Watershed - Lake Model to Support TMDL Determinations for Lake Thunderbird

18th Annual
EPA Region 6 Stormwater Conference
Workshop 5: TMDLs and You

Dynamic Solutions LLC

October 3, 2016
Oklahoma City, OK

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
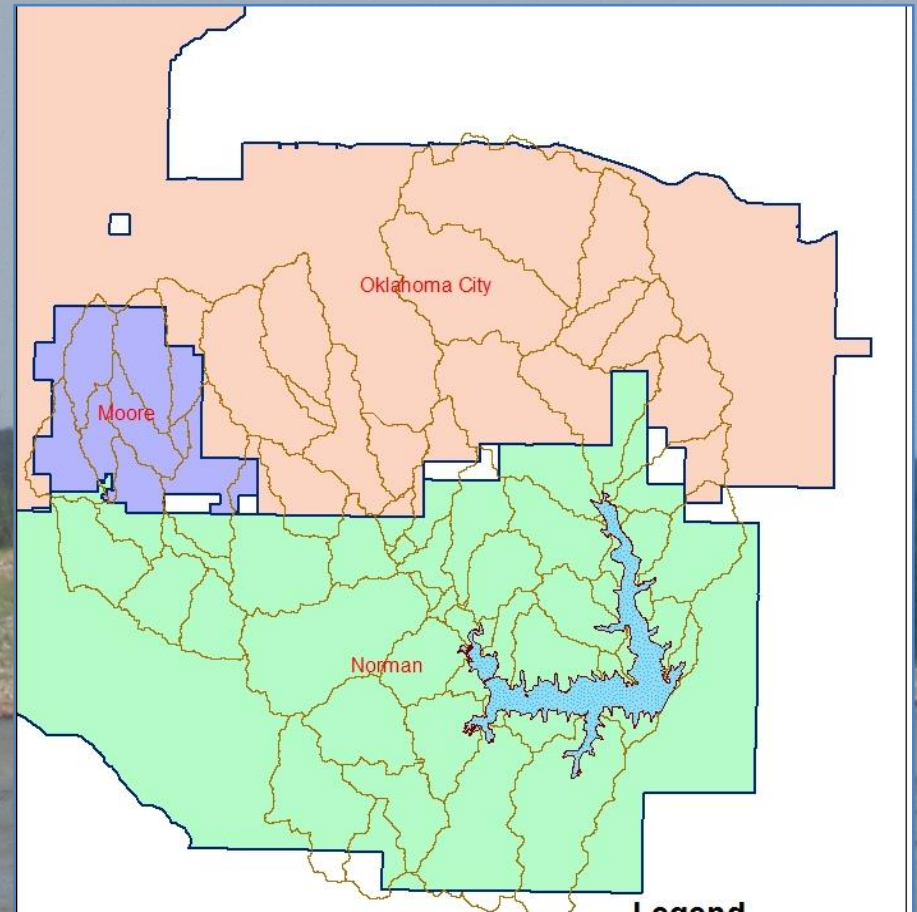
Designated Uses, 303(d) Impairments & WQ Targets

- 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 during stratified season

- Annual average chlorophyll < 10 µg/L
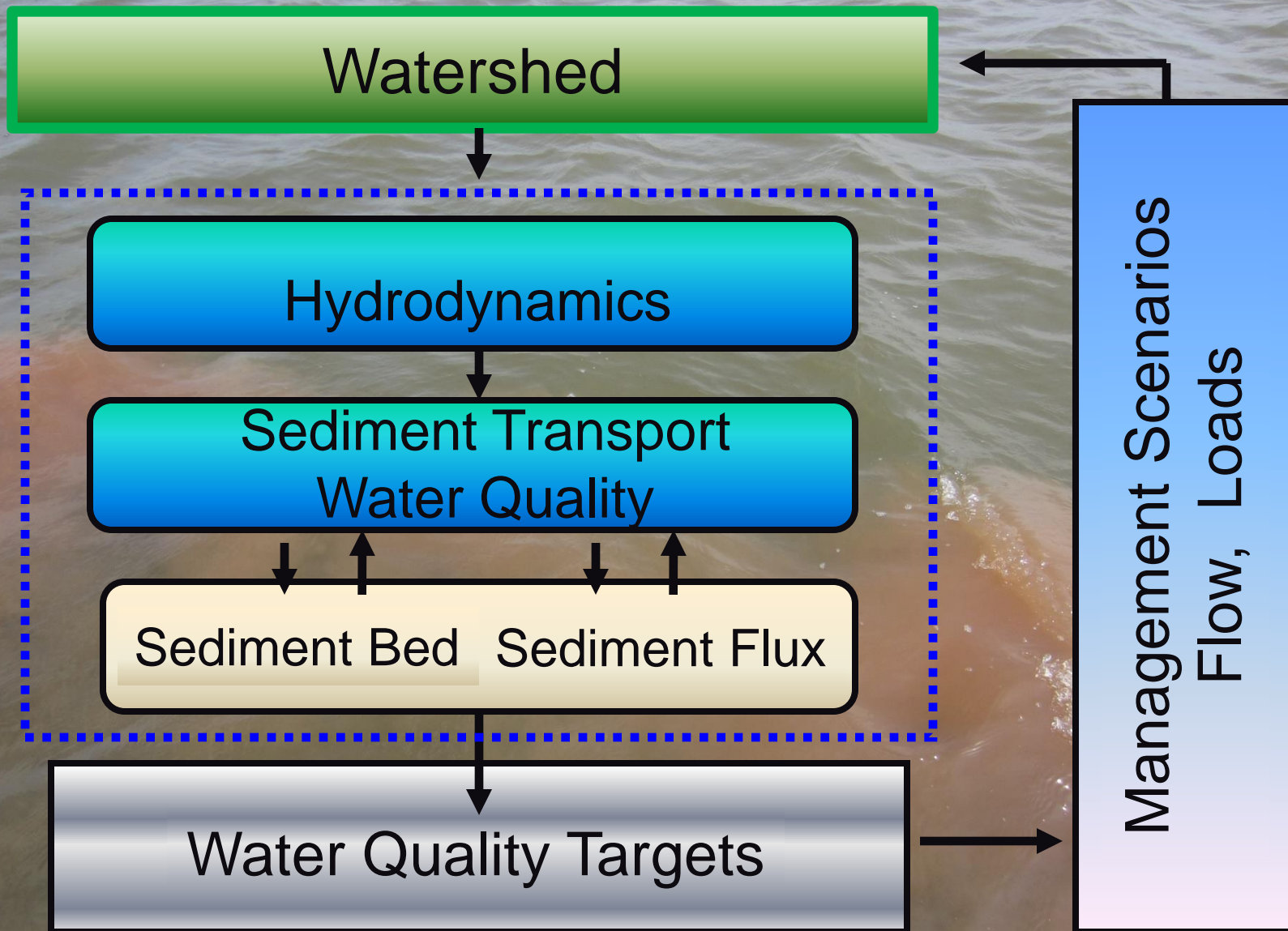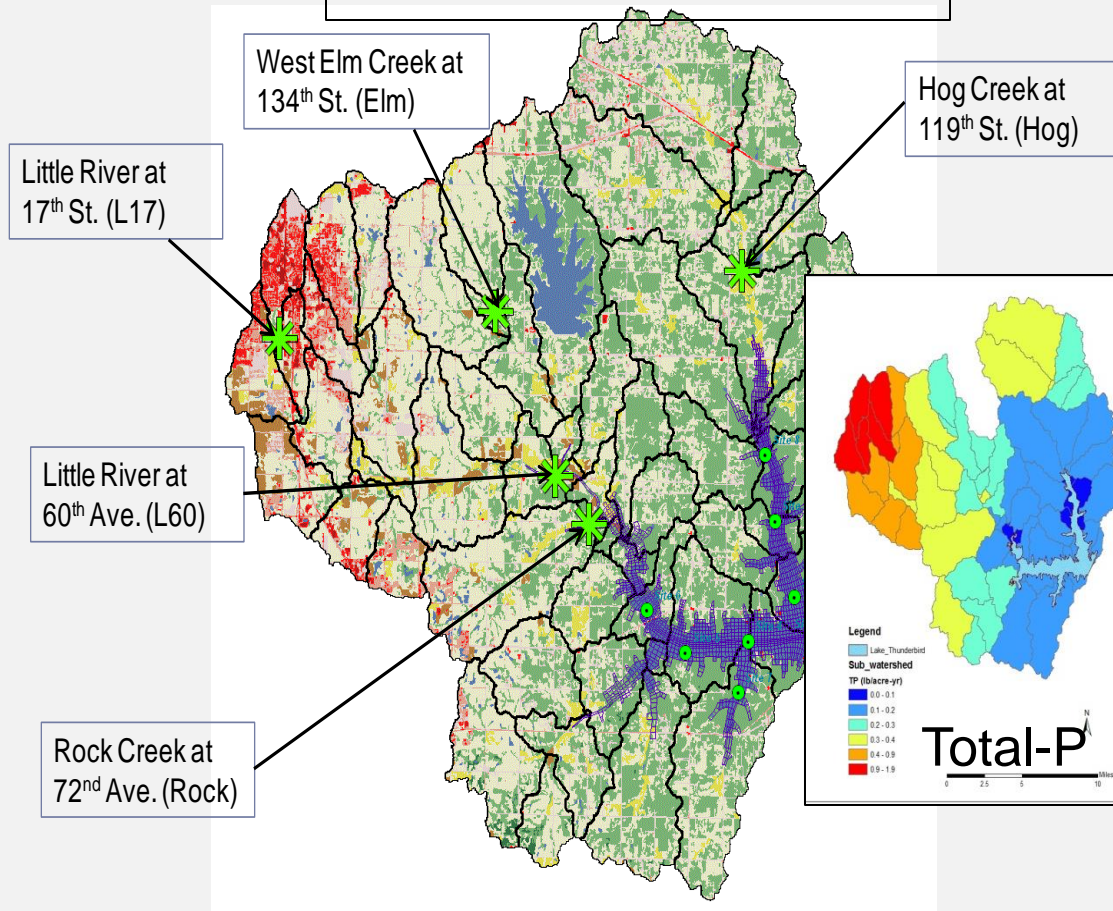
HSPF Watershed Model
Hydrologic Simulation Program-Fortran

- Rainfall/meteorology
- Topography
- Land uses/soils
- Stream channels
- Overland flow
- Infiltration
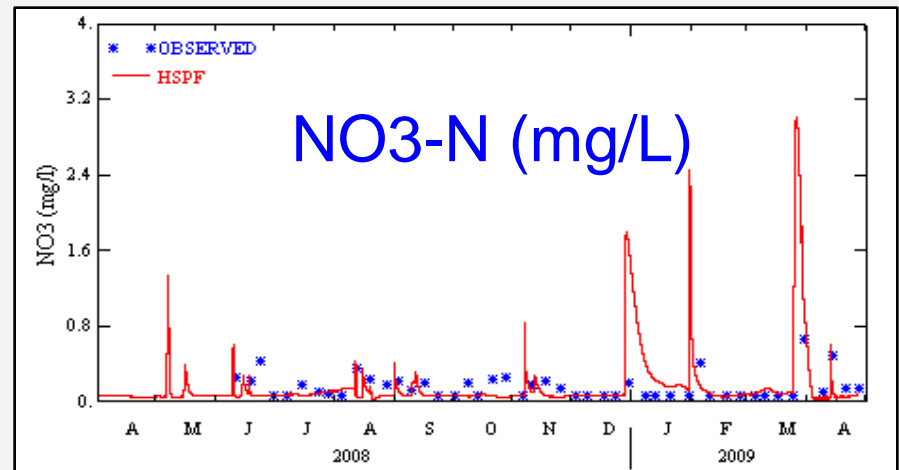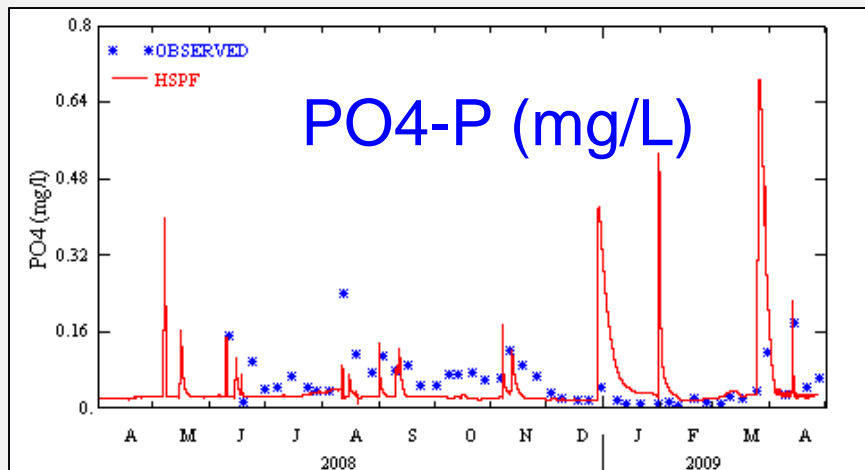- Groundwater
- Sub-watersheds

HSPF Watershed Model

66 Sub-Watersheds

West Elm Creek at 134th St. (Elm)

Hog Creek at 119th St. (Hog)

Little River at 17th St. (L17)

Little River at 60th Ave. (L60)

Rock Creek at 72nd Ave. (Rock)

Legend
Lake_Thunderbird
Sub_watershed
TP (lb/acre-yr)
0.0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.9
0.9 - 1.9

Total-P
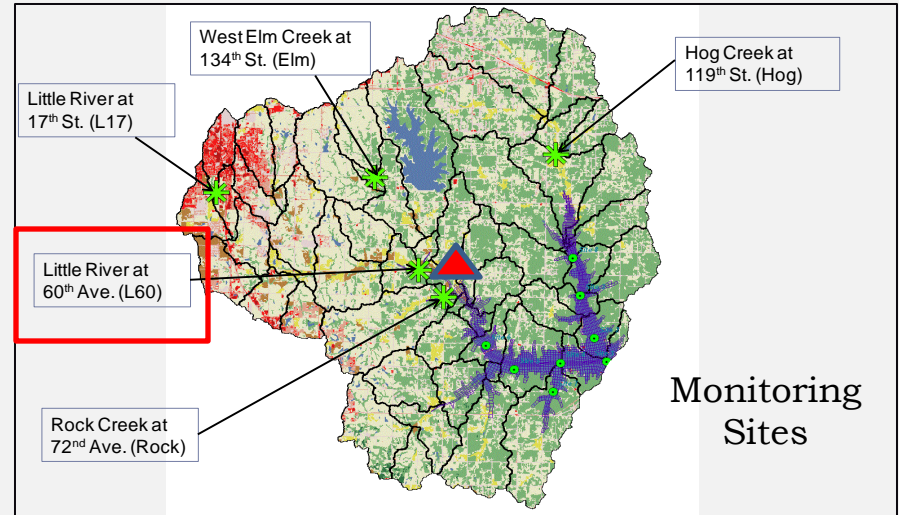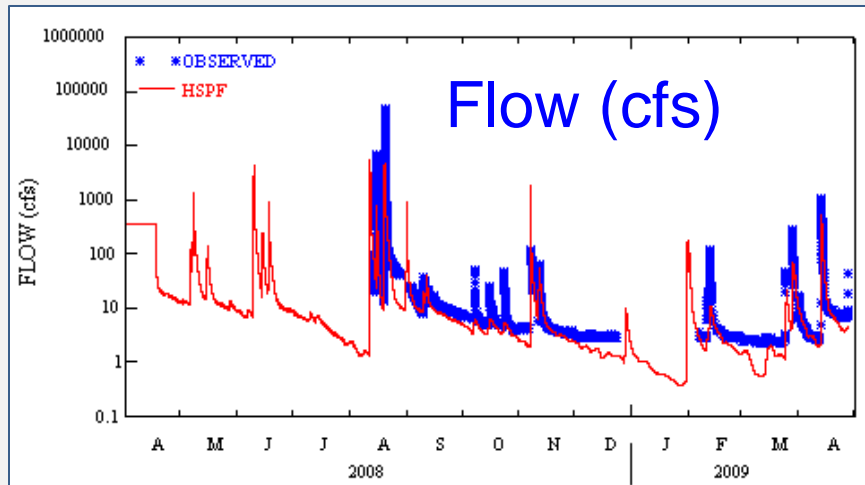
- 1 Yr Calibration
- 4/2008 - 4/2009
- Average hydrology
- WQ data measured at 5 sites (OCC)
- Flow, TSS, Water Temperature, DO, BOD, Nutrients (N,P), Algae

Flow, PO4, NO3: Little R @60ᵗʰ Ave

Flow (cfs)

Monitoring Sites

West Elm Creek at 134ᵗʰ St. (Elm)

Hog Creek at 119ᵗʰ St. (Hog)

Little River at 17ᵗʰ St. (L17)

Little River at 60ᵗʰ Ave. (L60)

Rock Creek at 72ⁿᵈ Ave. (Rock)

PO4-P (mg/L)

NO3-N (mg/L)

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
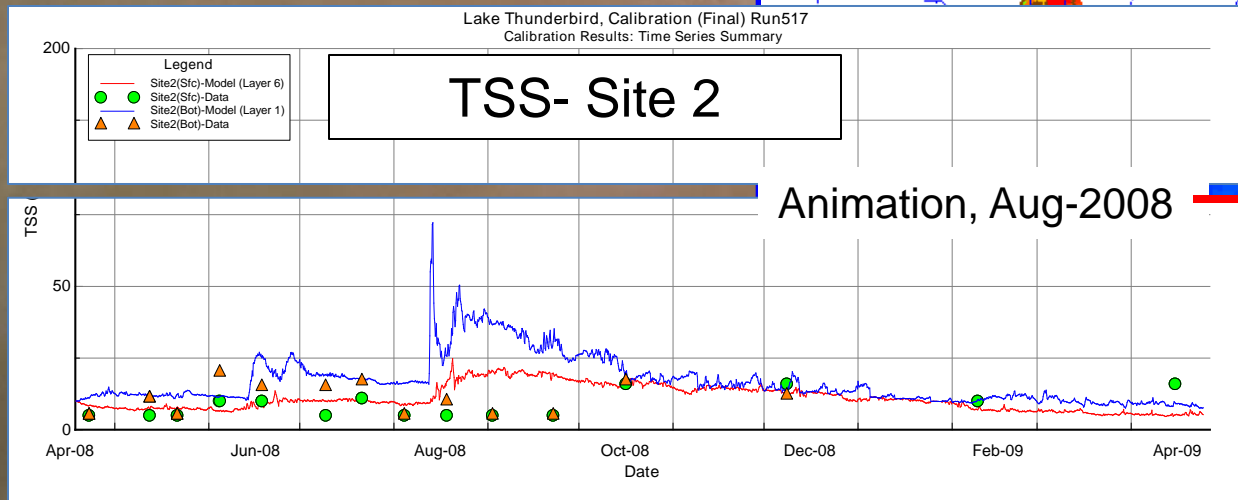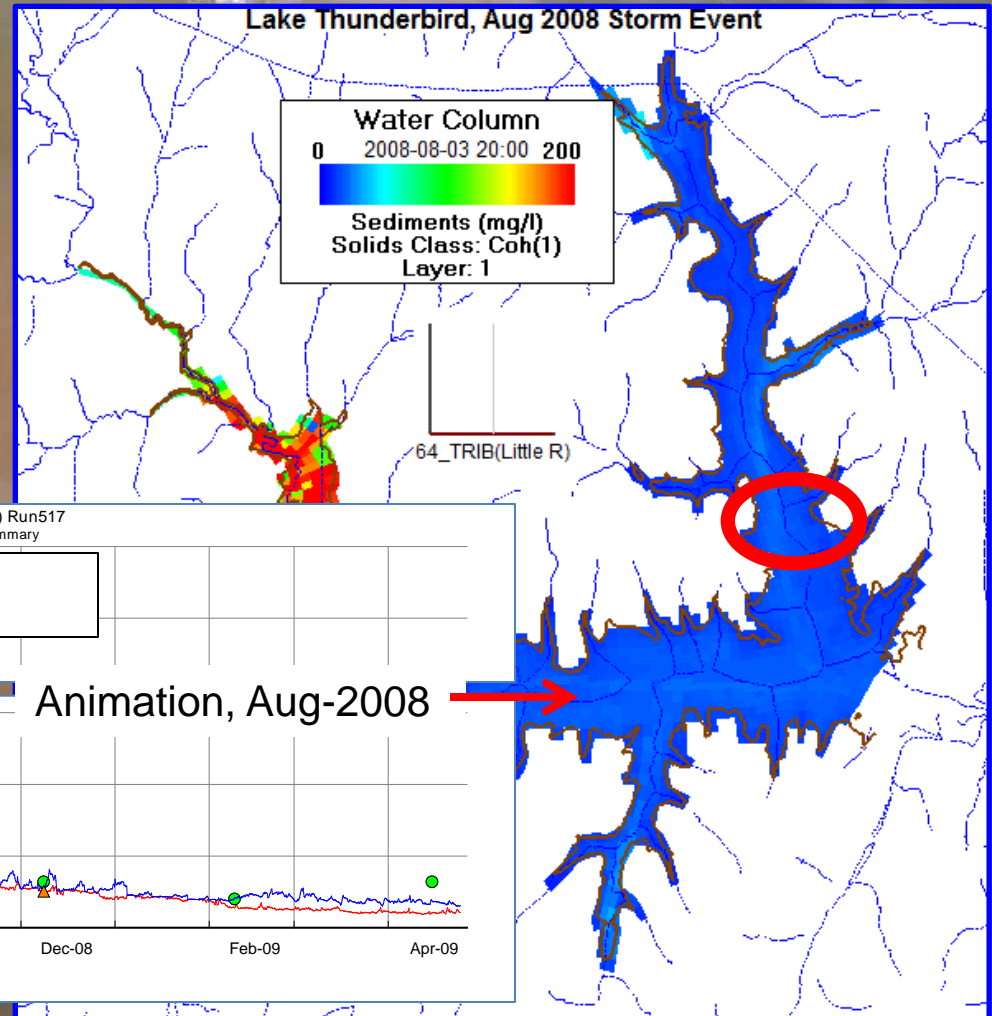- Internal source of nutrients from sediment bed
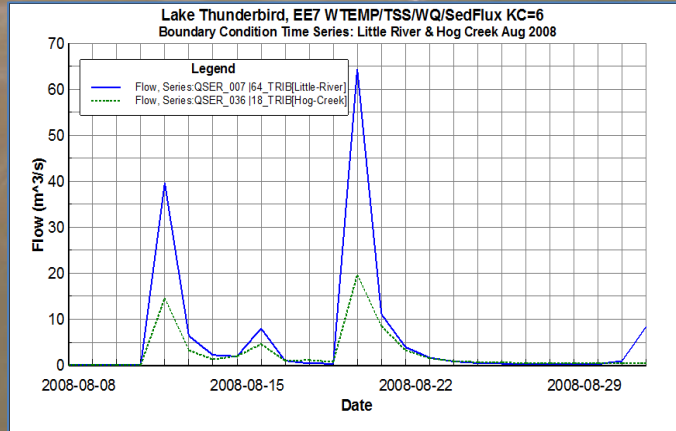
EFDC Lake Model

1660 Cells, 6 Layers
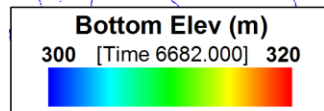
- <u>Loads:</u> HSPF Flow, WQ, Atm Dep N,P
- <u>Hydrodyn</u>: Lake level, Velocity, Wtemp
- <u>Sediment</u>: TSS, bed
- <u>WQ</u>: Chl, DO, C, N,P
- <u>Sed Flux</u>: SOD, N,P fluxes, Bed C,N,P
- <u>Calibration</u>: 8 sites, 1 yr, 4/2008-4/2009

Aug-2008 Storm, TSS

Lake Thunderbird, EE7 WTEMP/TSS/WQ/SedFlux KC=6
Boundary Condition Time Series: Little River & Hog Creek Aug 2008

Lake Thunderbird, Aug 2008 Storm Event

Water Column
0   2008-08-03 20:00   200
Sediments (mg/l)
Solids Class: Coh(1)
Layer: 1

64_TRIB(Little R)

Lake Thunderbird, Calibration (Final) Run517
Calibration Results: Time Series Summary

TSS- Site 2

Animation, Aug-2008

Secchi Depth & Algae Chl
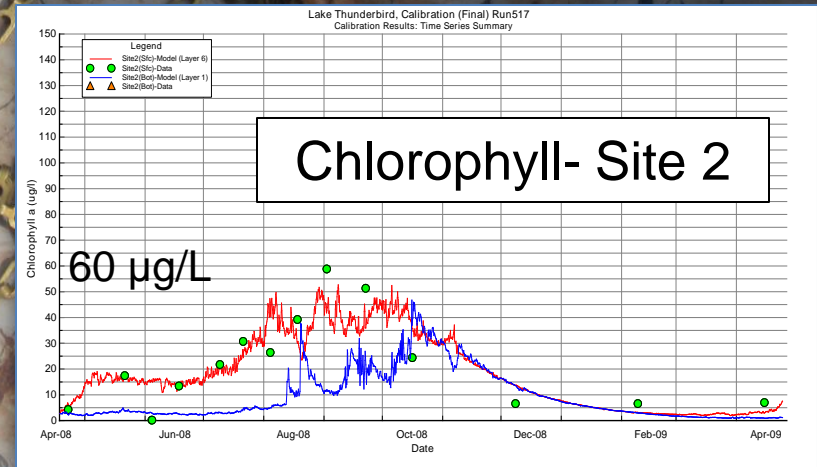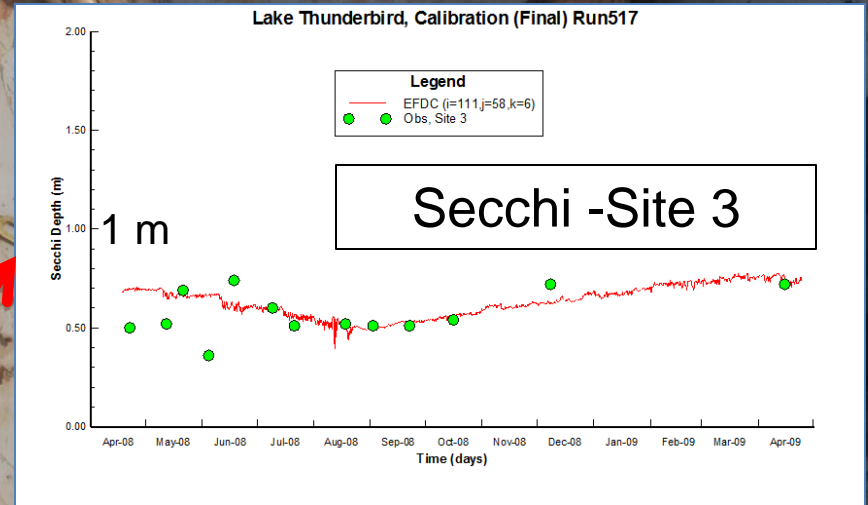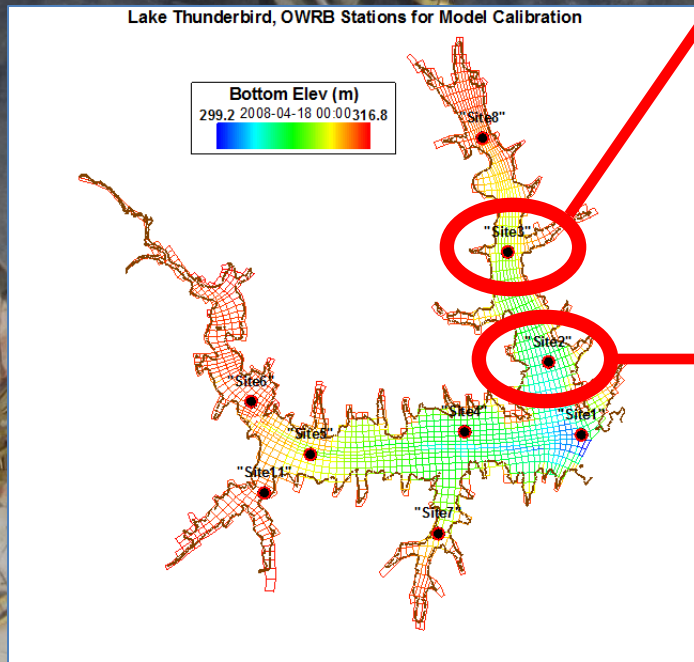
Dissolved Oxygen

Lake Thunderbird, OWRB Stations for Model Calibration

Bottom Elev (m)
299.2 2008-04-18 00:00 316.8

Lake Thunderbird, Calibration (Final) Run517
Calibration Results: Time Series Summary

Dissolved Oxygen- Site 2

Legend
— Site2(Sfc)-Model (Layer 6)
● Site2(Sfc)-Data
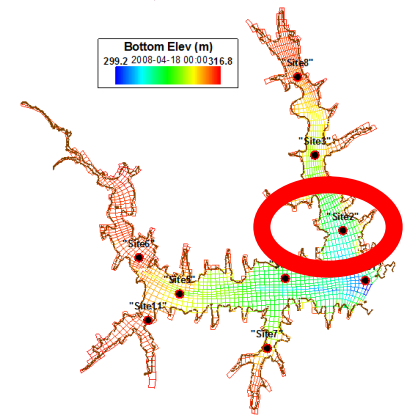— Site2(Bot)-Model (Layer 1)
▲ Site2(Bot)-Data

Dissolved Oxygen (mg/l)

Date

Lake Thunderbird, EE7 WTEMP/TSS/WQ/SedFlux KC=6
Boundary Condition Time Series: Little River & Hog Creek Aug 2008

Legend
— Flow, Series:QSER_007 |64_TRIB[Little-River]
---- Flow, Series:QSER_036 |18_TRIB[Hog-Creek]

Flow (m^3/s)

Date

River Flow
Aug-2008
Storm Events
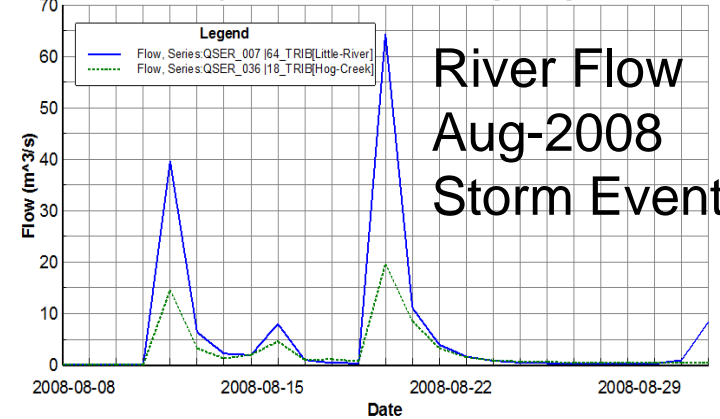
Aug-2008 Storm, Anoxic Volume

Lake Thunderbird, EE7 WTEMP/TSS/WQ/SedFlux KC=6
Boundary Condition Time Series: Little River & Hog Creek Aug 2008

River Flow
Aug-2008
Storm Events

Water Column
0   2008-08-03 20:00   50
Anoxic Volume (%)
DO Cutoff: 2 (mg/l)

64_TRIB(Little R)

Lake Thunderbird, Calibration (Final) Run517

Site 2 Anoxic Volume

50% Target

Legend
Site2Polygon, Anoxic Volume
Anoxic Volume Site 2 Aug-4-2008 09:56

Animation, Aug-2008

EFDC Sediment Flux Model
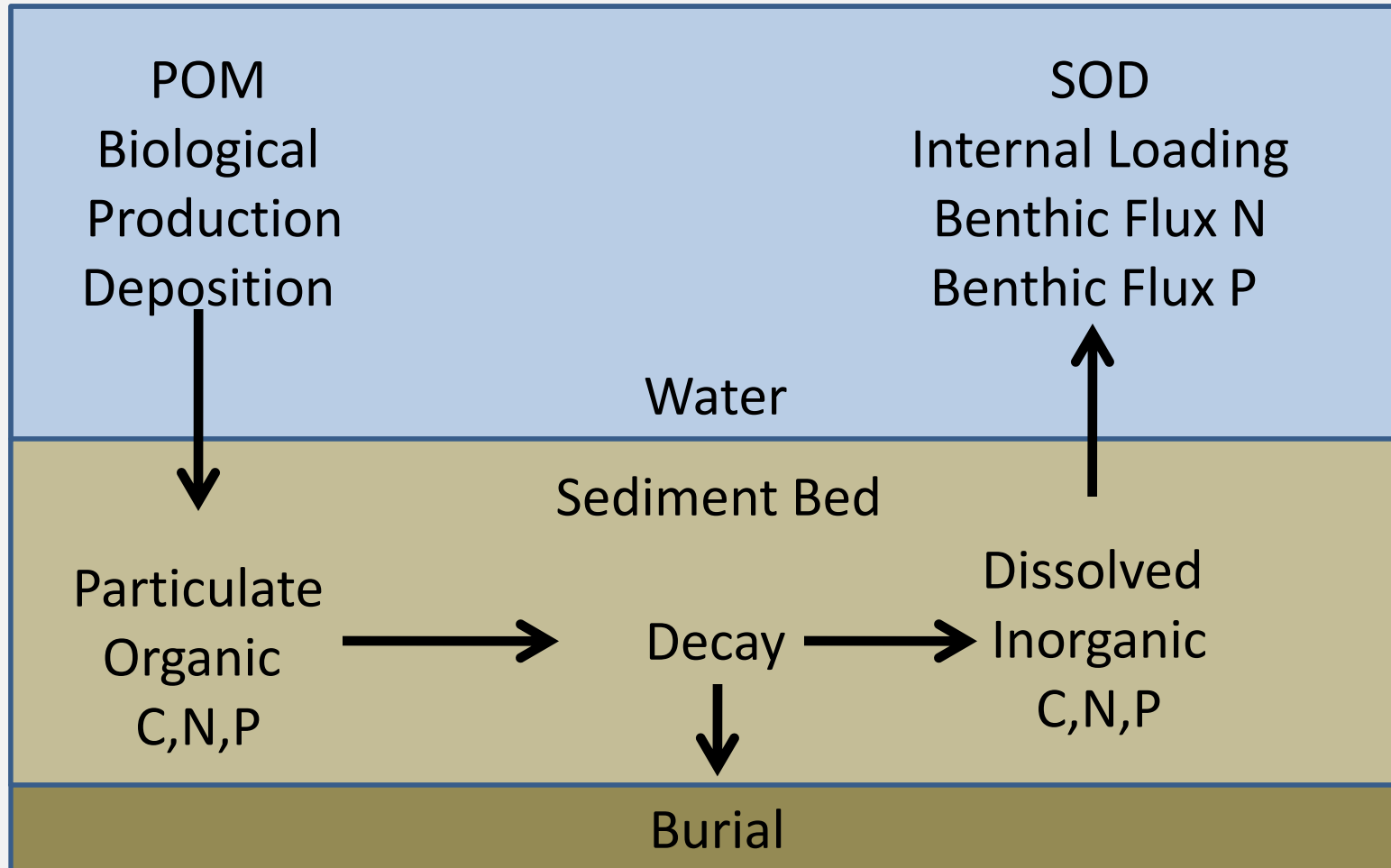
Sed Flux PO4: Model & Observations

Lake Thunderbird, Calibration (Final) Run517

10 mg P m^{-2} day^{-1}

Jul-Aug

Legend
- Site 1 (i=116,j=33)
- Site 2 (i=114,j=45)
- Site 4 (i=97,j=36)
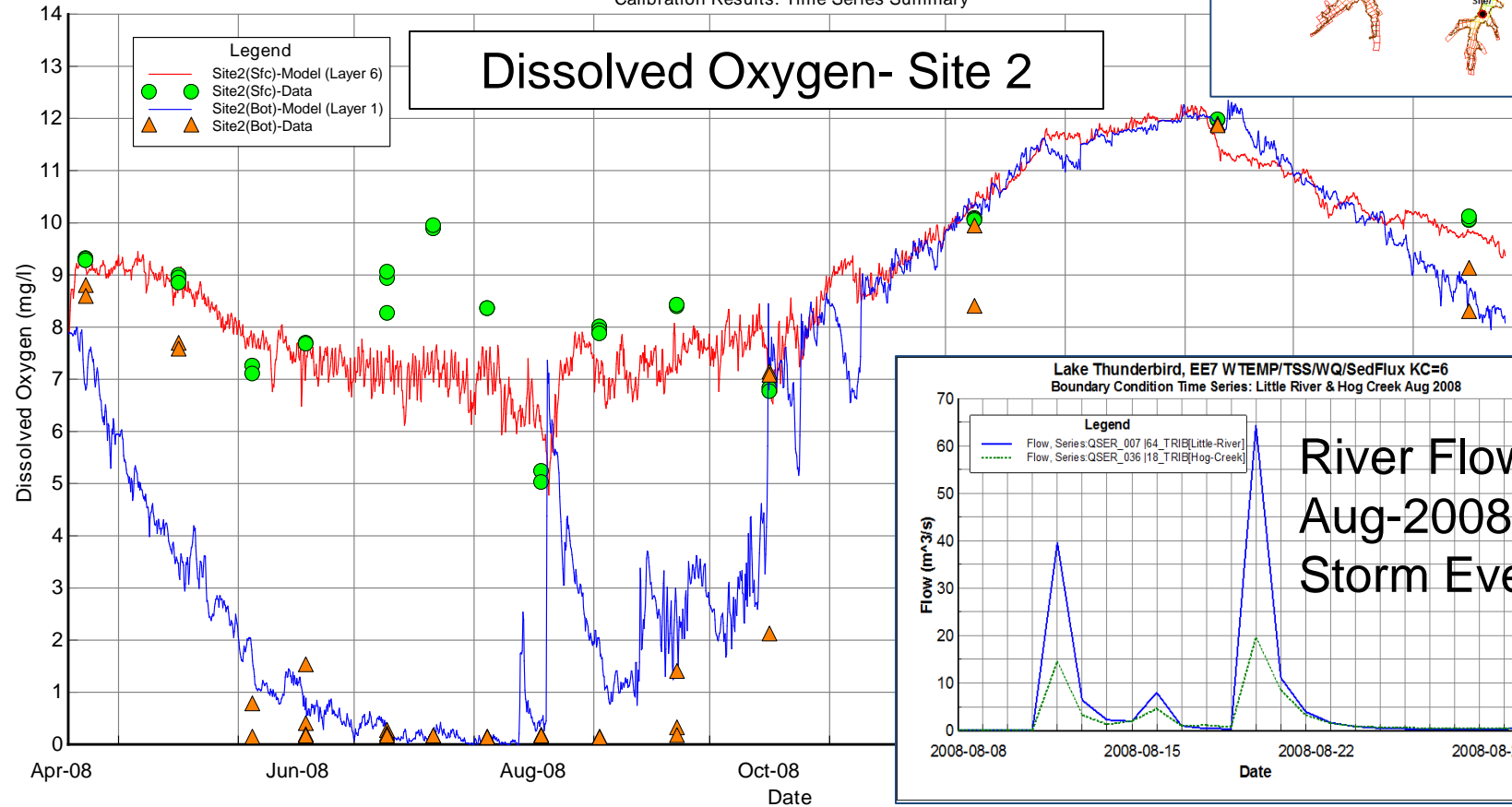

Lake Thunderbird, OWRB Stations for Model Calibration

Bottom Elev (m)
299.2 2008-04-18 00:00 316.8
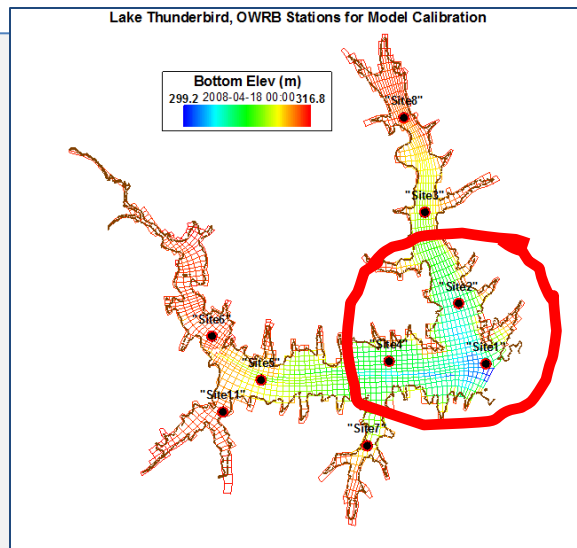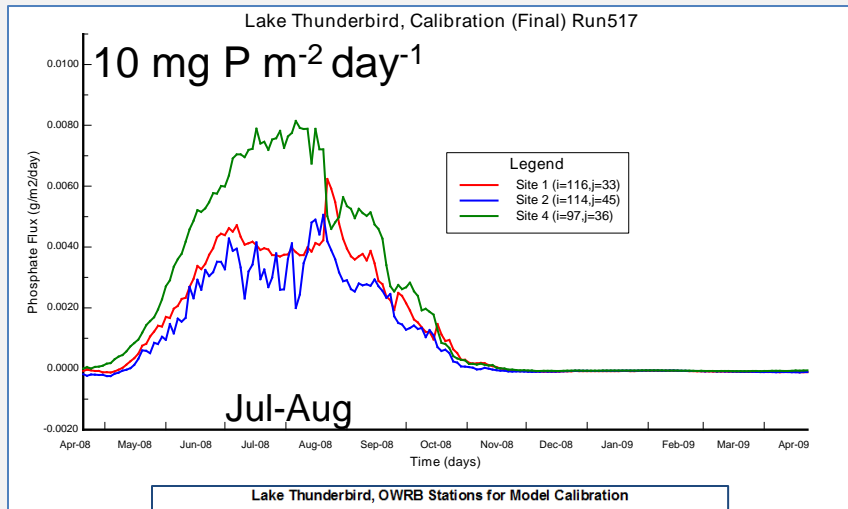
Lake Thunderbird, OK	
EFDC, Stratified, 15 May-1 Oct 2008	
Sed Flux	jPO4 (mg P m^{-2}day^{-1})
Zone	Avg (Low-High)
Whole Lake	5.2 (3.4-8.2)
Lacustrine	4.5 (3.4-5.4)
Transition	7.4 (7.2-7.7)
Riverine	5.9 (3.5-8.2)

N=17 Central Plains reservoirs

Phosphorus Release Rate (mg P/m^2/day)
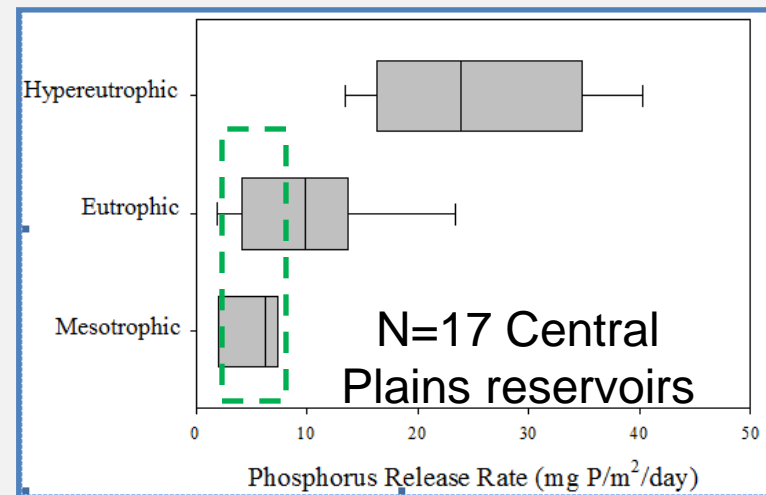
(Dzialowski & Carter, OSU)

How Well Did Model Match Data?

- Hydrodynamic model simulated seasonal stratification

- Model reproduced Aug-2008 storm event

- Model matched seasonal trends of water temperature, DO, secchi depth, nutrients & chlorophyll

- Internal load of P from sediment flux model comparable to other Central Plains reservoirs

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TMDL Management Scenario

- "What-if" 35% of TSS and nutrient (N,P) load is removed?

- Would Lake Thunderbird attain WQ targets for DO, turbidity, & Chlorophyll ?

- How long will it take to attain compliance with WQ targets?

- Lake model "Spin-up" runs for 8 years

Watershed

Reduce Loads

↓

Lake

↓

WQ Target Compliance

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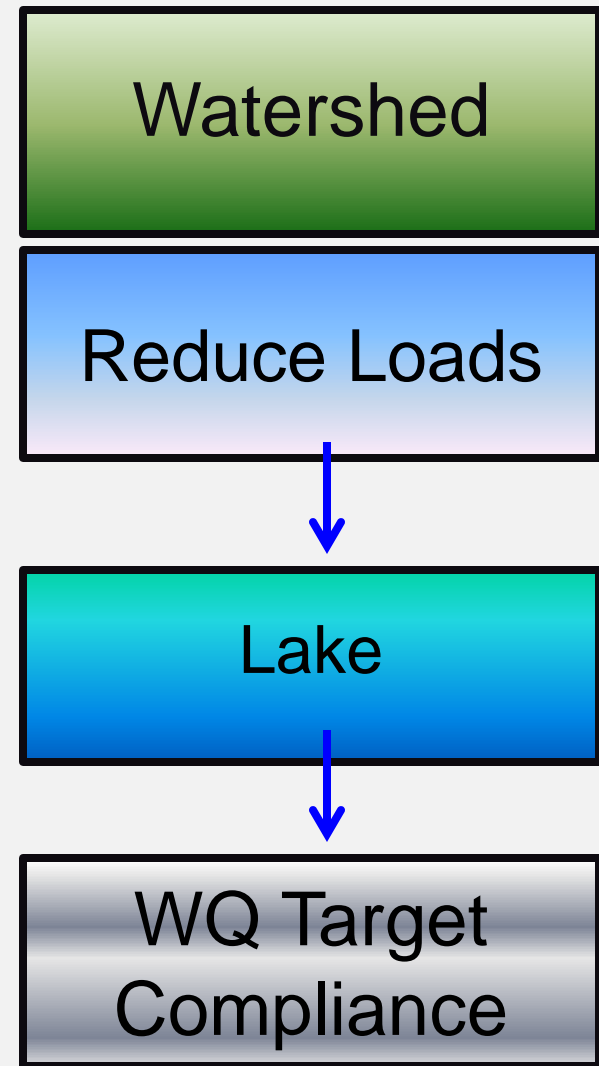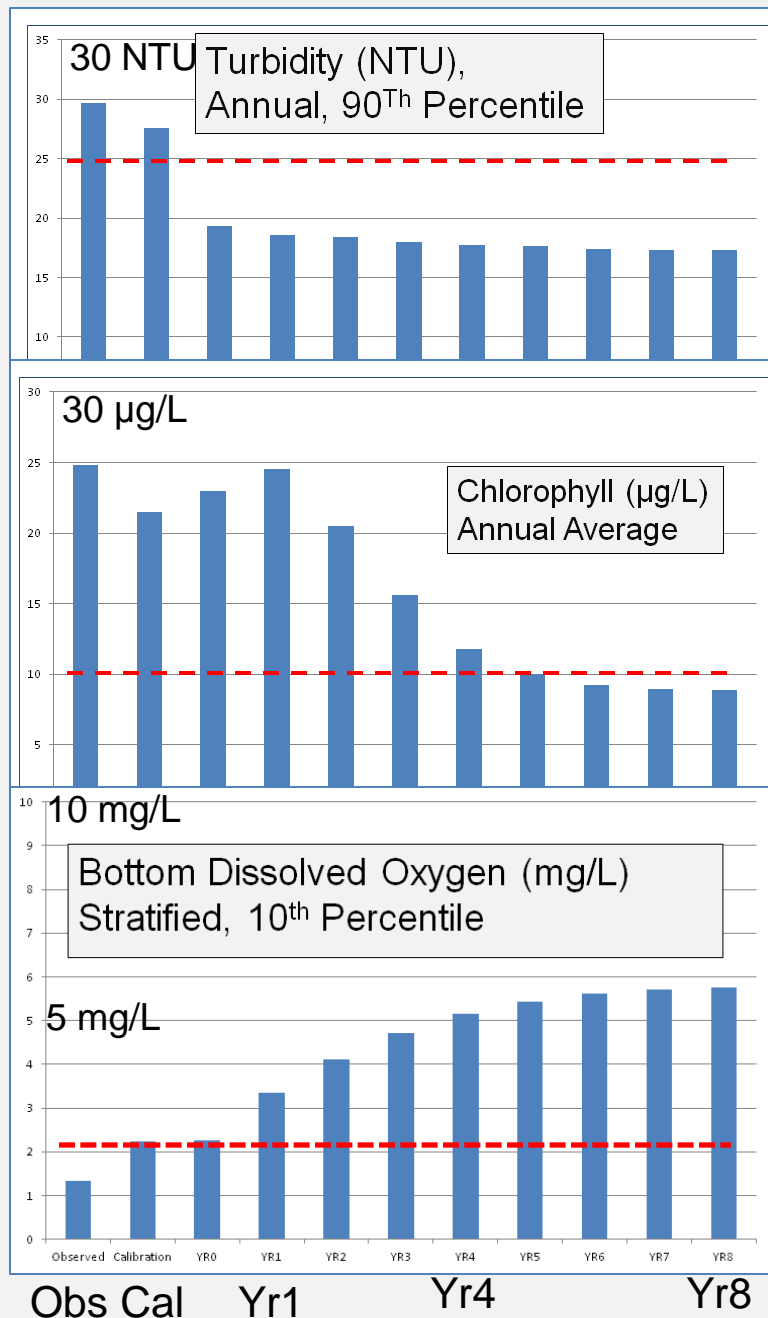
Meets Turbidity Target
< 25 NTU Turbidity

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

Sediment Flux Model "Spin-Up"

Internal PO4 Load

6 mg P m^{-2} day^{-1}

Sediment Flux Phosphate (mg/m^2 -day)

Cal   Y1   Y4   Y8

Sediment O2 Demand

1 g m^{-2} day^{-1}

Sediment Flux Oxygen (g/m^2-day)

Cal   Y1   Y4   Y8
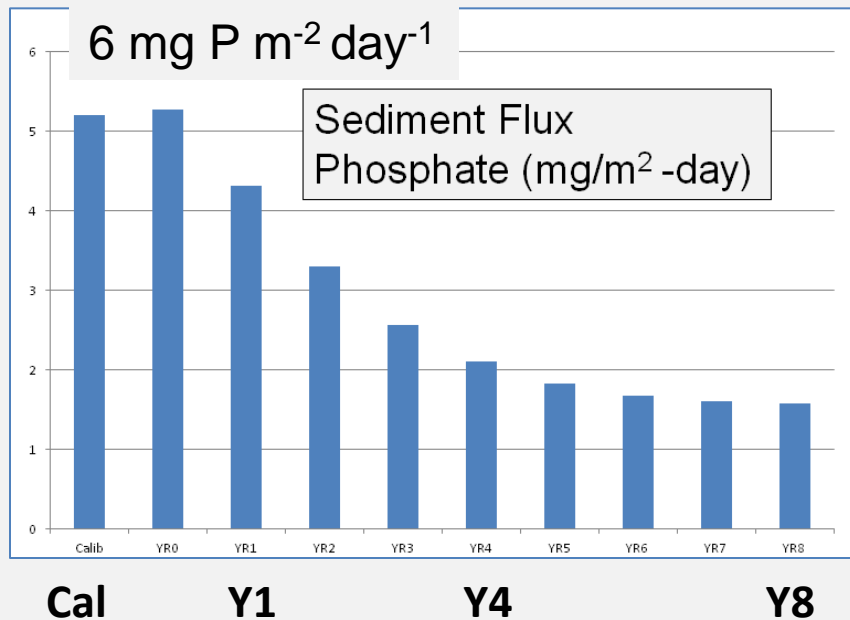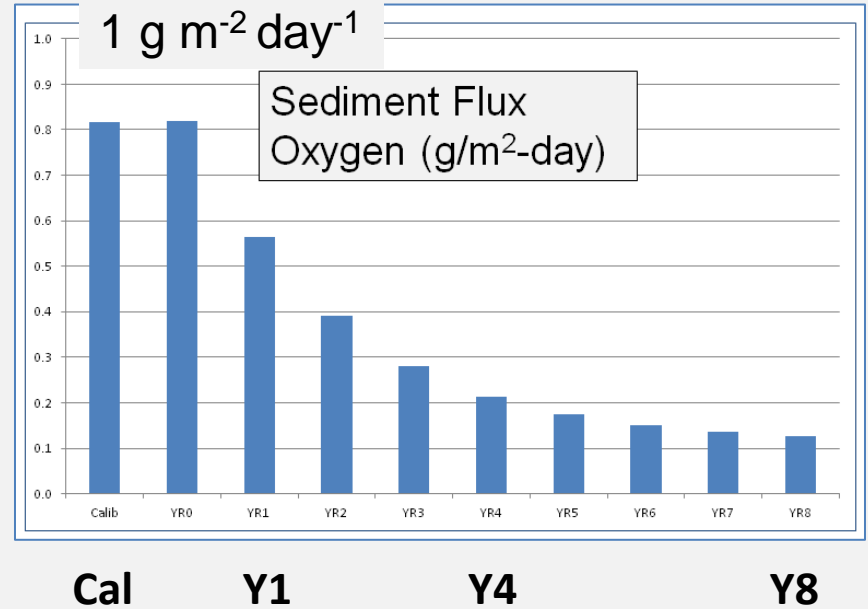
35% Load Reduction & TMDL

- Based on model "spin-up", 35% load reduction should attain compliance with WQ targets

- Probability distribution and statistics for HSPF watershed loading data to Lake Thunderbird used to compute TMDLs

- Statistics are mean, standard deviation, coeff_variation, and 95% probability level

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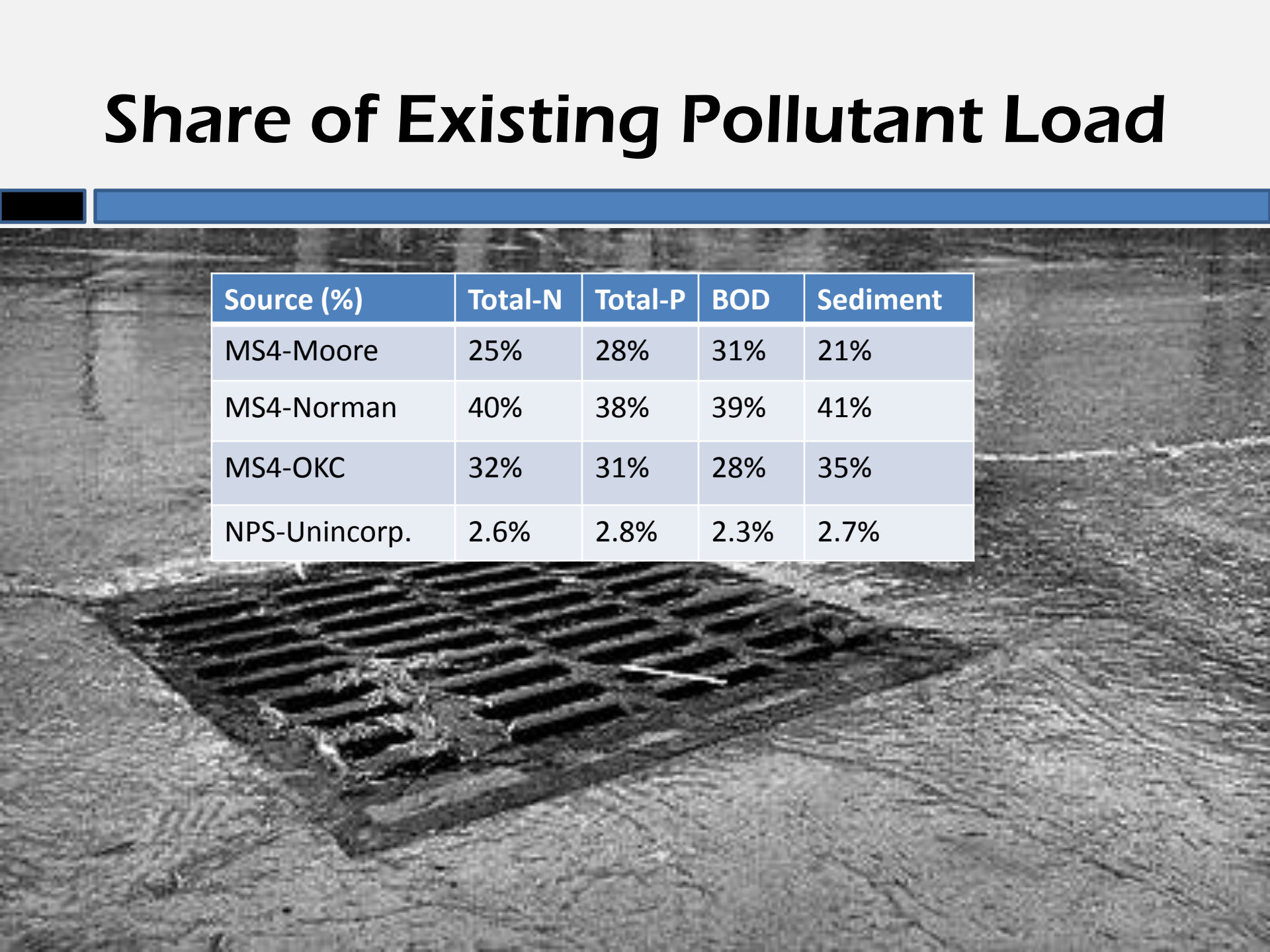
Probability Distribution for Loads

Max Daily Load (MDL) for TP

THUNDERBIRD[LOAD TO LAKE] Ln(TP) vs Z-Score

△ Ln(TP) Existing 2008-2009 ○ Ln(TP) 35%R

$$MDL = LTA * \exp\left(Z\sigma - 0.5\sigma^2\right)$$
$$\sigma^2 = \ln\left(1 + CV^2\right)$$
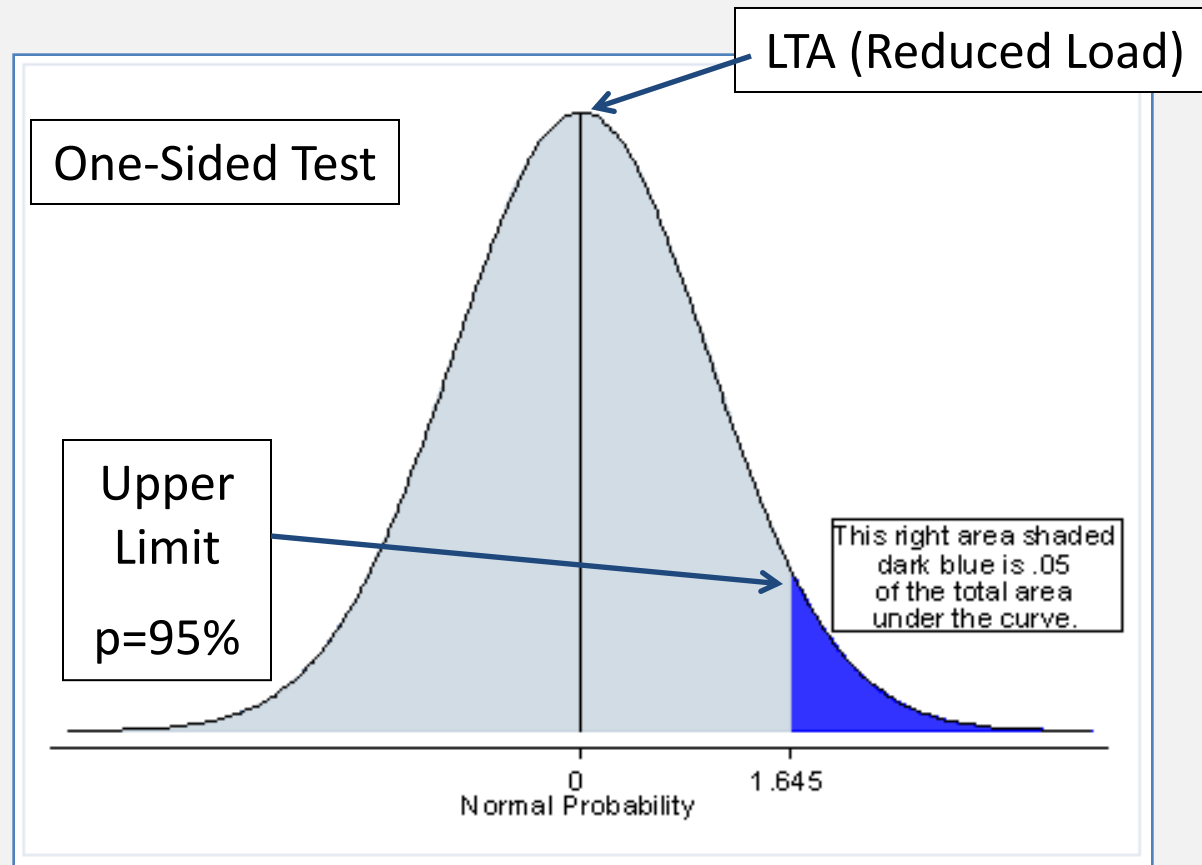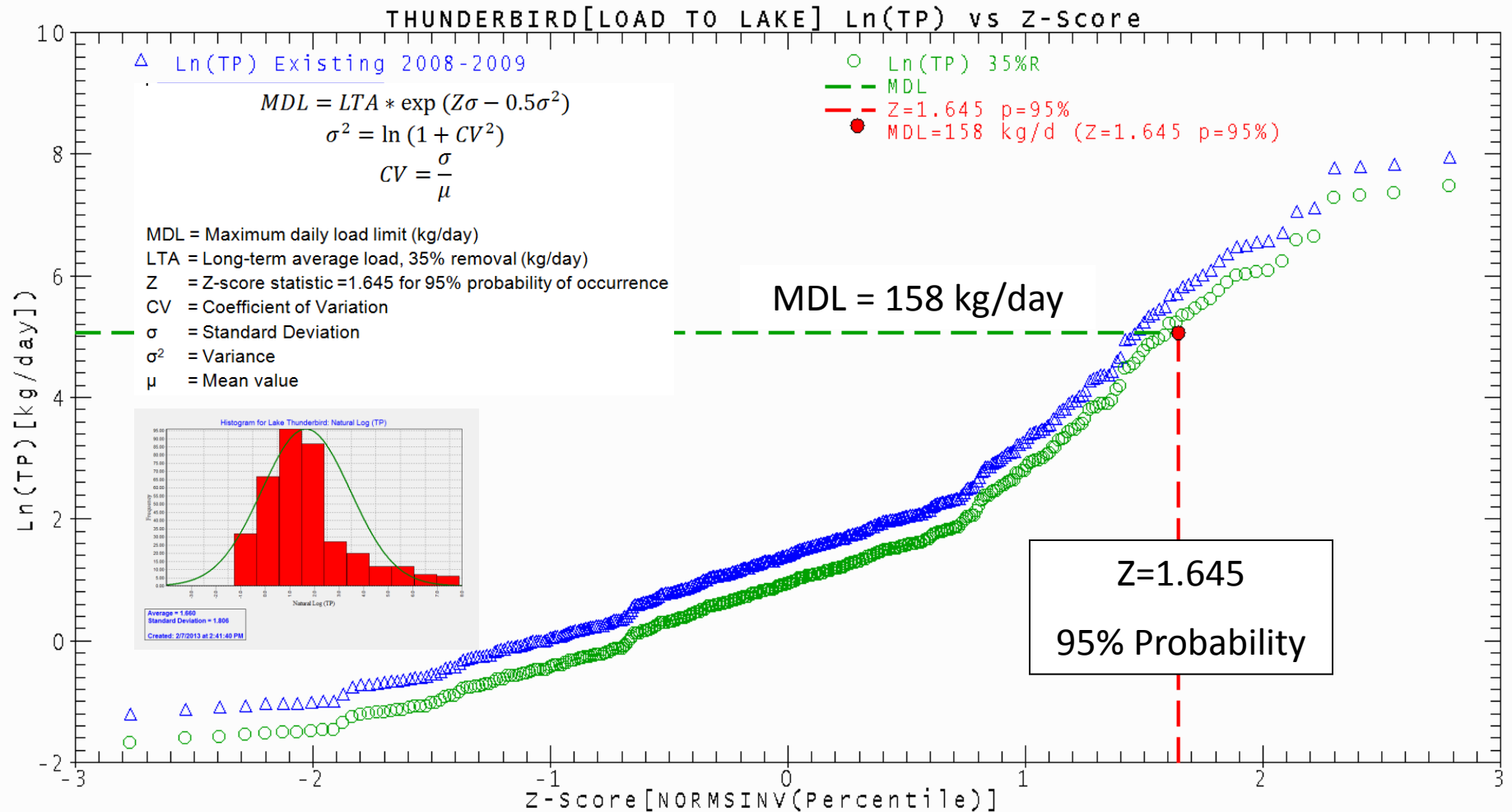$$CV = \frac{\sigma}{\mu}$$

MDL = Maximum daily load limit (kg/day)
LTA = Long-term average load, 35% removal (kg/day)
Z = Z-score statistic =1.645 for 95% probability of occurrence
CV = Coefficient of Variation
σ = Standard Deviation
σ^2 = Variance
μ = Mean value

— — MDL
— — Z=1.645 p=95%
● MDL=158 kg/d (Z=1.645 p=95%)

MDL = 158 kg/day

Z=1.645

95% Probability

Histogram for Lake Thunderbird: Natural Log (TP)

Average = 1.660
Standard Deviation = 1.806
Created: 2/7/2013 at 2:41:40 PM

Ln(TP) [kg/day]

Z-Score[NORMSINV(Percentile)]

Share of Existing Pollutant Load

Source (%)	Total-N	Total-P	BOD	Sediment
MS4-Moore	25%	28%	31%	21%
MS4-Norman	40%	38%	39%	41%
MS4-OKC	32%	31%	28%	35%
NPS-Unincorp.	2.6%	2.8%	2.3%	2.7%

How WLA's & LA Were Derived

LA
2.8%

Moore
28%

OKC
31%
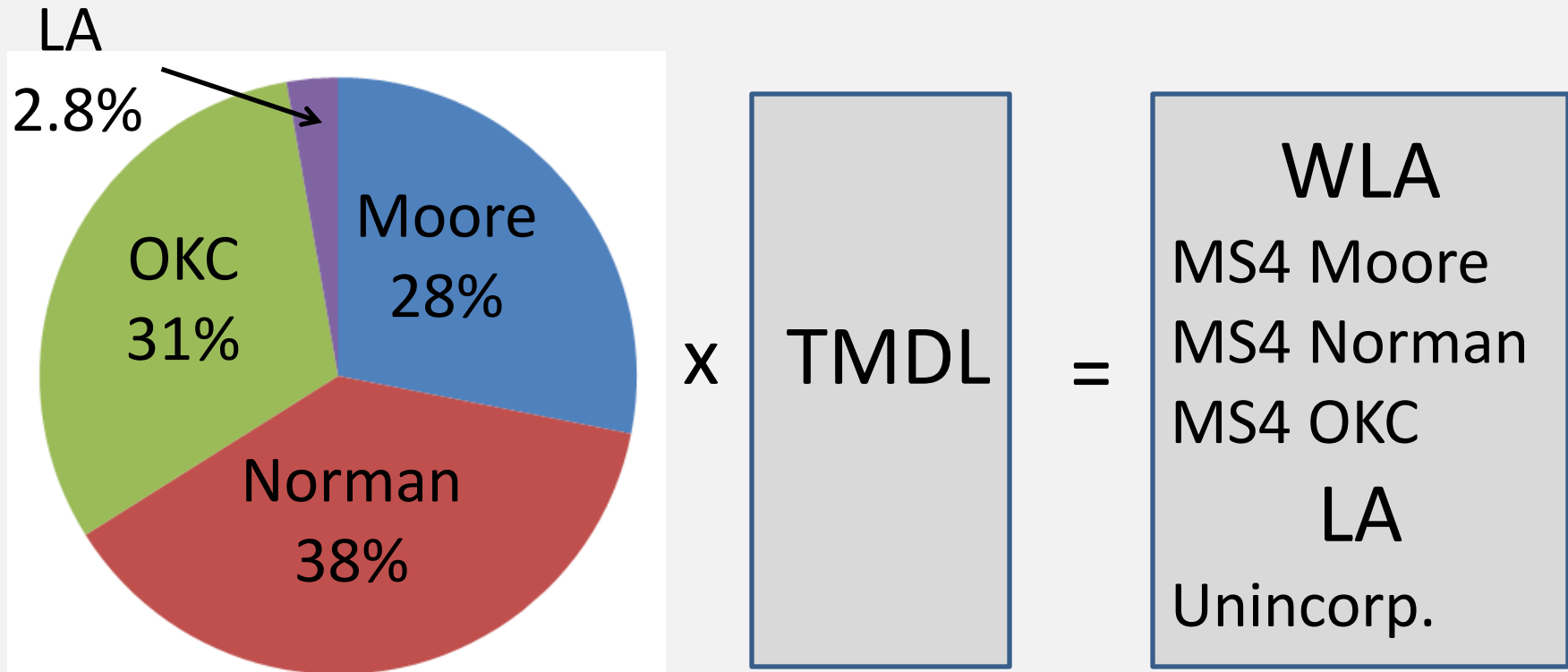
Norman
38%

Share of Existing TP Load

x | TMDL | =

WLA
MS4 Moore
MS4 Norman
MS4 OKC

LA
Unincorp.

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TMDL(kg/day)= LA+ WLA + MOS

WQ	TMDL	LA	WLA	WLA	WLA	MOS
			Moore	Norman	OKC	
Total-N	808	21	205	319	262	Implicit
Total-P	158	4	45	60	49	Implicit
BOD	2,481	57	781	956	687	Implicit
TSS	76,951	2,069	16,236	31,596	27,050	Implicit

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Summary

- Watershed-lake model provided good agreement with observed data

- Literature used to confirm sediment flux model

- 35% removal attains compliance with WQ targets for Turbidity, Chlorophyll & Oxygen

- Calibrated watershed-lake model provided Oklahoma DEQ with technically defensible tool

- 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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