Toward Modeling of River-Estuary-Ocean Interactions to Enhance Operational River Forecasting in the NOAA National Weather Service

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Acknowledgements

- Meteorological Development Laboratory (MDL) - Extra-tropical Storm Surge
- Chesapeake Bay Operational Forecast System (CBOFS) - Coastal Survey Development Lab (CSDL)
- Chesapeake Bay Inundation Prediction System (CIPS) - Virginia Institute of Marine Science
- FEMA Region 3

Outline

- Motivation
- Objectives
- Unsteady HEC-RAS model
- Calibration/validation
- Boundary conditions for operational forecasts
- Interplay between freshwater flow and tides
- Dynamically linking 1D, 2D, and 3D models
- Summary

River-Estuary-Ocean Modeling Supports CERIS

NOAA's Coast, Estuary, River Information Services (CERIS): Provide water information for coastal communities to assist with hazard mitigation, water resources management, and ecosystem management.

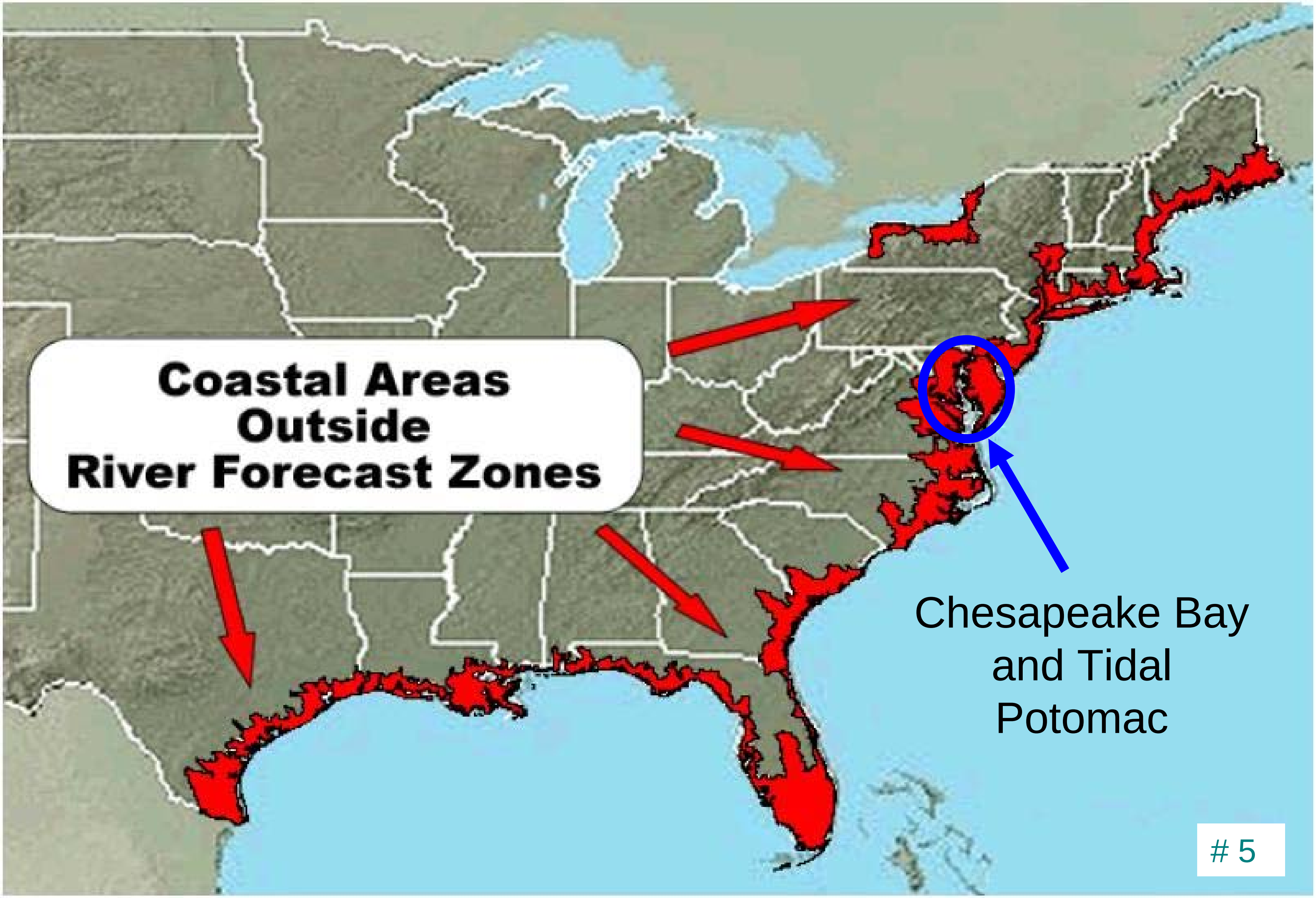
CERIS Themes

- Link NOAA freshwater and saltwater models

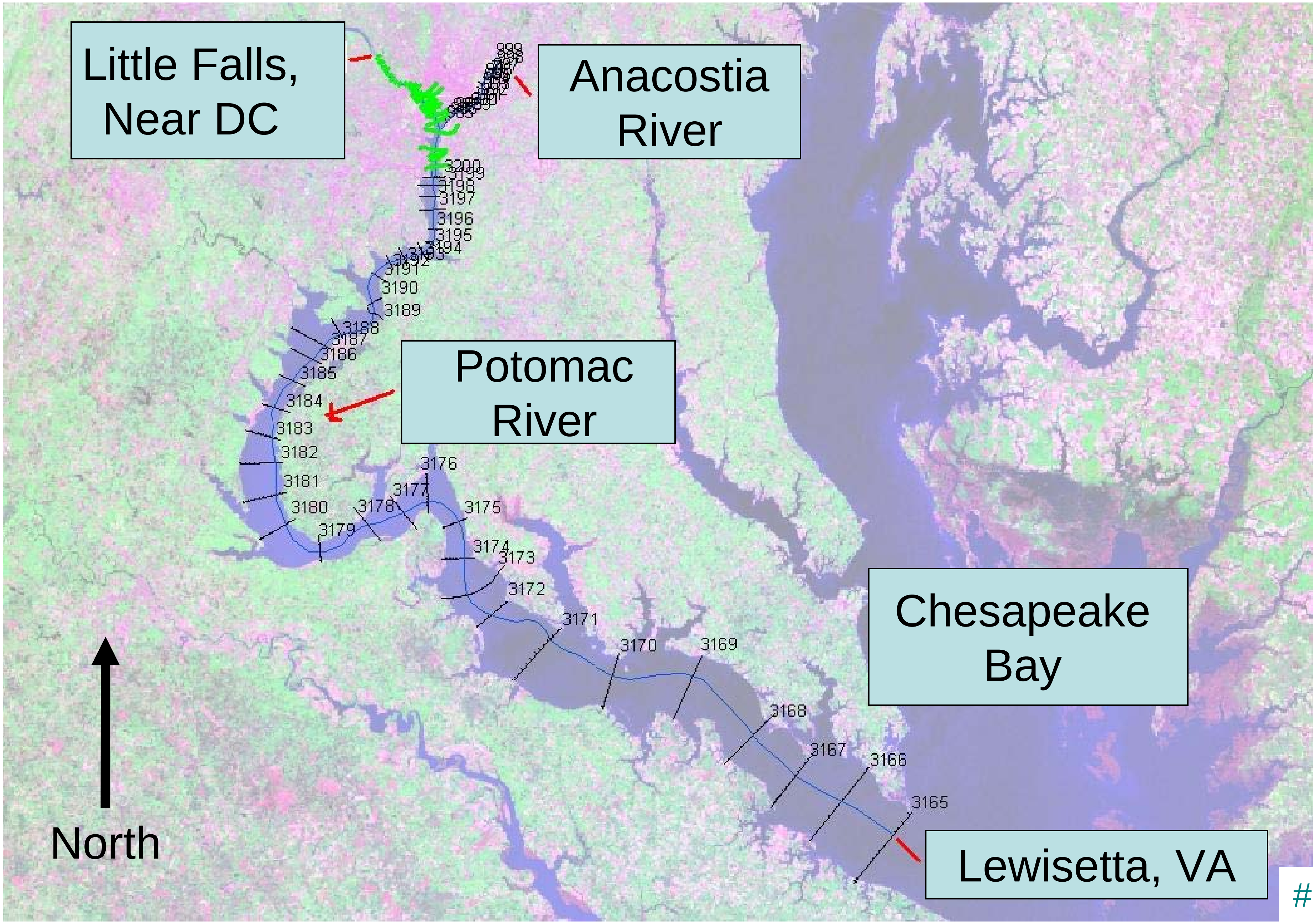
- Expand services to coastal watersheds without existing freshwater forecasts

- Coordinate delivery and dissemination of freshwater products and services

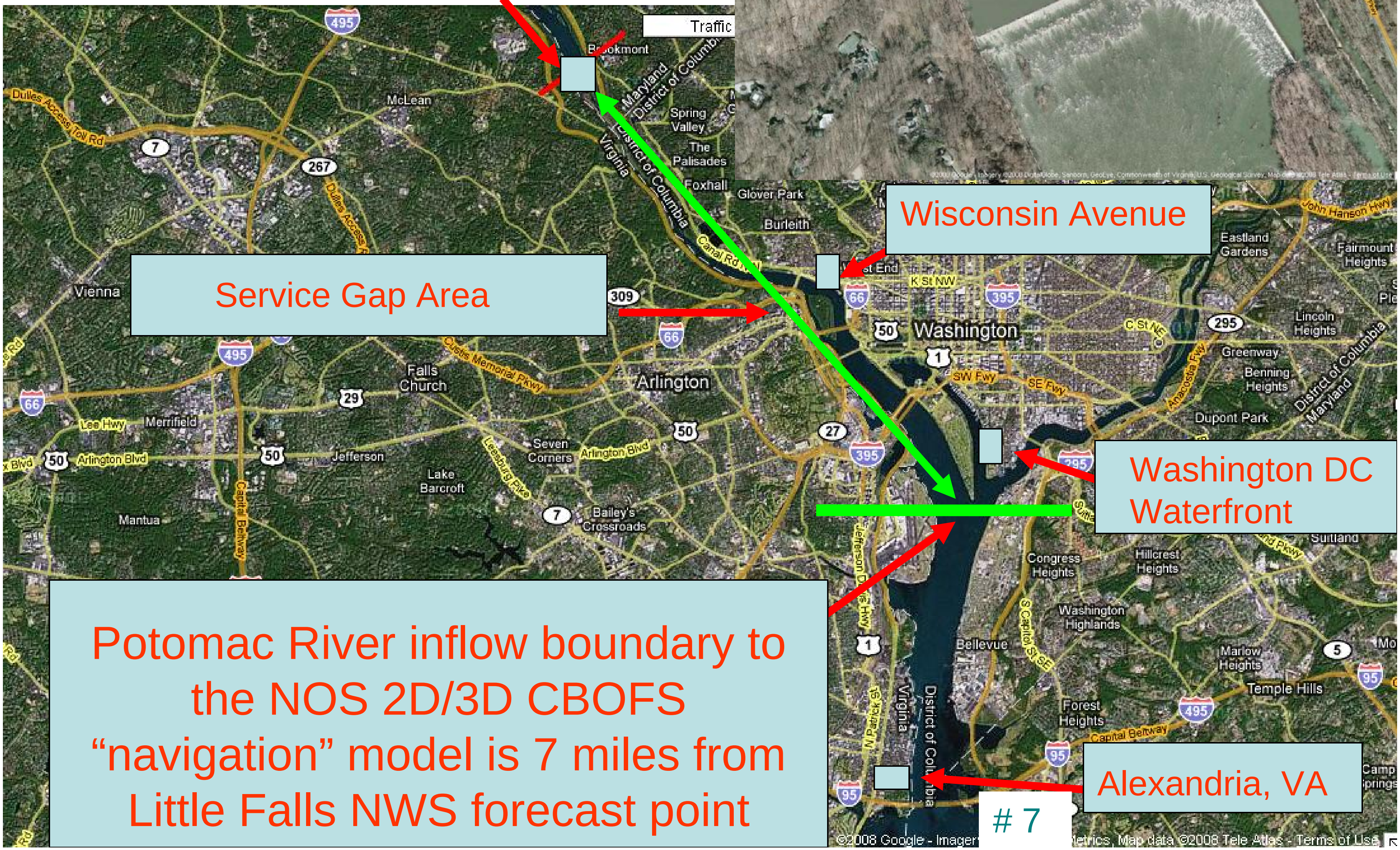
Service “gap” Areas and the Tidal Potomac River Study Location



Tidal Potomac River HEC-RAS Domain



Little Falls near Washington, DC MARFC's Forecast Point on the Potomac River



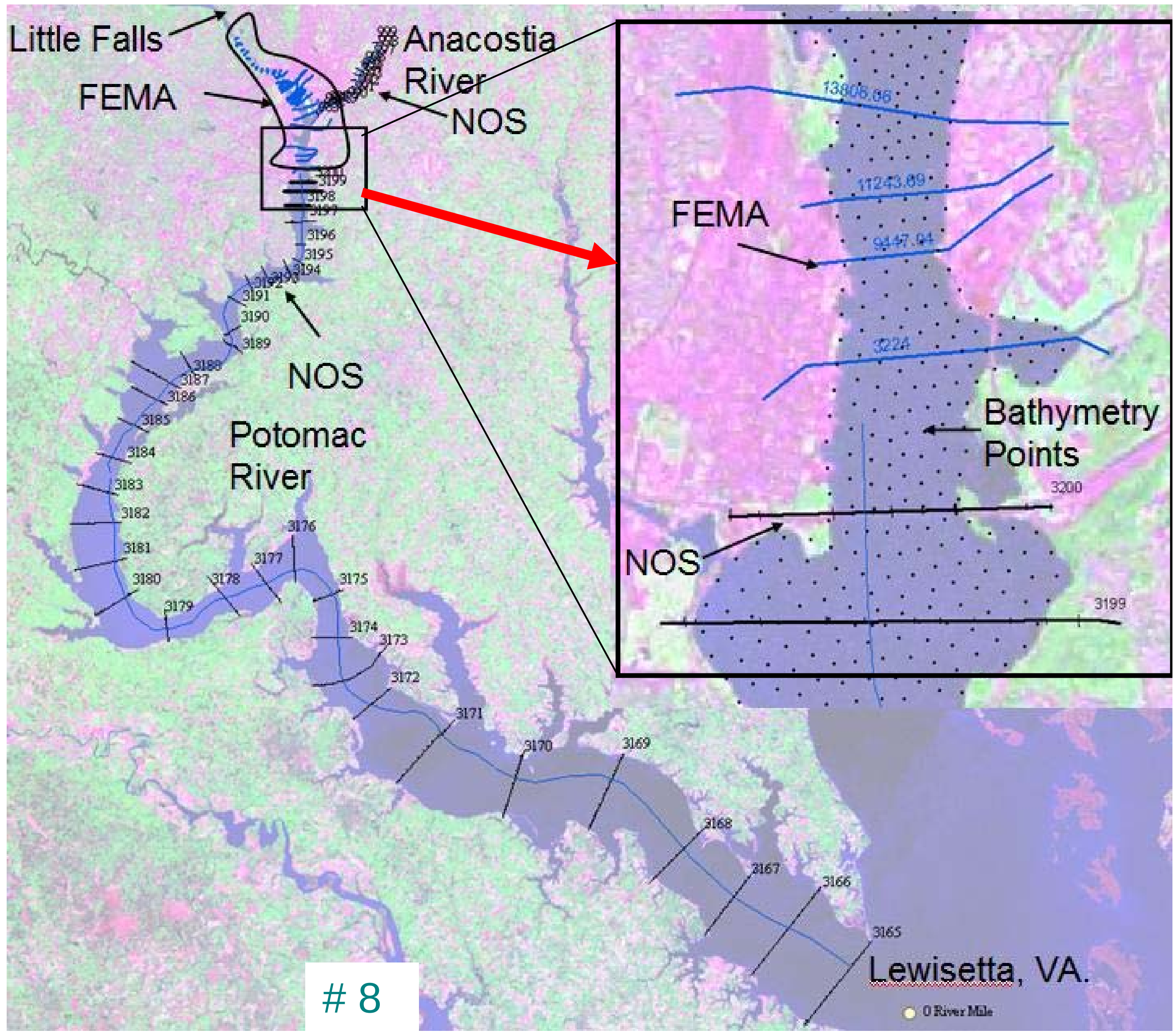
Unsteady HEC-RAS Model Development

Topographic and Bathymetric Data:

1. A geo-referenced HEC-RAS model of the Potomac River developed for FEMA Region 3.

2. An ADCIRC model developed by NOS.

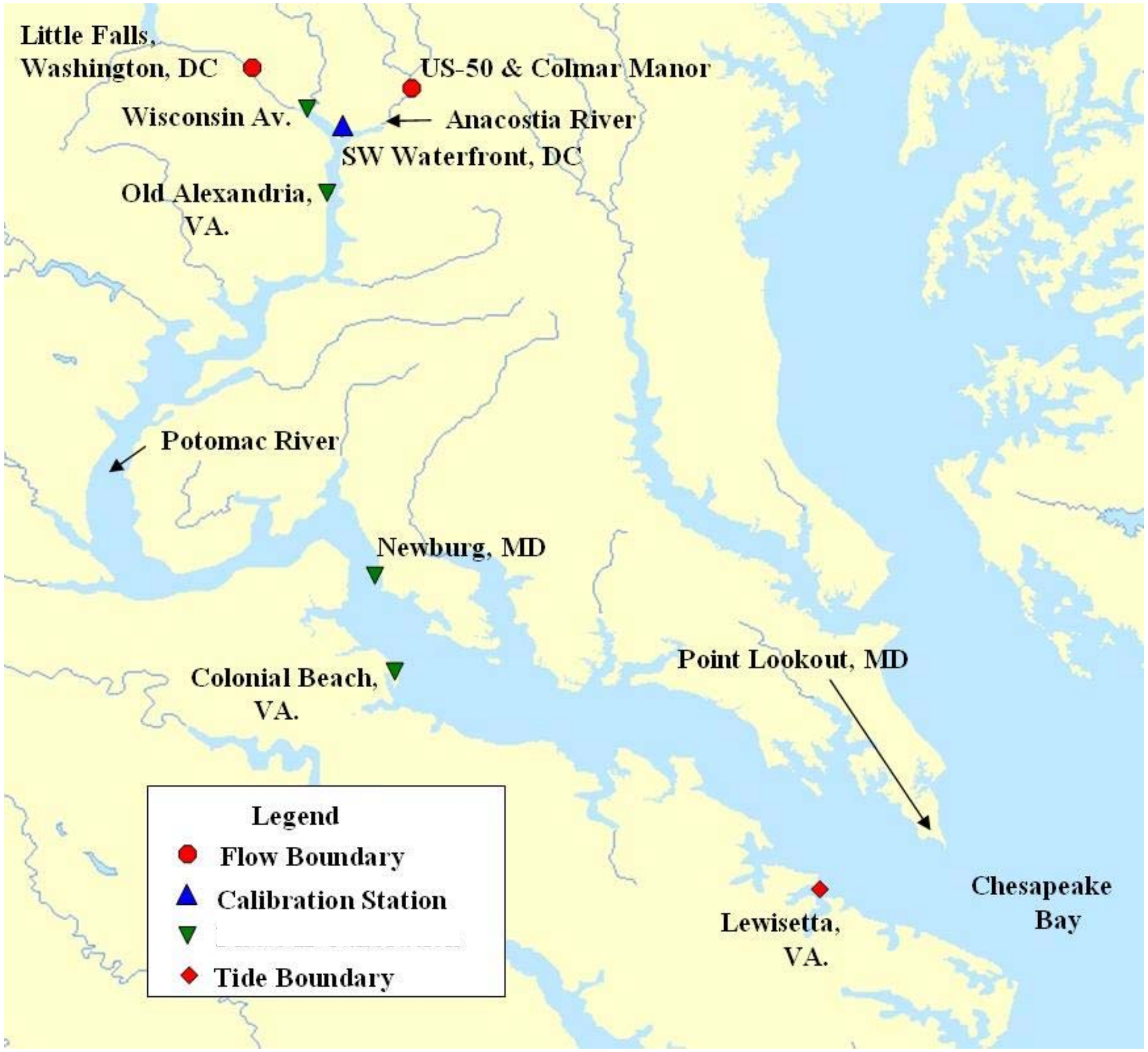
3. New HEC-RAS cross sections were developed and added to the FEMA model using NOS and USGS data.



Model Calibration and Validation

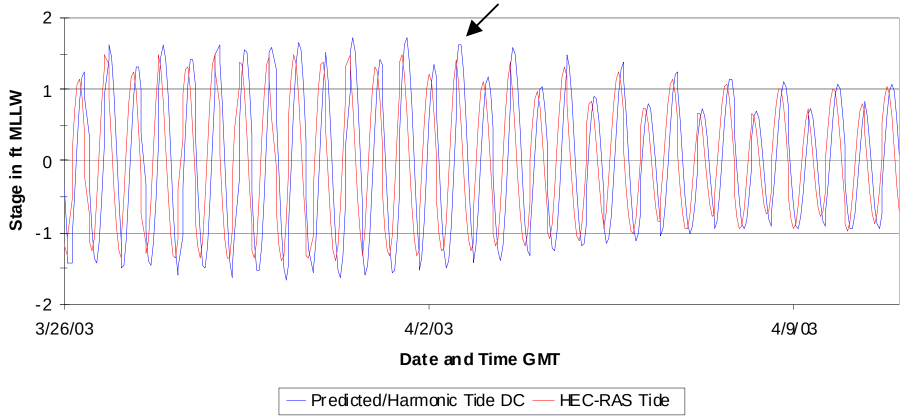
Calibration for:

1. Harmonic Tide
2. Observed Stage and Discharge Time Series
3. Historic Flood Events
4. Hurricane Surge

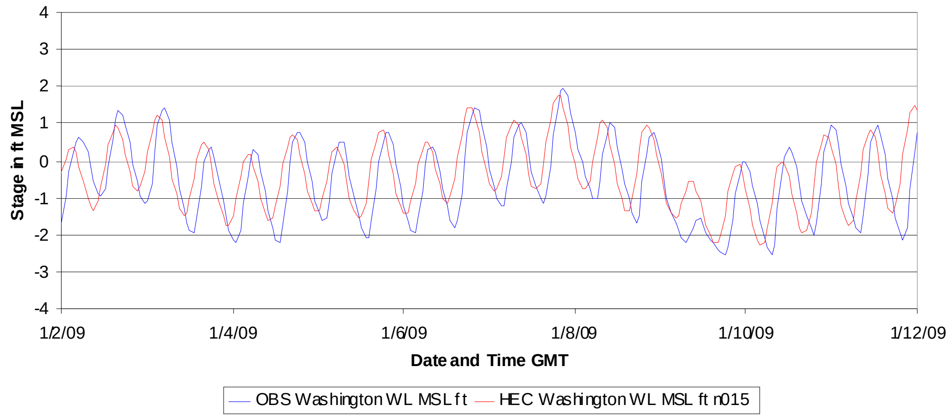


Model Calibration and Validation

HEC-RAS within 6 – 12 inches

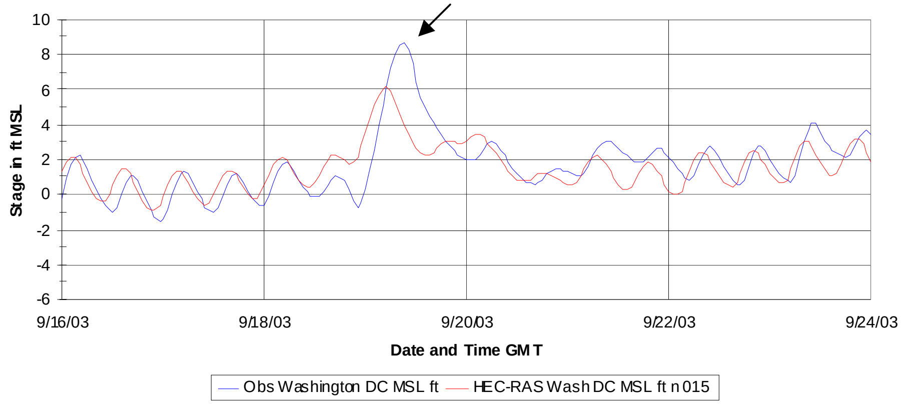


Tide at SW Washington DC

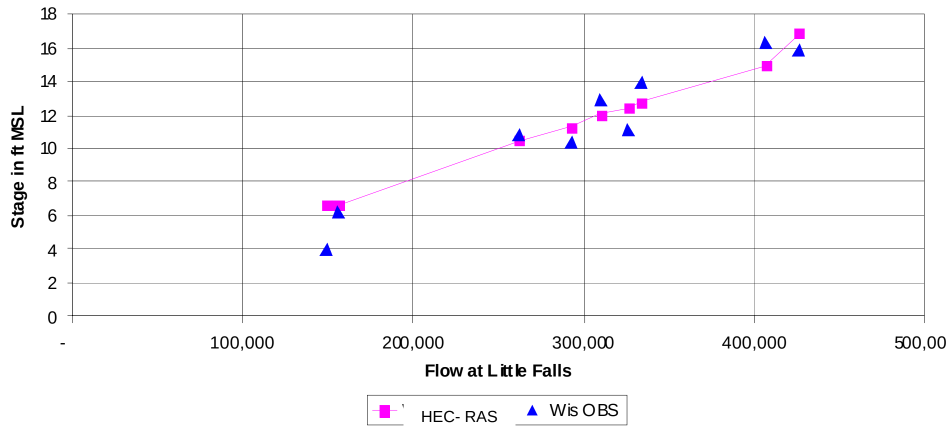


Stage at SW Washington DC

HEC-RAS within 2.5 ft



Hurricane Isabel Surge (2003) at SW Washington DC



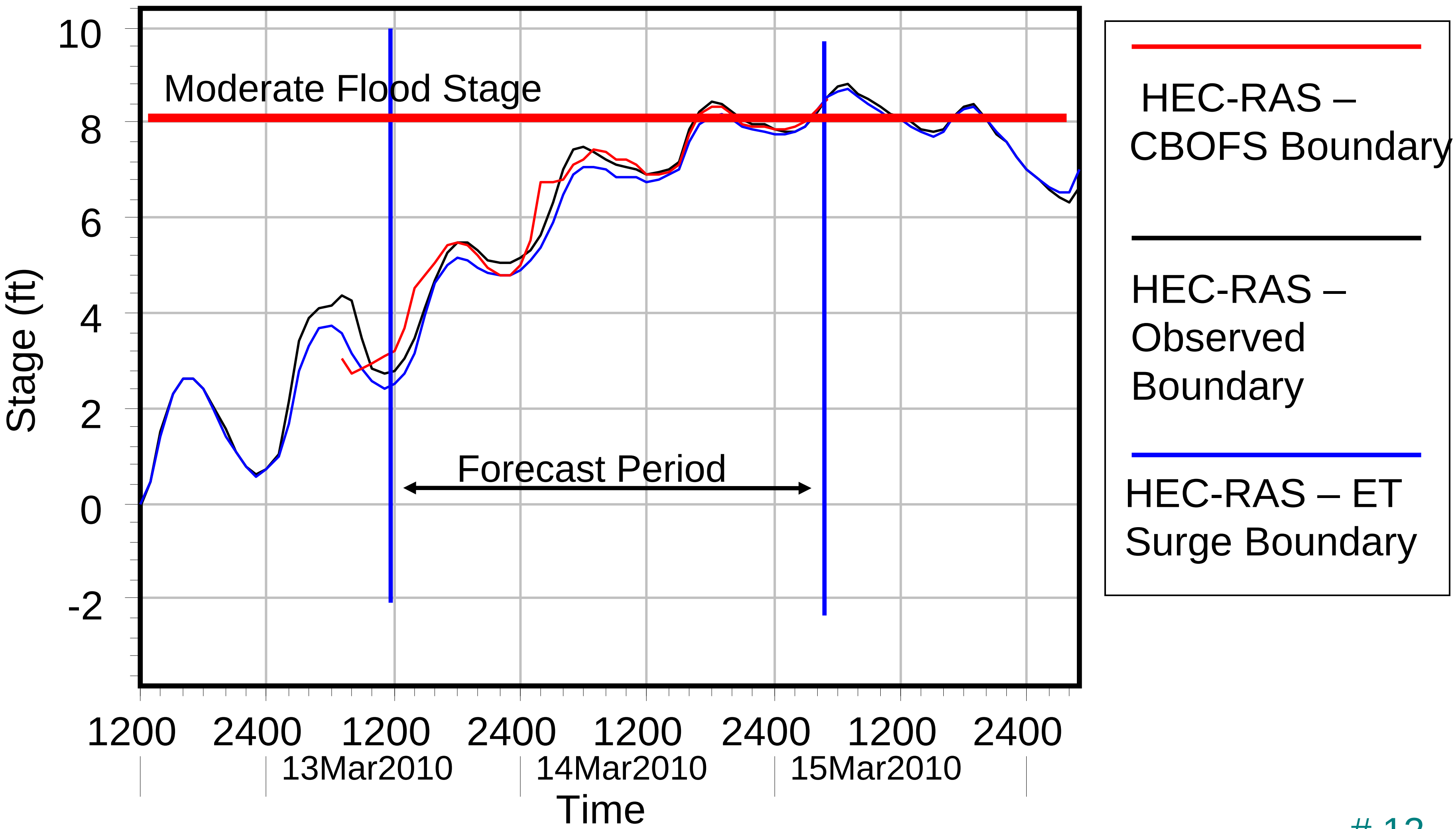
Historic Flood Stages at Wisconsin Avenue

“forecast” Mode

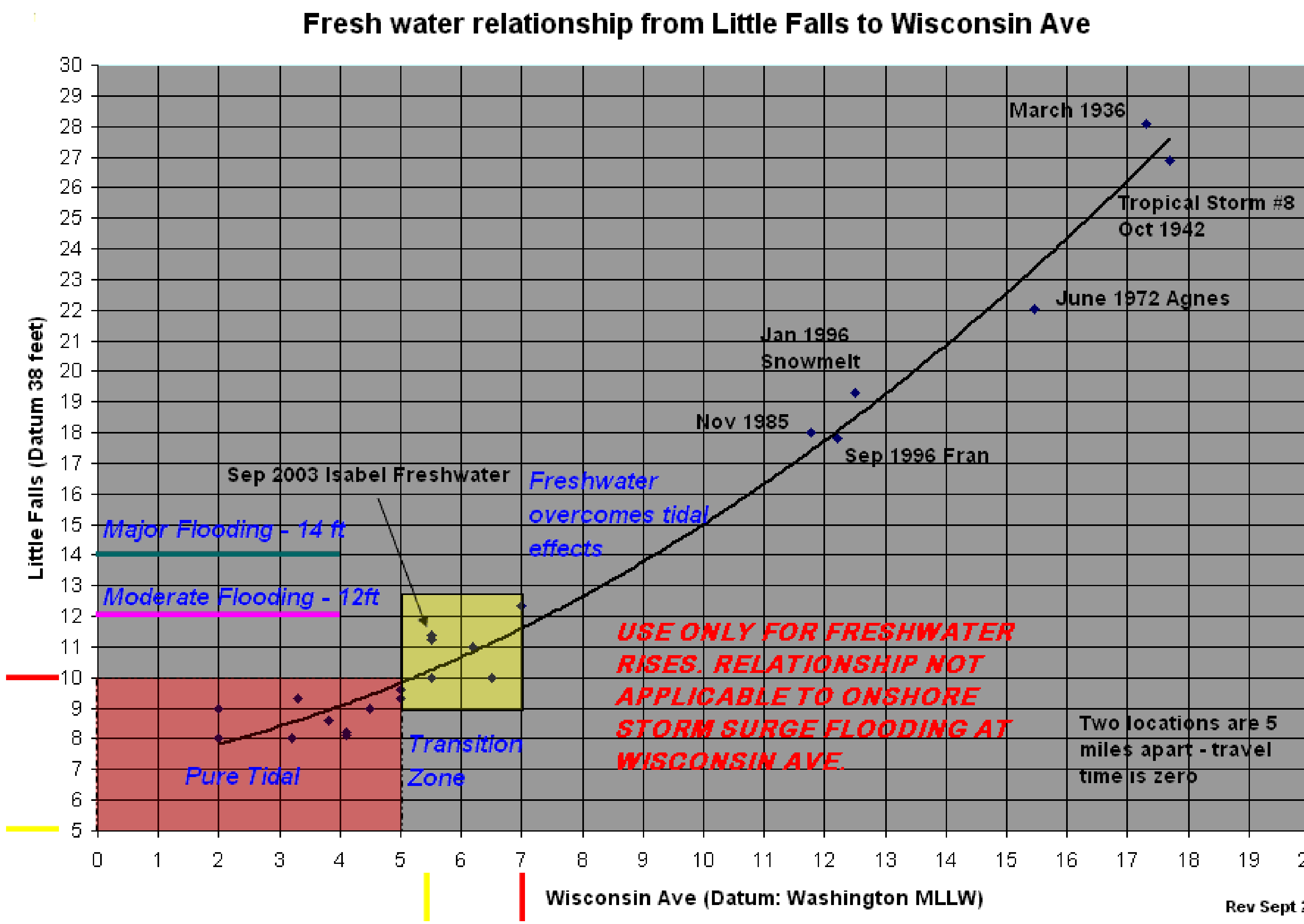
Two Sources for the Downstream Boundary Condition

1. ET Surge (MDL/NWS)
2. CBOFS (COOPS/CSDL/NOS)

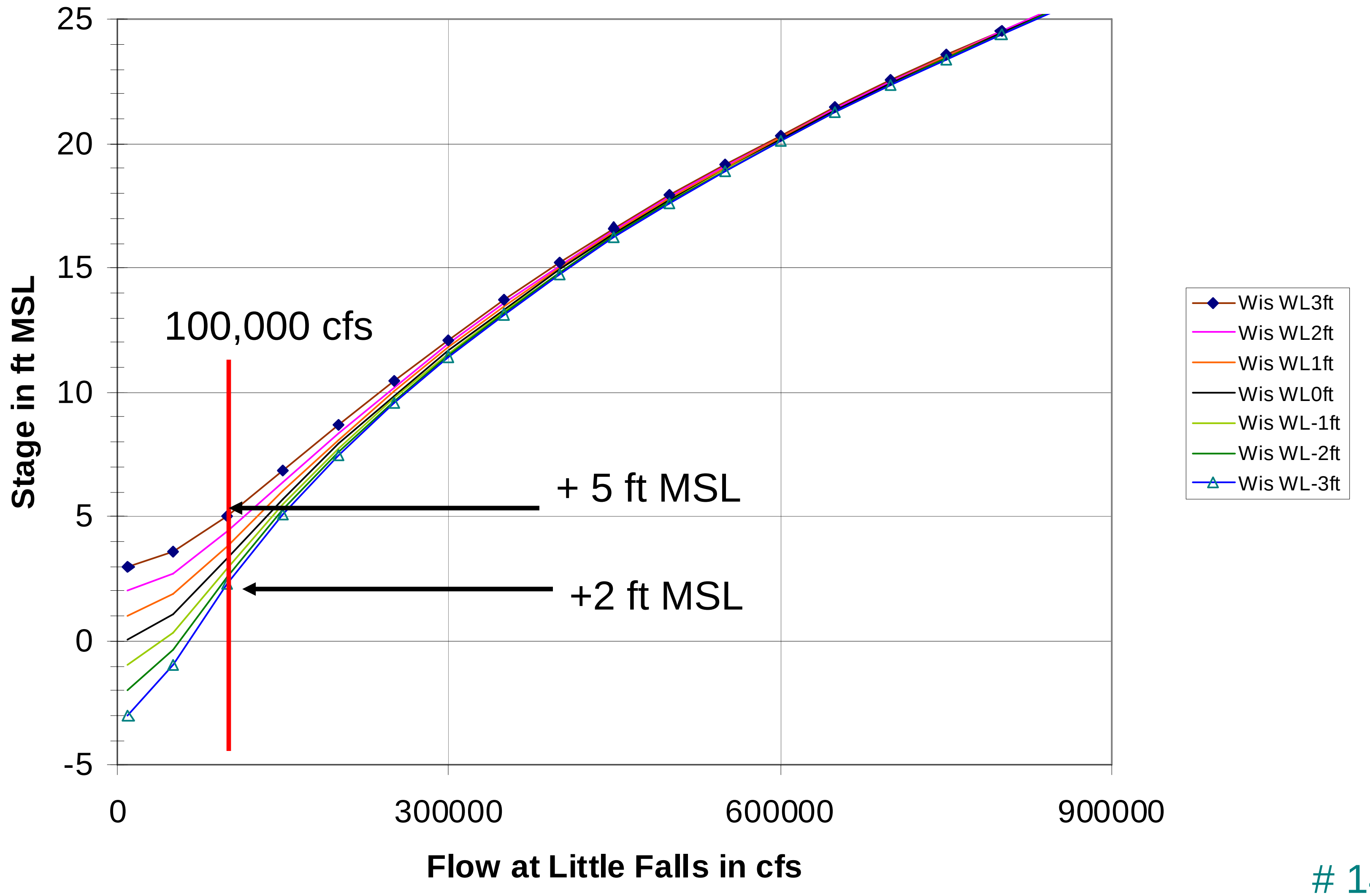
Model Hindcast in "Forecast" Mode – Stage at Wisconsin Avenue



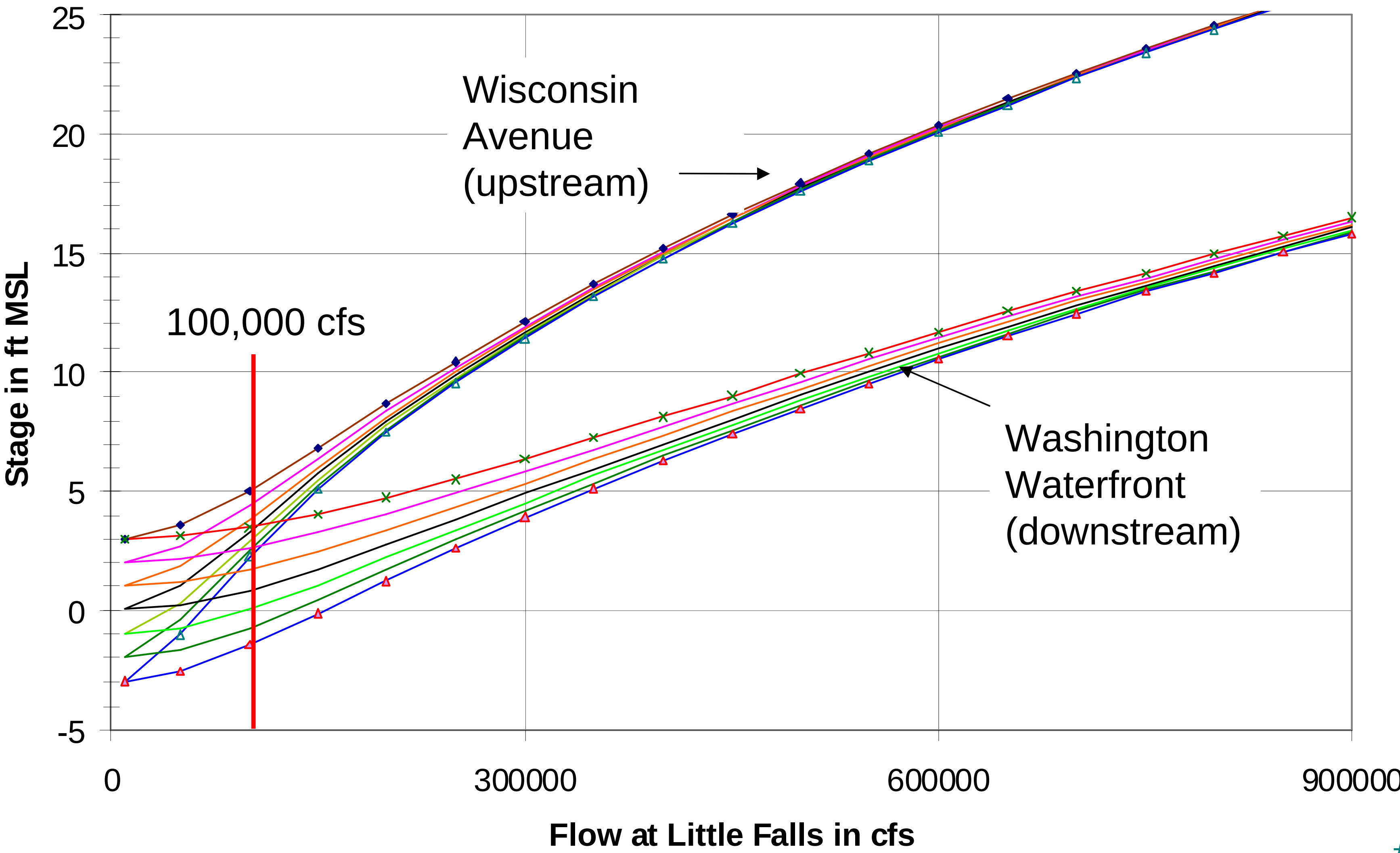
Importance of Tide Simulation in the Tidal Potomac River



Stage-Discharge Curves at Wisconsin Avenue for a Set of Constant Tides (-3 ft to +3 ft MSL) at Lewisetta



Stage-Discharge Curves at Wisconsin Avenue and Washington Waterfront (~ 3 Mile Apart) for a Set of Constant Tides (-3 ft to +3 ft MSL) at Lewisetta



Dynamically Linking 1D, 2D, and 3D models

- Model theory
- Model geometry
- Model capabilities

1D models (Such as SOBEK, HEC-RAS) solve (St. Venant equations)

(1) Continuity equation

$$\frac{\partial A_t}{\partial t}+\frac{\partial Q}{\partial x}=q_{\text{lat}}$$

In which A_t is the total cross-section area; Q_{lat} is the lateral discharge per unit length; Q is the discharge

(2) Momentum equation

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\alpha_B\frac{Q^2}{A_f}\right)+gA_f\frac{\partial h}{\partial x}+\frac{gQ|Q|}{C^2RA_f}-W_f\frac{\tau_{wi}}{\rho_w}+$$
$$gA_f(\eta+\xi Q|Q|)+\frac{g}{\rho_w}\frac{\partial\rho}{\partial x}A_{1\text{m}}=0$$

Where B is the boussinesq constant; A_f is the cross-section flow area; h is the water level; C is the Chézy coefficient; R is the hydraulic radius; W_f is the flow width, W_i is the wind shear stress; w is the water density; $A_{1\text{m}}$ is the first order moment cross-section.

3D models

Primitive Equations of Fluid Motions

(Navier–Stokes equations)

The primitive equations in Cartesian coordinates are shown here. The momentum balance in the x- and y-directions are:

$$\frac{\partial u}{\partial t} + \vec{v}\cdot\nabla u - fv = -\frac{\partial \phi}{\partial x} - \frac{\partial}{\partial z}\left(\overline{u'w'} - \nu\frac{\partial u}{\partial z}\right) + \mathcal{F}_u + \mathcal{D}_u \quad (1)$$

$$\frac{\partial v}{\partial t} + \vec{v}\cdot\nabla v + fu = -\frac{\partial \phi}{\partial y} - \frac{\partial}{\partial z}\left(\overline{v'w'} - \nu\frac{\partial v}{\partial z}\right) + \mathcal{F}_v + \mathcal{D}_v \quad (2)$$

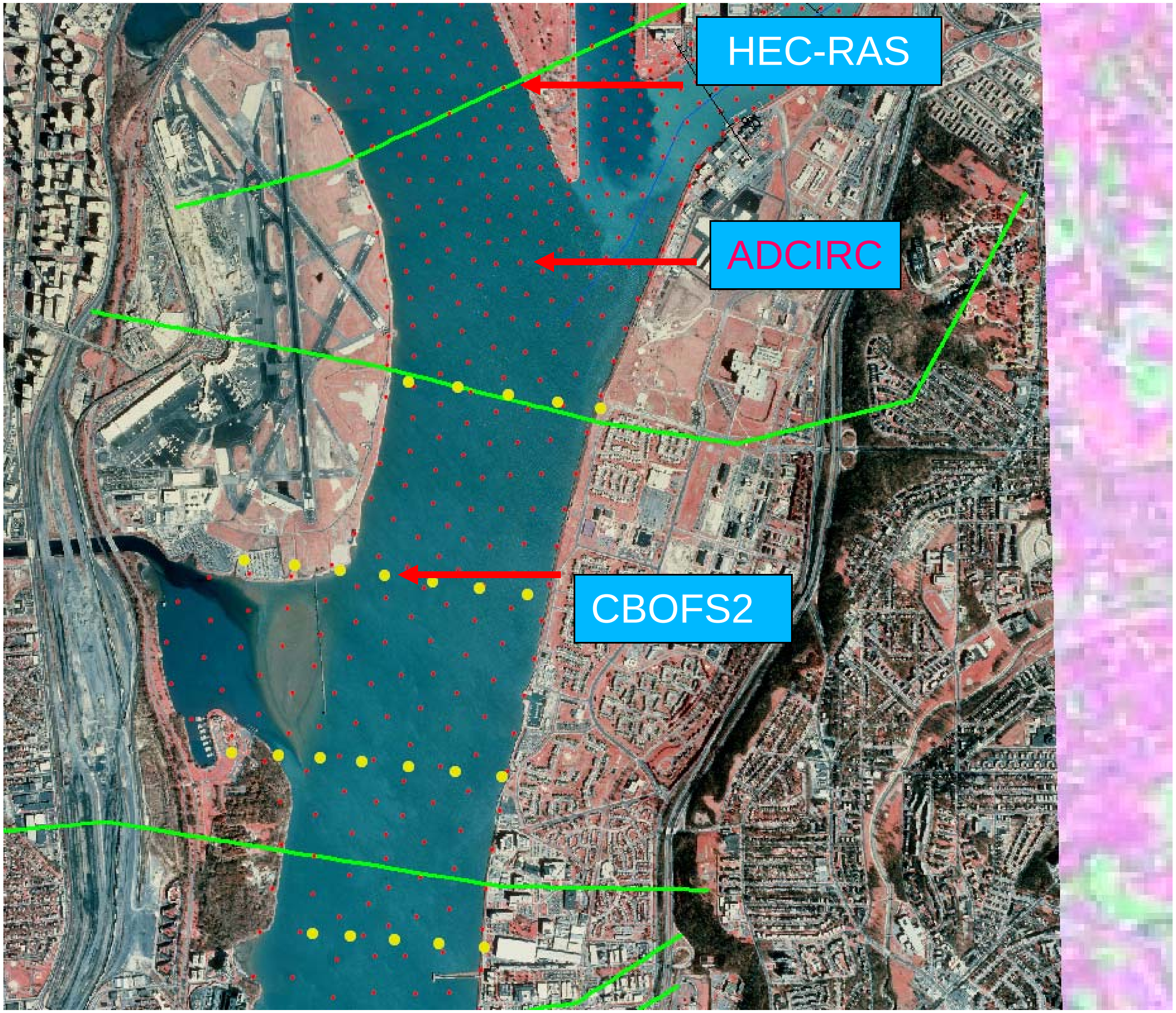
The time evolution of a scalar concentration field, $C(x, y, z, t)$ (e.g. salinity, temperature, or nutrients), is governed by the advective-diffusive equation:

$$\frac{\partial C}{\partial t} + \vec{v}\cdot\nabla C = -\frac{\partial}{\partial z}\left(\overline{C'w'} - \nu_\theta\frac{\partial C}{\partial z}\right) + \mathcal{F}_C + \mathcal{D}_C \quad (3)$$

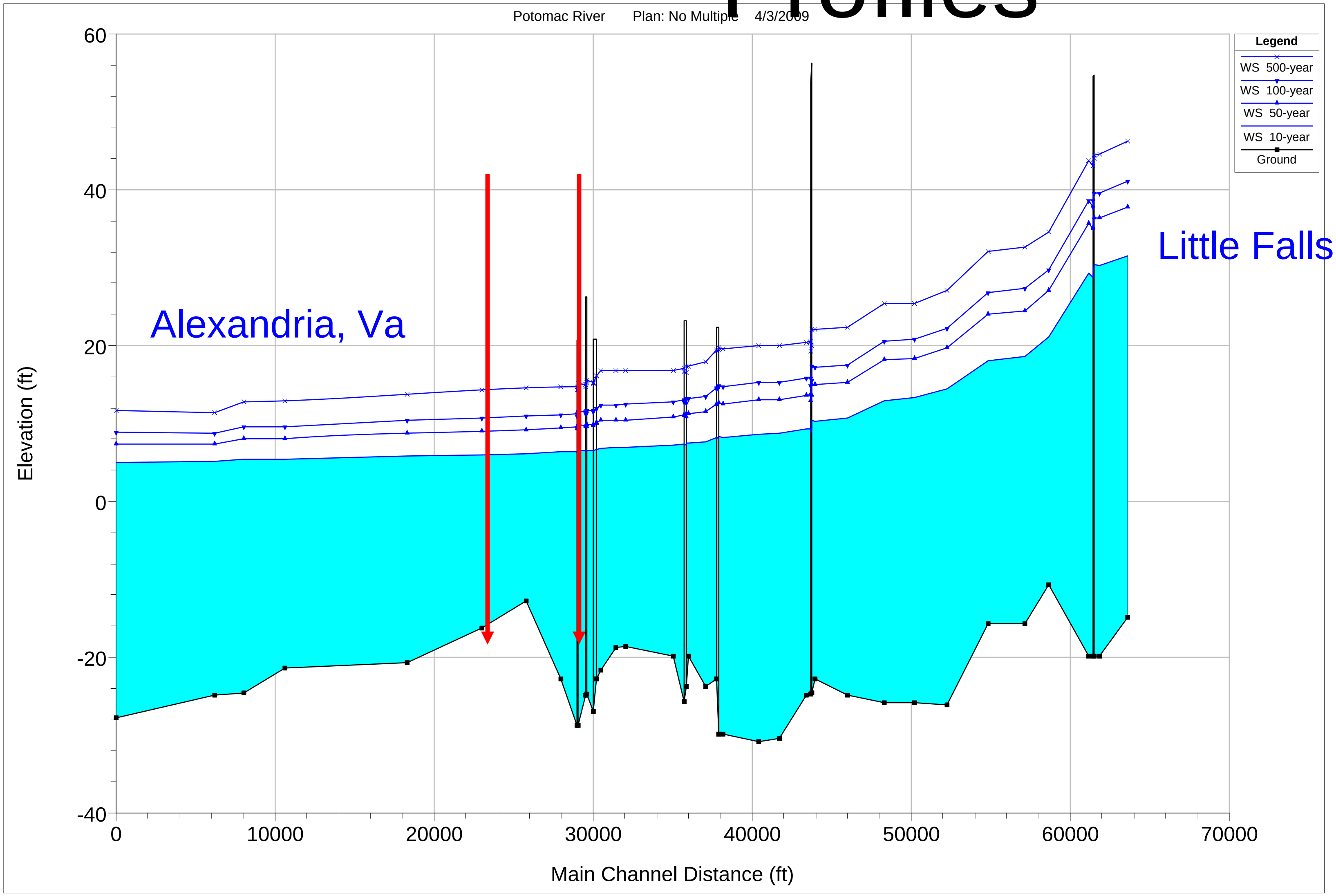
The equation of state is given by:

$$\rho = \rho(T, S, P) \quad (4)$$

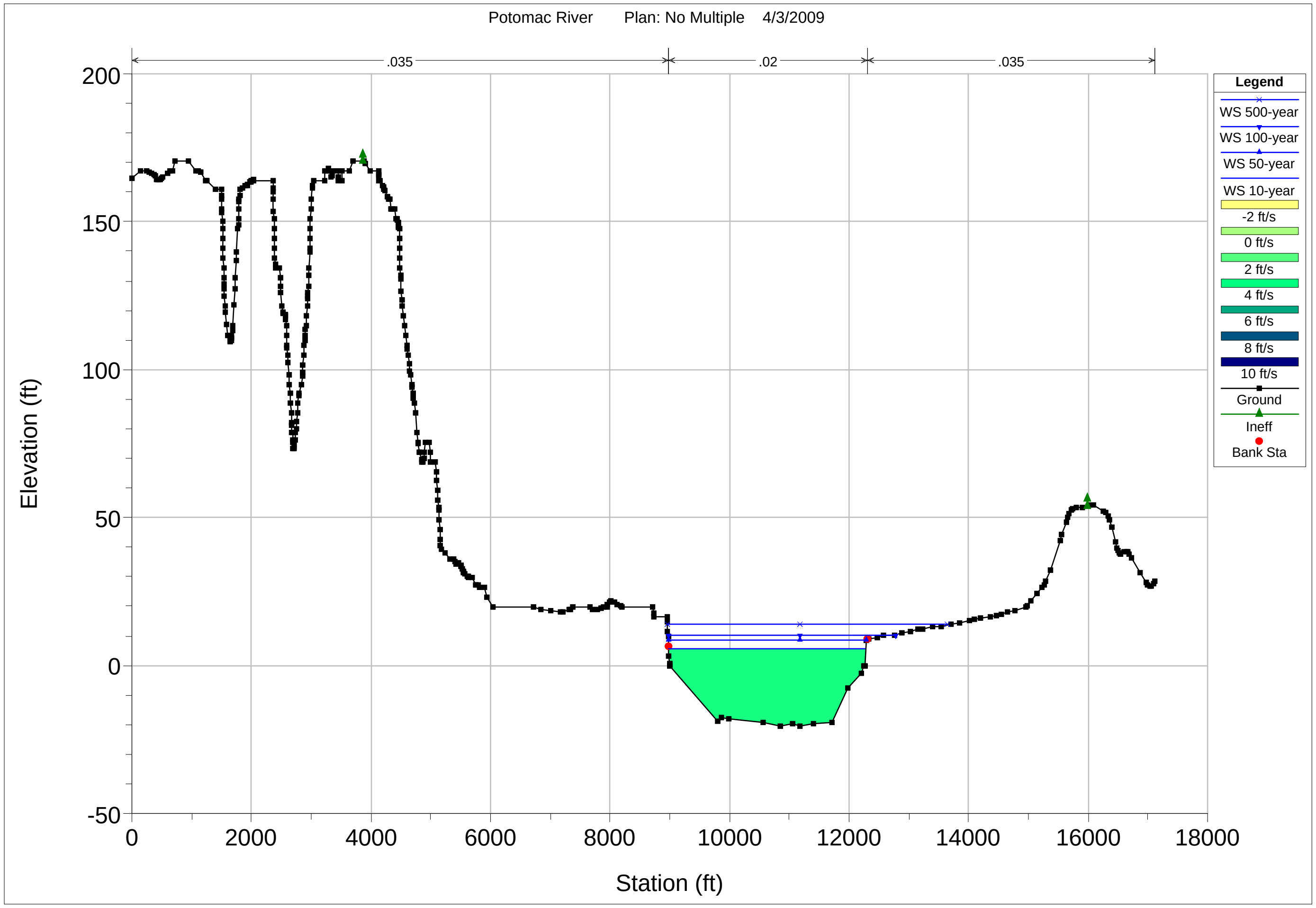
Model Geometry Comparisons



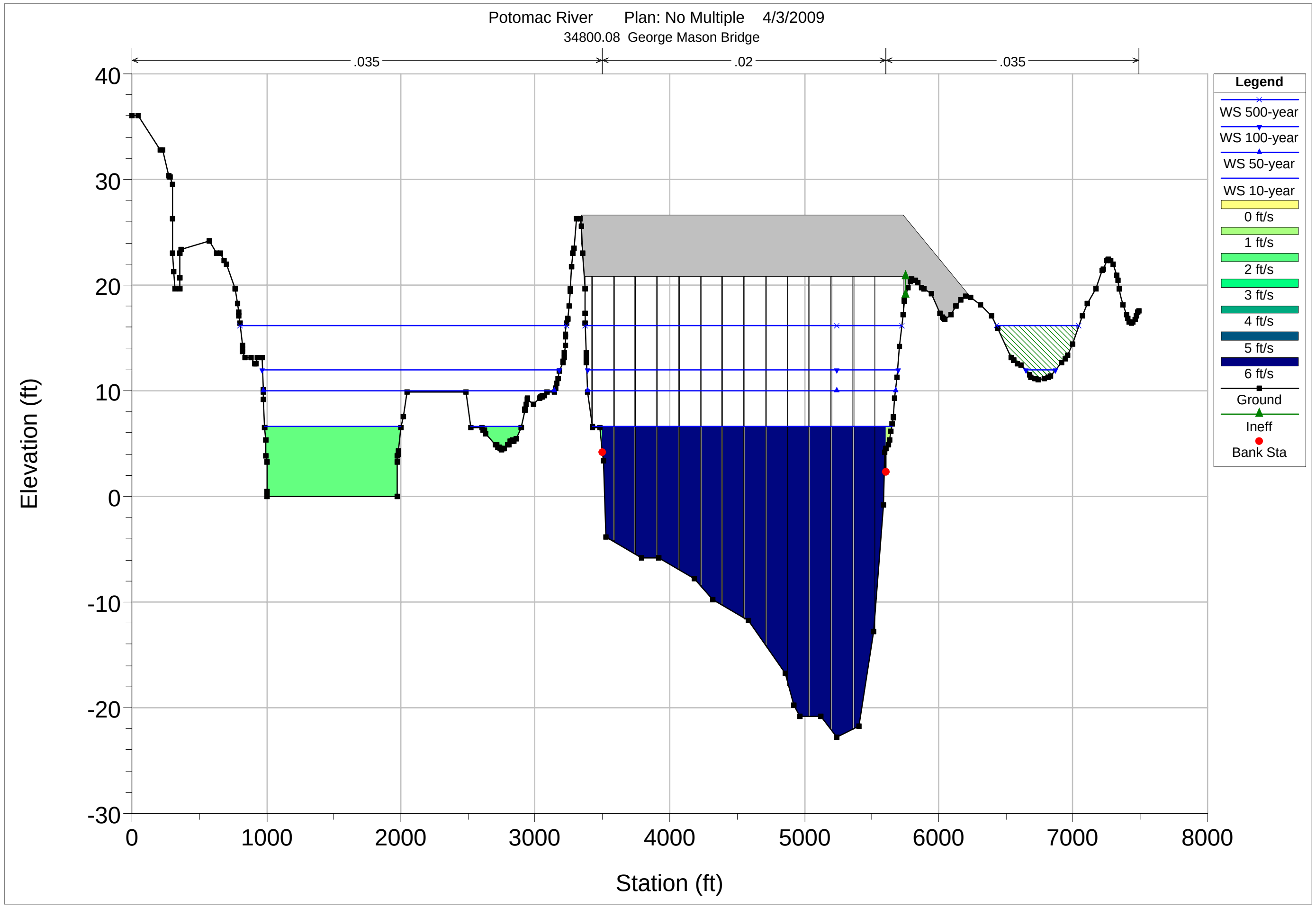
1D model - HEC-RAS Detailed Backwater Profiles



1D model - HEC-RAS Detailed Cross Sections



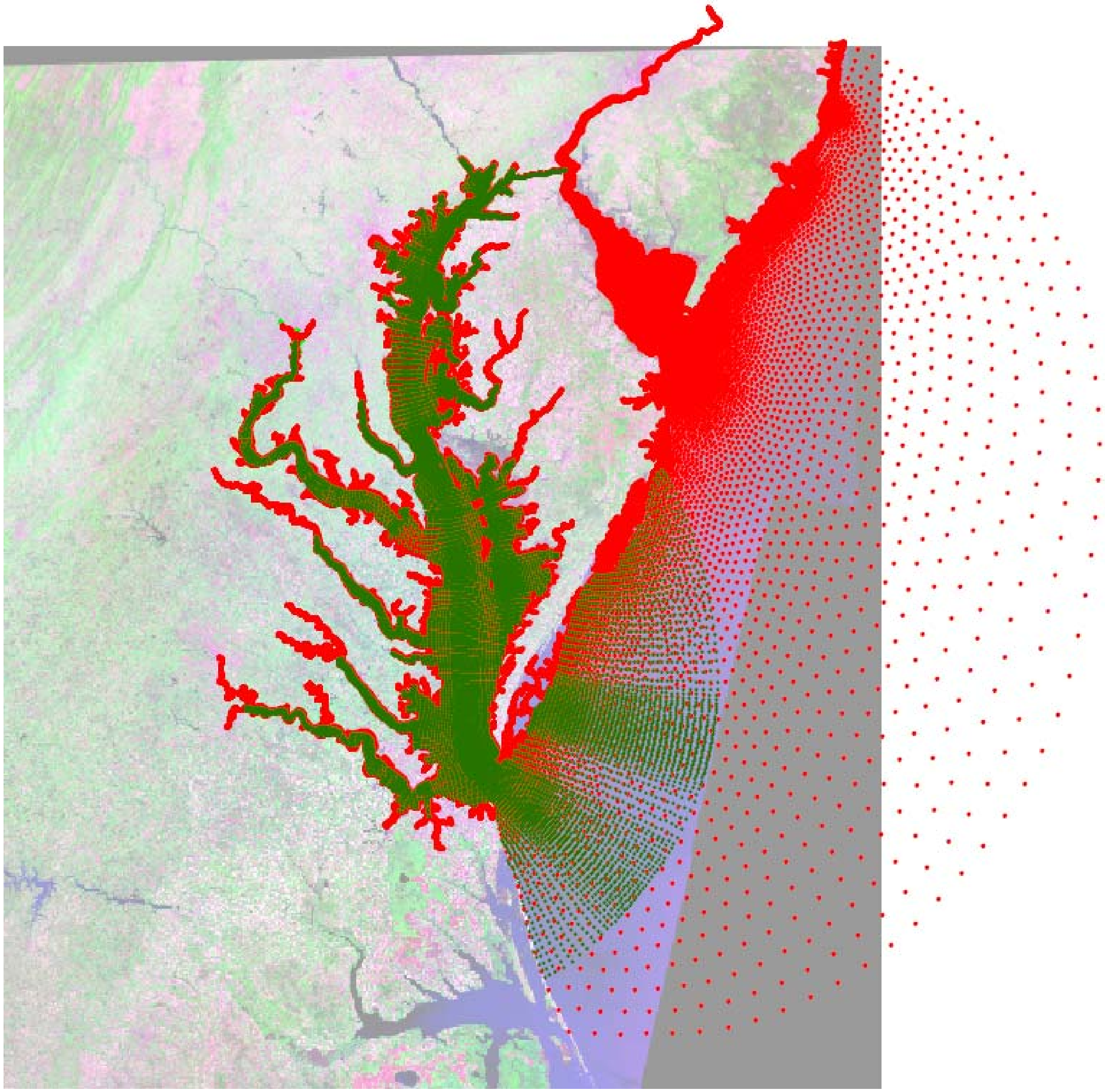
1D model - HEC-RAS Detailed Bridge Sections



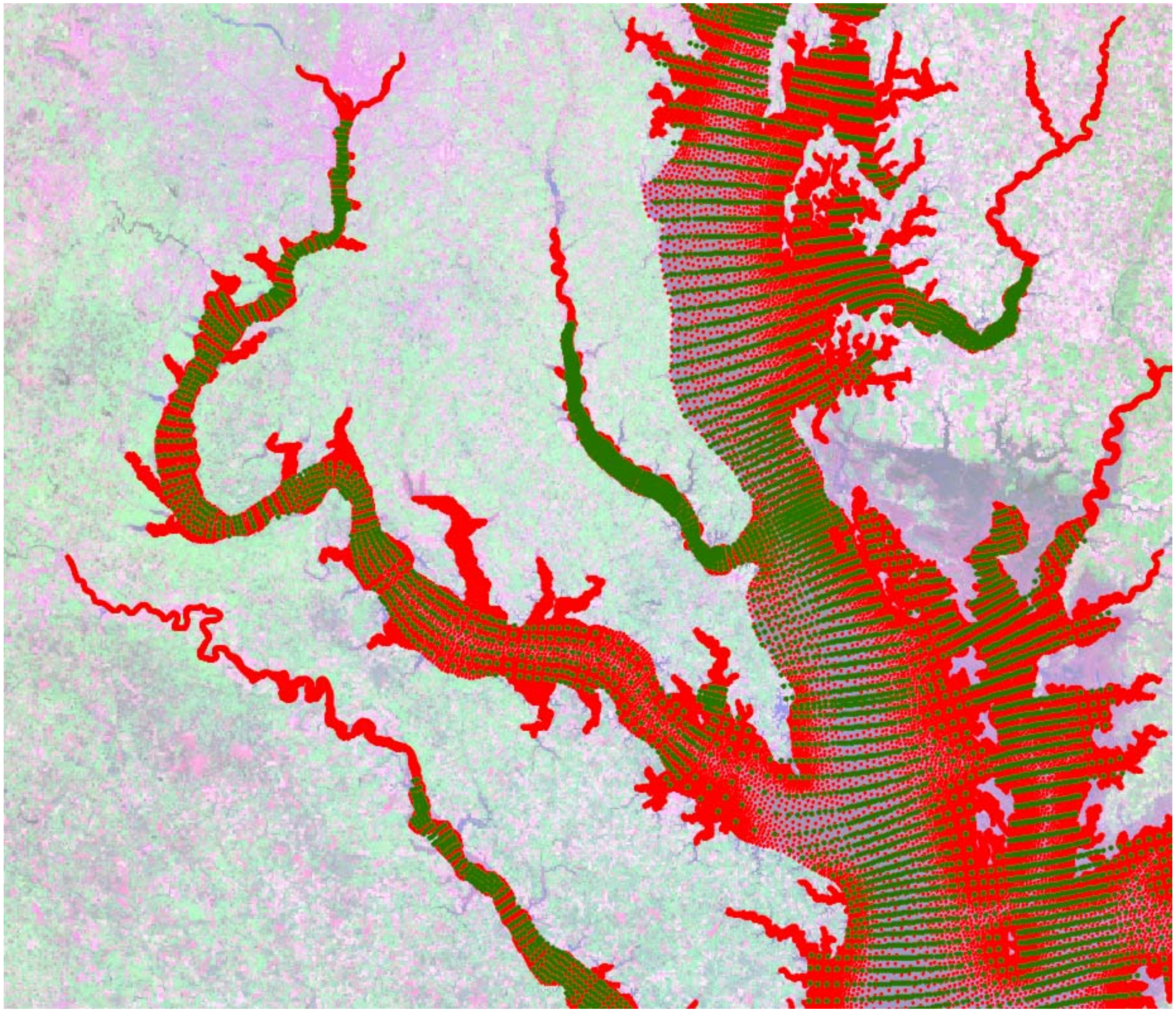
NOS 2D/3D models

- ADCIRC VDatum
- The Chesapeake Bay Operational Forecast System (CBOFS)
- Larger estuarine and ocean domain
- Better physical representation
- Detailed 3D model output

CBOFS2 and ADCIRC model domain

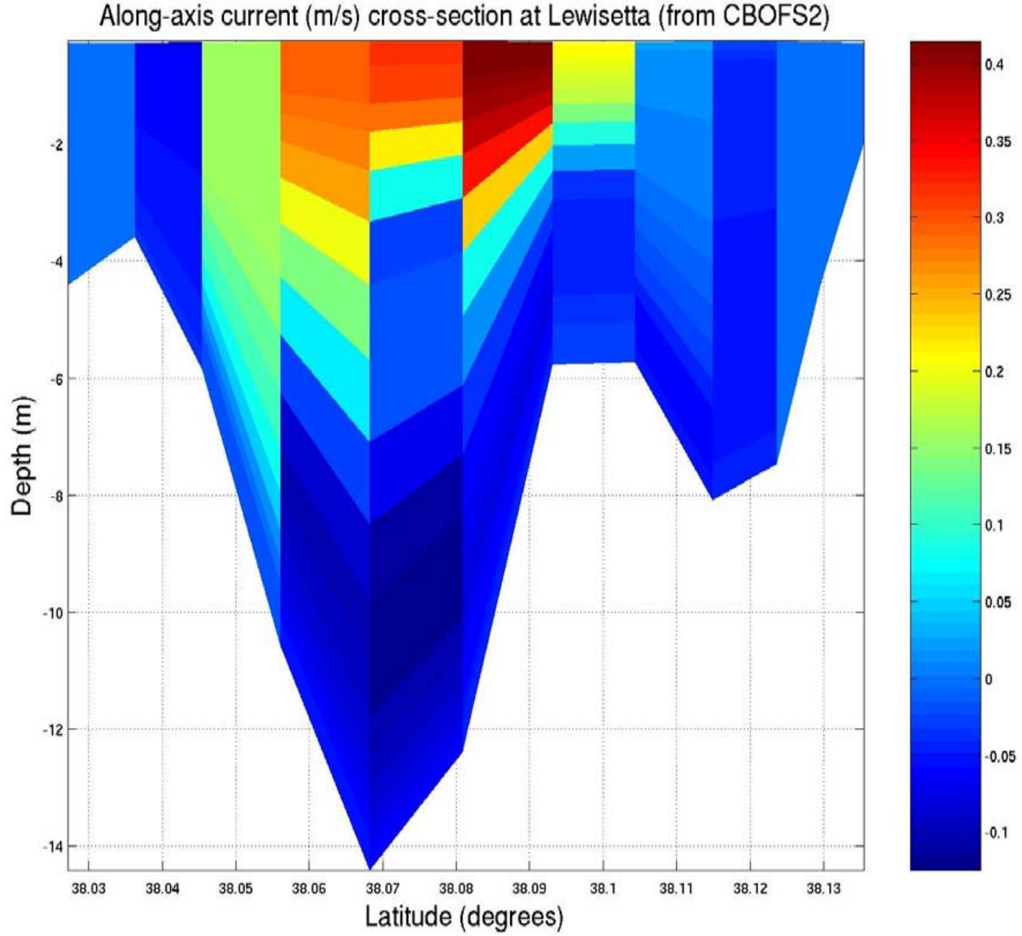


CBOFS2 and ADCIRC model domain



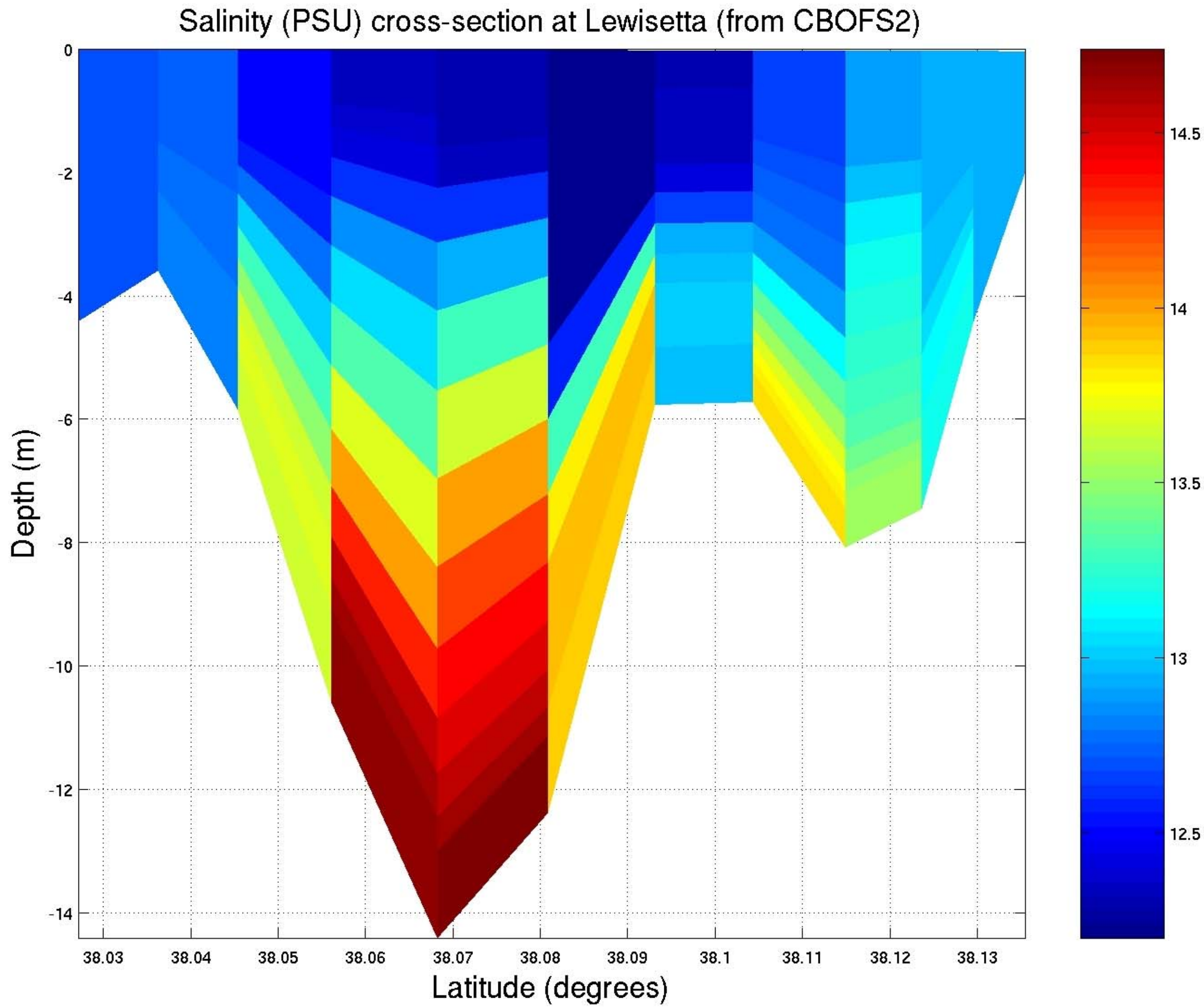
Layered Velocity - CBOFS2

From Hurricane Isabel



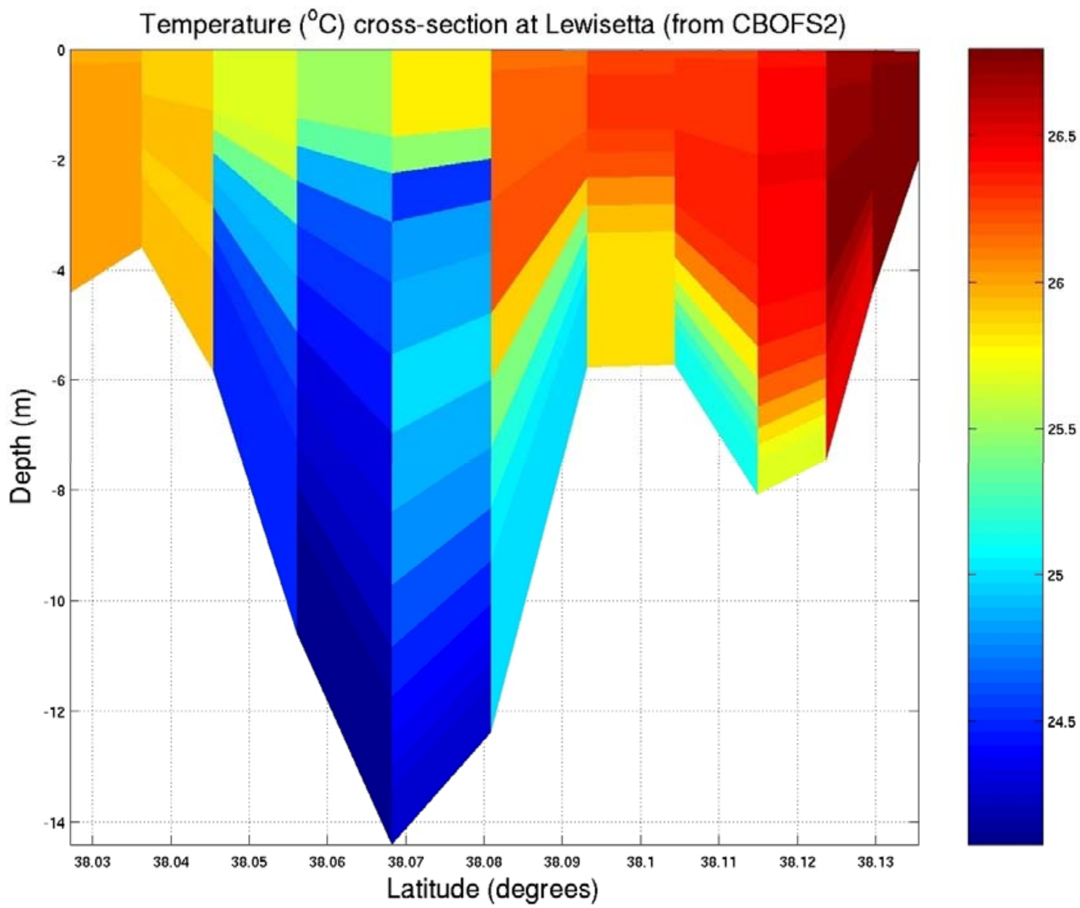
Layered Salinity - CBOFS2

From Hurricane Isabel



Layered water temperature - CBOFS2

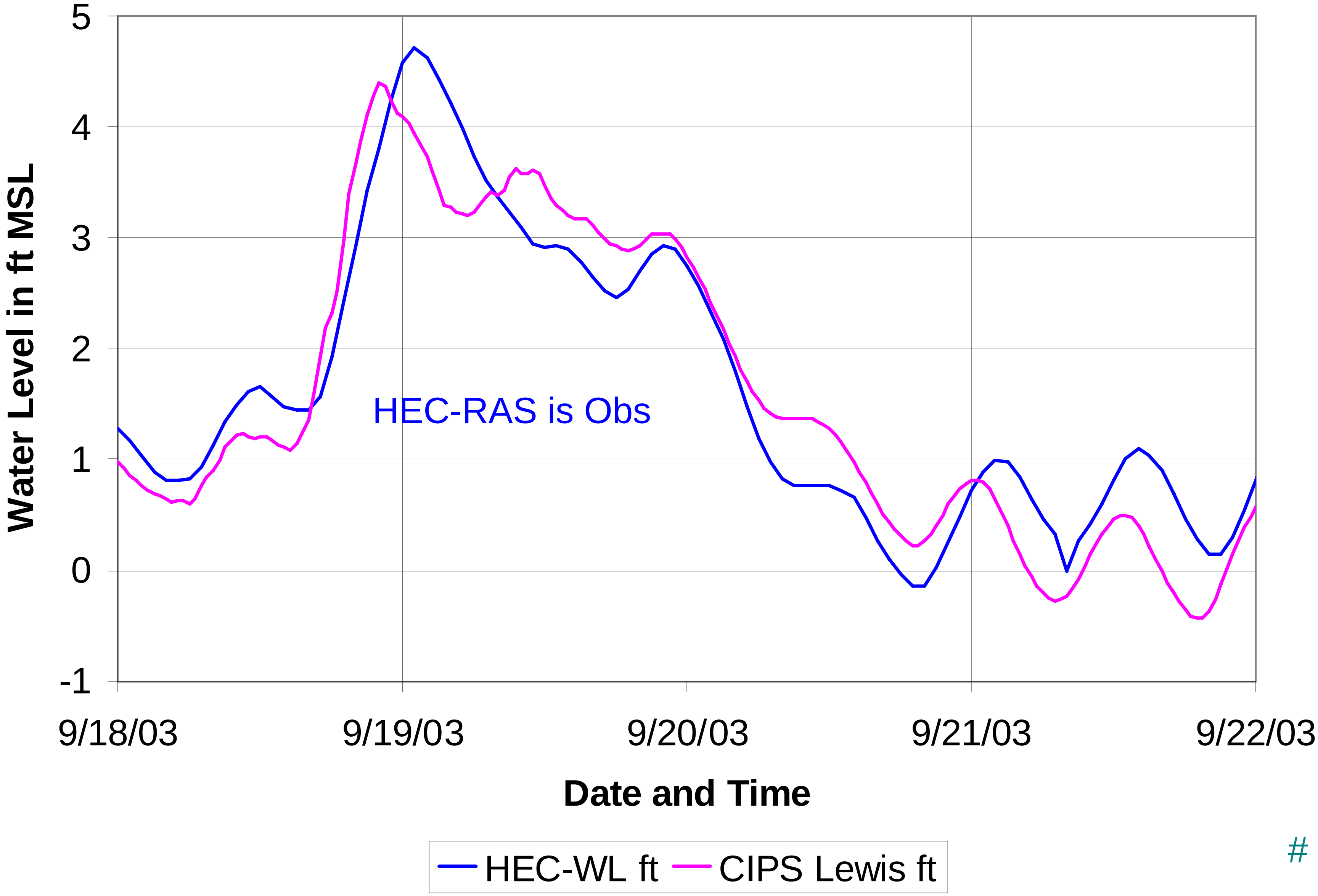
From Hurricane Isabel



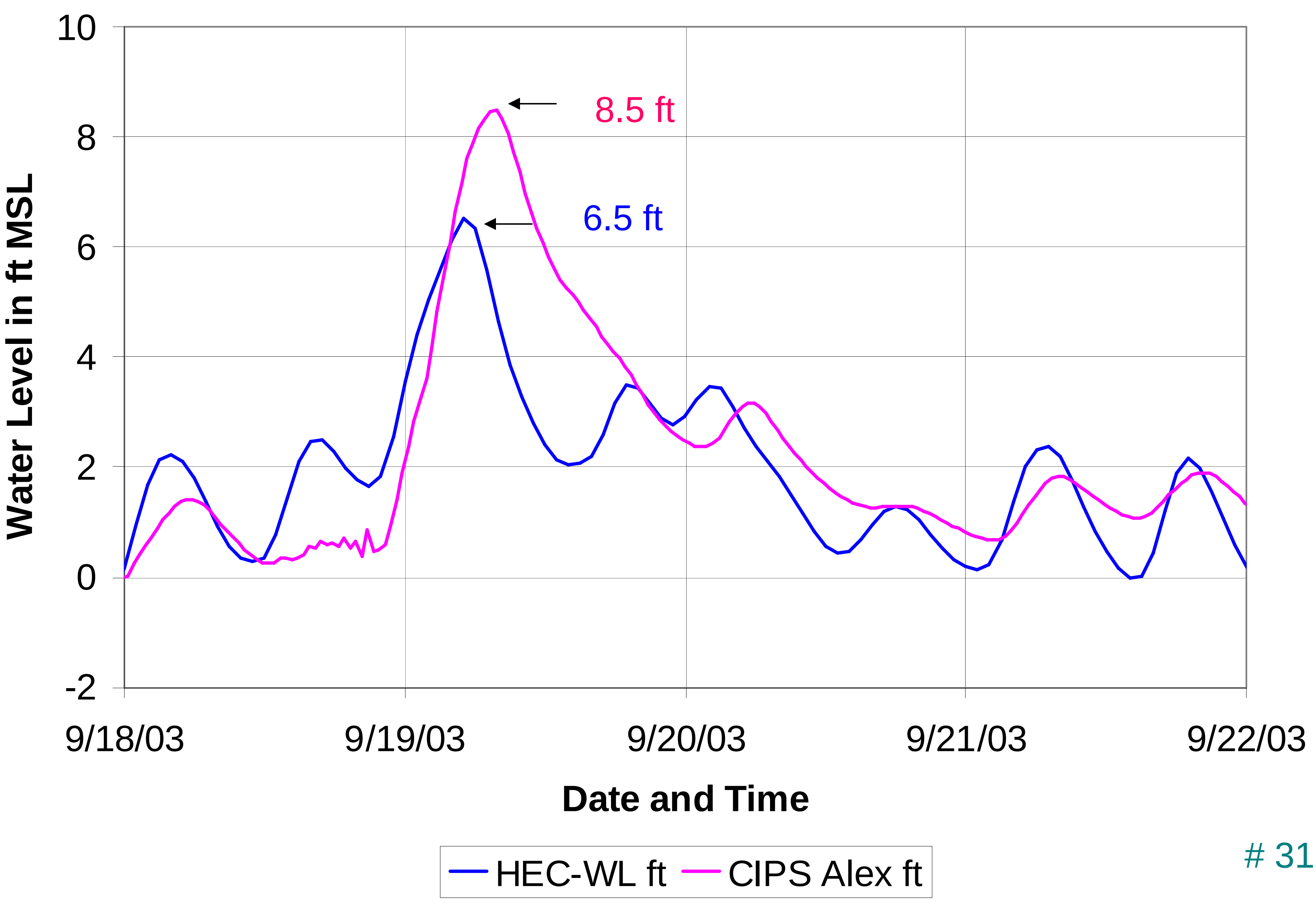
Hurricane Isabel 2003

Comparing HEC-RAS (1D) with CIPS (ELCIRC -2D)

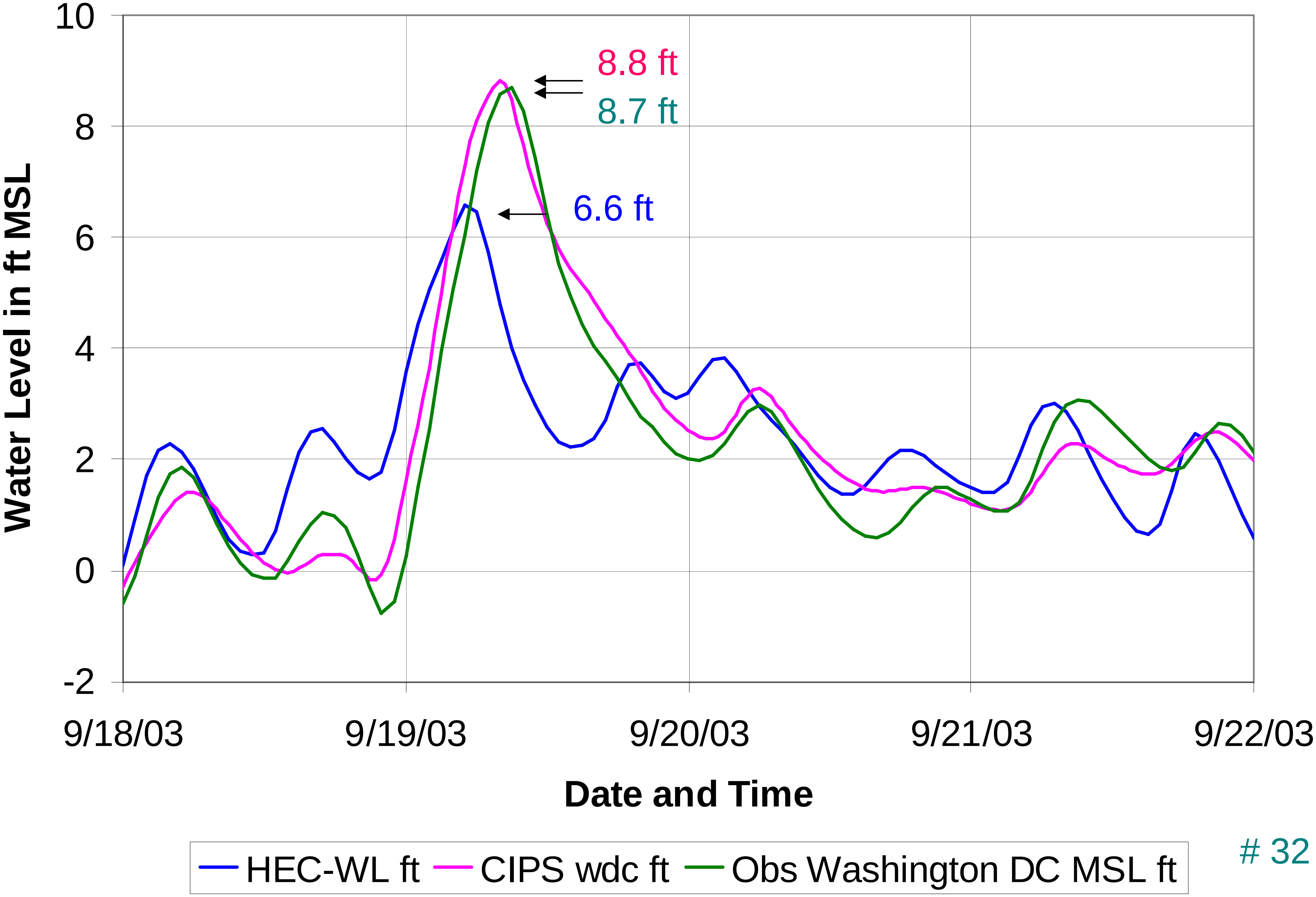
HEC-RAS & CIPS
Lewisetta, VA.



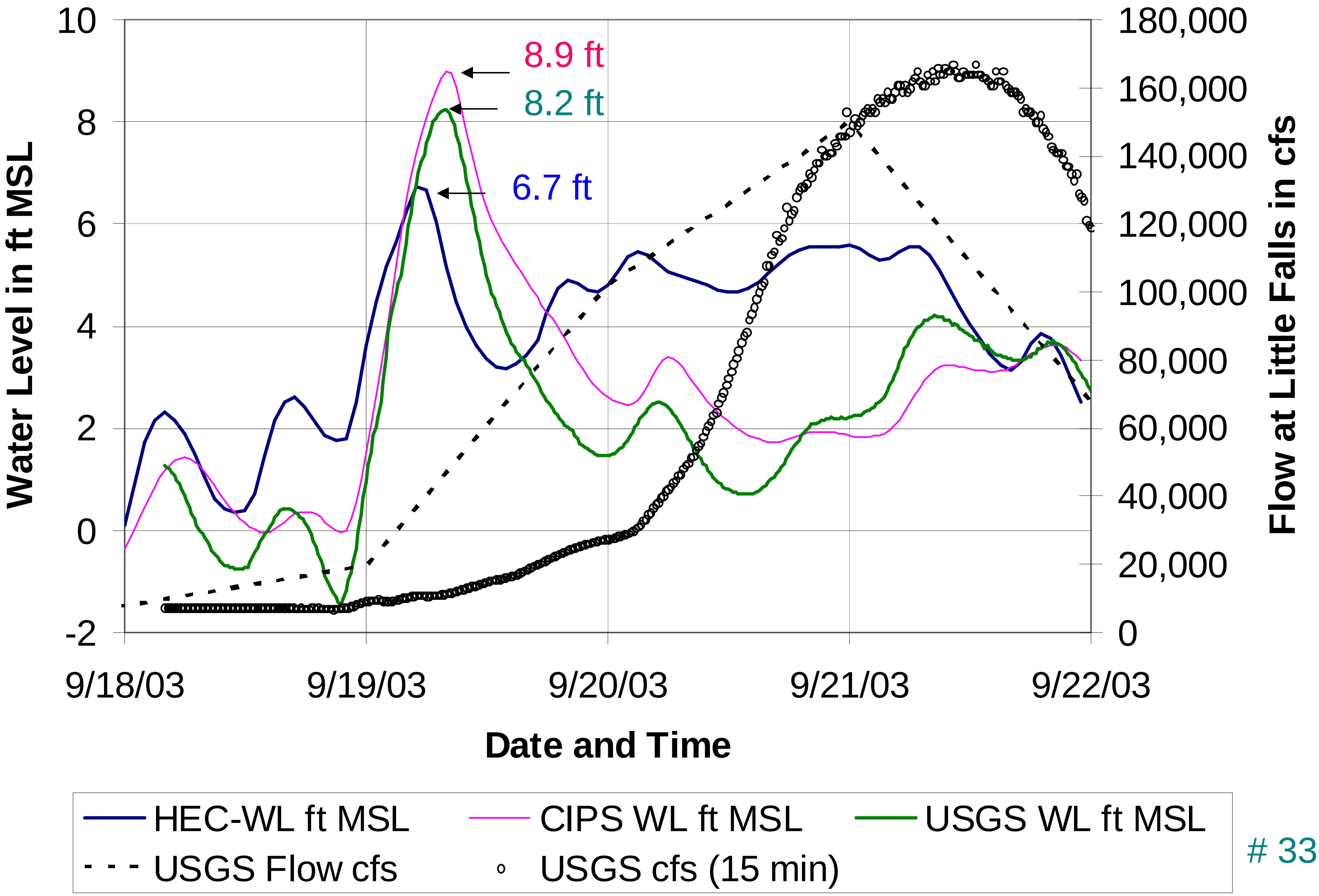
HEC-RAS & CIPS
Alexandria, Va.



HEC-RAS & CIPS
Washington DC, SW (CO-OPS)



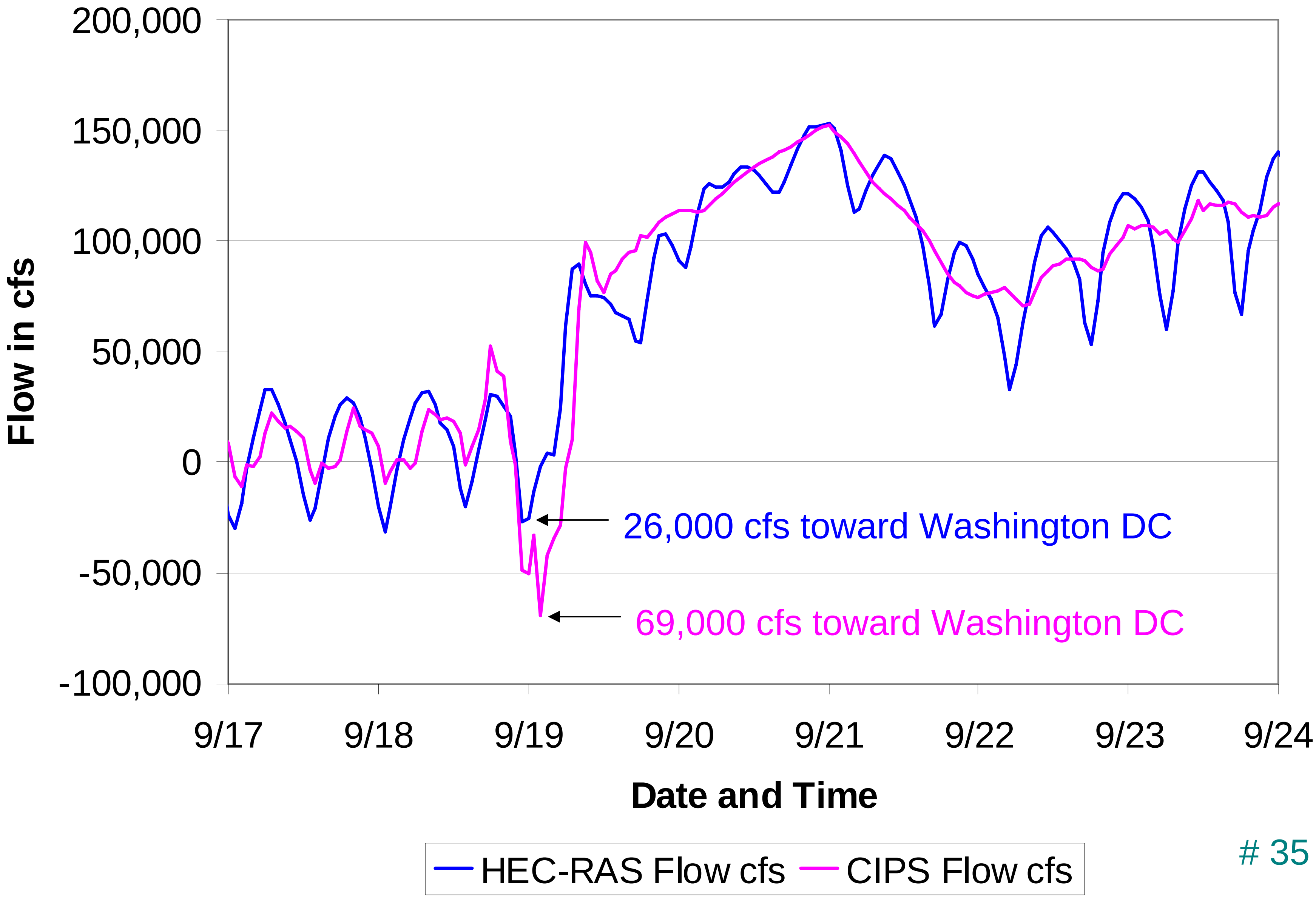
HEC-RAS & CIPS Wisconsin Avenue near Wash. DC



Hurricane Isabel 2003

Storm Surge Computed by HEC-RAS (1D) is lower than CIPS (ELCIRC -2D)

HEC-RAS & CIPS
Flow near Alexandria, Va.



Summary

- HEC-RAS results were within 6-12 inch of the predicted tide and within 1-2 feet of the observed hurricane surge and historic flood stages.
- In forecast mode, HEC-RAS models driven by ET Surge or CBOFS forecasts are within 6 – 12 inches of observations at Wisconsin Ave.
- HEC-RAS model accuracy becomes more dependent on estuary-ocean model boundary accuracy at points farther downstream and for events with lower freshwater flows.
- Tide/surge simulation is important to get backwater correct.
- 2D/3D models – better physics,, 2D/3D output
- CIPS has ***better transport than HEC-RAS with WL Boundary***

Thank you