Watershed, Hydrodynamic, Water Quality and Sediment Flux Modeling to Support TMDL Determinations, Lake Thunderbird

24th Annual Conference
Oklahoma Clean Lakes and Watersheds Association (OCLWA)

April 8-9, 2015
Stillwater, Oklahoma

Dynamic Solutions LLC

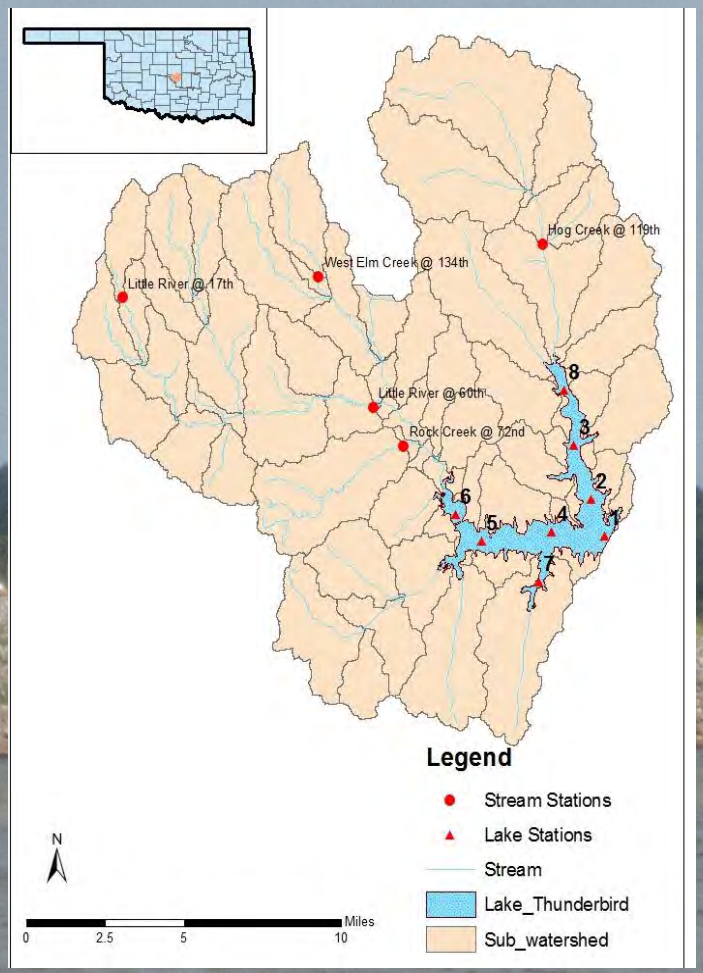
DEQ OKLAHOMA DEPARTMENT OF ENVIRONMENTAL QUALITY

Lake Thunderbird Watershed-Lake Model

- Watershed and Lake Thunderbird
- Pollutant Sources
- Designated Uses & Water Quality Impairments
- Watershed and Lake Model
- Management Scenario “What-if?”
- TMDL for Lake Thunderbird

Lake Thunderbird

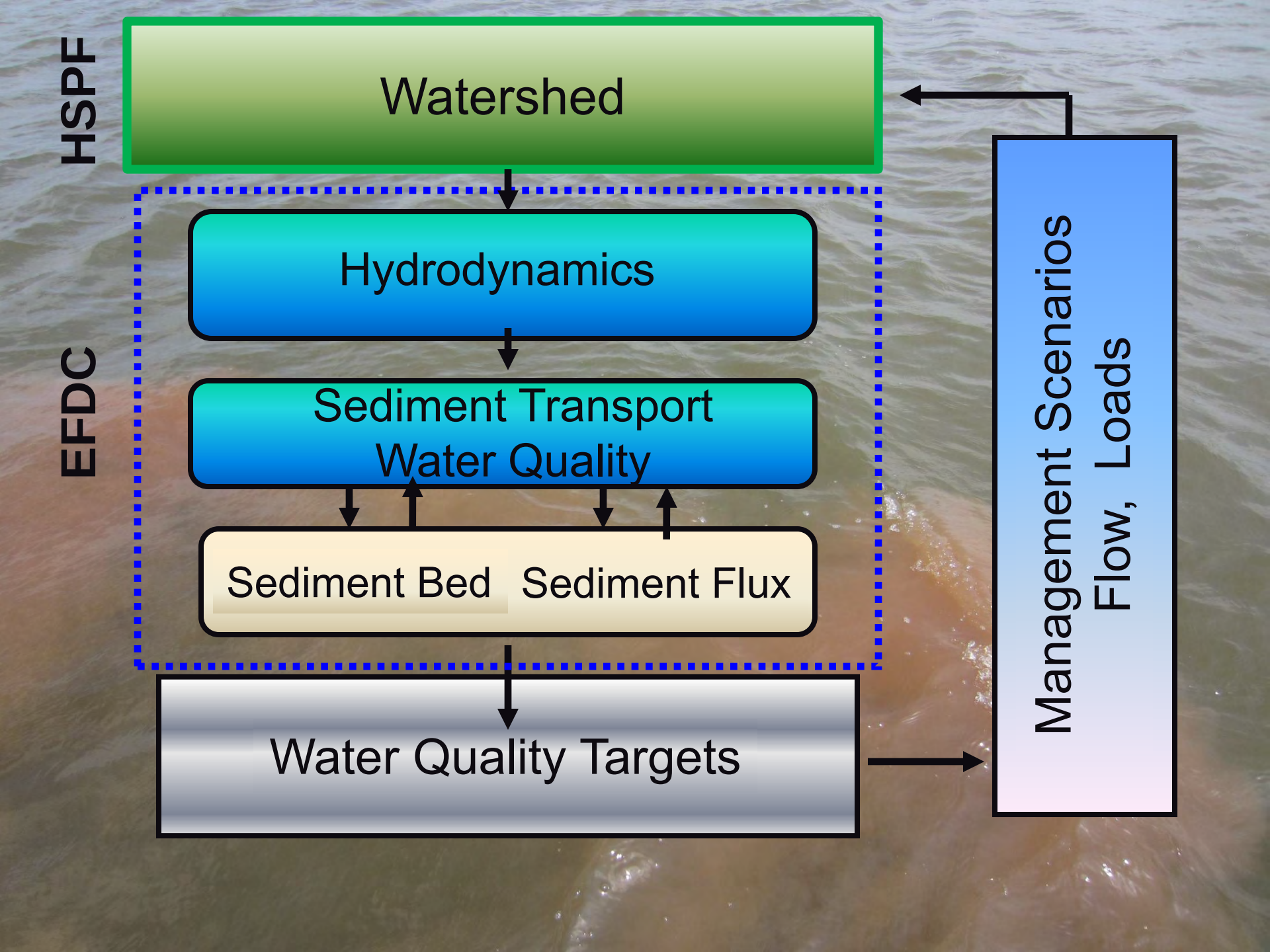
- Upper Little River basin (256 mi^2)
- 6,070 acre reservoir
- Public water supply for Norman, Midwest City & Del City (near OKC)
- Population 99,600 (2010)
- Urban stormwater runoff (Moore, Norman, OKC)
- Nonpoint source runoff from rural areas



Designated Uses, 303(d) Impairments & WQ Targets

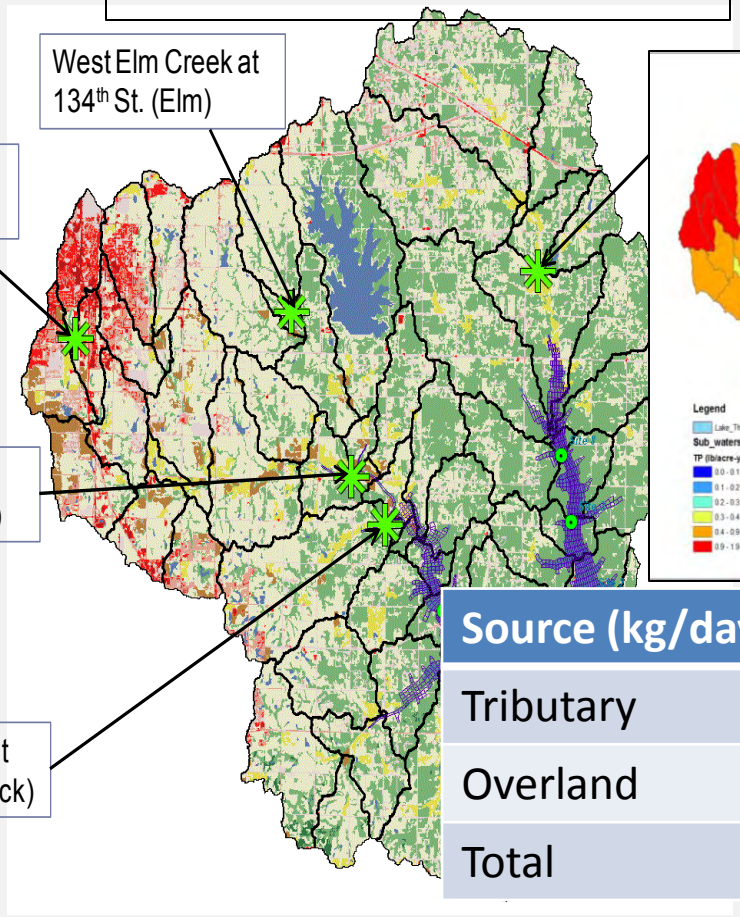
- Flood control, water supply, recreation, fish & wildlife propagation
- Sensitive Water Supply
- Impaired for Warm Water Fish & Wildlife Propagation
- Impaired for Public Water Supply

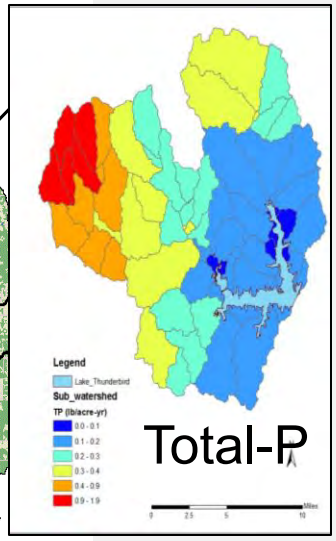
- Annual 90th percentile Turbidity < 25 NTU
- Surface DO > 5 mg/L
- Lake volume DO: < 50% can be < 2 mg/L, stratified season
- Annual average chlorophyll < 10 µg/L


HSPF
Watershed
EFDC
Hydrodynamics
Sediment Transport
Water Quality
Sediment Bed
Sediment Flux
Water Quality Targets
Management Scenarios
Flow, Loads

HSPF Watershed Model

64 Sub-Watersheds

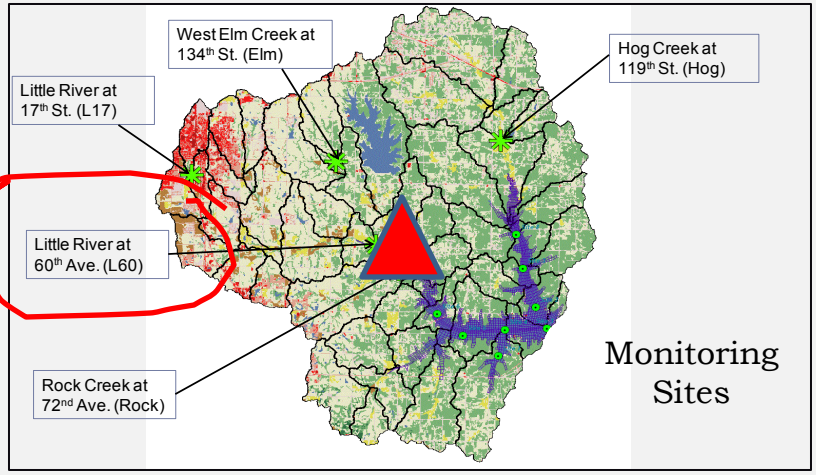


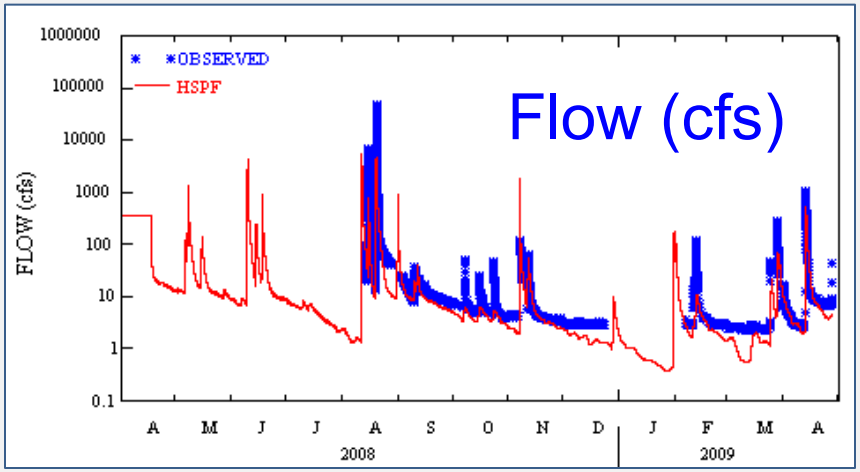


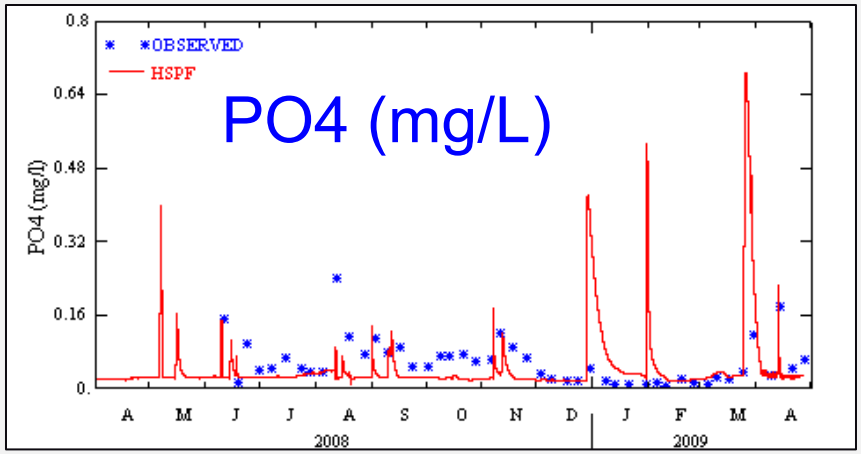
- 1 Yr Calibration
- 4/2008 - 4/2009
- Average hydrology
- WQ data, 5 sites,OCC
- HSPF: Flow, TSS, Temperature, DO, BOD, N,P, Algae

Source (kg/day)	Total-N	Total-P	BOD	Sediment
Tributary	303	60	610	29,933
Overland	19	3	37	1,553
Total	322	63	647	31,486

Streamflow & PO4: Little R. @60th







Lake Thunderbird Conceptual Model

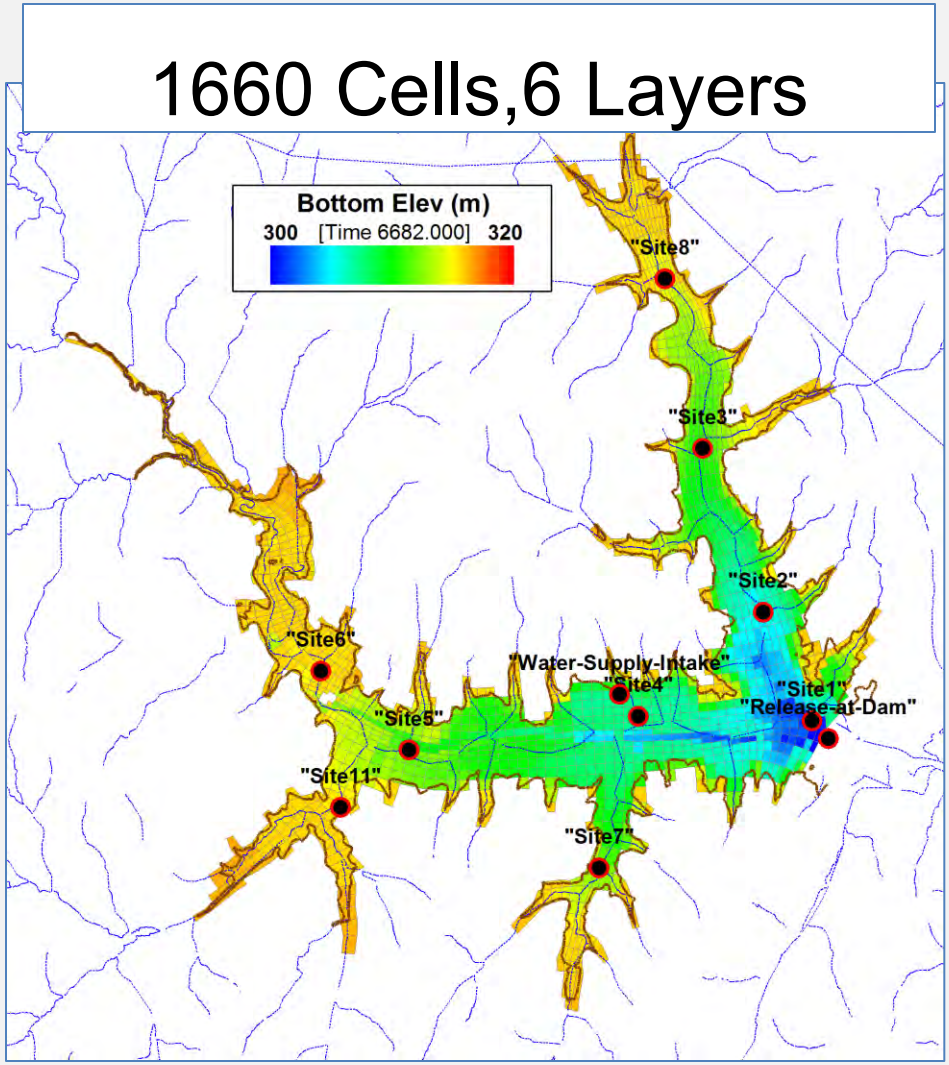
- Mass balance “cause-effect” watershed flow, loading and lake water quality
- Riverine, transition, lacustrine zones affect reservoir transport and water quality
- Stratified in summer; well-mixed in winter
- Hypolimnetic DO depletion controlled by stratification and sediment oxygen demand
- Internal source of nutrients from sediment bed

Lake Model Data Sources

- Bathymetry
- Watershed flow & loads
- Meteorology
- Lake level, dam release
- Water supply withdrawals
- WQ (T,DO,TSS,N,P,Chl)
- Sediment bed (TP, TKN)

- OWRB survey, 2001
- HSPF watershed model
- Oklahoma Mesonet
- USACE Tulsa District
- Central OK Master Conservancy District
- OWRB surveys, 8 sites
- OWRB surveys, 5 sites

EFDC Lake Model



- Loads: HSPF Flow, WQ, Atm Dep N,P
- Hydrodyn: Lake level, Velocity, Wtemp
- Sediment: TSS, bed
- WQ: Chl, DO, C, N,P
- Sed Flux: SOD, N,P fluxes, Bed C,N,P
- Calibration: 8 sites, 1 yr, 4/2008-4/2009

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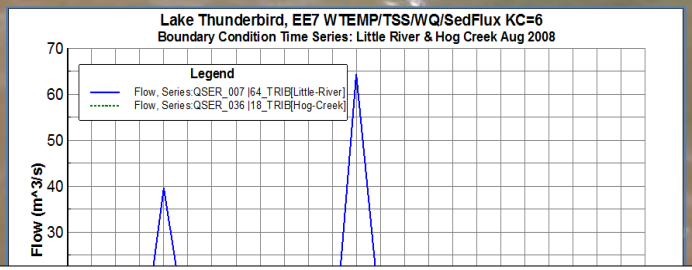
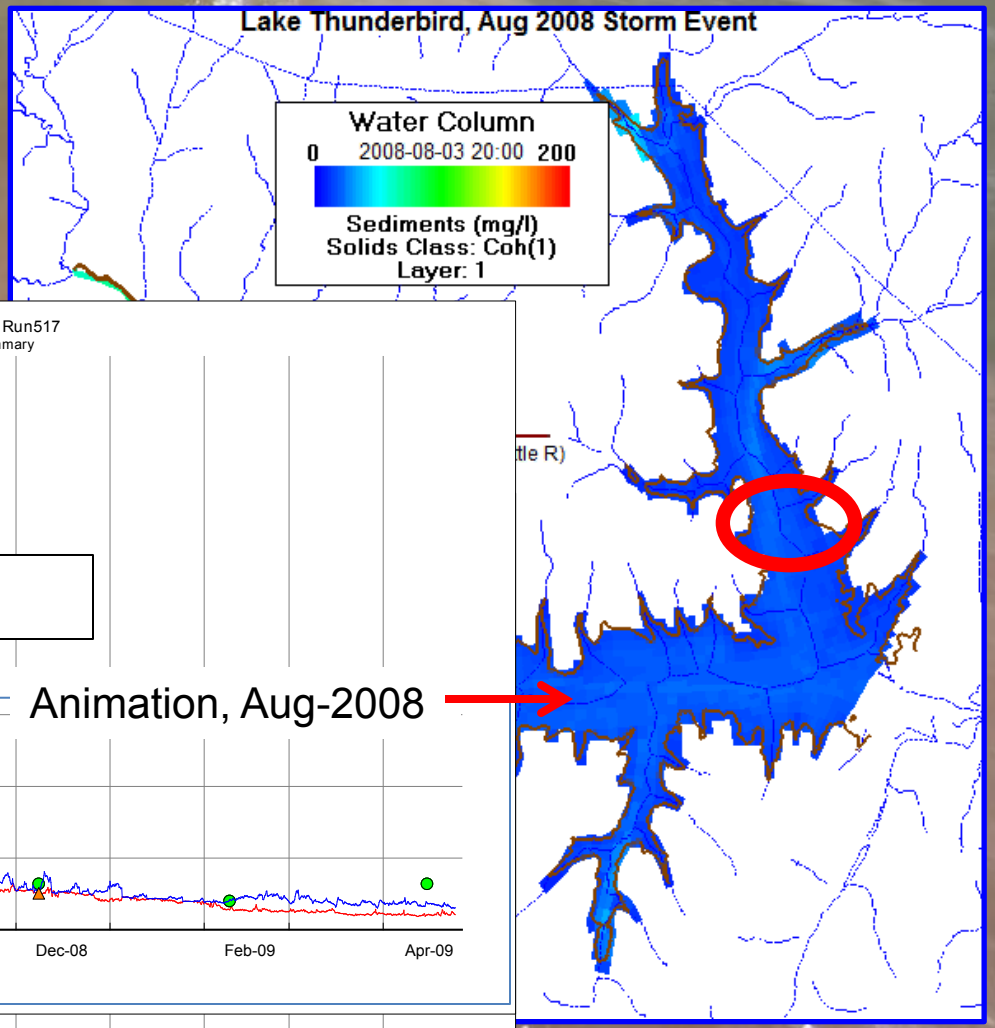
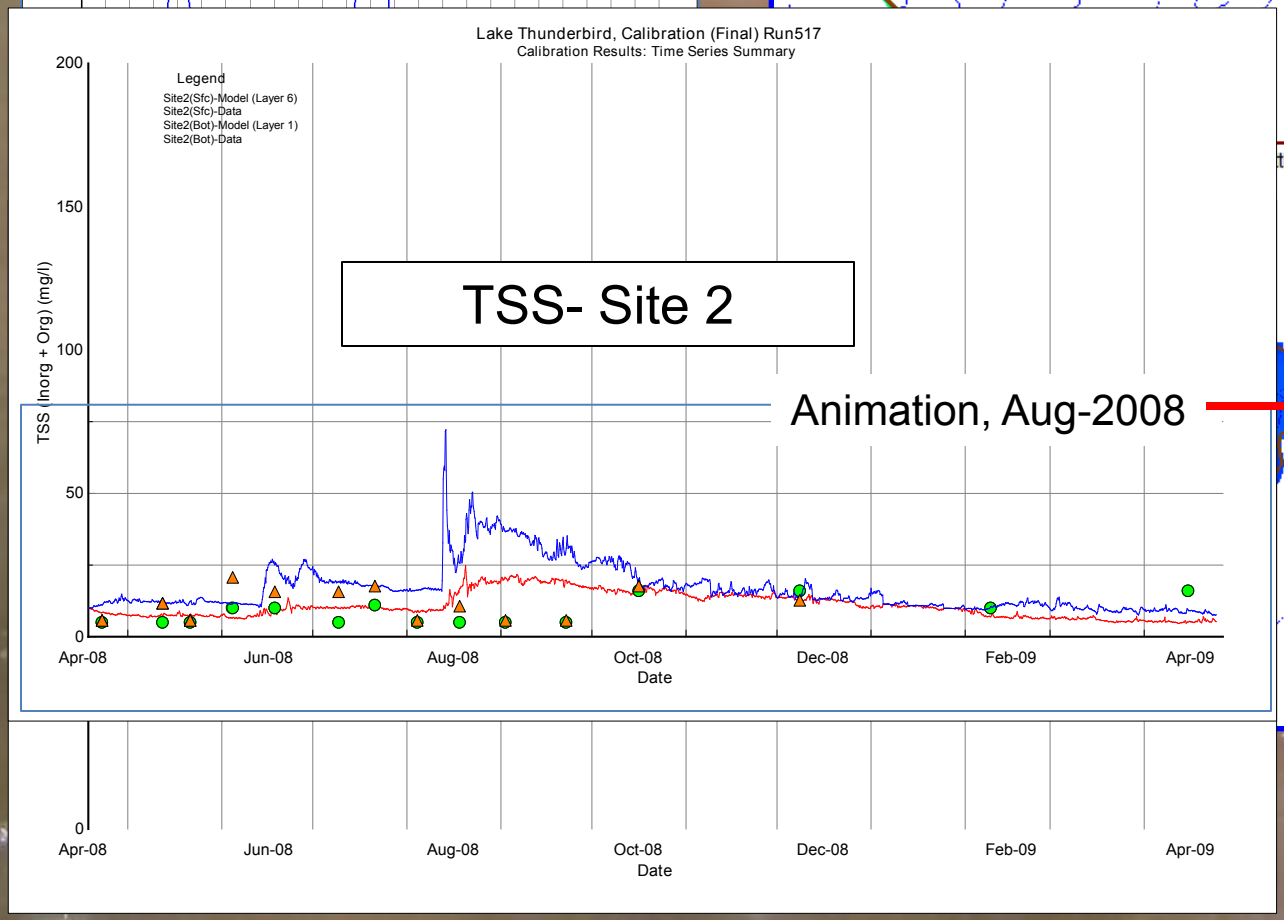
Aug-2008 Storm, TSS



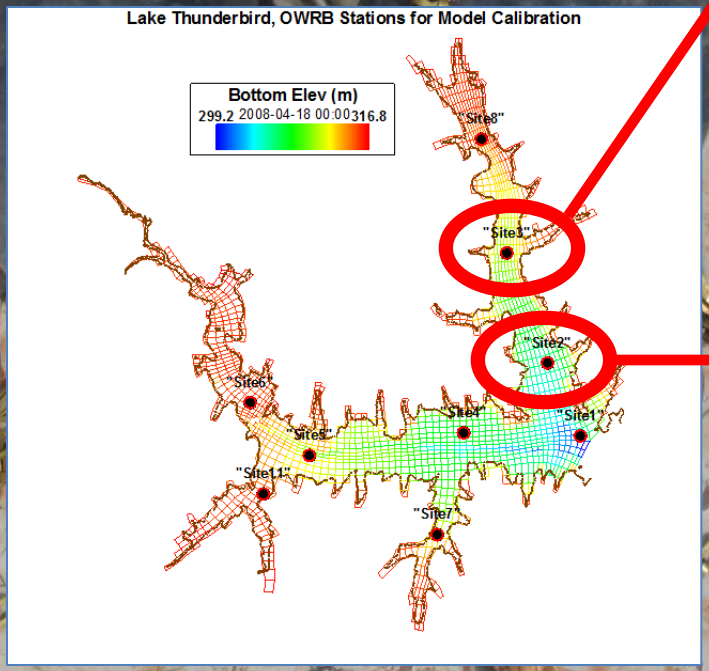


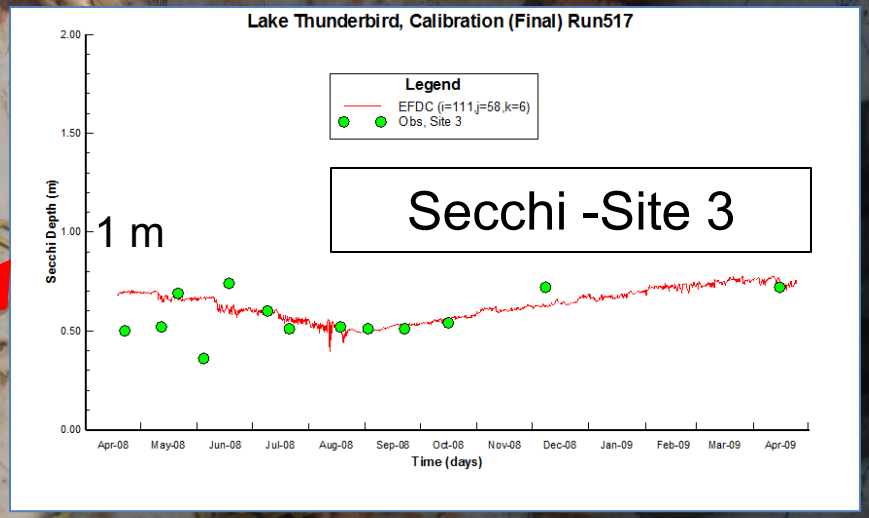


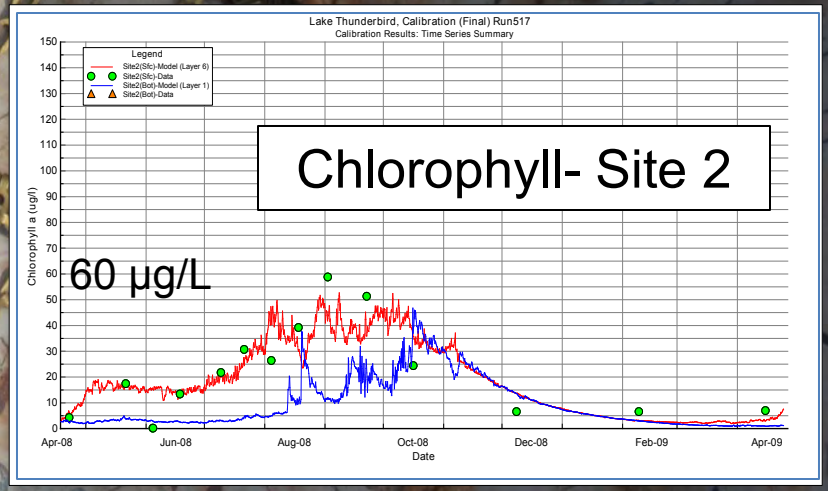
TSS- Site 2

Animation, Aug-2008

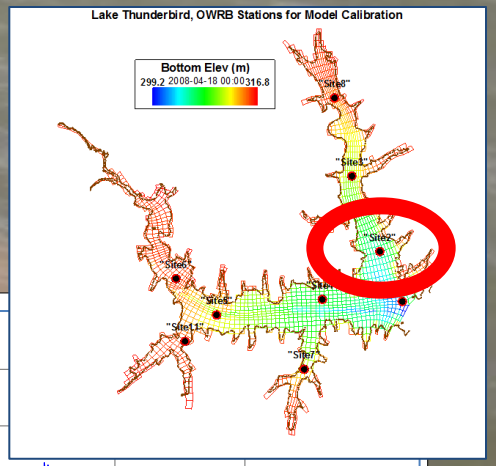
Secchi Depth & Algae Chl

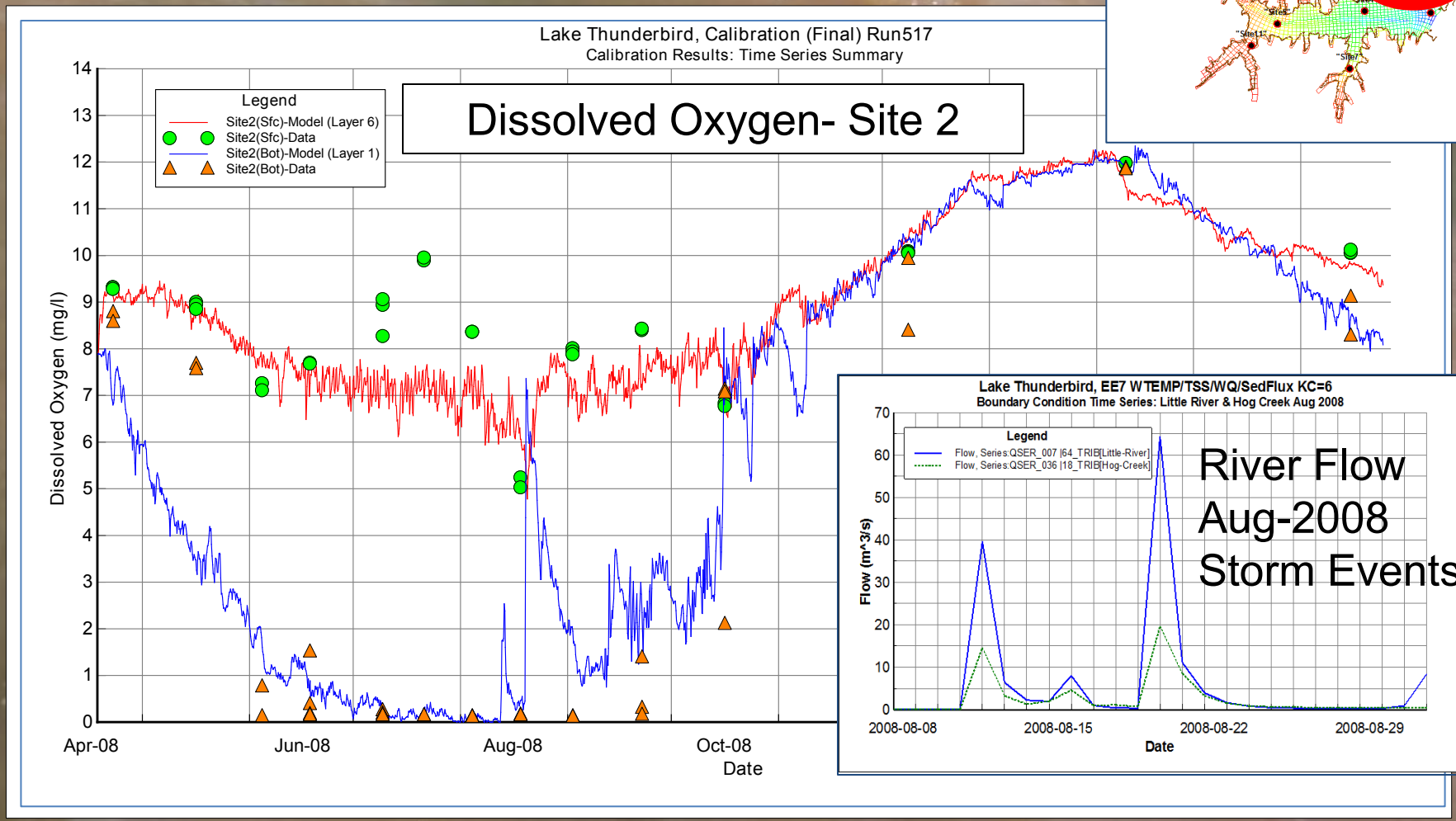




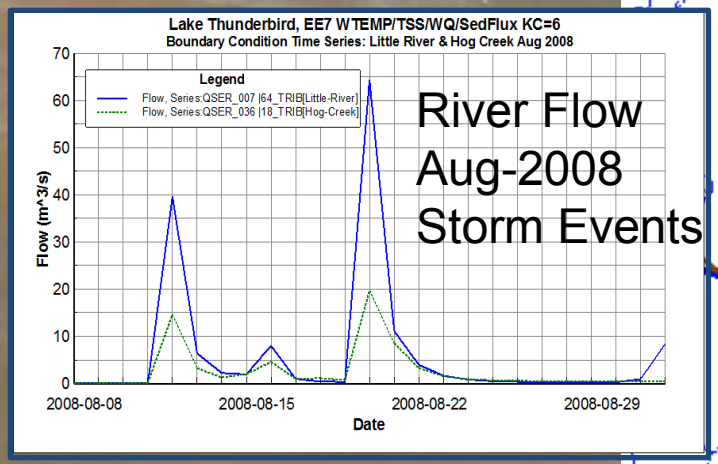


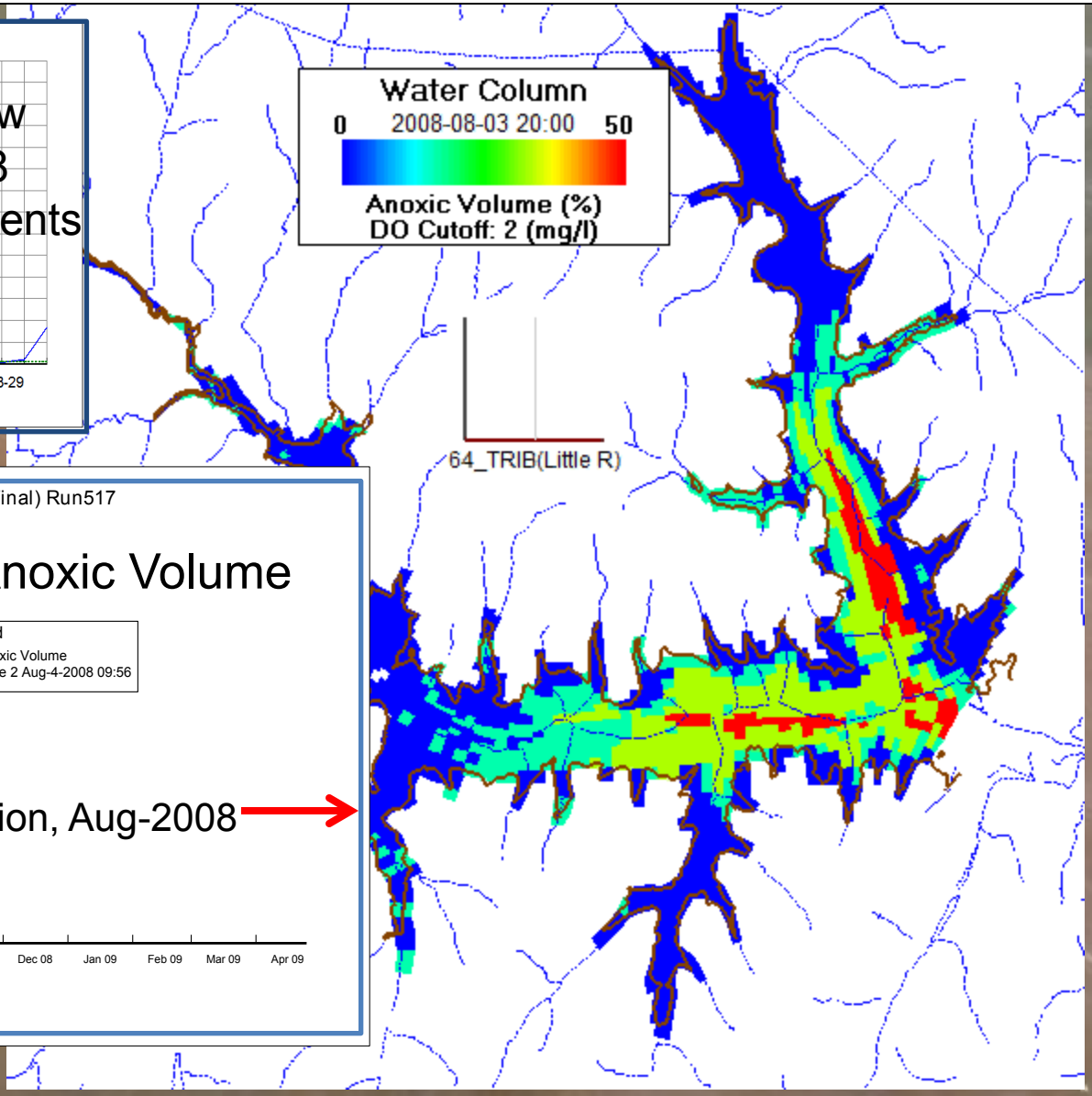
Dissolved Oxygen

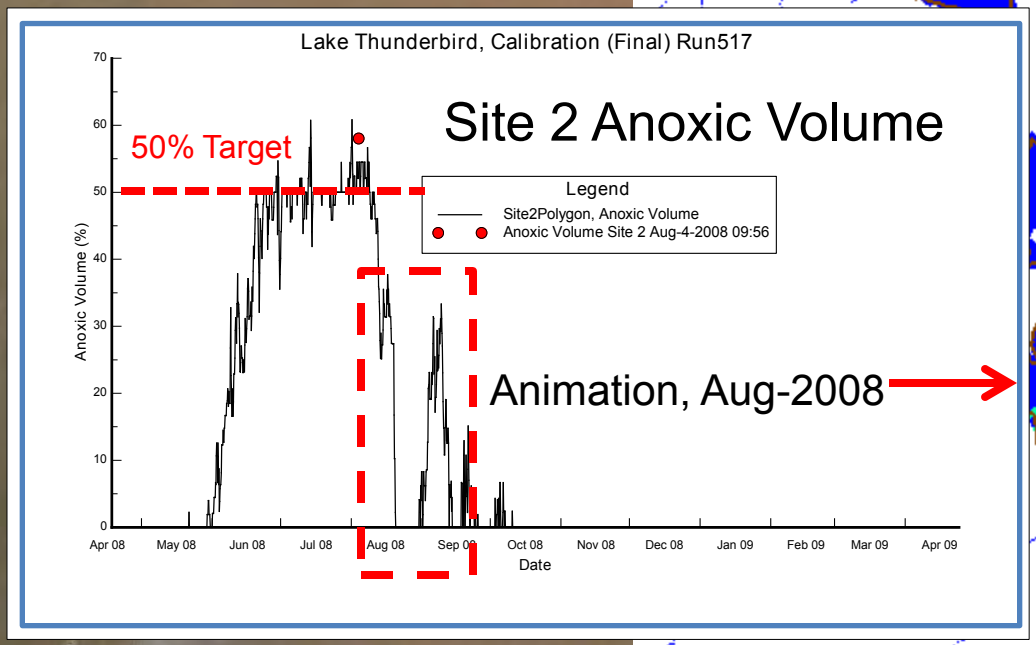




Aug-2008 Storm, Anoxic Volume







EFDC Sediment Flux Model

- Biological Production & Deposition of POM
- POM diagenesis (decay) in bed
- Sediment oxygen demand (SOD) & benthic N,P fluxes
- Sediment bed C,N,P data from OWRB

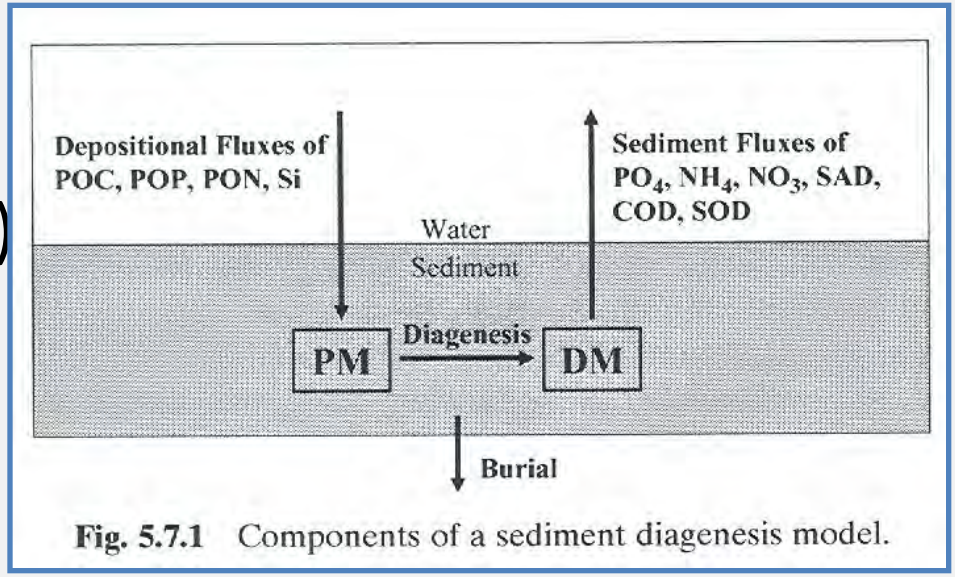
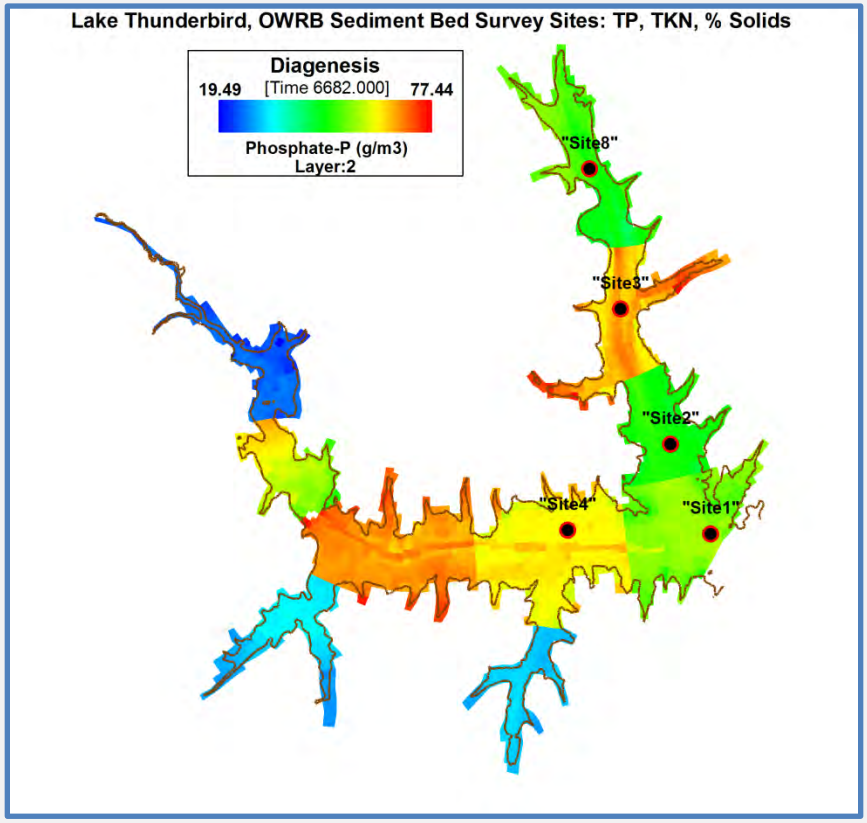


Fig. 5.7.1 Components of a sediment diagenesis model.

Di Toro (2001) *Sediment Flux Modeling*

Sediment Bed Surveys



- OWRB Surveys in July & December 2008
- TKN, TP, % Solids
- Lacustrine (Site 1,2,4)
- Transition (Site 3)
- Riverine (Site 8)
- OWRB data & literature; fill data gaps for TOP, PO4, NH4, NO3, TON, TOC by zones

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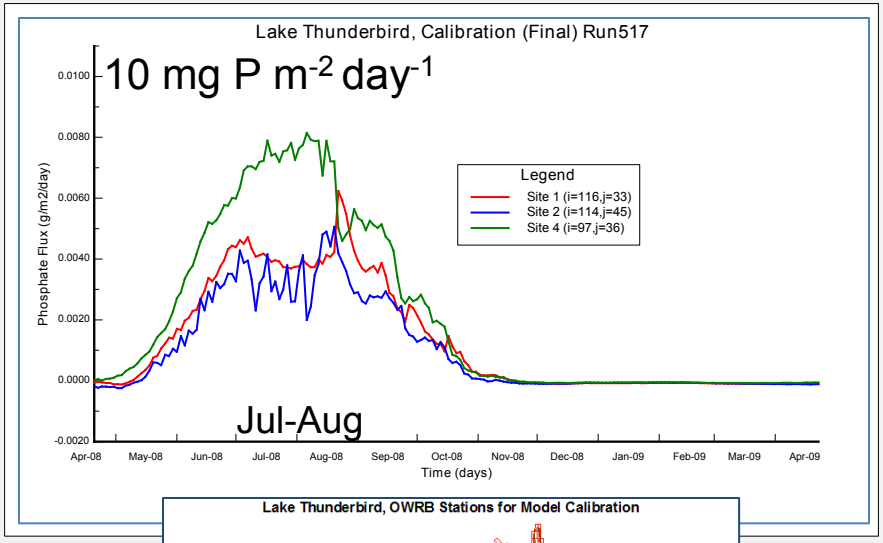
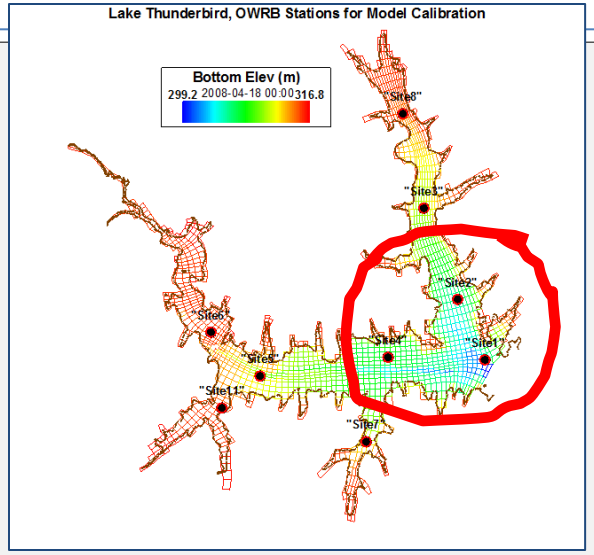
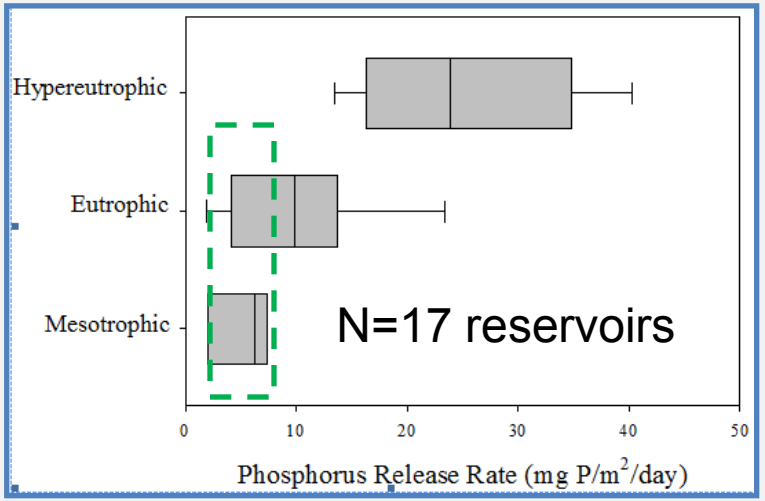
Sed Flux PO4: Model & Observations





Lake Thunderbird, OK	
EFDC, Stratified, 15 May-1 Oct 2008	
Sed Flux	jPO4 (mg P m^{-2} day^{-1})
Zone	Avg (Low-High)
Whole Lake	5.2 (3.4-8.2)
Lacustrine	4.5 (3.4-5.4)
Transition	7.4 (7.2-7.7)
Riverine	5.9 (3.5-8.2)



(Dzialowski & Carter, OSU)

How Well Did Lake Model Match Observed Data?

- Model generated seasonal stratification
- Good match to water temperature and dissolved oxygen
- Aug-2008 storm event reproduced
- Model matched seasonal trends of temperature, DO, secchi depth, nutrients & chlorophyll
- Sediment flux model SOD & internal load of P comparable to other Midwest reservoirs
- Model DO used to compute anoxic volume of lake as percentage for WQ target compliance

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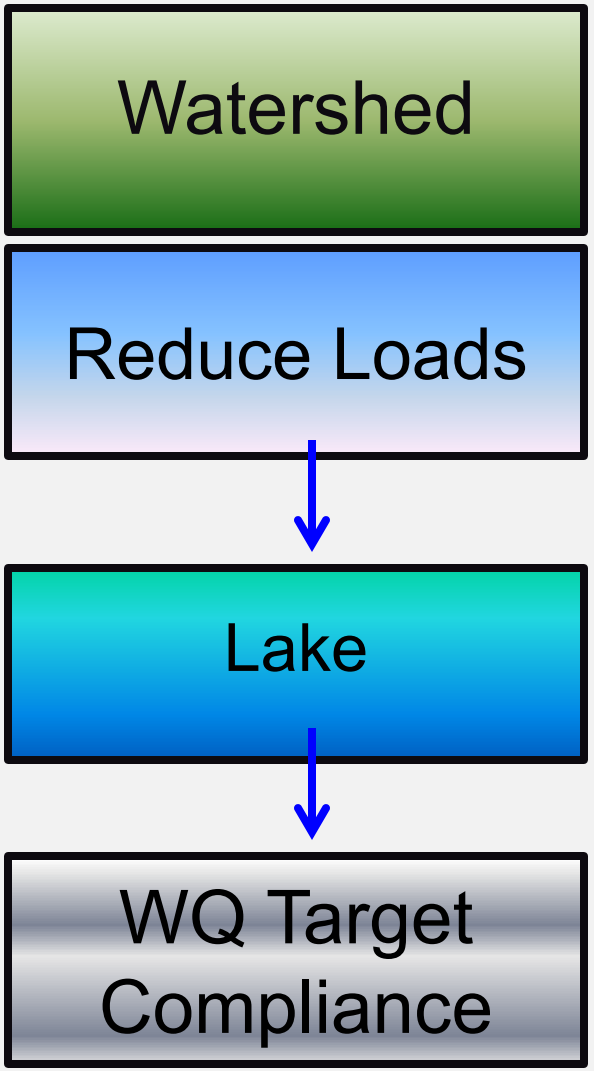
Management Scenario

- "What-if" 35% of TSS and nutrient (N,P) load is removed?
- Would lake attain WQ targets for turbidity, Chlorophyll & DO?
- How long will it take to attain compliance with WQ targets?
- Sediment flux model "Spin-up" runs, 8 years



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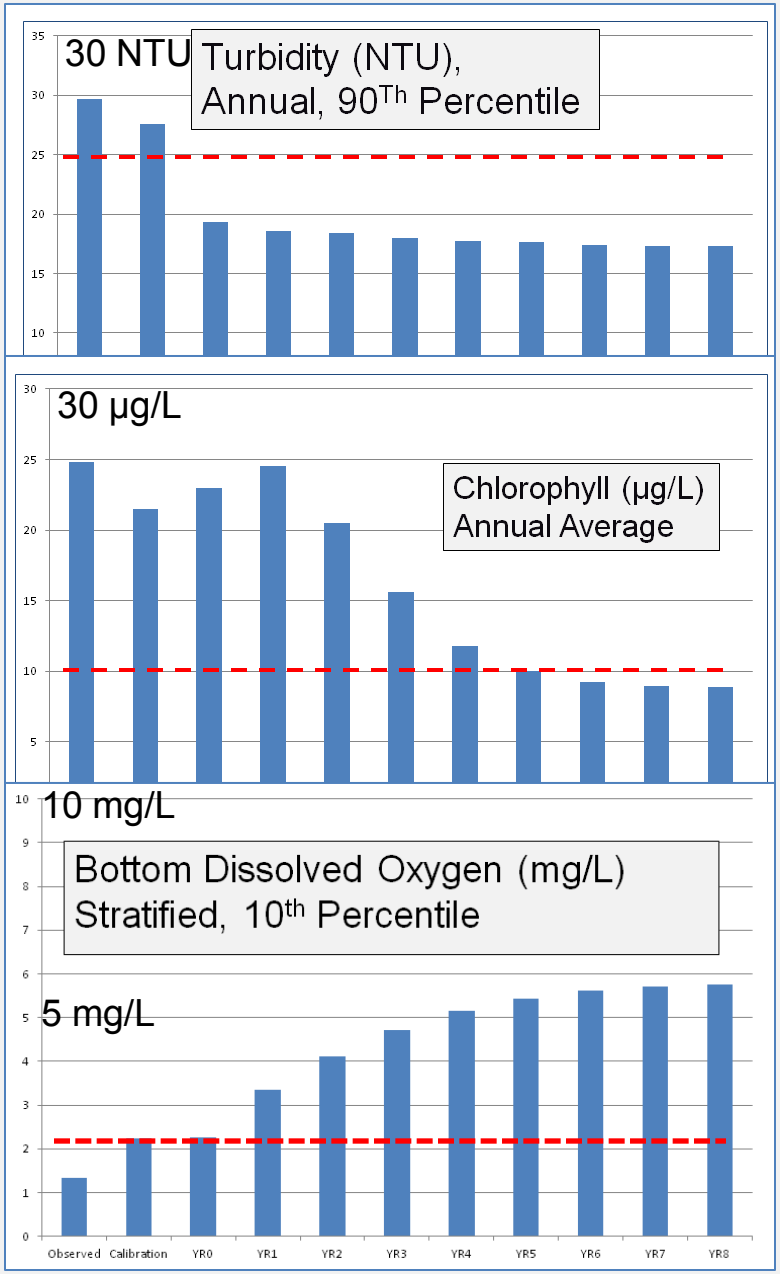

Meets Turbidity Target
< 25 NTU Turbidity

Meets Chl Target
<10 µg/L Chl

Meets DO Targets
(a) Sfc DO > 5 mg/L
(b) <50% Lake Volume
can be < 2 mg/L

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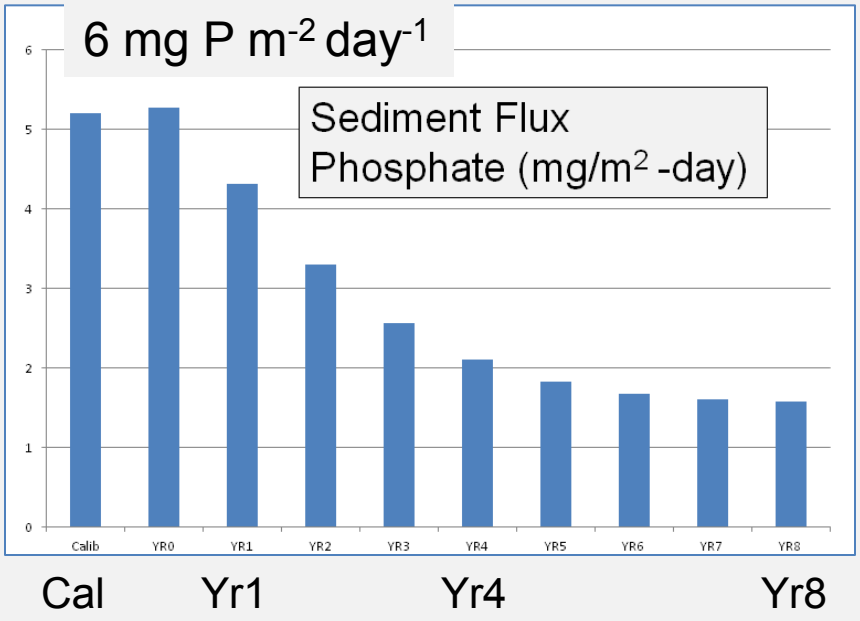
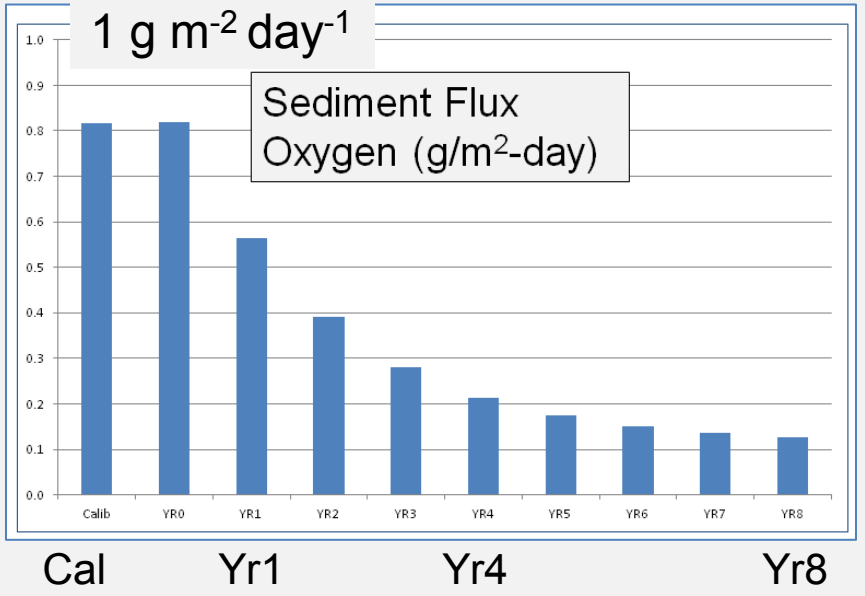
Sediment Flux: PO4 & SOD Calibration & 8 Yr Spin-up





35% Load Reduction & TMDL

- Based on “spin-up”, 35% load reduction should attain compliance with WQ targets
- Flow & TSS,BOD, N,P loads described by log-normal distribution
- Probability-based statistics of log-normal distribution of HSPF watershed loading data used to compute TMDLs
- TMDL computed from Long Term Average (LTA) load (35% R), CoeffVar, & 95% Confidence Interval

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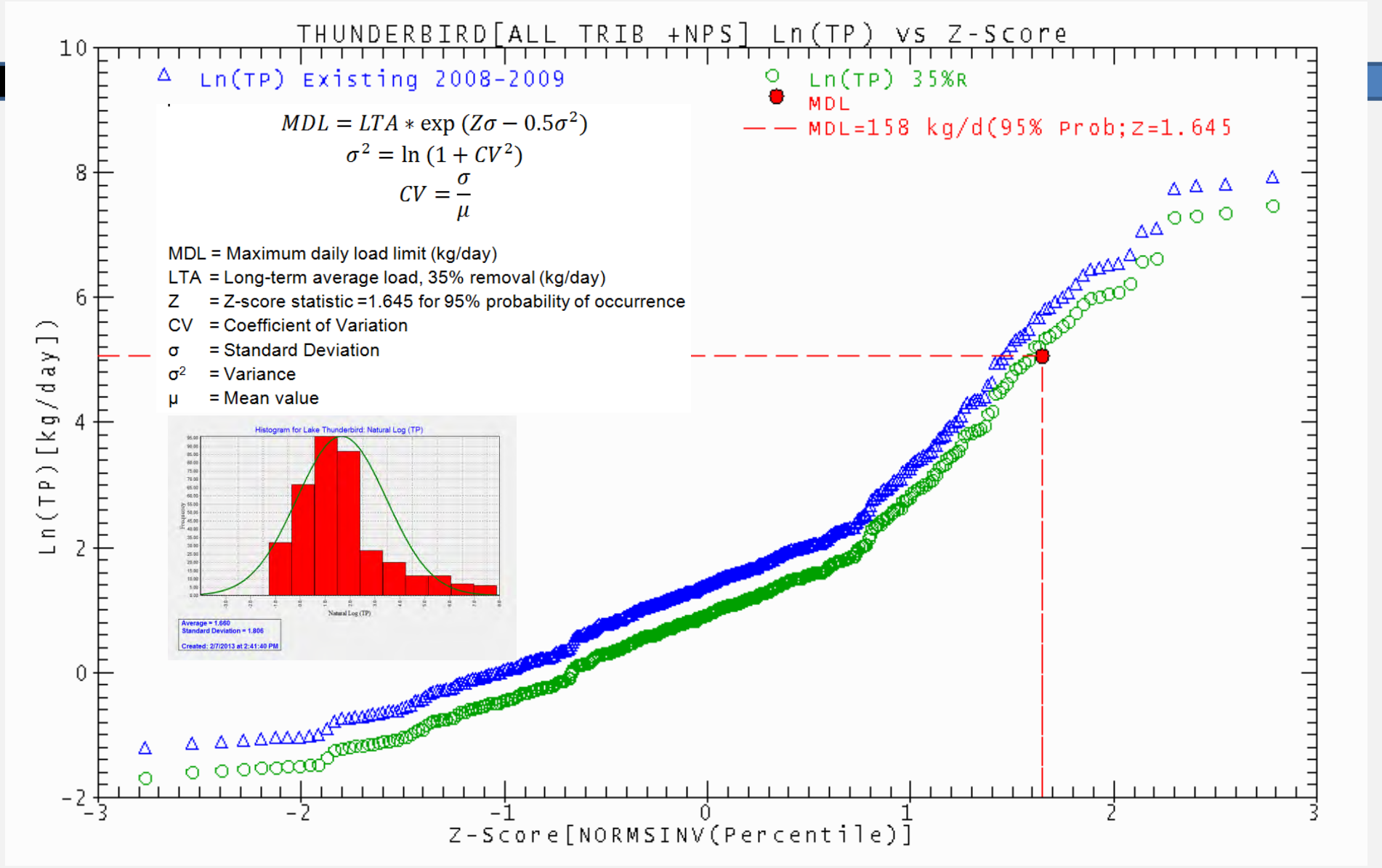
Maximum Daily Load,TP



Summary

- Calibrated Watershed-Lake model provided Oklahoma DEQ with technically defensible tool
- Literature used to help fill data gaps for sediment flux model
- 35% removal attains compliance with WQ targets for Turbidity, Chlorophyll & Oxygen
- Watershed-Lake model used to support TMDL Determinations for TN, TP, TSS, and BOD
- Lake Thunderbird TMDL approved by EPA Region 6 in Nov-2013

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Lake Thunderbird Watershed-Lake Model

Questions & Discussion

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Sediment Bed C,N,P Data Gaps

- Sediment Flux Model needs NH4, NO3, TON, TOP, PO4, TOC for initial conditions
- Nitrogen
- TKN from OWRB
- NH4 = 1% TKN
- NO3 = 1% NH4
- TON =99% TKN
- Phosphorus
- TP from OWRB
- TOP, PO4 = 50% TP (Nowlin et al.,2005,OH)
- Organic Carbon
- C:N = 15 (Kaushai & Binford, 1999, MA)
- TOC = TON * C:N

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SOD: Observations vs. Model

Reservoir	State	Observed	SOD (g $m^{-2}day^{-1}$)	Reference
Wister Lake	OK	Eutrophic	0.24-0.54	Haggard & Scott (2010)
Broken Bow	OK	Oligotrophic	1.49	Veenstra & Nolen (1991)
Texoma	TX,OK	Eutrophic	1.69	
Birch	OK	Eutrophic	3.2	
Pine Creek	OK	Mesotrophic	3.39	
Pat Mayse	TX	Eutrophic	4.08	

Reservoir	State	EFDC Zone	SOD (g $m^{-2}day^{-1}$)	Reference
Lake Thunderbird	OK	Eutrophic	Avg(Low-High)	EFDC, Stratified
		Whole Lake	0.8 (0.2-1.7)	15 May-1 Oct-2008
		Lacustrine	0.9 (0.6-1.1)	
		Transition	1.4 (1.1-1.7)	
		Riverine	0.2	

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Lake Model Performance
Relative RMS Error (%)

Parameter	Number Data Pairs	Relative RMS Error (%)	Target Relative-RMS Error (%)
Water Level	8921	0.6%	20%
Water Temperature	465	8%	50%
TSS	184	52%	50%
Chlorophyll	217	21%	100%
Dissolved Oxygen	432	19%	20%
Total-P	184	56%	50%
Total-N	114	55%	50%

Total Maximum Daily Loads

TMDL: kg/day	Total-N	Total-P	BOD	Sediment
Existing, 2008-2009	322	63	647	31,487
Load Removal	35%	35%	0%	35%
Long-Term Average Load	209	41	647	20,466
Coeff_Var (CV)	4.25	4.40	4.77	5.82
TMDL	808	158	2,481	76,951

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References

- Di Toro, D.M. 2001. *Sediment Flux Modeling*. Wiley Interscience, New York, NY.
- Dzialowski, A.R. and L. Carter (2011). Predicting internal nutrient release rates from Central Plains reservoirs for use in TMDL development. Final Report, Project Number: X7 97703801, Dept. Zoology, Oklahoma State University, Stillwater, OK, Submitted to U.S. Environmental Protection Agency, Region 7, TMDL Program, Water Quality Management Branch, Kansas City, KS.
- Haggard, B.E. and J.T. Scott .2011. Phosphorus release rates from bottom sediments at Lake Wister, Oklahoma,Summer, 2010. Arkansas Water Resources Center-University of Arkansas, Tech. Pub. Number MSC 364-Year 2011.
- Kaushai, S. and M. W. Binford. 1999. Relationship between C:N ratios of lake sediments, organic matter sources, and historical deforestation in Lake Pleasant, Massachusetts, US. Jour. Paleolimnology, 22:439-442.
- Nowlin, W.H., J.L. Evarts and M.J. Vanni 2005 Release rates and potential fates of nitrogen and phosphorus from sediments in a eutrophic reservoir. *Freshwater Biology*, 50, 301-322.
- Veenstra, J.N. and S. L. Nolen. 1991. *In-situ* sediment oxygen demand in five southwestern U.S. lakes. Water Research, 25(3):351-354.

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