

Watershed and Water Quality Modeling to Support TMDL Determinations Lake Oologah

**26th Annual Conference
Oklahoma Clean Lakes and Watersheds
Association (OCLWA)**

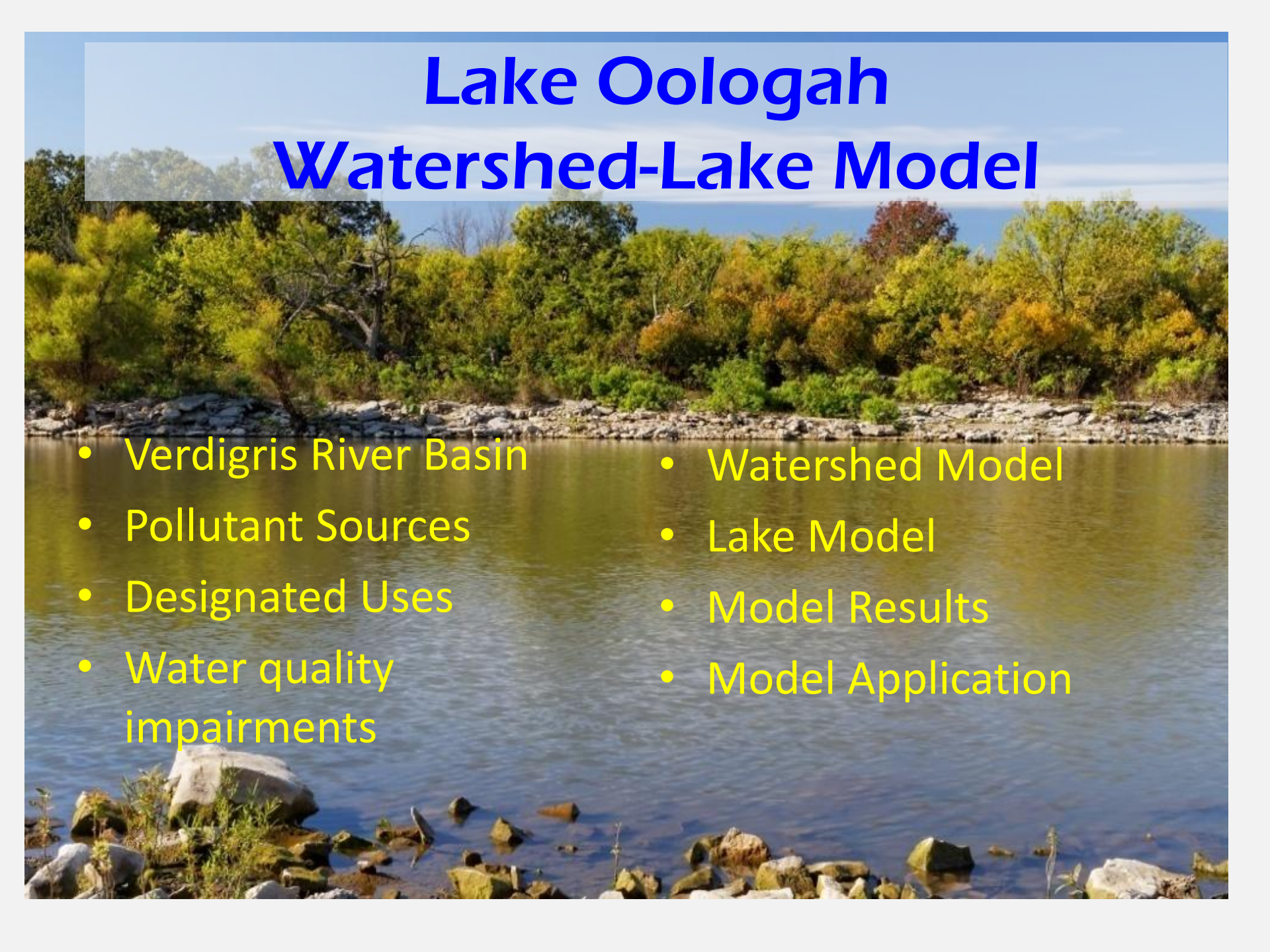


**April 5-6, 2017
Stillwater, Oklahoma**



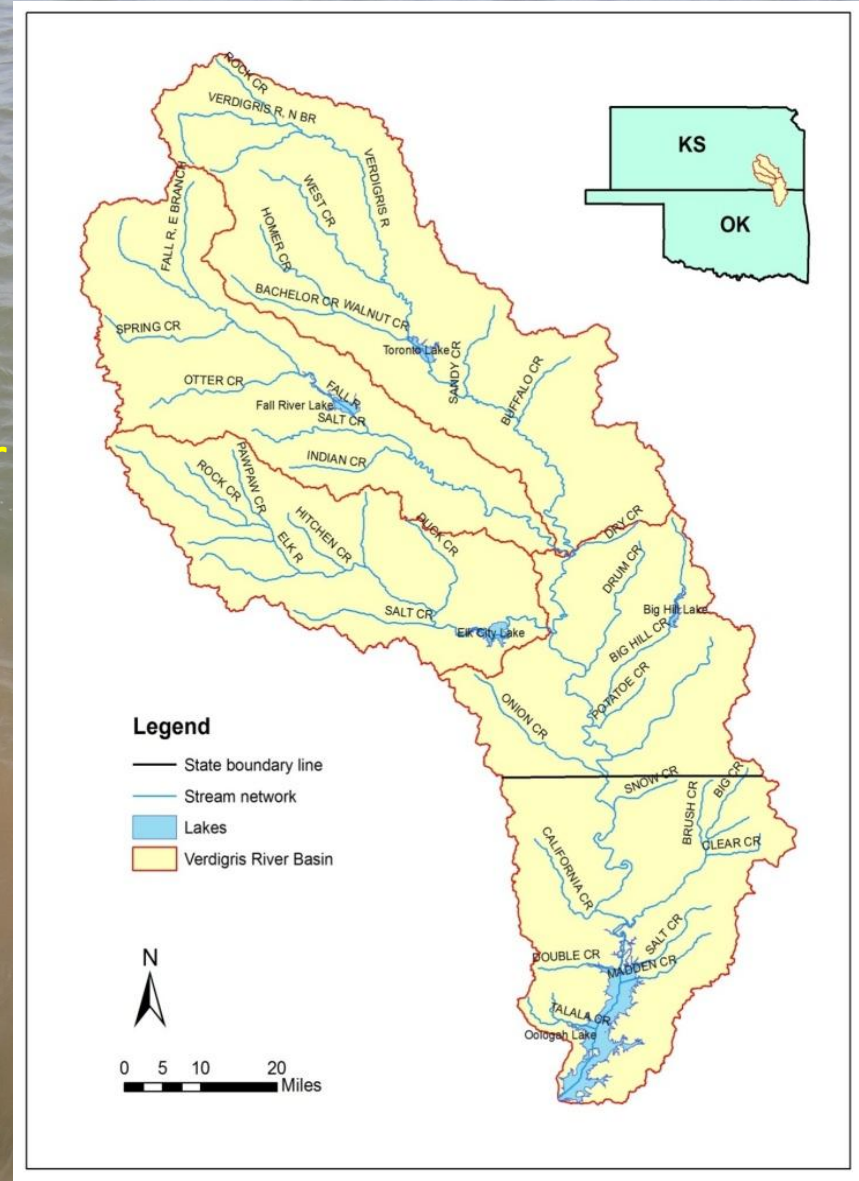
Lake Oologah

Watershed-Lake Model

- 
- Verdigris River Basin
 - Pollutant Sources
 - Designated Uses
 - Water quality impairments
 - Watershed Model
 - Lake Model
 - Model Results
 - Model Application

Lake Oologah

- Verdigris River Basin
- Area upstream of lake is 4,339 sq-miles (23% in OK)
- 31,040 acre USACE reservoir
- Public water supply for Tulsa, Public Service of OK; Collinsville, Chelsea, Claremore; RWDs Rogers, Nowata, Washington Co.
- Point source wastewater
- Nonpoint source runoff from urban/rural areas



Designated Uses

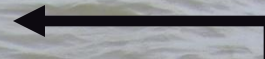
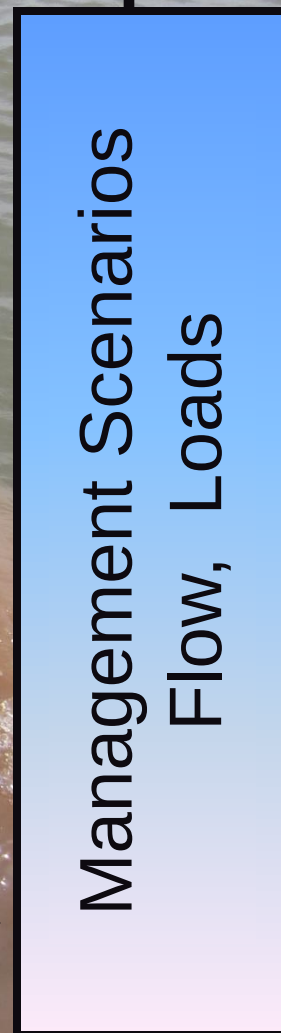
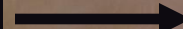
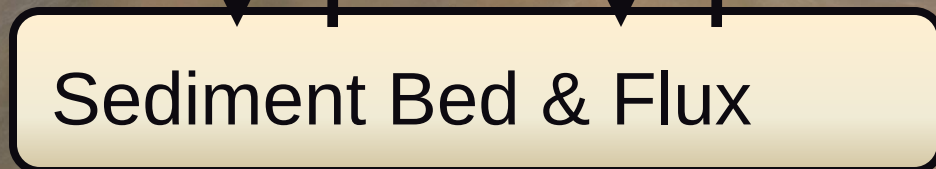
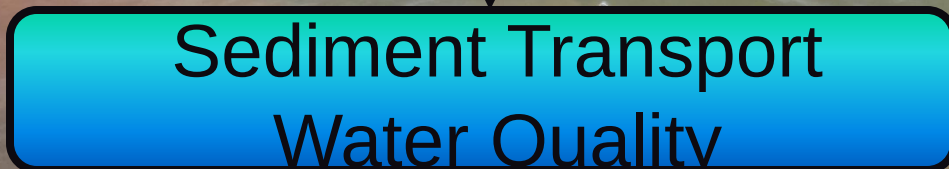
303(d) Impairments and WQ Targets

- Flood control, water supply, recreation, navigation, fish and wildlife propagation
- Impaired for Warm Water Fish and Wildlife Propagation
- Classified as eutrophic lake by Trophic State Index (TSI)
- Annual 90th percentile Turbidity < 25 NTU
- Surface DO > 5 mg/L
- Lake volume DO: < 50% can be < 2 mg/L during stratified season

HSPF



EFDC



HSPF Watershed Model

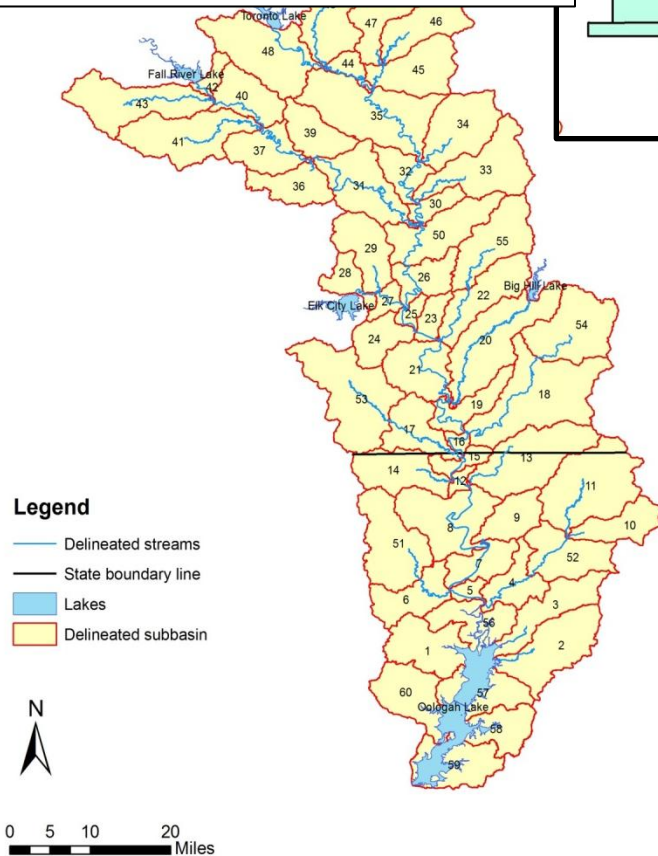
Hydrologic Simulation Program-Fortran



- Sub-watersheds
- Rainfall/meteorology
- Topography
- Land uses/soil types
- Stream channels
- Overland flow
- Infiltration/groundwater
- Flow (Q) and WQ (TSS, Wtemp, DO, BOD, N, P, Algae)

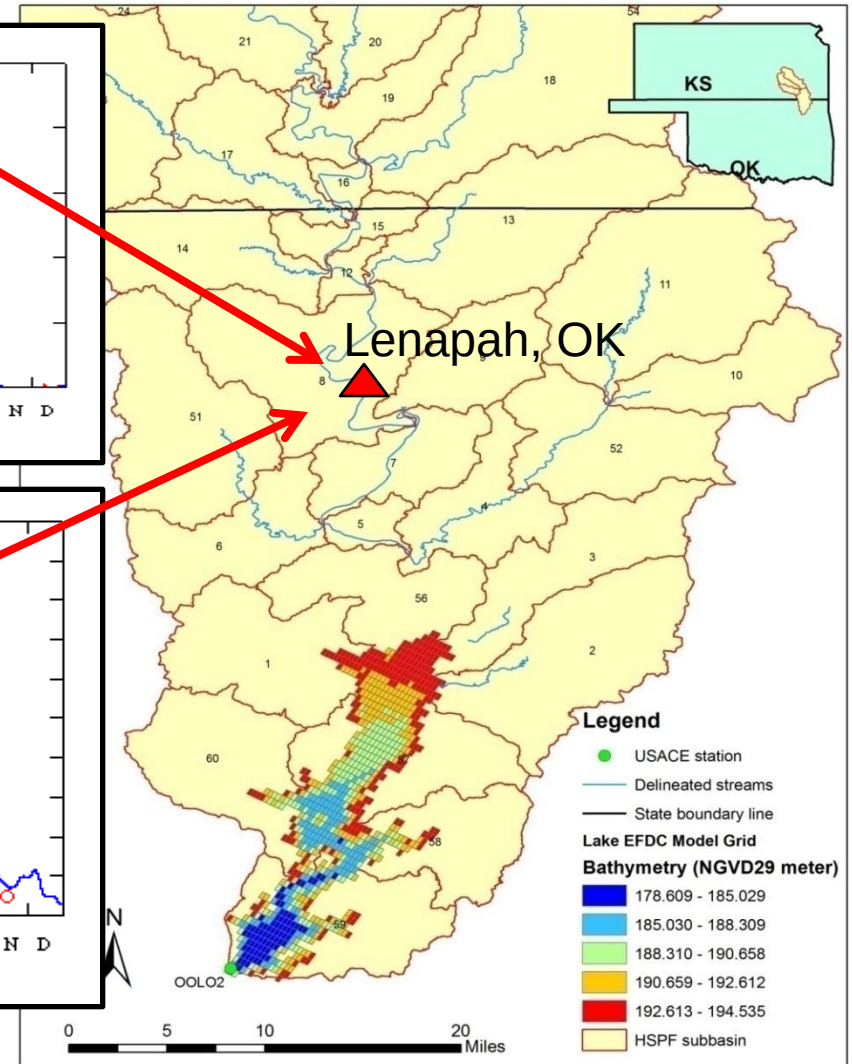
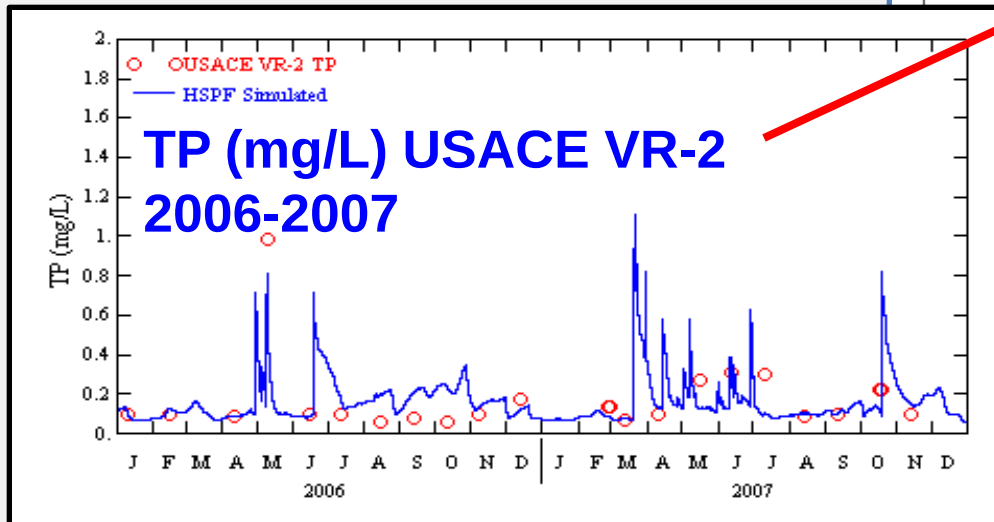
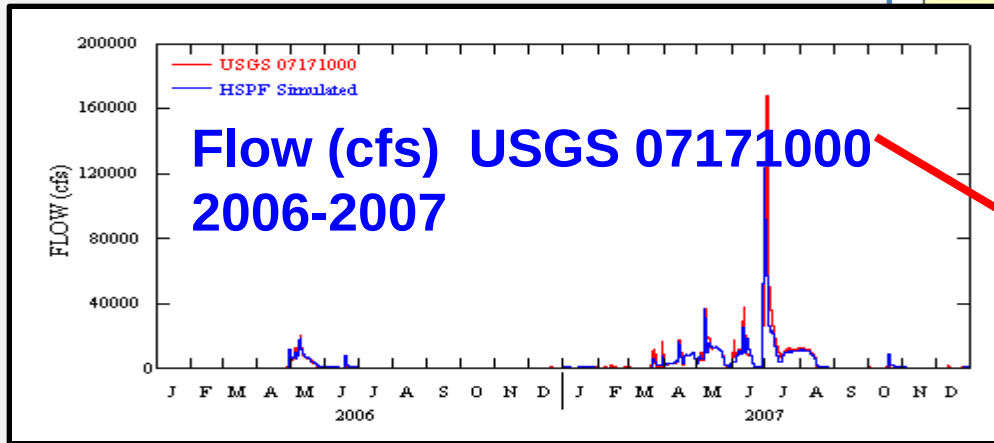
HSPF Watershed Model

Middle Verdigris
59 Sub-Watersheds

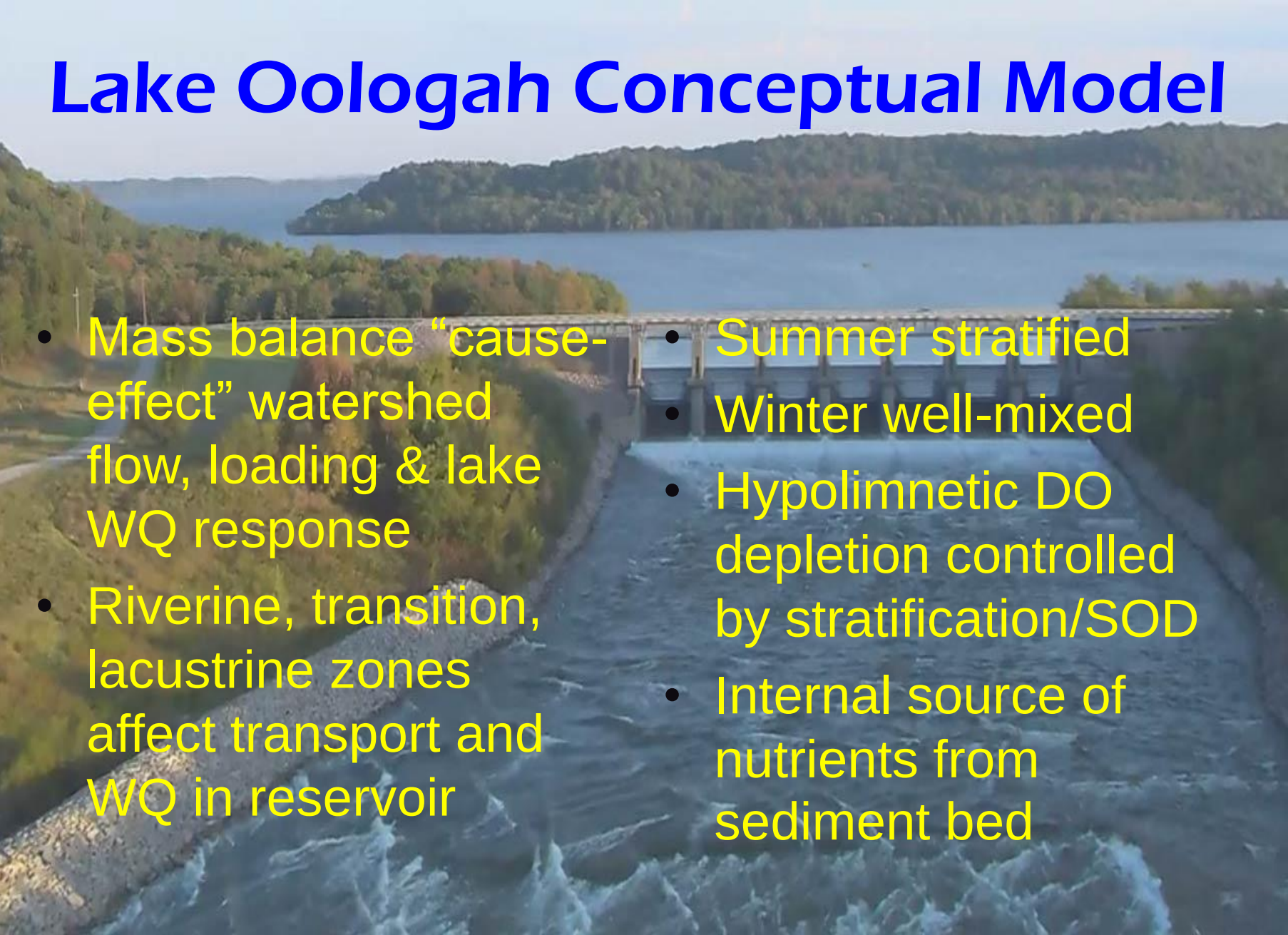


- 2 Yrs Calibration, 2004-2005
- 2 Yrs Validation, 2006-2007
- 2006 drought year
- Flow (USGS)
- WQ (EPA, OWRB, USACE)
- State variables are Flow, TSS, Water Temperature, DO, BOD, Nitrogen, Phosphorus, Algae

Flow and TP: Middle Verdigris R



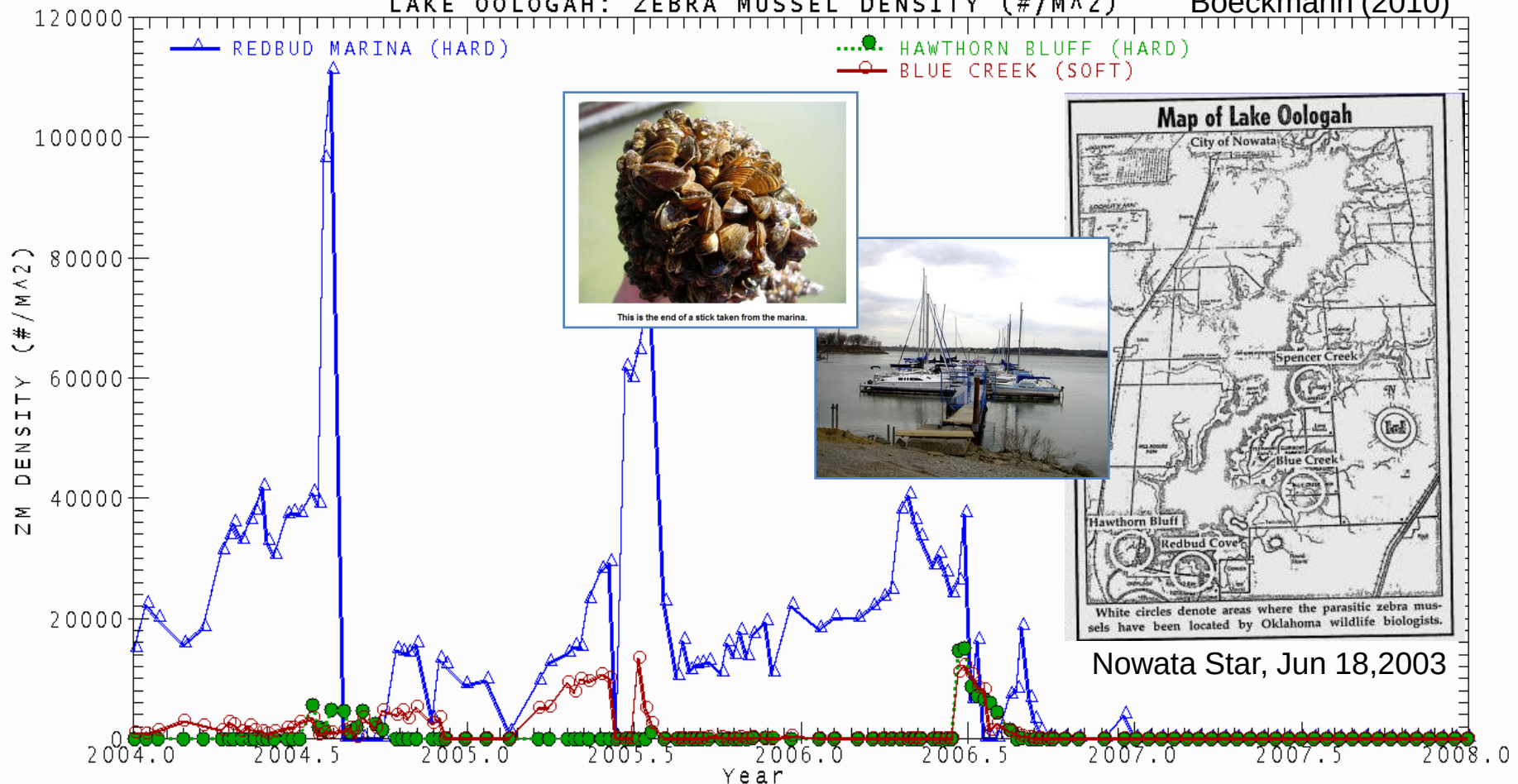
Lake Oologah Conceptual Model

- 
- Mass balance “cause-effect” watershed flow, loading & lake WQ response
 - Riverine, transition, lacustrine zones affect transport and WQ in reservoir
 - Summer stratified
 - Winter well-mixed
 - Hypolimnetic DO depletion controlled by stratification/SOD
 - Internal source of nutrients from sediment bed

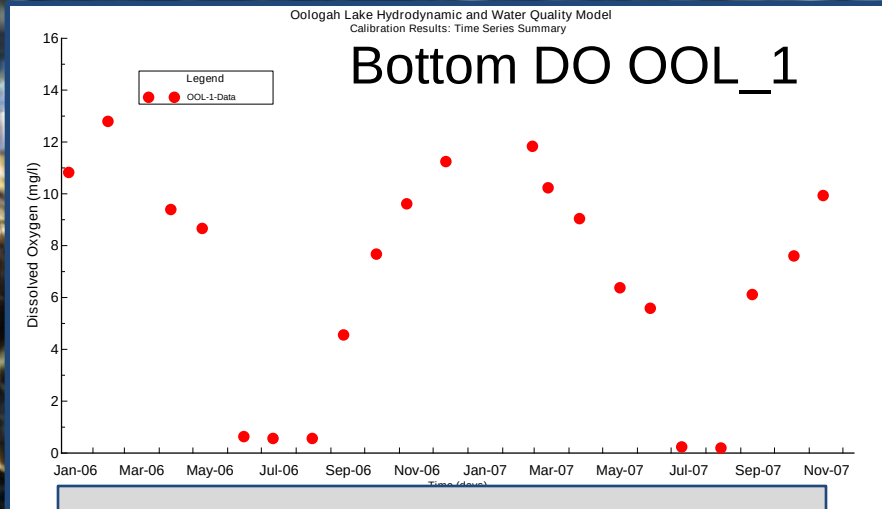
mussels found in Lake Oologah

LAKE OOLOGAH: ZEBRA MUSSEL DENSITY (#/M²)

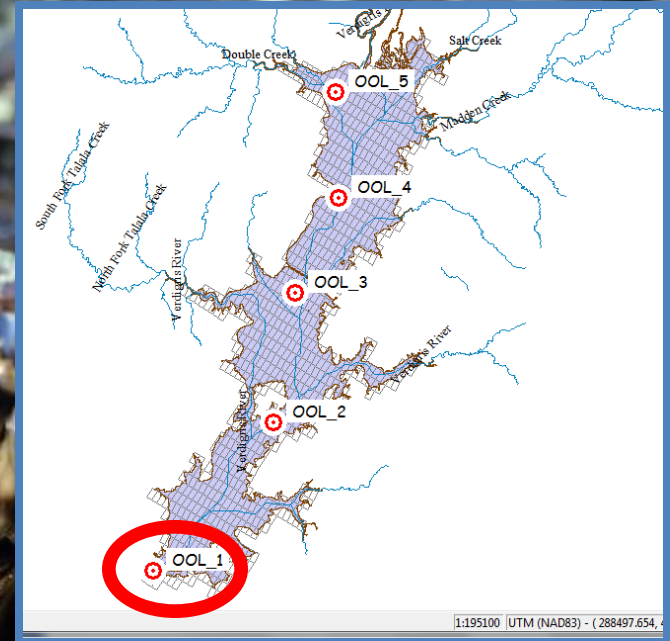
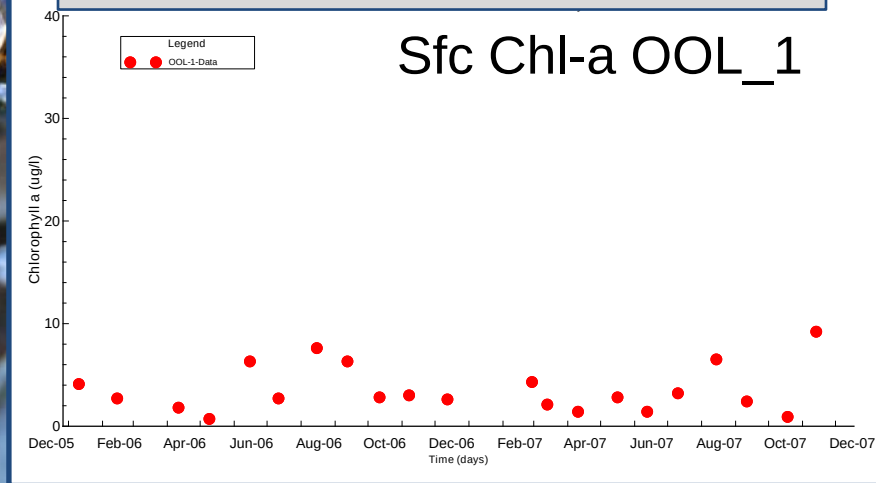
Boeckmann (2010)



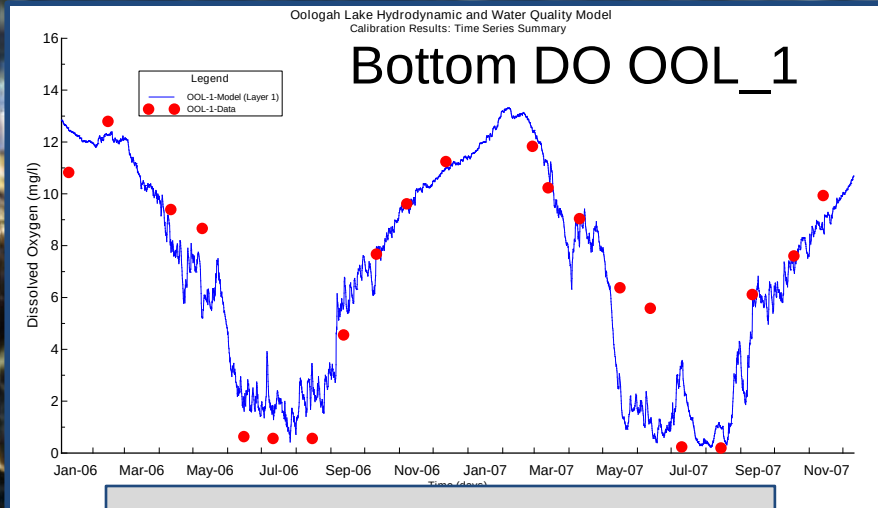
WQ Impact of Zebra Mussels?



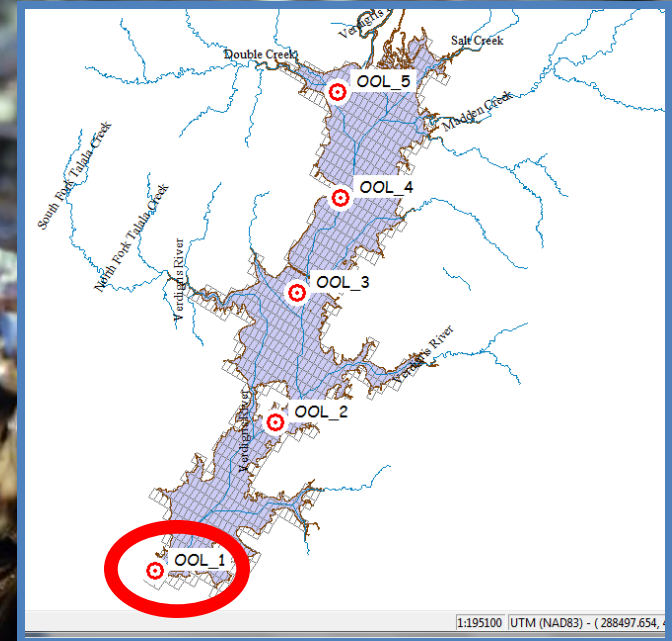
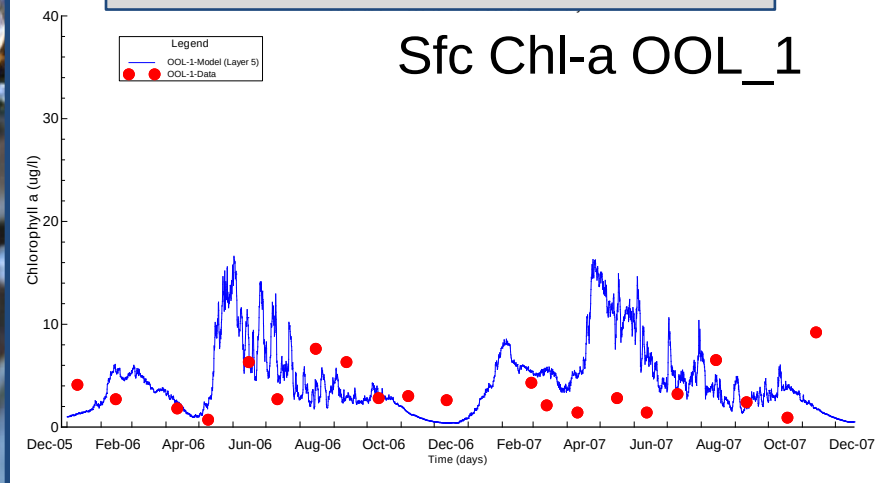
Jan 2006-Dec 2007



WQ Impact of Zebra Mussels?

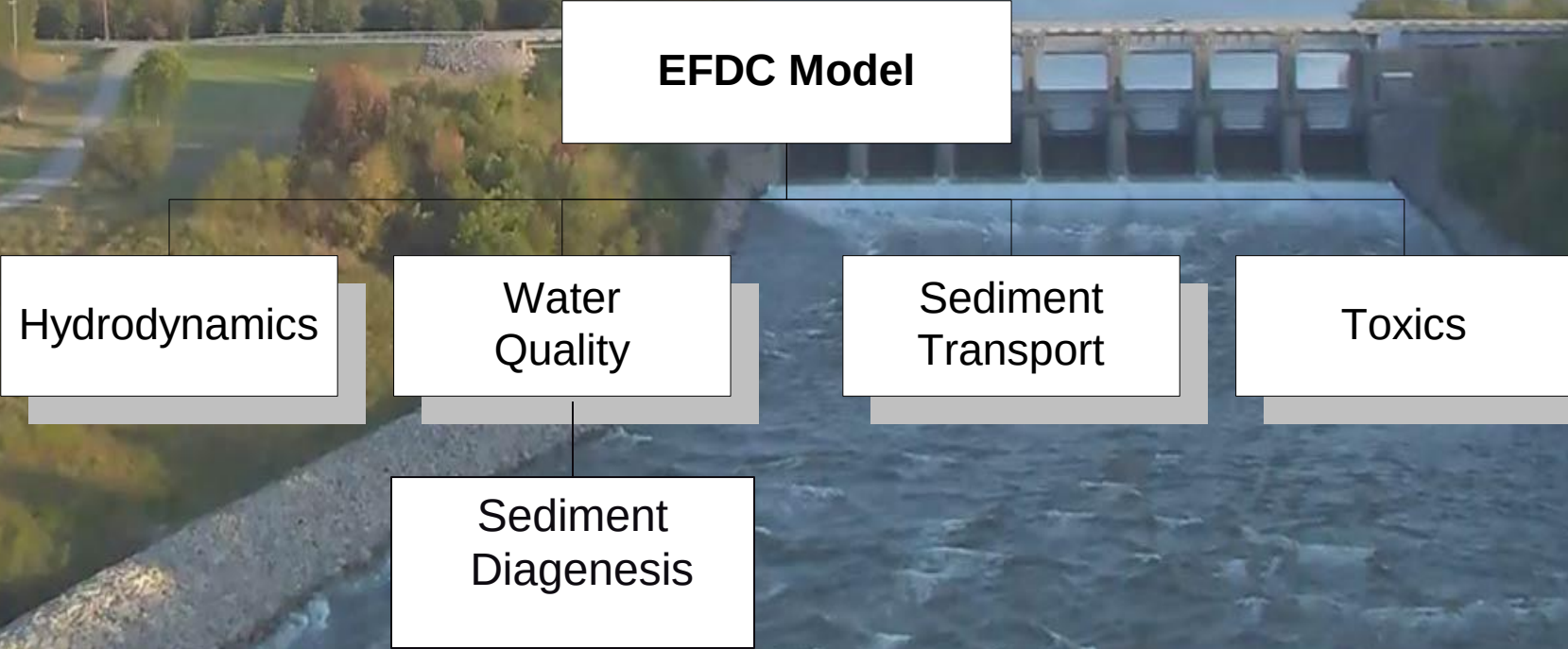


Model without Zebra Mussels



EFDC Surface Water Model

Environmental Fluid Dynamics Code



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graph TD; EFDC[EFDC Model] --> Hydrodynamics[Hydrodynamics]; EFDC --> WaterQuality[Water Quality]; EFDC --> SedimentDiagenesis[Sediment Diagenesis]; EFDC --> SedimentTransport[Sediment Transport]; EFDC --> Toxics[Toxics];
```

The diagram illustrates the components of the EFDC Model. At the top, a central box labeled "EFDC Model" is connected by a vertical line to a horizontal line. From this horizontal line, five vertical lines descend to five separate boxes arranged horizontally: "Hydrodynamics", "Water Quality", "Sediment Diagenesis", "Sediment Transport", and "Toxics". The "Water Quality" box is positioned above the "Sediment Diagenesis" box, and they are connected by a vertical line. The background of the diagram is a photograph of a large dam with water flowing over it, set against a backdrop of a lake and forested hills.

EFDC Model

Hydrodynamics

Water
Quality

Sediment
Diagenesis

Sediment
Transport

Toxics

Lake Model Data

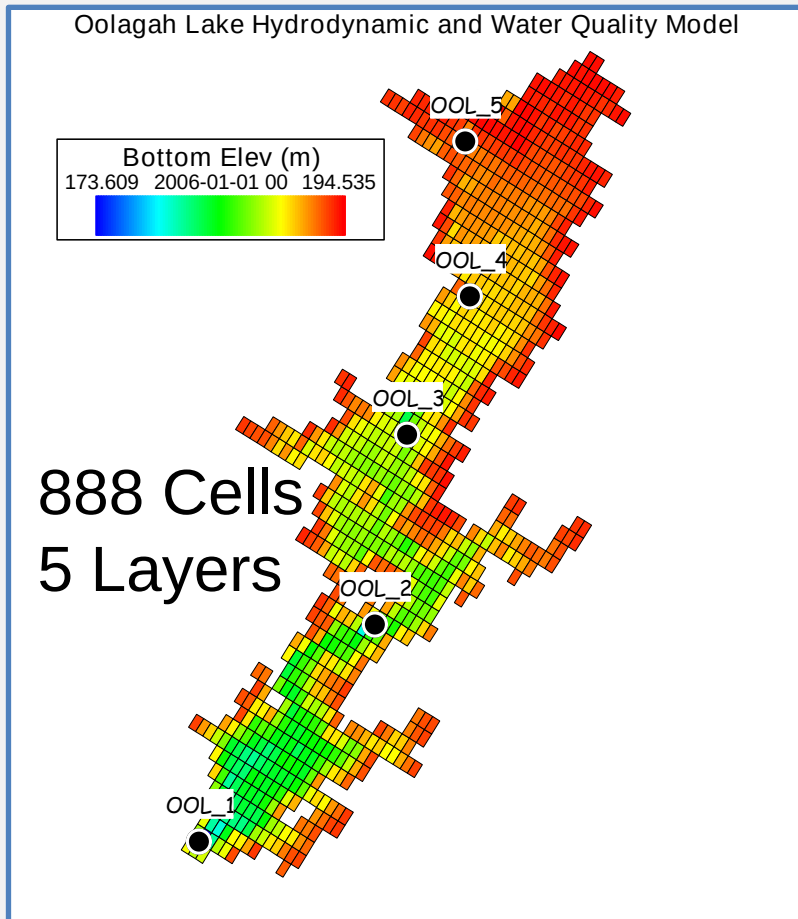
• Data Set

- Lake bathymetry, water level, dam releases
- Watershed flow/loads
- Wastewater flow/loads
- Meteorology
- WQ (T,DO,TSS,N,P,Chl, Secchi, Turbidity)
- Sediment bed (TP, TKN, TOC, solids)

• Data Source

- USACE Tulsa District & City of Tulsa “*Oologah Lake Watershed Assessment Study*” (2012)
- HSPF watershed model
- NPDES DMR records
- Oklahoma Mesonet
- USACE WQ and Sediment Bed Chemistry, 5 sites

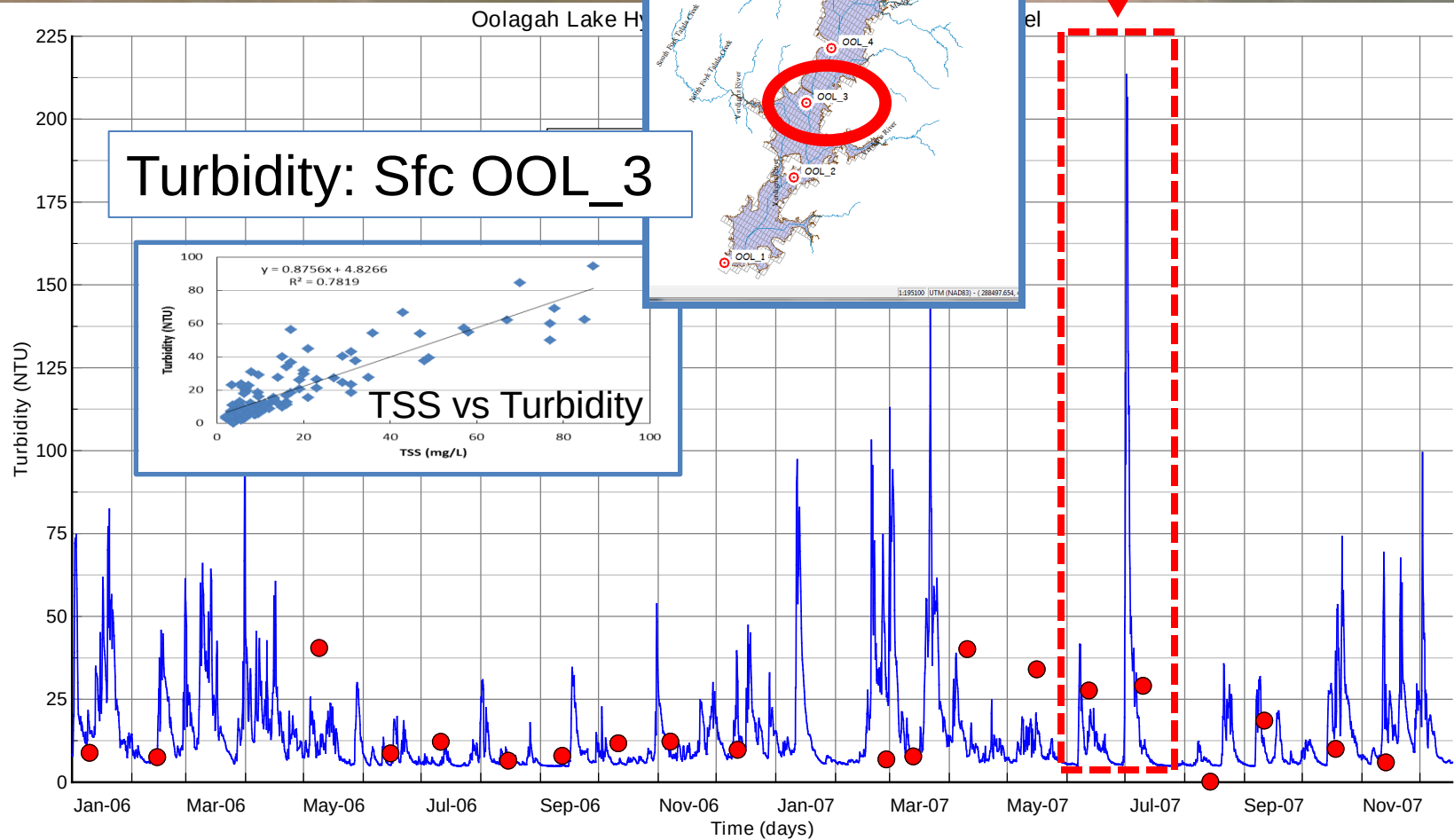
EFDC Lake Model



- External Load: HSPF & WWTP (Flow, WQ), AtmDep (N,P)
- Hydro: Lake level, Temp
- Sediment: TSS, BedSolids
- WQ: Chl, DO, C, N,P
- Internal Load: SOD, N,P fluxes, Bed C,N,P
- Cal/Val: 4 sites, 2 yrs, 1/2006-12/2007

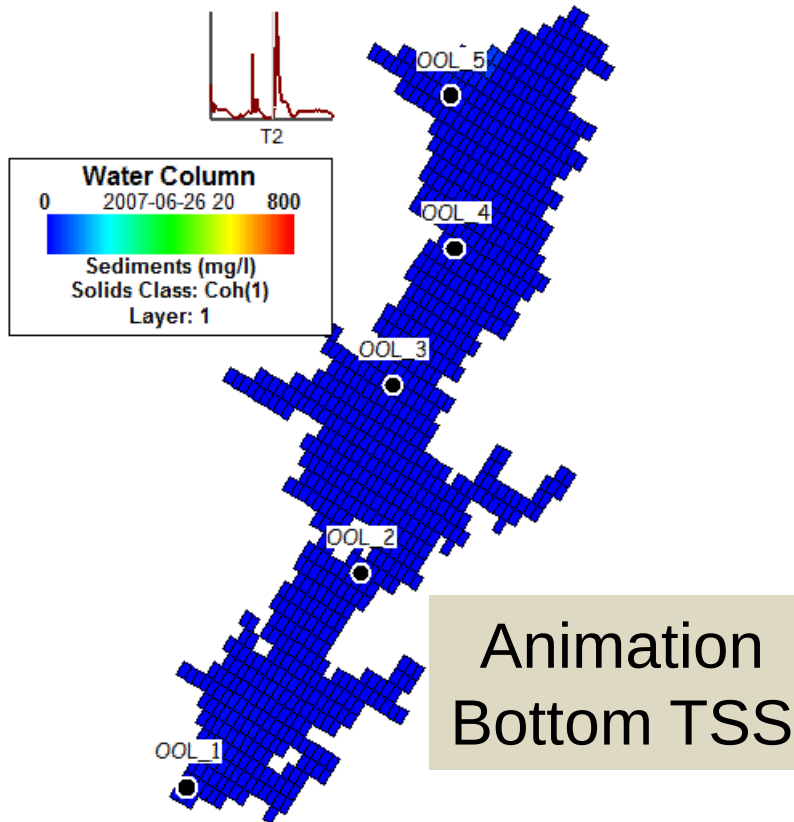
Turbidity

Storm: July 1-2, 2007



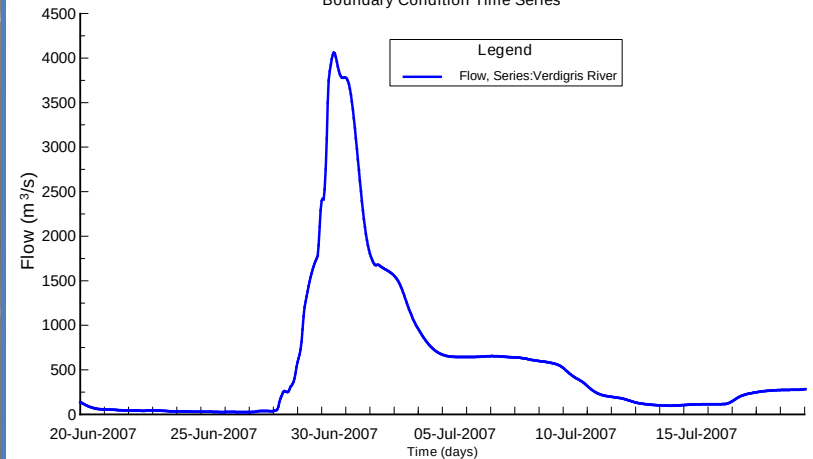
TSS, Storm: July 1-2, 2007

Oologah Lake Hydrodynamic and Water Quality Model



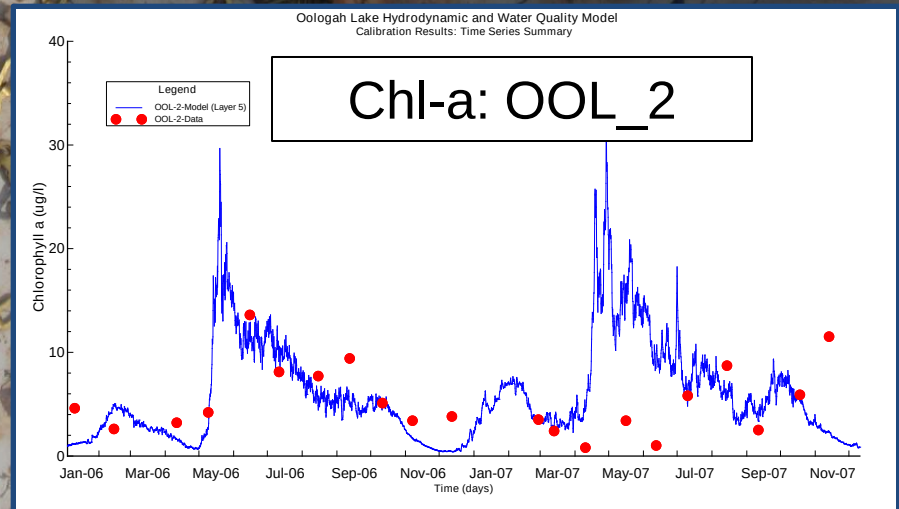
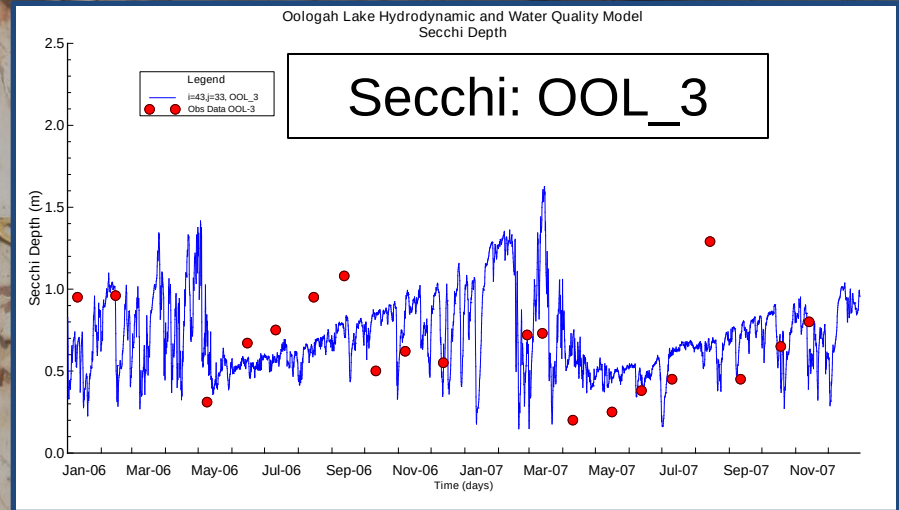
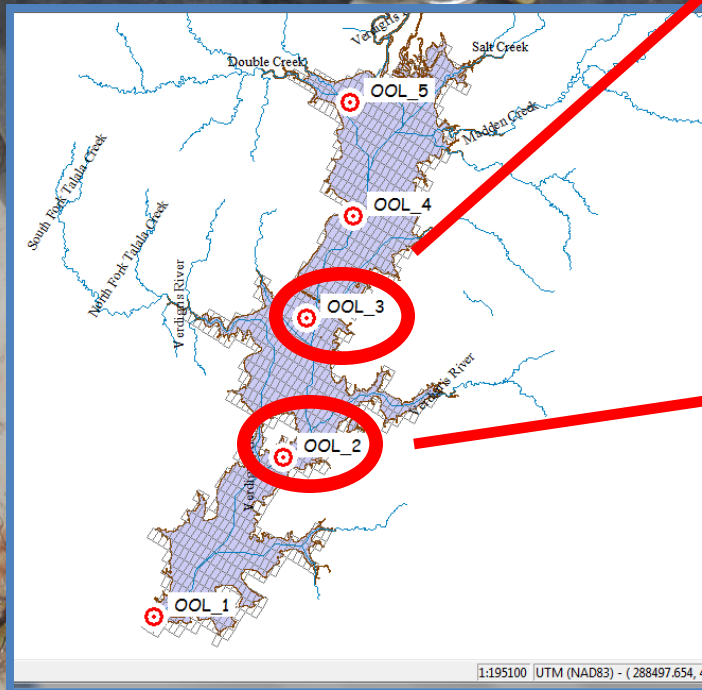
Flow (cms) Verdigris R, Lenapah, OK

Oologah Lake Hydrodynamic and Water Quality Model
Boundary Condition Time Series



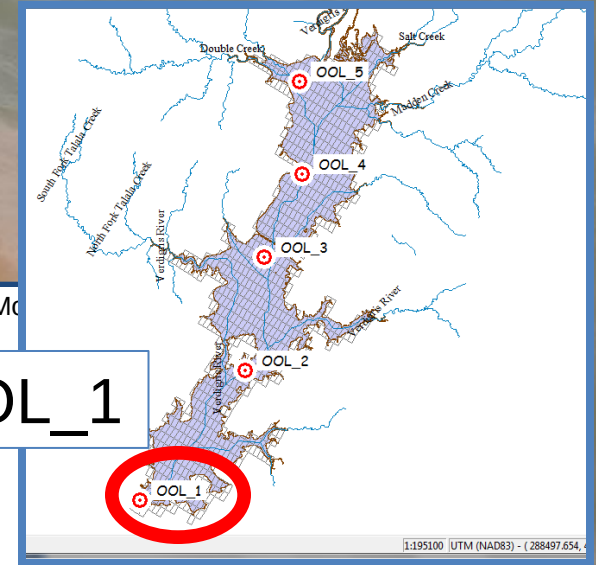
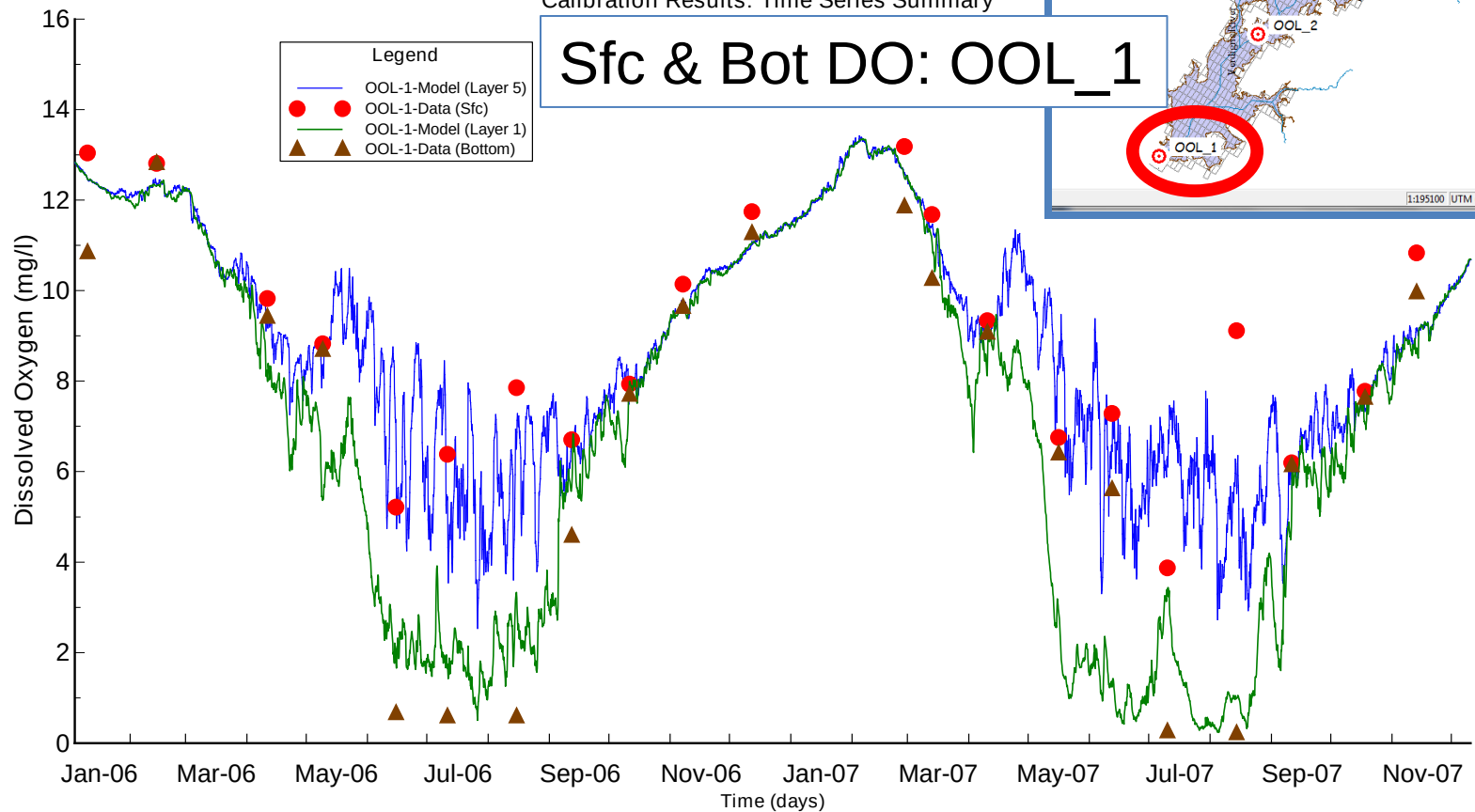
Storm: July 1-2, 2007

Secchi Depth and Chlorophyll

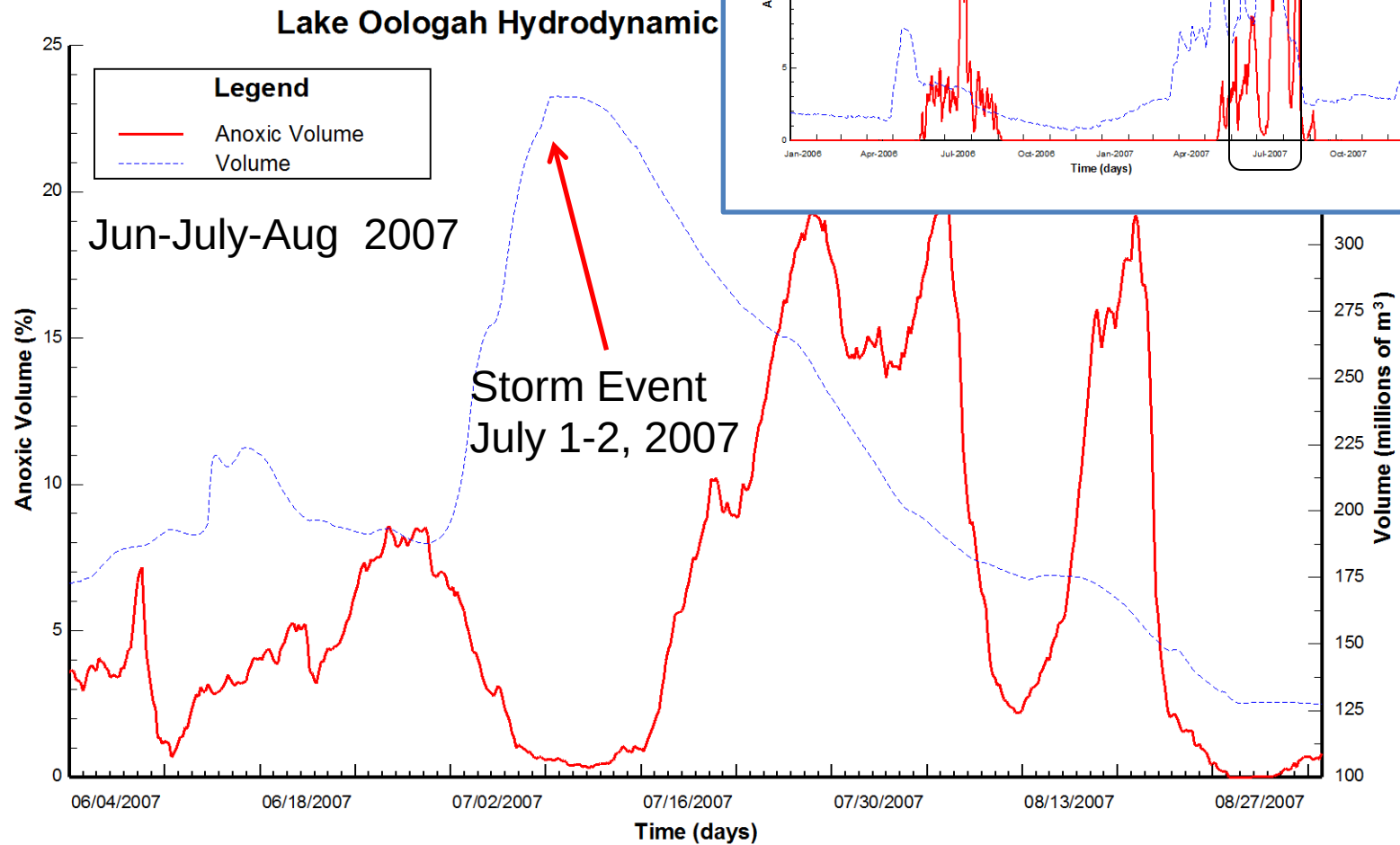
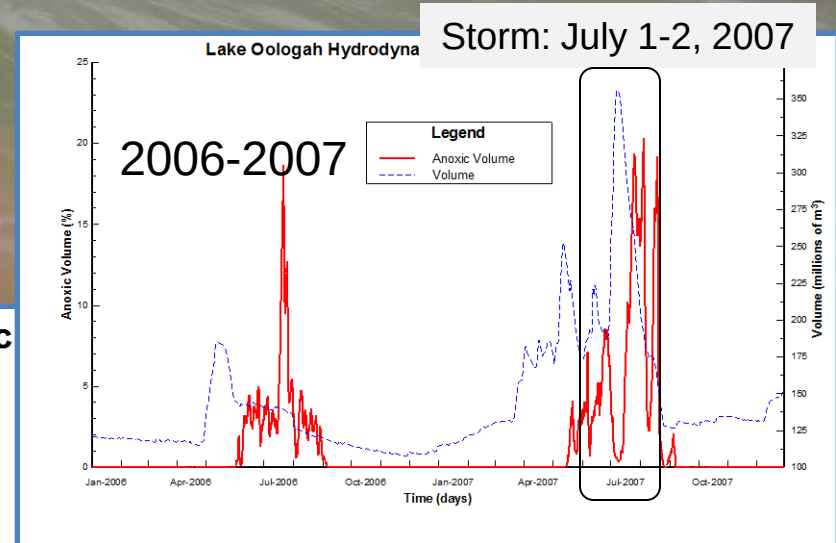


Dissolved Oxygen

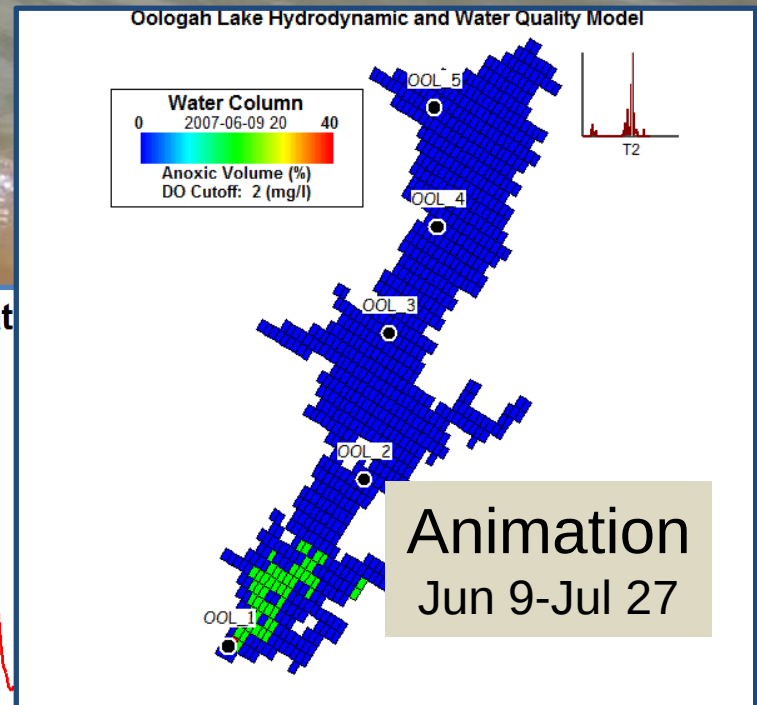
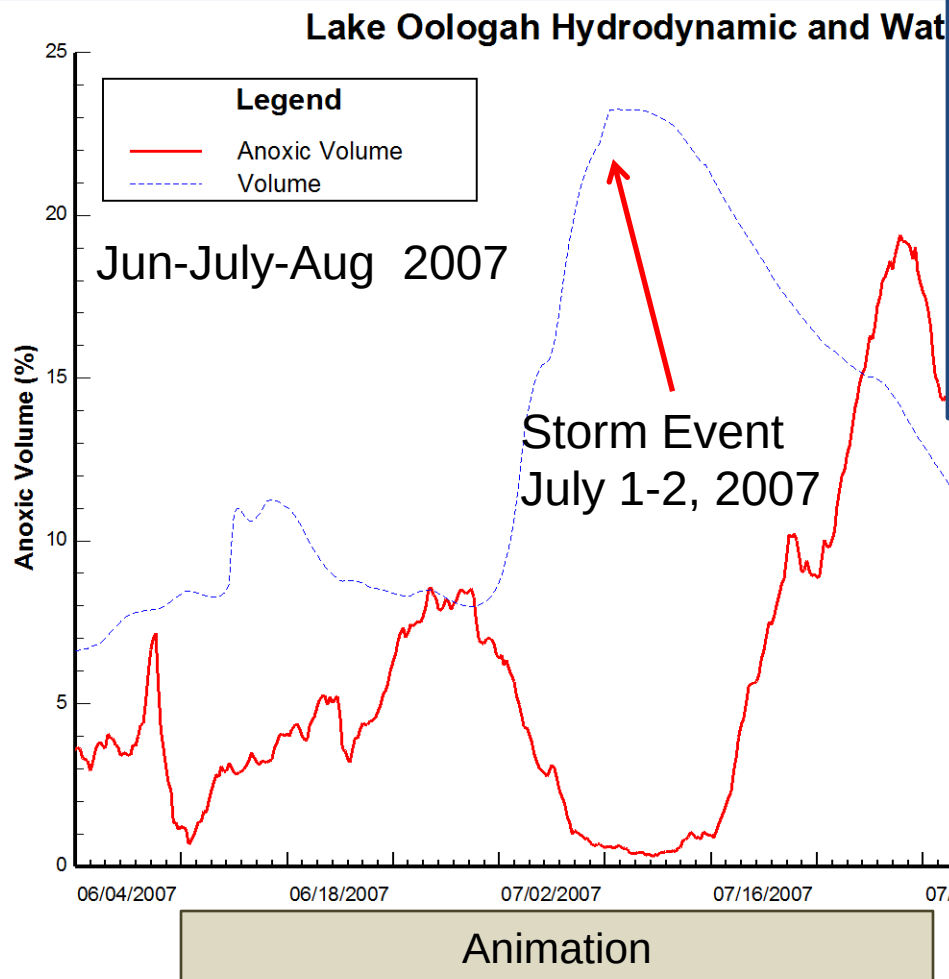
Oologah Lake Hydrodynamic and Water Quality Model
Calibration Results: Time Series Summary



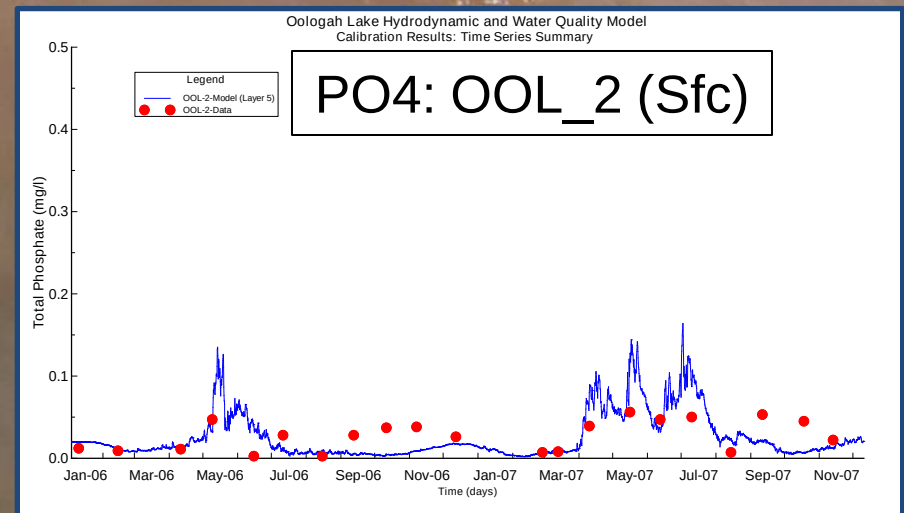
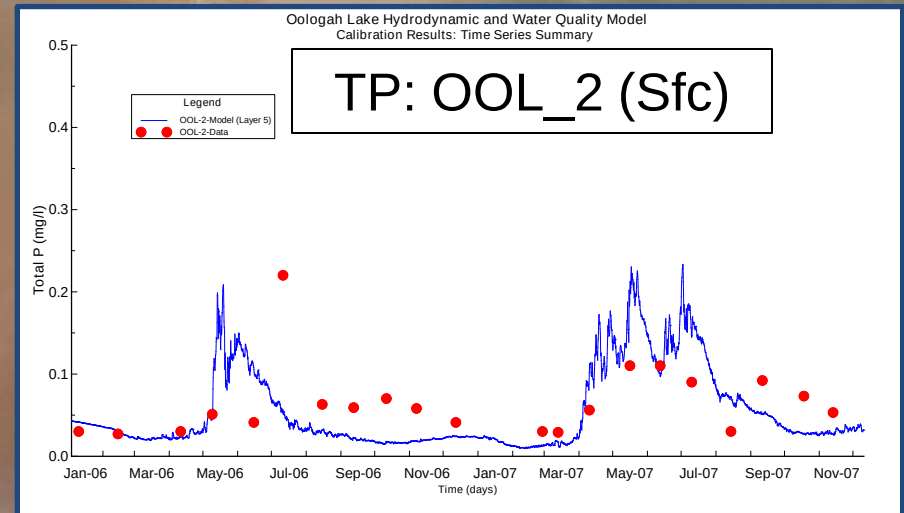
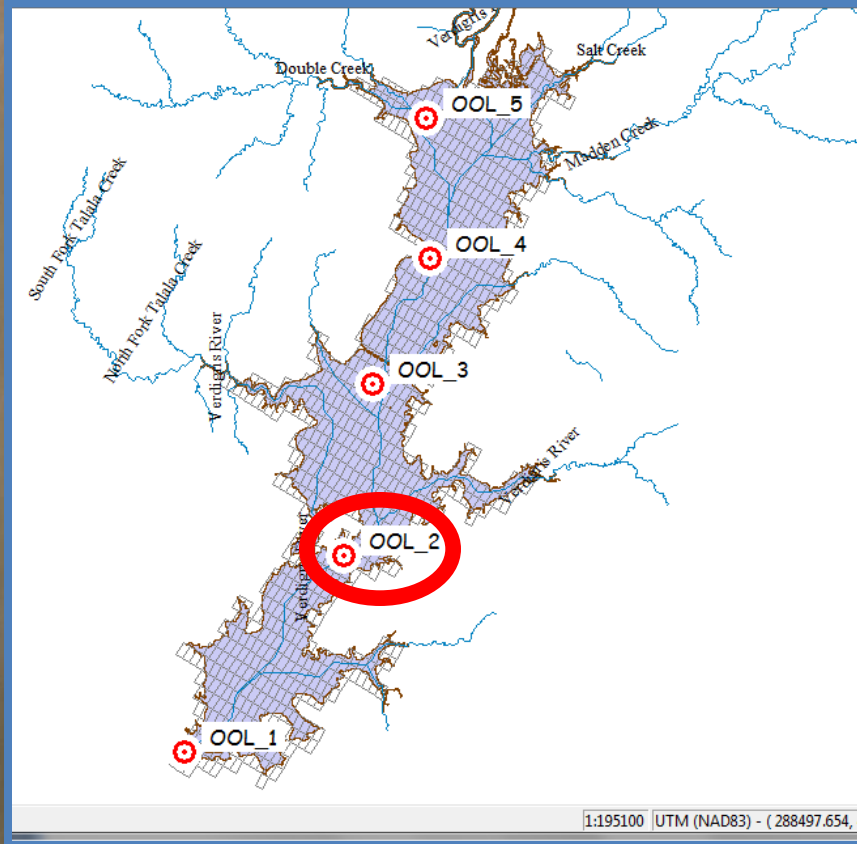
Anoxic Volume



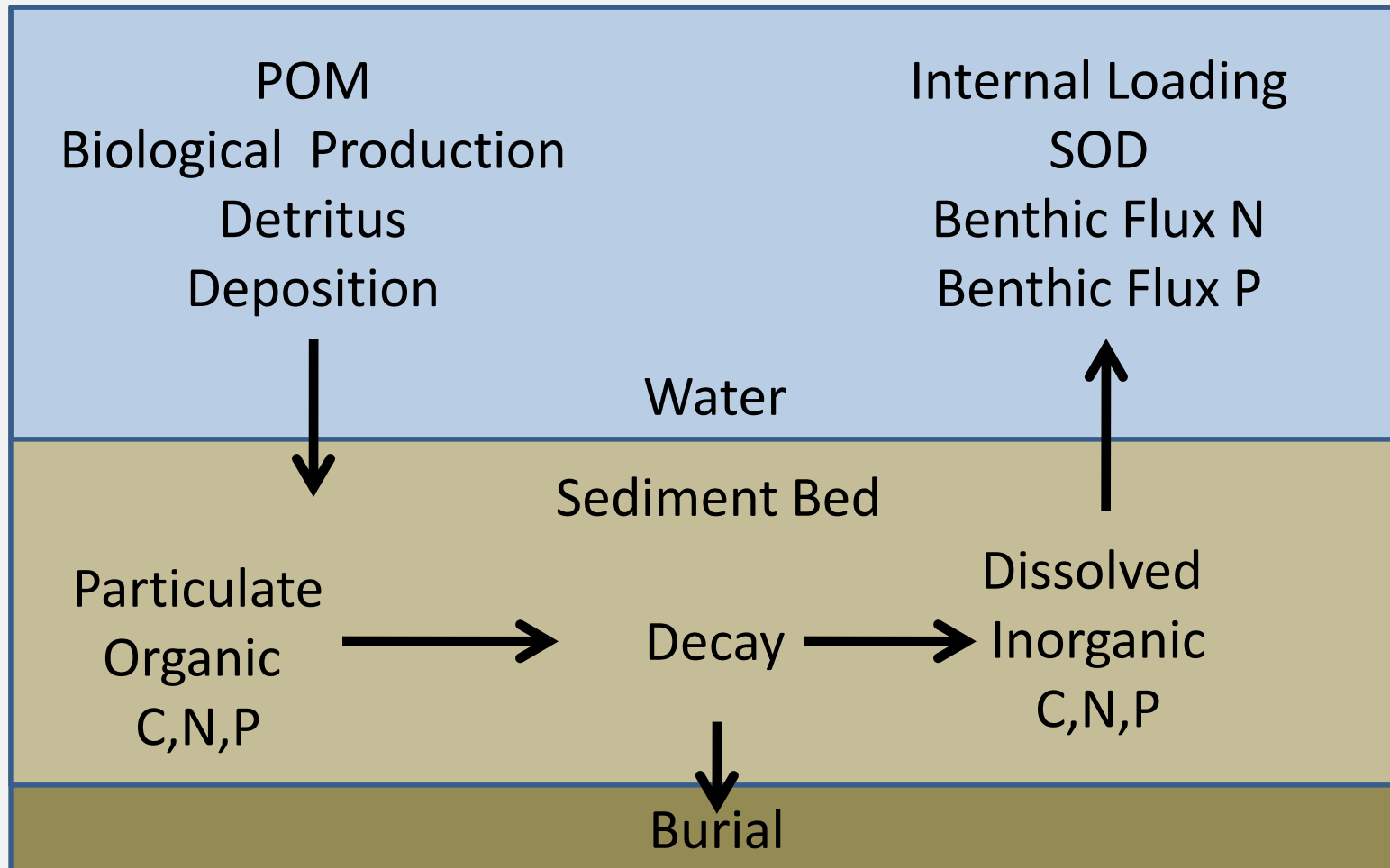
Anoxic Volume



Nutrients (TP and PO4)

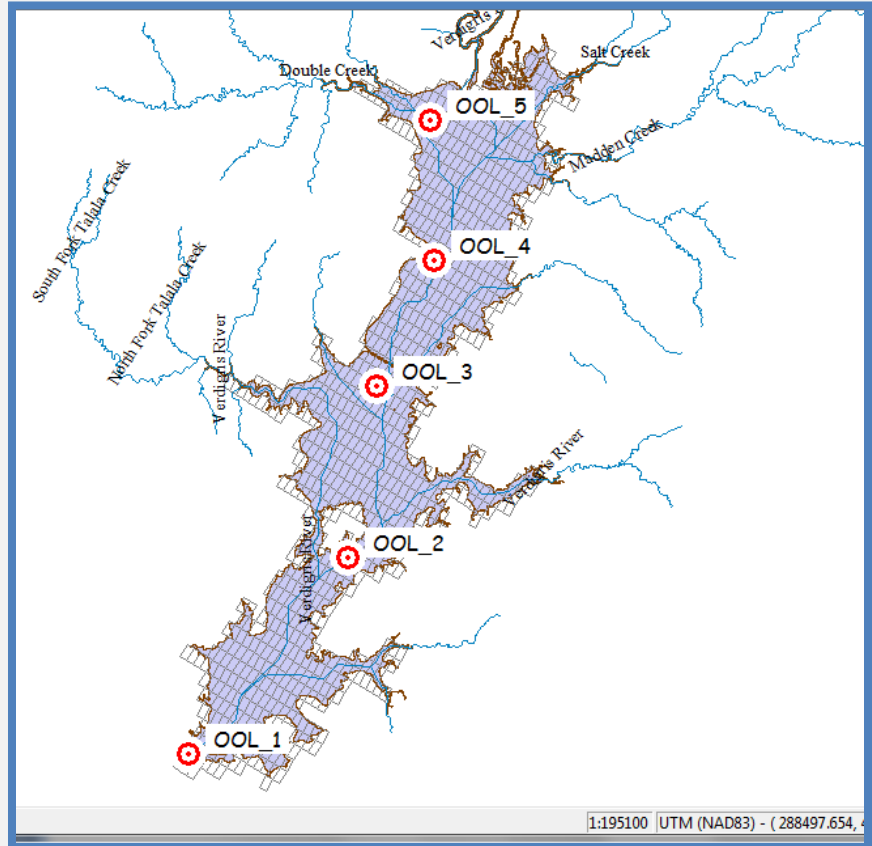


EFDC Sediment Flux Model

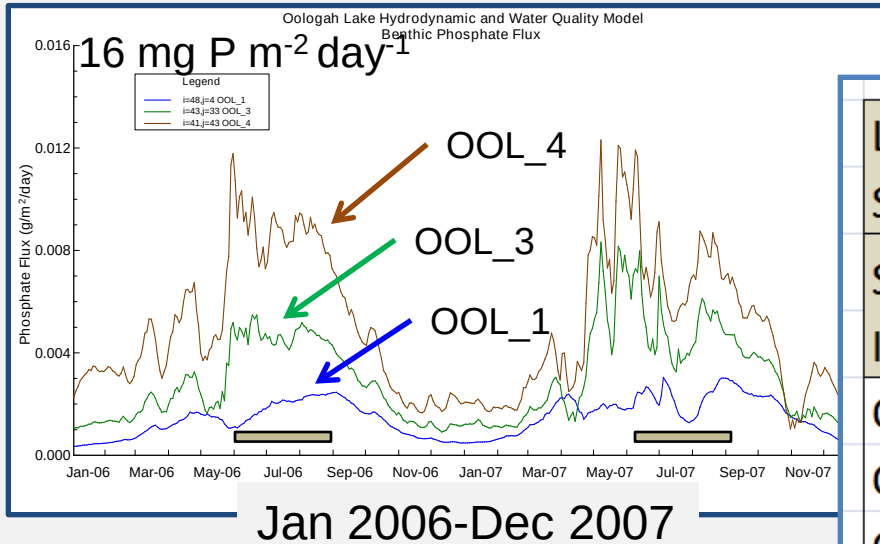


Sediment Bed Chemistry

- USACE Survey in Aug-2000
- TP, TKN, TOC
- Bulk density; % Solids; % Sand, Silt, Clay
- Initial conditions for Sediment Flux Model based on USACE bed chemistry data, 5 sites



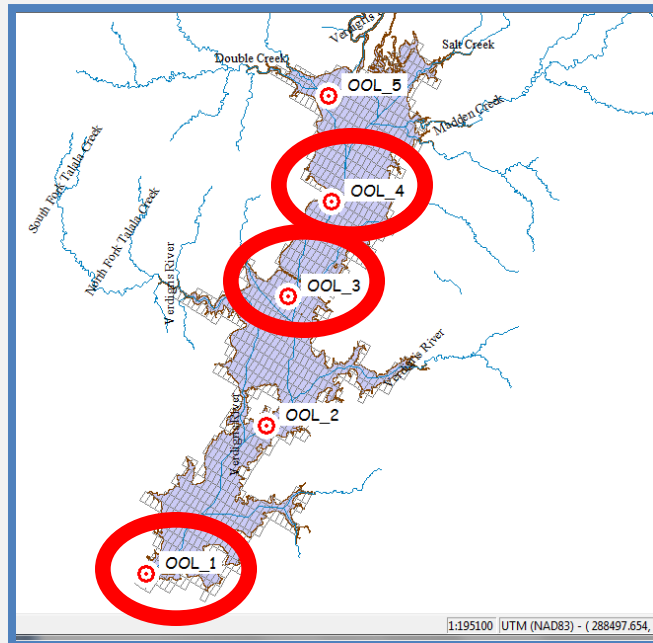
Sediment Flux PO₄: Model & Observed



Lake Oologah

Stratified: June 1-Sept 1 (2006-2007)

Station ID	PO ₄ Flux (mg/m ² -day)		
	Average	Low	High
OOL_1	2.5	1.5	3.4
OOL_3	4.9	3.3	8.0
OOL_4	8.1	5.2	11.9



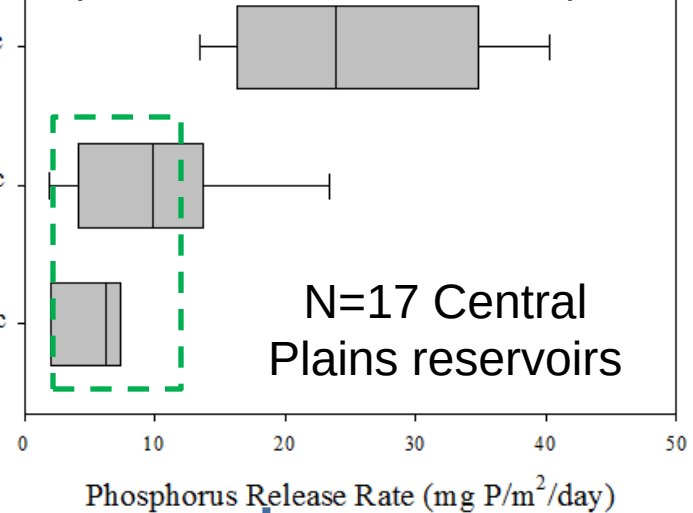
(Dzialowski & Carter, OSU)

Hypereutrophic

Eutrophic

Mesotrophic

N=17 Central
Plains reservoirs



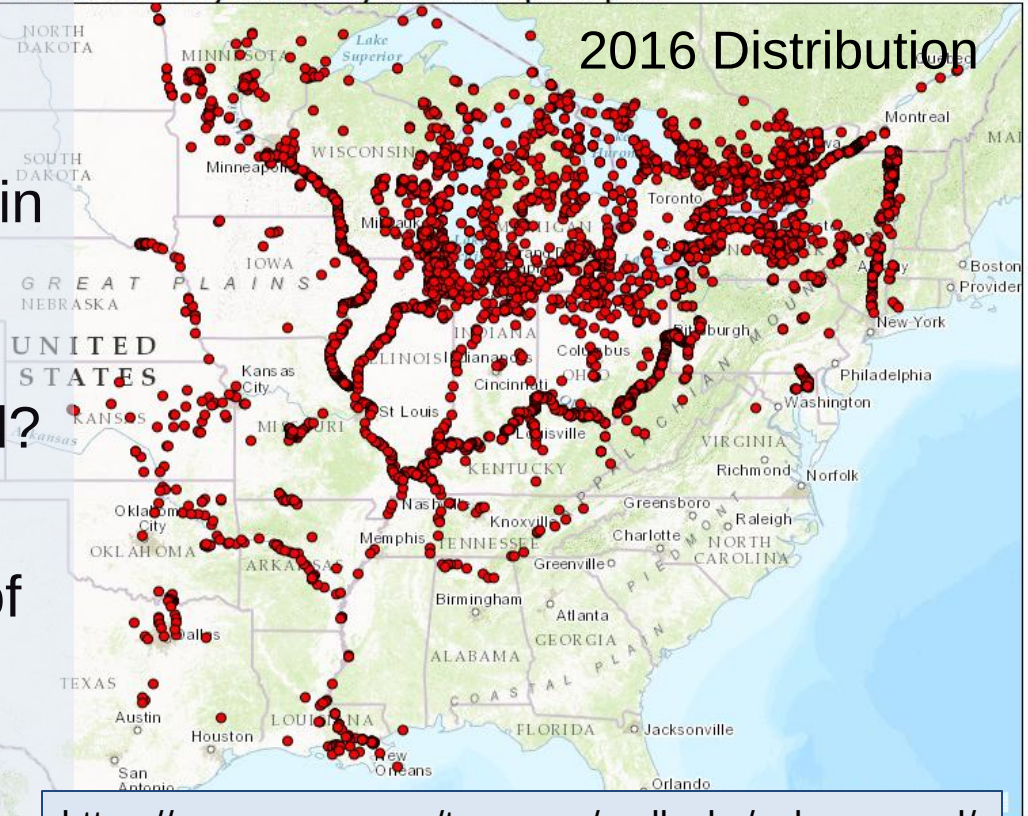
How Well Did Model Perform?

- Hydrodynamics: Simulated seasonal trends of water temperature and stratification
- Water Quality: Matched seasonal trends of DO, nutrients, chlorophyll, and secchi depth
- Sediment Flux: Internal benthic flux of phosphate comparable to observations from other mesotrophic and eutrophic Central Plains reservoirs

Zebra Mussels

Note: Time series reflects NAS data and may not accurately reflect actual species spread.

- WQ in 2006 (ZM present) vs. 2007 (ZM absent) ?
- WQ change not detected in USACE station data
- WQ impact of ZM in Lake Oologah may be localized?
- ZM in Lake Hefner (2016)
- Recommend monitoring of ZM to track density and WQ over the years



<https://nas.er.usgs.gov/taxgroup/mollusks/zebramussel/>

Summary

- HSPF watershed and EFDC lake model provides DEQ with a defensible tool for WQ assessments
- Water quality targets are DO and turbidity
- Model will be used by DEQ to support TMDL determinations for Lake Oologah (TN, TP, TSS)

Lake Oologah Watershed-Lake Model

Questions & Discussion

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