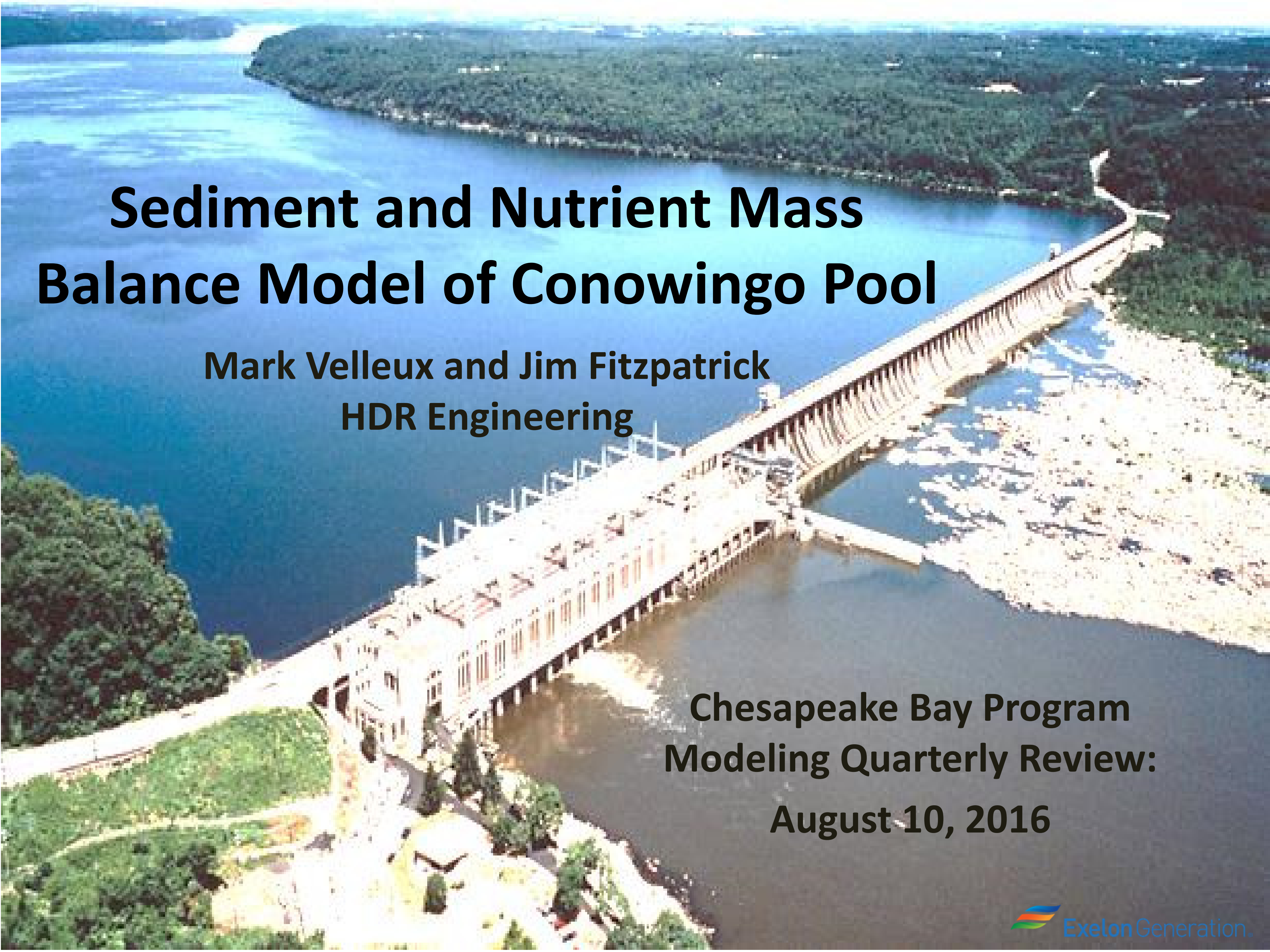


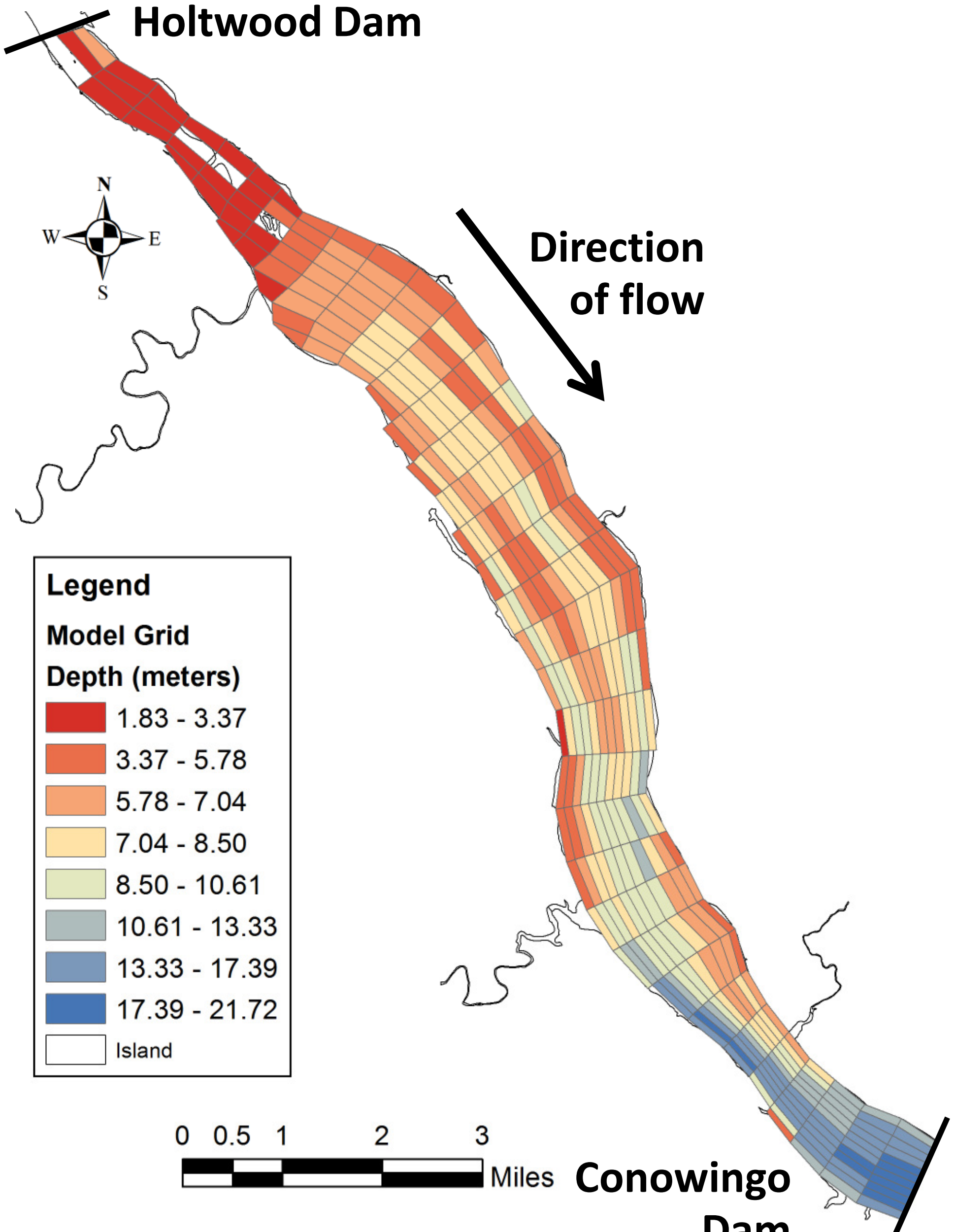
Sediment and Nutrient Mass Balance Model of Conowingo Pool

Mark Velleux and Jim Fitzpatrick
HDR Engineering

Chesapeake Bay Program Modeling Quarterly Review:
August 10, 2016

Exelon Generation

Model Grid and Spatial Resolution



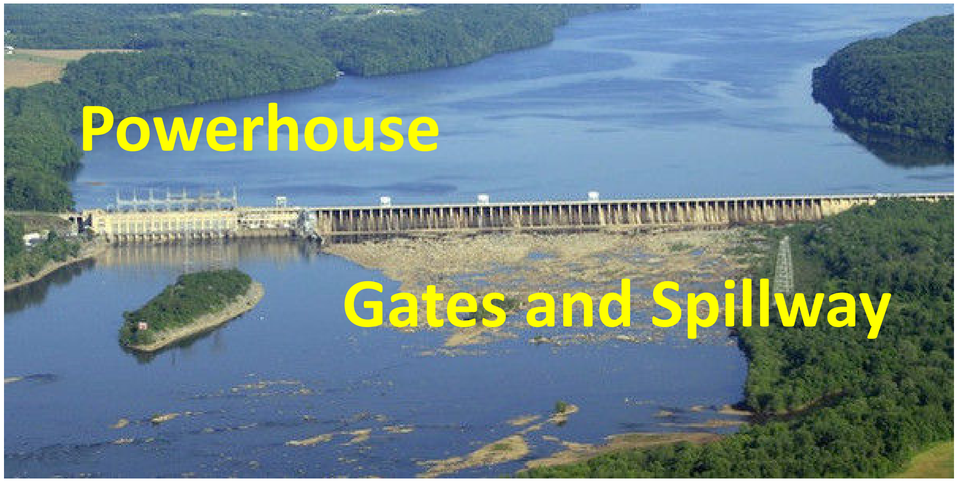
- Resolves primary features of physical system:
  - Remnant channels
  - Depth changes
- Provides 305 cells
  - More detail where Pond is wider
  - 5 vertical (sigma) layers
- Balance spatial resolution and computational burden
- Referenced to full pool:
  - 109.2 ft NGVD29
  - 2015 bathymetry shown
  - Data for 2008, 2011, 2012…

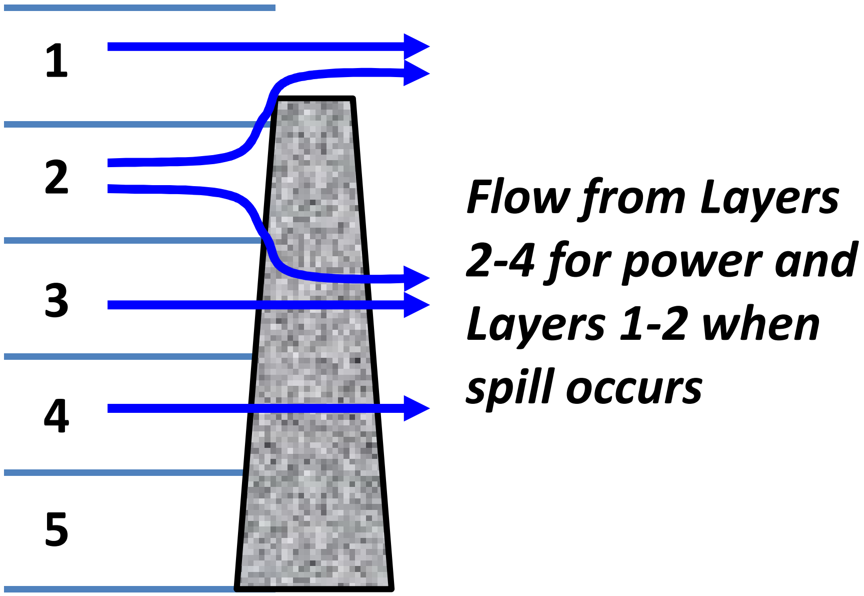
Hydrodynamics and Sediment Transport

- Represent spatial, temporal dynamics of flow and sediment transport in and out of Conowingo Pond
- Coupled with water quality/sediment flux model
  - Calibration: 2008-2014
  - Confirmation: 1996-2014
- Hydrodynamics:
  - Flow and temperature from USGS, HSPF, other sources
  - Reproduce water surface elevations and temperature
- Sediment Transport:
  - Five size classes: clay, silt, sand, gravel, coal
  - Erosion properties: Plasticity Index and SEDFLUME cores
  - Dynamic bed (depth change with erosion & deposition)

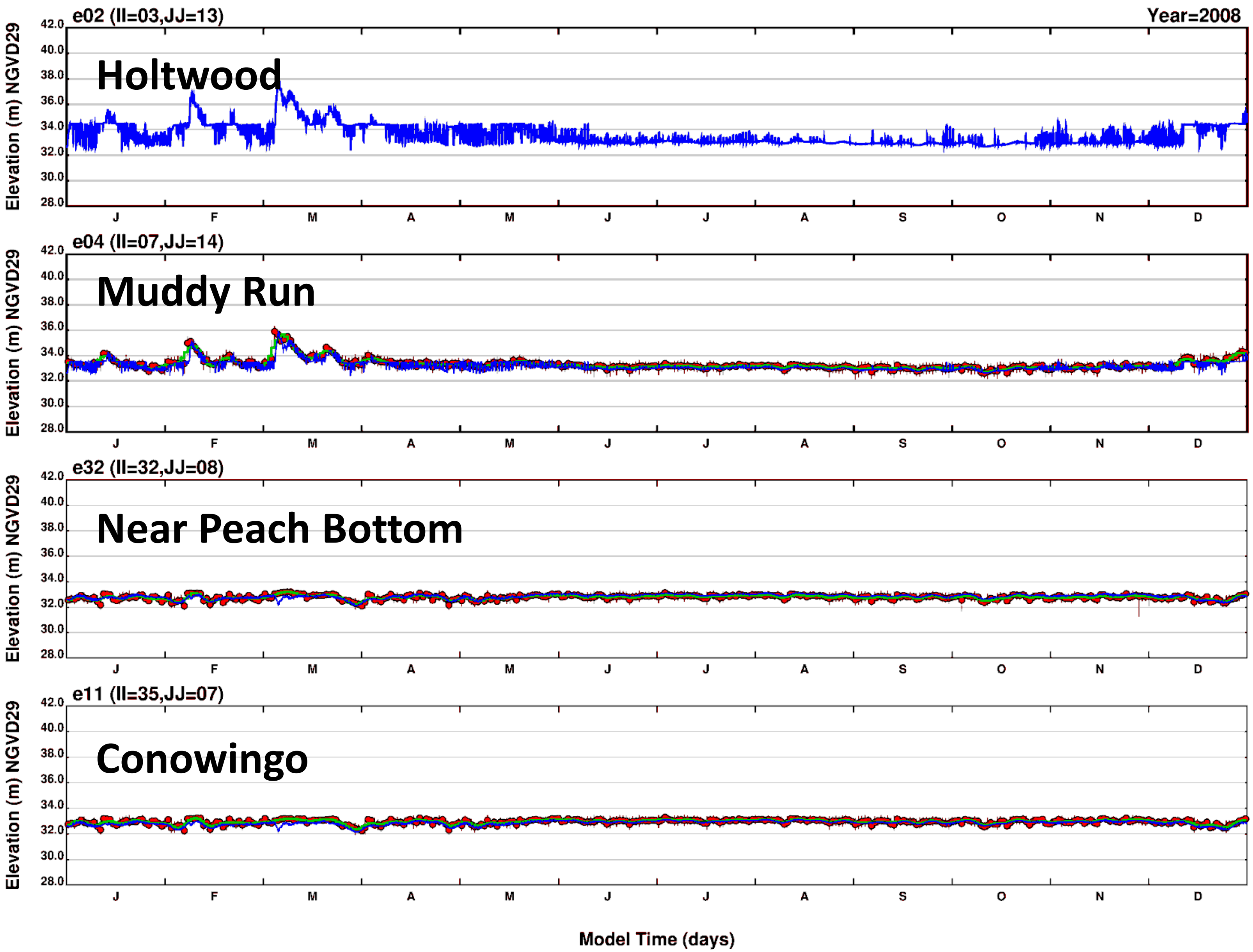
Representation of Dam Operations

- **3D with 5 vertical layers:**
  - **10 grid cells across Dam face**
- **Withdrawals**
  - **Powerhouse: 2 cells, Layers 2-4, all Q for Q < 86,000 cfs**
  - **Spill: 1-5 cells, Layers 1-2, Q – 86,000 for Q > 86,000 cfs**
- **Flow balance:**
  - **Used flow at Conowingo and elevations at Muddy Run, PBAPS, Conowingo**
  - **Captures cyclical up/down swings over time from hydropower operations**





Example Hydrodynamic Results: 2008



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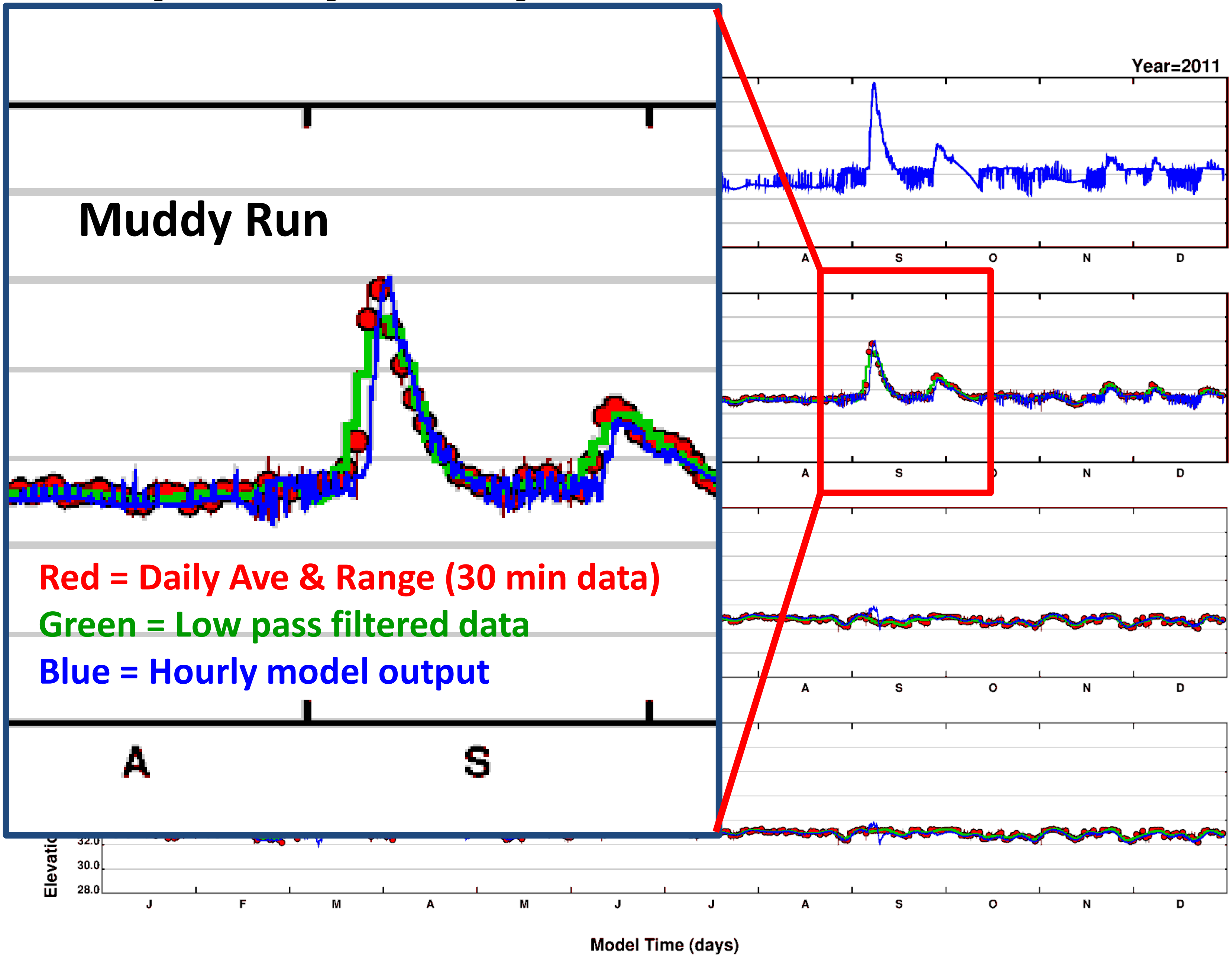
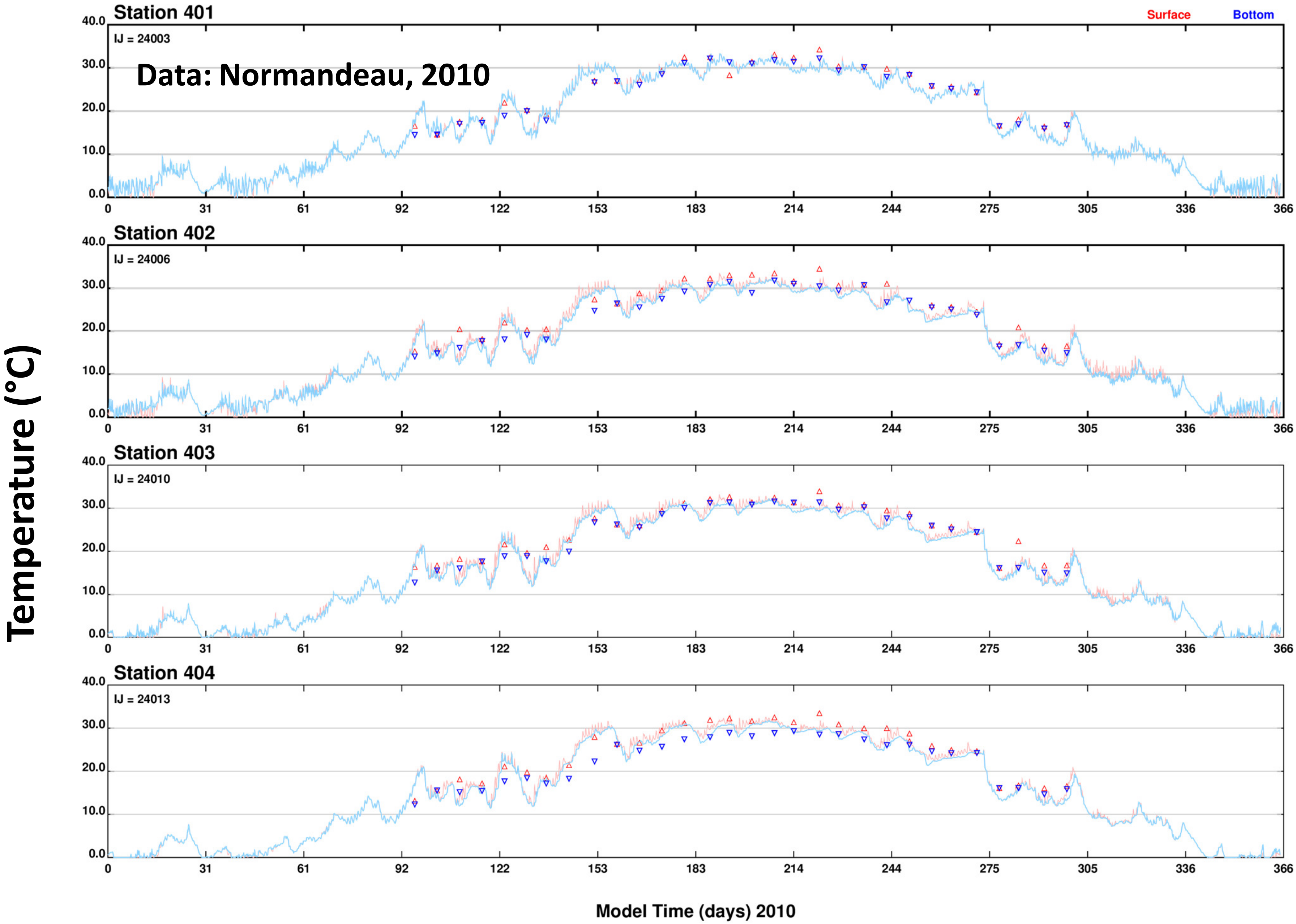
Example Hydrodynamic Results: 2011



Exelon Generation

Example Temperature Results: 2010



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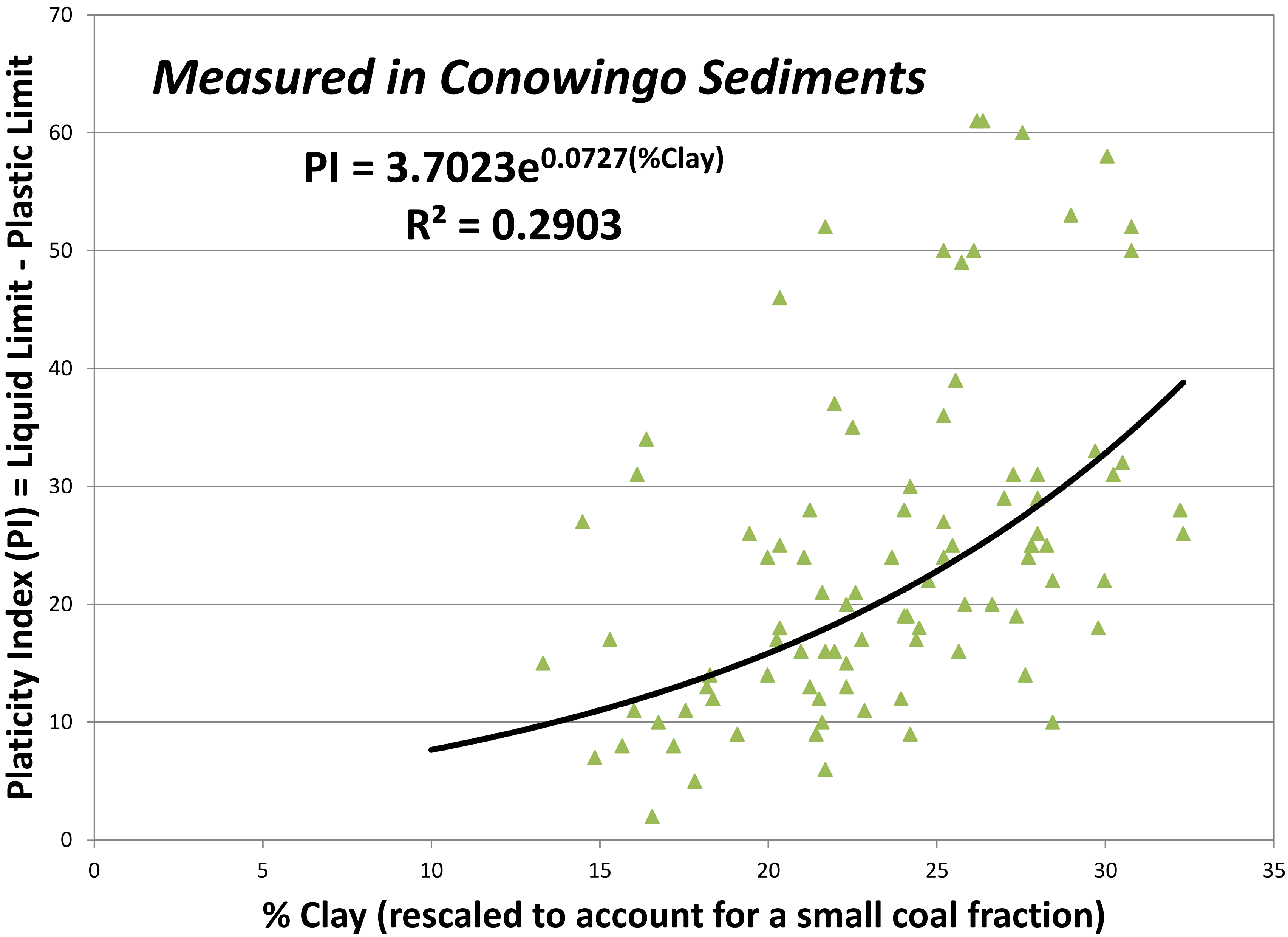
Sediment Transport

- Model development nearing completion
- Simulations performed: 2008-2014 (and 1996-2014)
- Sediment bed properties defined from USGS (1990, 1996), SRBC (2000), USACE (2012), and AECOM (2015) cores
  - Factions gravel, sand, silt, clay, and coal
  - Wet/dry bulk densities
  - Spatial variation estimated by geostatistics (cokriging with bed elevation/water depth)
- Analysis of USACE (2012) SEDFLUME cores:
  - Help define erosion characteristics of Pond sediment
  - Challenges arise from uncertainties in SEDFLUME data…

USACE SEDFLUME vs. Plasticity Index

- Critical shear stress (τ_e): controls when sediments erode
- Estimates from USACE SEDFLUME study ranged from just 2.25 to 16 dynes/cm^2 (0.225 – 1.6 Pa):
  - Limited to 15 – 30 cm of bed
  - Low values given high shear stresses that occur in Pond
  - May represent only reworked bed surface after TS Lee
- AECOM (2015) coring effort in Conowingo Pond measured geotechnical properties of collected sediments:
  - Atterberg Limits: Plastic Limit (PL), Liquid Limit (LL)
  - Plasticity Index (PI) → PI = LL – PL
  - Relationship between PI and %Clay (not bulk density…)

Plasticity Index and Clay Content



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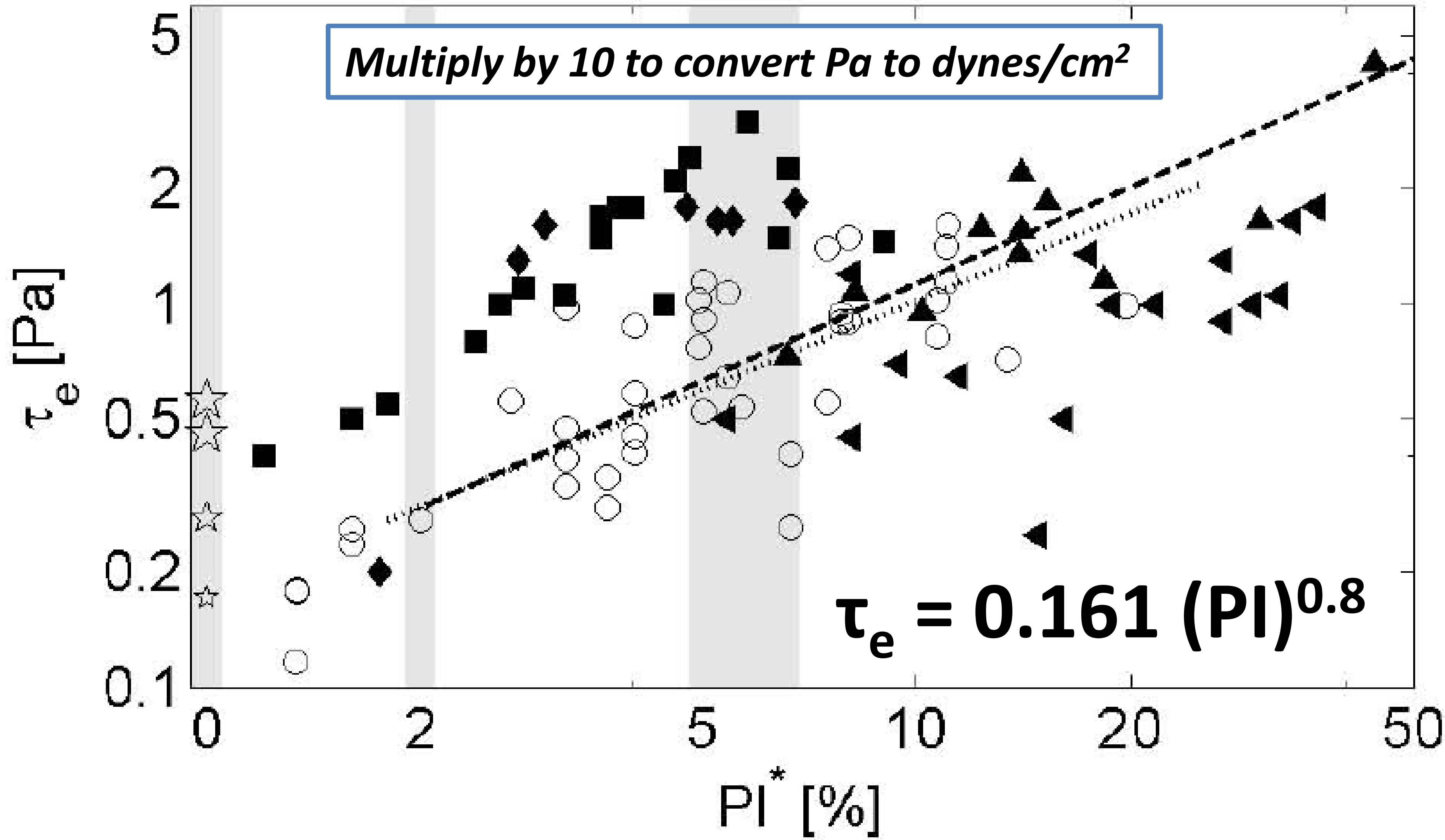
Critical Shear Stress and Plasticity Index



- Jacobs et al. (2011) Coastal Shelf Research, 31(10)

Size Classes and Settling Velocities

- **Drawn from Conowingo study by Sanford et al. (2016):**

Particle Size (mm)	.003	.009	.035	0.5
Ws (mm/s)	.0045	.07	1.2	50*

- **Augmented by Cheng (1997) settling speed relationship**
- **In the model (subject to revision):**

	Clay	Silt	Sand	Gravel	Coal
Diameter (μm)	3	35	500	4,000	354 (effective diameter)
Settling Speed (mm/s)	0.0004	1.2	50	273	42

- **Low settling speed for clay in attempt to match SSC at dam**

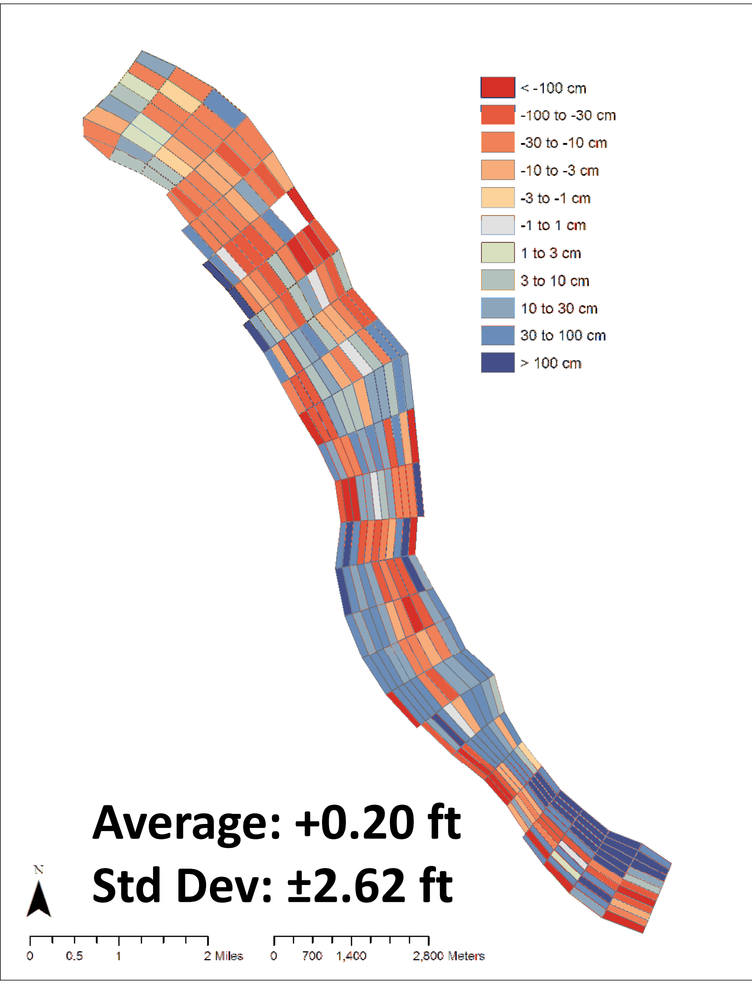
Bed Elevations: Geostatistical Analysis

- Used kriging: lowest interpolation error but still about ±1 ft
- Examined data multiple ways:
  - Grid-snapped: data adjusted to align x,y locations and point density year to year, also subsets of transects
  - Raw: all reported values without adjustment for location differences from year to year, use all transects

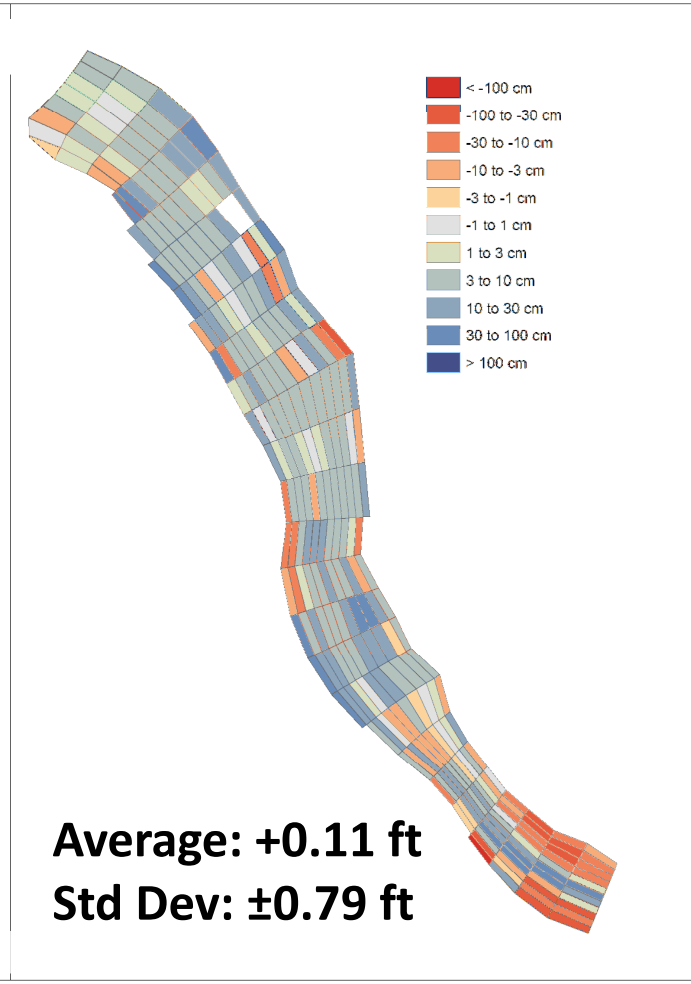
End	Start	Survey Type	Unweighted Average Difference (ft)	Area-Weighted Average Difference (ft)
2008	1996	Raw	0.705	0.433
2011	2008	Raw	0.204	0.064
2015	1996	Raw	1.022	0.642
2015	2008	Raw	0.317	0.210
2015	2011	Raw	0.113	0.145

Bed Elevation Changes: 2008-2015 (raw)

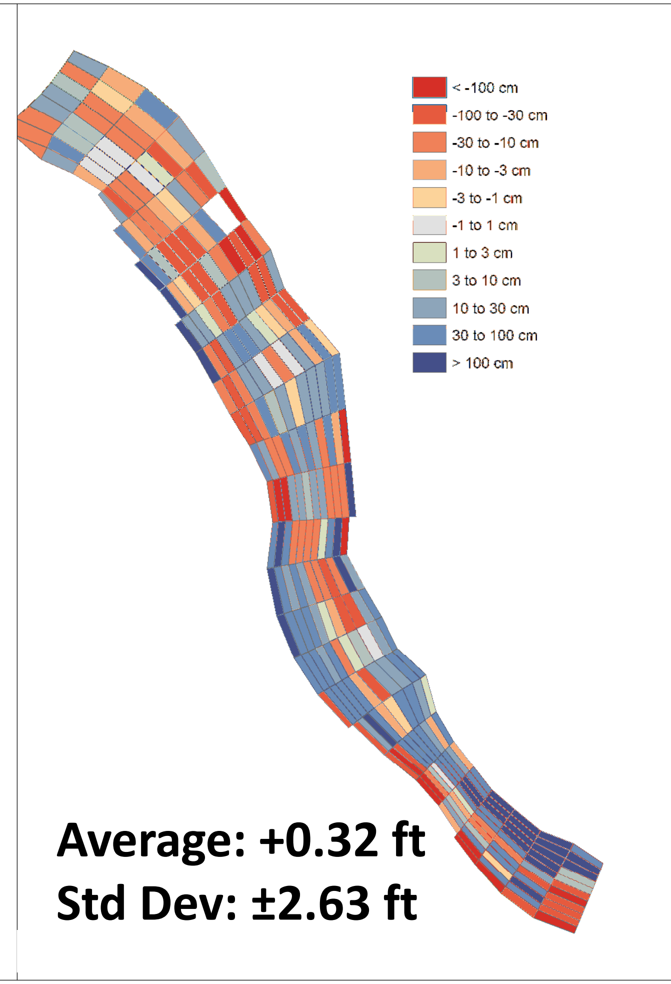
2011 minus 2008



2015 minus 2011



2015 minus 2008



Surfaces for each year generated by kriging. Interpolation error approximately ± 1 foot. Variation in areas immediately adjacent to shore may reflect possible measurement error, position uncertainty, differences in methods, etc. Averages shown are unweighted values.

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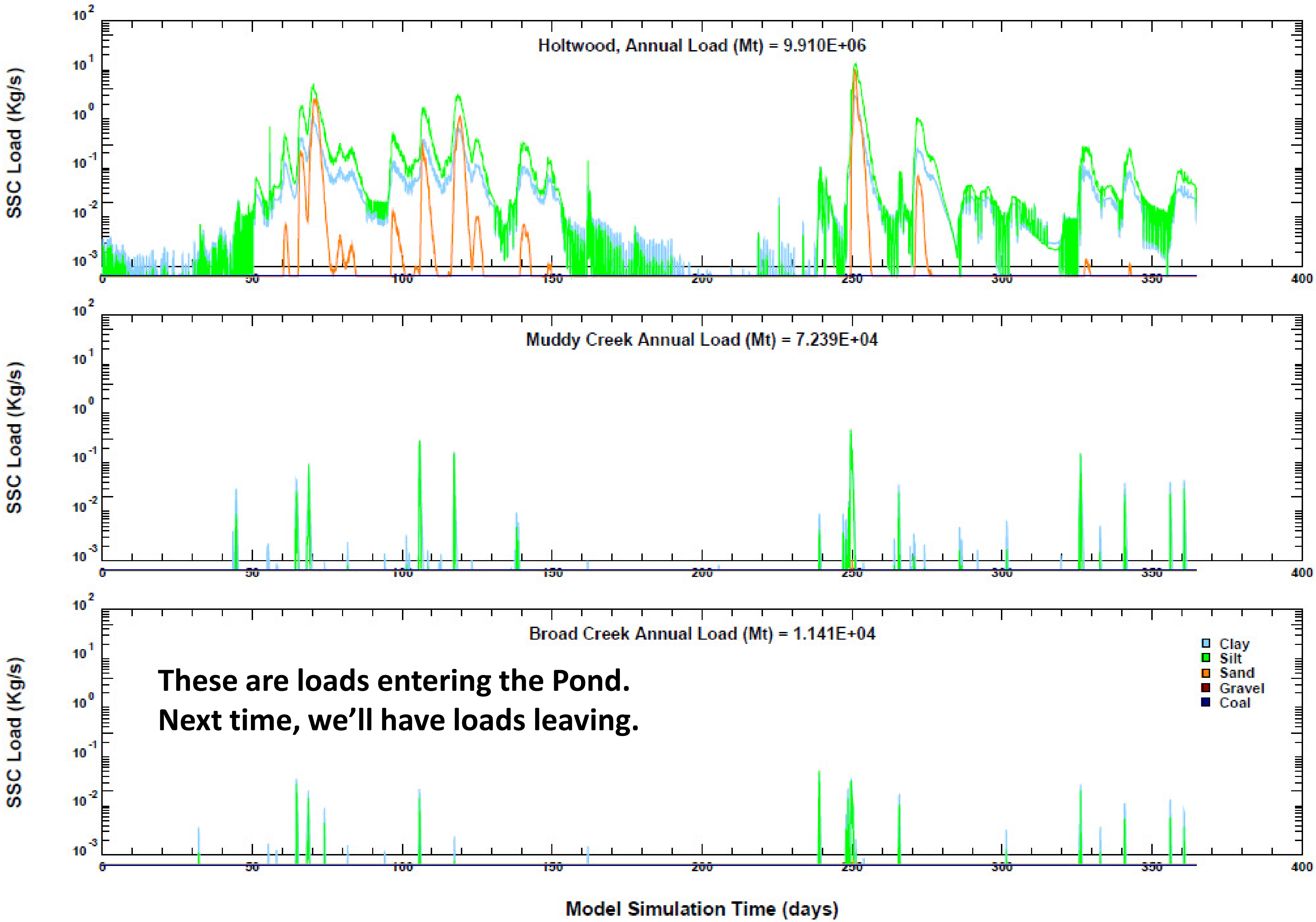
Uncertainties Propagate: A Partial List

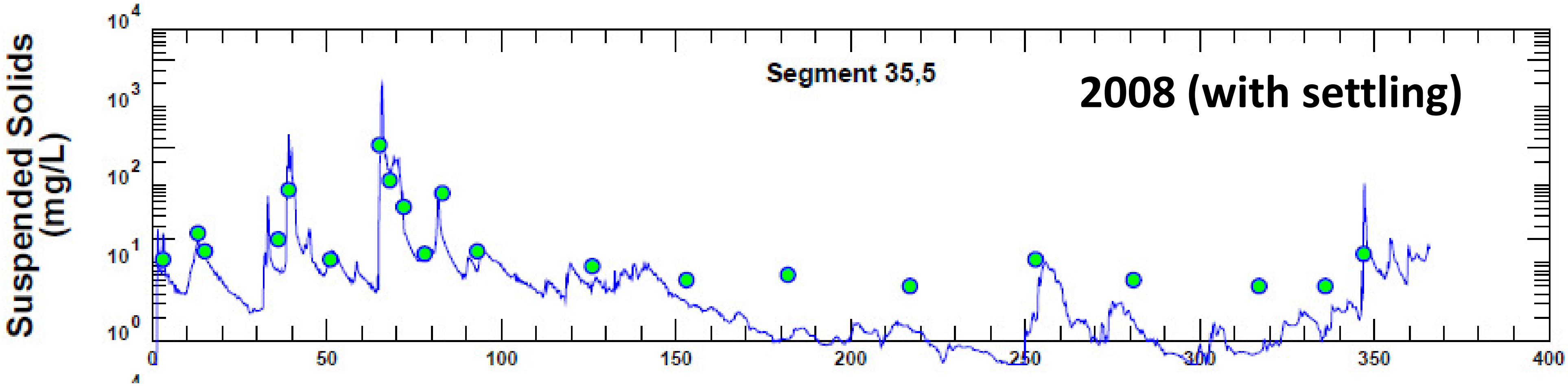
- Uncertainties and errors from upstream loads, flow balance and bed interpolations propagate through sediment model
- Sediment transport model fed by other models:
  - HSPF (Phase 6 Beta 2)
  - HEC-RAS (work by WEST)
- Sparse bed data given high spatial variation of properties and sediment bed elevation changes over time:
  - Measurement error and uncertainty
  - Interpolation uncertainty (RMS error) in geostatistics used to estimate bed properties and bed elevations
- Feedback between sediment transport and hydrodynamics

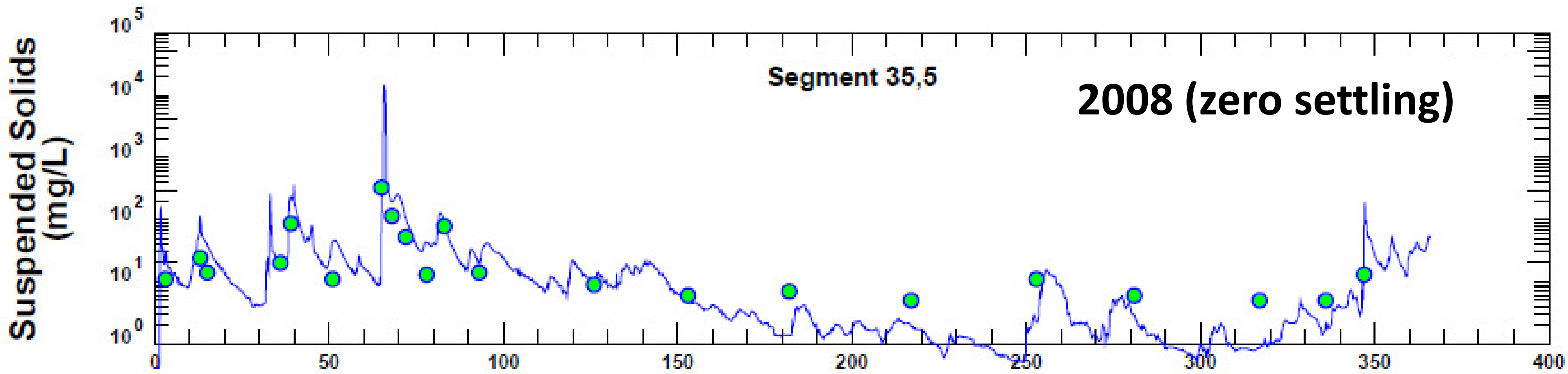
Model Driver: Loads to Pond



These are loads entering the Pond.
Next time, we'll have loads leaving.

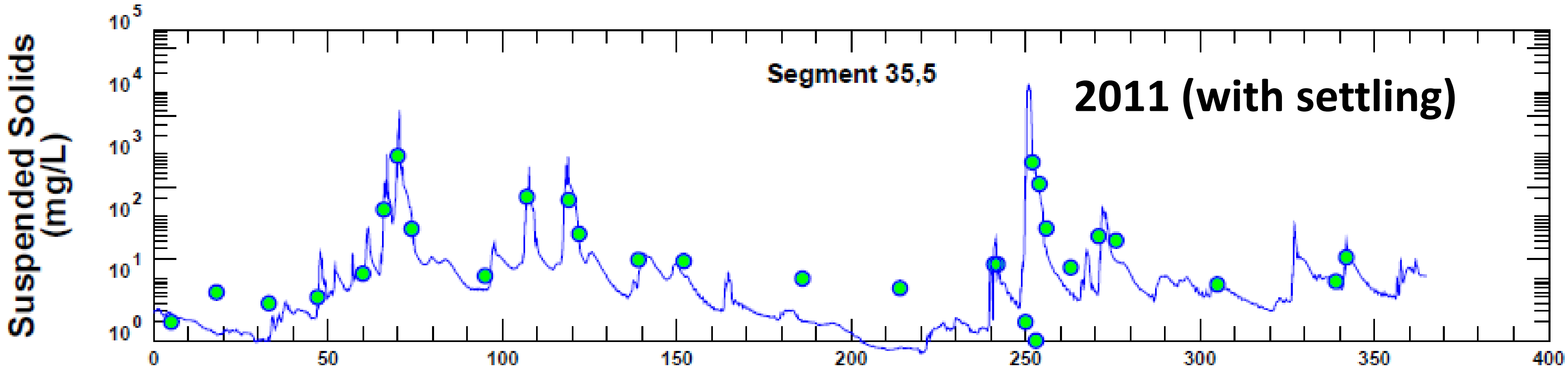
Model Performance: SSC at Conowingo

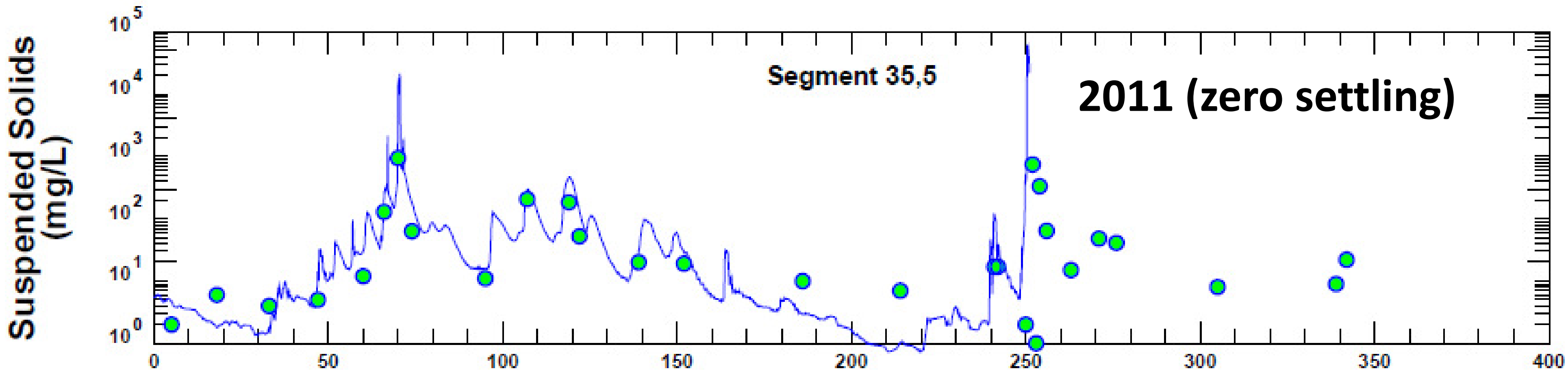




- Note: log scale for concentration (also: number of log cycles differ too)
- Most noticeable difference occurs June-September (Days 150-280)
- Differences likely driven by uncertain upstream loads and grain size

Model Performance: SSC at Conowingo



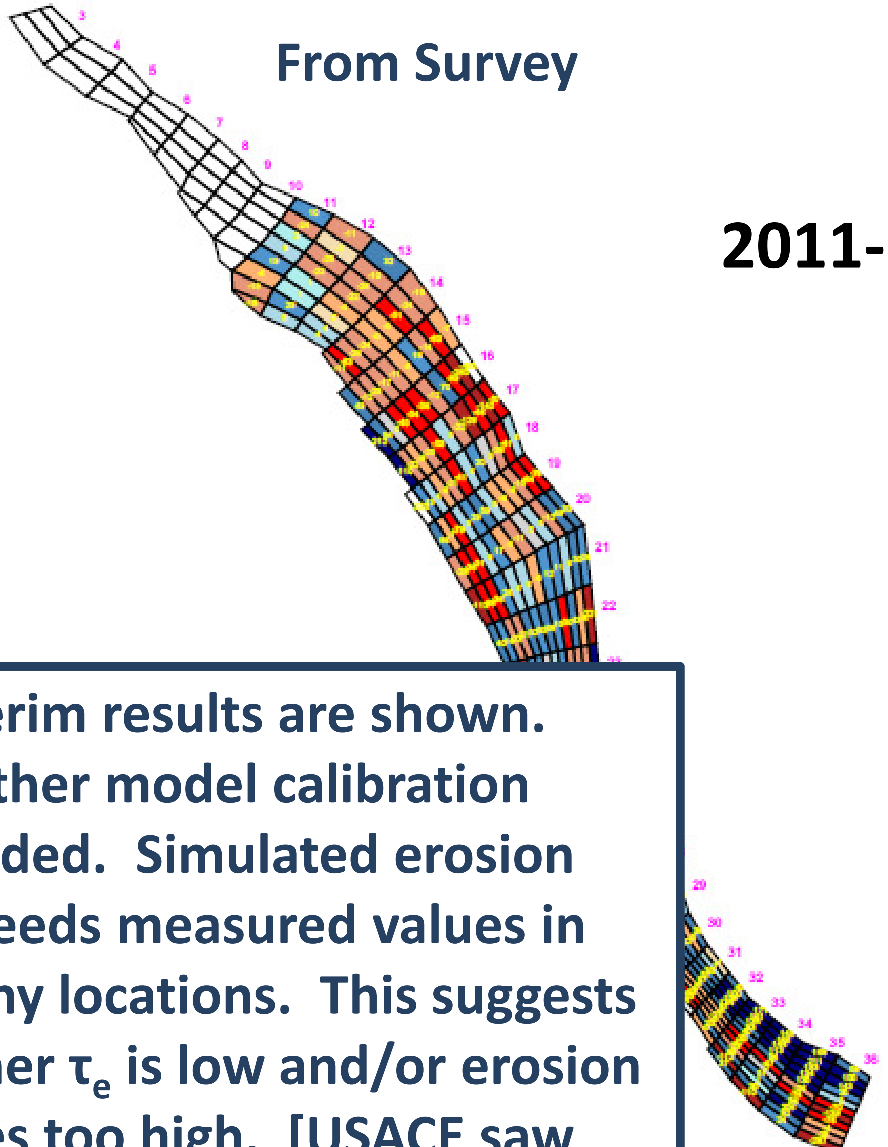


- **Note: log scale for concentration (also: number of log cycles differ too)**
- **As settling rates decrease, model is too high during events and still too low during summer (suggests upstream load too low)**

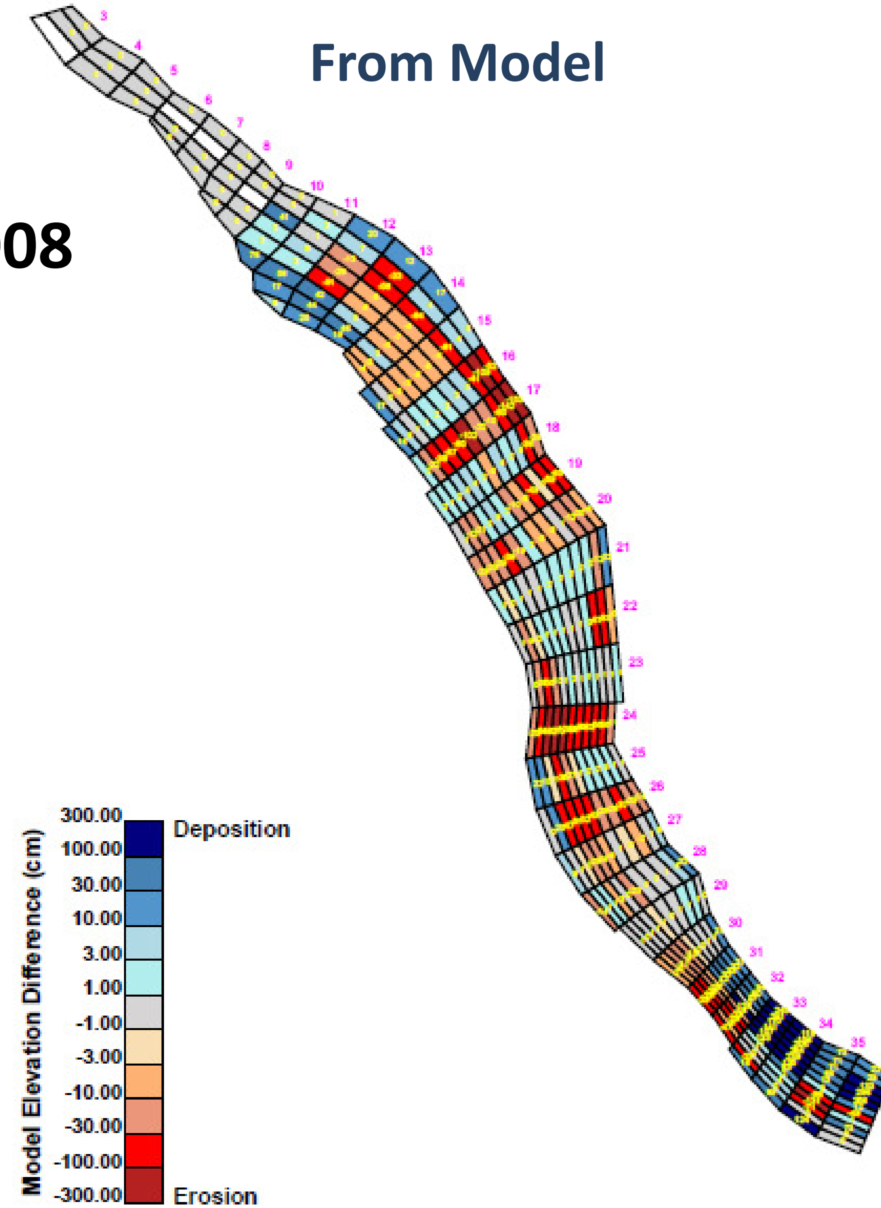
Exelon Generation.

Model Performance: Bed Elevation Changes

From Survey



From Model



2011-2008

Interim results are shown. Further model calibration needed. Simulated erosion exceeds measured values in many locations. This suggests either τ_e is low and/or erosion rates too high. [USACE saw this too…]


Questions?
Exelon Generation