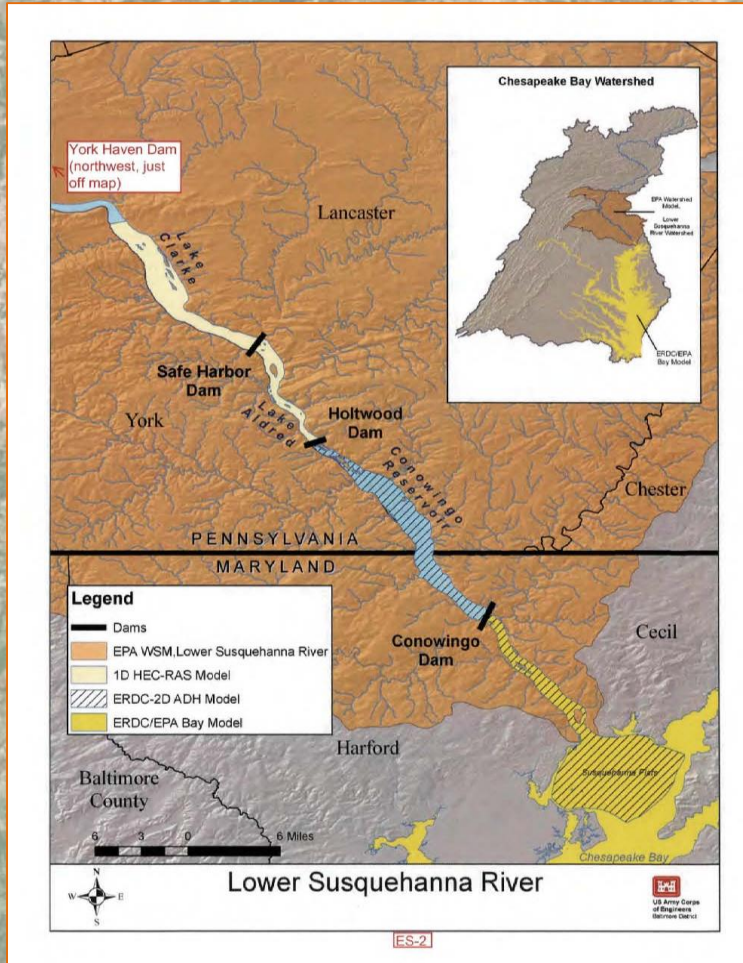
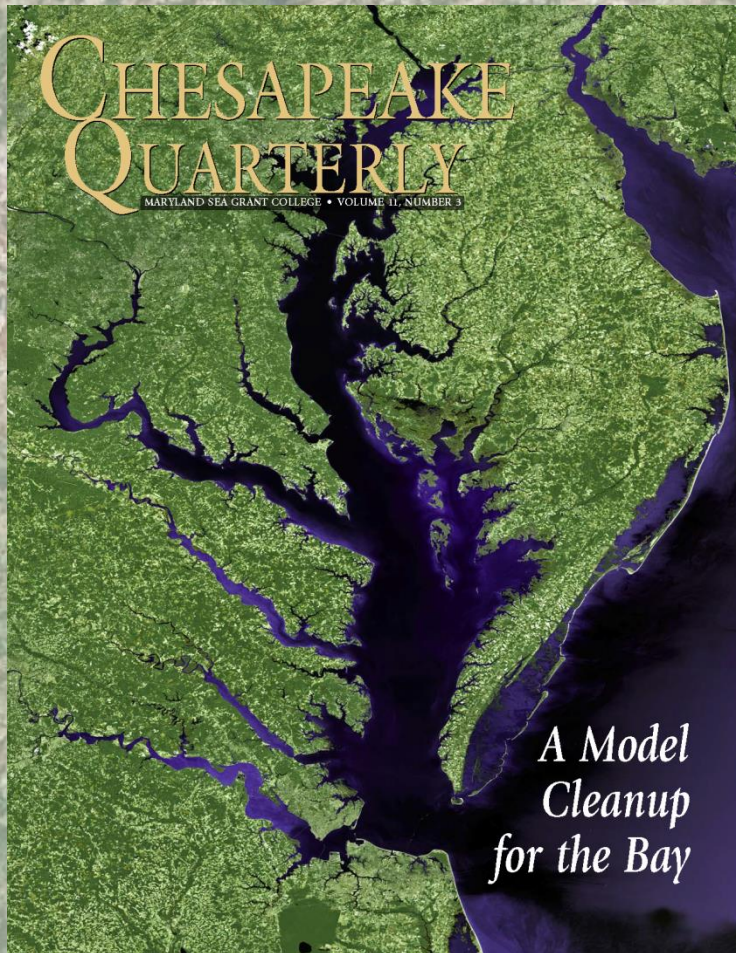


Background



- The Susquehanna River provides about half the freshwater flow to Chesapeake Bay.
- A series of three dams and reservoirs regulates flow and loads from the watershed to the bay.
- Lakes Clarke and Aldred have filled with sediment to the equilibrium level. The largest reservoir, Conowingo, is filled or nearly filled.

Problems for the TMDL?



- Reservoirs are full or nearly full to capacity with sediment.
- A major scour event transports solids and nutrients from the reservoir bottom to the bay.
- Lesser events may provide more frequent additional loading to the bay.
- Scoured solids and associated nutrients threaten the TMDL which incorporates historical deposition rates in Conowingo reservoir.

Lower Susquehanna River Watershed Assessment – A Partnership

- Baltimore District, USACE – Project management and reporting
- State of Maryland – Project sponsorship
- USEPA Chesapeake Bay Program – Assessment of impact on TMDL, watershed modeling
- US Geological Survey – Modeling of upper reservoir system
- ERDC Coastal and Hydraulic Lab – Sediment transport in Conowingo Reservoir
- ERDC Environmental Lab – Impact on Chesapeake Bay
- The Nature Conservancy – Public Relations and Advocacy

Objectives

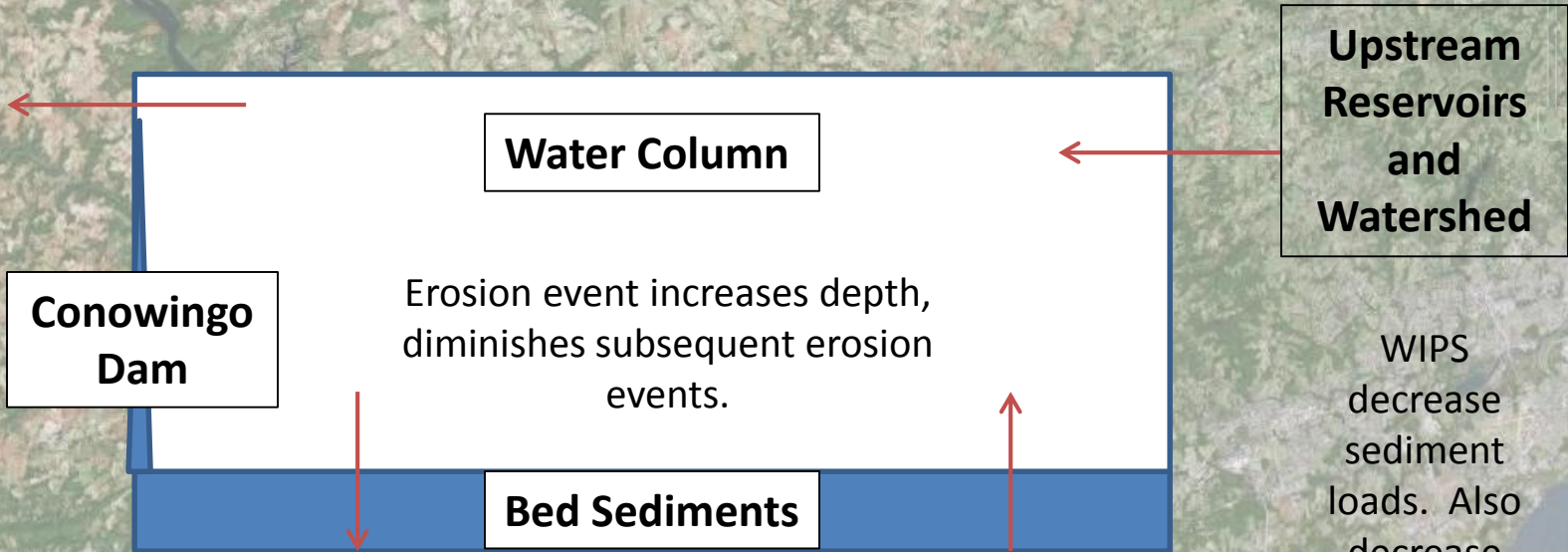
- Forecast and evaluate sediment loads to the system of hydroelectric dams located on the Susquehanna River,
- Analyze hydrodynamic and sedimentation processes and interactions within the lower Susquehanna River watershed,
- Consider structural and non-structural strategies for sediment management, and
- Assess cumulative impacts of future conditions and sediment management strategies on Chesapeake Bay.

Critical Components

- Identification of watershed-wide sediment management strategies,
- Use of engineering models to link incoming sediment and associated nutrient projections to in-reservoir processes at the hydroelectric dams and forecast impacts to living resources in the upper Chesapeake Bay,
- Use of the Chesapeake Bay Environmental Model Package (CBEMP), a cooperative effort of the US Environmental Protection Agency Chesapeake Bay Program and the US Army Engineer Research and Development Center, to assess cumulative impacts of the various sediment management strategies to the upper Chesapeake Bay, and
- Integration of the Maryland and Pennsylvania Watershed Implementation Plans for nitrogen, phosphorus, and sediment reduction, as required to meet Chesapeake Bay TMDL's.

Conceptual Model of Sediment Movement through Conowingo Reservoir

Sediment and nutrient releases are event-oriented.



Conowingo Dam

Water Column

Erosion event increases depth, diminishes subsequent erosion events.

Bed Sediments

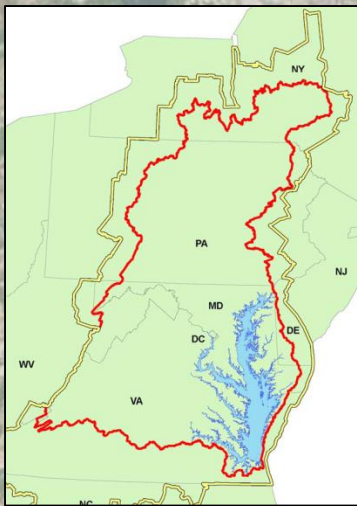
Upstream Reservoirs and Watershed

WIPS decrease sediment loads. Also decrease deposition.

Sedimentation rate is largely independent of bathymetry.

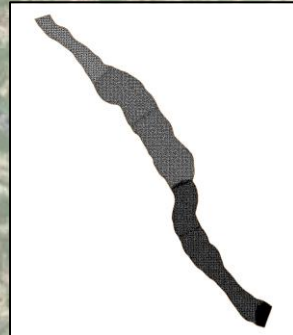
Scour is strongly dependent on bathymetry.

A Cascade of Models



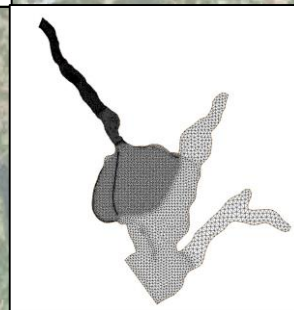
EPA Chesapeake Bay Program Watershed Model

- Simulates the 64,000 sq mile Chesapeake Bay Watershed.
- Provides daily loads of sediments and nutrients from 90 sub-basins.
- Simulates 1985 – 2005.



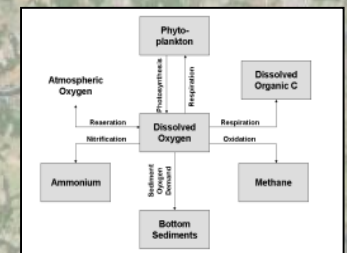
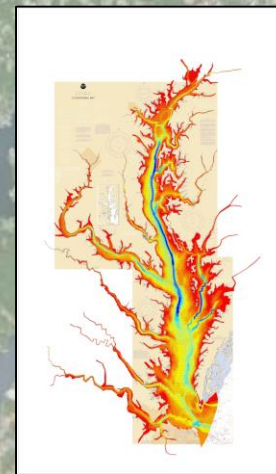
USACE ERDC Adaptive Hydraulics (ADH) Model

- State-of-the art for hydrodynamics and sediment transport.
- Unstructured grid for maximum resolution.
- Simulates Conowingo Reservoir and Susquehanna Flats 2008 – 2011.



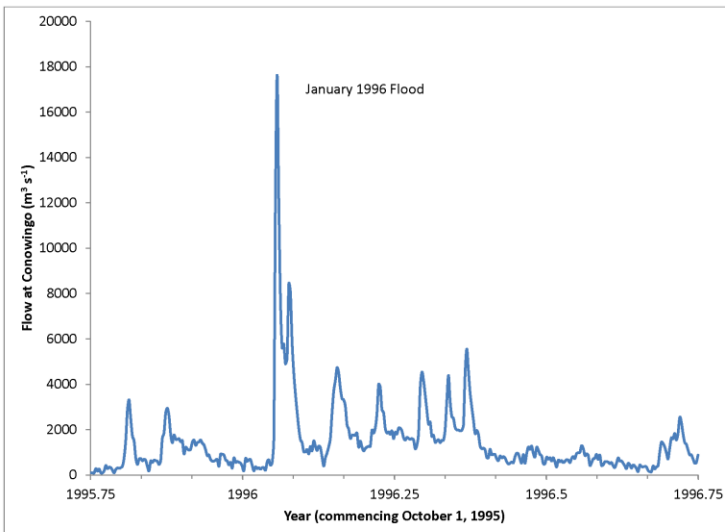
USACE ERDC CE-QUAL-ICM Model

- Simulates water quality, sediment, and living resources in three dimensions in 50,000 discrete cells.
- For this study, emphasis on chlorophyll, water clarity, and dissolved oxygen.
- Operational for 1985 – 2005.

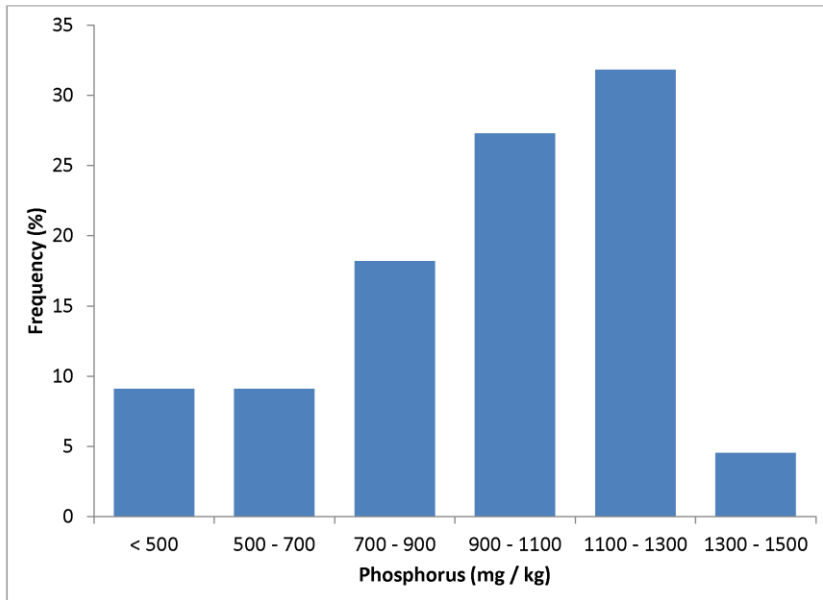


The Scenario Procedure

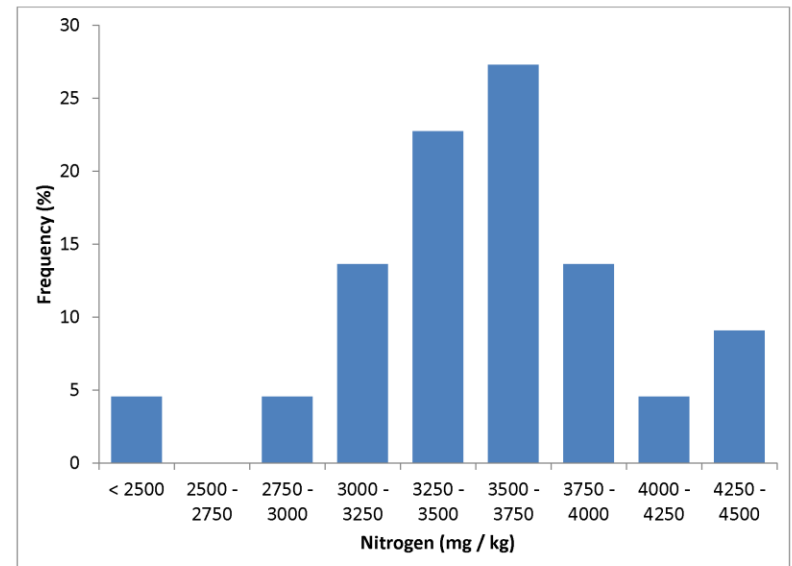
- Simulate ten years hydrology, 1991 – 2000.
- Calculate scour for the January 1996 flood event based on ADH. Add scoured nutrients and solids to watershed load.
- Watershed load from EPA CBP based on TMDL conditions.
- Focus on dissolved oxygen, chlorophyll, water clarity.



Bottom Composition

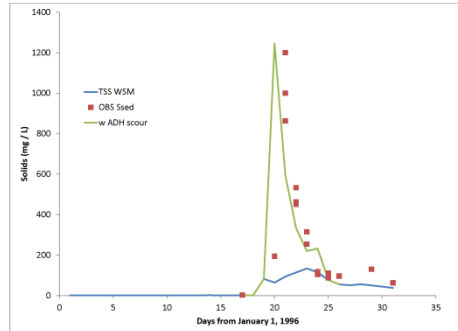
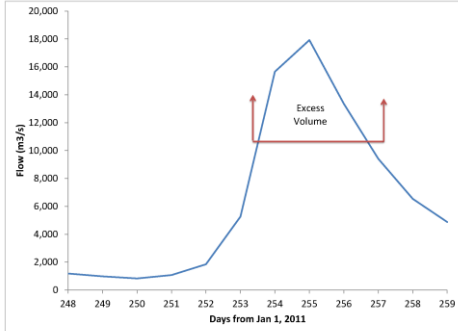


- There is three times as much nitrogen as phosphorus in bottom sediments, on a particle weight basis.
- A scour event is going to erode more nitrogen than phosphorus from the bottom.



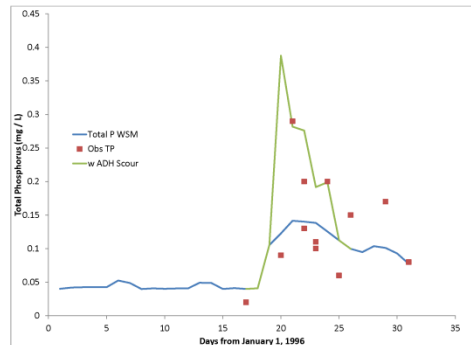
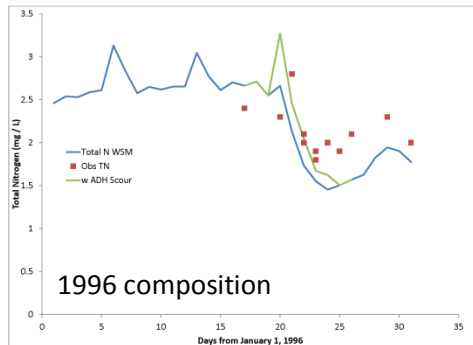
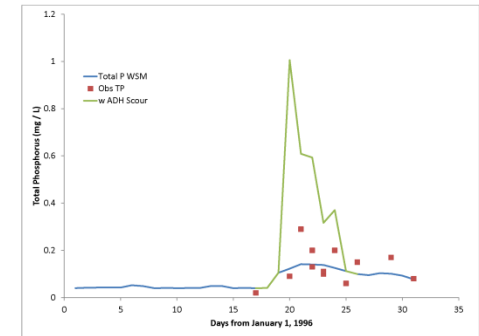
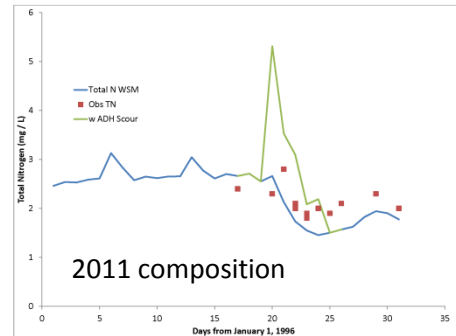
Data courtesy Mike Langland, USGS

Calculate Scour Loads



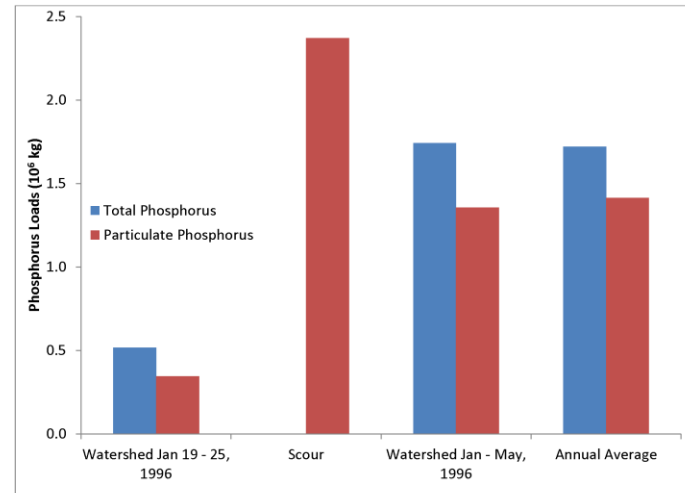
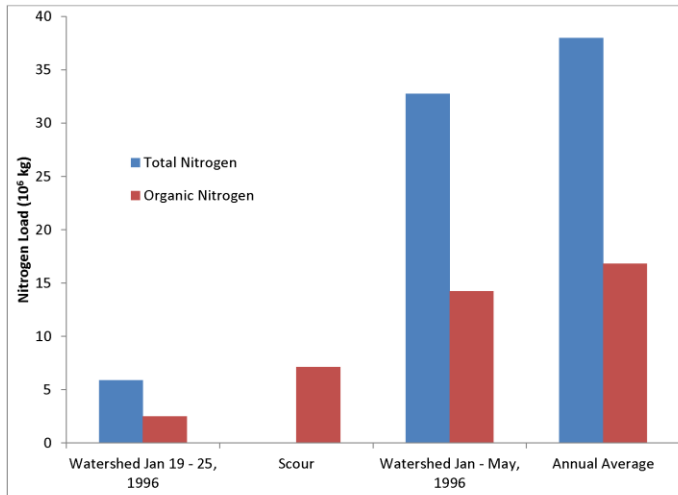
Interpolating ADH scour for Tropical Storm Lee provides good solids loads for January 1996.

Nutrient composition observed during 2011 Tropical Storm Lee is not appropriate for 1996

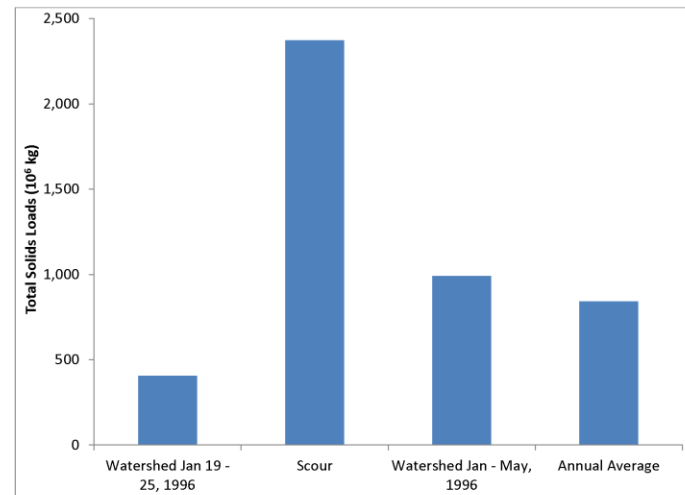


Solution: Run alternate scenarios with 1996, 2011 composition. More recent observations preferred for future projections.

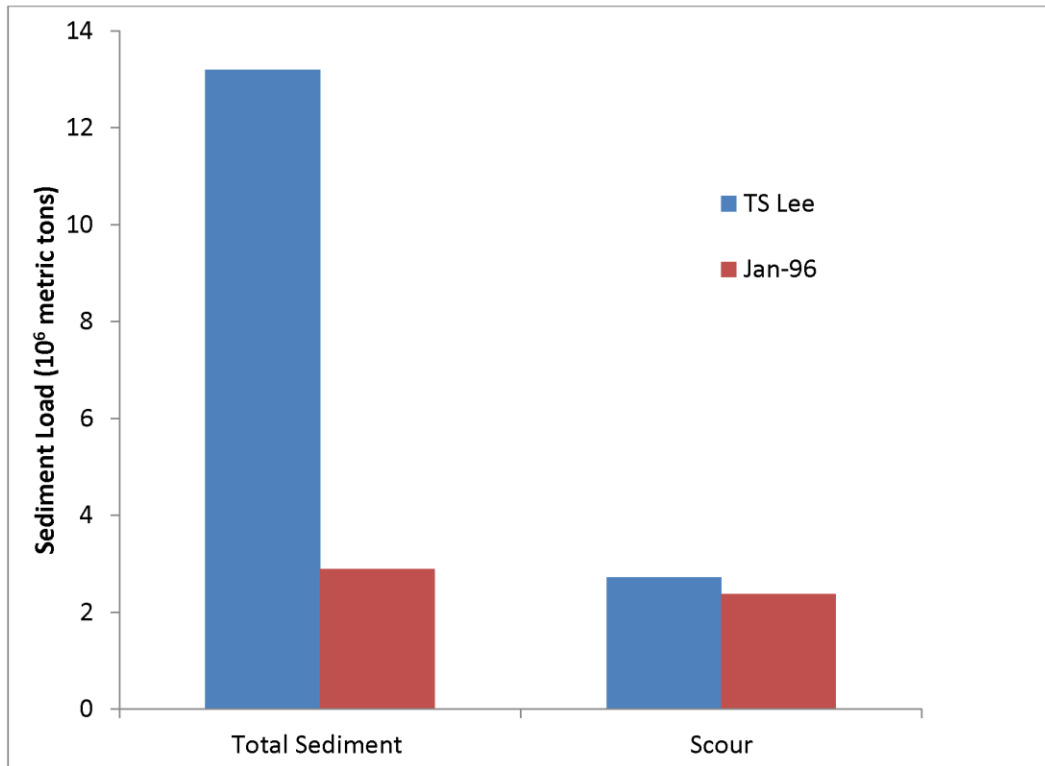
1996 Scour Loads vs Watershed Loads



- The nitrogen scour load is greater than the TMDL watershed storm load but a small fraction of the annual average load.
- The phosphorus scour load is immense compared to the TMDL watershed storm load or the annual average load.
- The solids scour load is immense compared to the TMDL watershed storm load or the annual average load.
- ***The nitrogen scour load is three times the phosphorus scour load.***

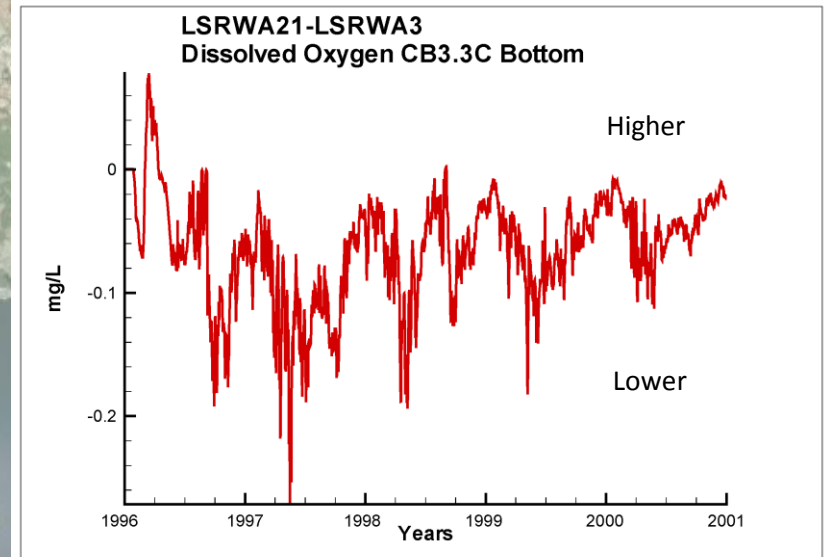
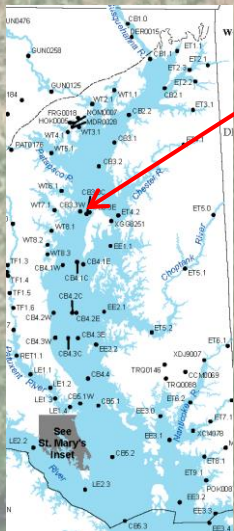
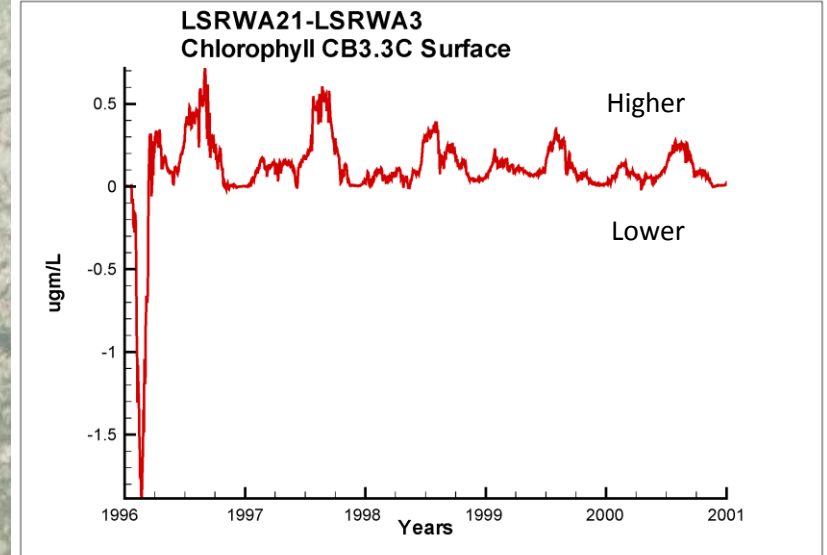
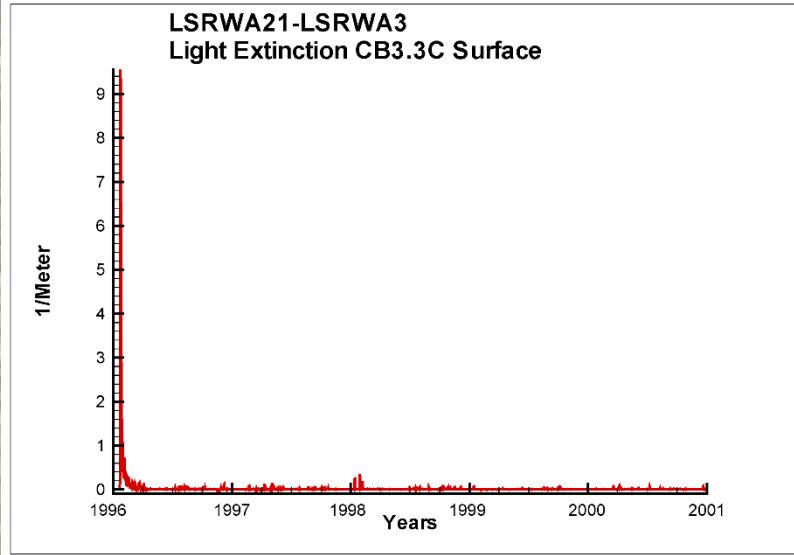


January 1996 vs. Tropical Storm Lee

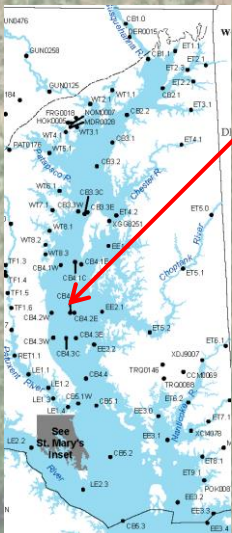
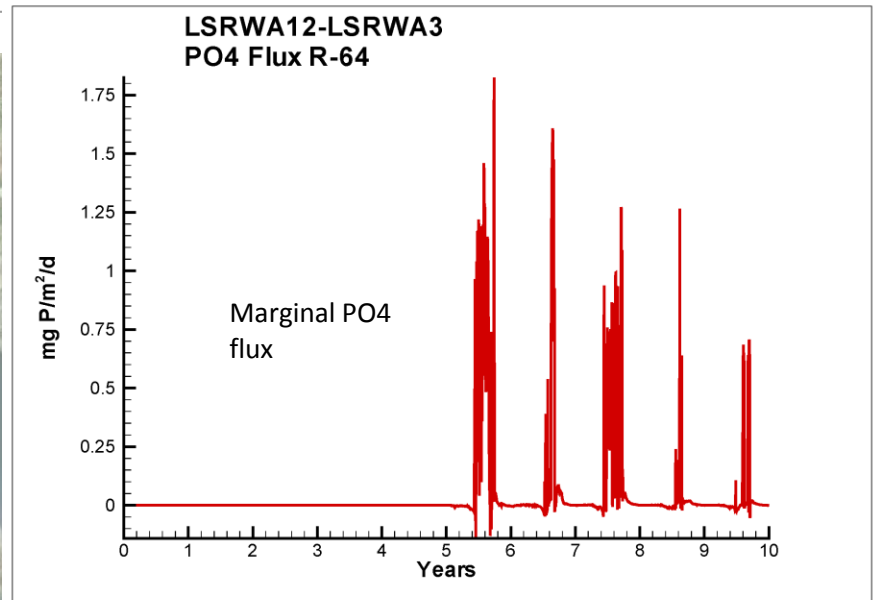
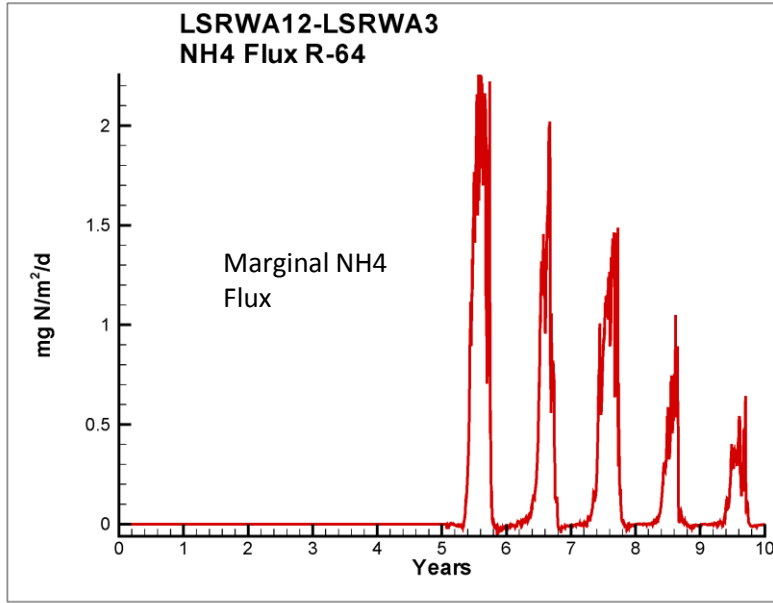


- The scour loads from the two events are similar. However, the watershed load from TS Lee vastly exceeded the watershed load in January 1996.
- Scour comprised 82% of the total sediment load during the January 1996 event but only 21% of the total sediment load during TS Lee.
- It's hard to generalize about a "typical" "extreme" event.

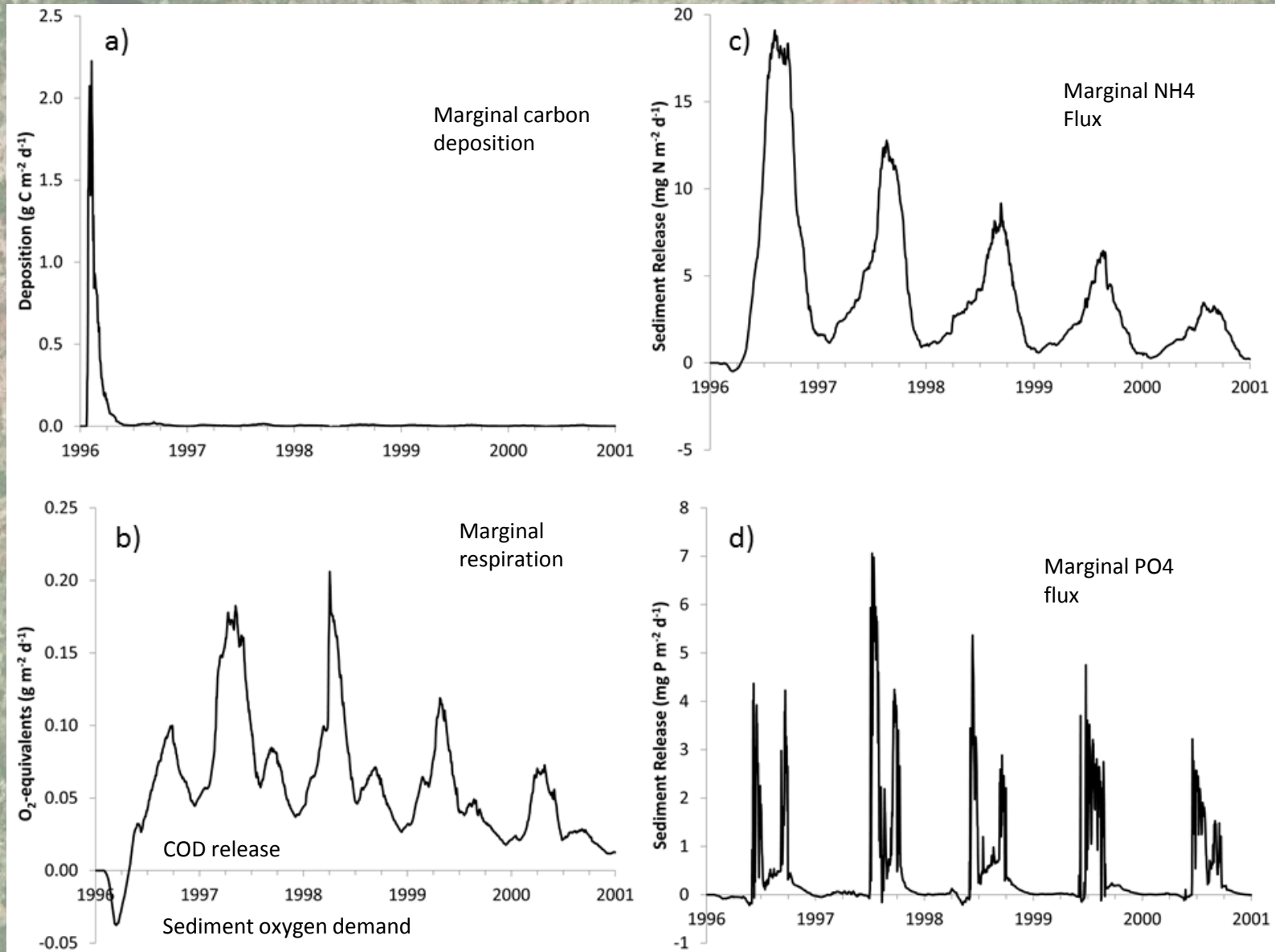
Marginal Effect of a Scour Event on TMDL Conditions



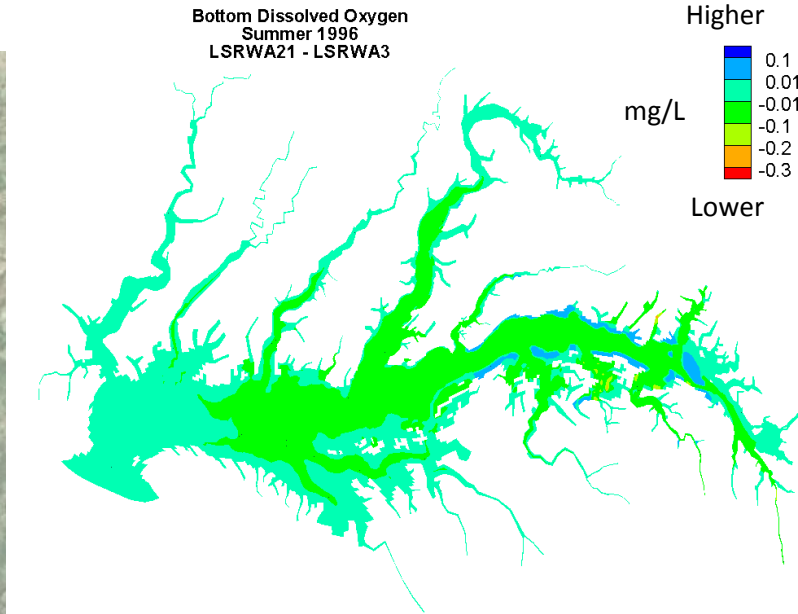
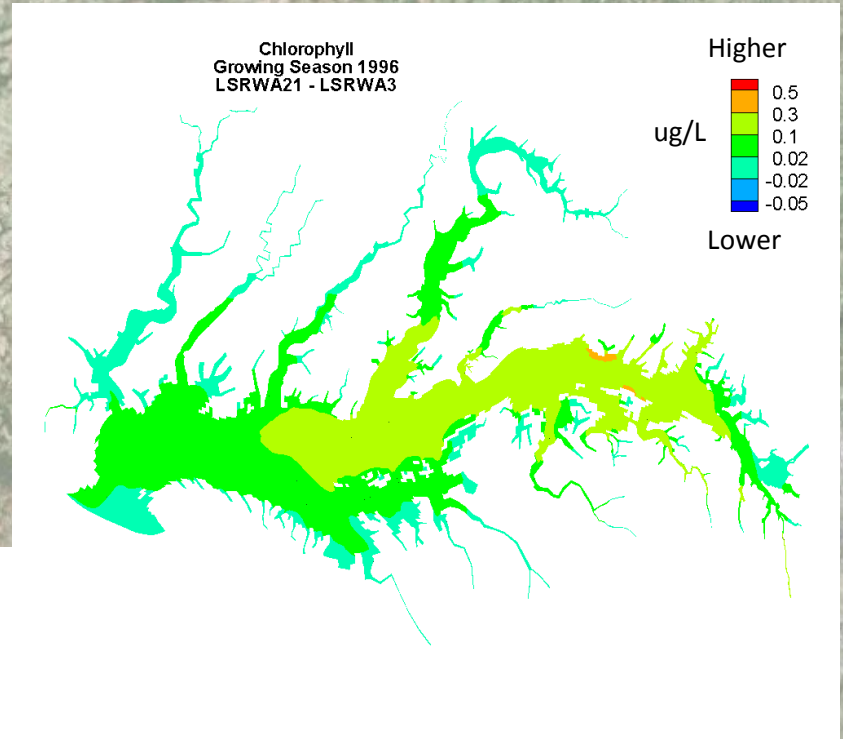
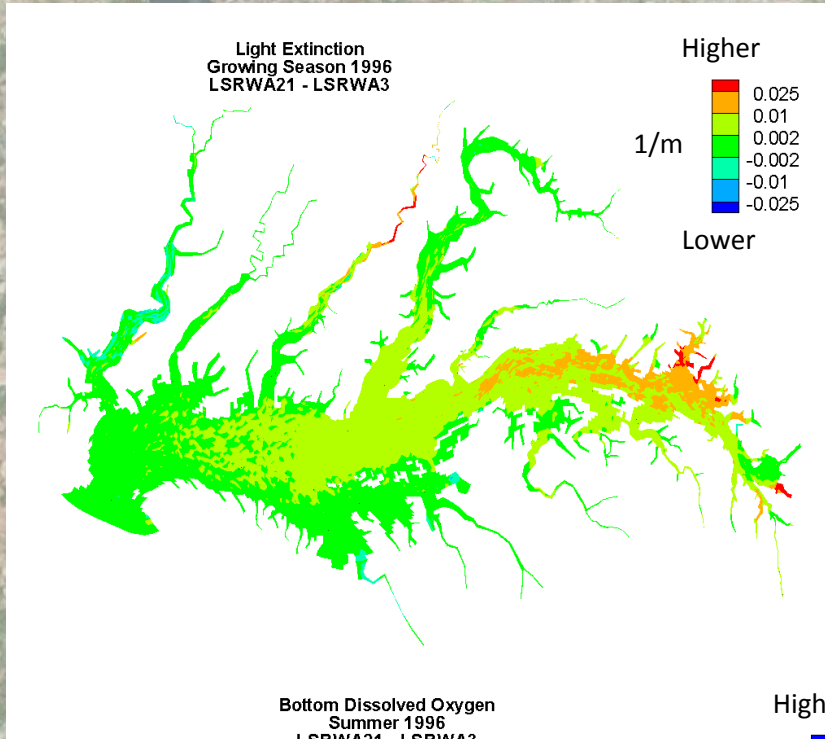
Enhanced Sediment Diagenesis due to Scoured Nutrients



What About Sediment Respiration?



Marginal Effect of a Scour Event on TMDL Conditions

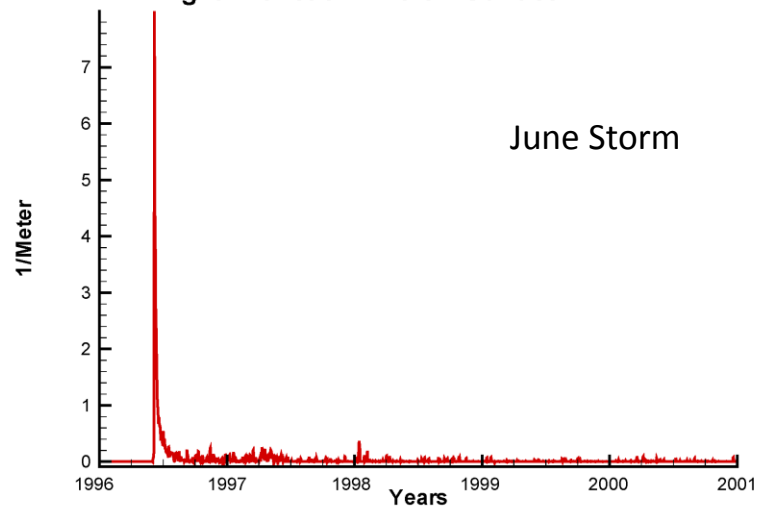


Sensitivity to Seasonality of Storm Events

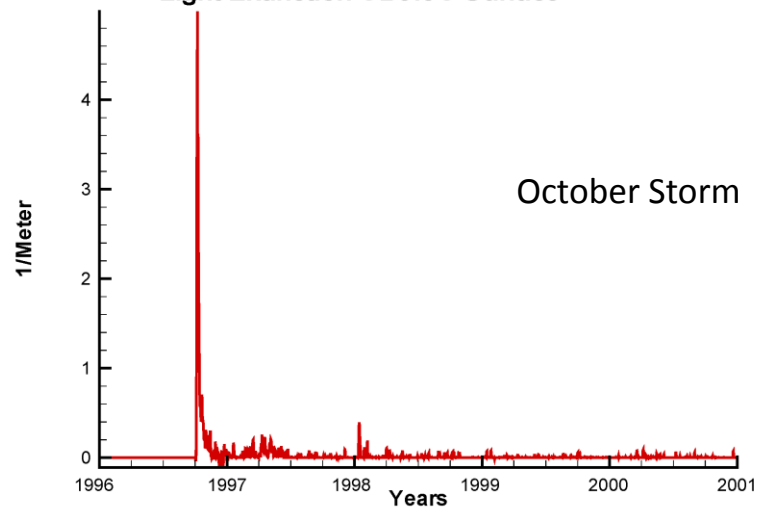
- Runoff events with flows sufficient to scour reservoir sediments occur at various times of the year.
- Floods occur in the Susquehanna in late winter and early spring due to precipitation and snowmelt.
- Tropical storm events are most common during late summer and early fall.
- The notorious Tropical Storm Agnes occurred in June 1972.
- To investigate the effect of storm season, scenarios were completed with the January 1996 Susquehanna storm flows and loads moved to June and October 1996. These were compared to a base scenario with the storm removed.

June vs October Storm

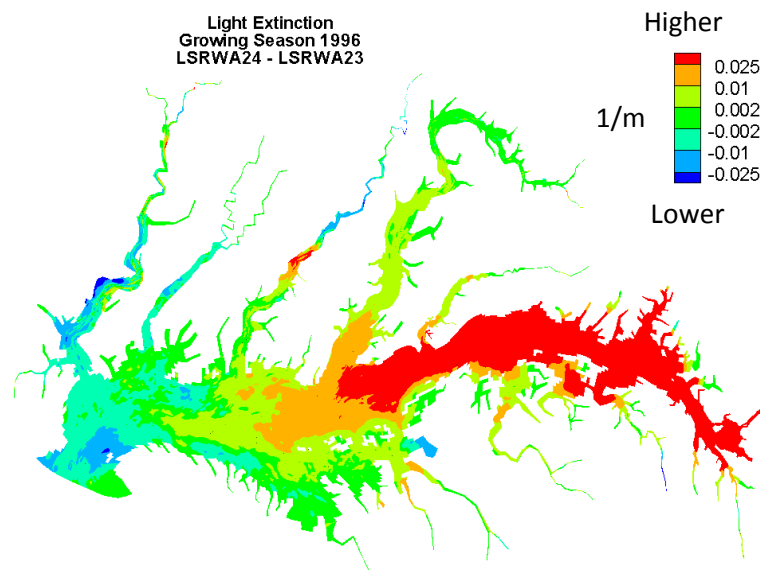
LSRWA24-LSRWA23
Light Extinction CB3.3C Surface



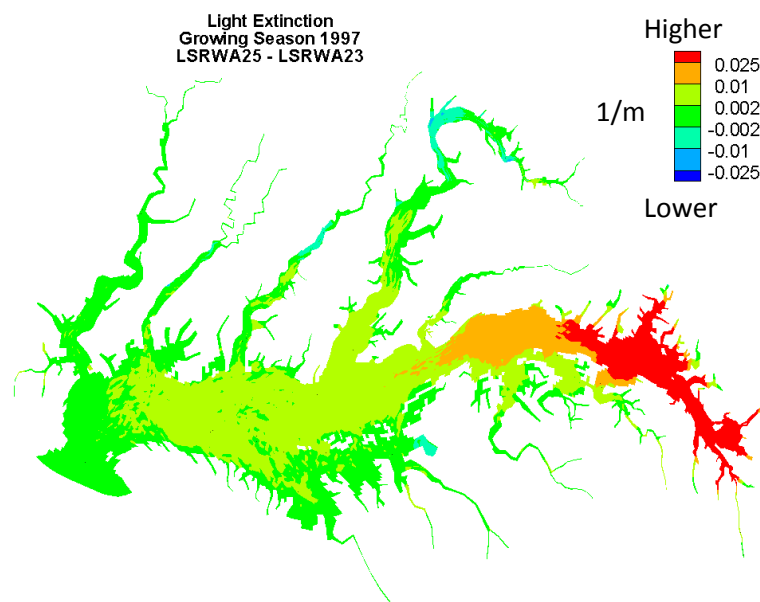
LSRWA25-LSRWA23
Light Extinction CB3.3C Surface



Light Extinction
Growing Season 1996
LSRWA24 - LSRWA23

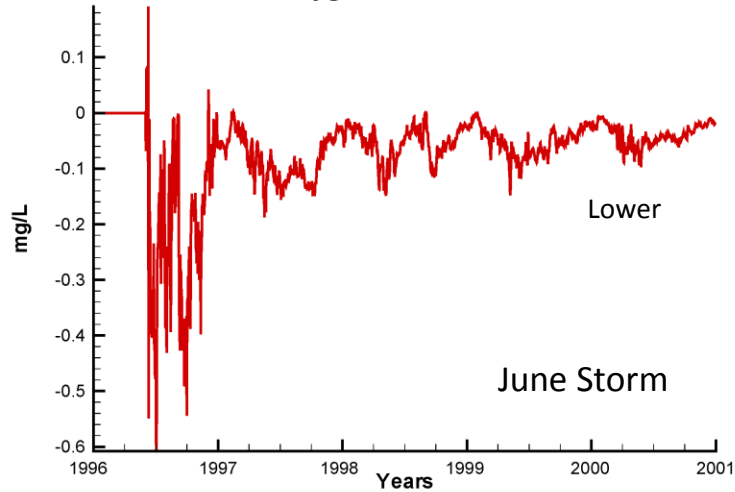


Light Extinction
Growing Season 1997
LSRWA25 - LSRWA23

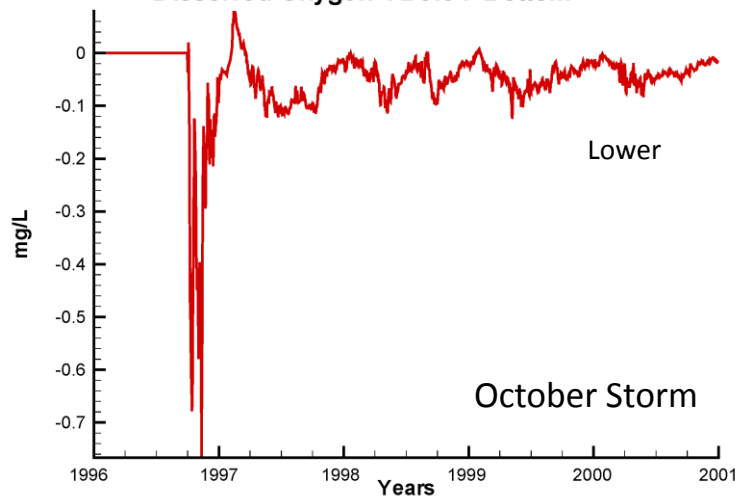


June vs October Storm

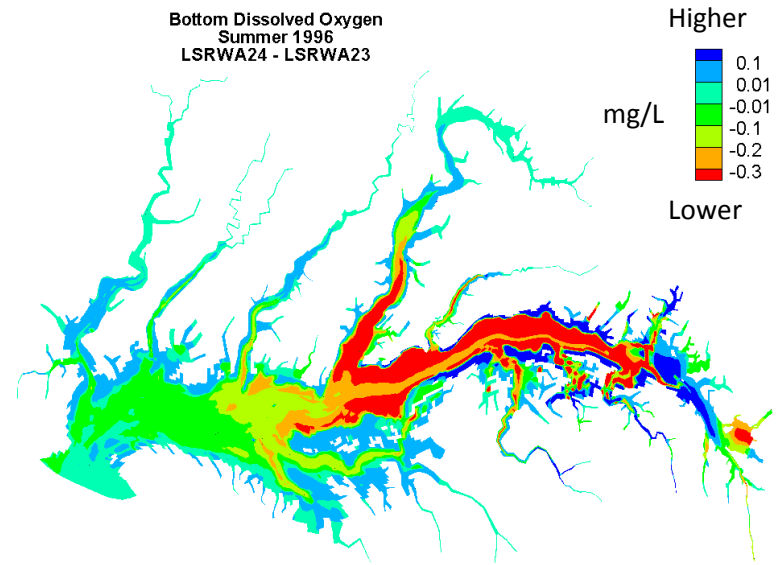
LSRWA24-LSRWA23
Dissolved Oxygen CB3.3C Bottom



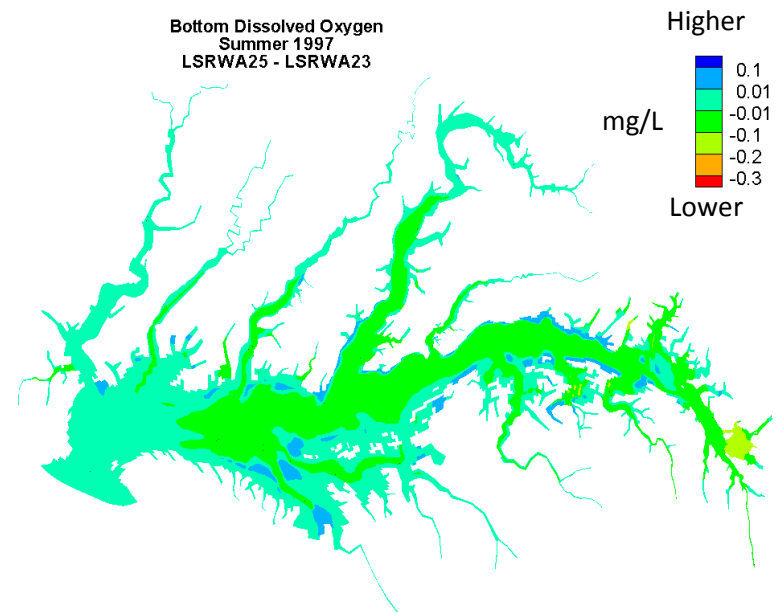
LSRWA25-LSRWA23
Dissolved Oxygen CB3.3C Bottom



Bottom Dissolved Oxygen
Summer 1996
LSRWA24 - LSRWA23



Bottom Dissolved Oxygen
Summer 1997
LSRWA25 - LSRWA23



Alternative Scenario

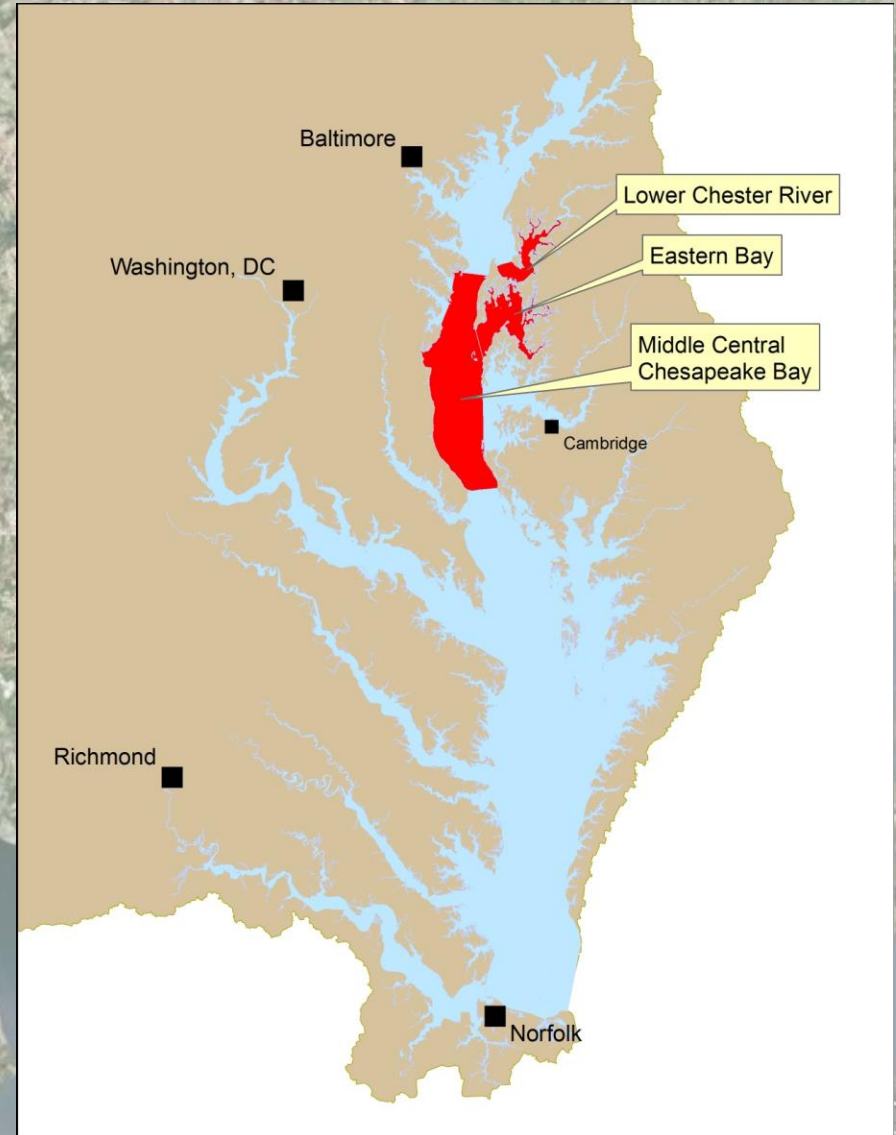
- The LSRWA emphasized effects on Chesapeake Bay water quality from a single scour event.
- The alternative scenario to a scour event is for more frequent, lesser loading events at lower flows due to reservoir infill.
- The alternative scenario was examined by the EPA CBPO.
- EPA adjusted Conowingo scour in their HSPF model to achieve a 50% increase in phosphorus loading and a 100% increase in sediment loading over a ten-year hydrologic interval, 1991 – 2000.
- The loading increases are consistent with the Hirsch (2012) projections.

Alternative Scenario

The results are not all that different:

- Attaining dissolved oxygen standards in the volume-time integral represented by deep-channel water from June to September is critical to the TMDL.
- A reservoir scour event places an additional 1% of the volume-time integral outside of DO standards.
- The scenario of more frequent loading events adds from 1% to 3% of the volume-time integral to the amount outside of DO standards.

This isn't an "either/or" situation. The future will include intervals when the reservoir is near equilibrium punctuated by mass scour events.



Conclusions

- A single scour event is not a cataclysm.
- Solids scour loads are less of a detriment than the accompanying loads of organic matter and nutrients.
- Nitrogen scour loads exceed phosphorus scour loads ($N \approx 3 \times P$).
- The major quantifiable detriment of scour loads to the TMDL is to dissolved oxygen.
- Recent examination of model results indicate that direct respiration of scoured organic carbon is a significant dissolved oxygen sink.
- Projections for the future need to consider alternate conditions of an infilled reservoir and of scour events followed by a period of infilling.

What Do We Need?

- Better information on particulate material passing over Conowingo Dam:
 - Suspended vs. scoured
 - C:N:P ratios, inorganic P
 - Reactivity
- Consider more erosion events e.g. Tropical Storm Lee vs. 1996 ice dam.
- Consider both scour events and infilled reservoir.