Natural System Regional Simulation Model v2.0
Results and Evaluation

South Florida Water Management District (SFWMD)
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INTRODUCTION

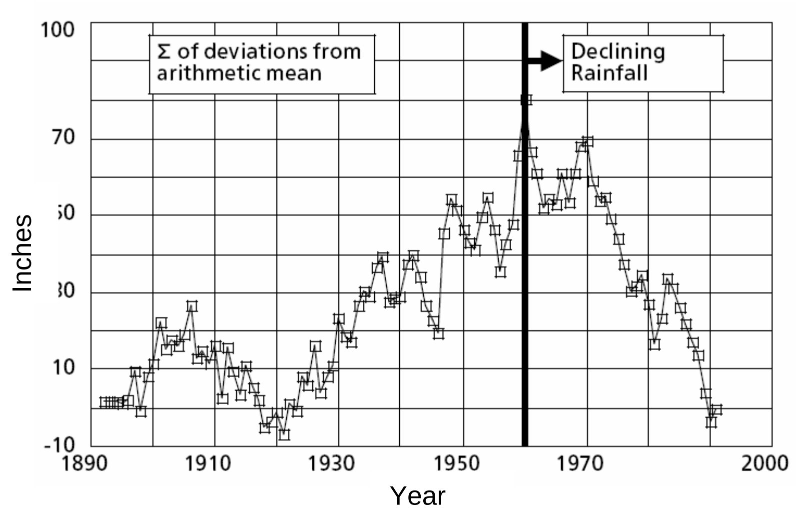
Verification of NSRSM v2.0 is not possible using traditional model calibration and verification procedures which involve the comparison of computed and measured data at discrete points of the model domain. NSRSM "soft" calibration is based on an approach developed by District staff for the North Palm Beach County Natural System Model (Arteaga, 2005); model output is evaluated for performance relative to pre-development landscapes (vegetation communities within a hydrologically distinct area) existing at the time of the mid-1800 Government Land Office surveys (Appendix E).

This report presents model results for the NSRSM v2.0 base condition simulation (1965-2000) compared to reference ranges developed from the best available estimates of pre-drainage hydrology from literature.

Studies pertaining to historical south Florida vegetation community composition and hydrologic requirements have concluded that a significant amount of information is available to provide reference range estimates (McVoy et al. 2005, Fennema 2003, Duever 2000). Reference ranges represent the hydrologic conditions necessary for the sustainability of documented pre-drainage vegetation communities, with the understanding that vegetation community composition is dynamic at multiple temporal scales due to hydrologic variables (e.g. slow variable- sea level rise, medium- multi-decadal climate oscillation, and fast- seasonal rainfall variability [Gunderson, 1994]).

Model output is evaluated at the landscape level using hydrologic performance measures including inundation duration (hydroperiod), seasonal (wet/dry) water depth, and seasonal amplitude. It is important to note that the NSRSM base simulation POR (1965-2000) is representative of a drier than average decadal climate oscillation (SFWMD, 1996) resulting in declining rainfall (**Fig 1**). Model results are expected to fall within lower reference range values.

Figure 1. Decline in Rainfall in South Florida since 1960.
Summation of the annual deviations from measures of central tendency. (SFWMD, 1996)

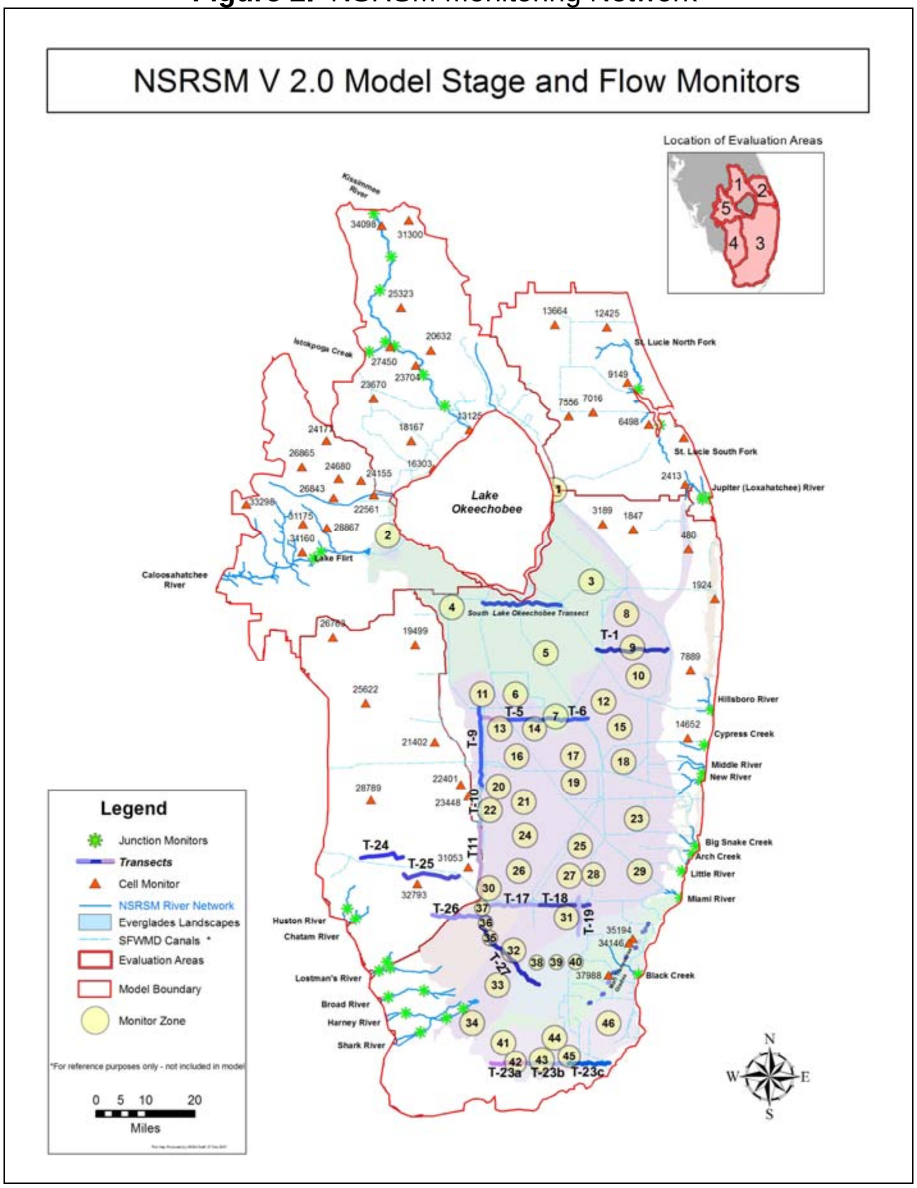


PERFORMANCE MONITORING

Model output monitoring sites within the NSRSM domain are displayed in **Fig. 2.** An additional monitor location map is provided as an attachment.

- Cell monitors (red triangles) output landscape classification, inundation duration, stage, and computed ET for a mesh cell.
- Monitor Zones (yellow circles) output landscape classification, inundation duration, stage, and computed ET for an aggregation of cells selected as an indicator region for a landscape.
- Junction monitors (green stars) record flows at a point where two river segments (as opposed to natural river junctions) join.
- Overland flow transects (blue lines) output surface water flow volumes.
- Water budgets are output for Everglades basin landscapes (shaded areas).

Figure 2. NSRSM Monitoring Network



Performance Measures

NSRSM output is processed for each cell and zone monitor to provide long-term (35 yr) hydrologic statistics for a specified landscape. This information was used to "soft calibrate" the model. Performance measures include

PM-1. **Inundation Duration**- Percent of time water levels remain aboveground for the simulation period. For this evaluation, we consider this value to be representative of the average annual hydroperiod. Values are compared to reference ranges for simulation evaluation.

PM-2. **Seasonal Water Levels -** Long-term average of annual Water year (WY) maxima (wet season) and minima (dry season) for a cell/zone for the simulation period. Where WY = May 1 through April 30. Values are compared to reference ranges for simulation evaluation.

PM-3. **Seasonal Amplitude for Everglades peat landscapes**- The difference between average annual maximum depth and average annual minimum depth over period of simulation. Values are compared to reference ranges in the Everglades basin for simulation evaluation.

PM-4. **Evapotranspiration (ET) for Everglades wetlands**- Computed evapotranspiration (ETc) is calculated for mesh cells within Everglades landscapes for the simulation period 1996 -1997, and for zones within the Everglades as a long-term average of all zones within a specified landscape for the entire simulation period of record.

Reference Ranges

Details of PM-1 through PM-3 reference range development are included in the Appendices:

- Appendix A.1 – Evidence, from the historical record, for reference ranges relating to pre-drainage Everglades wetland hydrology (McVoy et al., 2005)

- Appendix E – Hydrologic characteristics of south Florida landscapes inferred from soil data (Zahina et al., 2006)

- Appendix E and I – Hydrologic characteristics of pre-development south Florida landscapes investigated in the Southwest Florida Feasibility Study (Duever, 2000)

A summary of reference ranges by landscape is provided in **Table 1**.

Table 1: Reference ranges for NSRSM landcover.

Sources: Green Highlighted Rows; Duever, Appendix I; Yellow – McVoy et al., 2005; Blue – Zahina et al., 2006

Landscape	Hydroperiod (Months)	Seasonal Max. (ft)	Seasonal Min. (ft)
Intra-tidal Wetland	Tidal		
Beach	Variable		
Forested Freshwater Wetland	6 - 10	2	-1
Cypress Swamp	6 - 8	1.5	-1.5
Hardwood Swamp	8 - 10	2	-1
Non-forested Freshwater Wetland	6 - 12	2.5	-2
Long-hydroperiod Marsh	9 - 12	2	-0.5
Ridge and Slough Marsh	9 - 12	2	0
Ridges	9-10		
Sloughs	12		
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
Wet Prairie	2 - 6	1	-2
Wet Prairie with Scattered Trees	2 - 6	1	-2
Wet Prairie with Cypress	2 - 6	1	-2
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	

It is important to note that elevation contours developed for the historical ridge and slough landscape in the Everglades basin were assumed to represent the average elevation of landscape components (Appendix B.2). Estimated pre-drainage water levels for the landscape (1 ft min. and 3 ft. max) were adjusted accordingly to account for the (modeled) average of ridge, slough, and tree island elevations within a mesh cell, based on a weighted mean of the component contribution to the landscape (Table 2).

The resulting reference values for long term average seasonal water levels in the ridge and slough landscape ranges from 2 ft maximum (wet season) to 0 ft. minimum (dry season).

Table 2. Ridge and Slough Landscape Component Analysis

Component	***Area (ac)***	***%***	***Average Elevation (ft)***
Total Area	1,497,570	100%	-
Slough	688,882	46%	0.0
Ridge	688,882	46%	1.5
Bay Head	44,927	3%	3.5
Tree Islands	74,879	5%	3.5
Weighted Mean	0.97		

The reference range for PM-4 (Evapotranspiration for Everglades wetlands) was derived from annual average values from a two year (1996-1997) USGS study of Evapotranspiration in the remnant Everglades (German 2000). Observed values from landscapes having a sawgrass component (**Table 3**) were referenced.

Table 3. Observed values of annual average ET in the remnant Everglades

Landuse	Comments	Avg Ann ET (inches)
Dense Sawgrass	Dry part of most years	46.2
Medium Sawgrass	Dry part of some years	49.6
Medium Sawgrass	Never Dry	46.6
Sparse Sawgrass	Never Dry	51.2
Sparse Rushes	Dry part of every year	43.5
Sparse Sawgrass	Dry part of every year	42.4

PERFORMANCE INDICATORS

Performance indicators were developed to provide additional information relating to hydrologic characteristics of the simulated natural system. If available, historical estimates are provided for reference. However, these estimates have a greater uncertainty than the performance measure reference ranges so were not used as a primary targets for “soft” calibration.

Seasonal and Interannual Variability

Stage hydrographs for selected zones were evaluated in terms of correspondence to characteristic seasonal (wet/dry) and interannual (multi-decadal oscillation) hydropatterns described in Appendix A.1.

River Flows

Quantitative flow data for south Florida east coast natural rivers prior to extensive channel modifications for drainage and navigation is very limited. However, substantial survey information is available to define pre-development physical dimensions of the rivers (**Appendix G**). The sum of simulated long-term annual average flows to tide for eight east coast rivers are compared to the discharge determined by a SFWMD spreadsheet analysis (**Appendix G**). Lower west coast rivers have not experienced significant improvement therefore flows are compared to current monitoring data (Levesque, 2004). Kissimmee River flows are compared to historical estimates in Kissimmee River Restoration Studies **Appendix A.3**. Caloosahatchee flow rate reference values are from 1926 USGS data (reference unavailable).

Overland Flow

Quantitative information relating to overland flow volume and directionality is not easily extracted from the historical record due to data collection limitations. As an indicator of NSRSM performance, overland flow characteristics should be comparable (within the limits of uncertainty) to the conceptual hydrologic model description in **Appendix A.** NSRSM surface water flow for specified transects is processed for the same transect locations as 2x2 model output, and for the same seasonal distributions; June 1 – Oct 31 (wet season), Nov 1 – May 31(dry season). The purpose of this was to have a comparison (but not a target) to previous model flow volumes.

Lake Okeechobee Stage

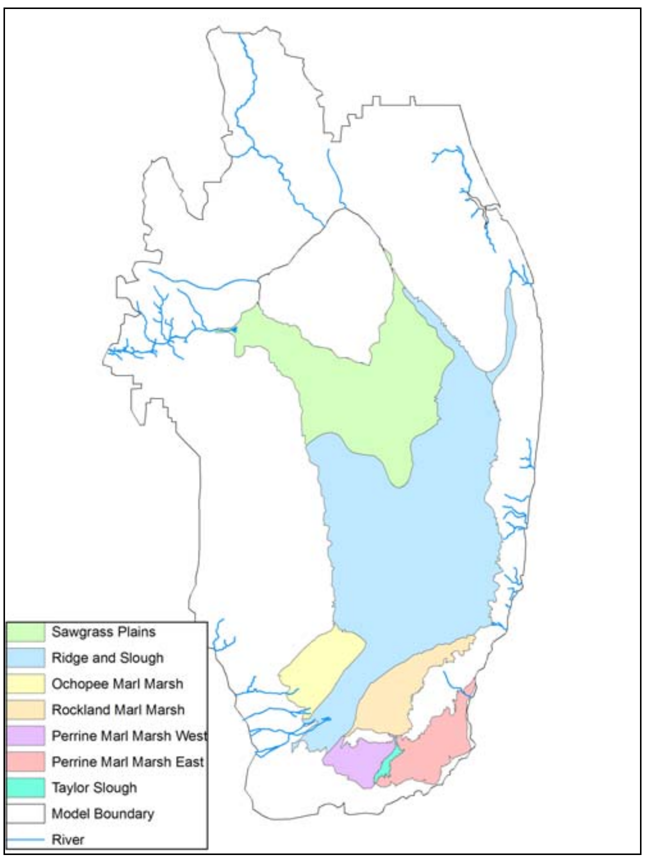
A stage hydrograph for Lake Okeechobee is provided as an indicator of lake performance for comparison to hydrologic characteristics described in **Appendix A** and land surface elevation information (**Appendix B.2**).

Water Budget

Water budgets (surface water and groundwater inflows and outflows plus rain minus ET and change in storage), were prepared for Everglades landscapes; sawgrass plains, ridge and slough, and the marl prairies.

NSRSM v2.0 was divided into seven zones representing each landscape in the Everglades as shown in **Fig 3**. The average annual volume for each of the seven zones was computed using a long term annual average of 34 water years (water years 1966 to 1999). Each water year begins on May 1 and ends on April 30 of the following year (e.g., May 1, 1966 to April 30, 1967). Annual volume for each zone is computed along each colored border within a zone, a flow section.

Figure 3. Location of water budget zones

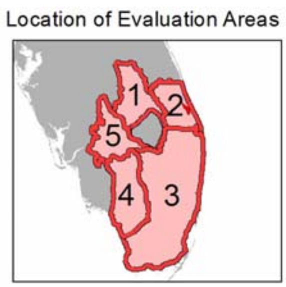


RESULTS

Model results are presented in two sections; performance measure (PM) results, and performance indicator (PI). Evaluation of results is discussed in the final section of this report.

PM Results

Landscape long-term average inundation duration, seasonal water levels, and seasonal amplitude are compared to reference ranges for model validation. Model results are presented by evaluation area, beginning with the Everglades basin in Evaluation Area 3.



Evaluation Area 3

This evaluation area includes most of the Everglades Basin in addition to the eastern coastal landscapes. Locations of monitors are shown in **Fig. 2**.

PM-1 Inundation Duration (Hydroperiod)

Performance Objectives: Top of bar should fall within reference ranges indicated by green box. 9-10 months for sawgrass plains and 6-9 months for marl marsh.

Figure 4. Inundation duration results for Everglades sawgrass plains landscape

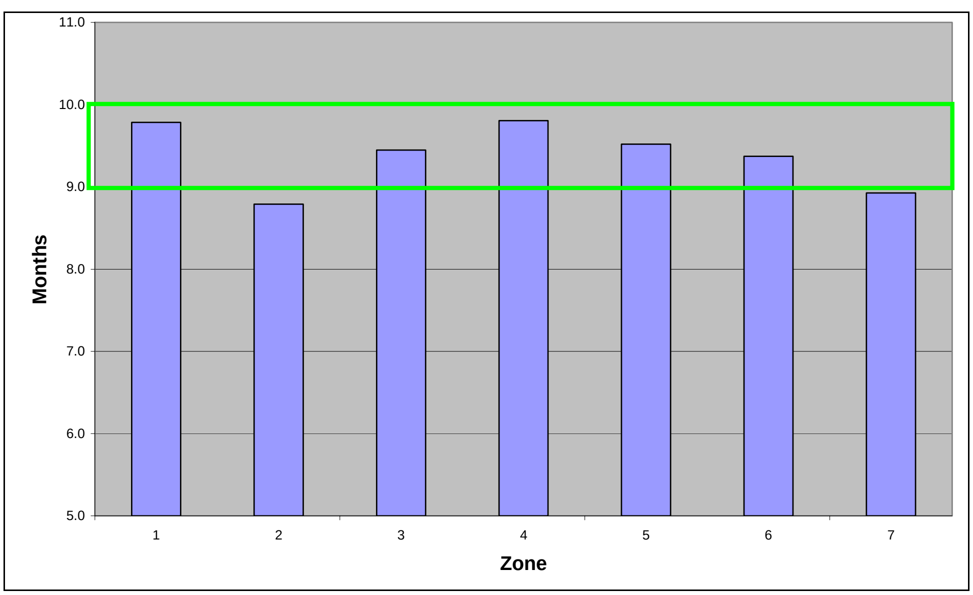
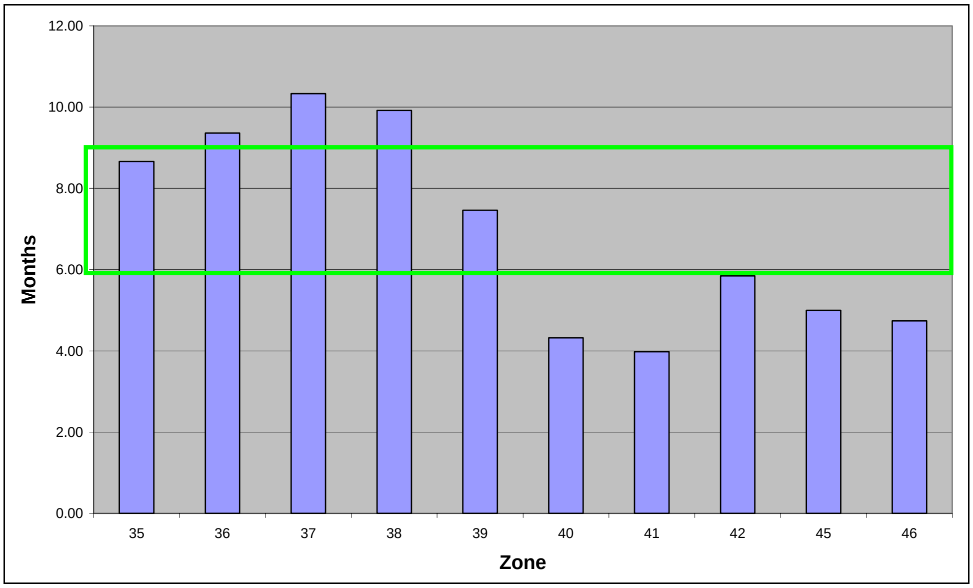
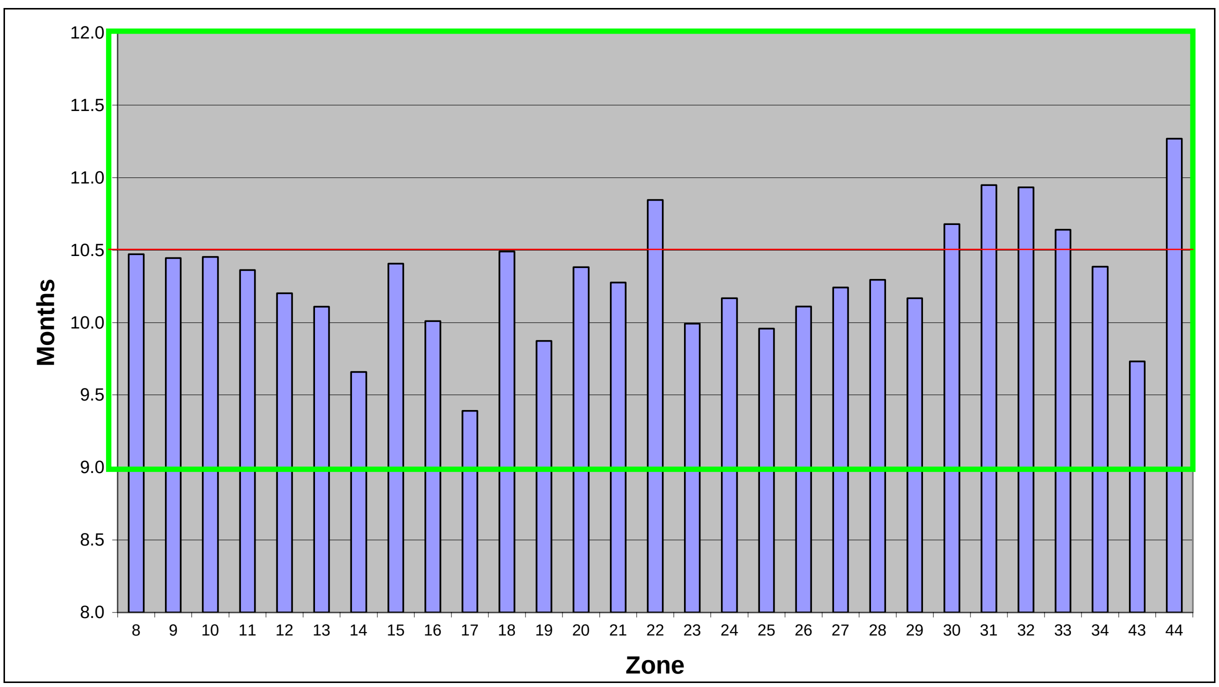


Figure 5 Inundation duration results for Everglades marl marsh landscape



Ridge and Slough Performance Objectives: Top of bar for each zone should definitely fall within reference range of 9-12 months indicated by a green box. Values more than 1 ft below red line (estimated average of landscape) are considered low.

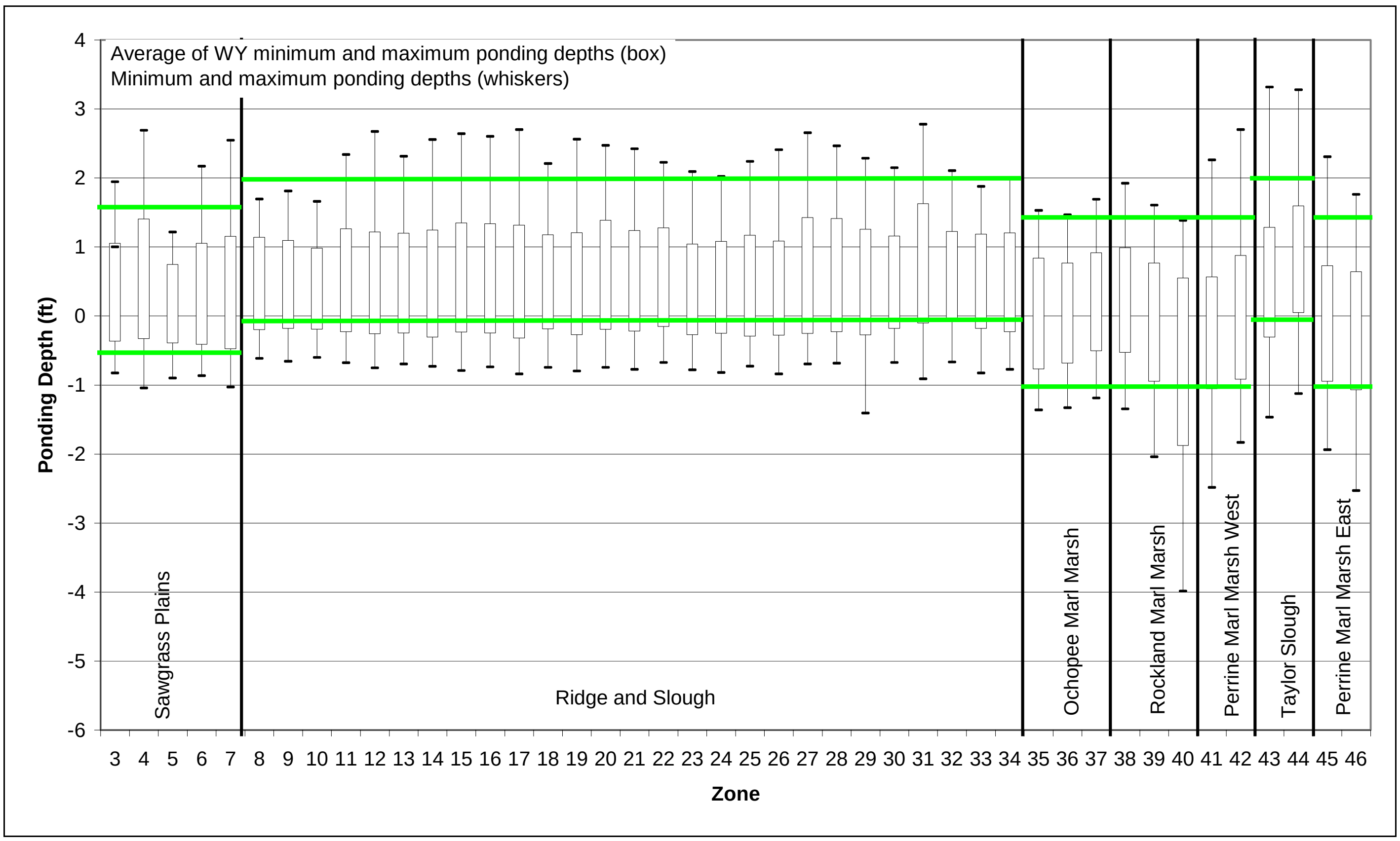
Figure 6. Inundation duration results for Everglades ridge and slough landscape



PM-2 Seasonal Water Levels

Performance Objective: Long-term average maximum (wet season) water levels indicated by box top for each zone should be within a .5 ft range of the upper green reference line. Long-term average minimum (dry season) water levels indicated by box bottom should be within a .5 ft range of the lower green reference line. A summary of reference ranges by landscape is provided in Table 1.

Figure 7. Long-term average seasonal water levels for Everglades landscapes



PM-3 Seasonal Amplitude for Everglades Landscapes

Performance Objective: Values should approach the 2 ft. reference range.

Table 4. Simulated seasonal amplitude for Everglades peat landscapes

Landscape	Seasonal Amplitude (feet)
Sawgrass Plains	1.5
Ridge and Slough	1.5
Taylor Slough	1.6

PM- 4 Computed Evapotranspiration (ET)

Uncertainty for the computed ET 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 semi-quantitative" (German, 2000).

Performance Objective for mesh cells and monitoring zones: ETc should fall within the reference range of 42 – 51 inches.

Table 5. Computed ET (ETc) for mesh cells (POR 1996-1997)

CellId	Landuse	ETc (inches)
3864	Ridge and Slough	42.51
4620	Sawgrass Plains	44.07
4593	Ridge and Slough	42.30
8993	Ridge and Slough	43.19
14803	Ridge and Slough	42.33
28176	Ridge and Slough	44.55
34256	Ridge and Slough	44.54
44855	Everglades Marl Marsh	43.12
42591	Everglades Marl Marsh	45.40
4357	Ridge and Slough	42.39

Table 6. Long-term annual average ETc for monitor zones (1966 – 2000)

Everglades Landscape	Long-term annual average ETc (inches)
Sawgrass Plains	44
Ridge and Slough	44
Marl Prairie	42

Hydroperiod (PM-1) and Seasonal Water Level (PM-2) results from all other monitoring cells adjacent to the historical Everglades in Evaluation Area 3 are presented in Table 3.

Performance objectives: Simulated inundation duration (hydroperiod) should fall within the reference ranges in the green column labeled reference hydroperiod. Simulated water levels should approach the reference values in the green column labeled reference seasonal water level.

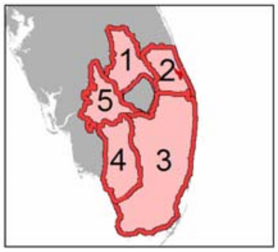
Table 7. Evaluation Area 3 results for mesh cells outside of the Everglades

CellId	Landcover	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)
3189	Cypress Swamp	6 - 8	10.27	85.6	1.5	-1.5	1.15	-0.81
480	Long-hydroperiod Marsh	9 - 12	10.63	88.5	2	-0.5	1.24	-0.70
1847	Long-hydroperiod Marsh	9 - 12	9.15	76.3	2	-0.5	0.87	-1.07
1924	Mesic Pine Flatwoods	<1	11.11	92.6	<-2		3.77	0.14
7889	Mesic Pine Flatwoods	<1	1.51	12.6	<-2		0.22	-4.21
37988	Mesic Pine Flatwoods	<1	0	0	<-2		-4.41	-9.53
14652	Wet Prairie	2 - 6	7.52	62.7	1	-2	0.94	-3.22

Hydroperiod and Seasonal Water Level results from all other monitoring cells in evaluation areas 1, 2, 4 and 5 are presented in the following four tables.

Performance objectives: Simulated inundation duration (hydroperiod) should fall within the reference ranges in the green column labeled reference hydroperiod. Simulated water levels should approach the reference values in the green column labeled "Reference Seasonal Water Level".

Location of Evaluation Areas

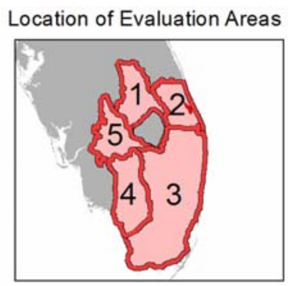


Evaluation Area 1

This evaluation area includes the lower Kissimmee River Basin and northern Okeechobee basins

Table 8. Evaluation Area 1 Results

CellId	***Landcover***	***Reference Hydroperiod***	***Simulated Inundation Duration***		***Reference Seasonal Water Level***		***Simulated Long Term Water Levels***	
			Months	***% POR***	***Wet (ft)***	***Dry (ft)***	***Avg Max (ft)***	***Avg Min (ft)***
20632	Dry Prairie	<1	0.03	0.3	<-2		-0.86	-6.63
23704	Dry Prairie	<1	0.25	2.1	<-2		0.17	-6.99
25323	Dry Prairie	<1	1.34	11.2	<-2		0.14	-4.07
31300	Dry Prairie	<1	1.07	8.9	<-2		0.10	-4.36
8805	Hardwood Swamp	8 - 10	10.02	83.5	2	-1	0.89	-0.93
13125	Long-hydroperiod Marsh	9 - 12	9.84	82	2	-0.5	1.13	-0.65
16303	Long-hydroperiod Marsh	9 - 12	9.02	75.1	2	-0.5	0.87	-0.38
23670	Non-forested Freshwater Wetland	6 - 12	7.89	65.8	2.5	-2	2.65	-1.65
27450	Non-forested Freshwater Wetland	6 - 12	10.25	85.4	2.5	-2	3.85	-0.82
34098	Non-forested Freshwater Wetland	6 - 12	8.91	74.3	2.5	-2	4.07	-1.12
5574	Sawgrass Plains	9 - 10	9.64	80.4	1.5	-0.5	1.18	-0.34
18167	Wet Prairie	2 - 6	8.66	72.1	1	-2	1.39	-1.17

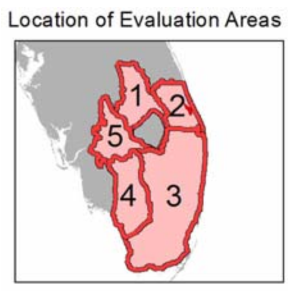


Evaluation Area 2

Evaluation Area 2 includes the St. Lucie River watershed east of Lake Okeechobee

Table 9. Evaluation Area 2 Results

CellId	***Landcover***	***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)***
7556	Long-hydroperiod Marsh	9 - 12	12	100	2	-0.5	2.17	0.60
2413	Mesic Pine Flatwoods	<1	0.92	7.7	<-2		1.98	-10.50
5060	Mesic Pine Flatwoods	<1	0.01	0.1	<-2		-2.62	-8.15
6498	Mesic Pine Flatwoods	<1	0.79	6.6	<-2		1.72	-6.90
9149	Mesic Pine Flatwoods	<1	0.91	7.6	<-2		1.53	-7.73
12425	Mesic Pine Flatwoods	<1	0.31	2.6	<-2		0.02	-5.66
13664	Wet Prairie	2 - 6	9.39	78.3	1	-2	1.45	-1.04



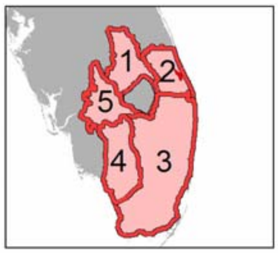
Evaluation Area 4

Evaluation Area 4 includes Big Cypress basin

Table 10. Evaluation Area 4 Results

CellId	***Landcover***	***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)***
32793	Cypress Swamp	6 - 8	10.44	87	1.5	-1.5	1.38	-0.88
21402	Hardwood Swamp	8 - 10	8.94	74.5	2	-1	0.85	-1.40
26763	Medium-hydroperiod Marsh	6 - 10	8.41	70.1	1.5	-0.5	0.93	-1.23
25622	Mesic Pine Flatwoods	<1	2.36	19.6	<-2		0.25	-3.11
28789	Wet Prairie	2 - 6	7.76	64.7	1	-2	0.68	-1.46
22401	Wet Prairie with Scattered Trees	2 - 6	9.56	79.7	1	-2	1.35	-1.32
23448	Wet Prairie with Scattered Trees	2 - 6	10.93	91.1	1	-2	1.43	-0.64
31053	Wet Prairie with Scattered Trees	2 - 6	9.56	79.6	1	-2	0.98	-1.36

Location of Evaluation Areas



Evaluation Area 5

Evaluation Area 5 includes the Caloosahatchee watershed

Table11. Evaluation Area 5 Results

CellId	***Landcover***	***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)***
24680	Dry Prairie	<1	0.34	2.9	<-2		1.07	-8.02
26843	Dry Prairie	<1	0.04	0.4	<-2		-0.78	-7.73
24155	Mesic Hammock	<1	0.82	6.9	<-2		1.98	-5.27
28867	Mesic Pine Flatwoods	<1	0.8	6.7	<-2		0.34	-4.53
31160	Mesic Pine Flatwoods	<1	0.88	7.4	<-2		0.26	-6.44
24177	Mesic Uplands	<1	1.42	11.8	<-2		0.50	-5.53
22561	Non-forested Freshwater Wetland	6 - 12	11.51	95.9	2.5	-2	5.62	-0.04
26865	Non-forested Freshwater Wetland	6 - 12	8.06	67.2	2.5	-2	10.10	-10.47
33298	Non-forested Freshwater Wetland	6 - 12	6.43	53.6	2.5	-2	1.00	-1.88
23059	Sawgrass Plains	9 - 10	10.09	84.1	1.5	-0.5	1.17	-0.19
31175	Wet Prairie	2 - 6	0.87	7.2	1	-2	0.71	-5.09

PI Results

Performance Indicators include natural river flows, stage hydrographs for specified landscapes, overland flow across selected transects, average annual flow vectors, Lake Okeechobee stages for the period of simulation, and water budgets for Everglades landscapes.

Natural River Flows

Kissimmee, Caloosahatchee, and the east coast river simulated flows are compared to historical estimates (**Tab. 12**). Lower west coast rivers have not experienced significant improvement therefore flows are compared to current monitoring data (**Figures 8 - 10**).

Evaluation Objective: Compare simulated performance with reference values provided. Identify areas of correspondence/concern.

Table 12. Natural System River Flows

Water Body	Reference Discharge Rate or Volume	Monitoring Location	NSRSM Simulated Long-term Average Annual Flow
Kissimmee River	800 – 2000 cfs		
		K1	920 cfs
		K2	957 cfs
		K3	1167cfs
		K4	950 cfs
		K5	973 cfs
		K6	804 cfs
Caloosahatchee River	800 – 1000 cfs	Lake Flirt	854 cfs
East Coast Rivers Hillsboro River Cypress Creek Middle River New River Snake Creek Arch Creek Little River Miami River	**Maximum** discharge capacity for 8 east coast rivers identified in left column = 4 M Ac-ft/yr Uncertainty +/- 1 M Ac-ft/yr	See Monitor Locater Map	Average Annual Discharge 1.7 M Ac-ft/yr

Figure 8. Simulated vs Observed Flows for Broad River

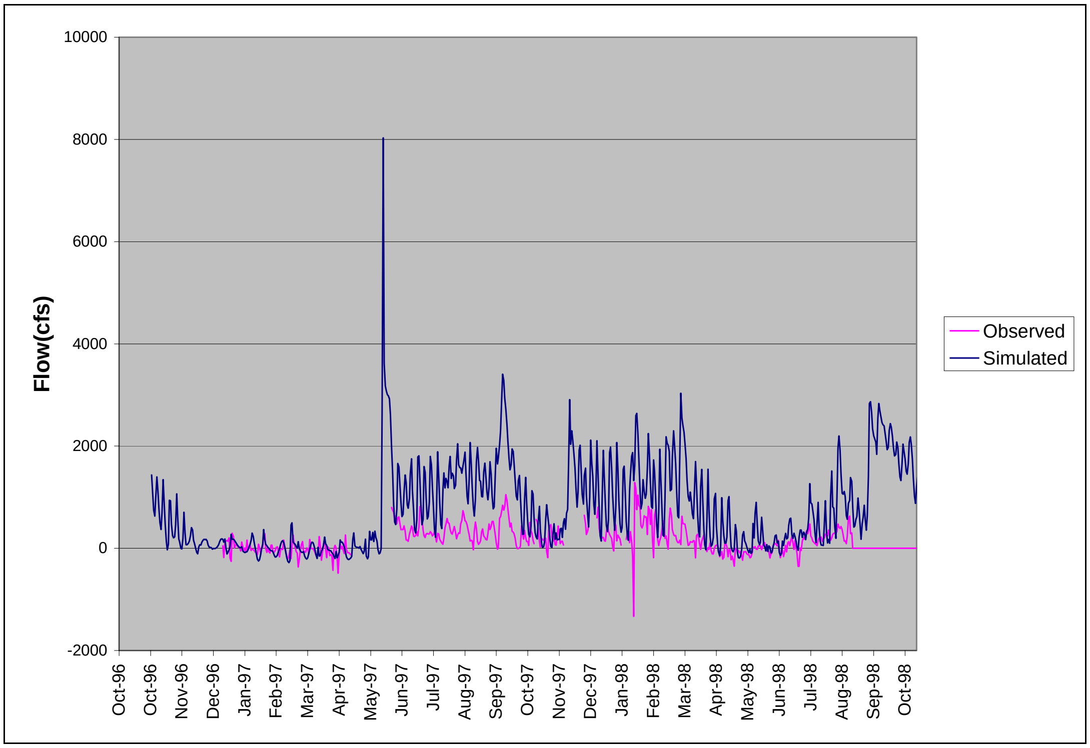


Figure 9. Harney River Flows

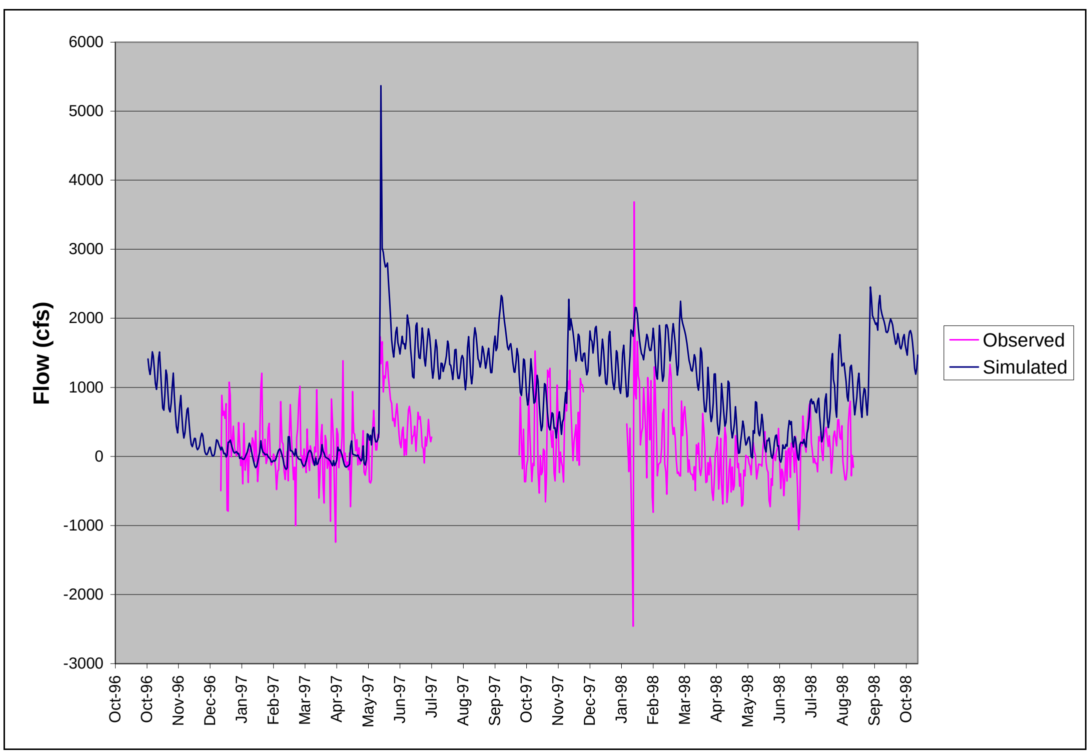
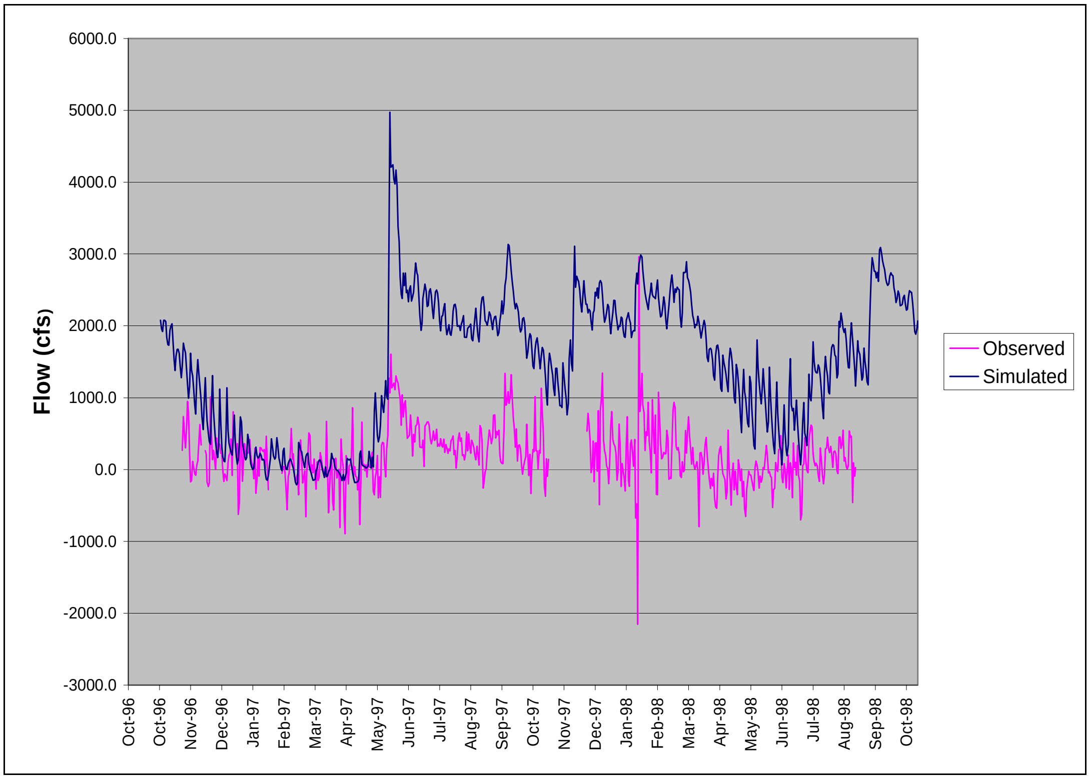


Figure 10. Shark River Flows



Stage Hydrograph

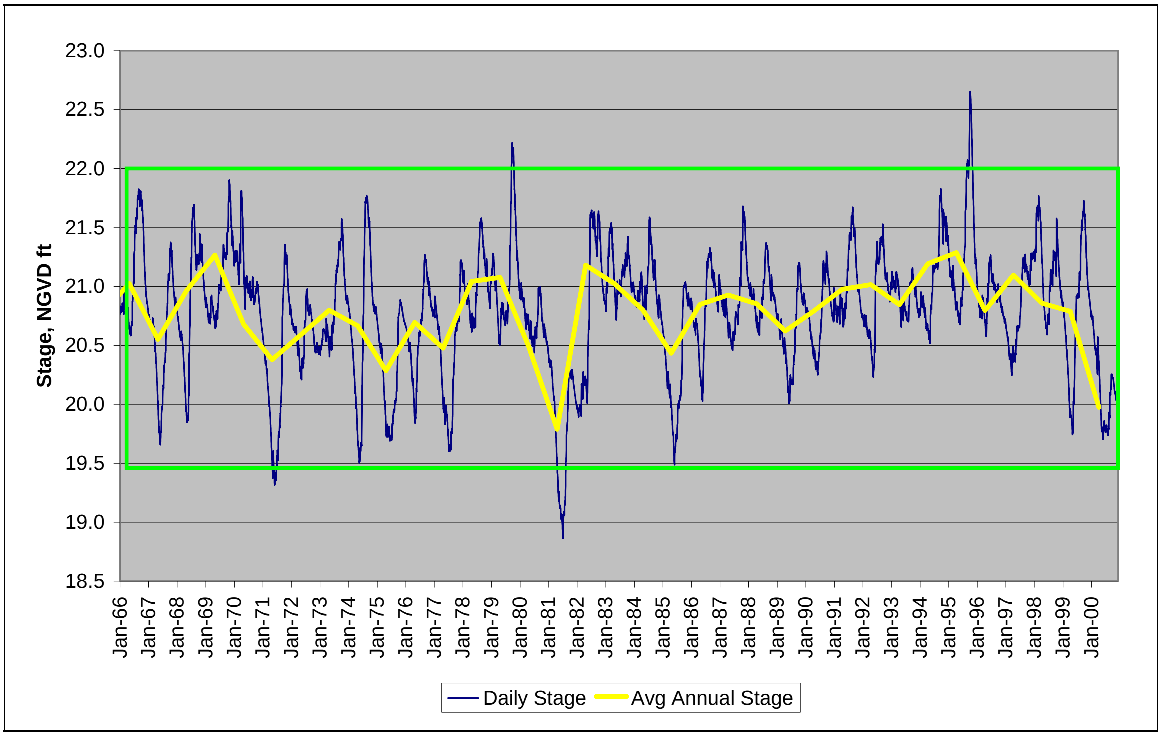
Stage hydrographs and stage duration curves for all model monitoring cell and zone output can be accessed on line: ftp://ftp.sfwmd.gov/pub/pln/oom/nsrsm/

Evaluation Objective: Stage hydrographs were evaluated for annual and inter-annual hydropatterns. Stage duration curves were evaluated for inundation duration. The percent of the total period of record inundated (hydroperiod) is included as a metric in PM-1.

Lake Okeechobee Stage

Evaluation Objective: Interannual variability is compared to pre-development hydrologic characteristics for Lake Okeecobee described in Appendix A.1. Stage amplitude is compared to the estimated historical range indicated by green lines in the figure below.

Figure 11. Lake Okeechobee stage hydrograph for simulation period



Overland Flow Transects

Evaluation Objective: No reference values are available for pre-development surface water flow volumes.

The graph and associated table below compare NSRSM v2.0 results to NSM v. 4.6.2 Sens[itivity Run] 4 flows for the same transects. T17 and T18 (center) are also compared to NSM v4.6.2 flows.

For Clarification:

NSM v4.6.2 is the current version of the 2x2 Natural System Model

NSM v4.6.2Sens4 is a sensitivity run that was designed to test the updated pre-drainage Everglades topography (same contours used in NSRSM)

Figure 12. Long-term average annual overland flow

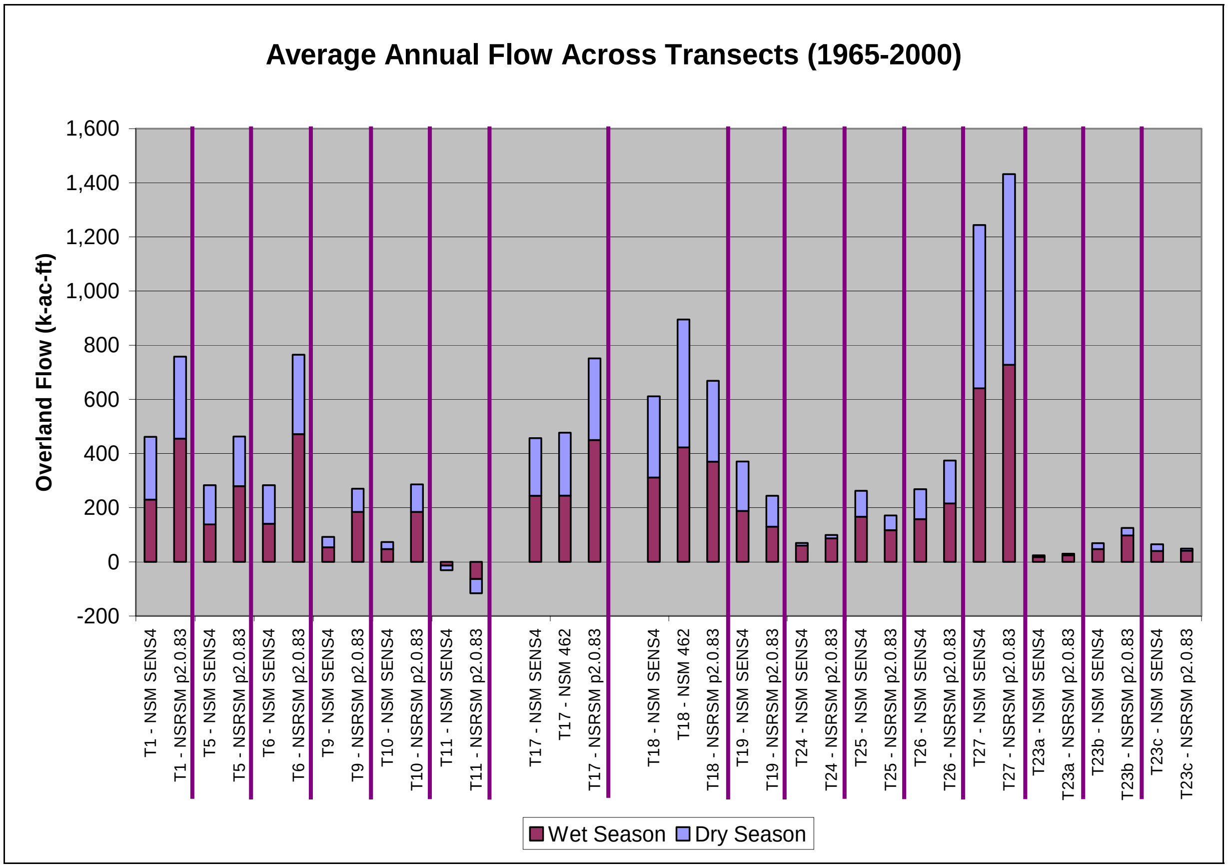


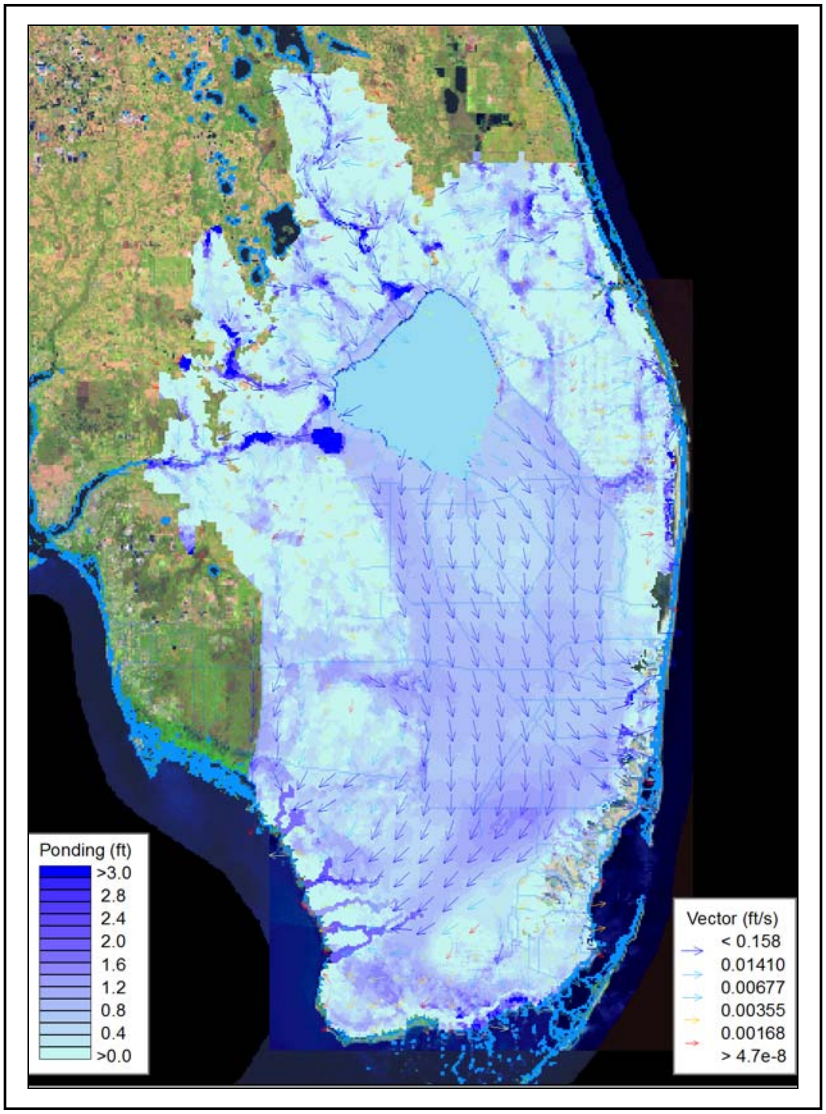
Table 13. Overland transect flow (K Acre Feet) corresponding to Figure 11

	T1	*T5*	*T6*	*T9*	*T10*	*T11*	*T17*	*T18*	*T19*	*T23a*	*T23b*	*T23c*	*T24*	*T25*	*T26*	*T27*
NSRSM p2.0.83 (1965-2000) Wet Season	455	279	472	185	185	-63	449	370	130	25	98	41	87	117	216	727
NSRSM p2.0.83 (1965-2000) Dry Season	302	183	293	85	102	-53	301	298	114	5	28	8	13	54	159	705
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							245	423								
NSM462 (1965-2000) Dry Season							232	472								

Overland Flow Vectors

Evaluation Objective: Reference characteristics for this performance indicator can not be quantified. Overland flow patterns for the Everglades basin should have the characteristic directionality detailed in **Appendix A.1**.

Figure 13. Long-term Average Monthly Ponding and Flow Vectors for October



Water Budget

Evaluation Objective: Identify major components of the water budget for Everglades landscapes The unit of flow for each section is k-ac-ft/year. Each flow section is divided into surface and groundwater components. Each figure is annotated with a number representing each flow section and an arrow representing flow direction.

Sawgrass Plains

The Sawgrass Plains zone was divided into six flow sections, as shown below. The residual flow for this landscape is 0.62%. A topographic high in the Sawgrass Plains causes 60% of the combined overland flow of section 1 and 5 to pass though section 1. The overland flow from Lake Okeechobee, section 6, accounts for only 15% of the total flow in this landscape while rainfall and ET account for 31% and 27%, respectively.

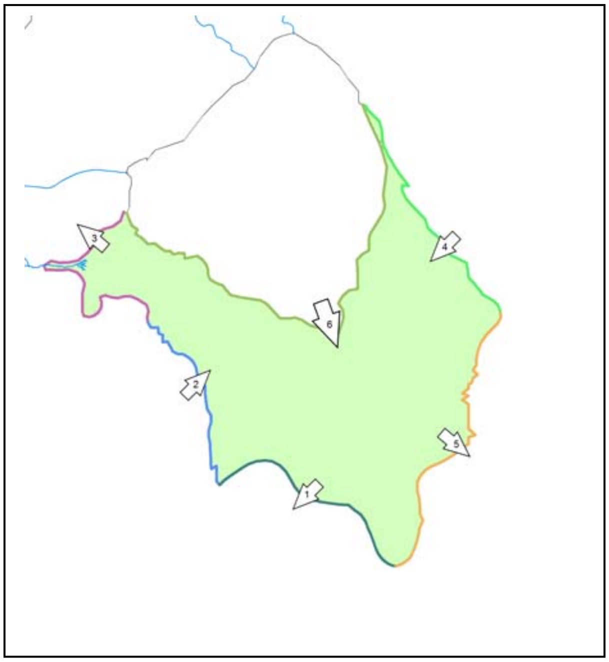


Table 14. Sawgrass Plains water budget

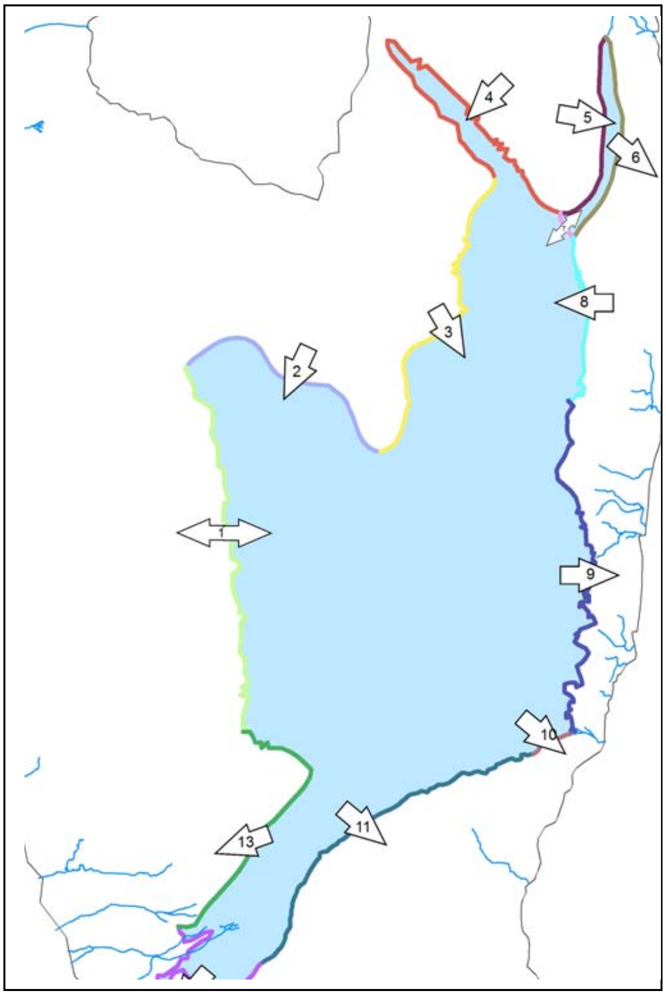
Flow Section	Flow (k-ac-ft/yr)
River Flow (Caloosahatchee River)	83.9
River Seepage	14.2
1 - Groundwater	0.0
1 – Overland Flow	1175.7
2 - Groundwater	0.2
2 – Overland Flow	143.9
3 - Groundwater	2.2
3 – Overland Flow	241.0
4 - Groundwater	0.0
4 – Overland Flow	214.5
5 - Groundwater	0.1
5 – Overland Flow	790.5
6 – Groundwater	6.9
6 – Overland Flow	1395.6
ET (Computed)	2507.2
Rainfall	2867.1
Storage Change	3.2

Ridge and Slough

The Ridge and Slough zone was divided into 13 flow sections. The residual flow for this landscape is 0.69%. Overland flow to the east coast rivers, section 9, accounts for 7% of the total flow in this landscape while rainfall and ET account for 36% and 30%, respectively. Overland flow through Shark Slough, section 12, and Shark and Harney Rivers, account for 7.5% of the flow in this landscape.

Table 15. Ridge and Slough Water Budget

Flow Section	Flow (k-ac-ft/yr)
River Flow	1080.9
River Seepage	90.8
1 – Groundwater (out)	0.1
1 – Groundwater (in)	0.0
1 – Overland (out)	19.2
1 – Overland (in)	154.6
2 - Groundwater	0.0
2 – Overland	1181.1
3 - Groundwater	0.1
3 – Overland	794.2
4 - Groundwater	0.3
4 – Overland	112.4
7 - Groundwater	0.0
7 – Overland	77.6
8 - Groundwater	2.3
8 – Overland	55.8
9 - Groundwater	105.4
9 – Overland	1311.4
10 - Groundwater	23.2
10 – Overland	7.9
11 - Groundwater	5.1
11 – Overland	3.7
12 - Groundwater	1.0
12 – Overland	241.2
13 - Groundwater	0.4
13 – Overland	608.9
ET (Computed)	5310.1
Rainfall	6368.5
Storage Change	0.7



Flow Section	Flow (k-ac-ft/yr)
5 - Groundwater	0.5
5 - Overland	132.2
6 - Groundwater	0.0
6 - Overland	94.9
7 – Groundwater (out)	0.0
7 – Groundwater (in)	0.0
7 – Overland (out)	77.5
7 – Overland (in)	0.0
ET (Computed)	90.4
Rainfall	130.3
Storage Change	0.0

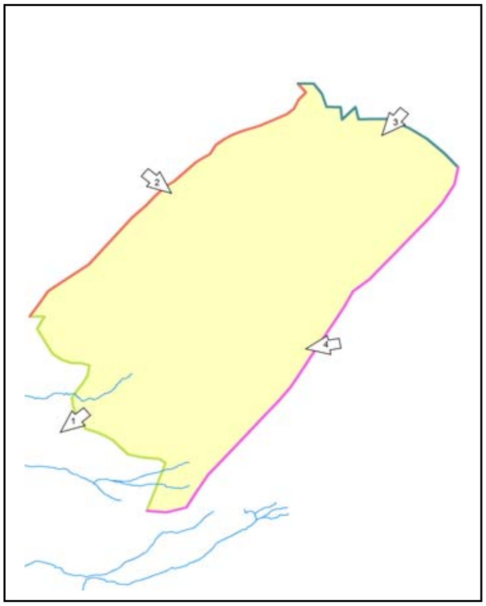
A separate budget was prepared for sections 5 through 7 which represent the Loxahatchee Slough. The residual flow for this landscape is 0.02%. The model shows 12% of the total flow in this landscape exiting Loxahatchee Slough to the Ridge and Slough landscape. A negligible amount enters the Loxahatchee Slough.

Ochopee Marl Marsh

The Ochopee Marl Marsh zone was divided into 4 flow sections. The residual flow for this landscape is 1.3%. Overland flow through section 4 accounts for 20% of the total flow in this landscape. 31% of the total flow in this landscape exits the system through the rivers and overland flow section 1. Rainfall and ET account for 22% and 18% of the total flow in this landscape, respectively.

Table 16. Ochopee Marl Marsh Water Budget

Flow Section	Flow (k-ac-ft/yr)
River Flow	600.7
River Seepage	56.0
1 – Groundwater	0.1
1 – Overland	289.1
2 - Groundwater	0.0
2 – Overland	155.0
3 - Groundwater	0.1
3 – Overland	562.8
4 - Groundwater	0.3
4 – Overland	46.1
ET (Computed)	518.8
Rainfall	625.8
Storage Change	0.5

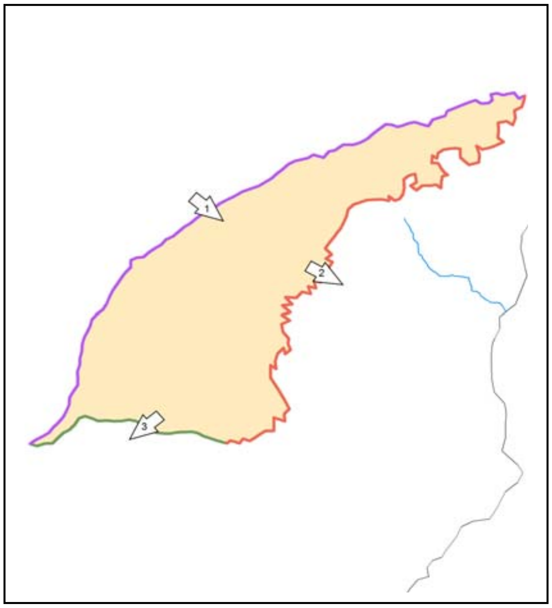


Rockland Marl Marsh

The Rockland Marl Marsh zone was divided into 3 flow sections. The residual flow for this landscape is 0.0%. 9% of the total flow in this landscape enters through overland section 2. Rainfall and ET account for 49% and 35% of the total flow in this landscape, respectively.

Table 17. Rockland Marl Marsh Water Budget

Flow Section	Flow (k-ac-ft/yr)
1 – Groundwater	5.1
1 – Overland	3.7
2 - Groundwater	67.7
2 – Overland	126.2
3 - Groundwater	15.0
3 – Overland	15.9
ET (Computed)	513.2
Rainfall	728.9
Storage Change	0.1

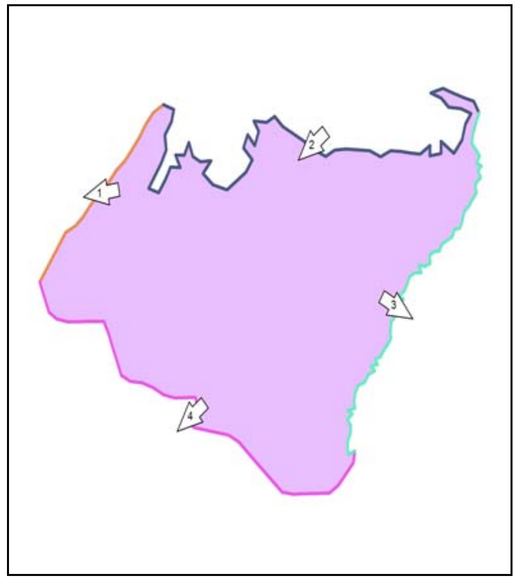


Perrine Marl Marsh West

The Perrine Marl Marsh West zone was divided into 4 flow sections. The residual flow for this landscape is 0.0%. Overland flow through sections 3 and 4 accounts for 5% and 11% of total flow in this landscape, respectively. Groundwater and overland flow through section 2 account for 8% of the total flow in this landscape. Rainfall and ET account for 42% and 34% of the total flow in this landscape, respectively.

Table 18. Perrine Marl Marsh W. Water Budget

Flow Section	Flow (k-ac-ft/yr)
1 – Groundwater	1.0
1 – Overland	0.1
2 - Groundwater	22.3
2 – Overland	37.8
3 - Groundwater	1.7
3 – Overland	40.4
4 - Groundwater	0.0
4 – Overland	86.1
ET (Computed)	263.6
Rainfall	332.9
Storage Change	0.1

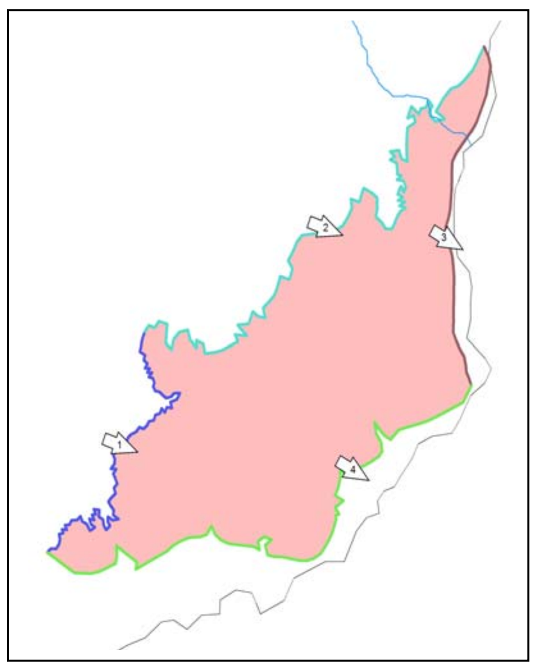


Perrine Marl Marsh East

The Perrine Marl Marsh East zone was divided into 4 flow sections. The residual flow for this landscape is 1.48%. Overland flow through section 4 accounts for 12% of the total flow in this landscape. Rainfall and ET account for 35% and 28% of the total flow in this landscape, respectively.

Table 19. Perrine Marl Marsh E. Water Budget

Flow Section	Flow (k-ac-ft/yr)
River Flow	22.9
River Seepage	21.0
1 – Groundwater	2.8
1 – Overland	68.4
2 - Groundwater	118.3
2 – Overland	50.1
3 - Groundwater	69.1
3 – Overland	43.9
4 - Groundwater	12.0
4 – Overland	201.8
ET (Computed)	7.8
Rainfall	471.6
Storage Change	598.6



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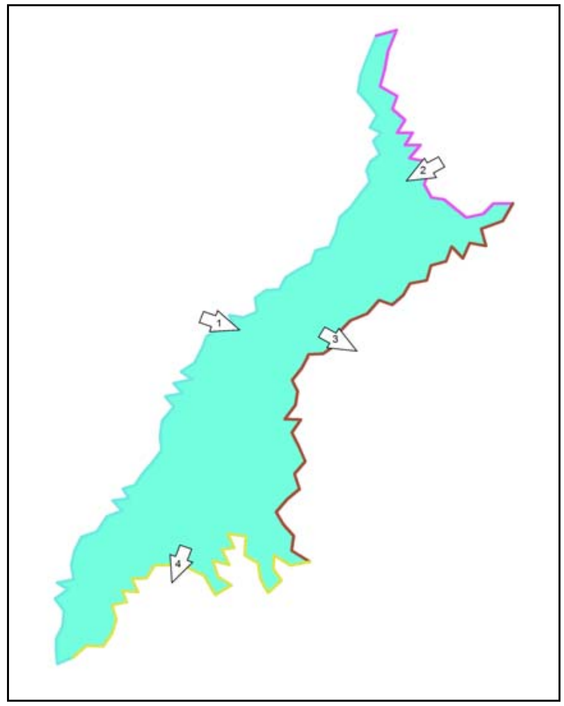
Taylor Slough

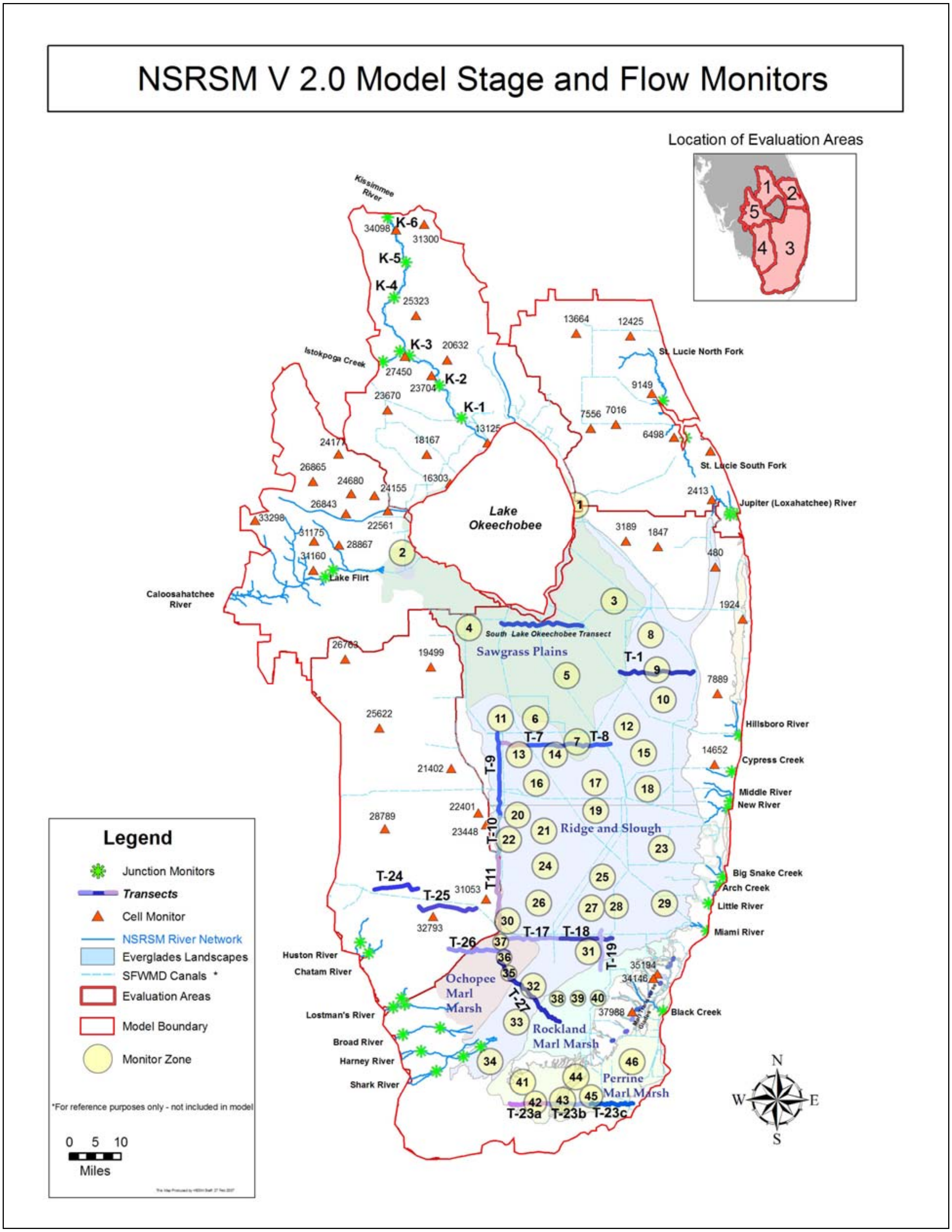
The Taylor Slough zone was divided into 4 flow sections. The residual flow for this landscape is 0.01%. Overland flow through section 4 accounts 28% of the total flow in this landscape. Overland flow into the system from sections 1 and 2 account for 14% and 16% of the total flow in this landscape, respectively. Rainfall and ET account for 17% and 15% of the total flow in this landscape, respectively.

Table 20. Taylor Slough Water Budget

Flow Section	Flow (k-ac-ft)
1 – Groundwater	1.7
1 – Overland	40.4
2 - Groundwater	5.7
2 – Overland	44.8
3 - Groundwater	0.0
3 – Overland	18.9
4 - Groundwater	0.2
4 – Overland	79.5
ET (Computed)	42.6
Rainfall	48.6
Storage Change	0.0



ATTACHMENT A



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DISCUSSION

NSRSM validation (determination of whether the model meets its requirements in terms of the methods employed and the results obtained) will be an ongoing process. As part of this process, an evaluation of NSRSM version 2.0 performance relative to historical estimates of pre-drainage hydrology is presented in this section beginning with an analysis of the performance measure output followed by the performance indicators.

PERFORMANCE MEASURES

PM-1 Inundation Duration (Hydroperiod)

Performance Objectives for Everglades Landscapes:

Sawgrass Plains 9-10 month hydroperiod

Marl Marsh 6-9 month hydroperiod

Ridge and Slough 9-12 month hydroperiod with optimum levels (for the averaged landscape) in the 10.5 foot range +/- 1 ft.

In general, inundation durations for landscapes in the Everglades basin fall within long-term average ranges notwithstanding the drier than average rainfall for the base condition simulation.

Landscape specific comments:

Sawgrass plains zone 1 and zones 3-6 hydroperiods meet or exceed the minimum requirements of 9 months inundation, and do not exceed the maximum of 10 months resulting in characteristic pre-drainage hydroperiods for this region. Inundation duration for zones 2 and 7 is 8.8 and 8.9 months respectively. Drier than average conditions in these zones might be attributed to declining rainfall during the simulation period. Additionally, Zone 7 is located directly downstream from the topographical “hump” formed by the northern Everglades land surface elevations which tend to divide the flow from Lake Okeechobee east and west creating slightly drier conditions in the north central Everglades.

Ridge and Slough monitoring zone inundation durations are generally within the reference range for this averaged landscape. For most zones, the lower than average rainfall input for the simulation period results in hydroperiods falling slightly short of the (long-term average) landscape optimum (10.5 months) but remaining within the uncertainty band of +/- 1 foot. Zones 14 and 17 are the driest zones with simulated hydroperiods of 9.7 and 9.4 months respectively. These two zones are located downstream of the topographical hump in the northern Everglades and receive reduced flows from the Lake. Inundation duration output from zones 43 and 44 in Taylor Slough do not appear to be consistent. Upon further examination, it was determined that slightly higher land surface elevations in zone 43 compared to 44 should be adjusted lower to better represent Taylor slough topography. The resulting hydroperiod should be an average between the current inundation durations for the two zones; approximately 10.5 months.

Hydroperiod performance for the Ochopee and Rockland marl marshes (zones 35-40) is generally characteristic of pre-drainage Everglades patterns; longer hydroperiods occur adjacent to the ridge and slough landscape. Hydroperiods in rockland marl zones 38, 39, and 40 become increasingly shorter from west to east as the landscape slopes up to meet the Atlantic Coastal Ridge. The remaining marl zones, 41, 42, 45, and 46, located in the southern Perrine marl marsh, are slightly under reference range hydroperiods. Considering the hydrologic separation of this area from the main system and the low rainfall period of record, the simulated inundation durations averaging 5 months do not appear uncharacteristic for this region.

Performance Objectives for all other Evaluation Areas: Simulated hydroperiods should fall within the reference range for a specific landscape. Refer to Results and Evaluation Section I, **Tab. 1** for a list of landscape reference ranges.

In all other evaluation areas, correspondence was generally good between simulated hydroperiods and reference ranges. Exceptions to this are discussed below.

Evaluation area 3, monitoring cell 1924: This coastal landscape is misclassified as a mesic pine flatwood. Hydroperiods of 11 months would indicate that it should be re-classified to marsh. Vegetation communities in this region are in the process of verification using the methodology detailed in Appendix E.

Evaluation area 4, monitoring cells for wet prairie communities: Simulated hydroperiods for wet prairie exceed the reference range. Wet prairie vegetation communities in eastern Big Cypress are in the process of verification using the methodology detailed in Appendix E. It is anticipated that this area will ultimately be re-classified as marsh, in which case the simulated hydroperiods would correspond to longer duration reference ranges.

PM-2 Seasonal Water Levels

Performance Objective: Long-term average maximum (wet season) and minimum (dry season) water levels for each zone should be within 0.5 ft of reference max and min levels.

Seasonal water levels for Everglades landscapes (Results and Evaluation Section I, Figure 7) generally meet performance objectives. Levels are in the low range as expected due to the declining rainfall during this period of record (POR). Hydrologic Process Module (HPM) refinements may be needed to adequately model the dynamic storage and higher water levels resulting from the thick peat layer in the northern Everglades.

For all other evaluation areas, seasonal water levels generally correspond to reference ranges. Notable exceptions include:

Evaluation area 3, monitoring cell 1924- As previously mentioned, this cell is potentially mis-classified. Current vegetation verification efforts will determine the correct classification.

Evaluation area 1, mesic pine flatwoods – Water levels in this vegetation community are slightly higher than optimum indicating a reclassification to hydric pine flatwoods may be necessary. Current vegetation verification efforts will determine the correct classification.

Evaluation area 5, monitoring cell 26865 – Water level performance in this cell is extreme however surrounding cells do not exhibit the same behavior. This cell is being investigated.

PM-3 Seasonal Amplitude for Everglades Landscapes

Seasonal amplitudes ranging from 1.5 – 1.6 feet in Everglades landscapes are lower than the reference amplitude (2 ft.). This may be due to the lower than average rainfall for the simulation period.

PM-4 Computed Evapotranspiration (ET)

Considerable effort went into preparing potential ET input for south Florida regional modeling (Appendix D). As indicated in **Fig**. **20,** computed ET values generally have good correspondence to reference ranges within Everglades wetlands where observed ET data is currently available.

PERFORMANCE INDICATORS

Natural river flows correspond well to available reference information. Performance graphic enhancement includes additional information regarding seasonal variability.

Lake Okeechobee simulated stages are within reference ranges. The lake overflows its southern shore (20.5 ft) within reference levels and timing linked to the sustainability of the surrounding landscape.

Summed results from overland flow transects 17 and 18 across Tamiami Trail show annual average flows of 1.4 M Ac-ft with a noticeable shift in distribution of flows (west) compared to previous model simulations (NSM v.4.6.2 and Sens 4). Flows are more characteristically evenly distributed across the landscape. All other transects have reasonable flow performance.

Simulated distribution and directionality of long-term average flows (Results and Evaluation Section I, **Fig. 13**) is generally aligned with historical estimates (Appendix A). One exception is the Loxahatchee Slough region. It is believed that the Loxahatchee Slough has bi-directional flow; in and out of the Everglades basin. According to the water budget, it appears that Loxahatchee Slough is only discharging to the Everglades. This may be the result of long-term average flow vectors calculated from a drier than average period of record. Further analysis of the results may show bi-directional flow. It is recommended to compute a water budget for a dry month and a wet month.

SUMMARY

NSRSM v2.0 base condition model performance is within the mid- to lower-values of the reference ranges. This was expected considering the less than average rainfall input for the simulation period. In meeting expectations, the NSRSM becomes a useful tool which can be used to better understand the natural hydrology of south Florida. However, results must be interpreted within the limits of model uncertainty. The following sensitivity tests are recommended to identify sources uncertainty:

1) The peat layer is incorporated into the overland flow conveyance lookup table. The effects of this layer are significant when the water level is below land surface elevation. The hydraulic conductivity of the layer is about 30 ft/d with a thickness of 50 ft and peat has a hydraulic conductivity of 0.8 ft/d with thickness ranging from 2 ft to 17 ft. A sensitivity run without the peat layer will determine its effect.

2) The elevations and percentages of slough, ridge, and tree island are based on historical records. A sensitivity analysis with varying combinations of percentage and elevation values will help determine the effects of the S-V relationship.

3) The only data available for river bed conductance is from field observation in the Kissimmee River. The bed conductance for other rivers is based on estimates of horizontal conductivity from adjacent cells. A sensitivity analysis using bed conductance of the Kissimmee River for other rivers will determine its impact.

4) Elevations for Mullet Slough, Buttonwood Embankment and rim of Lake Okeechobee are estimated from literature. A sensitivity analysis using a reasonable range of elevations will determine their impact.

5) Shunts are user specified watermovers that connect Lake Okeechobee with the sawgrass plains. The shunts have a conveyance (ft/sec) parameter that governs the flow. In reality, the water moves as freely as possible from the lake to the sawgrass plains, therefore, a large conveyance should be assigned to the model. Lake Okeechobee uses a shunt conveyance multiplier of 10.0 to allow water to move easily. A sensitivity analysis using a value of 1.0 will determine its impact.

6) Historically, most of the lower east coast rivers discharge to a lagoon. When the water level in the lagoon reaches a critical threshold, the lagoon will suddenly discharge to the ocean; this is called a "blow out". The stage-discharge relationship is used to simulate "blow out". Bracketing stage-discharge relationship for lakes within a range will determine the sensitivity.

7) The historic extent and boundary of the ridge and slough and sawgrass plains landscapes may vary. A sensitivity analysis varying the extent of these landscape types will determine their impact.

8) The overland flow conveyance lookup table is based on Kadlec's equation. The model uses one value from a range of values from USGS OFR-0354. A sensitivity analysis using the minimum, average, and maximum should be performed.

9) Since the simulated period of record is drier than normal, a sensitivity analysis should be performed by increasing the rainfall by 10% and 20%. This could provide a range "normal" and "wet" simulated period of record.