Environmental Modeling

A Few Examples

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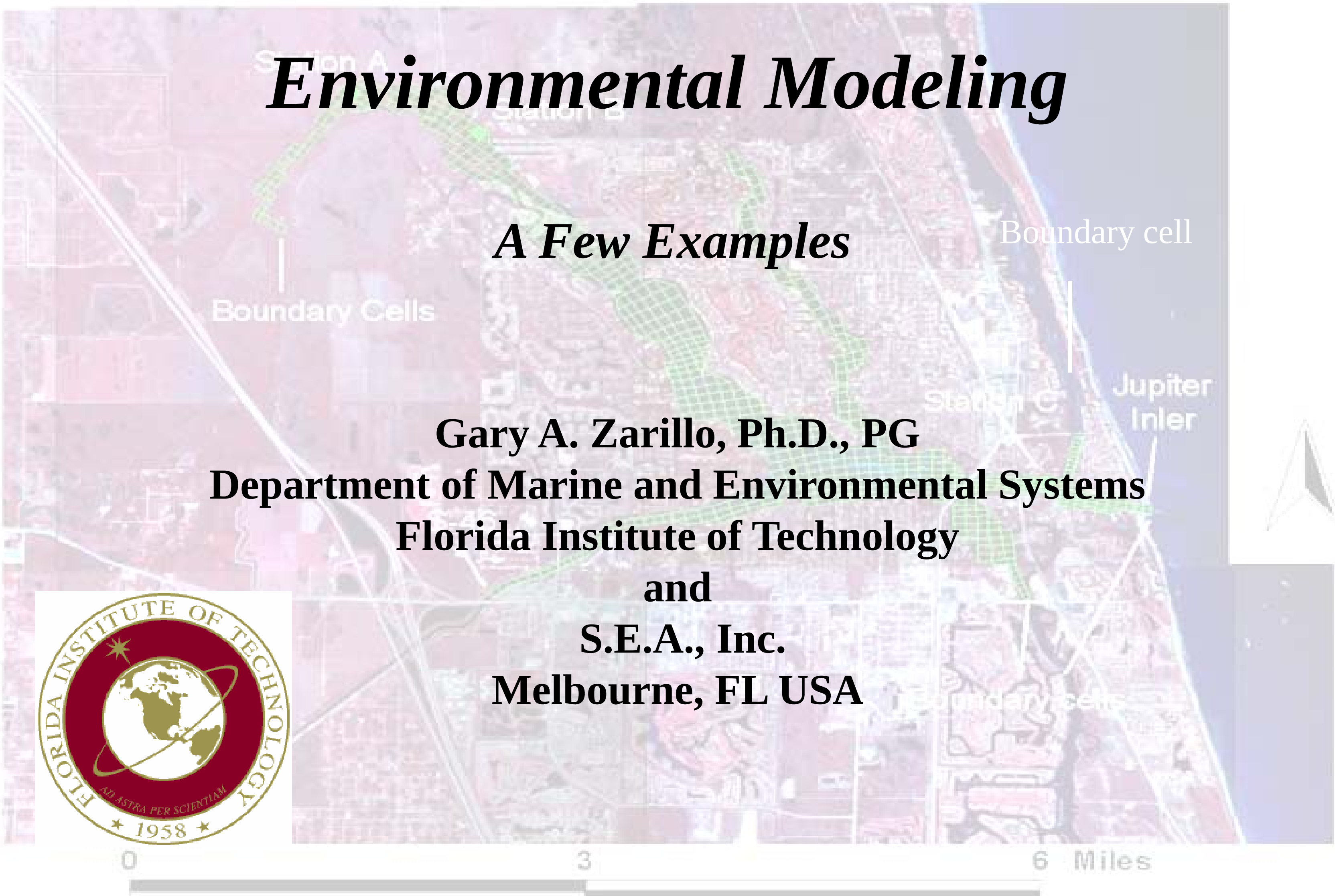
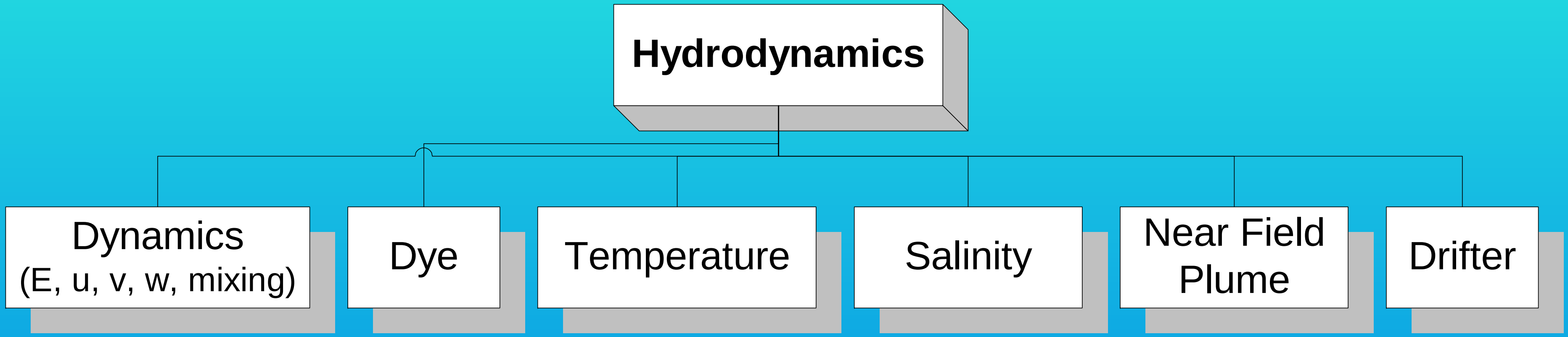


Desired Capabilities

- Three-Dimensional Hydrodynamics with Coupled Salinity and Temperature Transport
- Directly Coupled Water Quality-Eutrophication Model
- Directly Coupled Toxic Contaminated Sediment Transport and Fate Model
- Integrated Near-field Mixing Zone Model
- Preprocessing Software for Grid Generation and Input File Creation
- Post processing Software for Analysis, Graphics and Visualization
- Track Record: Estuarine and Coastal Ocean Applications

THE EFDC/HEM3D EXAMPLE

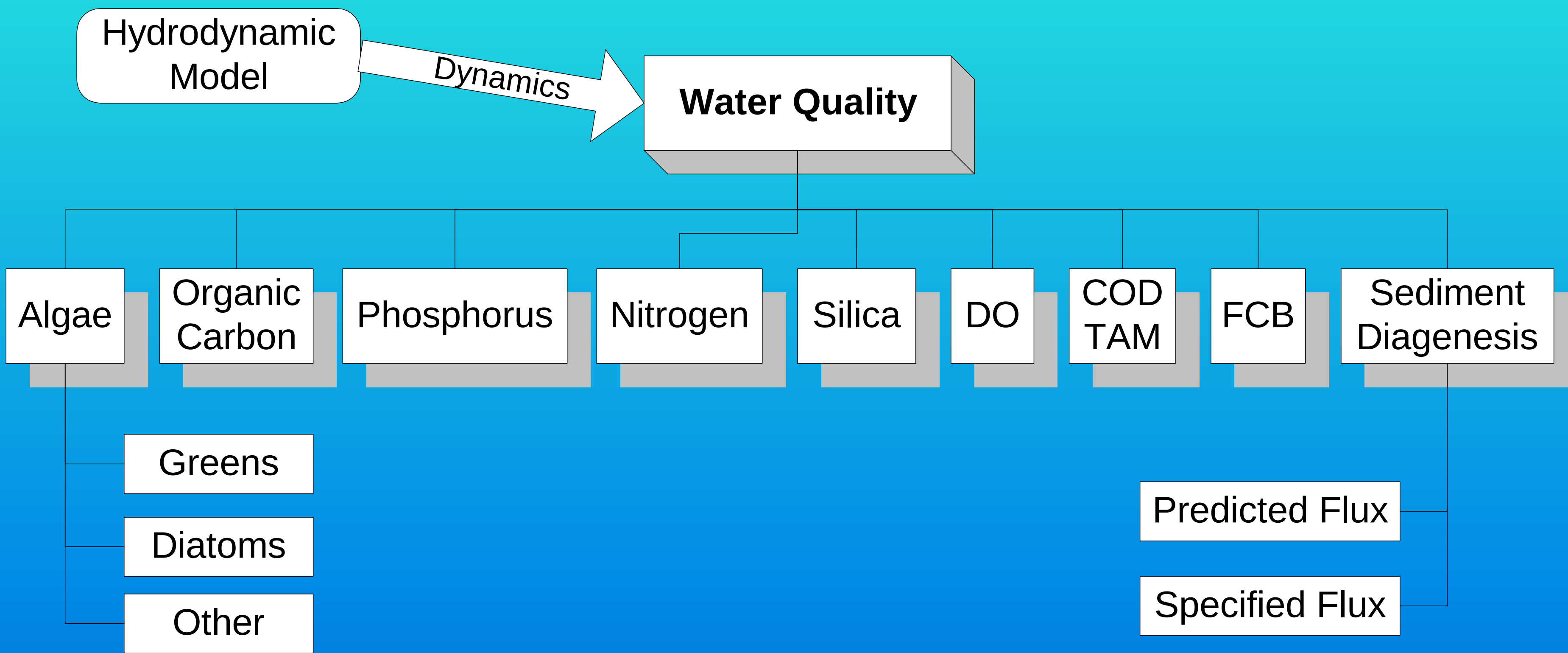
- Boundary Fitted Curvilinear Grid
- Includes Turbulence Closure Model
- Highly Efficient Semi-Implicit Solution
- Functionally Equivalent to POM/ECOM, CH3D-WES and TRIMM
- Developed at VIMS *(Hamrick, 1992, Park et. al., 1995)*
- U.S. EPA Supported Model


Hydrodynamics
Dynamics
(E, u, v, w, mixing)
Dye
Temperature
Salinity
Near Field
Plume
Drifter

HEM3D WATER QUALITY-EUTROPHICATION

- Directly Coupled to Hydrodynamics
- Based on CE-QUAL-IC Kinetics *(Chesapeake Bay WQ Model*, *Cerco et. al.*, *1991)*
- 22 Water Column State Variables including Multiple Classes of Algae and Organic Carbon, Nitrogen and Phosphorous
- Optional 27 State Variable Sediment Diagenesis Sub-model
- Reduced Number of State Variable Classes Available for Simplified runs
- Reduced Number of State Variable Version Equivalent to WASP5

Interaction of Hydrodynamic and Water Quality Calculations



Model Dimensionality Considerations for Coastal/Estuarine Settings

- **Deep and Narrow Navigation Channel**
- **Shallow Lateral Flanks**
- **Estuary Circulation Enhanced by Deep Channel and Shallow Flanks**
- **Tidally Energetic - Salinity Stratification Primarily in Channel**
- **Extensive Marsh and Tidal Flats**
- **Both Lateral and Vertical Resolution Required**

HEM3D WQ State Variables

1) cyanobacteria
2) diatom algae
3) green algae
4) refractory particulate organic carbon
5) labile particulate organic carbon
6) dissolved carbon
7) refractory part. organic phosphorus
8) labile particulate organic phosphorus
9) dissolved organic phosphorus
10) total phosphate
11) refractory part. organic nitrogen
12) labile part. organic nitrogen
13) dissolved organic nitrogen
14) ammonia nitrogen
15) nitrate nitrogen
16) particulate biogenic silica
17) dissolved available silica
18) chemical oxygen demand
19) dissolved oxygen
20) total active metal
21) fecal coliform bacteria
22) macroalgae

HEM3D WQ Calculations

Conservation of Mass Equation

$$\frac{\partial C}{\partial t} + \frac{\partial (u\,C)}{\partial x} + \frac{\partial (v\,C)}{\partial y} + \frac{\partial (w\,C)}{\partial z}$$

$$= \frac{\partial}{\partial x}\left(K_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial C}{\partial z}\right) + S_C$$

C = concentration of a water quality state variable

u, *v*, *w* = velocity components

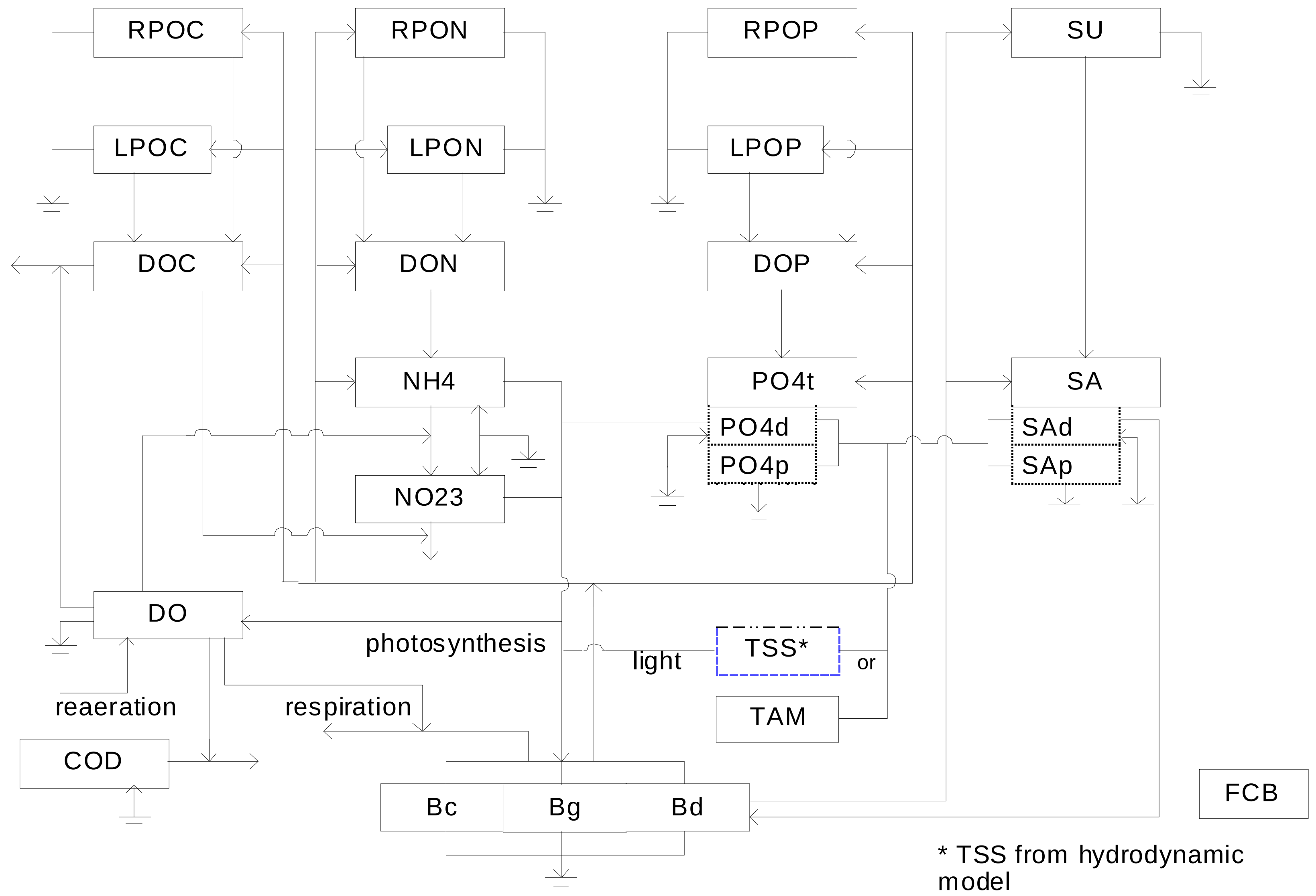
Kx, *Ky*, *Kz* = turbulent diffusivities

Sc = internal and external sources and sinks per unit volume.

$$\frac{\partial C}{\partial t} = K \bullet C + R$$

(***Kinetic processes only, where k = kinetic rate, R = source/sink term)***

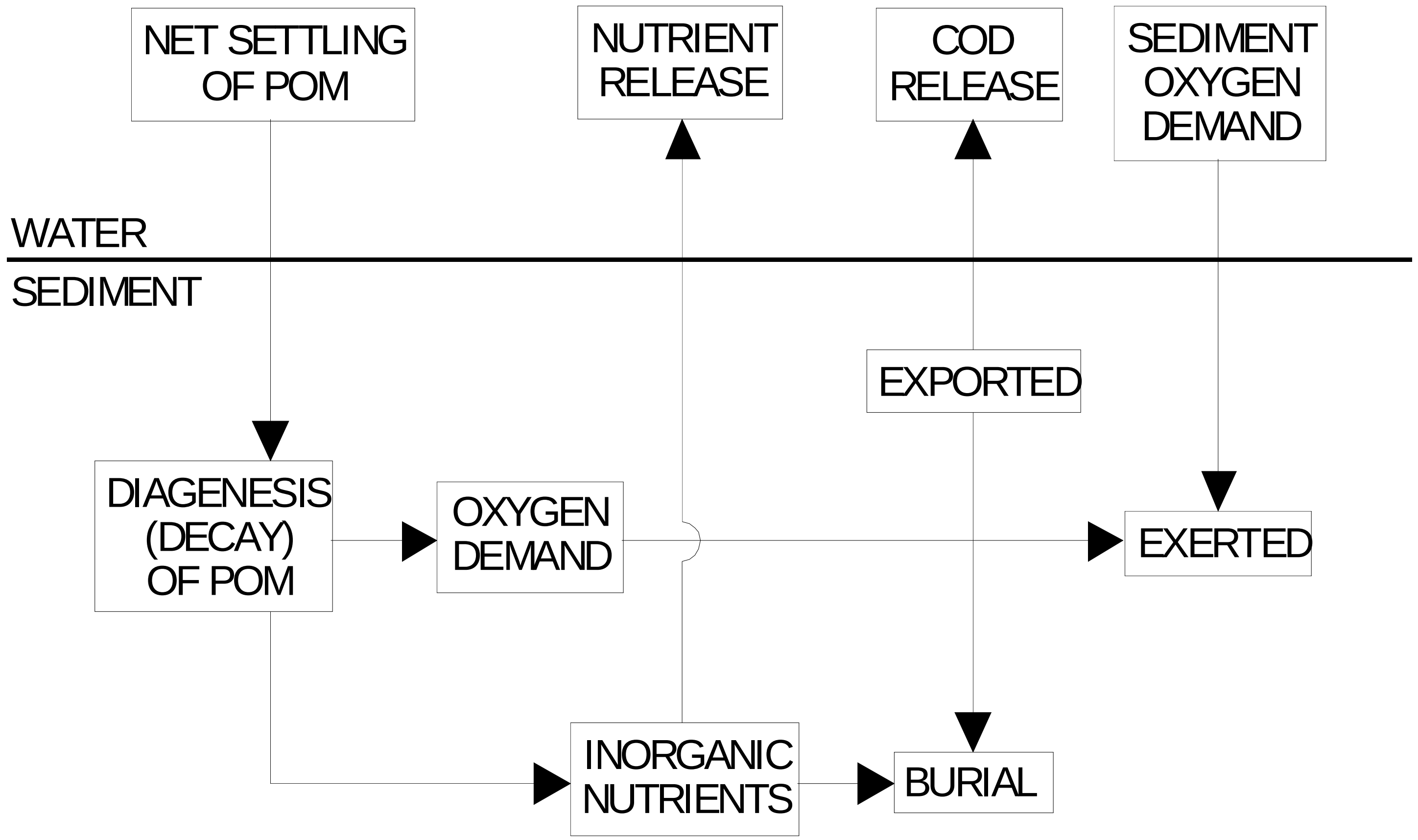
HEM3D Water Quality Schematic



HEM3D Sediment Diagenesis Model

- **Developed by DiToro & Fitzpatrick for Chesapeake Bay Model**
- **27 State Variables and Fluxes**
- **Three basic processes:**
  - ***Depositional flux of POM from water column***
  - ***Diagenesis (decay) of POM in sediments***
  - ***Flux of substances produced by diagenesis***
- **Benthic sediments represented by 2 layers**
  - ***Upper layer can be oxic or anoxic***
  - ***Lower layer is always anoxic***

Sediment Diagensis Model Schematic



EFDC/HEM3D Hydrodynamic and Water Quality Model of the

Loxahatchee River and Estuary

Southeast Florida, USA

Gary A. Zarillo, Ph.D., PG

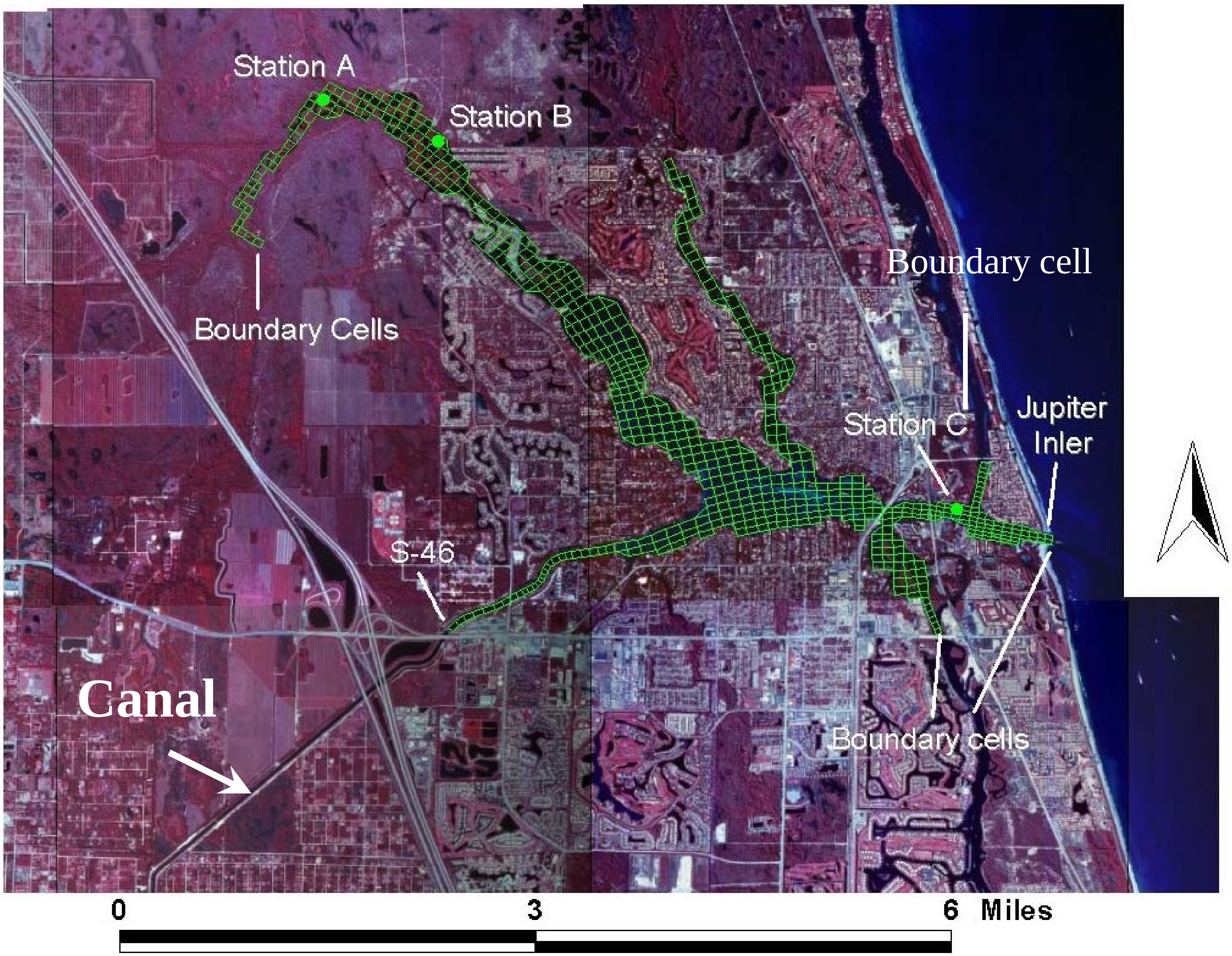
- **Total Organic Carbon**
- **Dissolved Organic Nitrogen**
- **Particulate Organic Nitrogen**
- **Dissolved Organic Phosphorus**
- **Particulate Organic Phosphorus**
- **Ammonia**
- **Nitrate+Nitrite**
- **Dissolved Oxygen**

Model Setup

Boundary conditions for model runs include:

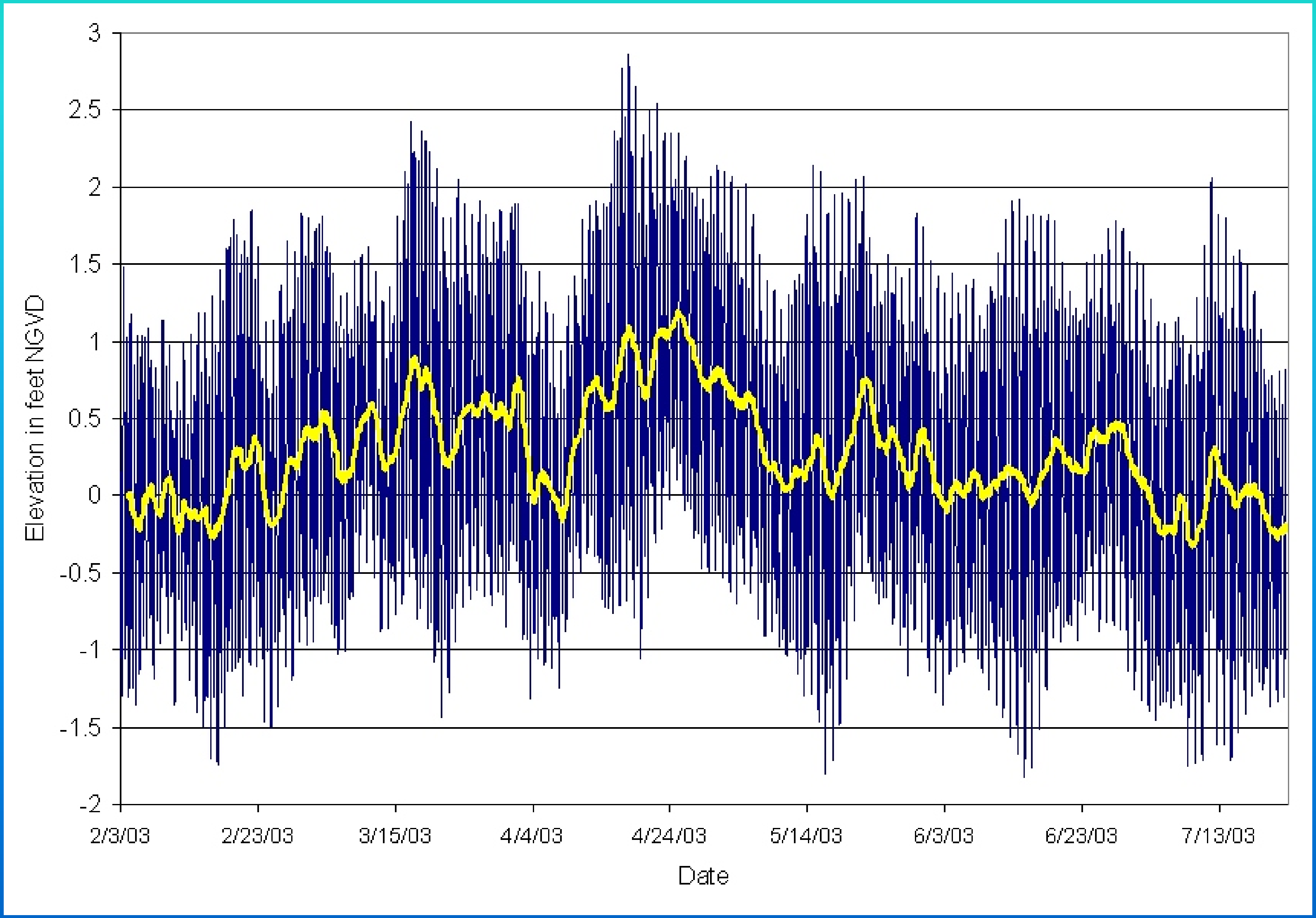
- Time series of water surface elevation
- Salinity
- Water temperature
- Freshwater inflow
- Meteorological parameters
- Other measured water quality parameters that may be available

Model Computational Grid: Horizontal Cells-603; Vertical Layers-5

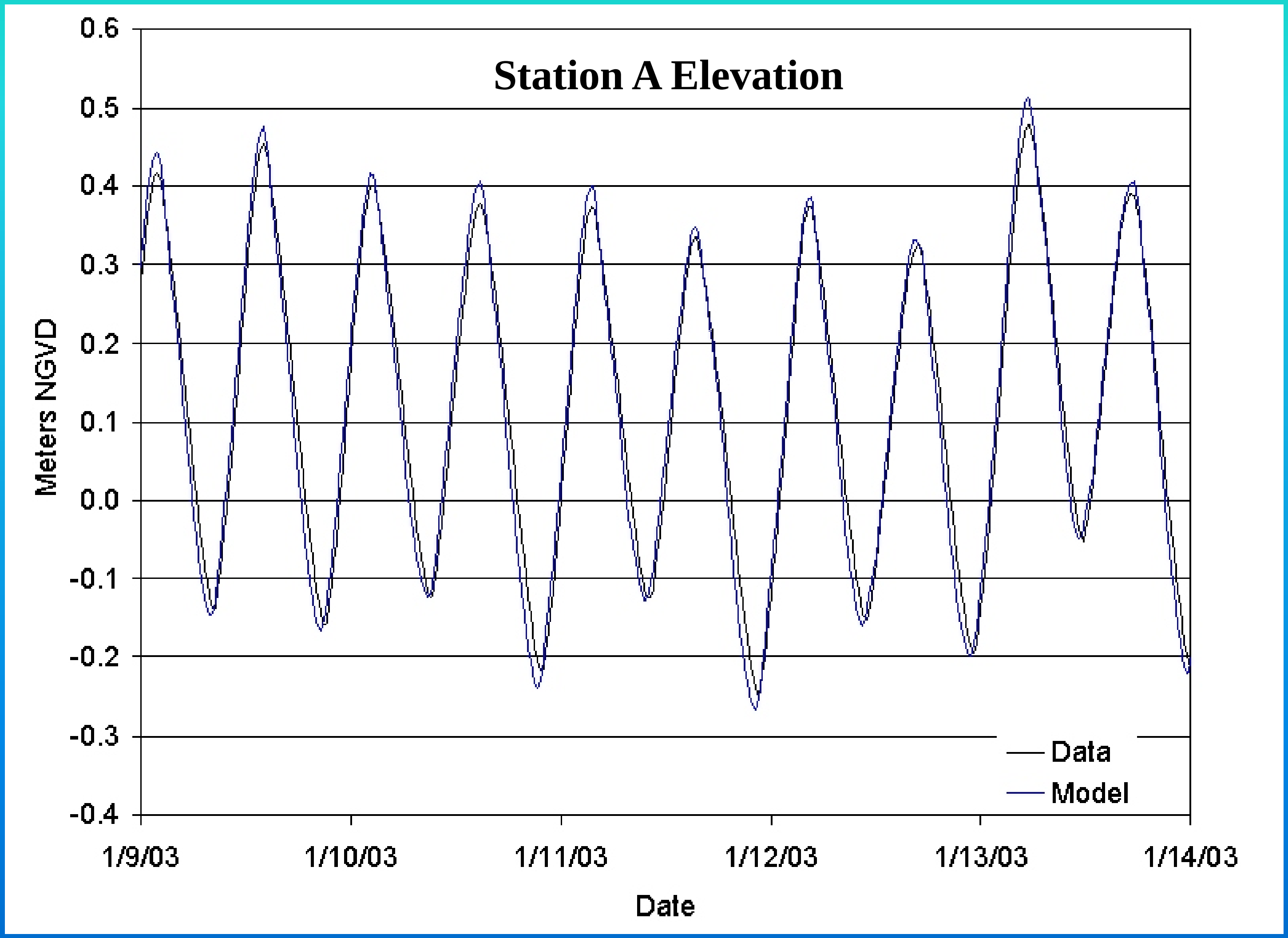


Forcing at the Ocean Boundaries

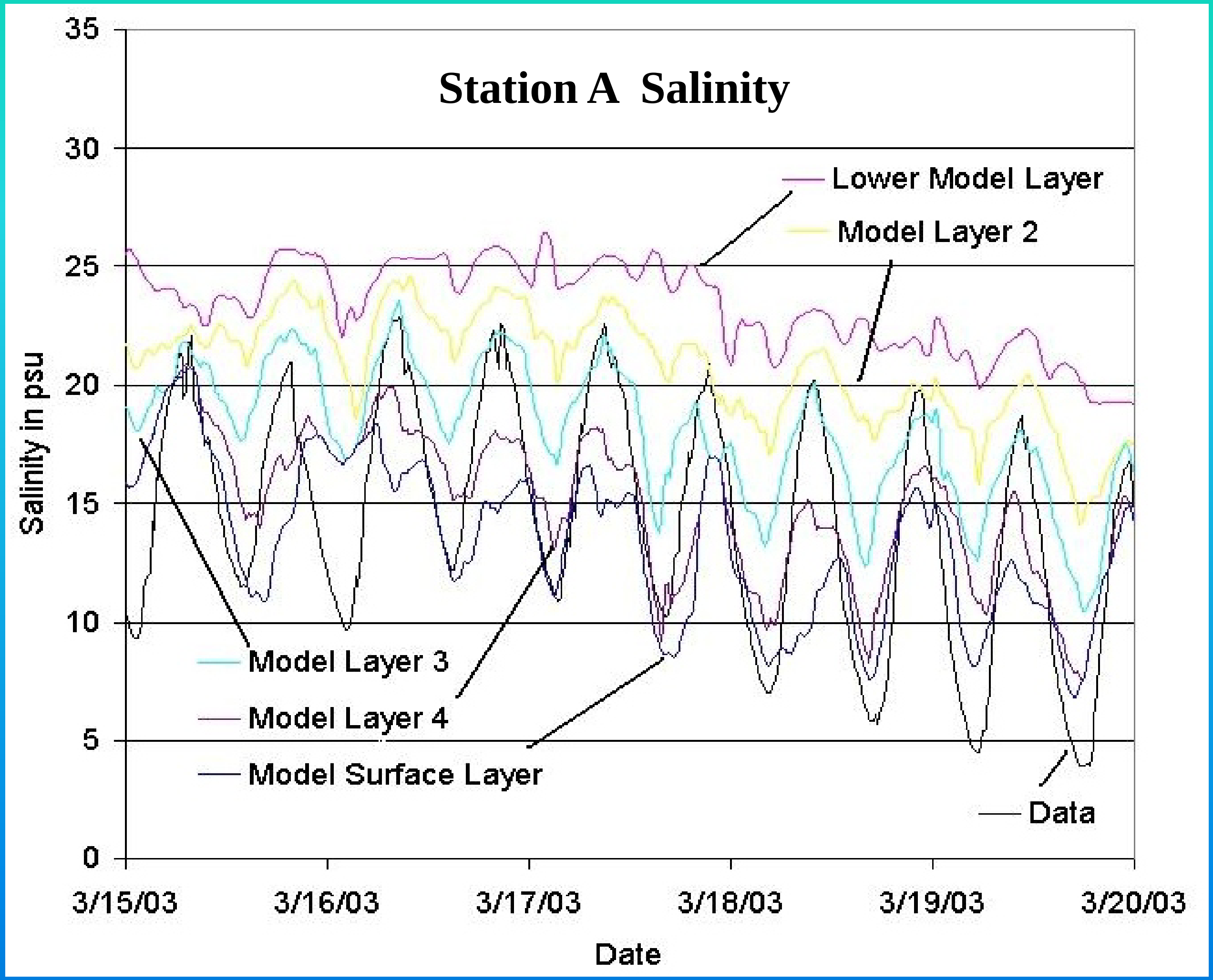
Jupiter Inlet - water elevation time series



Model Calibration and Verification



Model Calibration and Verification



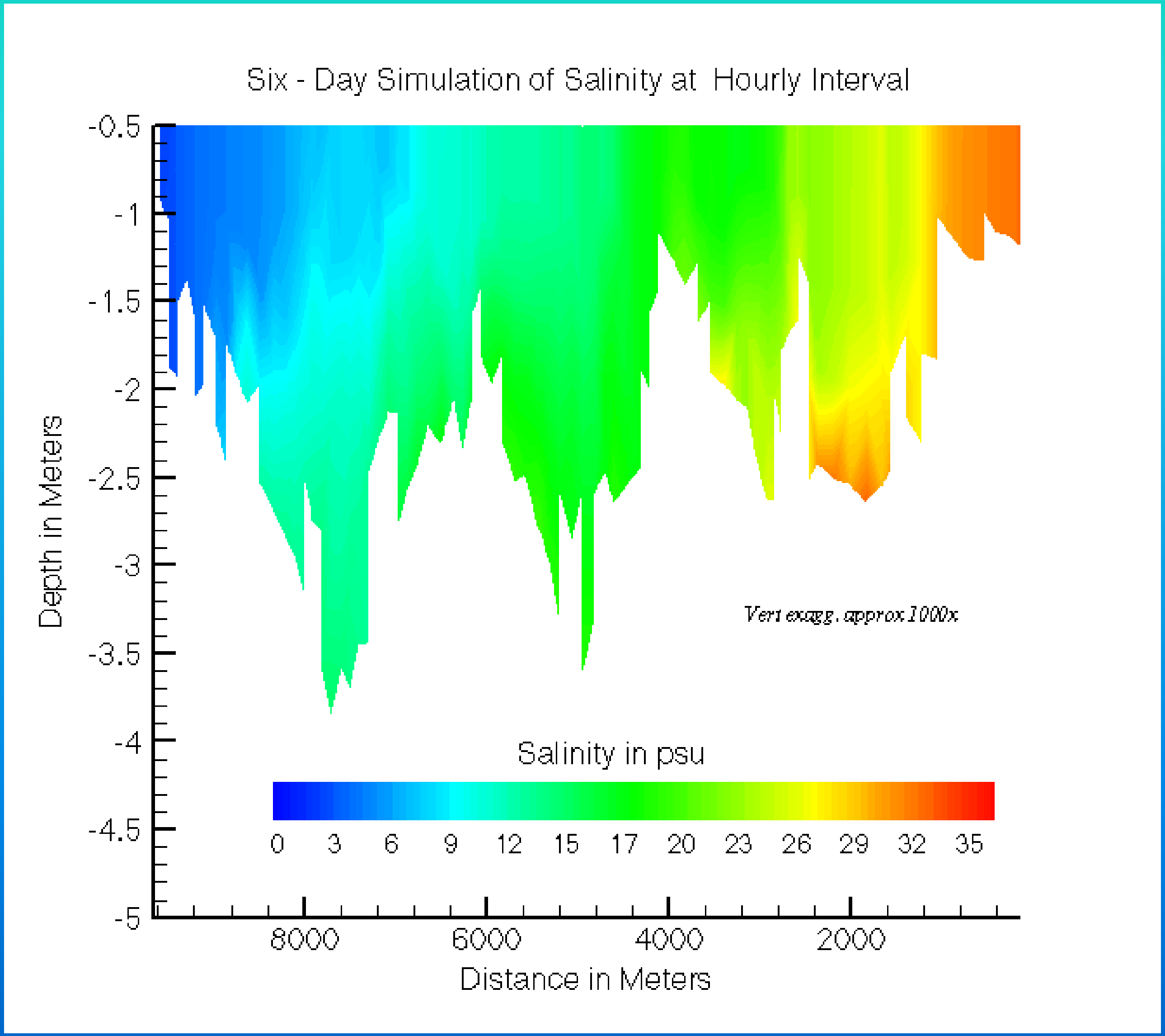
RMS/Range	RMS/Range	RMS/Range	RMS/Range	RMS/Range
57.6%	46.0%	28.4%	**15.6%**	**12.3%**

Model Layers ***bottom*** ***4*** ***3*** ***2*** ***surface***

Calibration Stats.

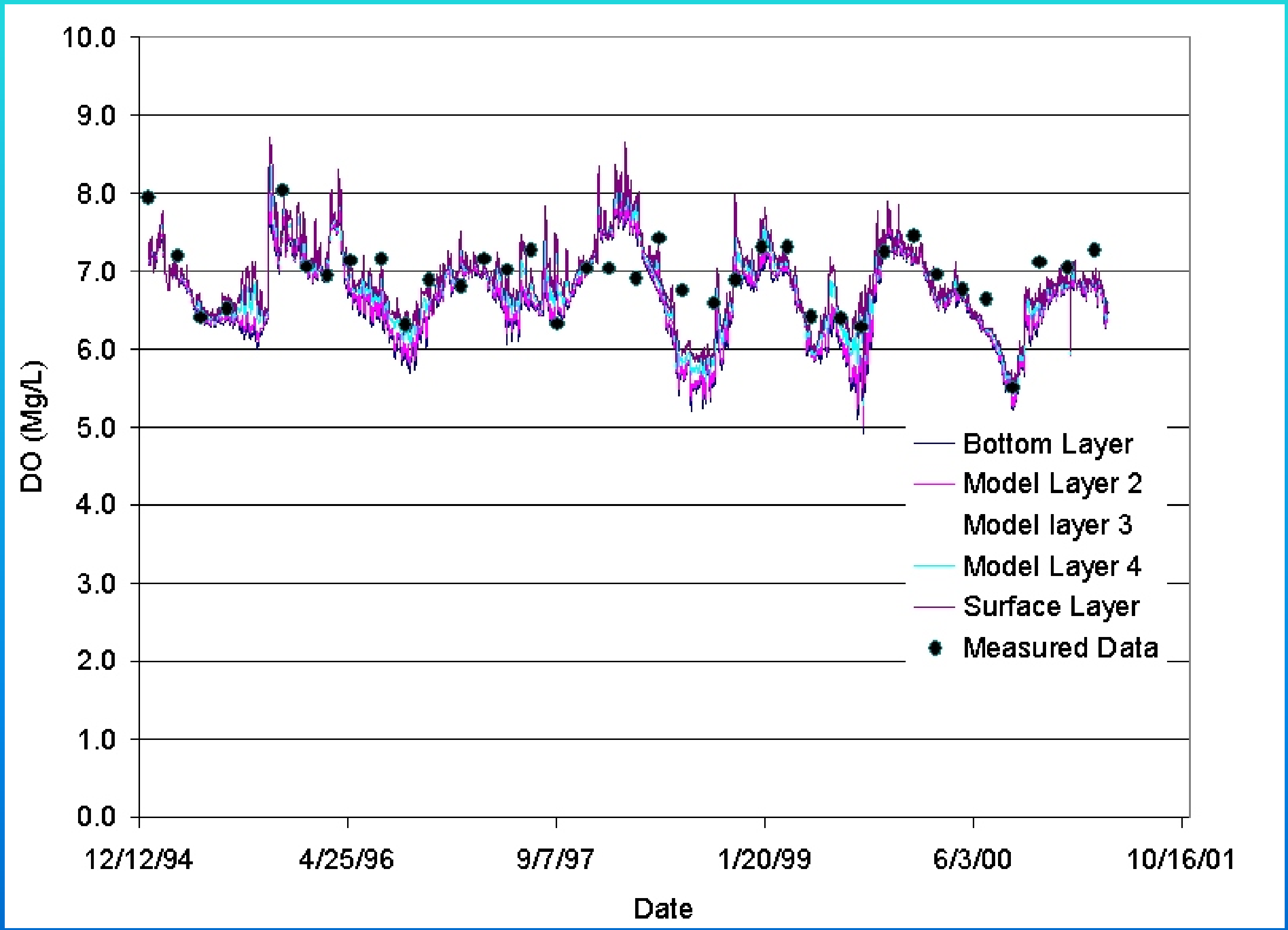
Data vs. model surface layer

Model Simulations

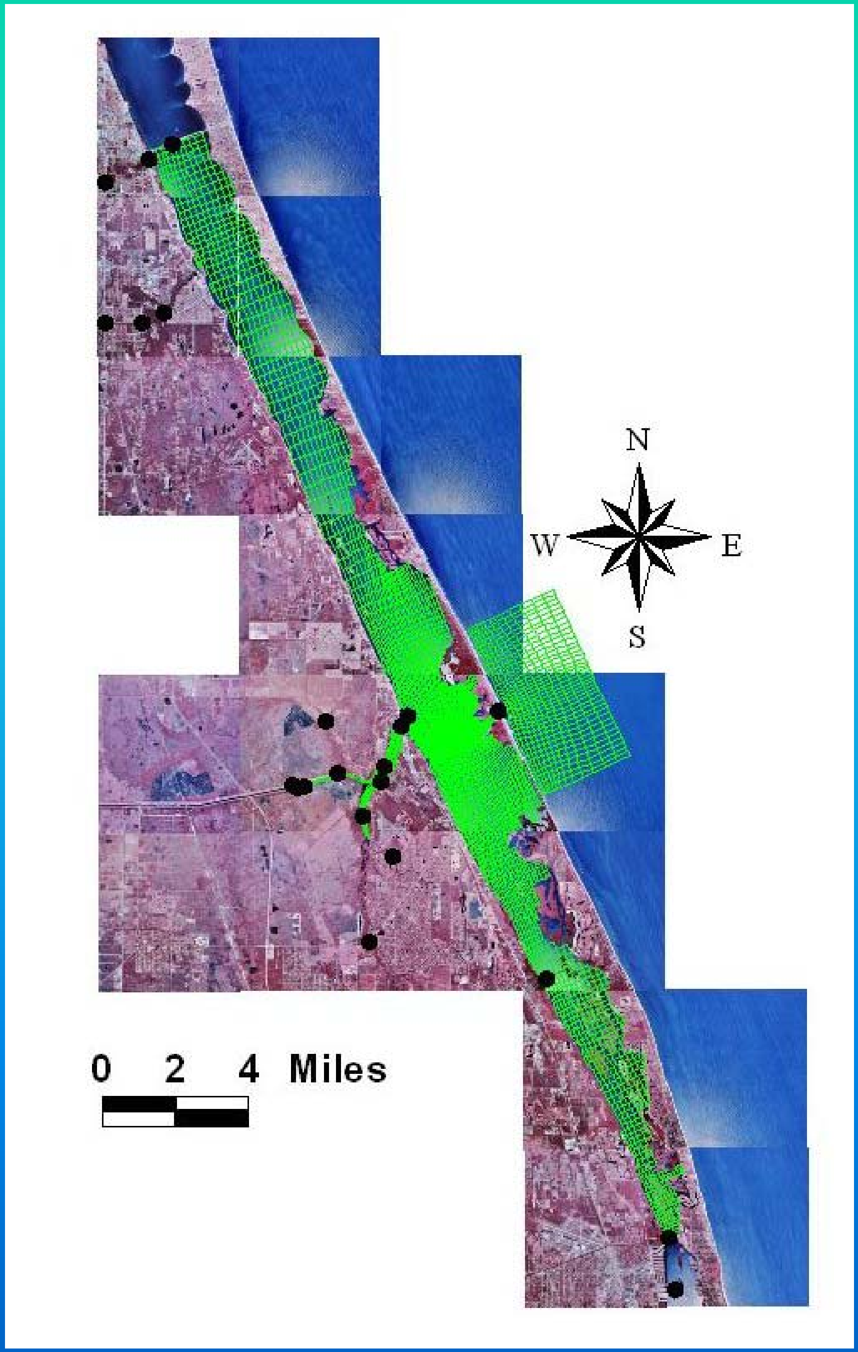


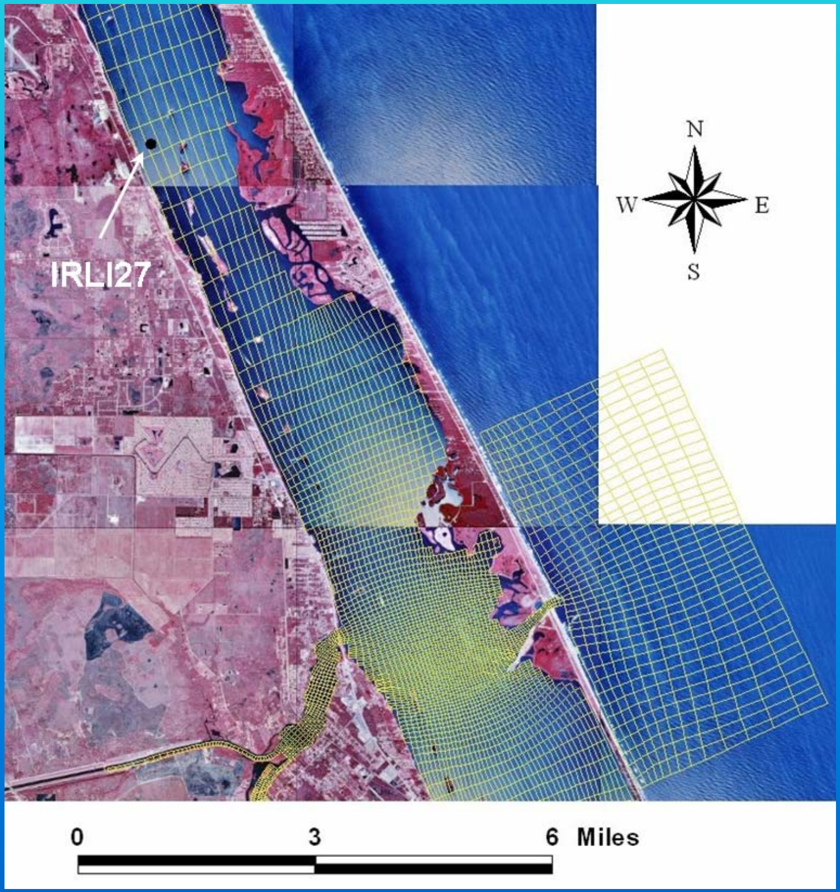
(Animation)

Dissolved Oxygen Calibration



EFCD/HEM3D
Sebastian Inlet, FL
(Dredging Impact Study)

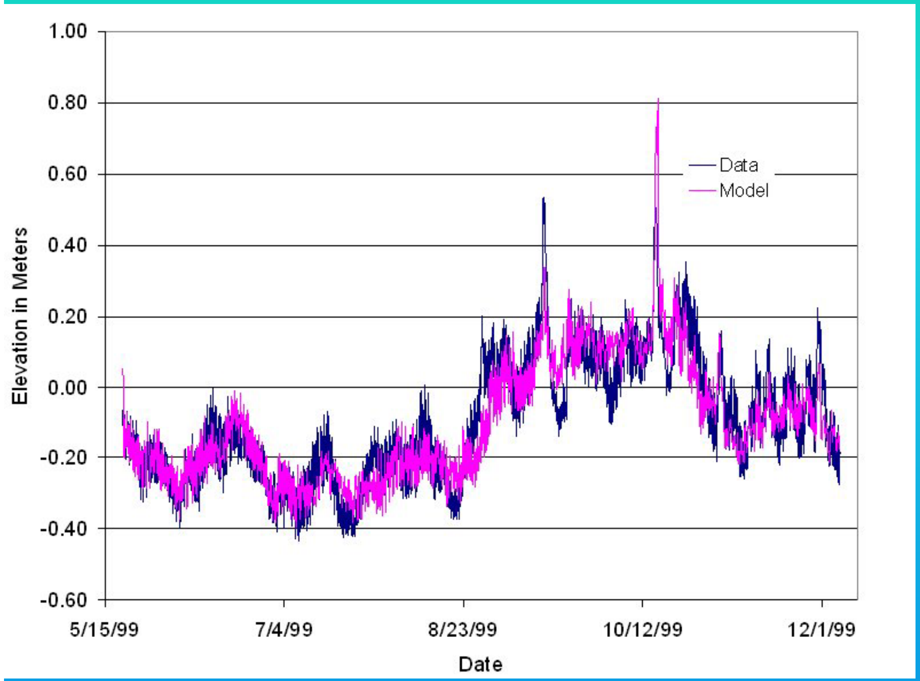




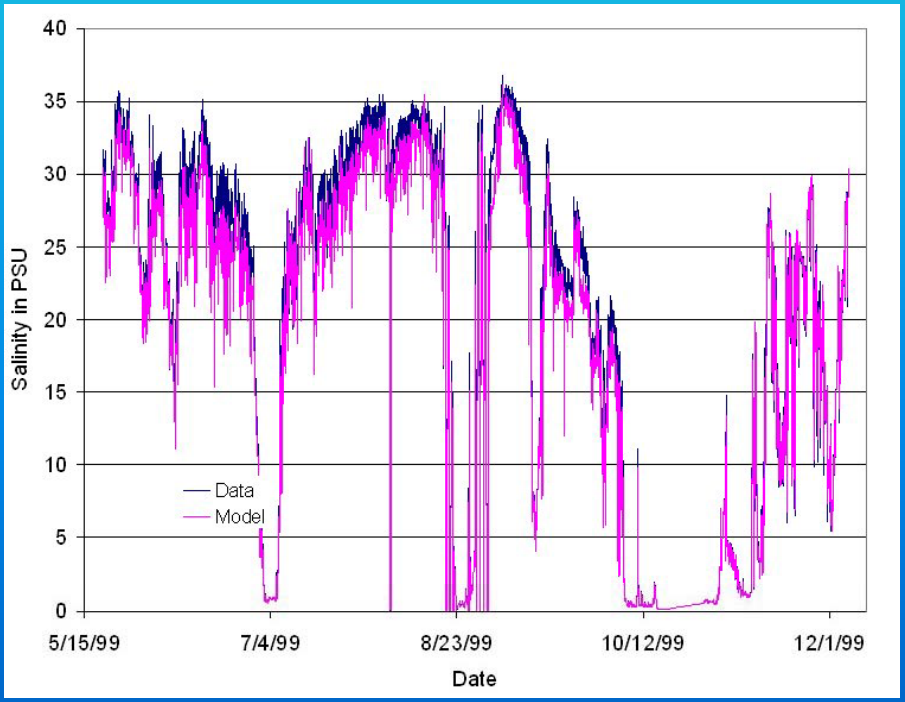
Calibration and Validation Statistics

	Calibration Period		Verification Period	
Parameter	RMS	RMS/RANGE	RMS	RMS/RANGE
Salinity surface	4.7 psu	16.6%	5.6 psu	17.3%
Salinity bottom	0.8 psu	4.8%	1.5 psu	4.1%
Temperature bottom	1.8 ^oC	8.2%	0.76 ^oC	4.2%%
Temperature surface	2.09 ^oC	10.9%	2.8 ^oC	15.7%
Water level	0.08 m	7.7%	0.09 m	9.4%

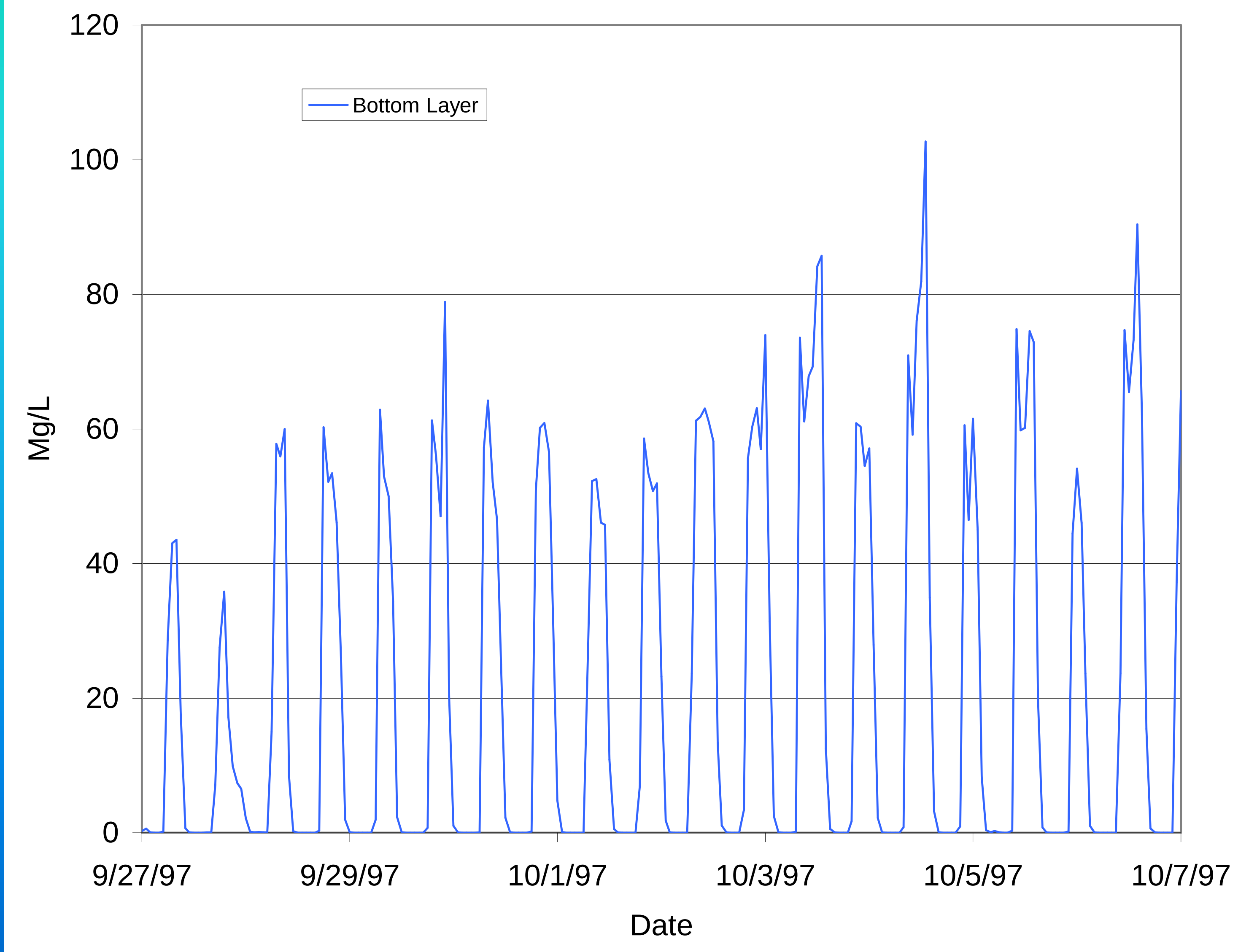
Water Level Calibration



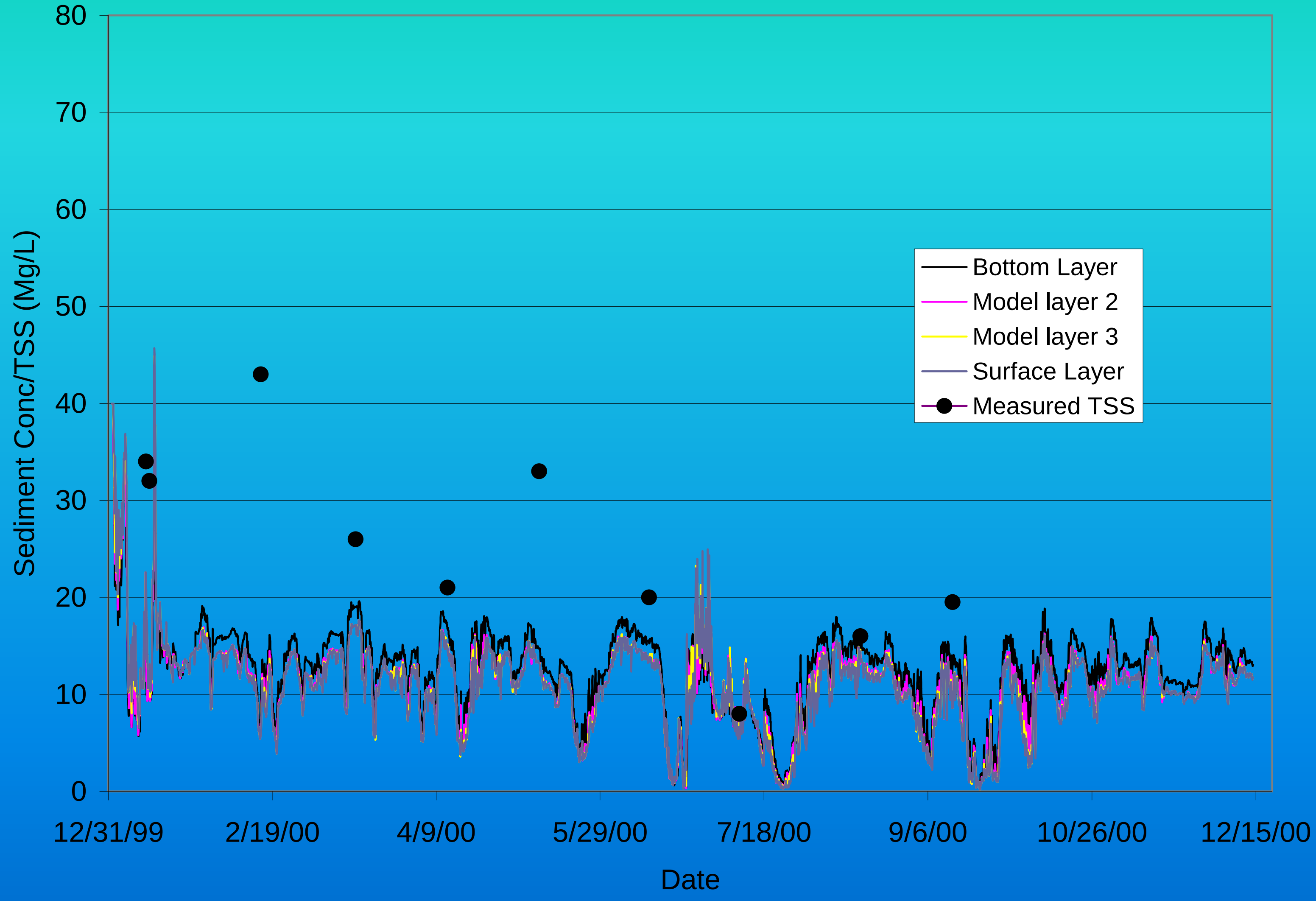
Salinity Calibration



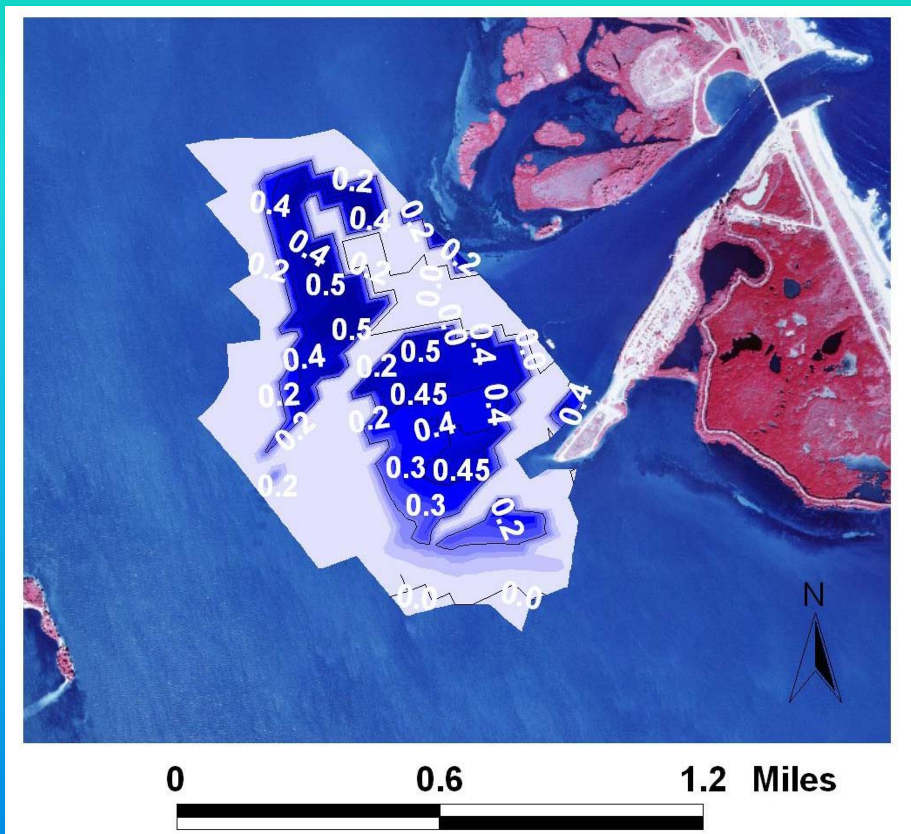
Suspended Sediment Time Series: Flood Shoal



Suspended Sediment vs. TSS



Predicted Topographic Change - 1999

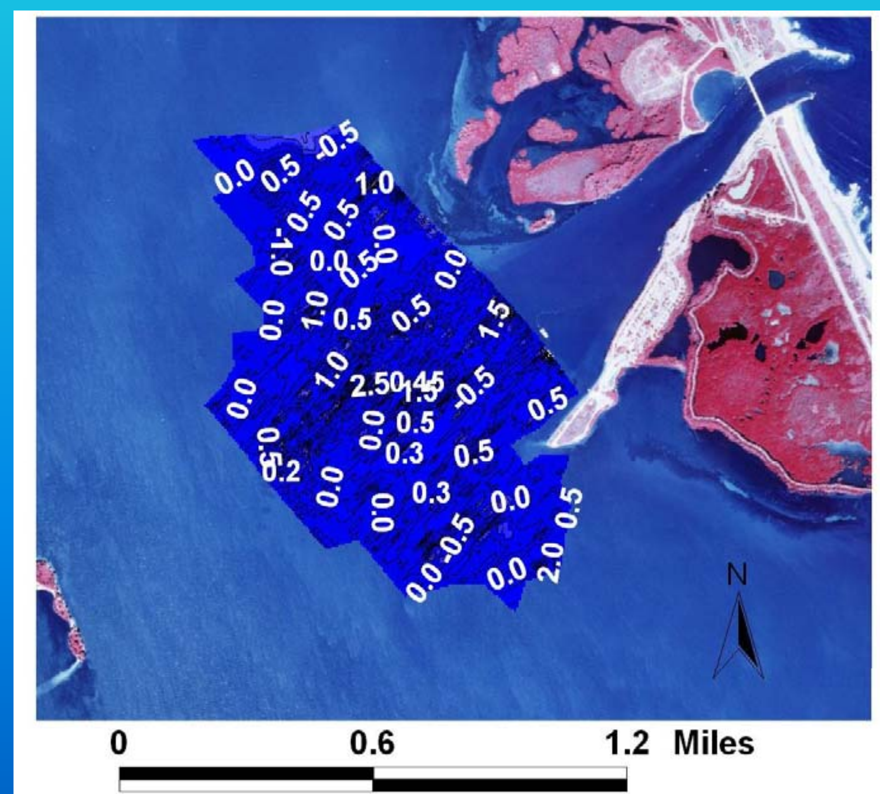


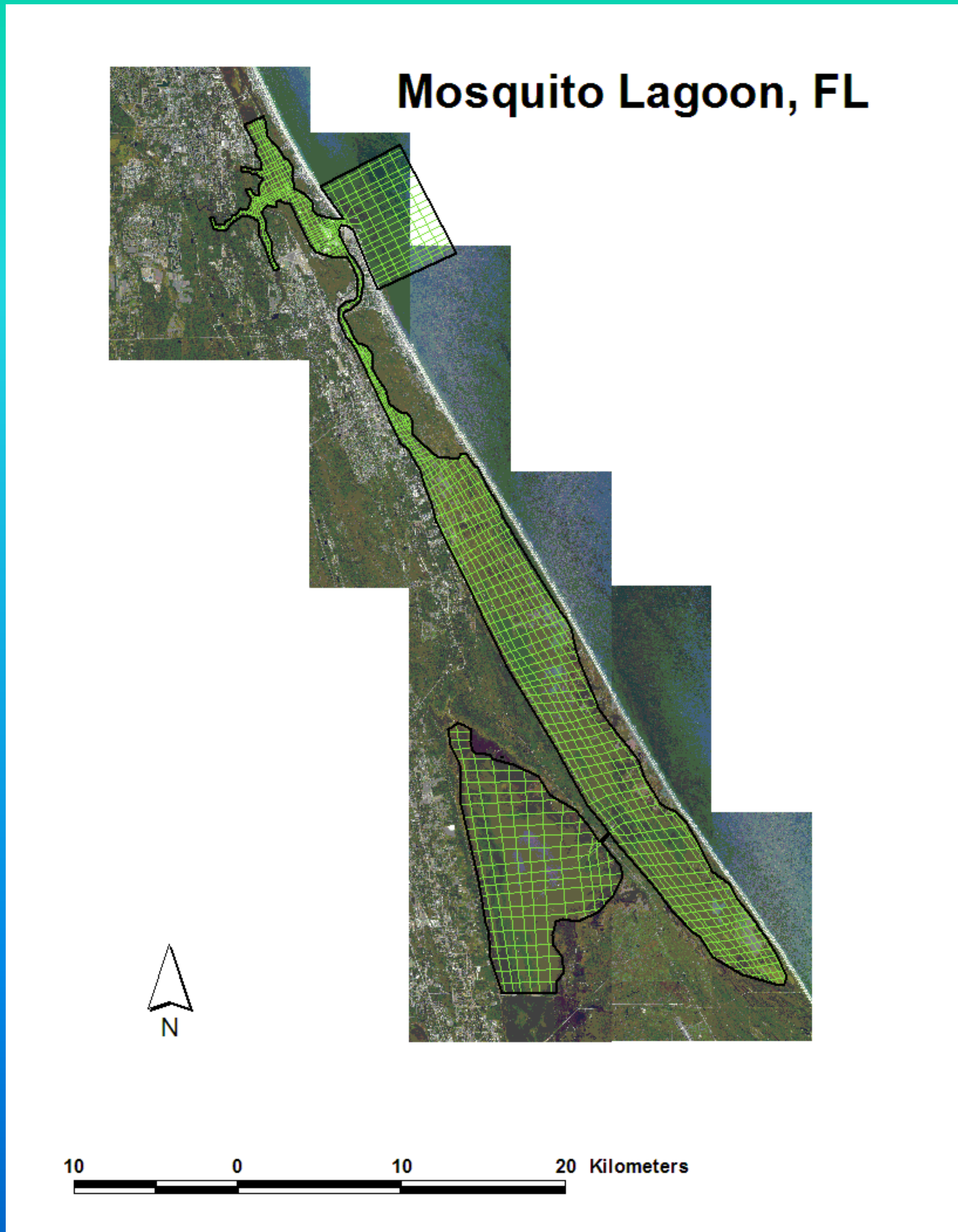
BELV(L)=belv(L)-dt*sdblv*sedf(L,1,NS)

BELV(L)=belv(L)-dt*sdblv*sndf(L,1,NX)

Net Topographic Values in Feet

Measured Topographic Change - 1999

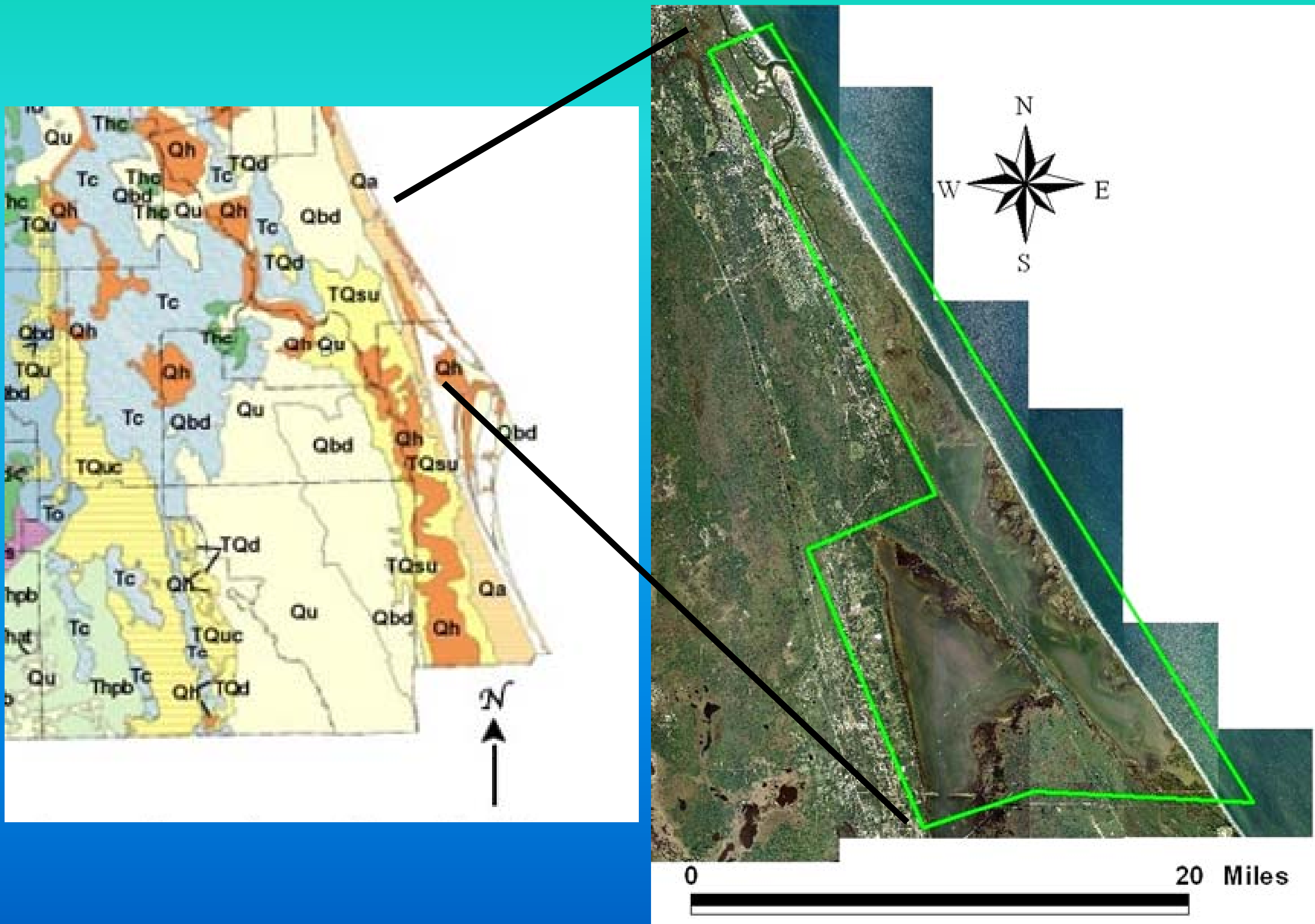




Mosquito Lagoon Hydrological Model

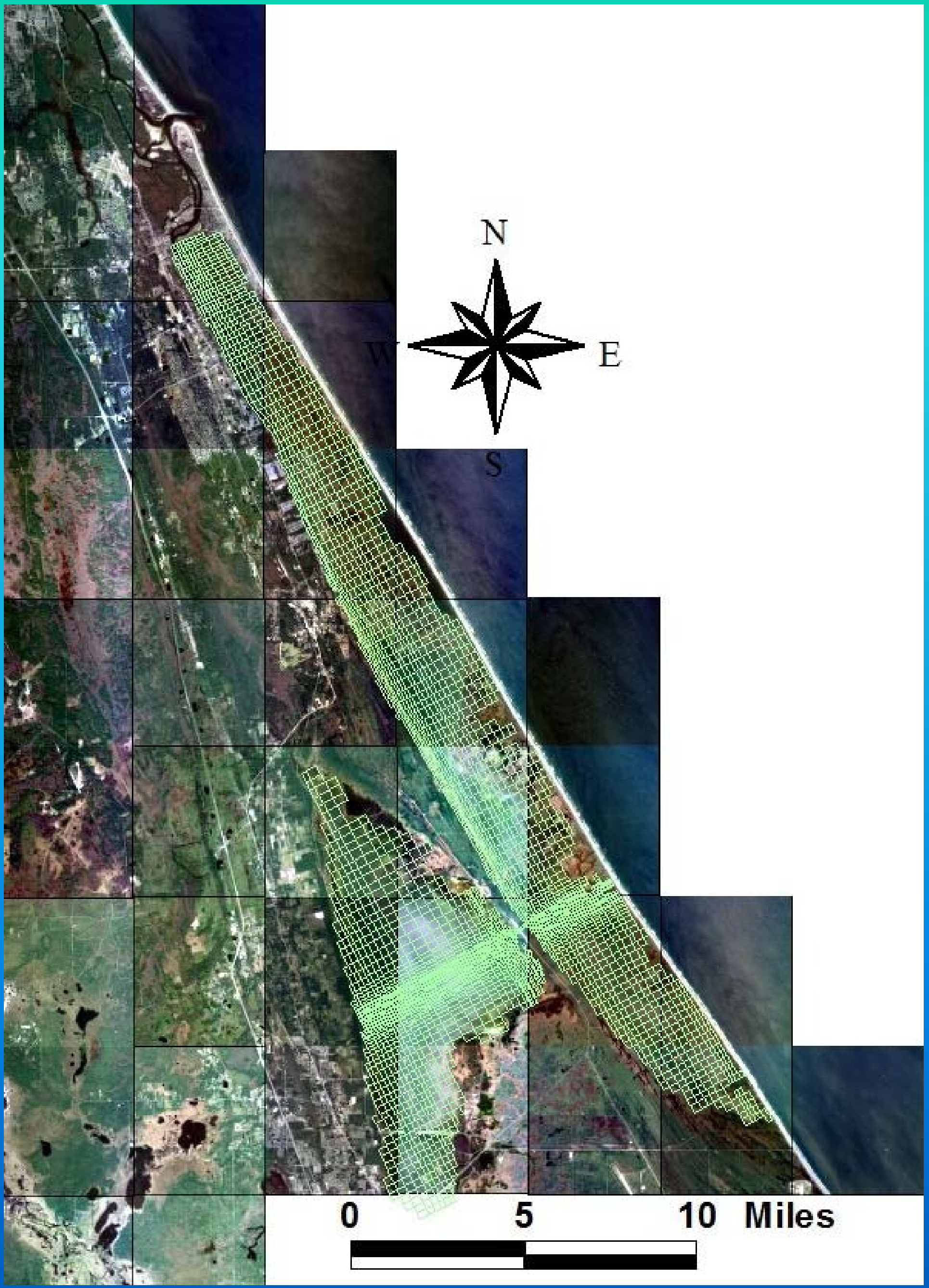
For U.S. National Park Service

Location



Model Grid

- Approximately 3,200 cells
- Cells from 20 m to 150 m

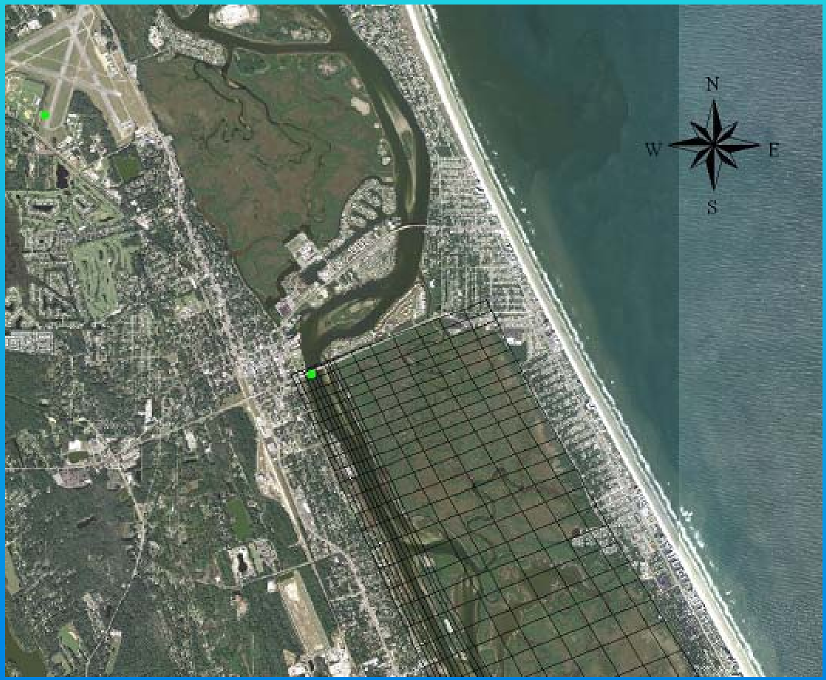


Model Grid Detail

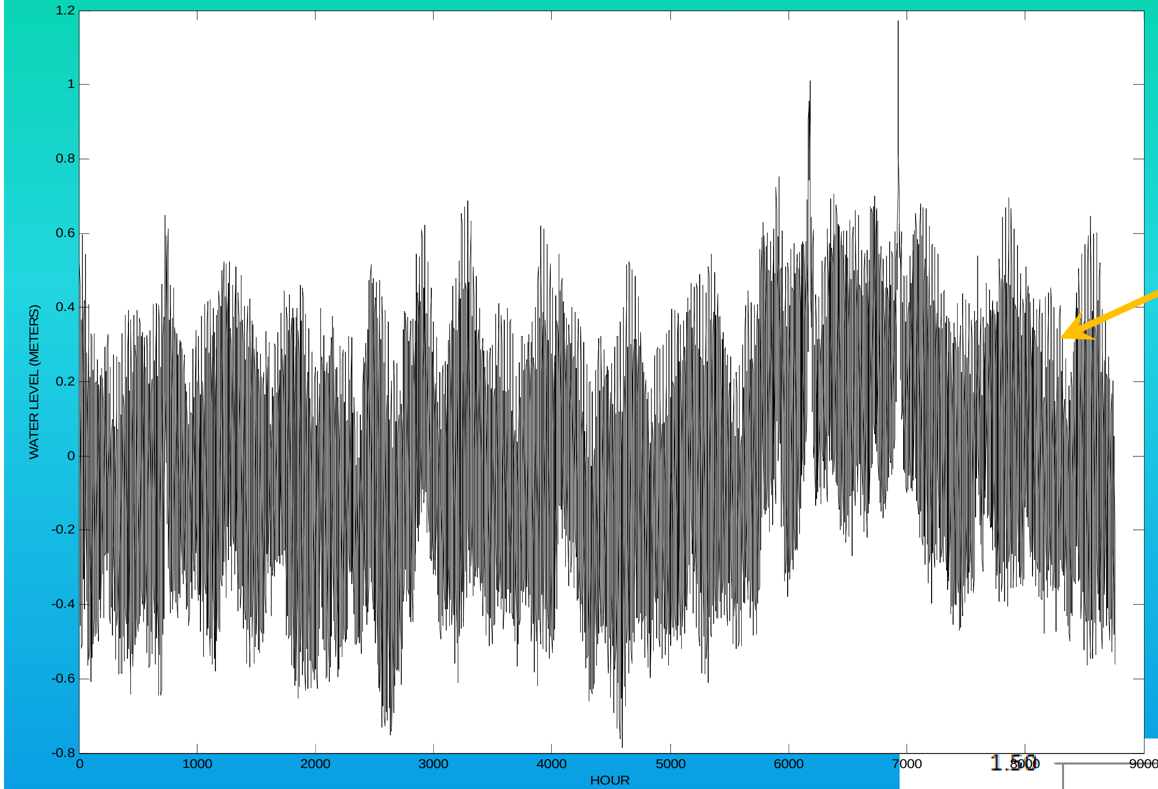
Haulover Canal

Model Grid Detail

North Model Boundary

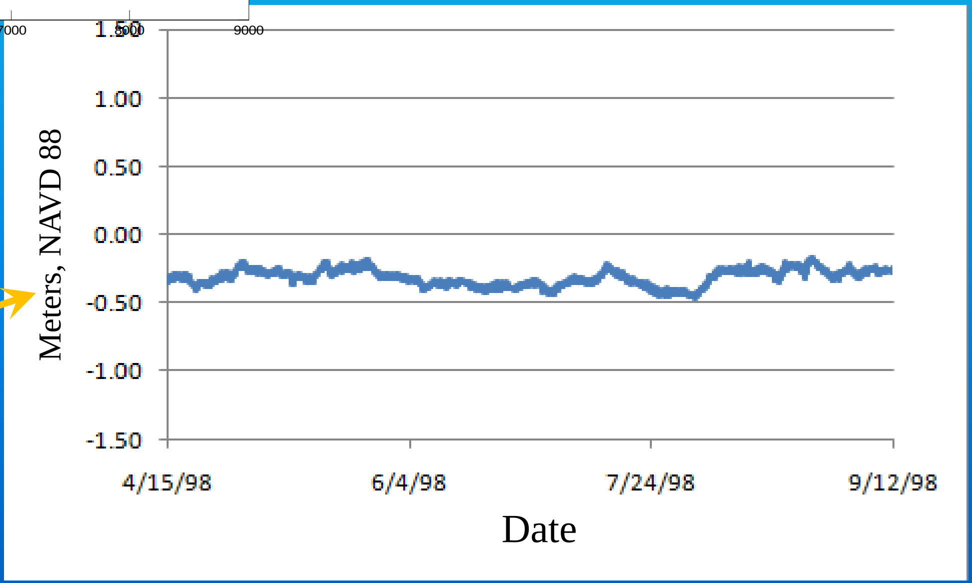


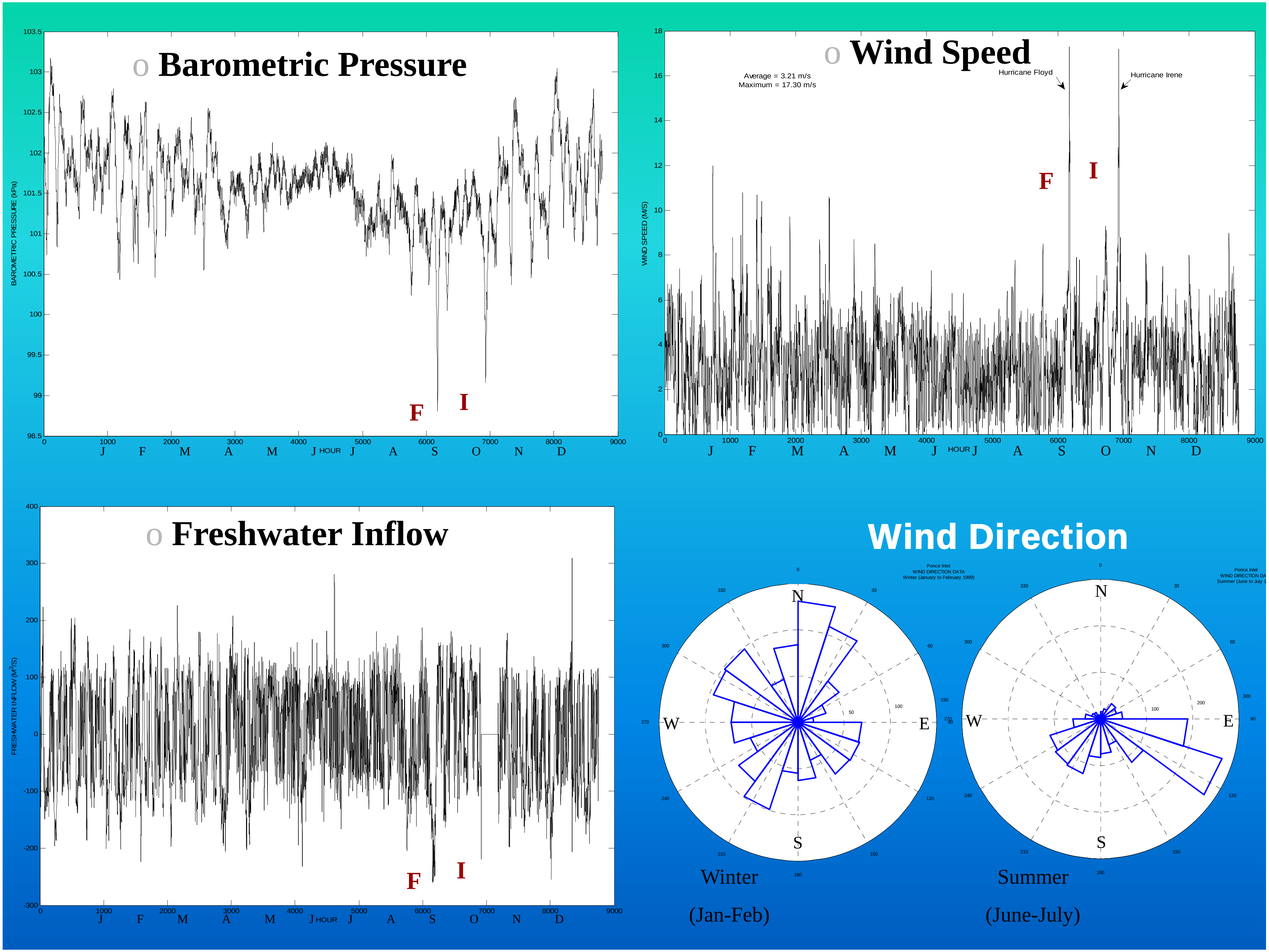
Water Level Boundary Conditions



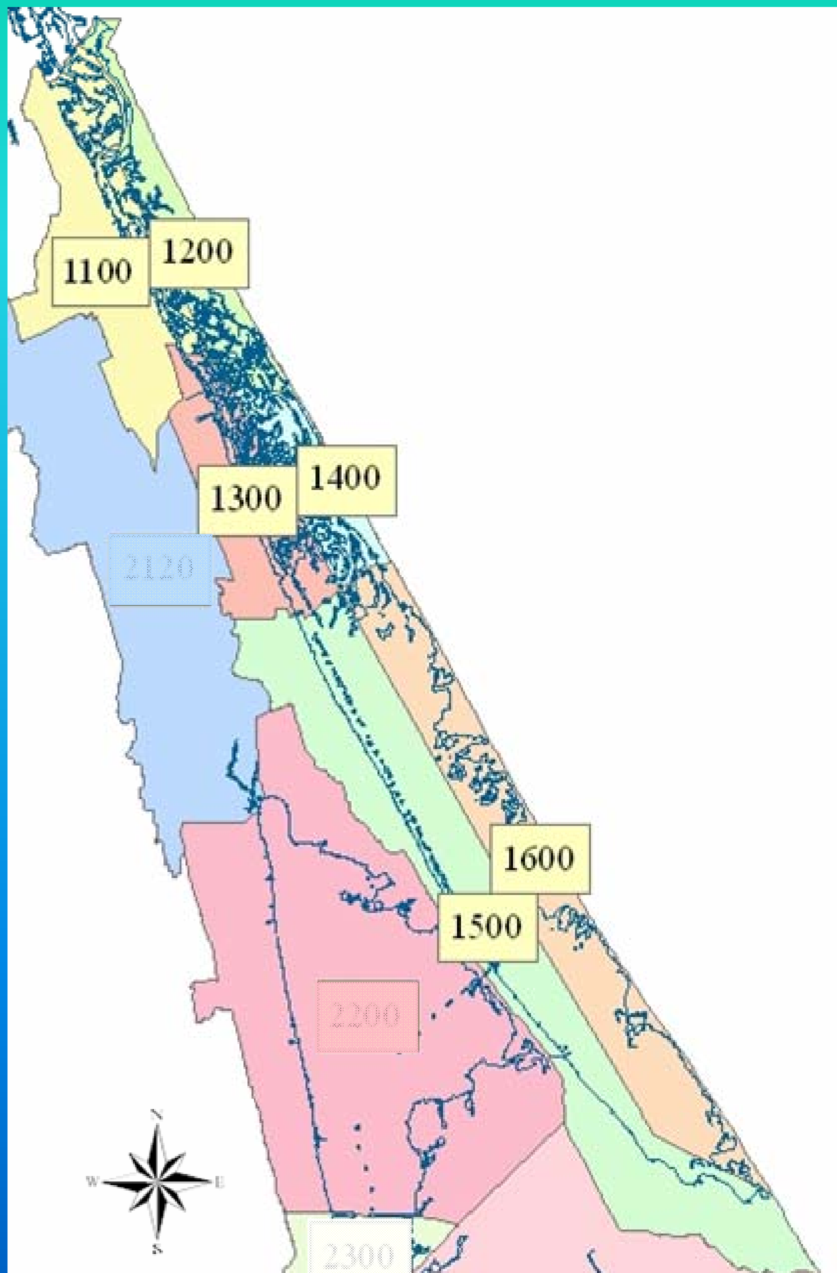
Water Elevation data from North Mosquito Lagoon

Water Level Series Model South Boundary




o Barometric Pressure
BAROMETRIC PRESSURE (kPa)
HOUR
J F M A M J J A S O N D
F I
o Wind Speed
Average = 3.21 m/s
Maximum = 17.30 m/s
Hurricane Floyd
Hurricane Irene
WIND SPEED (M/S)
o Freshwater Inflow
FRESHWATER INFLOW (M^3/S)
Wind Direction
Ponce Inlet
WIND DIRECTION DATA
Winter (January to February 1999)
N
E
S
W
Winter
(Jan-Feb)
Summer
(June-July)

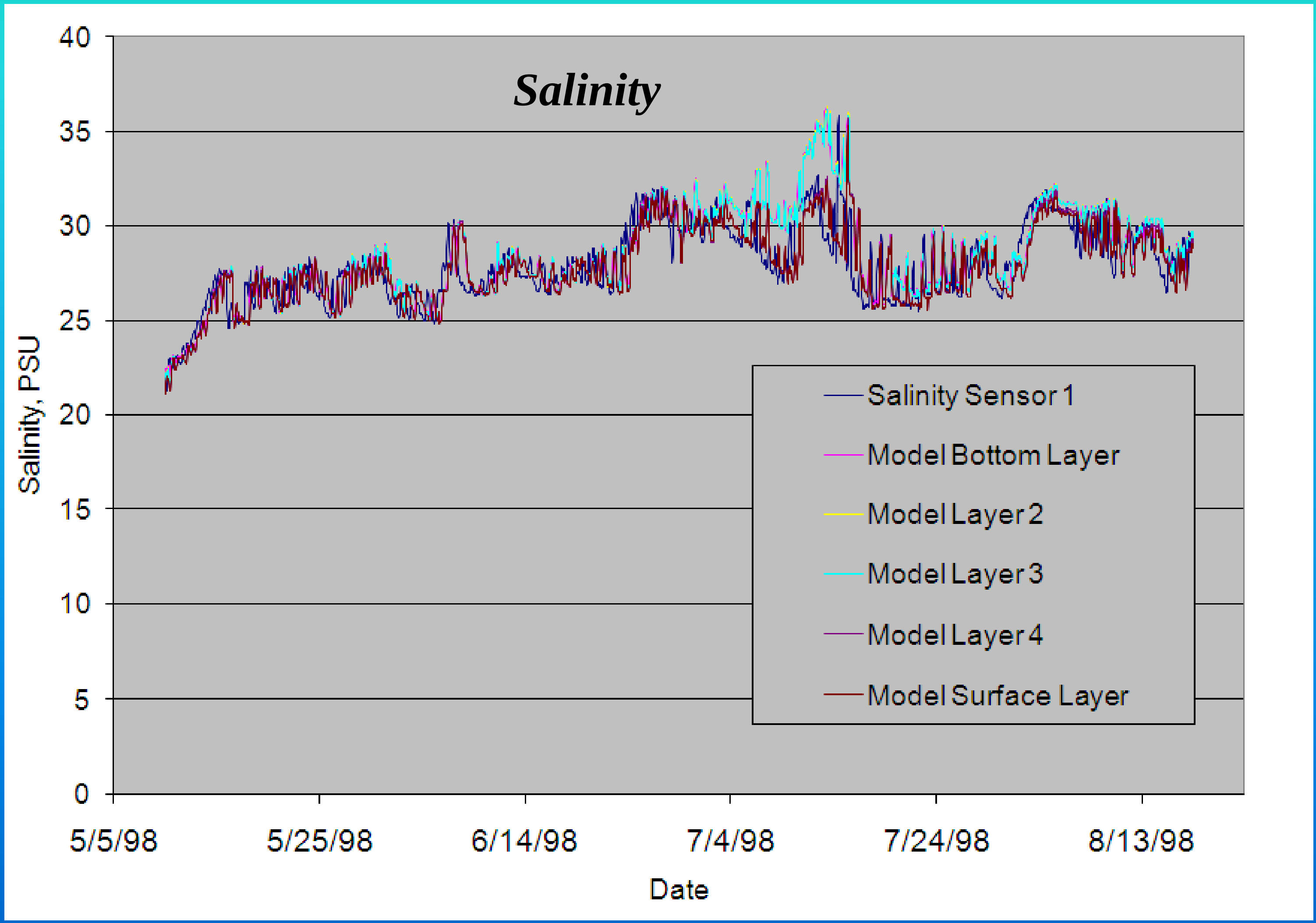
Watershed Drainage Sub-Areas



- Six WQ data sets
- 1994 – 2003
- Flow (CFS); TSS, TP, PO_4, and TN (lbs/day)

Map courtesy of SJRWMD

Model Calibration/Validation



Model Calibration/Validation

Calibration Results

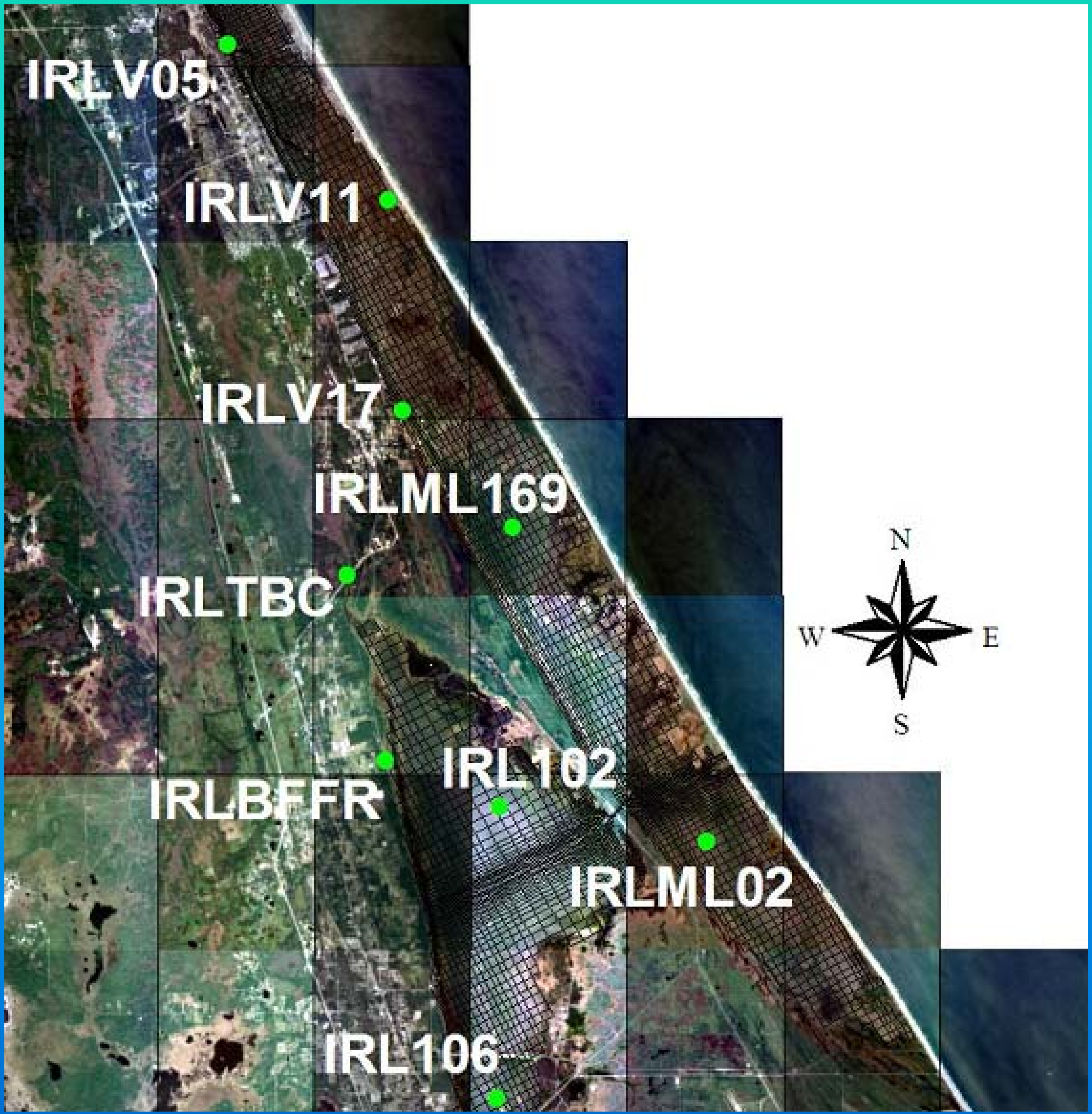
Statistic	Water Level	Salinity 1	Temp 1	Salinity 2	Temp 2
RMSE	0.05 cm	1.03 psu	1.01 C	1.02 psu	1.07 C
Percent	11%	7%	13%	7%	14%
R^2	0.80	0.85	0.84	0.88	0.81

Validation Results

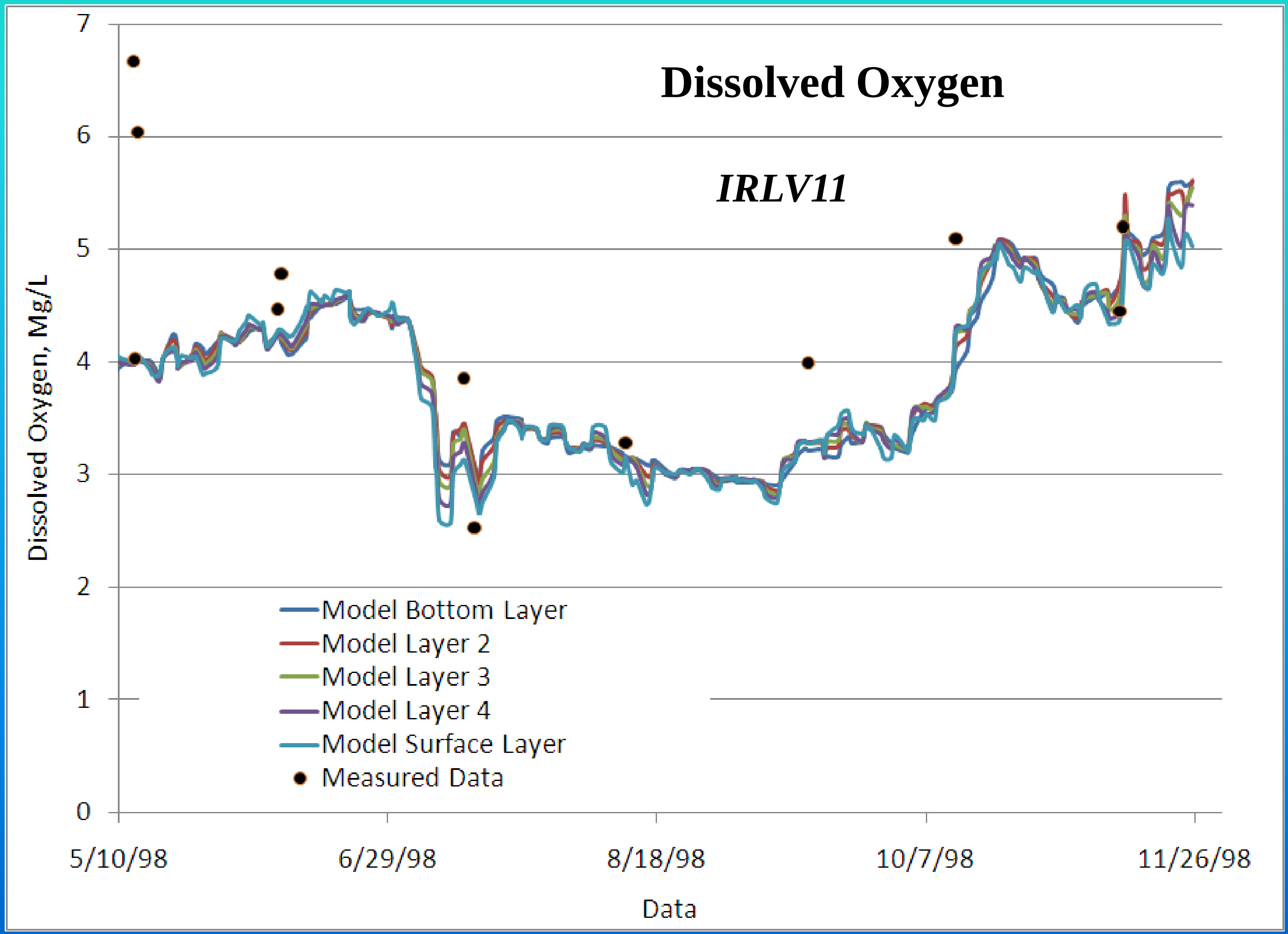
Statistic	Water Level	Salinity 1	Temp 1	Salinity 2	Temp 2
RMSE	0.07 cm	1.46 psu	1.65 C	1.36 psu	1.46 C
Percent	0.19	11%	14%	0.08	12%
R^2	0.80	0.79	0.77	0.81	0.78

Water Quality Stations

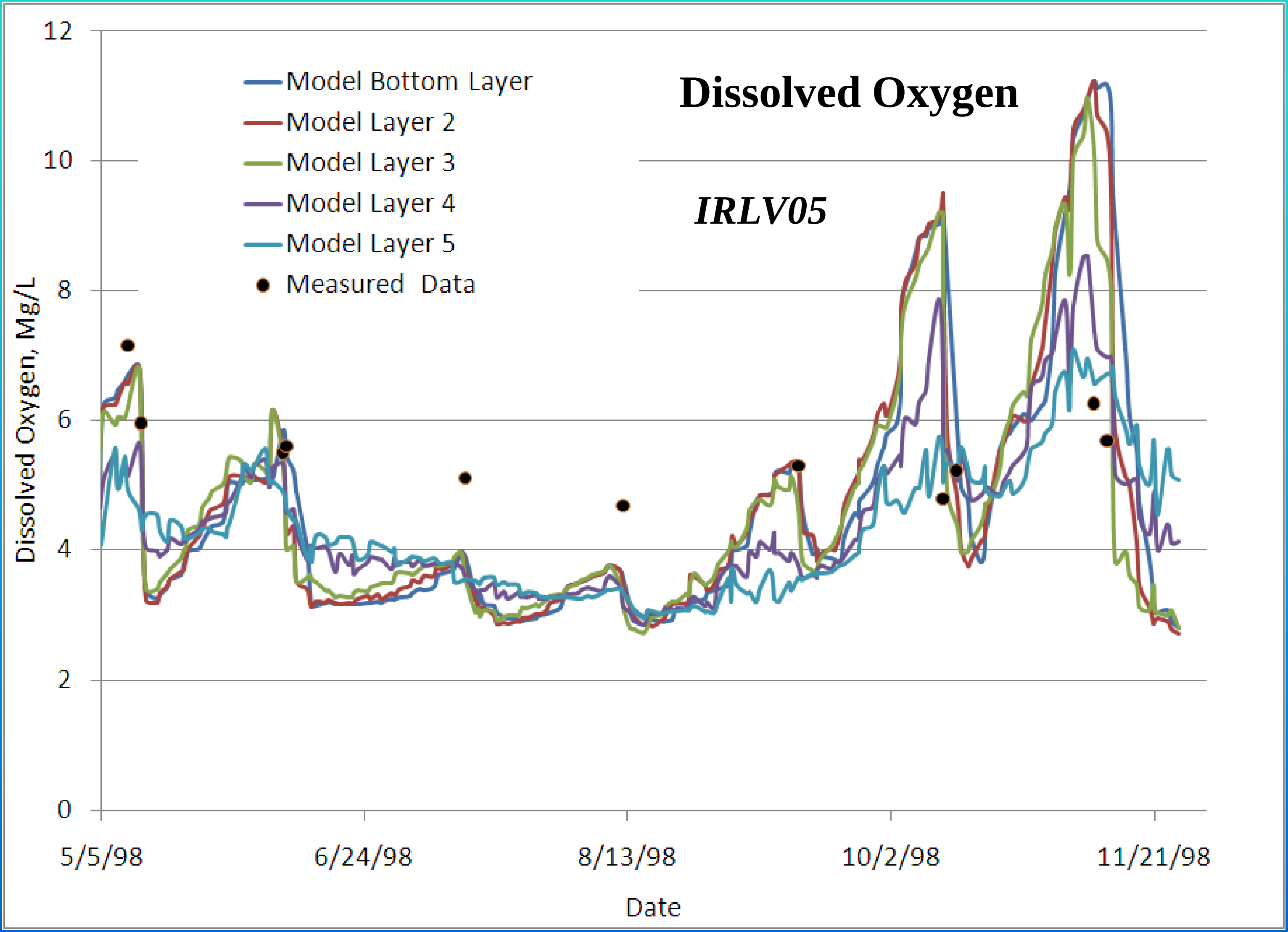
Boundary Conditions
and
Calibration



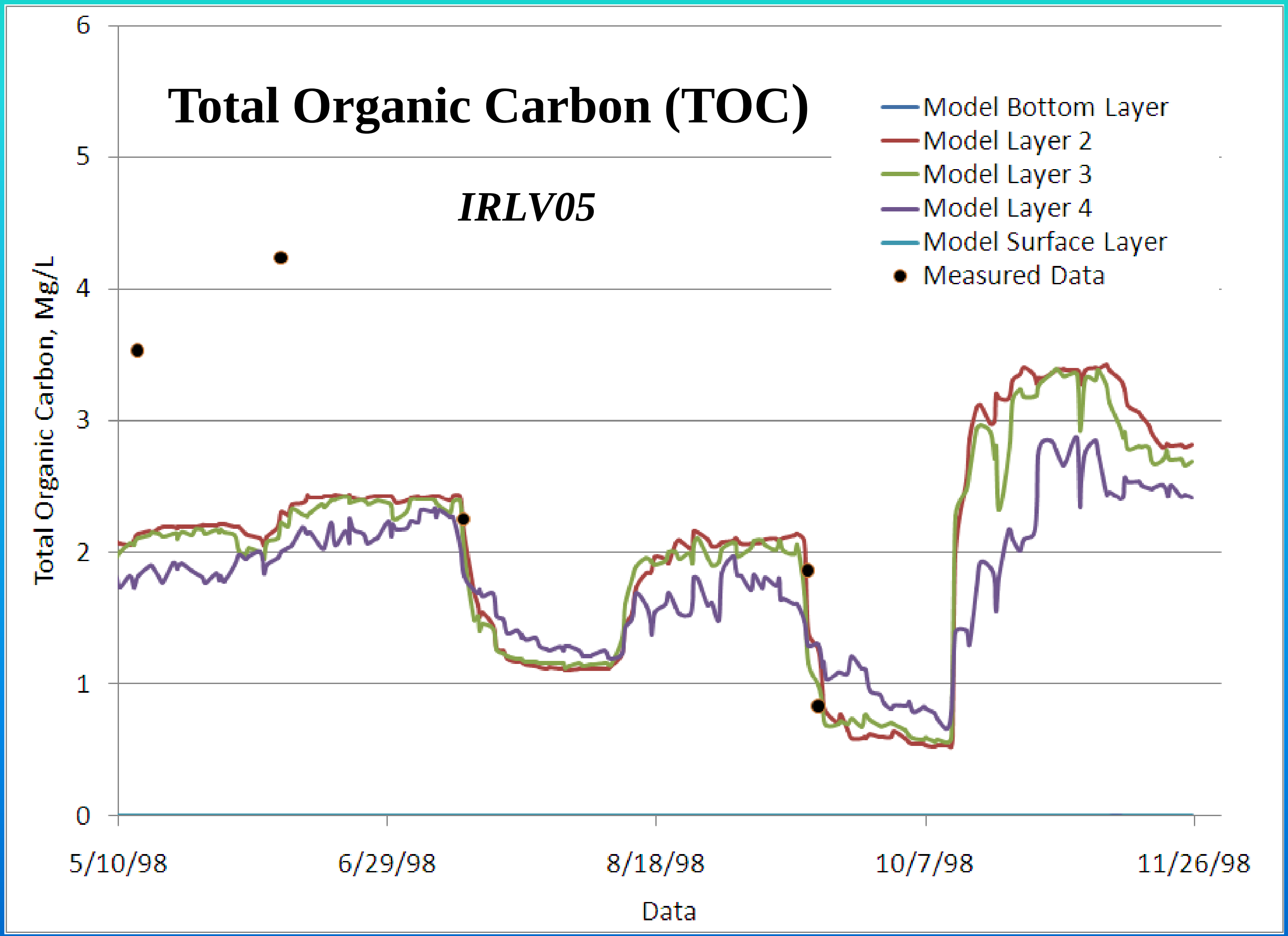
Model Calibration/Validation



Model Calibration/Validation



Model Calibration/Validation



Model Application Runs

- ❑ Evaluate the sensitivity of the estuary to changes in freshwater flows and pollutant loadings.
- ❑ Evaluate the effectiveness of load reductions in accordance with management priorities.
- ❑ Develop recommendations for practical and feasible restoration actions and plans for management.
- ❑ Develop recommendations for pollutant load limitations. (TMDL)
- ❑ Develop pollution load reduction goals.

SALINITY DISTRIBUTION and FLOW MANAGEMENT STUDIES of LAKE WORTH LAGOON

Lake Worth Lagoon
Hydrodynamic and Salinity Model

(Contract No. C-11818)

by

Gary A. Zarillo, Ph.D., PG

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Project Goal and Objectives

Apply the Environmental Fluid Dynamics Code (EFDC) three-dimensional model for predicting the Lake Worth Lagoon salinity regime in response to freshwater inflow

- ***Data Collection:*** **Four month field survey to collect water level, salinity and velocity measurements for model boundary conditions and model calibration**

- **Model Setup: Develop computational grid, boundary conditions, and input files**

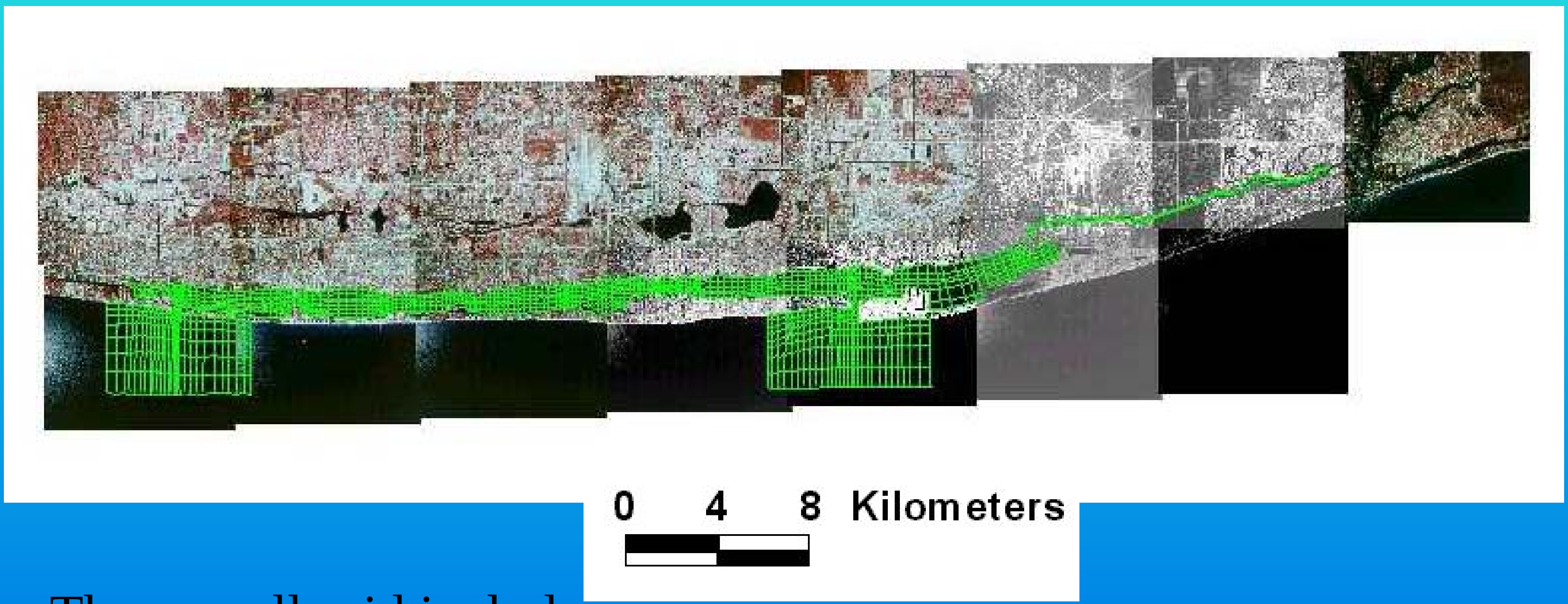
- ***Model Calibration:*** **Adjustments to the mean elevations of water level time series at the model boundaries and local and regional adjustments of roughness height**

- ***Model Validation:*** **Model simulations without further adjustments to the calibrated model**

- ***Model Simulations:*** **Three distinct test cases were conducted using the calibrated EFDC model to compare the predicted salinity regime of the Lake Worth Lagoon under historical and reduced freshwater inflow.**

Project Area

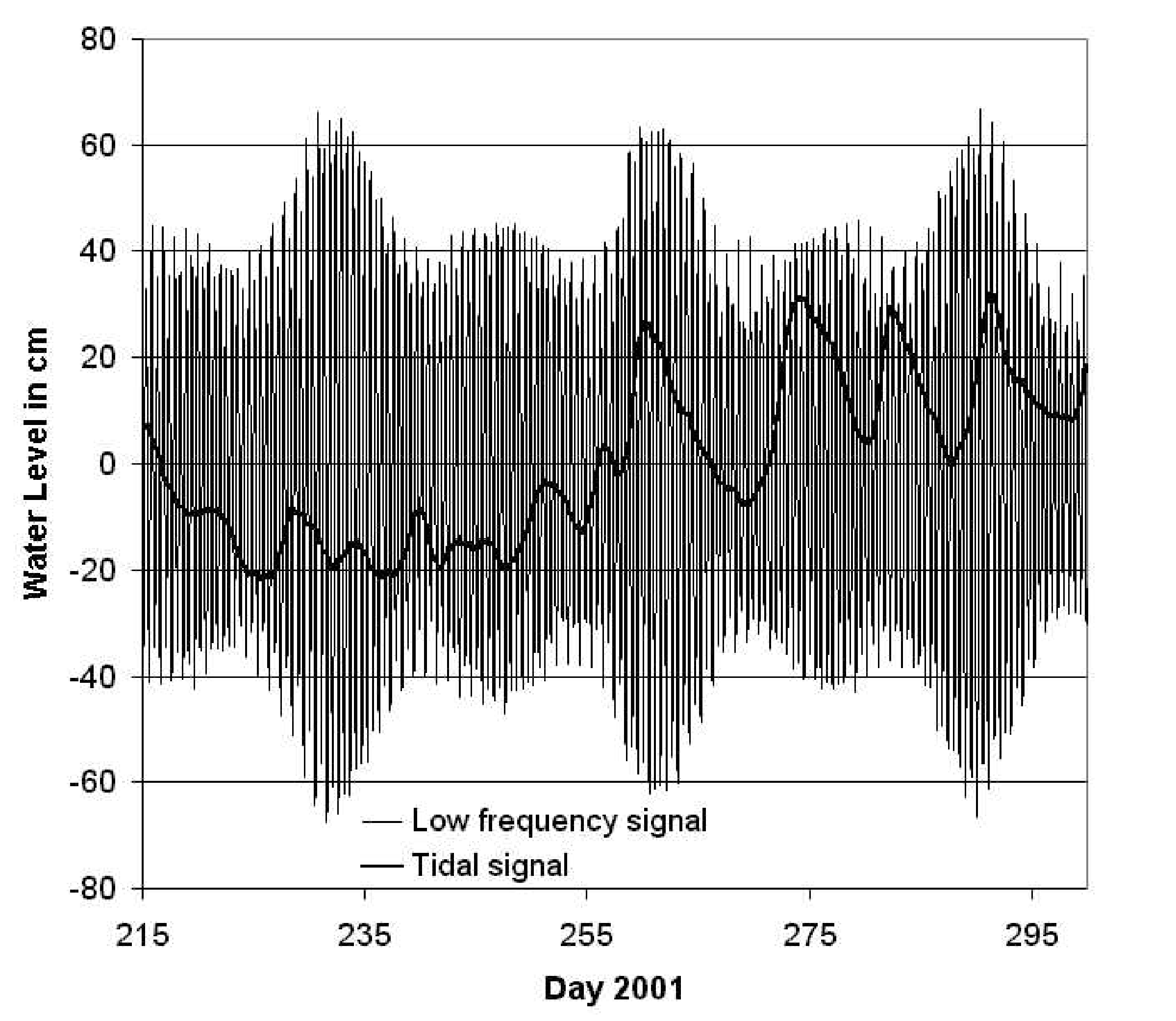
(*Model Domain*)



The overall grid includes approximately **2,355 active** water cells and **5 layers** in the vertical dimension.

Forcing at the Ocean Boundaries

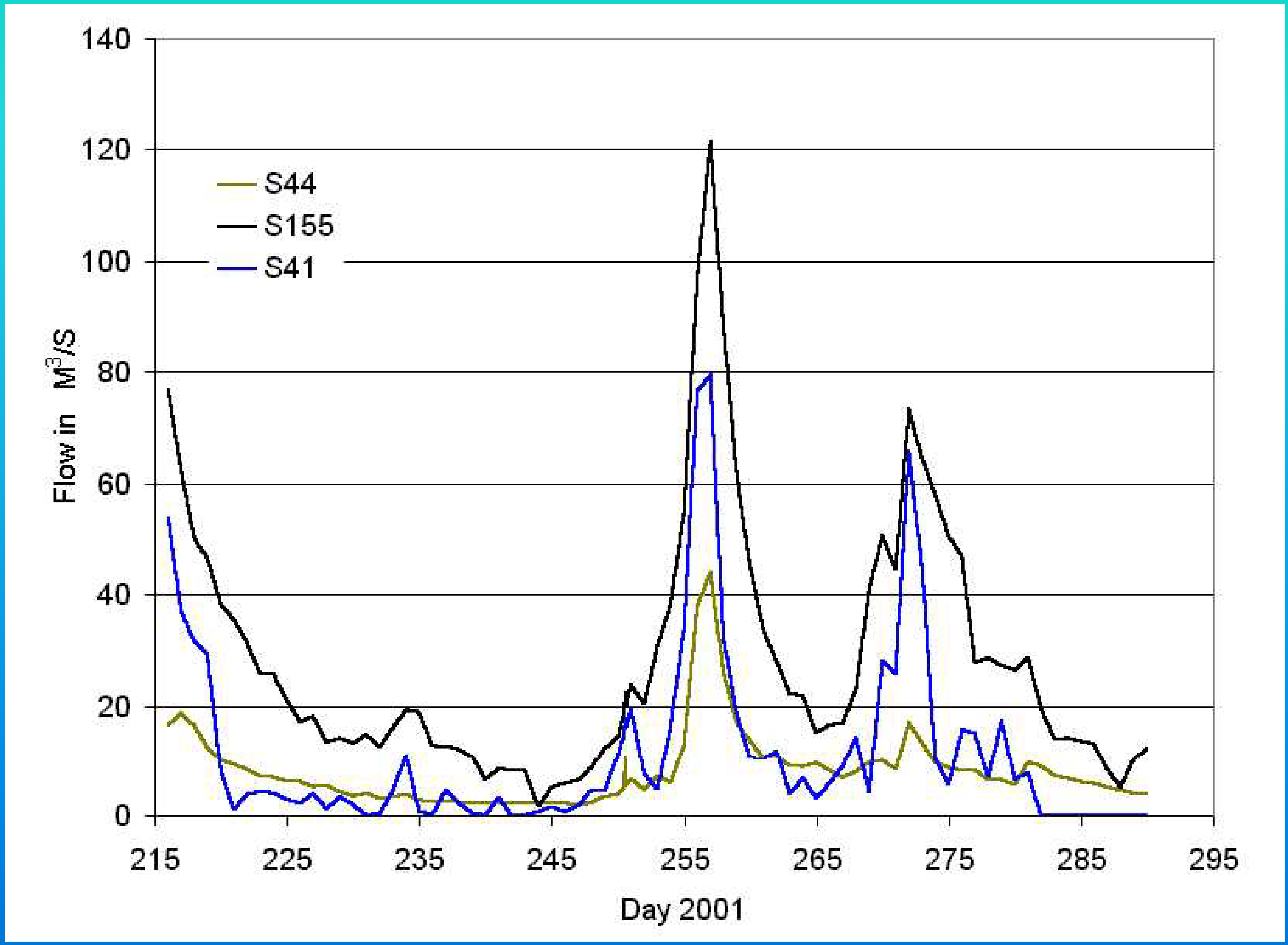
Palm Beach Inlet



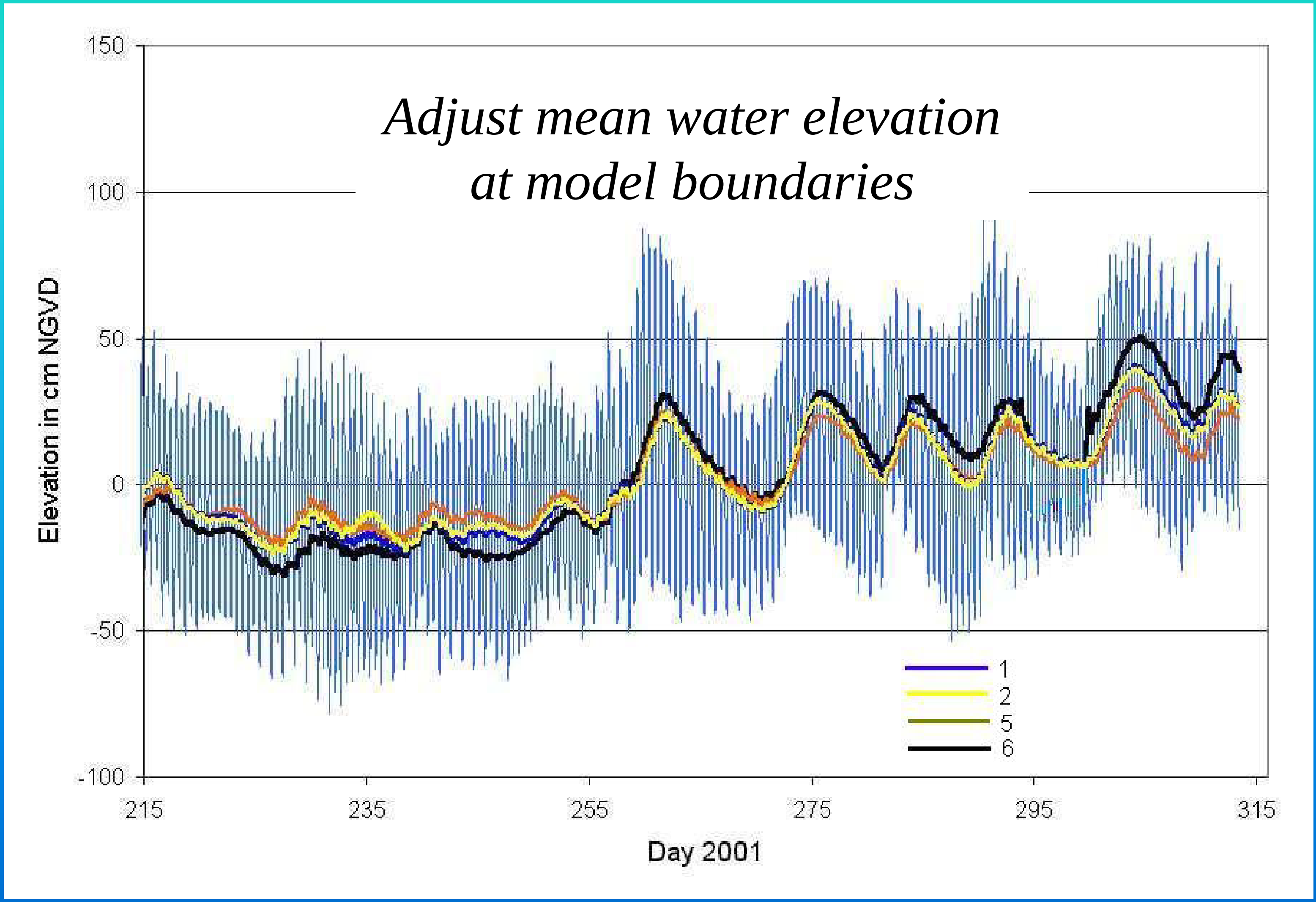
Other Boundary Conditions

- *Water Level TS*
- *Salinity/Temp TS*
- *Freshwater Flows*
- *Meteorological*

Freshwater Inputs



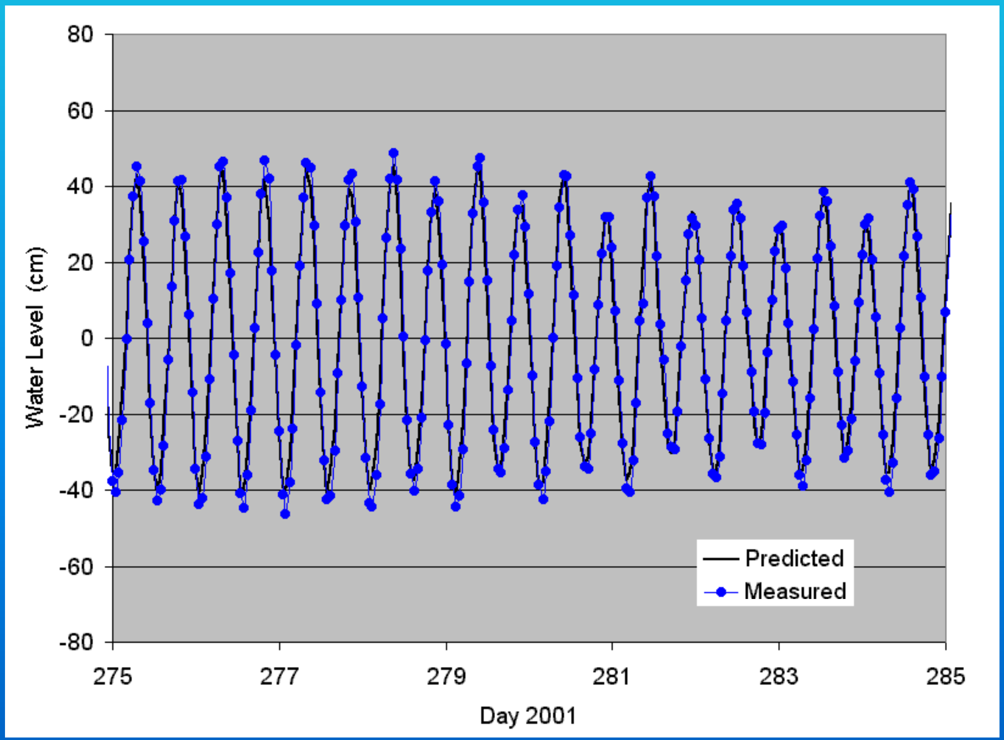
Model Calibration



Model Calibration and Validation

Station	Mean Error (ME)	Average Std Error (AVSE)	Relative Error (RE)	Average Relative Error (AVRE)	RMS/RANGE
2	0.28	3.24	0.44	3.49%	3.73%
5	0.58	3.70	0.52	2.51%	6.51%

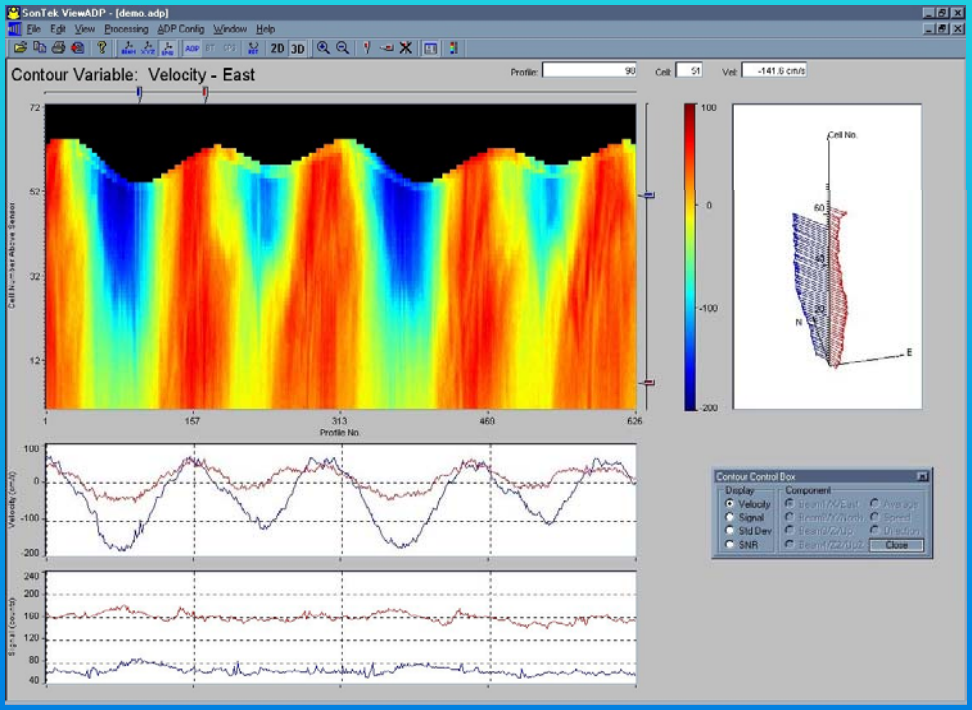
Tidal Constituent	**Amplitude (cm) (Data)**	**Amplitude (cm) (Model**	Phase in deg GMT - Data	Phase in deg. GMT Model
M2	**42.2**	**41.1**	95.3	93.8
S2	**8.1**	**7.8**	332.7	333.8
N2	**12.0**	**11.1**	93.5	91.6
K1	**3.0**	**2.4**	55.5	64.8
O1	**2.7**	**3.0**	140.5	140.4

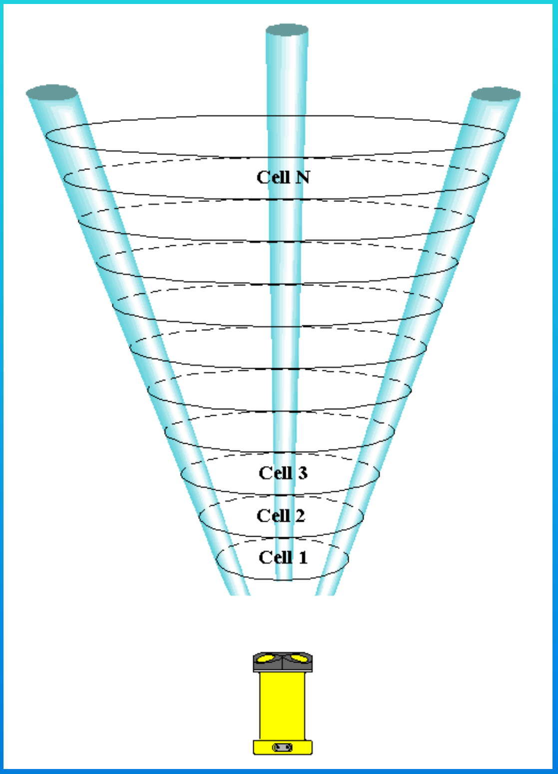


Station 4 Elevation

Model Calibration and Validation

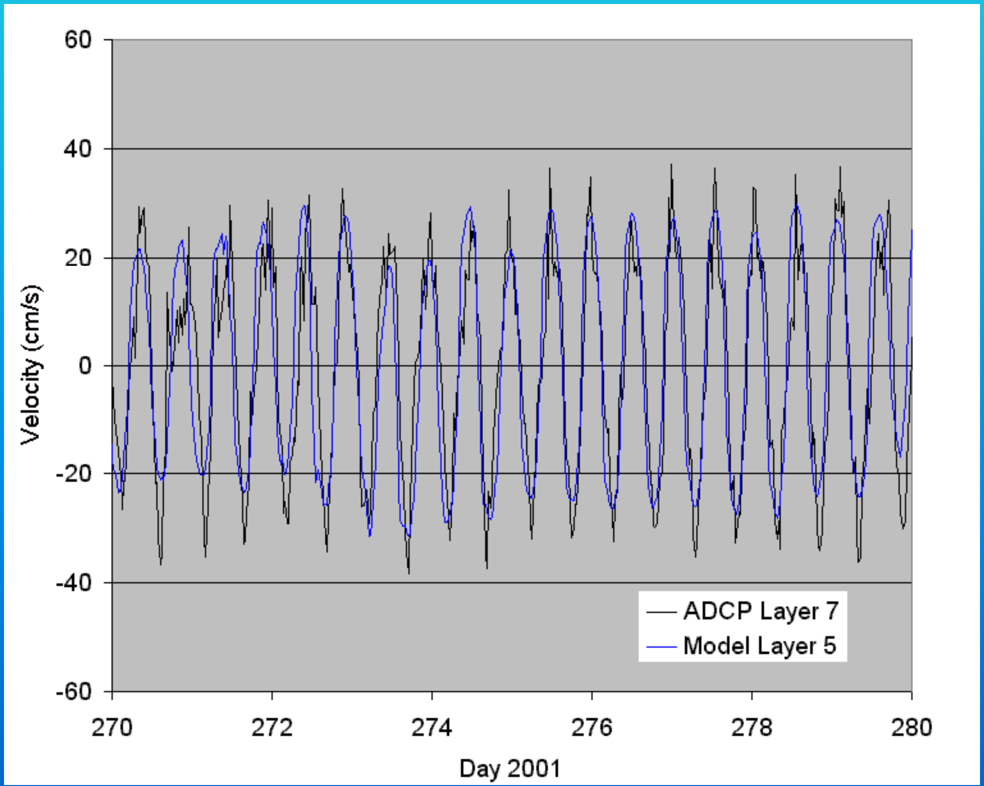
Acoustic Doppler Profiler Measurements





Model Calibration and Validation

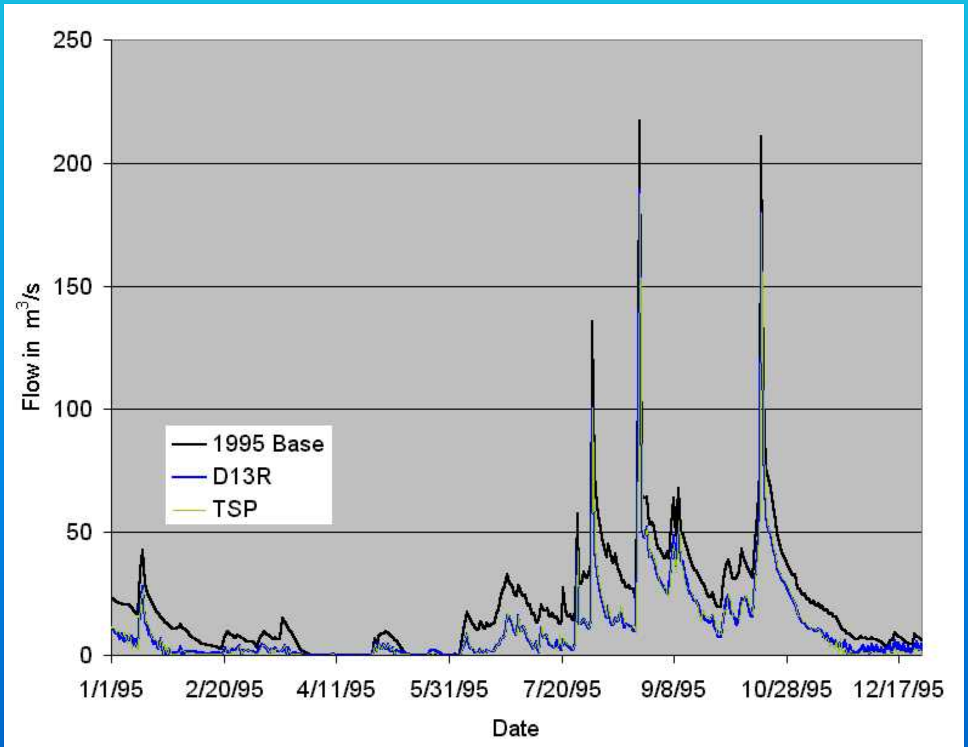
Model Layer	ADCP 1 (Bottom)	ADCP 2	ADCP 3	ADCP 4	ADCP 5	ADCP 6	ADCP 7	ADCP 8 (Surface)
1 (bottom)	18.3%	14.3%						
2		14.1%	11.7%					
3			16.4%	15.7%	18.1%			
4				23.6%	16.6%	18.6%		
5 (surface)							17.6%	17.0%



Station 4 Velocity

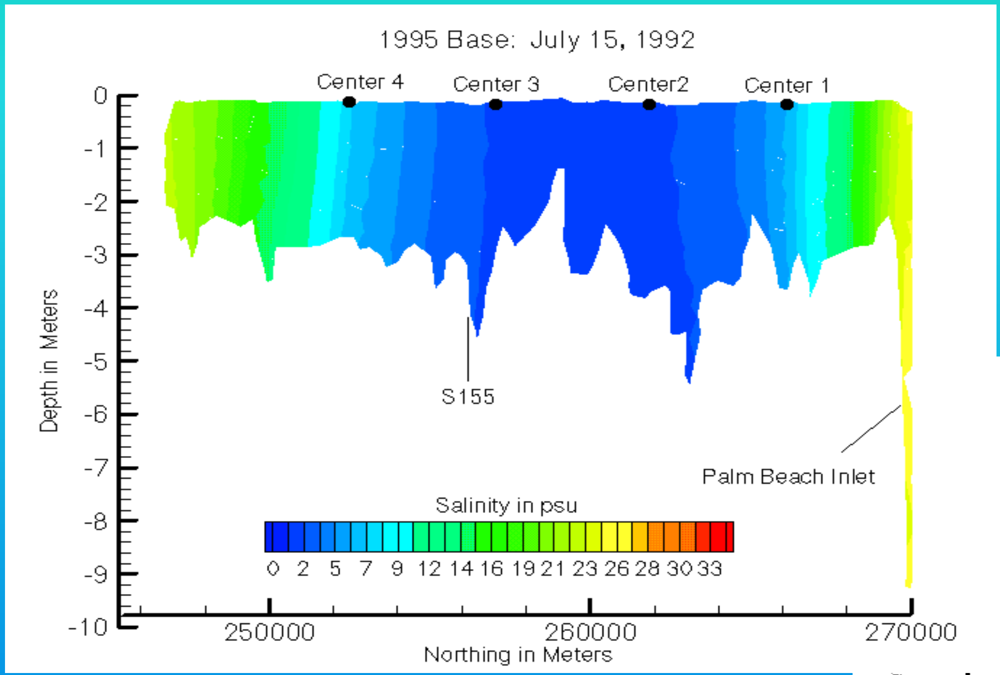
Model Application

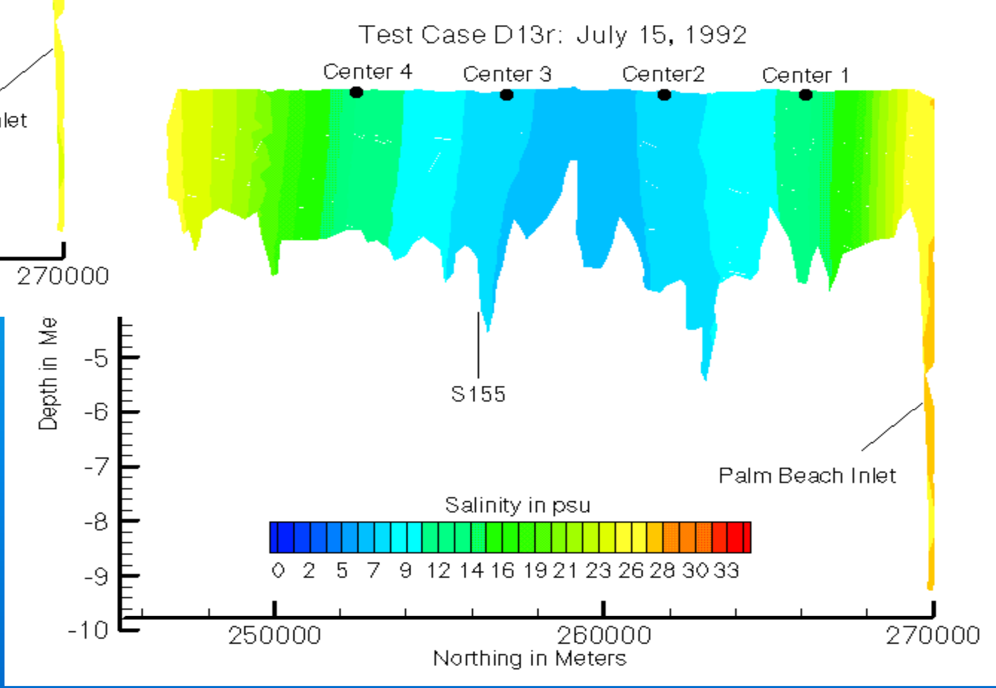
Case	Period	Freshwater runoff	Data Source
Base	1988-1995	Full historical	SFWMD Hydrologic Model
D13R	1988-1995	Reduced Historical	SFWMD Hydrologic Model
Tsp	1988-1995	Reduced Historical	SFWMD Hydrologic Model



S155 Flows - 1995

Model Simulations



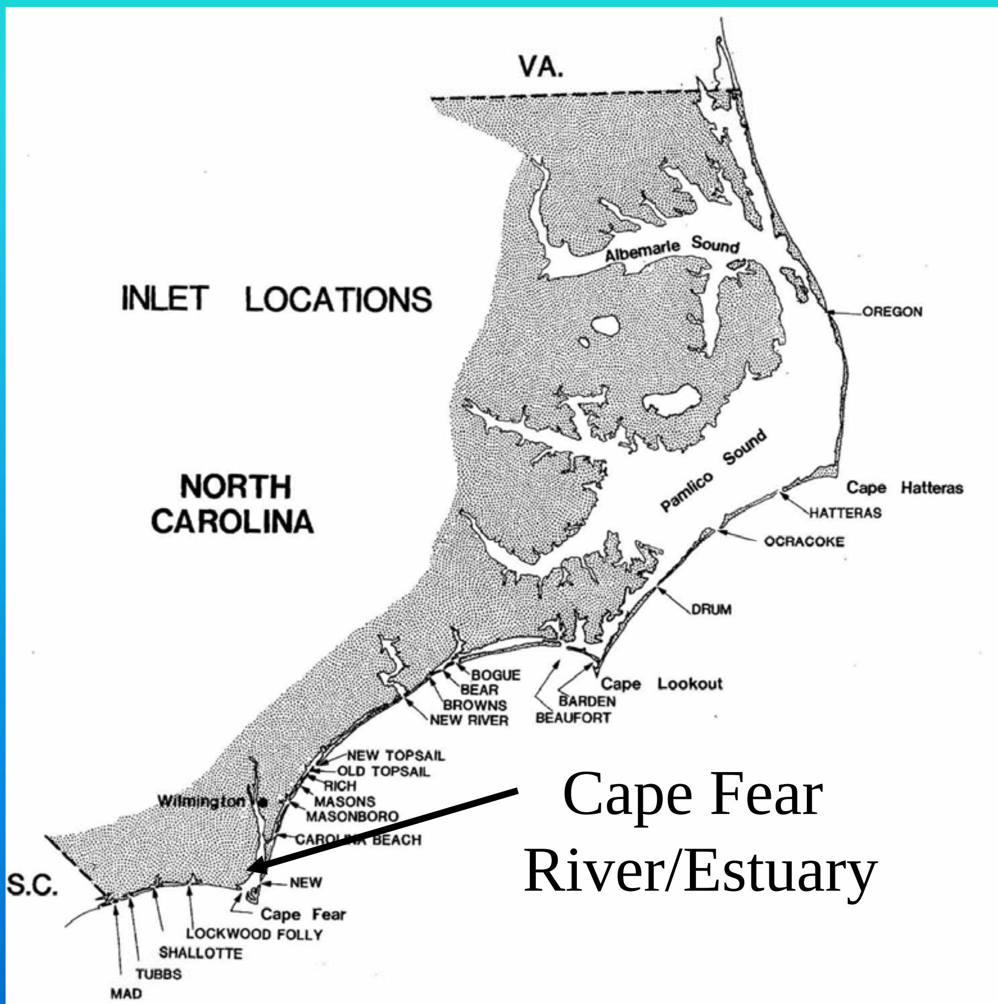


Animations

Numerical Modeling of Sedimentation in the Cape Fear River Estuary, NC

Gary A. Zarillo, Ph.D., PG

Project Location
Cape Fear River Estuary, NC



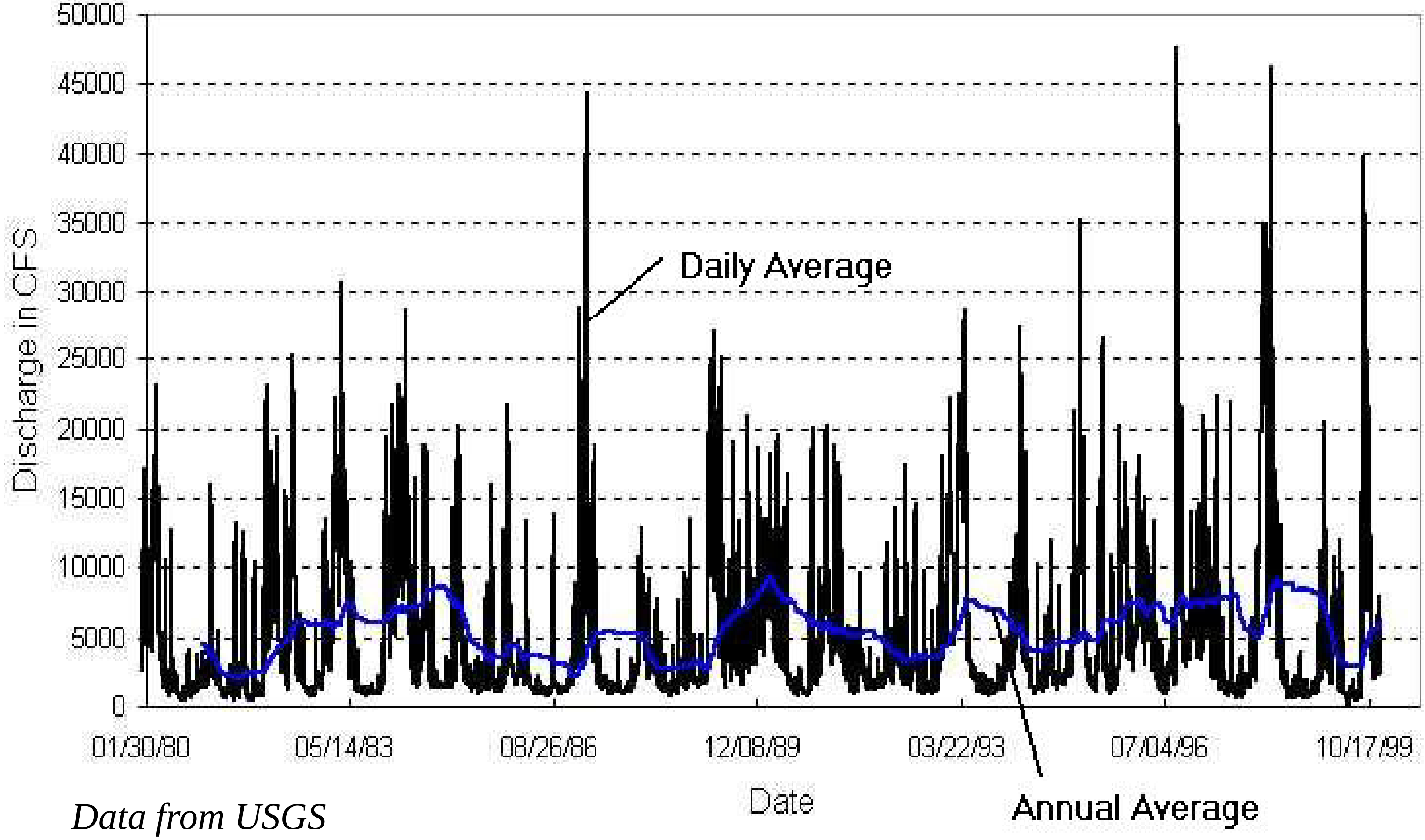
Goals and Objectives

Overall Goal of the Project: *Quantify sedimentation rates in the lower Cape Fear River*

Objectives

- ***Understand physical processes in the lower Cape Fear River***
- ***Design a model application to capture the relevant processes***
- ***Calibrate the model with measured data where possible***
- ***Apply the model to quantify sedimentation rates***
- ***Apply results for best management of dredging activities***

Cape Fear River Basin Discharge in CFS



Data from USGS

Lower Cape Fear River Tidal Regime

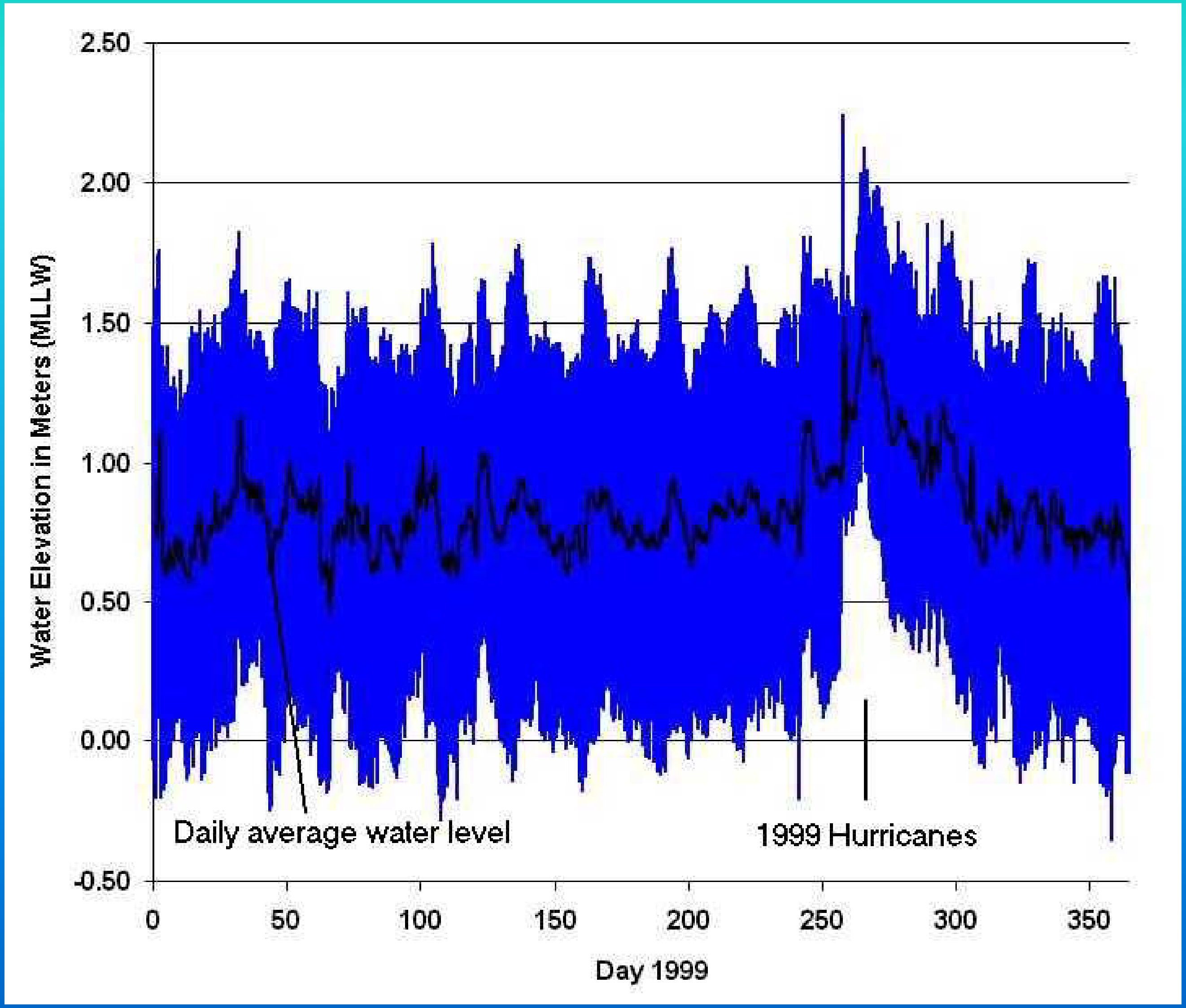
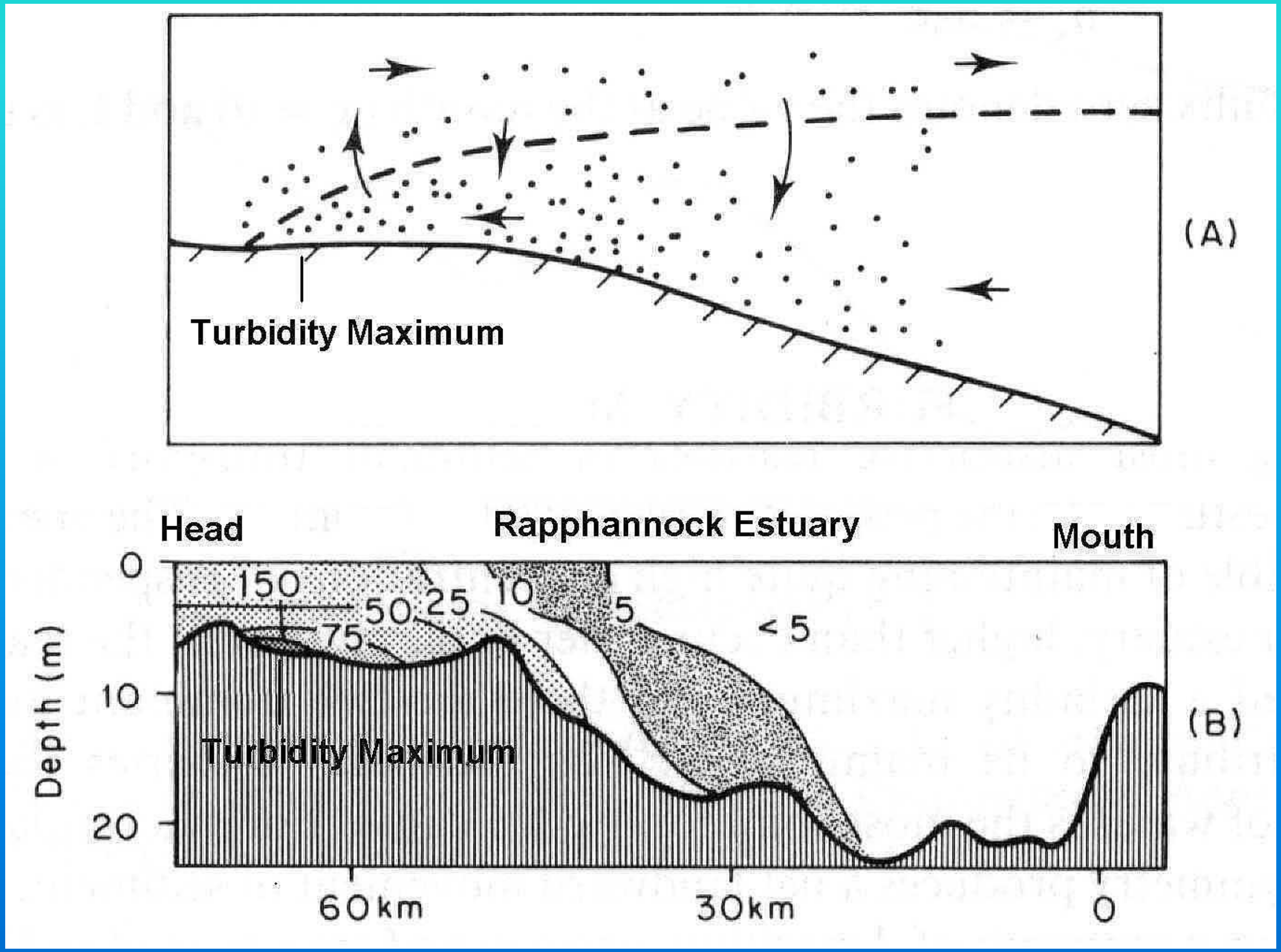


Table 1. Average Annual Historical Shoaling Rates by Reach (cu.yds./year)

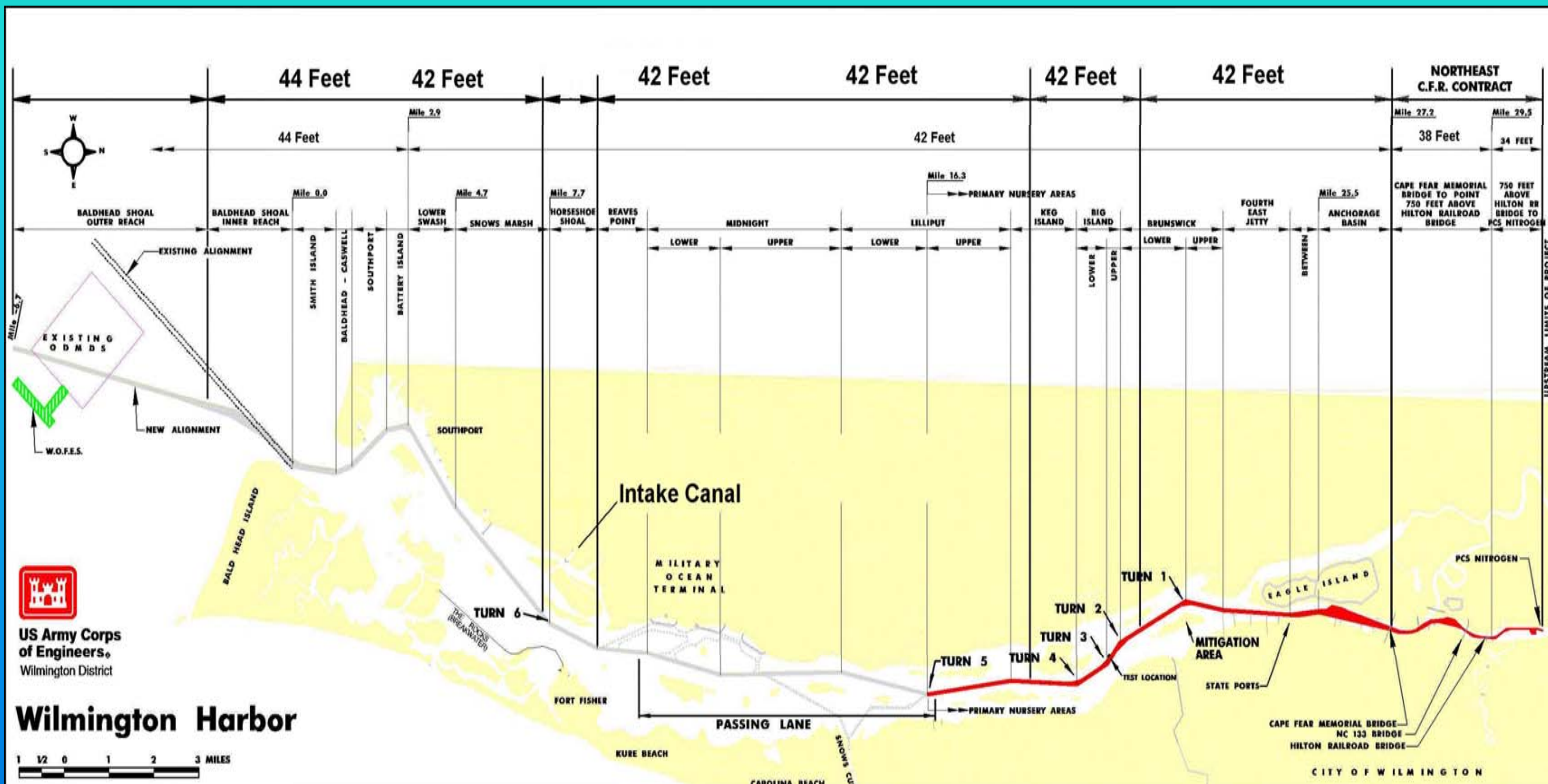
Channel Reach	Average Annual Maintenance Volume	Maintenance Frequency
25' Project	12,600	5 yr.
32' Project	14,100	3 yr.
Anchorage Basin & Approach	932,900	Yearly
Between Channel	61,500	Yearly
Fourth East Jetty	19,600	2 yr.
Upper Brunswick	17,100	4 yr.
Lower Brunswick	29,800	4 yr.
Upper Big Island	2,400	4 yr.
Lower Big Island	8,000	2 yr.
Keg Island	34,100	2 yr.
Upper Lilliput	48,900	2 yr.
Lower Lilliput	43,000	2 yr.
Upper Midnight	**107,000**	**2 yr.**
Lower Midnight	25,500	2 yr.
Reaves Point	21,200	2 yr.
Horseshoe Shoal	45,700	2 yr.
Snow Marsh	14,800	2 yr.
Lower Swash	12,000	2 yr.
Baldhead Shoal, Smith Island, Baldhead-Caswell, Southport, Battery Island	855,400	Yearly

Total, Average Annual Volume 2,305,600 cy (from U.S. Army Corps Engs, 1996).

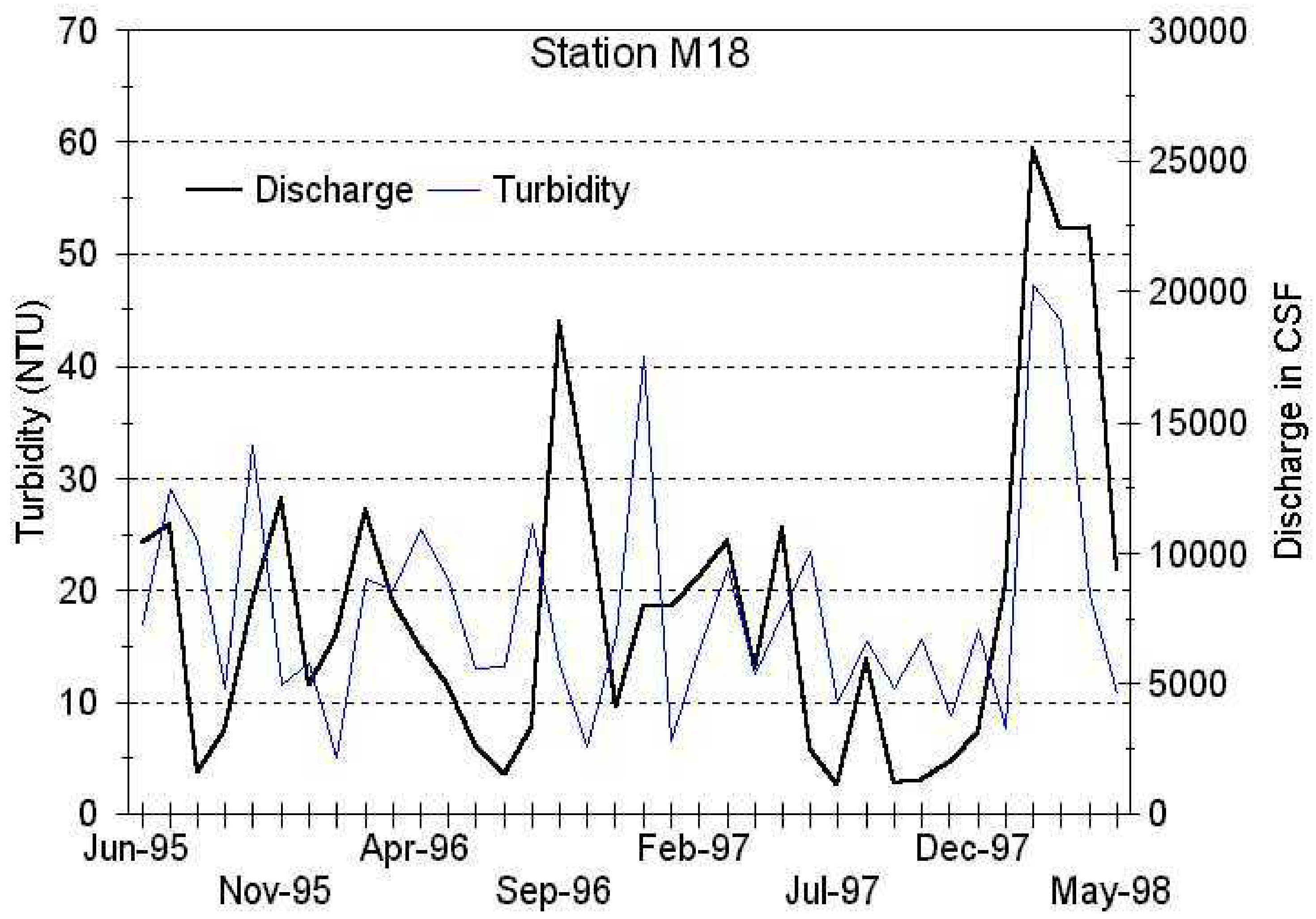
Estuarine Turbidity Maximum Contributes to Shoaling ?



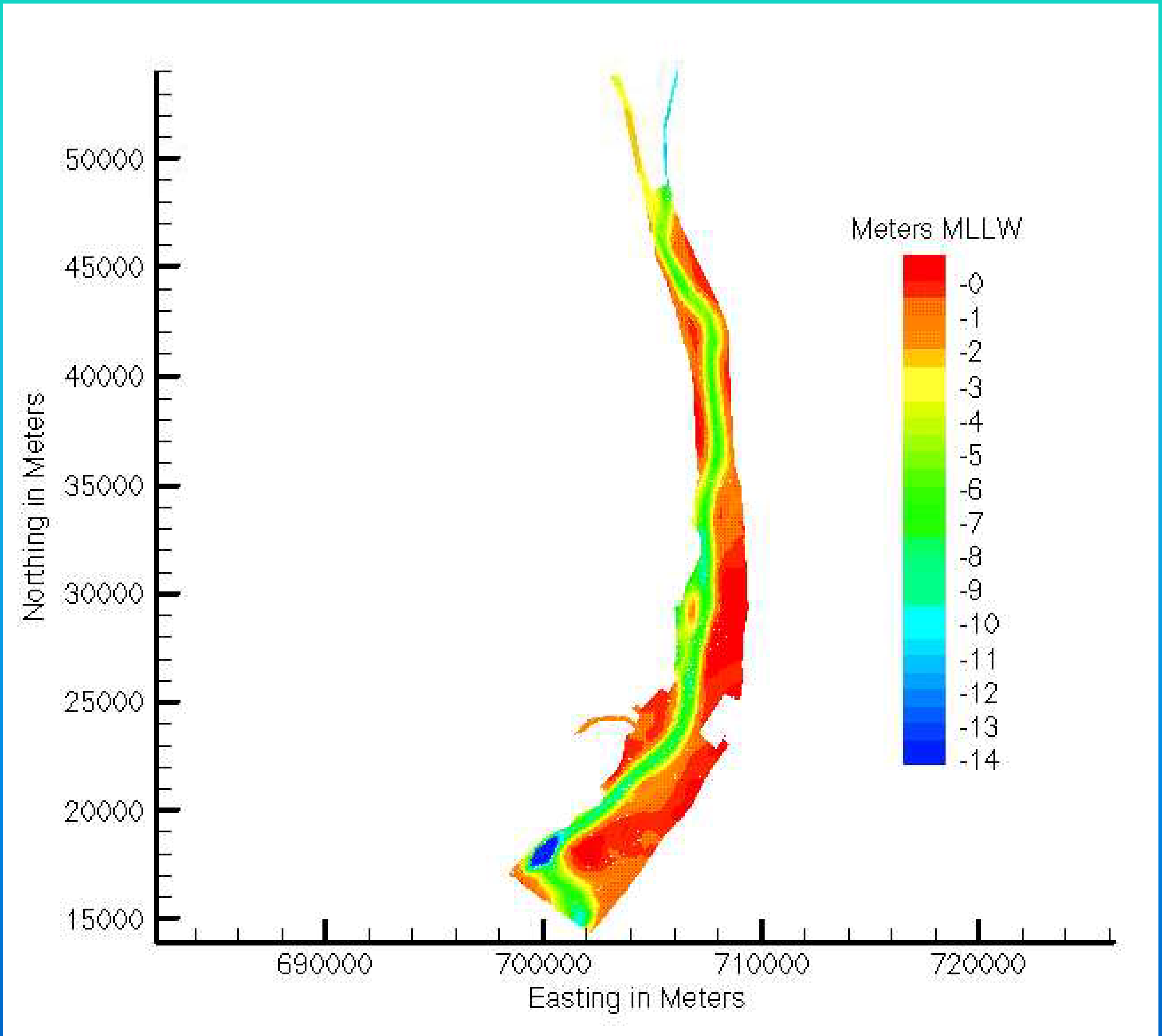
USACOE Navigation Project



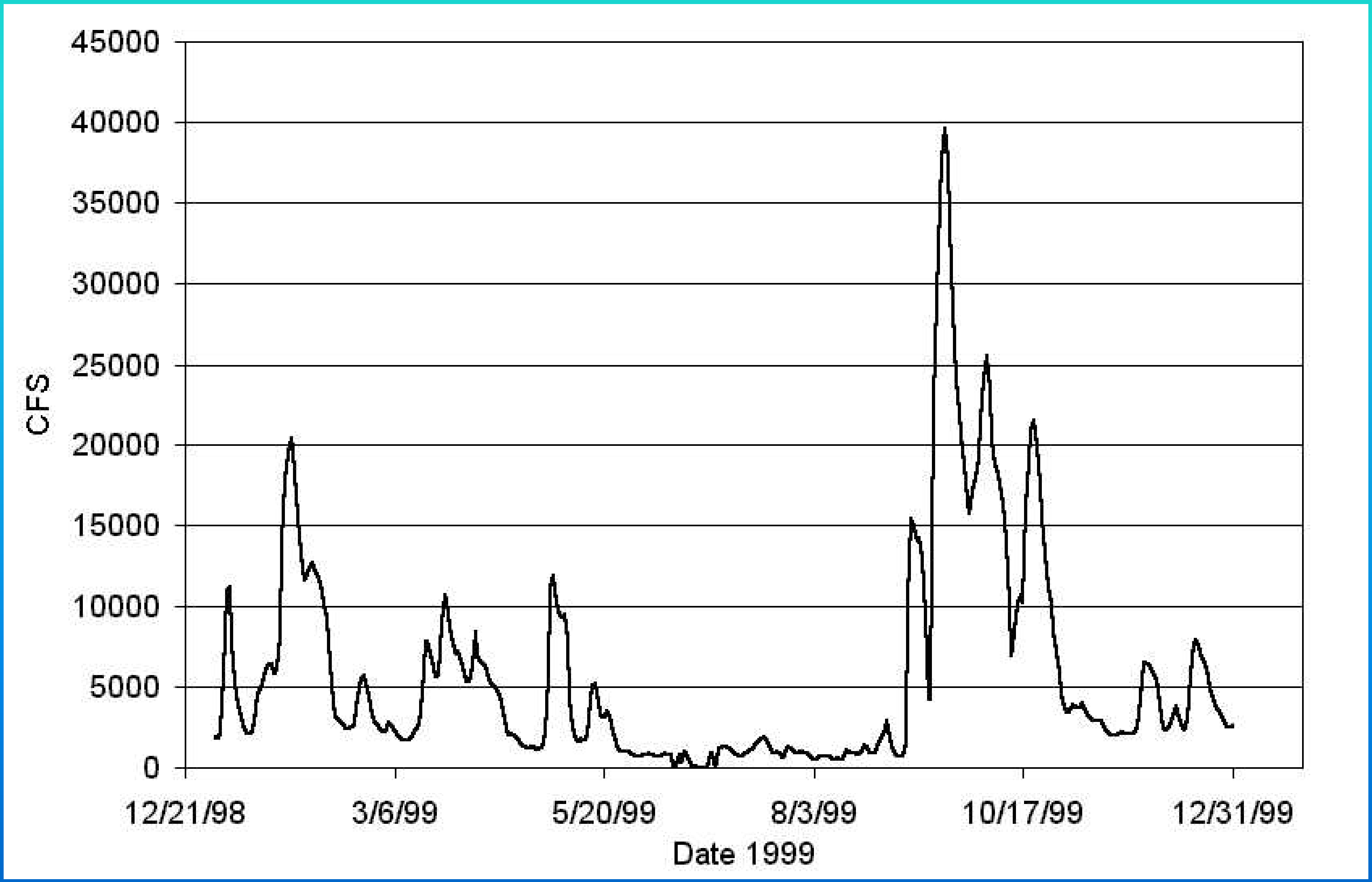
Conditions n the Lower Estuary



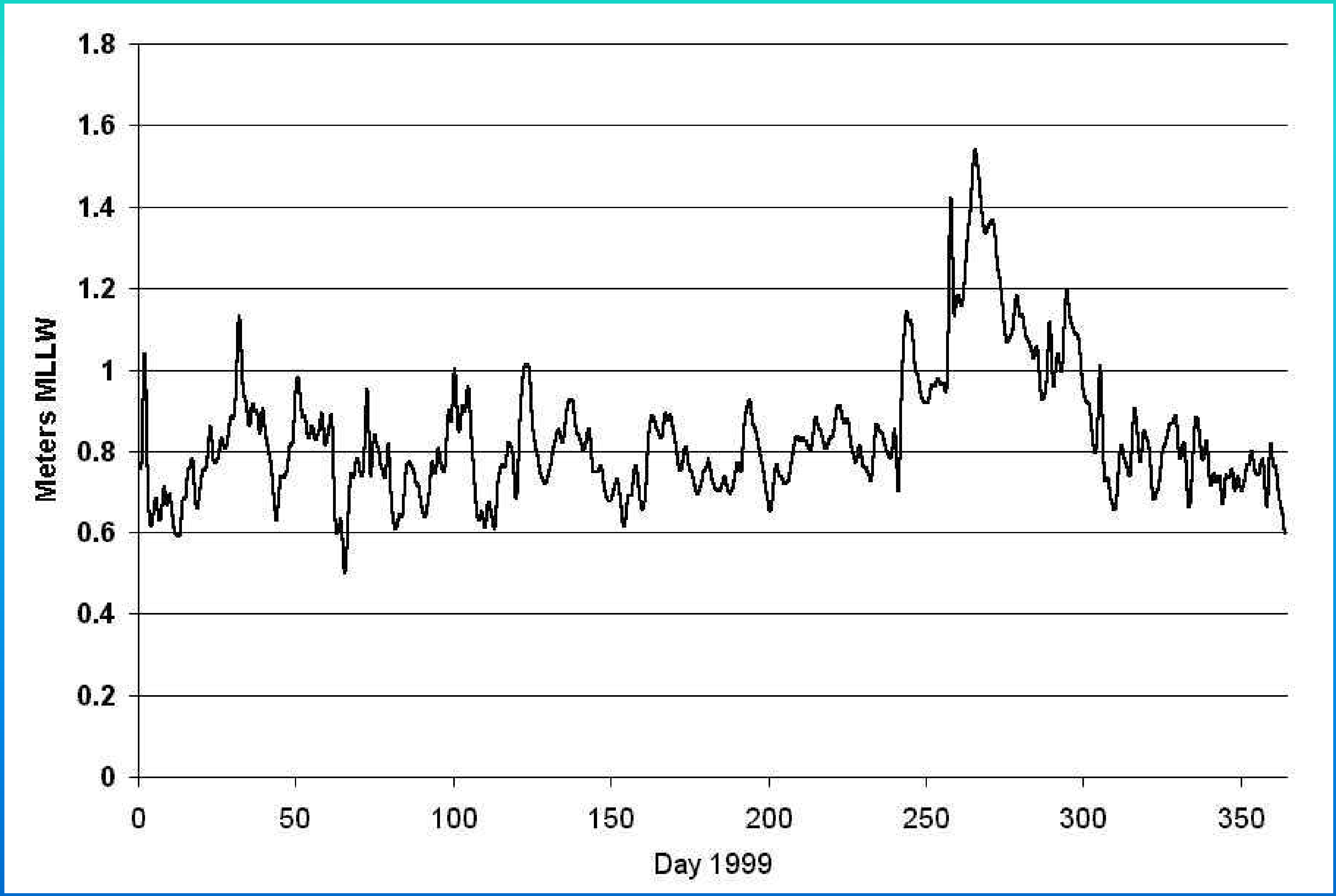
Model Bottom Topography



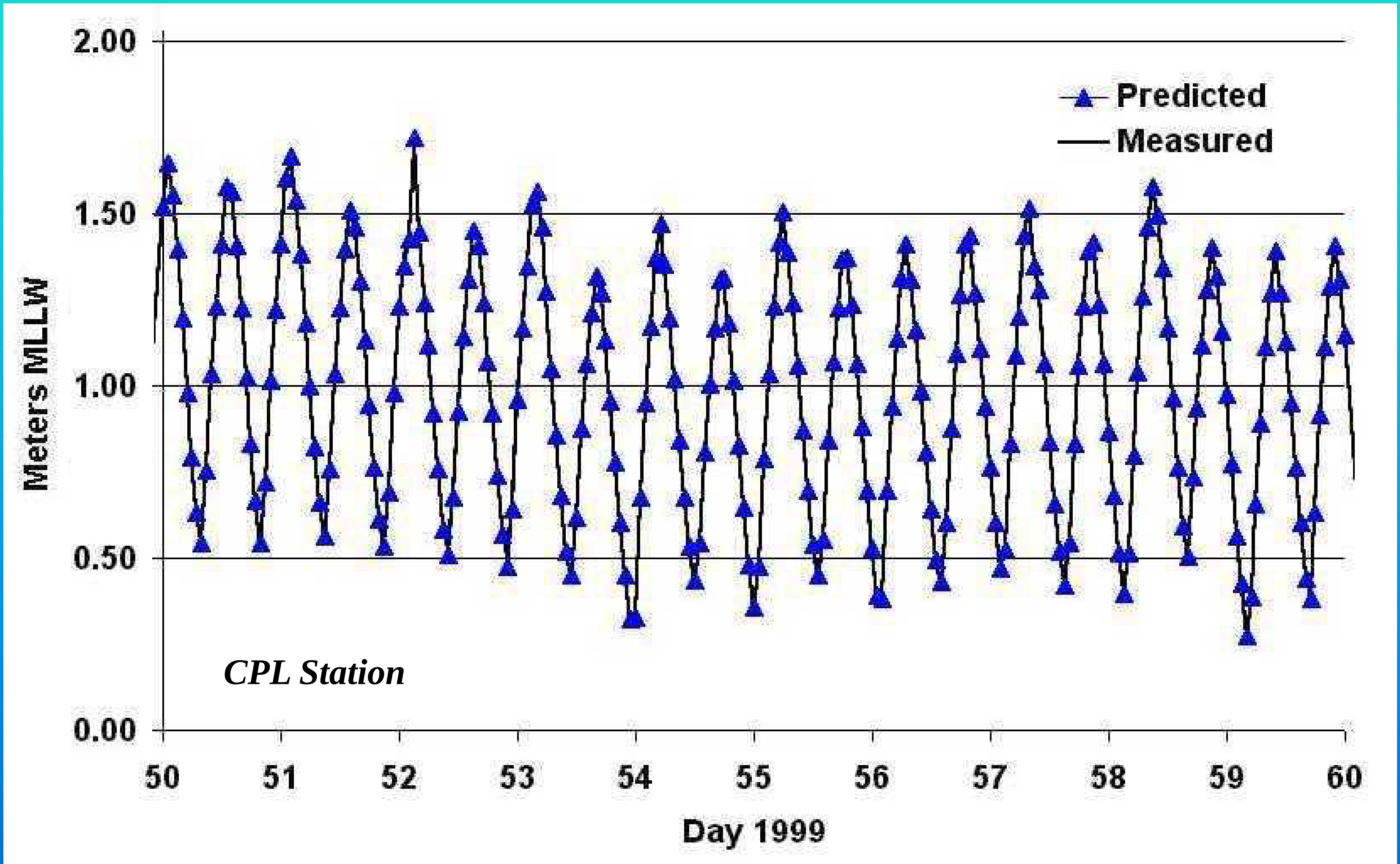
River Discharge (1999)



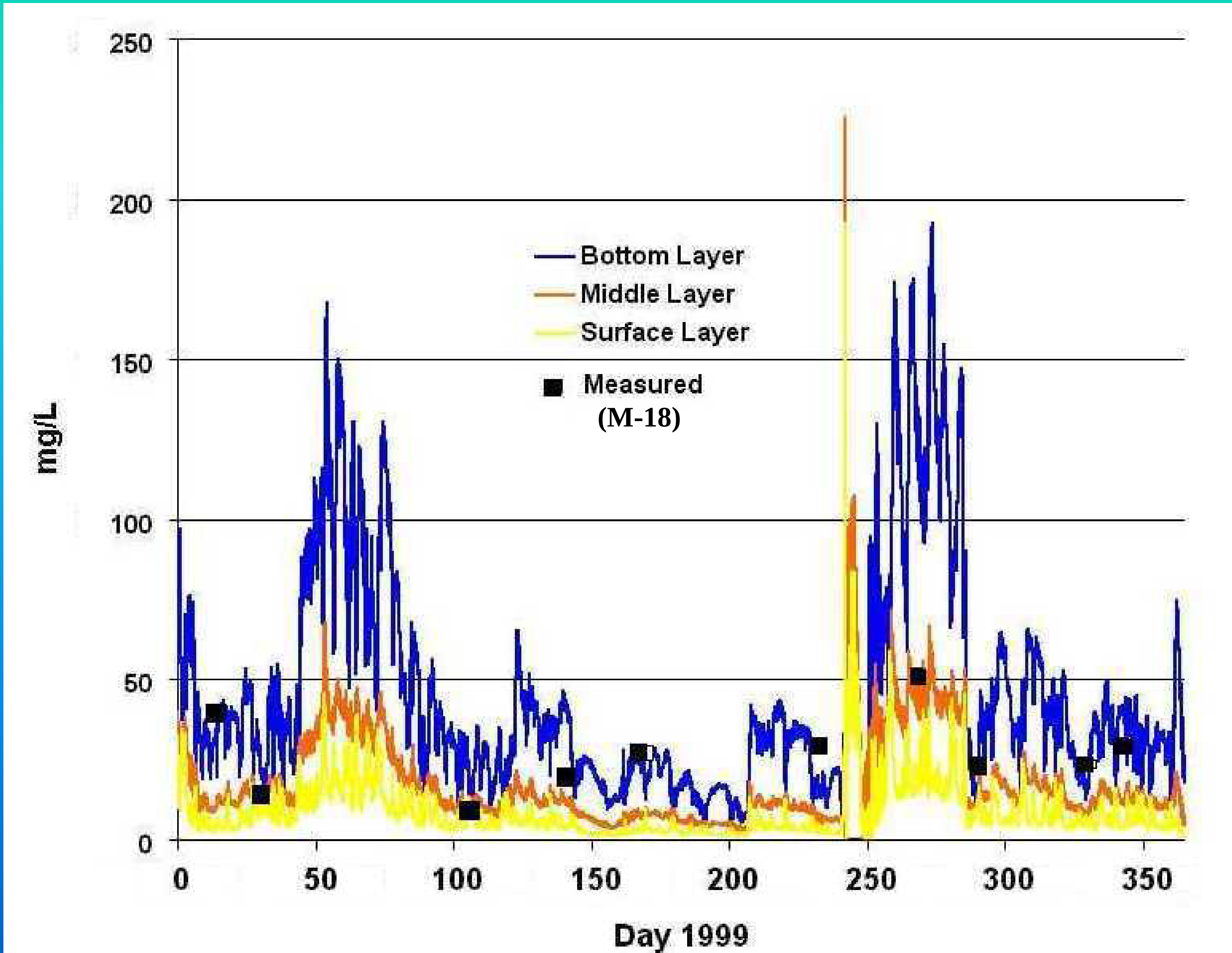
Water Elevation Inputs (Low Frequency Component)



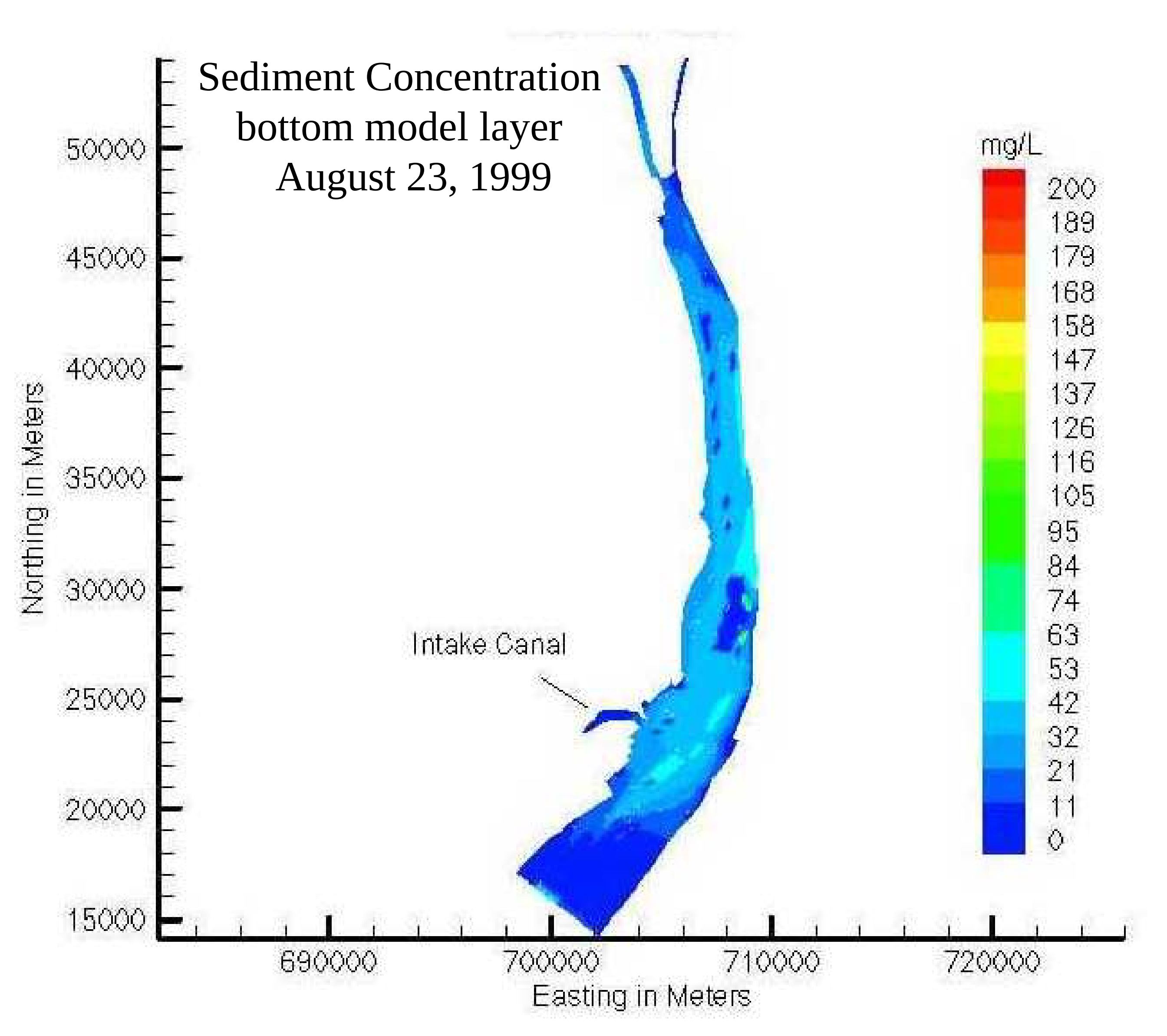
Model Calibration - Water Level/Tides



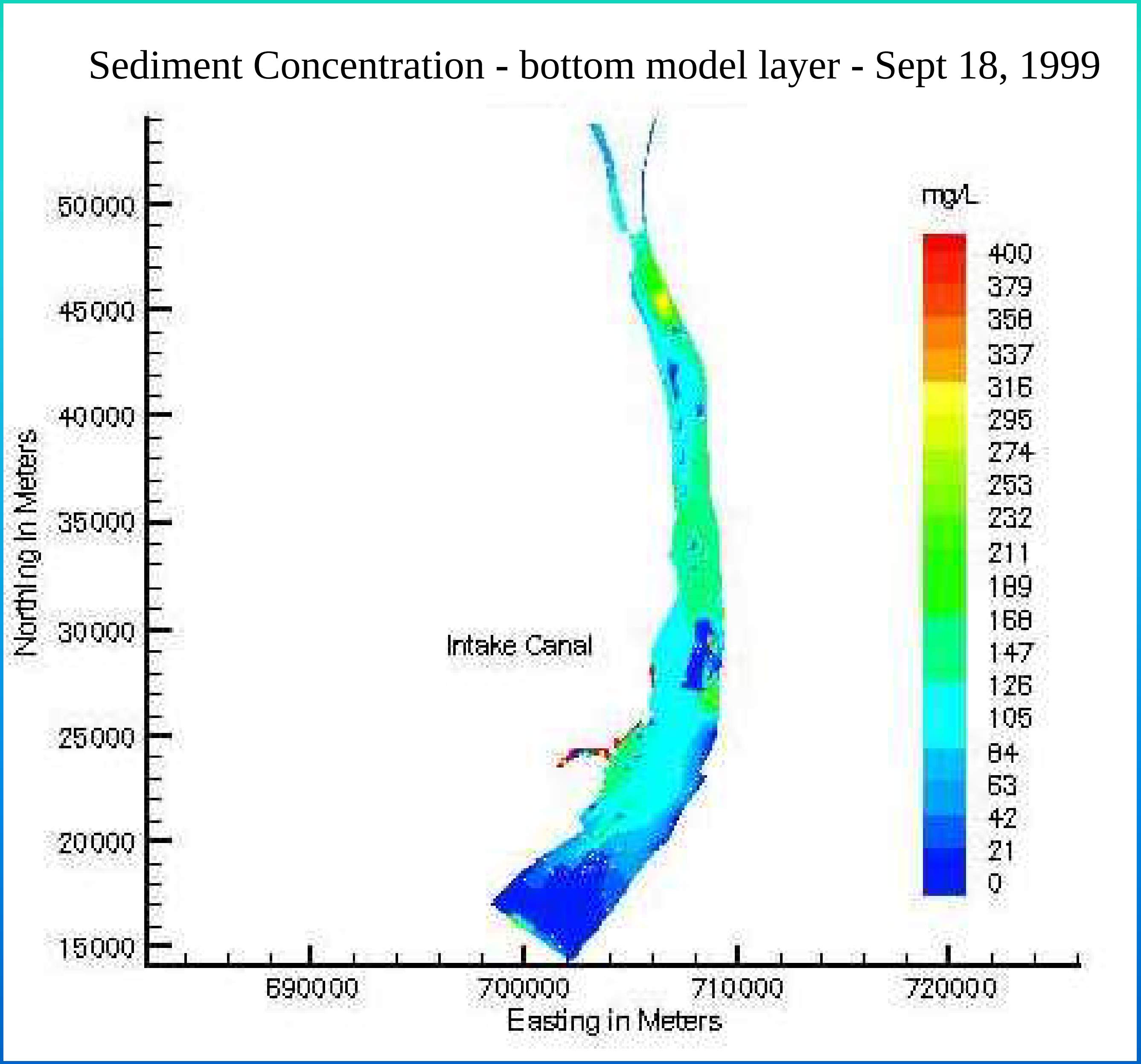
Model Calibration - Turbidity



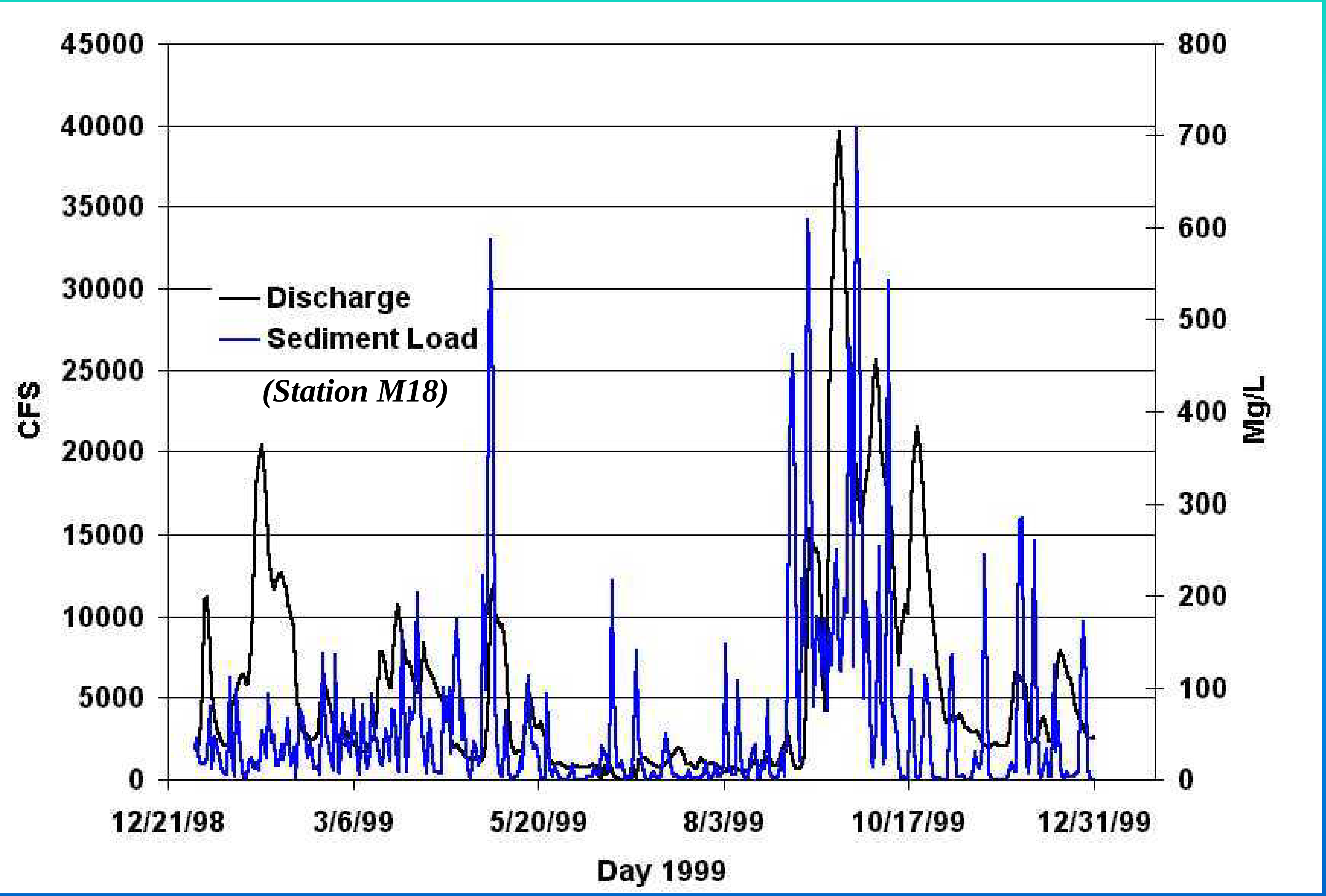
Model Simulations and Tests *(Sediment Regime)*



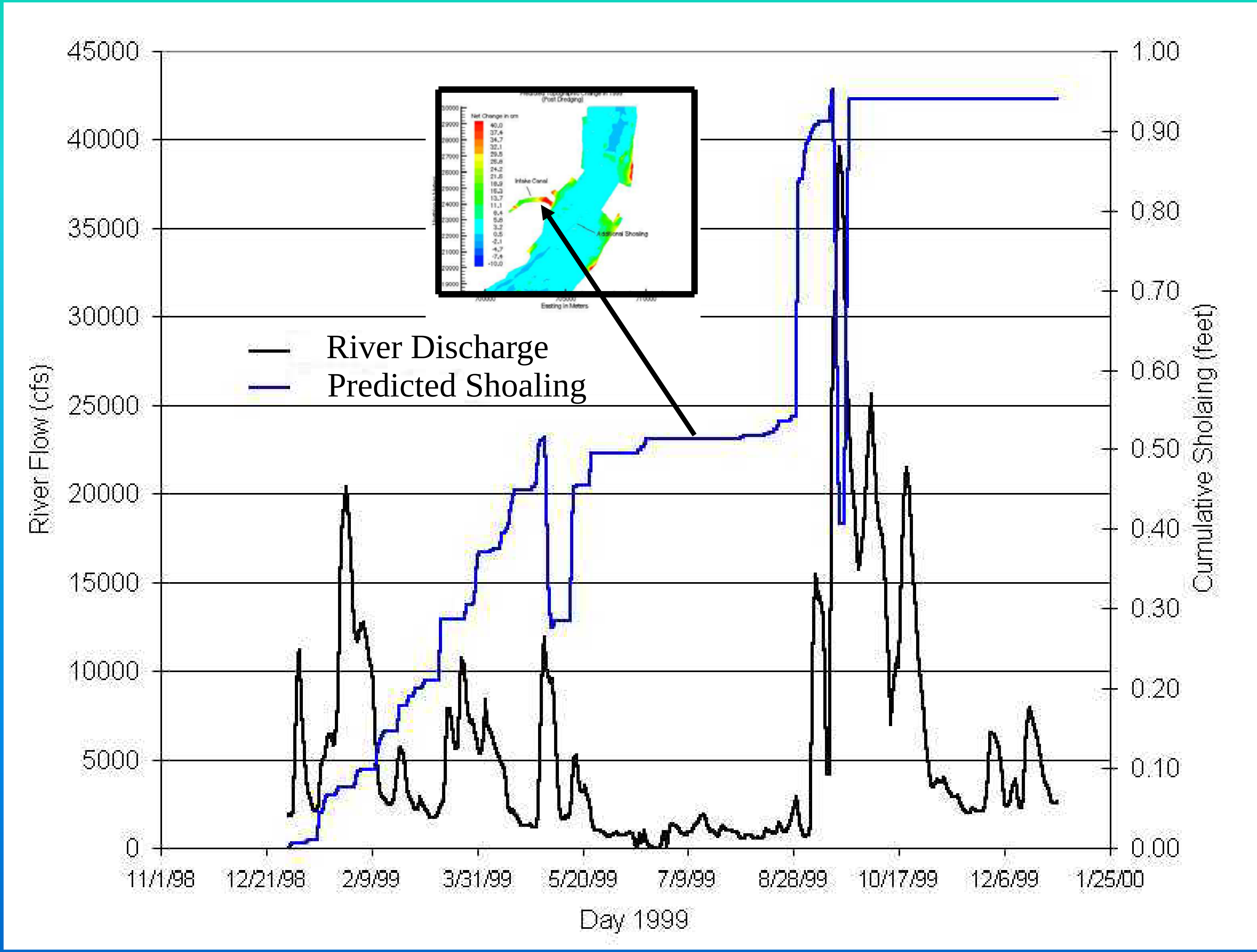
Model Simulations and Tests (Sediment Regime)



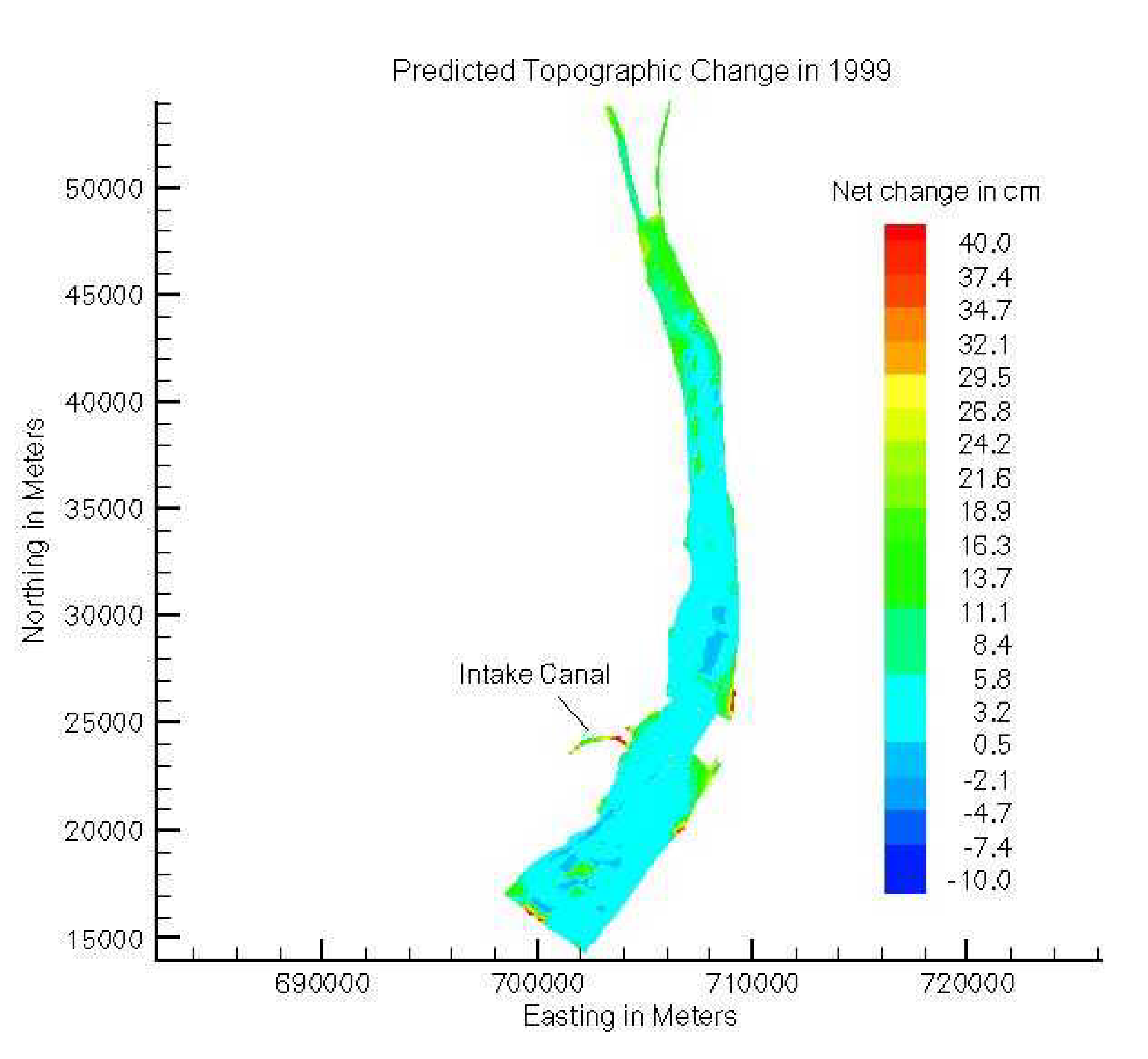
Model Simulations and Tests (Sediment Regime)



Model Simulations and Tests (Sediment Regime)

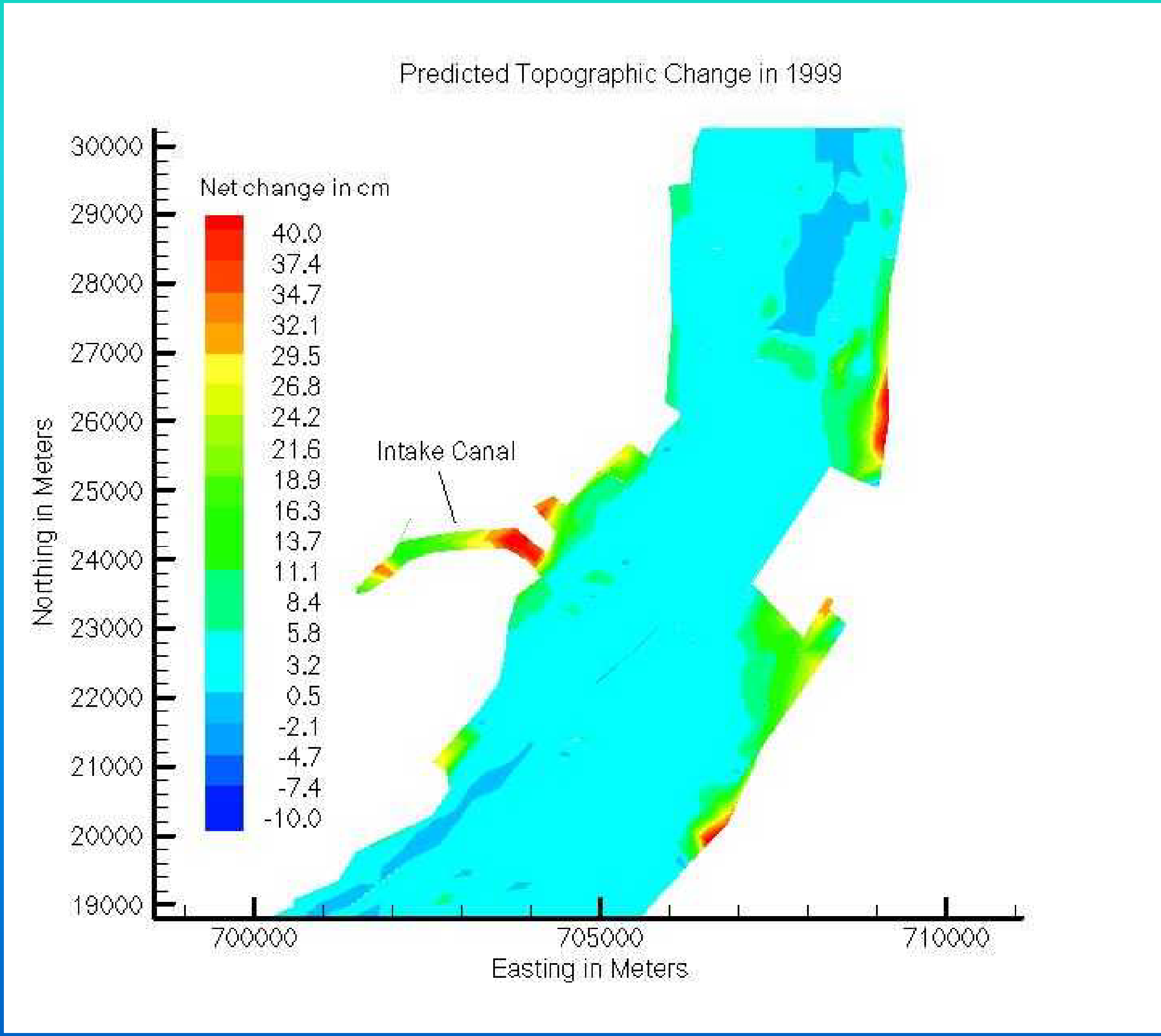


Shoaling and Topographic Change - Existing Conditions

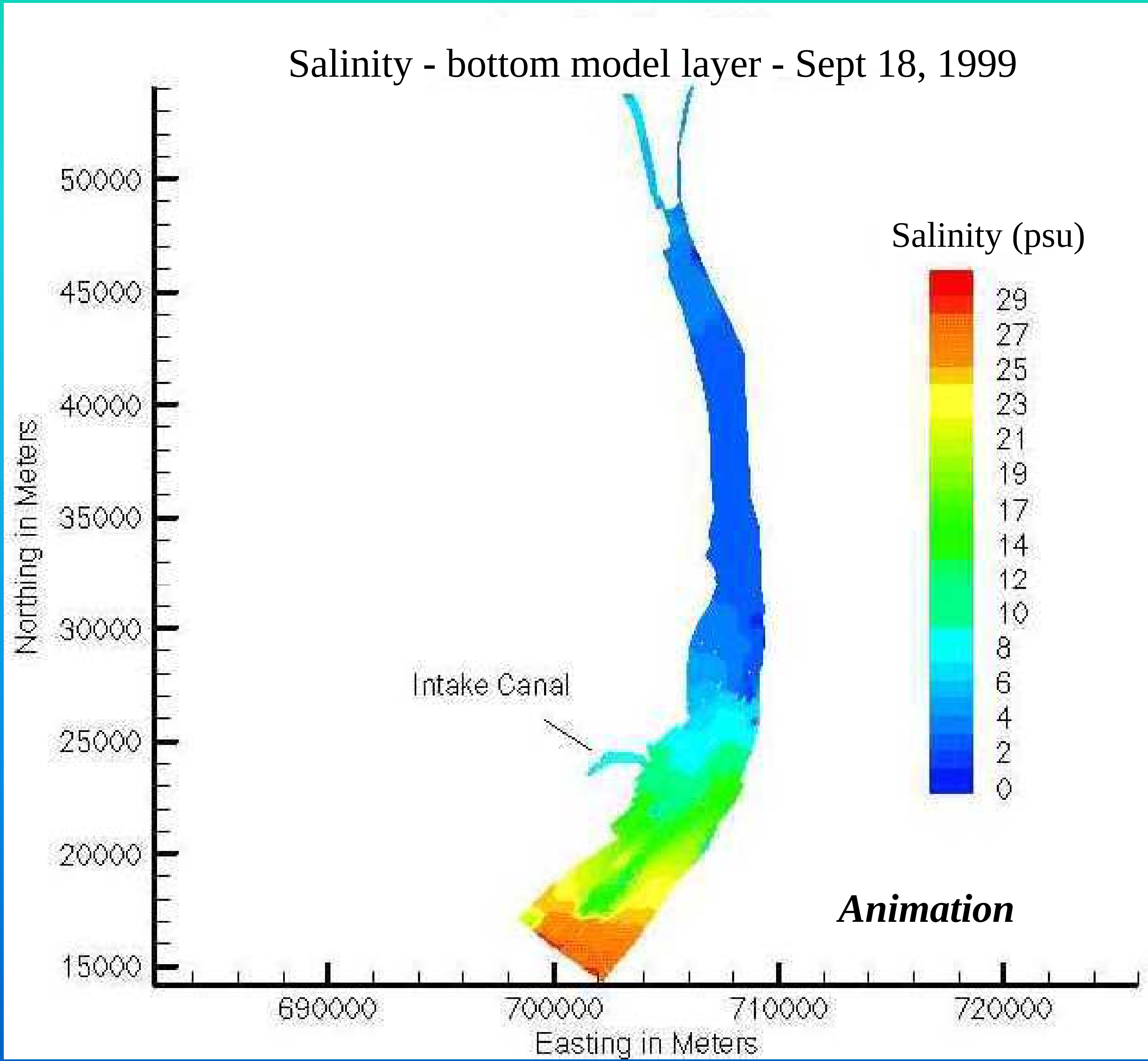


Model Simulations and Tests

(Shoaling and Topographic Change - Existing Conditions)



Model Simulations and Tests (Salinity Regime)



Animation

Conclusions

The major controls on sedimentation in the lower Cape Fear River include variations in freshwater and sediment discharge from the Cape Fear River Basin

Shoaling in the lower estuary is episodic, correlating with storms and high river discharge

Sediment loading to the Cape Fear Estuary could be controlled by best management practices in the upper river basin

Locally sedimentation could be managed by dredging for improved tidal flushing