Setup, Formulation and Validation of a Spatially Explicit Hydrodynamic and Surface Water Chloride Concentration Model

U.S. Fish & Wildlife Service
Arthur R. Marshall
Loxahatchee National Wildlife Refuge

Chunfang Chen[1]*, Ehab Meselhe[1], Michael Waldon[2]

[1] University of Louisiana at Lafayette, Center for Louisiana Water Studies, Institute of Coastal Ecology and Engineering, Lafayette, LA
[2] U.S. Fish and Wildlife Service, Arthur R. Marshall Loxahatchee National Wildlife Refuge
*Presenter Contact Information : P.O. Box 4031, Lafayette, LA 70504, E-mail: tracy.chen0@gmail.com

University of Louisiana Lafayette
Center for Louisiana Water Studies
Institute of Costal Ecology and Engineering

Introduction

The Arthur R. Marshall Loxahatchee National Wildlife Refuge (Refuge), overlays Water Conservation Area 1 (WCA-1), which is a freshwater wetland located in Palm Beach County, Florida. It is a remnant of the historical northern Everglades (Figure 1). The Refuge area under study consists of a marsh of approximately 140,000 acres, and a rim canal that is roughly 1,000 acres in size (Figure 2).

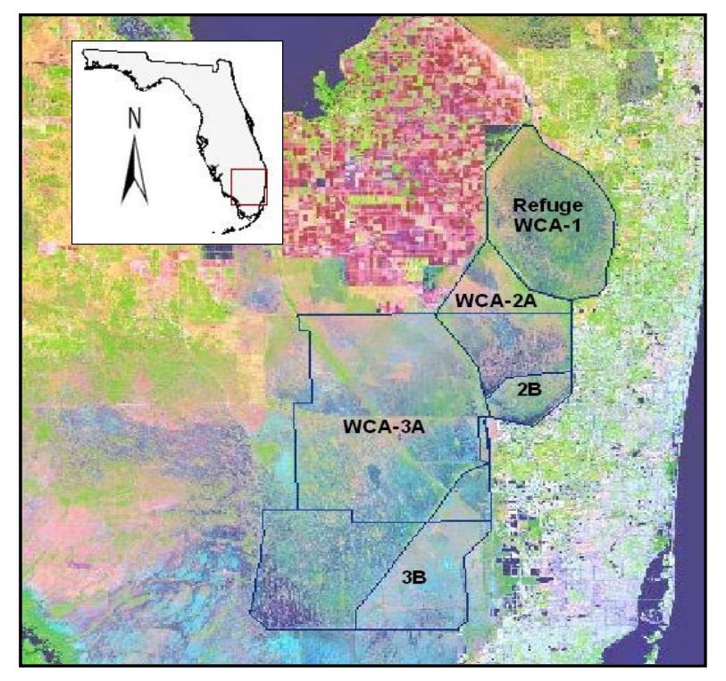


Figure 1 – Loxahatchee Wildlife Refuge and other Everglades Water Conservation Areas (SFWMD, 2000)

A_{marsh} = 140,000 acres

A_{canal} = 1,000 acres

Figure 2 – Images of the Refuge's marsh and canal areas

Objective

The U.S. Fish and Wildlife Service recognized that there have been changes to the water quantity, timing, and quality which have caused negative impacts to the Refuge's ecosystem (USFWS, 2000). It is important to manage water for the benefit of fish and wildlife in the Refuge. Meanwhile, it is crucial to minimize nutrient loading, and address flood protection and water supply needs through a series of water management decision rules (called a water regulation schedule). Hence, the main objective of this study is to develop a spatially explicit model that can be used to:

- Provide a useful management tool for the Refuge.
- Analyze alternative water regulation schedules.
- Test various management scenarios.

Observed Parameters

Observed data for the period of simulation (2000-2006) were compiled and evaluated by the modeling team.

Precipitation (P)

- There are 6 gages maintained by the South Florida Water Management District (SFWMD) - 5 gages inside the Refuge and 1 gage just northwest of the Refuge (Figure 3).
- There are 10 gages north east of the Refuge maintained by the ACME Drainage District (Figure 3). Only Gages 6, 8, and 10 are used.

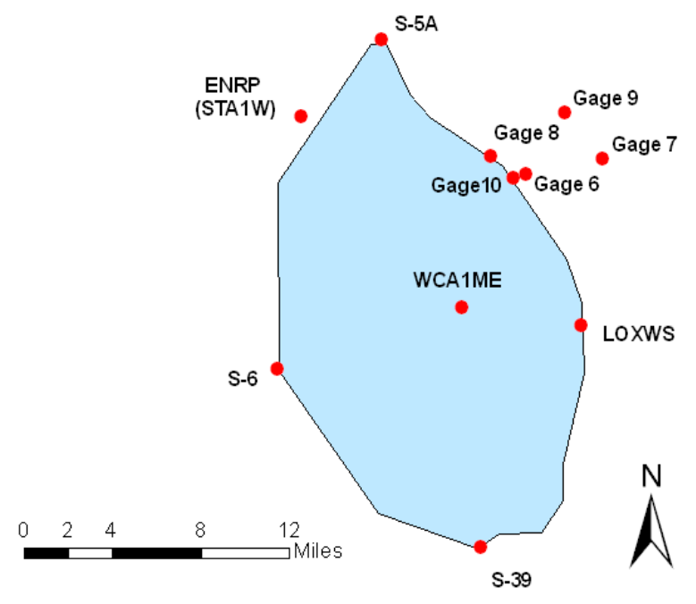


Figure 3: Precipitation and ET gages

Evapotranspiration (ET)

- ET data are available from station STA1-W (Figure 3).
- Inverse distance method is used to estimate spatially varied daily rates of precipitation and ET.
- ET is reduced by an coefficient that varies linearly with depth when depth is below 0.2 m. The coefficient decreases from 1.0 to 0.2 as depth approaches zero.

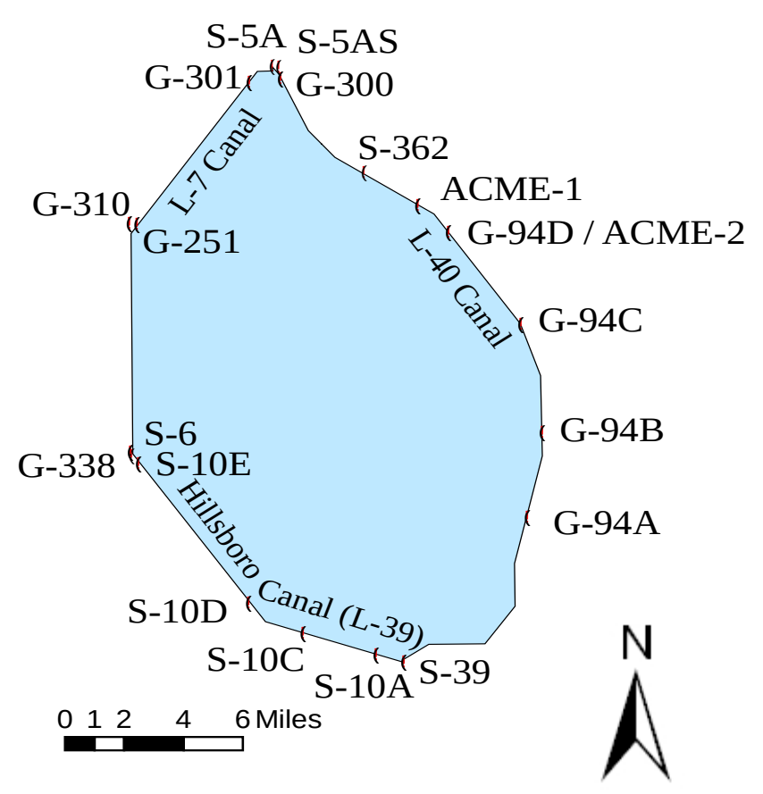


Figure 4: Inflow and outflow structures

Inflow and Outflow

- There are 19 hydraulic structures located around the perimeter of the canal; only 17 were in operation during the period of study (Figure 4).

Model

MIKE FLOOD

- Hydrodynamic model coupling MIKE21 with MIKE11
- Finite difference solver
- Flooding and drying capabilities
- Marsh and canal friction linked to water depth
- Spatially varied marsh resistance, precipitation, and ET included
- Water constituent transport driven by advection-dispersion (AD) process (can be also coupled with other processes defined in ECO LAB)
- Developed by DHI Water & Environment (DHI, 2005)

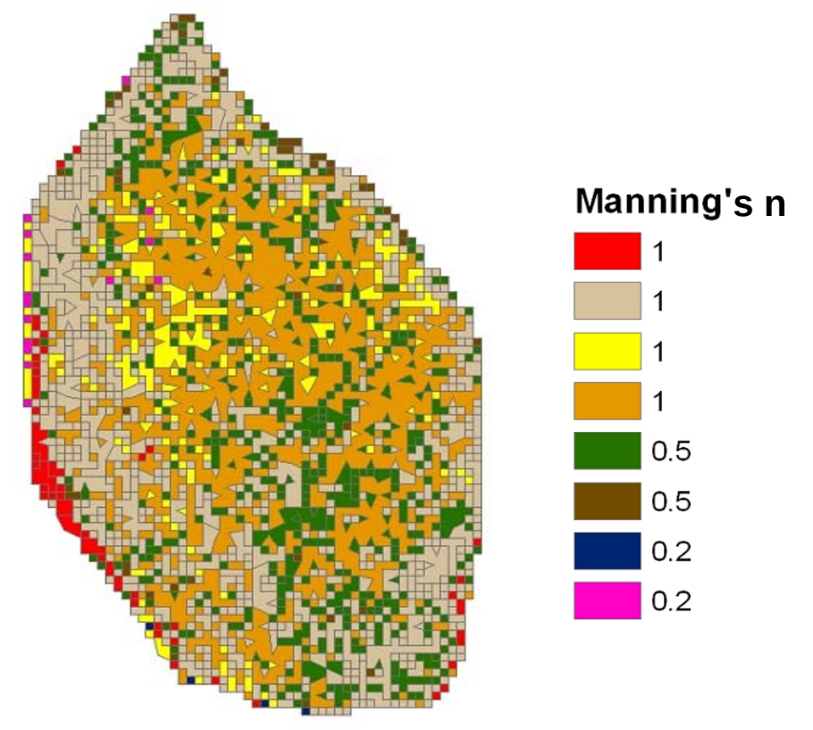


Figure 6: Resistance map (Manning's n)

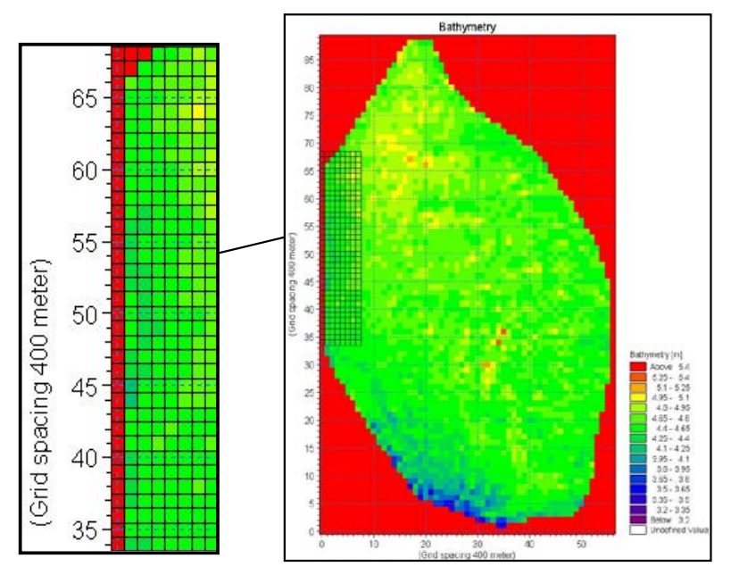


Figure 5: Grid for the marsh

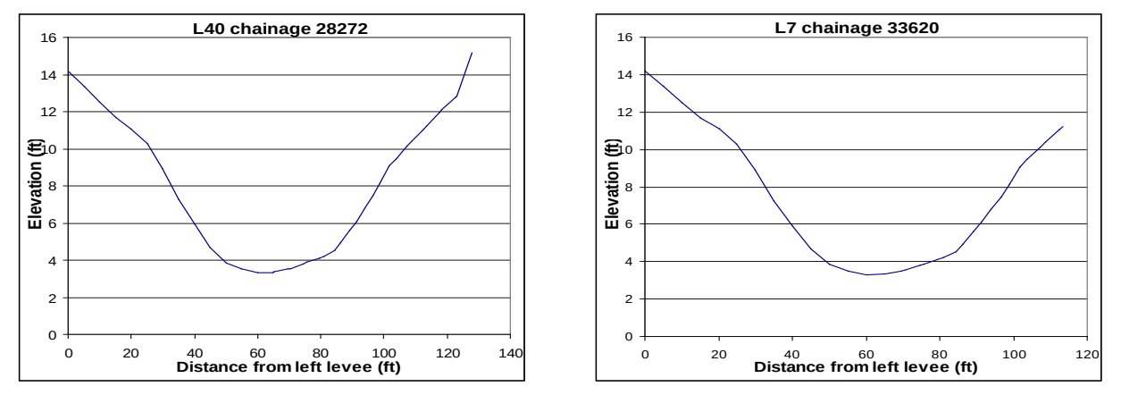


Figure 7: Sample cross sections for the canal

ECO LAB

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

MIKE FLOOD ECOLAB Equations:

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

$$A_{cell}\frac{dhc}{dt}=Q_iC_ib-Q_oC_o+Disp+Source-K_sC$$

❖ Chloride (CL) is modeled as conservative tracer

❖ CL modeling supports model development for other constituents - total phosphorus and sulfate.

Calibration

Model Setup

- Dynamic cell link of MIKE21 to MIKE11
- Uniform initial water level in marsh and canal
- Spatially varied initial concentration in marsh
- Uniform initial concentration in canal
- Time integration method – Euler
- Time step – 3 min

Calibration Parameters

- Canal roughness (Manning's n) – 0.03
- Seepage – 2.25 m^3/s both in marsh and canal
- Flooding/drying depth in marsh – 0.01/0.005 m
- Wet deposition – 2 mg-CL/L
- Dry deposition – 0.5 g-CL/m^2-yr
- Transpiration percentage in ET – 35%
- Dispersion – 6 concentric zones (0.001 to 2 m^2/s) in marsh, 50 m^2/s in canal
- Internal load for TP in canal – 7.36 mg/m^2-day
- Initial biomass TP storage – 0.1 g/m^2

Calibration and Validation Stations

- Stage stations – USGS
- Water quality stations – EVPA, XYZ, and Enhanced stations

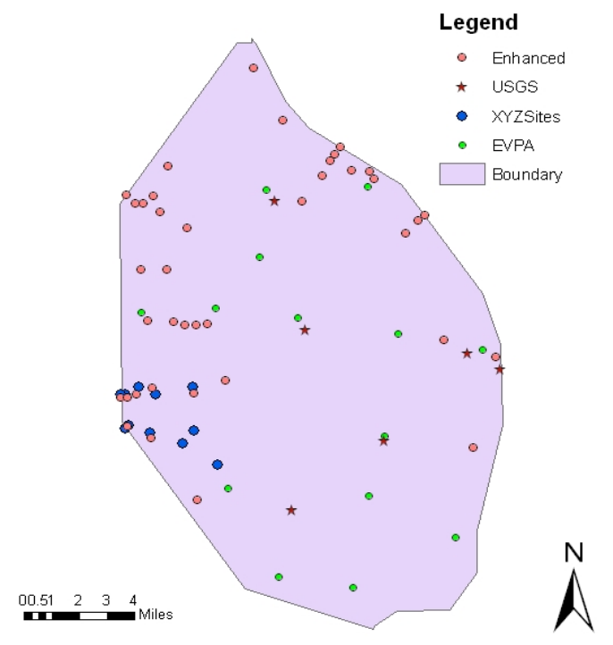
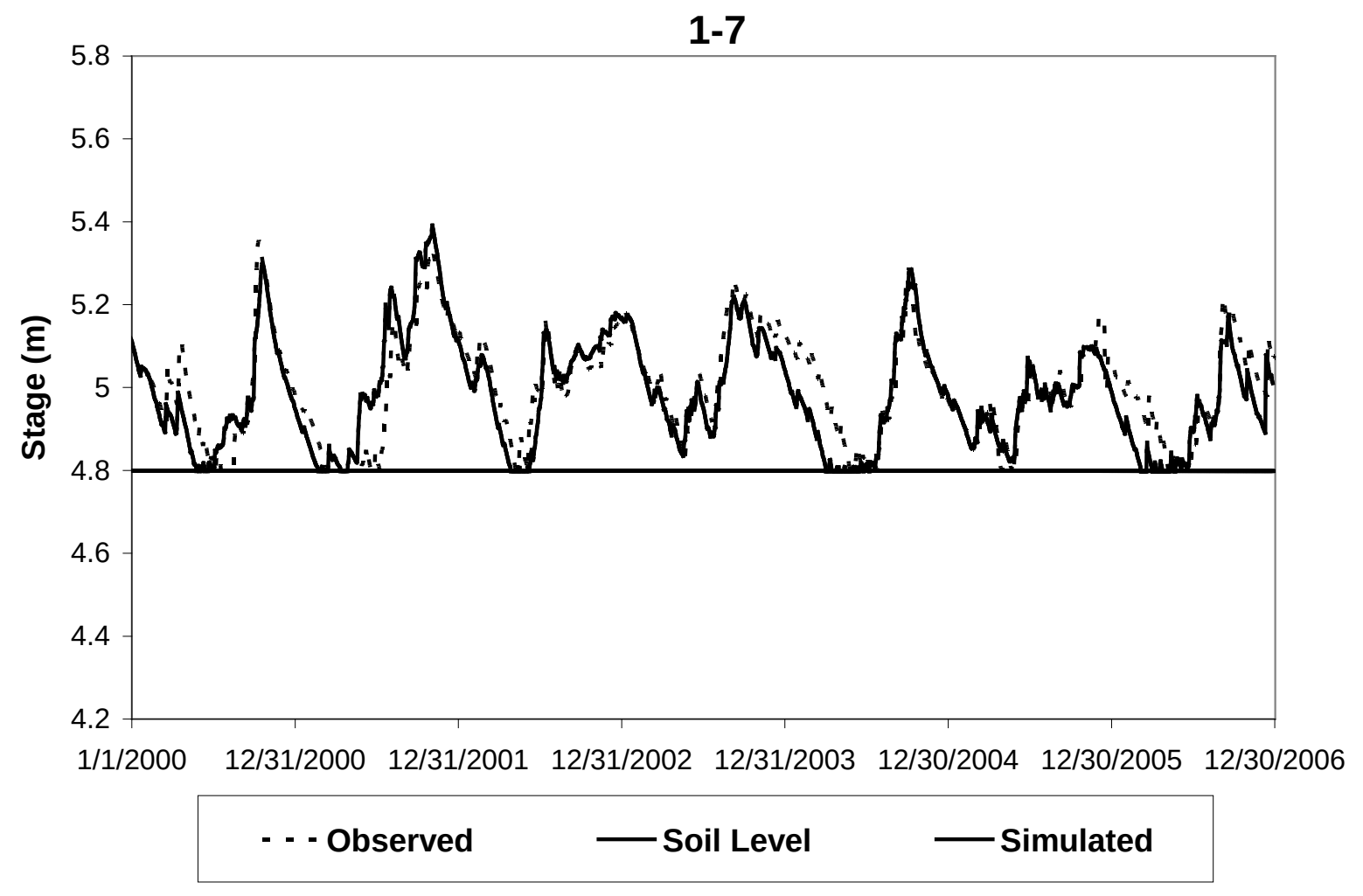
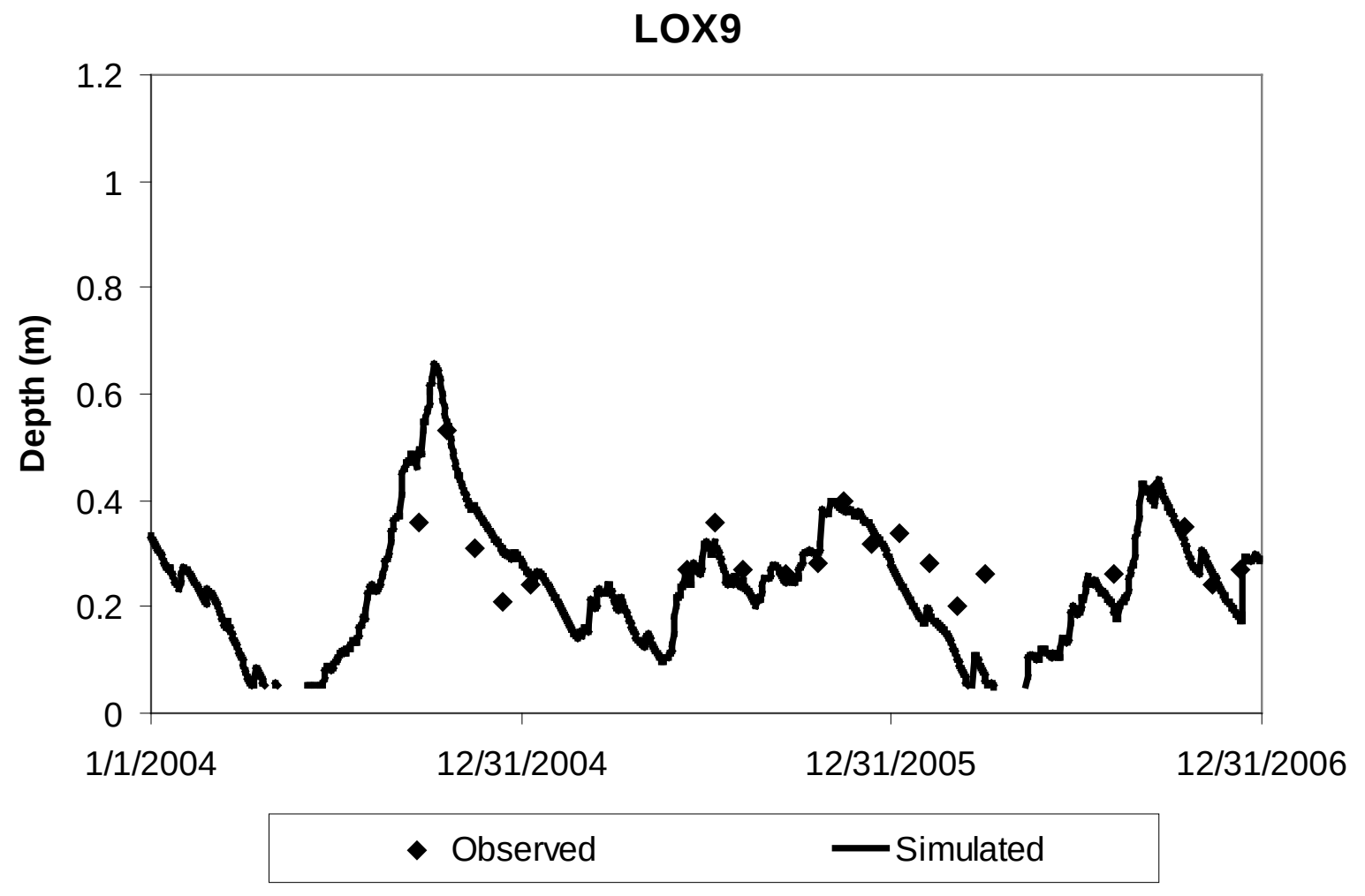


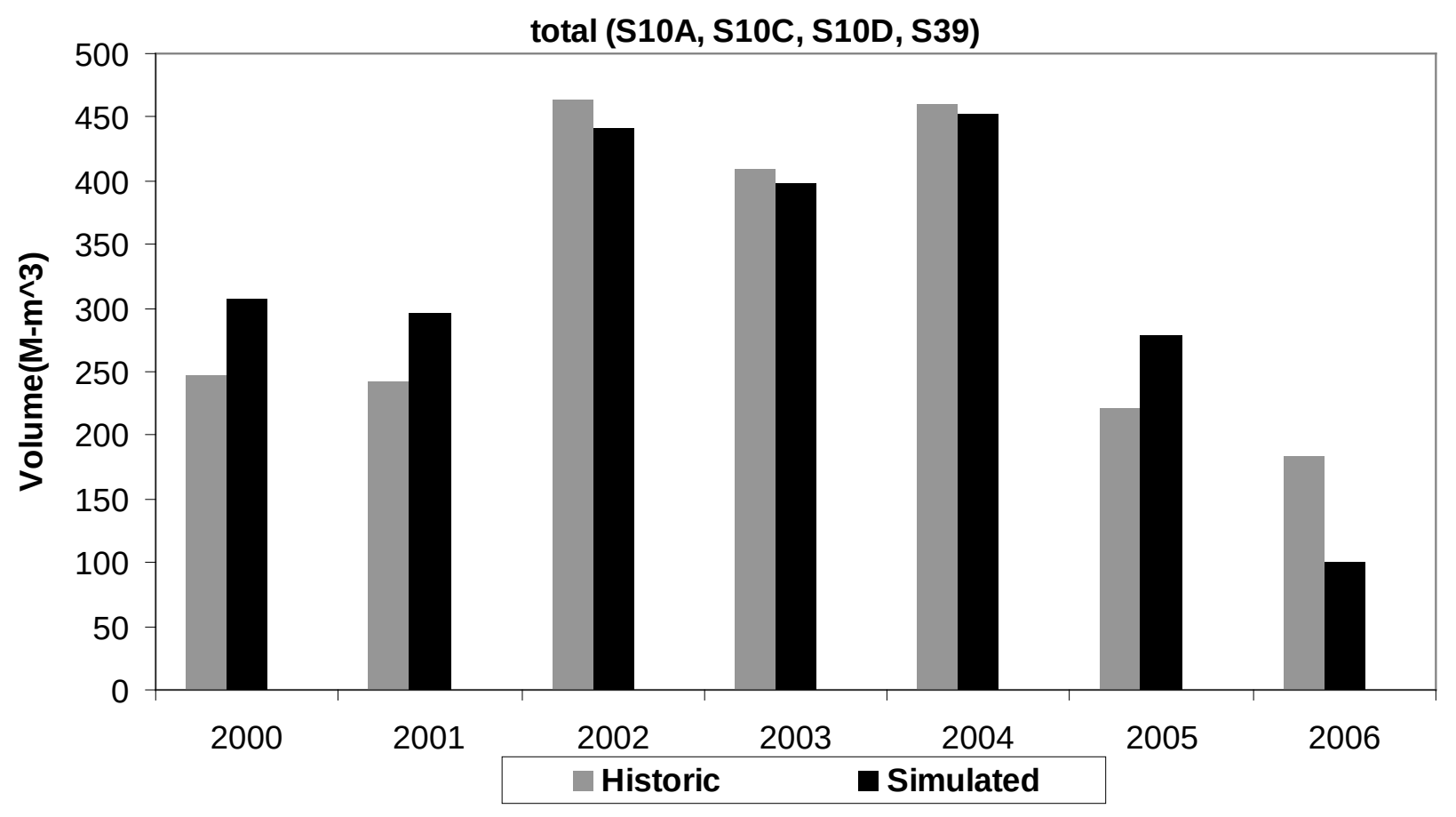
Figure 10: Stage and water quality stations

Results – Hydrodynamics (stage, depth, and outflow)



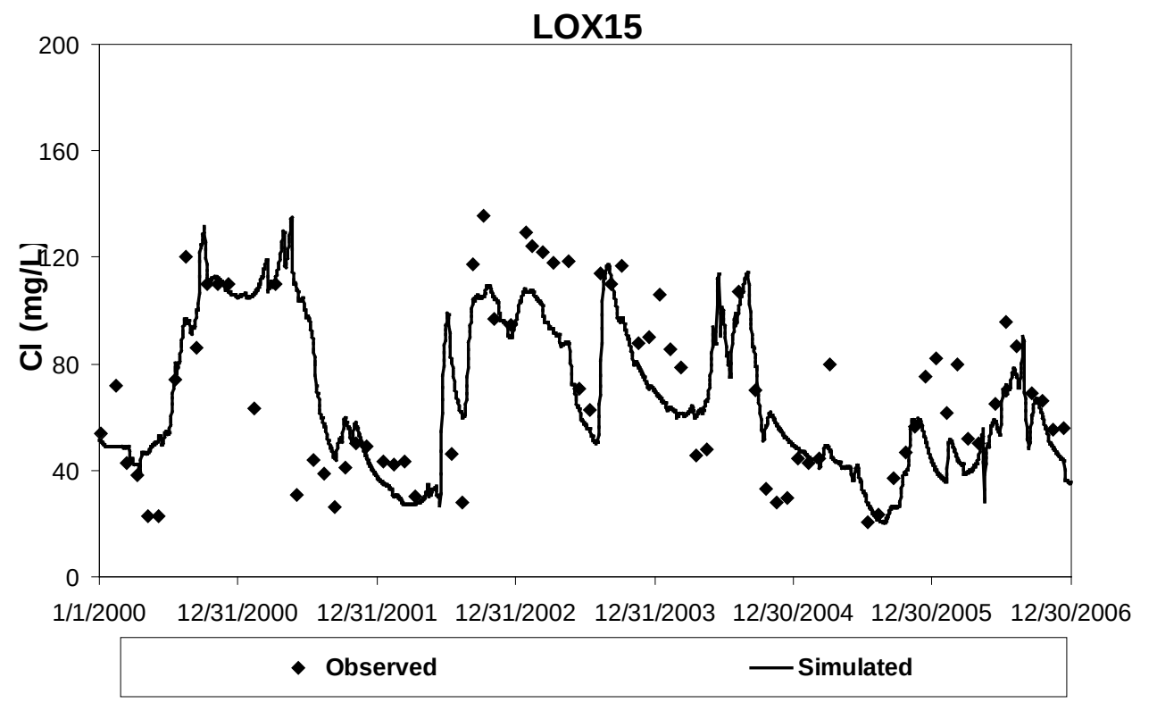


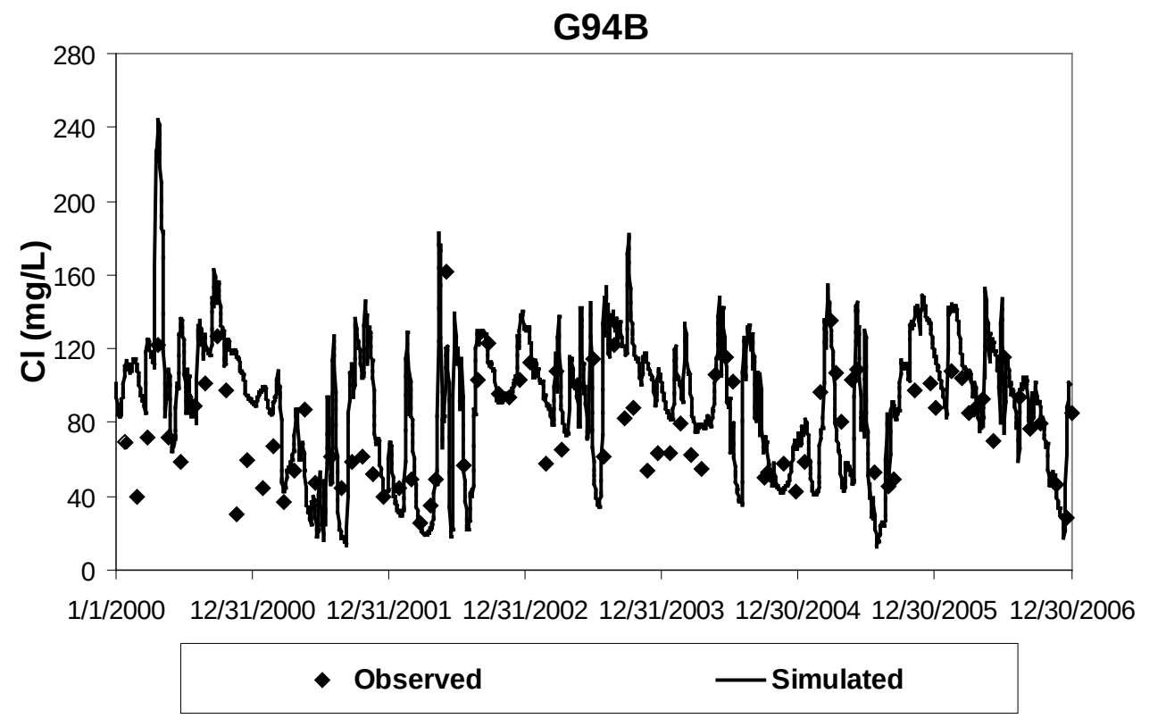
Here stage and depth at interior sites are presented. Stage is the water surface elevation, and depth is the measured depth to consolidated sediment (DCS) measured during water quality sampling. DCS was not recorded prior to mid-2004, and is at times not recorded when depth is too shallow to sample. Use of DCS to supplement automated stage recordings provides a greatly expanded distribution of sites for hydrodynamic model calibration and testing.

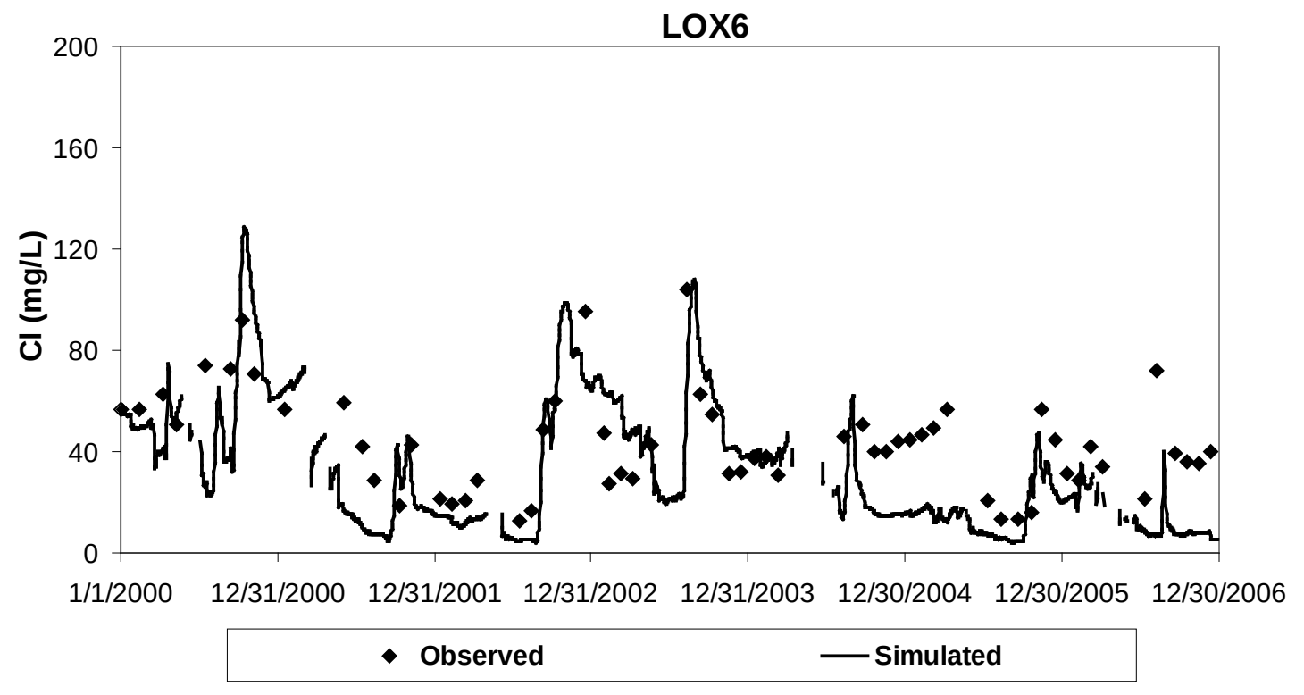


Outflow primarily results from regulatory releases. Model calibration used calculated, rather than historic, daily regulatory releases. Modeled outflow combines calculated regulatory release flows based on the Refuge regulation schedule with water supply releases and releases specifically linked to forecasts of large storms or hurricanes.

Results – Chloride (CL)

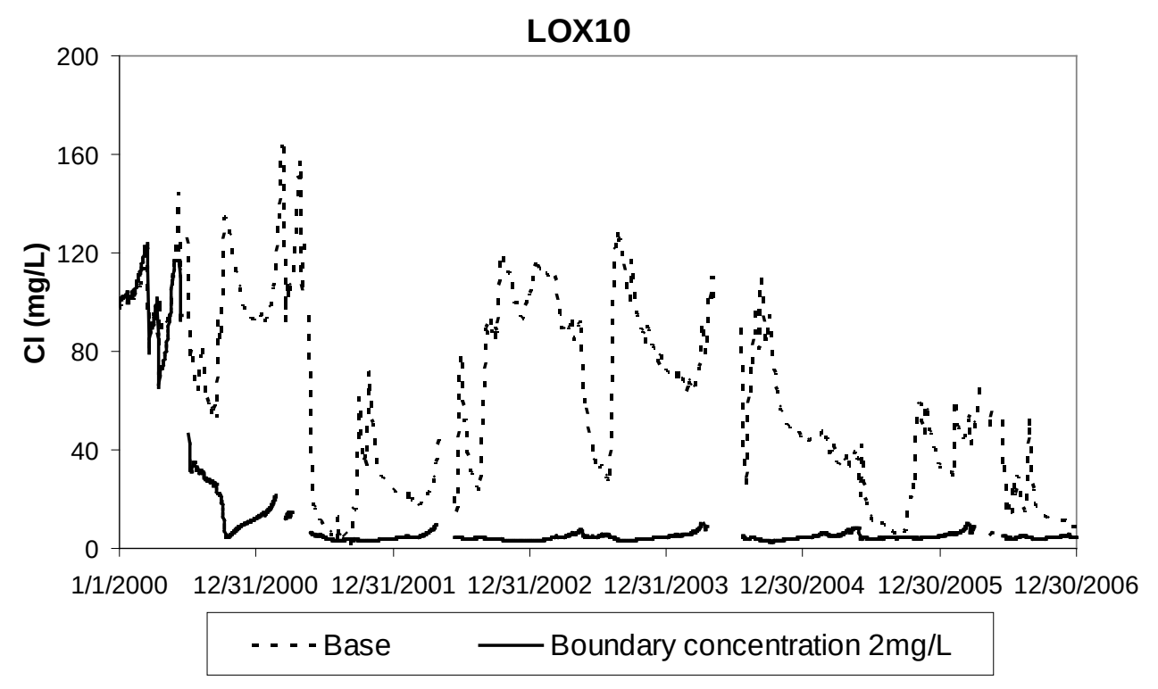


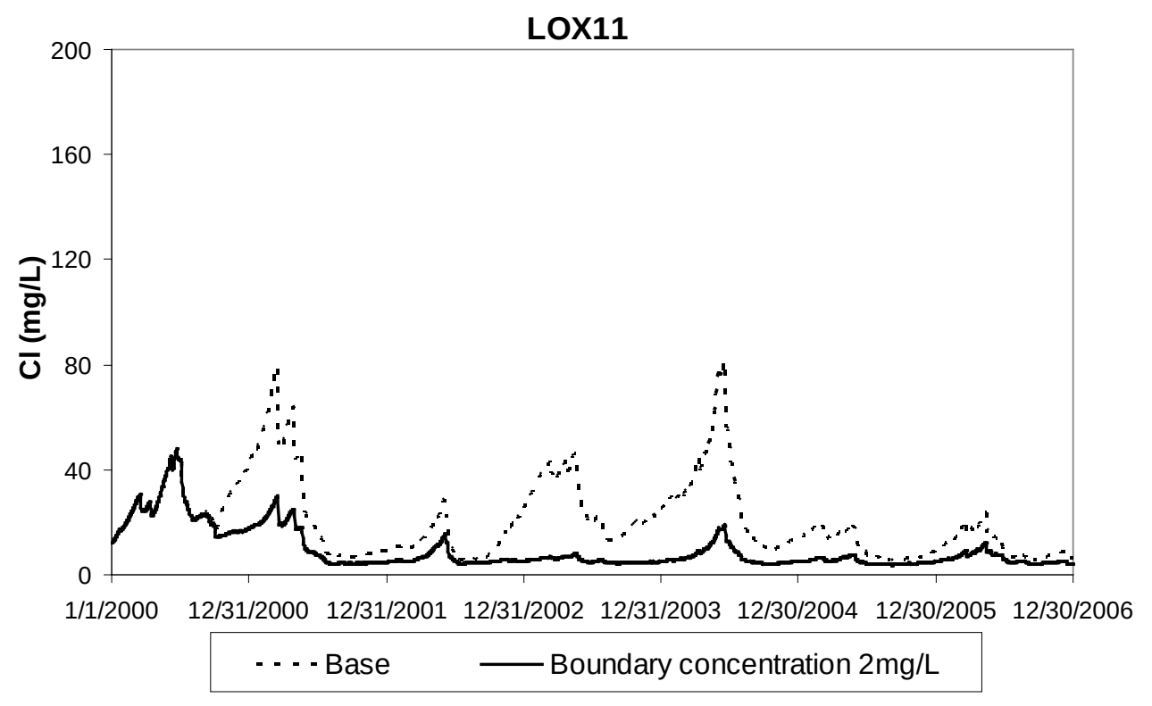




Observed and simulated chloride concentration at a southern marsh side (LOX15), central site (LOX6), and east-central canal site (G94B). Note the high frequency of variation in the canal relative to the marsh.

Application – Test of influence of inflow on interior CL





The Refuge marsh exhibits low chloride concentrations relative to pumped inflow (often well above 100 mg/L), but significantly higher concentrations than in rainfall (approximately 2 mg/L). It has been suggested that the elevated interior chloride concentration results from evaporation and dry deposition. Alternatively, interior chloride levels may result from intrusion of pumped inflow. We tested these hypotheses by setting the inflow concentration equal to the rainfall concentration. Two sites are displayed here, LOX10 is closer to the canal, and LOX 11 is more interior. We found elevated marsh concentrations primarily originate from intrusion of inflowing chloride load which may be concentrated further by evaporation.

Conclusions and Future Developments

Conclusions

- Model results are in good agreement with observations.
- Model is computationally efficient (1 year simulation requires 3 CPU hours on Pentium(R) 4 3.2GHz).

Future/Ongoing Developments

- Modeling of TP and Sulfate (SO_4) ongoing.
- Management scenarios will be assessed.

References

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Acknowledgements and Disclaimer

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