Spatially-explicit Hydrodynamic and Water Quality Modeling of the A.R.M. Loxahatchee National Wildlife Refuge Part I - Model Setup and Calibration

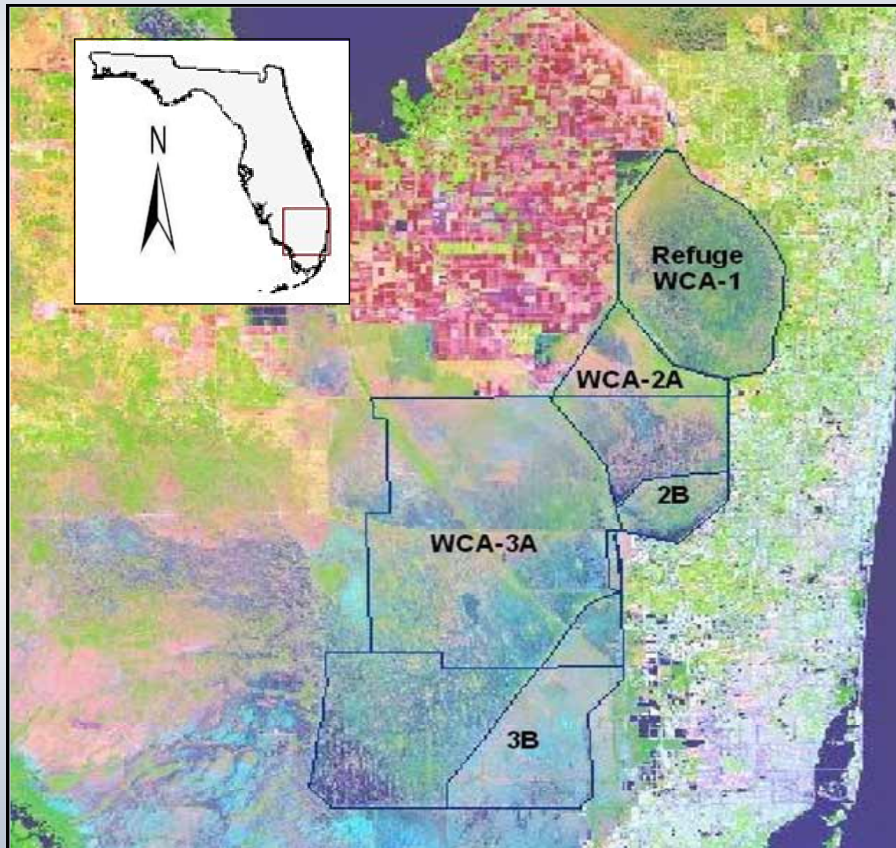
Chufang Chen[1], Ehab Meselhe[2], Michael Waldon[3], Hongqing Wang[2], and Matthew Harwell[3]

[1] University of Florida, School of Natural Resources and Environment

[2]Center for Louisiana Water Studies, University of Louisiana at Lafayette, Lafayette, LA

[3]DOI Everglades Program Team – USFWS, Boynton Beach, FL

Background

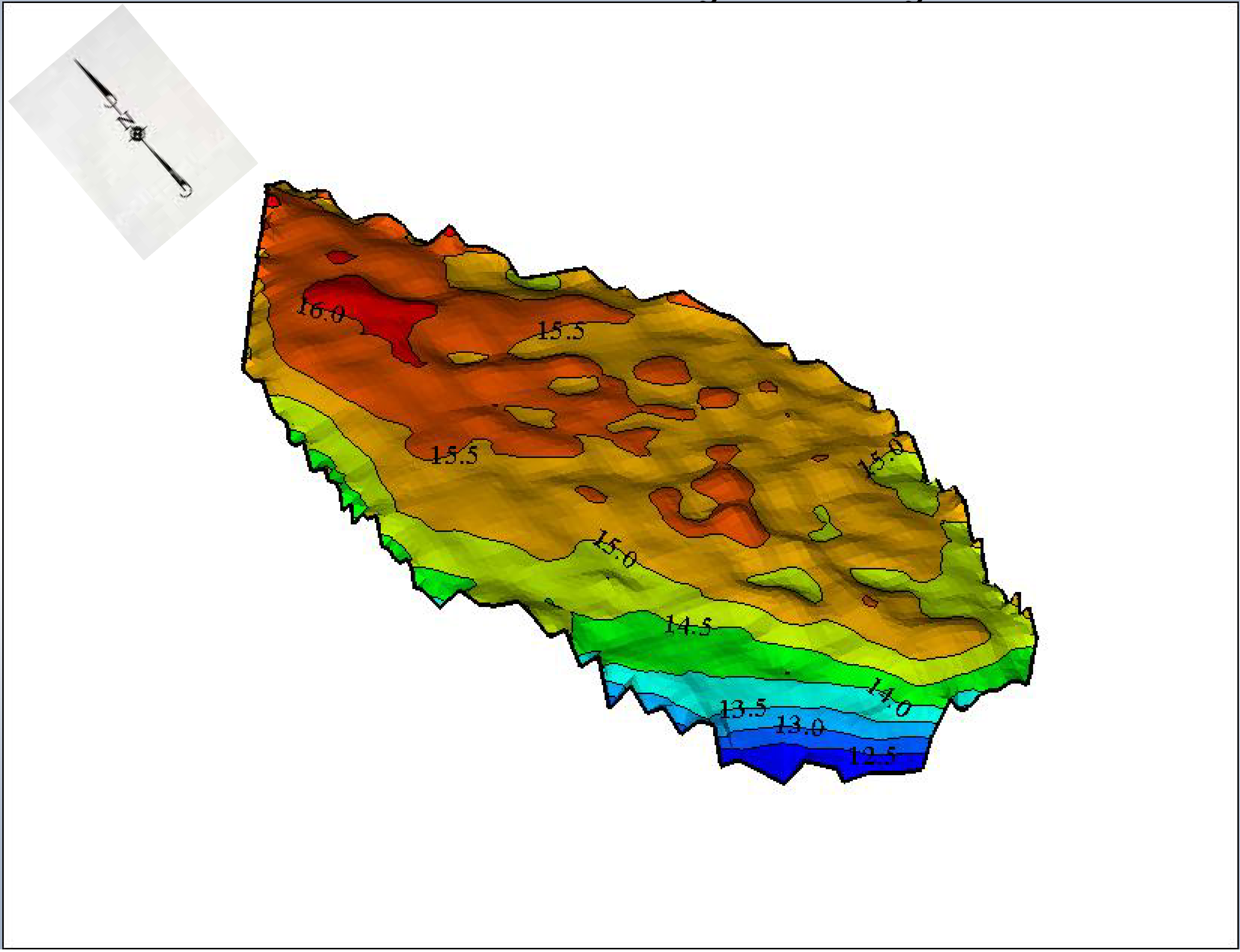


Background

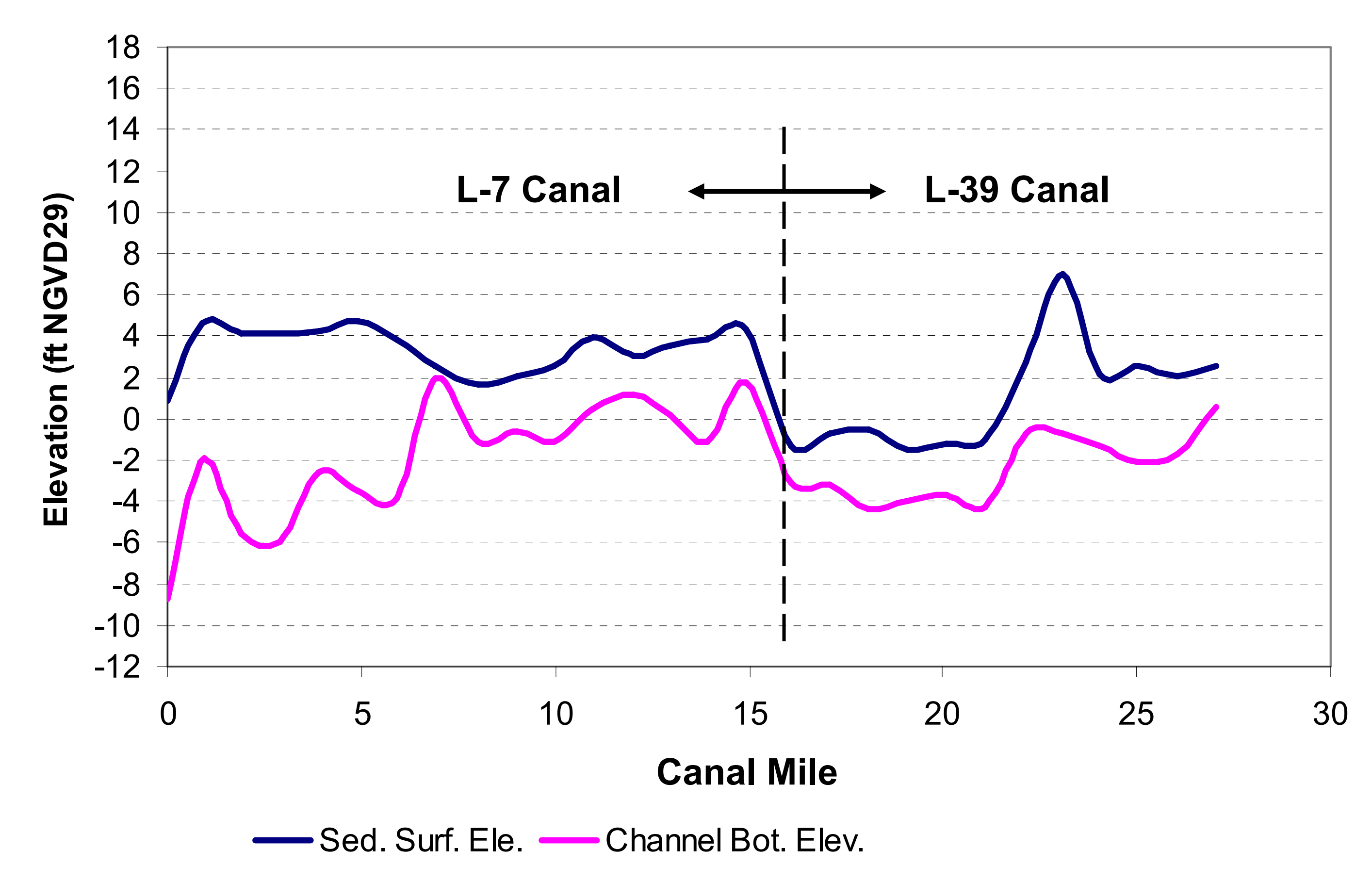
- Changes in water quantity, timing and quality are impacting the Refuge's ecosystem.

- It is a priority for the Refuge to ensure appropriate water management decision rules (regulation schedule)
  - Fish and Wildlife
  - Nutrients' Loading
  - Flood Control
  - Water Supply

Marsh Bathymetry

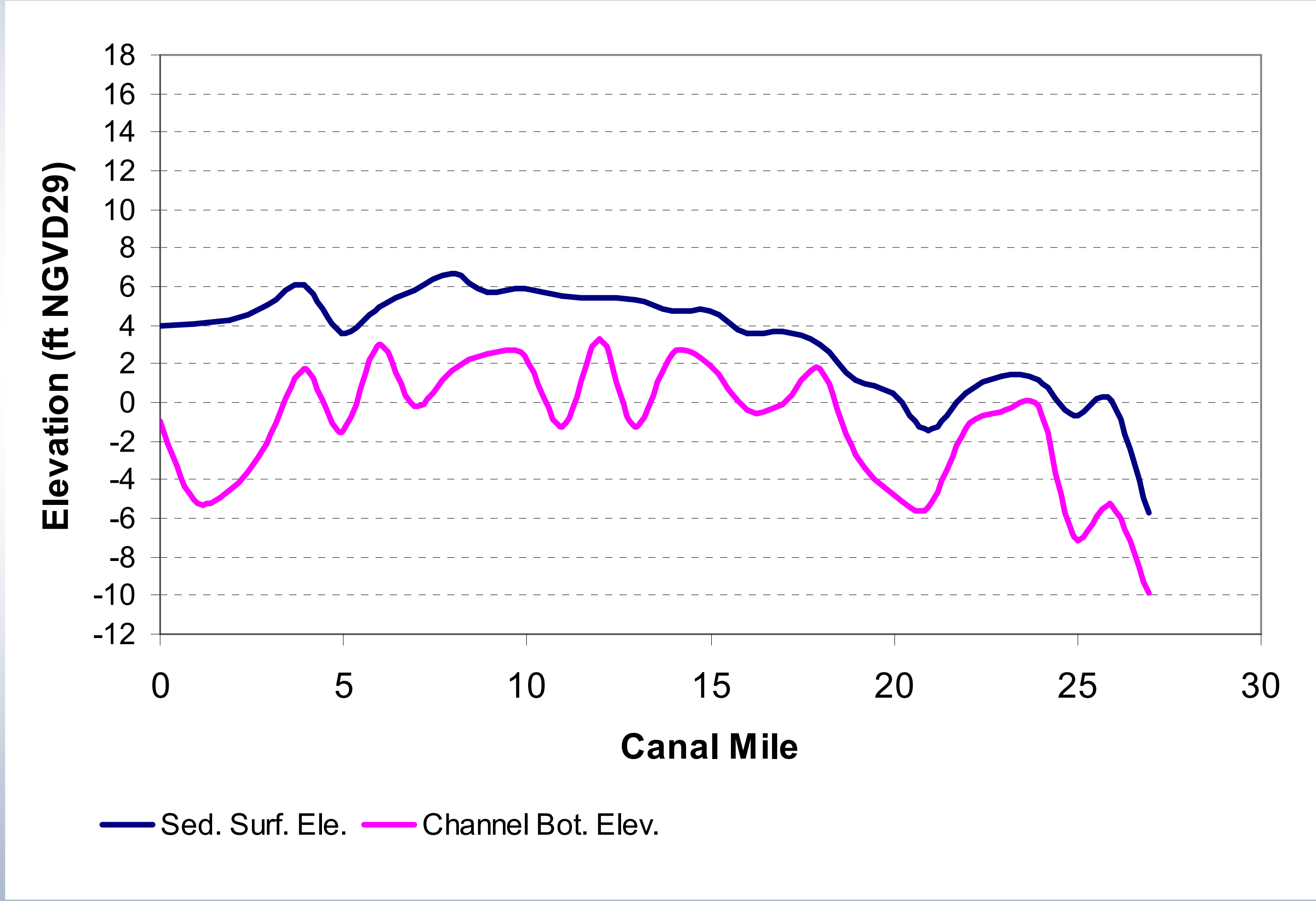


L-7 & L-39 Canal Bathymetry

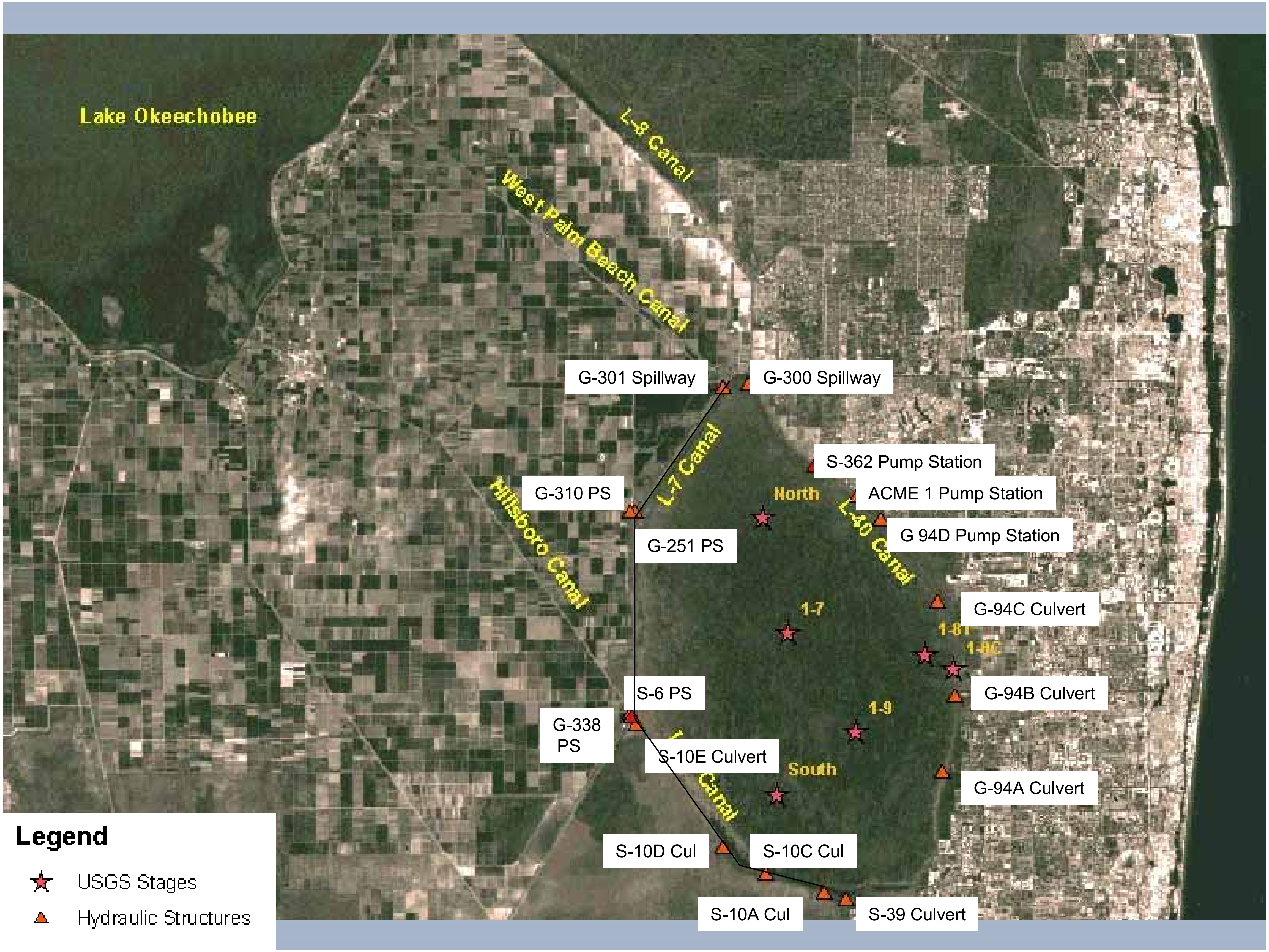


Obtained from University of Florida - IFAS

L-40 Canal Bathymetry

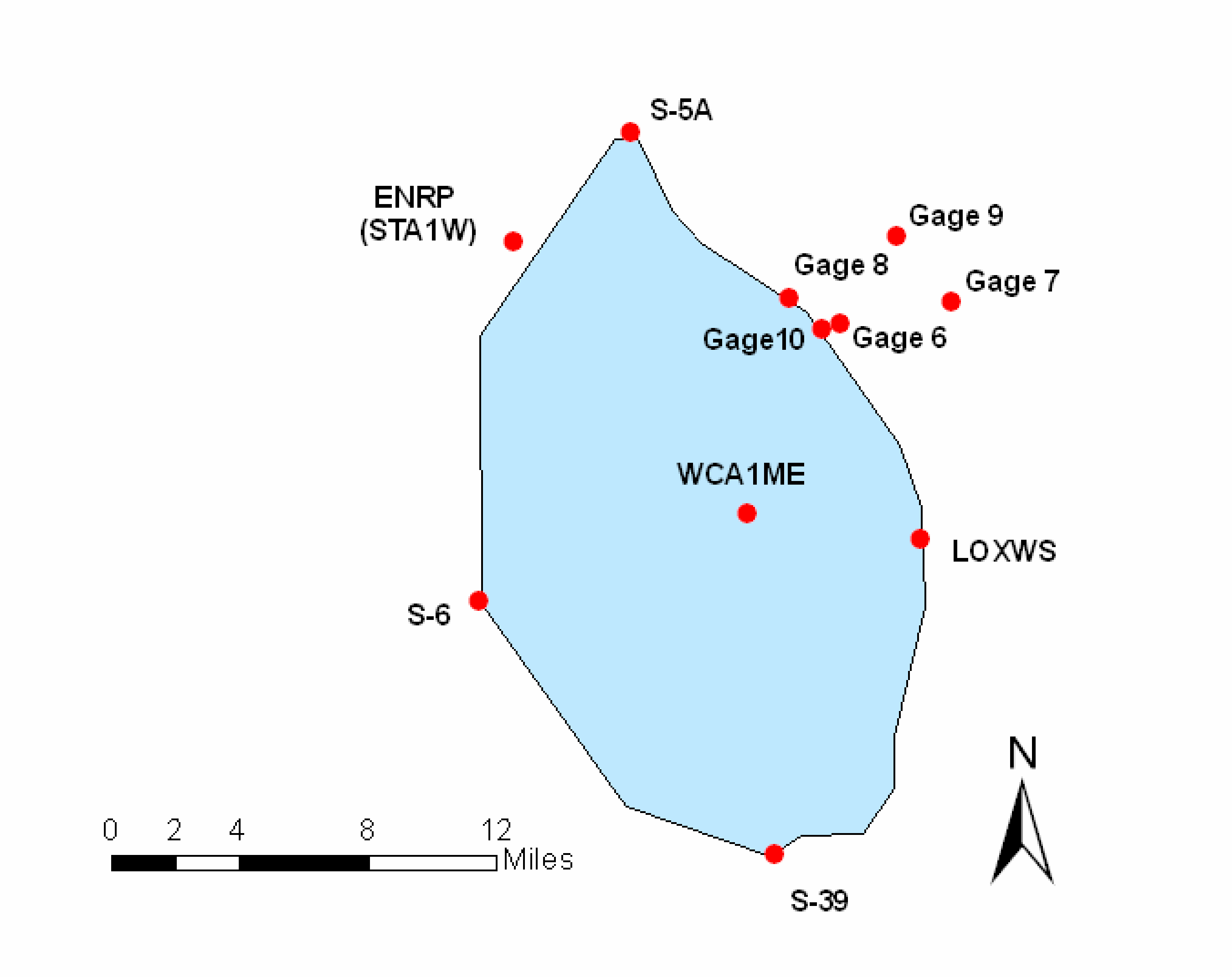


Obtained from University of Florida - IFAS



Lake Okeechobee
L-8 Canal
West Palm Beach Canal
Hillsboro Canal
L-7 Canal
L-40 Canal
G-301 Spillway
G-300 Spillway
S-362 Pump Station
ACME 1 Pump Station
G 94D Pump Station
G-310 PS
G-251 PS
North
1-7
G-94C Culvert
G-94B Culvert
1-9
S-6 PS
G-338
PS
S-10E Culvert
South
G-94A Culvert
S-10D Cul
S-10C Cul
S-10A Cul
S-39 Culvert
Legend
USGS Stages
Hydraulic Structures

Precipitation and Evapotranspiration



Evapotranspiration

- Reduction factor f_{ET}

$$ET = f_{ET} * ET_{obs}$$

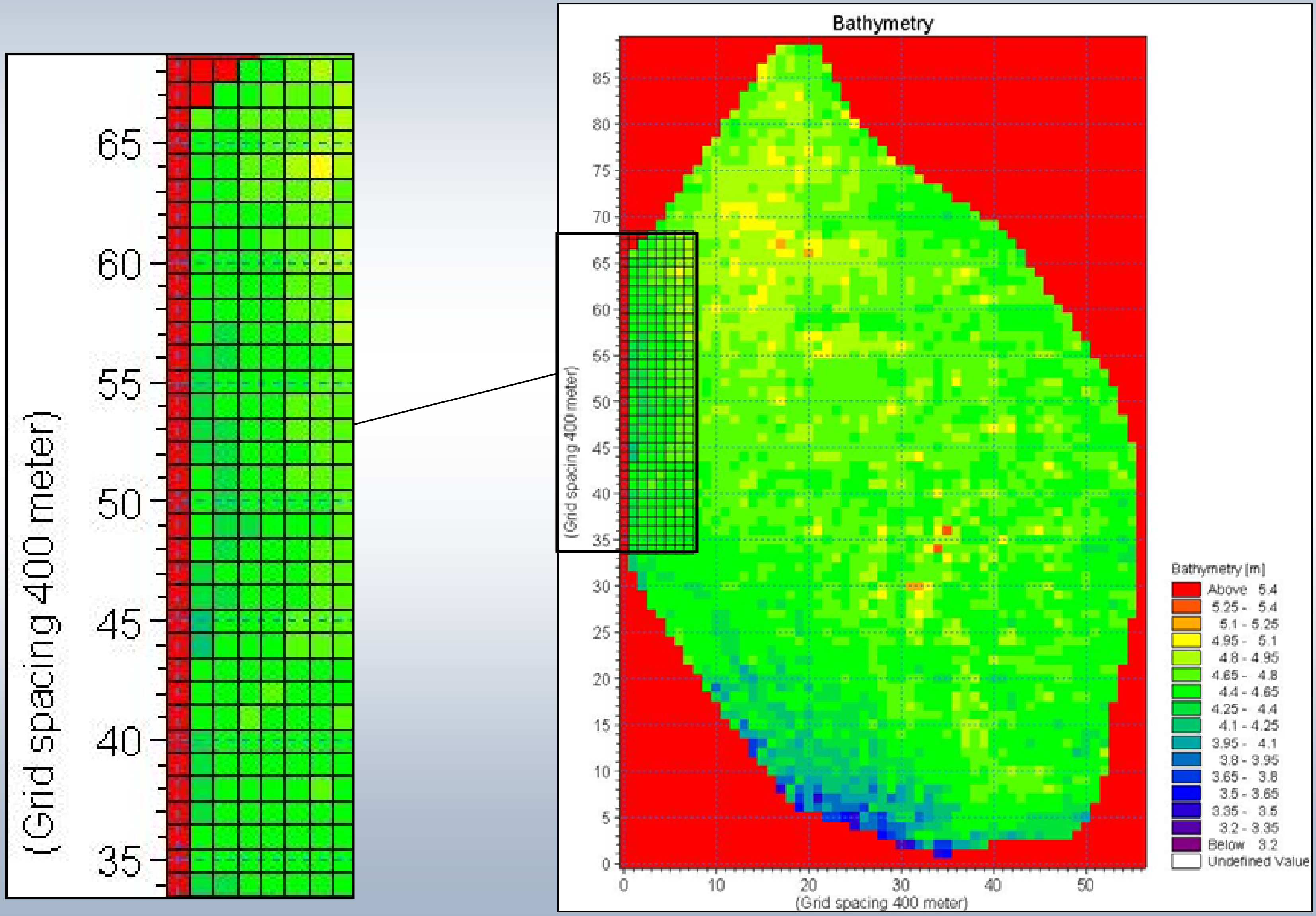
$$f_{ET} = Maximum\left[f_{ET\min}, Minimum\left(1, \frac{H}{H_{ET}} \right) \right]$$

  - f_{ETmin} is the minimum percentage that ET can be reduced
  - H is the water depth
  - H_{ET} is the depth below which ET is reduced
  - ET is reduced to 20% when the depth = 0 and is 100% when the depth is ≥ 0.20 m.

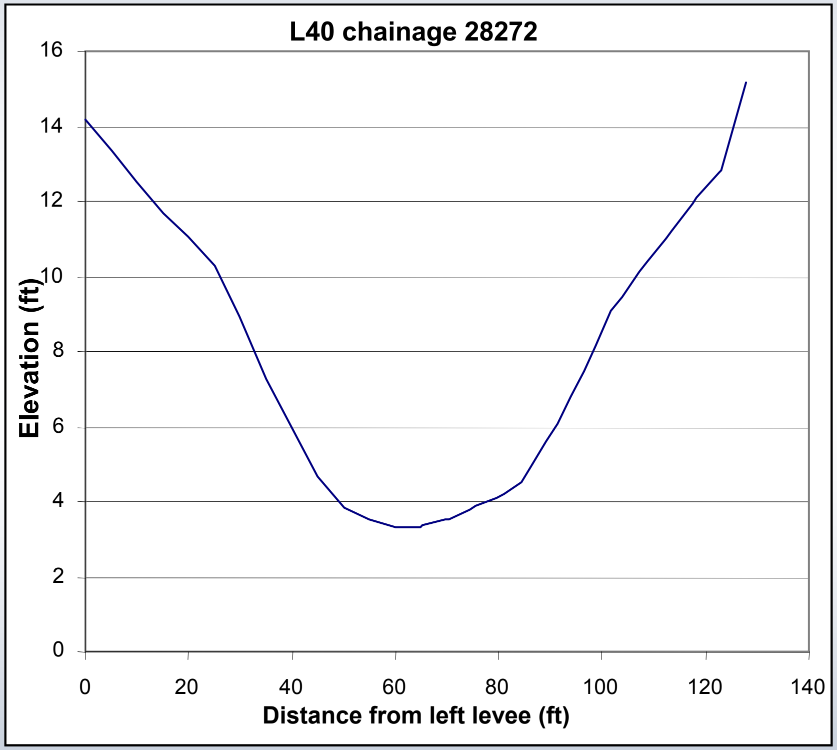
MIKE FLOOD

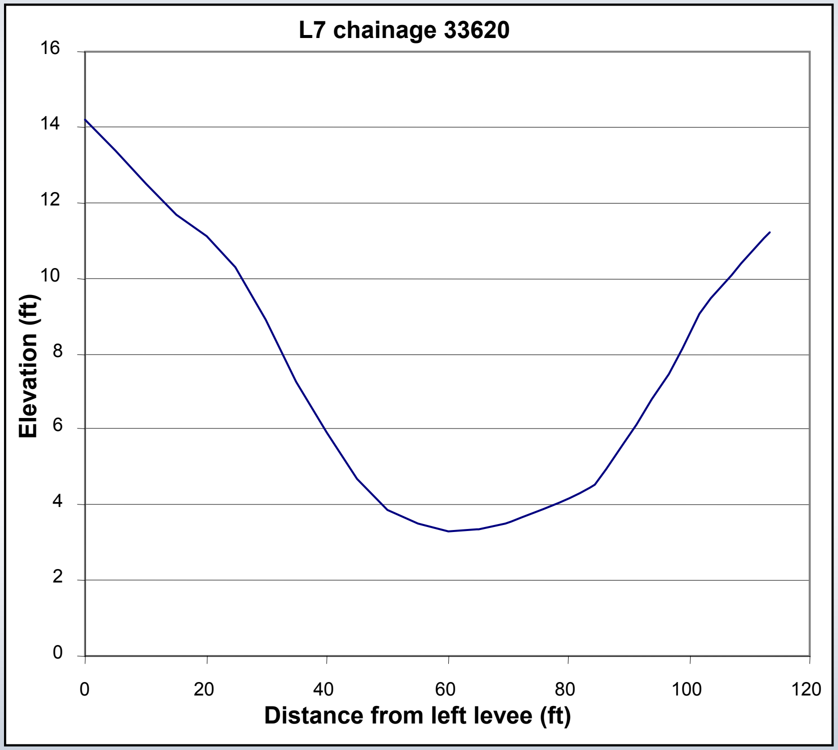
- Dynamic model coupling MIKE21 with MIKE11
- Finite difference solver
- Flooding and drying capabilities
- Groundwater losses in canal and marsh can be included
- Spatially variable marsh resistance, precipitation, ET and dispersion coefficient can be included
- Control structure can be used to access alternative of Regulation Schedule
- Developed by DHI Water & Environment (DHI, 2008)

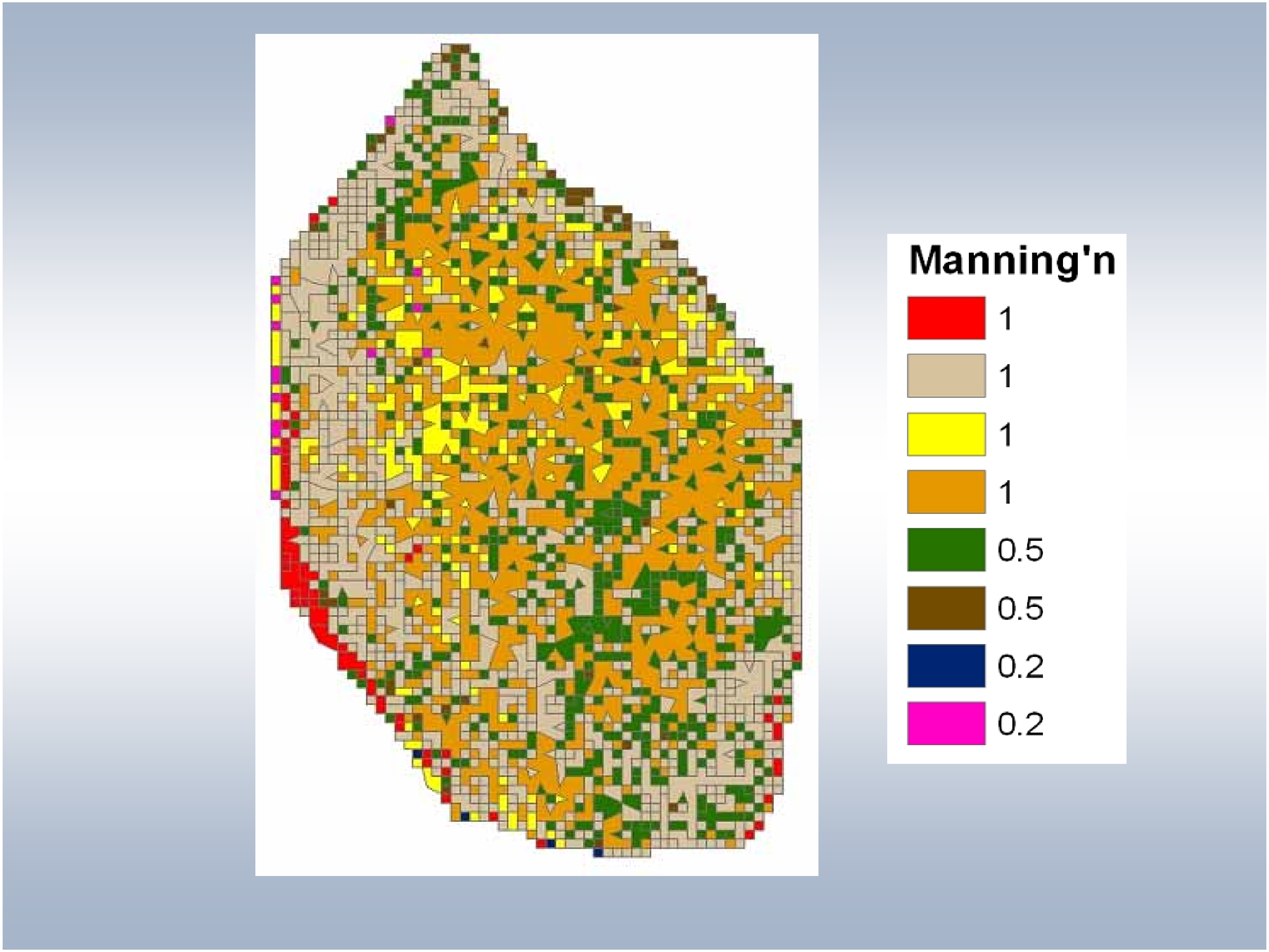
Grid for Marsh Simulation



Canal in MIKE 11







Manning'n
1
1
1
1
0.5
0.5
0.2
0.2

Model Setup

- Period of study 1995-2006
  - calibration 2000-2004
  - validation 1995-1999, 2005-2006
- Lateral cell link of MIKE21 to MIKE11
- Initial water level – uniform in the marsh and canal
- Initial concentration – spatially varied in marsh based on measurements using inverse distance, uniform in canal
- Time integration method – Euler
- Time step – 5 min for hydrodynamics, variable for water quality ranging from 1 min to 3 min

Model Calibration - Hydrodynamics

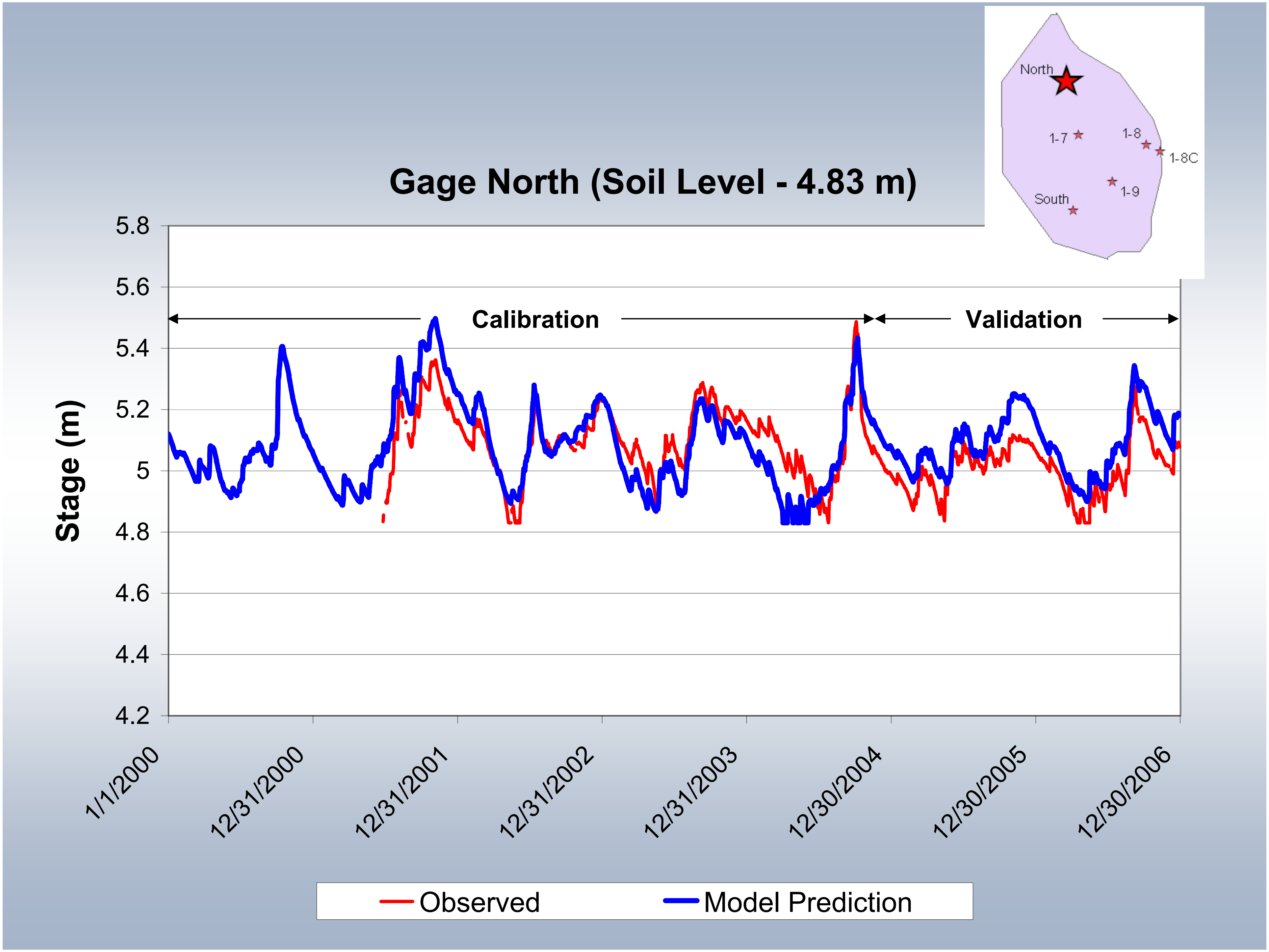
Parameters:

- Marsh and canal roughness: bed resistance is calculated based on Manning's equation

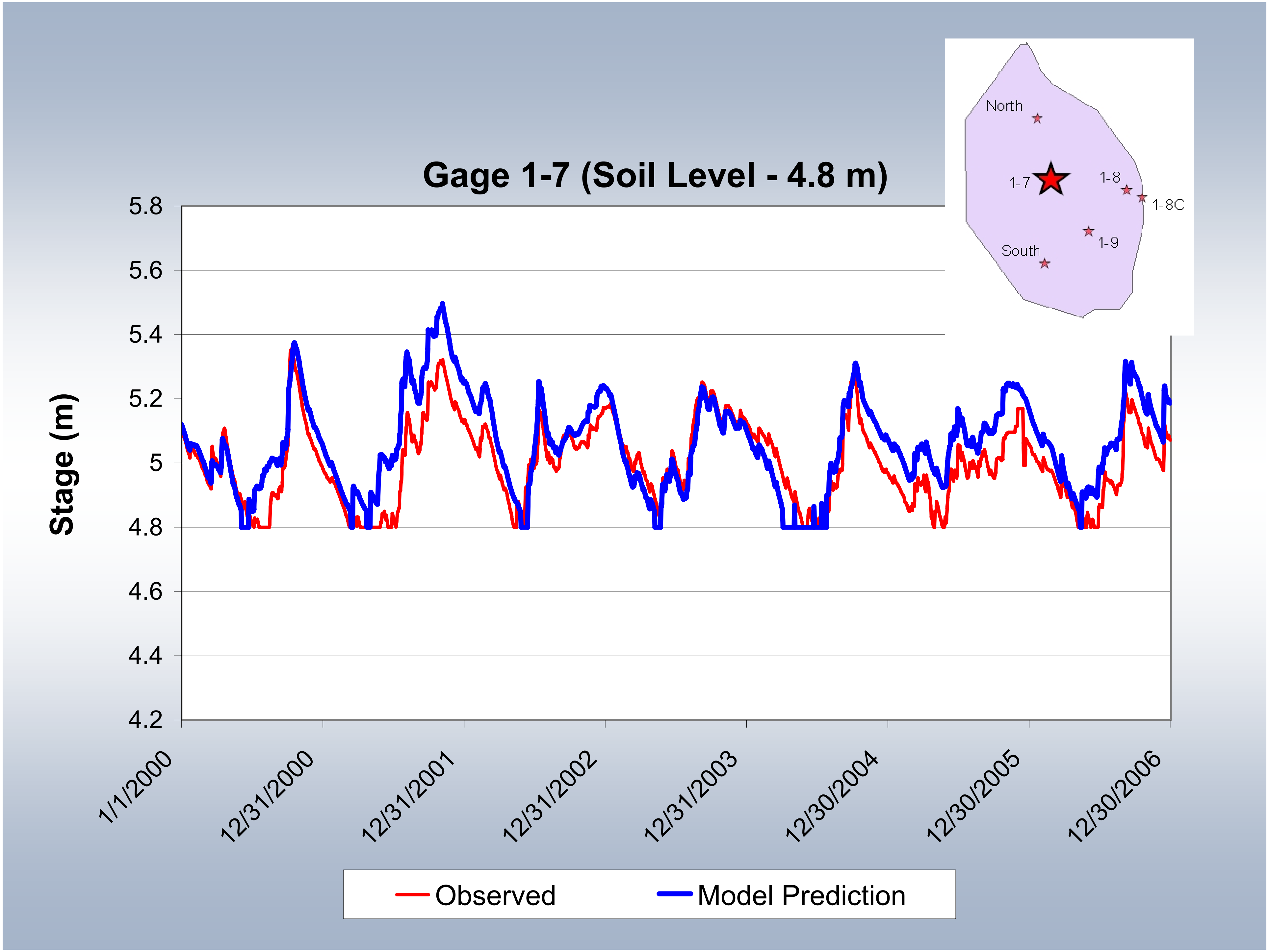
- Wetting and drying depths

- Coefficients for ET reduction - f_{ETmin} and H_{ET}

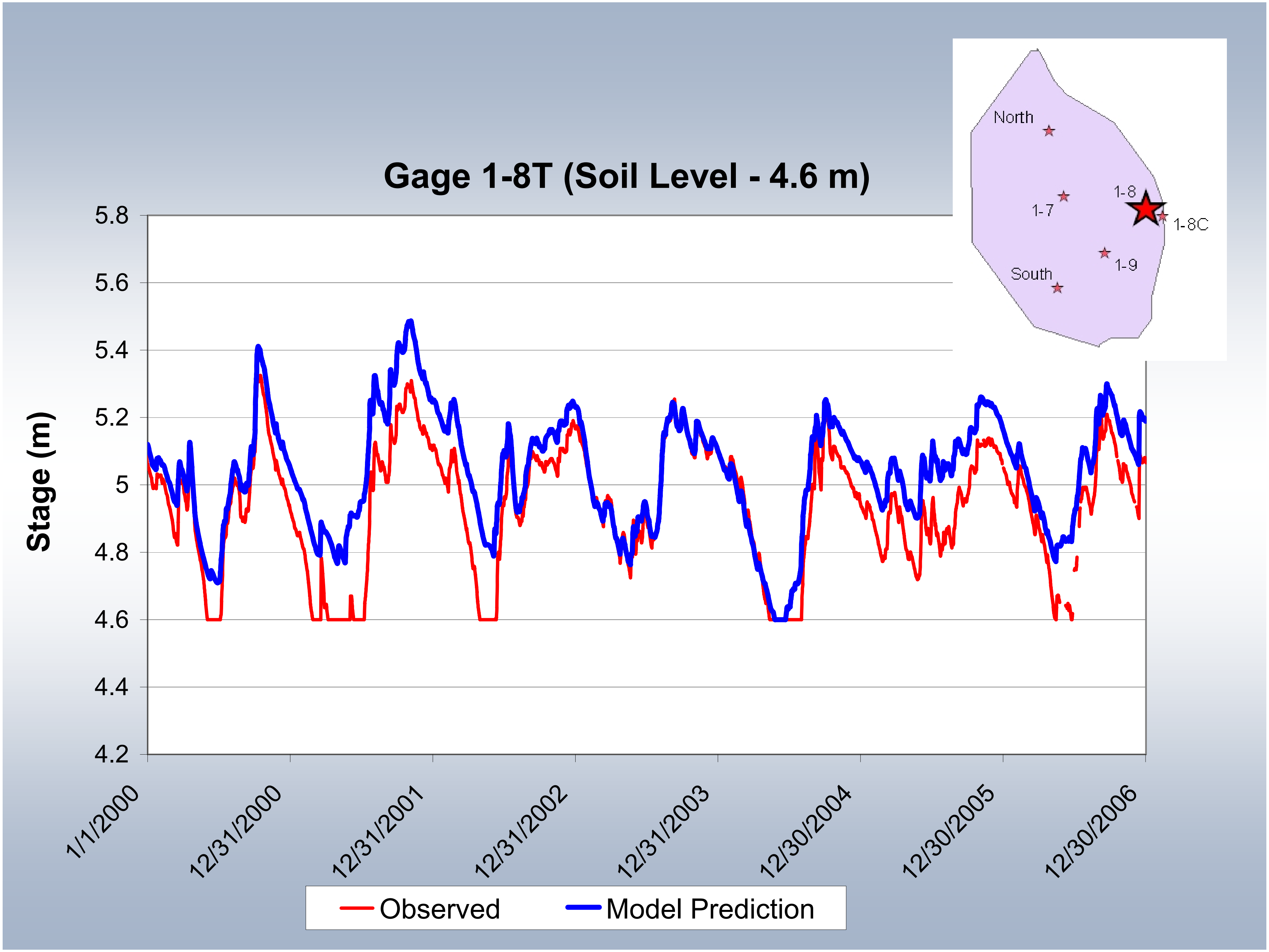
- Seepage rate in the marsh and the canal

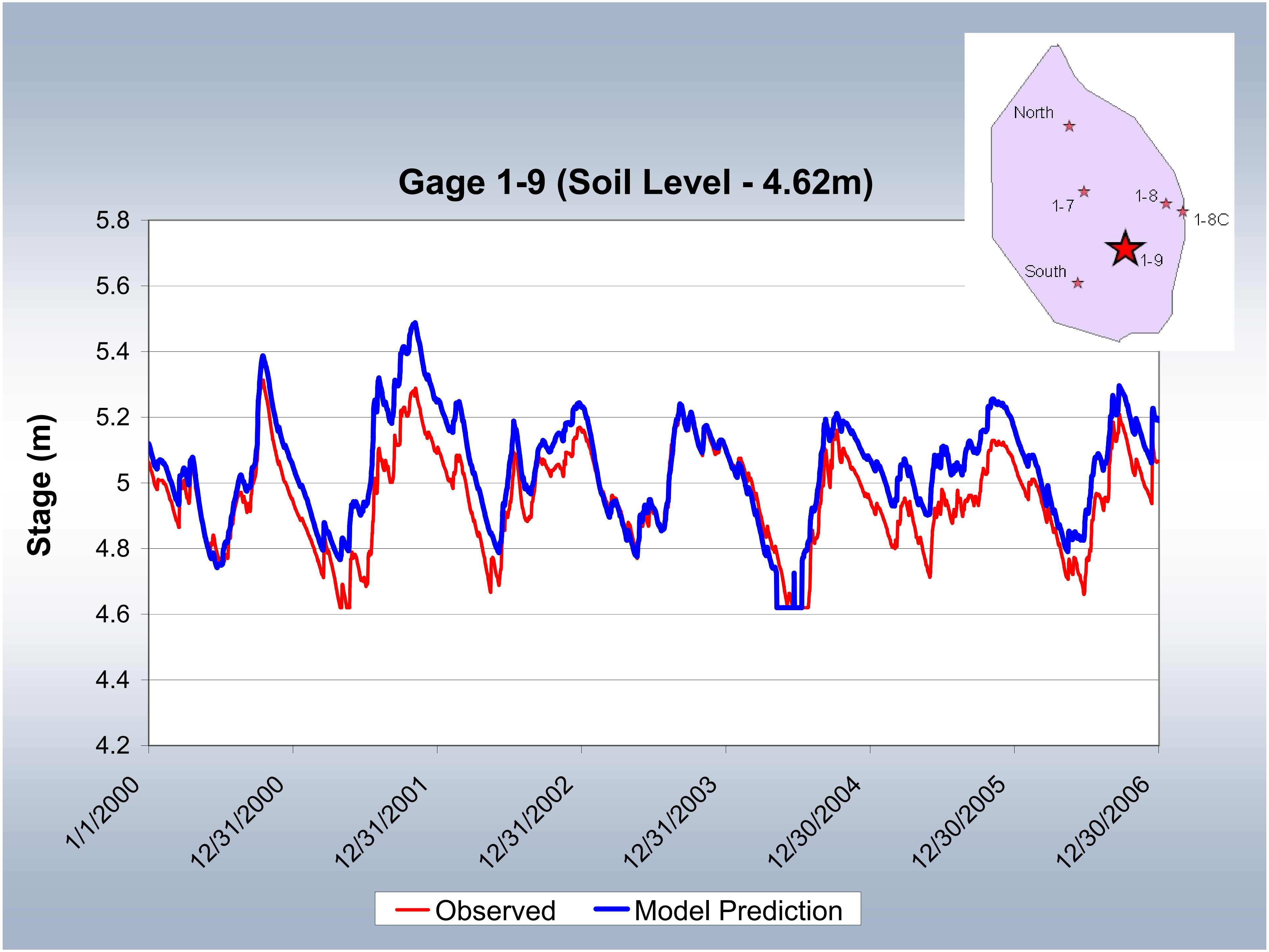


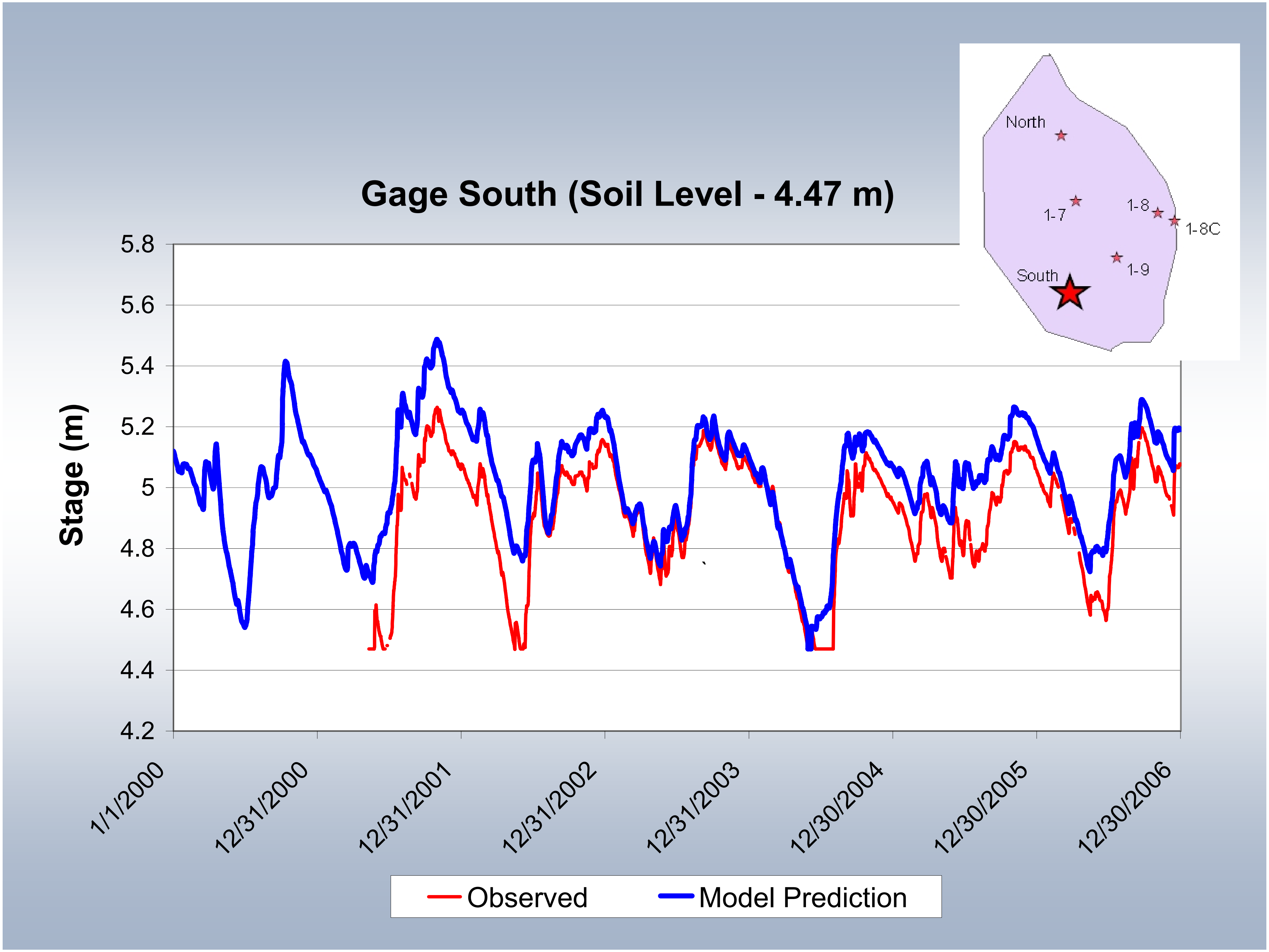
Gage North (Soil Level - 4.83 m)
North
1-7
1-8
1-8C
1-9
South
Calibration
Validation
Stage (m)
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
1/1/2000
12/31/2000
12/31/2001
12/31/2002
12/31/2003
12/30/2004
12/30/2005
12/30/2006
Observed
Model Prediction

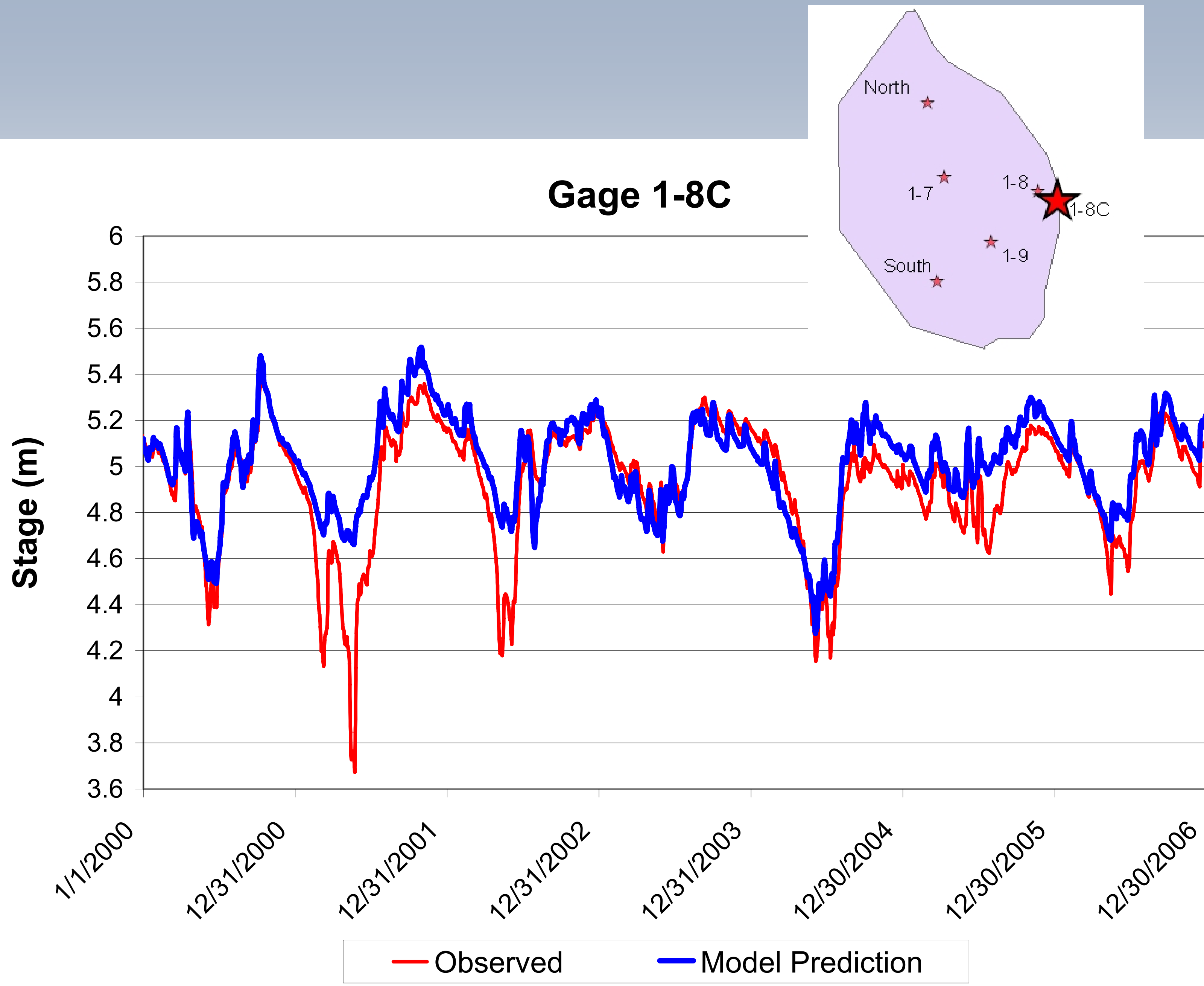


Gage 1-7 (Soil Level - 4.8 m)
Stage (m)
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
1/1/2000
12/31/2000
12/31/2001
12/31/2002
12/31/2003
12/30/2004
12/30/2005
12/30/2006
Observed
Model Prediction
North
1-7
1-8
1-8C
1-9
South


Gage 1-8T (Soil Level - 4.6 m)
Stage (m)
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
1/1/2000
12/31/2000
12/31/2001
12/31/2002
12/31/2003
12/30/2004
12/30/2005
12/30/2006
Observed
Model Prediction
North
1-7
1-8
1-8C
1-9
South


Gage 1-9 (Soil Level - 4.62m)
Stage (m)
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
1/1/2000
12/31/2000
12/31/2001
12/31/2002
12/31/2003
12/30/2004
12/30/2005
12/30/2006
Observed
Model Prediction
North
1-7
1-8
1-8C
1-9
South


Gage South (Soil Level - 4.47 m)
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
Stage (m)
1/1/2000
12/31/2000
12/31/2001
12/31/2002
12/31/2003
12/30/2004
12/30/2005
12/30/2006
Observed
Model Prediction
North
1-7
1-8
1-8C
1-9
South



Gage 1-8C
Stage (m)
6
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
4
3.8
3.6
1/1/2000
12/31/2000
12/31/2001
12/31/2002
12/31/2003
12/30/2004
12/30/2005
12/30/2006
Observed
Model Prediction
North
1-7
1-8
1-8C
1-9
South

Calibration Statistics (2000-2004)

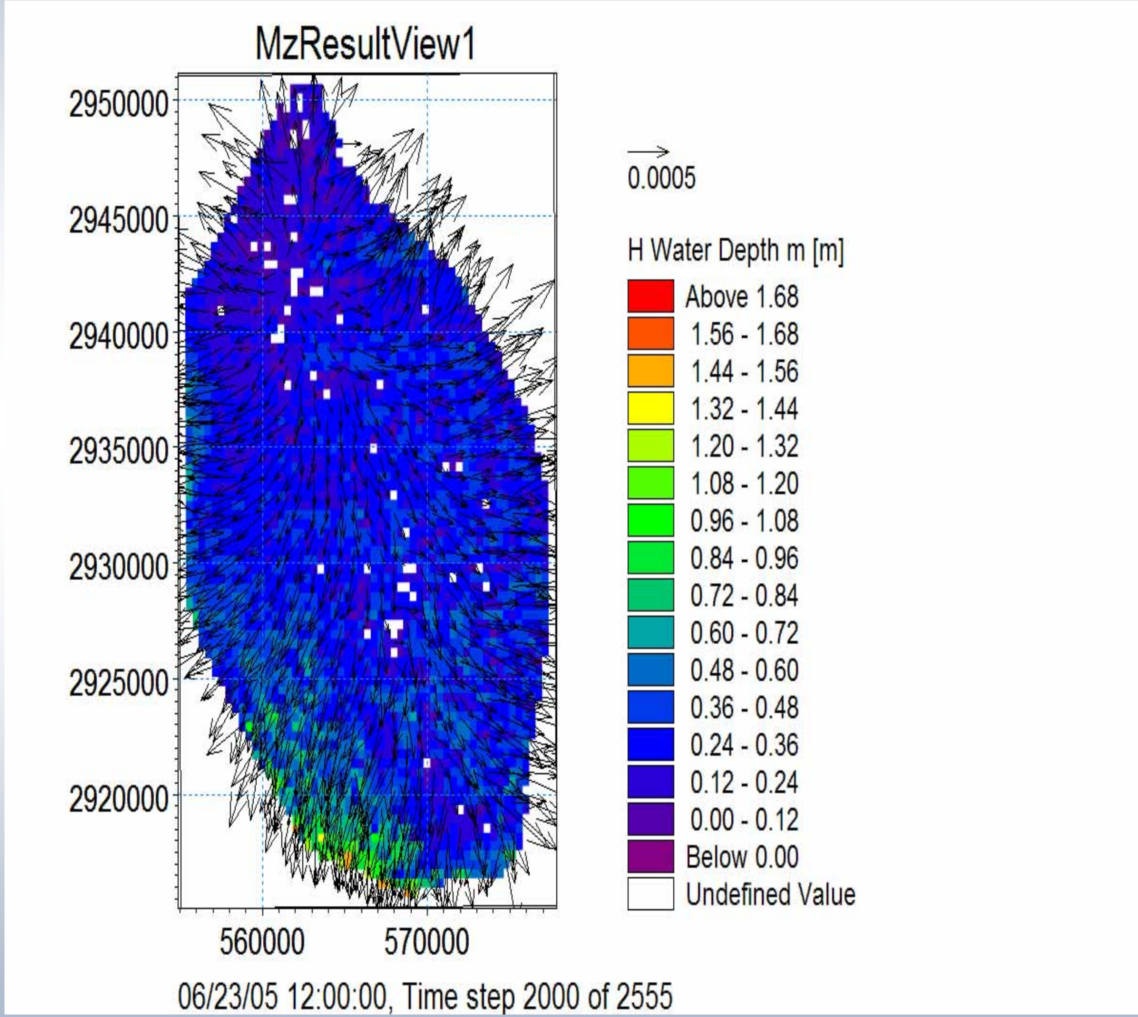
Parameter	North	1-7	1-8T	1-9	South	1-8C
Bias (m)	0	0.041	0.093	0.07	0.117	0.067
RMSE (m)	0.085	0.088	0.125	0.102	0.15	0.155
Variance Reduction	46%	66%	82%	77%	80%	74%
R (Correl Coef)	0.82	0.87	0.45	0.91	0.9	0.86
Nash-Sutcliffe Eff	0.669	0.708	0.631	0.72	0.614	0.566

Validation Statistics (2005-2006)

Parameter	North	1-7	1-8T	1-9	South	1-8C
Bias (m)	0.083	0.101	0.129	0.117	0.133	0.111
RMSE (m)	0.087	0.106	0.136	0.121	0.14	0.131
Variance Reduction	88%	89%	91%	93%	91%	83%
R (Correl Coef)	0.96	0.95	0.96	0.97	0.96	0.91
Nash-Sutcliffe Eff	0.534	0.487	0.405	0.479	0.434	0.463

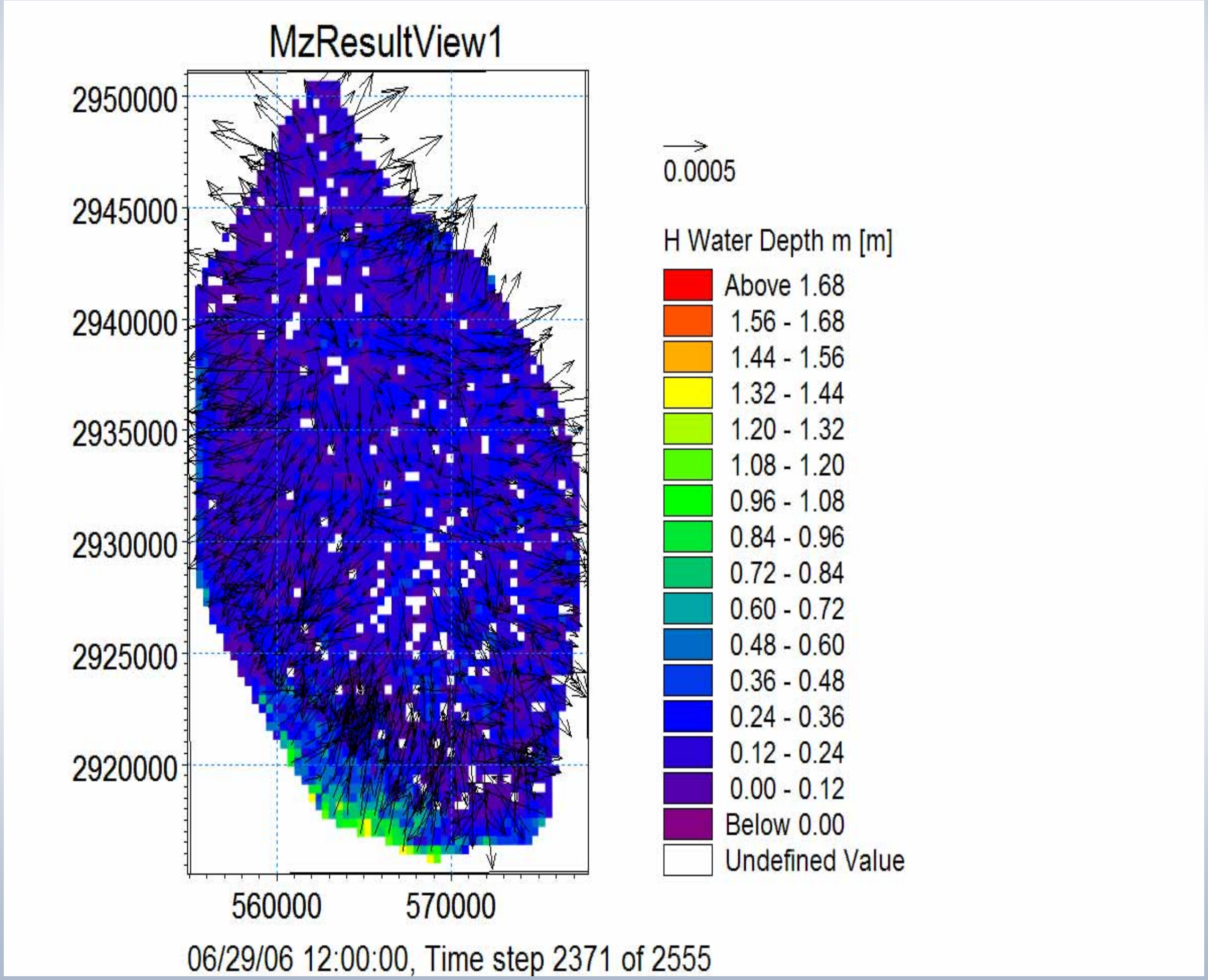
Hydrodynamic Animation I

06/2005-01/2006



Hydrodynamic Animation II

06/2006-12/2006



Water Quality Modeling

Modules: AD and ECO Lab

- AD: Standard advection-dispersion module

- ECO Lab
  - Open process module for ecological modeling
  - Template independent of grid system
  - Components - state variables, constants, forcings, auxiliary variables, processes, and derived outputs

ECO Lab

MIKE FLOOD ECO Lab Equations:

Rate of mass accumulation = Mass inflow - Mass outflow + Dispersion in – Dispersion out + Production - Disappearance

$$A_{cell}\frac{dhc}{dt} = Q_i C_i b - Q_o C_o + Disp + Source - K_s C$$

- Mass inflow – aerial deposition

  wet deposition = rain rate * rain concentration

  dry deposition = loading rate

- Mass outflow

  evaporation = does not transport mass

  transpiration = ET * % trans * C

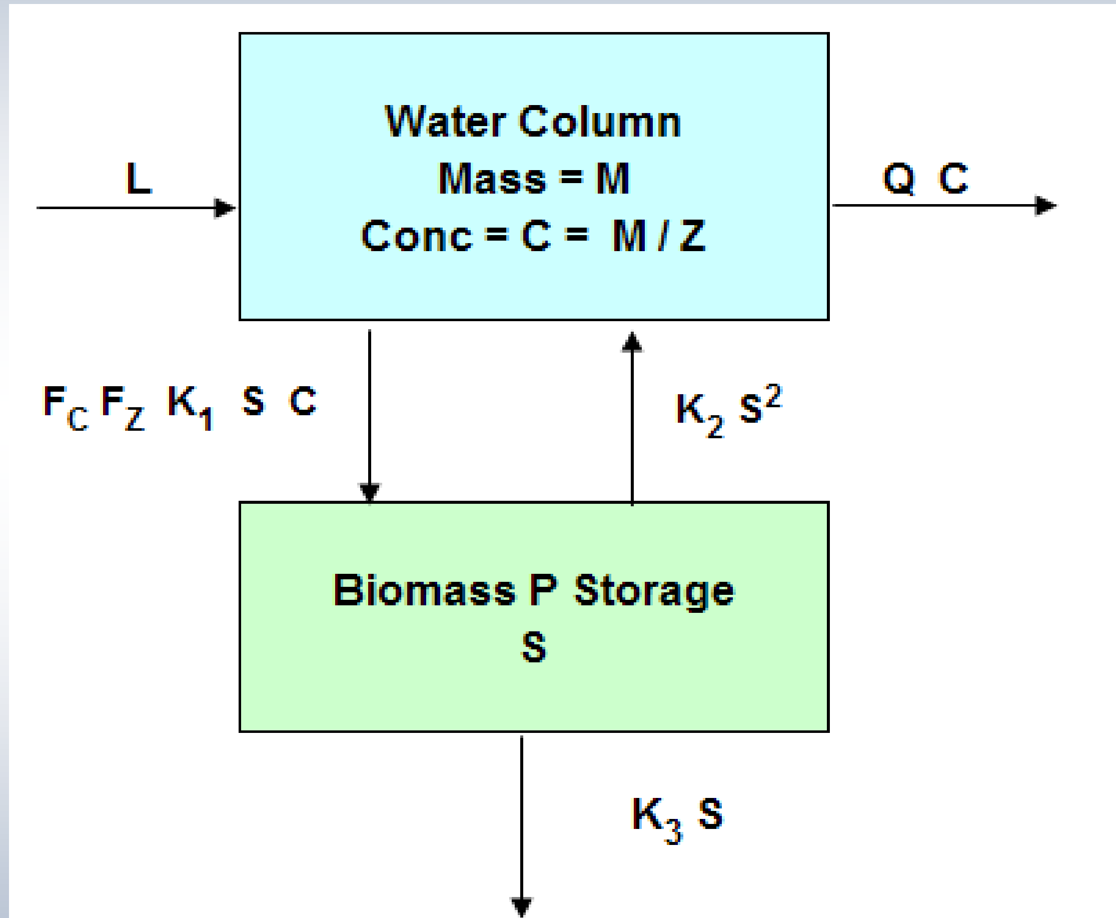
ECO Lab (cont.)

- Chloride (CL) is modeled as conservative tracer
- Sulphate is modeled using Monod relationship with half saturation constant

$$disappearance\ rate = -k_0 \frac{c}{k_{1/2} + c}$$

- Total Phosphorus (TP) is modeled following DMSTA dynamics (Walker and Kadlec, 2005) (http://www.wwwalker.net/dmsta/index.htm)
  - water column storage
  - biomass storage

DMSTA



TP cycling processes

Auxiliary variables

- Concentration multiplier F_c

$$\frac{0.3}{0.3 + C}$$

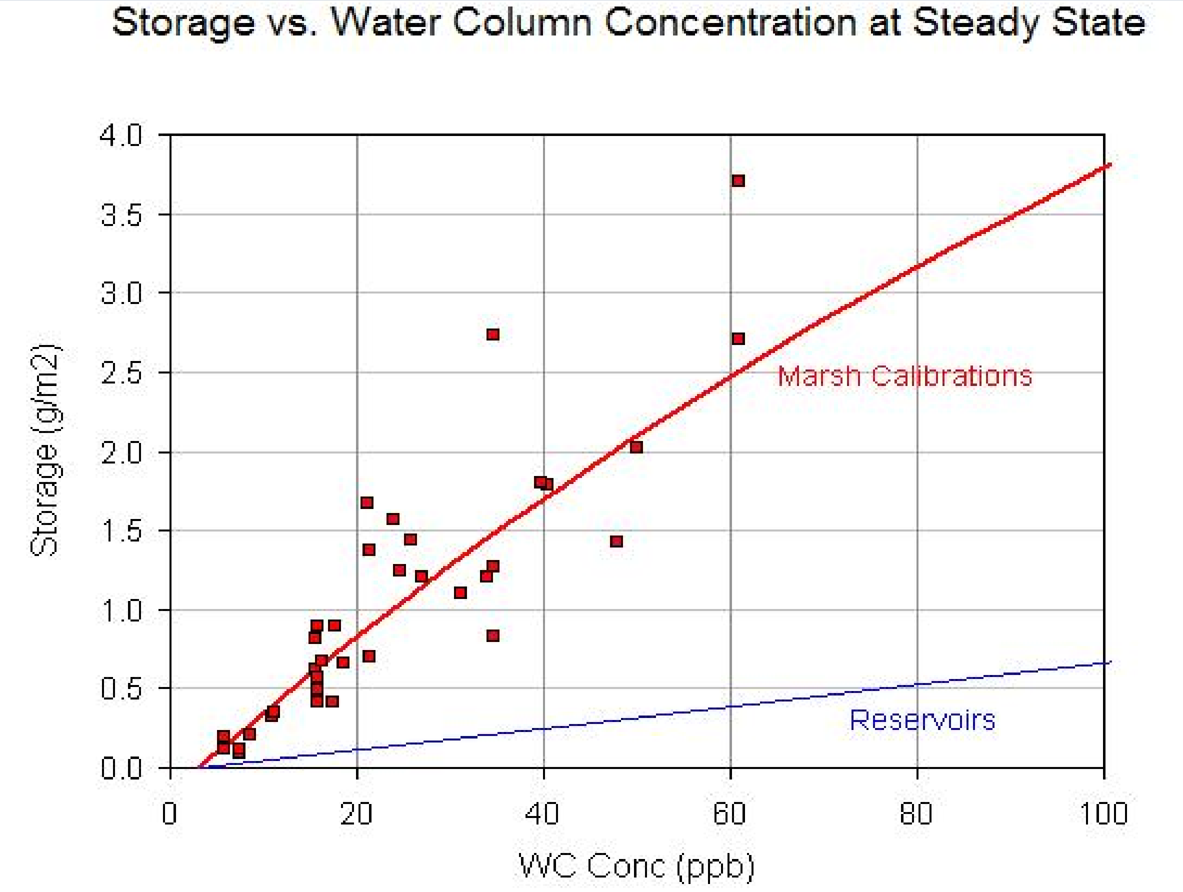
- Depth function F_z

$$\begin{cases} 1 & Z_x \leq 0 \\ \min(1, depth / Z_x) & otherwise \end{cases}$$

DMSTA Calibration Parameters

Maximum Uptake Rate	K1	0.24	m^3/mg-year
Recycle Rate	K2	0.005	m^2/mg-year
Burial Rate	K3	0.75	1/year
Depth Scaling Factor	Z_x	0.6	

- Initial P storage in the sediment layer



http://www.wwwalker.net/dmsta/doc/doc_storage.htm

Conclusions

- Model results in good agreement with observations.
- Statistics are encouraging that model would meet project objectives.
- Model is computationally efficient (Intel (R) T7600 2.33GHz, 3.25GB RAM)
  - to run 1 year of hydrodynamic requires 0.75 CPU hours
  - to run 1 year for CL requires 2.0 CPU hours
- New model of 400m resolution available for Refuge restoration planning applications and the Everglades simulation.

Future/Ongoing Developments

- Validate models for the Period of Record between 1995 and 1999
- Ground water seepage will be enhanced by MIKE SHE.
- Regulation Schedule and management scenarios are being assessed.

Questions?