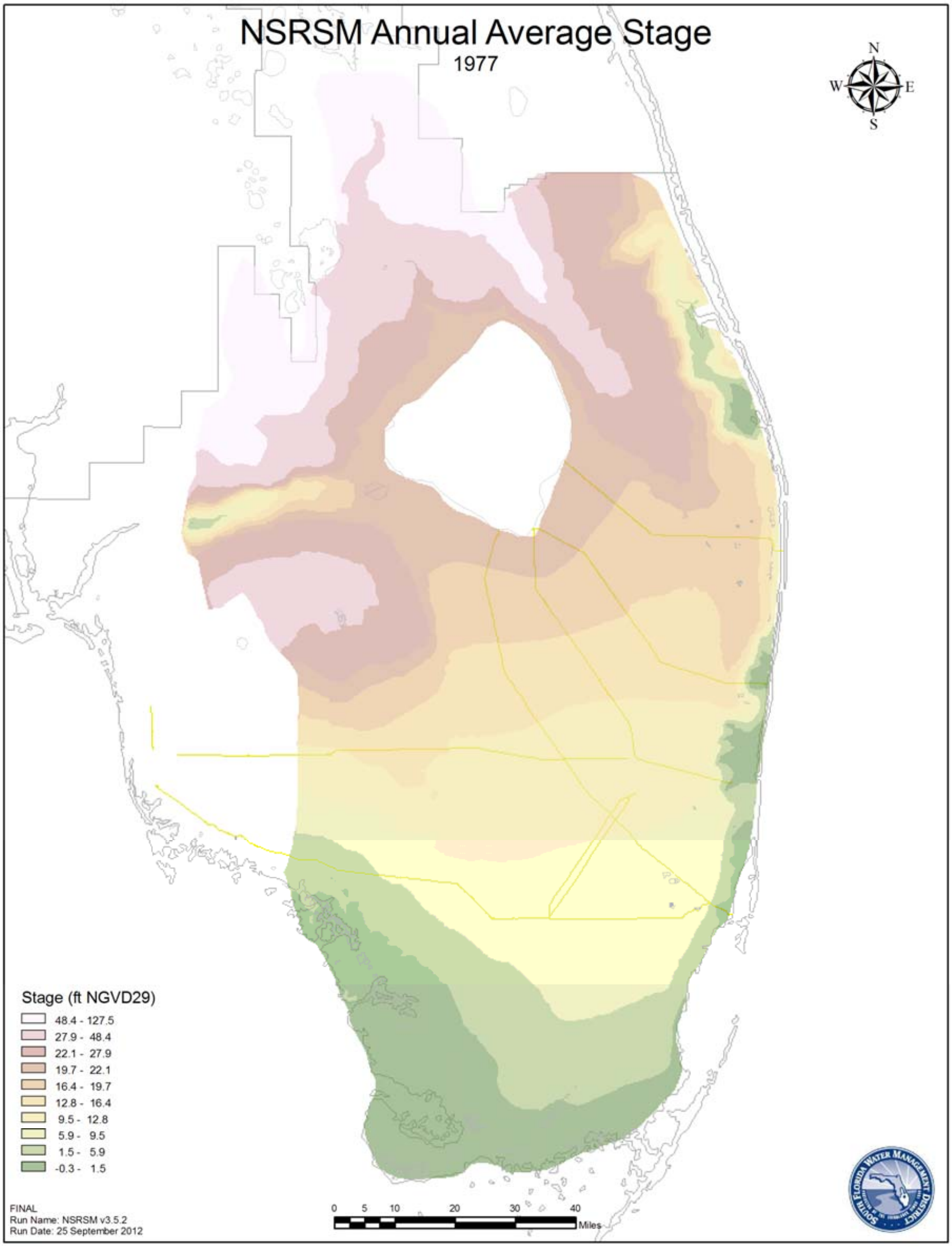

Figure K-12. Annual average stage values for the NSRSM model domain for 1977.

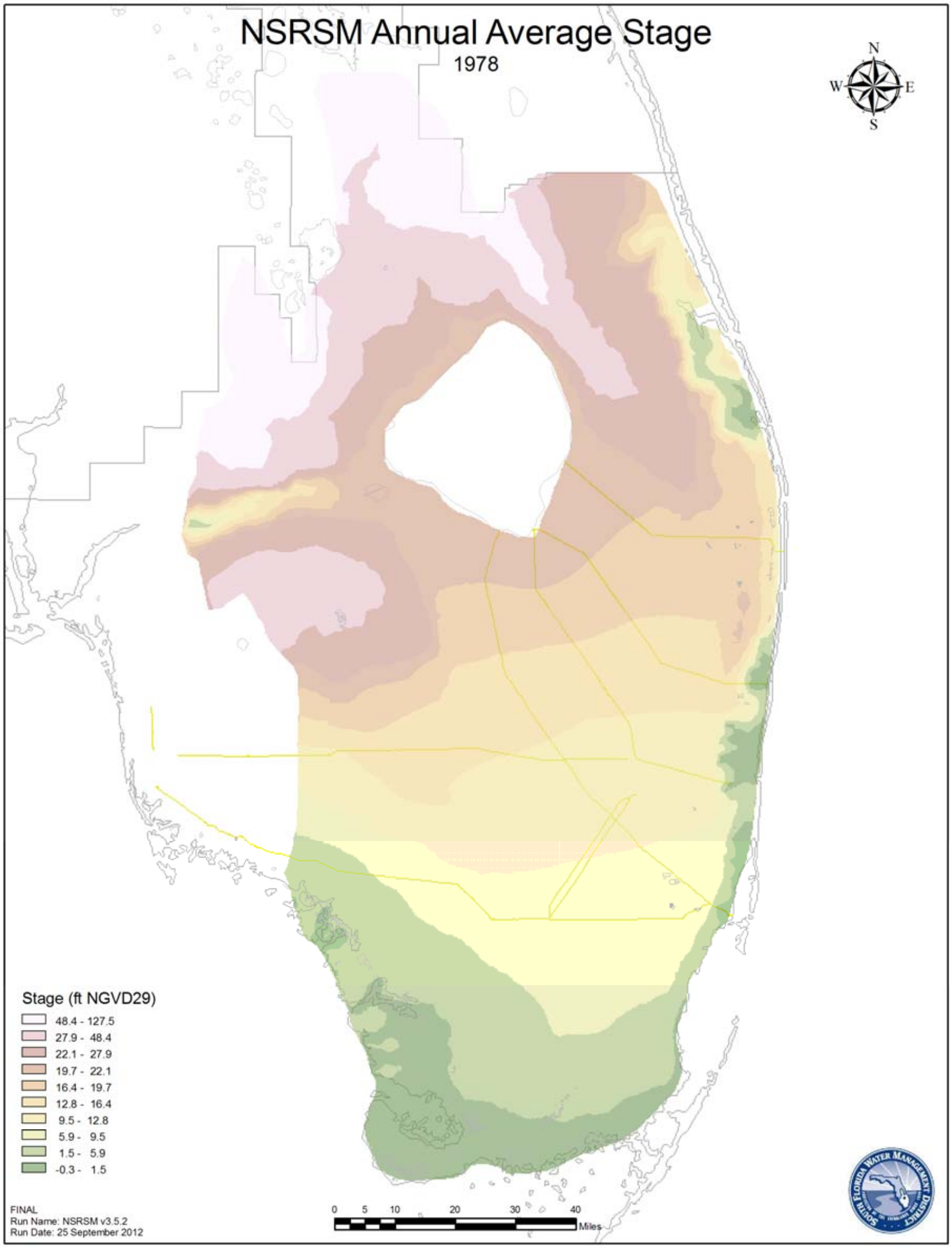

Figure K-13. Annual average stage values for the NSRSM model domain for 1978.

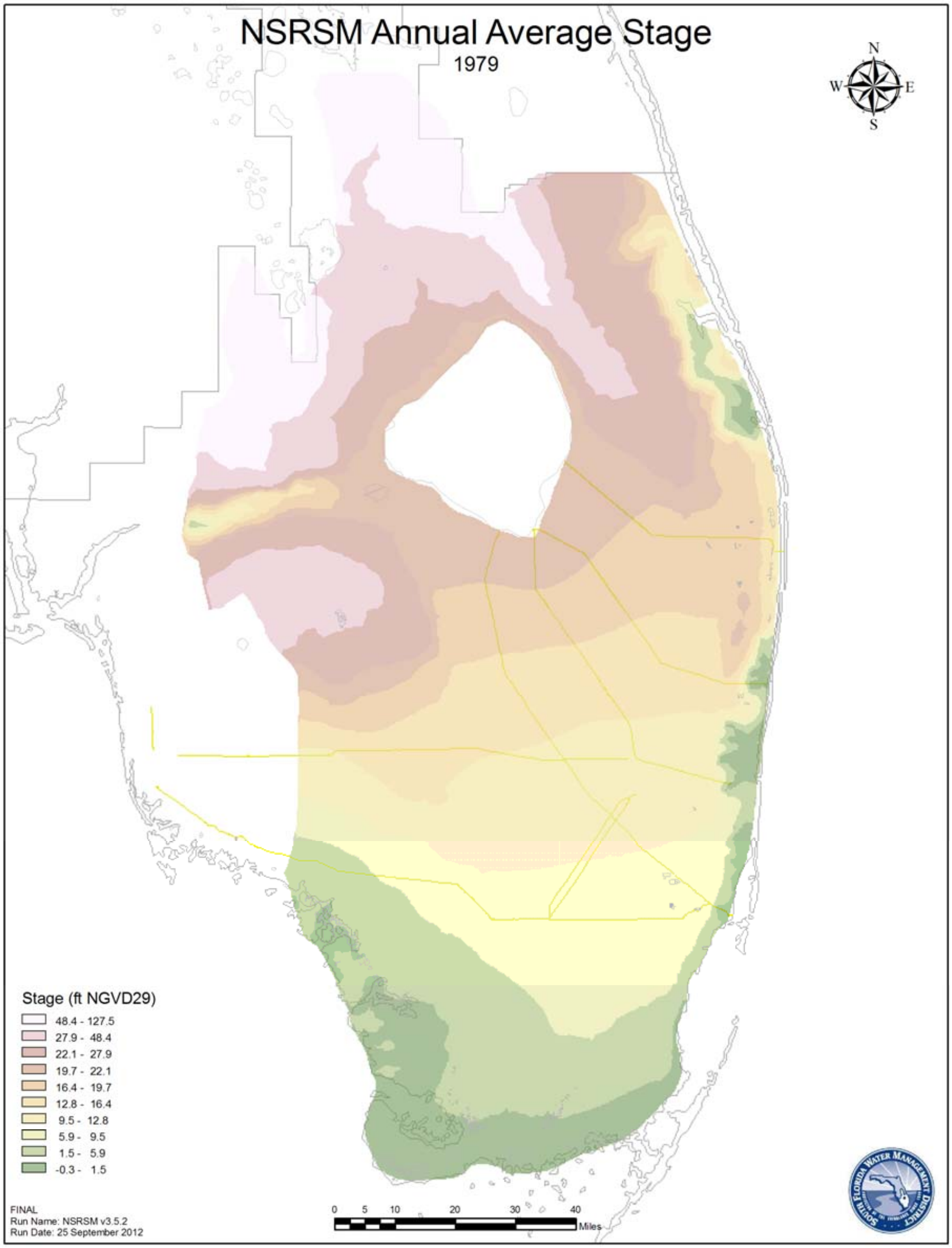

Figure K-14. Annual average stage values for the NSRSM model domain for 1979.

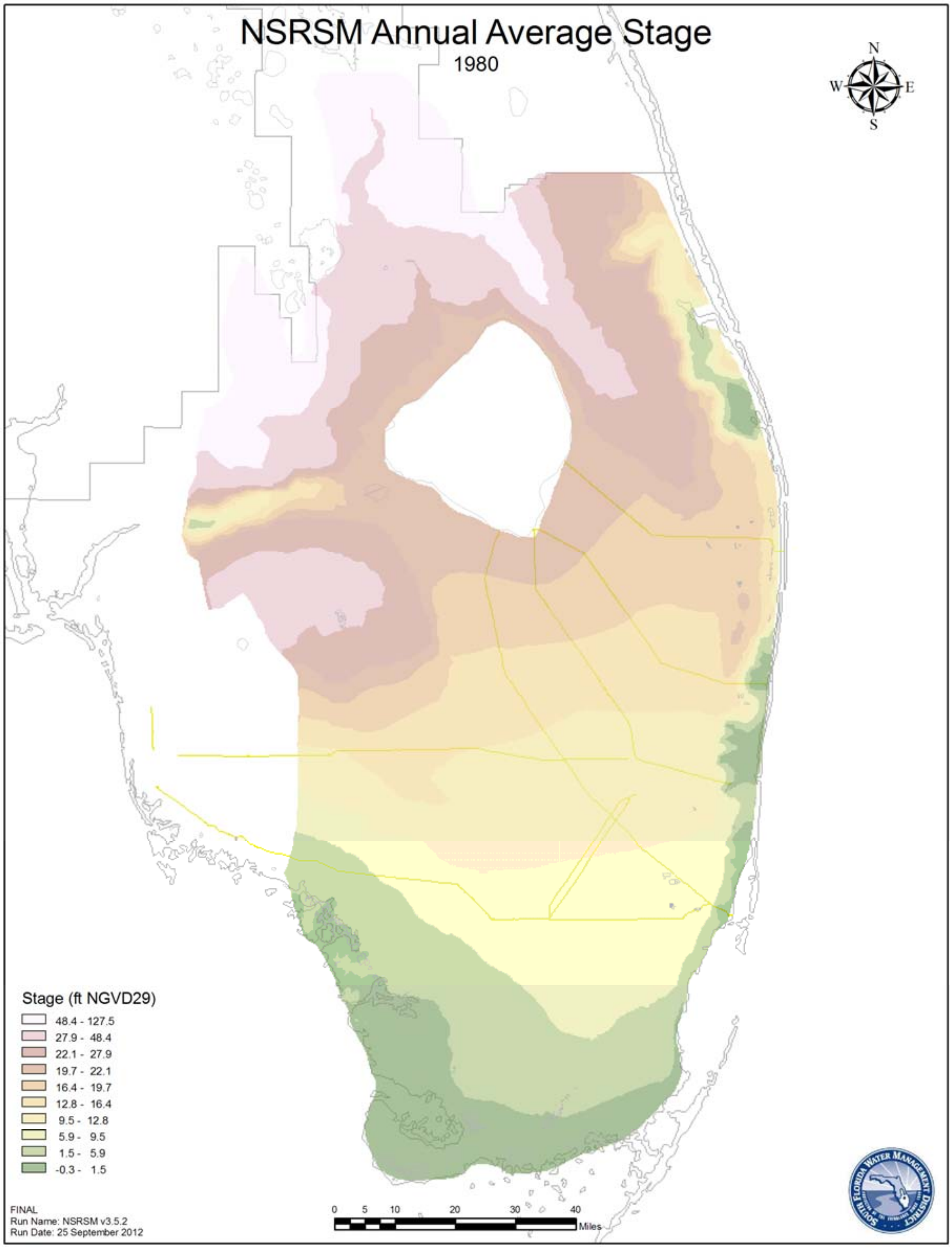

Figure K-15. Annual average stage values for the NSRSM model domain for 1980.

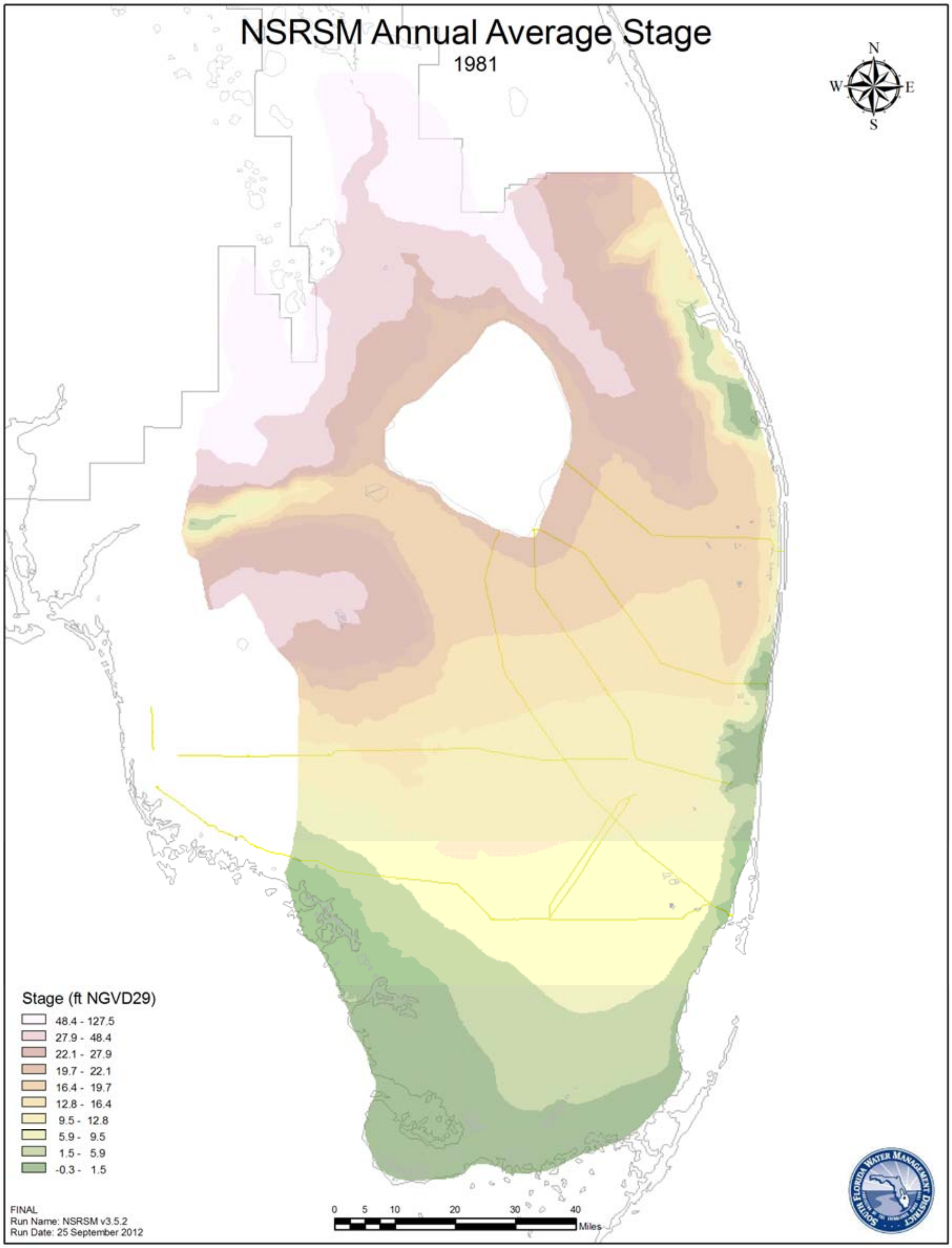

Figure K-16. Annual average stage values for the NSRSM model domain for 1981.

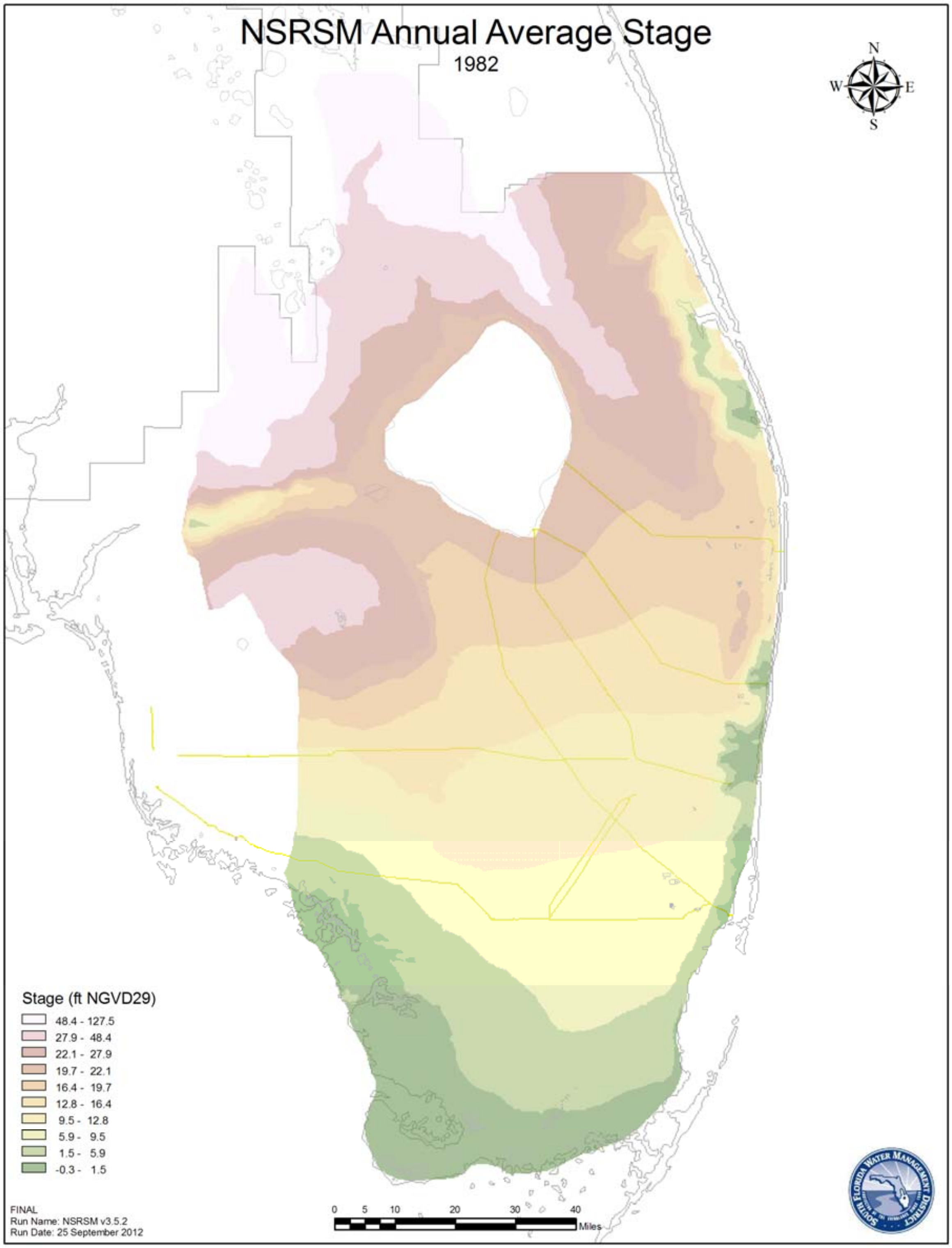

Figure K-17. Annual average stage values for the NSRSM model domain for 1982.

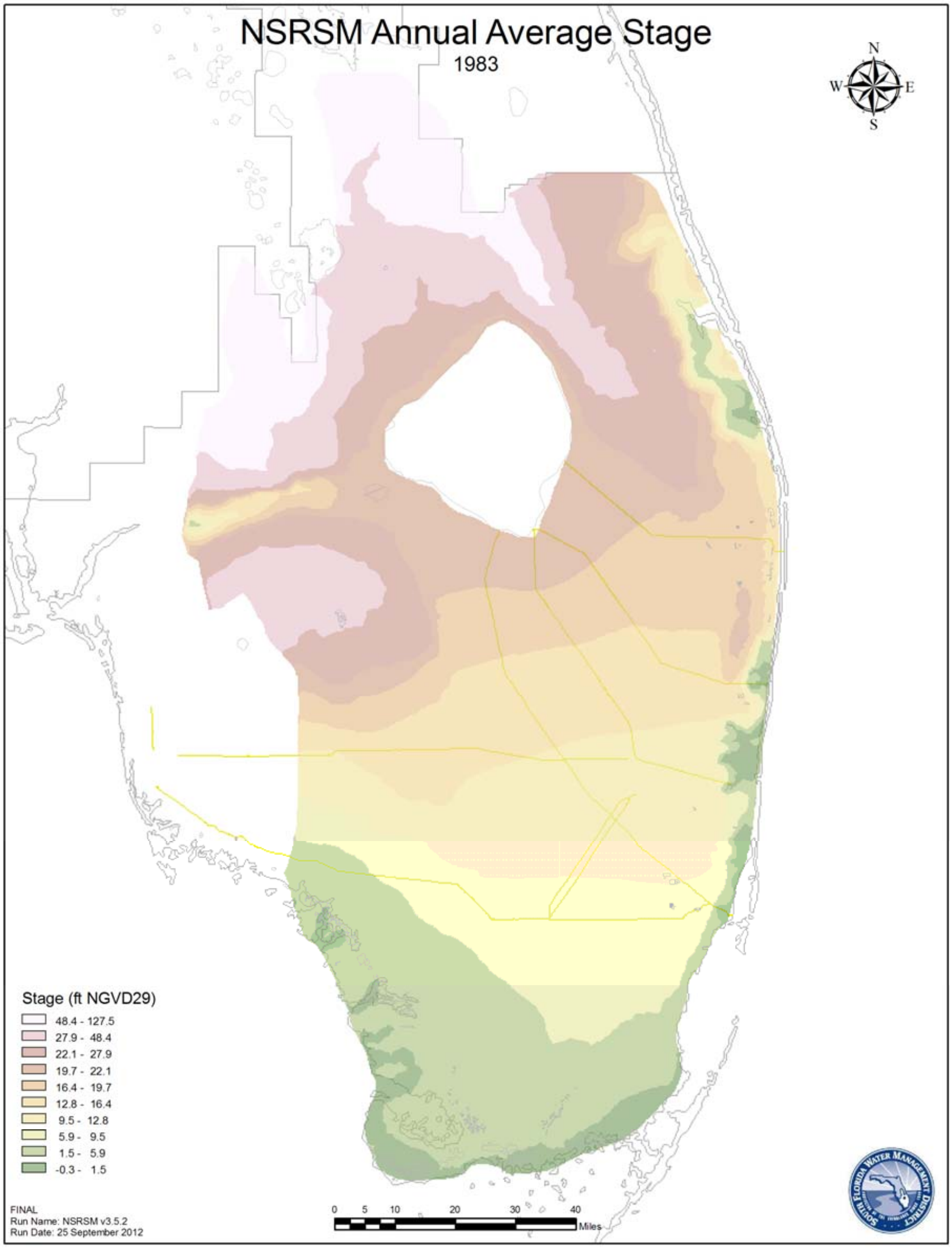

Figure K-18. Annual average stage values for the NSRSM model domain for 1983.

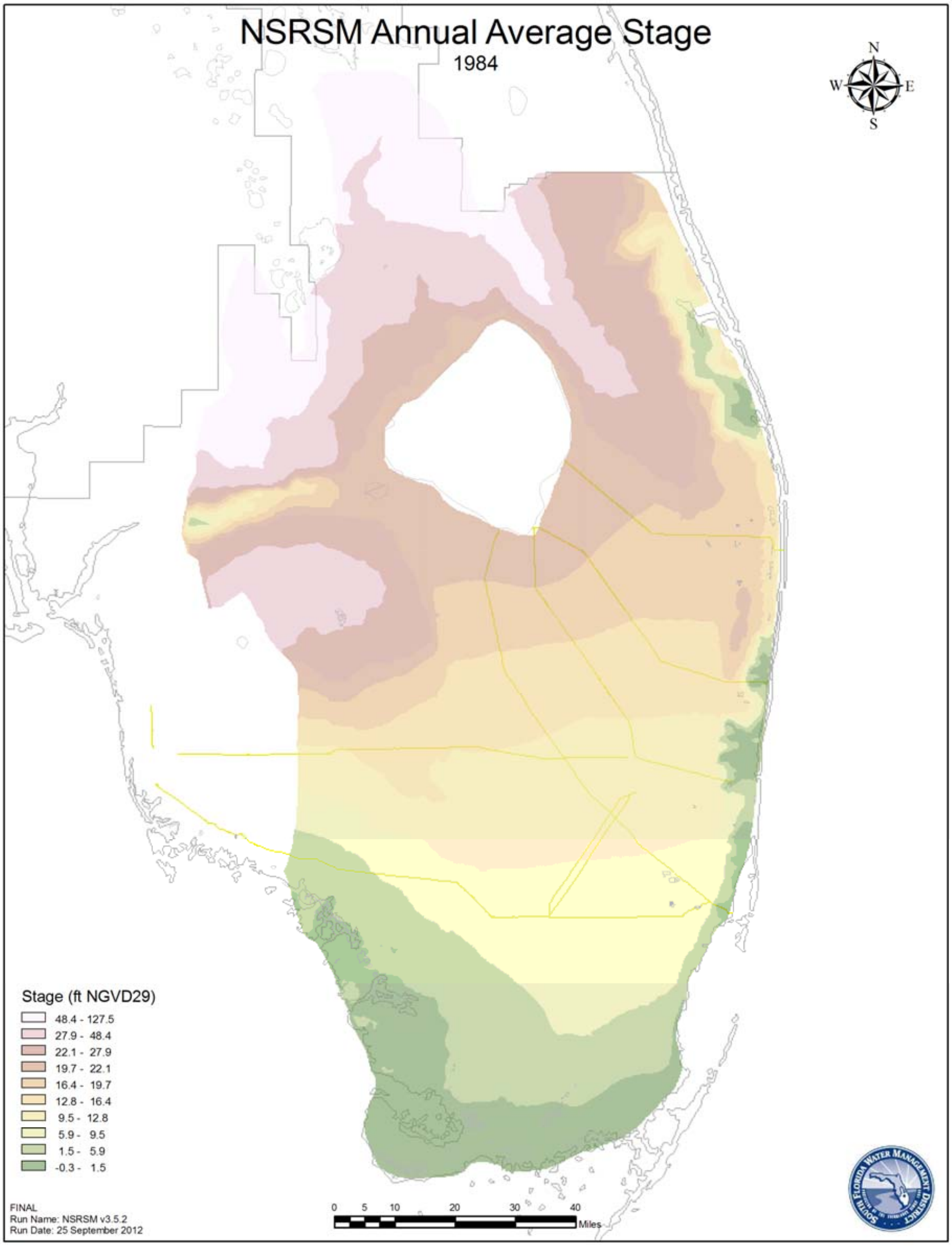

Figure K-19. Annual average stage values for the NSRSM model domain for 1984.

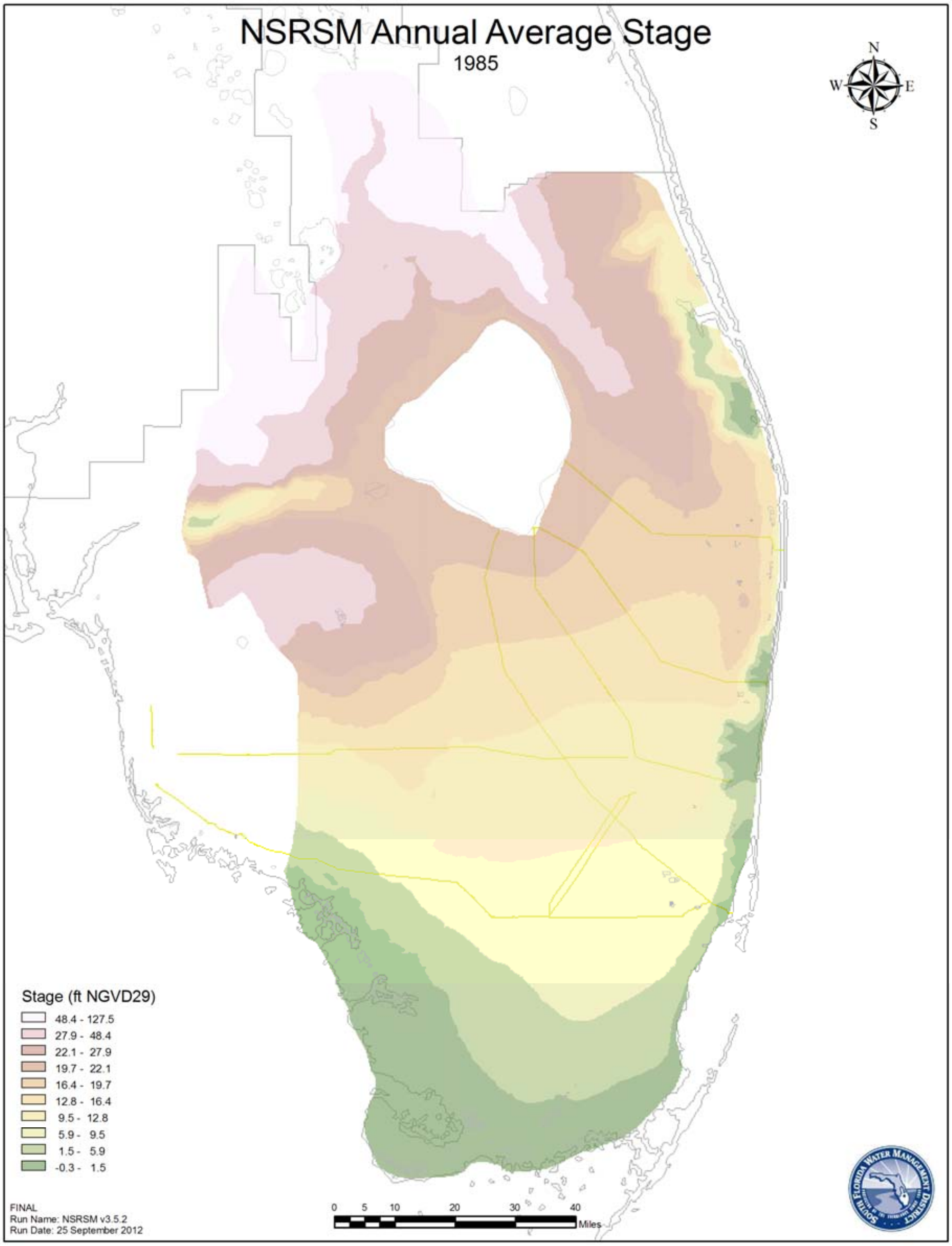

Figure K-20. Annual average stage values for the NSRSM model domain for 1985.

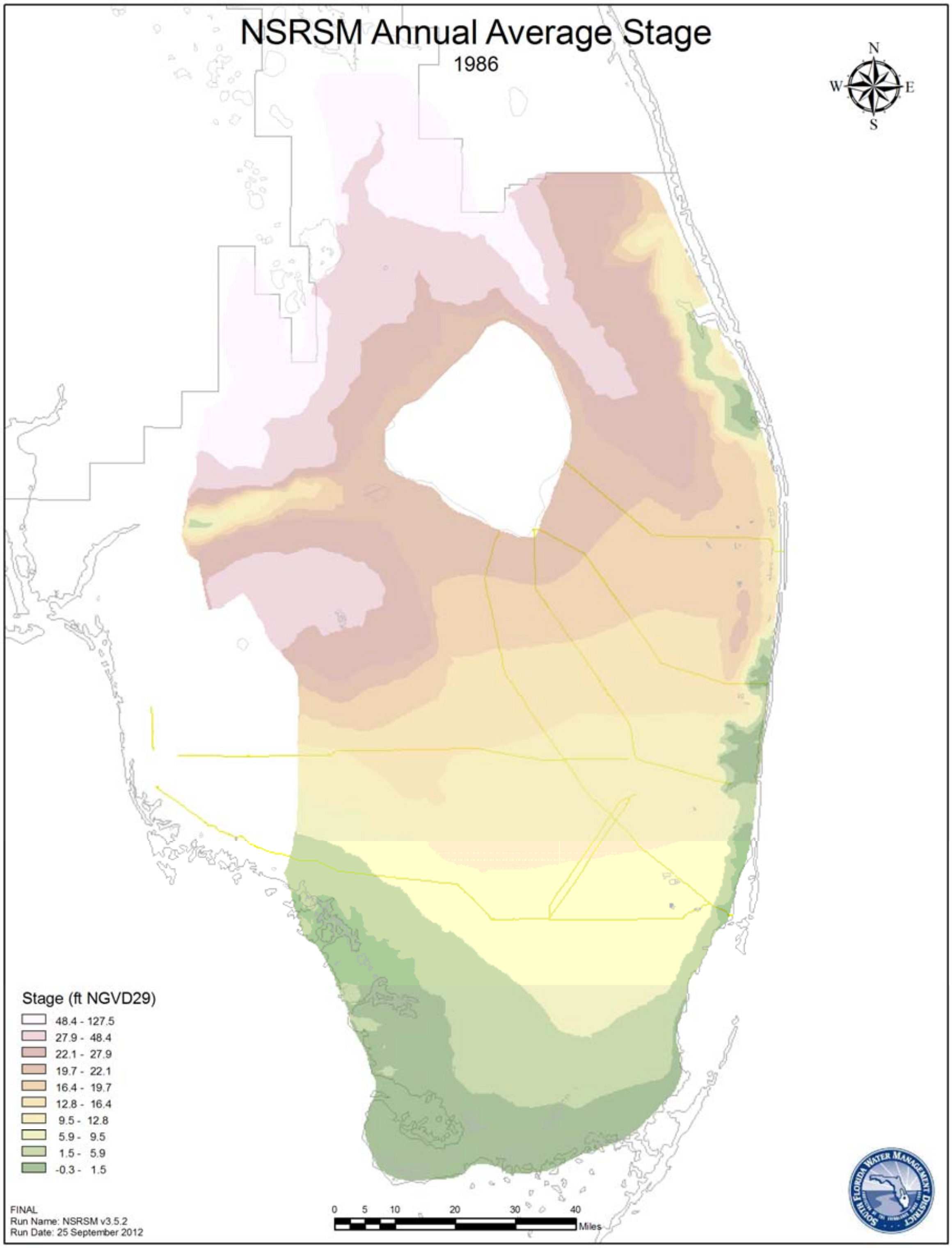

Figure K-21. Annual average stage values for the NSRSM model domain for 1986.

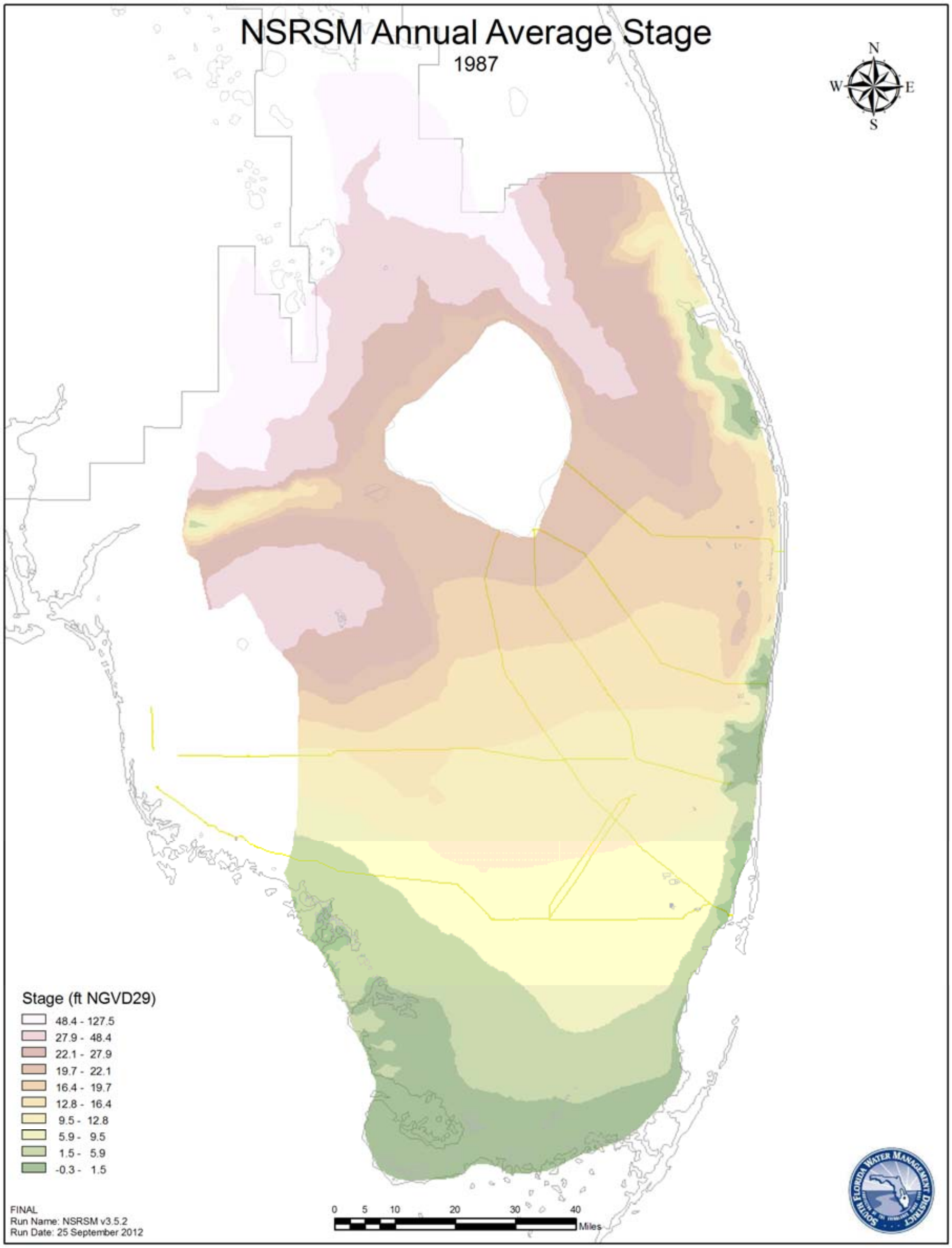

Figure K-22. Annual average stage values for the NSRSM model domain for 1987.

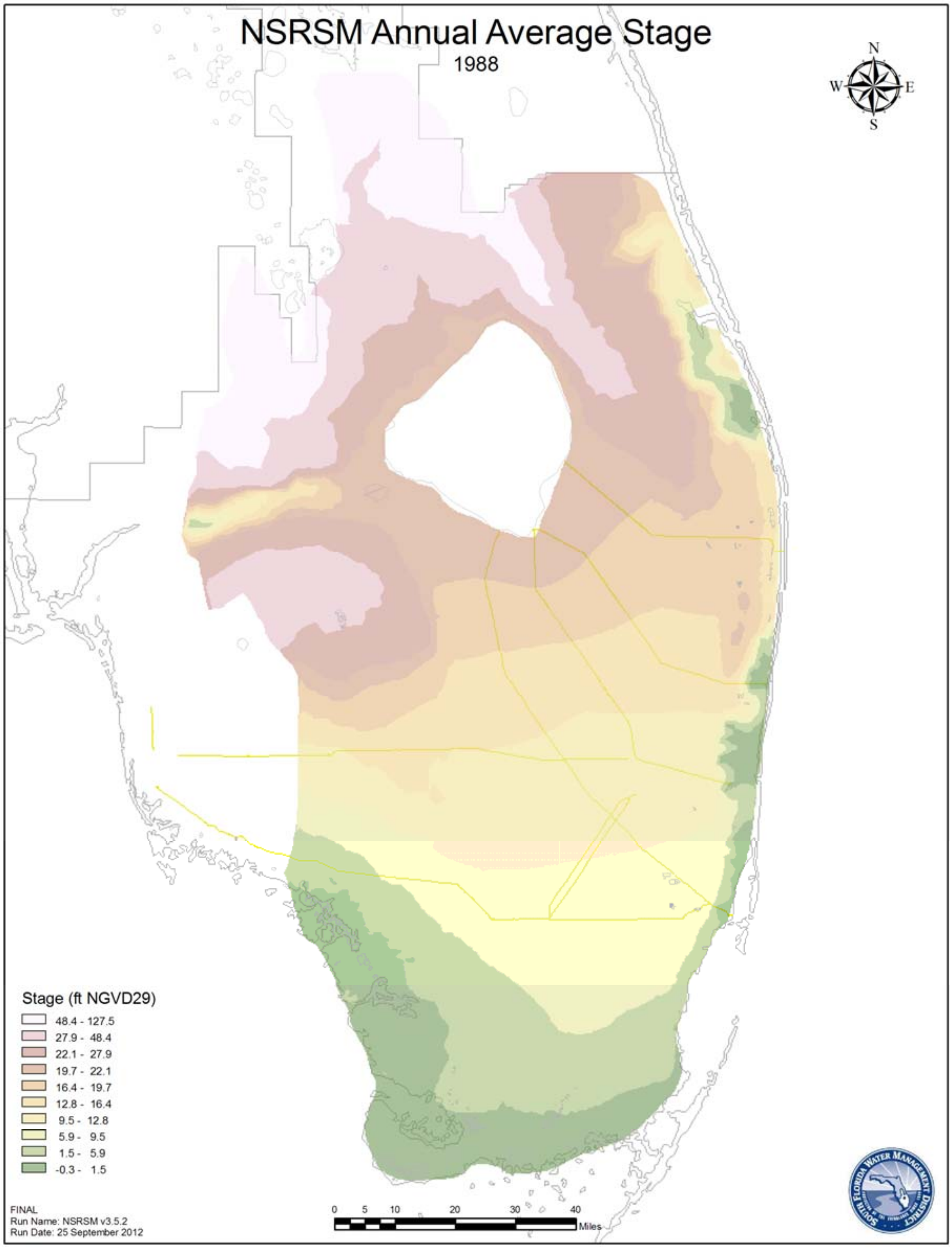

Figure K-23. Annual average stage values for the NSRSM model domain for 1988.

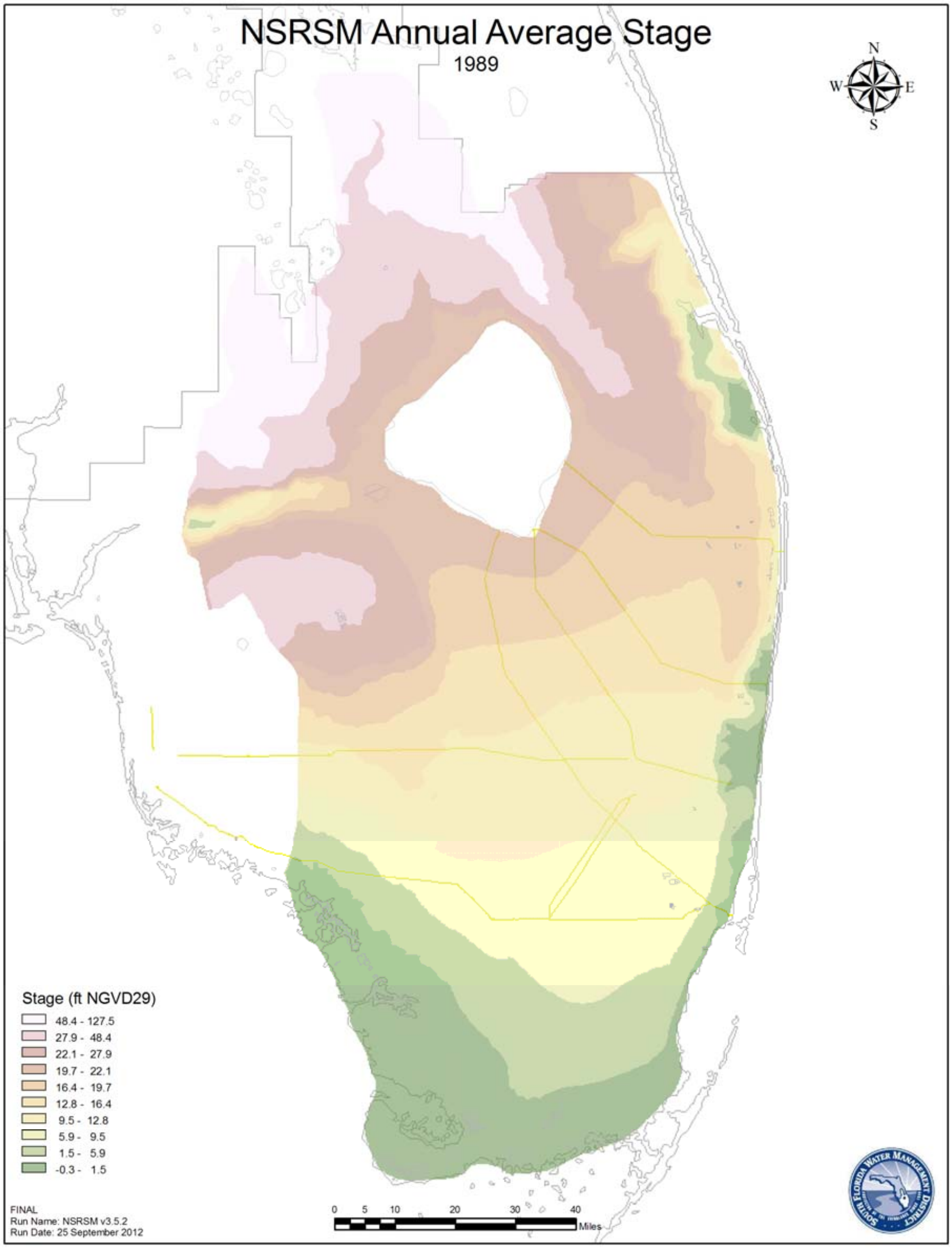

Figure K-24. Annual average stage values for the NSRSM model domain for 1989.

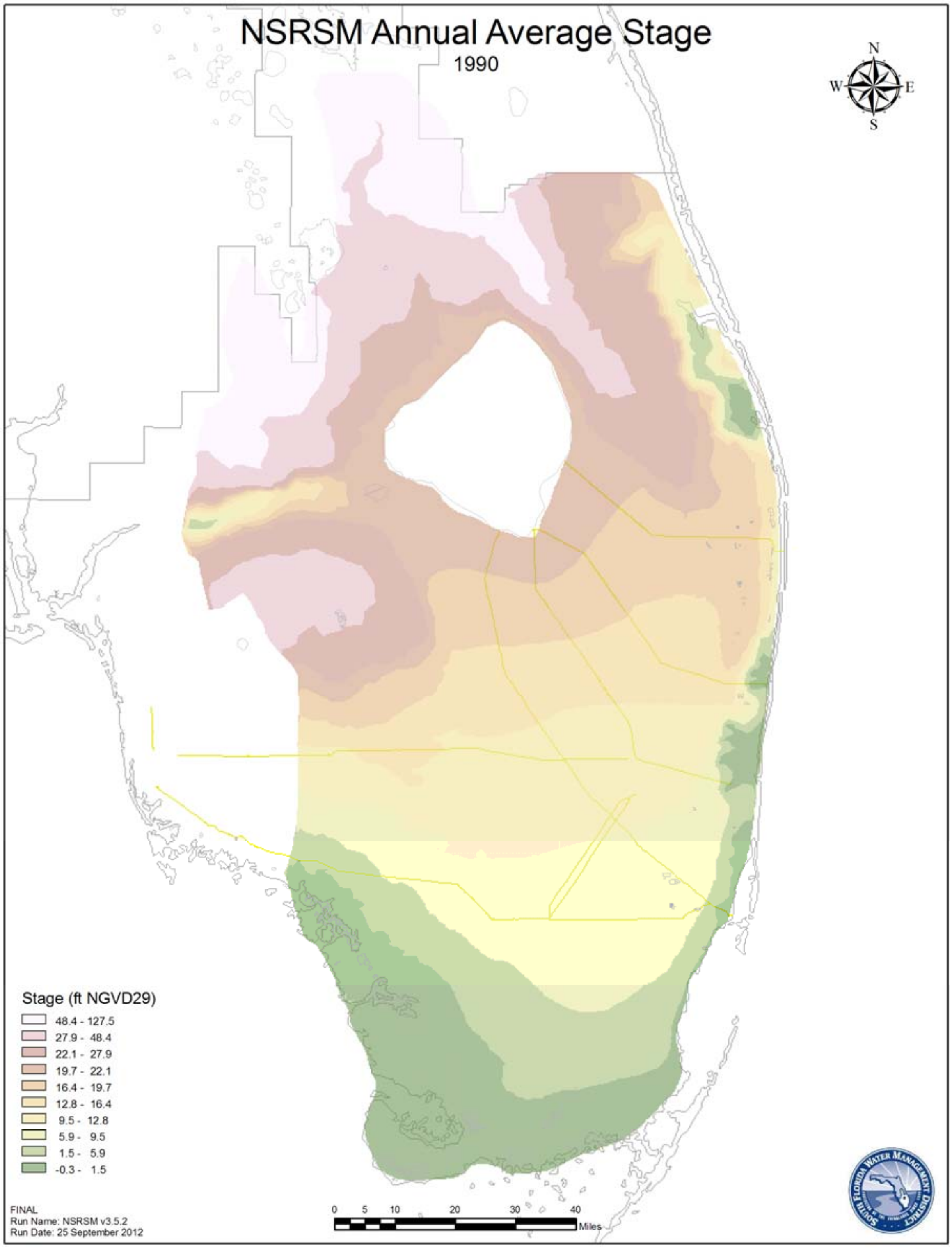

Figure K-25. Annual average stage values for the NSRSM model domain for 1990.

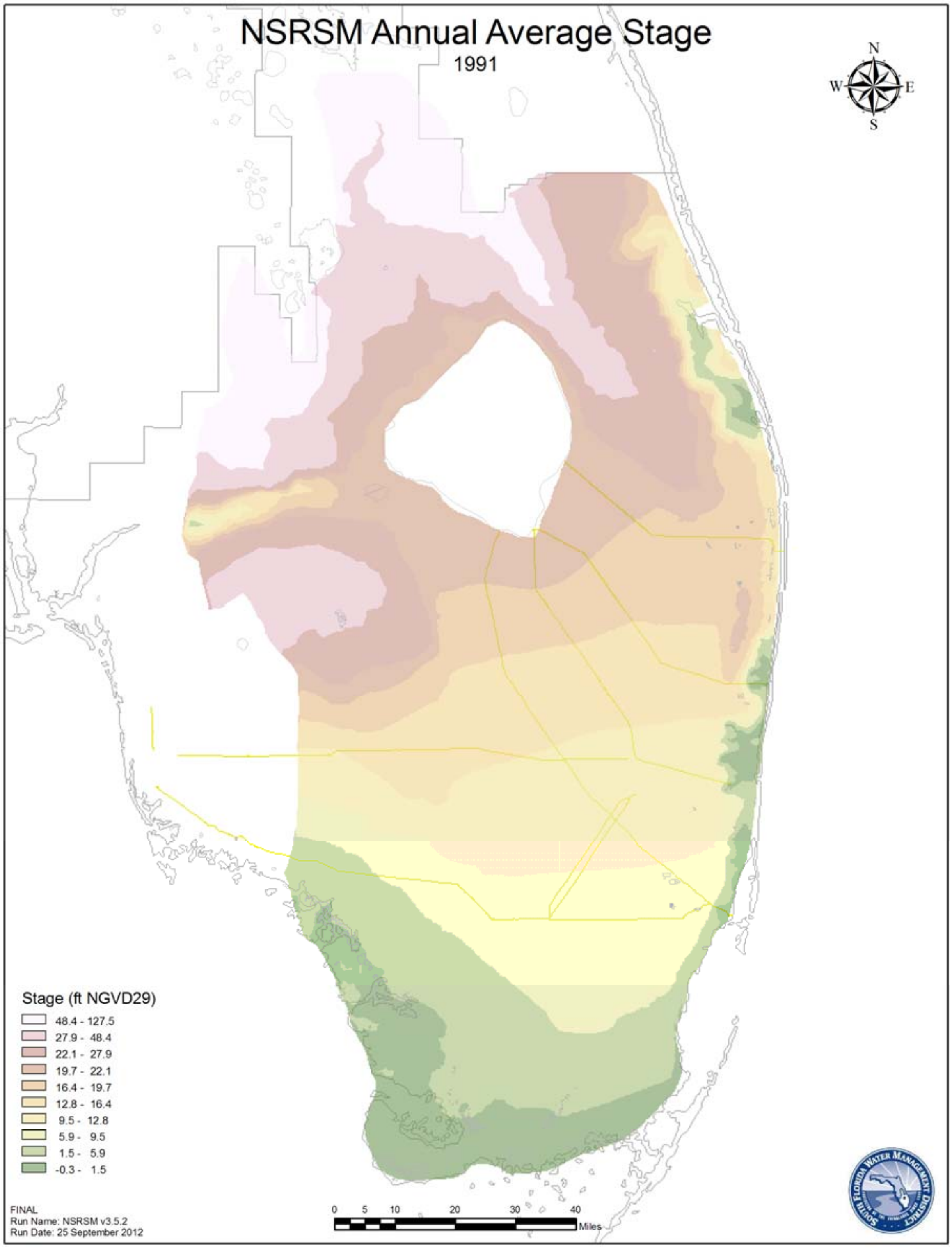

Figure K-26. Annual average stage values for the NSRSM model domain for 1991.

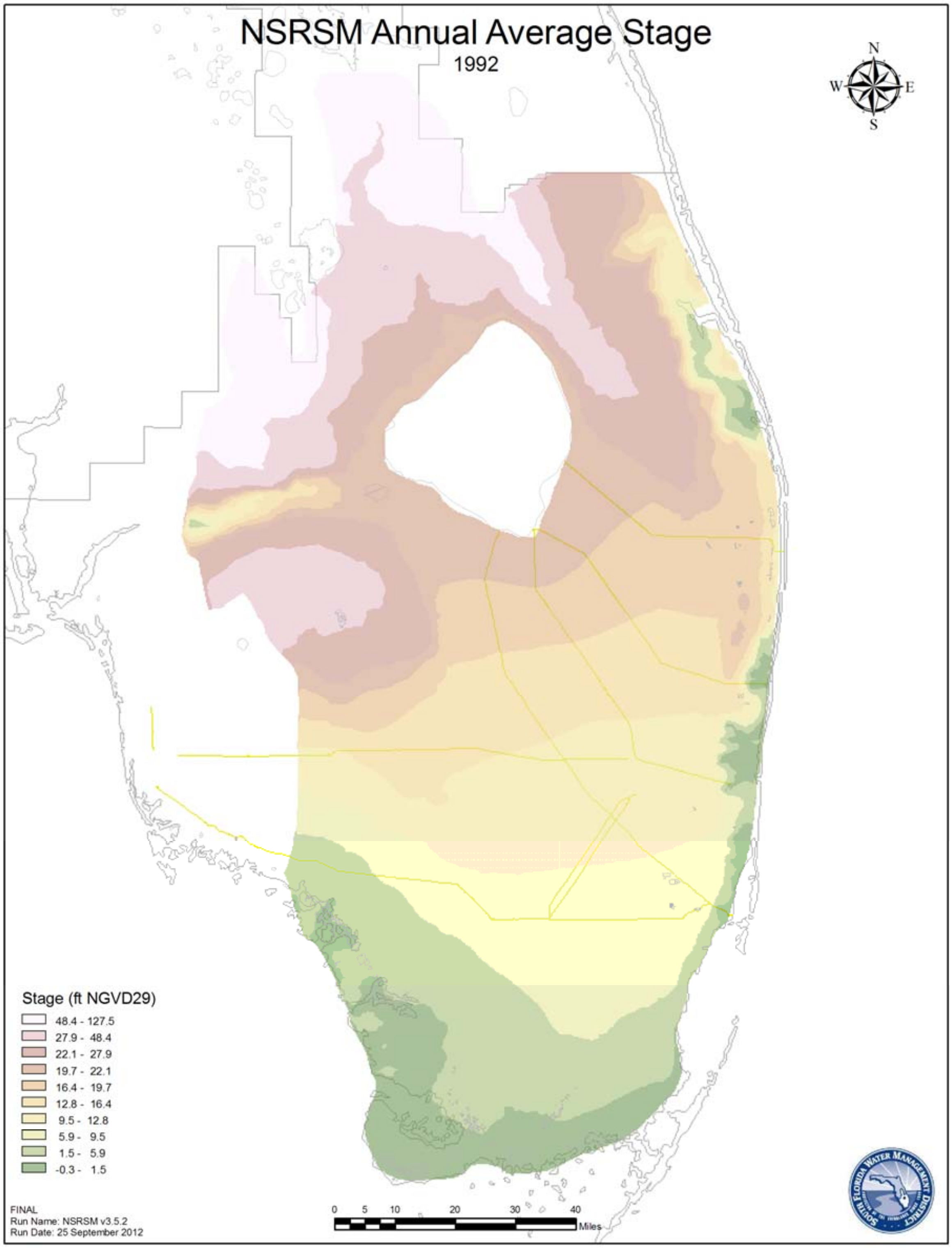

Figure K-27. Annual average stage values for the NSRSM model domain for 1992.

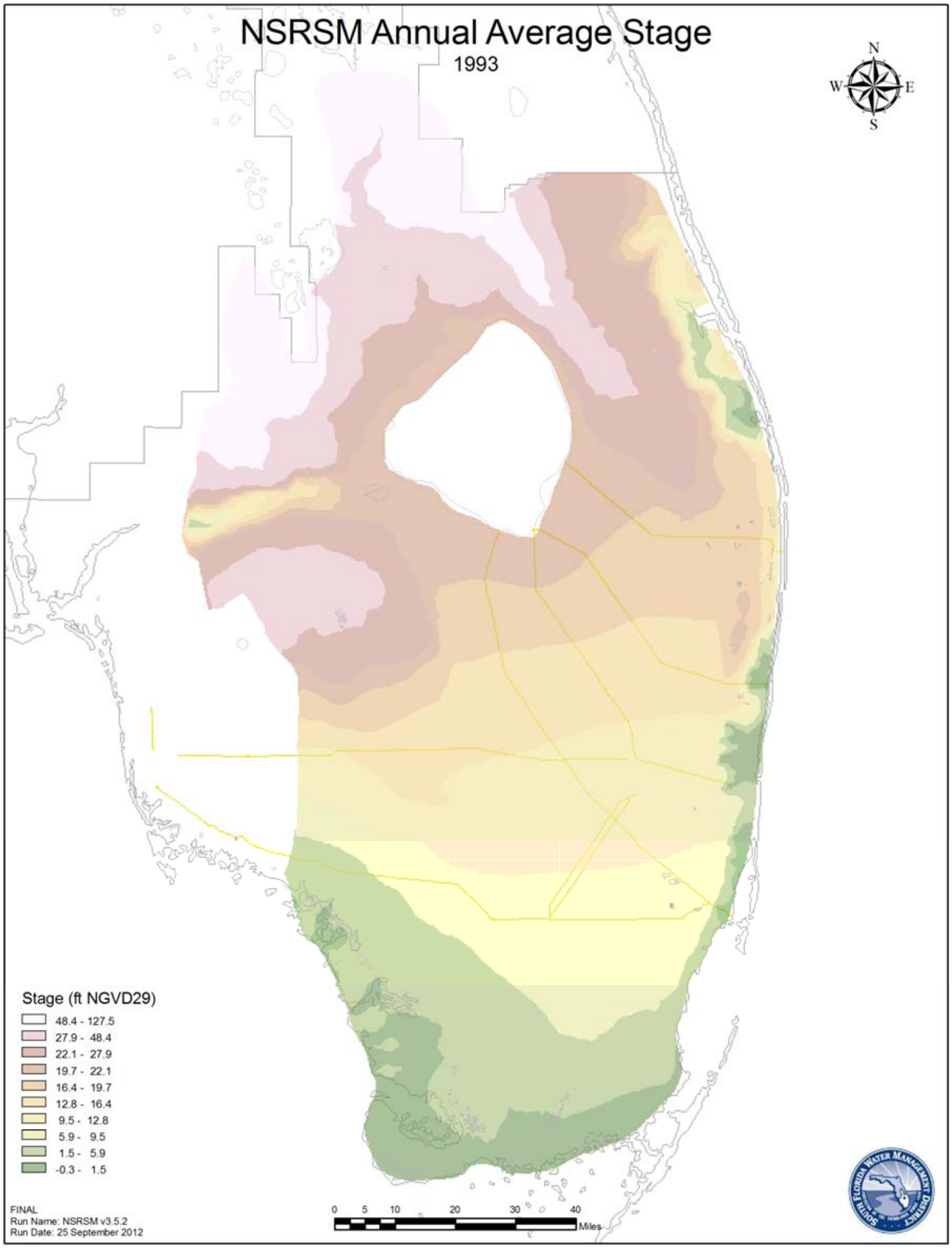

Figure K-28. Annual average stage values for the NSRSM model domain for 1993.

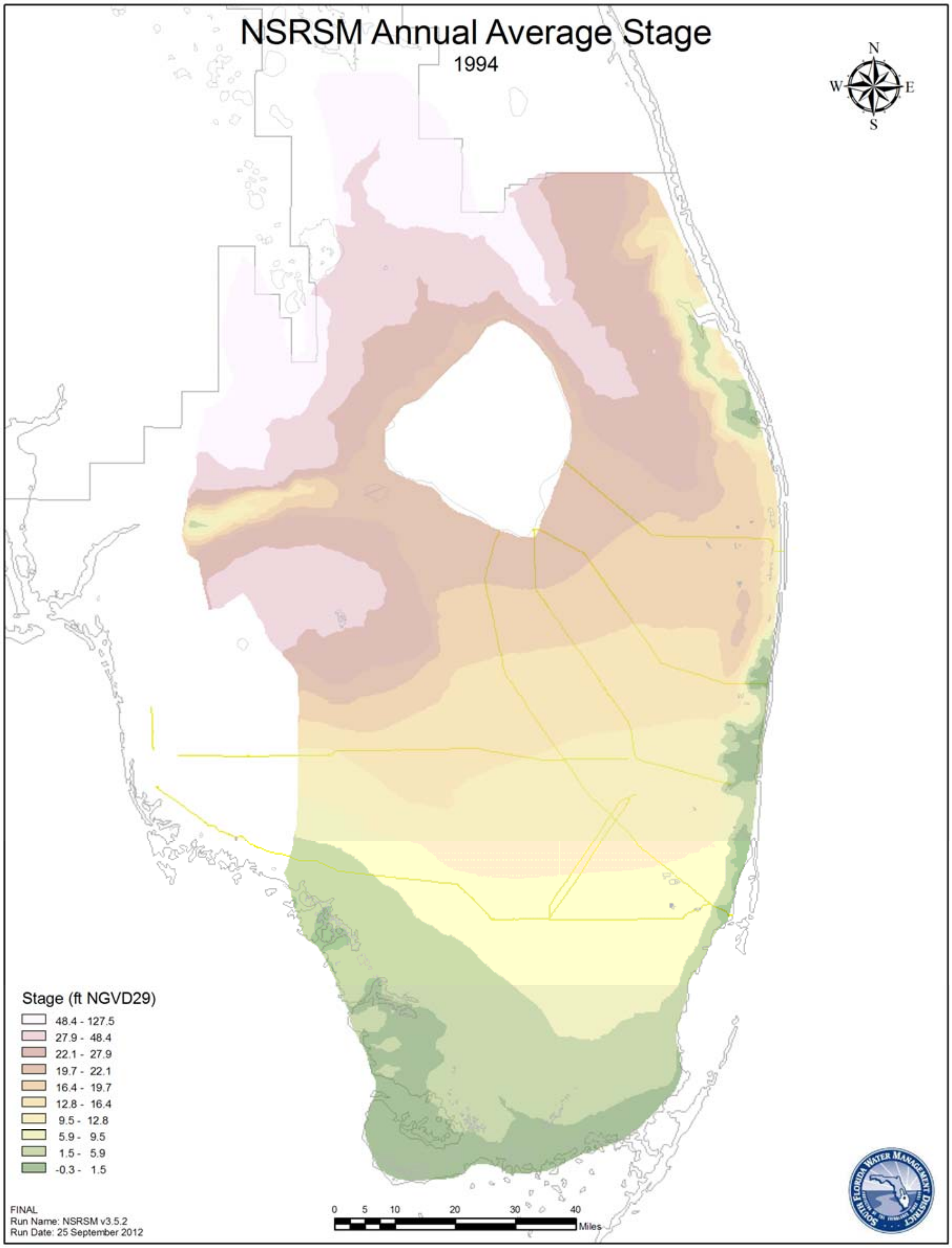

Figure K-29. Annual average stage values for the NSRSM model domain for 1994.

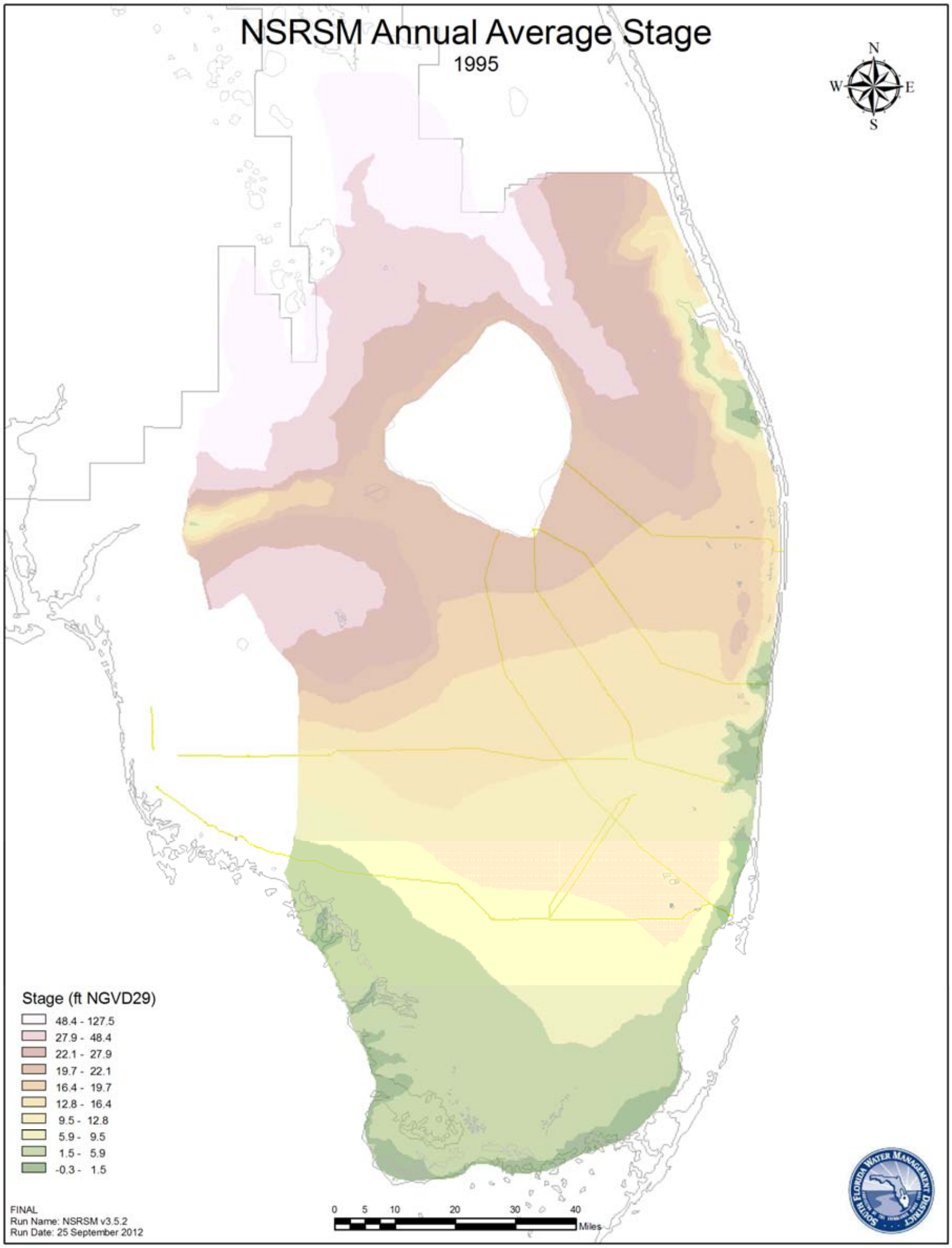

Figure K-30. Annual average stage values for the NSRSM model domain for 1995.

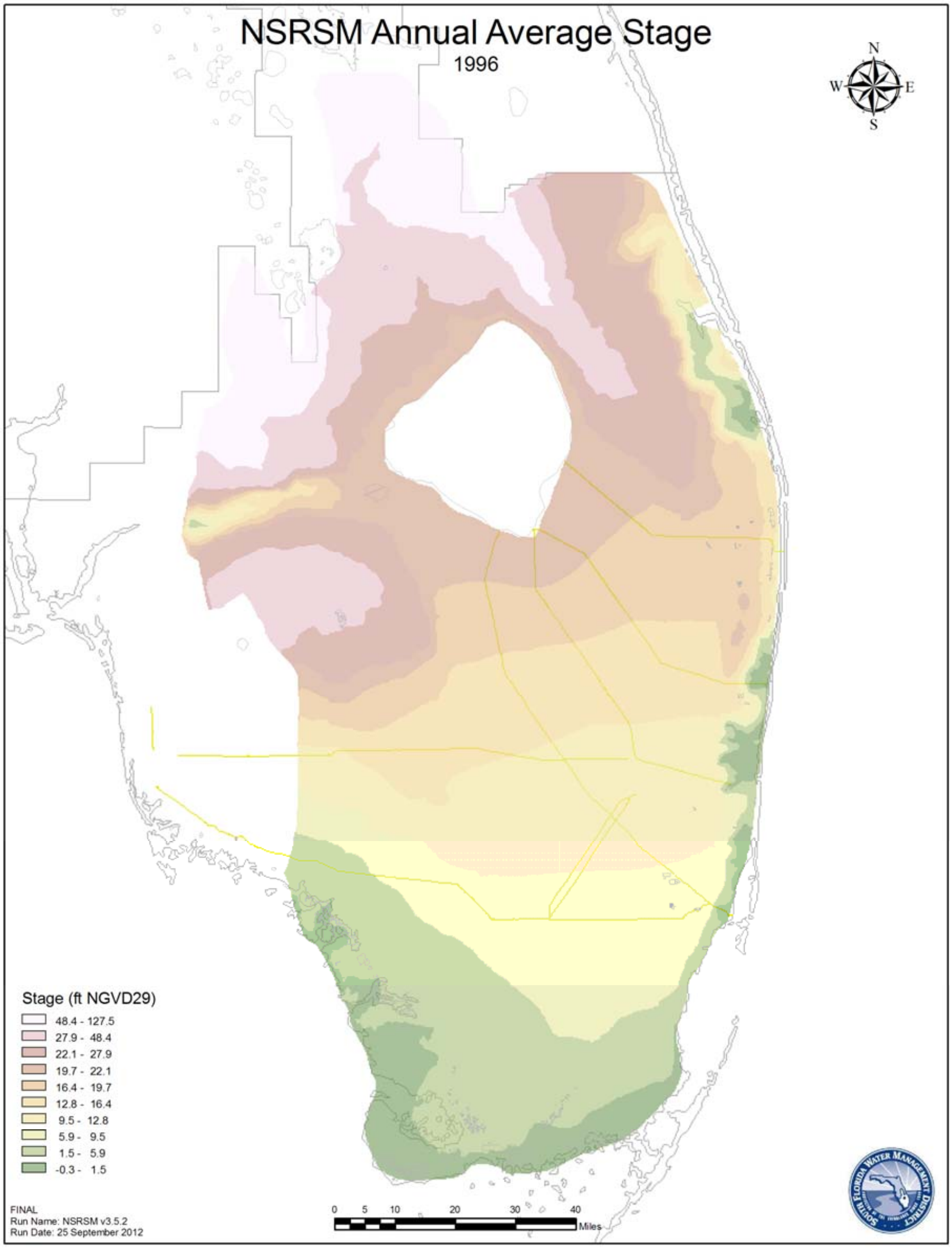

Figure K-31. Annual average stage values for the NSRSM model domain for 1996.

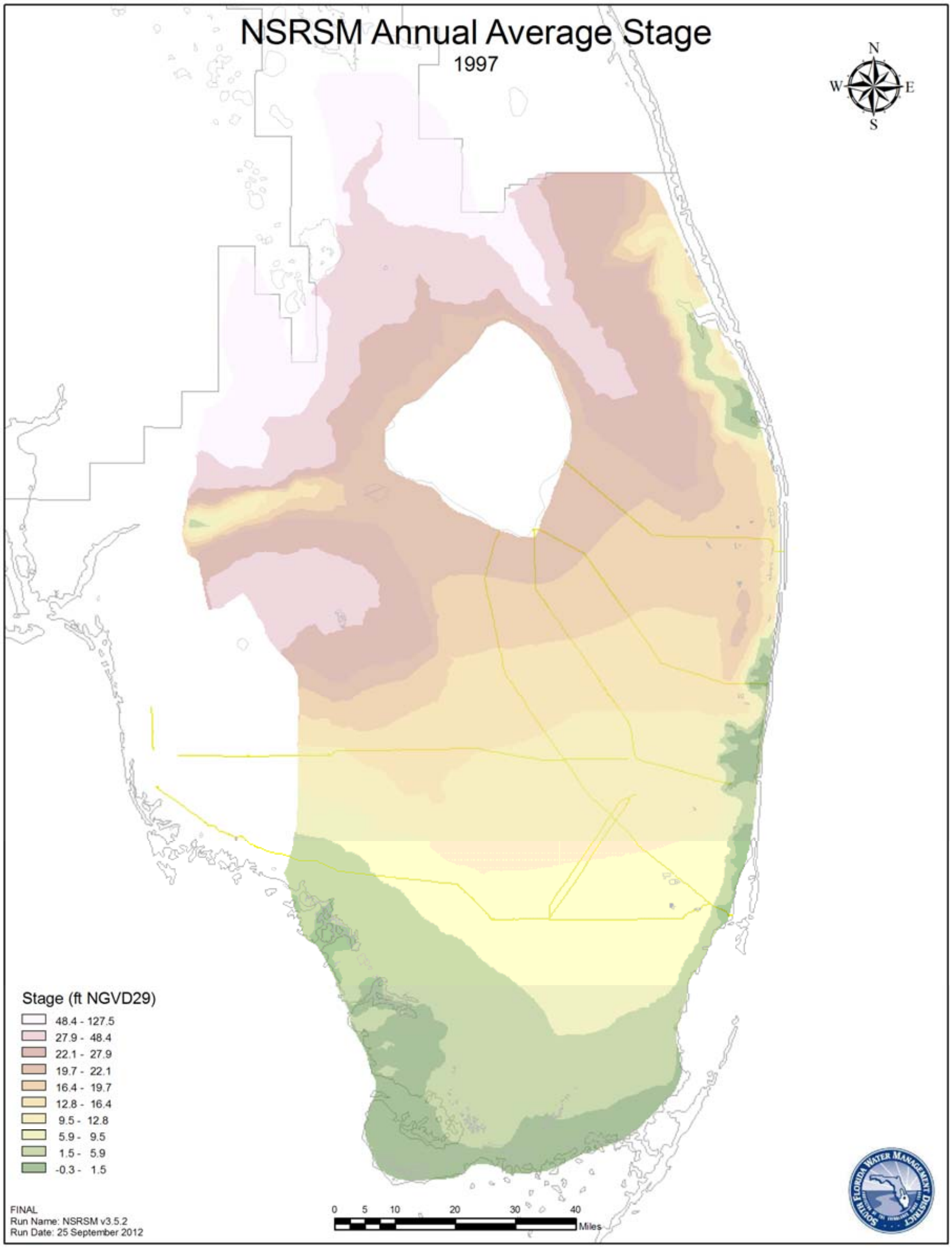

Figure K-32. Annual average stage values for the NSRSM model domain for 1997.

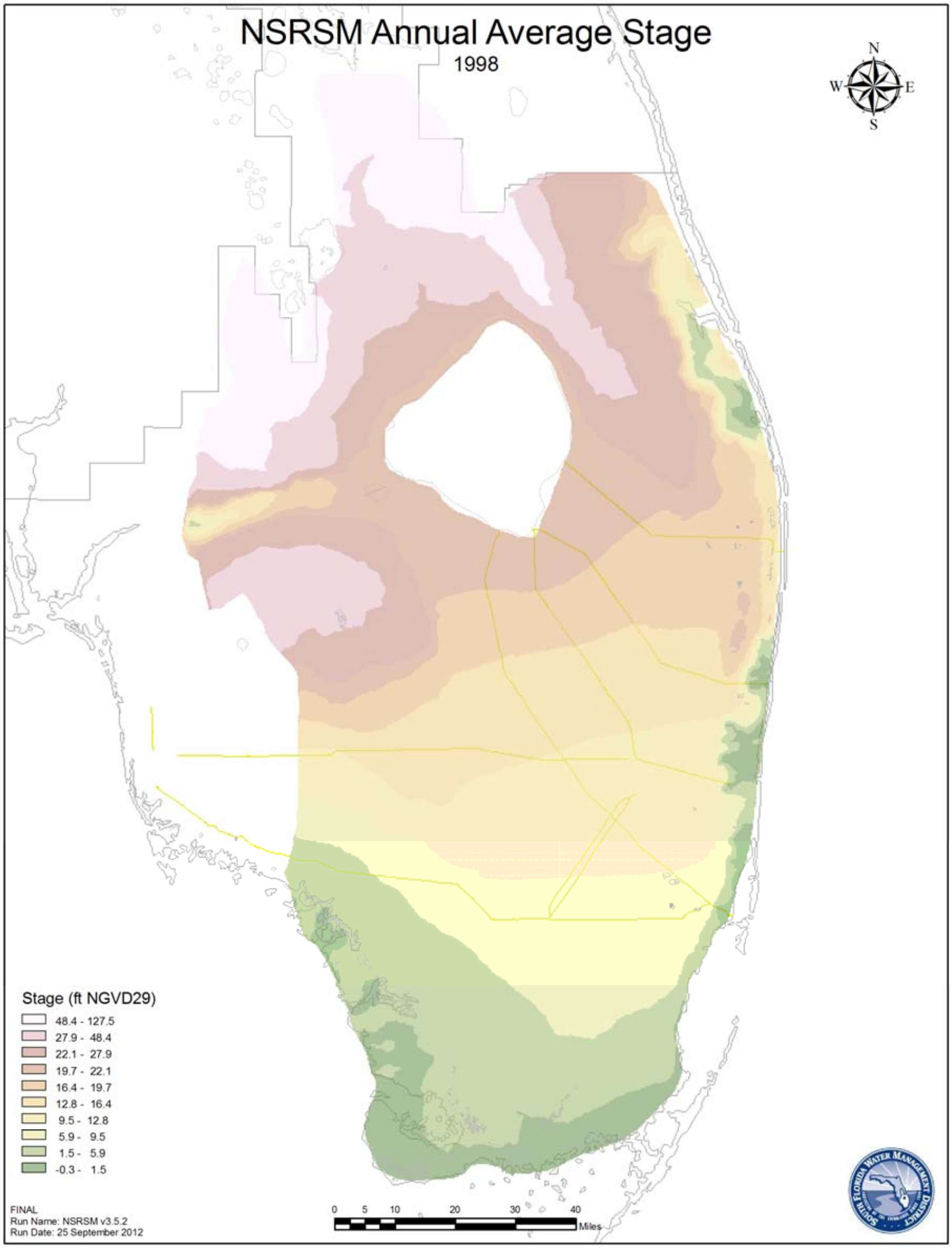

Figure K-33 Annual average stage values for the NSRSM model domain for 1998.

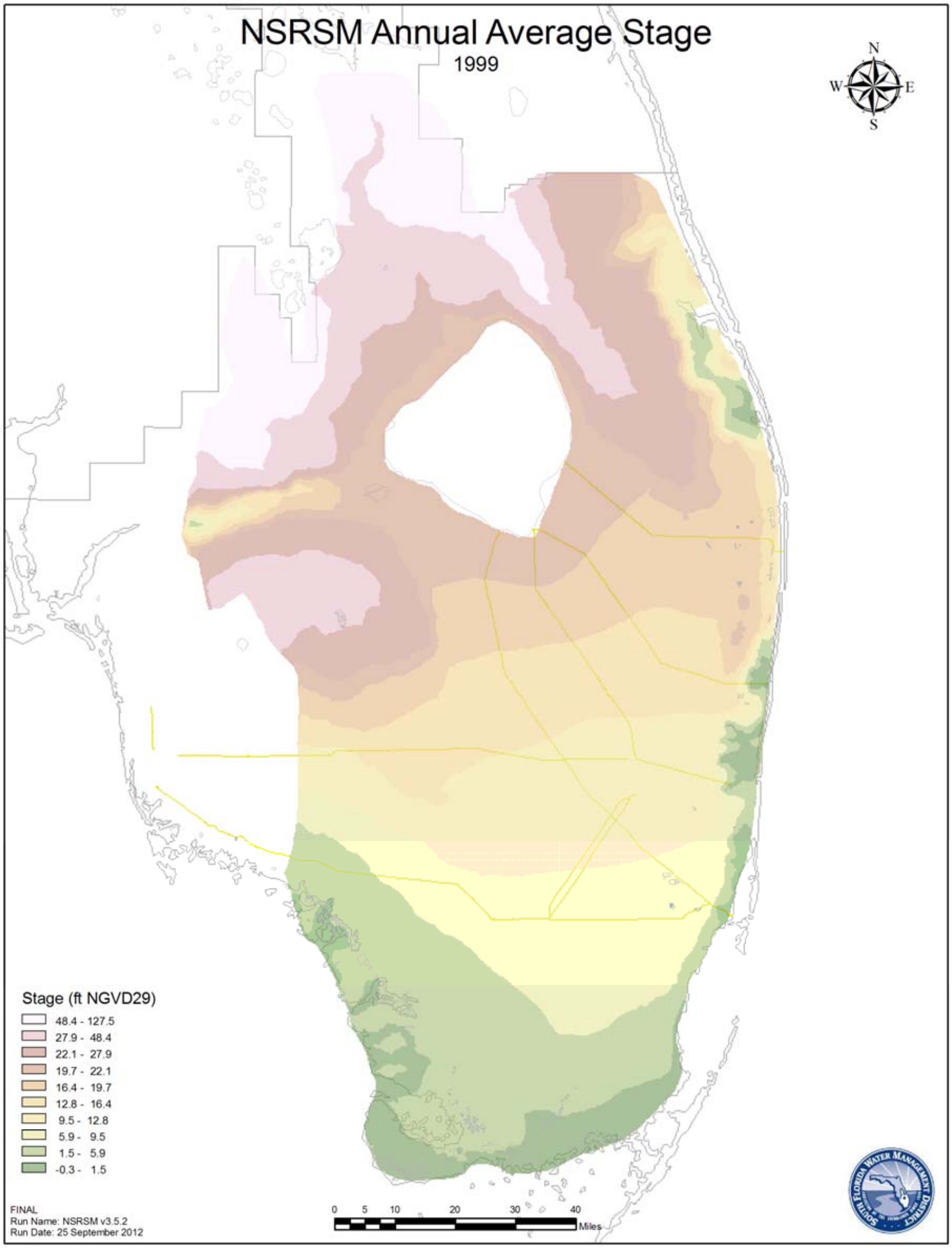

Figure K-34. Annual average stage values for the NSRSM model domain for 1999.

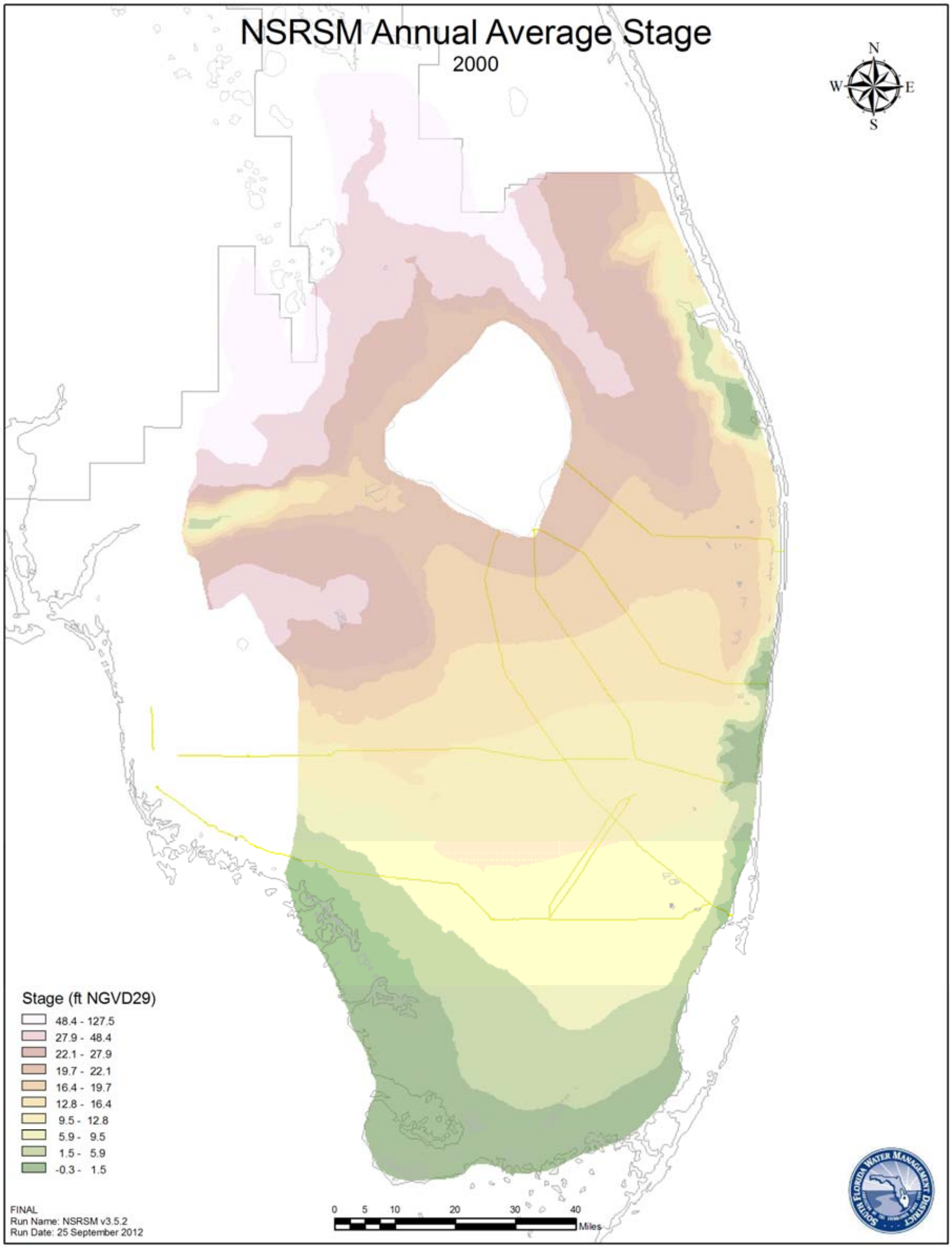

Figure K-35. Annual average stage values for the NSRSM model domain for 2000.

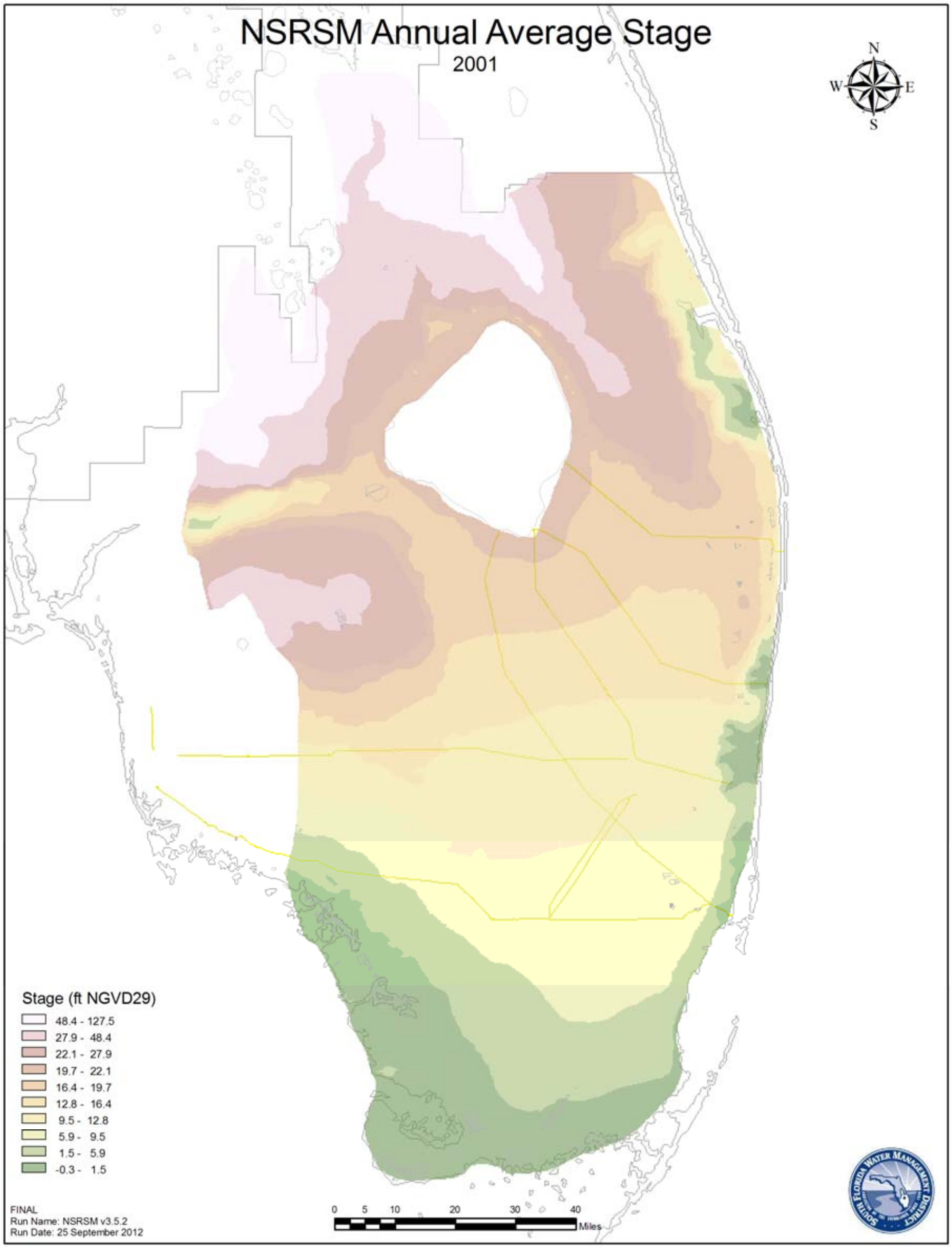

Figure K-36. Annual average stage values for the NSRSM model domain for 2001.

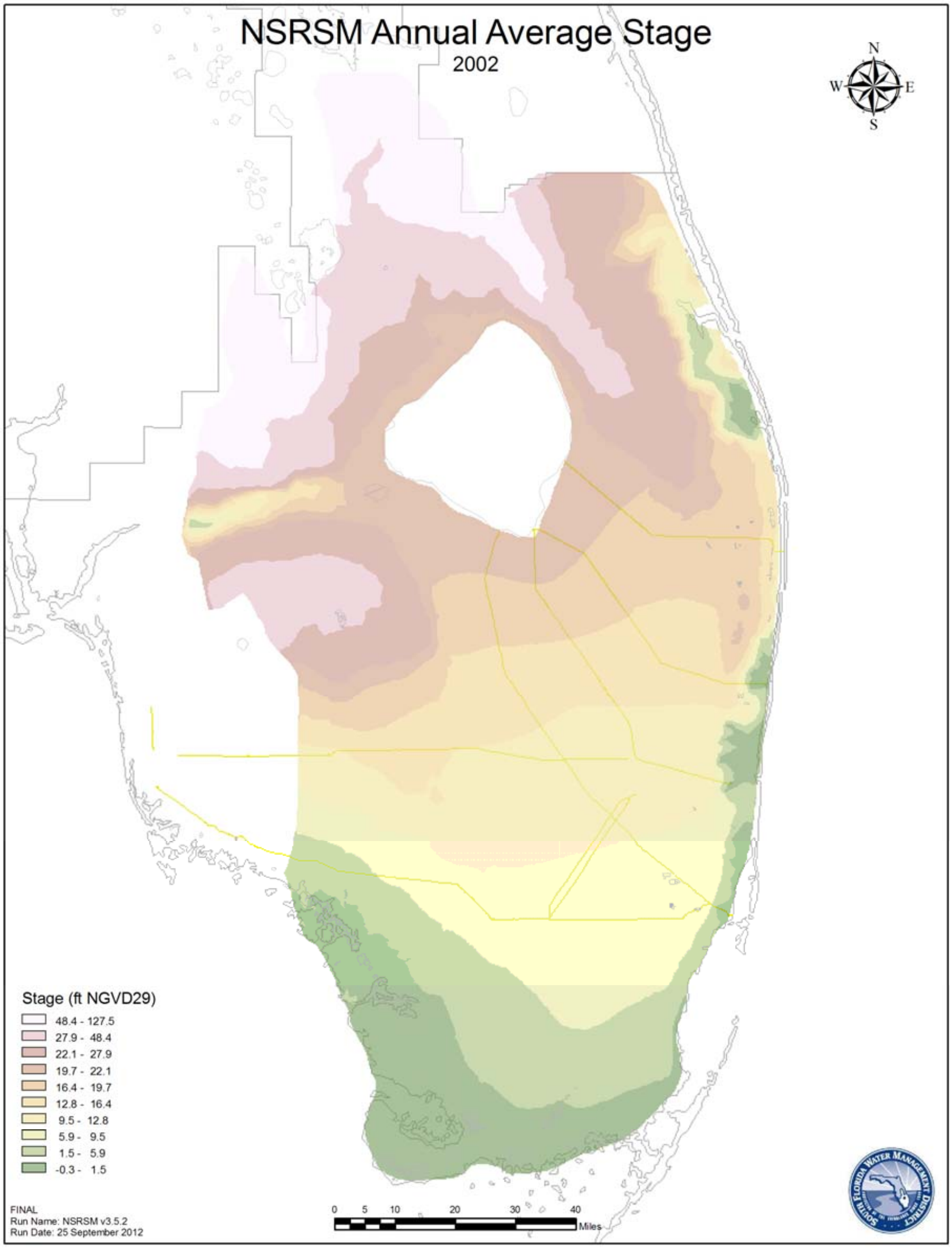

Figure K-37. Annual average stage values for the NSRSM model domain for 2002.

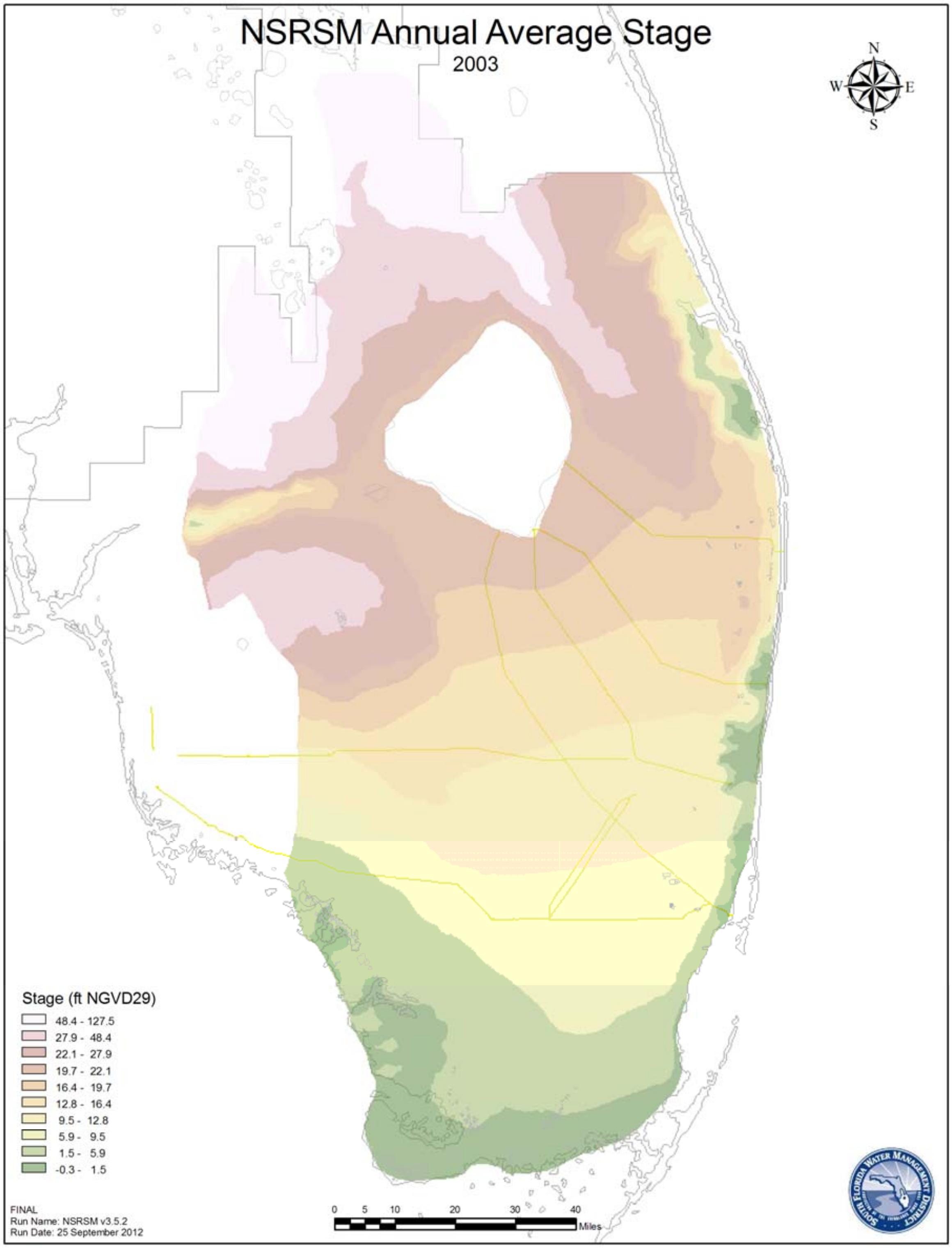

Figure K-38. Annual average stage values for the NSRSM model domain for 2003.

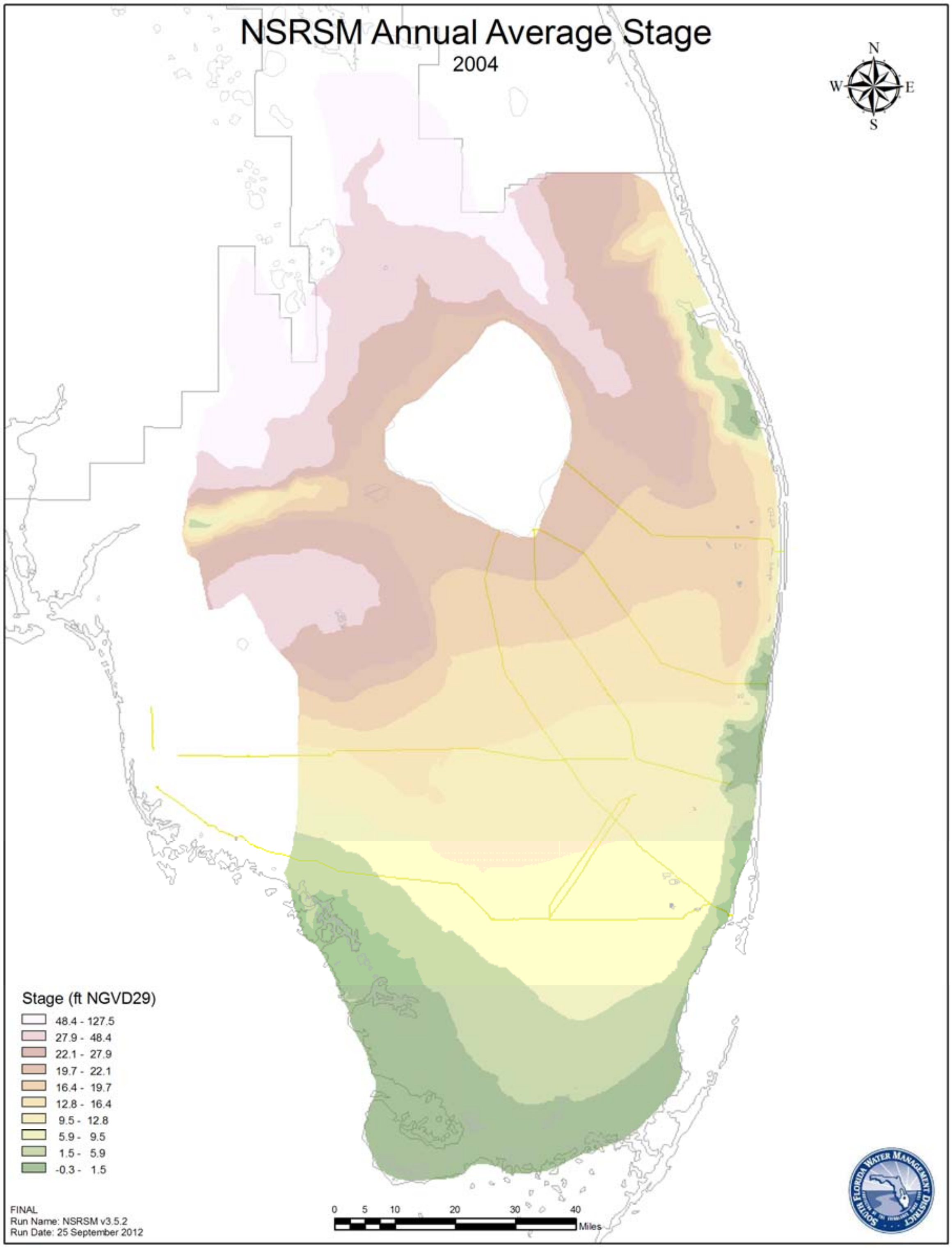

Figure K-39. Annual average stage values for the NSRSM model domain for 2004.

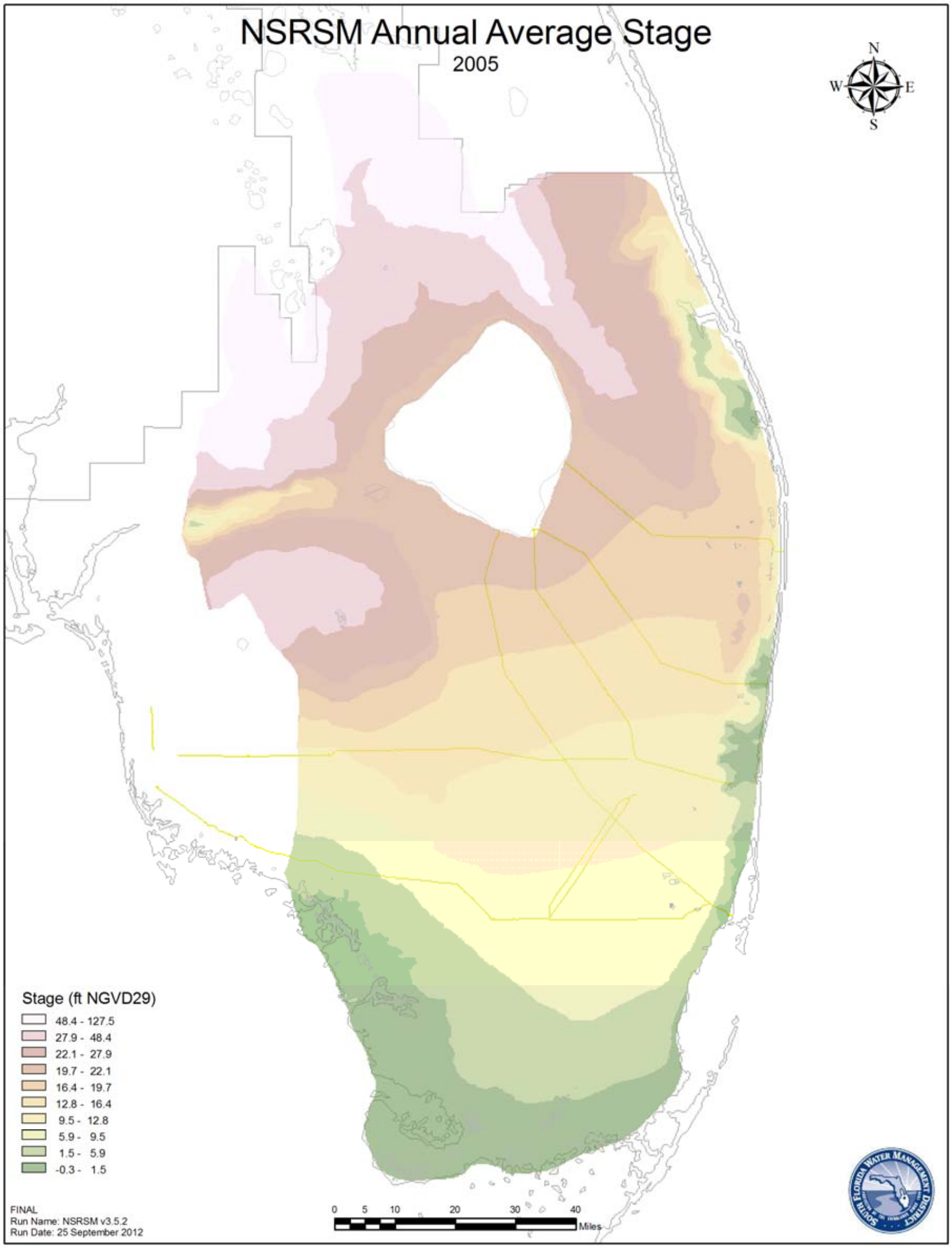

Figure K-40. Annual average stage values for the NSRSM model domain for 2005.

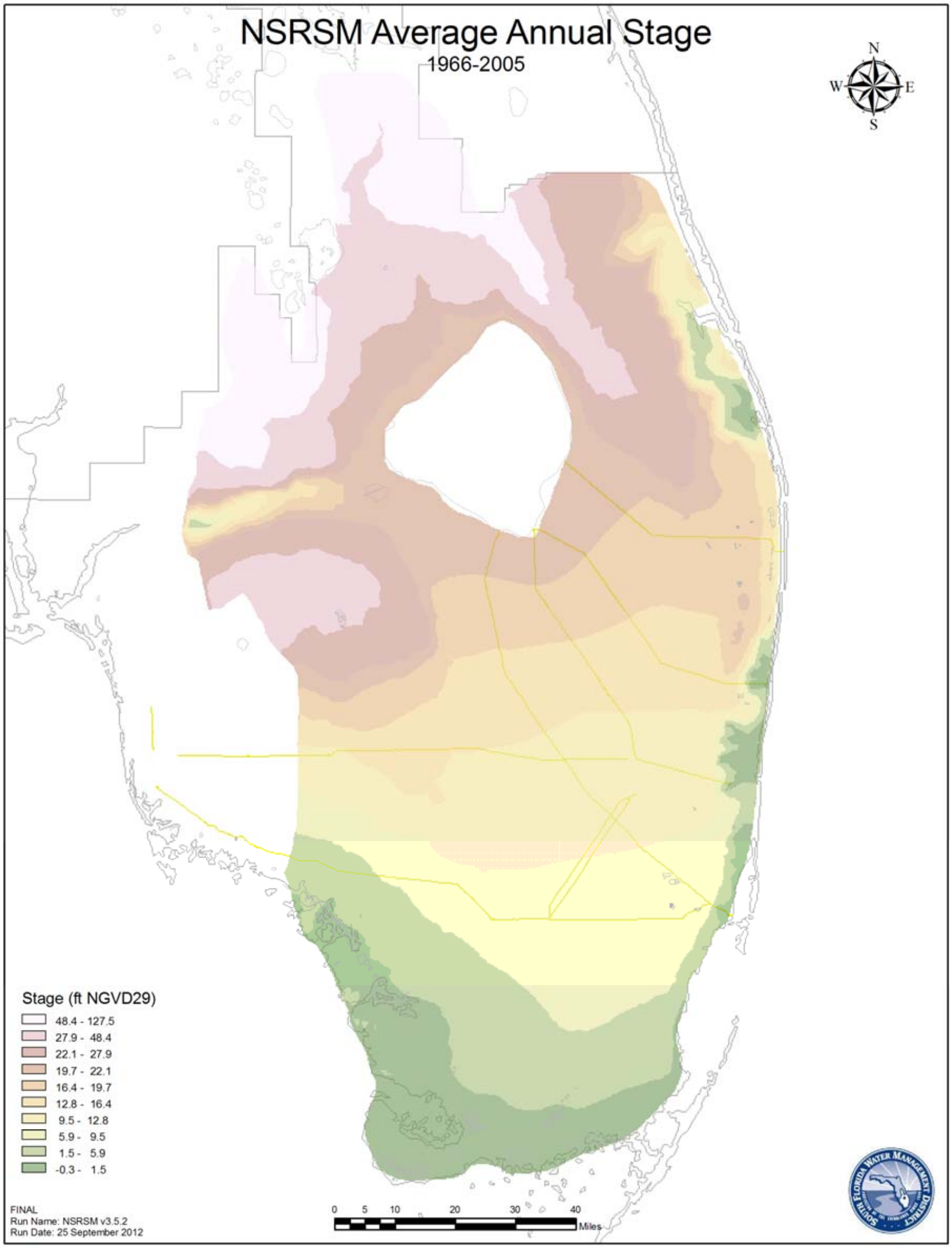

Figure K-41. Average annual stage values for the NSRSM model domain for the period 1966-2005.

K.2 PONDING

Figures K-42 through **K-81** display annual average ponding depth values for the NSRSM model domain for 1966 through 2005, respectively. **Figure K-82** displays the average annual ponding depth for the entire period of record, 1966-2005.

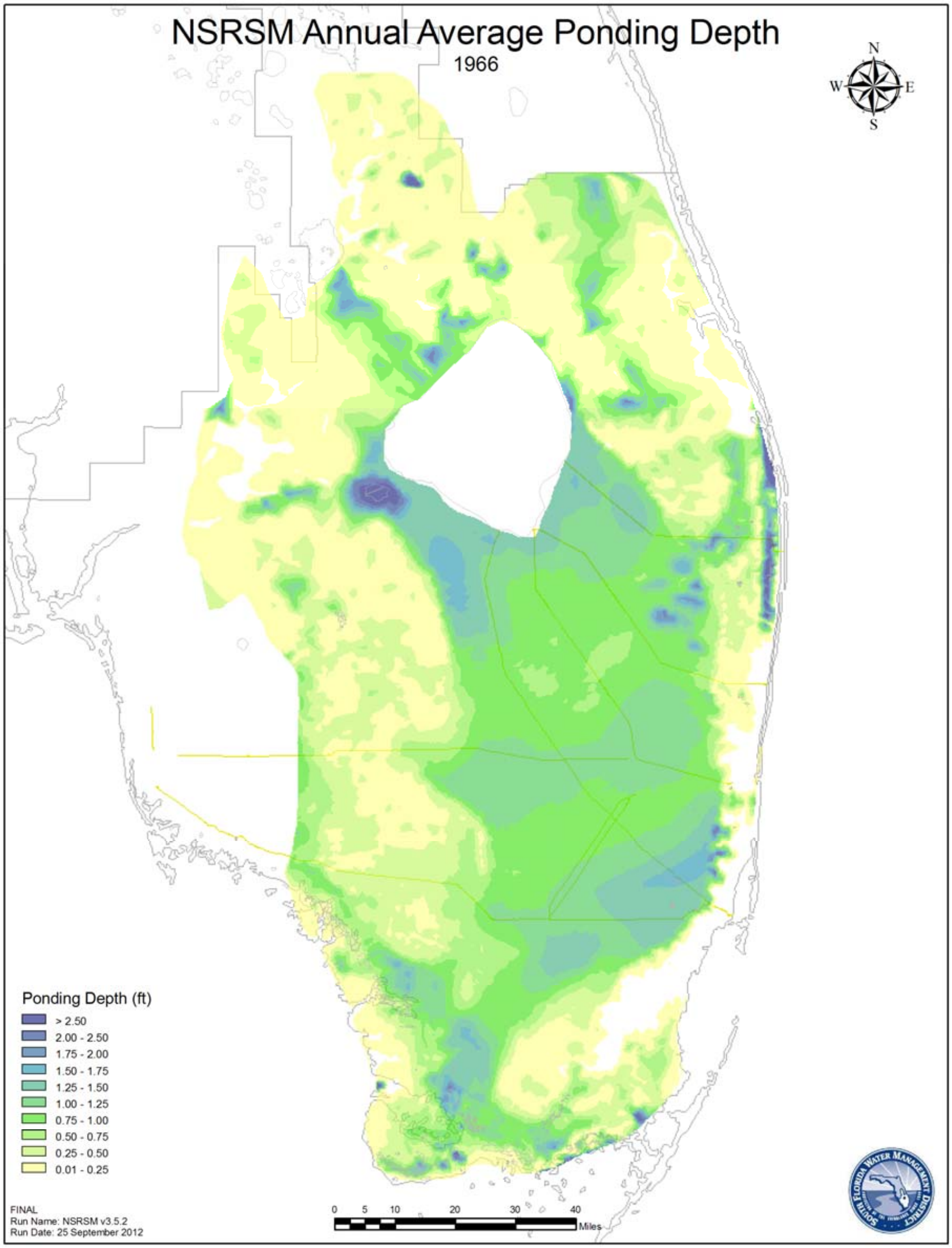

Figure K-42. Annual average ponding depth values for the NSRSM model domain for 1966.

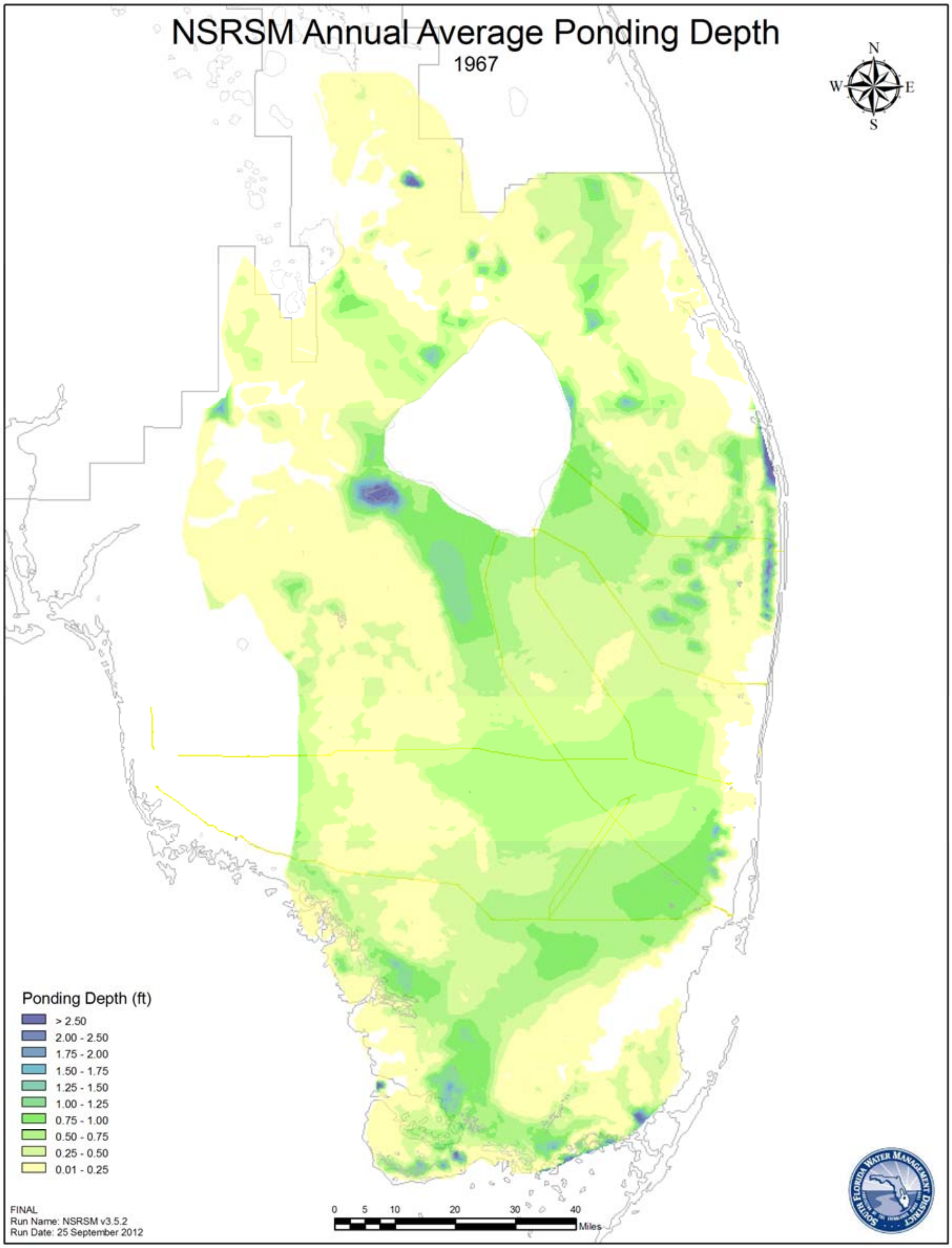

Figure K-43. Annual average ponding depth values for the NSRSM model domain for 1967.

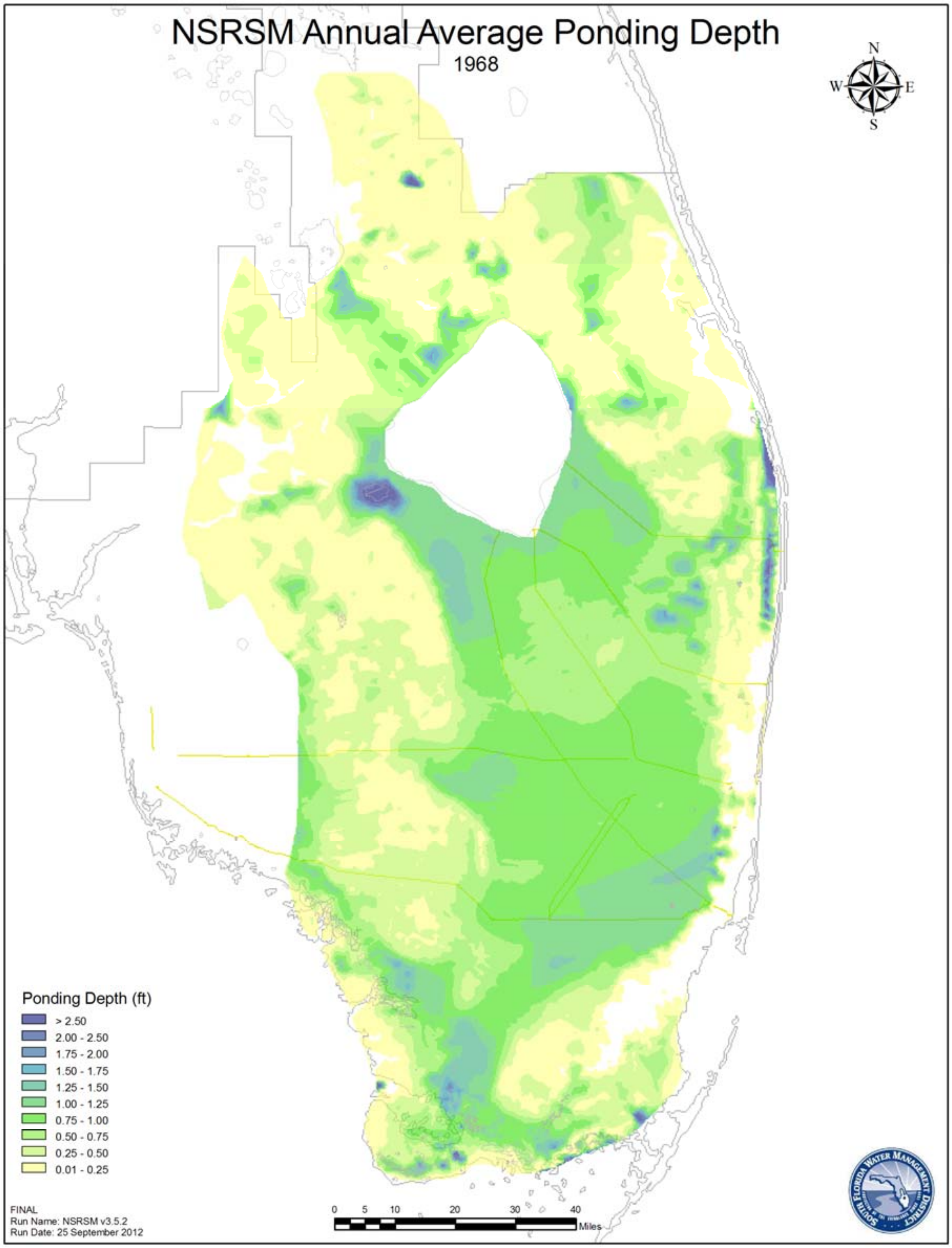

Figure K-44. Annual average ponding depth values for the NSRSM model domain for 1968.

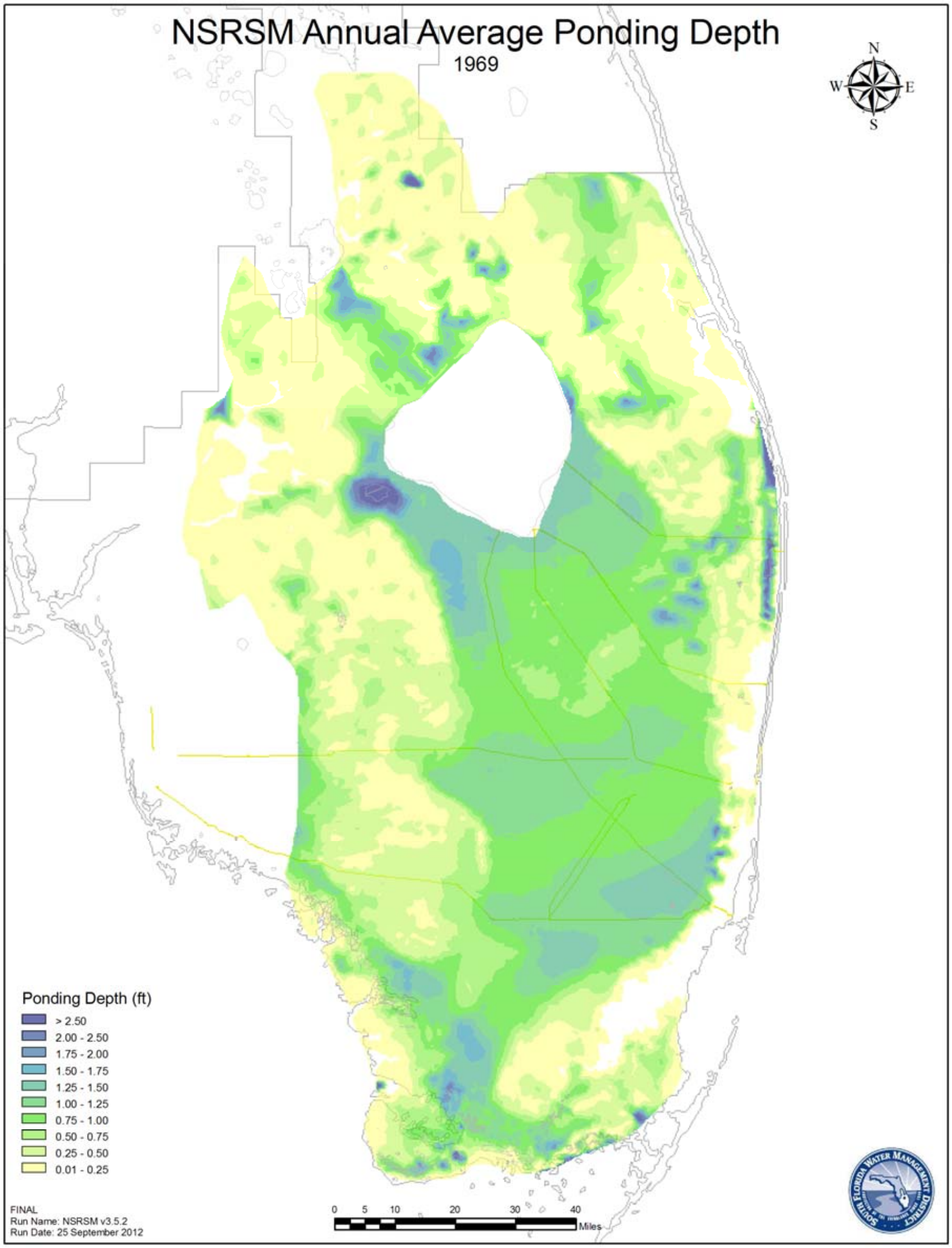

Figure K-45. Annual average ponding depth values for the NSRSM model domain for 1969.

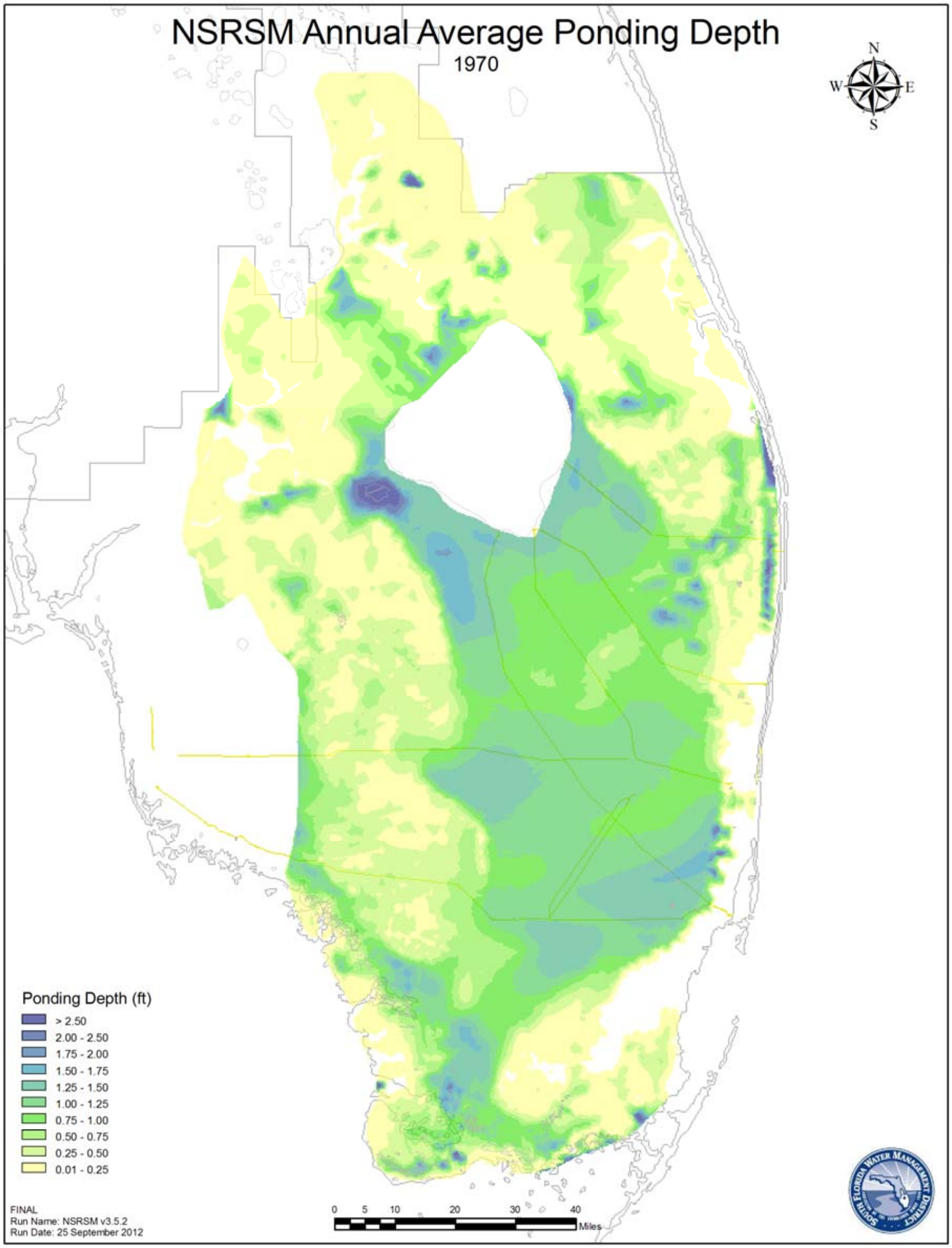

Figure K-46. Annual average ponding depth values for the NSRSM model domain for 1970.

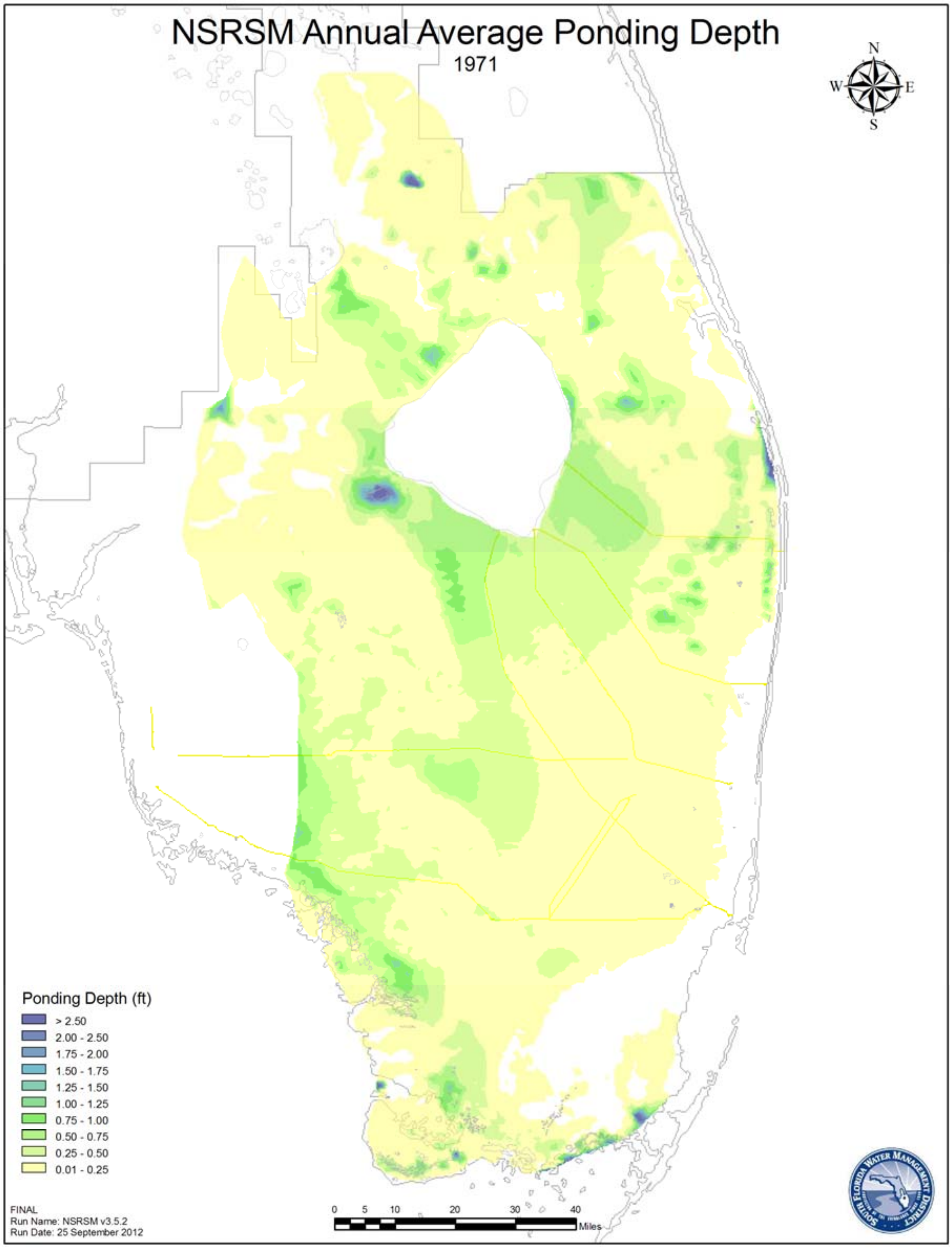

Figure K-47. Annual average ponding depth values for the NSRSM model domain for 1971.

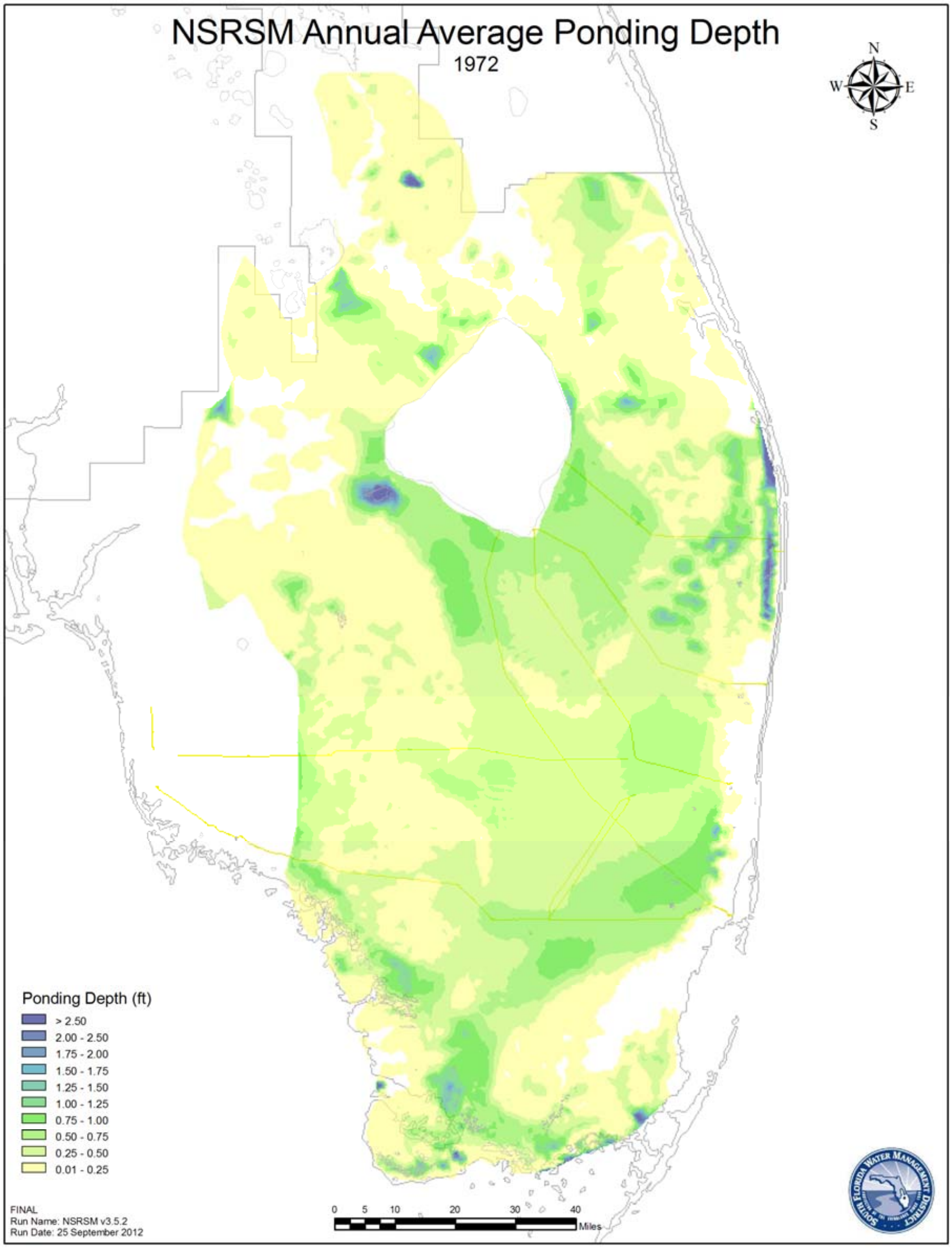

Figure K-48. Annual average ponding depth values for the NSRSM model domain for 1972.

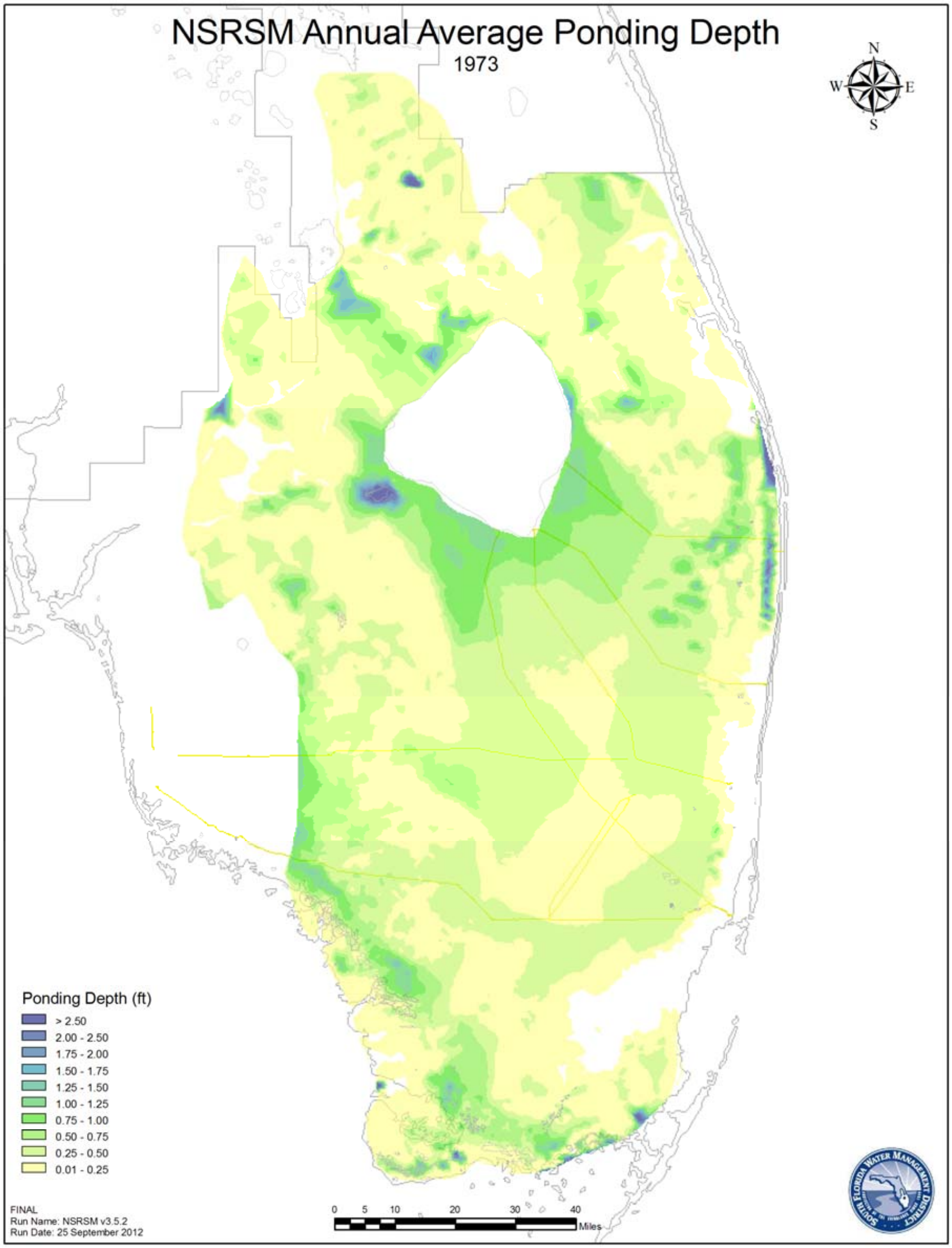

Figure K-49. Annual average ponding depth values for the NSRSM model domain for 1973.

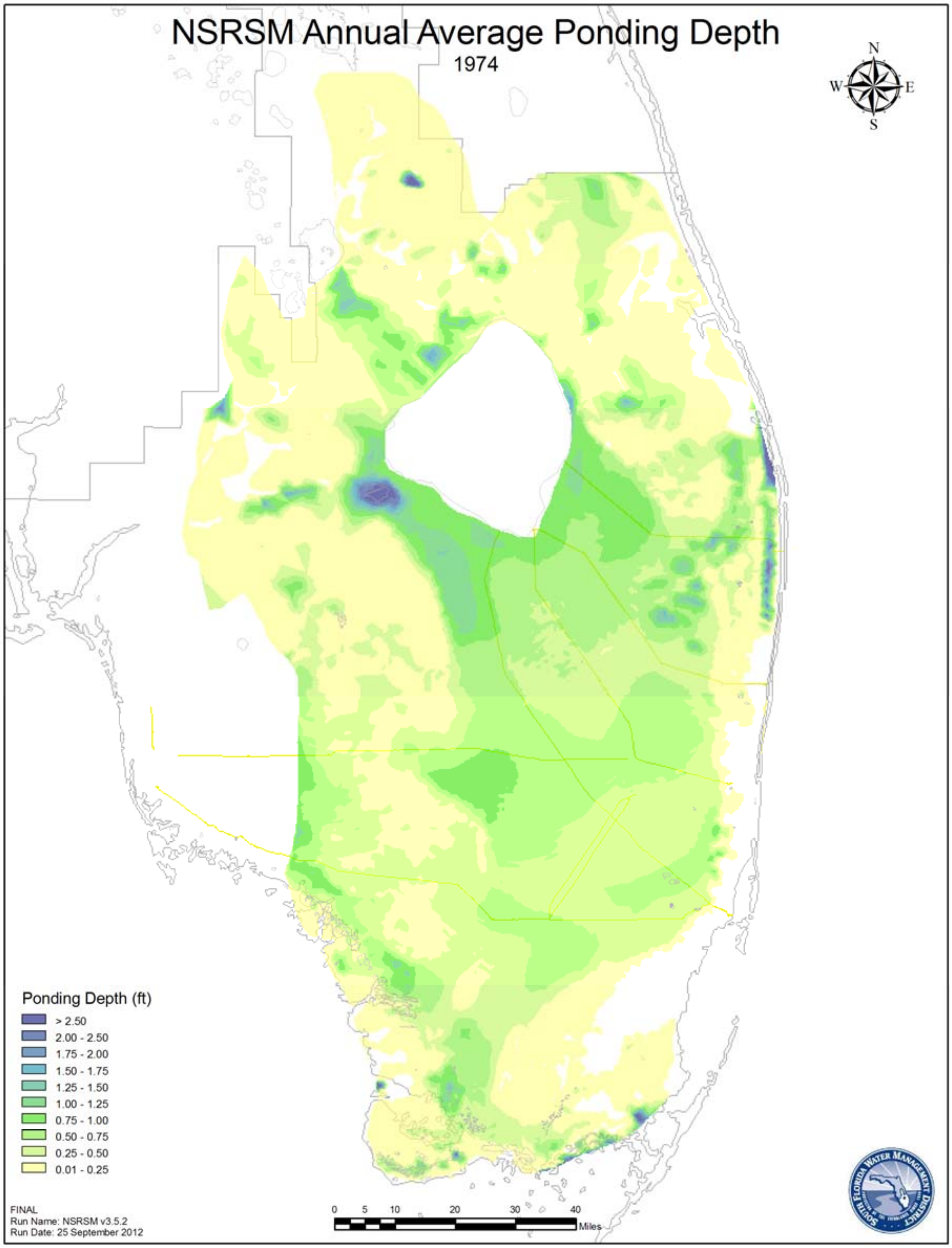

Figure K-50. Annual average ponding depth values for the NSRSM model domain for 1974.

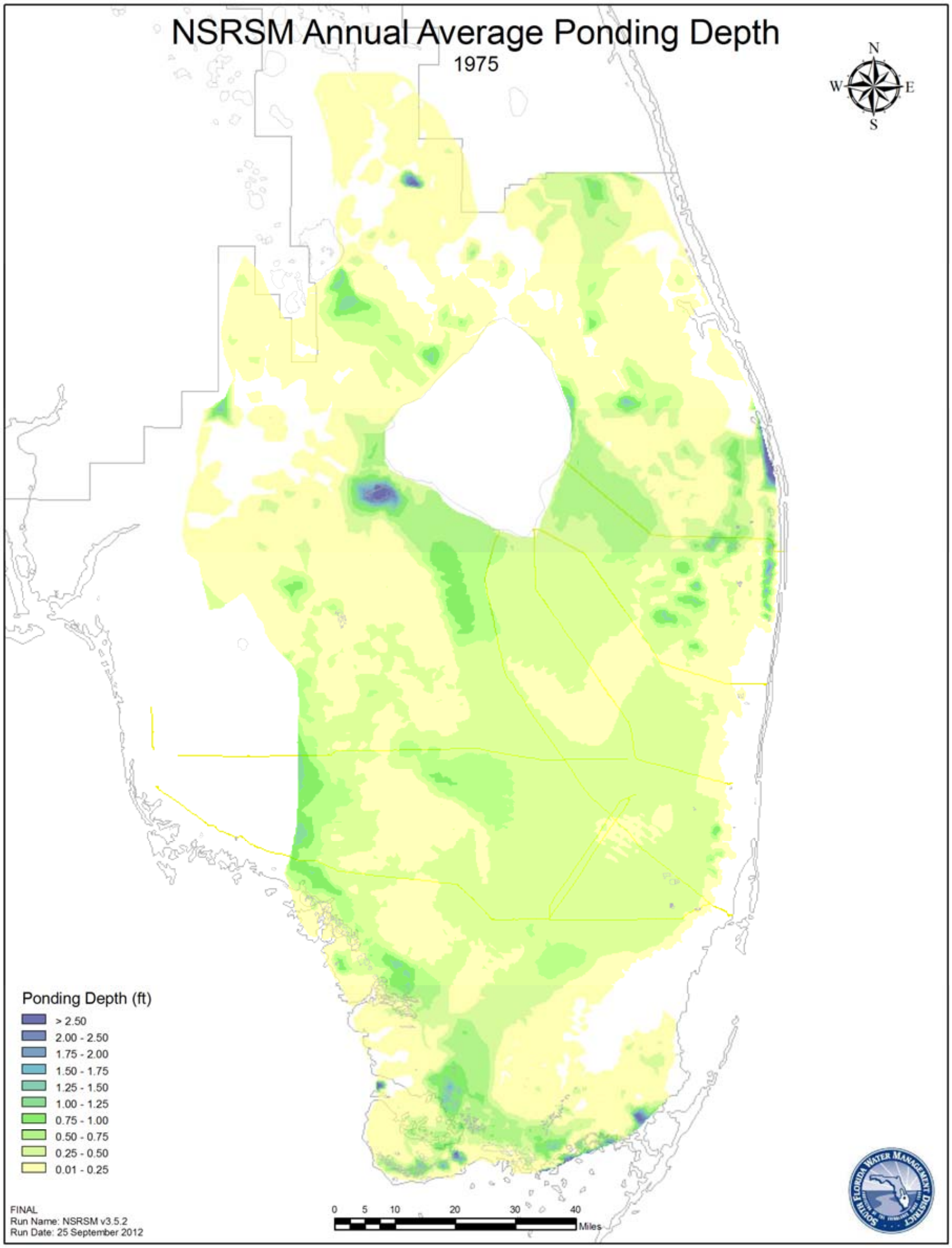

Figure K-51. Annual average ponding depth values for the NSRSM model domain for 1975.

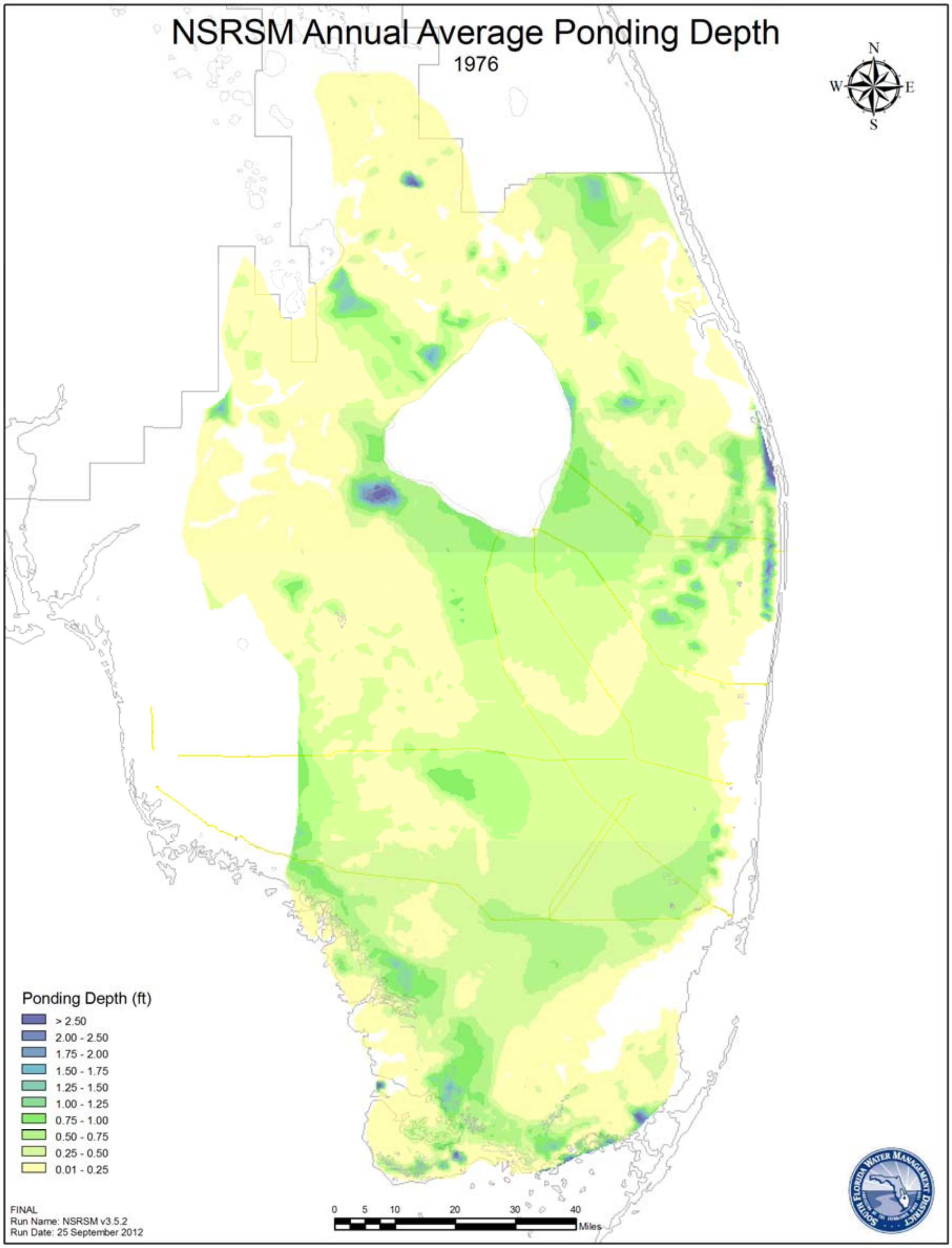

Figure K-52. Annual average ponding depth values for the NSRSM model domain for 1976.

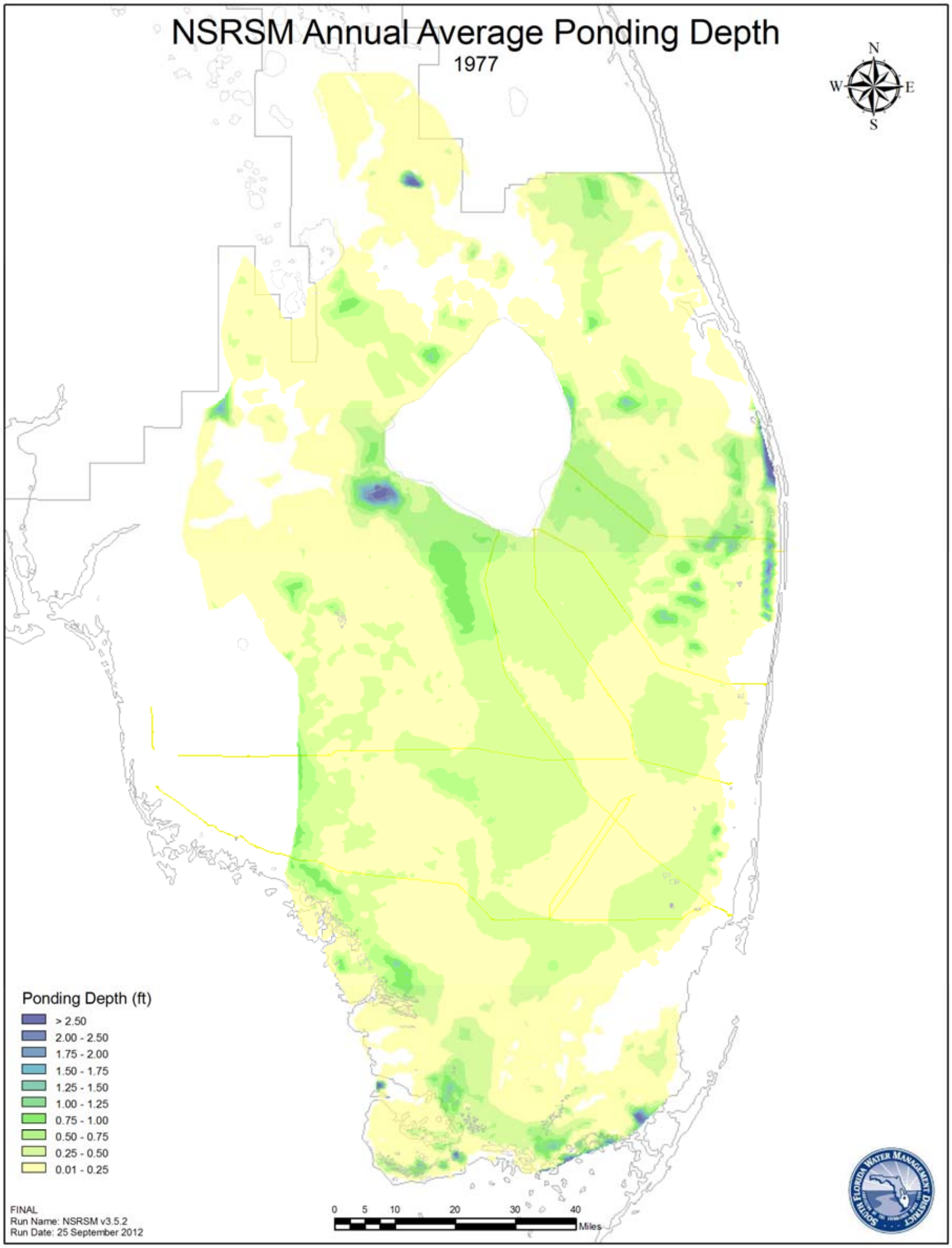

Figure K-53. Annual average ponding depth values for the NSRSM model domain for 1977.

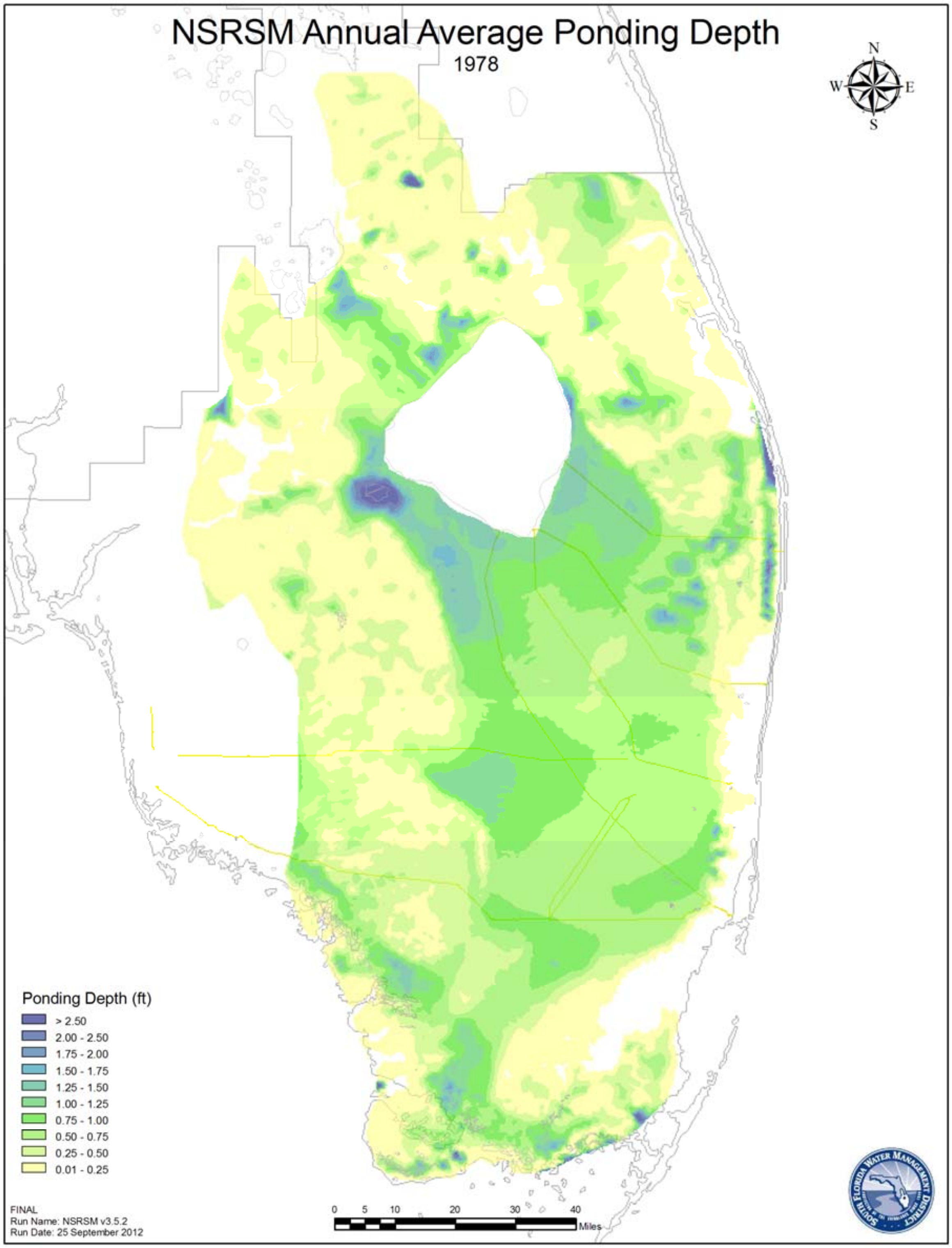

Figure K-54. Annual average ponding depth values for the NSRSM model domain for 1978.

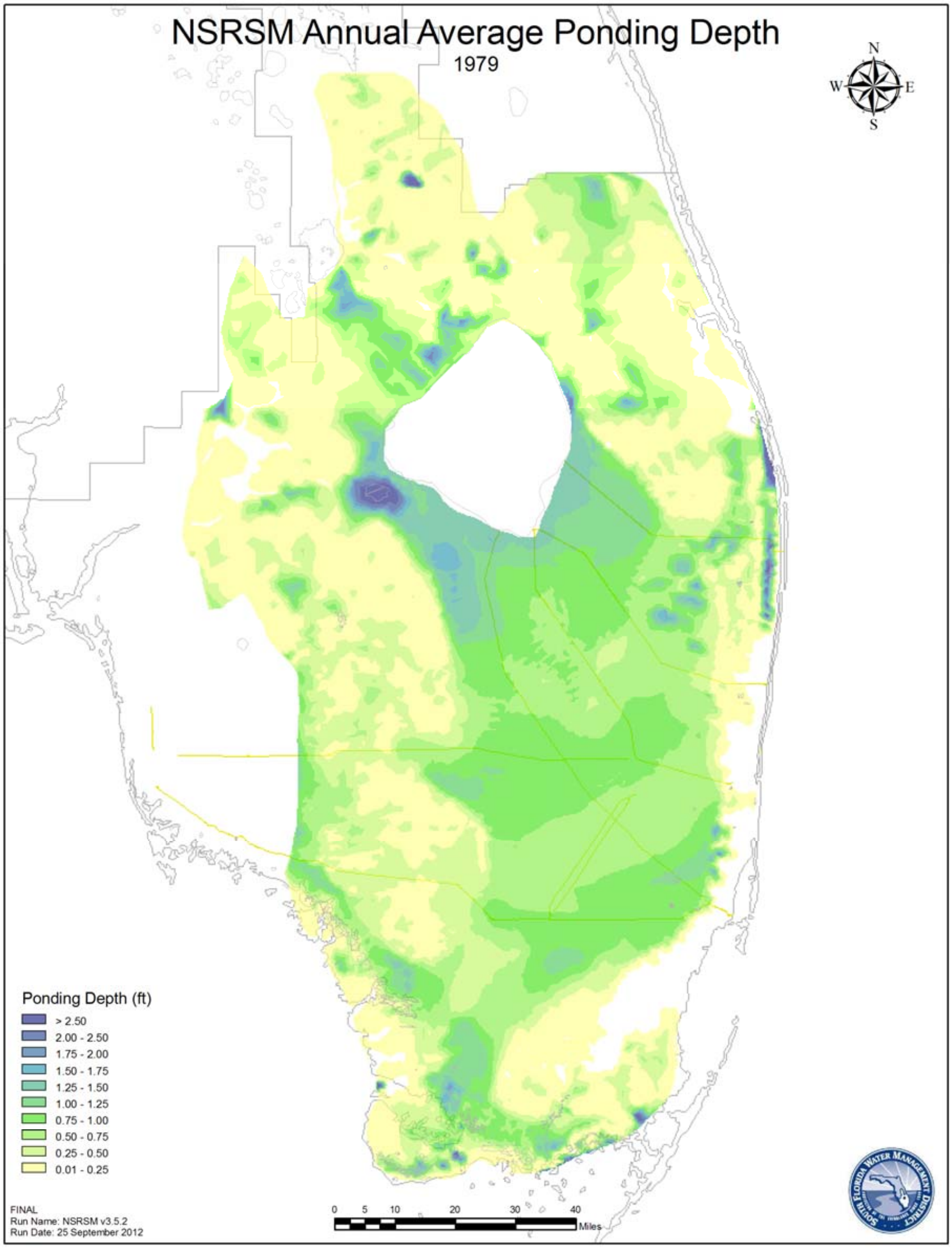

Figure K-55. Annual average ponding depth values for the NSRSM model domain for 1979.

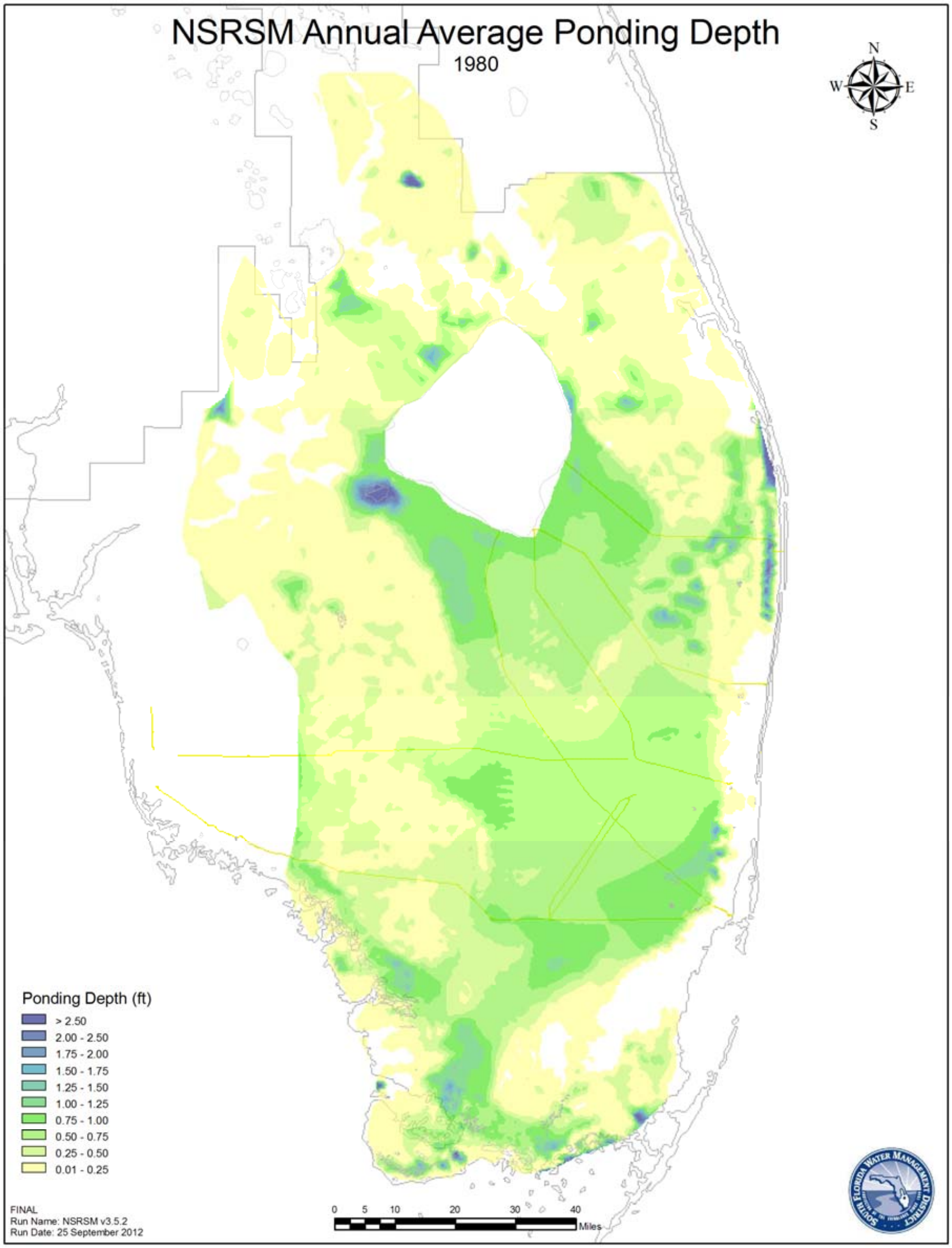

Figure K-56. Annual average ponding depth values for the NSRSM model domain for 1980.

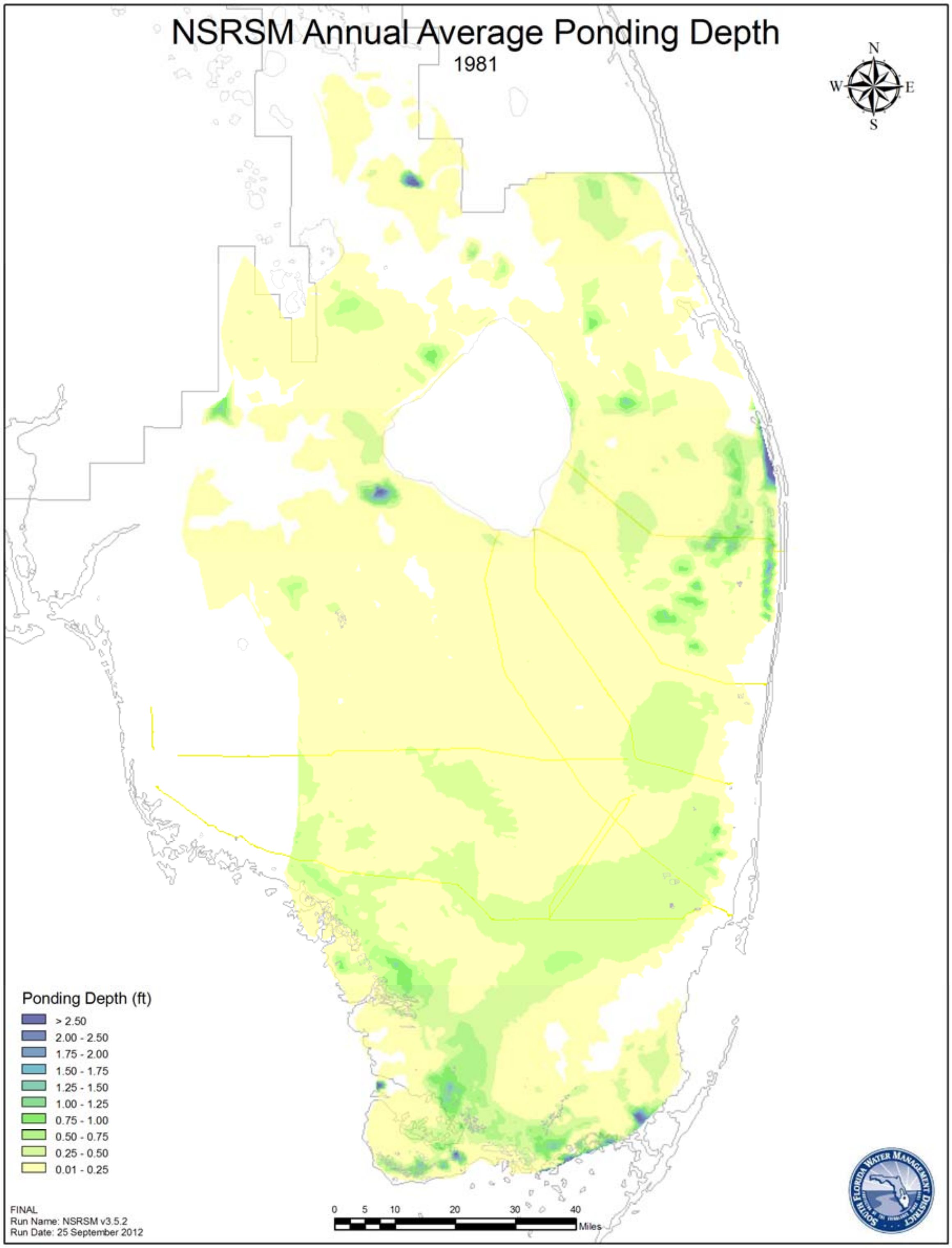

Figure K-57. Annual average ponding depth values for the NSRSM model domain for 1981.

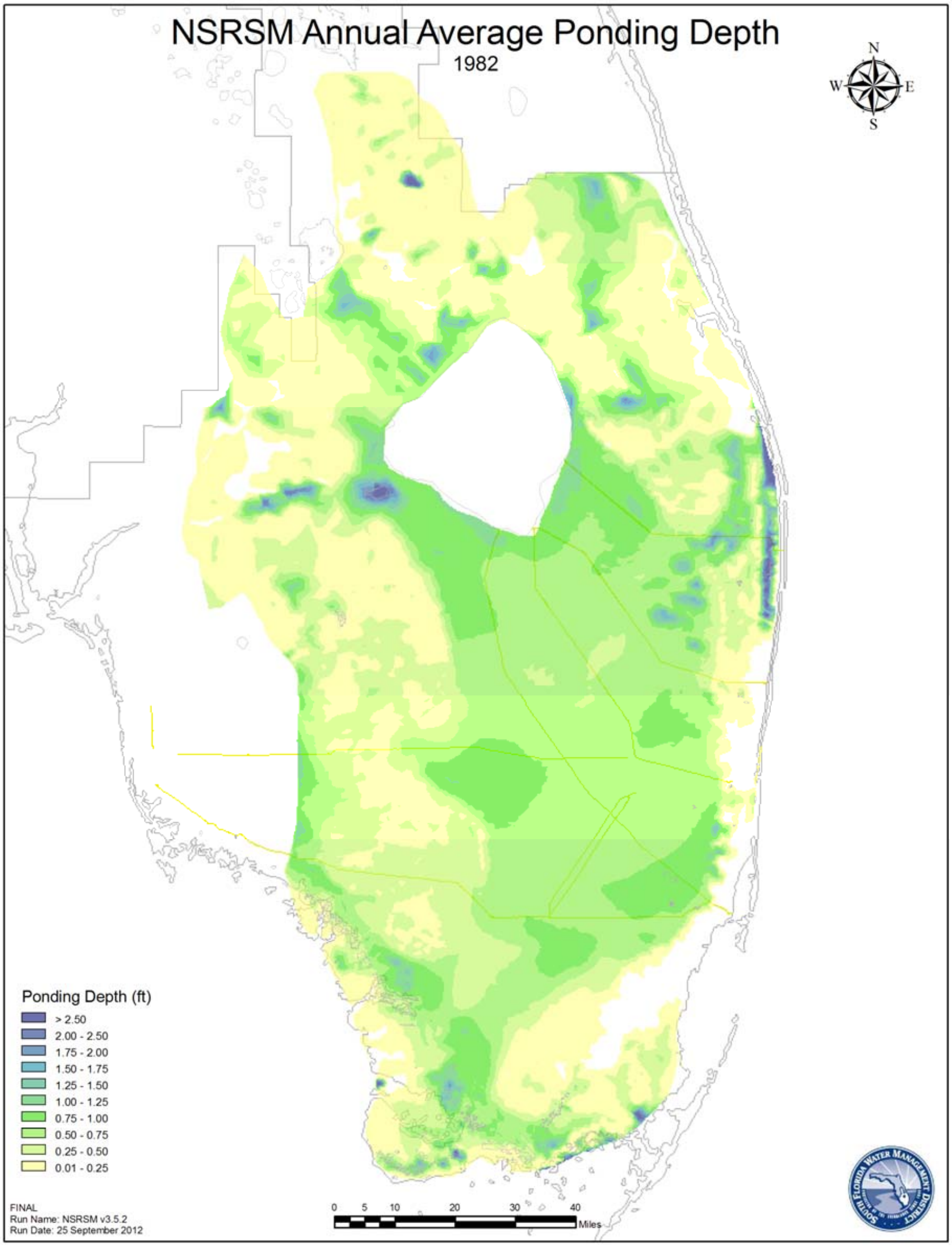

Figure K-58. Annual average ponding depth values for the NSRSM model domain for 1982.

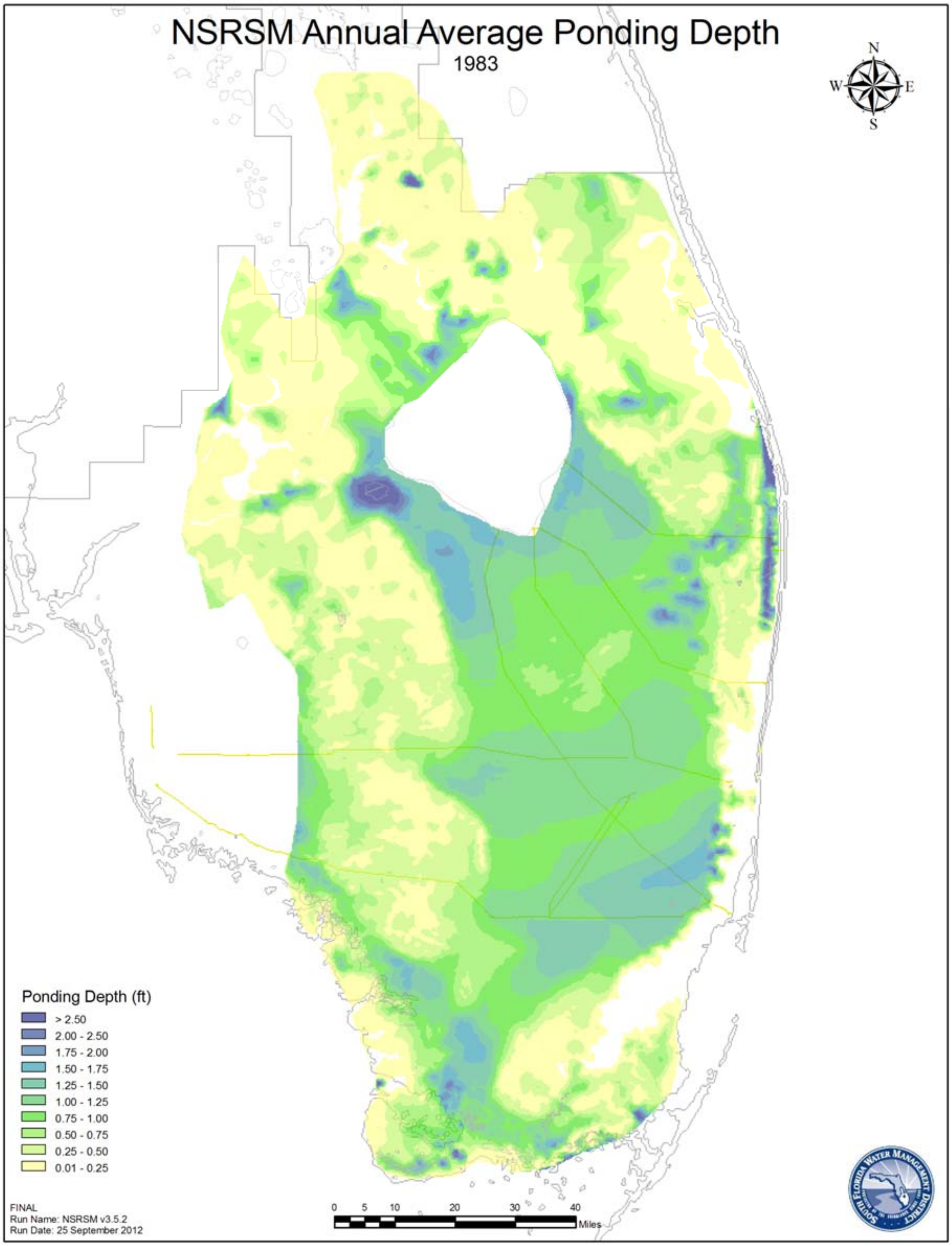

Figure K-59. Annual average ponding depth values for the NSRSM model domain for 1983.

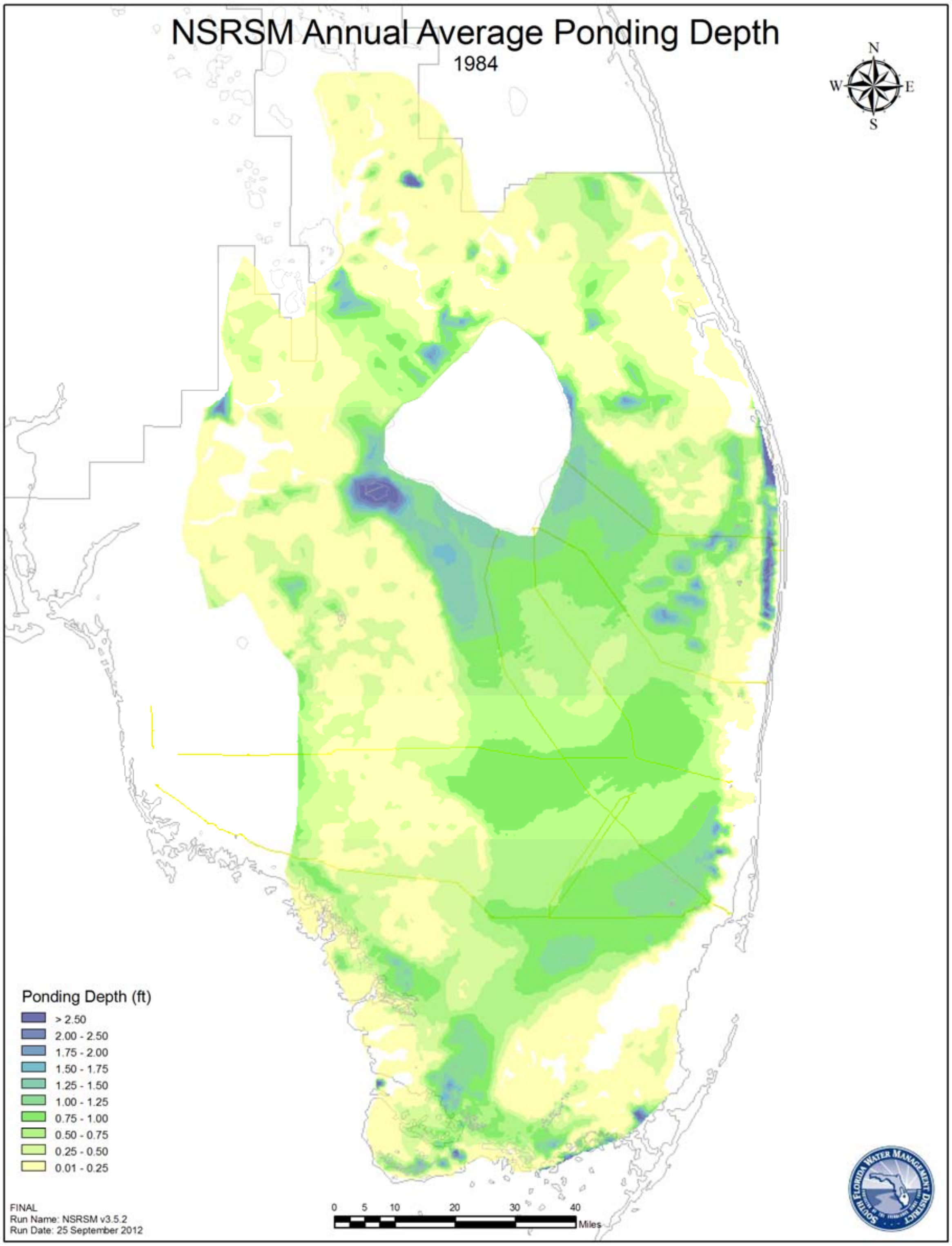

Figure K-60. Annual average ponding depth values for the NSRSM model domain for 1984.

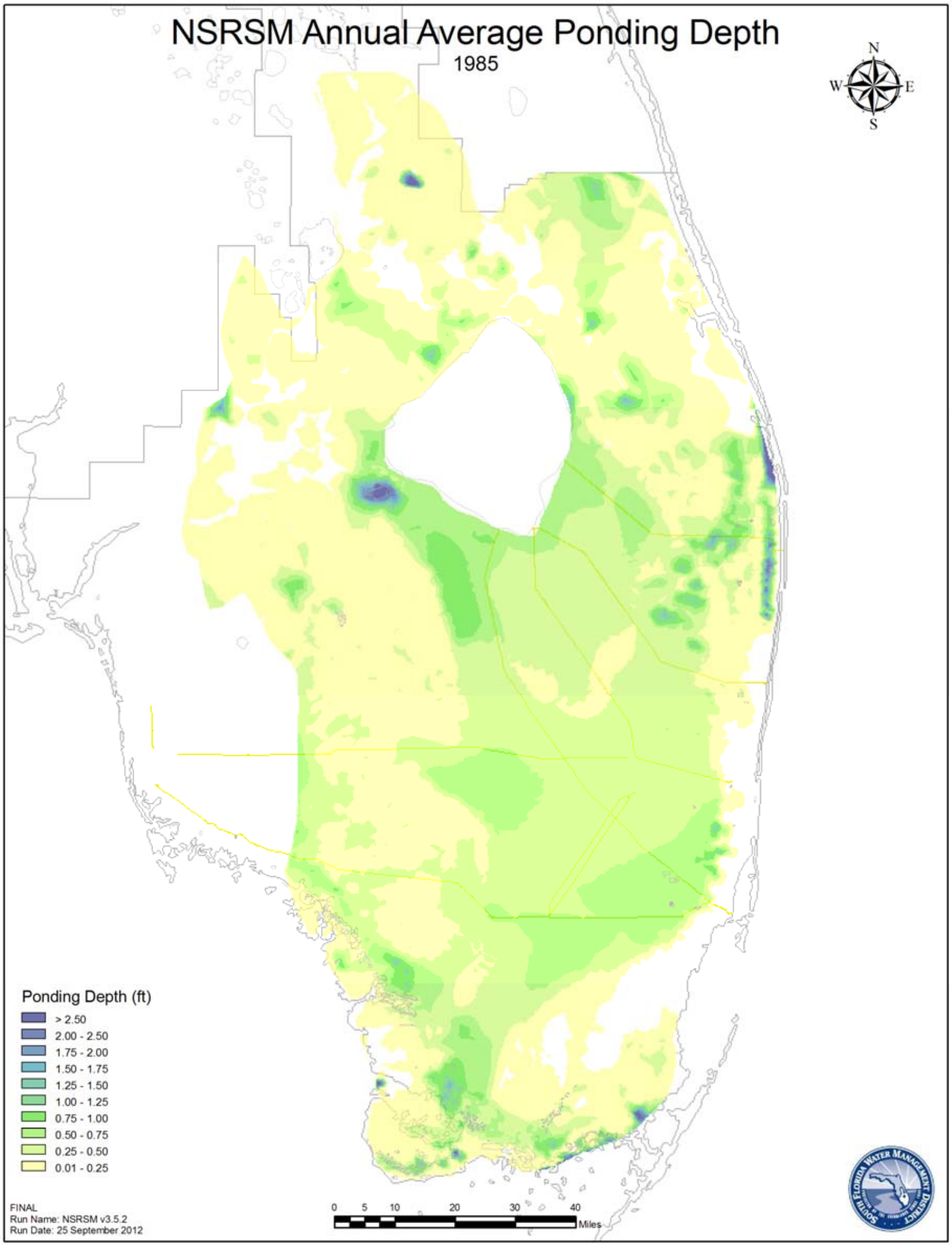

Figure K-61. Annual average ponding depth values for the NSRSM model domain for 1985.

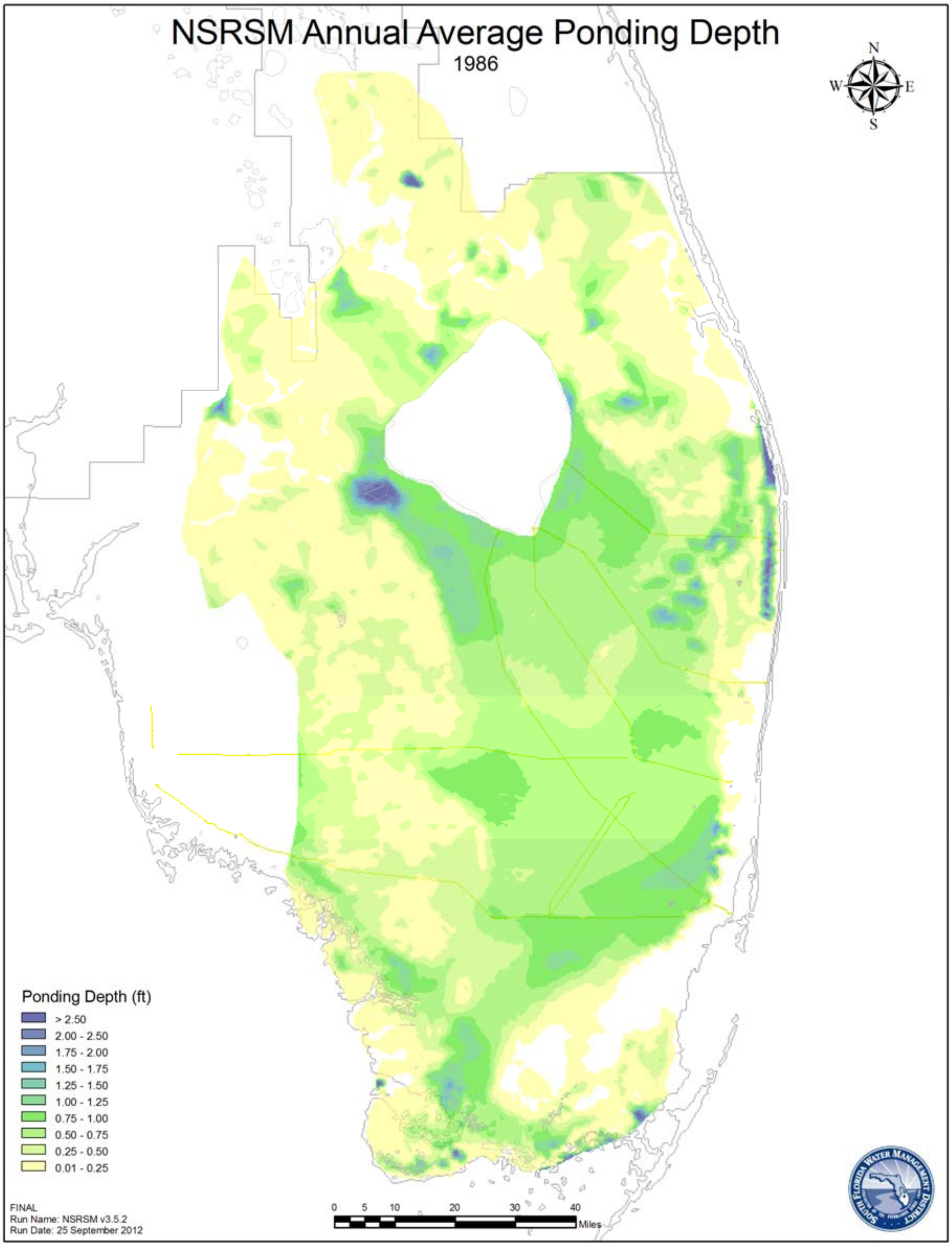

Figure K-62. Annual average ponding depth values for the NSRSM model domain for 1986.

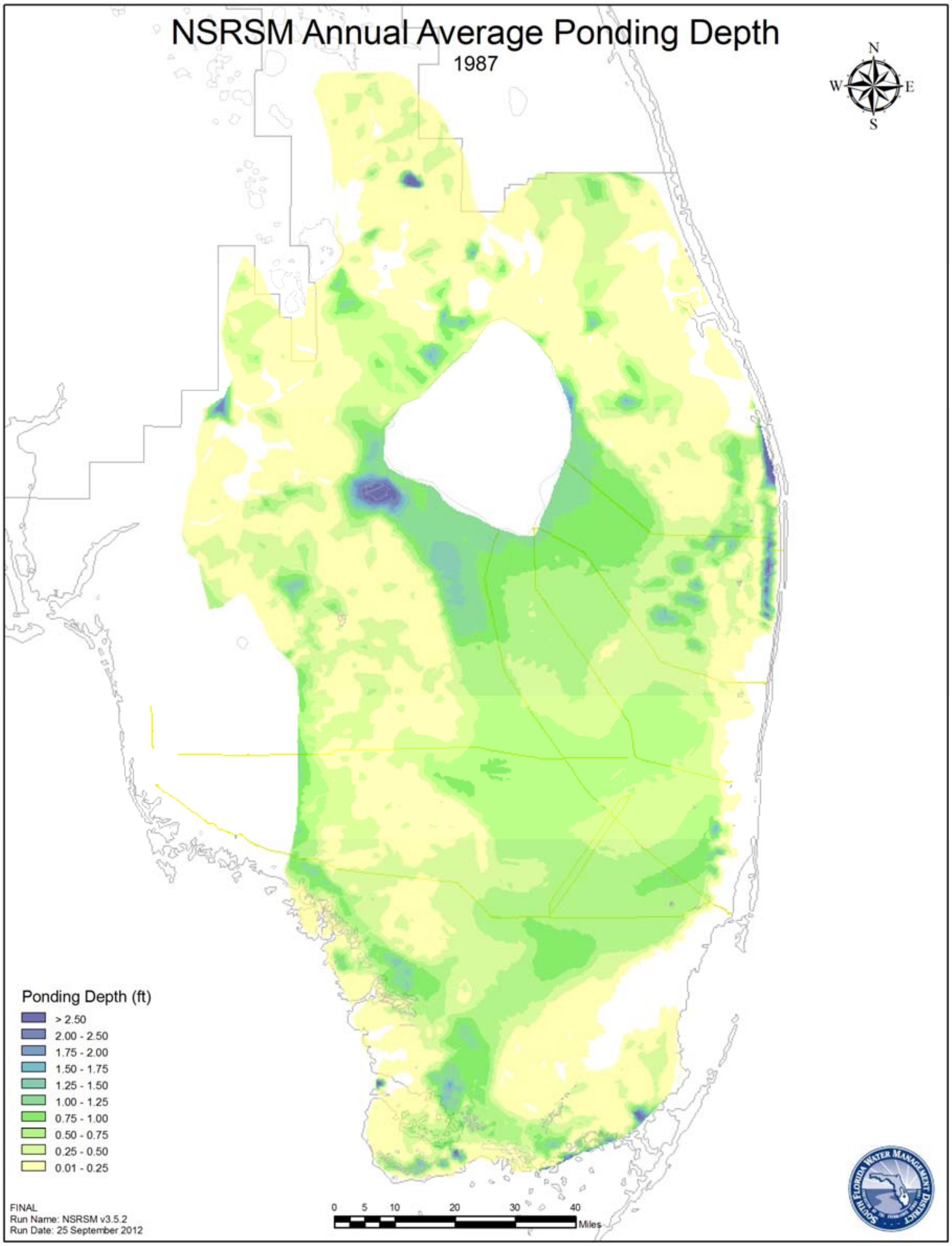

Figure K-63. Annual average ponding depth values for the NSRSM model domain for 1987.

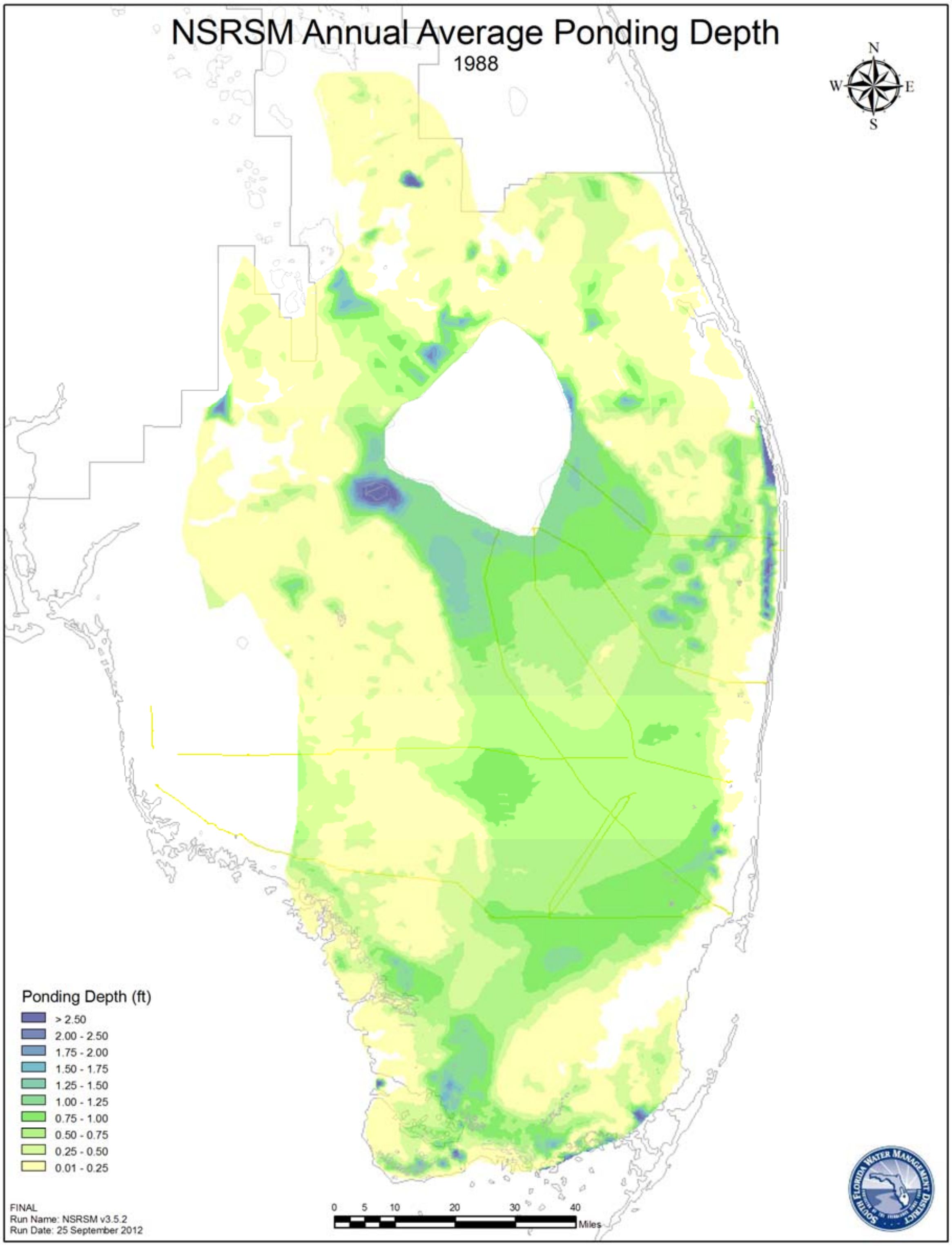

Figure K-64. Annual average ponding depth values for the NSRSM model domain for 1988.

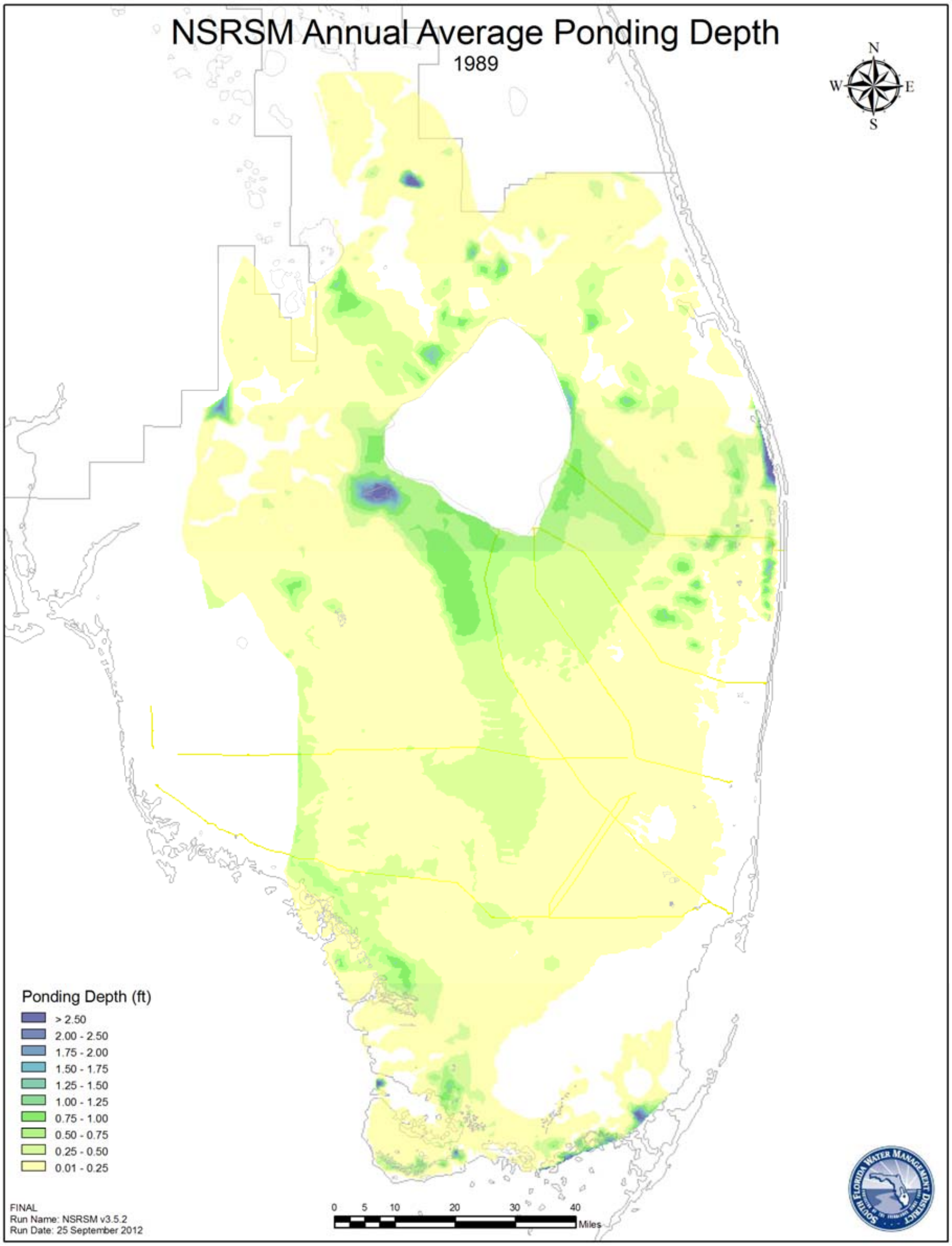

Figure K-65. Annual average ponding depth values for the NSRSM model domain for 1989.

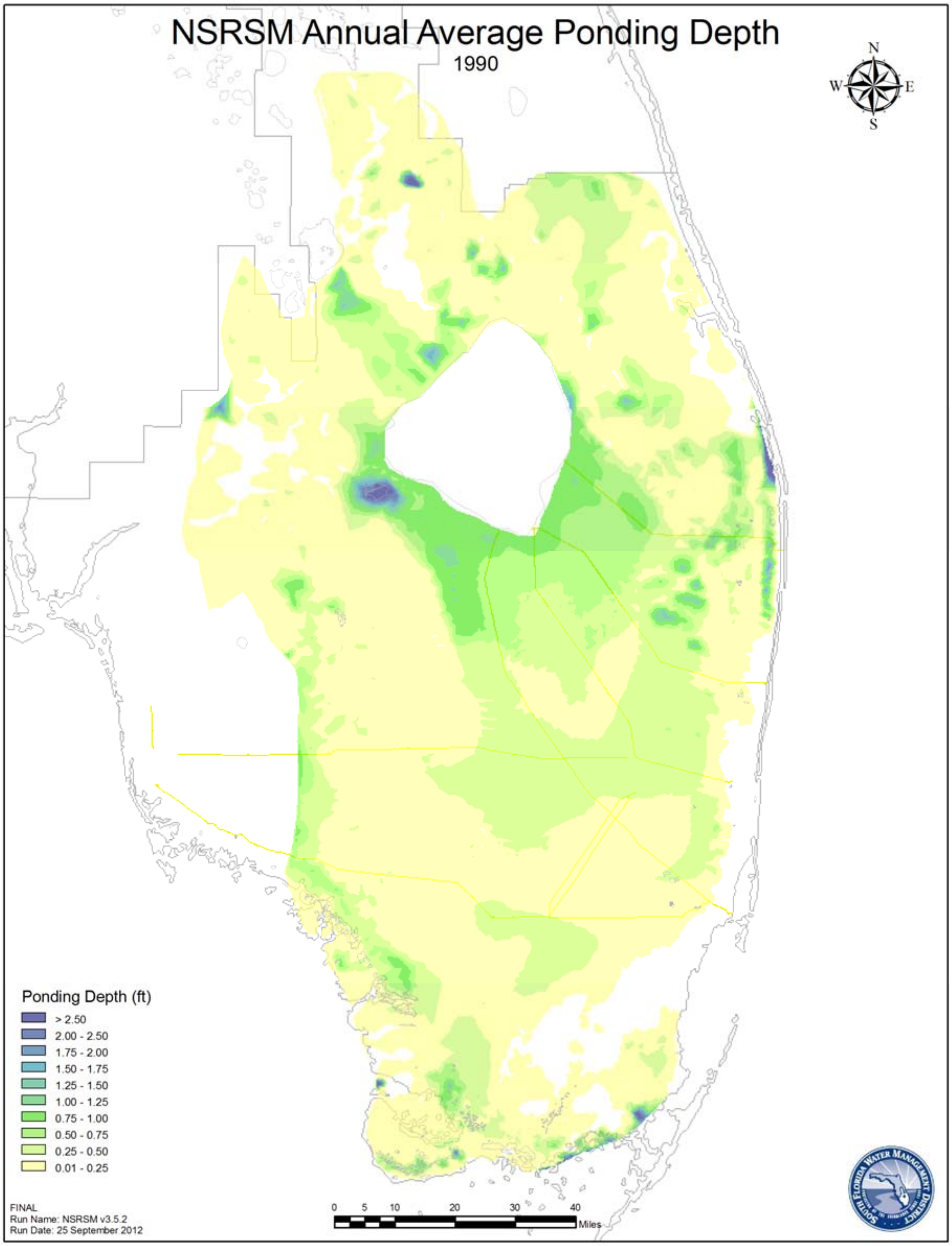

Figure K-66. Annual average ponding depth values for the NSRSM model domain for 1990.

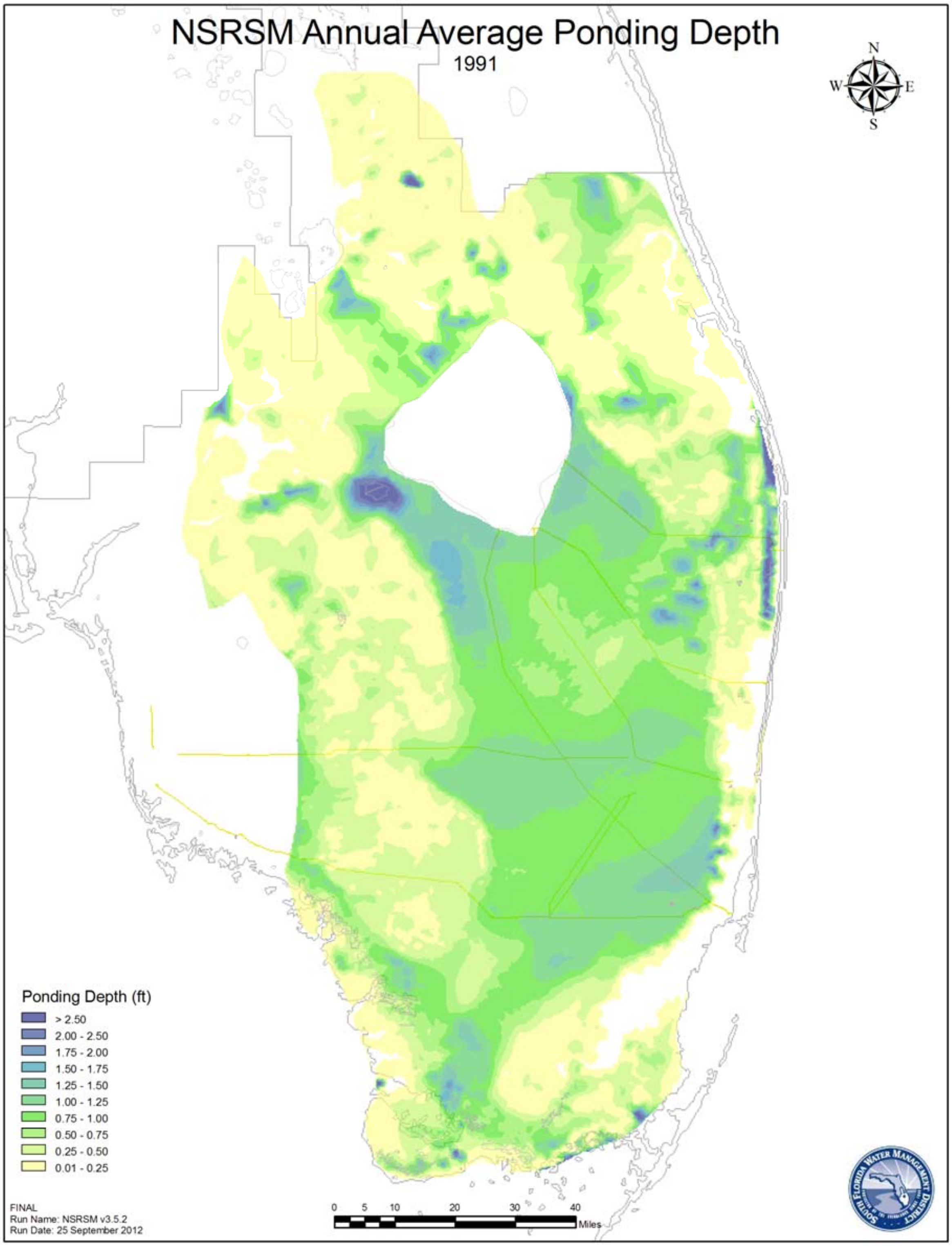

Figure K-67. Annual average ponding depth values for the NSRSM model domain for 1991.

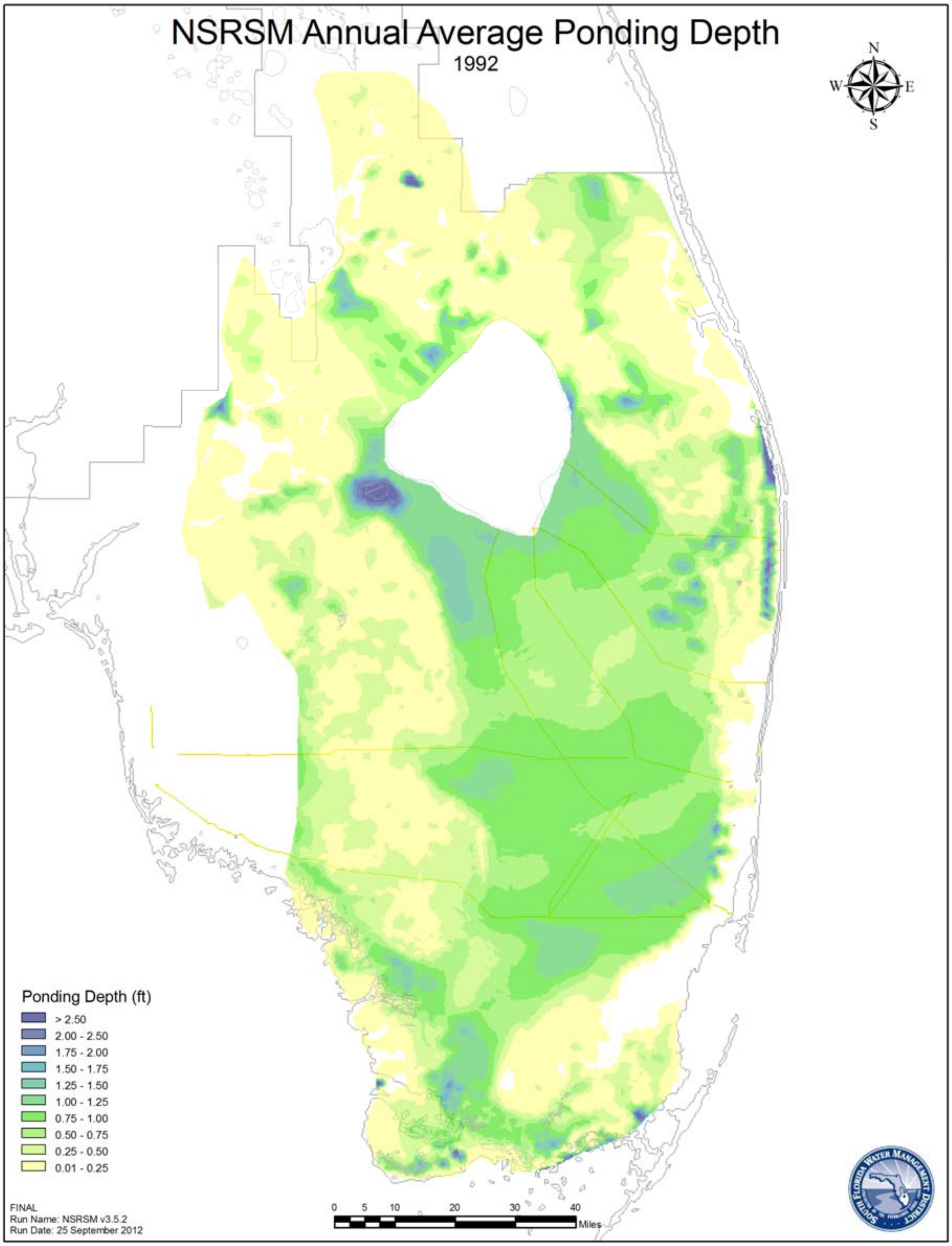

Figure K-68. Annual average ponding depth values for the NSRSM model domain for 1992.

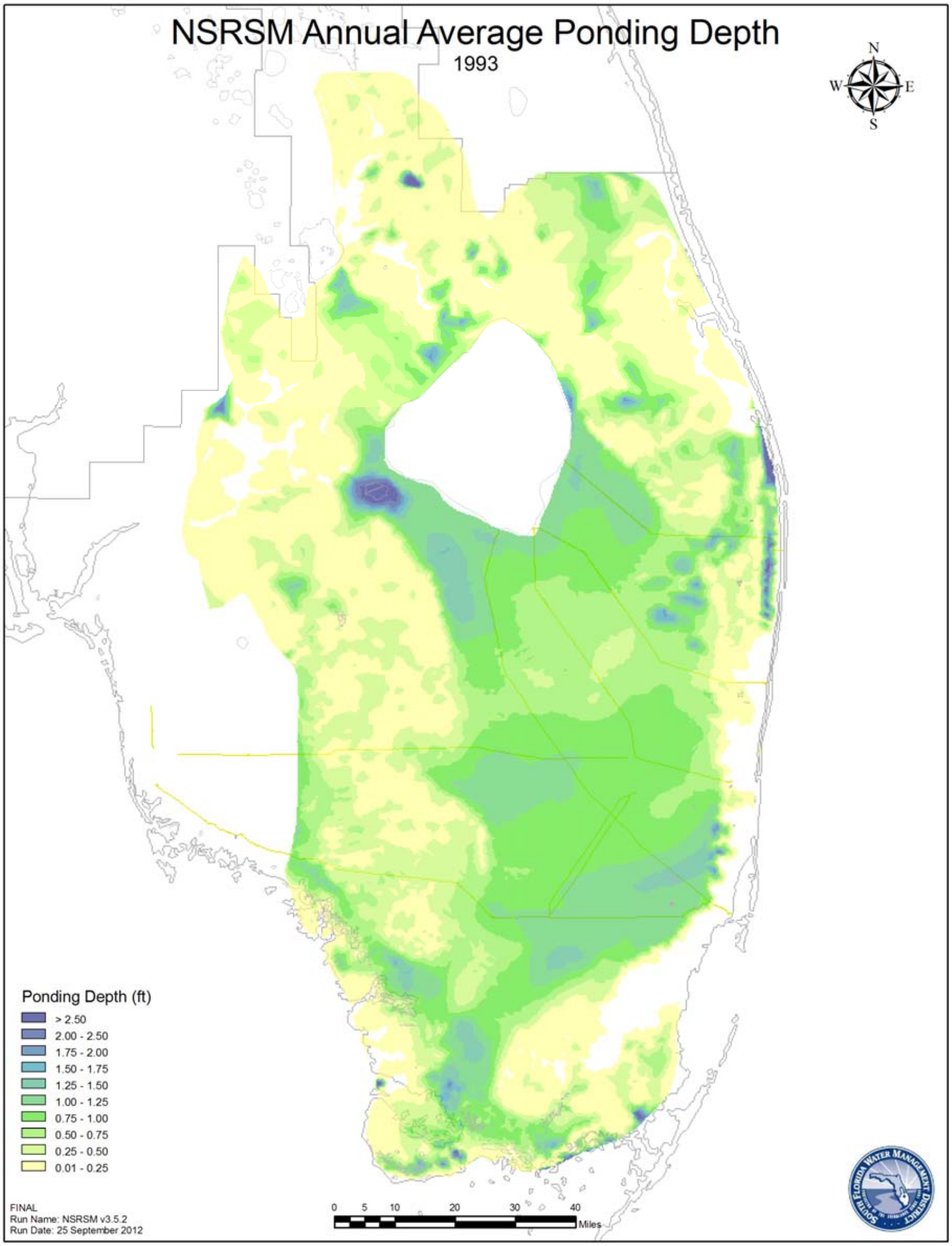

Figure K-69. Annual average ponding depth values for the NSRSM model domain for 1993.

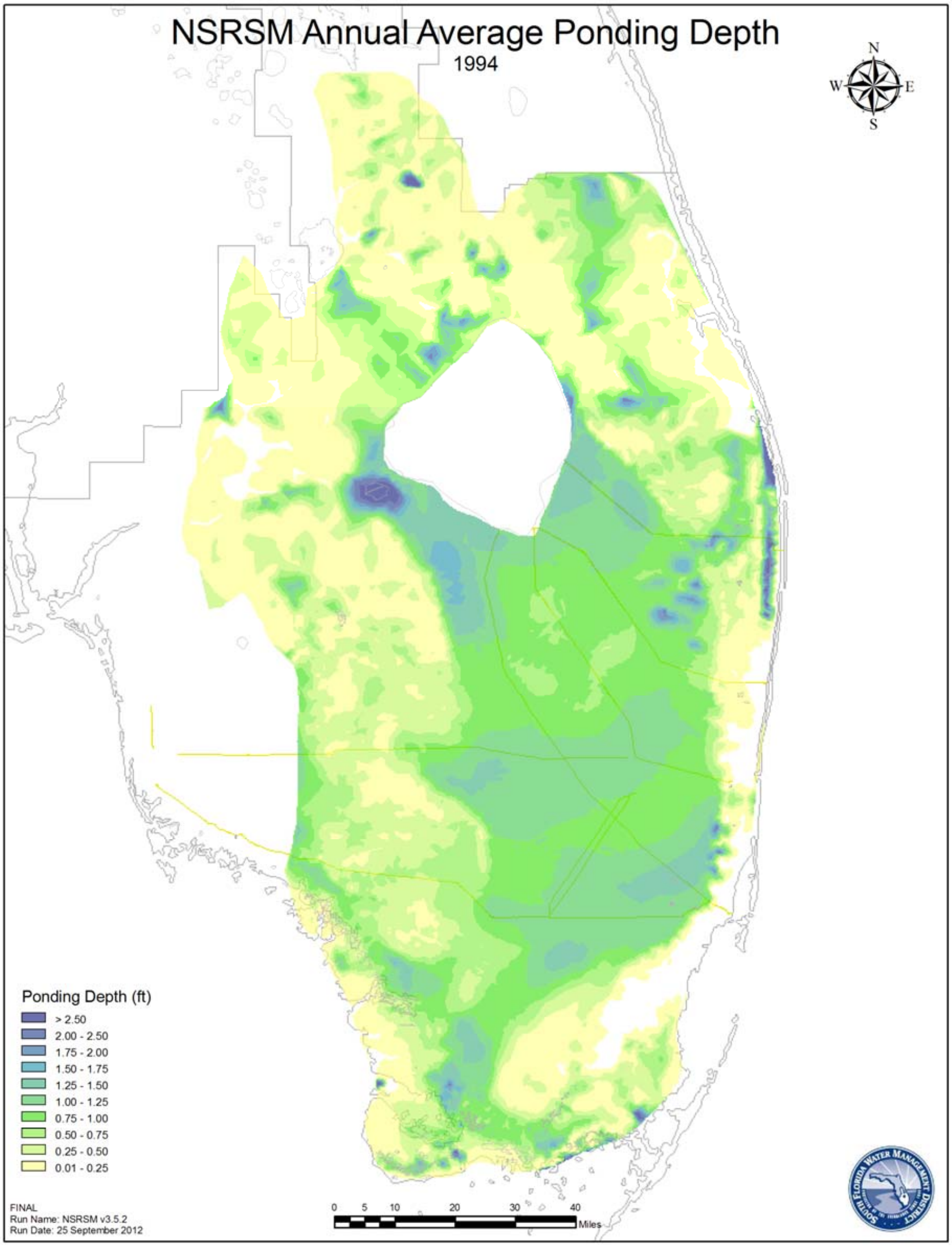

Figure K-70. Annual average ponding depth values for the NSRSM model domain for 1994.

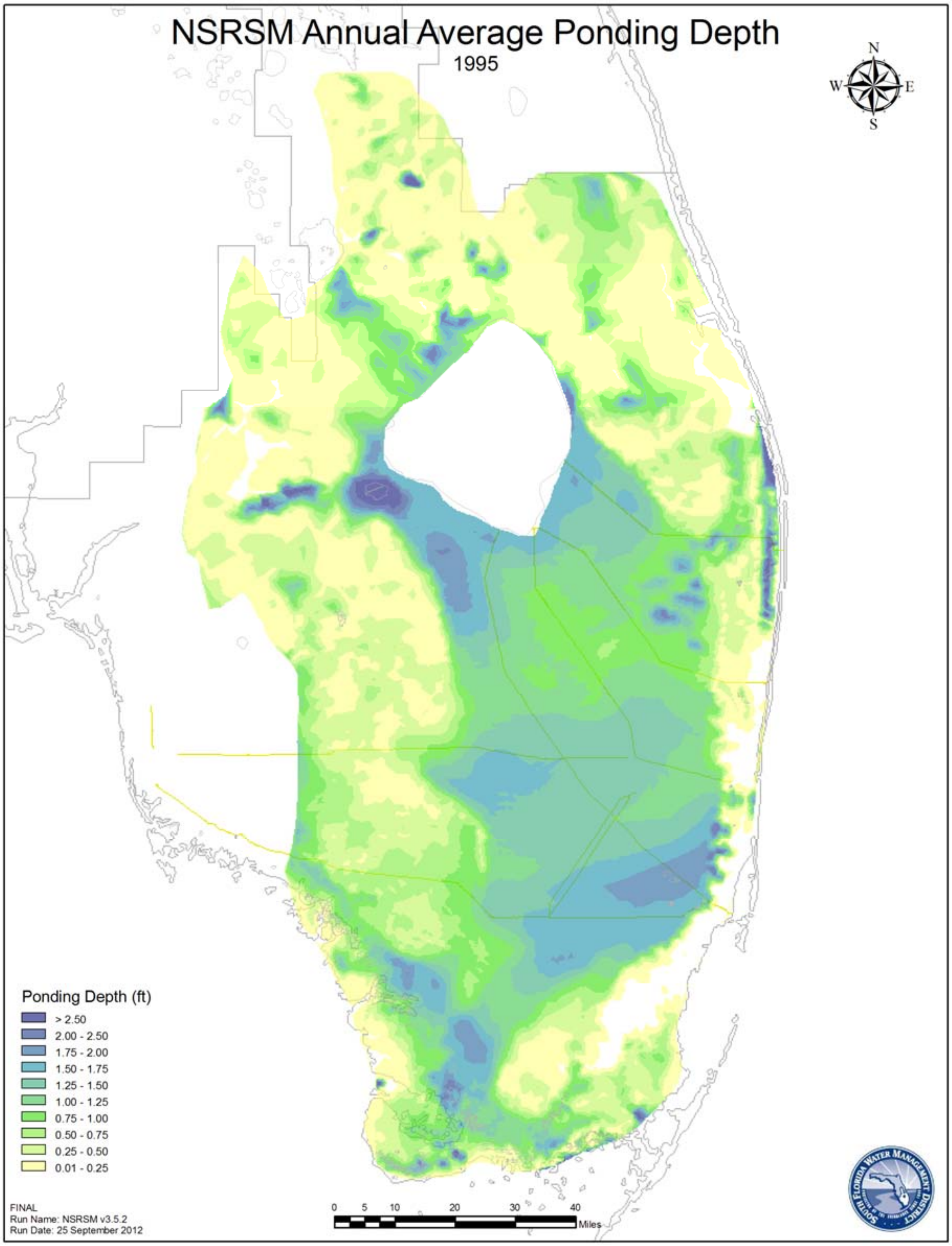

Figure K-71. Annual average ponding depth values for the NSRSM model domain for 1995.

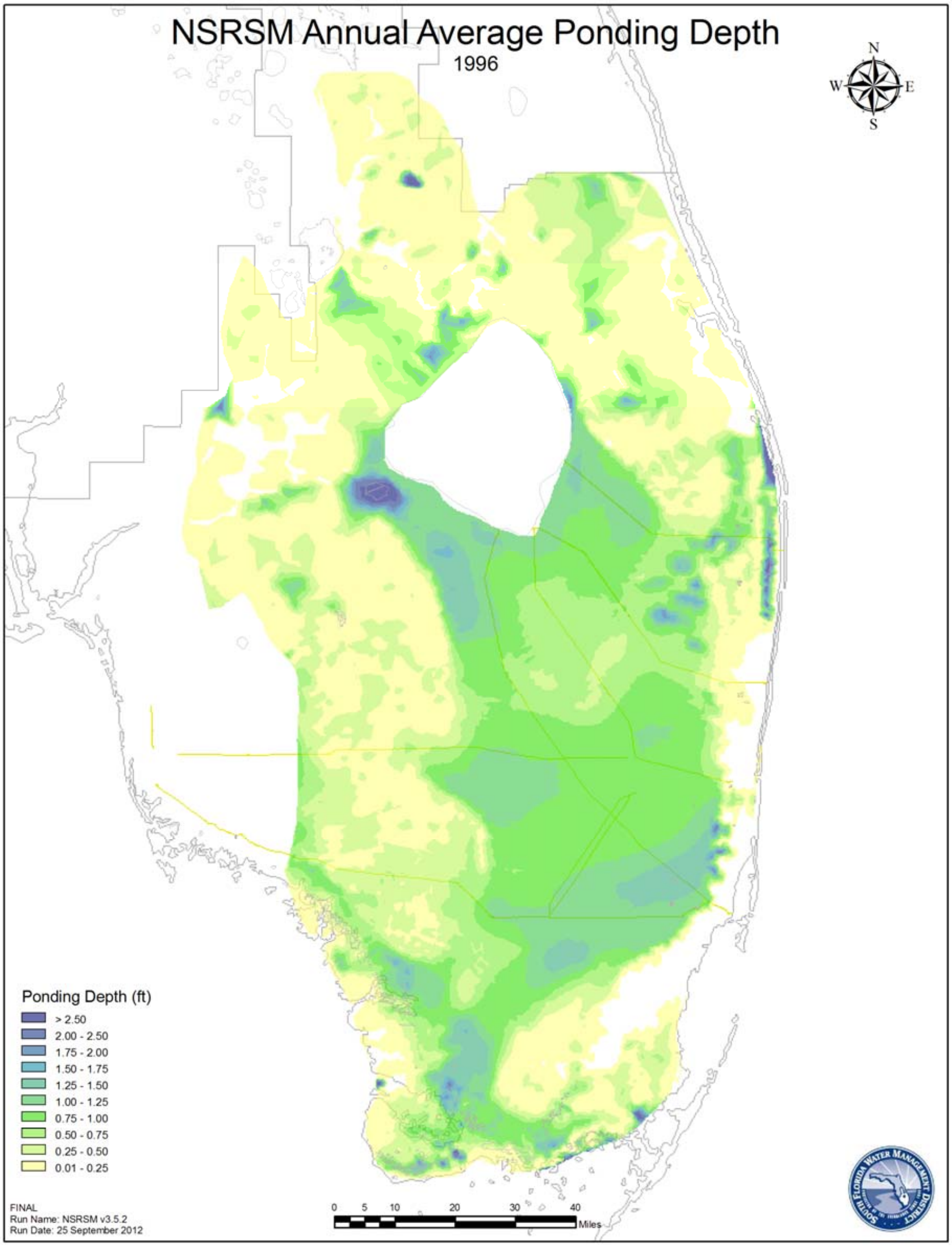

Figure K-72. Annual average ponding depth values for the NSRSM model domain for 1996.

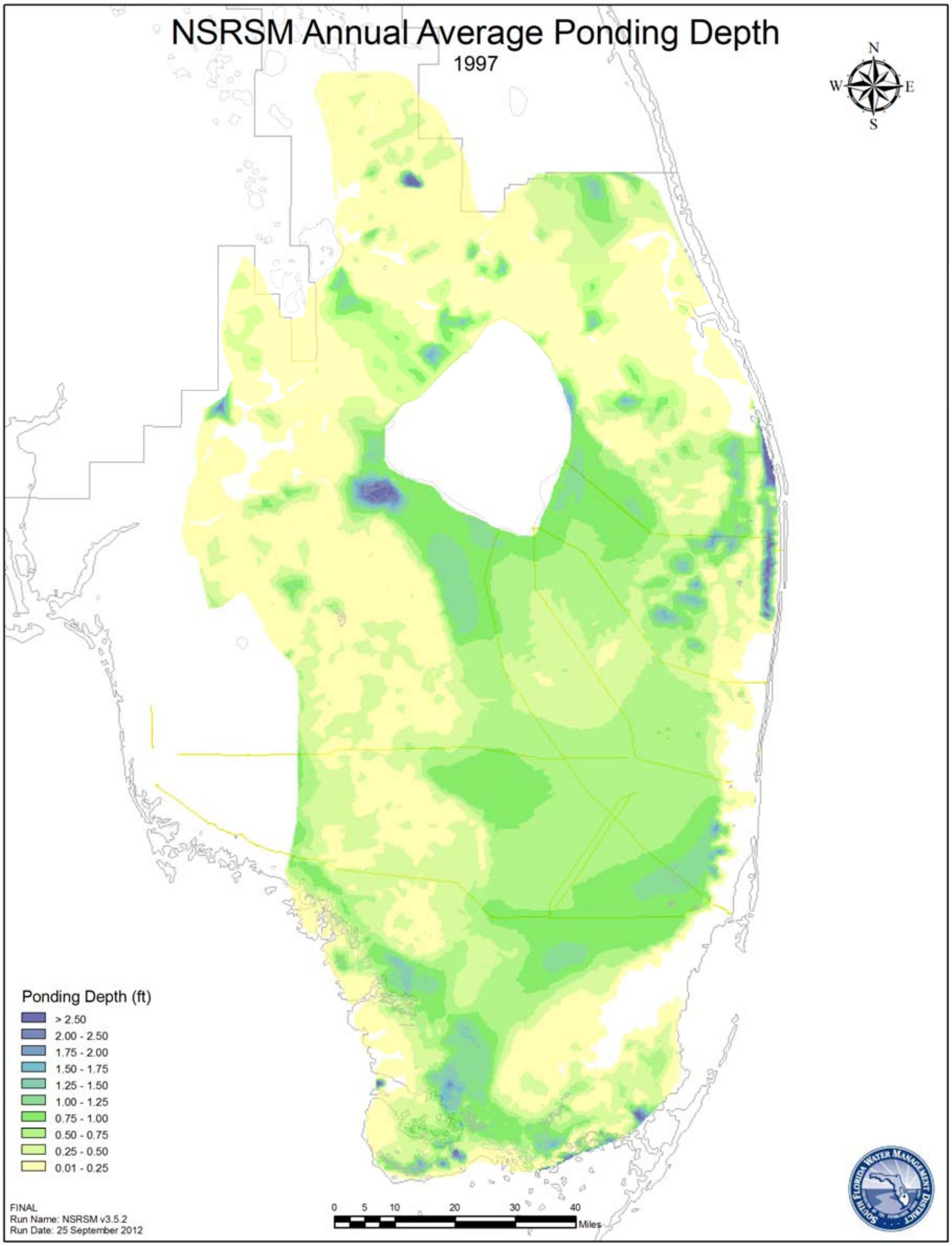

Figure K-73. Annual average ponding depth values for the NSRSM model domain for 1997.

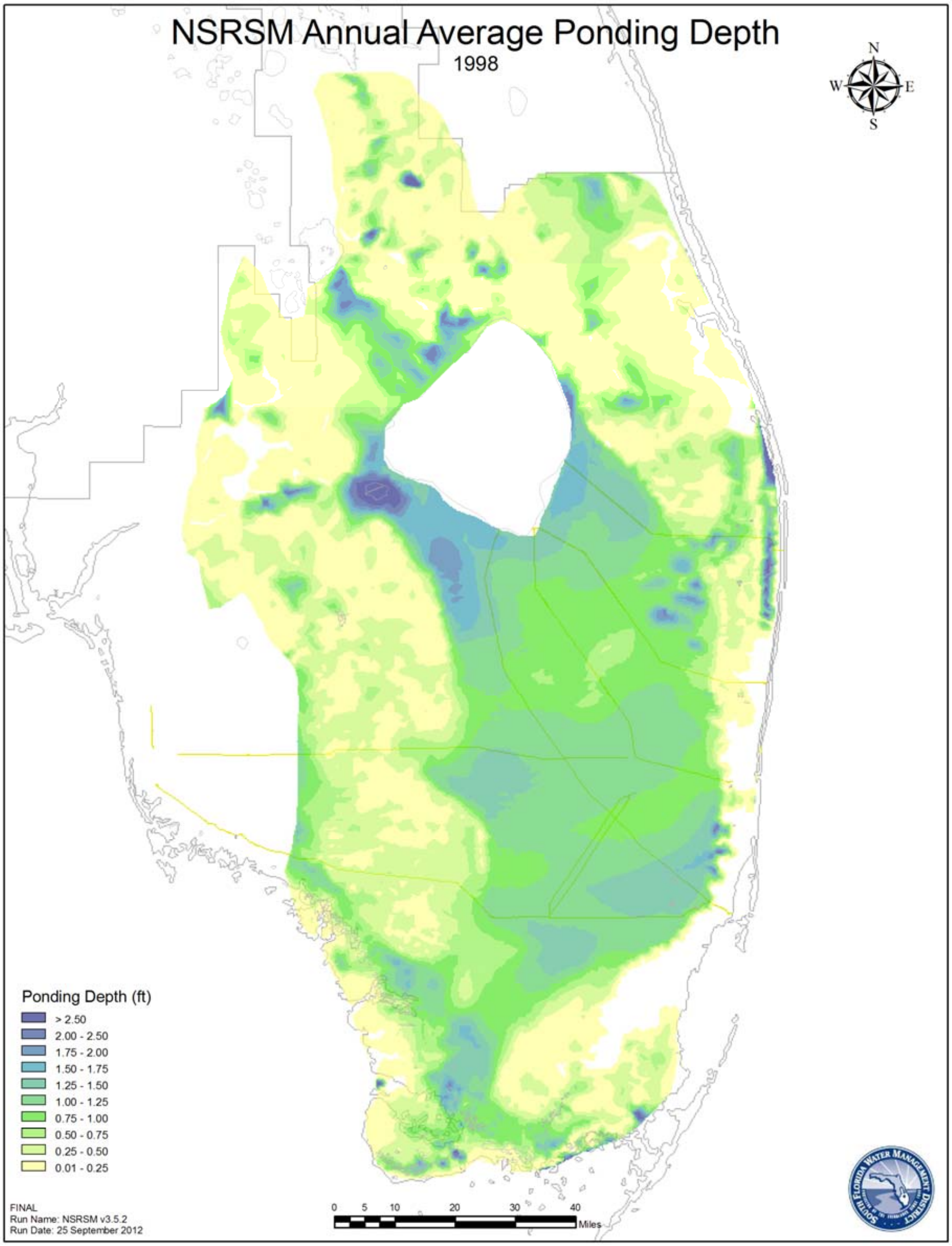

Figure K-74. Annual average ponding depth values for the NSRSM model domain for 1998.

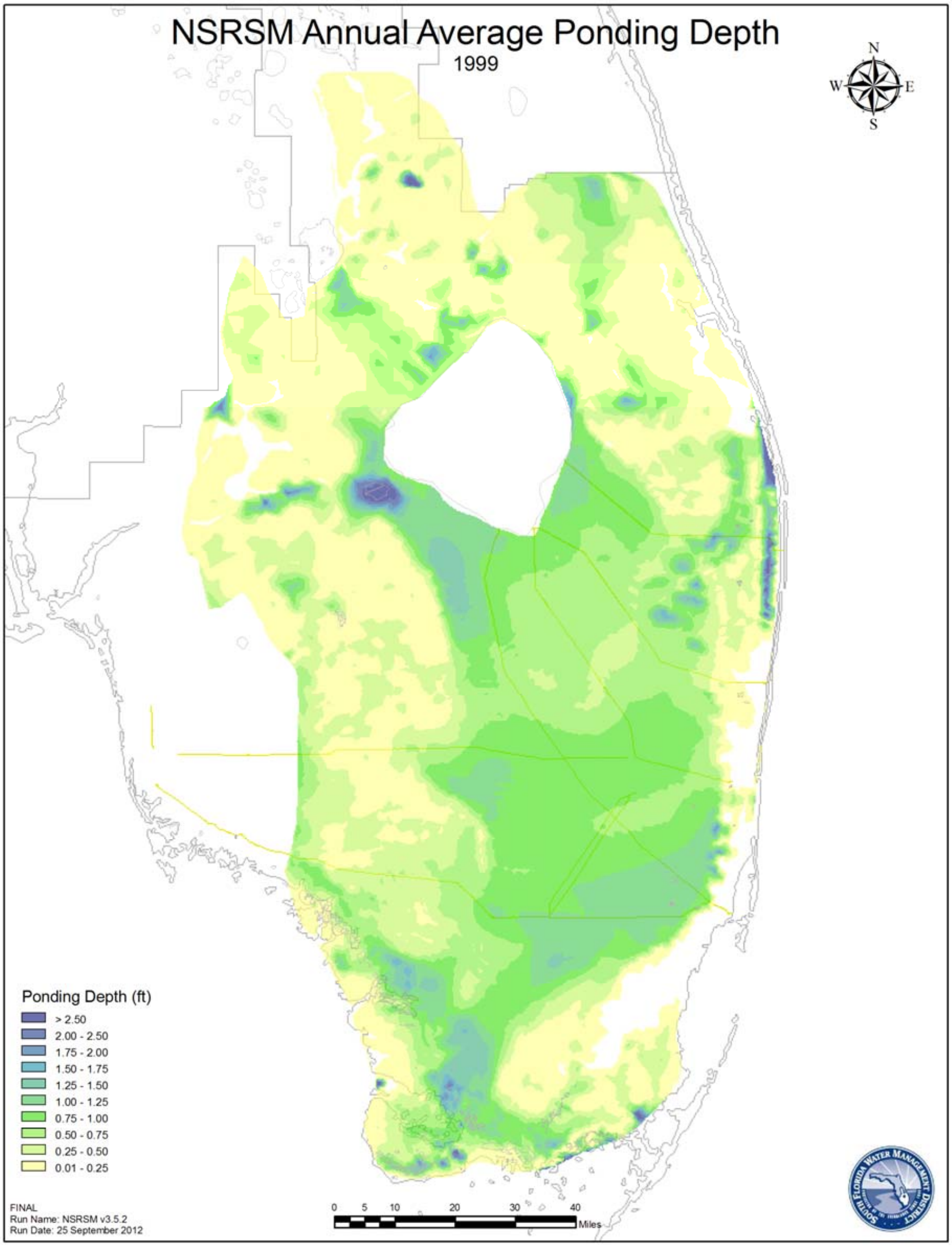

Figure K-75. Annual average ponding depth values for the NSRSM model domain for 1999.

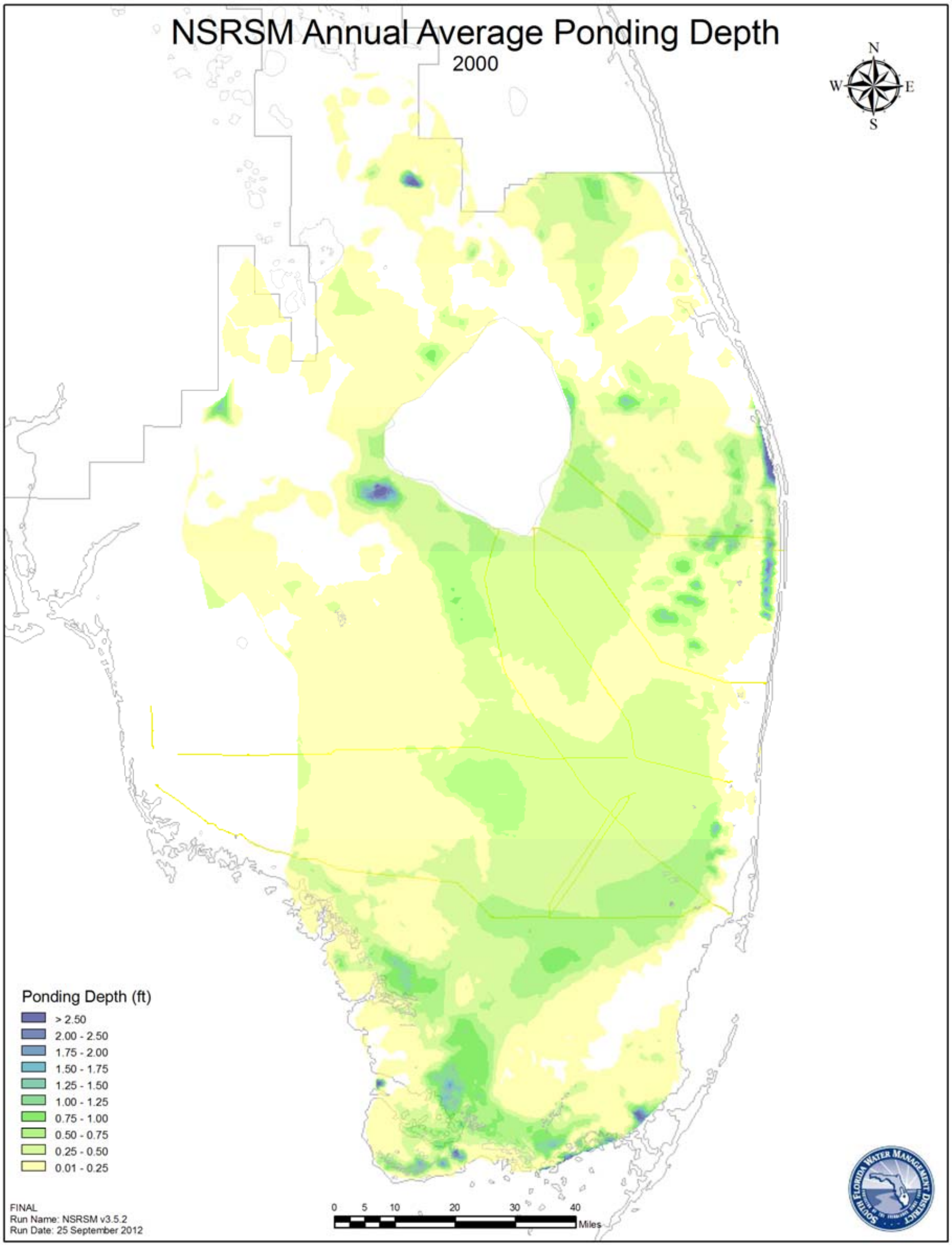

Figure K-76. Annual average ponding depth values for the NSRSM model domain for 2000.

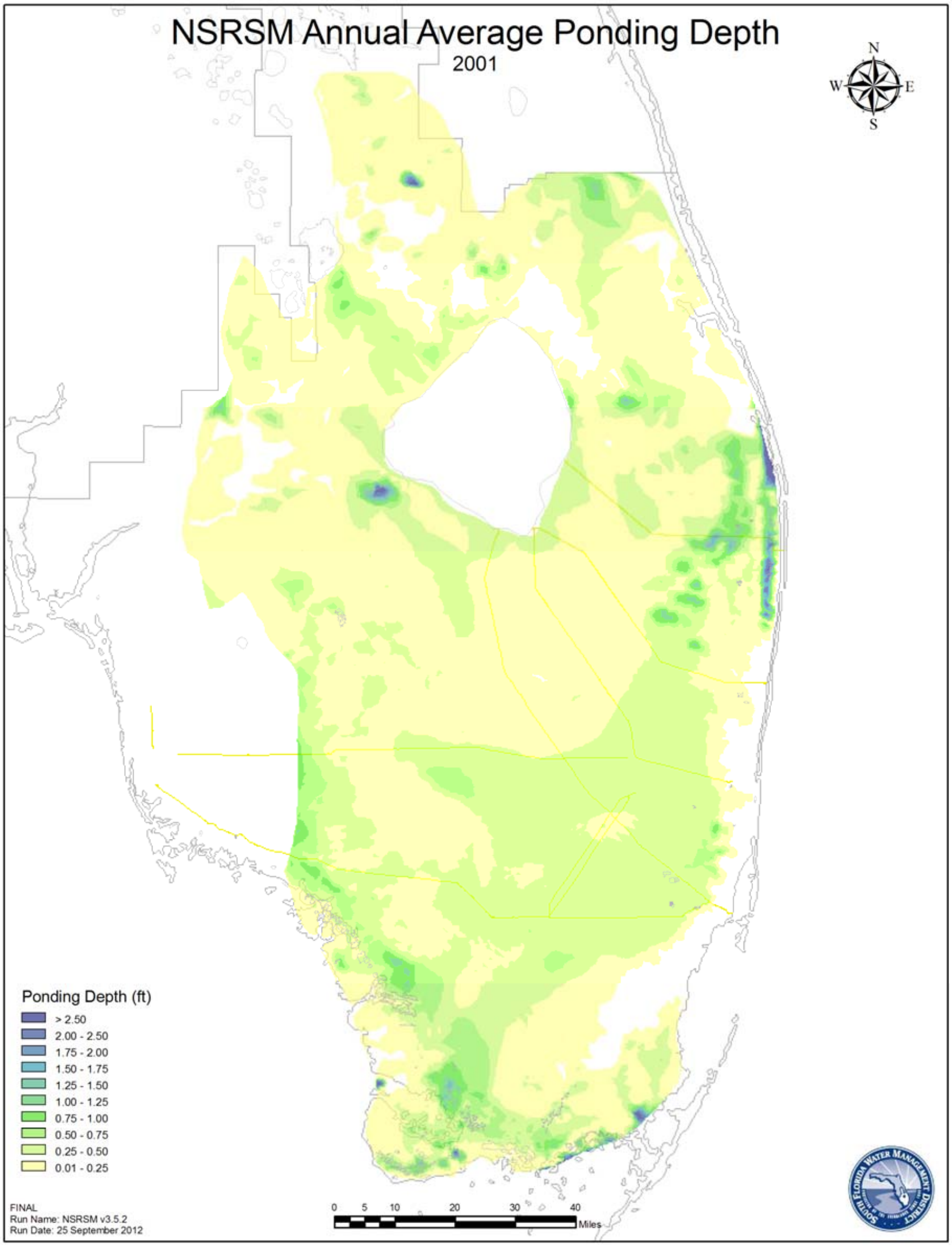

Figure K-77. Annual average ponding depth values for the NSRSM model domain for 2001.

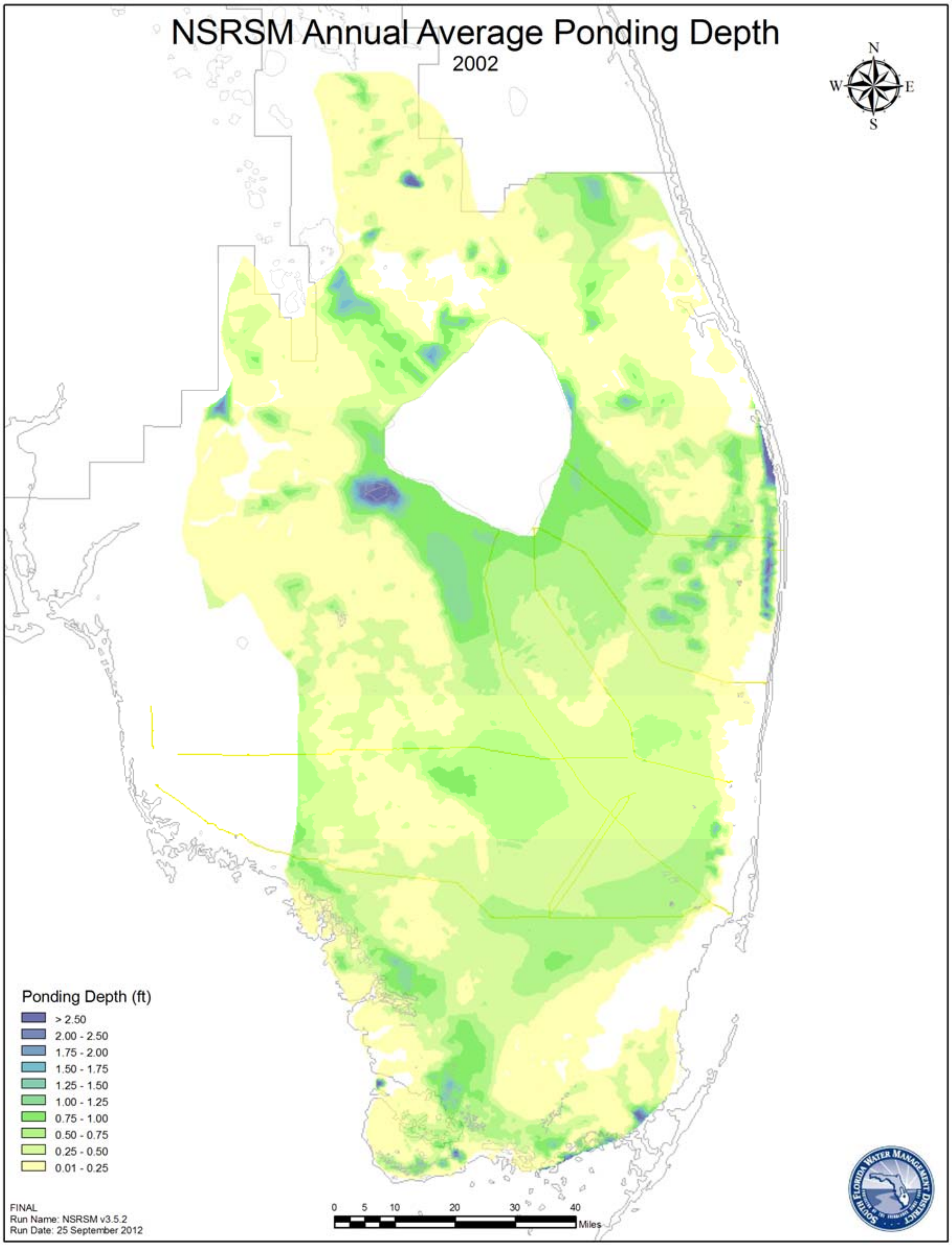

Figure K-78. Annual average ponding depth values for the NSRSM model domain for 2002.

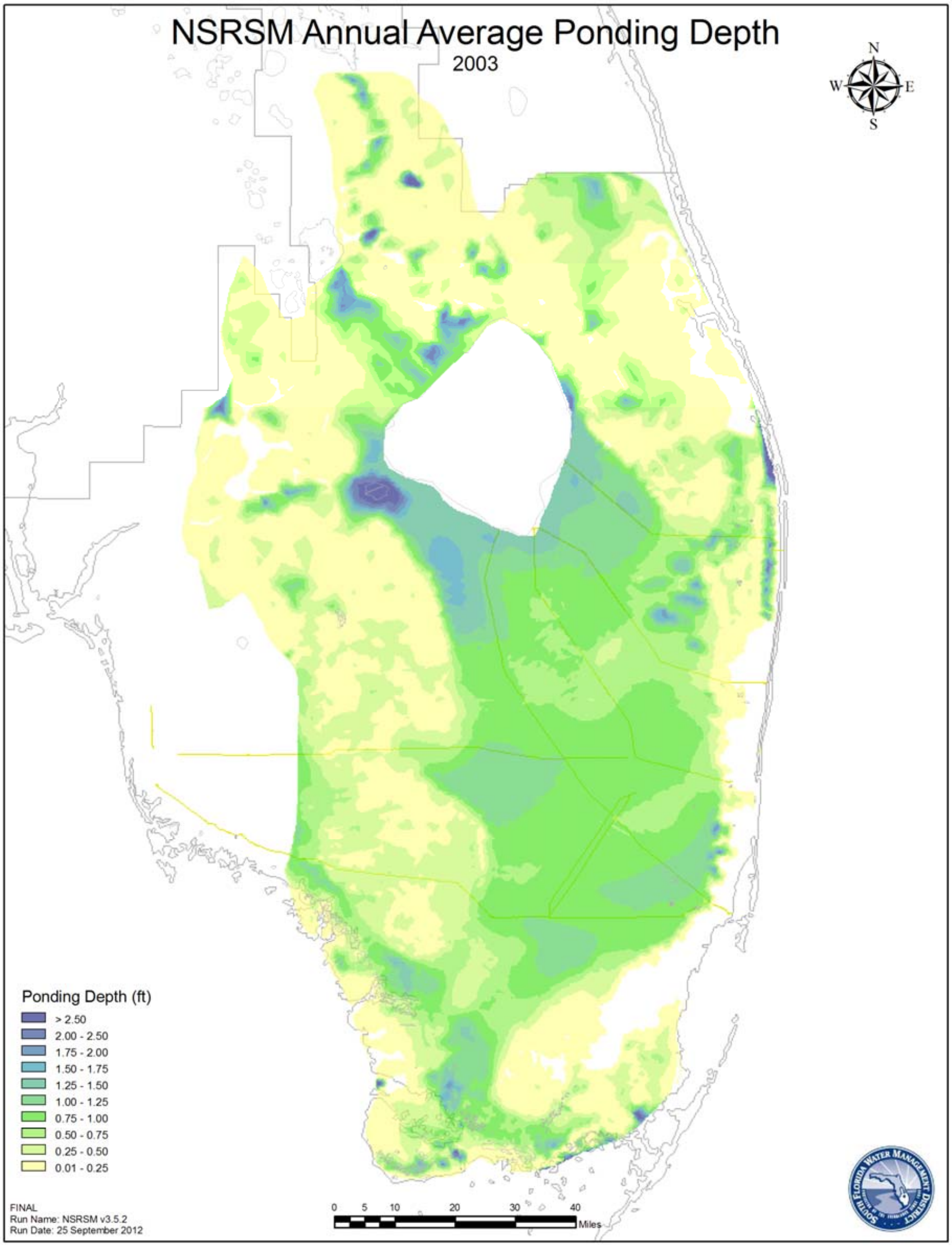

Figure K-79. Annual average ponding depth values for the NSRSM model domain for 2003.

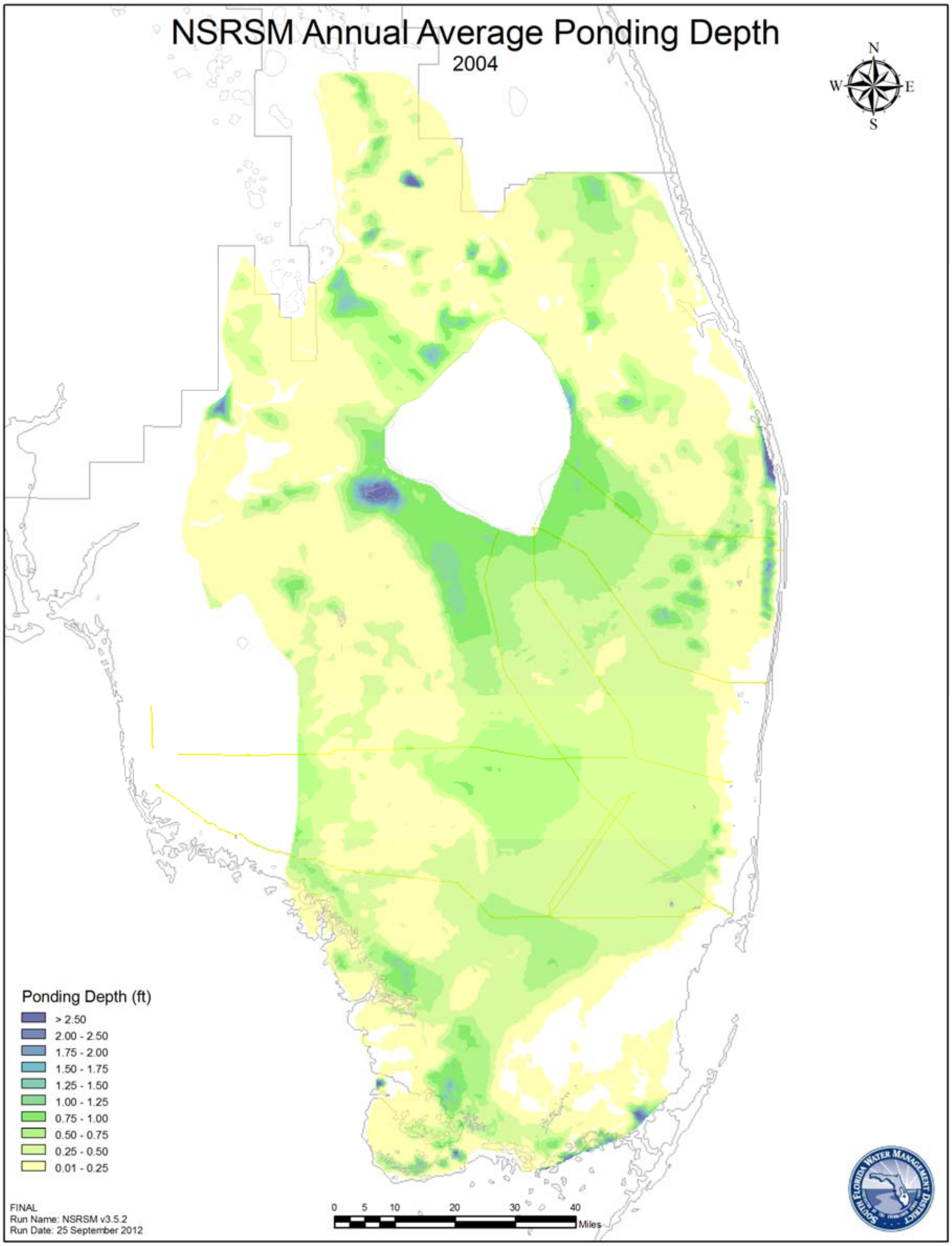

Figure K-80. Annual average ponding depth values for the NSRSM model domain for 2004.

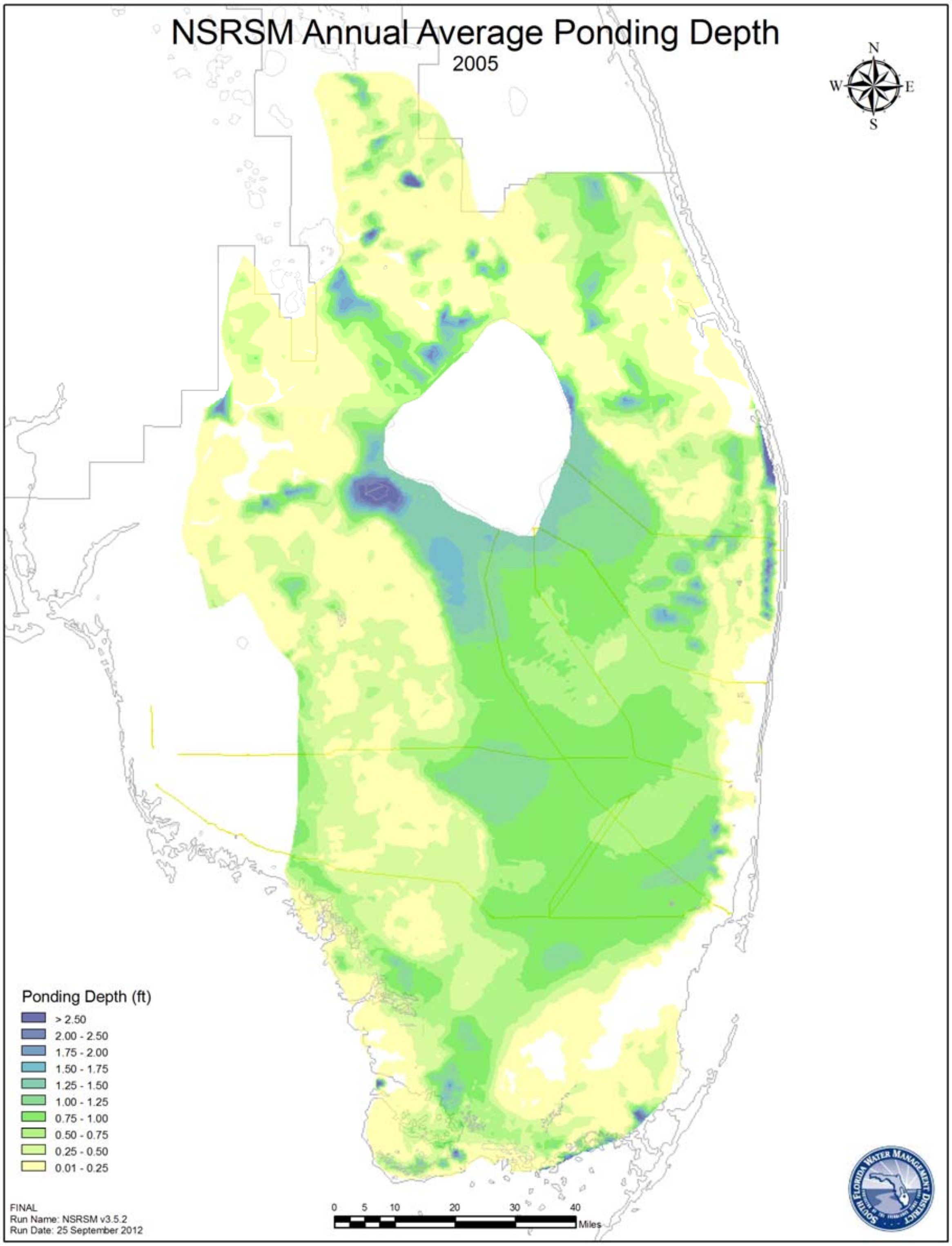

Figure K-81. Annual average ponding depth values for the NSRSM model domain for 2005.

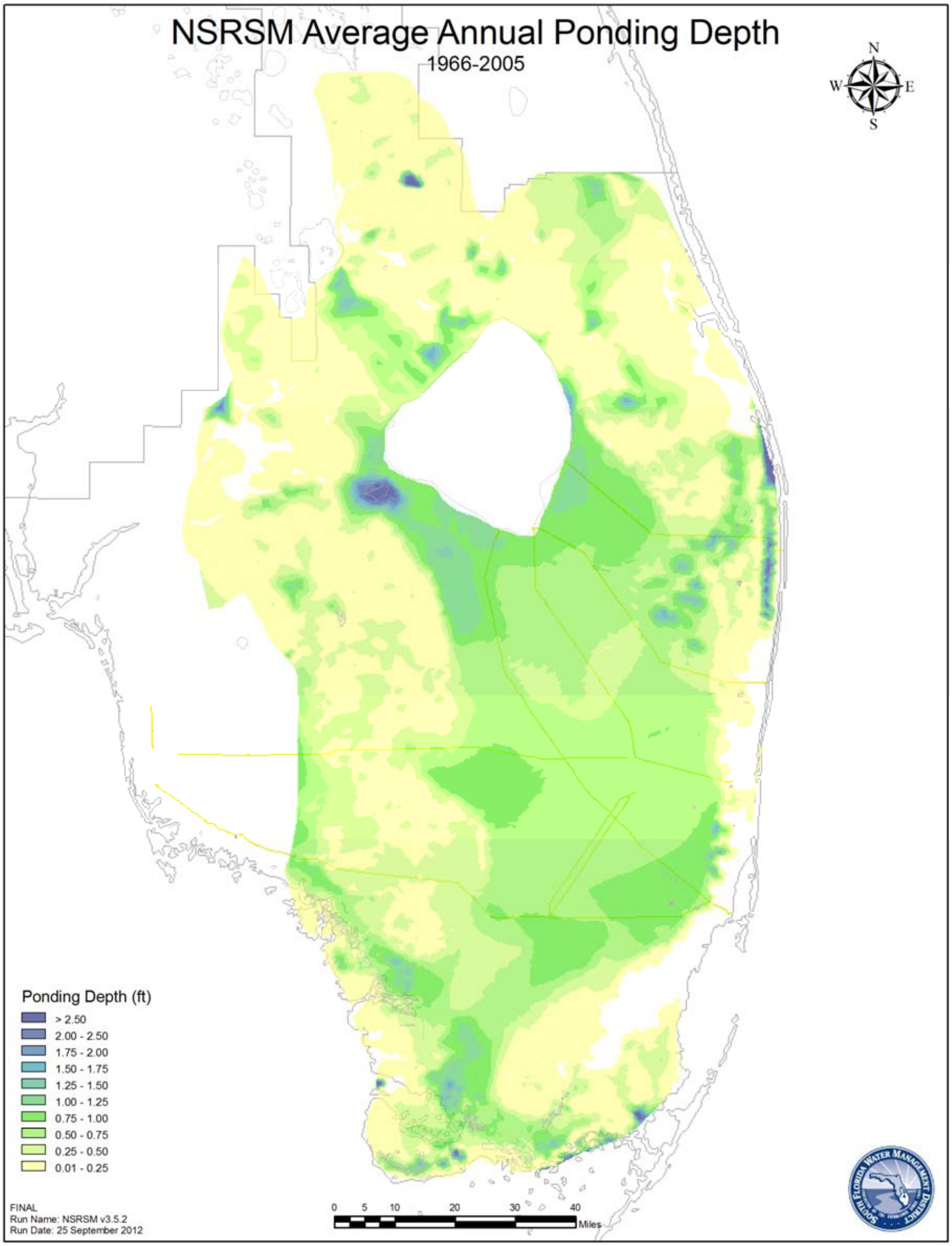

Figure K-82. Average annual ponding depth values for the NSRSM model domain for the period 1966-2005.

K.3 FLOW DIRECTION

Figures K-83 through **K-122** display annual average overland flow vector values for the NSRSM model domain for 1966 through 2005, respectively. **Figure K-123** displays the average annual overland flow vector values for the entire period of record, 1966-2005.

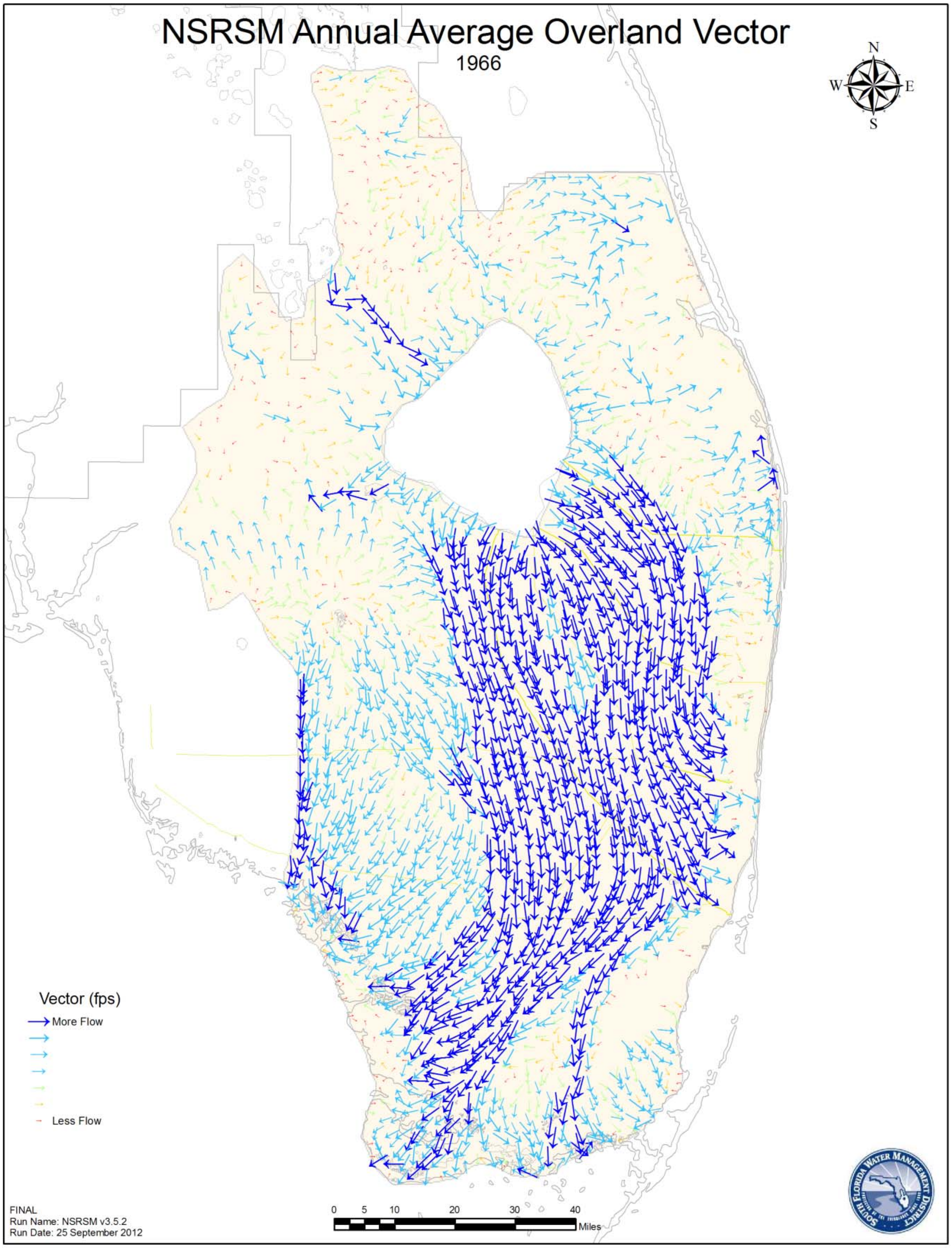

Figure K-83. Annual average overland flow values for the NSRSM model domain for 1966.

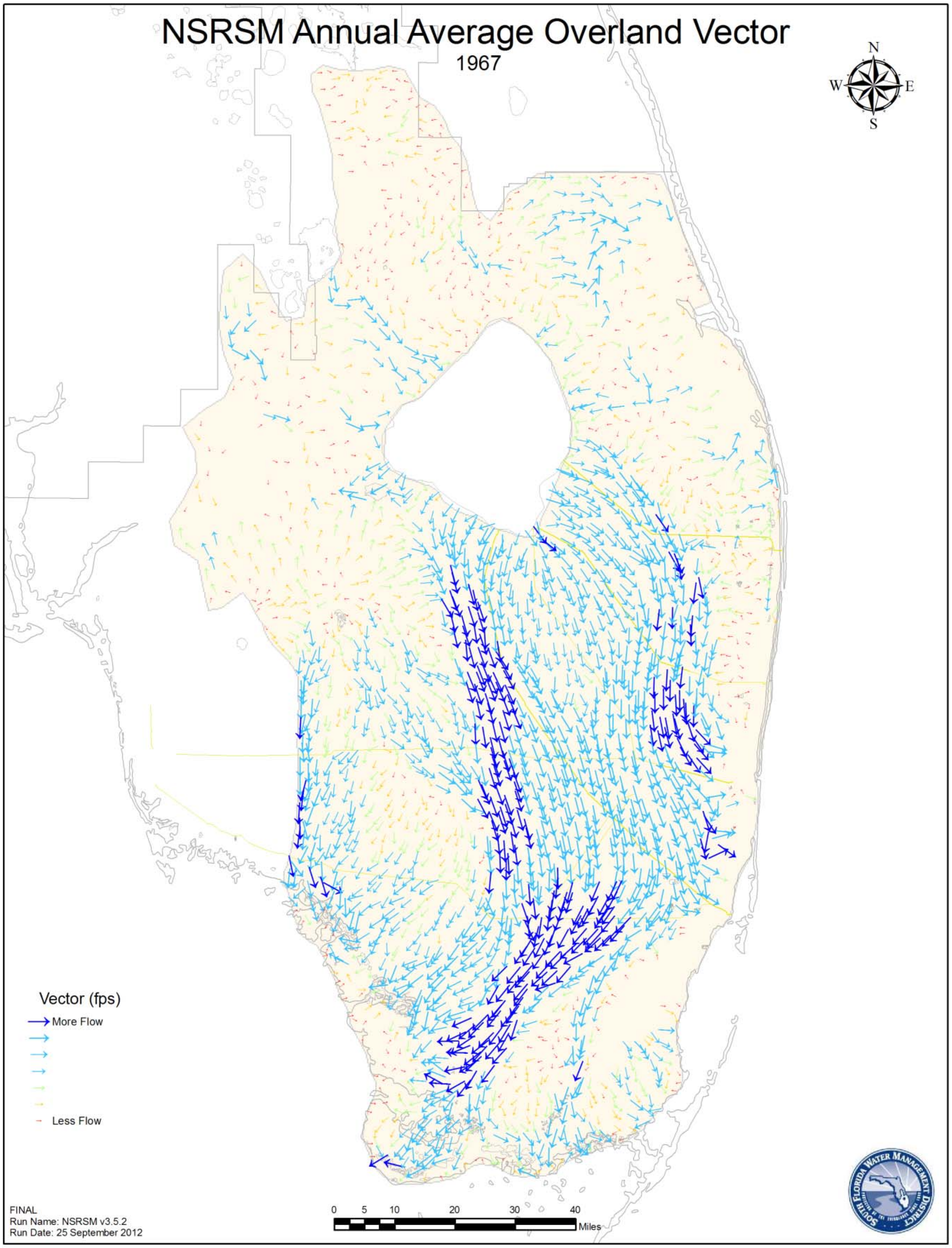

Figure K-84. Annual average overland flow values for the NSRSM model domain for 1967.

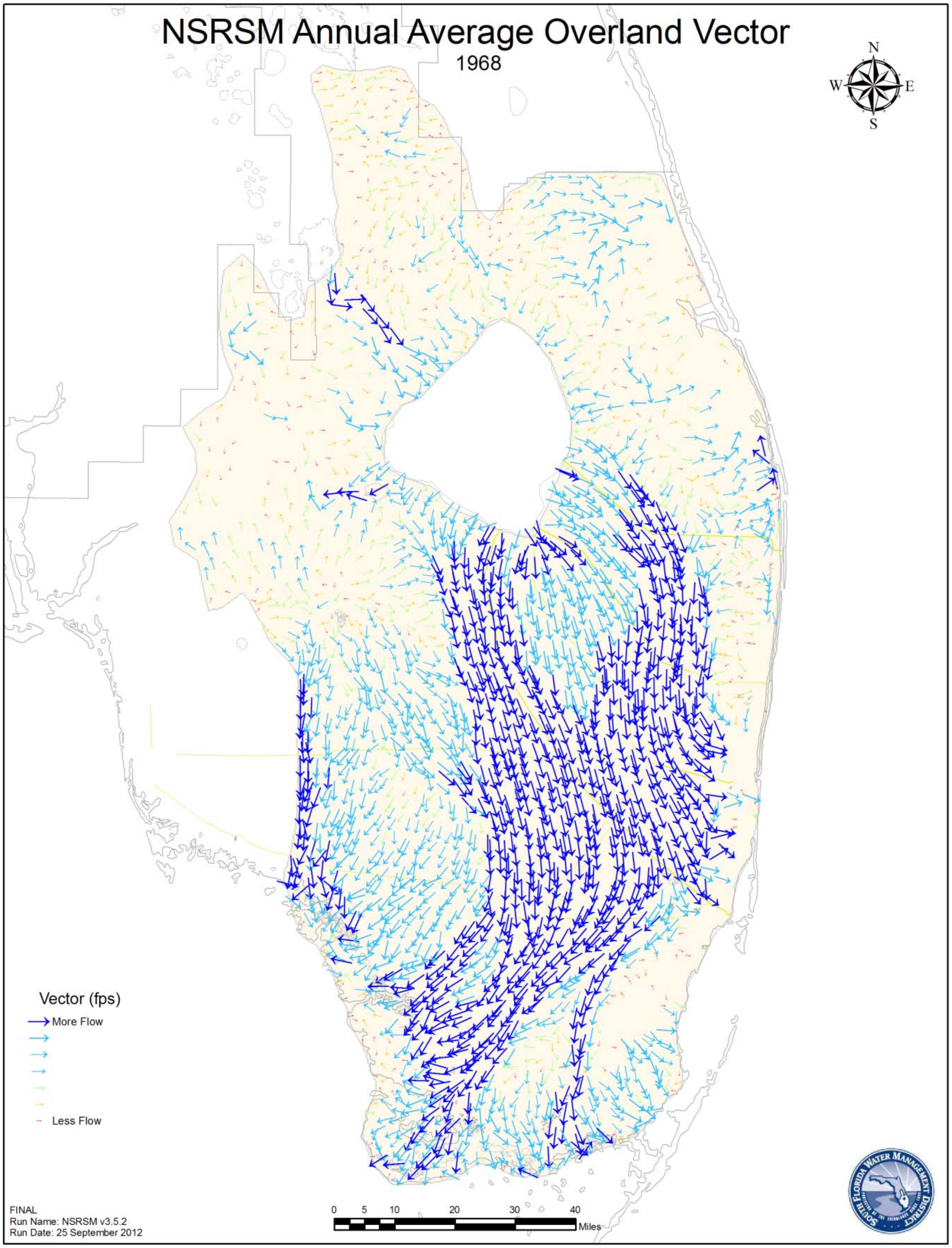

Figure K-85. Annual average overland flow values for the NSRSM model domain for 1968.

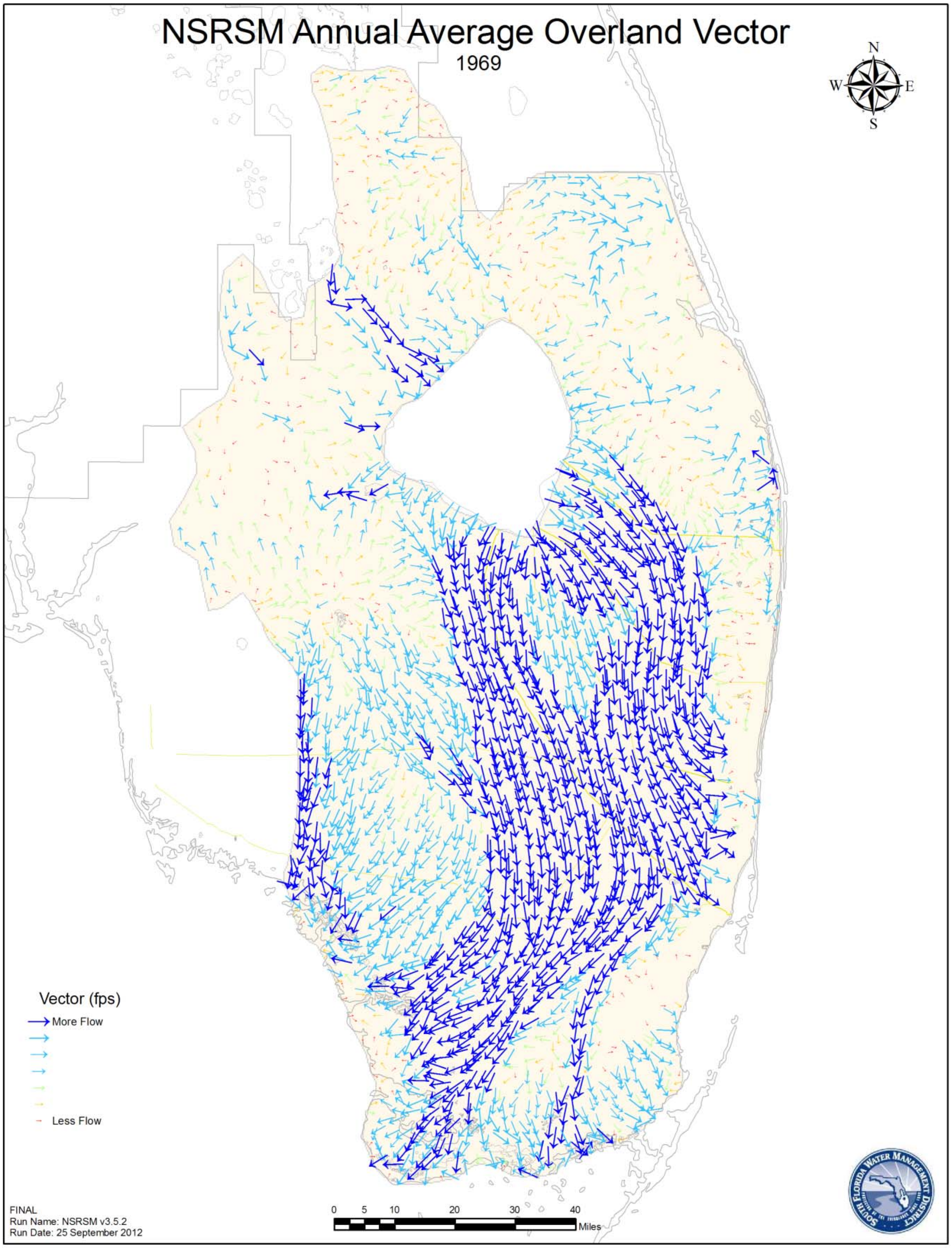

Figure K-86. Annual average overland flow values for the NSRSM model domain for 1969.

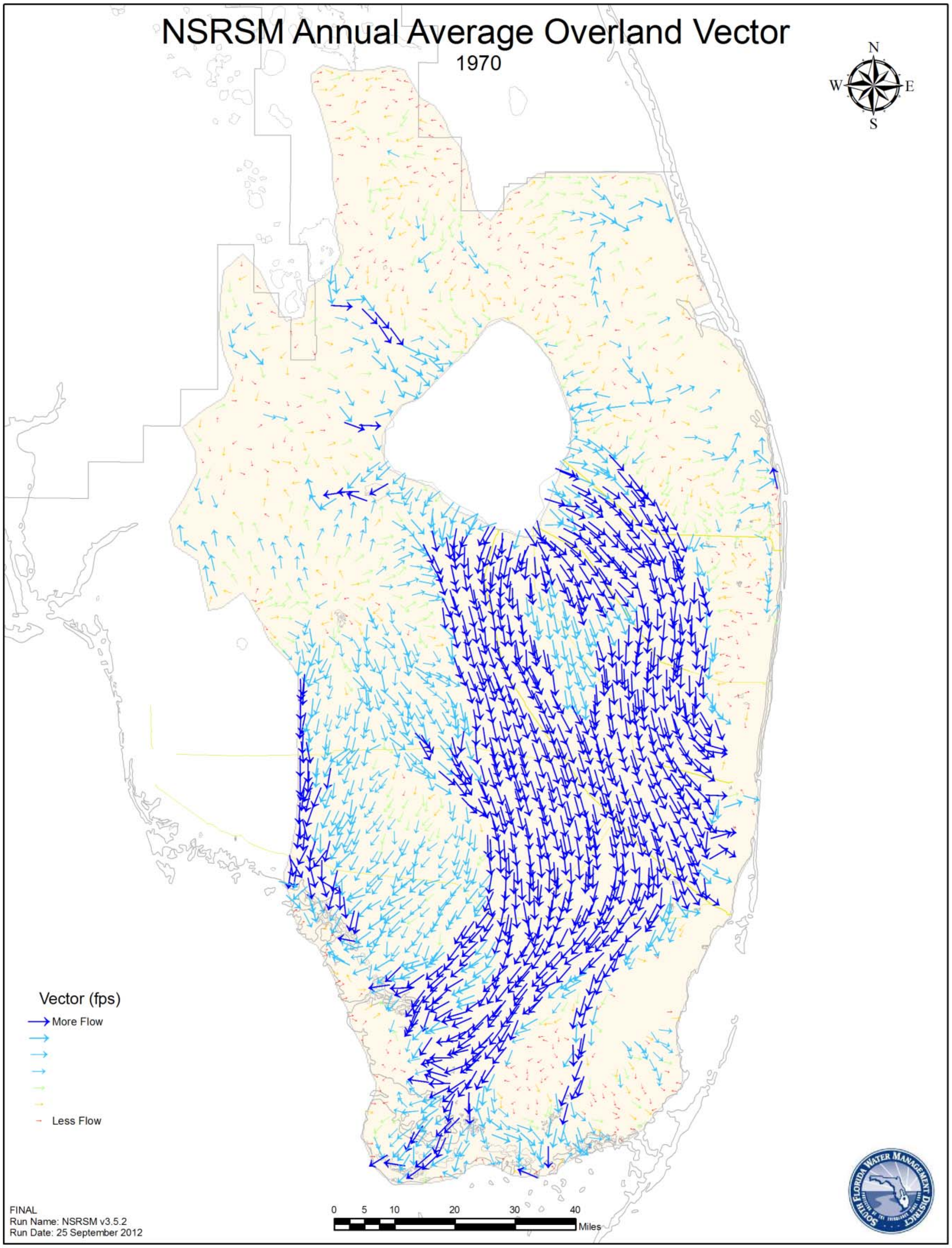

Figure K-87. Annual average overland flow values for the NSRSM model domain for 1970.

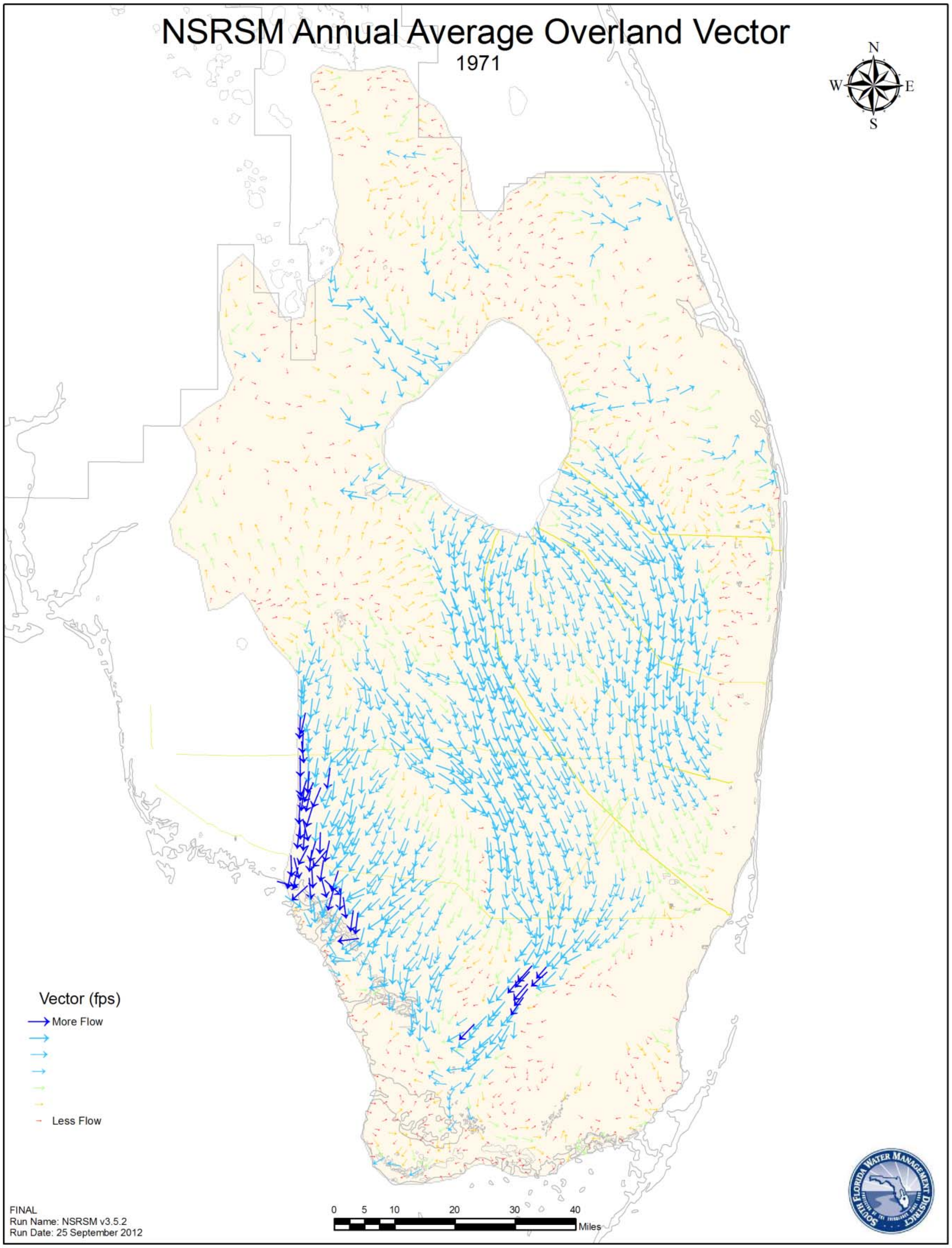

Figure K-88. Annual average overland flow values for the NSRSM model domain for 1971.

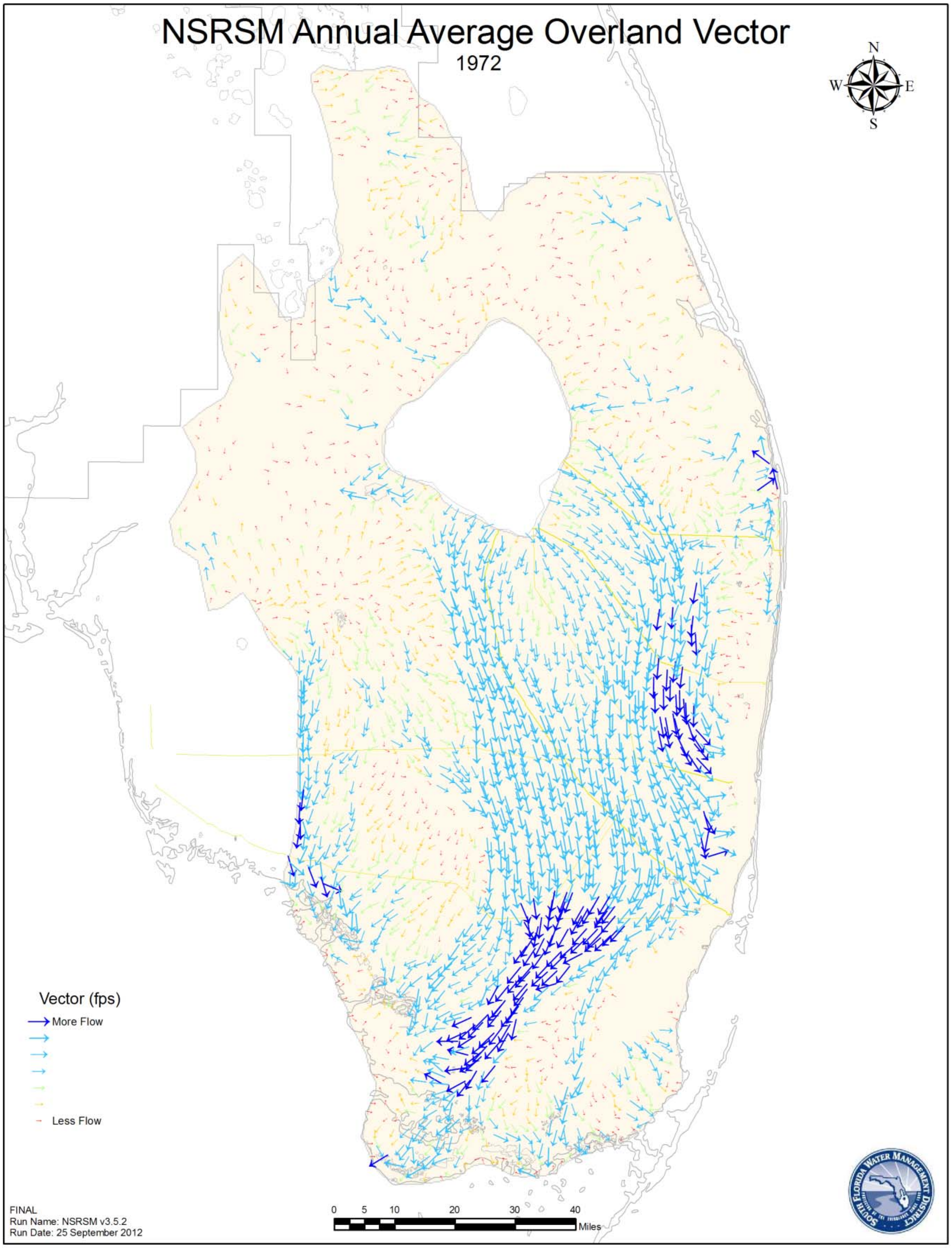

Figure K-89. Annual average overland flow values for the NSRSM model domain for 1972.

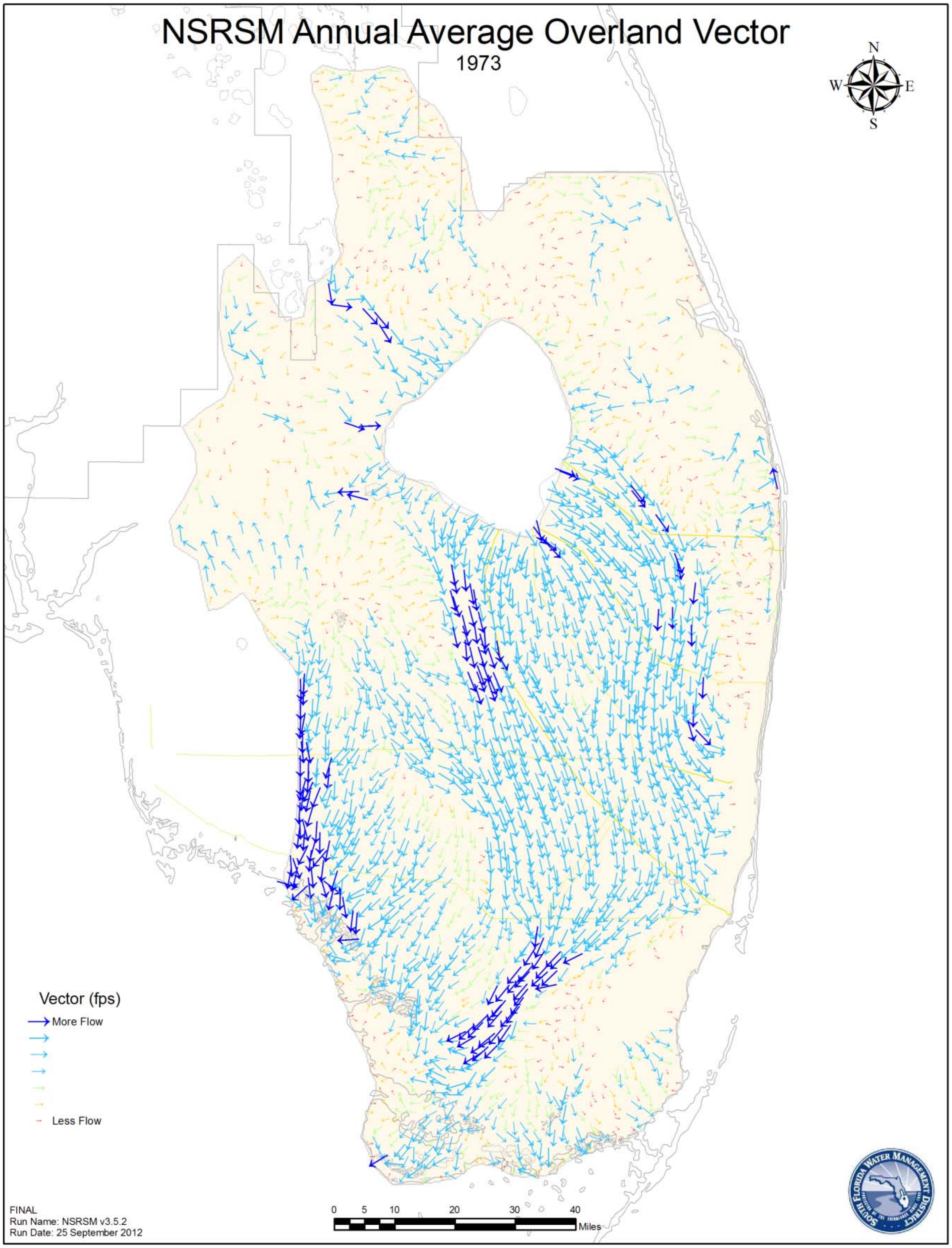

Figure K-90. Annual average overland flow values for the NSRSM model domain for 1973.

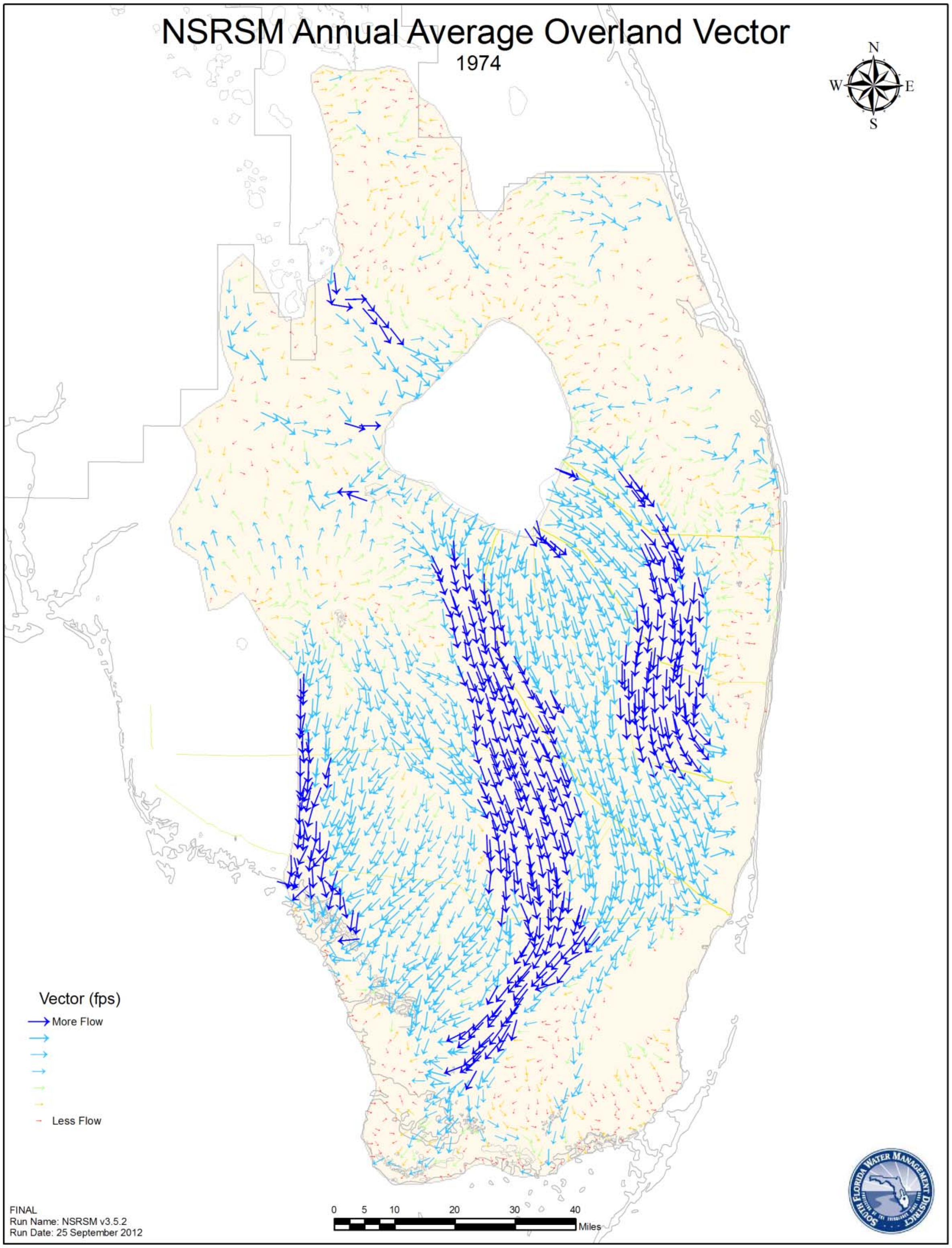

Figure K-91. Annual average overland flow values for the NSRSM model domain for 1974.

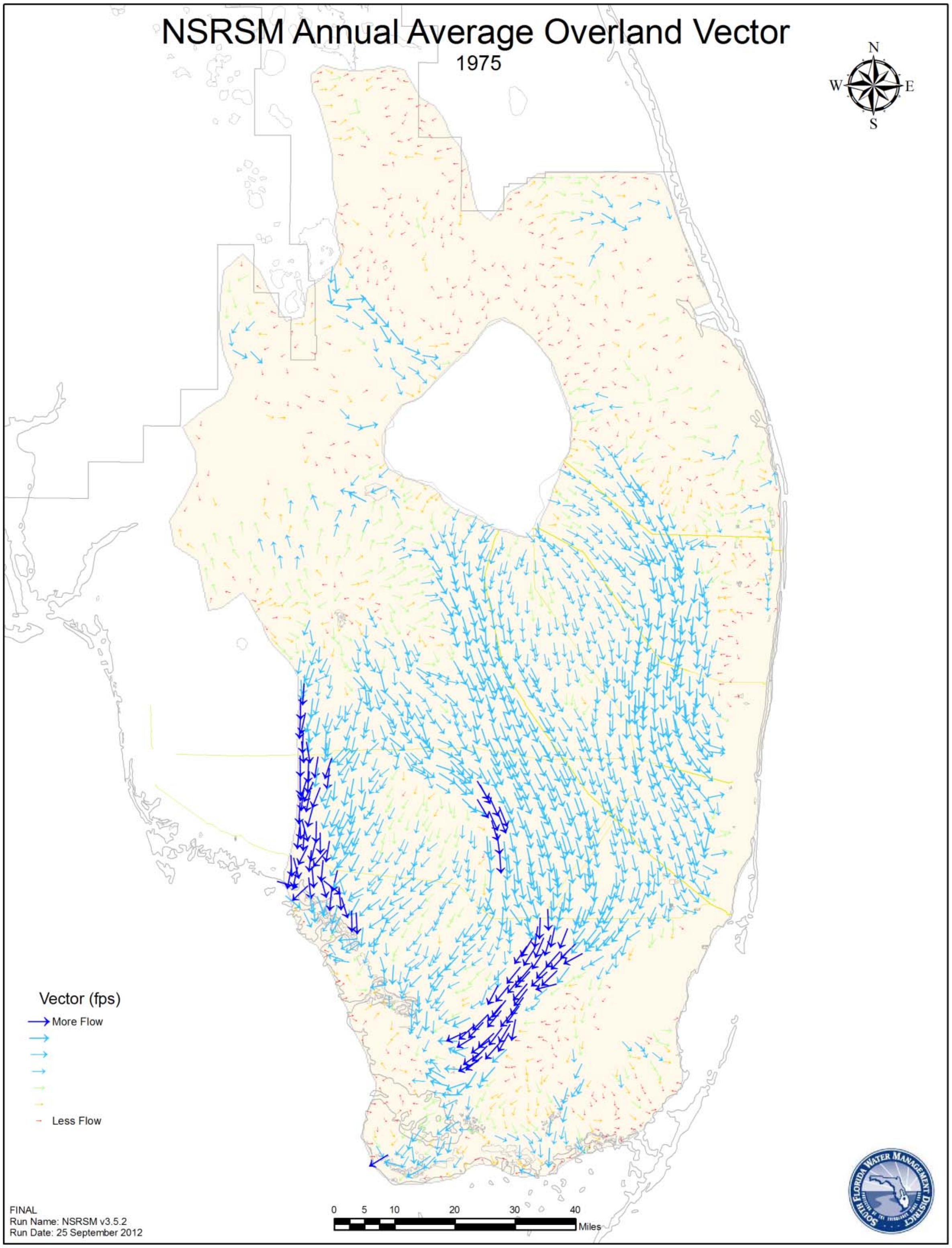

Figure K-92. Annual average overland flow values for the NSRSM model domain for 1975.

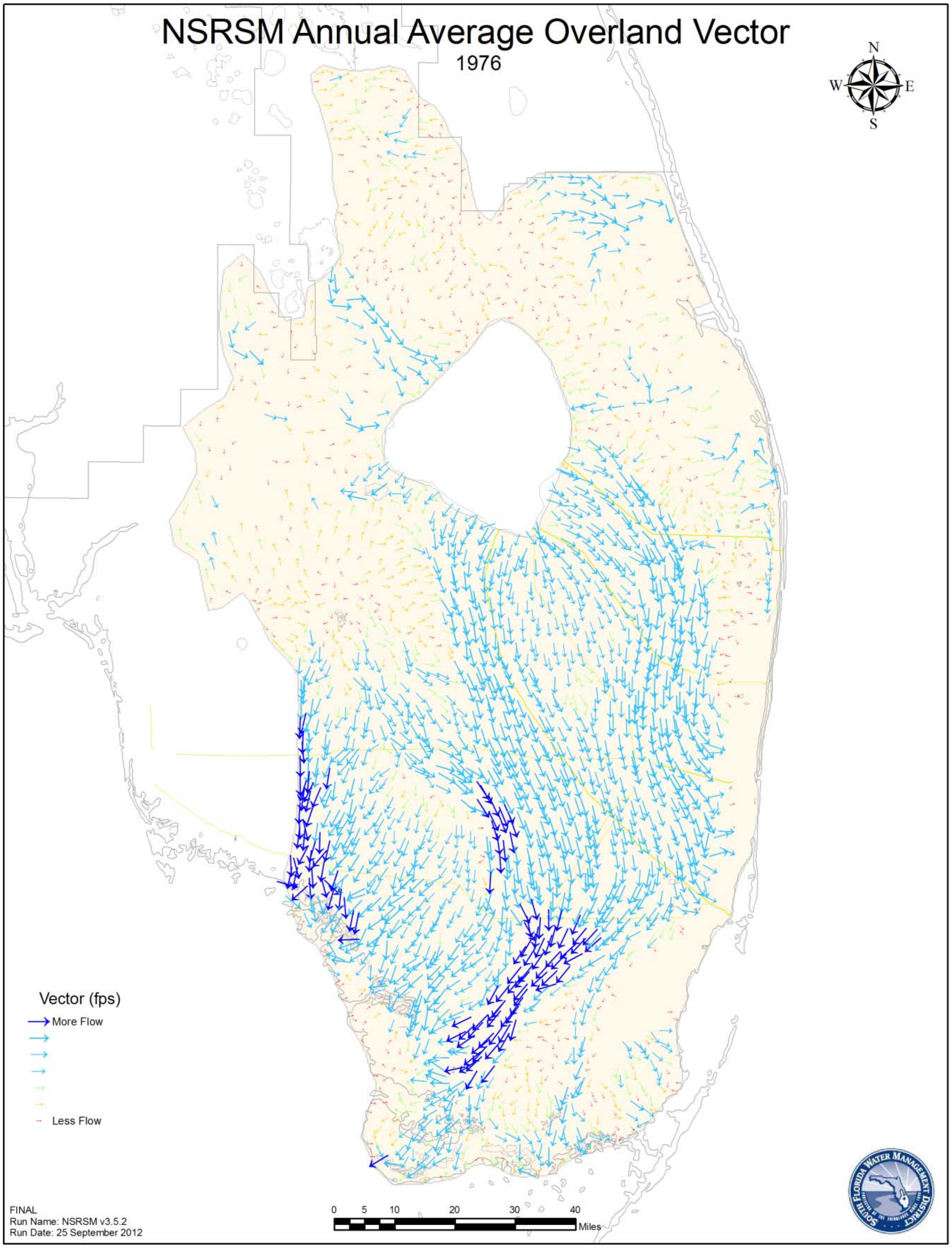

Figure K-93. Annual average overland flow values for the NSRSM model domain for 1976.

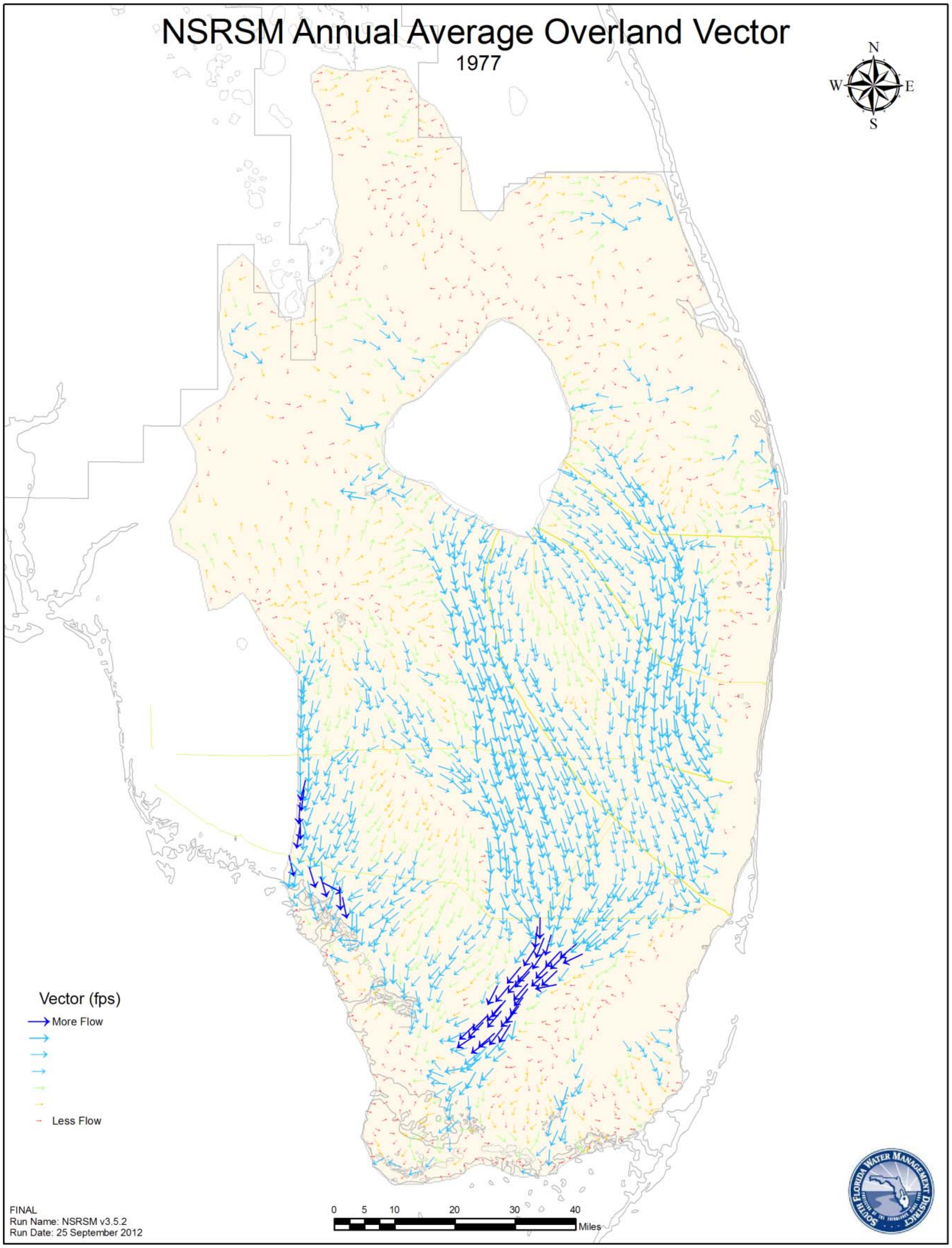

Figure K-94. Annual average overland flow values for the NSRSM model domain for 1977.

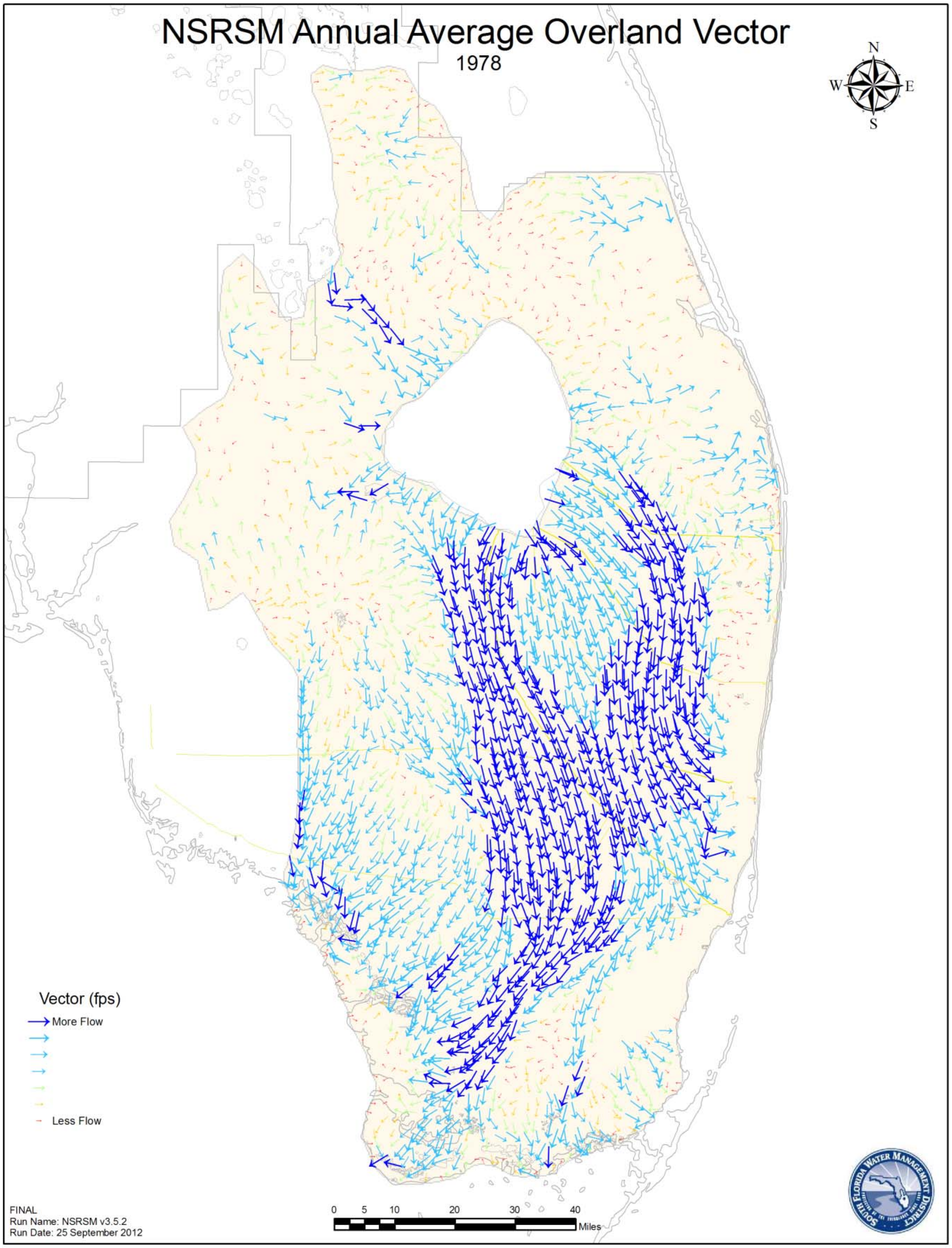

Figure K-95. Annual average overland flow values for the NSRSM model domain for 1978.

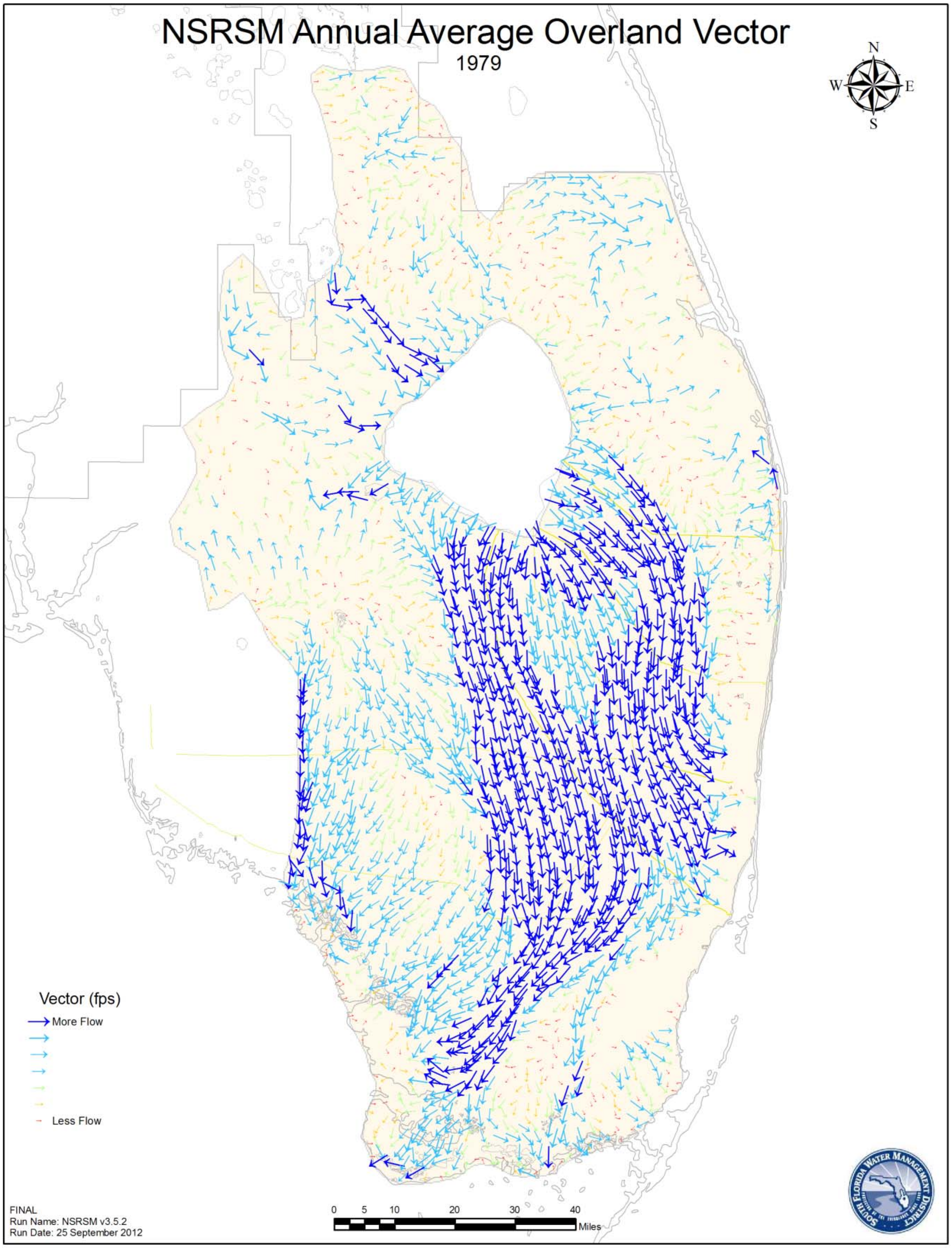

Figure K-96. Annual average overland flow values for the NSRSM model domain for 1979.

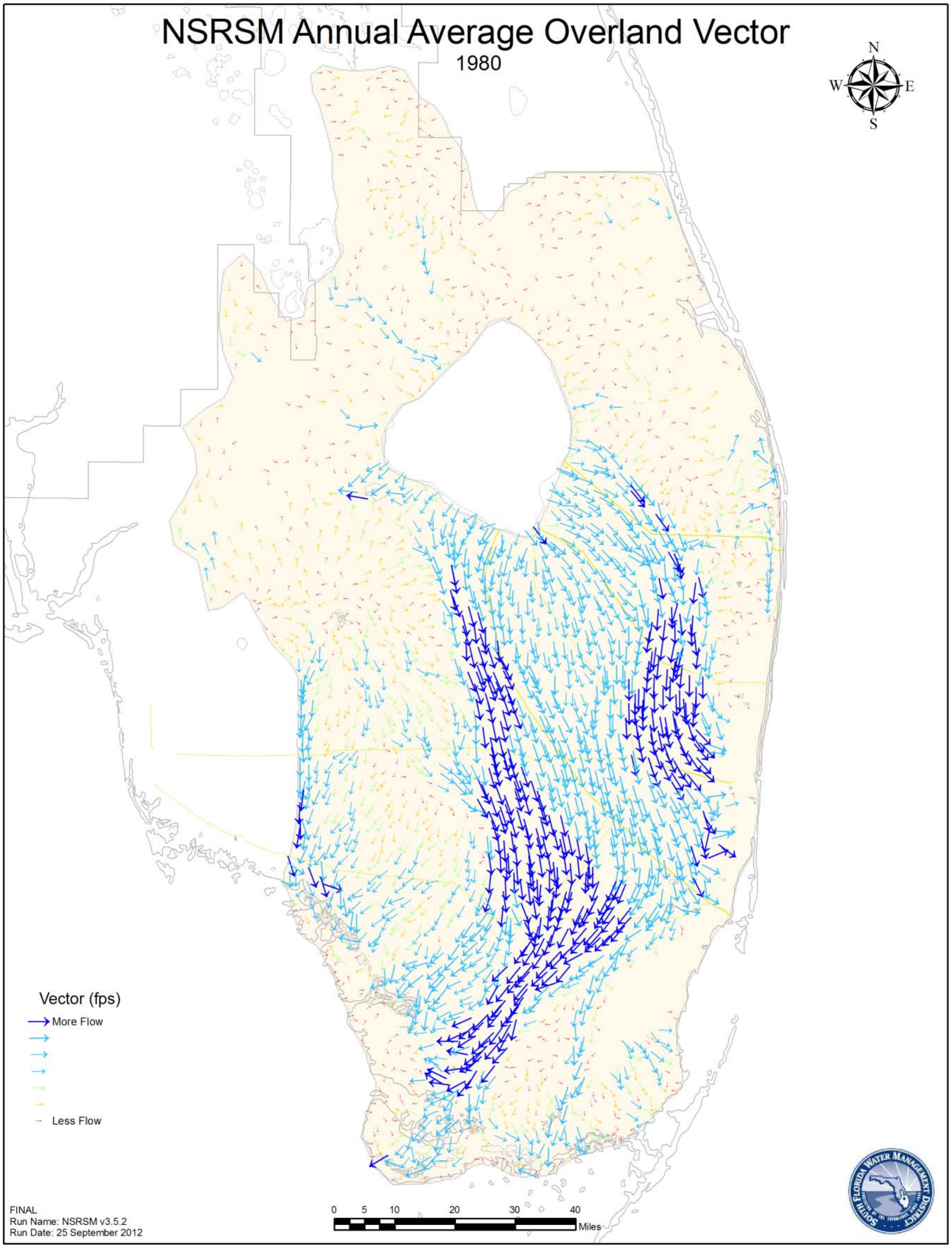

Figure K-97. Annual average overland flow values for the NSRSM model domain for 1980.

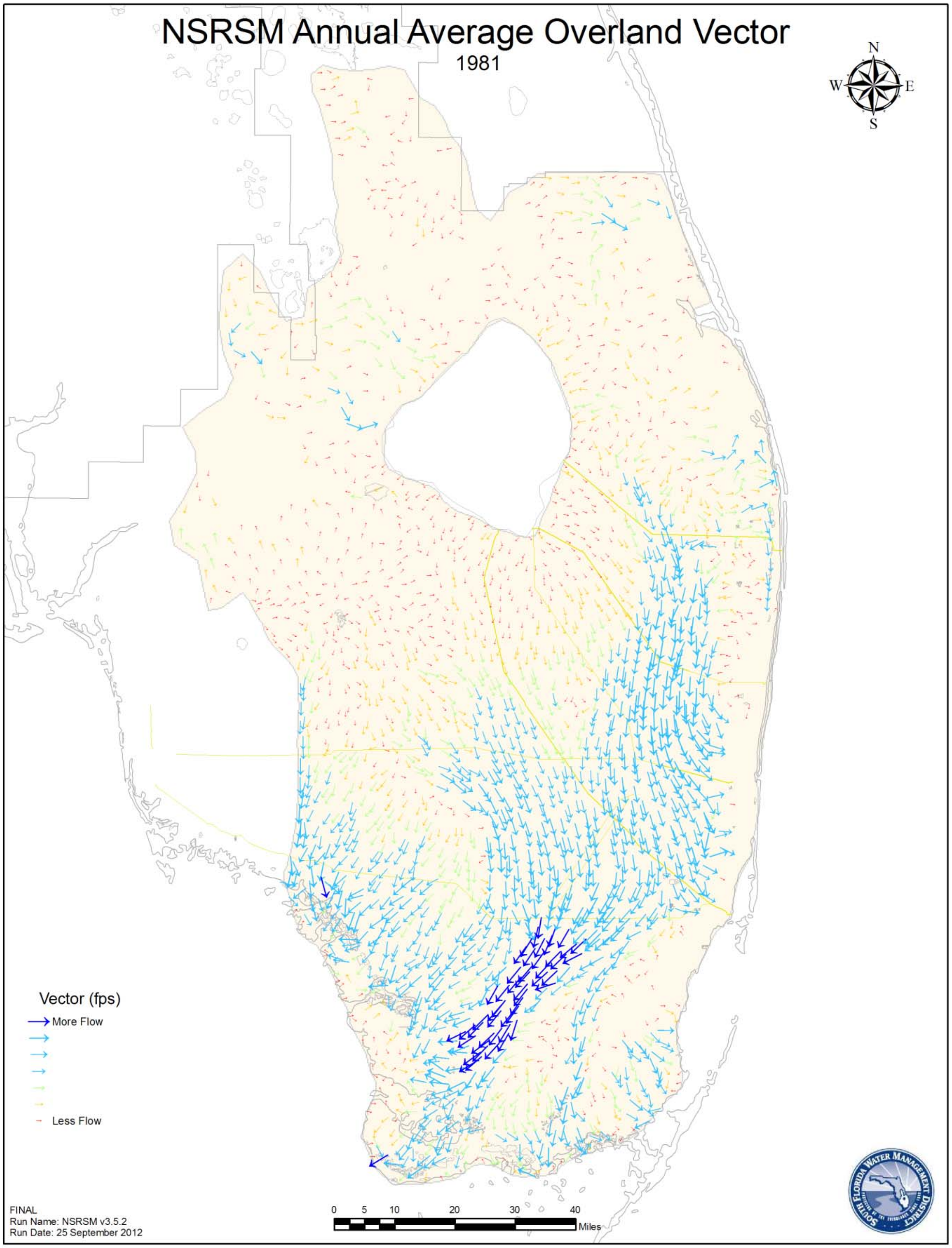

Figure K-98. Annual average overland flow values for the NSRSM model domain for 1981.

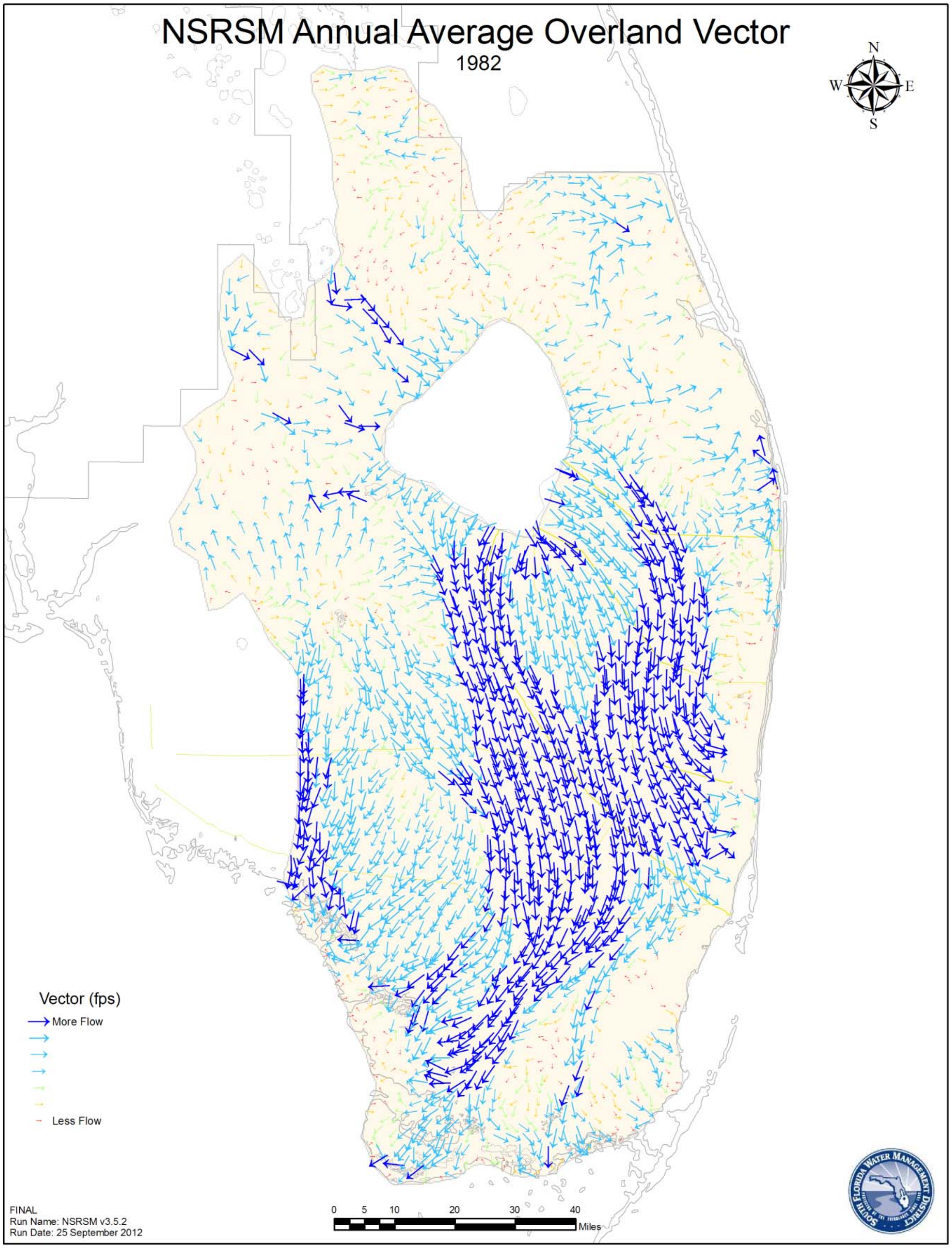

Figure K-99. Annual average overland flow values for the NSRSM model domain for 1982.

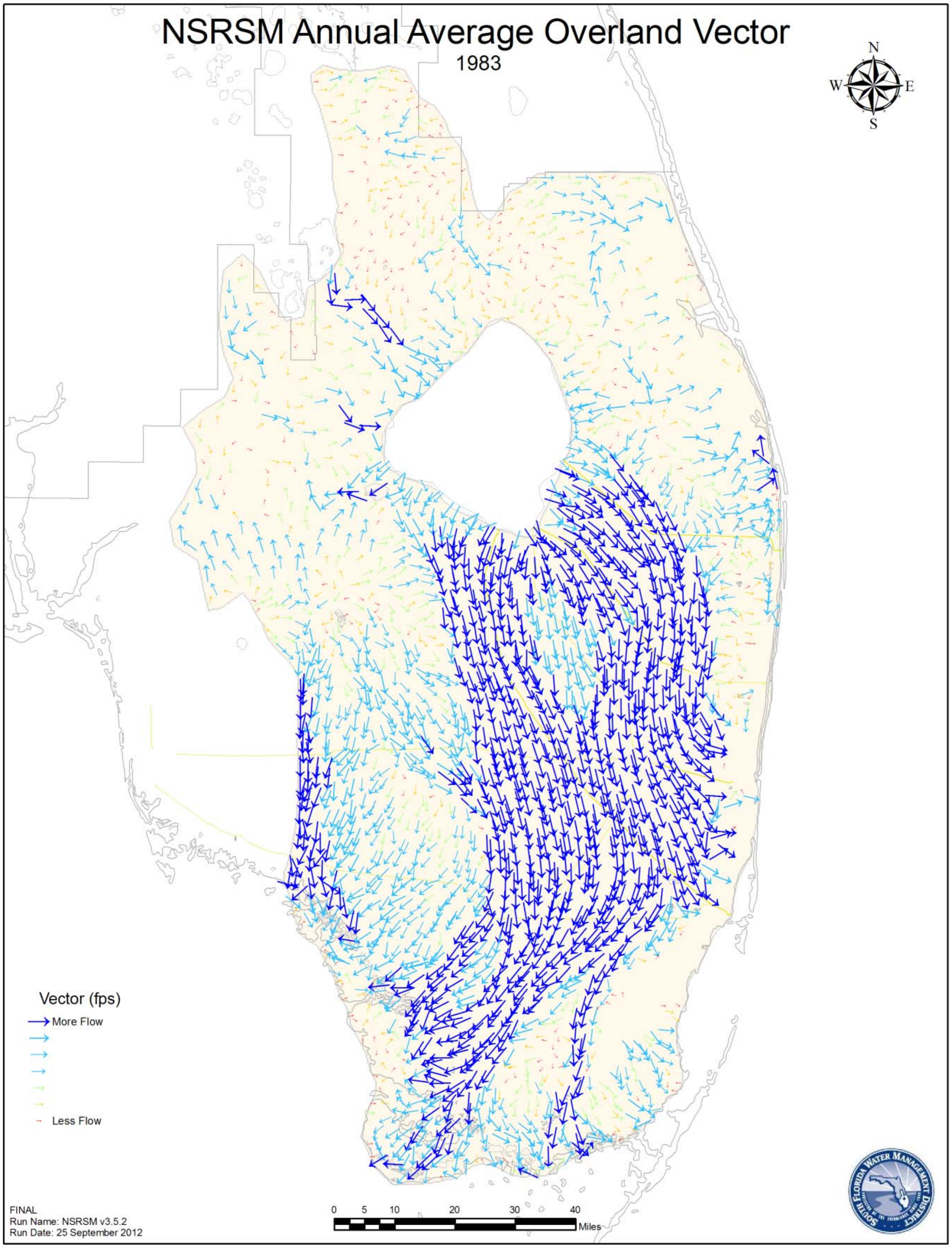

Figure K-100. Annual average overland flow values for the NSRSM model domain for 1983.

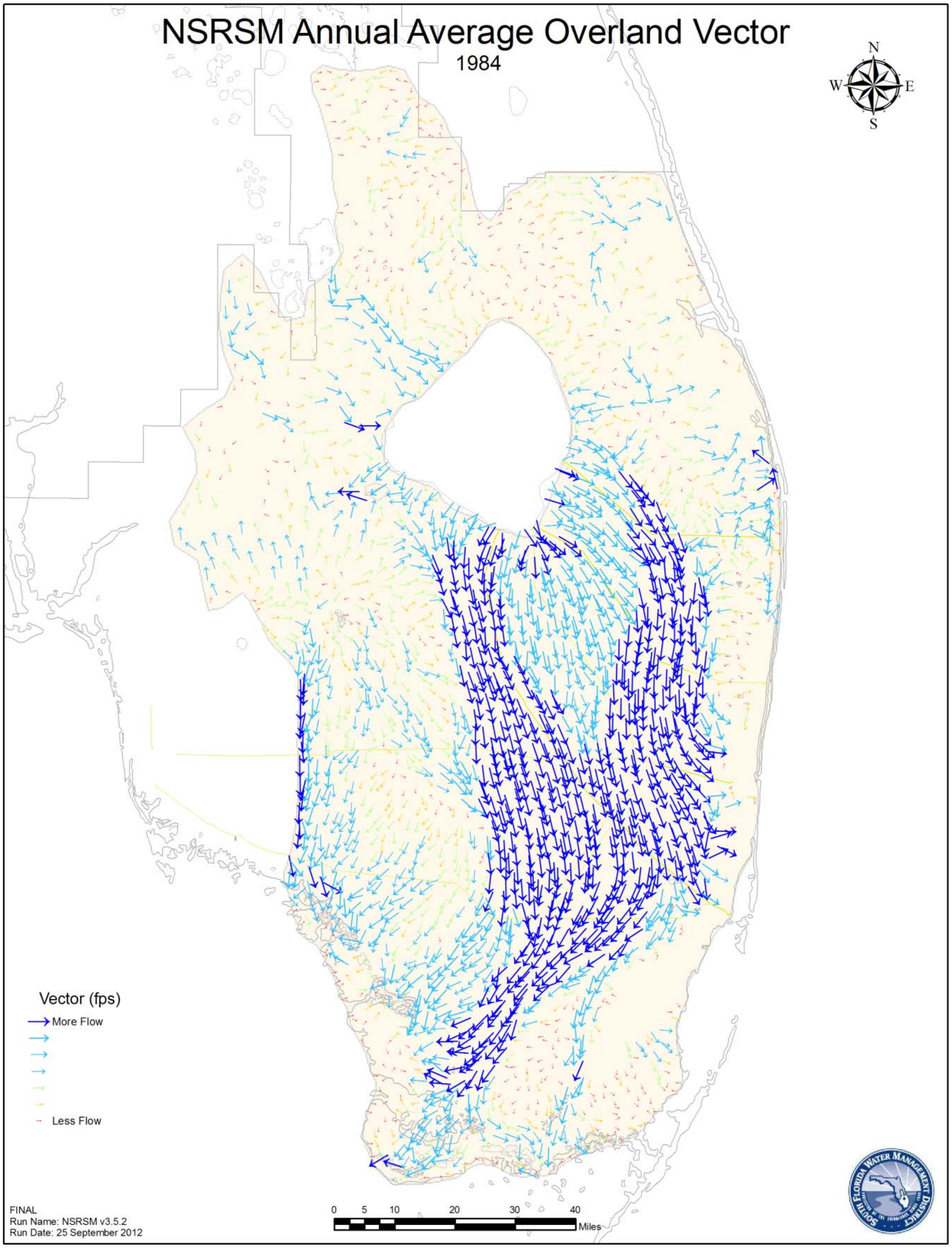

Figure K-101. Annual average overland flow values for the NSRSM model domain for 1984.

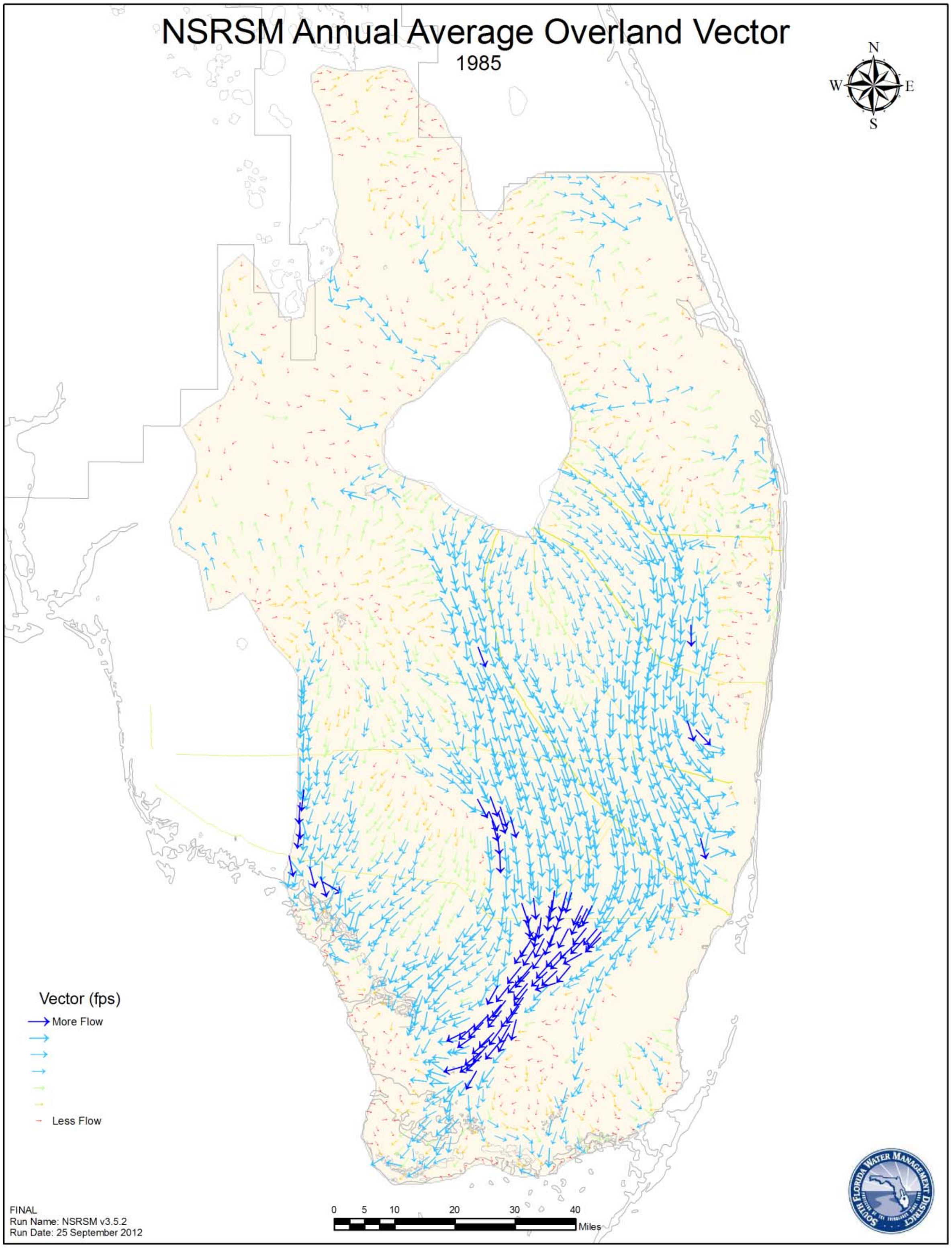

Figure K-102. Annual average overland flow values for the NSRSM model domain for 1985.

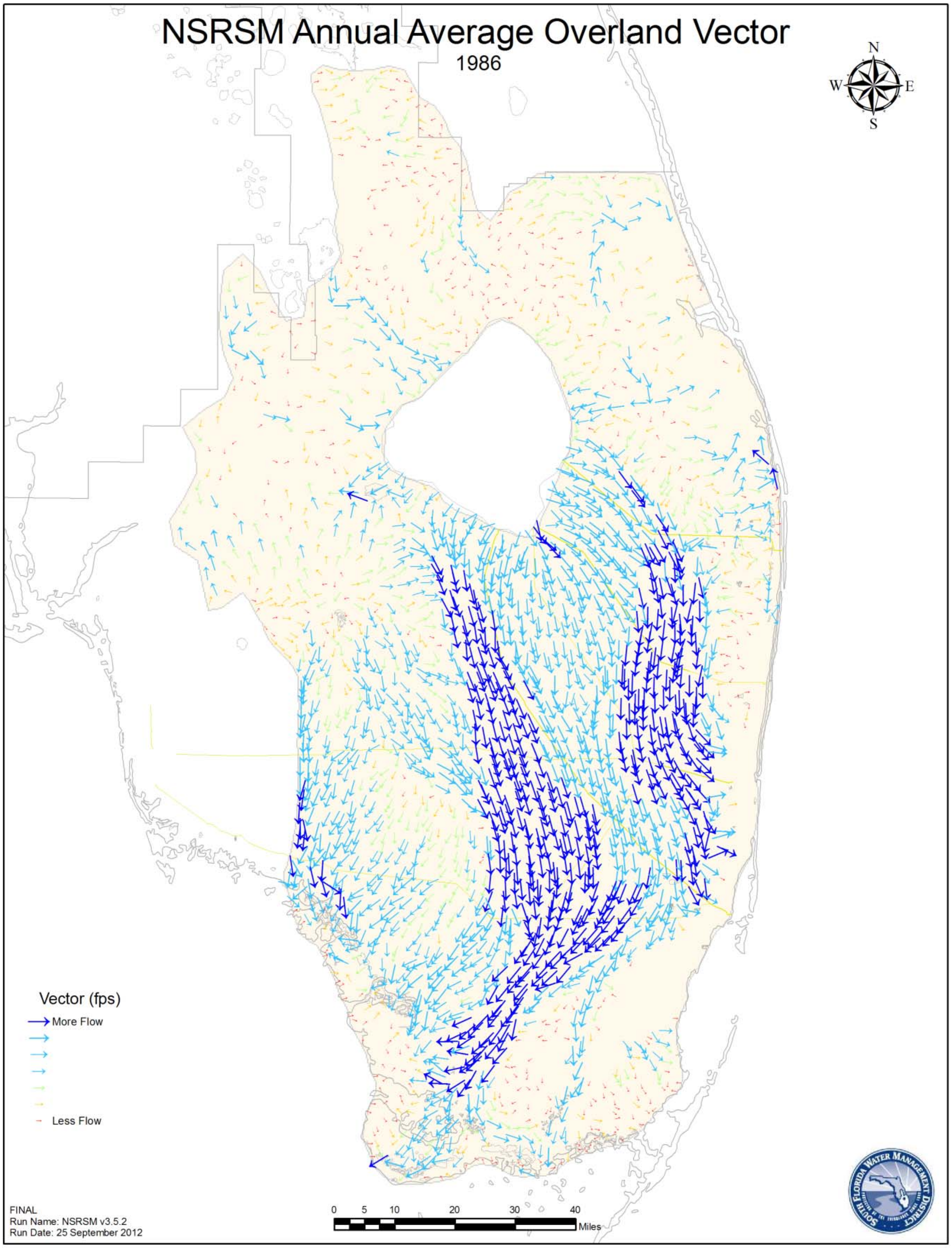

Figure K-103. Annual average overland flow values for the NSRSM model domain for 1986.

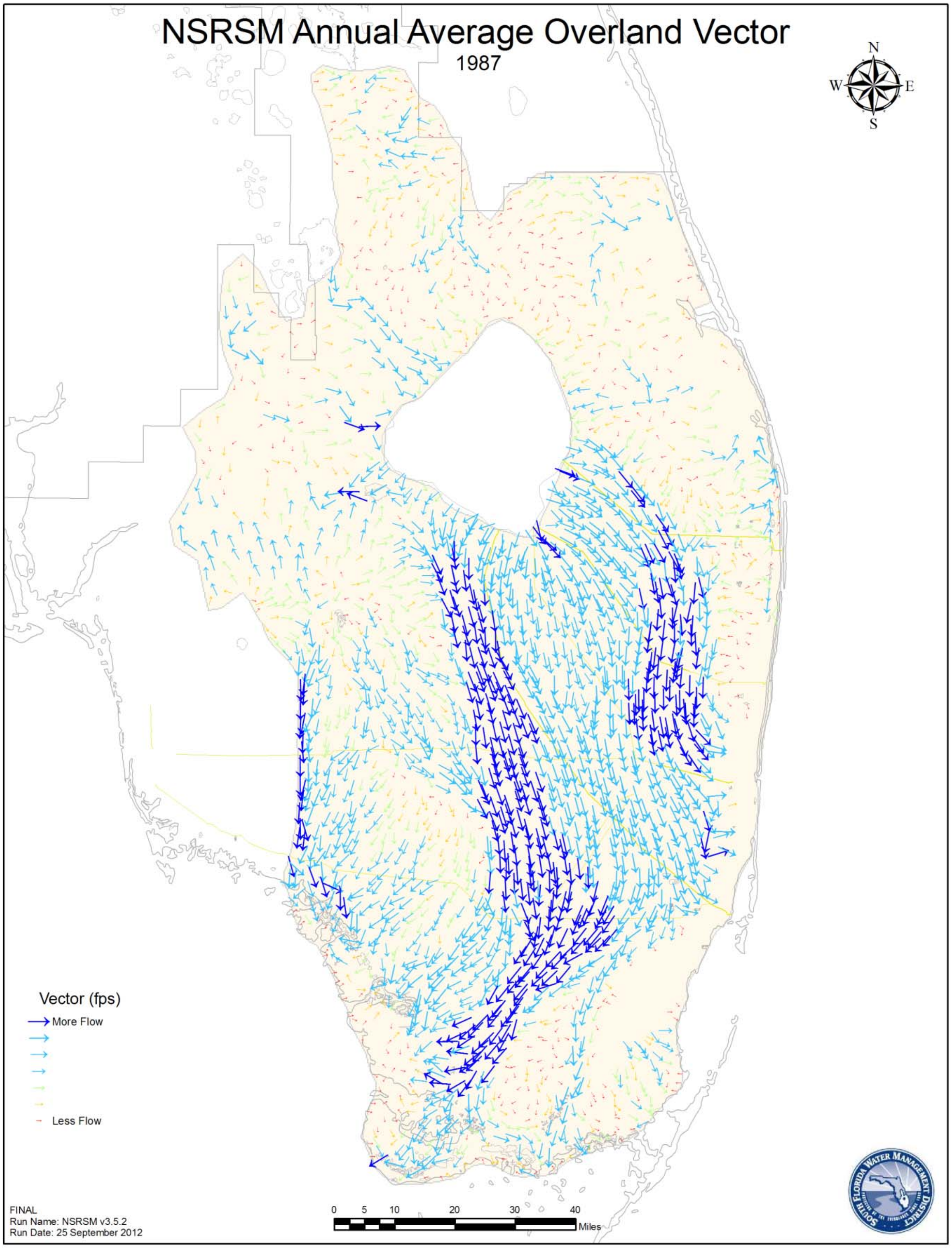

Figure K-104. Annual average overland flow values for the NSRSM model domain for 1987.

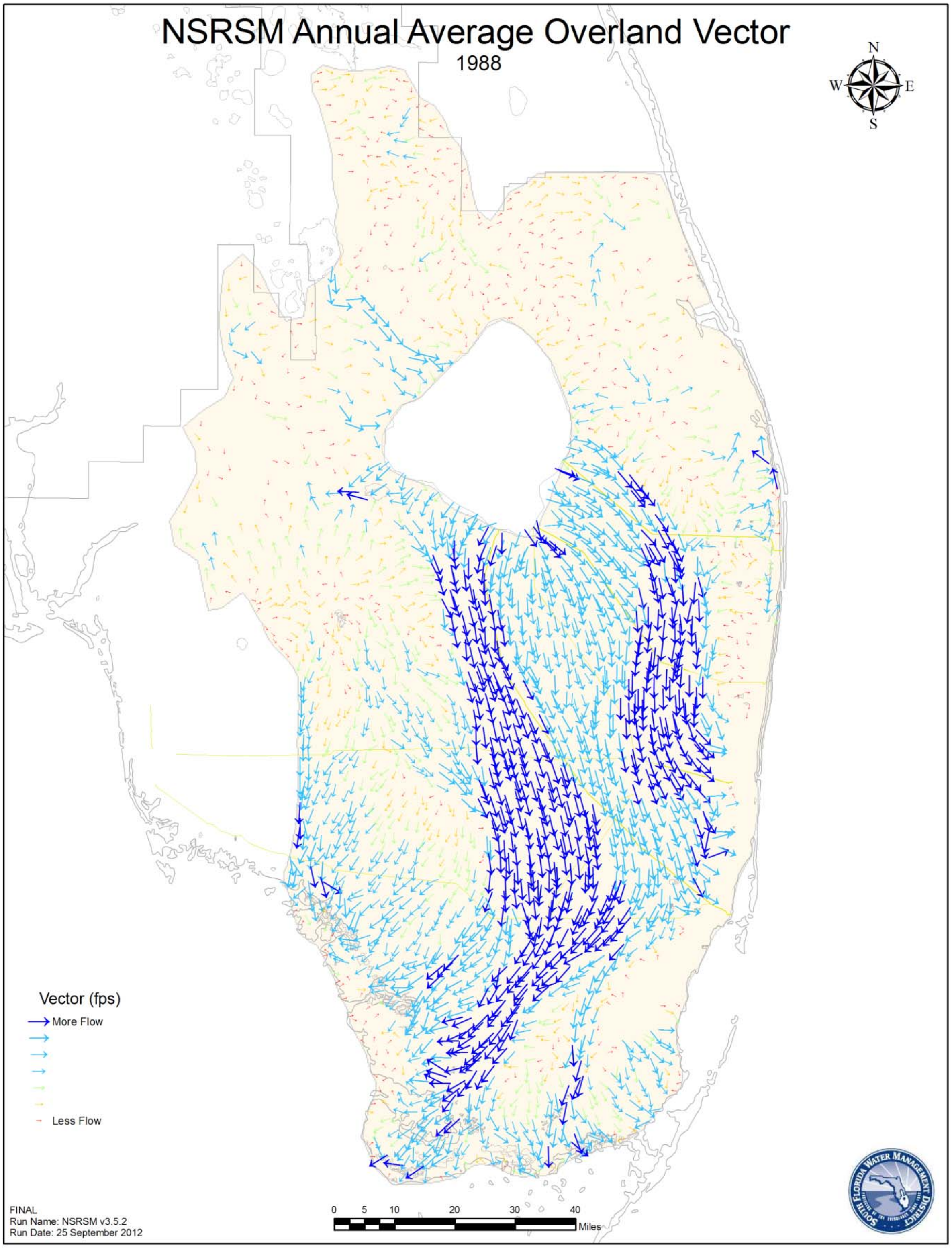

Figure K-105. Annual average overland flow values for the NSRSM model domain for 1988.

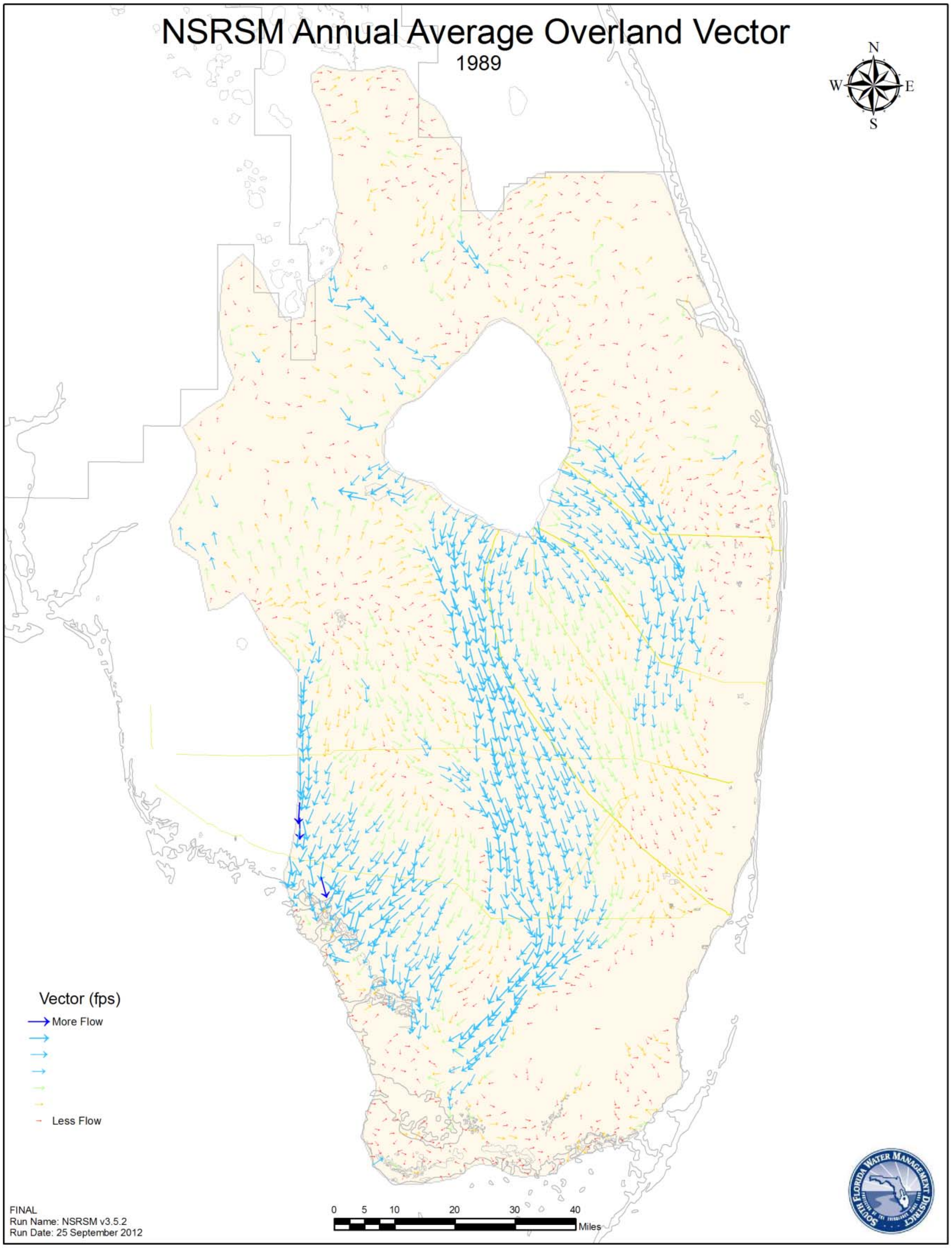

Figure K-106. Annual average overland flow values for the NSRSM model domain for 1989.

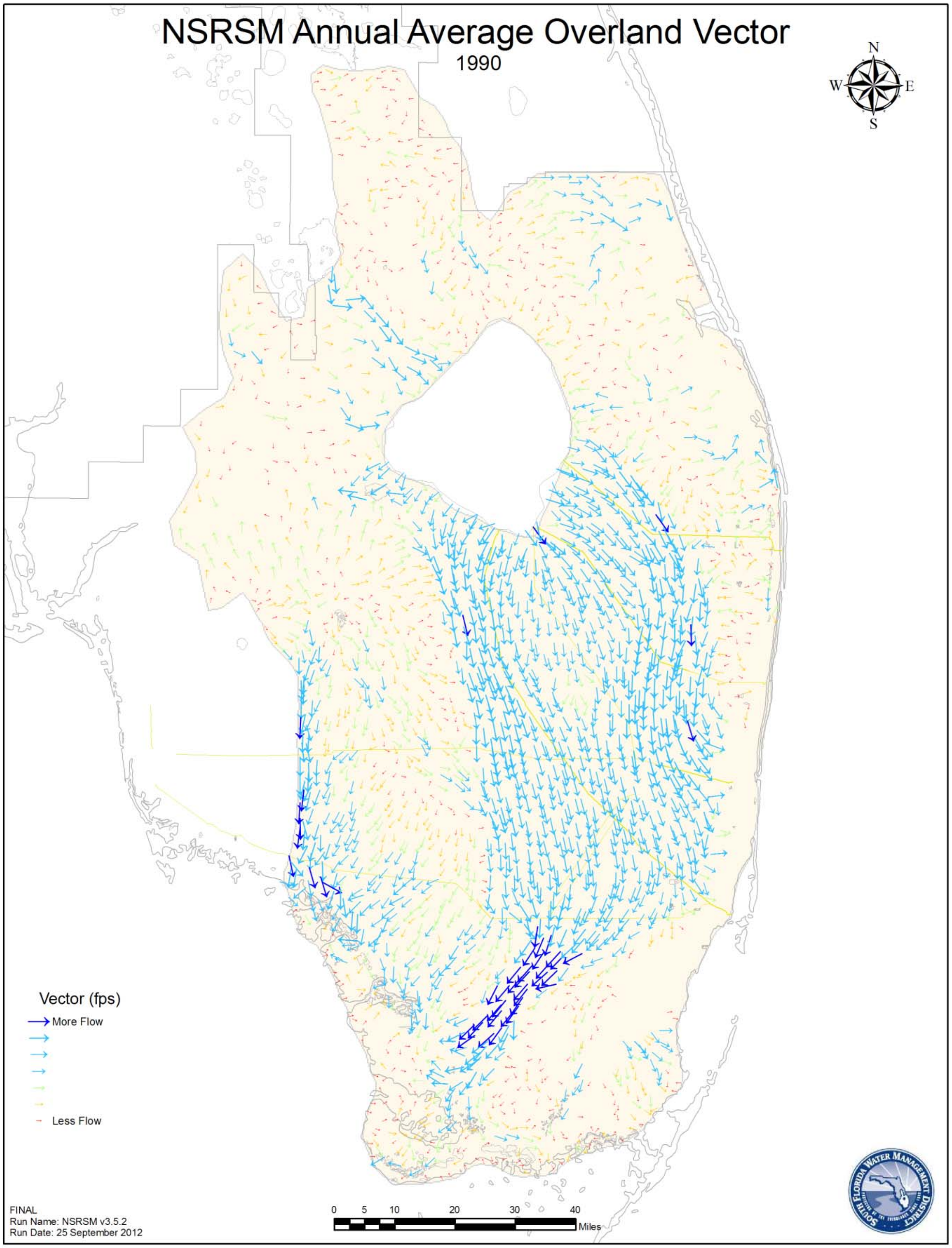

Figure K-107. Annual average overland flow values for the NSRSM model domain for 1990.

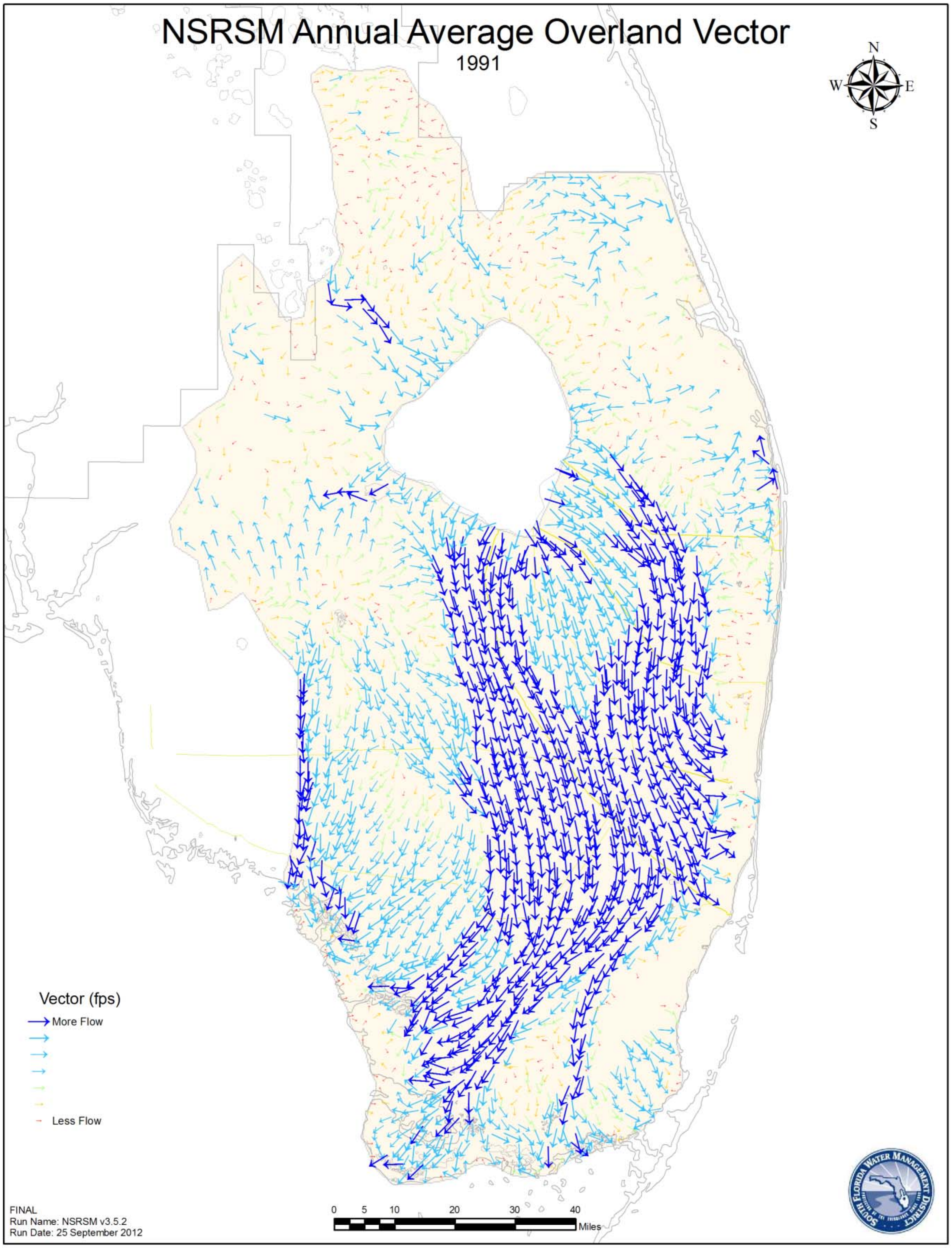

Figure K-108. Annual average overland flow values for the NSRSM model domain for 1991.

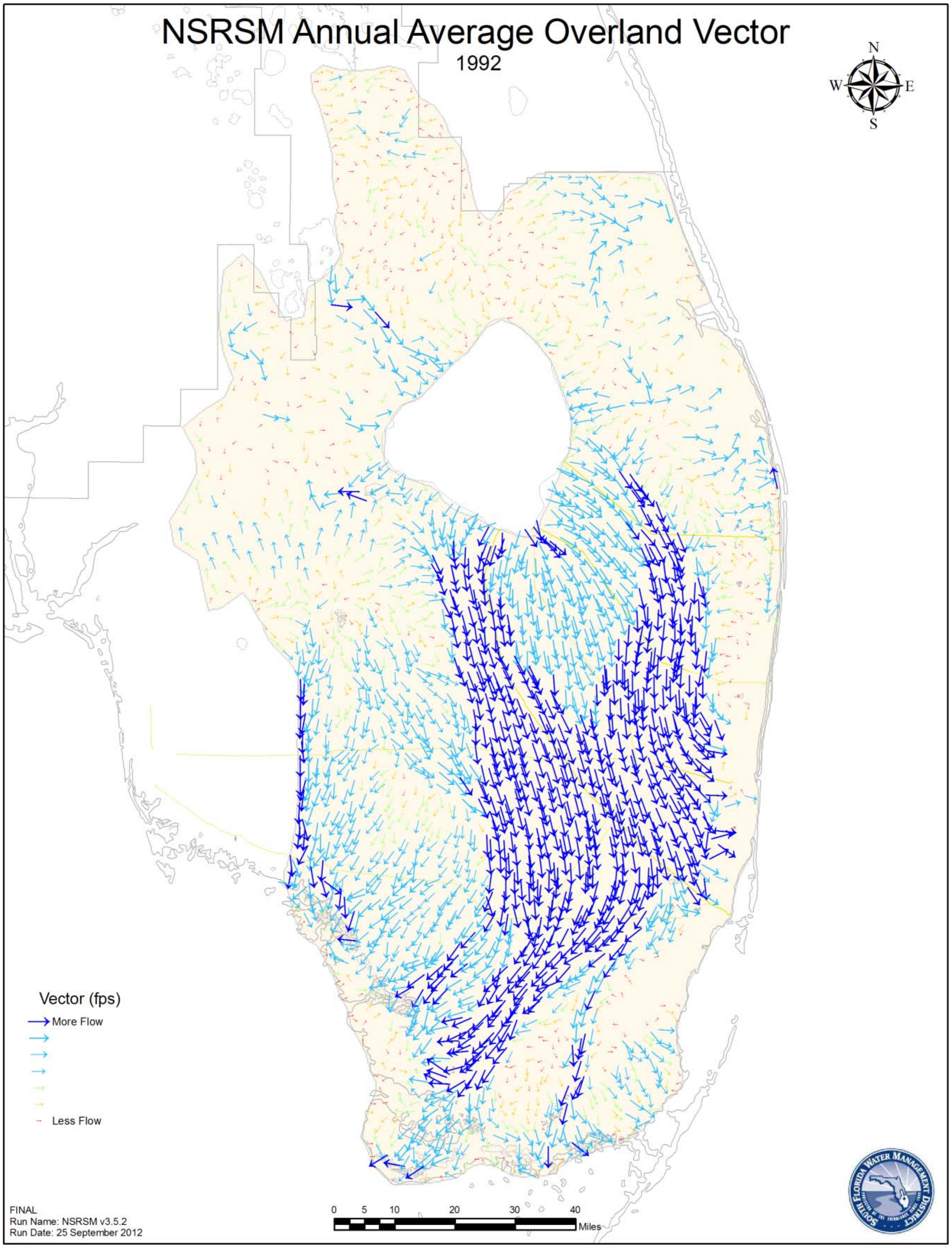

Figure K-109. Annual average overland flow values for the NSRSM model domain for 1992.

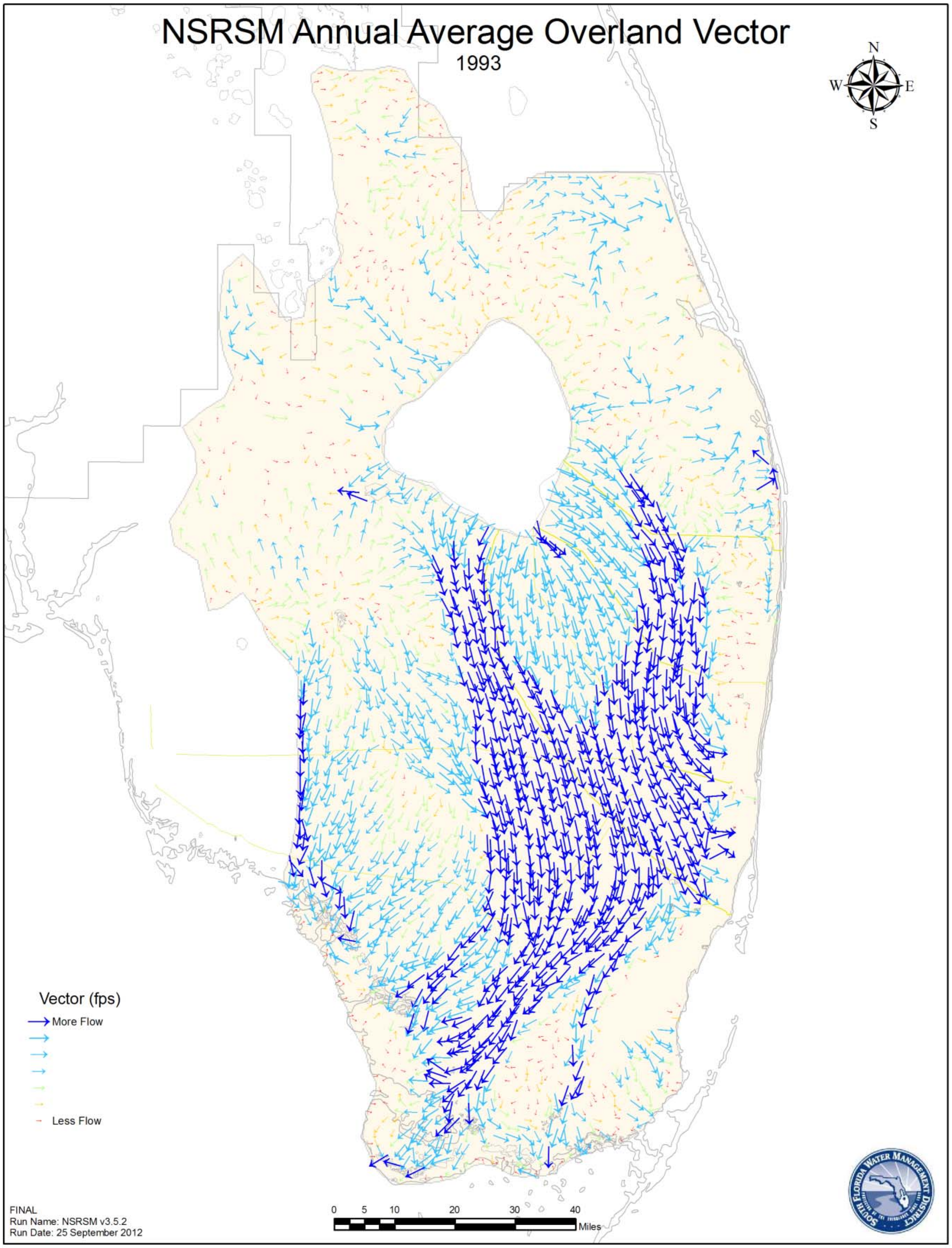

Figure K-110. Annual average overland flow values for the NSRSM model domain for 1993.

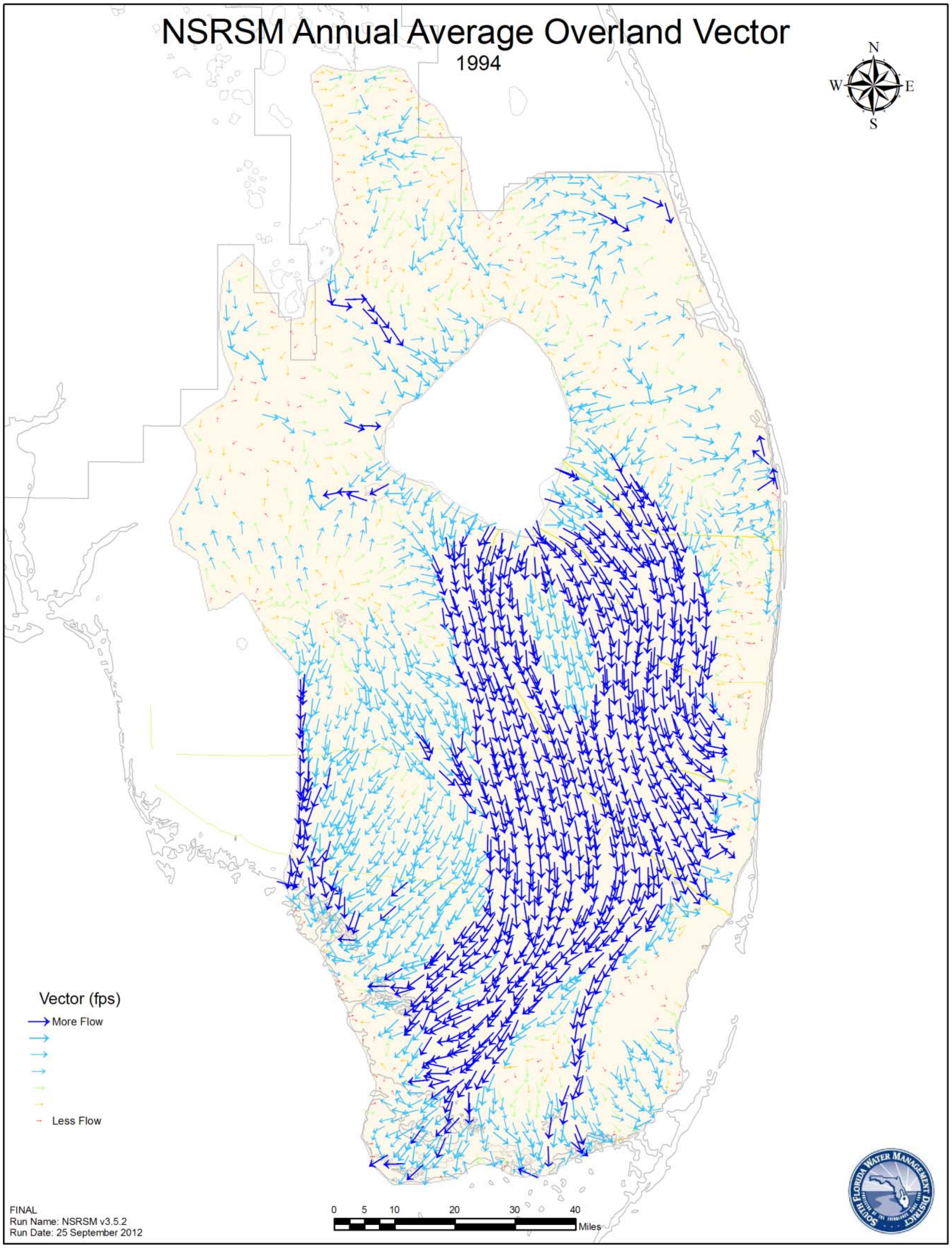

Figure K-111. Annual average overland flow values for the NSRSM model domain for 1994.

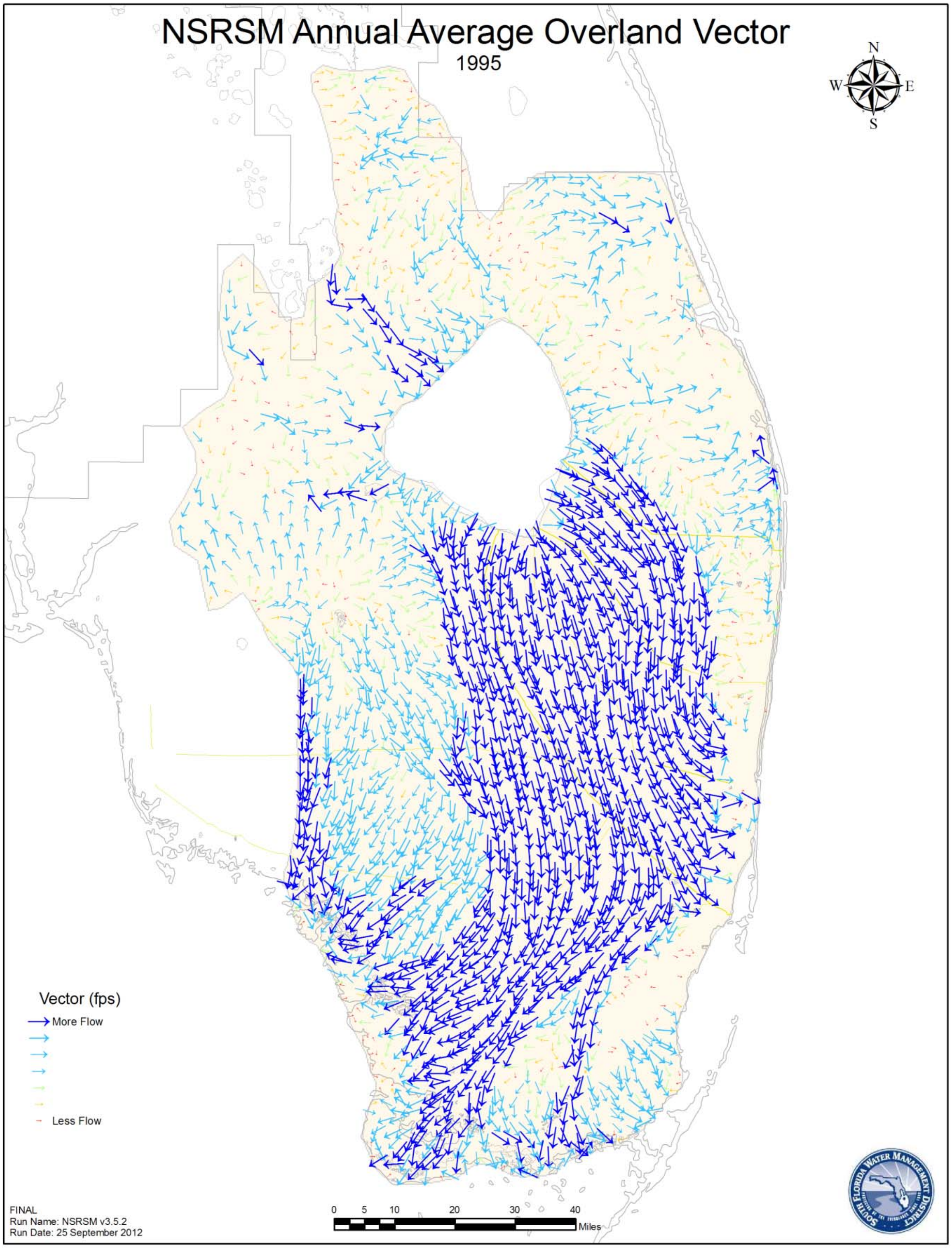

Figure K-112. Annual average overland flow values for the NSRSM model domain for 1995.

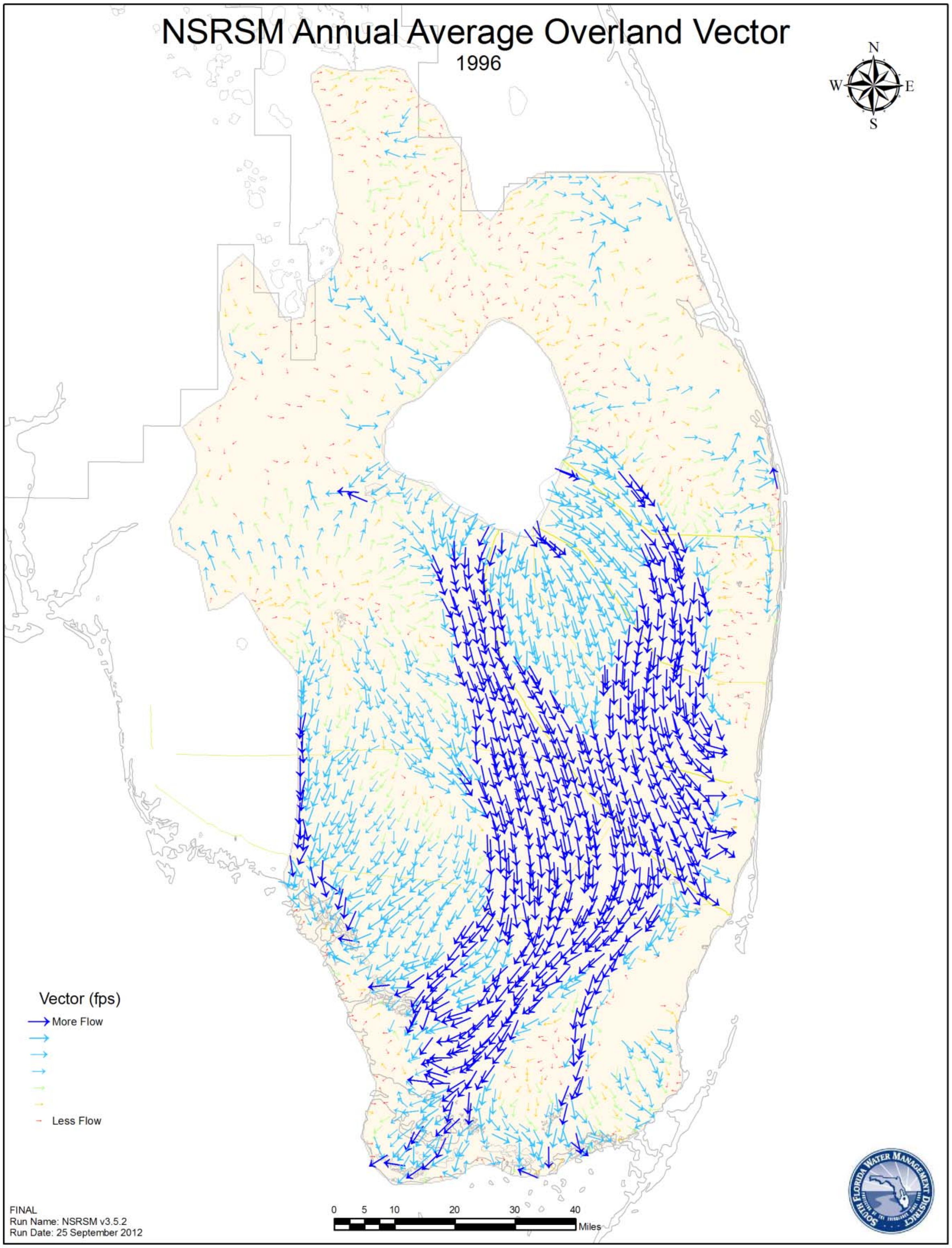

Figure K-113. Annual average overland flow values for the NSRSM model domain for 1996.

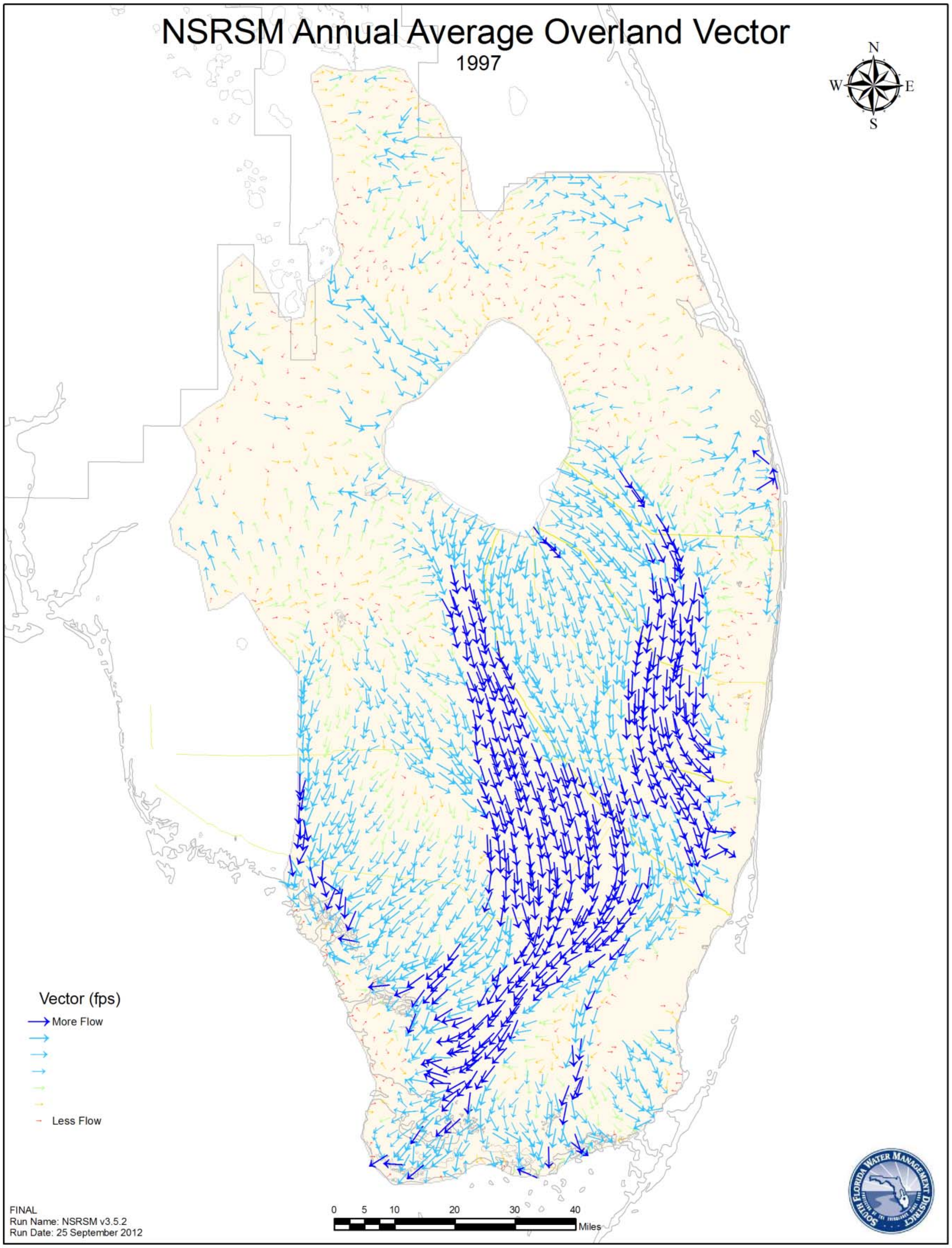

Figure K-114. Annual average overland flow values for the NSRSM model domain for 1997.

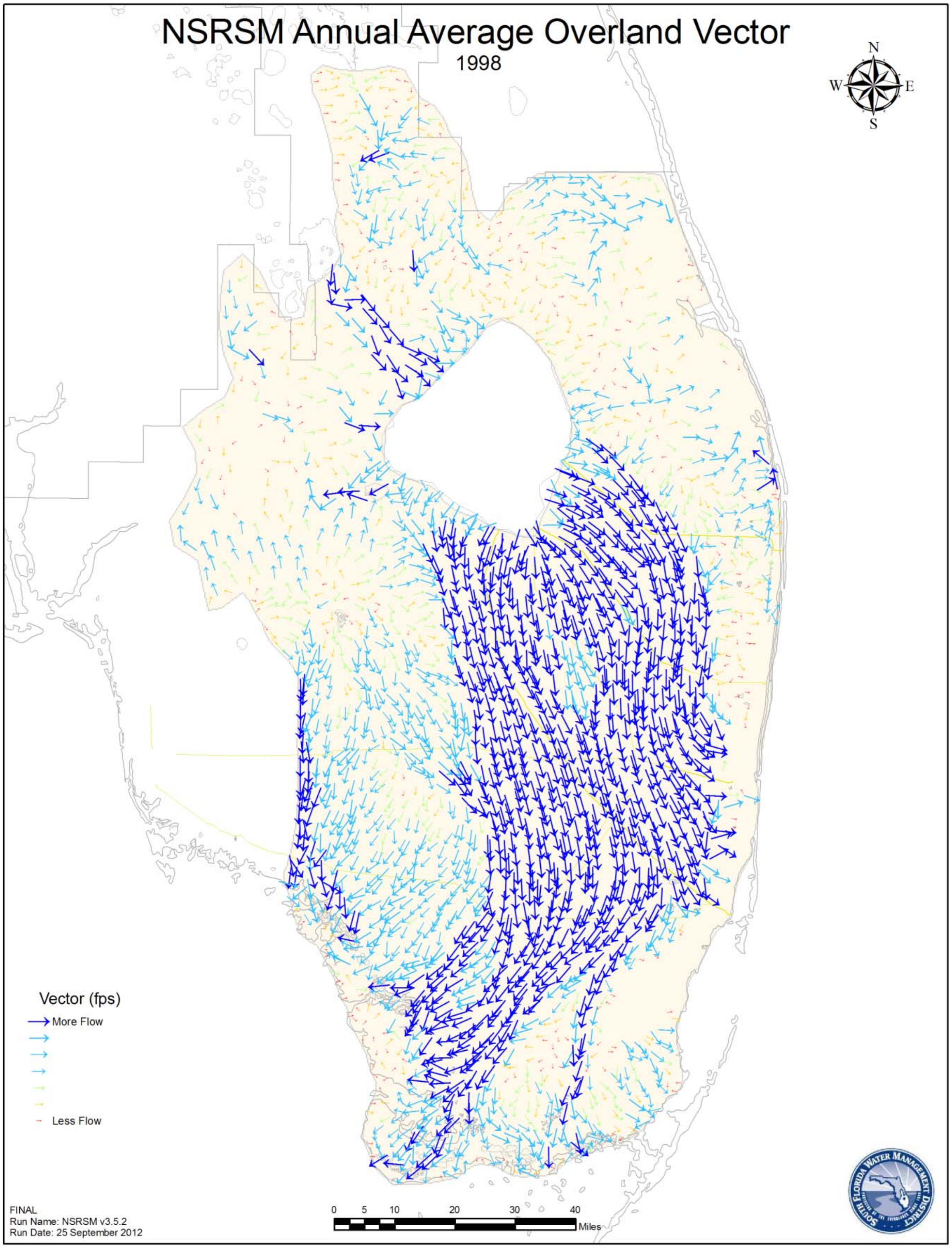

Figure K-115. Annual average overland flow values for the NSRSM model domain for 1998.

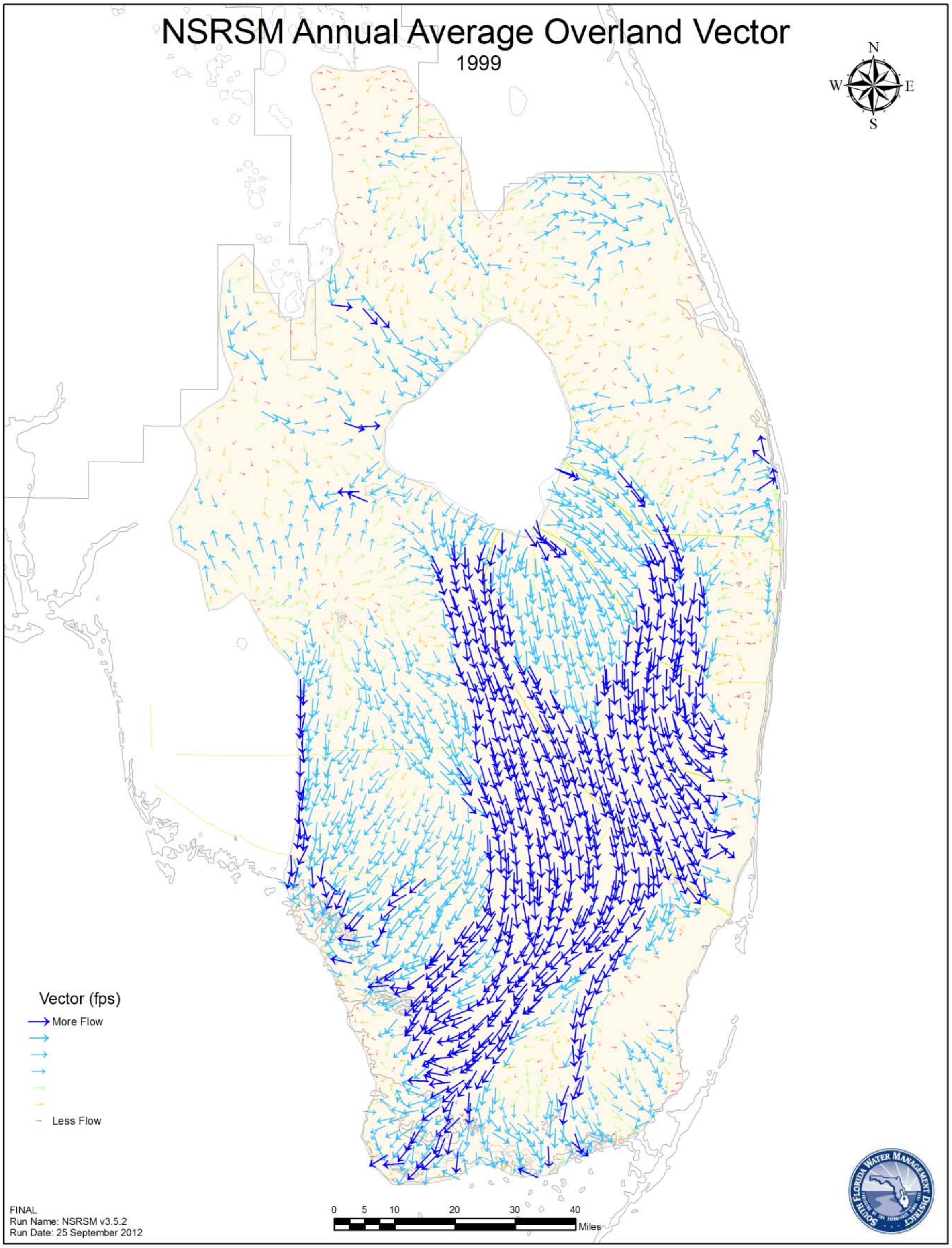

Figure K-116. Annual average overland flow values for the NSRSM model domain for 1999.

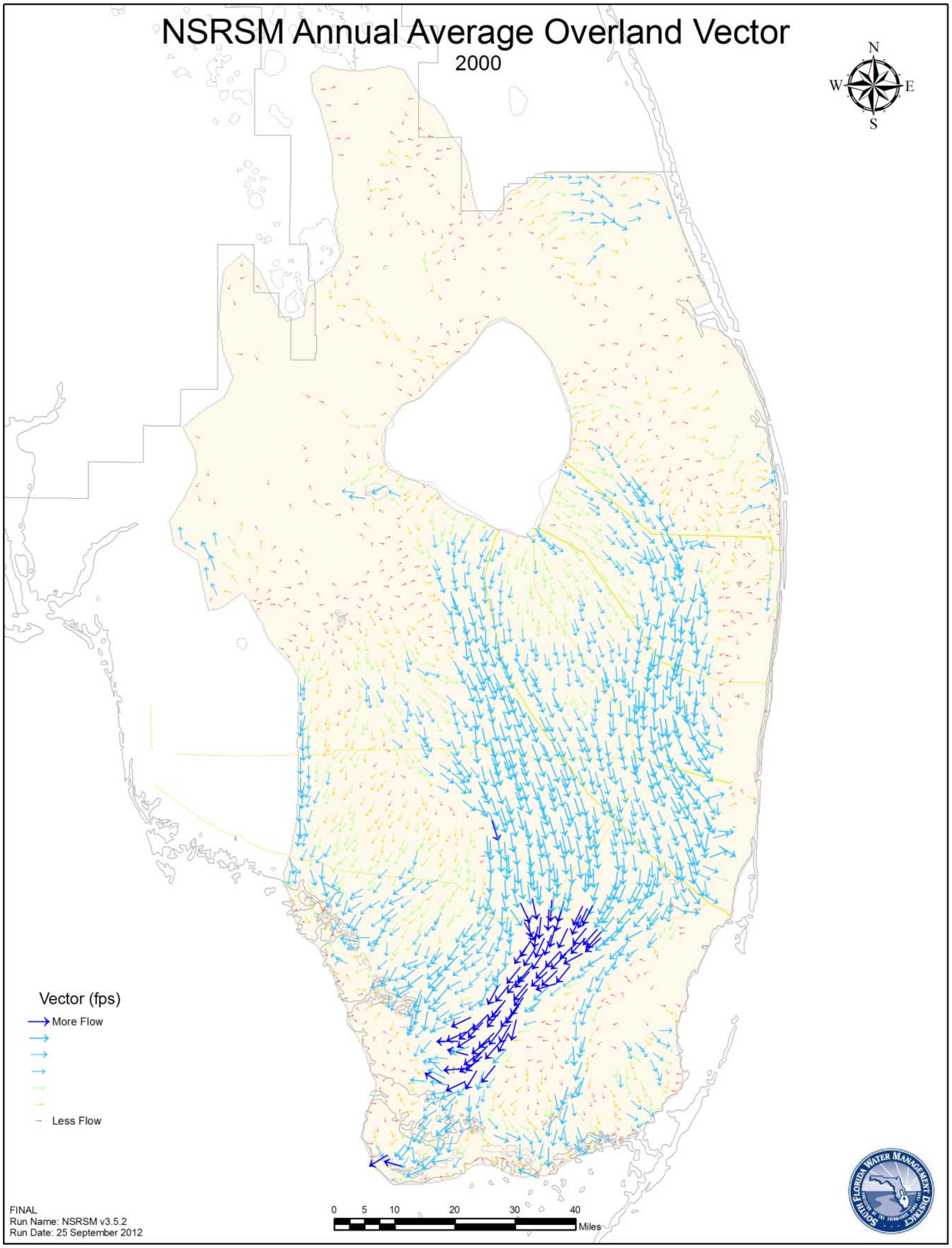

Figure K-117 Annual average overland flow values for the NSRSM model domain for 2000.

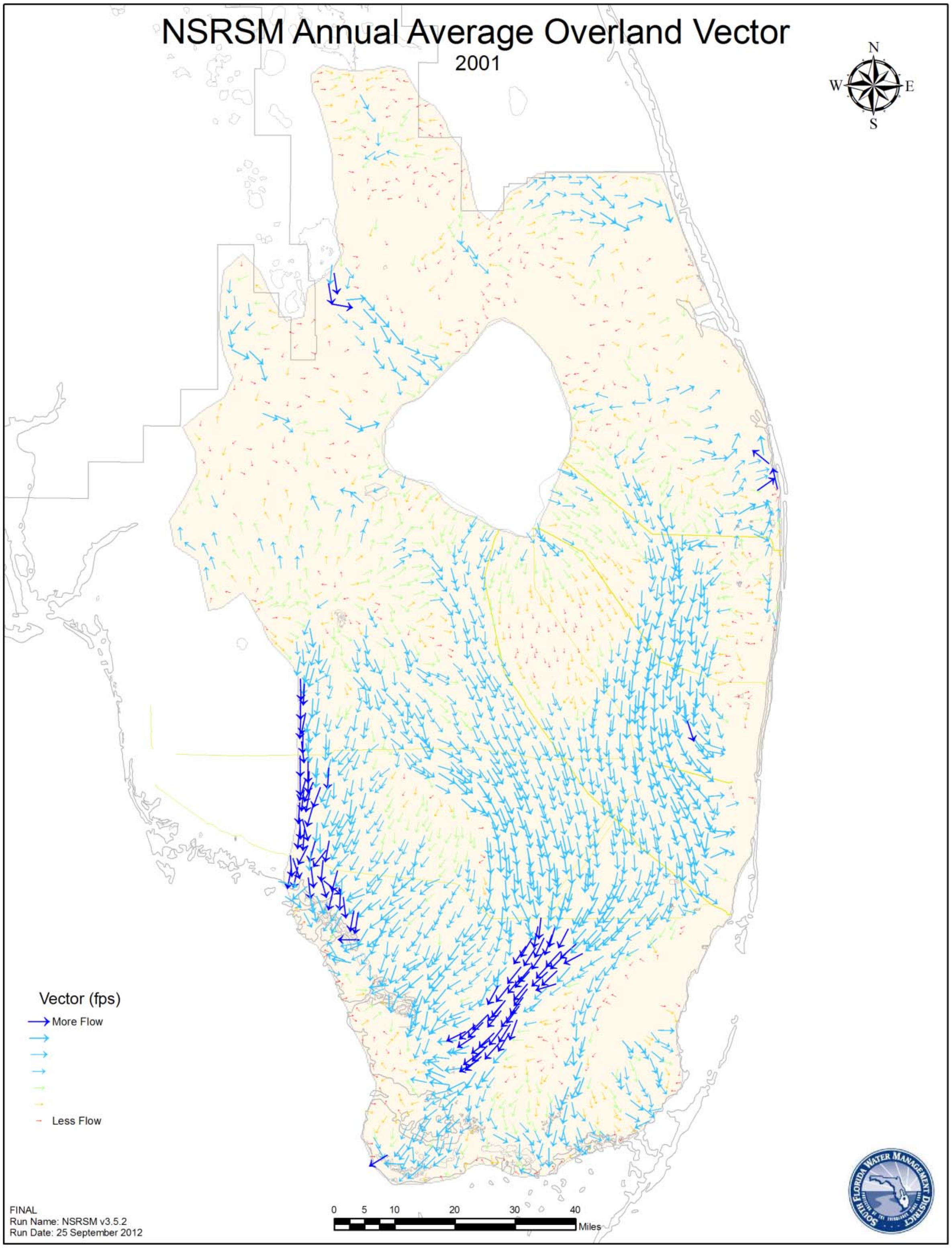

Figure K-118. Annual average overland flow values for the NSRSM model domain for 2001.

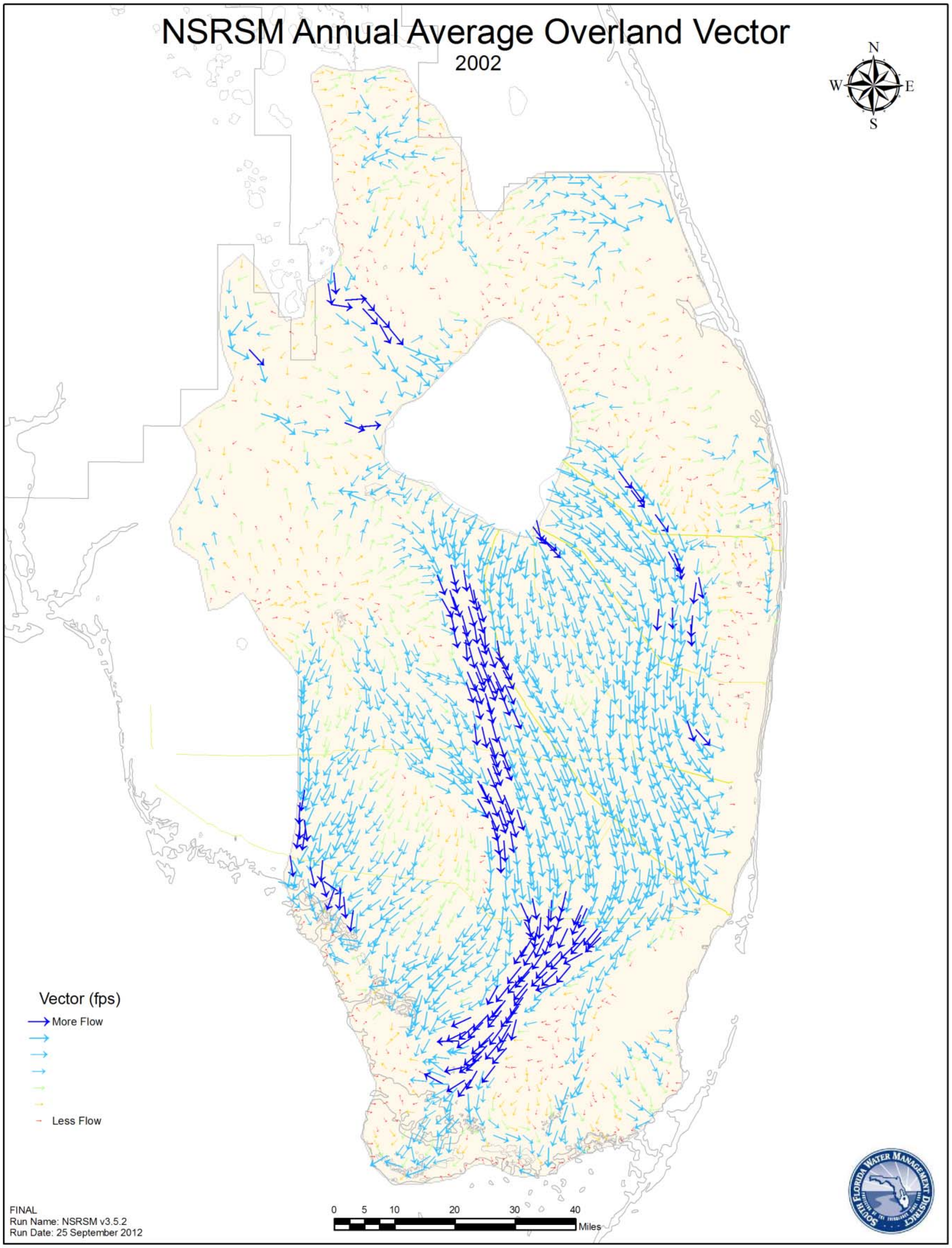

Figure K-119. Annual average overland flow values for the NSRSM model domain for 2002.

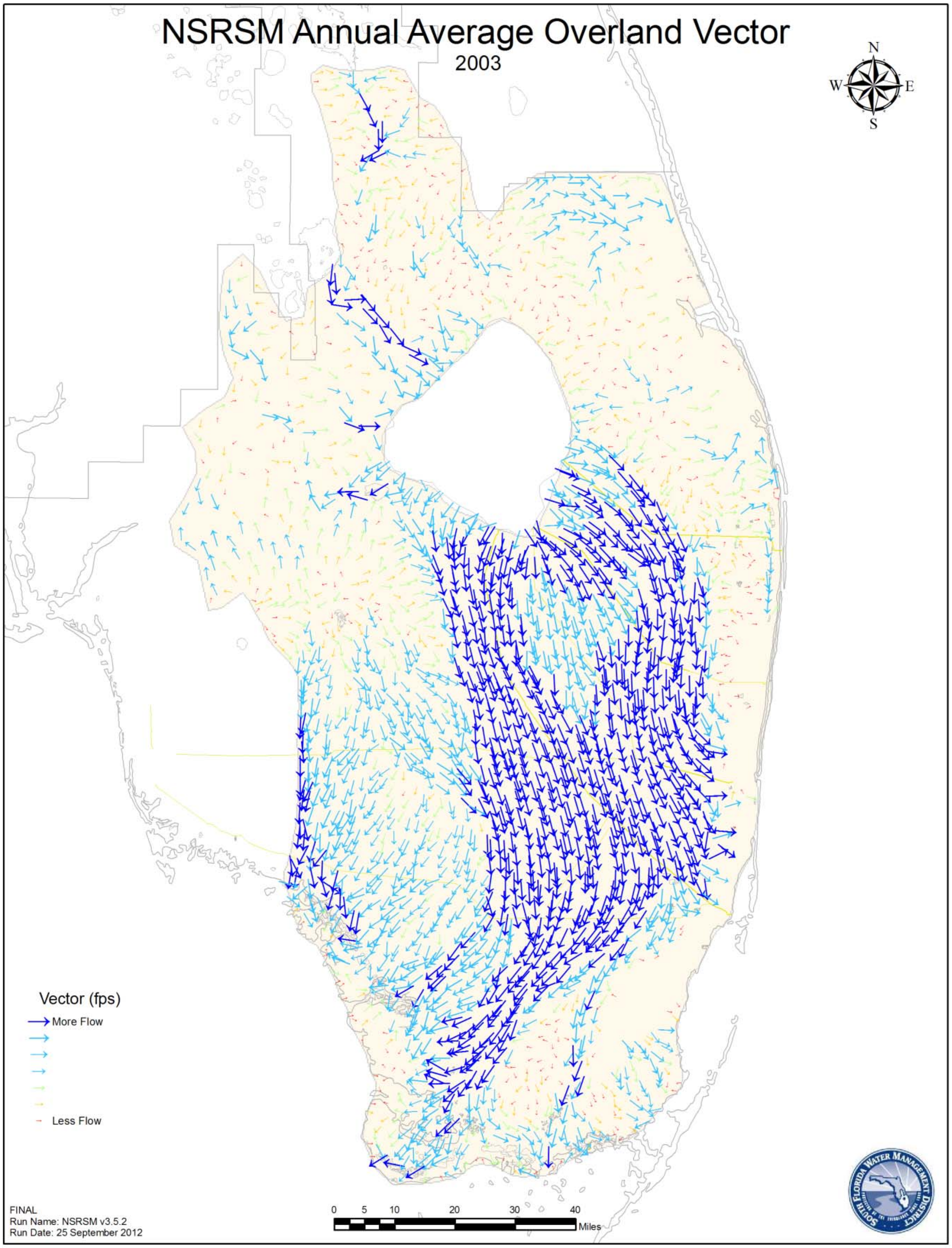

Figure K-120. Annual average overland flow values for the NSRSM model domain for 2003.

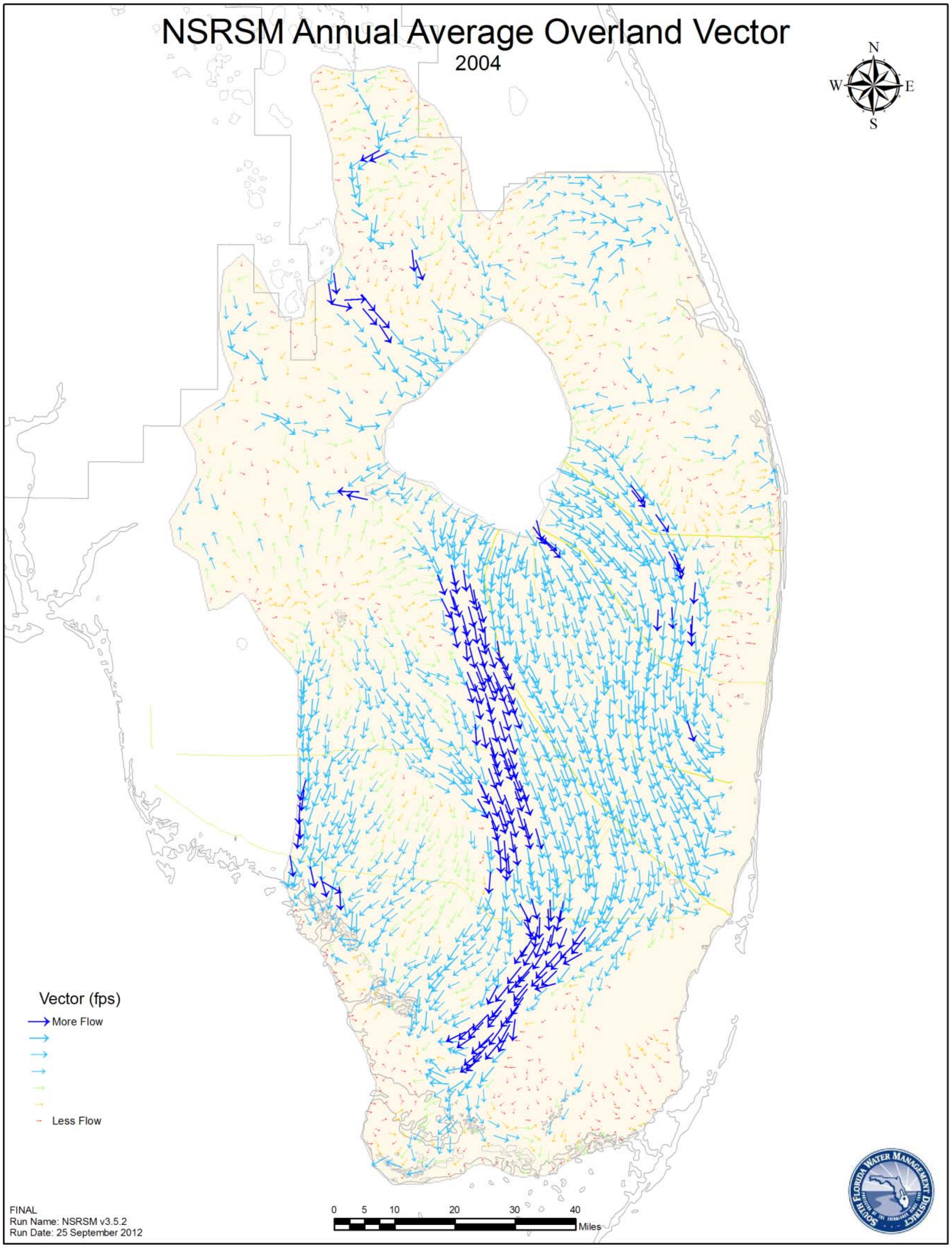

Figure K-121. Annual average overland flow values for the NSRSM model domain for 2004.

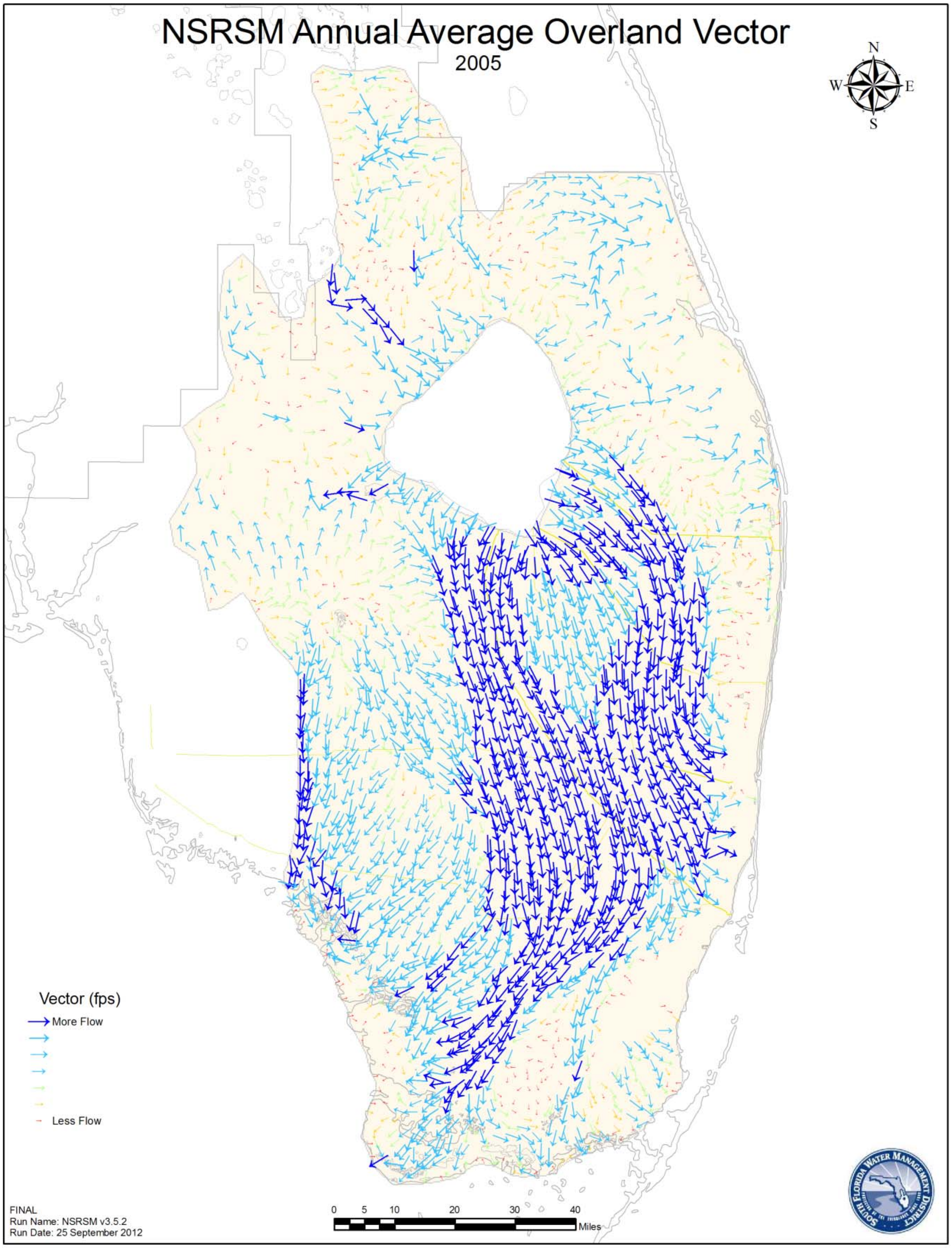

Figure K-122. Annual average overland flow values for the NSRSM model domain for 2005.

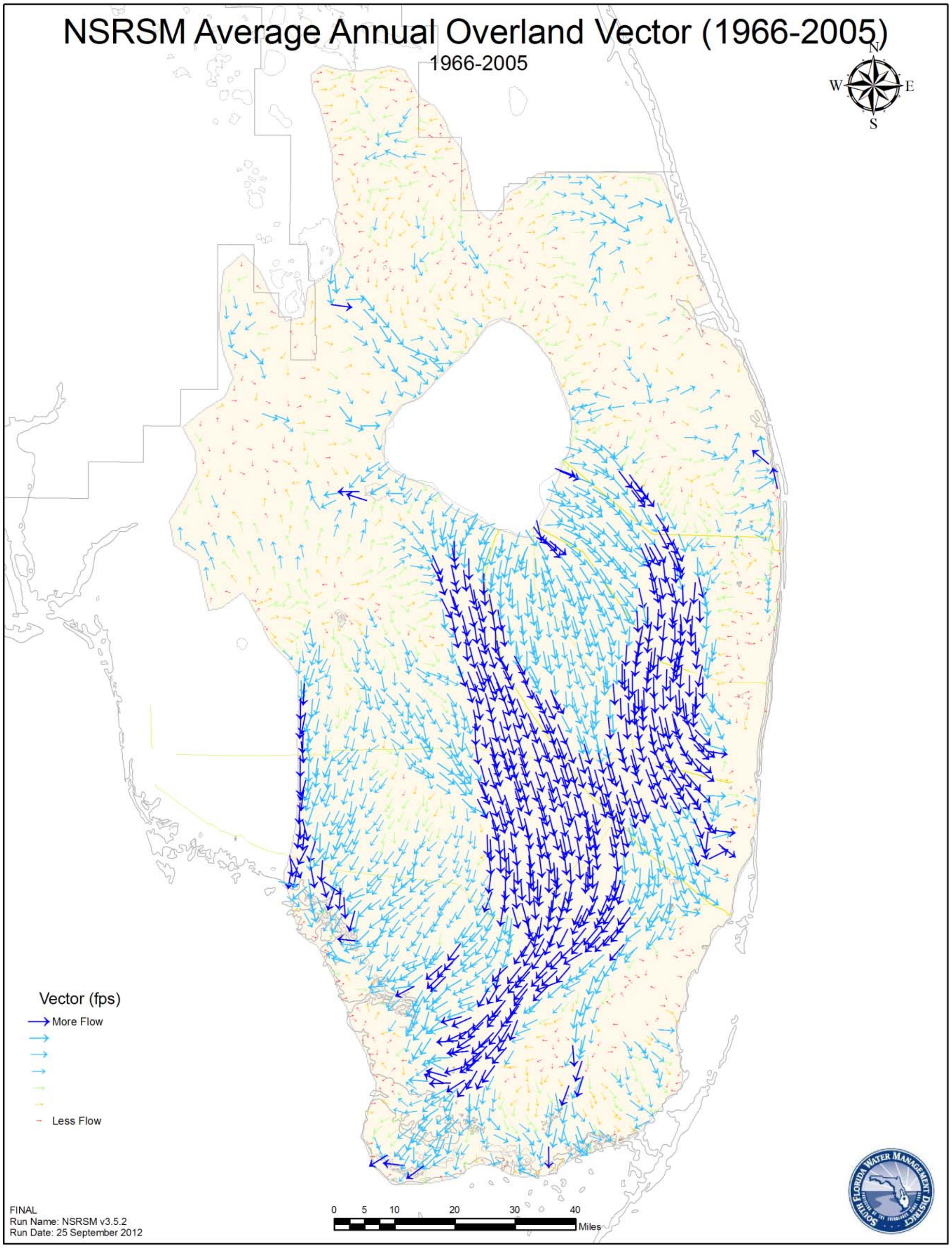

Figure K-123. Average annual overland flow values for the NSRSM model domain for the period 1966-2005.

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Figures K-124 through **K-163** display annual average hydroperiod distribution for the NSRSM model domain for 1966 through 2005, respectively. **Figure K-164** displays the average annual hydroperiod distribution for the entire period of record, 1966-2005.

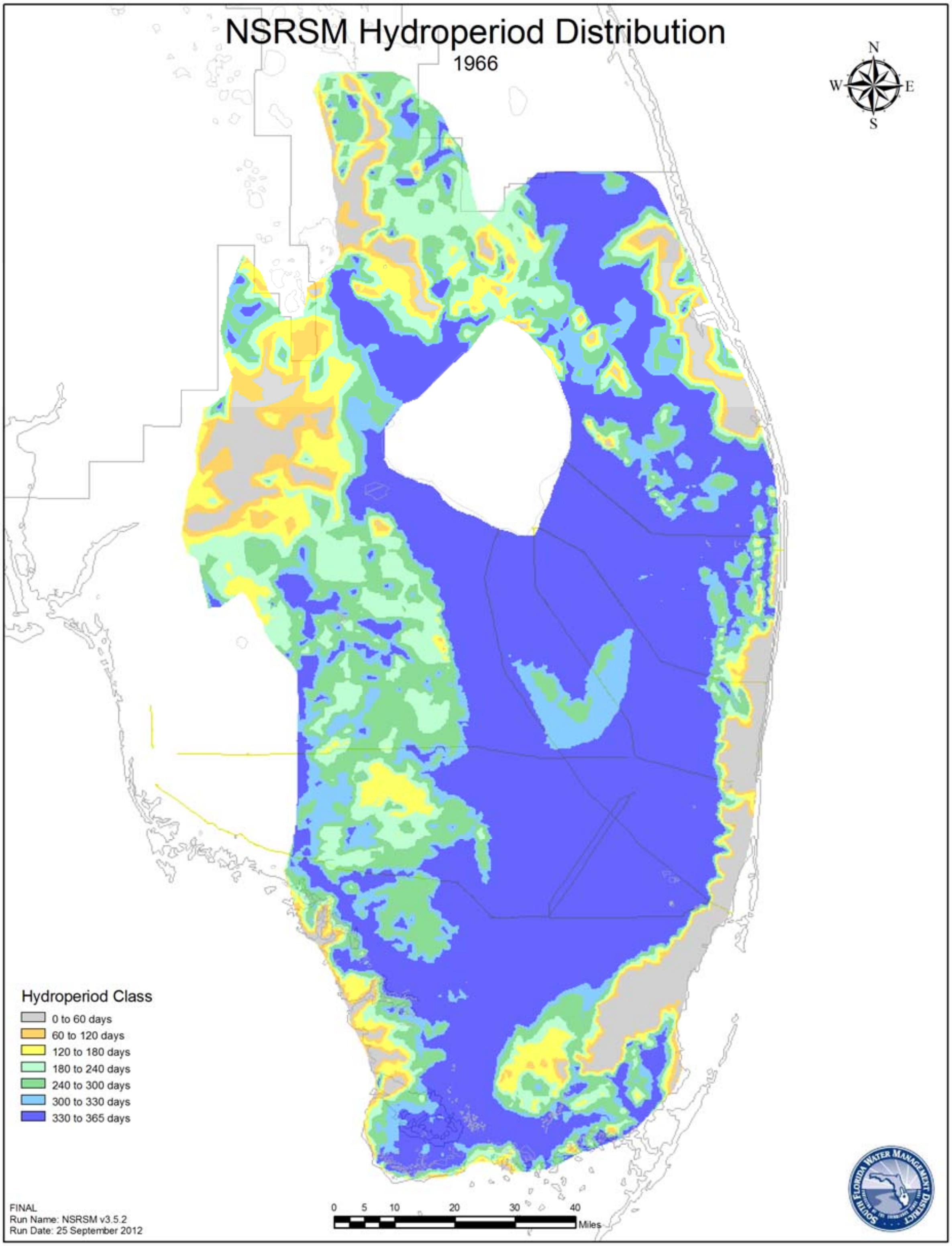

Figure K-124. Annual average hydroperiod distribution for the NSRSM model domain for 1966.

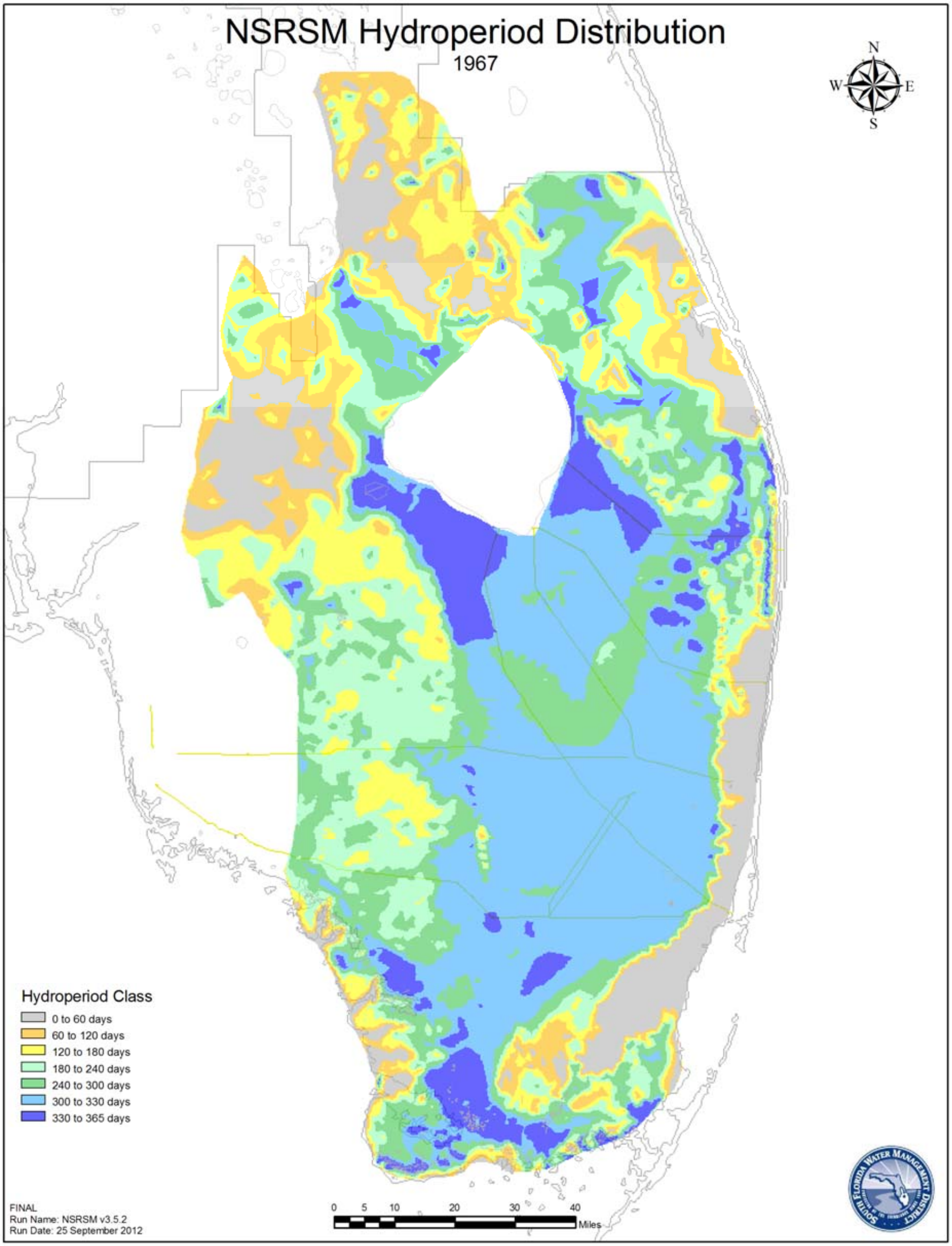

Figure K-125. Annual average hydroperiod distribution for the NSRSM model domain for 1967.

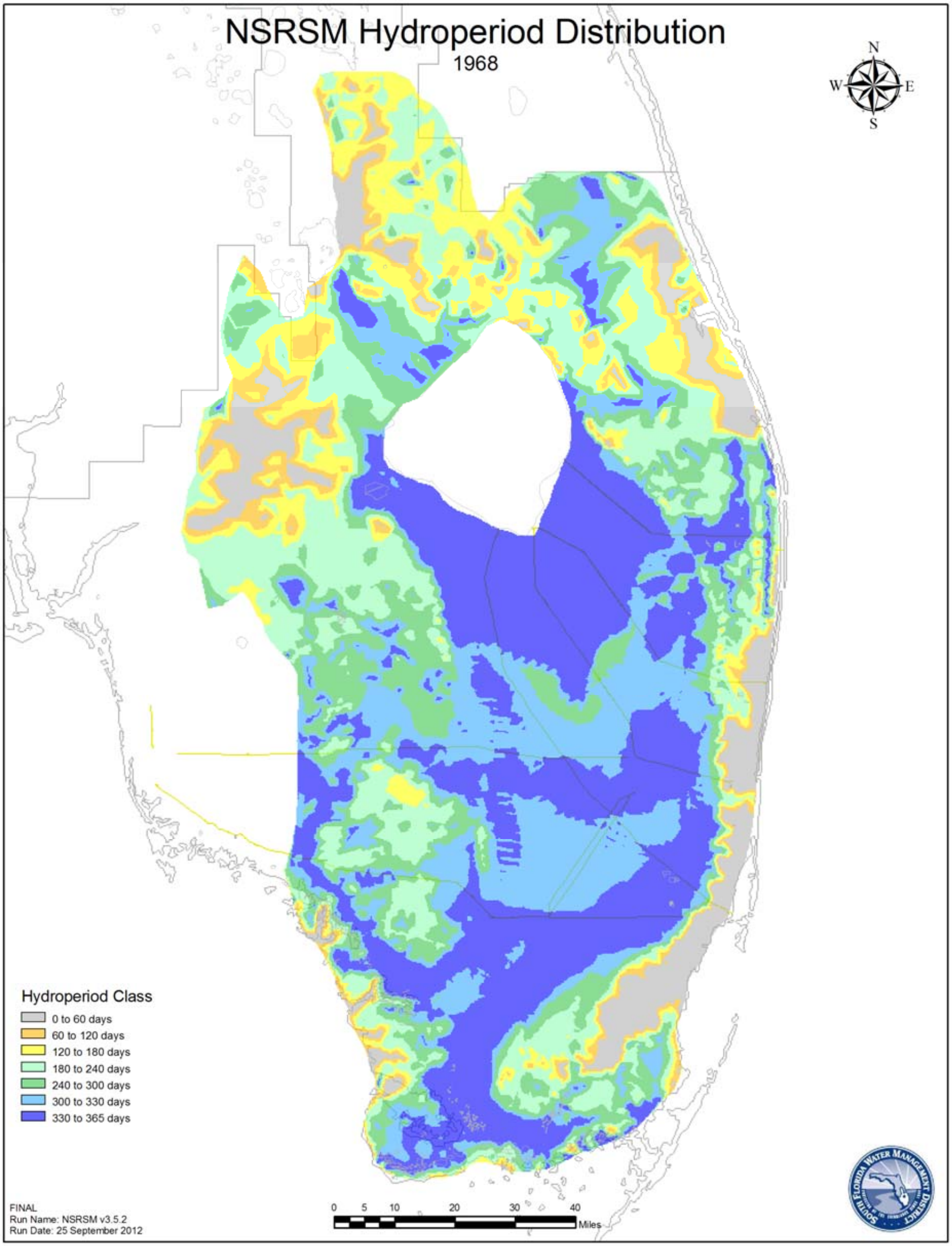

Figure K-126. Annual average hydroperiod distribution for the NSRSM model domain for 1968.

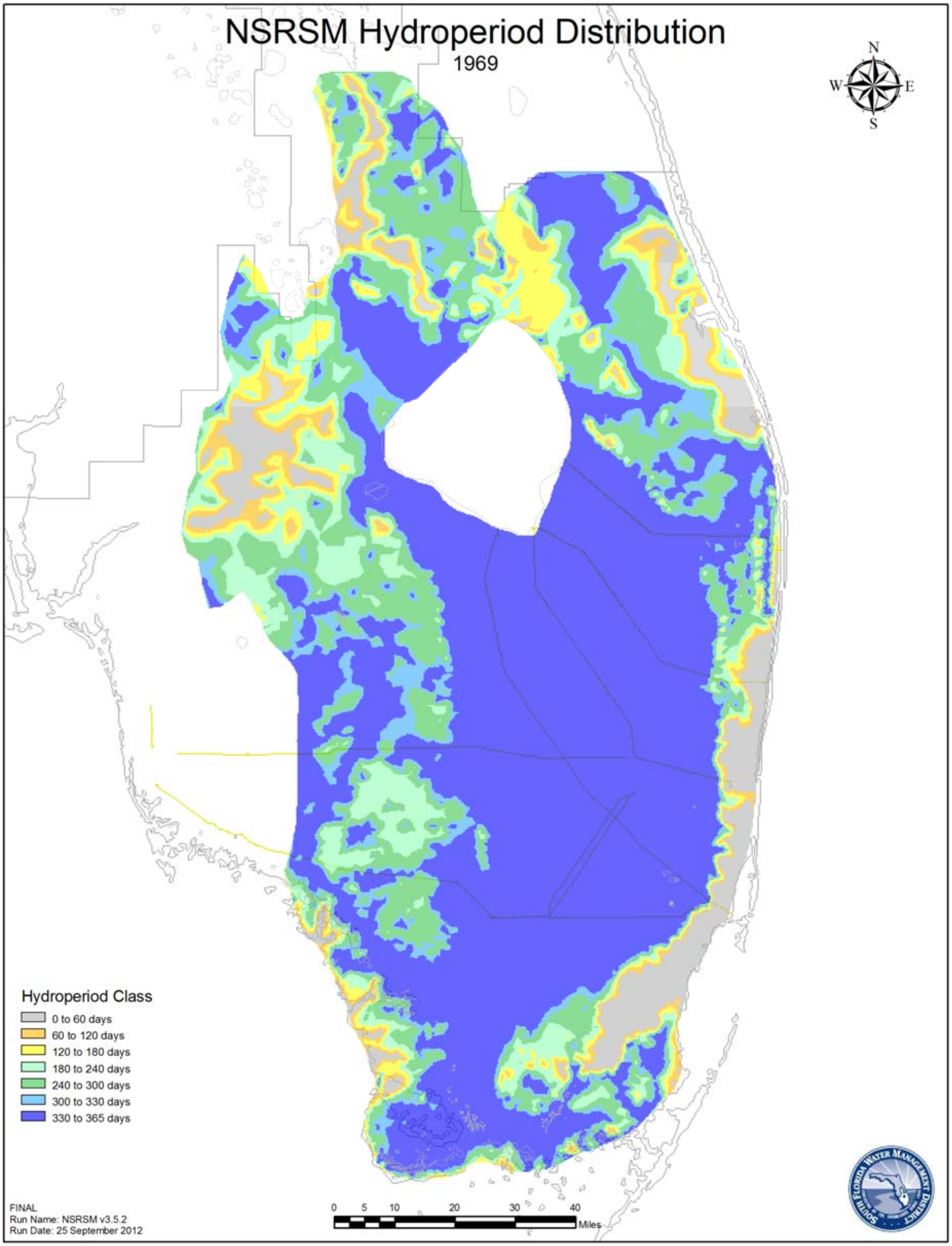

Figure K-127. Annual average hydroperiod distribution for the NSRSM model domain for 1969.

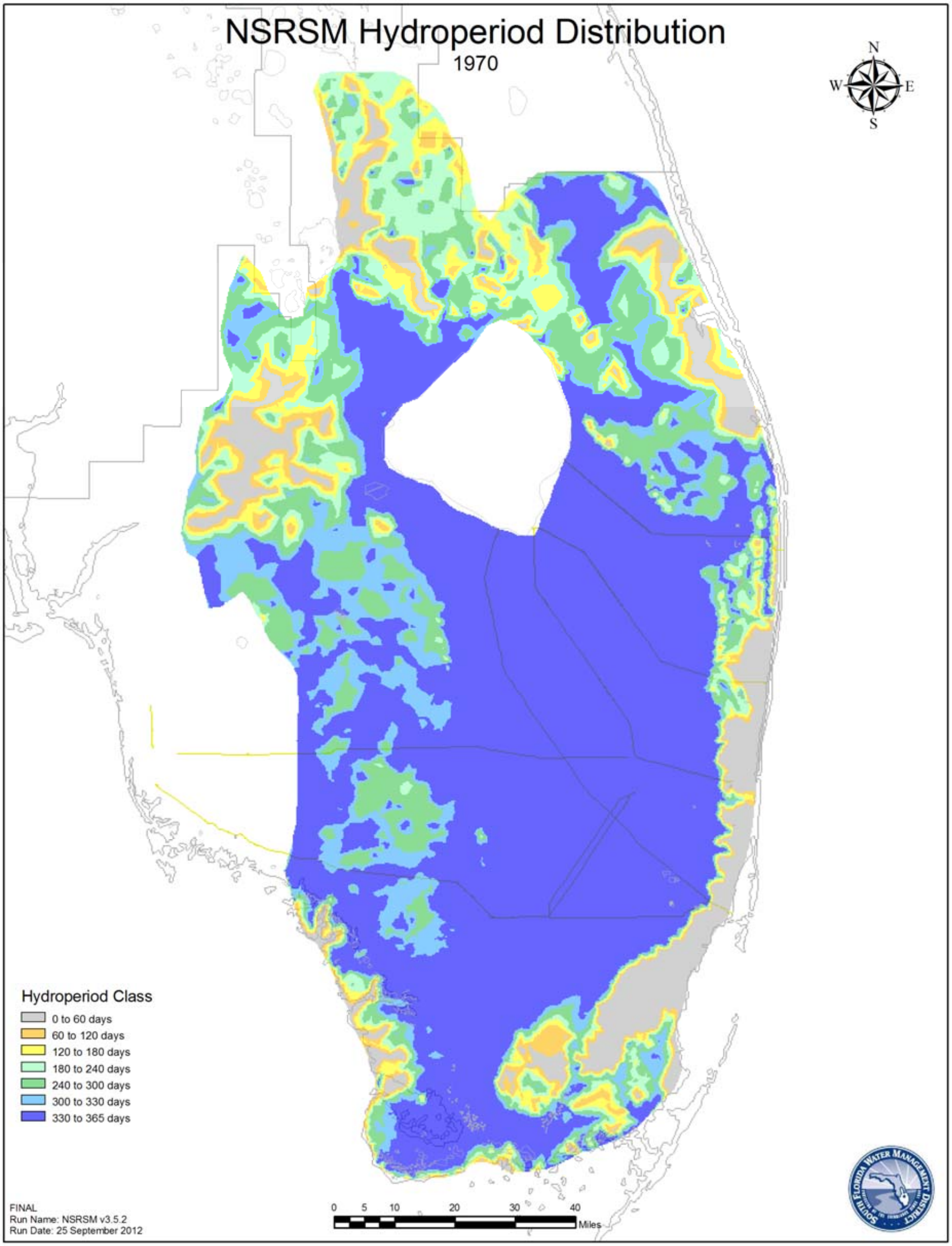

Figure K-128. Annual average hydroperiod distribution for the NSRSM model domain for 1970.

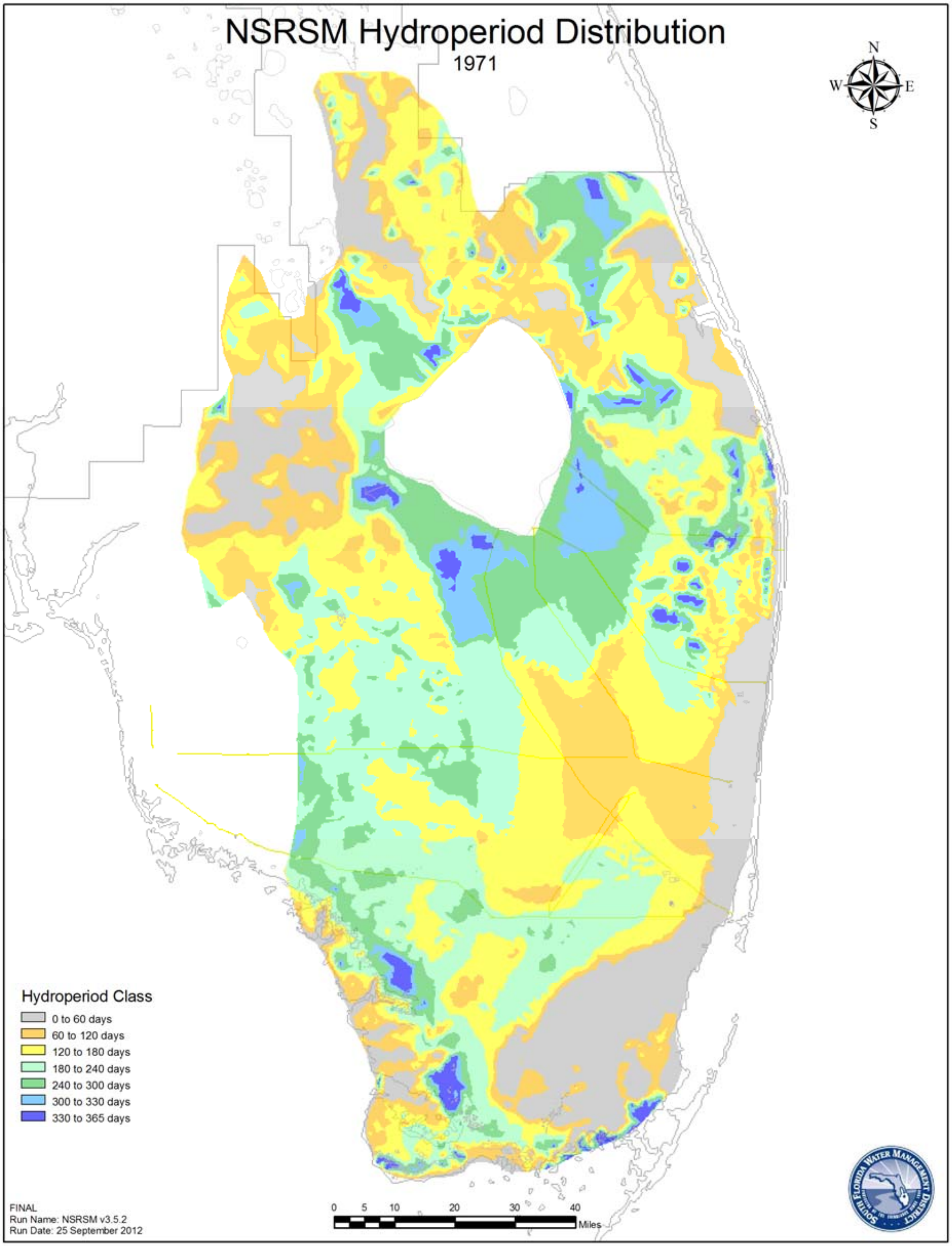

Figure K-129. Annual average hydroperiod distribution for the NSRSM model domain for 1971.

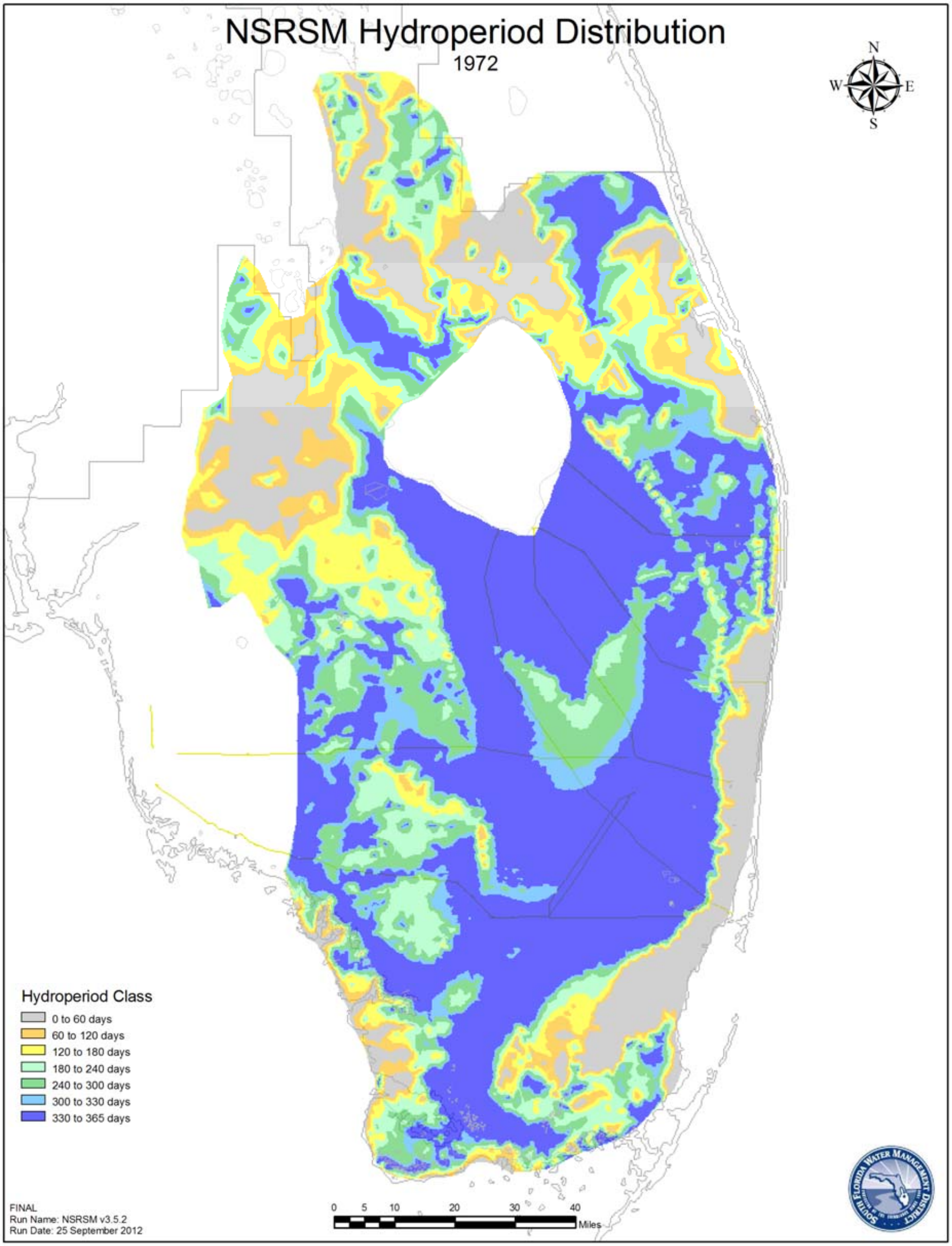

Figure K-130. Annual average hydroperiod distribution for the NSRSM model domain for 1972.

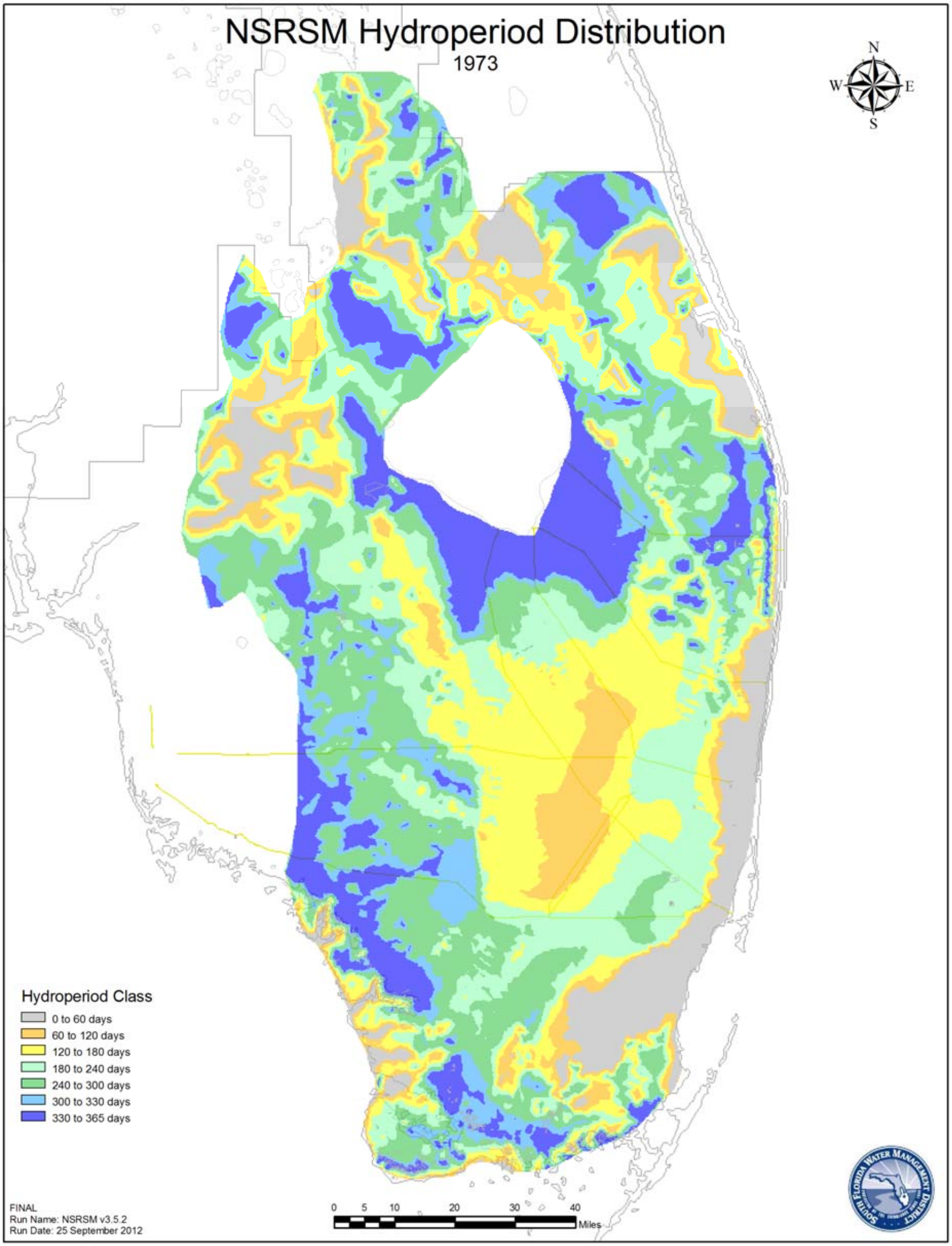

Figure K-131. Annual average hydroperiod distribution for the NSRSM model domain for 1973.

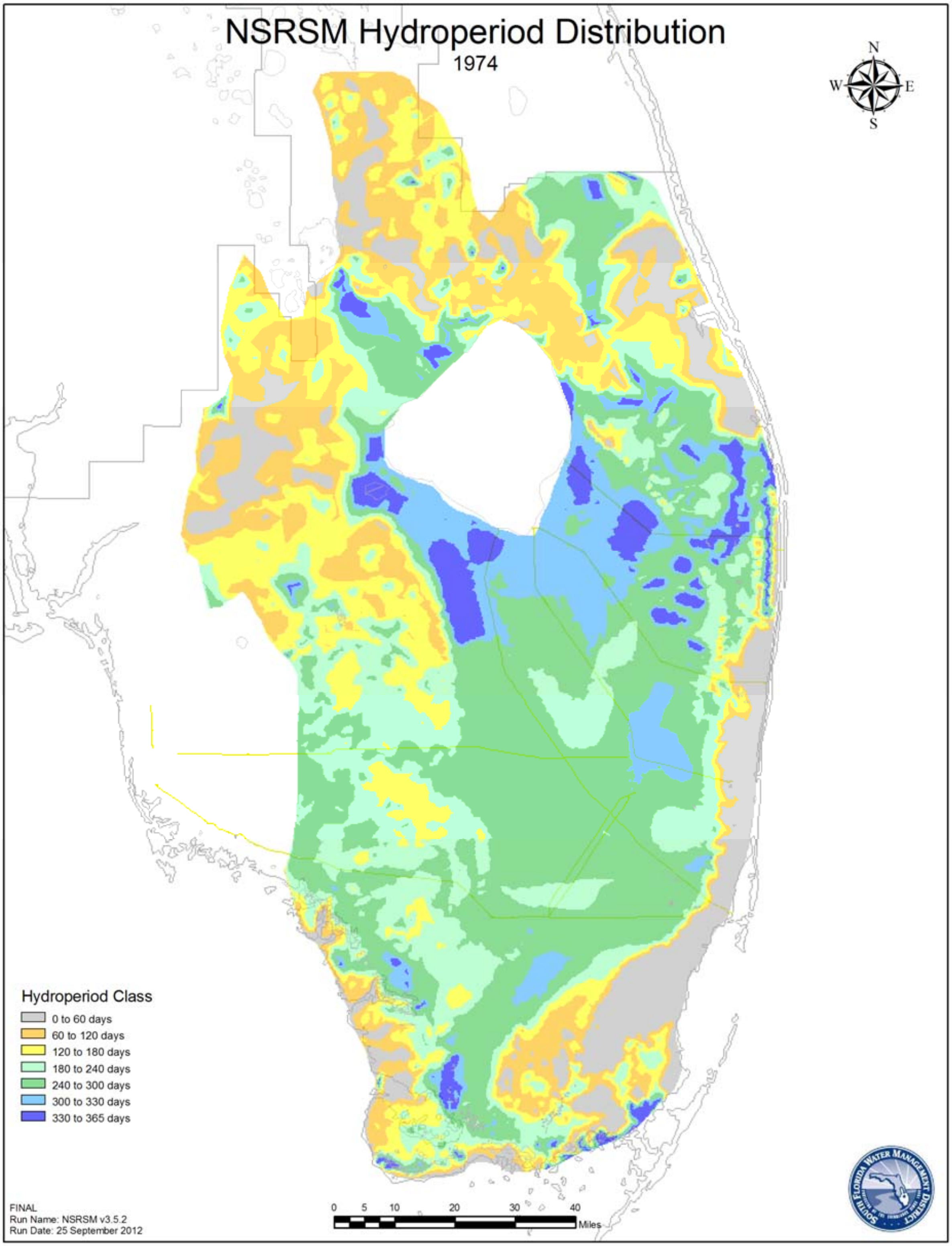

Figure K-132. Annual average hydroperiod distribution for the NSRSM model domain for 1974.

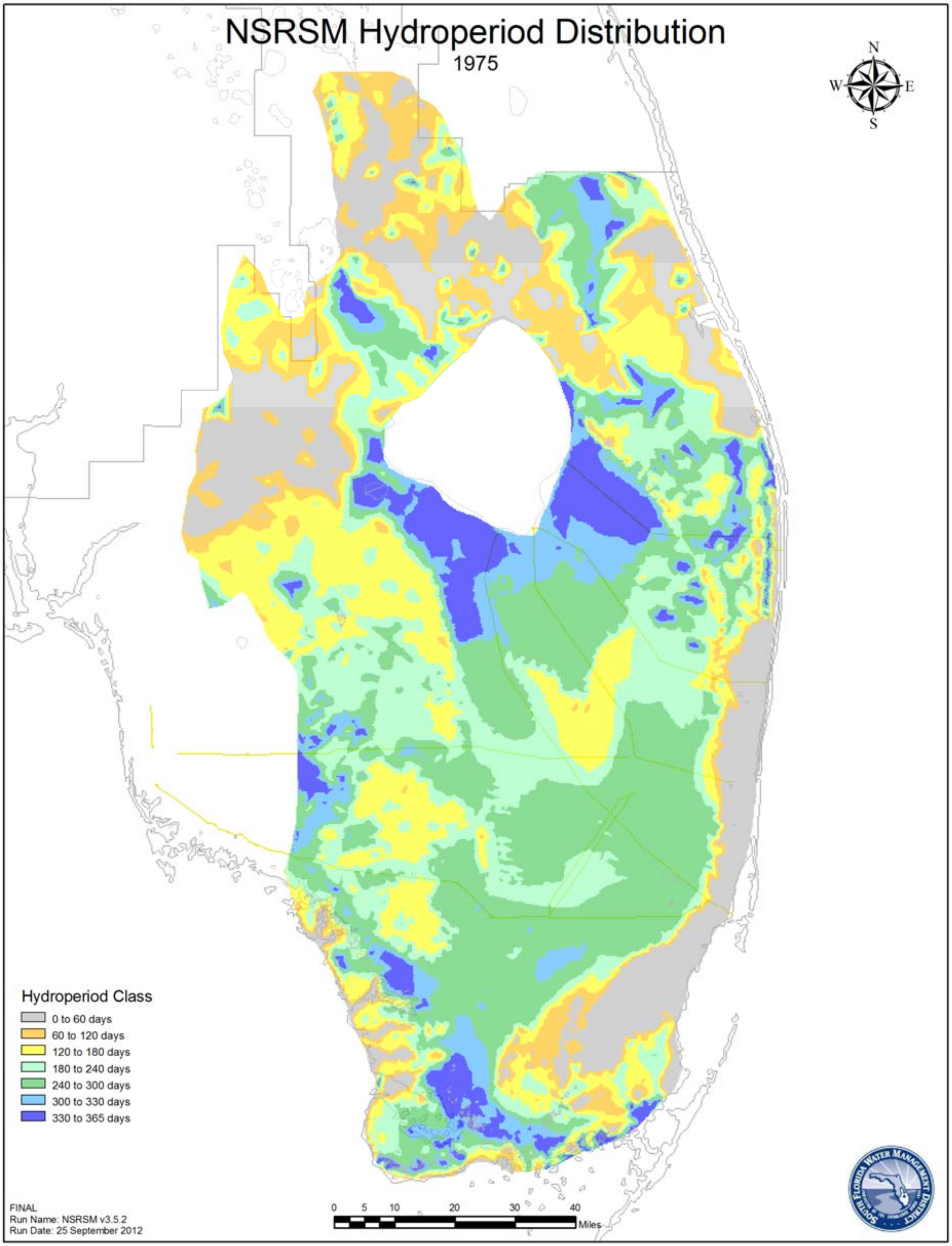

Figure K-133. Annual average hydroperiod distribution for the NSRSM model domain for 1975.

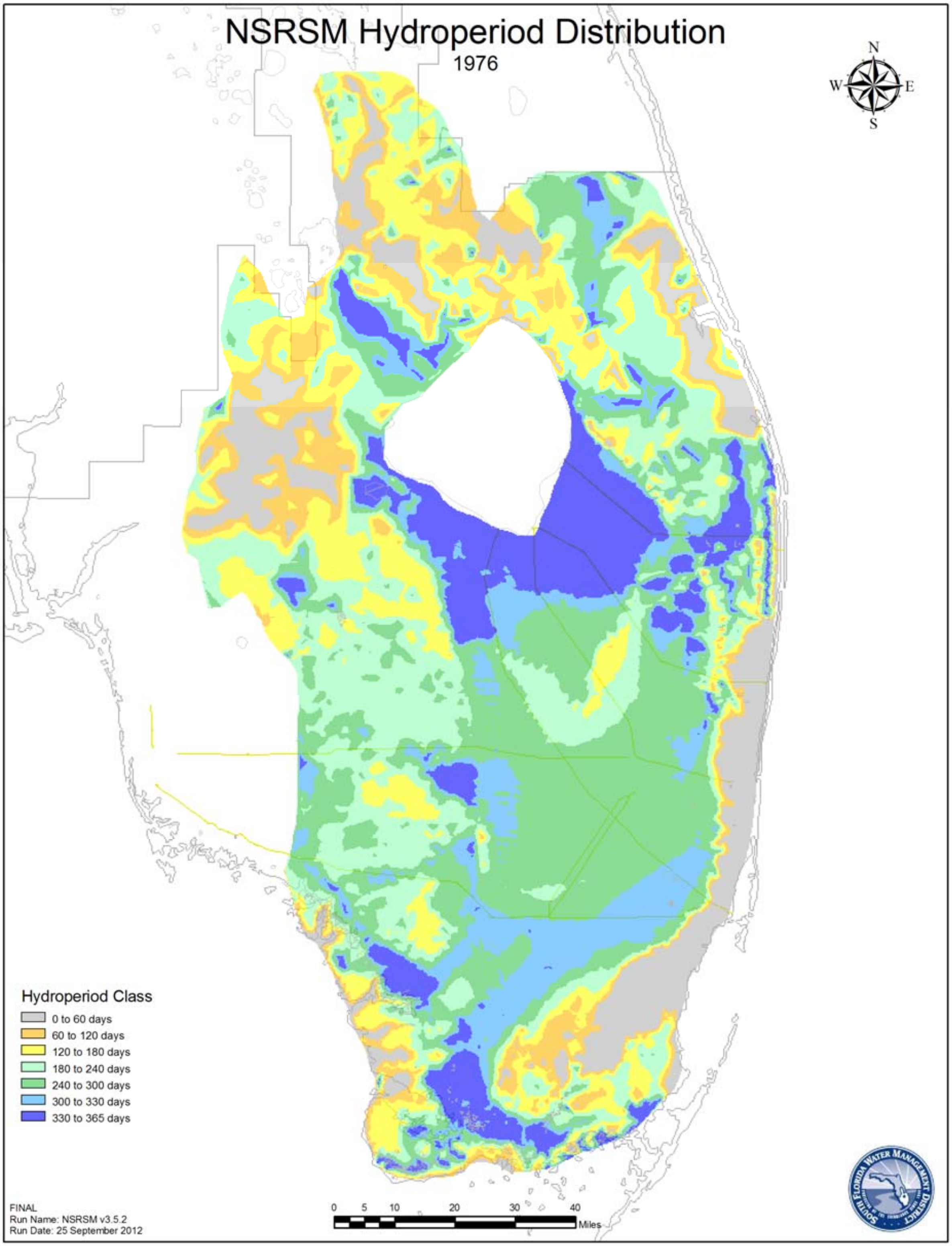

Figure K-134. Annual average hydroperiod distribution for the NSRSM model domain for 1976.

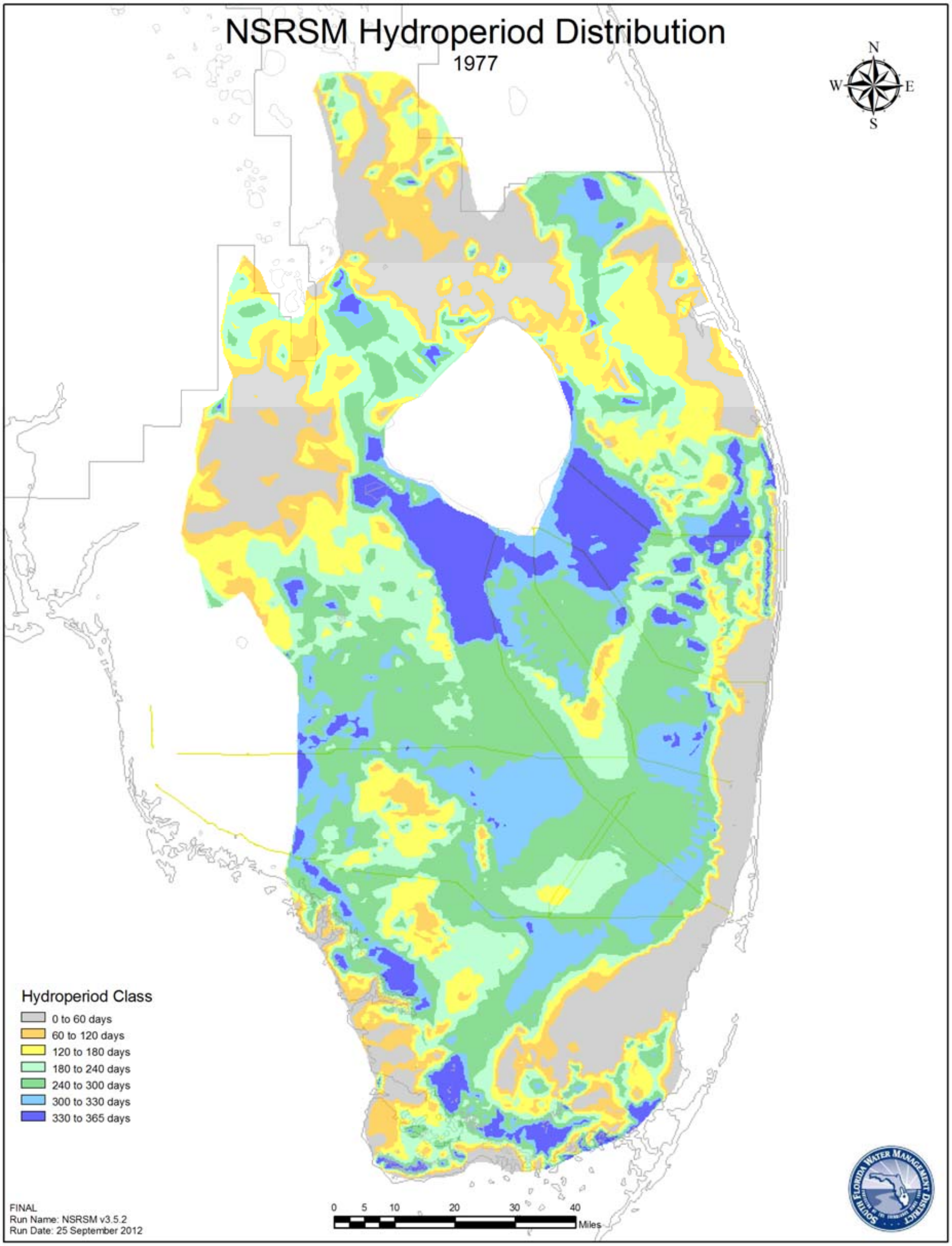

Figure K-135. Annual average hydroperiod distribution for the NSRSM model domain for 1977.

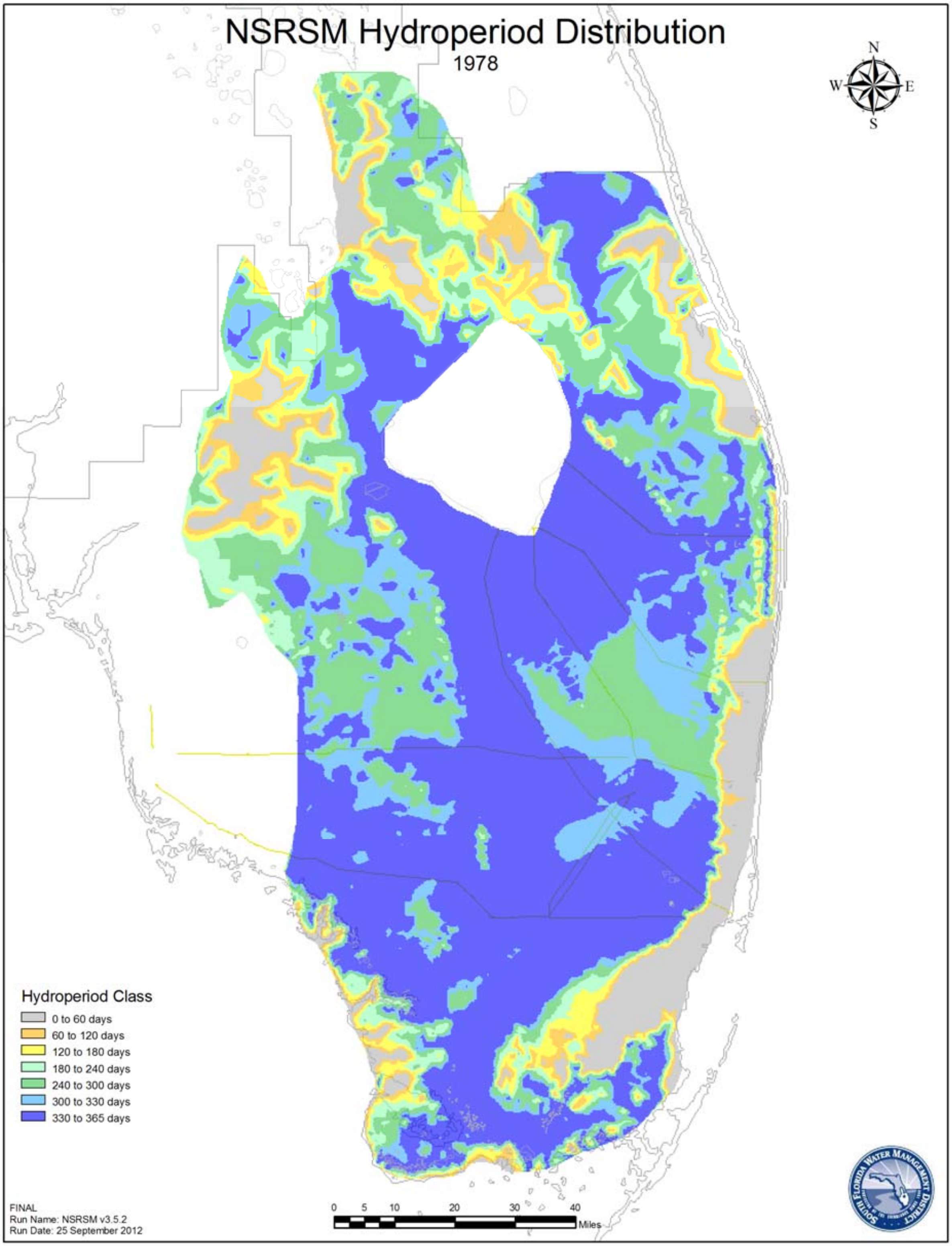

Figure K-136. Annual average hydroperiod distribution for the NSRSM model domain for 1978.

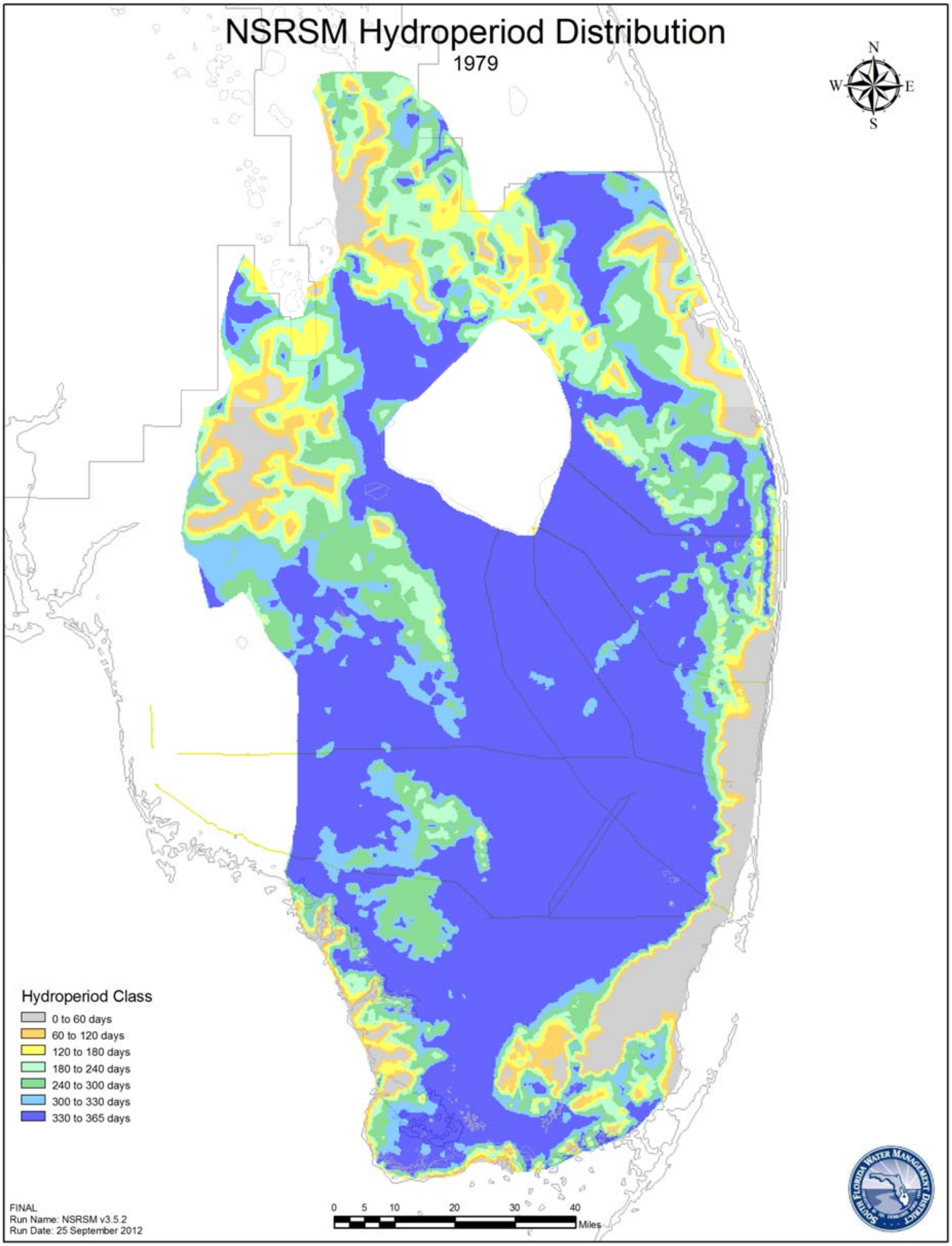

Figure K-137. Annual average hydroperiod distribution for the NSRSM model domain for 1979.

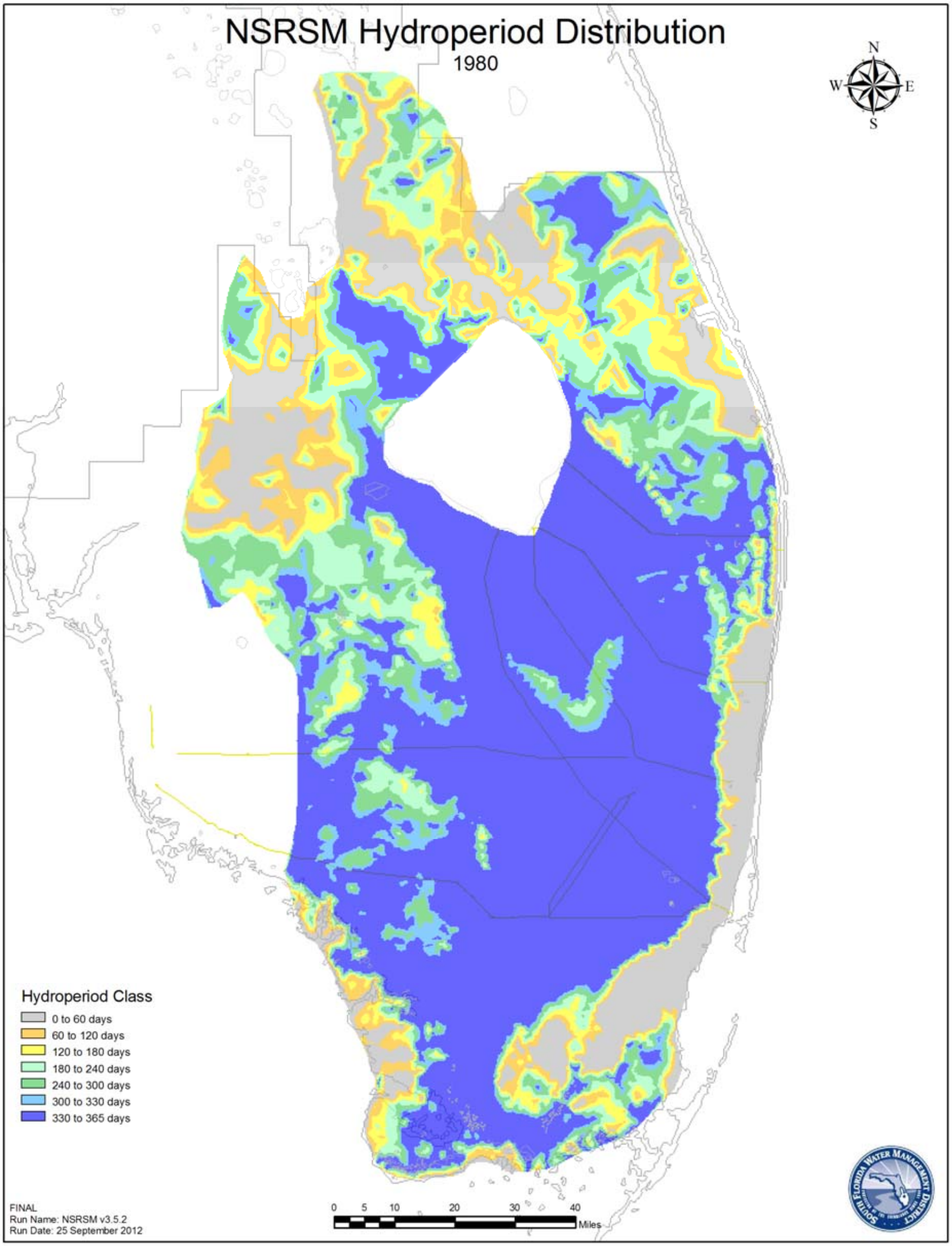

Figure K-138. Annual average hydroperiod distribution for the NSRSM model domain for 1980.

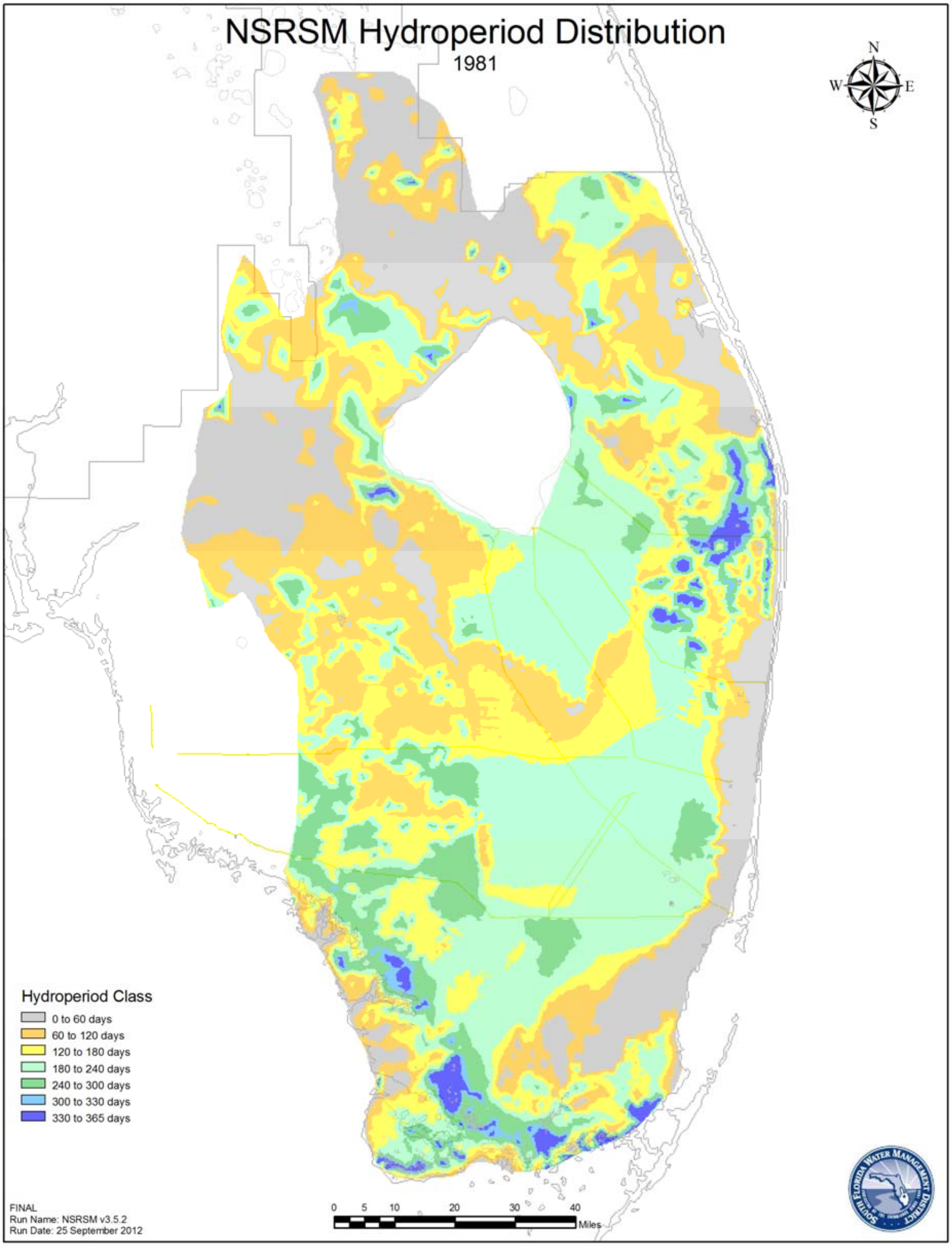

Figure K-139. Annual average hydroperiod distribution for the NSRSM model domain for 1981.

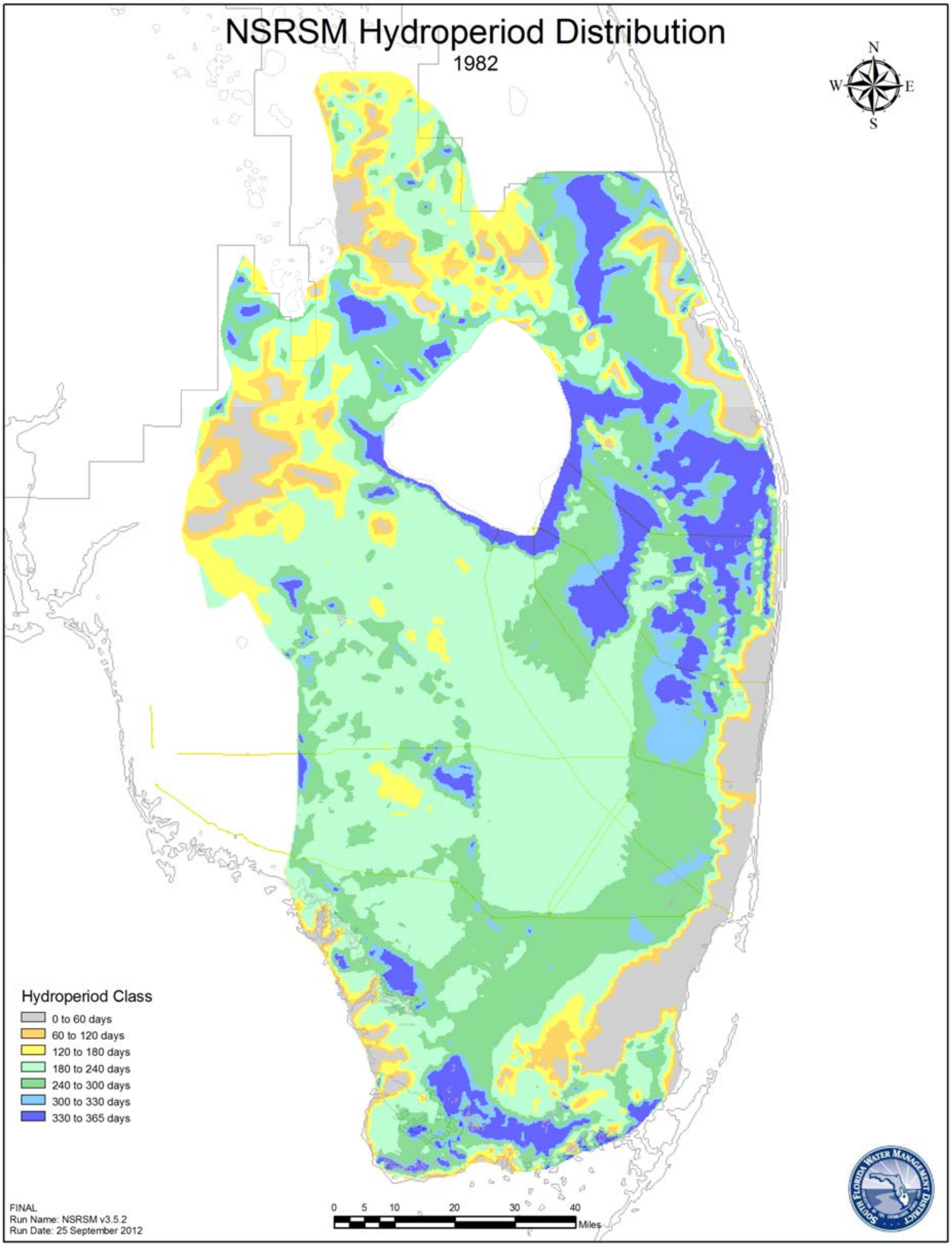

Figure K-140. Annual average hydroperiod distribution for the NSRSM model domain for 1982.

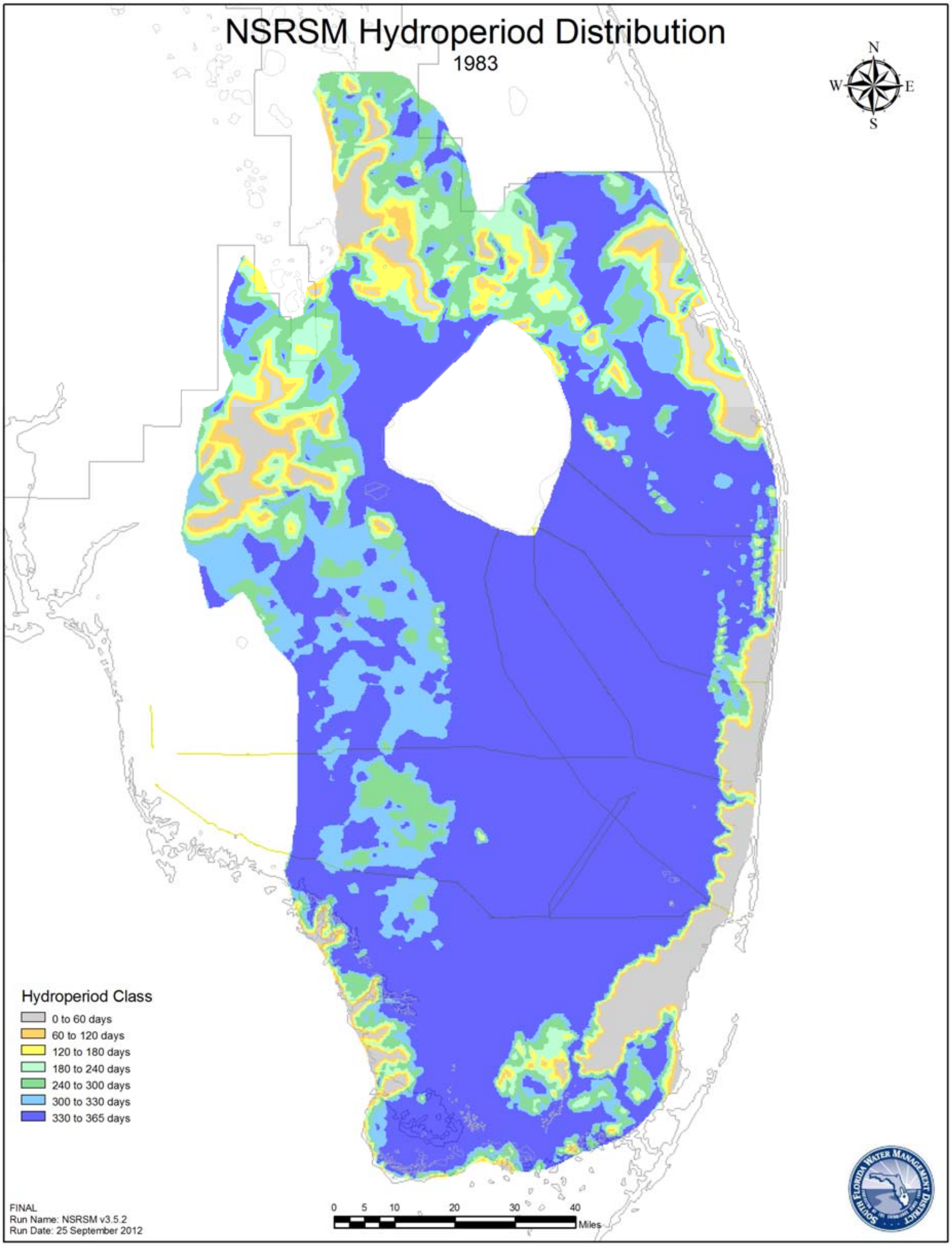

Figure K-141. Annual average hydroperiod distribution for the NSRSM model domain for 1983.

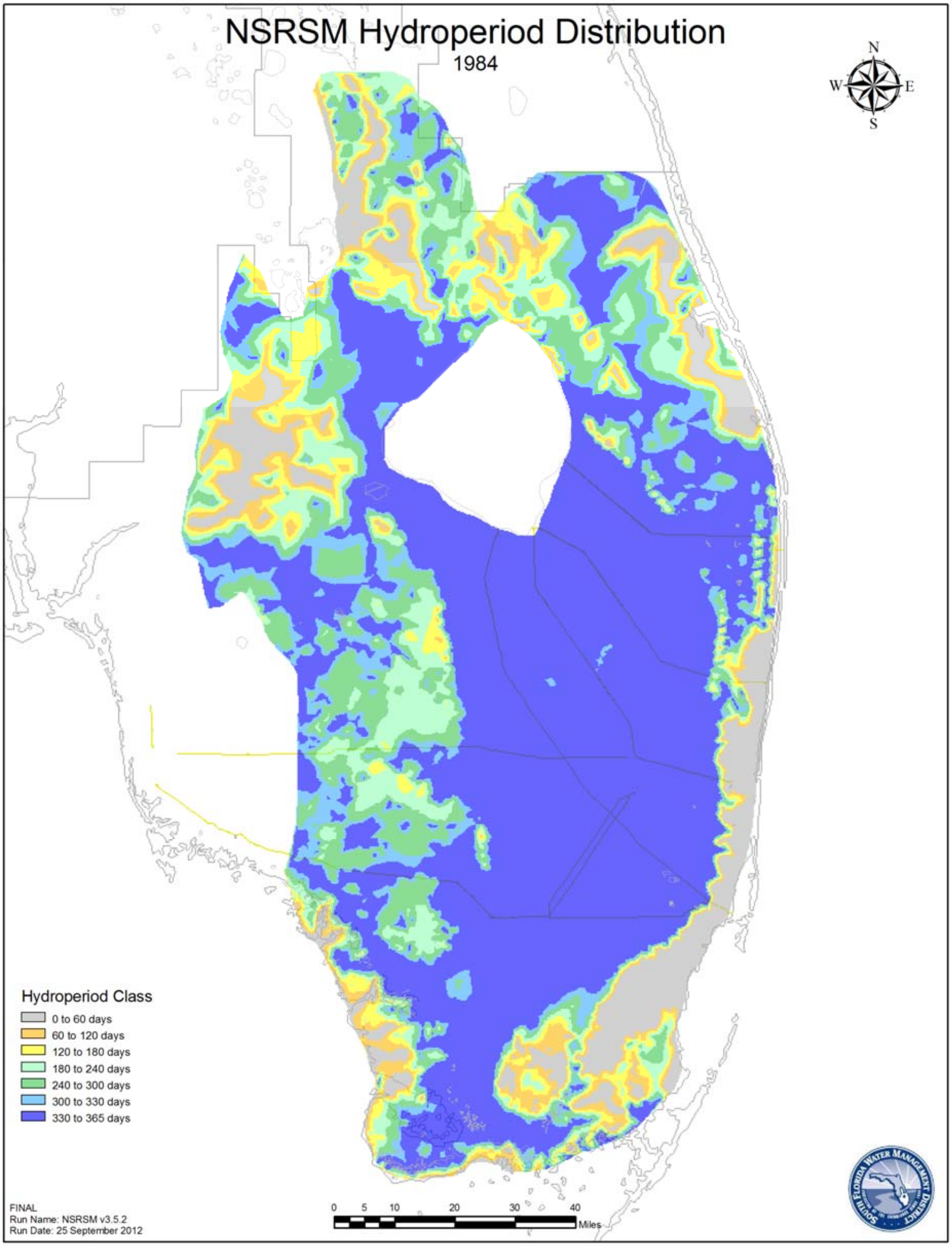

Figure K-142. Annual average hydroperiod distribution for the NSRSM model domain for 1984.

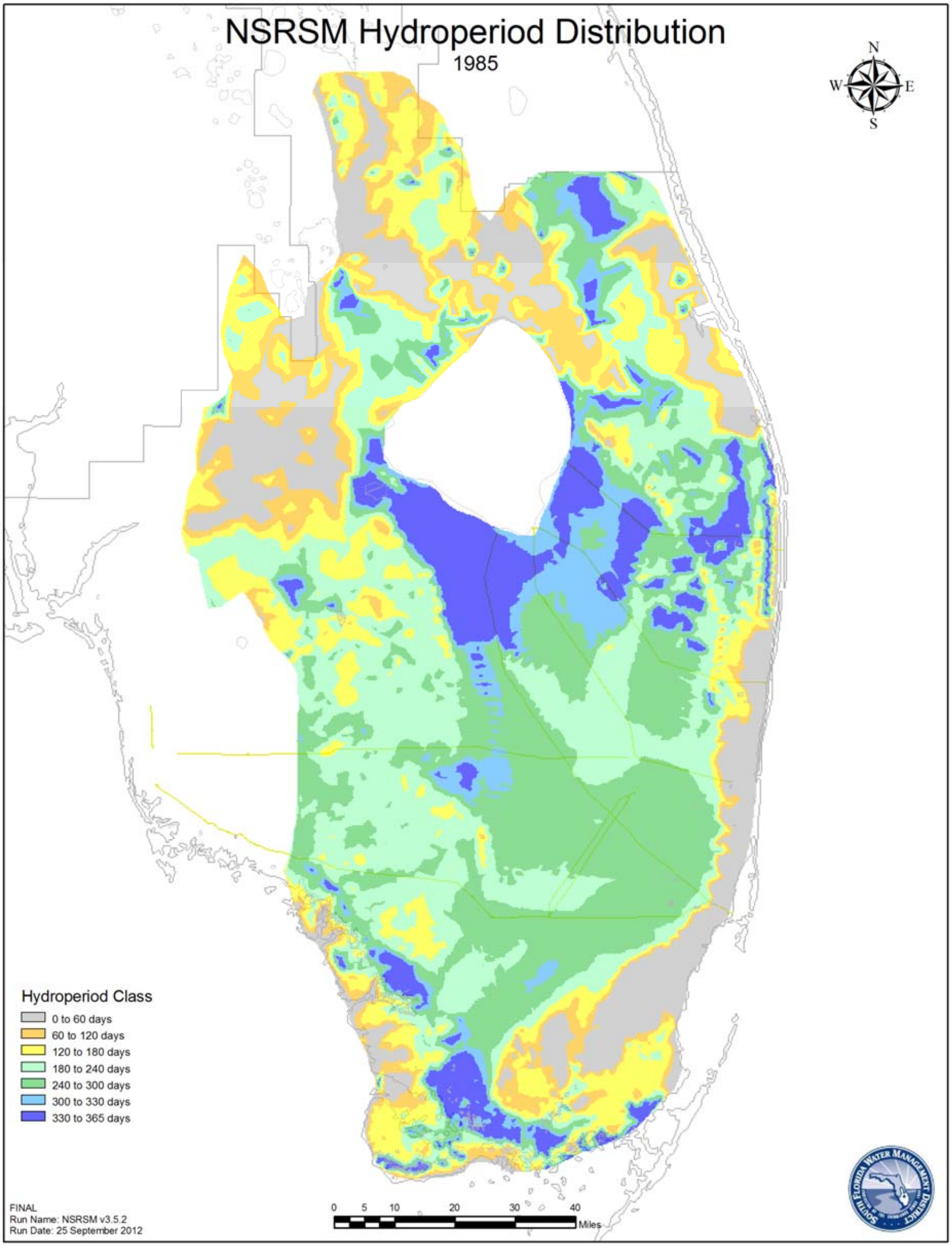

Figure K-143. Annual average hydroperiod distribution for the NSRSM model domain for 1985.

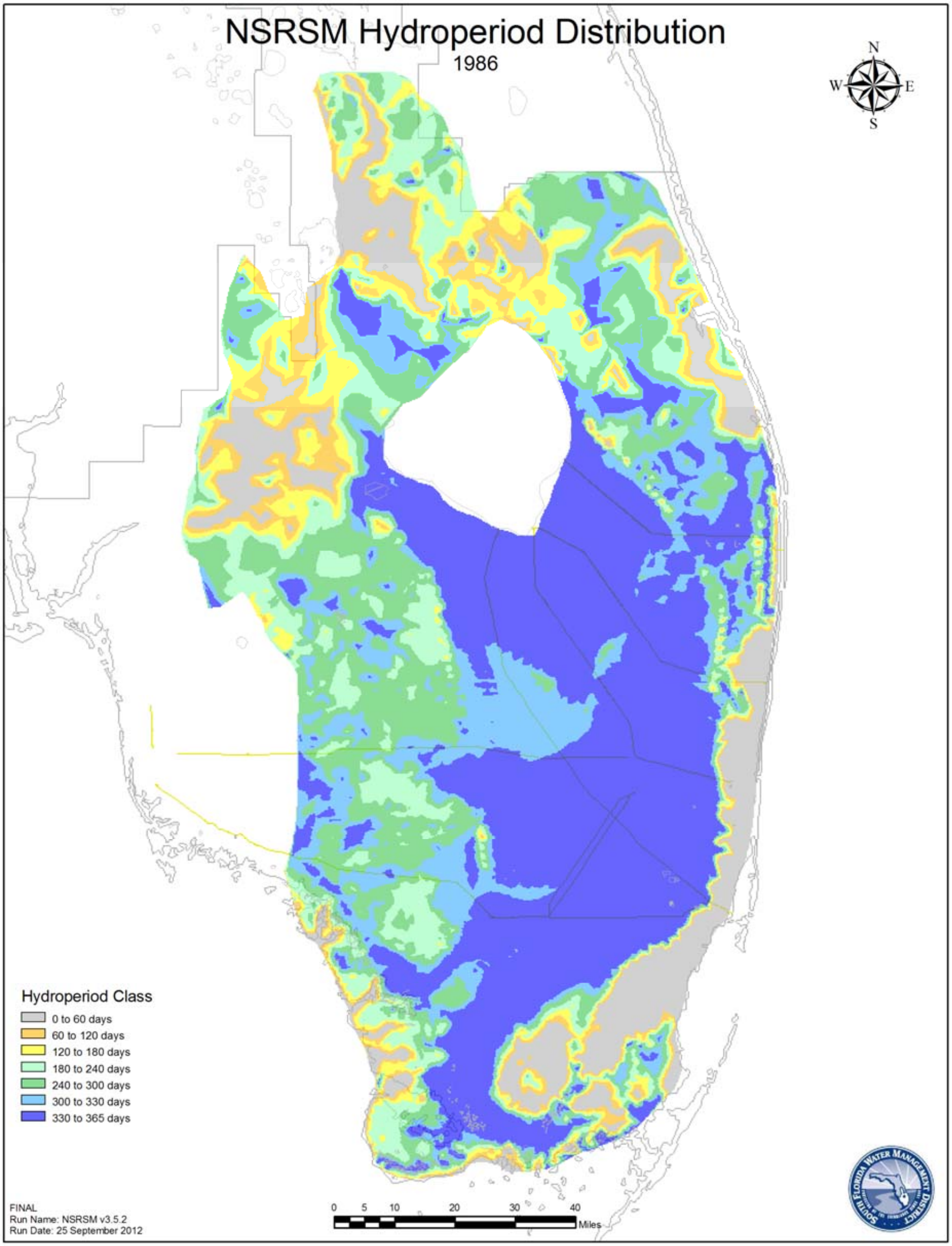

Figure K-144. Annual average hydroperiod distribution for the NSRSM model domain for 1986.

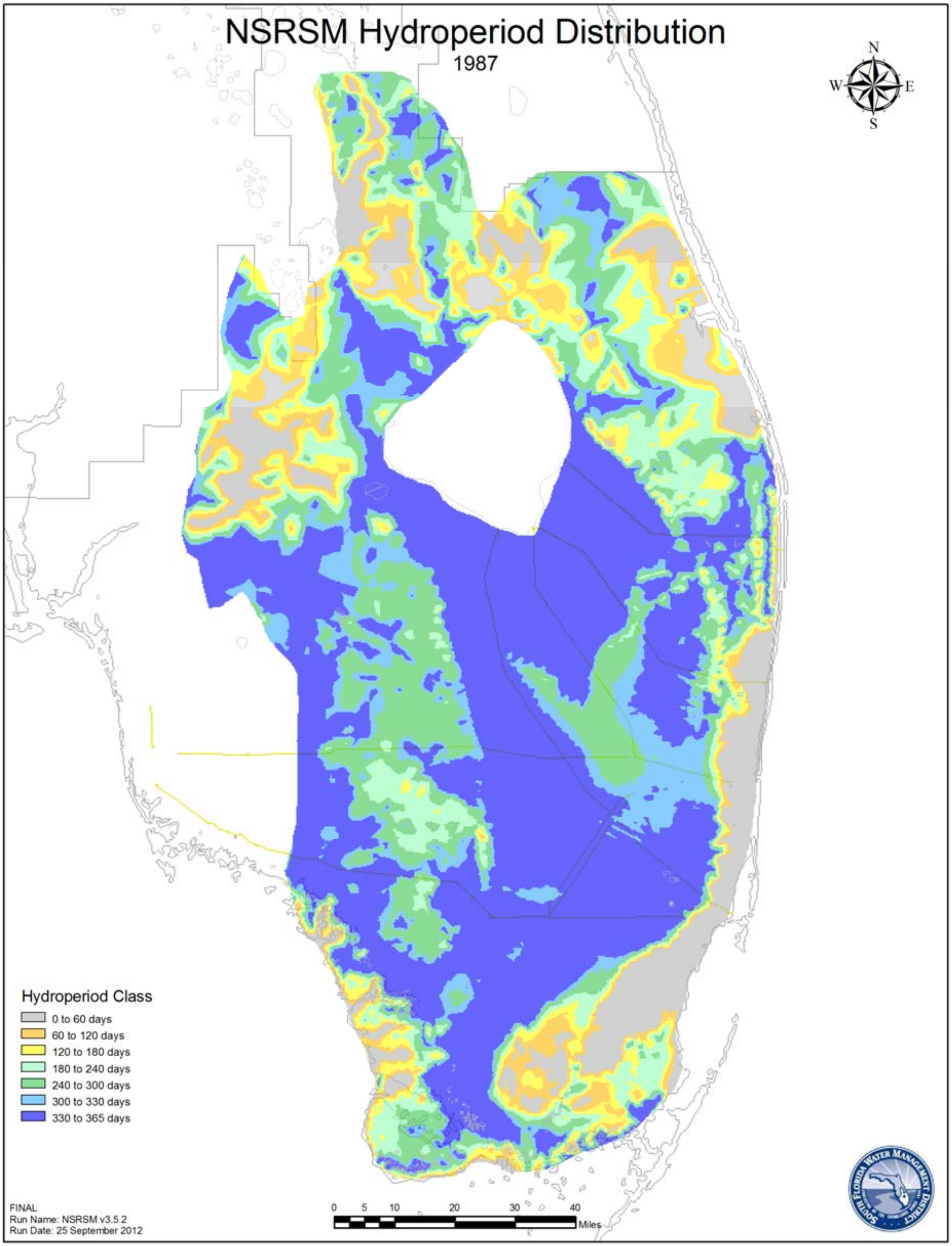

Figure K-145. Annual average hydroperiod distribution for the NSRSM model domain for 1987.

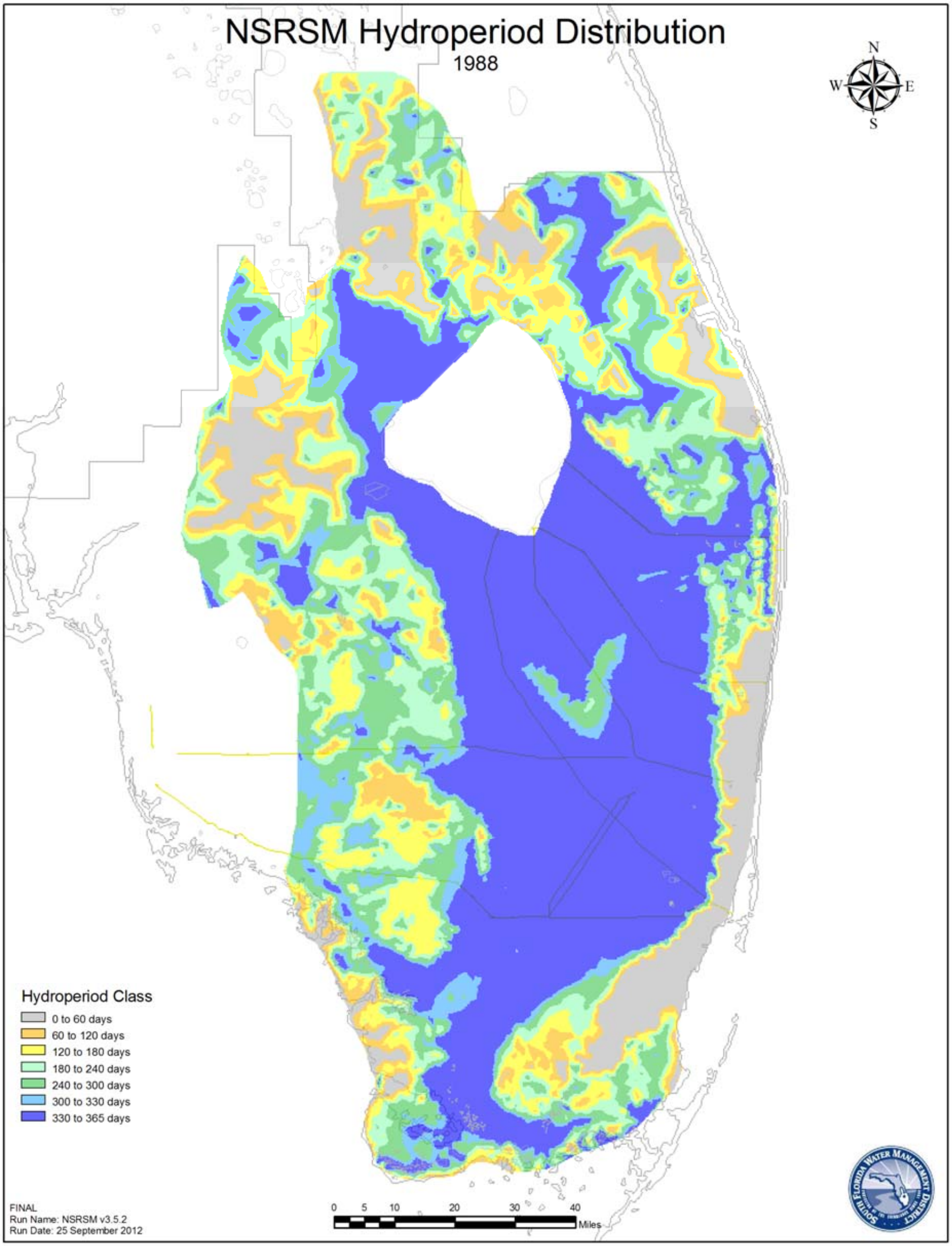

Figure K-146. Annual average hydroperiod distribution for the NSRSM model domain for 1988.

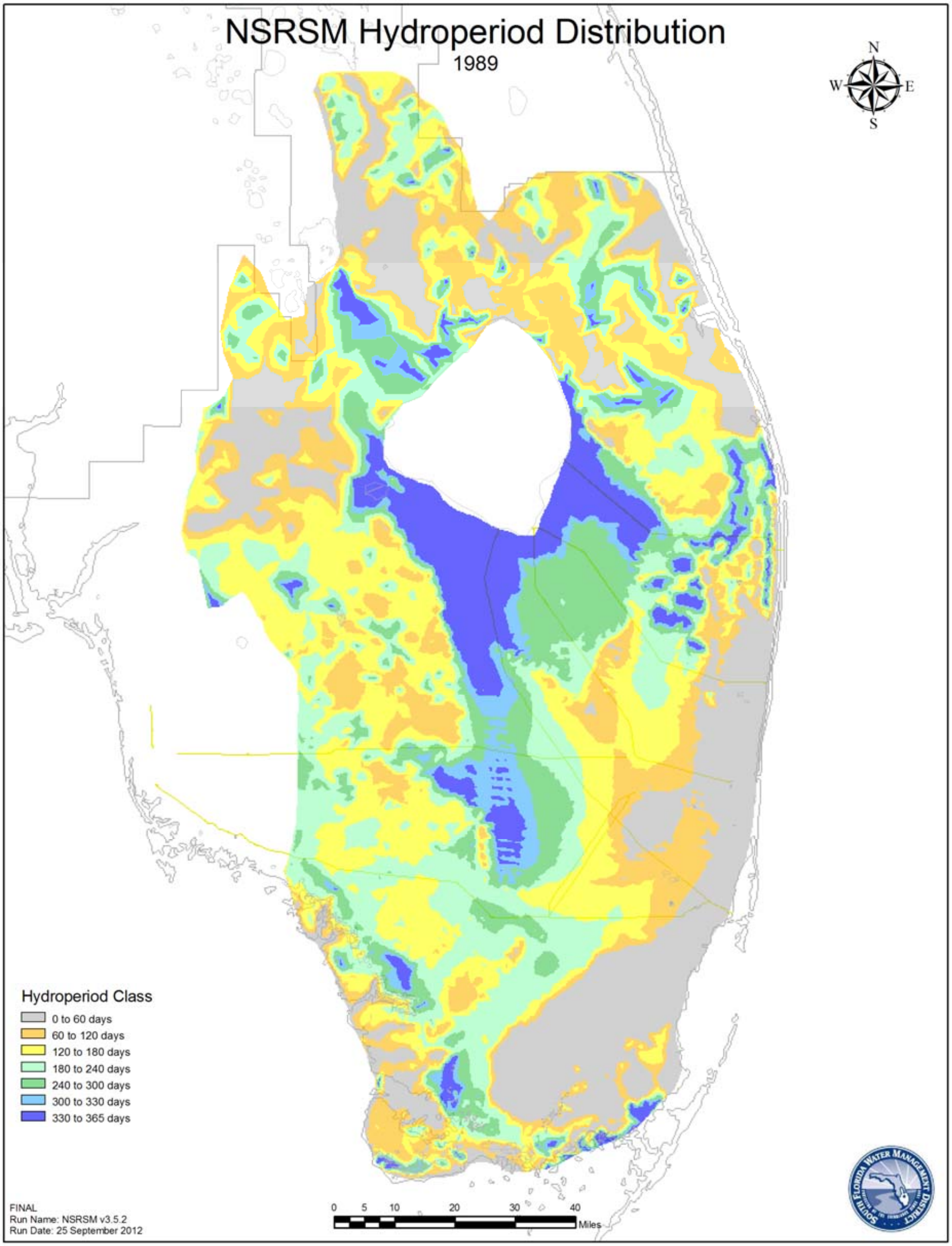

Figure K-147. Annual average hydroperiod distribution for the NSRSM model domain for 1989.

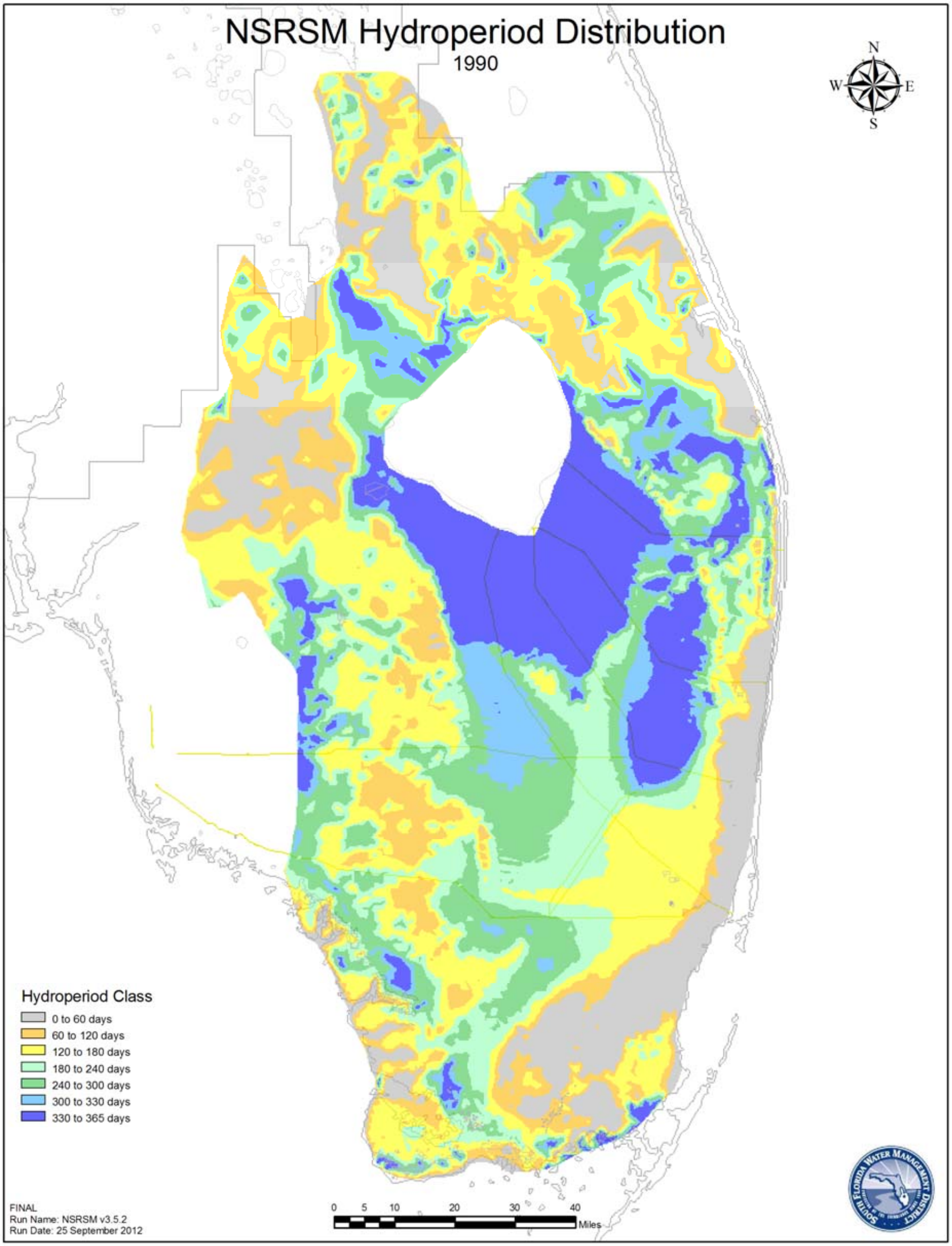

Figure K-148. Annual average hydroperiod distribution for the NSRSM model domain for 1990.

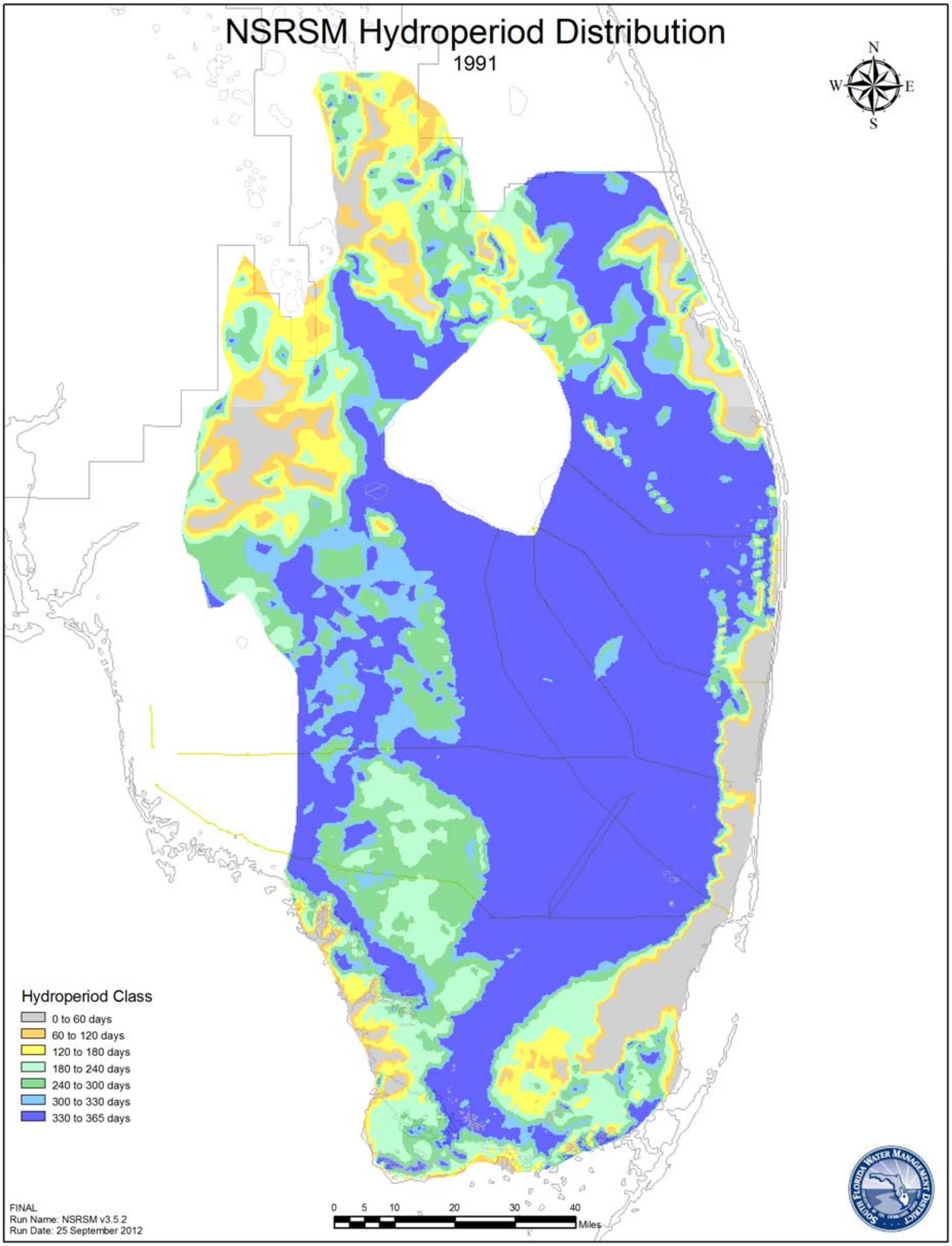

Figure K-149. Annual average hydroperiod distribution for the NSRSM model domain for 1991.

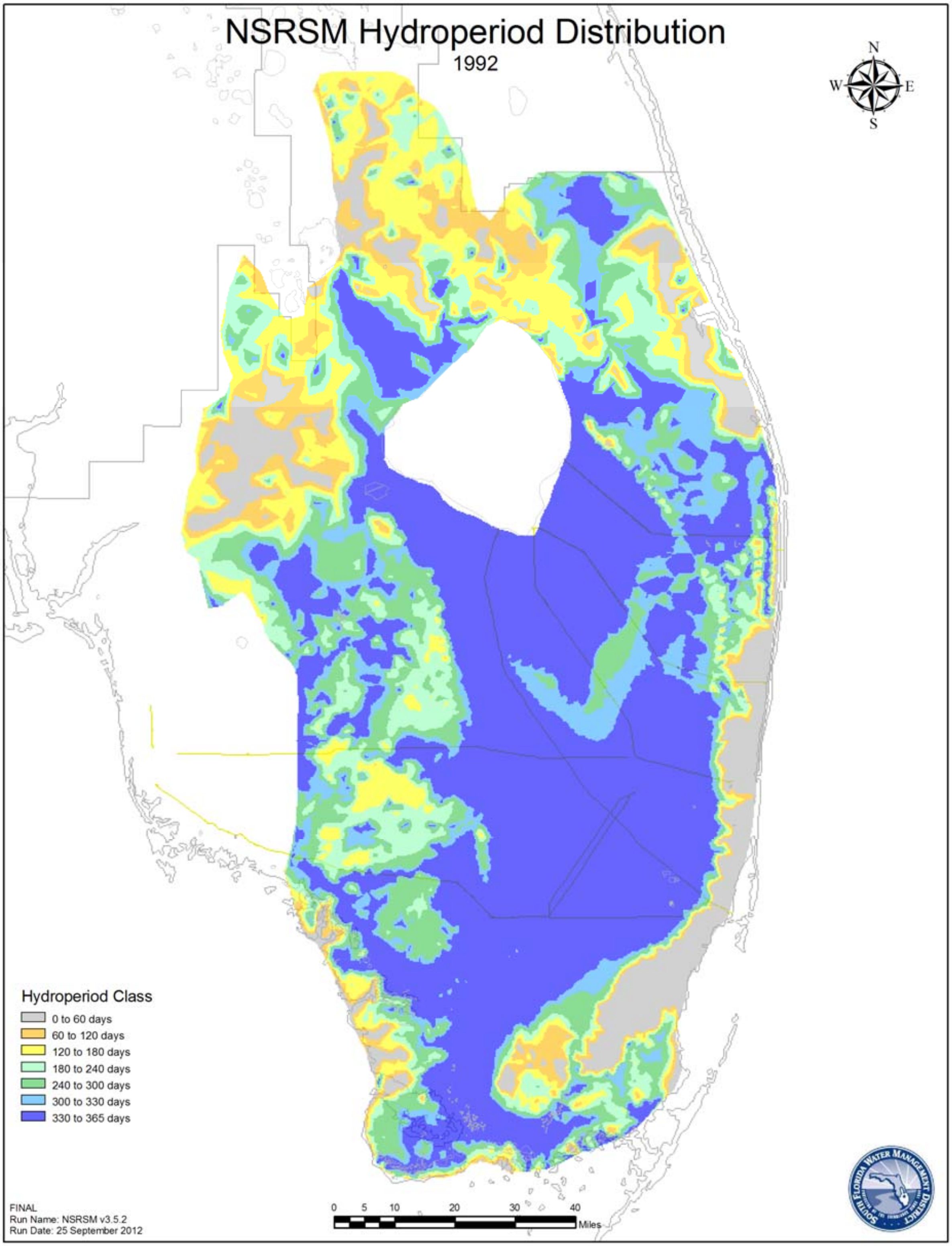

Figure K-150. Annual average hydroperiod distribution for the NSRSM model domain for 1992.

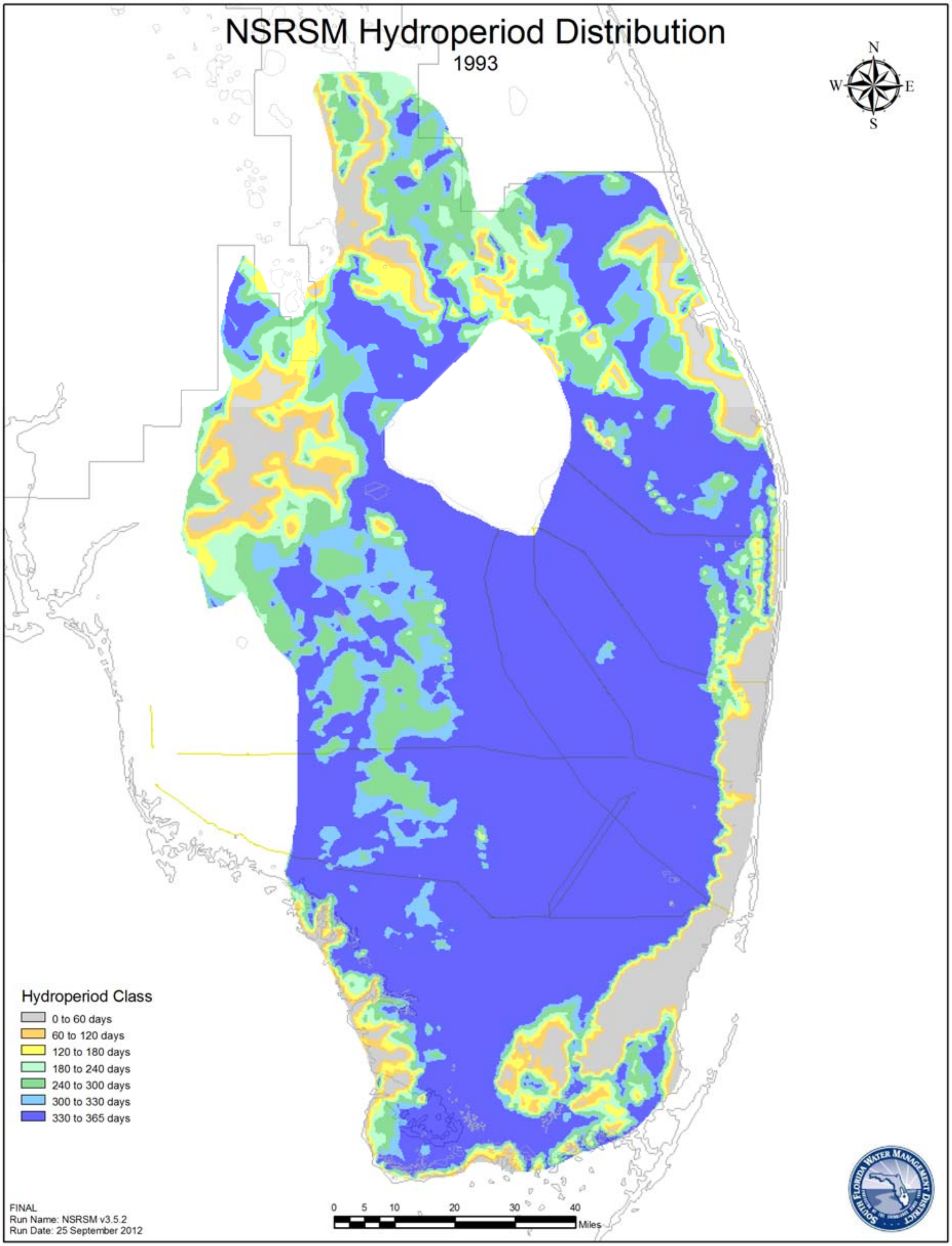

Figure K-151. Annual average hydroperiod distribution for the NSRSM model domain for 1993.

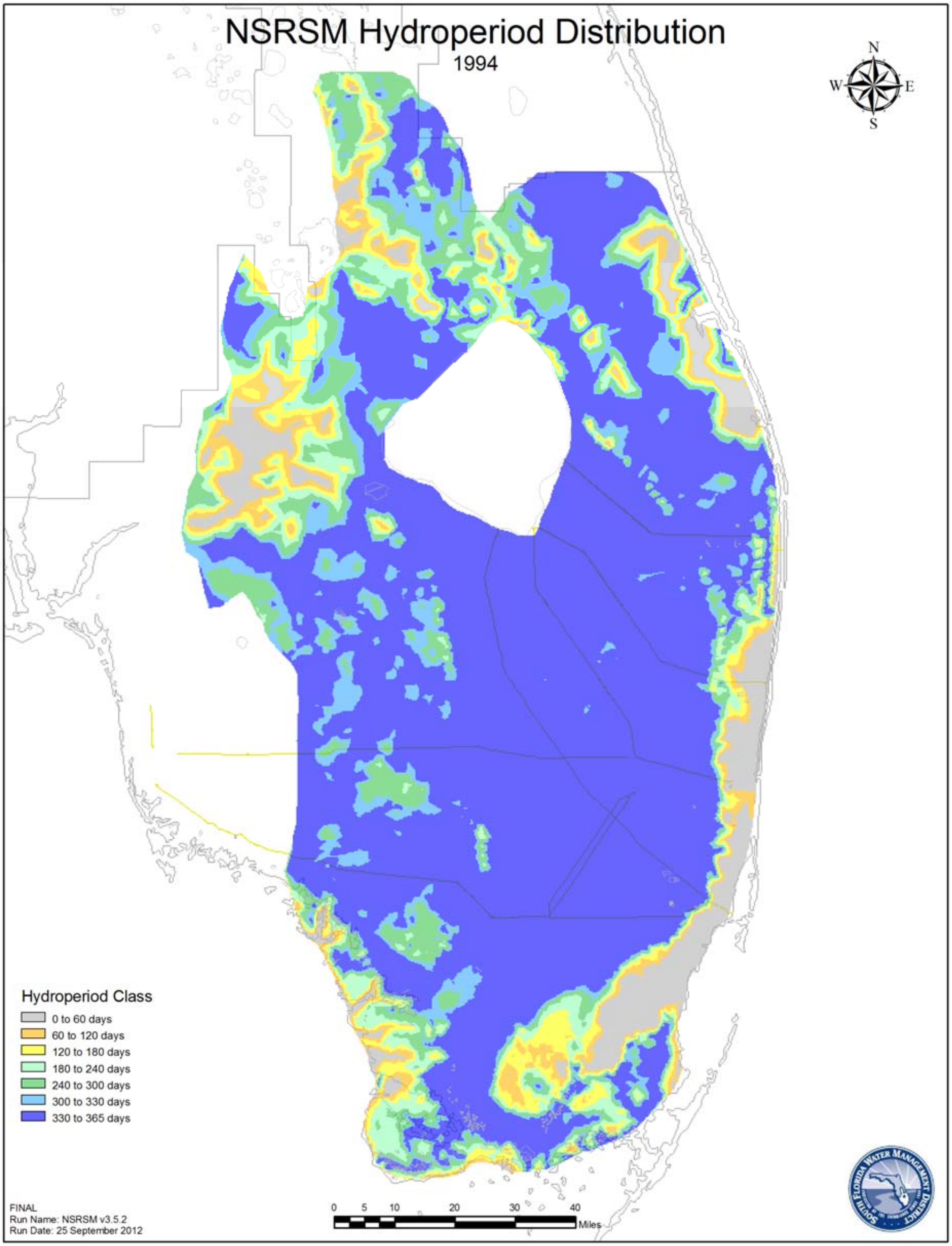

Figure K-152. Annual average hydroperiod distribution for the NSRSM model domain for 1994.

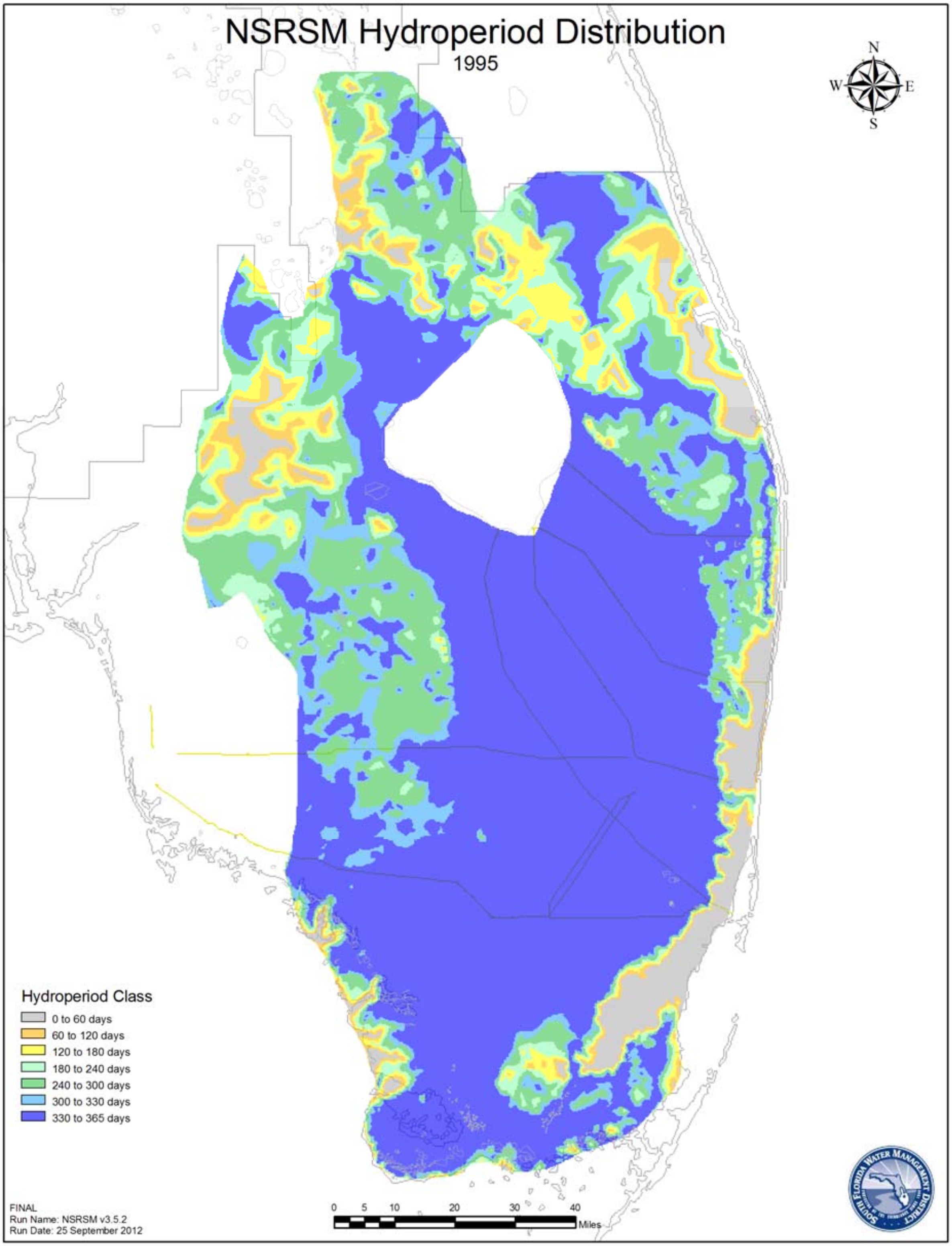

Figure K-153. Annual average hydroperiod distribution for the NSRSM model domain for 1995.

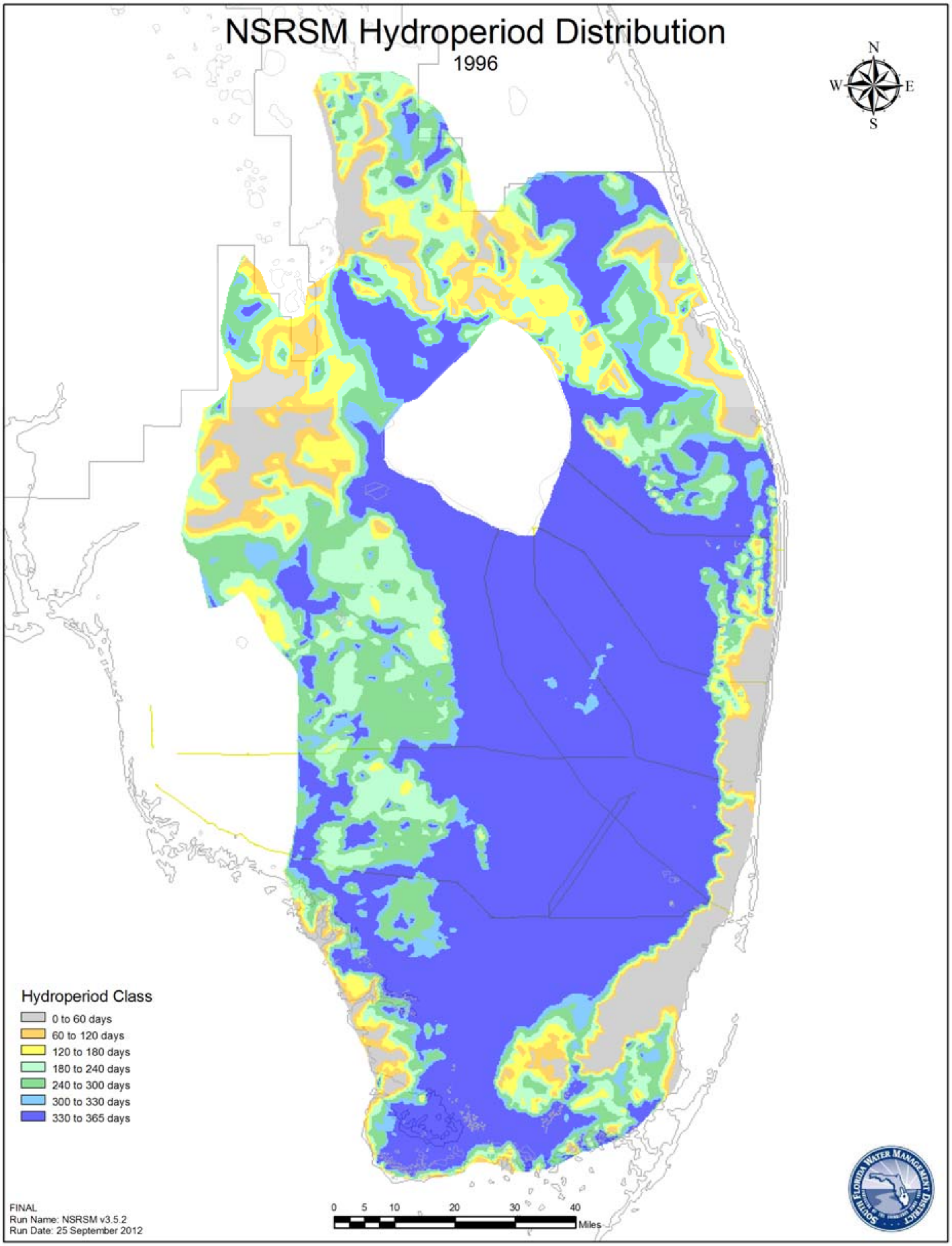

Figure K-154. Annual average hydroperiod distribution for the NSRSM model domain for 1996.

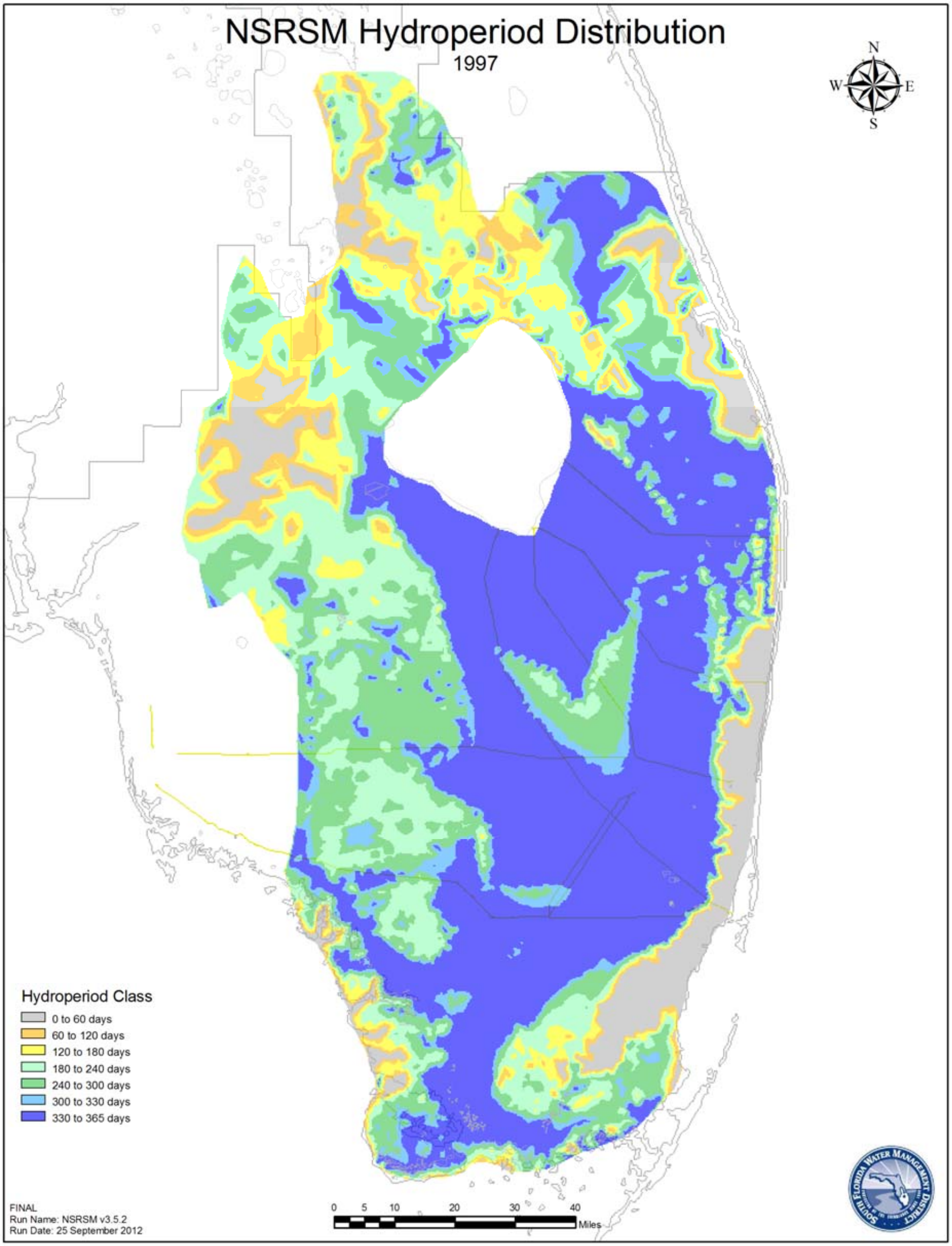

Figure K-155. Annual average hydroperiod distribution for the NSRSM model domain for 1997.

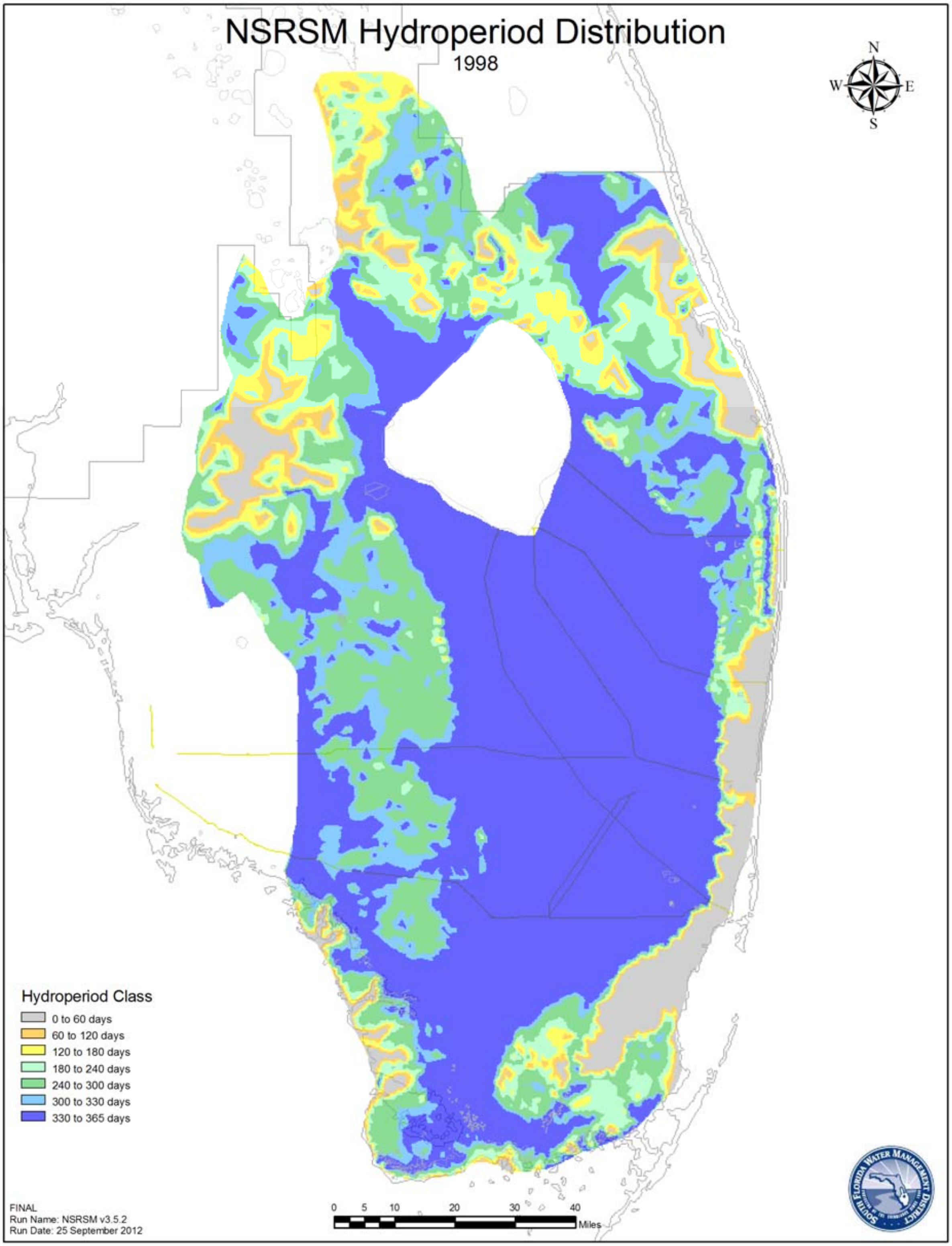

Figure K-156. Annual average hydroperiod distribution for the NSRSM model domain for 1998.

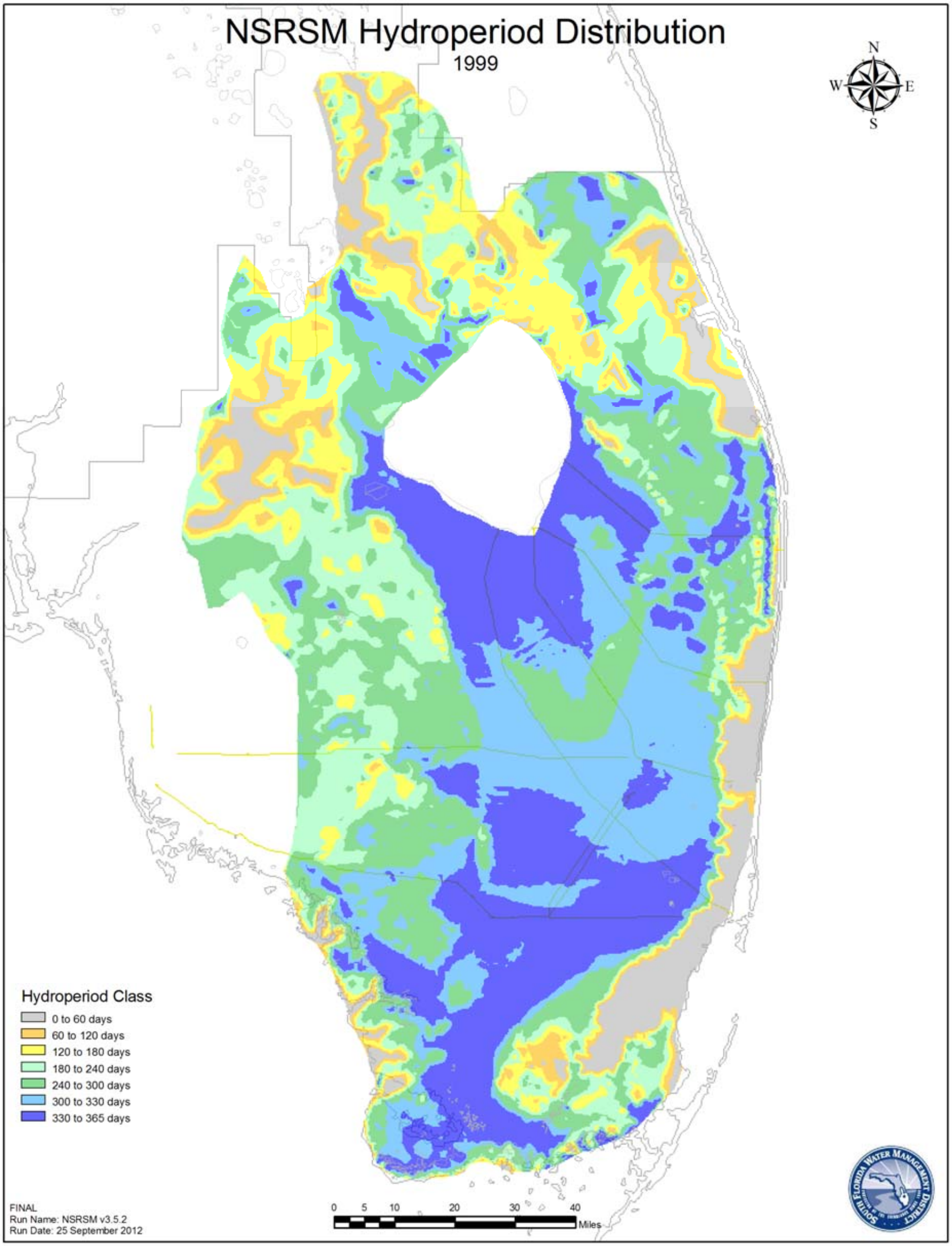

Figure K-157. Annual average hydroperiod distribution for the NSRSM model domain for 1999.

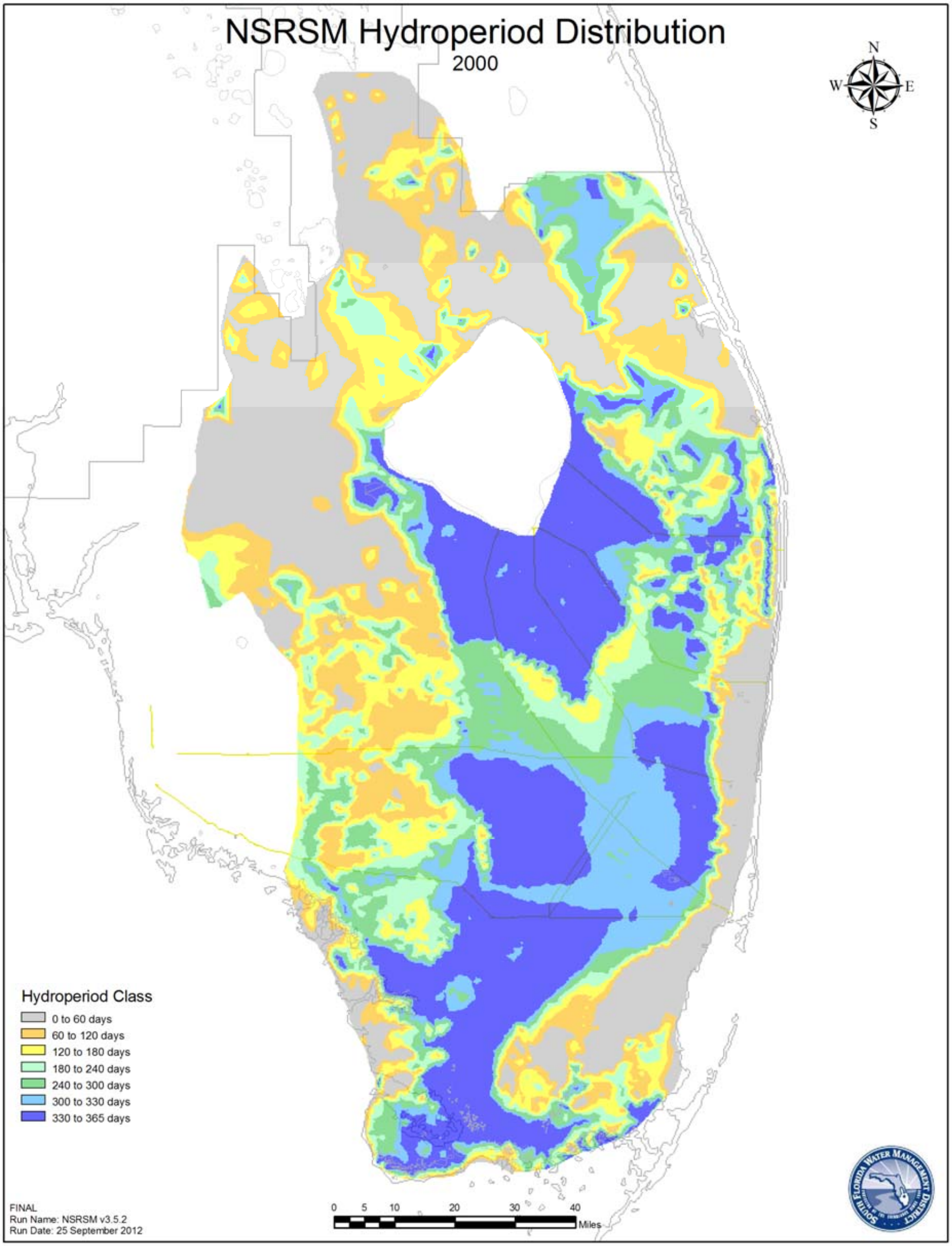

Figure K-158. Annual average hydroperiod distribution for the NSRSM model domain for 2000.

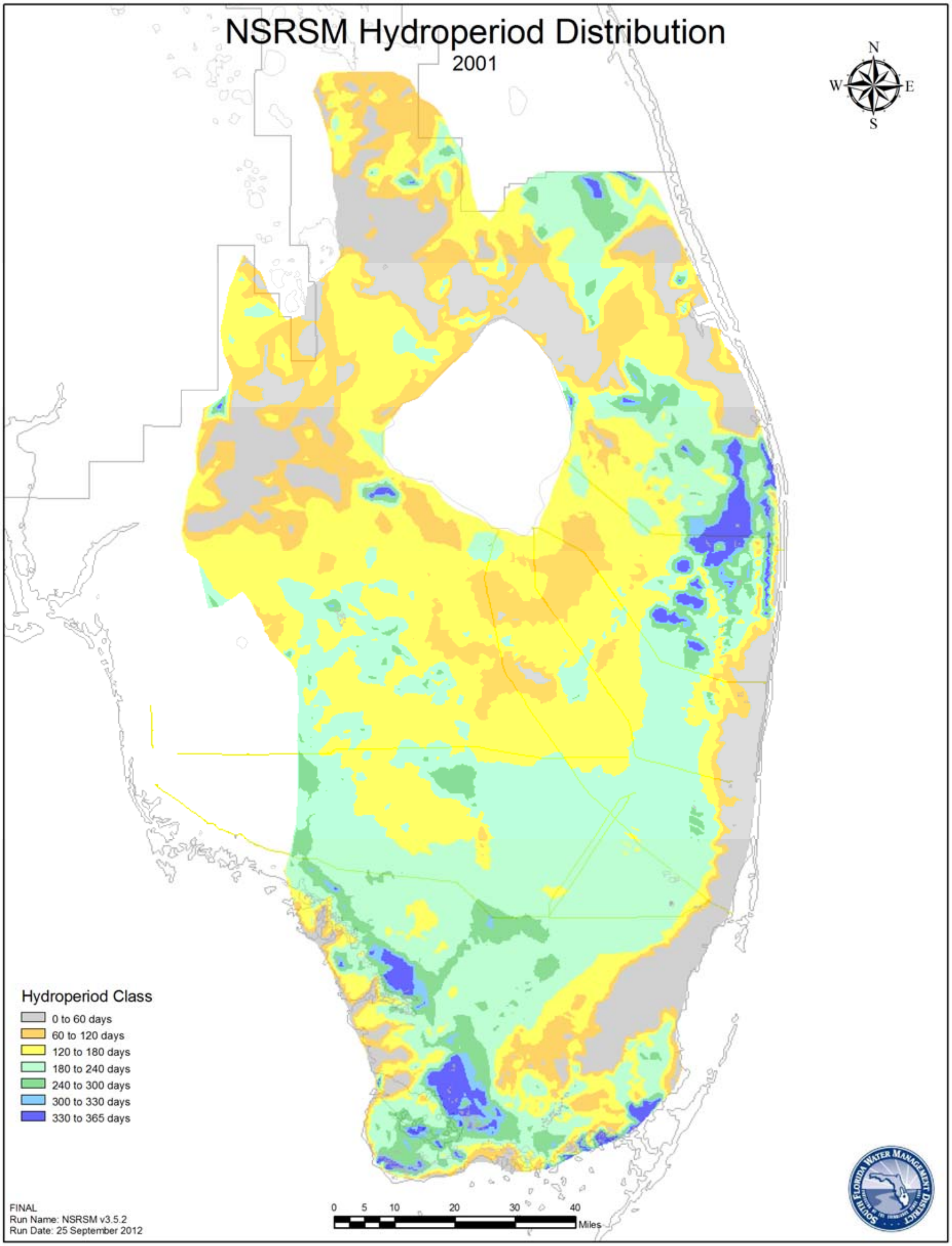

Figure K-159. Annual average hydroperiod distribution for the NSRSM model domain for 2001.

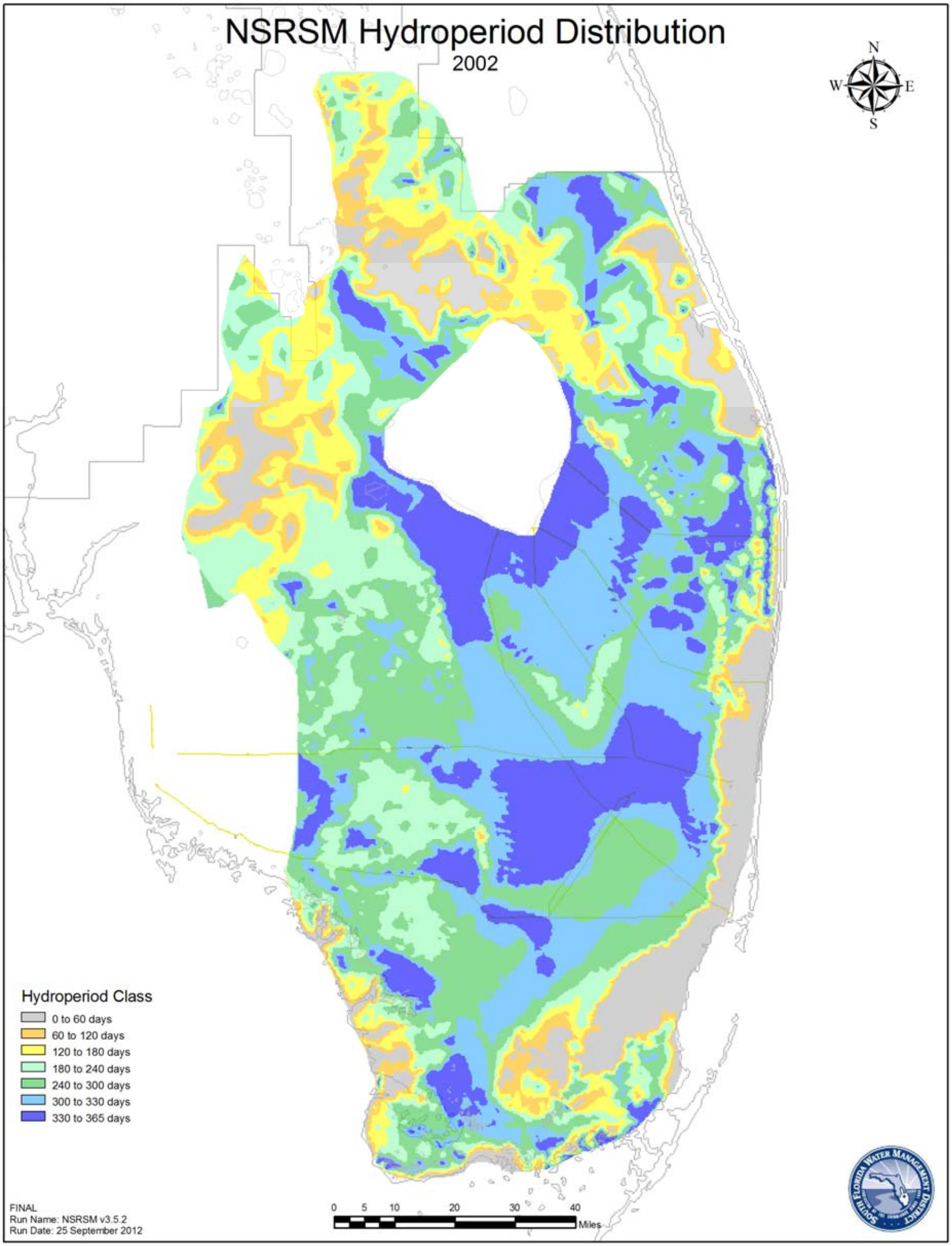

Figure K-160. Annual average hydroperiod distribution for the NSRSM model domain for 2002.

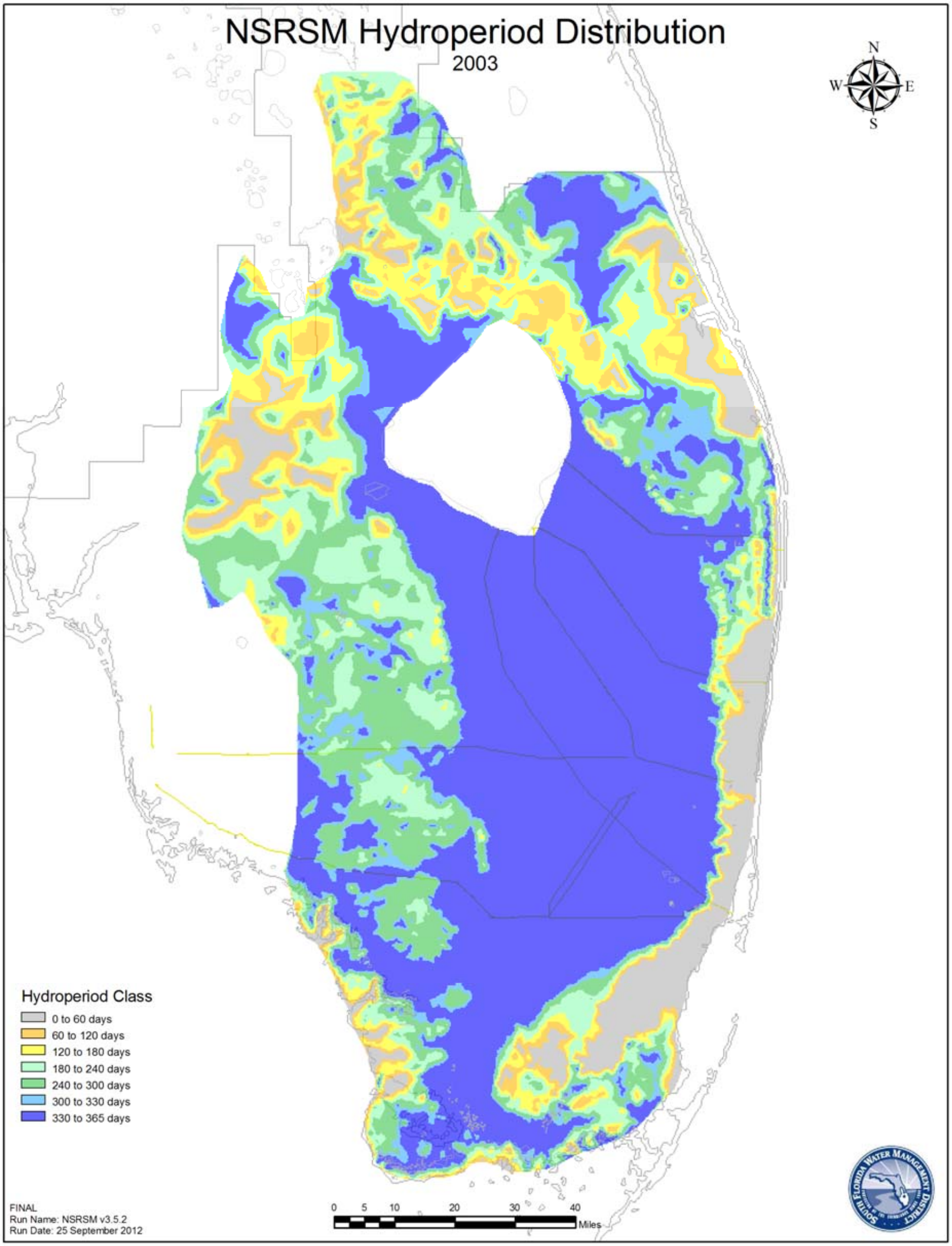

Figure K-161. Annual average hydroperiod distribution for the NSRSM model domain for 2003.

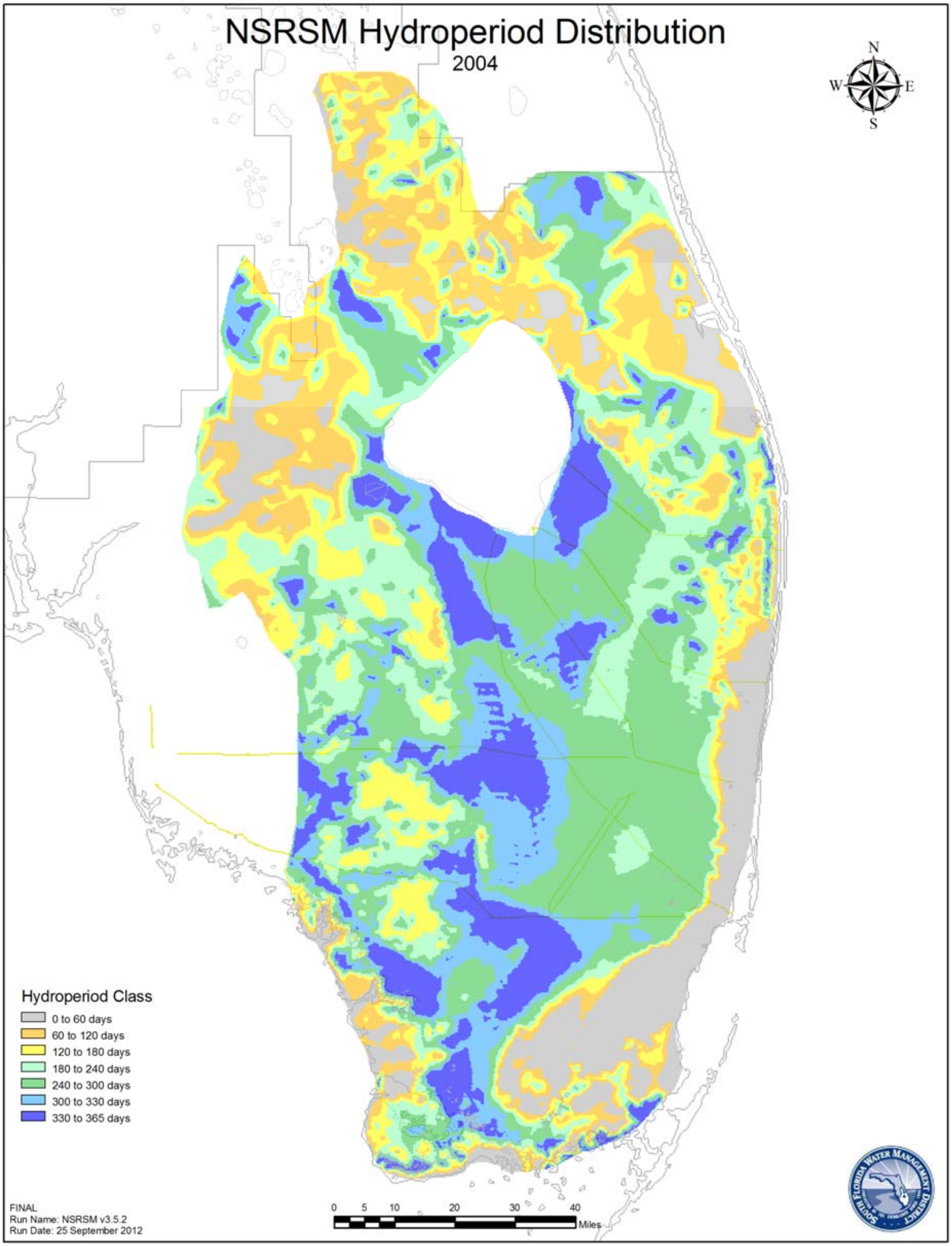

Figure K-162. Annual average hydroperiod distribution for the NSRSM model domain for 2004.

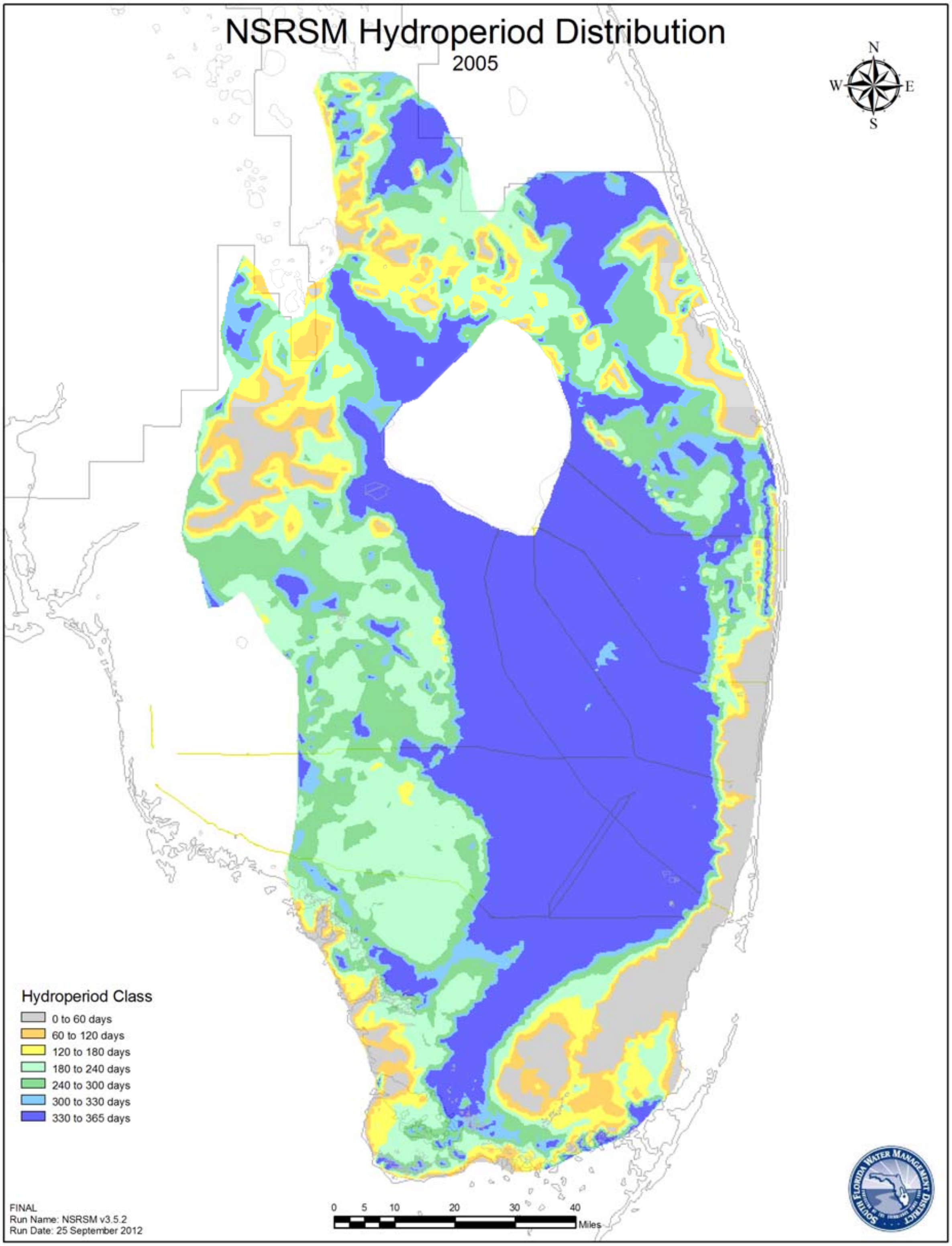

Figure K-163. Annual average hydroperiod distribution for the NSRSM model domain for 2005.

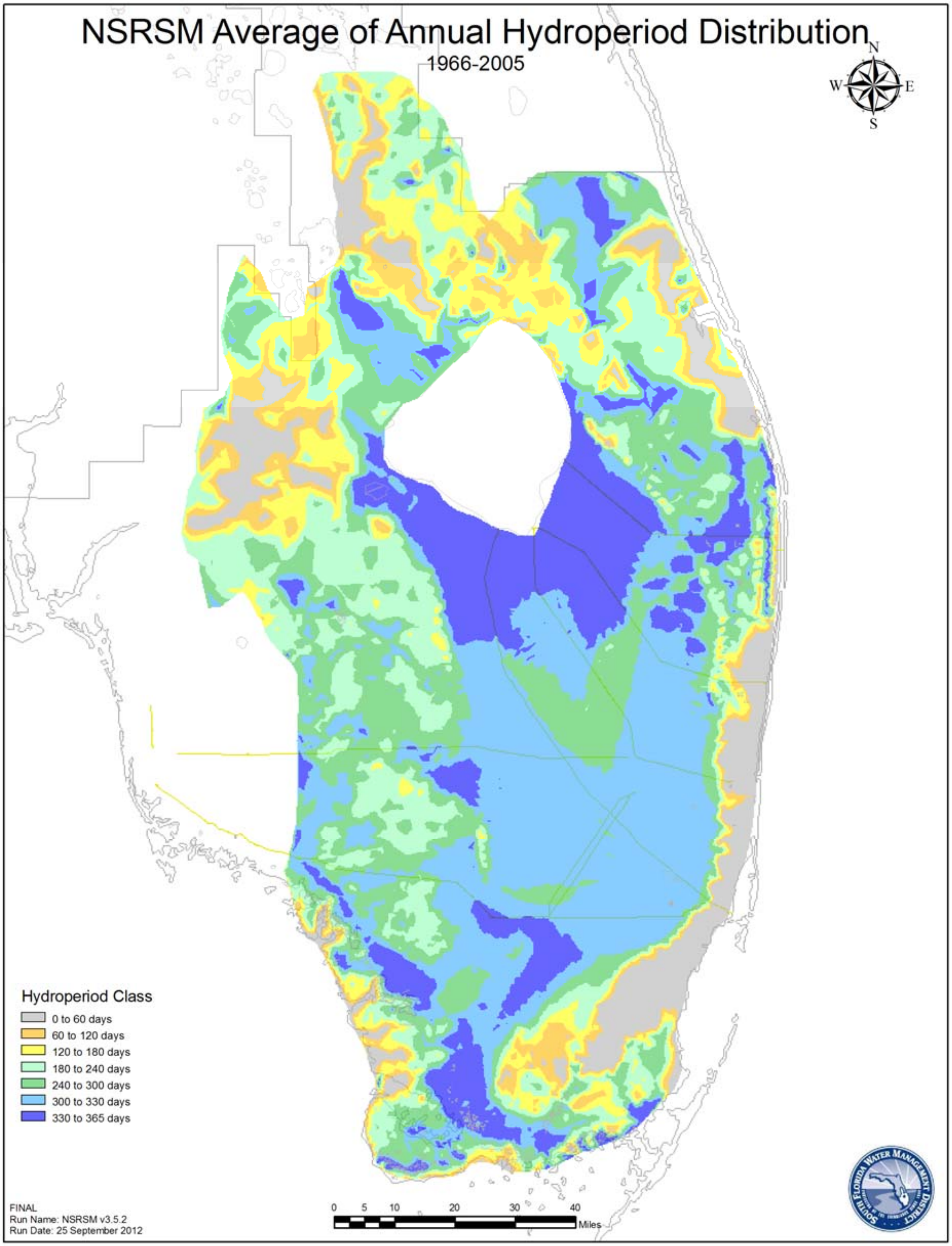

Figure K-164. Average annual hydroperiod distribution for the NSRSM model domain for the period 1966-2005.

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3301 Gun Club Road
West Palm Beach, Florida 33406

Mailing Address:
P.O. Box 24680
West Palm Beach, FL 33416-4680

Telephone: (561)686-8800
800-432-2045 (Florida only)

sfwmd.gov