Susquehanna Reservoir Sediment Transport Simulation and Effects in Chesapeake Bay using HEC-RAS, AdH and the Water-Quality Model

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Topics

- Background / Project Objectives
- HEC-RAS Data Selection
- Sediment transport calibration / simulation
- Model results (all 3)
- Summary

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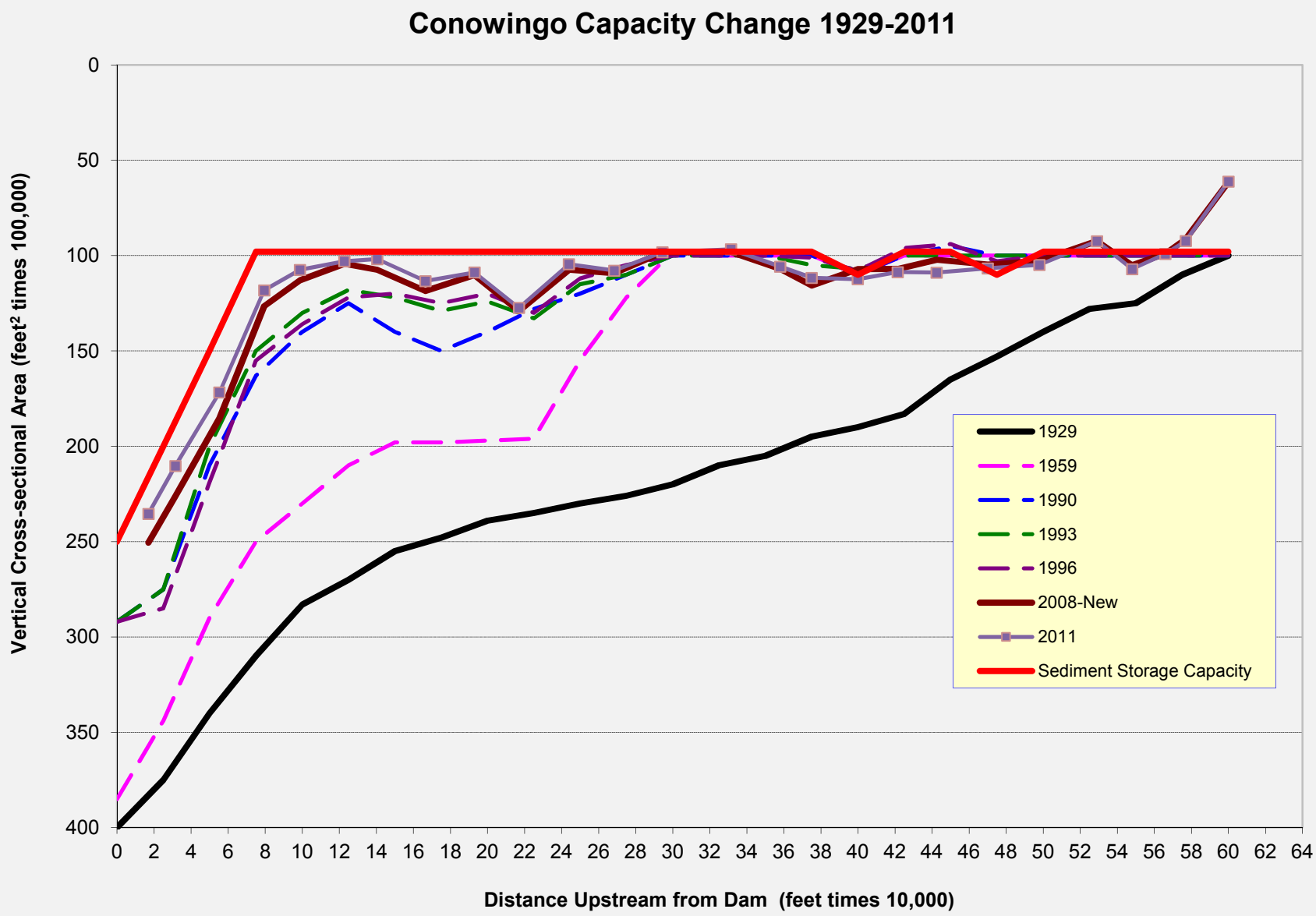
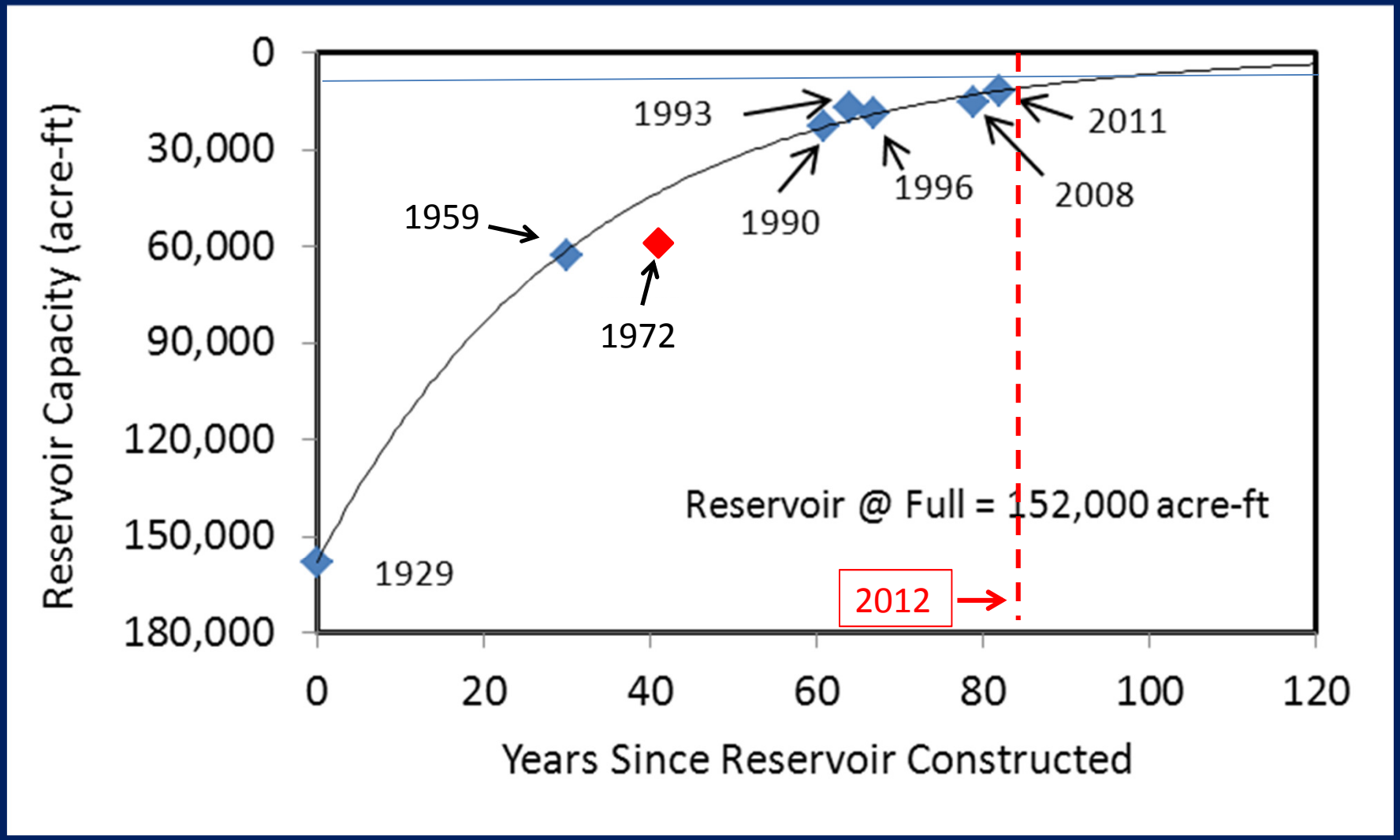
Background

- USGS collected bathymetry in 1990, 1993, 1996, and 2008
- Collected sediment cores (above) plus 2001, analyzed for size, nutrients, major ions, organics, and metals (Sediment Task Force)
- Document change in sediment storage capacity, size composition, and sediment chemistry
- Previous USGS HEC-6 Model (1995)
- Implications of Remaining Capacity
  - Chesapeake Watershed TMDL
  - PA/NY reduce more to meet goals

Changes in Bathymetry with Time

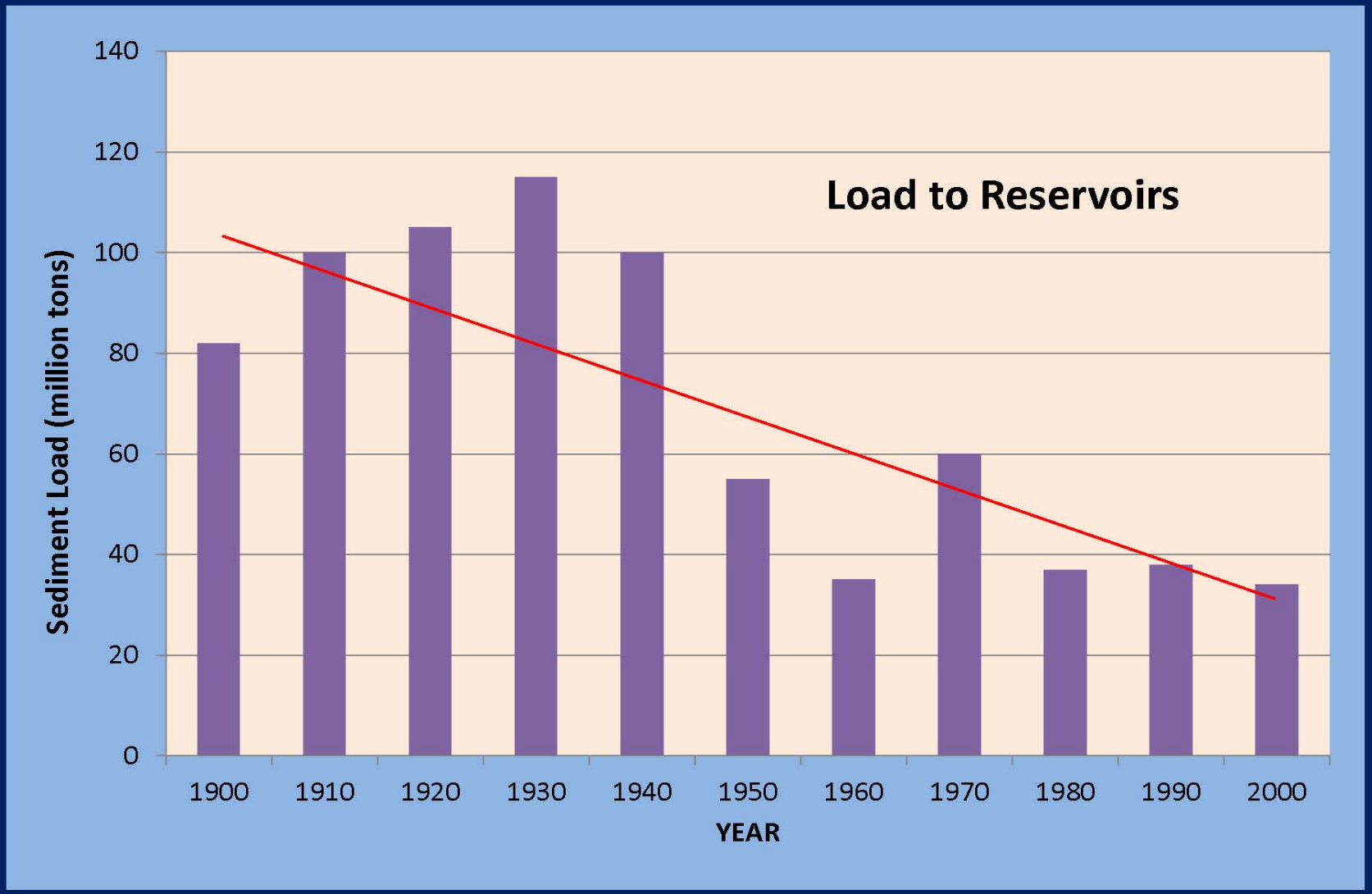


Changes in Bathymetry with Time



2012 – only 10-15% of original volume remains to fill to capacity

Sediment inputs have been decreasing (about 2/3 less)



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Modeling Objectives

- Construct, calibrate, and validate a HEC-RAS 1-D sediment model for the entire Reservoir system (~33 miles)
- GOAL - Simulate the loads in and out, bed-form change, and particle size distribution
- Product - Produce input boundary condition files for Conowingo Reservoir for USACE AdH 2-D model
- AdH model provide inputs (nutrients and sediments) to the CB Water-Quality Model for scenario runs.

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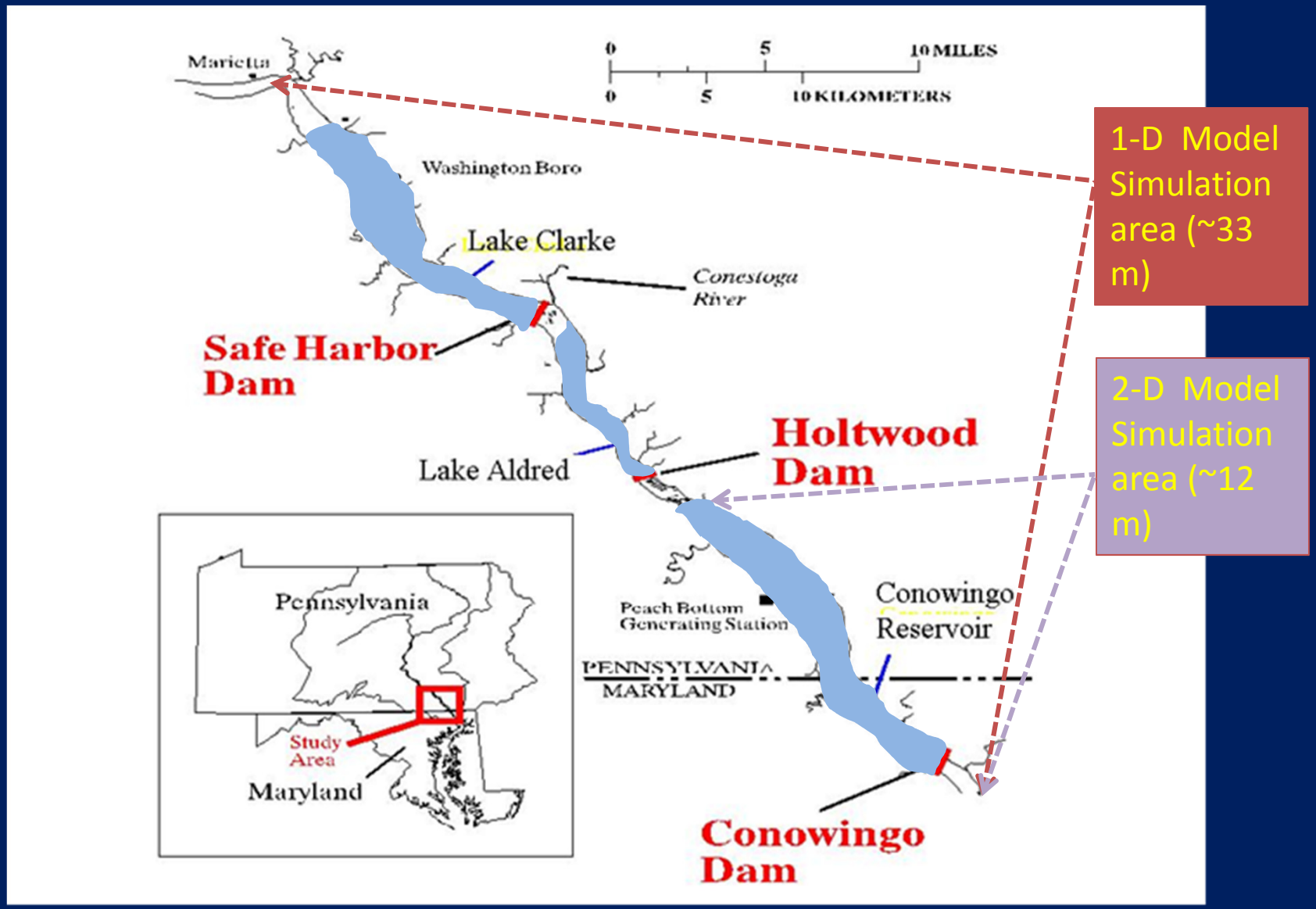
Susquehanna River Reservoirs



Definitions

- 1-D sediment model – model either erodes OR deposits, not both on same transect, 2-D both
- Shear stress (SS) – force of water acting on the channel sides and bed, 1-D model can only have one value, 2-D can vary with depth
- Critical Shear Stress (CSS) – shear stress required to mobilize sediments, (different for each particle size), 1-D model can only have one value, 2-D can vary with depth
- Generally, if SS < CSS, then deposition, if SS = CSS, then "equilibrium", if SS > SCC, then degradation (scour)

HEC-RAS Model – 3 main steps

1) Prepare Input data – sediment and flow

2) Construct Geometric and Hydraulic framework

3) Calibrate to observed data

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Input Data

- Sediment

  - transport curves or estimated daily sediment loads

  - core data (particle size and depth)

- Flow

  - rating curve or actual daily flow data

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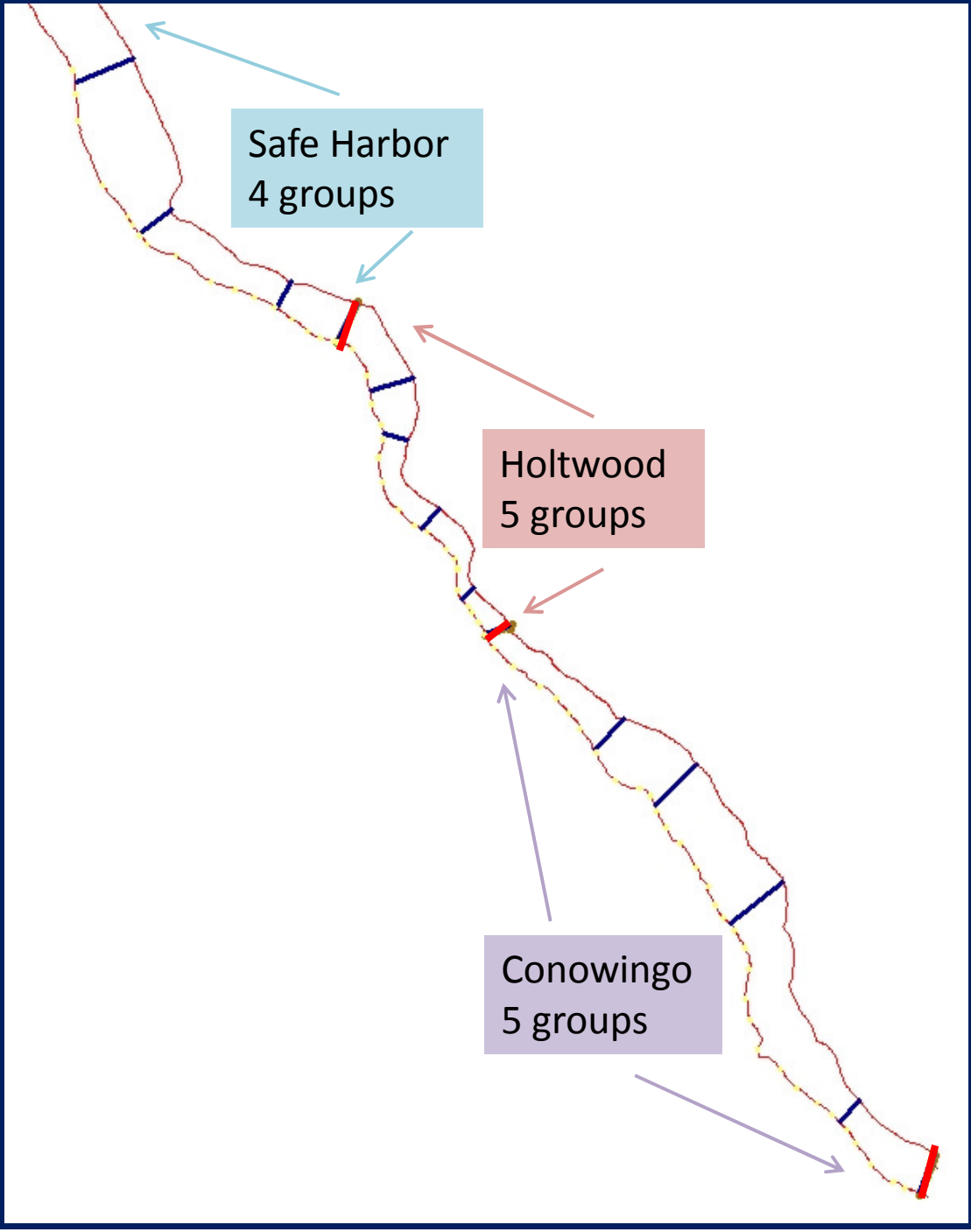
Bed Material Grouping (cores)

Assigned average (non-varying) shear stress based on particle size and bed thickness

and

USACE Sediment Flume data



HEC-RAS Model – 3 main steps

1) Prepare Input data – sediment and flow

2) Construct Geometric and Hydraulic framework

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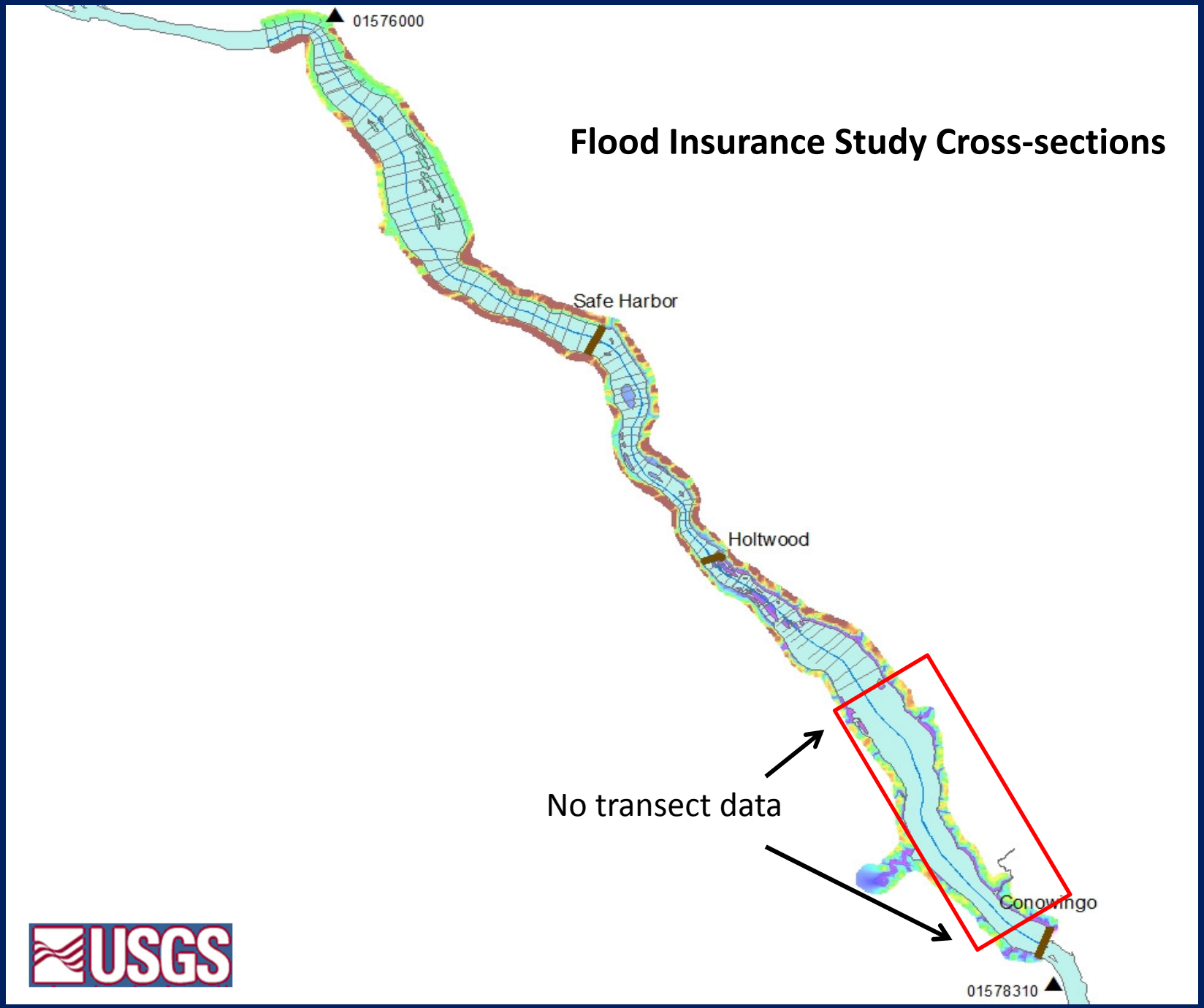
Model Geometry Options :

1. Adapt HEC-6 model (USGS, 1995)
   - Performed poorly, no digital files, not vialbe
2. Convert HEC-2 (FIS) model to RAS sed model
   - Covers 75% of reach, XS stationing errors, no XS bathymetry, and poor XS alignment current bathymetry
3. Construct new RAS model
   - Alignment of XS cut lines with current bathymetry
   - Model geometry better suited for sediment model (i.e., no structures, fewer XS)
   - Use Lidar-derived topography for channel banks

USGS

Flood Insurance Study Cross-sections



Options :

- Adapt HEC-6 model (USGS, 1995)
  - Performed poorly, no digital files
- Convert HEC-2 (FIS) model to RAS sed model
  - poor coverage, XS stationing errors, no XS bathymetry, not viable
- Construct new RAS model
  - Alignment of XS cut lines with current bathymetry
  - Model geometry better suited for sediment model (i.e., no structures, fewer XS)
  - Use Lidar-derived topography for channel banks

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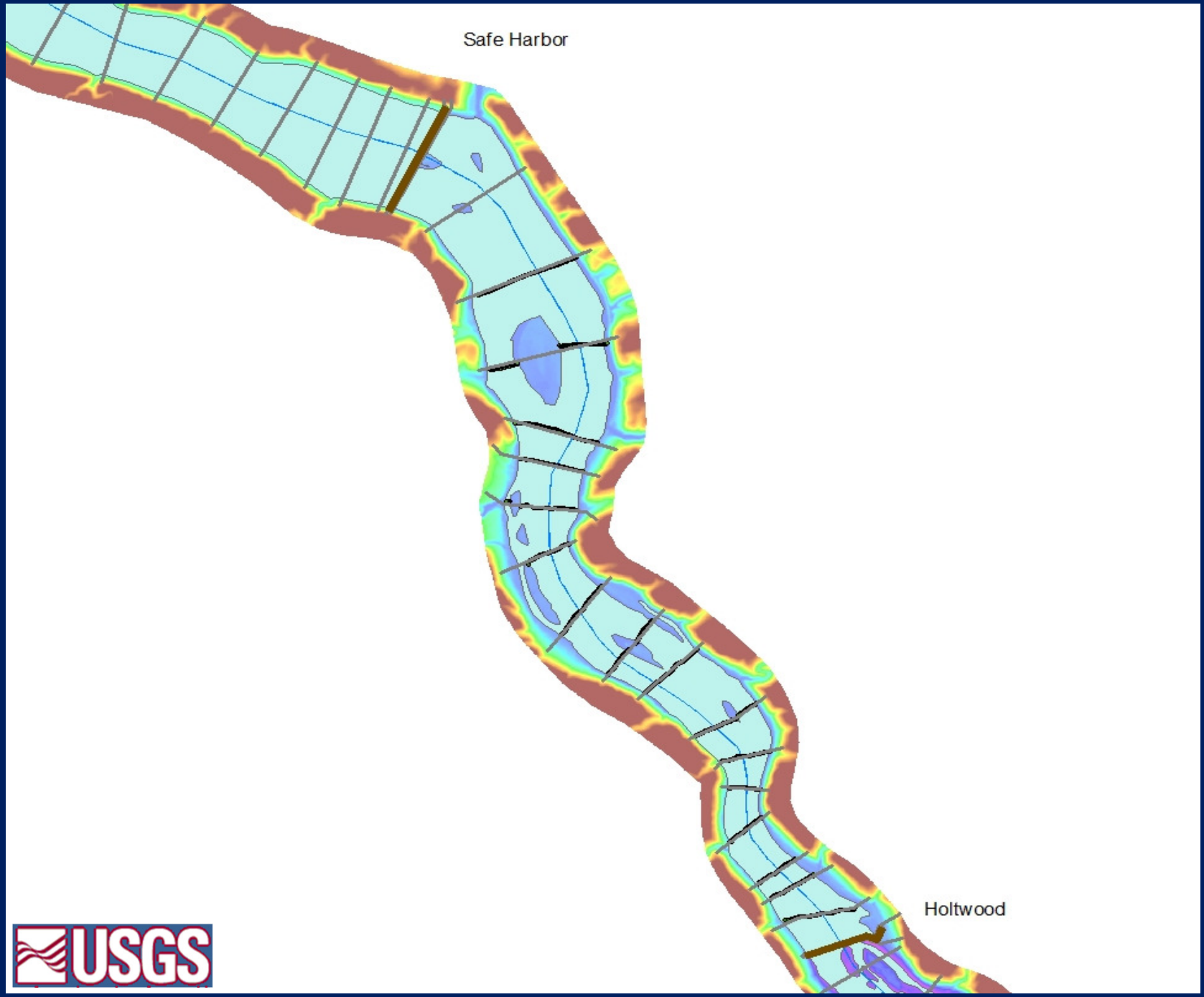
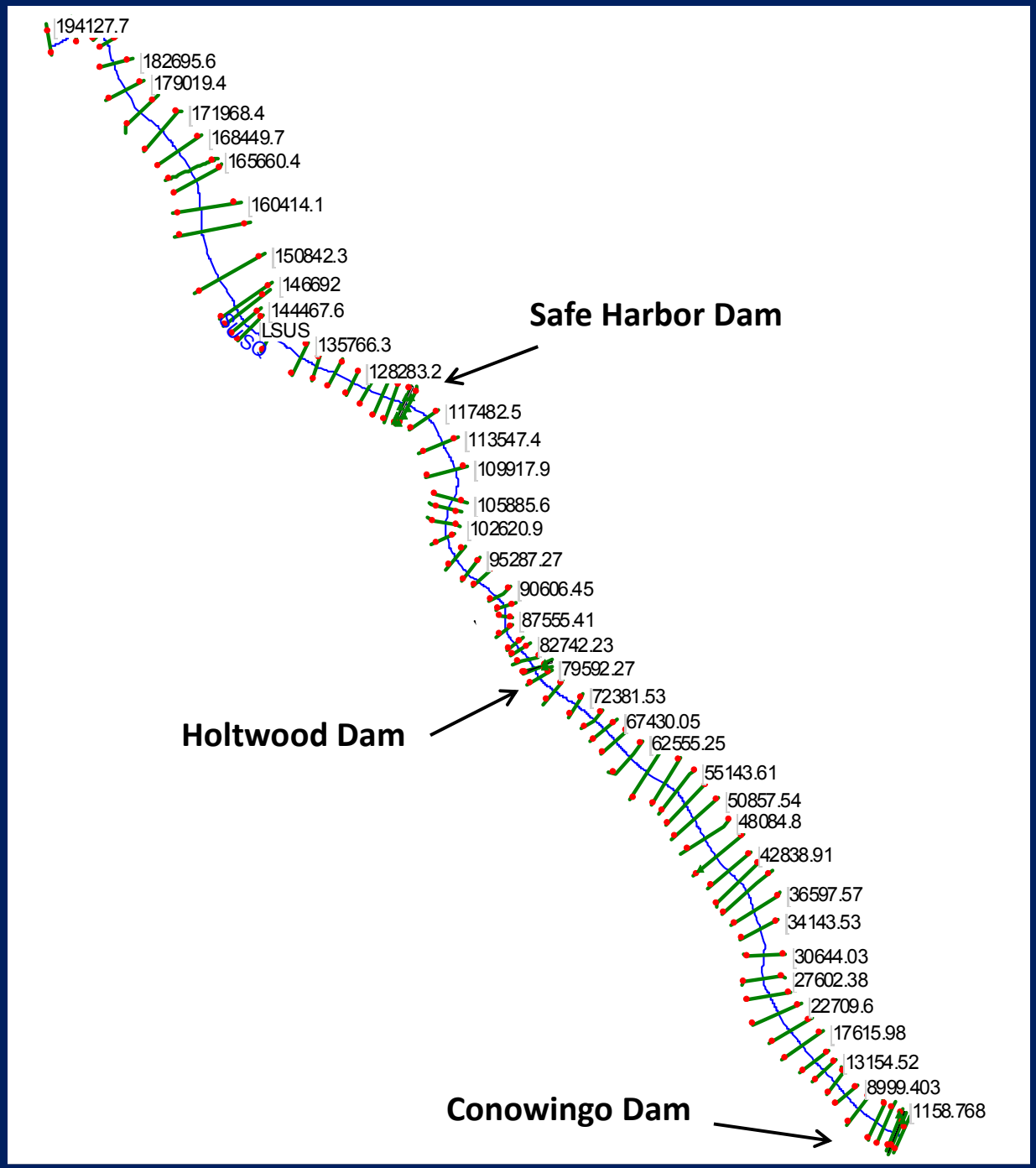

Safe Harbor
Holtwood

Final Model Cross-sections

34 in Conowingo
18 In Holtwood
28 in Safe Harbor
80 X-sections

Avg one X-section every 0.4 mile



Hydraulics

Hydraulic Options :

- Discharge Rating Curve
- Actual daily value discharge

Gate and Spillway Simulation

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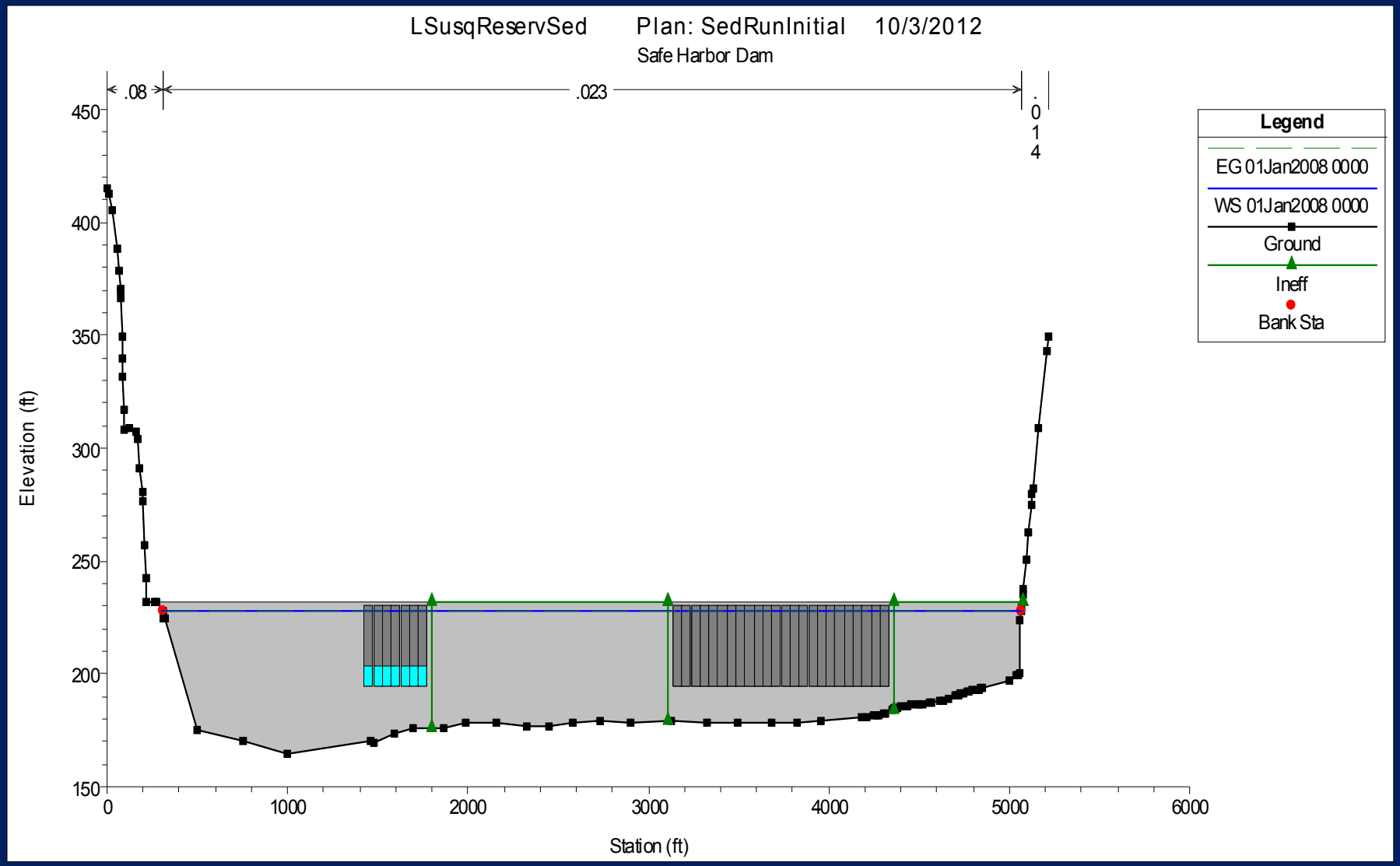
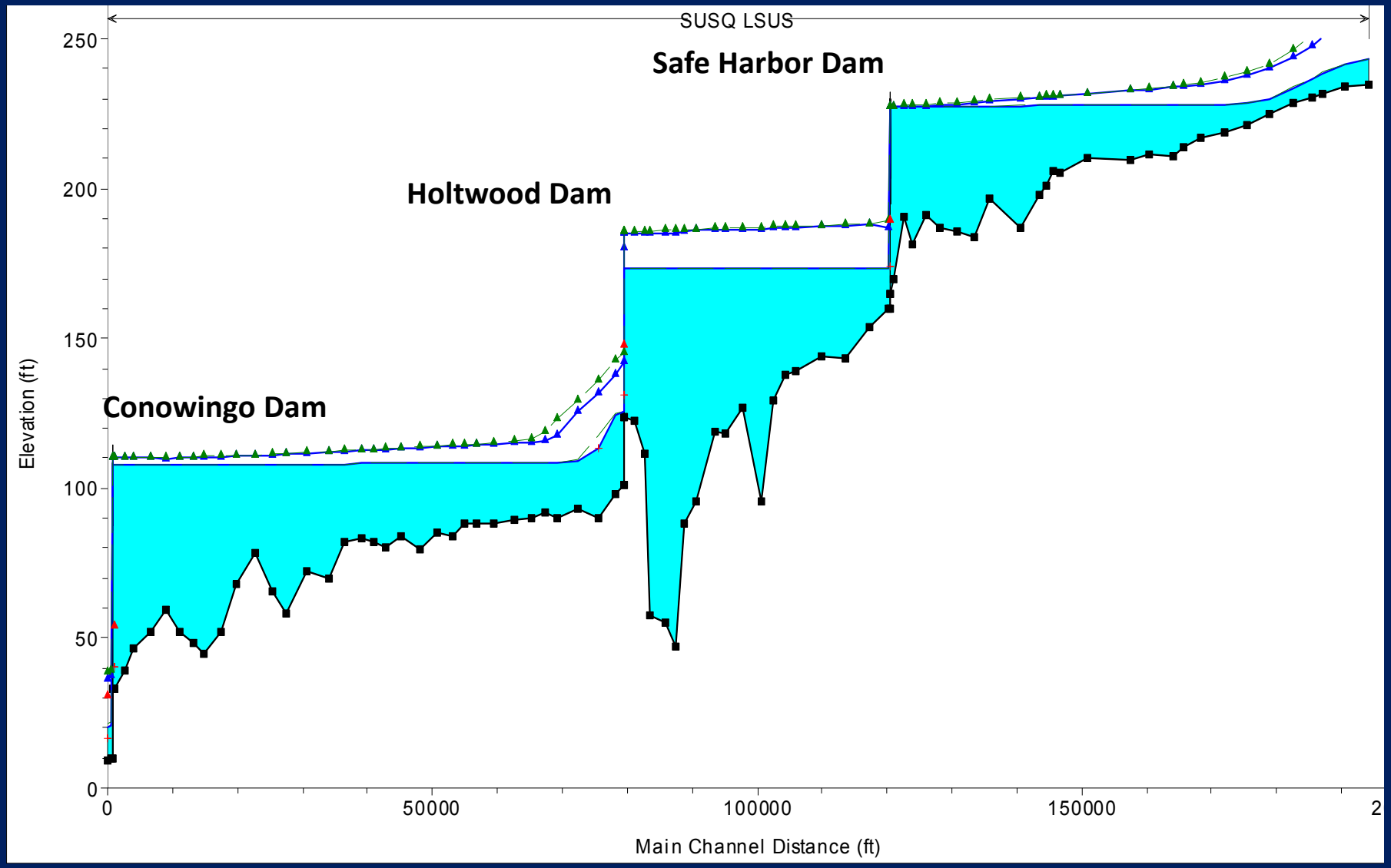
Gate and spillway Representation (Safe Harbor)



Reservoir System Hydraulic Representation



HEC-RAS Model – 3 main steps

1) Prepare Input data – sediment and flow

2) Construct Geometric and Hydraulic framework

3) Calibrate to observed data

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Simulation targets ("calibration" data)

- Reasonable estimates of particle size distributions and sediment depth's in the Reservoir System.
- Bathymetry from 2008 and 2011 surveys
- Daily streamflow and sediment loads for 2008-2012
- More detailed sediment loads and flow from Sept. 2011 flood (Tropical storm Lee)

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HEC-RAS Model Calibration Issues

- 2008-2011 Bathymetry data indicates both deposition and scour in same X-Section, 1-D model simulates only one occurrence
- Modeled "fall velocity" (silts and clays) about 2X lower (lack of deposition) then expected from literature values and 2-D model, and CAN NOT adjust model values
- Model only allows one critical shear stress value, SEDFLUME data indicates wide variability (8x)
- Increasing the critical shear resulted in an increase in scour (contradictory effect) in some spatial areas

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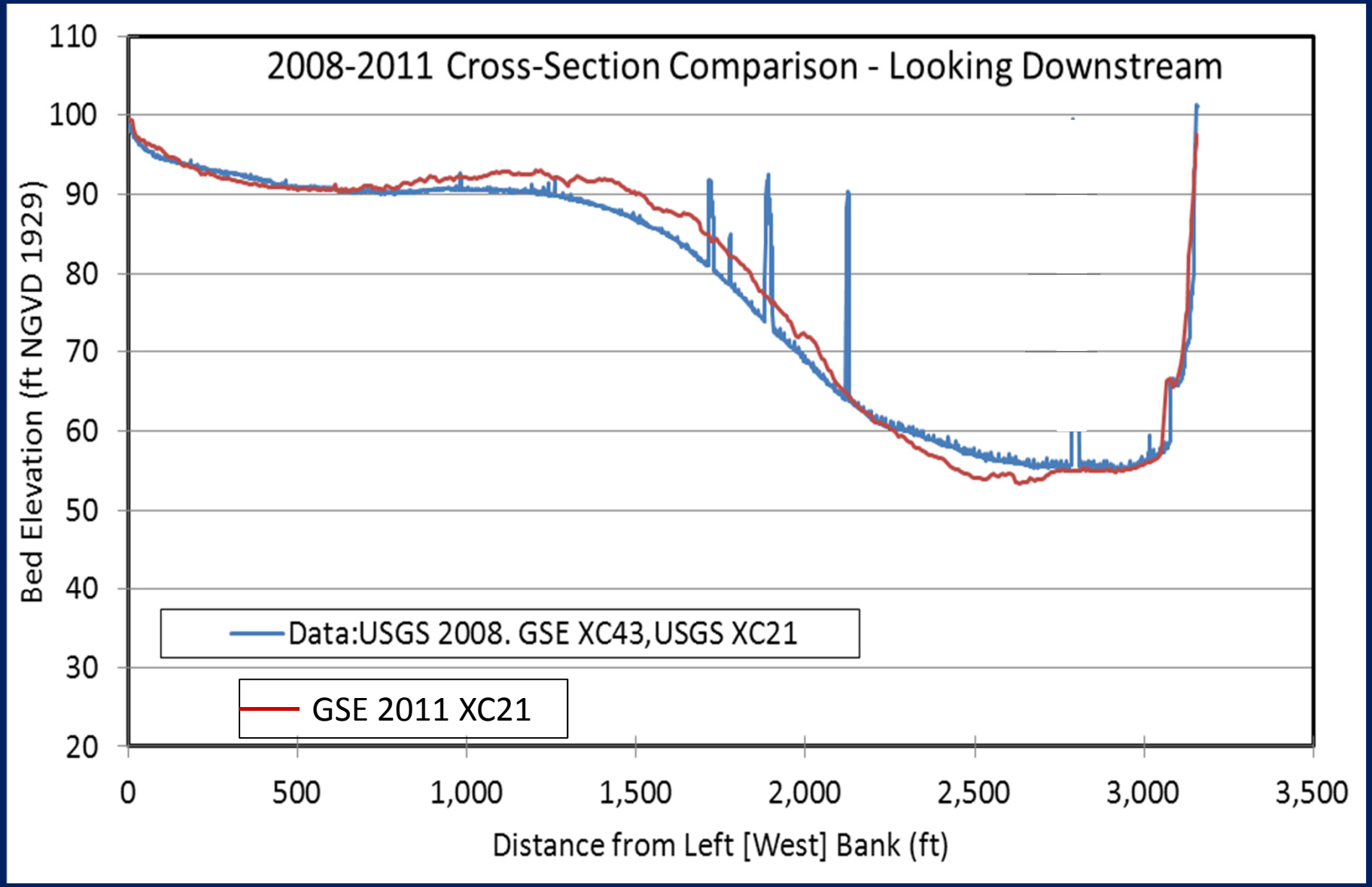
2008-2011 Cross-Section Comparison - Looking Downstream
Bed Elevation (ft NGVD 1929)
110
100
90
80
70
60
50
40
30
20
0
500
1,000
1,500
2,000
2,500
3,000
3,500
Distance from Left [West] Bank (ft)
Data:USGS 2008. GSE XC43,USGS XC21
GSE 2011 XC21

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Results – Model Development

- Due to uncertainty (fall-velocity and bed sorting), built and verified 2 models, one net "depositional" one net "scour"
- Both boundary condition outputs delivered to USACE for 2-D model calibration
- "Depositional" model recommended and produced "best" overall results
- "Scour" model performed better for T.S. Lee and other short-term high flow scour events
- Allows for range in uncertainty

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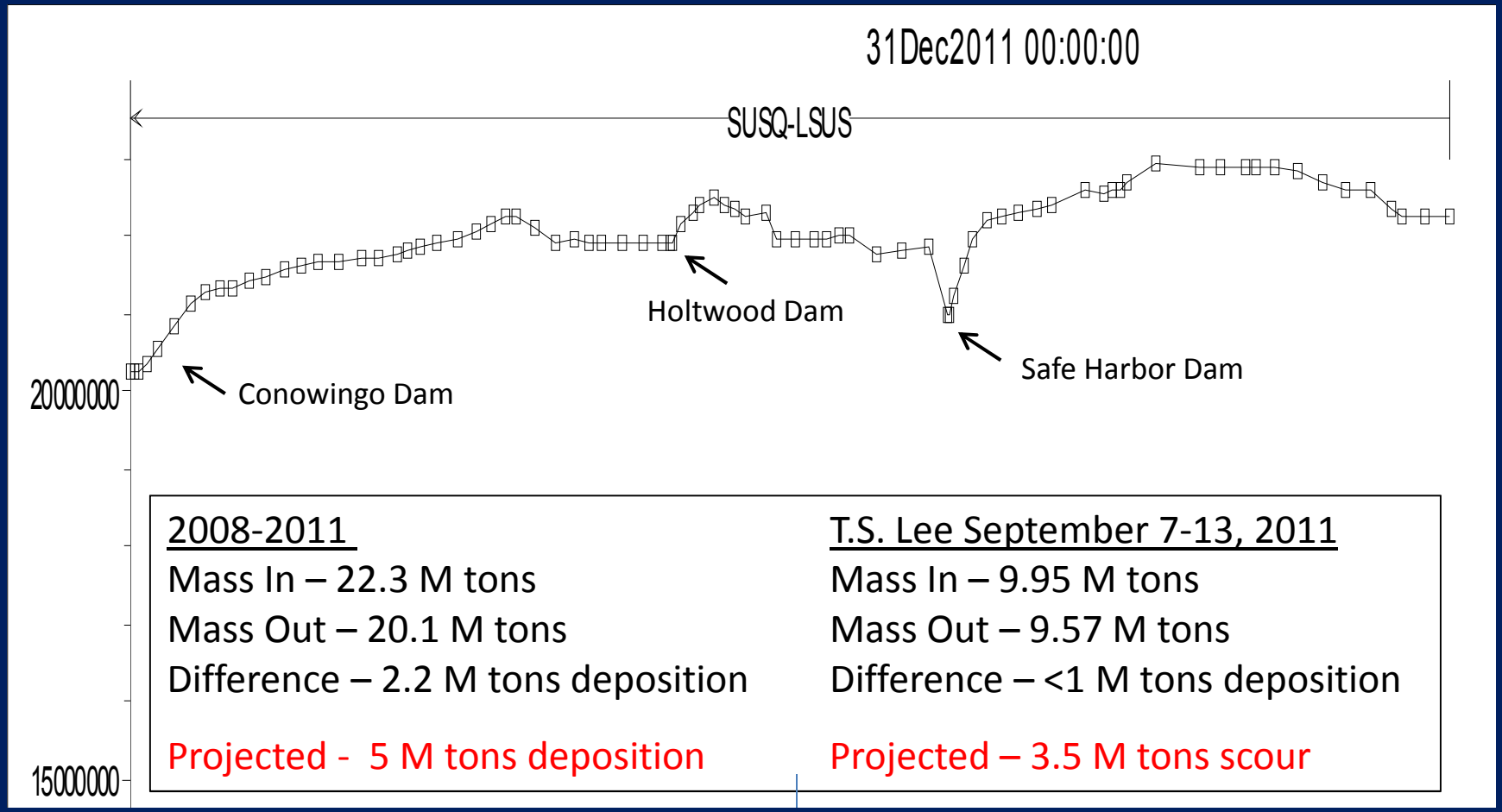
HEC-RAS Deposition Model

(Transport Function – *Laursen (Copeland)*, Sorting Method – *Exner5*, Fall Velocity Method – *Ruby*, Cohesive shear – *0.018 lbs/sqft*))

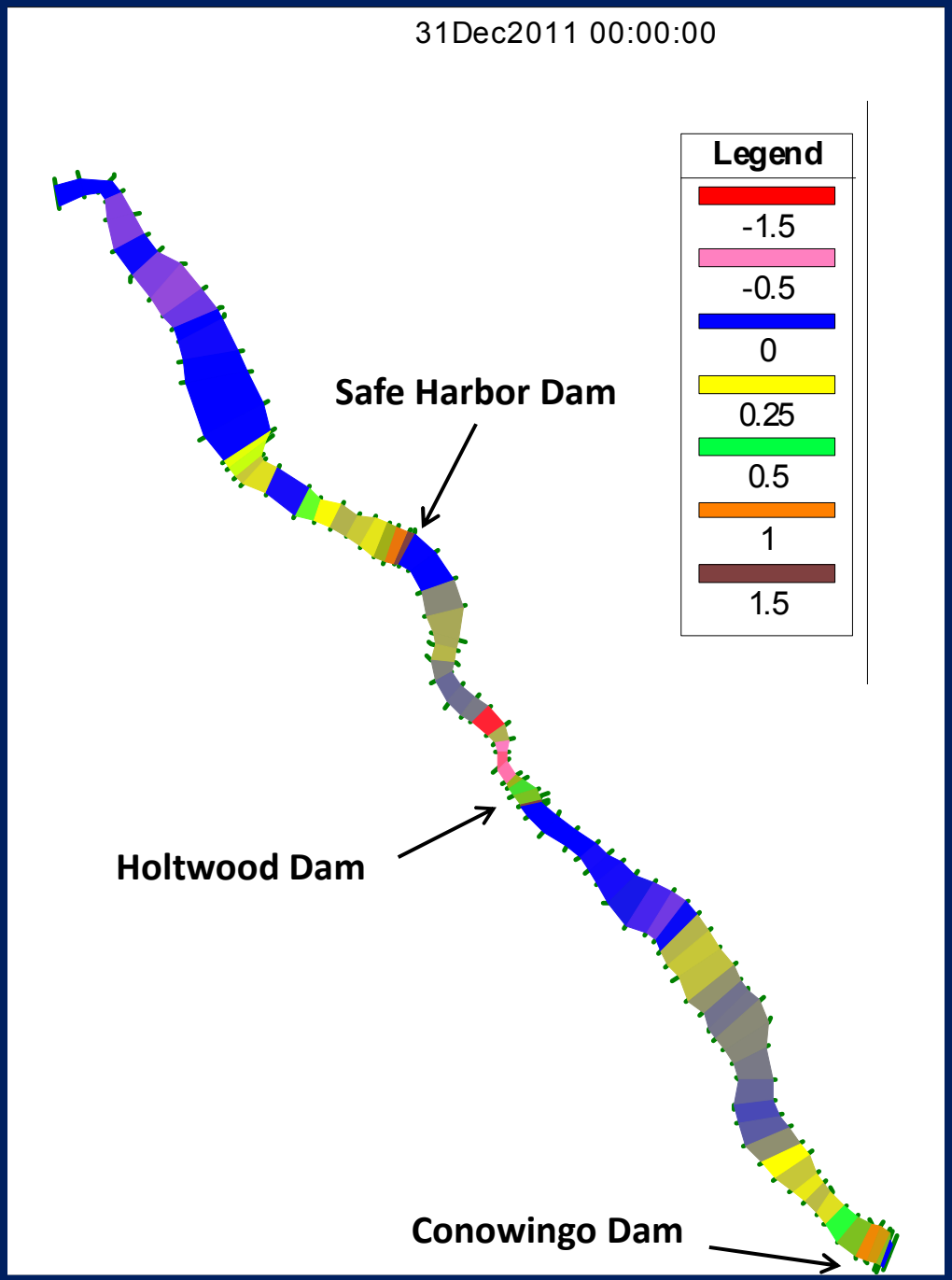


2008-2011	T.S. Lee September 7-13, 2011
Mass In – 22.3 M tons	Mass In – 9.95 M tons
Mass Out – 20.1 M tons	Mass Out – 9.57 M tons
Difference – 2.2 M tons deposition	Difference – <1 M tons deposition
Projected - 5 M tons deposition	Projected – 3.5 M tons scour

0 10,000 200,000

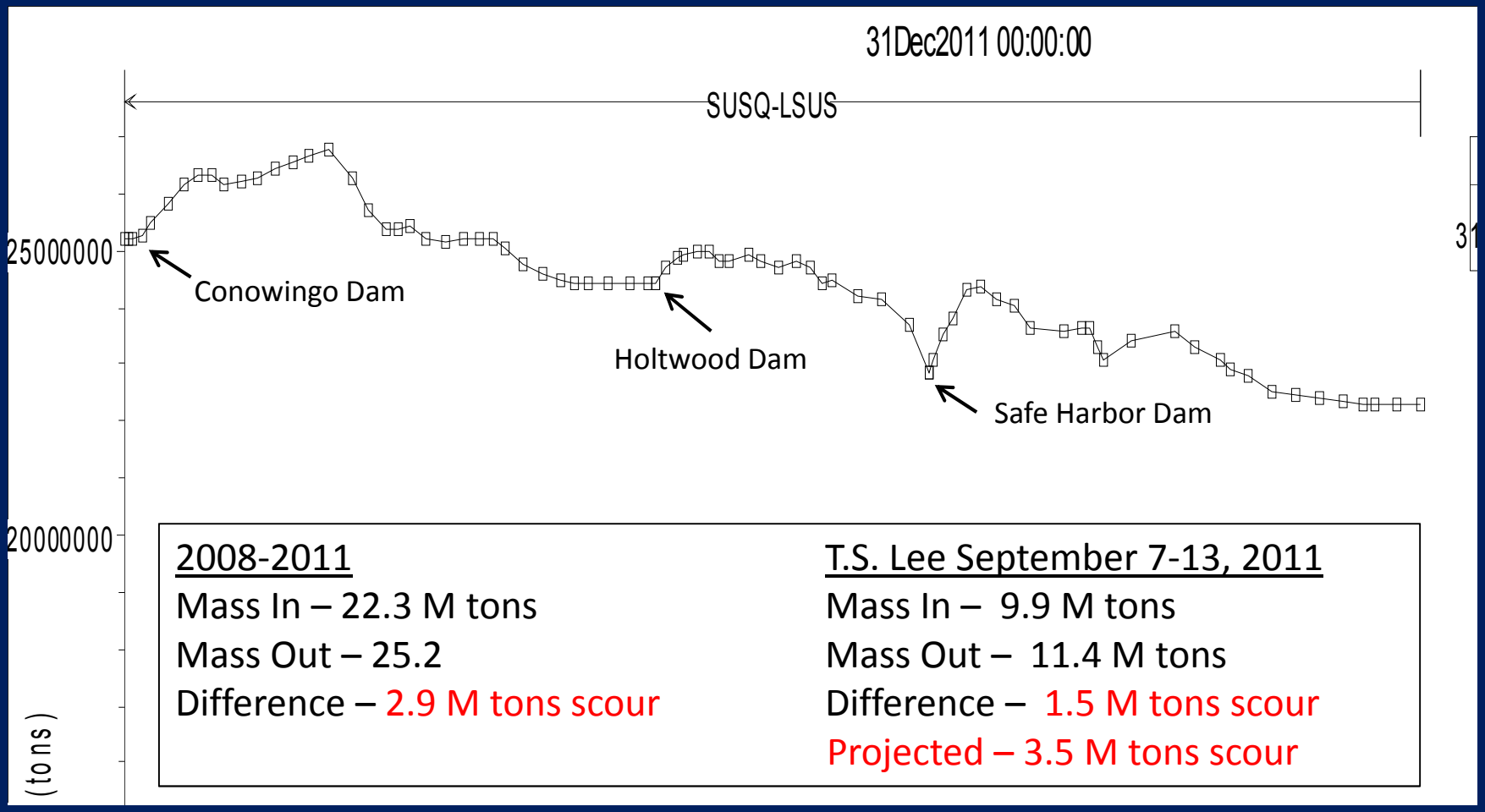
Distance Upstream (ft)

HEC-RAS Deposition Model – Bed Elevation Change (ft)



HEC-RAS Scour Model

(Transport Function – *Laursen (Copeland)*, **Sorting Method - *Active Layer***, **Fall Velocity Method – *Van Rijn***, Cohesive shear – *0.018 lbs/sq ft*))



2008-2011	T.S. Lee September 7-13, 2011
Mass In – 22.3 M tons	Mass In – 9.9 M tons
Mass Out – 25.2	Mass Out – 11.4 M tons
Difference – 2.9 M tons scour	Difference – 1.5 M tons scour
	Projected – 3.5 M tons scour

0 10,000 200,000

Distance Upstream (ft)

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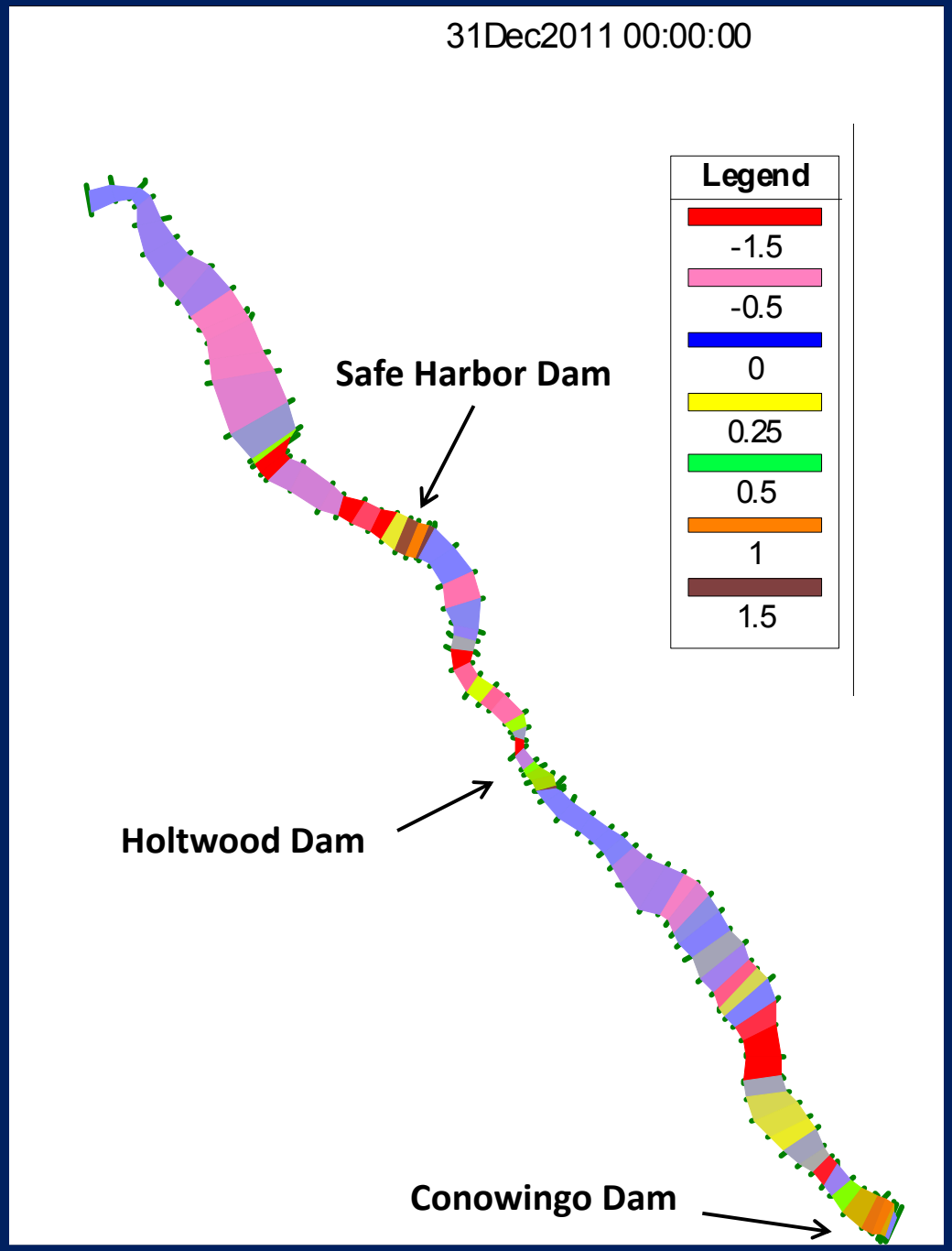
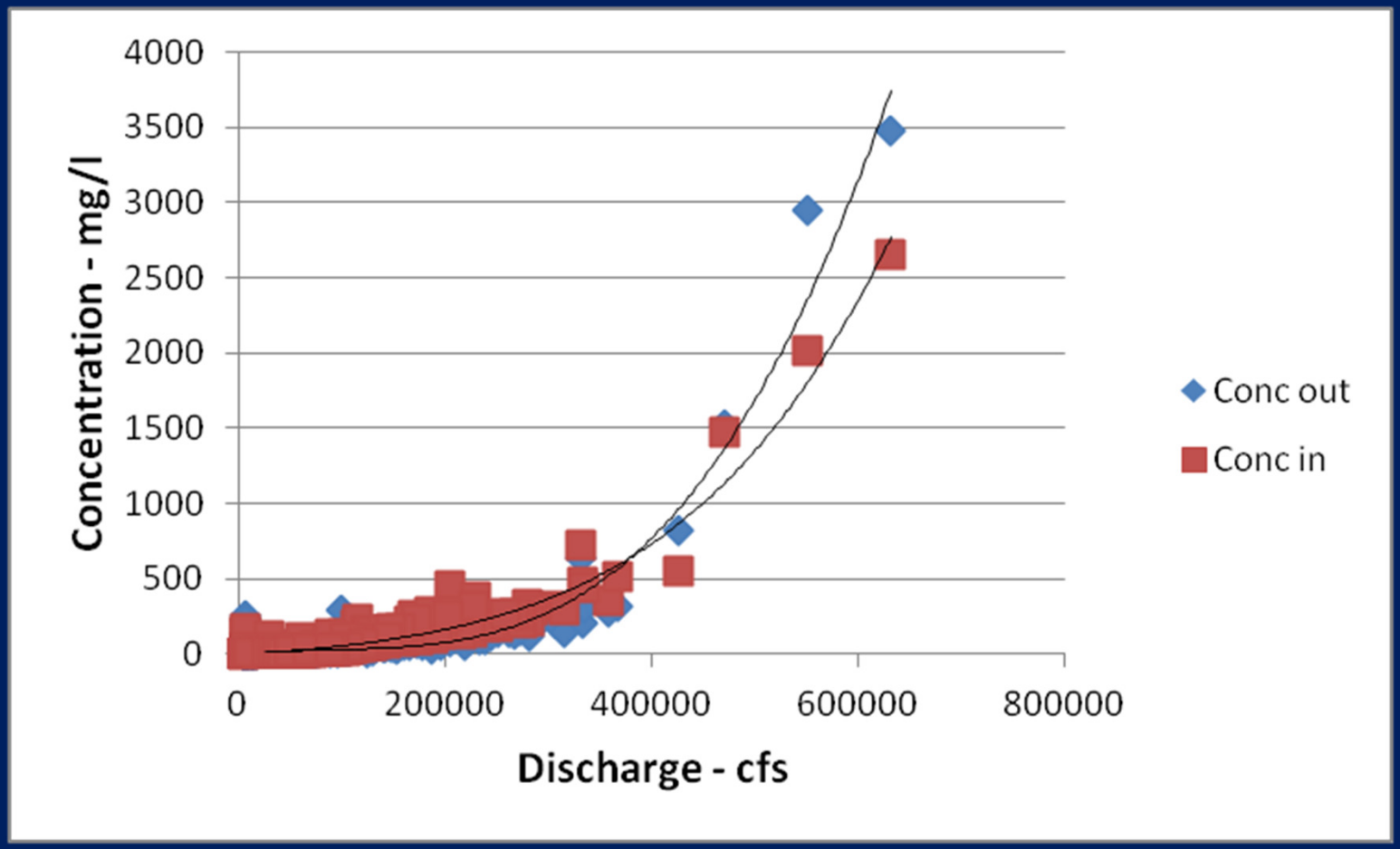
HEC-RAS Scour Model – Bed Elevation Change (ft)



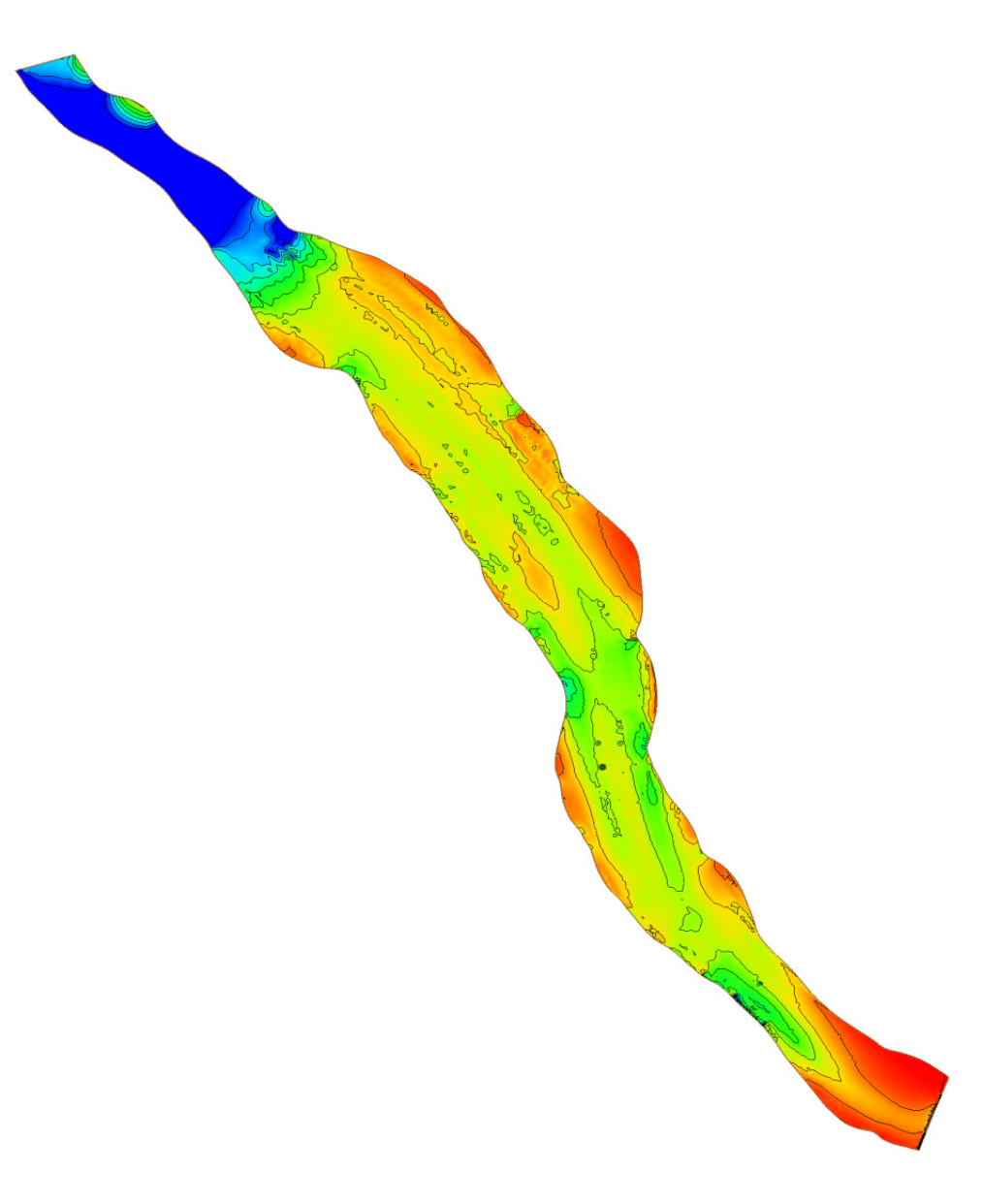
USACE ADH 2-D Model – Conowingo only

Lower Susquehanna River Watershed Assessment Study

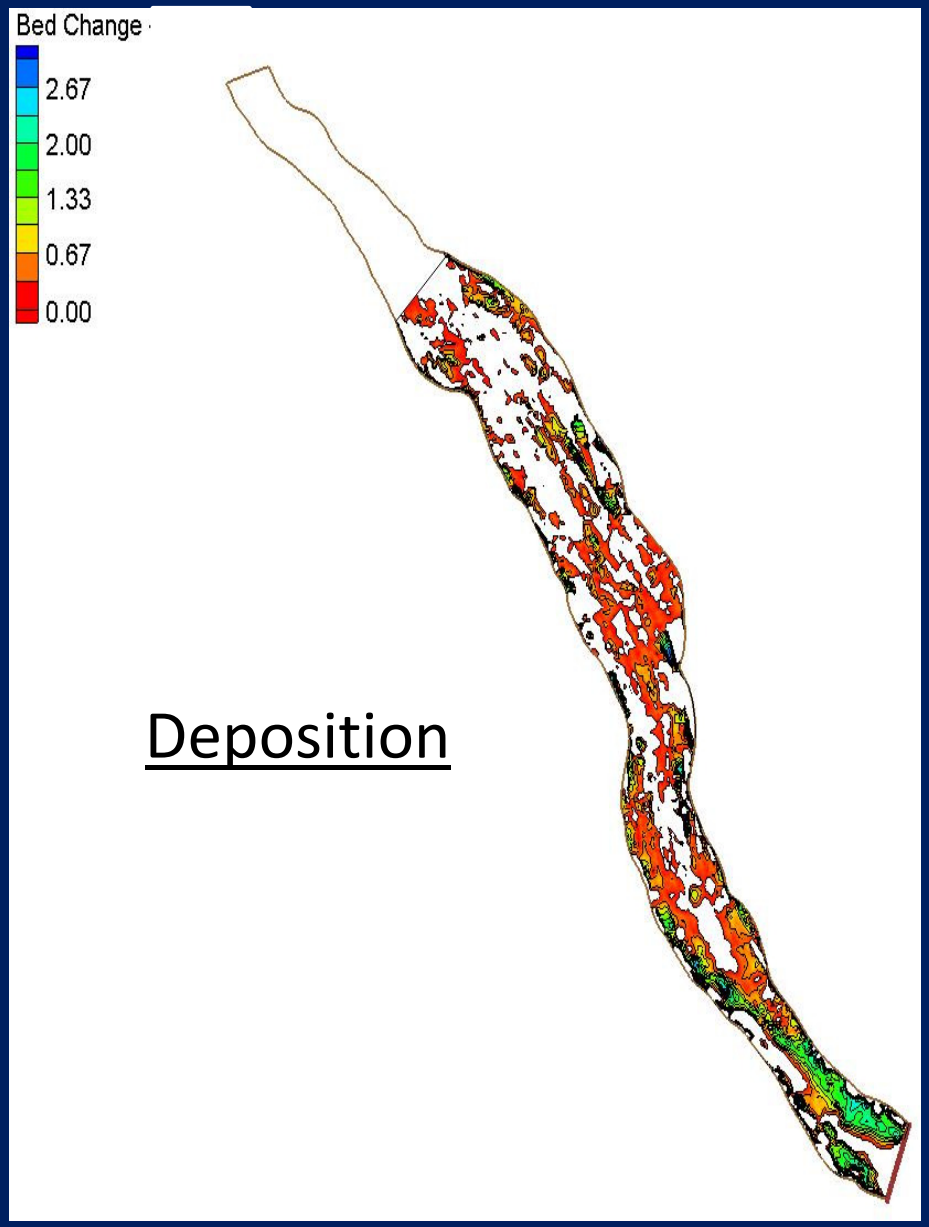


USACE ADH 2-D Model – Conowingo only

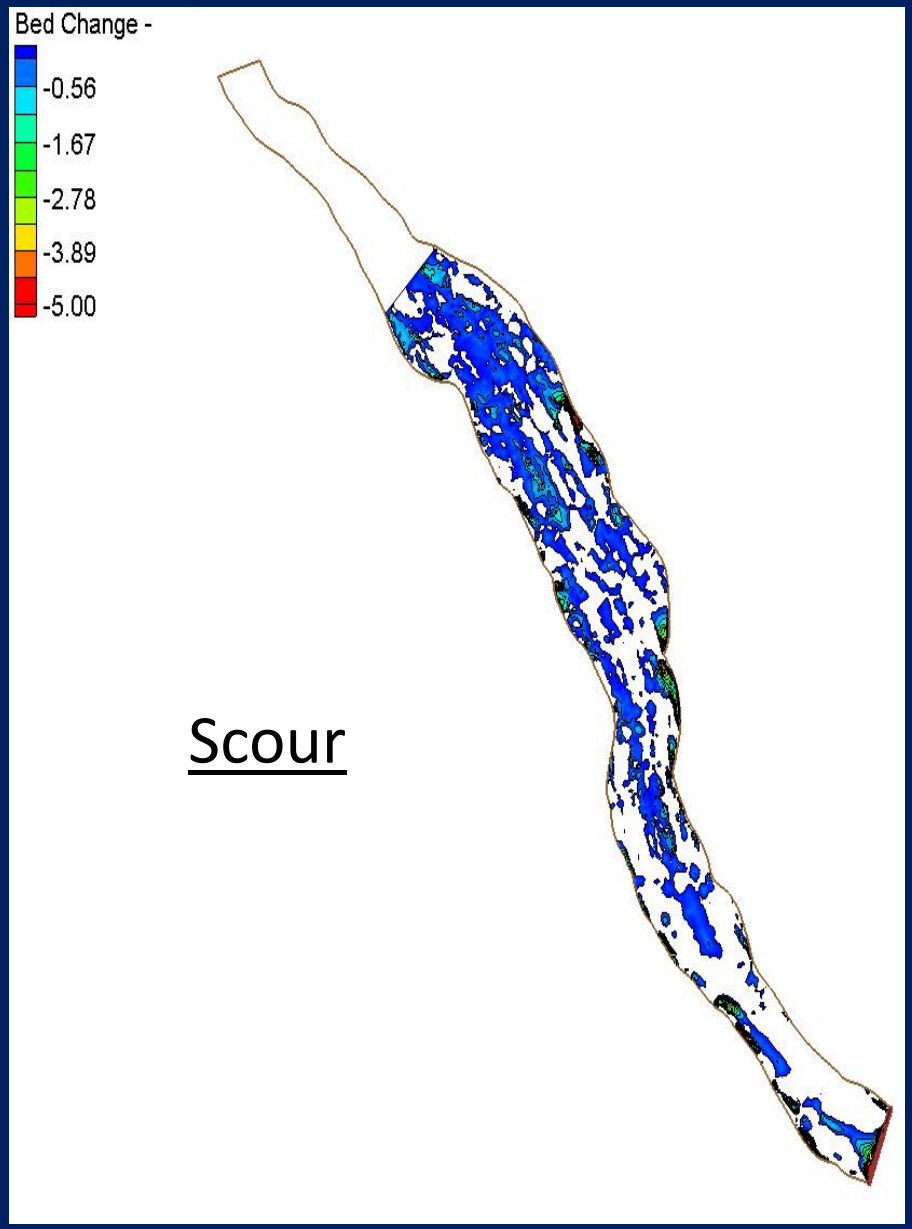
Bed Shear - blue (high shear) to red (low shear)



ADH 2-D Model – Conowingo Reservoir

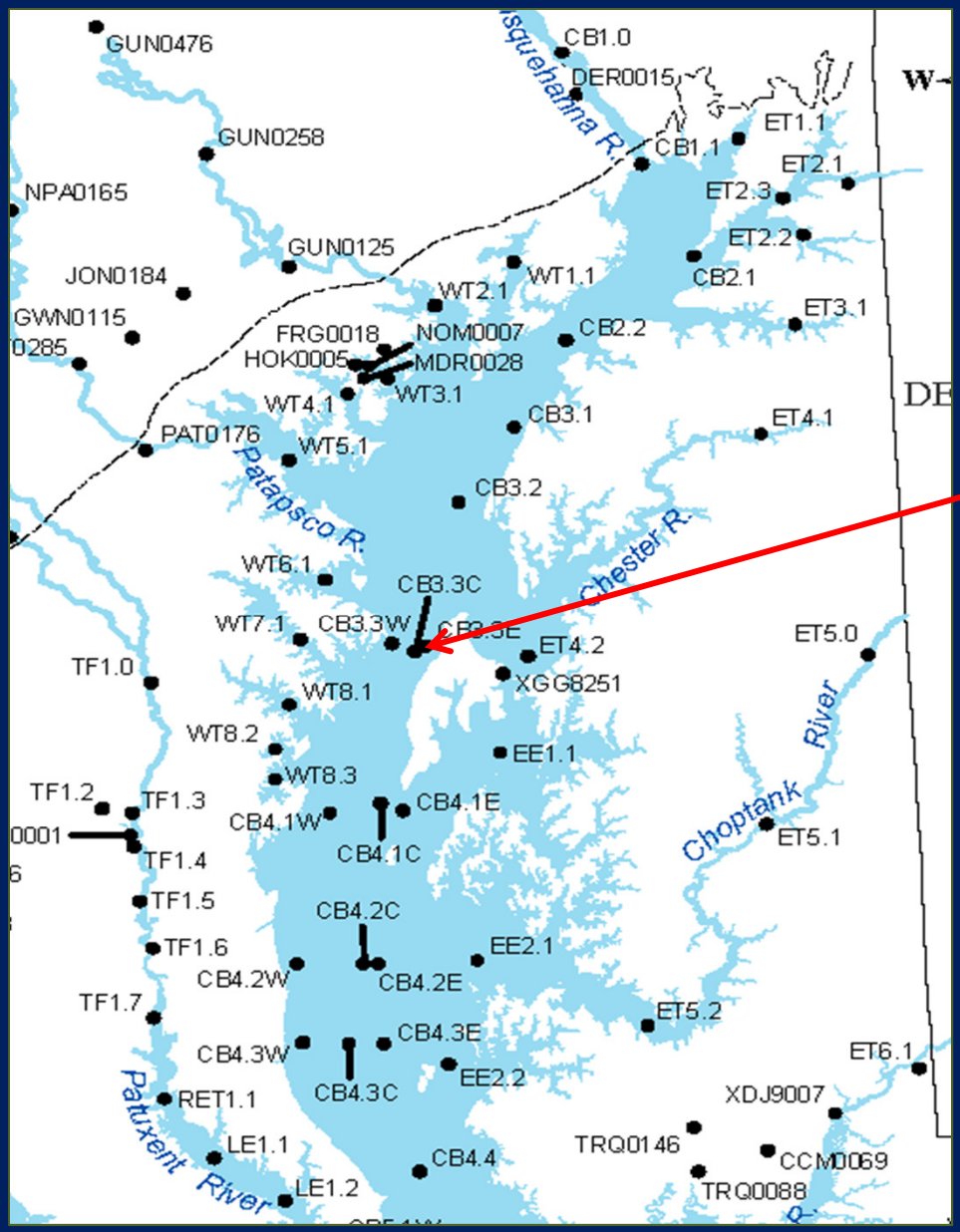


Deposition



Scour

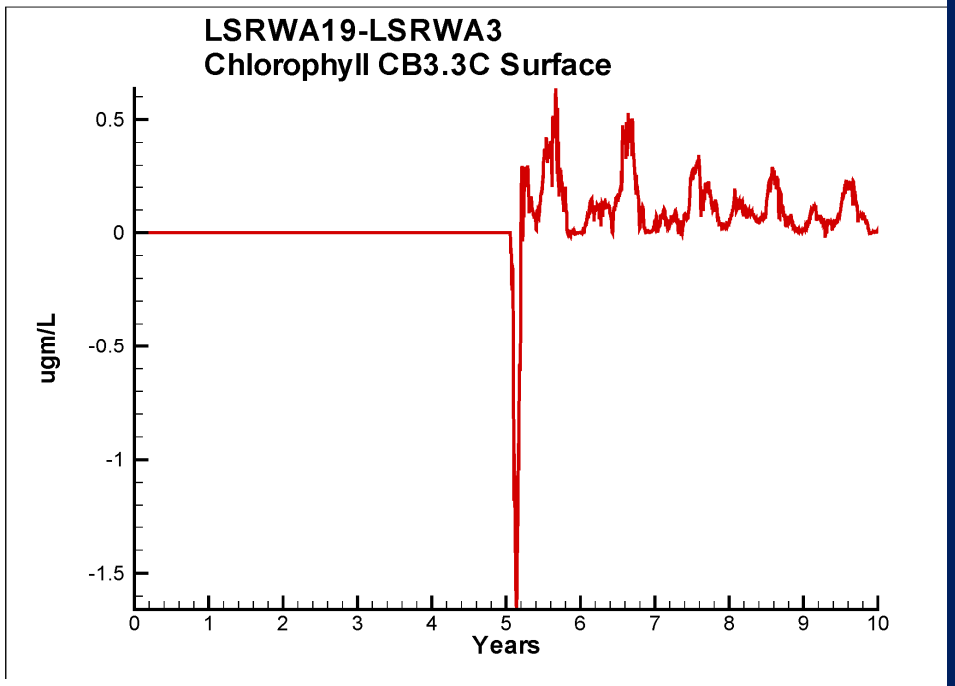
USACE/EPA Chesapeake Bay Models



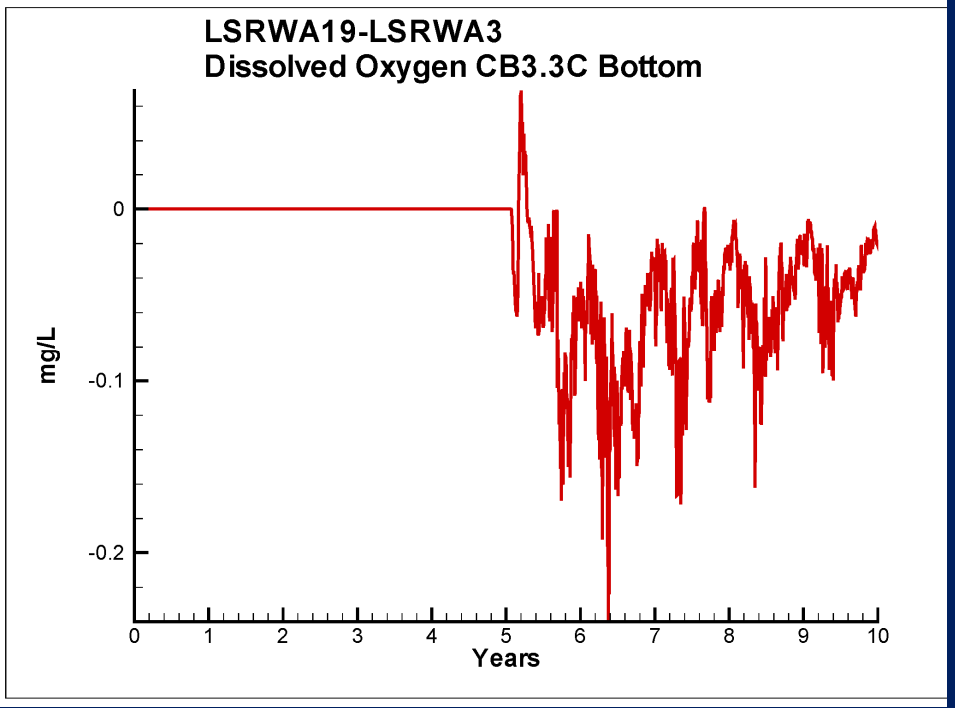
Results for CB3.3, reference point for middle of Bay

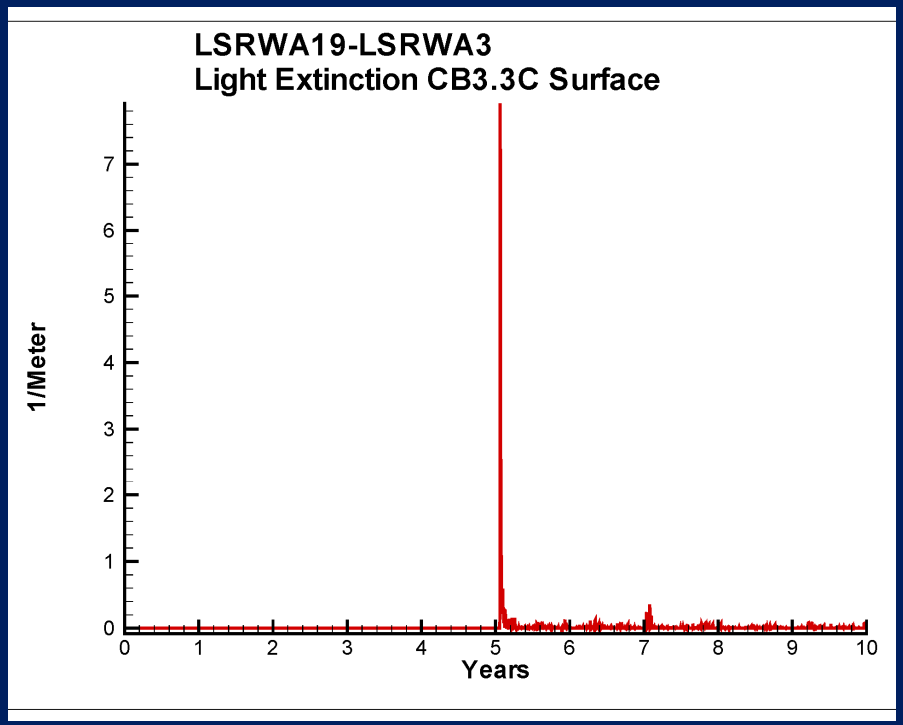
Simulations for Chlorophyll, DO, light, and nutrients

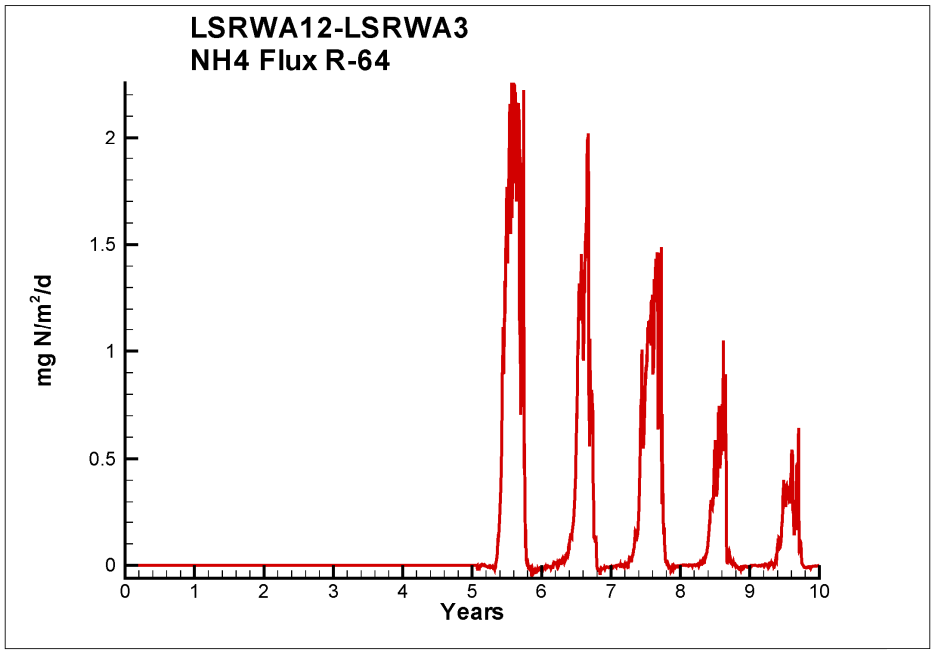
- Reservoir Full
- Full with WIP's
- Vary timing of scour events



Reservoir Full, Full WIP's, Major Scour Event

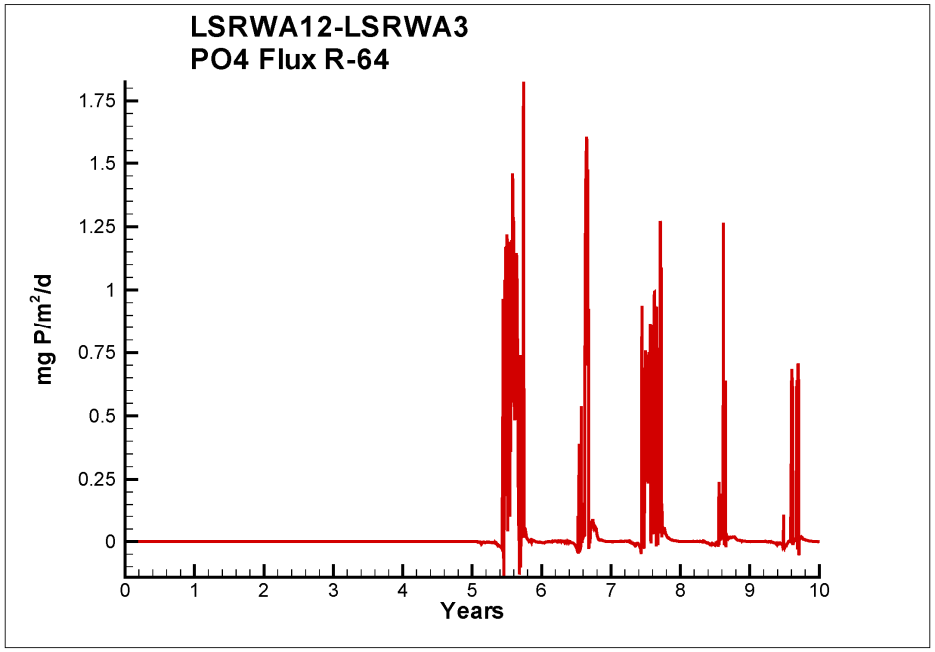


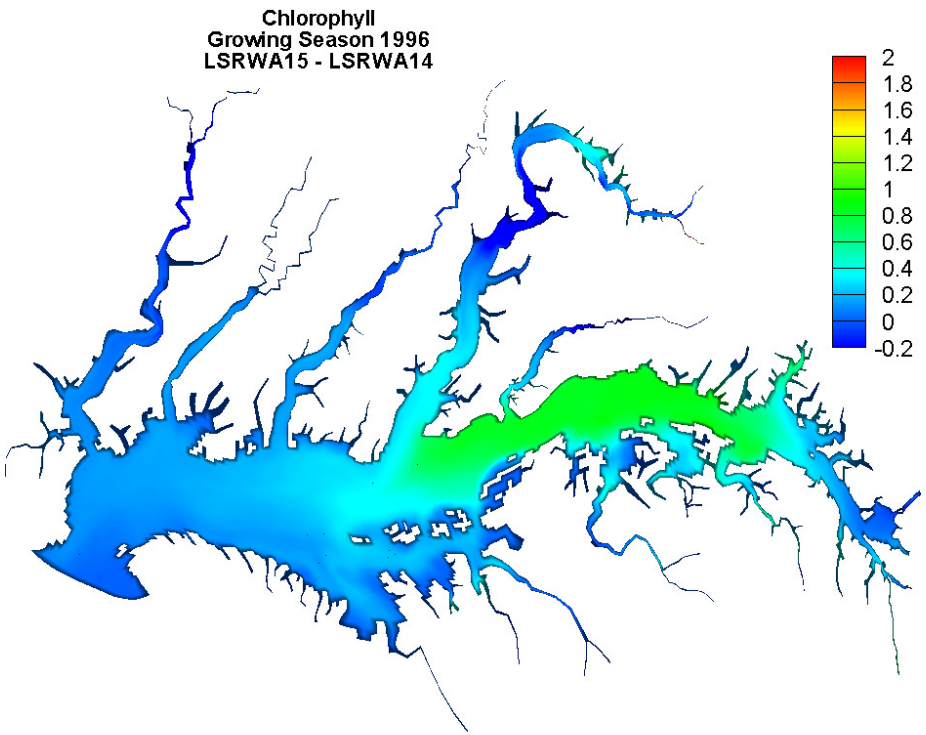




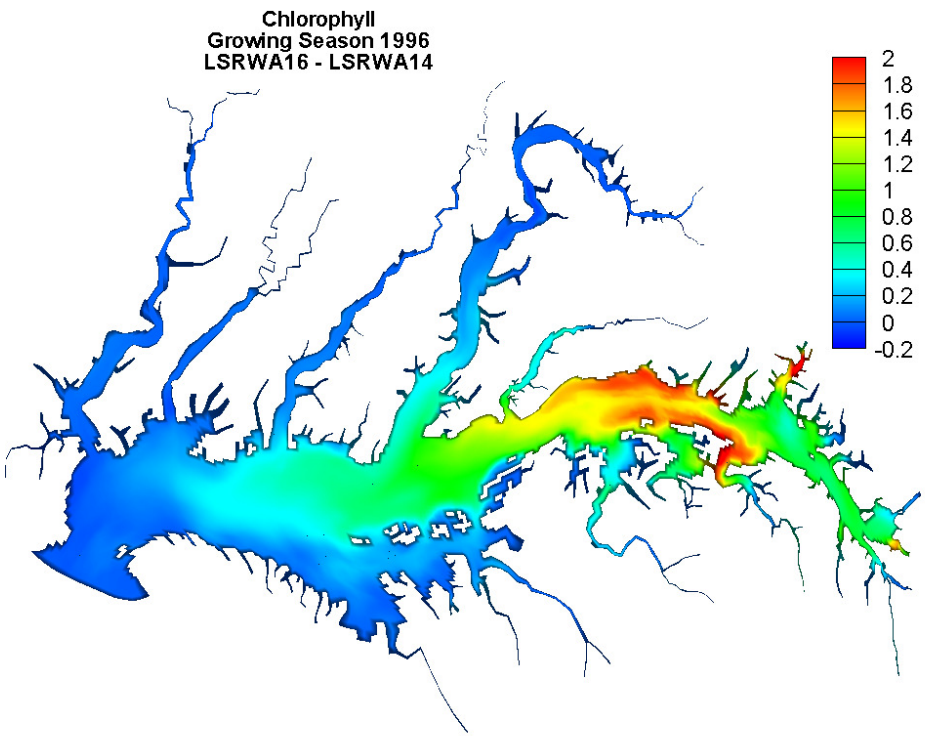
Reservoir Full, Full WIP's, Major Scour Event

Nutrients from the scour event deposit in bottom sediments and persist for years. Solids from scour event are inert after deposition.



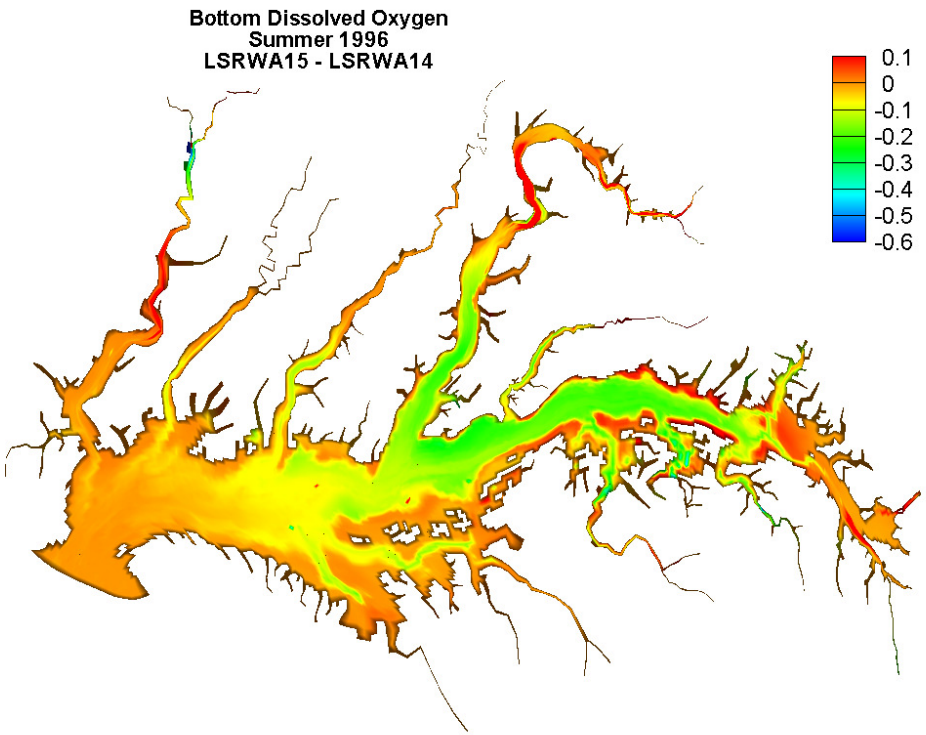


Reservoir Full, Full WIP's, Major Scour Event, Varying Months

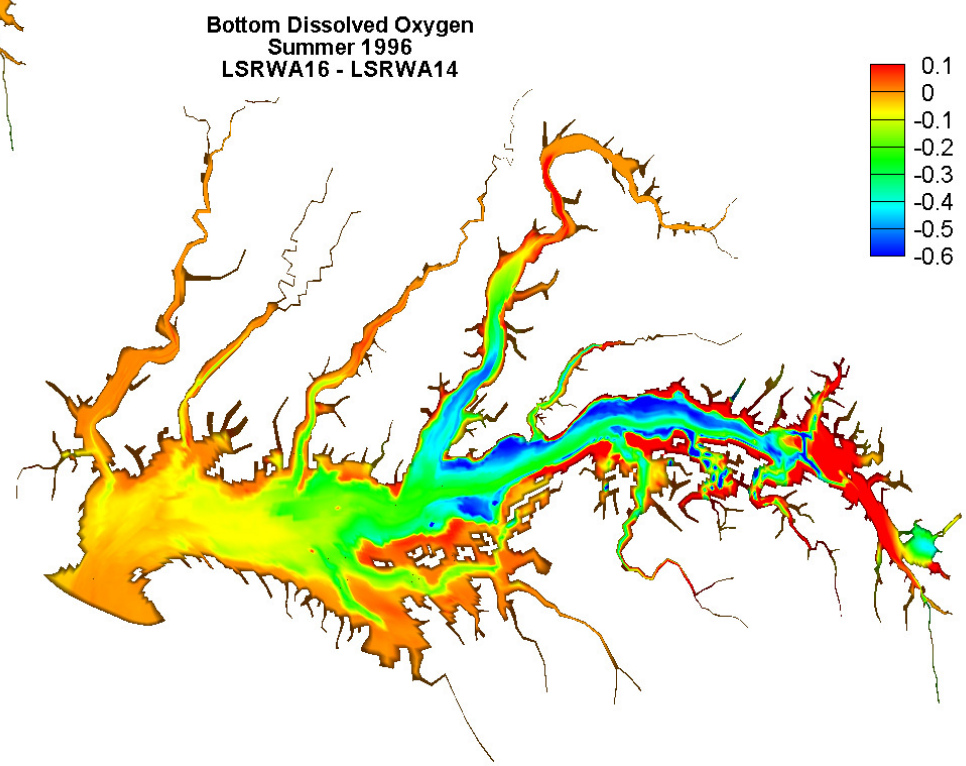


Effect of January Storm

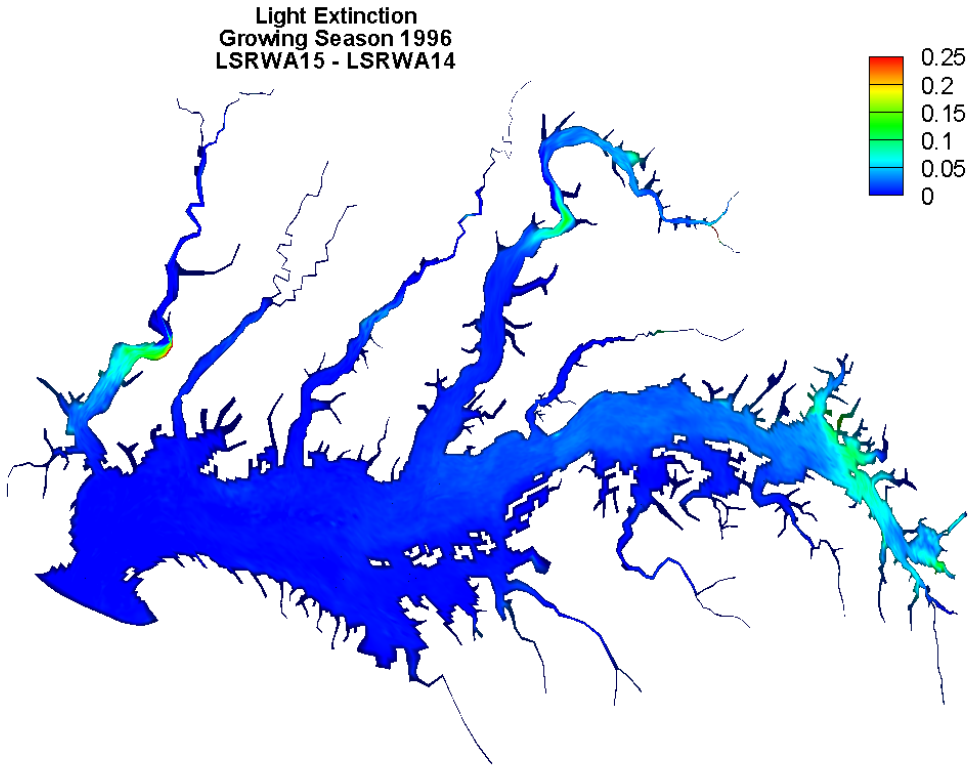
Effect of June Storm



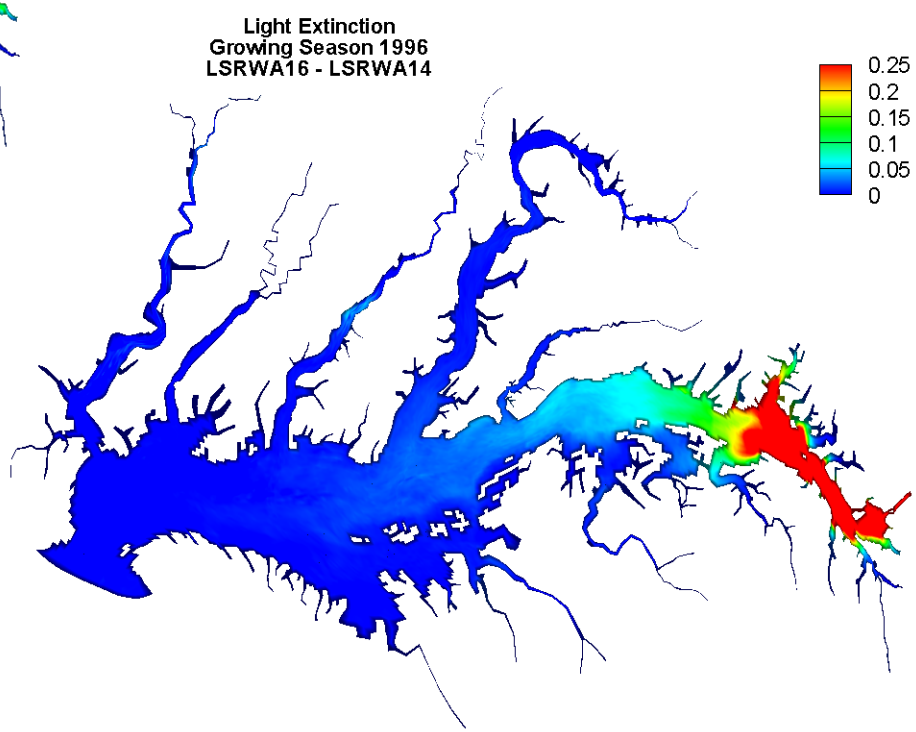
Effect of January Storm



Effect of June Storm



Effect of January Storm



Effect of June Storm

Summary HEC-RAS Model

- Generally not conducive for cohesive (silts/clays) simulations
- The 2 models provide a range of uncertainty in the boundary condition files
- Estimated total sediment transport most likely underestimated but "reasonable"
- Both models indicate upper 2 reservoirs still play a "role" in sediment transport

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Summary AdH-2D Model

- Present day conditions have 50% more scour potential as compared to 1996
- Present day conditions have 50% less storage capacity as compared to 1996
- Negligible difference in 2011 and Full Simulations indicates Reservoir close to full capacity

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Summary Bay WQ Model

- Sediment and nutrient releases are event-oriented (floods)
- Erosion events increase depth and diminish subsequent erosion events
- WIPs decrease reservoir sediment deposition and decrease loads to Bay

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