Hydrology, water quality, and response in the Winnebago Pool Lakes to changes in phosphorus loading

Dale Robertson

USGS

DNR Data collection & Mark Sesing

WISCONSIN DEPT. OF NATURAL RESOURCES

SWAT Watershed Modeling

CADMUS

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All Analyses are in Draft Form

Dale Robertson

Research Hydrologist (Biogeochemistry)

Contact Info

Short Biography

Dale Robertson is a Research Hydrologist with the U.S. Geological Survey, Wisconsin Water Science Center in Middleton, Wisconsin. He is an Adjunct Professor at the University of Wisconsin-Green Bay, Michigan Technological University, and University of Toledo, and a Honorary Fellow with the Center for Limnology at the University of Wisconsin-Madison. His current research with the USGS deals with modeling eutrophication and mixing in lakes, estimating loads and concentrations of nutrients and sediment in streams over large geographic areas, such as the Great Lakes and Mississippi River Basins, developing nutrient criteria for streams and rivers, and examining the effects of climate change on the physical dynamics, ice cover, and productivity of lakes.

Education

- **B.S.** in Biology, Chemistry, and Mathematics - St. Norbert College, DePere, Wisconsin, 1976-1981.
- **M.S.** in Oceanography and Limnology - University of Wisconsin-Madison, Wisconsin. Thesis: "Interbasin Separation and Its Impact on the Annual Heat Budgets of the Individual Basins in Trout Lake, Wisconsin," 1981-1984.
- **Ph.D.** in Oceanography and Limnology - University of Wisconsin-Madison, Wisconsin. Dissertation: "The Use of Lake Water Temperature and Ice Cover as Climatic Indicators", 1984-1989.
- **Post-Doctoral Research Fellow**, in Reservoir Modeling - Centre for Water Research, University of Western Australia, Perth. 1989-1991.

Publications

Robertson, D.M., Saad, D.A., Schwarz, G.E., 2014, Spatial Variability in Nutrient Transport by HUC8, State, and Subbasin Based on Mississippi/Atchafalaya River Basin SPARROW Models: Journal of the American Water Resources Association. DOI: 10.1111/jawr.12153. [Link]

LaBeau, M.B., Robertson, D.M., Mayer, A.S., Pijanowski, B.C., and Saad, D.A., 2014, Effects of future urban and biofuel crop expansions on the riverine export of phosphorus to the Laurentian Great Lakes: Ecological Modelling v. 277, p. 27–37, DOI: 10.1016/j.ecolmodel_2014.01.016 [Link]

Baldwin, Austin K.;Robertson, Dale M.;Saad, David A.;Magruder, Christopher, 2013. Refinement of regression models to estimate real-time concentrations of contaminants in the Menomonee River drainage basin, southeast Wisconsin, 2008--11. U.S. Geological Survey Scientific Investigations Report 2013-5224, viii, 113 p.; seven appendixes [Link]

Juckem, Paul F.;Robertson, Dale M., 2013. Hydrology and water quality of Shell Lake, Washburn County, Wisconsin, with special emphasis on the effects of diversion and changes in water level on the water quality of a shallow terminal lake. U.S. Geological Survey Scientific Investigations Report 2013-5181, Report: x, 77 p.; Appendix 1: PDF file; Appendix 2: PDF file [Link]

Powers, S.M., Robertson, D.M., and Stanley, E.H., 2013, Effects of lakes and reservoirs on annual river nitrogen, phosphorus, and sediment export in agricultural and forested landscapes: Hydrological Processes, DOI: 10.1002/hyp.10083. [Link]

Robertson, D.M. and Saad, D.A., 2013, SPARROW models used to understand nutrient sources in the Mississippi/Atchafalaya River Basin: Journal of Environmental Quality. v. 42, no. 5, p. 1422-1440, DOI: 10.2134/jeq2013.02.0066. [Link]

Areas of Expertise

Biogeochemistry - Hydrology/Limnology

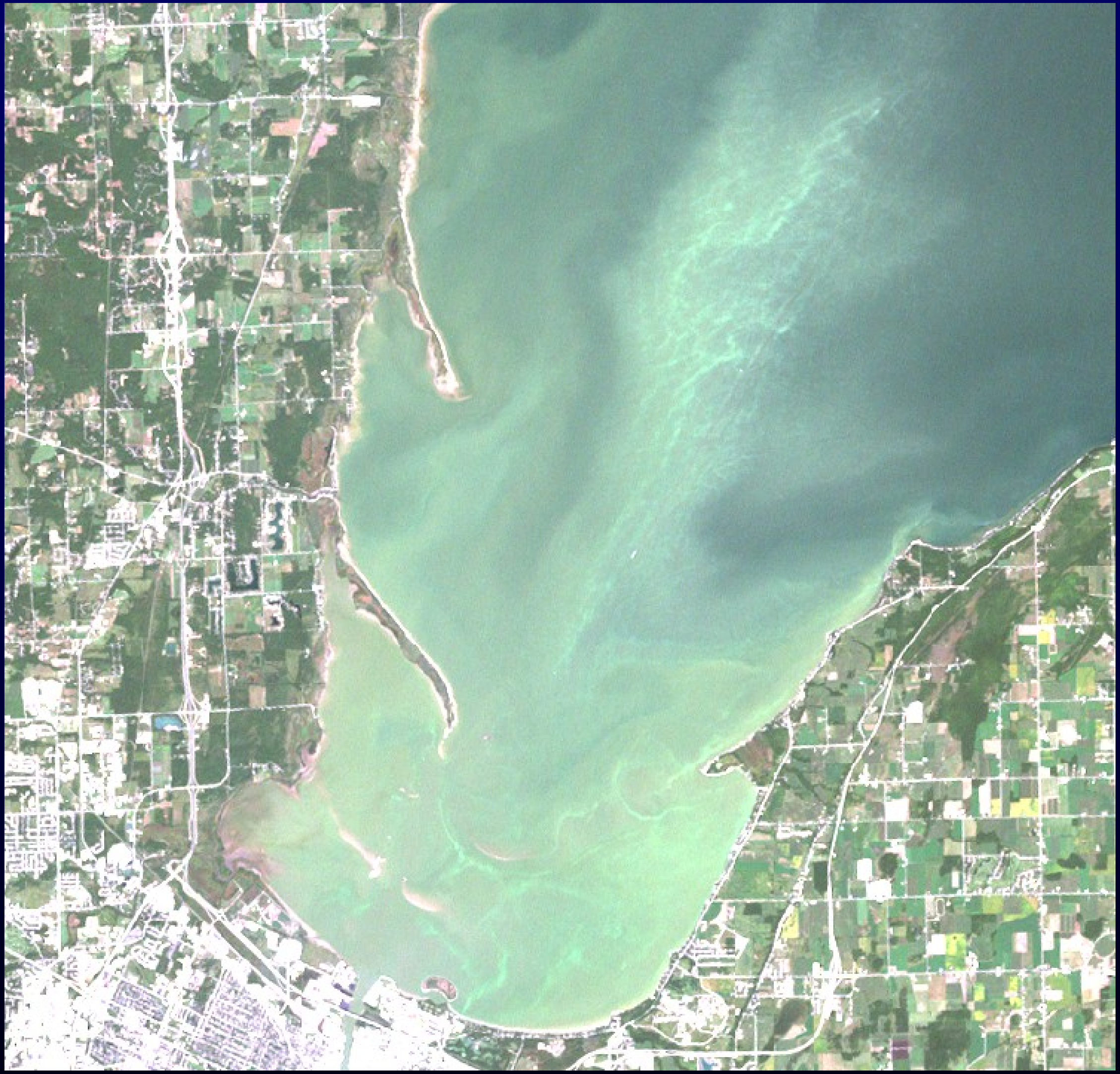
- Eutrophication - Nutrient Transport and Fate
- Limnology
- Water-quality modeling in Lakes
- Watershed modeling (SPARROW)
- Influence of environmental factors, watershed management strategies, and in-lake management alternatives on the water quality of rivers and lakes
- Climate Change - Ice as climatic indicators
- Regional loading estimates

Projects

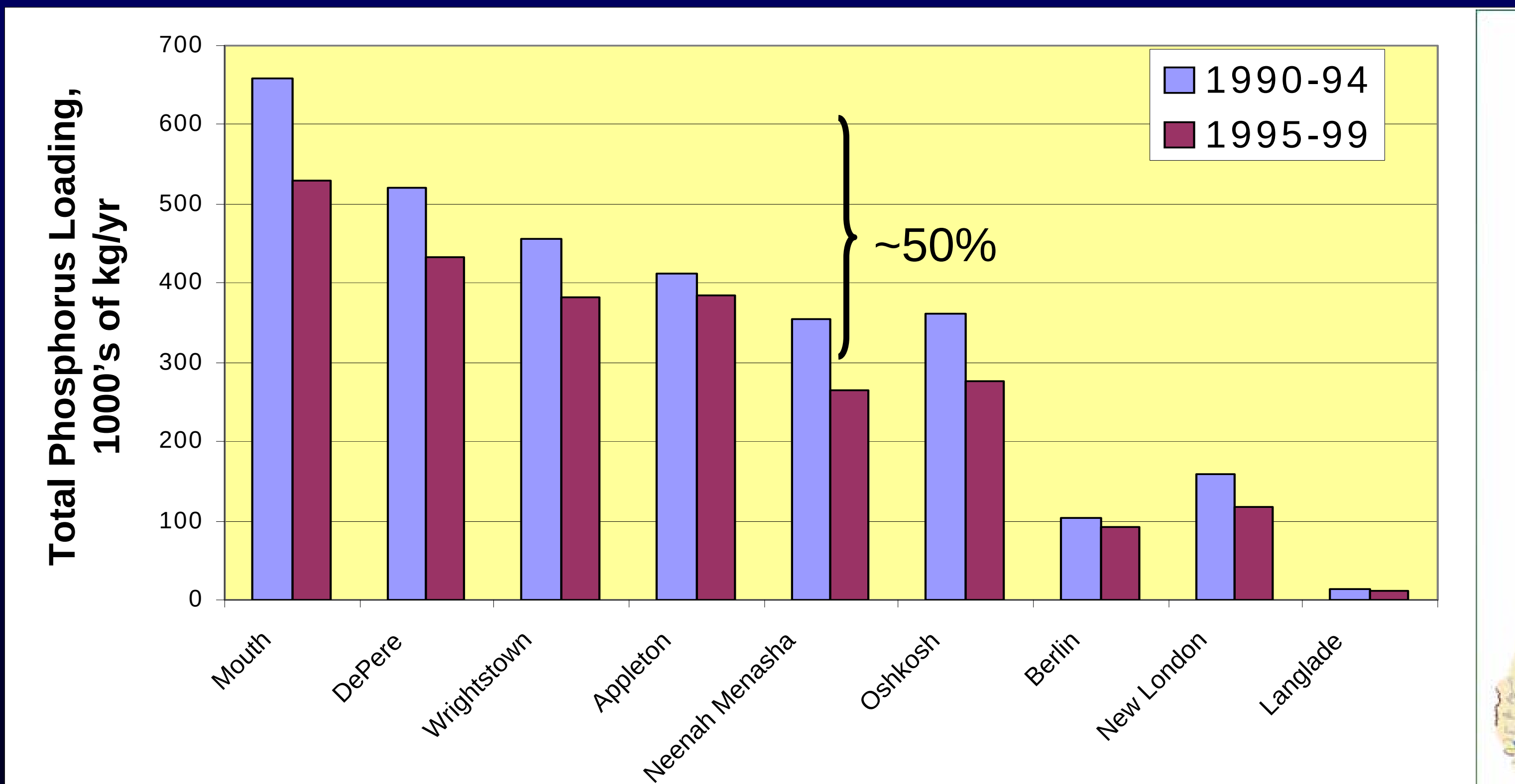
Current Projects

- SPARROW Modeling - SPARROW Watershed Modeling in the Central US and Canada
- Winnebago Pool Lakes (Upper Fox TMDL) - Assessment of the Water Quality of the Winnebago Pool Lakes, Wis, and Their

Nutrient Loading from the Fox River has been shown to drive Algal blooms and anoxia in Green Bay

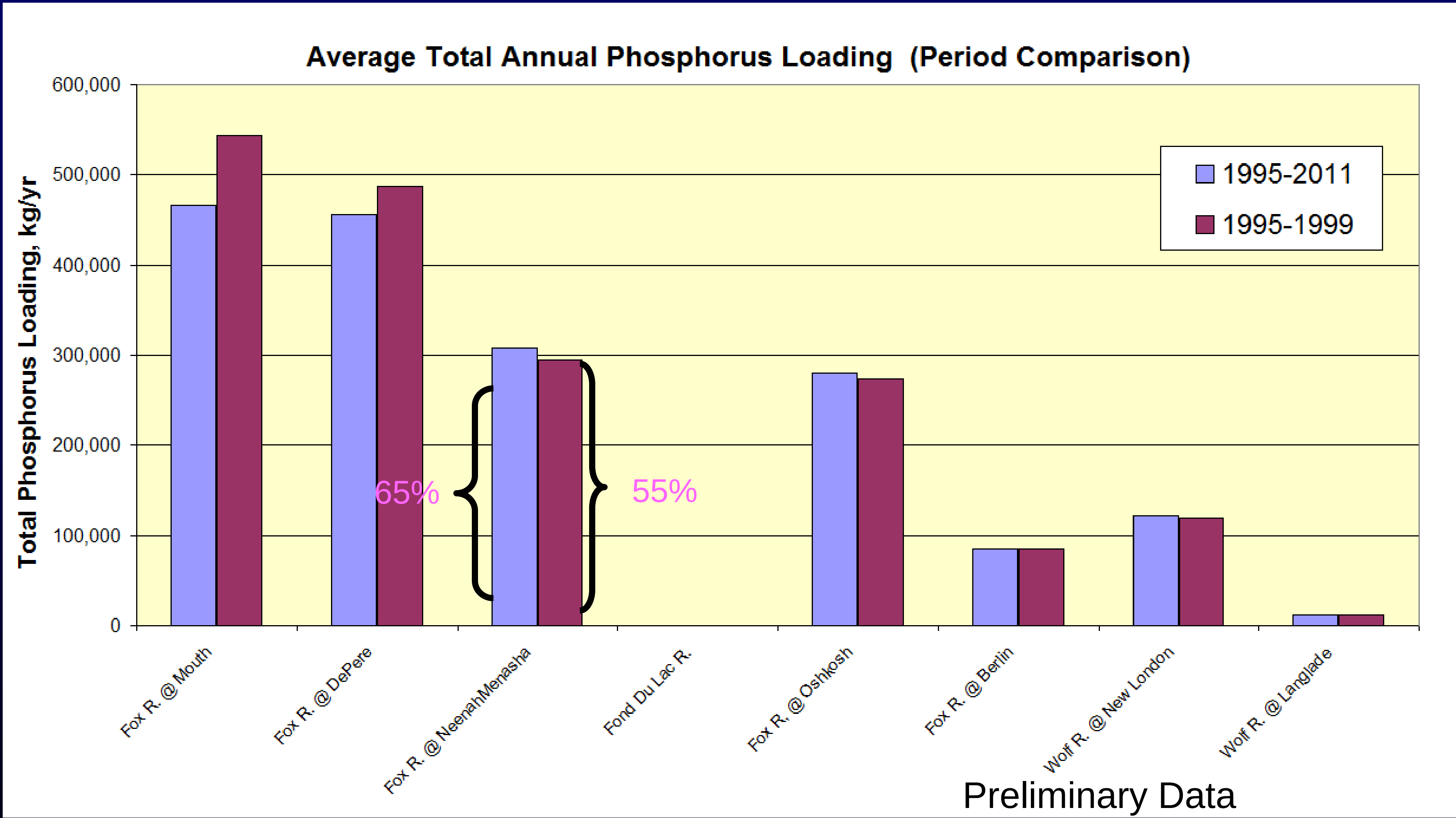


Previous work by the USGS has shown ~50% of the load comes from Lake Winnebago



Outlet of
Lake
Winnebago

Updated data indicate that Winnebago contributes closer to 60%



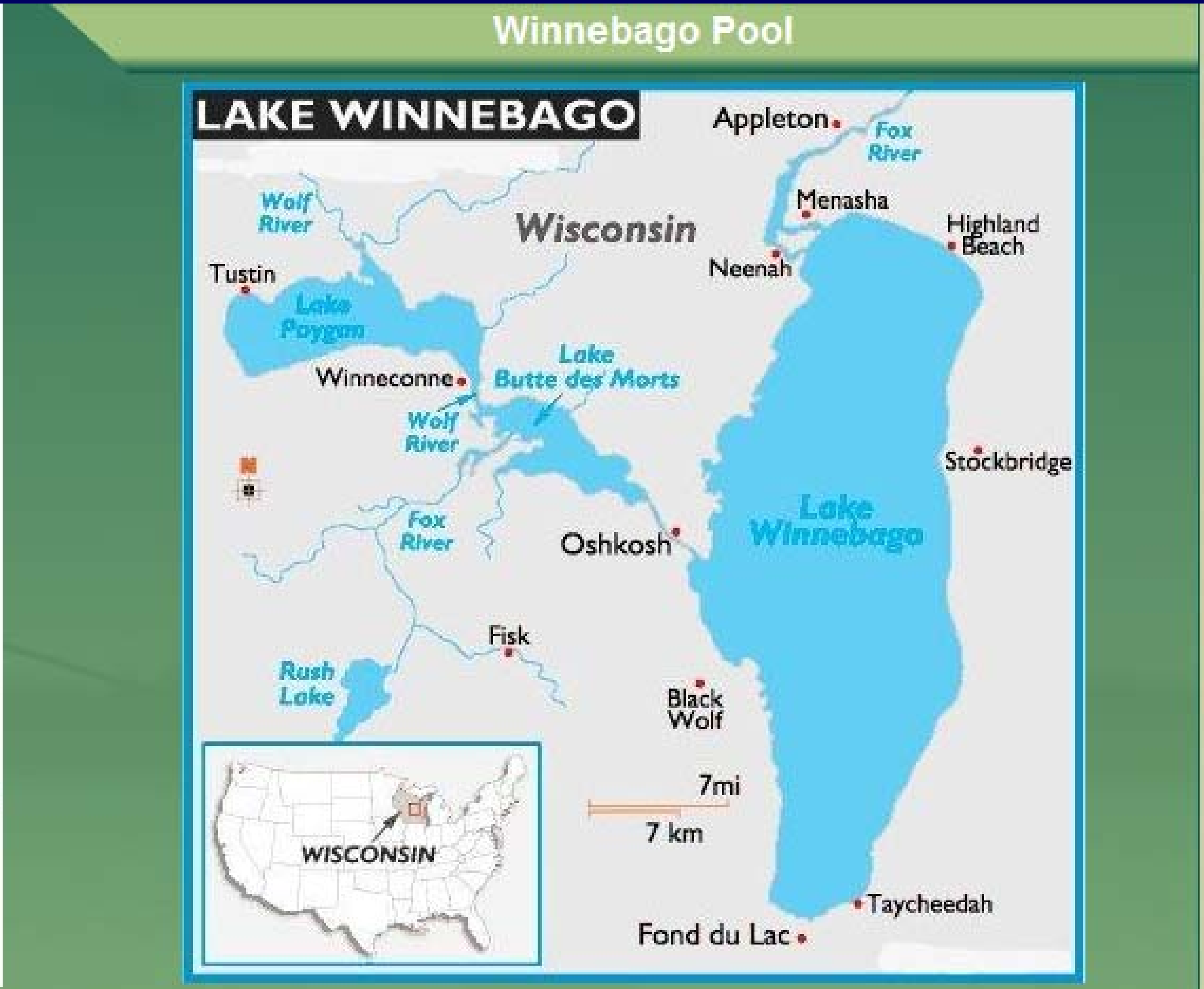
Outlet of Lake Winnebago

All Analyses are in Draft Form

Algal Blooms in Lake Winnebago – 2010 example

All 4 Lakes are on the Wisconsin DNR’s Impaired Waters List

Assessment of the hydrology, water quality, and response to simulated changes in phosphorus loading of the Winnebago Pool Lakes, Wisconsin



Specific Goals of Winnebago Pool Study

1. Determine how water quality of each of the pool lakes responds to changes in phosphorus input, and what types of load reductions are needed to delist the Pool Lakes.
2. Evaluate the current (primarily 2009-11) water quality of the four Winnebago Pool lakes.
3. Determine if there are long-term trends in water quality.
4. Quantify the current water and phosphorus budgets for the lakes (including internal phosphorus loading).

Specific Goals of Winnebago Pool Study

1. Evaluate the current (primarily 2009-11) water quality of the four Winnebago Pool lakes.
2. Determine if there are long-term trends in water quality.

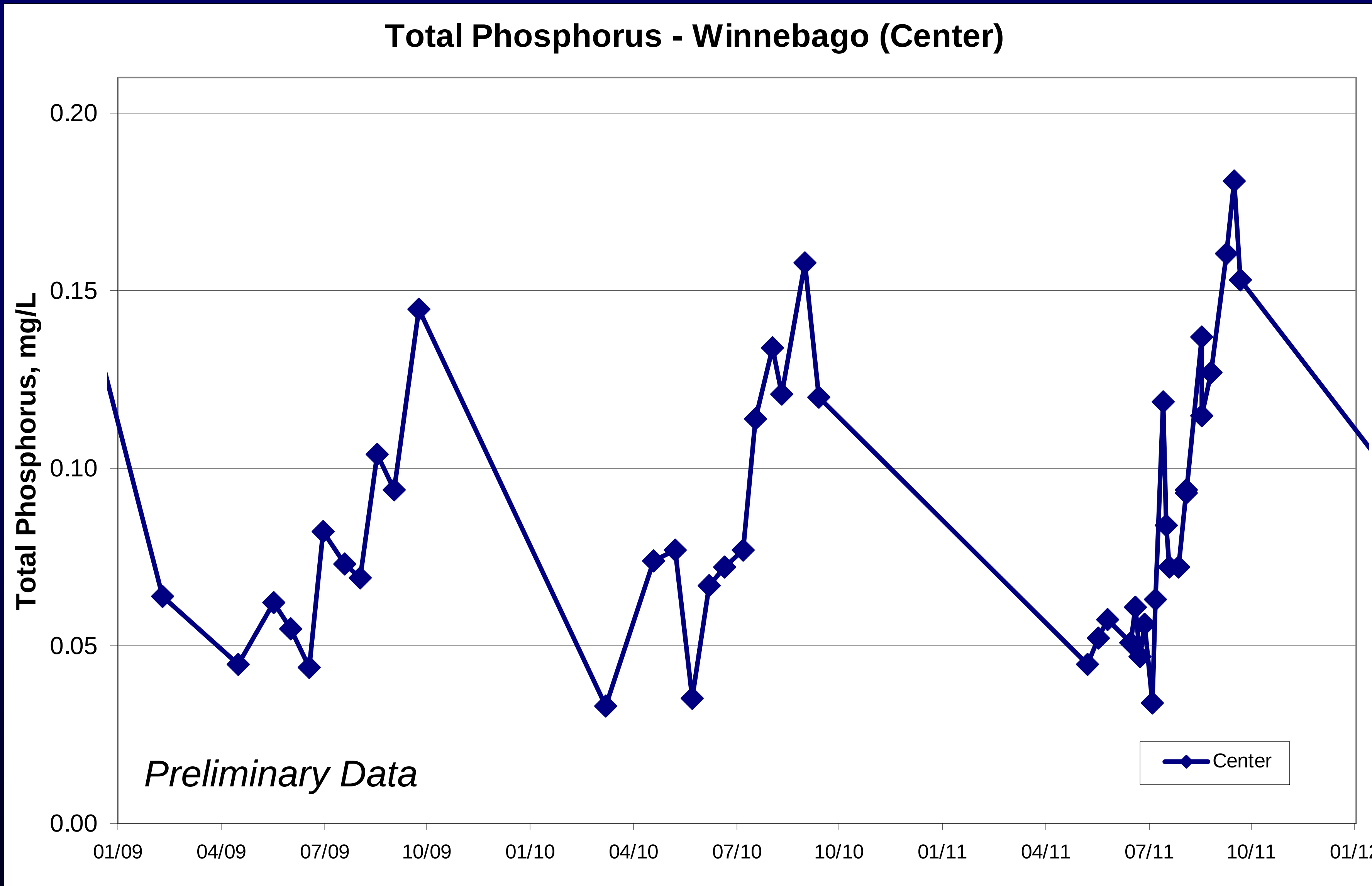
Lake Sampling – By Wisconsin DNR

★ Sampling Locations Over past several years

Sampling Biweekly April-Sept

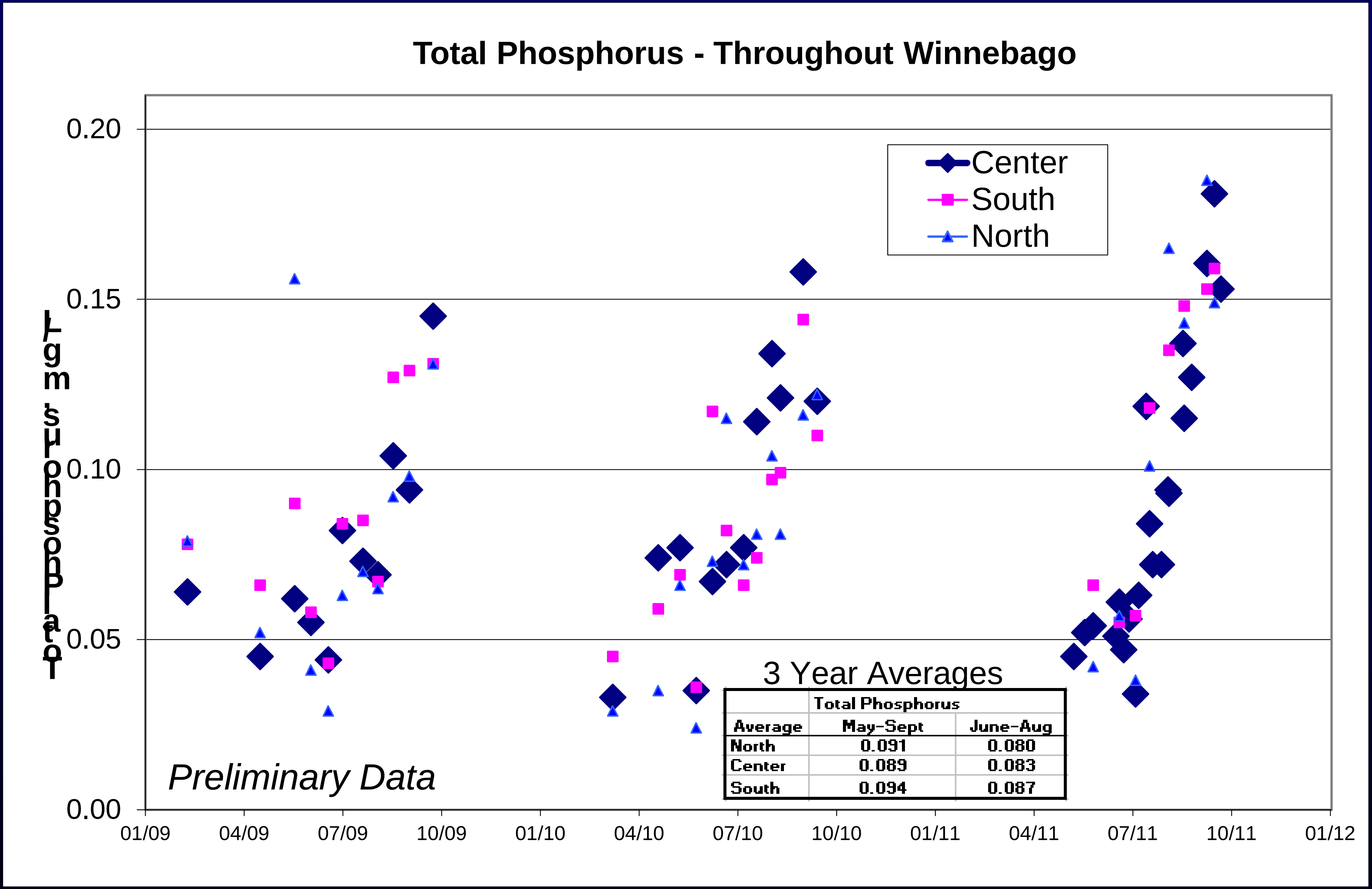
For:
Temp/DO Profiles
Secchi
TP
N Series
Chl

Data Collection: Primarily WDNR



Winnebago acts like a typical shallow lake, with concentrations increasing throughout summer

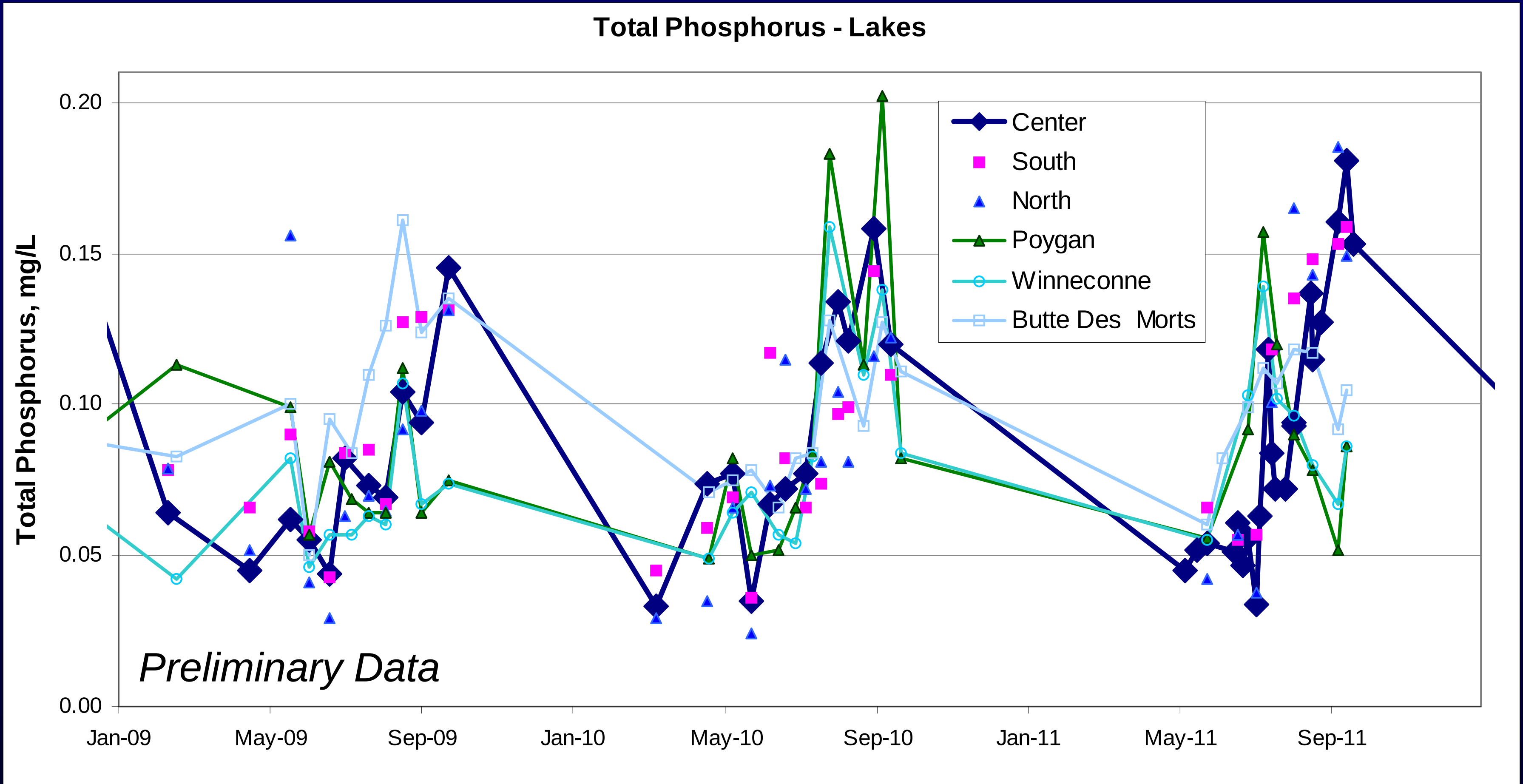
All Analyses are in Draft Form



	Total Phosphorus	
Average	May-Sept	June-Aug
North	0.091	0.080
Center	0.089	0.083
South	0.094	0.087

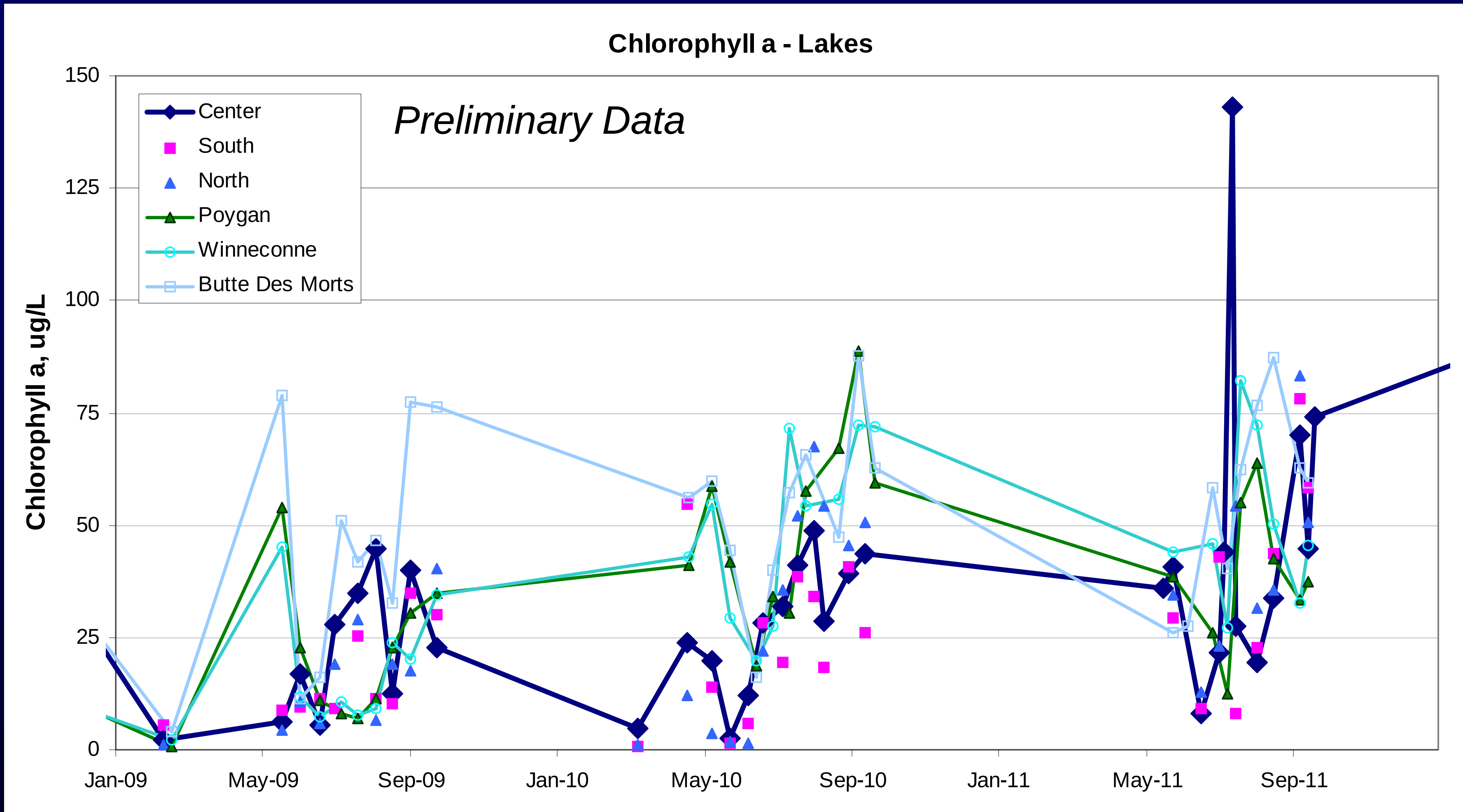
> On Average pretty similar throughout the lake.

All Analyses are in Draft Form



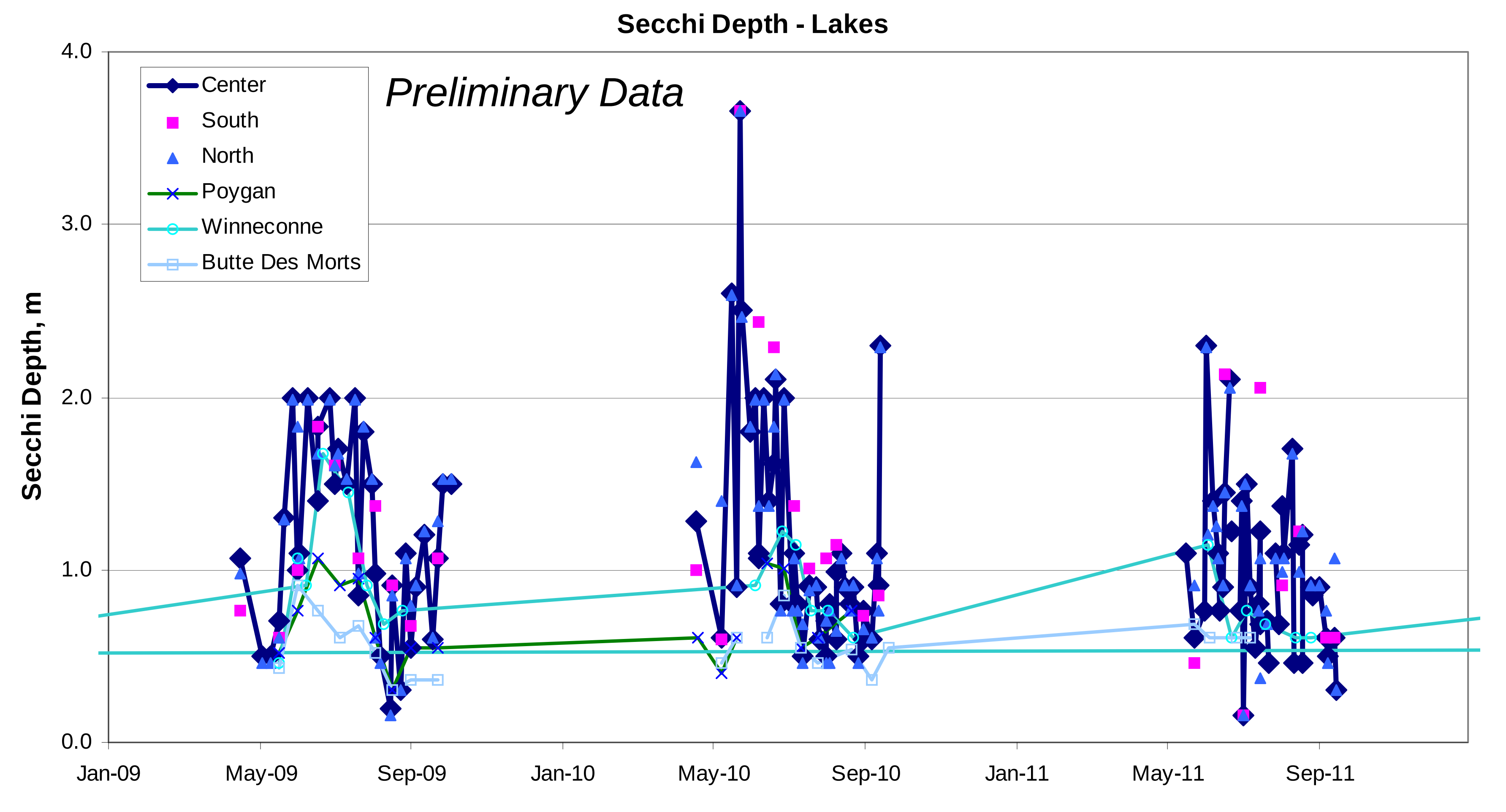
> On Average pretty similar throughout all four lakes.

All Analyses are in Draft Form



> Winnebago has less algae than the other three lakes.

All Analyses are in Draft Form



> On Average water clarity is better in Winnebago than the other 3 lakes.

All Analyses are in Draft Form

Overall Averages For 2009-11

	June-Aug	May-Sept		June-Aug	May-Sept
Total Phosphorus, mg/L			**TSI - Total Phosphorus**		
North	0.080	0.091	North	66.1	67.4
Center	0.083	0.089	Center	67.0	67.6
South	0.087	0.094	South	67.7	68.6
Lake Average	0.083	0.091	Lake Average	66.9	67.9
Outlet Average	0.102	0.093	Outlet Average	69.4	67.6
Secchi, meters			**TSI - Secchi**		
North	1.18	1.17	North	59.5	59.8
Center	1.14	1.12	Center	59.9	60.5
South	1.43	1.22	South	56.7	59.8
Lake Average	1.25	1.17	Lake Average	58.7	60.0
Chlorophyll a, ug/L			**TSI - Chlorophyll a**		
North	27.4	28.8	North	60.0	59.5
Center	28.9	30.2	Center	61.2	61.2
South	19.9	23.9	South	58.0	58.9
Lake Average	25.4	27.6	Lake Average	59.7	59.9
Outlet Average	24.6	22.4	Outlet Average	54.9	55.3
Total Nitrogen, ug/L			**TSI - Total Nitrogen**		
North	1.145	1.222	North	56.1	57.0
Center	1.181	1.226	Center	56.6	57.2
South	1.075	1.171	South	55.2	56.5
Lake Average	1.134	1.206	Lake Average	56.0	56.9
Outlet Average	1.276	1.208	Outlet Average	57.6	56.7
Dissolved Phosphorus, ug/L					
North	0.017	0.020			
Center	0.020	0.024			
South	0.034	0.031			
Lake Average	0.024	0.025			
Outlet Average	0.044	0.037			

Preliminary Data

Overall Averages For 2009-11

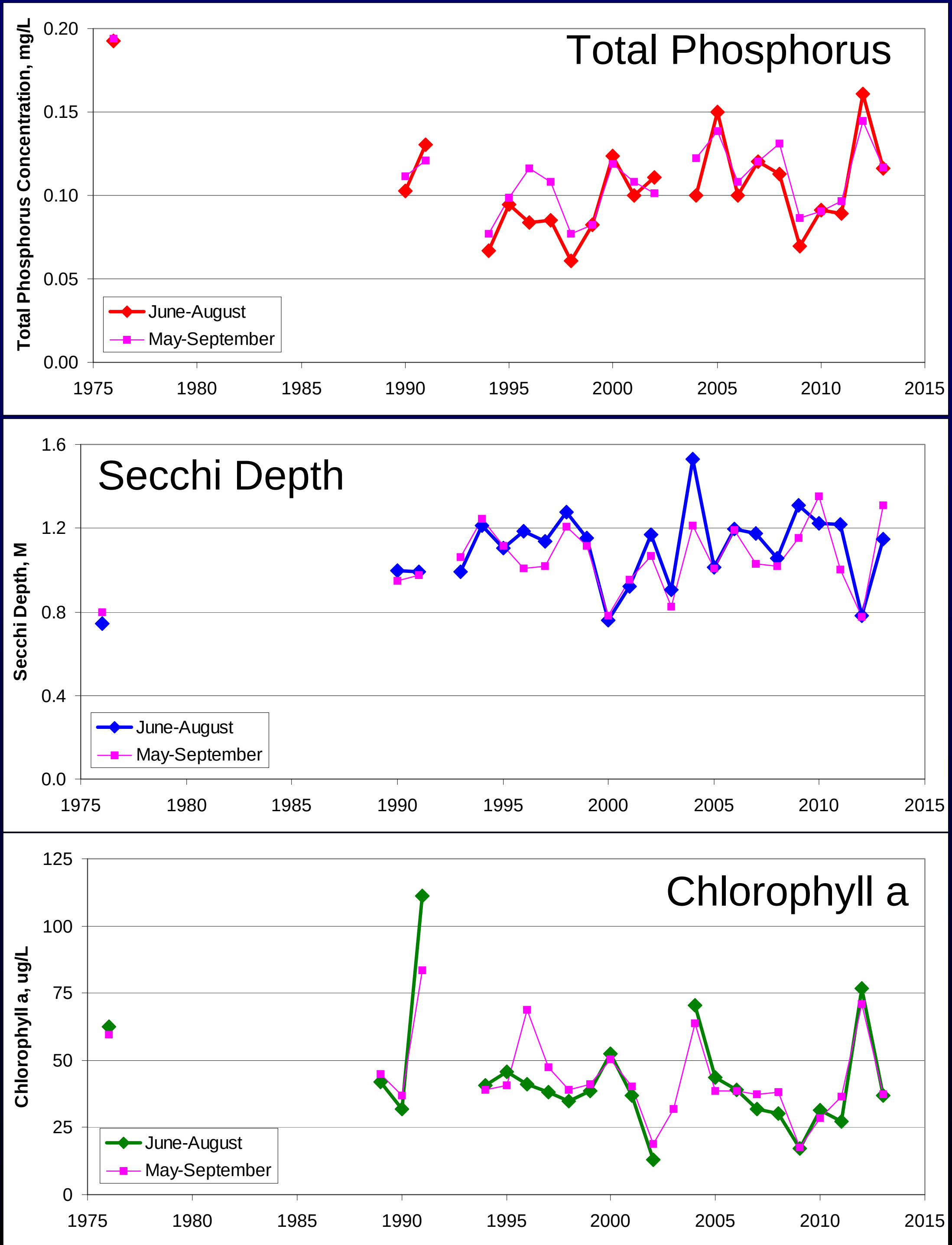
Total Phosphorus, mg/L	June-Aug	May-Sept	TSI - Total Phosphorus	June-Aug	May-Sept
Poygan	0.094	0.090	Poygan	68.8	68.0
Winneconne	0.088	0.084	Winneconne	67.9	67.3
Butte des Morts	0.100	0.099	Butte des Morts	70.1	70.0
Winn. Fox Inlet	0.103	0.095	Winn. Fox Inlet	70.6	69.2
Winnebago	0.083	0.091	Winnebago	66.9	67.9
Outlet	0.102	0.093	Outlet	69.4	67.6
Secchi, meters			**TSI - Secchi**		
Poygan	0.72	0.65	Poygan	65.3	66.9
Winneconne	0.73	0.65	Winneconne	65.2	66.9
Butte des Morts	0.57	0.54	Butte des Morts	68.7	69.5
Winnebago	1.25	1.17	Winnebago	58.7	60.0
Chlorophyll a, ug/L			**TSI - Chlorophyll a**		
Poygan	32.4	38.5	Poygan	62.4	64.6
Winneconne	37.7	40.6	Winneconne	63.5	65.1
Butte des Morts	45.8	52.2	Butte des Morts	66.9	68.3
Winn. Fox Inlet	35.6	43.0	Winn. Fox Inlet	62.8	65.4
Winnebago	25.4	27.6	Winnebago	59.7	59.9
Outlet	24.6	22.4	Outlet	54.9	55.3
Total Nitrogen, ug/L			**TSI - Total Nitrogen**		
Poygan	1.520	1.498	Poygan	60.3	60.1
Winneconne	1.419	1.416	Winneconne	59.3	59.2
Butte des Morts	1.656	1.612	Butte des Morts	61.6	61.2
Winn. Fox Inlet	1.723	1.621	Winn. Fox Inlet	62.0	61.2
Winnebago	1.134	1.206	Winnebago	56.6	57.2
Outlet	1.276	1.208	Outlet	57.6	56.7
Dissolved Phosphorus, ug/L					
Poygan	0.013	0.009			
Winneconne	0.007	0.005			
Butte des Morts	0.004	0.004			
Winn. Fox Inlet	0.007	0.003			
Winnebago	0.024	0.025			
Outlet	0.044	0.037			

Preliminary Data

Lake Winnebago:

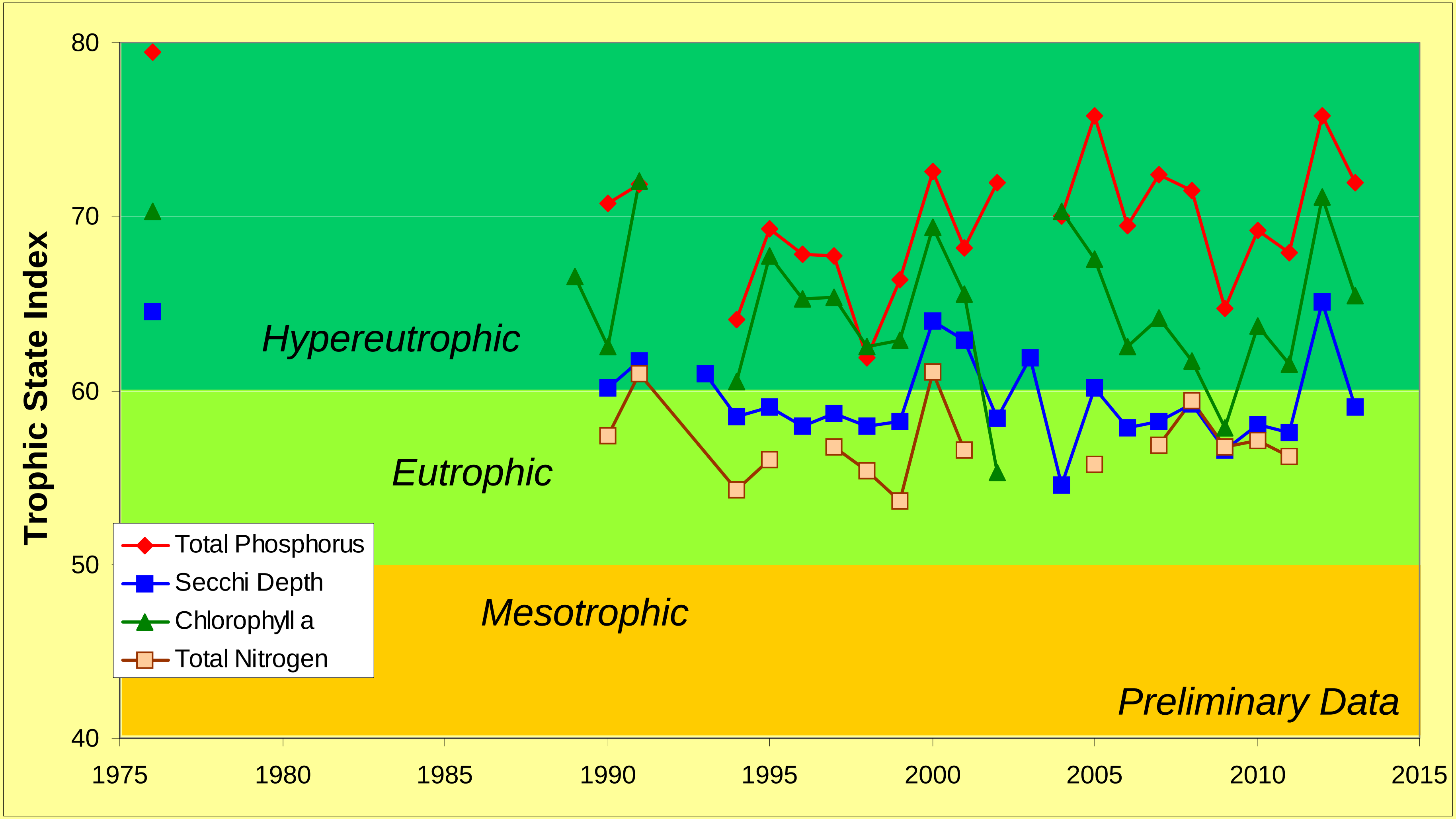
Interannual Variability and Long-term Changes

Average of 3 parts of Lake



Preliminary Data

Long-Term Trends in the Water Quality of Lake Winnebago
Lakewide Average



* Based on June-August Water Quality

Specific Goals of Winnebago Pool Study

1. Evaluate the current (primarily 2009-11) water quality of the four Winnebago Pool lakes.
2. Determine if there are long-term trends in water quality.
3. Quantify the current water and phosphorus budgets for the lakes (including internal phosphorus loading).
4. Determine how water quality of each of the pool lakes respond to changes in phosphorus input, and what types of load reductions are needed to delist the Pool Lakes.

Most of the Phosphorus comes with water, so we first we need a good water budget:

Water Budget

Change in Storage = Inputs – Outputs

Ground water – *Feinstein Model*

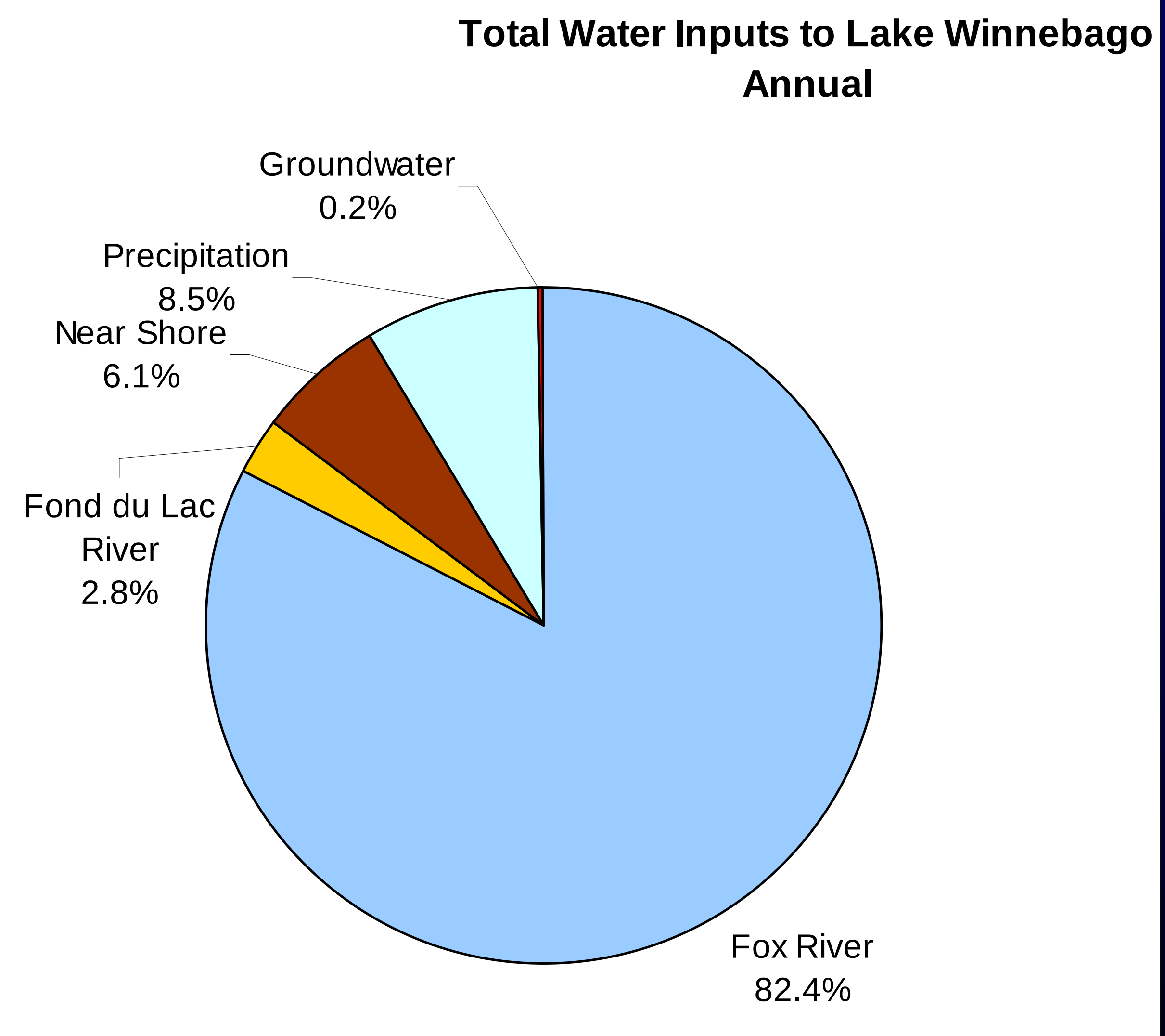
$$\Delta S = P + Q_I + G_N - E$$

Precipitation
Oshkosh Met Station

Surface water
Fox R + Fond du Lac R extrapolated

Evaporation
Farnsworth

Inputs of Water to Lake Winnebago



Preliminary Data

Phosphorus Budget

Point Sources –
DNR estimates

$$\text{Net P Input} = P + G_W + S + P_S + Q_I + I_{Internal} - Q_o$$

Δ Concentration

Precipitation
Conc. From nearby lake study

Ground Water
Conc. From nearby lake study

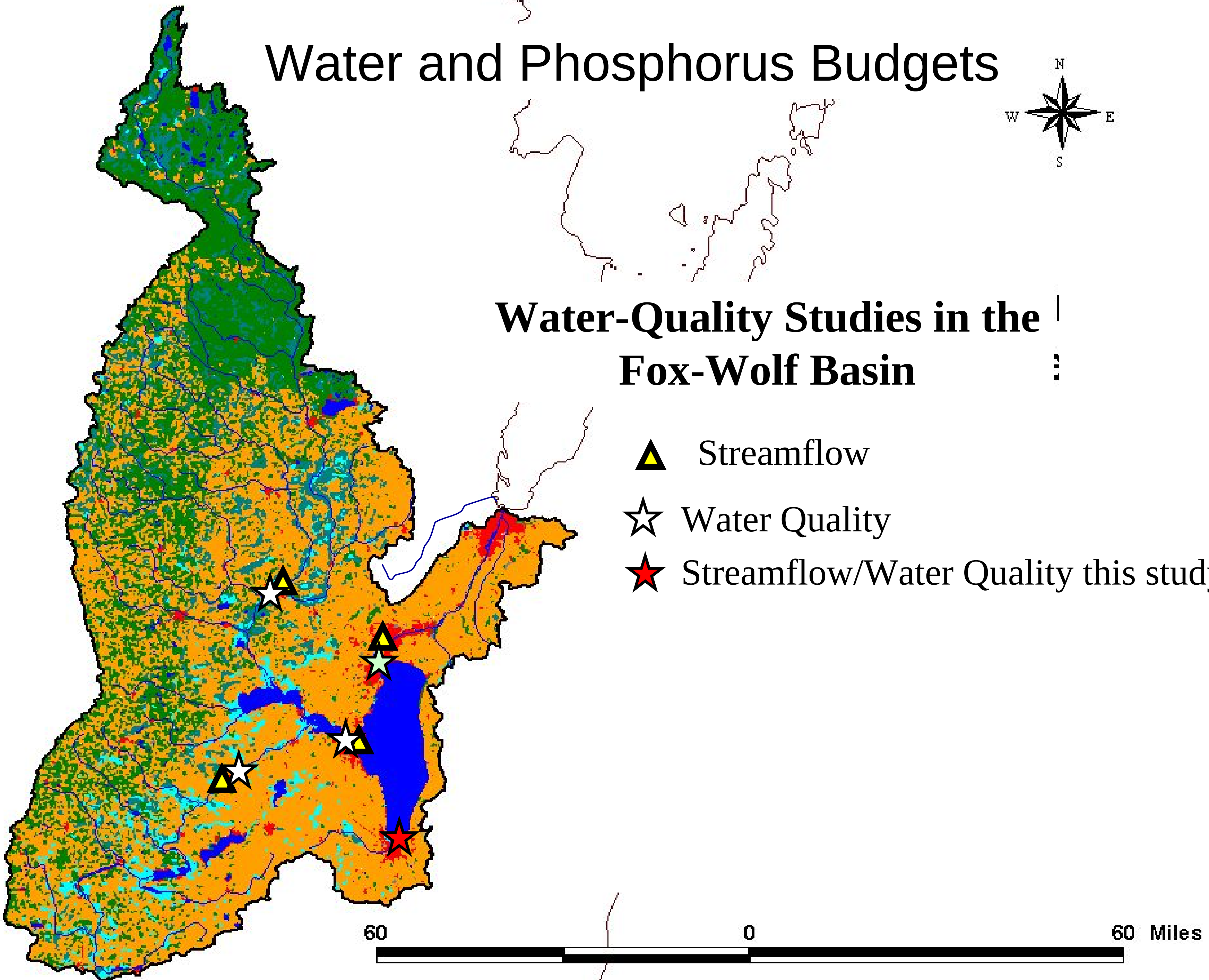
Septic Systems

Modeled here based on # nearshore residents

Inflow
Monitored and Modeled

Outflow
Monitored

Water and Phosphorus Budgets



Estimating Loads at the Monitoring Sites – Using a Regression Approach

Daily Concentration = f (flow, seasonality, time trend)

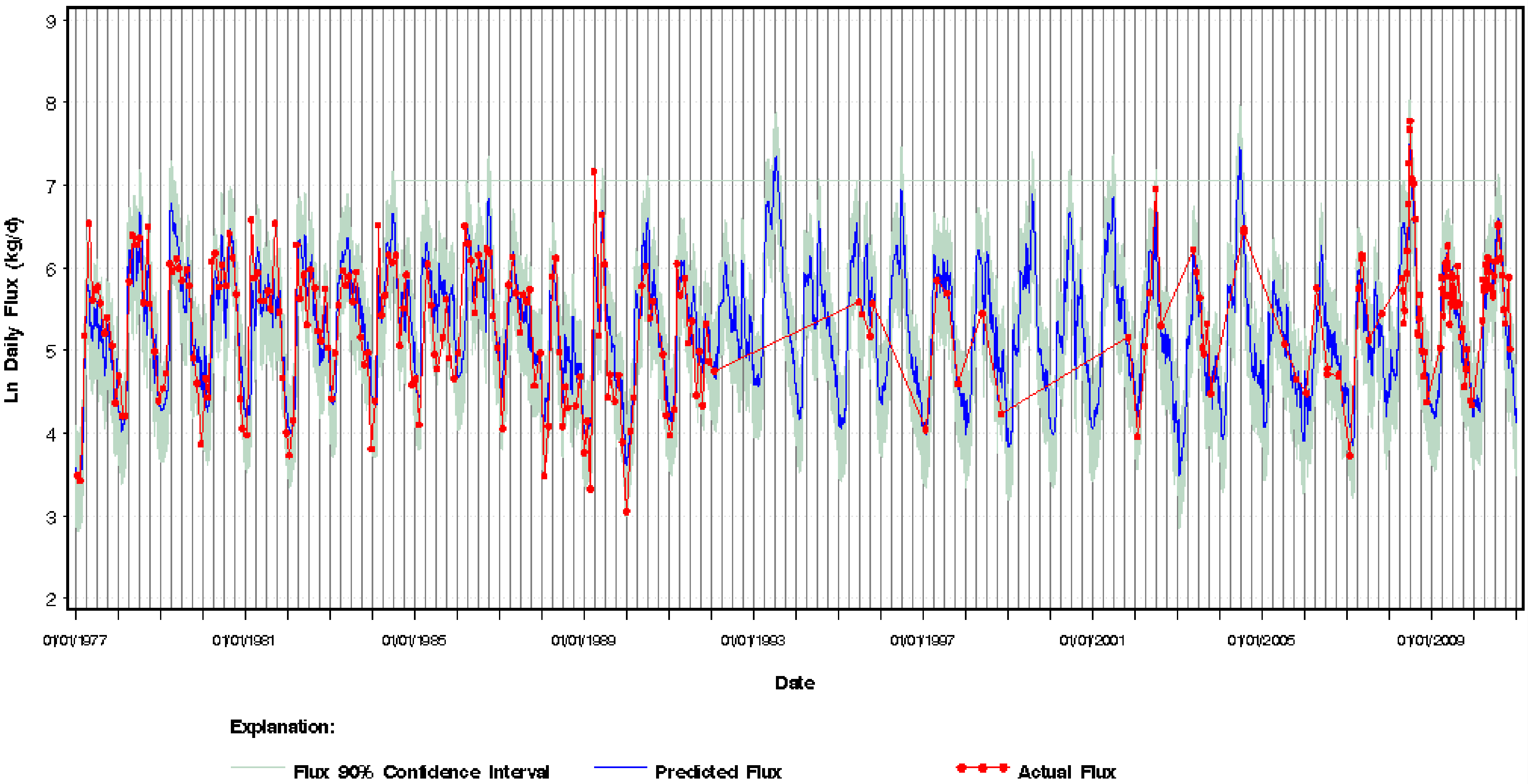
Form of the Fluxmaster Load Model

$$\ln(\text{Conc}) = a \ln(Q) + b \sin(\text{jday}/365) + c \cos(\text{jday}/365) + d\,(\text{decimal year}) + e$$

Actual and Predicted TP Flux

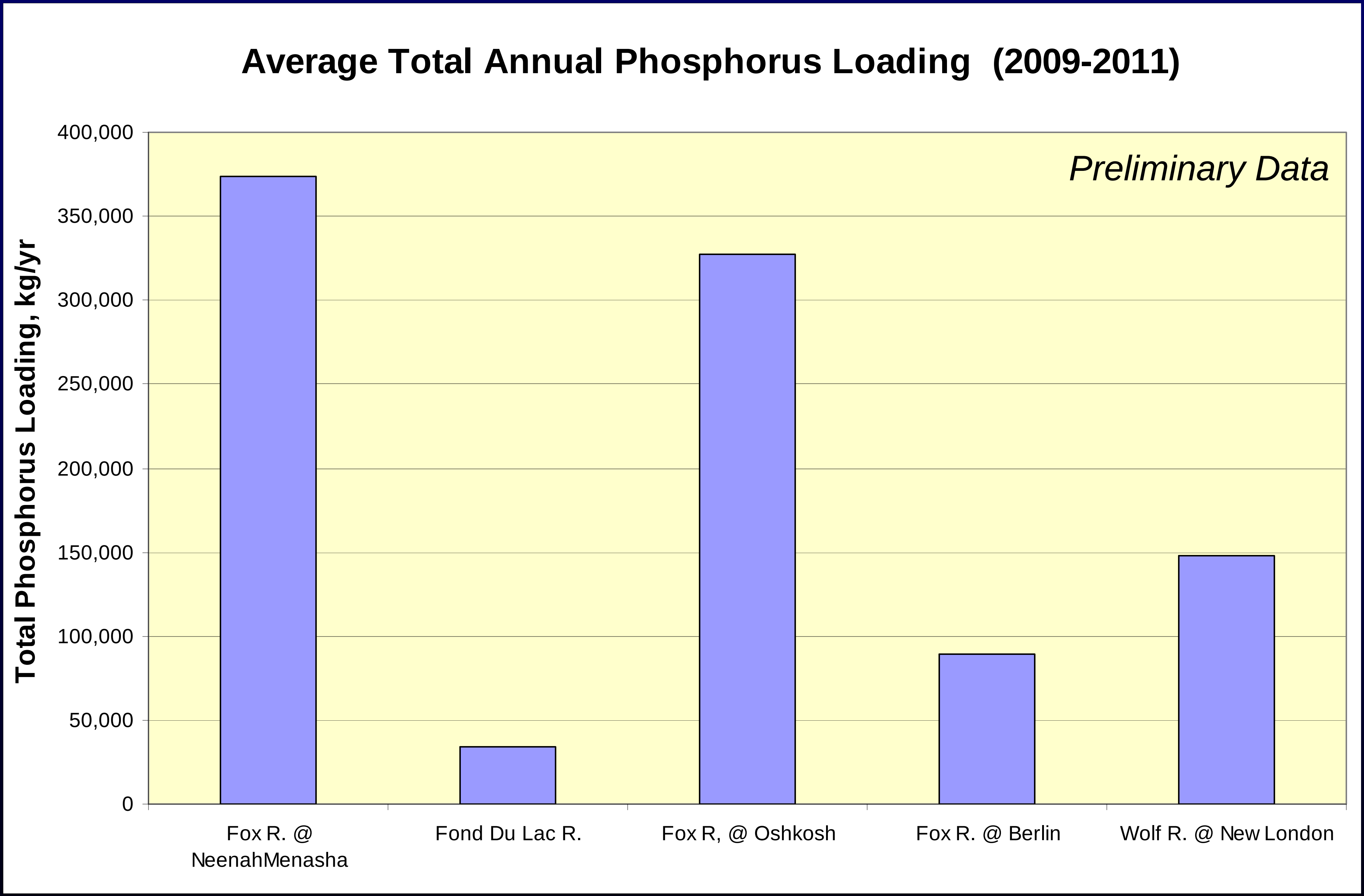
for the Fox R. at Berlin

(Parameter 00665 at Station 243020)



FLUX: period for avg.: 01/01/1977 – 12/31/2010 [34 prediction years], method: 2, SE avg. flux as pct: 2.40%, trend: −0.43% [not sig.], O/E: 0.99;
WQ: N: 286 [0 censored], RMSE: 0.348, reference concentration: 7.19E−02 mg/L; **FLOW:** trend: −0.18% [not sig.], variation[WQ sample/flow record]: 1.14

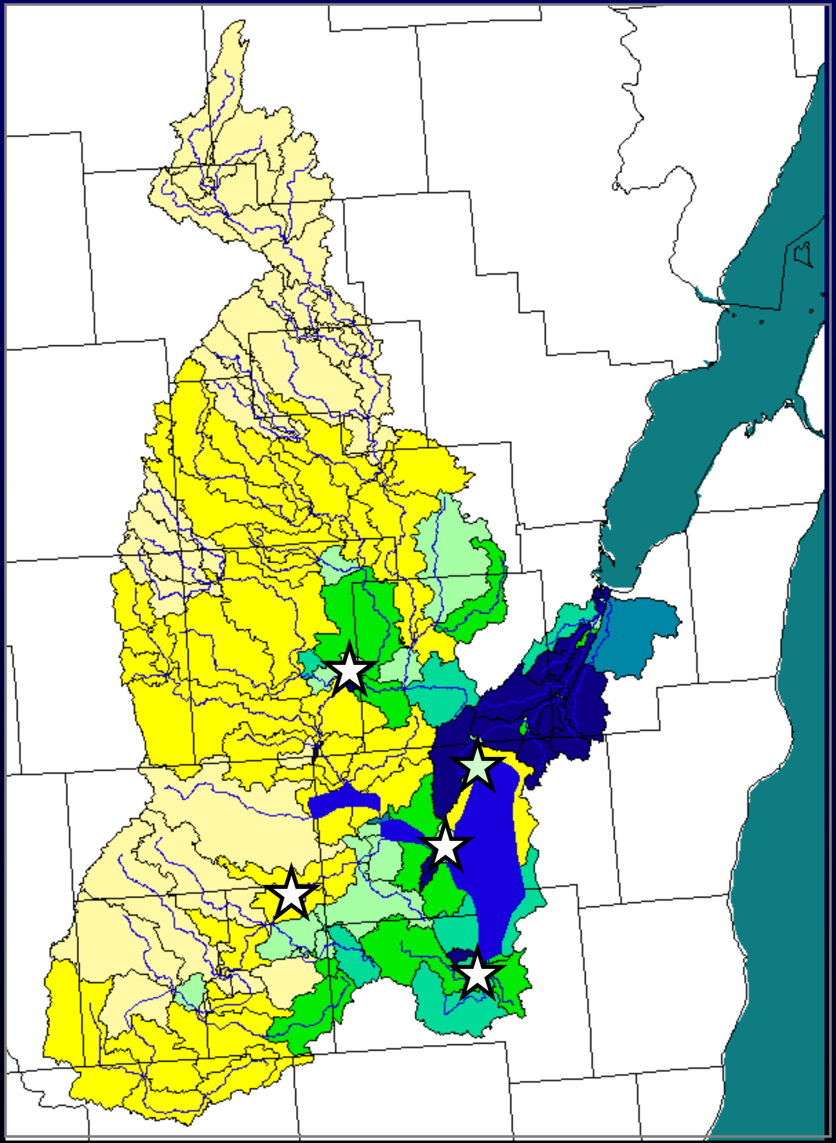
Predicted values are adjusted for retransformation bias, making them upward biased in log space.

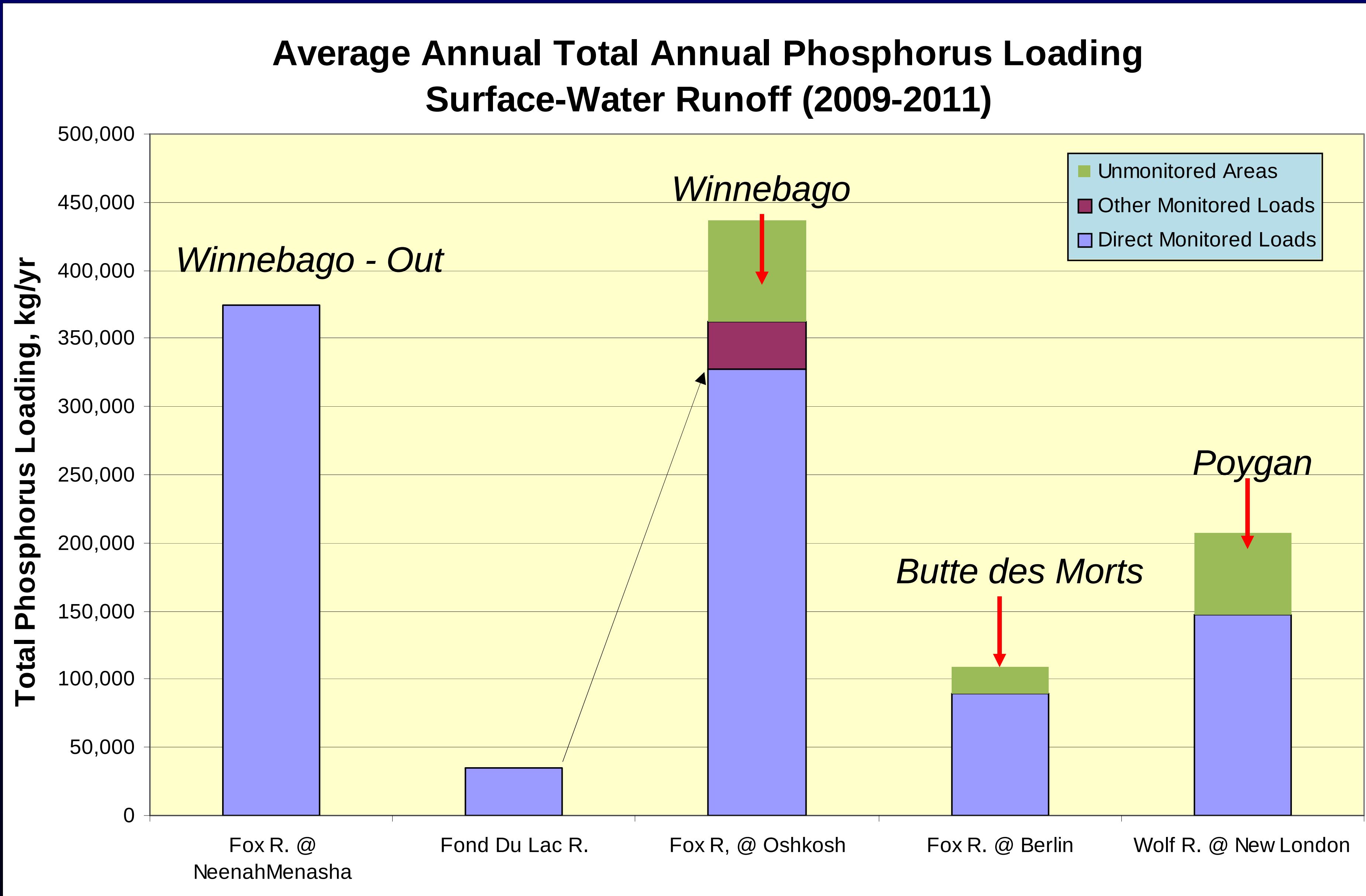


Average Total Annual Phosphorus Loading (2009-2011)
Preliminary Data
Total Phosphorus Loading, kg/yr
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Fox R. @ NeenahMenasha
Fond Du Lac R.
Fox R, @ Oshkosh
Fox R. @ Berlin
Wolf R. @ New London

Phosphorus Input from Ungaged Areas

SPARROW (USGS) Results





Preliminary Data

Internal Phosphorus Loading – By USGS

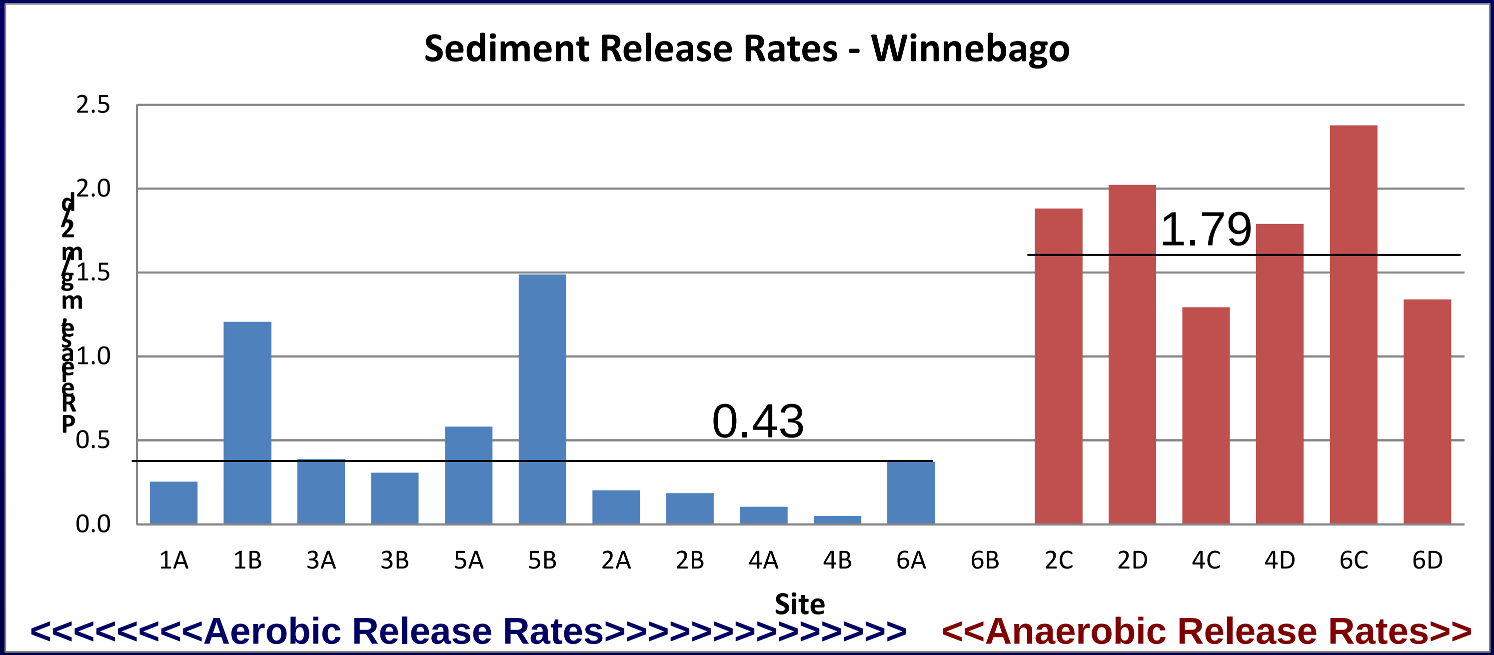
★ Core Locations

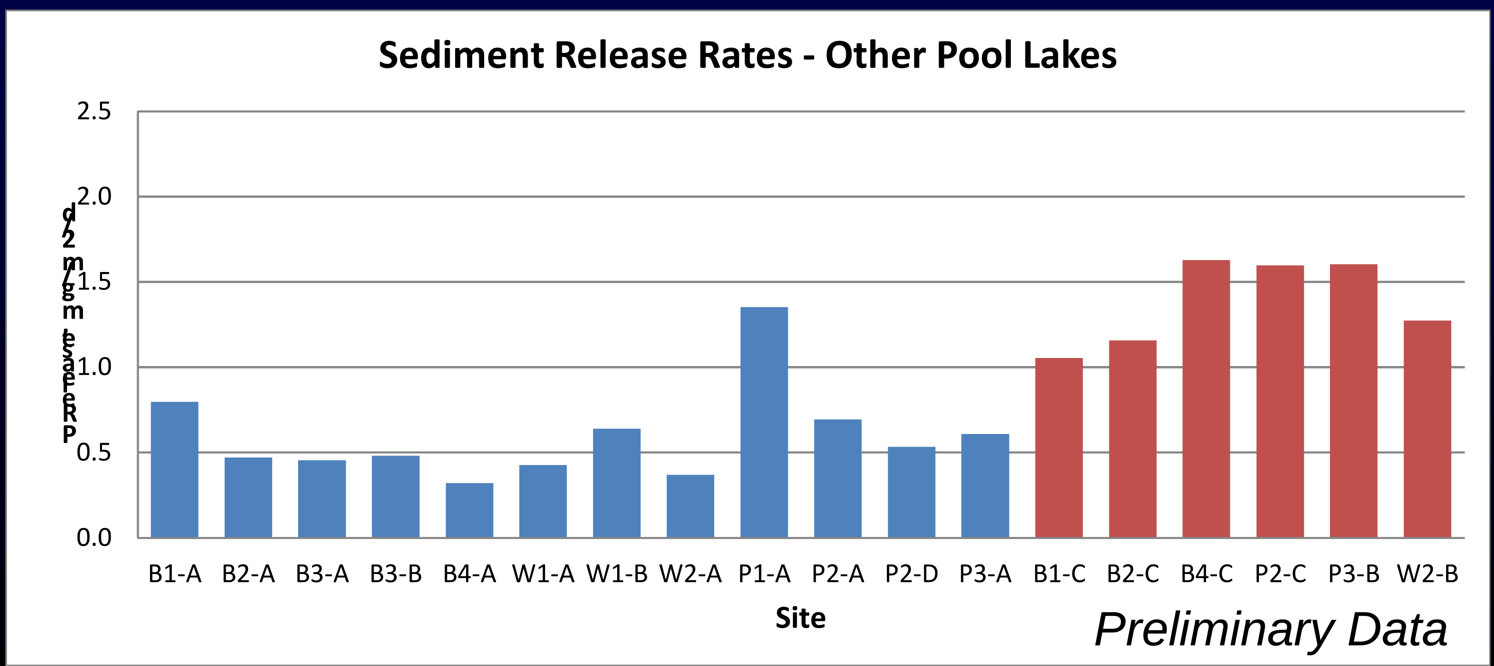
Sampling Sediment Cores

- Cores collected Aug. 2010
- P Release – aerobic and anaerobic Conducted by the SLOH

What is added from the Lake Sediments?

Internal Phosphorus Release



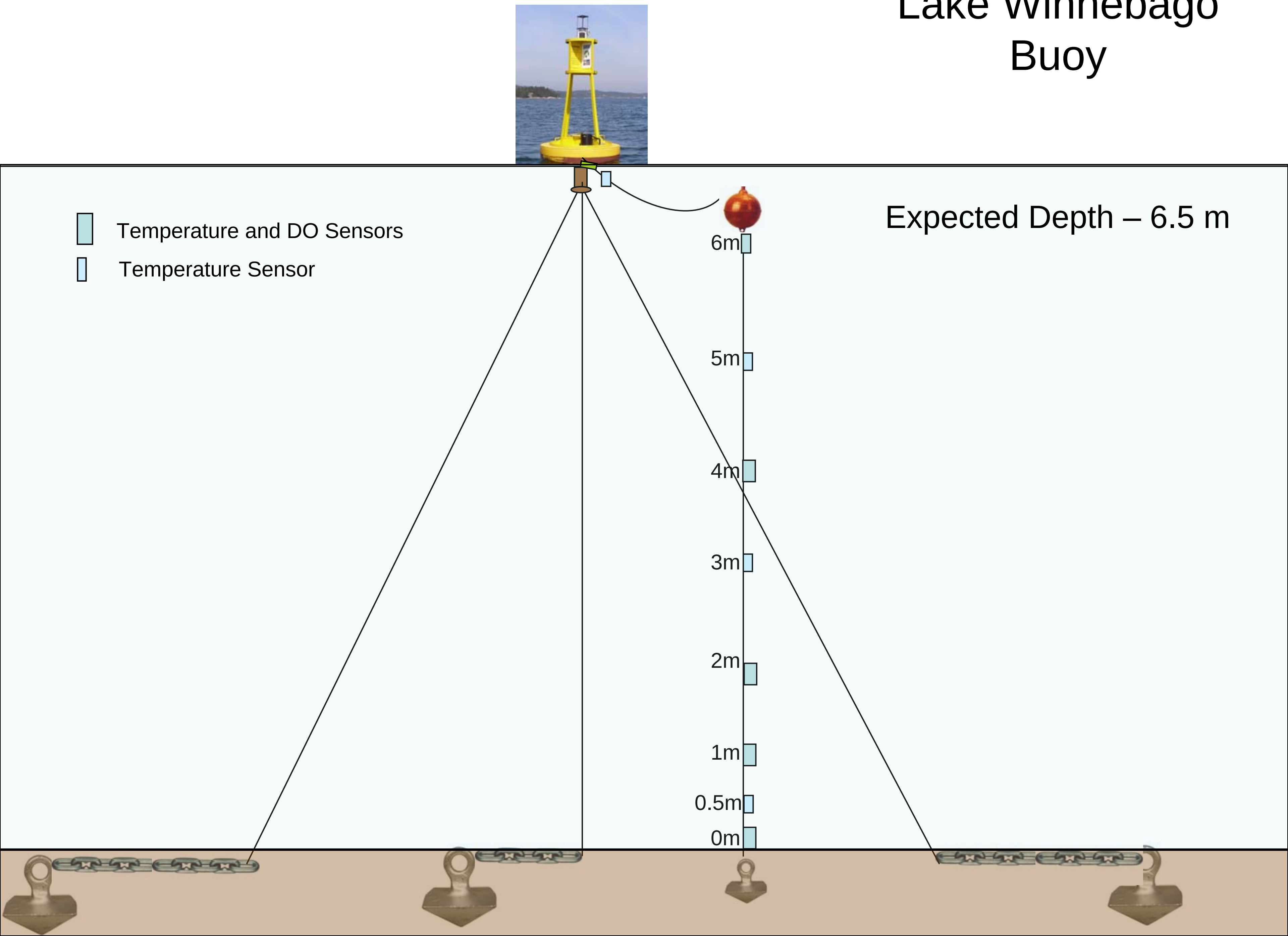


Lake Sampling – By USGS

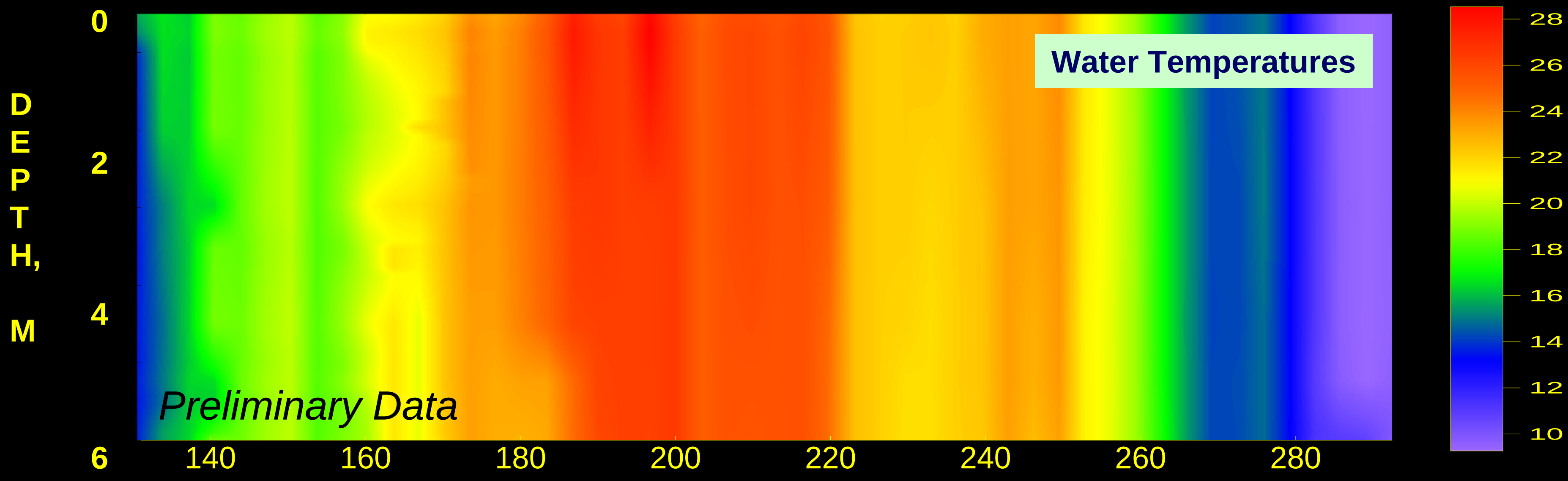
★ Core Locations

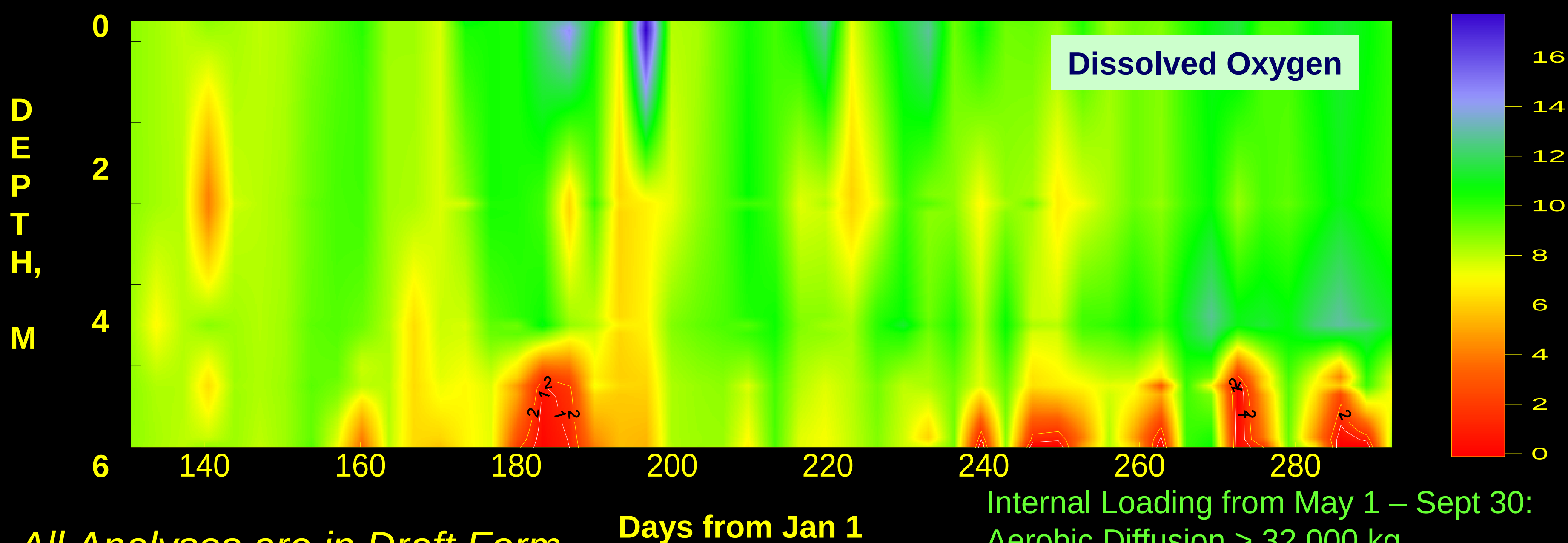
Buoy
- Weather Station
- Temp/DO
- Profiles

Lake Winnebago Buoy



Temperature and Dissolved oxygen in Lake Winnebago – May-Oct, 2012

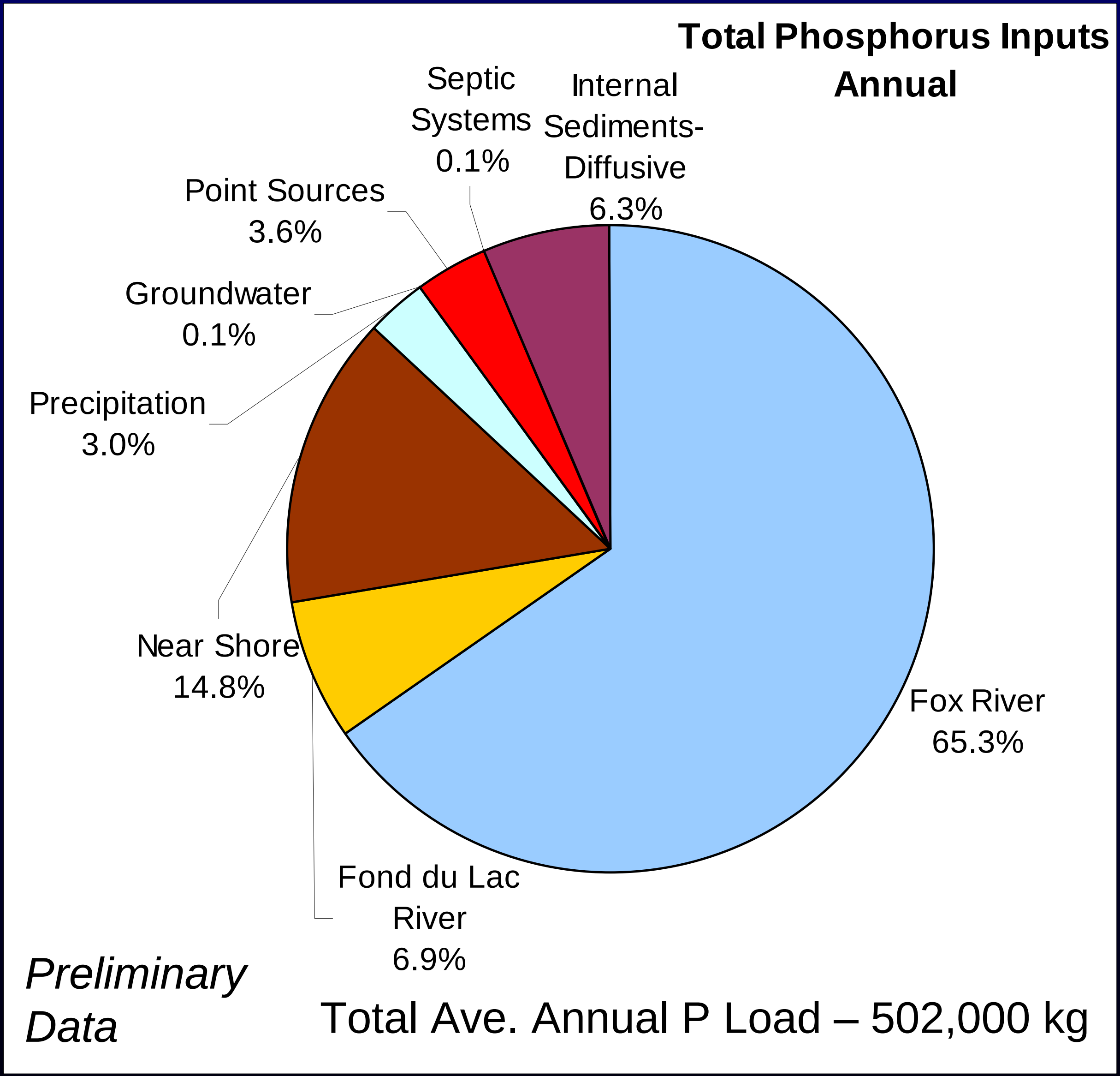




Internal Loading from May 1 – Sept 30:
Aerobic Diffusion > 32,000 kg

All Analyses are in Draft Form

Inputs of Phosphorus Into Lake Winnebago



** Internal Loading based on Aerobic Release Rates

Specific Goals of Winnebago Pool Study

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Wisconsin Lake Modeling Suite Applied to Lake Winnebago

WiLMS

Phosphorus Predictions & Uncertainty Analysis

Observed spring overturn total phosphorus (SPO): 69.0 mg/m^3

Observed growing season mean phosphorus (GSM): 91.0 mg/m^3

Back calculation for SPO total phosphorus: 0.0 mg/m^3

Back calculation GSM phosphorus: 0.0 mg/m^3

Nurnberg Model Input - Est. Gross Int. Loading: 0 kg

% Confidence Range: 70

Lake Phosphorus Model	Low Total P (mg/m^3)	Most Likely Total P (mg/m^3)	High Total P (mg/m^3)	Predicted -Observed (mg/m^3)	% Dif.	Confidence Lower Bound	Confidence Upper Bound	Parameter Fit?	Back Calculation (kg/year)	Model Type
Walker, 1987 Reservoir	55	53	328	-38	-42	38	221	FIT	0	GSM
Canfield-Bachmann, 1981 Natural Lake	74	72	266	-19	-21	22	207	FIT	1	GSM
Canfield-Bachmann, 1981 Artificial Lake	58	57	162	-34	-37	18	164	FIT	1	GSM
Rechow, 1979 General	65	63	391	-28	-31	43	264	FIT	0	GSM
Rechow, 1977 Anoxic	128	125	774	34	37	92	522	FIT	0	GSM
Rechow, 1977 water load<50m/year	88	85	528	-6	-7	59	357	P	0	GSM
~~Rechow, 1977 water load>50m/year~~	~~N/A~~	~~N/A~~	~~N/A~~	~~N/A~~	~~N/A~~	~~N/A~~	~~N/A~~	~~N/A~~	~~N/A~~	~~N/A~~
~~Walker, 1977 General~~	~~99~~	~~95~~	~~599~~	~~26~~	~~30~~	~~57~~	~~400~~	~~FIT~~	~~0~~	~~SPO~~
~~Vollenweider, 1982 Combined OECD~~	~~83~~	~~82~~	~~275~~	~~16~~	~~23~~	~~35~~	~~198~~	~~FIT~~	~~0~~	~~ANN~~
~~Dillon-Rigler-Kirchner~~	~~53~~	~~52~~	~~322~~	~~17~~	~~25~~	~~30~~	~~247~~	~~P~~	~~0~~	~~SPO~~
~~Vollenweider, 1982 Shallow Lake/Res.~~	~~54~~	~~53~~	~~264~~	~~27~~	~~34~~	~~31~~	~~186~~	~~FIT~~	~~0~~	~~ANN~~
~~Larsen-Mercier, 1976~~	~~92~~	~~89~~	~~552~~	~~20~~	~~20~~	~~63~~	~~372~~	~~P Pin~~	~~0~~	~~SPO~~
~~Nurnberg, 1984 Oxic~~	~~71~~	~~69~~	~~420~~	~~22~~	~~24~~	~~44~~	~~291~~	~~P~~	~~0~~	~~ANN~~

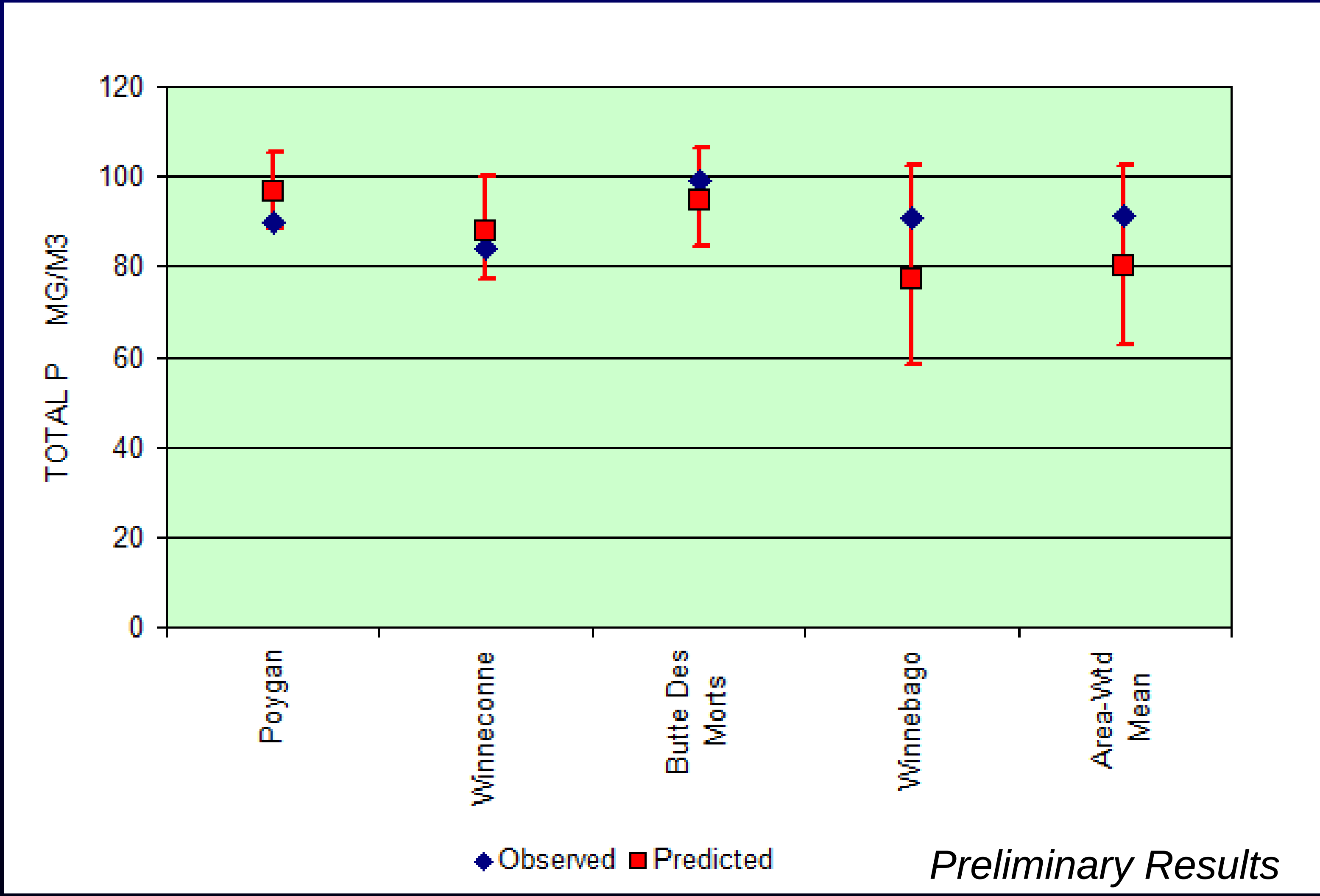
Finished | Write Results | Display Parameter Values | Help

Preliminary Results

All applicable models underestimate Inlake P concentrations

> Internal Loading underestimated

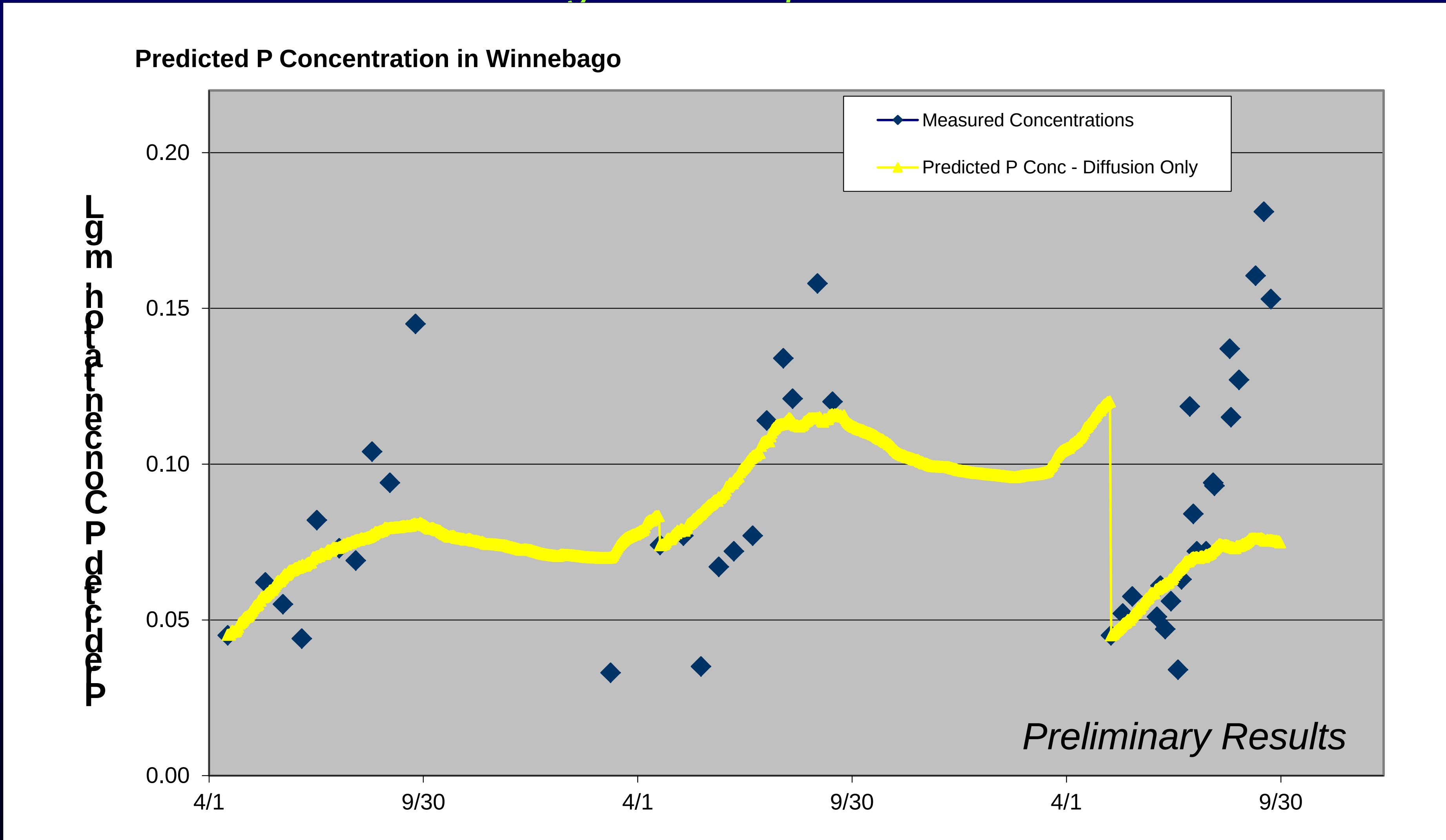
Army Corps' BATHTUB Program



Looks like Internal Loading is underestimated in Lake Winnebago.

Daily Mass Balance Model (developed just for this study)

Predicted Changes in Phosphorus Concentrations



Looks like Internal Loading is way underestimated.

Revisit Internal Loading – Additional input from Internal Loading because of Physical Mixing of the Sediments

Phosphorus Budget

Point Sources –
DNR estimates

$$\text{Net P Input} = P + G_W + S + P_S + Q_I - Q_o + I_{nternal}$$

Δ Concentration

Precipitation
Conc. From nearby lake study

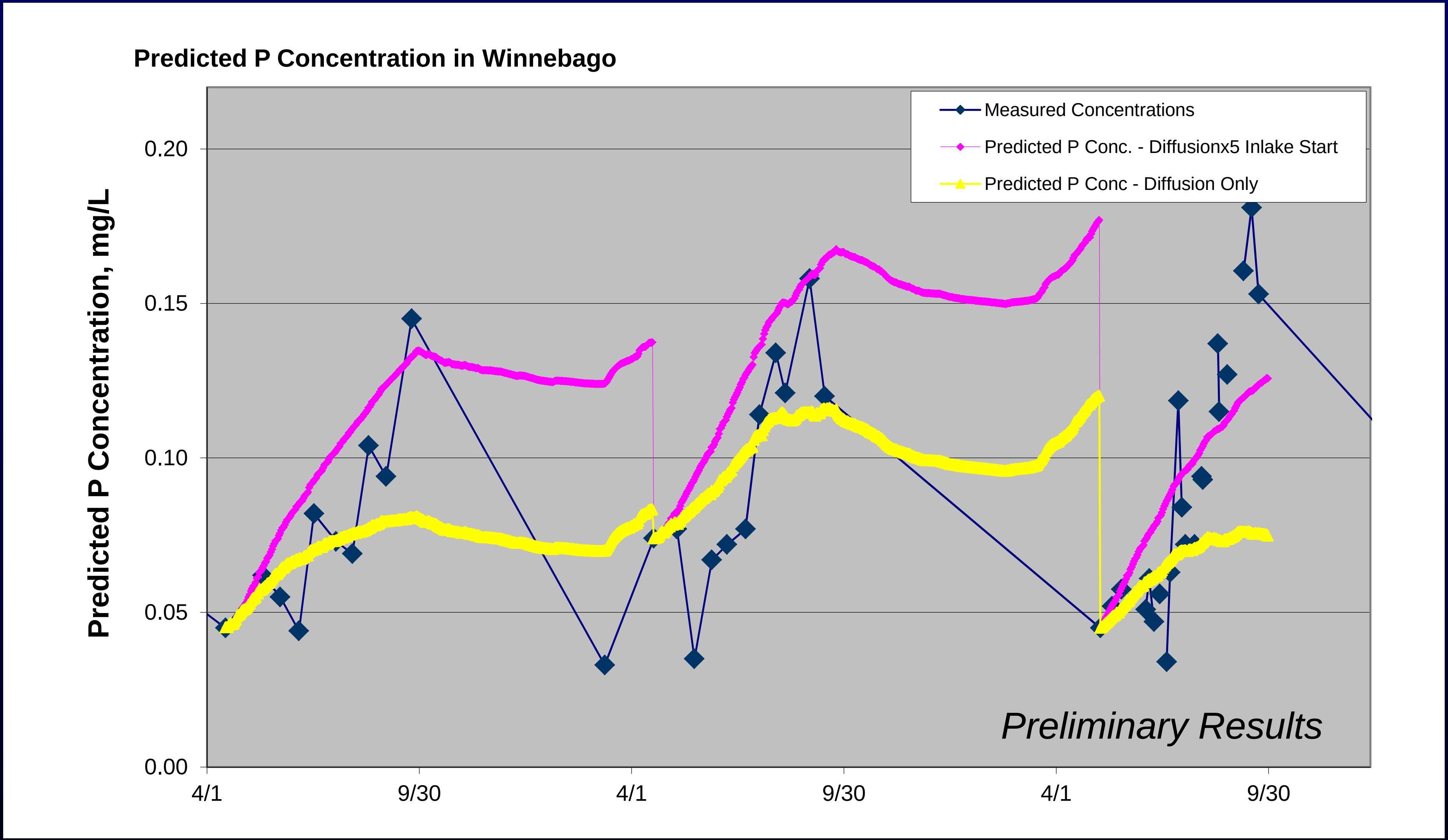
Ground Water
Conc. From nearby lake study

Septic Systems
Modeled here based on # nearshore residents

Inflow
Monitored and Modeled

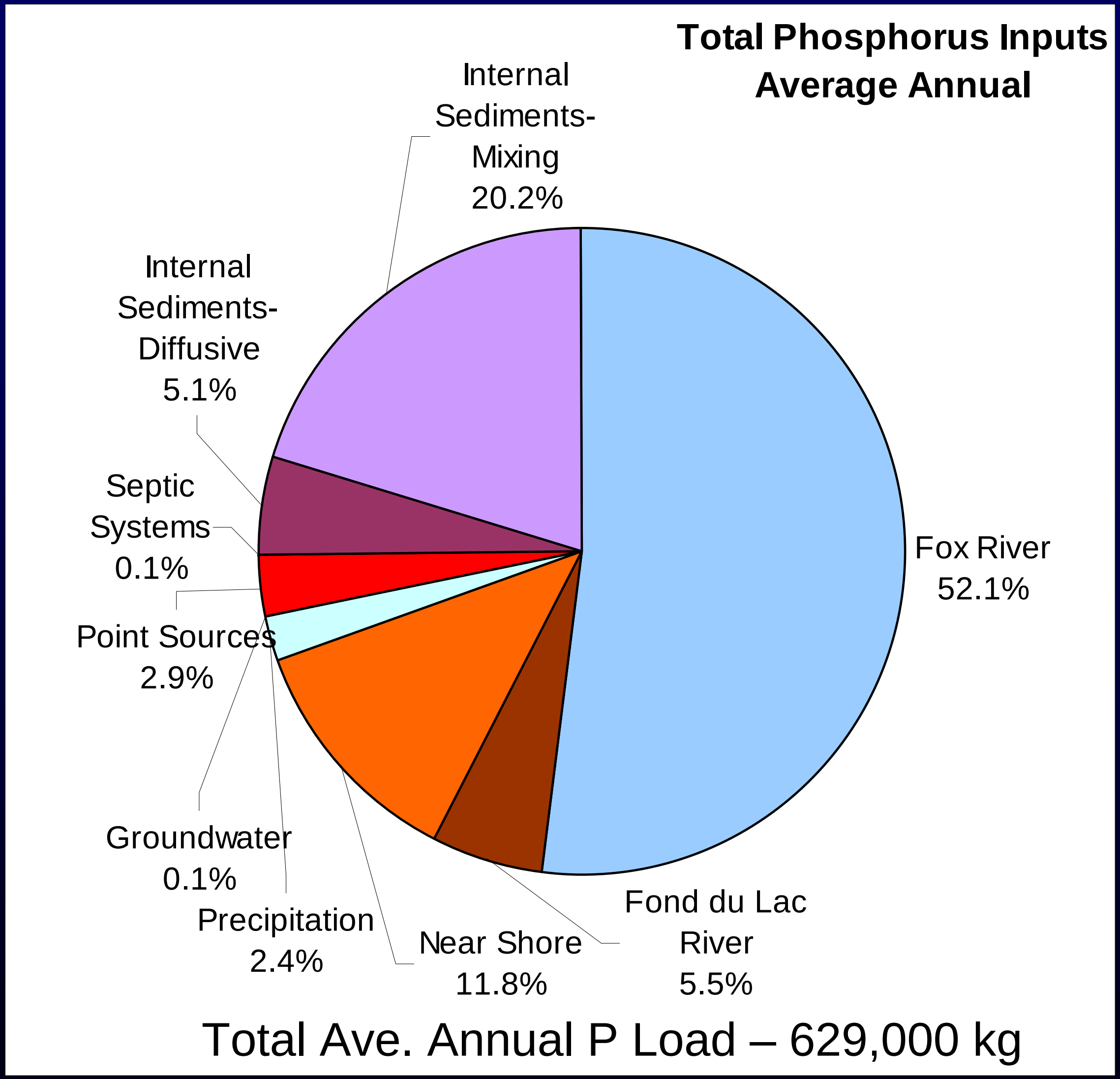
Outflow
Monitored

Predicted Changes in Phosphorus Concentrations based on Daily Mass Balance Model



Internal Loading: 32,000 kg > 160,000 kg

Annual Inputs of Phosphorus Into Lake Winnebago



Preliminary Data

** Internal Loading based on Aerobic Release Rates and Mixing

** Internal Loading represents 35% of the growing season loading

Phosphorus Budget

Point Sources –
DNR estimates

Net P Input = $P + G_W + S + P_S + Q_I - Q_o + I_{nternal}$

Δ Concentration

Precipitation
Conc. From nearby lake study

Ground Water
Conc. From nearby lake study

Septic Systems
Modeled here based on # nearshore residents

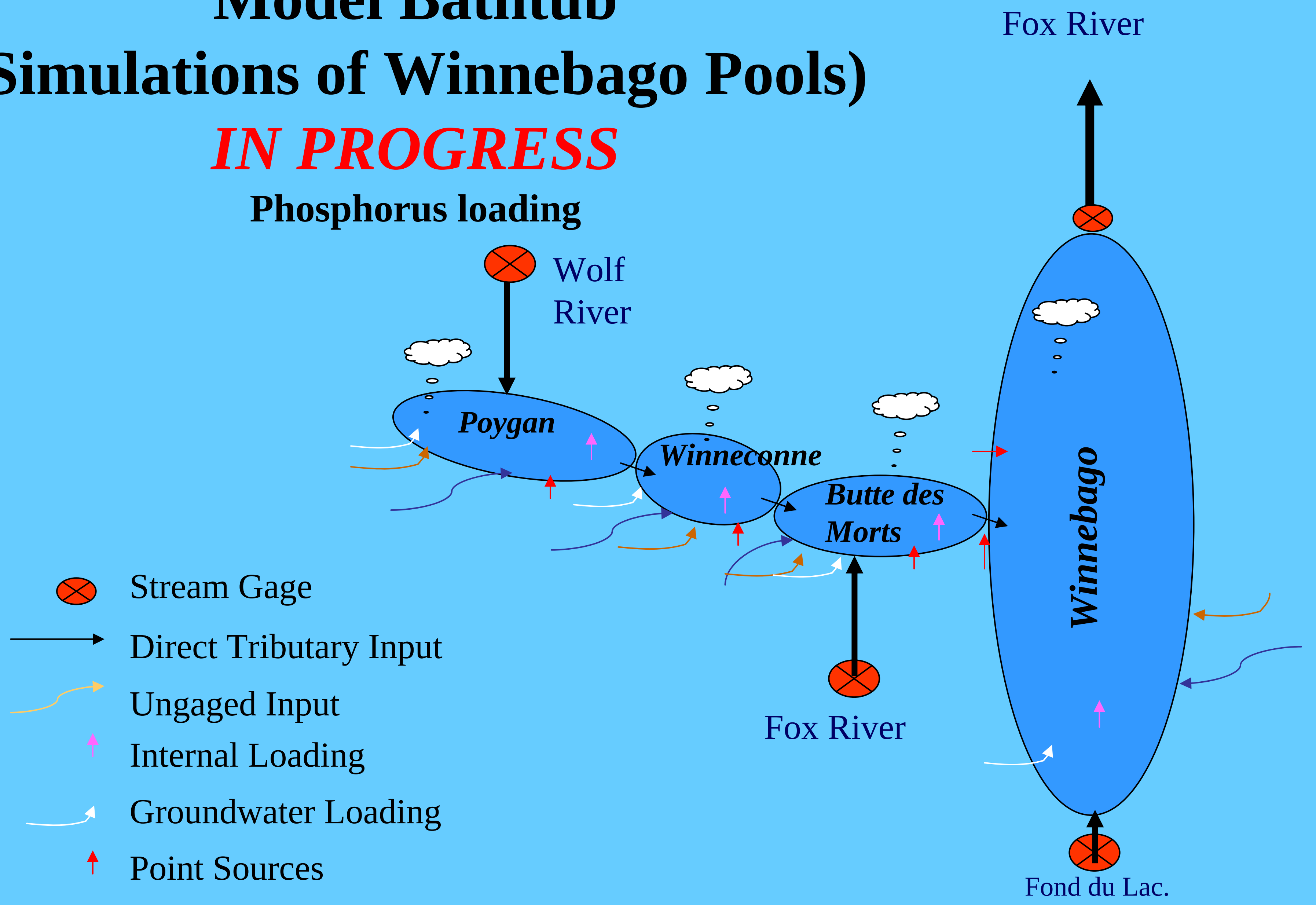
Inflow
Monitored and Modeled

Outflow
Monitored

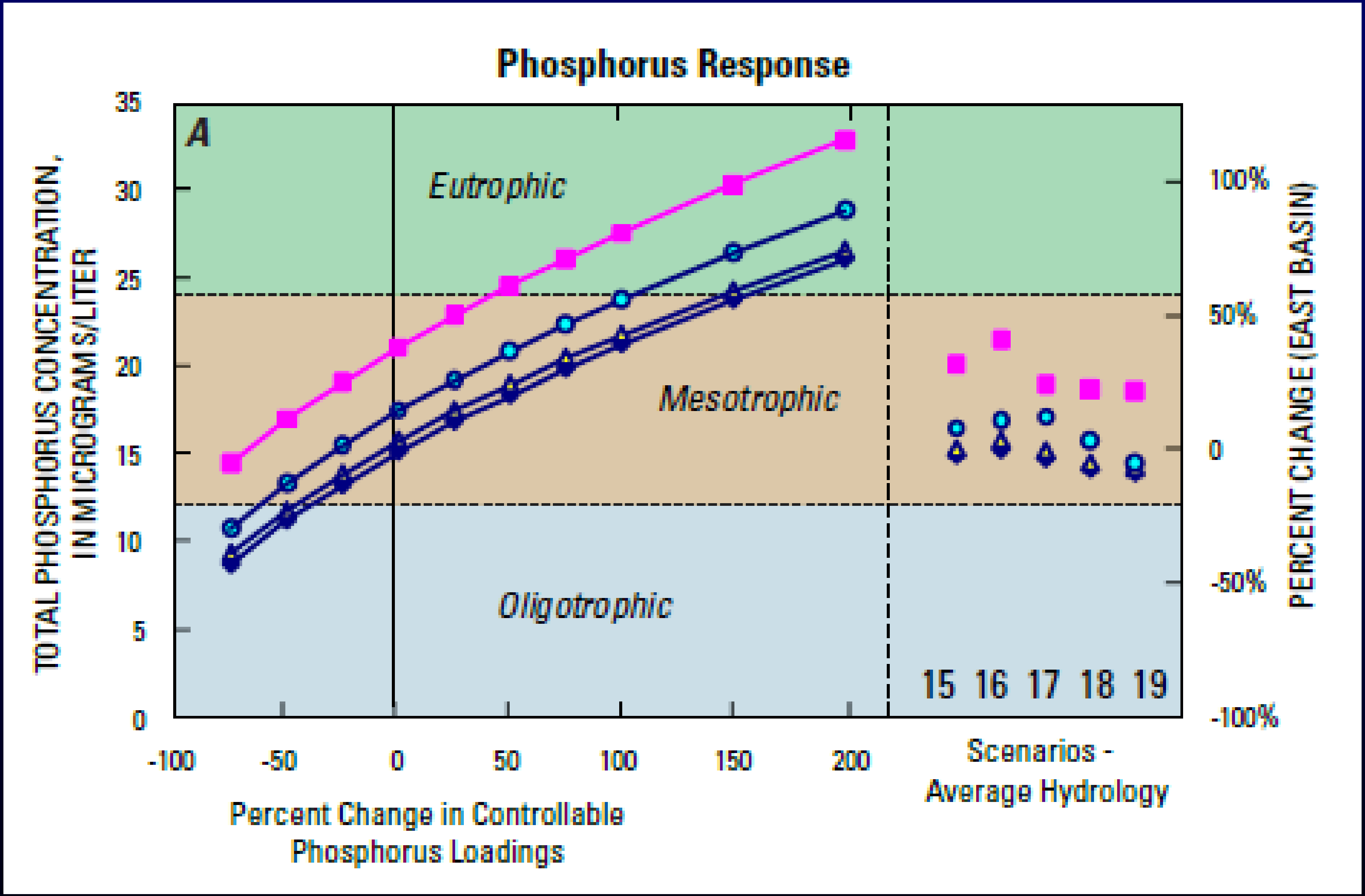
Schematic for the Eutrophication Model Bathtub (Simulations of Winnebago Pools)

IN PROGRESS

Phosphorus loading

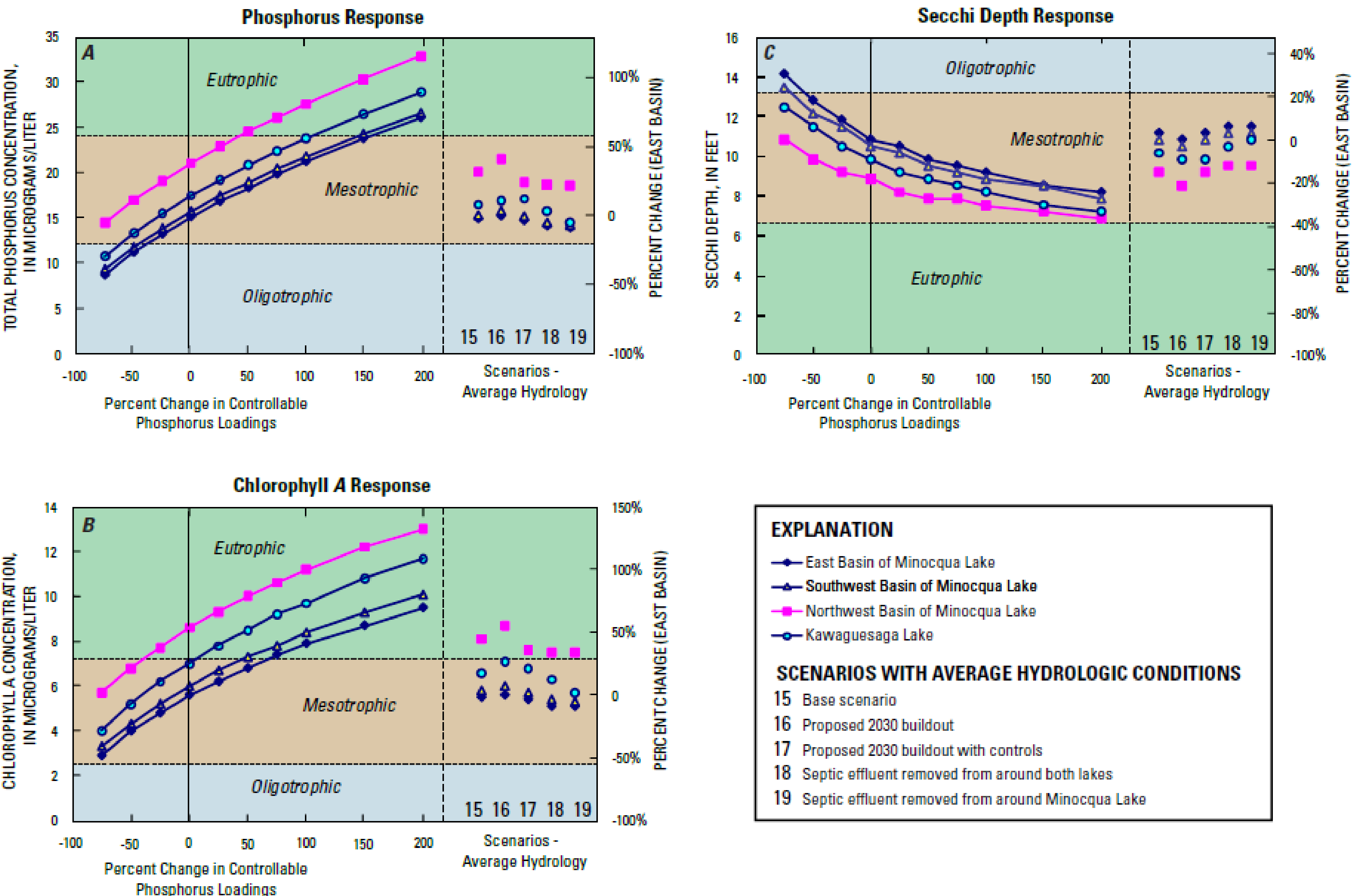


Example--Simulating the effects of Changes in Phosphorus Loading with Bathtub



*** Not for the Winnebago Pool Lakes

Example--Simulating the effects of Changes in Phosphorus Loading with Bathtub

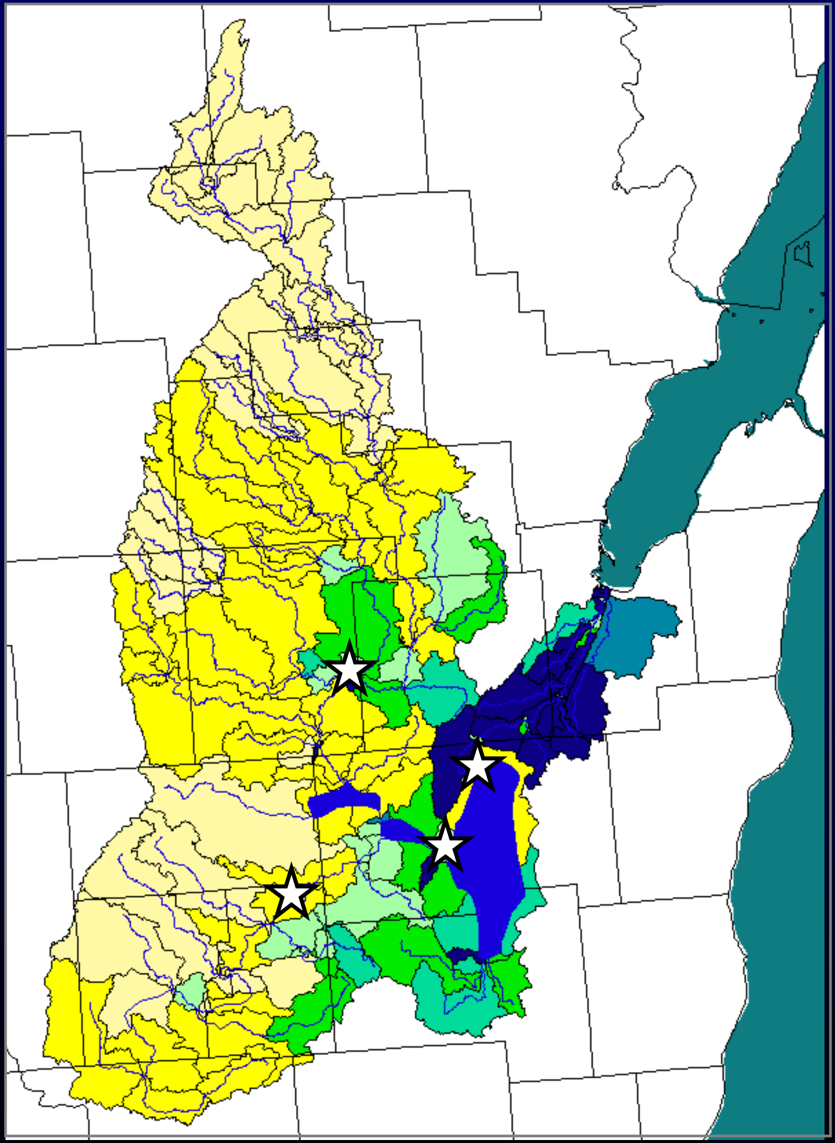


Steps from here:

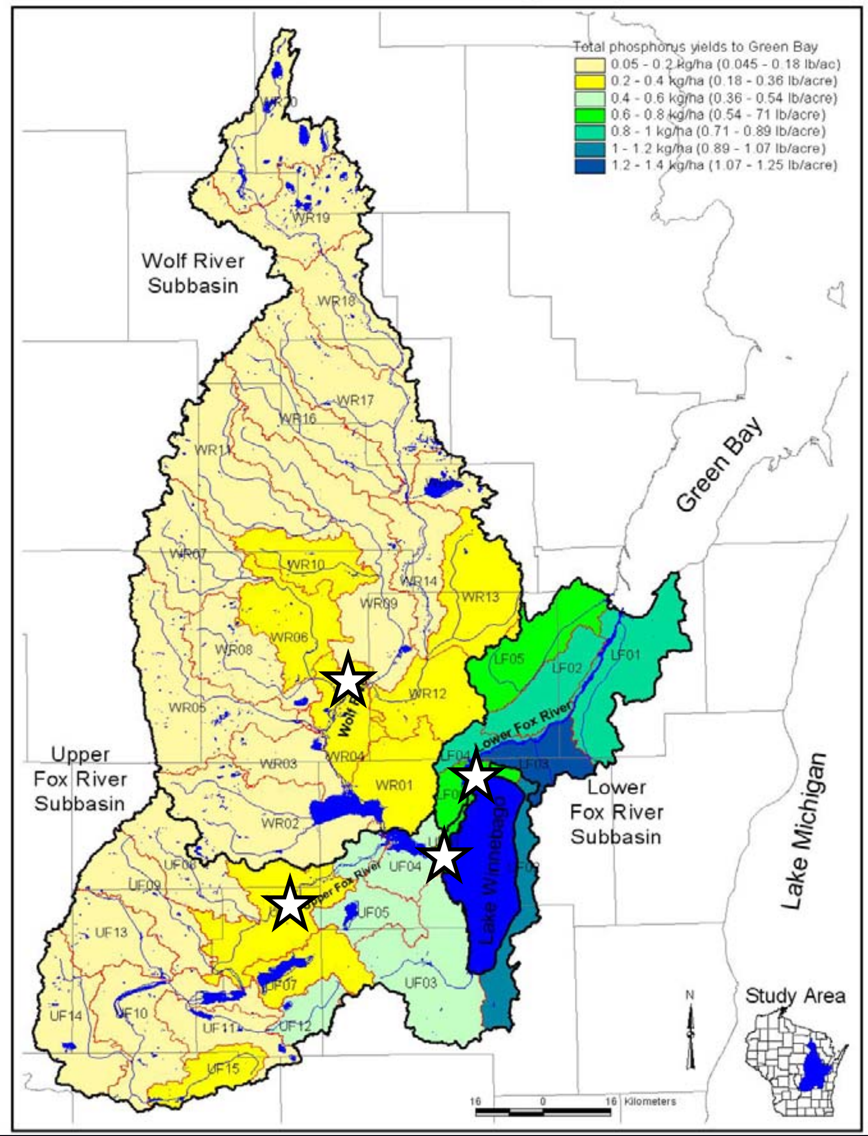
1. Finalize watershed modeling.
2. Finalize external loading to lake.
3. Finalize internal loading to lake.
4. Develop Response Curves.
5. Run Specific Scenarios.

Refinements in Phosphorus Input from Ungaged Areas

SPARROW (USGS) Results

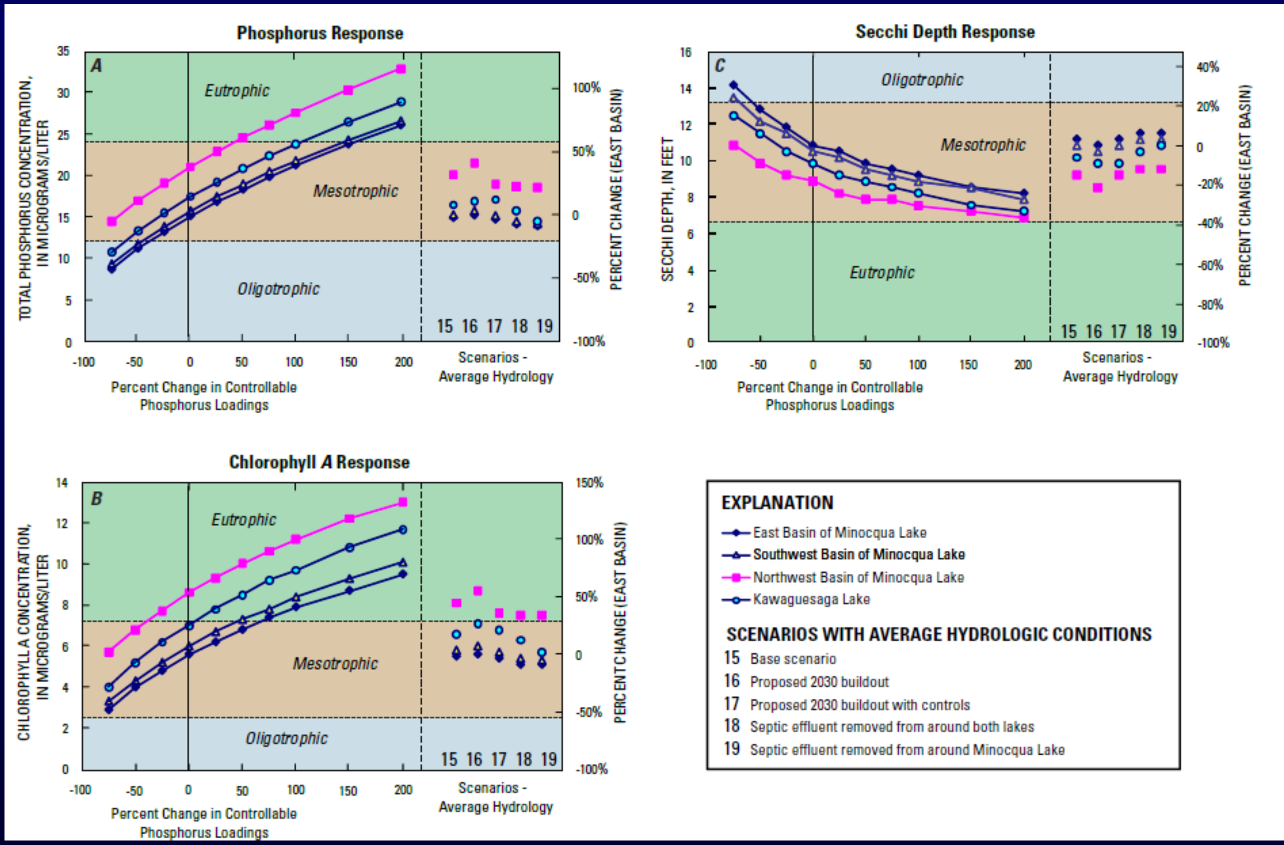


SWAT Preliminary Results



Steps from here:

1. Finalize watershed loading.
2. Finalize external loading to lake.
3. Finalize internal loading to lake.
4. Develop Response Curves.
5. Run Specific Scenarios.



Hydrology, water quality, and response in the Winnebago Pool Lakes to changes in phosphorus loading

Questions??

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