Assessing Ecological Function with Hydrologic Models in Restoration: Matching Expectations with Predictive Capability

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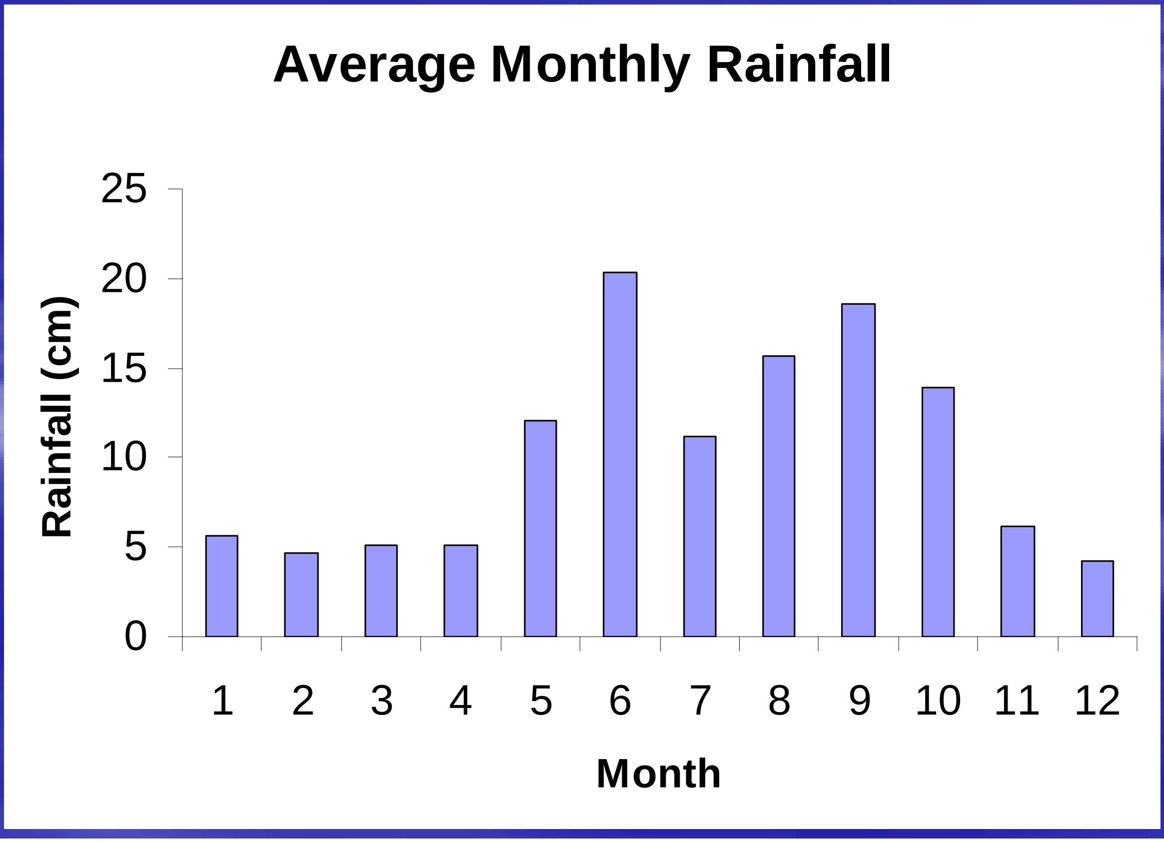
Hydrologic Setting

- South Florida's Everglades is America's only extensive subtropical wetlands. The organisms, flora and fauna, have adapted to the unique climatic conditions and resulting hydrology. Rainfall is distributed unevenly between the wet and dry seasons, which are roughly June through October, and November through May, respectively.



Hydrologic Response

This rainfall distribution results in an analogous hydrologic pattern, alternating high flows and flooding followed by extended drawdown.

Ecological Response

This hydrologic pattern results in some unique responses in the Everglades.

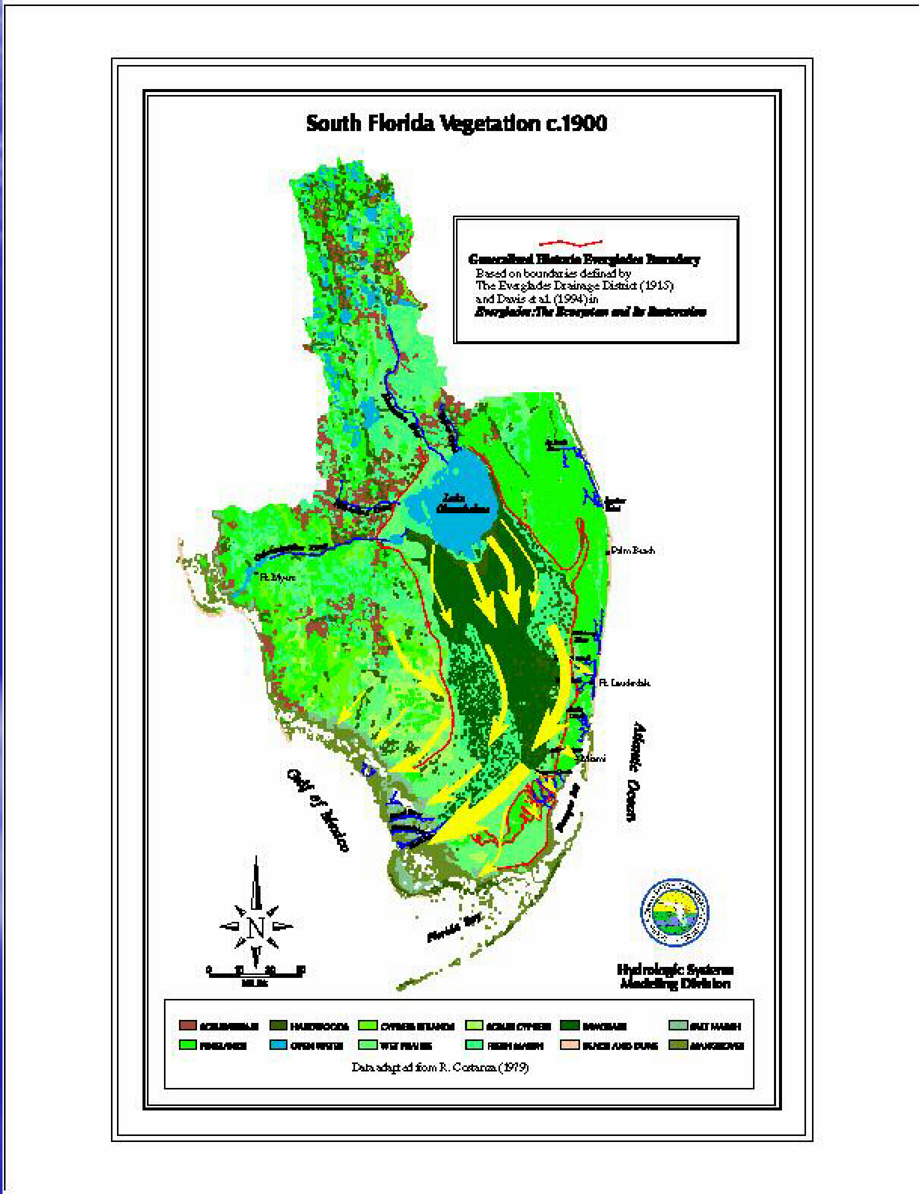
When the Everglades are flooded, fish and macro-invertebrates reproduce and grow in the expansive wetlands.

As the water recedes fish and other aquatic organisms are concentrated and become easy prey for a variety of wading birds which time their breeding and nesting to coincide with this natural cycle.

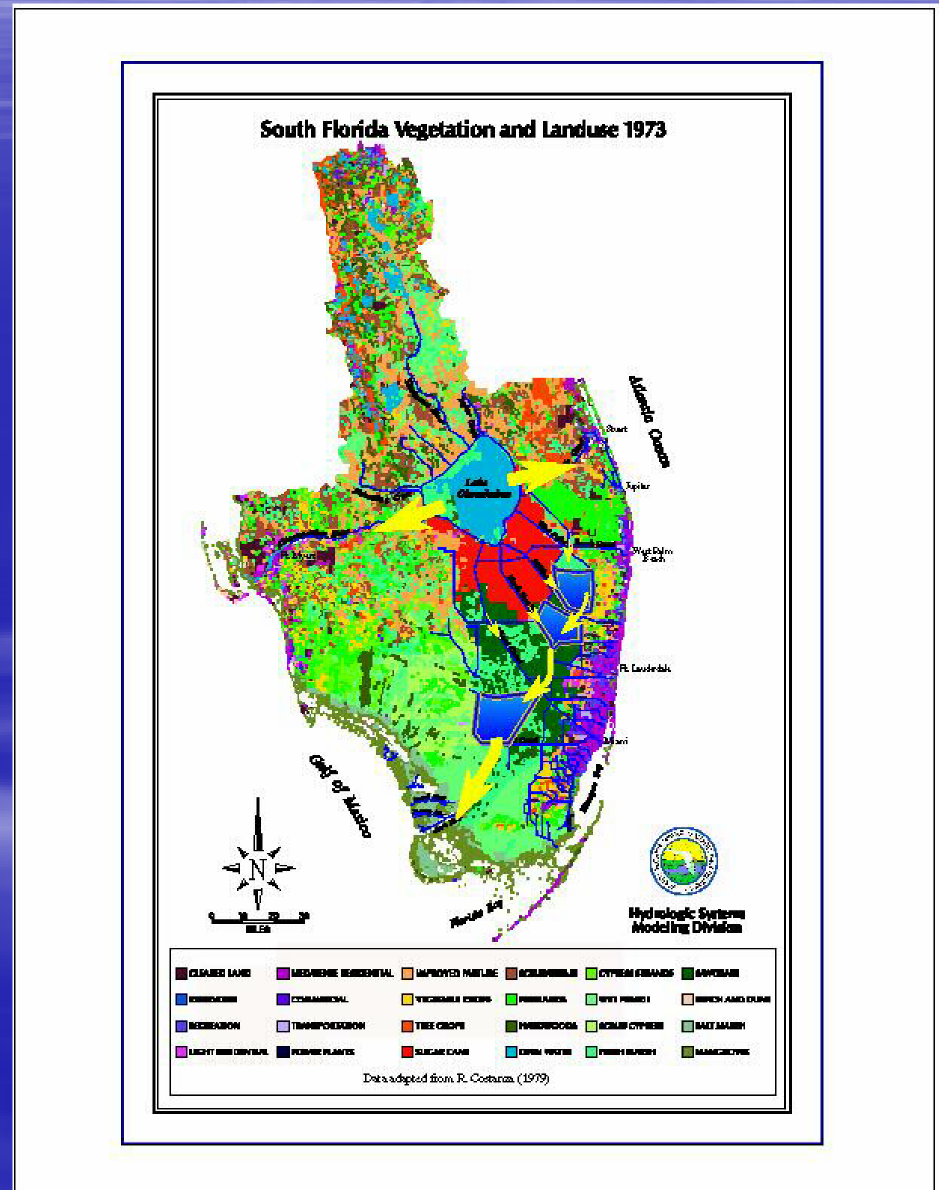
Many other species, Cape Sea Side Sparrow, American Alligator, and others, also time breeding and nesting around this cycle.

Hydrologic Alteration

Everglades Before Alteration

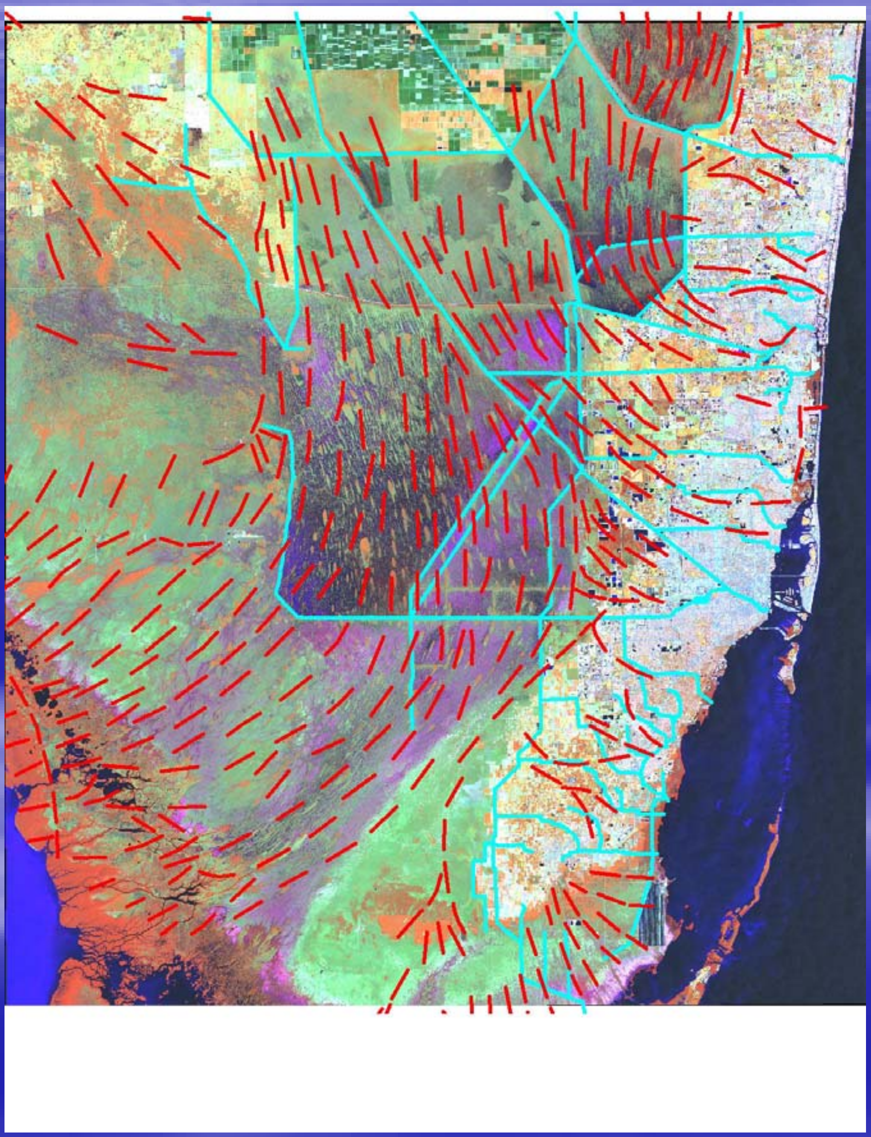


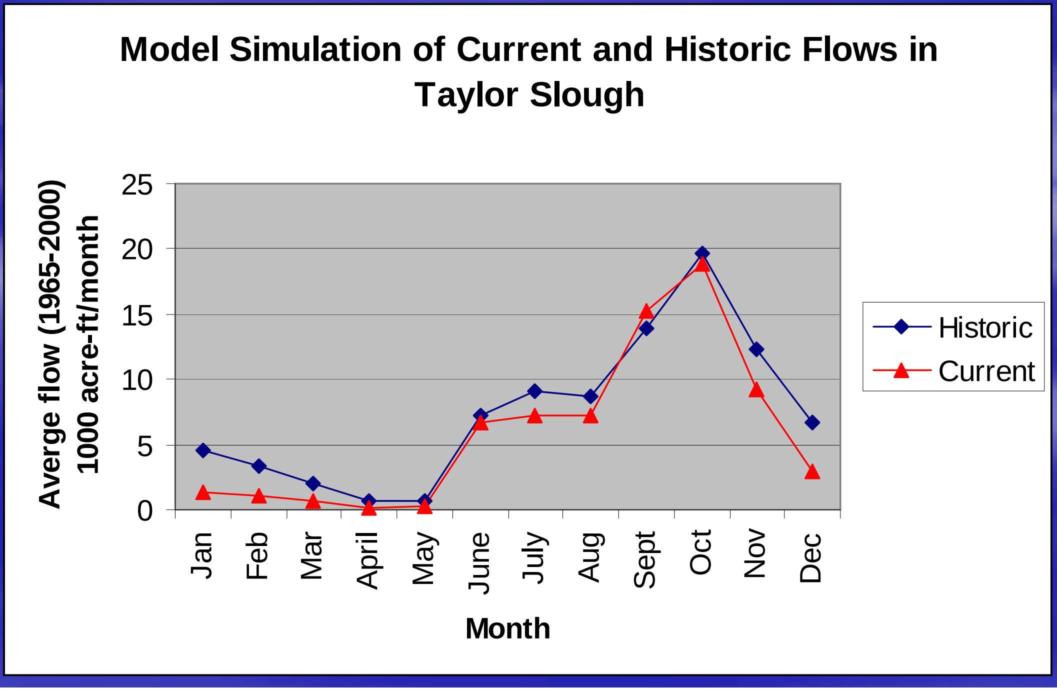
Everglades after C&SFP



Hydrologic Result

Current Everglades Flow Vectors





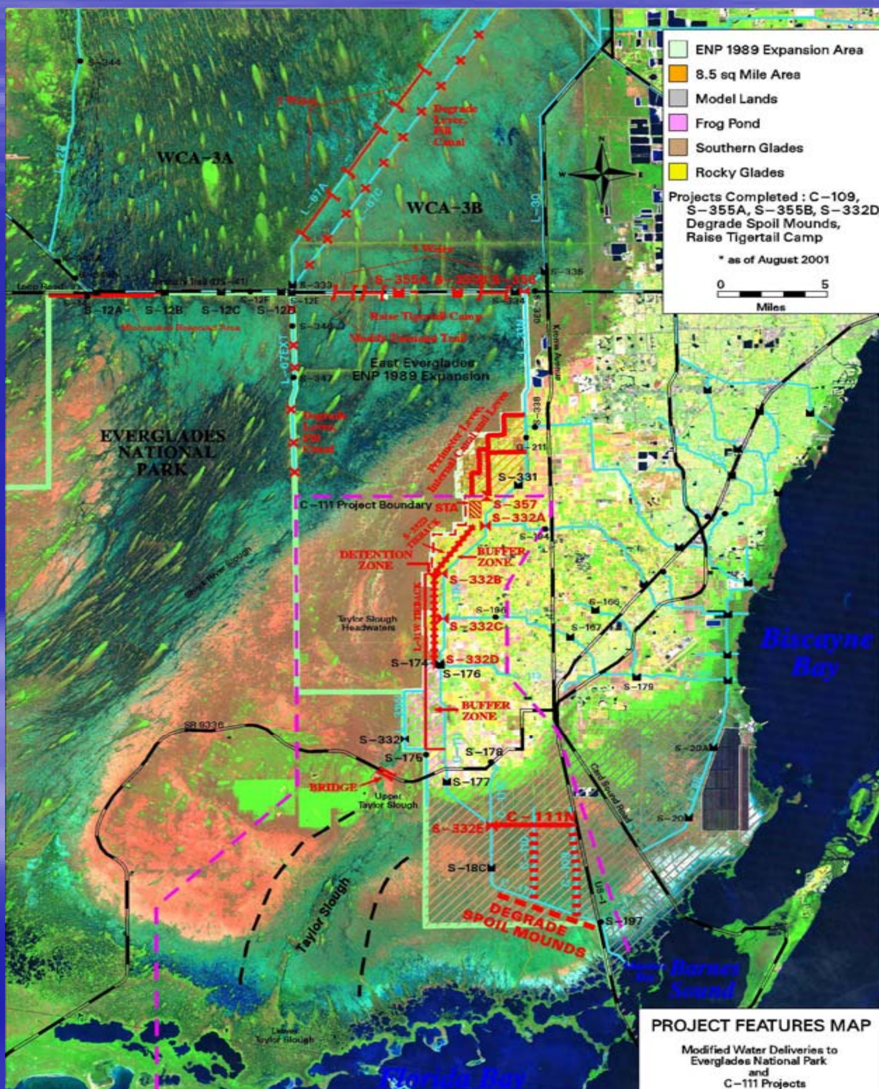
Ecologic Result

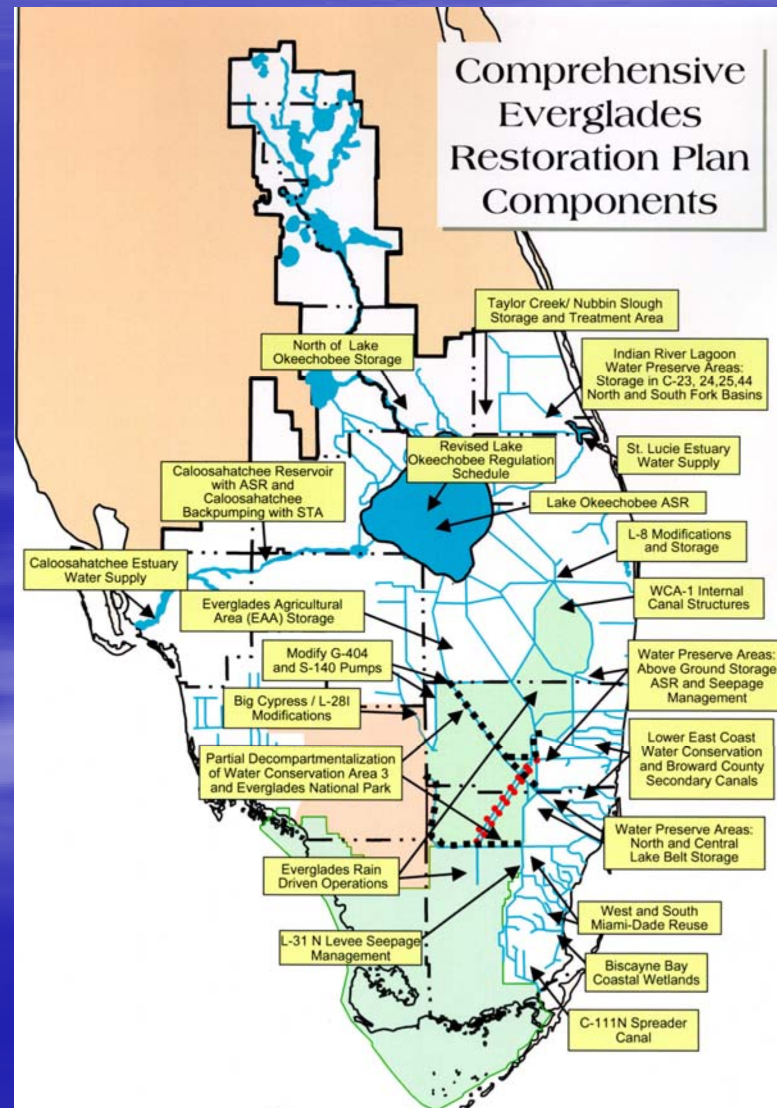
- Disturbed flooding and drying patterns throughout the system.
- Since the organisms are highly adapted to the natural cycle of flooding and drying, this has had near catastrophic effects.
- Current wading bird populations are at roughly 10% of historical numbers
- Many species of wading birds, the Cape Sable Seaside Sparrow, American crocodile, and others, have become endangered or threatened with extinction.
- Salinities in Florida and Biscayne Bays have risen, resulting in broad changes in species composition within the bays.

Everglades Restoration

Modified Water Delivers (MWD)

Comprehensive Everglades Restoration Project (CERP)





Methodology

- Alternative project plans are evaluated with hydrologic, hydrodynamic, and when available, ecological computer models to estimate the potential effects of the project features on the natural and man-made system.

- Criteria for a successful project, called performance measures (PMs), are developed to judge the effects of the project features on hydrology, water quality, and ecological PMs related to habitat, communities, as well as individual organisms.

- The alternative that appears to provide the "best" combination of ecological benefits, without negatively affecting flood control and endangered species, becomes the tentatively selected plan (TSP) that is taken forward to the engineering study and eventually the construction phase.

THE PROBLEM

Ecologist

- Ecologist develop performance measures, including PMs that detail the needs of specific key species.
- The ecologist generally do not understand hydrologic and hydrodynamic modeling concepts and limitations.
- They often assume that the models can simulate whatever is desired.

Engineers

- Engineers build the numerical hydrologic and hydrodynamic models
- Have a limited appreciation of how the models will be applied toward the decision-making based on ecological performance measures.
- Because of their background, engineers construct models that perform well for typical engineering applications, such as flood analysis and water control.

The Divide

- This large divide between the people who develop and apply the models and the people that use the results of the modeling to assess the project benefits, can result in models that cannot be used to assess the ecological criteria.

Selected Key Species

- **Coastal Wading Birds – Wood Stork and Roseate Spoonbill**
- Depend on proper timing and depth of inundation of key feeding areas.
- **Wood Stork Target**: Acres wood stork habitat from November 1 and May 15, with an emphasis on November/December timeframe. Wood stork habitat is defined as the number of acres with a depth of water between 0.1 and 0.25 meters.
- **Roseate Spoonbill Target:** Water depths should be no more than 12 cm deep on the coastal wetlands surface each week between mid-November and January somewhere within the foraging range of the spoonbill colonies (approximately the mangrove and freshwater wetlands inland 8 km from the coast from Taylor River to the Turkey Point cooling canals) from mid-November through the end of January.

Selected Key Species

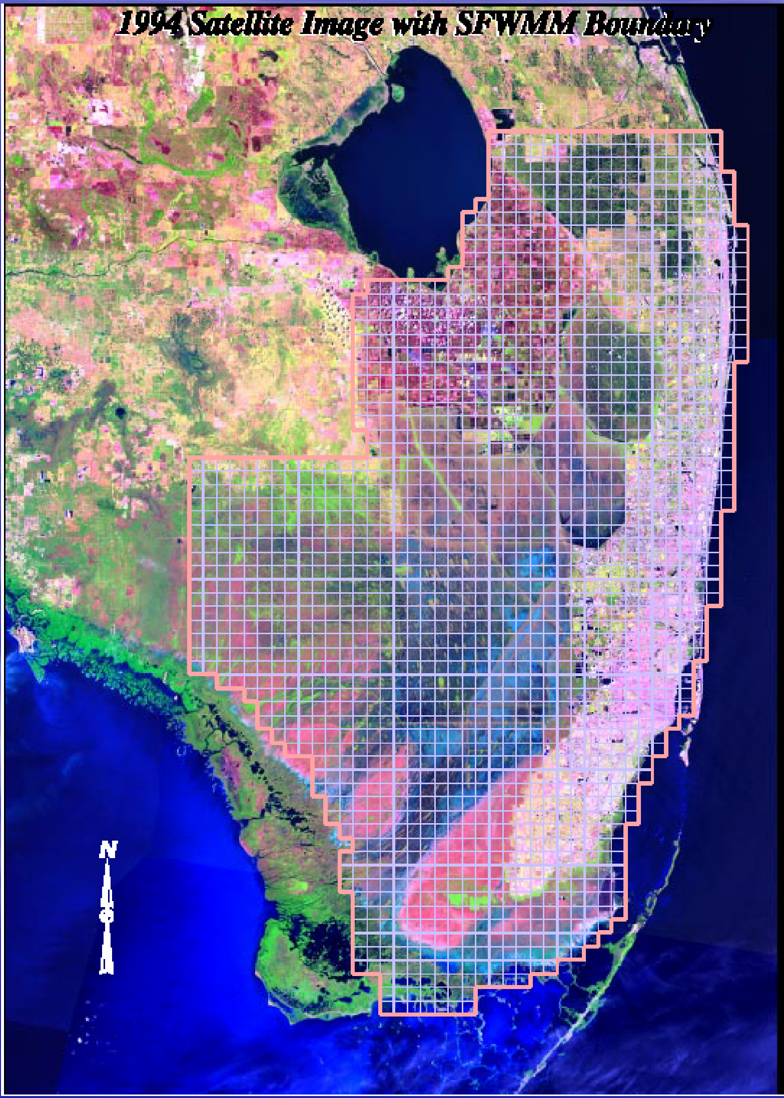
- **American Alligator -** Successful courtship requires flooded areas available in April and May.
- **Target**: Maximize the area of surface flooding in the sloughs during the alligator courtship period in April and May

Selected Key Species

- **Cape Sable Seaside Sparrow**
- Performance measures link flooding duration with vegetation
- type and nesting success.
- **Target:** 2-6 months per year of flooding in CSSS habitat for the middle 60% of years.
- **Target:** > 60 days with days below ground surface between
- March 1 and July 15th

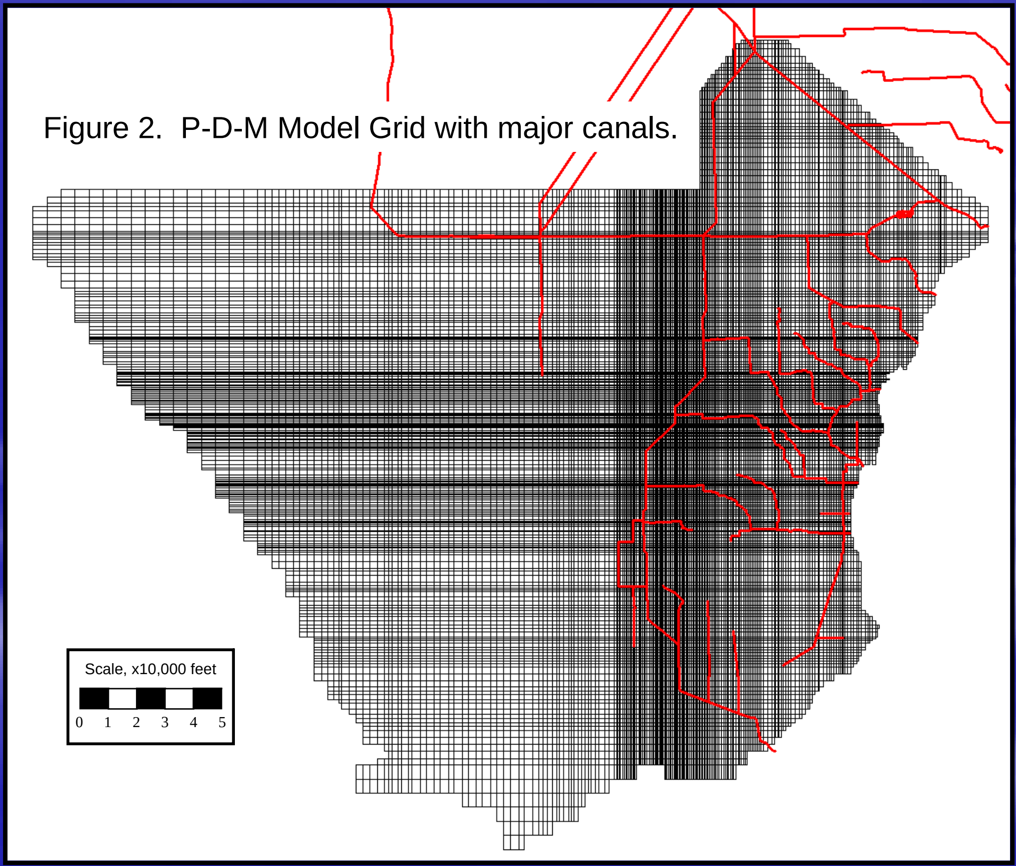
Hydrologic Models
South Florida Water Management Model (SFWMM)

- Divides south Florida into 2 mile by 2 mile structured grid
- Sequentially coupled surface water groundwater model
- Daily time step
- Empirical relationships at grid level
- Calculates a stage (water surface elevation) for each cell every day for 36 years (1965 - 2000)
- Calculates overland flow velocities for each cell
- Computes canal and structure flows



Hydrologic Models
MODBRANCH_P_D_M

- Finite difference saturated groundwater model (MODFLOW) combined with dynamic canal routing model (BRANCH)
- No overland flow component
- Surface water is simulated with additional subsurface layer
- Top layer is marsh (surface water) with high permeability
- Grid size from 63m to 1524m
- 1 hr time step
- Simulates wet, dry and average years



Surface Water Depth Predictions Inadequate to Analyze Water Bird PM

- Tables indicate groundwater/surface water elevation prediction accuracy for both models for a dry year, 1989, and a wet year, 1995.
- These correspond to the calibration and verification periods, respectively.
- Statistics are in feet
- Neither model can simulate water surface elevations within the required accuracy to determine adequate wading bird habitat. Average errors are greater than 0.5 feet.

Dry Year Depth Prediction Accuracy
Values are in feet

Table 8. MODBRANCH and SFWMM2x2 Statistical Summary, 1989

MODBRANCH 1989 (99 stations, daily values)										
	Pearson's r	Average Absolute Difference	Average (model-field)	RMSE	Systematic RMSE	Unsystematic RMSE	SysRMSE / RMSE	Index of Agreement	slope	intercept
Averages	0.81	0.59	0.23	0.69	0.60	0.26	0.65	0.76	0.69	1.05
Medians	0.85	0.40	0.12	0.48	0.41	0.24	0.74	0.78	0.69	0.93
Standard Deviation	0.17	0.78	0.91	0.81	0.83	0.12	0.28	0.15	0.33	1.36
1989 SFWMM 2x2 v3.7 (81 stations, weekly values)										
	Pearson's r	Average Absolute Difference	Average (model-field)	RMSE	Systematic RMSE	Unsystematic RMSE	SysRMSE / RMSE	Index of Agreement	slope	intercept
Averages	0.81	0.69	-0.07	0.78	0.60	0.39	0.47	0.79	1.03	-0.11
Medians	0.87	0.48	-0.04	0.57	0.33	0.36	0.41	0.85	0.96	-0.11
Standard Deviation	0.20	1.17	1.31	1.18	1.21	0.18	0.29	0.17	0.45	1.43

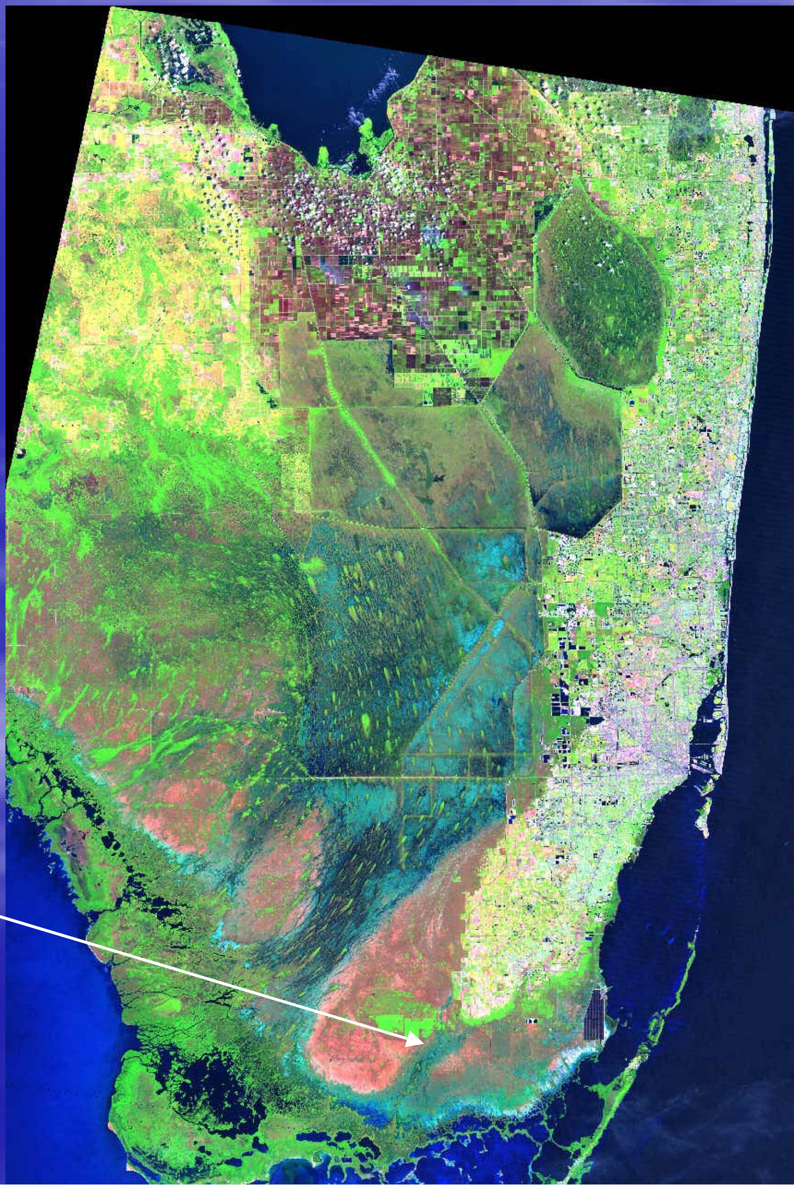
Wet Year Depth Prediction Accuracy
All Values in Feet

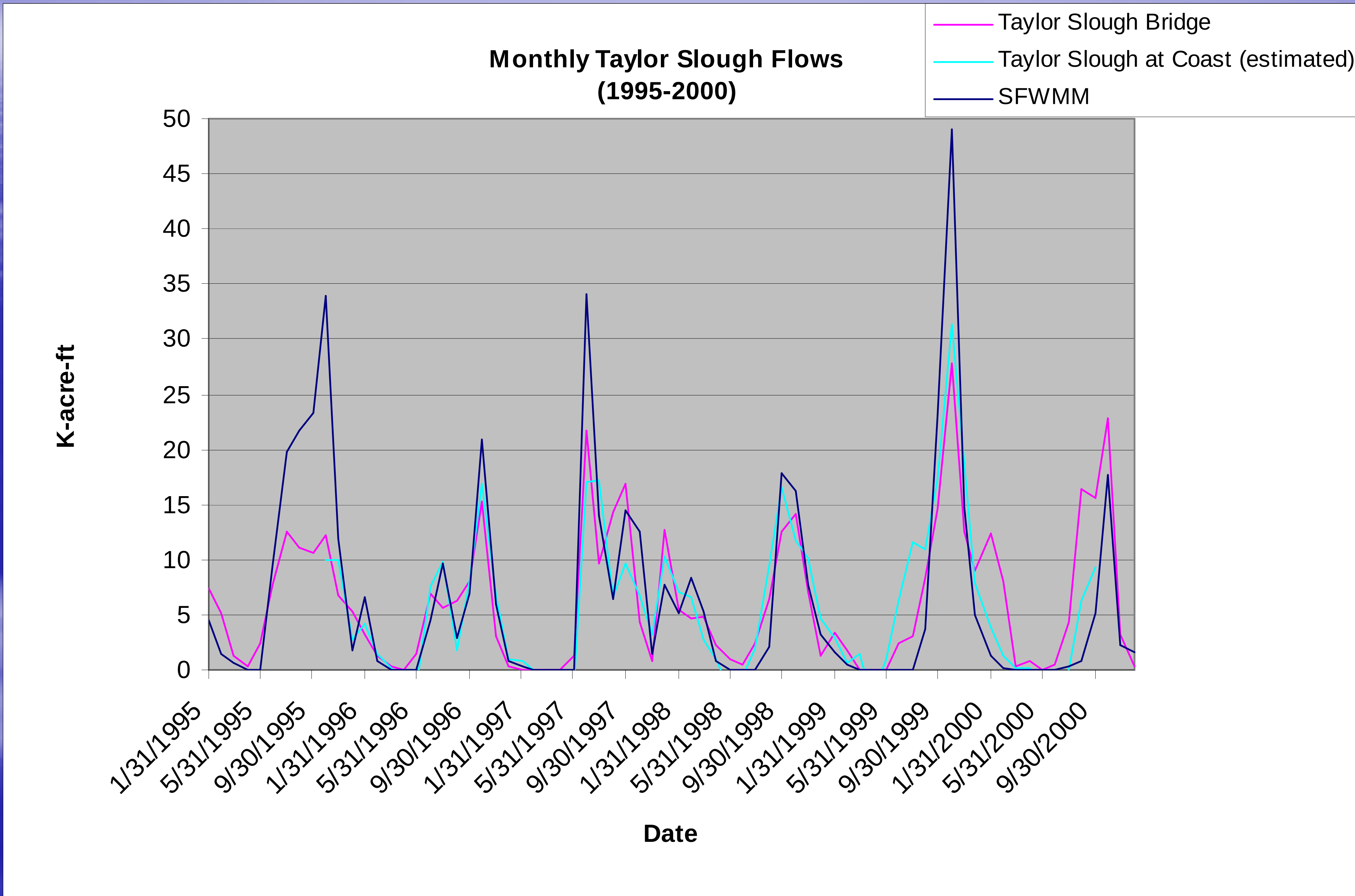
Table 10. MODBRANCH and SFWMM2x2 Statistical Summary, 1995										
MODBRANCH 1995 (102 stations, daily values)										
	Pearson's r	Average Absolute Difference	Average (model-field)	RMSE	Systematic RMSE	Unsystematic RMSE	SysRMS E/ RMSE	Index of Agreement	slope	intercept
Averages	0.82	0.57	0.15	0.66	0.56	0.27	0.62	0.77	0.77	0.91
Medians	0.85	0.40	0.05	0.49	0.38	0.25	0.73	0.82	0.75	0.88
Standard Deviation	0.13	0.74	0.88	0.77	0.80	0.12	0.30	0.16	0.28	1.34
1995 SFWMM 2x2 v3.7 (77 stations, weekly values)										
	Pearson's r	Average Absolute Difference	Average (model-field)	RMSE	Systematic RMSE	Unsystematic RMSE	SysRMS E/ RMSE	Index of Agreement	slope	intercept
Averages	0.83	0.75	0.02	0.83	0.75	0.26	0.69	0.73	0.78	0.80
Medians	0.89	0.41	-0.09	0.46	0.37	0.23	0.81	0.80	0.73	0.77
Standard Deviation	0.15	1.09	1.31	1.12	1.14	0.16	0.30	0.19	0.31	1.67

Surface Water Flow Predictions Inadequate to Asses Alligator Habitat

• MODBRACH grossly underestimates flow for both the wet and dry years, even the annual values. Annual flows at key locations, Tamiami Trail, and Taylor Slough are off by 90% and 55%, respectively.

• The SFWMM predicts annual and seasonal flows but fails to predict the monthly values of flow in key alligator habitat, such as Taylor Slough (picture to right).




Monthly Taylor Slough Flows
(1995-2000)
Taylor Slough Bridge
Taylor Slough at Coast (estimated)
SFWMM
K-acre-ft
50
45
40
35
30
25
20
15
10
5
0
1/31/1995
5/31/1995
9/30/1995
1/31/1996
5/31/1996
9/30/1996
1/31/1997
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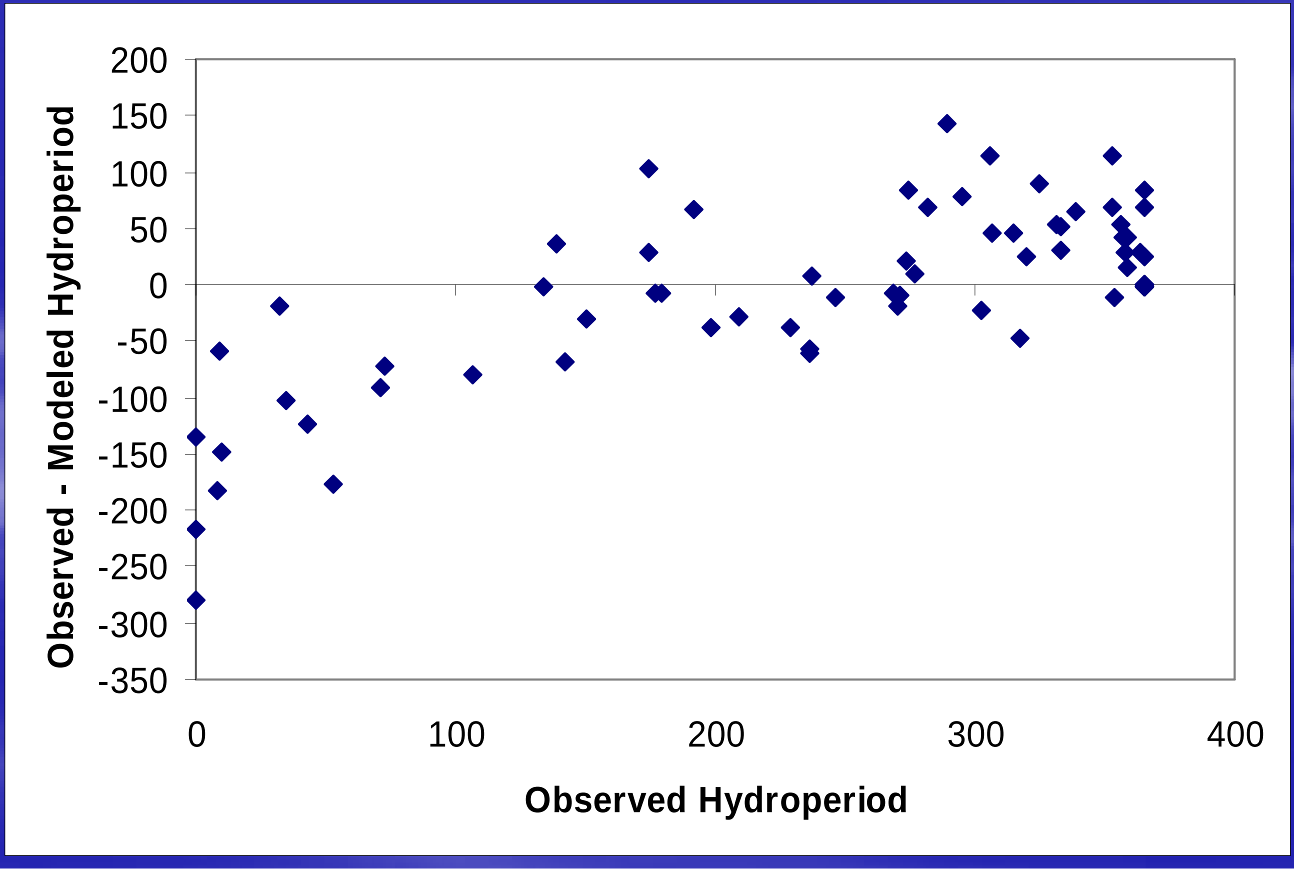
9/30/2000
Date

Hydroperiod Predictions Inadequate to Assess Sparrow Nesting Habitat

SFWMM observed hydroperiods vs. prediction error (1995-2000) Model underestimates long hydroperiods and overestimate short hydroperiods with more error seen for short hydroperiods. Cape Sable Seaside Sparrow habitat is predominately short hydroperiod.



Result

- Inability to assess ecological performance measures with available hydrologic data.
- Inability to quantify ecological benefits of proposed actions.
- Inability to justify potential harm to existing users – farmers, cities, etc.
- Perpetual stalemate – MWD is more than 10 years behind schedule, CERP could follow the same path.

Suggestions for Improvements

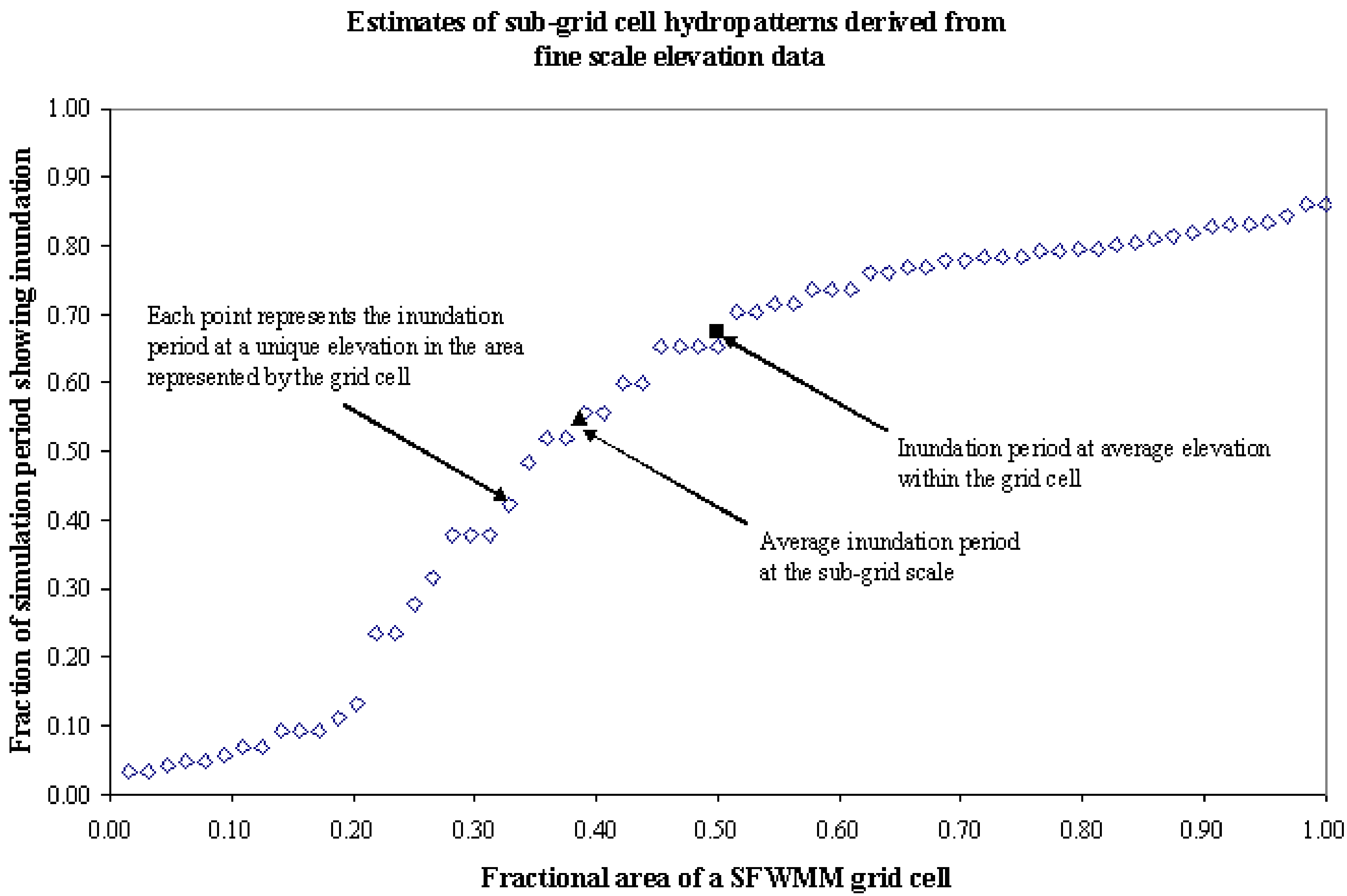
For relatively small clearly defined critical areas within the larger domain, use finer resolution inset models to improve accuracy.

• In lieu of inset models, or for large domains, account for sub-grid heterogeneity with statistical or deterministic descriptions of the sub-grid features.

• To reduce model uncertainty, attempt to develop performance measures that are evaluated over larger intervals of both time and space.

• Formulate performance measures in terms of current conditions and trends desired.

• Evaluate performance measures with full knowledge of the model weaknesses. Focus on model strengths and avoid making decisions based on inaccurate predictions.


Estimates of sub-grid cell hydropatterns derived from fine scale elevation data
Fraction of simulation period showing inundation
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Fractional area of a SFWMM grid cell
Each point represents the inundation period at a unique elevation in the area represented by the grid cell
Inundation period at average elevation within the grid cell
Average inundation period at the sub-grid scale