Allocation of Nutrient Inputs to the Laurentian Great Lakes by Source and River Basin Using SPARROW Models

Dale Robertson and David Saad

U.S. Geological Survey,
Wisconsin Water Science Center

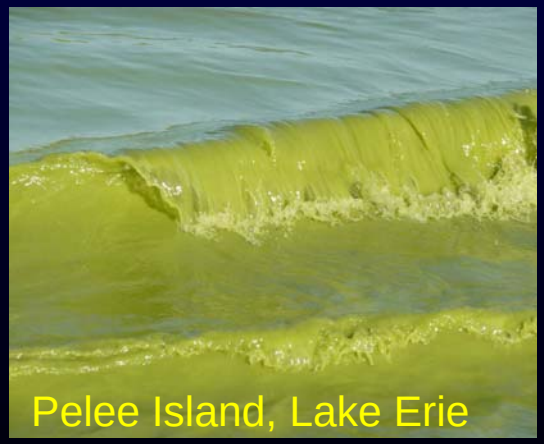
National Water Quality Monitoring Conference
April 29, 2010

*dzrobert@usgs.gov
(608) 821-3867

USGS
science for a changing world

Eutrophication Issues in the Great Lakes


Lake Erie


Pelee Island, Lake Erie


Manitowoc, Lake Michigan


Cladophora on Beaches

Goals of Study:

1. Determine P (*and N*) loading to each Great Lake (U.S. contributions).

2. Determine P loading from each tributary > 150 km^2.

3. Rank the tributaries based on loads and yields.

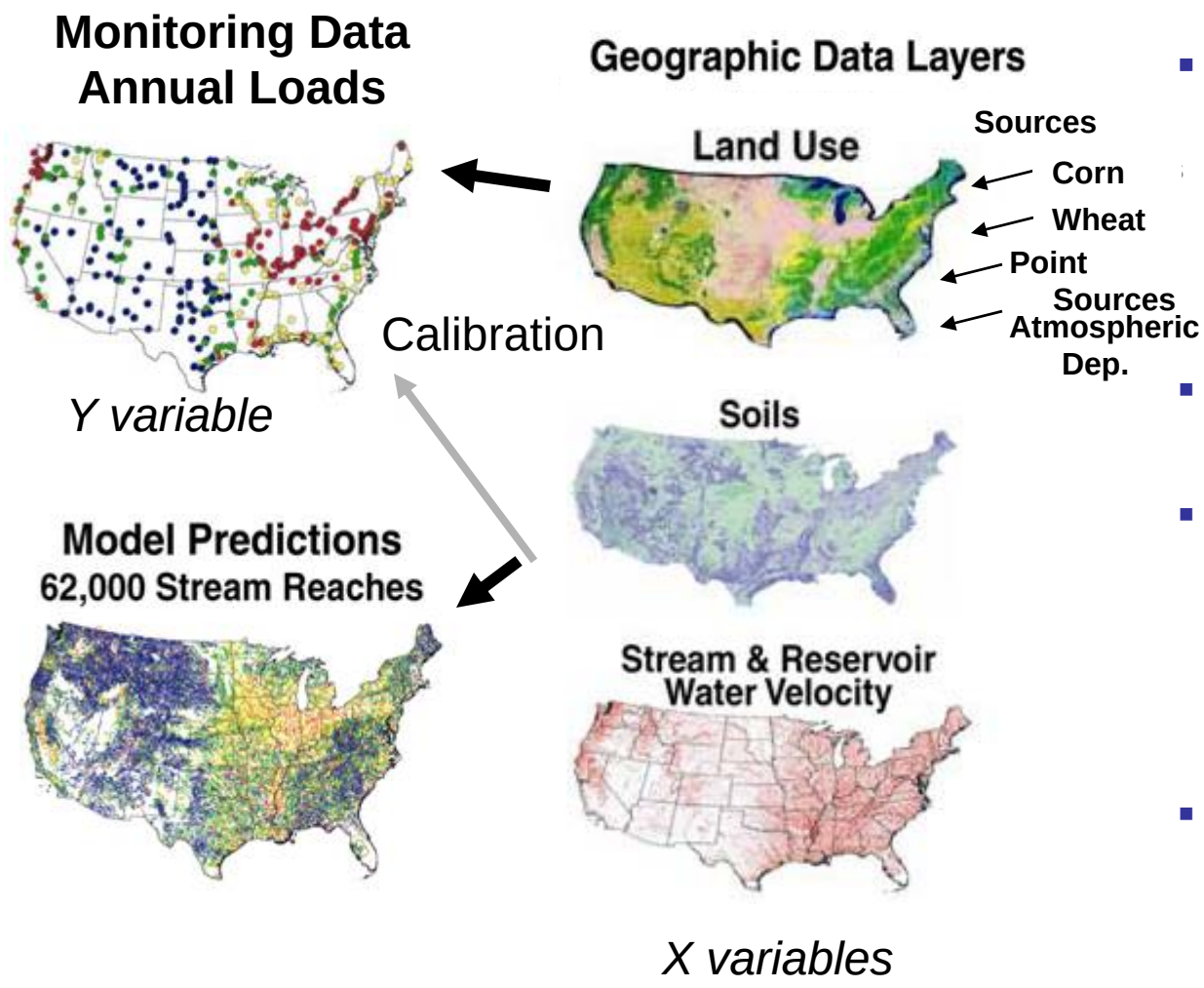
4. Determine relative importance of nutrient sources.

5. Compare yields from Great Lakes tribs with those of nearby major river basins.

Approach - SPARROW Water-Quality Model –

SPAtially Referenced Regression on Watershed Attributes

http://water.usgs.gov/nawqa/sparrow



- **Hybrid statistical/ mechanistic process structure; mass-balance constraints; data-driven, nonlinear estimation of parameters**
- **Separates land and in-stream processes**
- **Predictions of mean-annual flux reflect long-term, net effects of nutrient supply and loss processes in watersheds**
- **Once calibrated, the model has physically interpretable coefficients; model supports hypothesis testing and uncertainty estimation**

Regression Equation behind the SPARROW Model

Load at a specific site

Flux from Within a SPARROW Watershed

Flux from Upstream SPARROW Watersheds

$$F_i^* = \left(\sum_{n=1}^{N_S} S_{n,i} \alpha_n D_n\left(\mathbf{Z}_i^D;\boldsymbol{\theta}_D\right) \right) T'\left(\mathbf{Z}_i^S, \mathbf{Z}_i^R;\boldsymbol{\theta}_S,\boldsymbol{\theta}_R\right) + \left(\sum_{j \in J(i)} F_j' \right) \delta_i T\left(\mathbf{Z}_i^S, \mathbf{Z}_i^R;\boldsymbol{\theta}_S,\boldsymbol{\theta}_R\right)$$

Sources

Land-to-Water Delivery

Transport/Decay

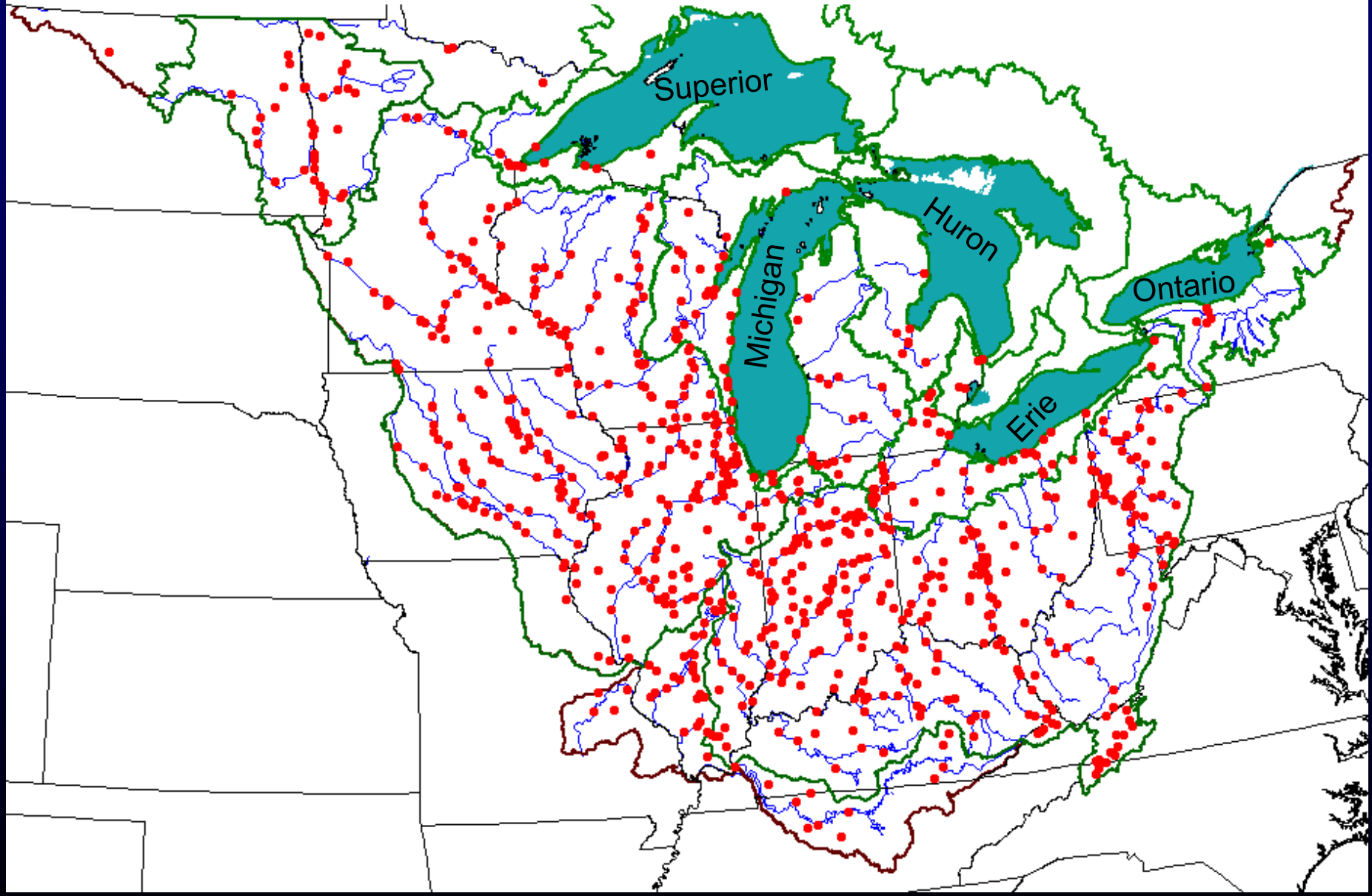
Transport

Calibration Coefficients

Calibration of National model was based on using 425 sites with coinciding loads and GIS information and the Upper Midwest Model based on 810 sites.

810 Sites with mean annual P loads to calibrate the model

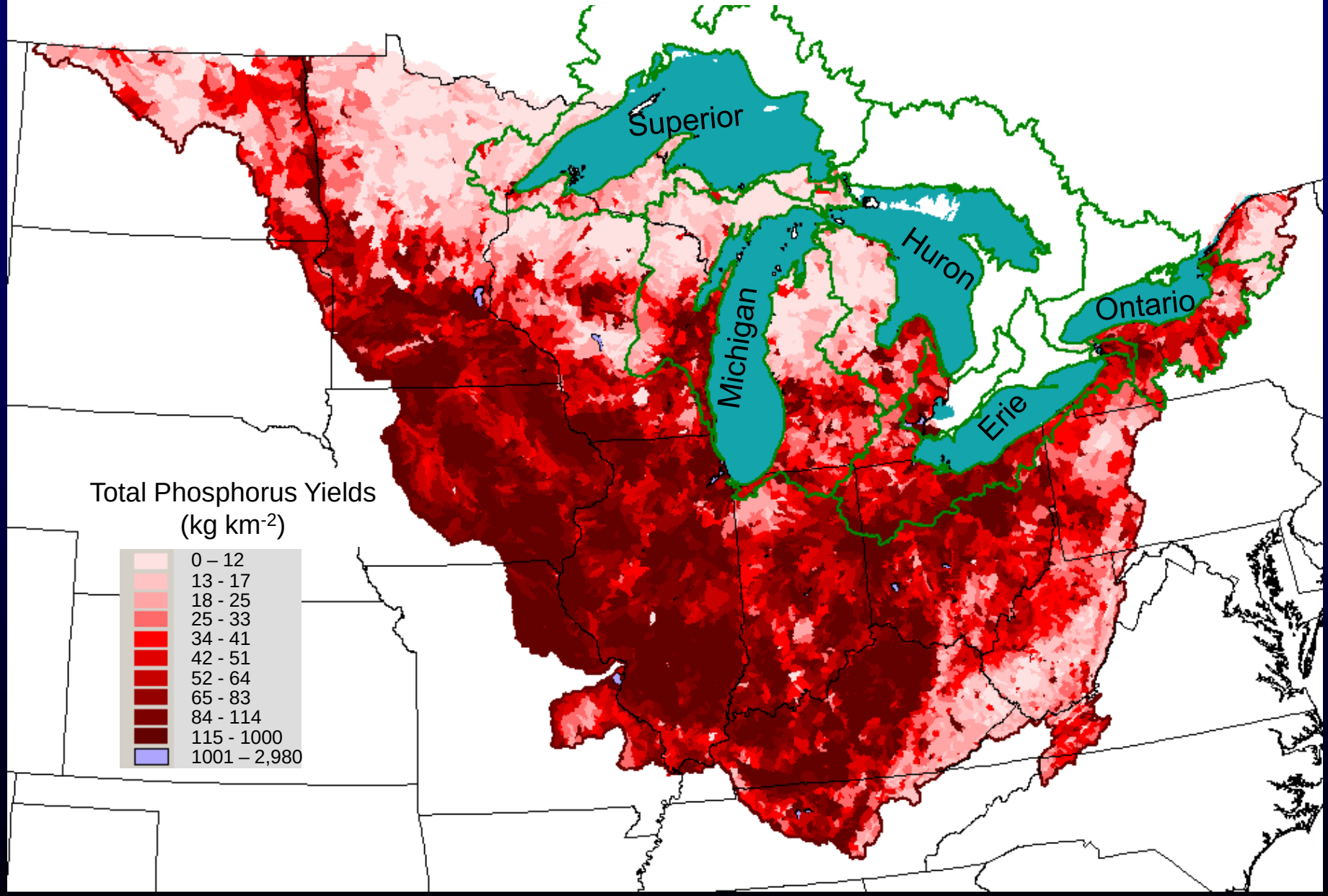
Normalized to 2002

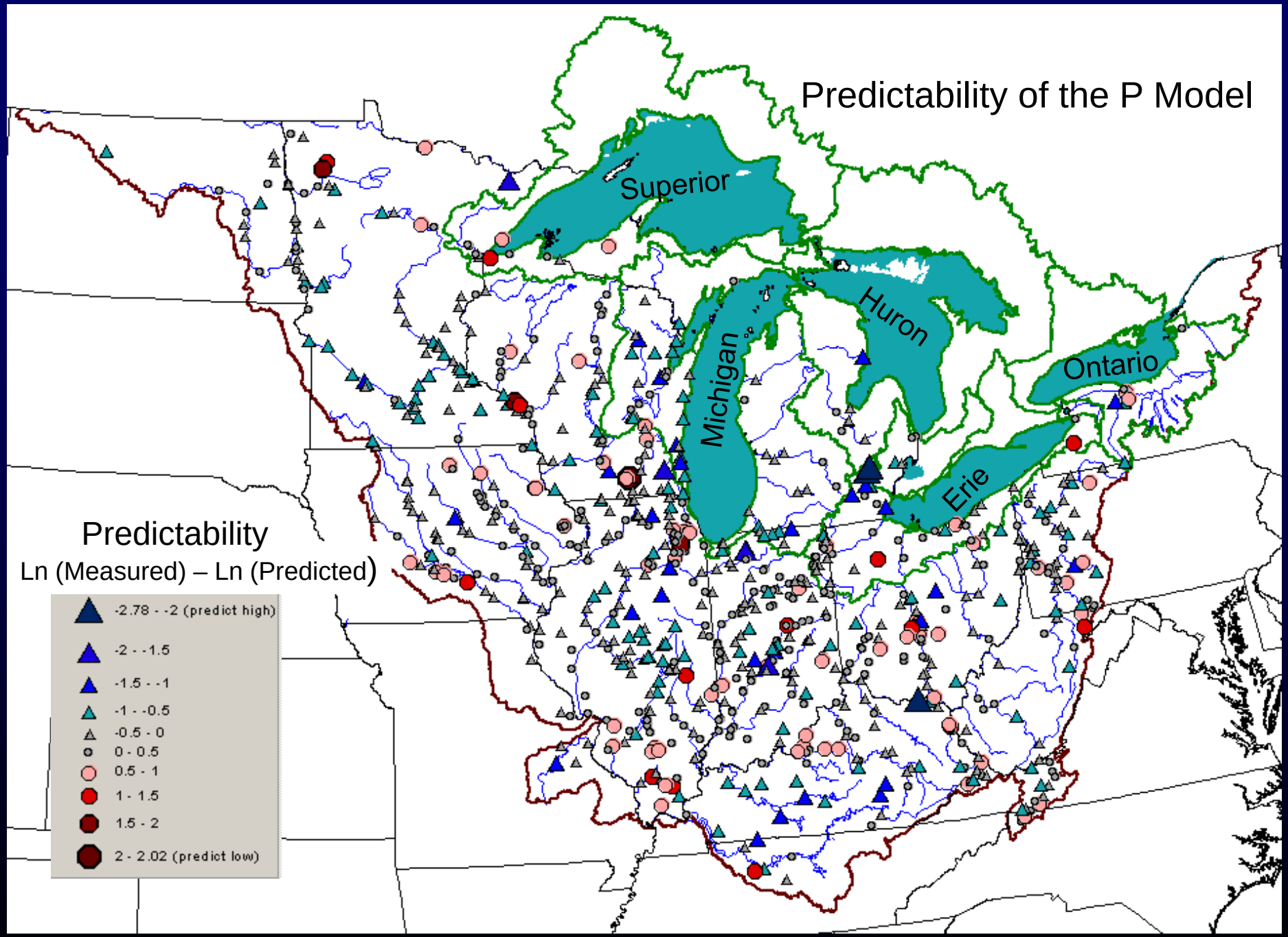


Summary of Upper Midwest SPARROW model and calibration results for TP.

Parameter	Coefficient units	Coefficient value	Coefficient Standard error	P value	Coefficient value (mean bootstrap estimate)	Coefficient 90% Confidence Limits (NLLSR) Low	High
Sources							
Point sources (total)	fraction, dimensionless	1.068	0.142	0.0000	1.083	0.835	1.302
Manure (confined)	fraction, dimensionless	0.086	0.011	0.0000	0.085	0.068	0.104
Manure (unconfined)	fraction, dimensionless	0.032	0.010	0.0009	0.033	0.015	0.049
Fertilizers (farm)	fraction, dimensionless	0.029	0.004	0.0000	0.029	0.023	0.036
Forested areas	kg km^{-2} yr^{-1}	14.700	1.723	0.0000	14.600	11.800	17.500
Urban areas	kg km^{-2} yr^{-1}	52.300	14.400	0.0001	48.900	28.600	76.000

Distribution in Incremental Phosphorus Yields




Predictability of the P Model
Superior
Michigan
Huron
Erie
Ontario
Predictability
Ln (Measured) – Ln (Predicted)
-2.78 - -2 (predict high)
-2 - -1.5
-1.5 - -1
-1 - -0.5
-0.5 - 0
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.02 (predict low)

Annual TP loading and yields into each Great Lake and the nearby major river basins.

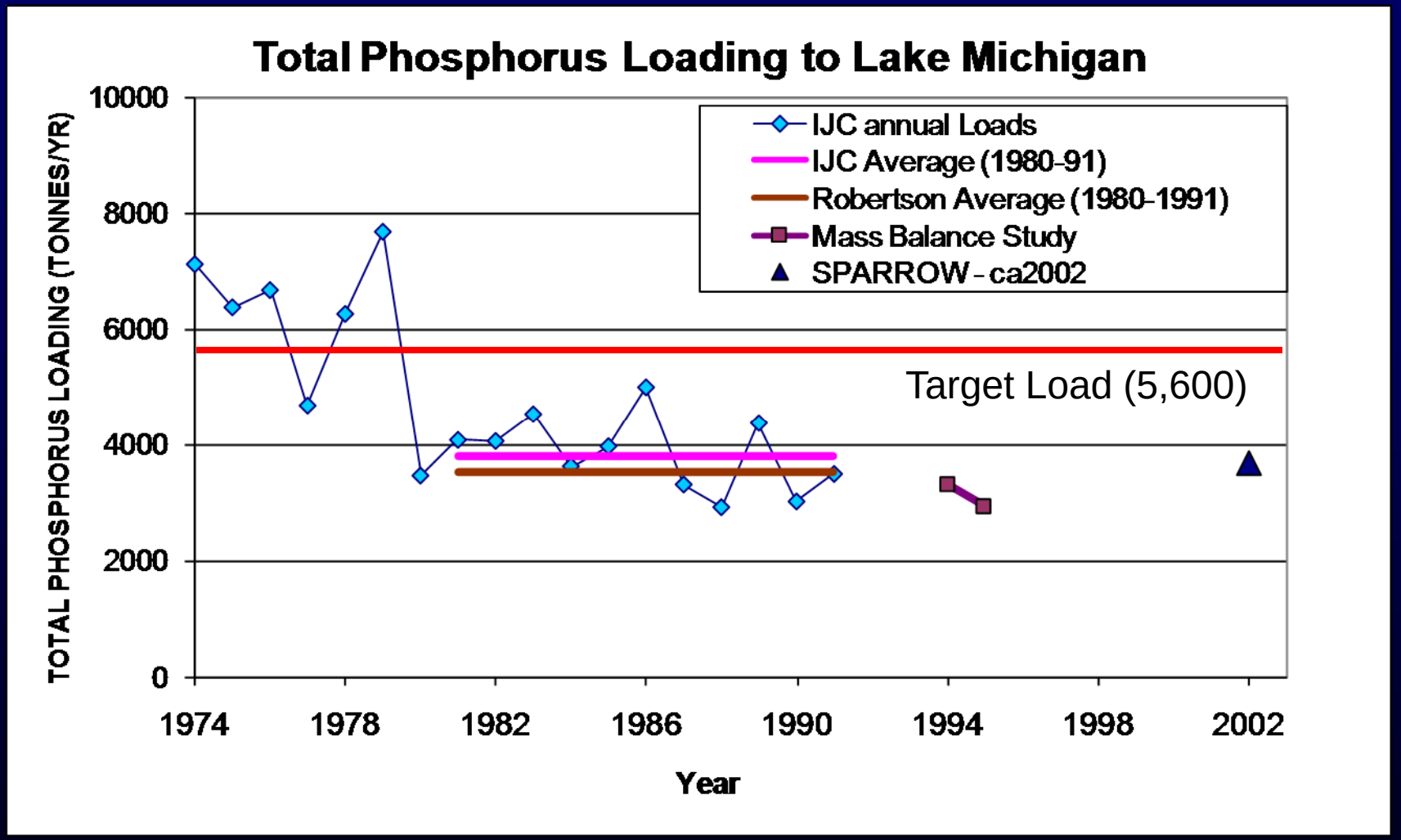
Great Lake/ River Basin	U.S. Drainage Area (km^2)	Total U.S. Load (Tonnes)[a]	Total U.S. Yield ($kg\ km^{-2}$)[a]
Superior	43,594	782	17.9
Michigan	116,395	3,431	29.5
Huron	41,369	927	22.4
Erie	55,488	4,611	83.1
Ontario	35,661	1,803	50.6

[a]Loads and yields from the U.S. part of each lake's watershed, and do not include direct atmospheric

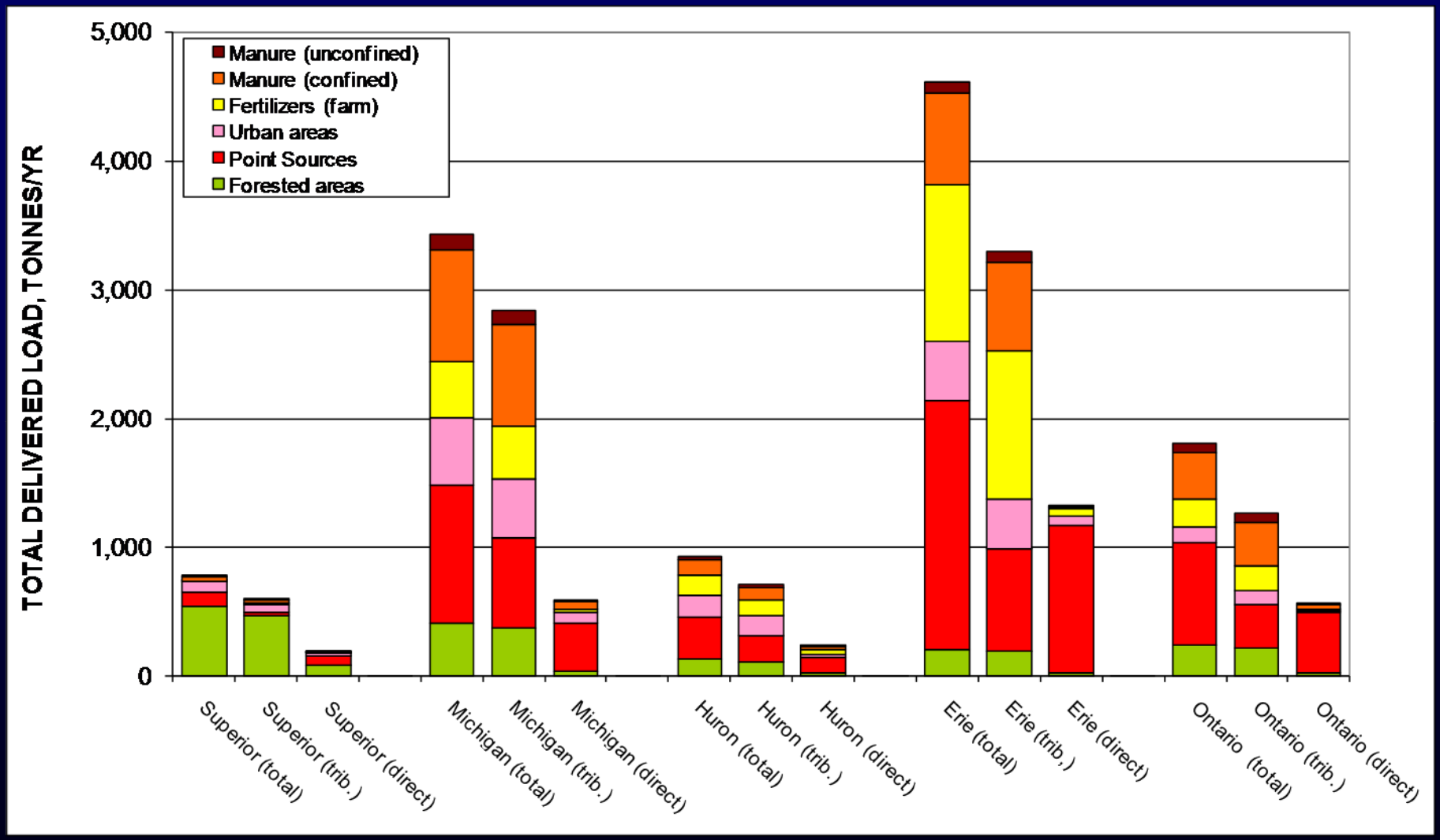
Annual TP loading and yields into each Great Lake and the nearby major river basins.
[NA, not available]

Great Lake/ River Basin	U.S. Drainage Area (km^2)	Total U.S. Load (Tonnes)[a]	Total U.S. Yield ($kg\ km^{-2}$)[a]	Direct Point Sources	Present Study U.S. "Watershed" Loading (Tonnes)		1983-85 U.S. "Watershed" Loading (Tonnes)
Superior	43,594	782	17.9	75	707	↓	1,503
Michigan	116,395	3,431	29.5	374	3,057	—	3,227
Huron	41,369	927	22.4	126	801	↓	1,549
Erie	55,488	4,611	83.1	1,146	3,465	↓	5,668
Ontario	35,661	1,803	50.6	464	1,339	—	1,267
Red River	84,508	1,939	22.9	NA	NA		NA
Upper Mississippi River	446,475	31,360	70.2	NA	NA		NA
Ohio River	373,067	27,713	74.3	NA	NA		NA

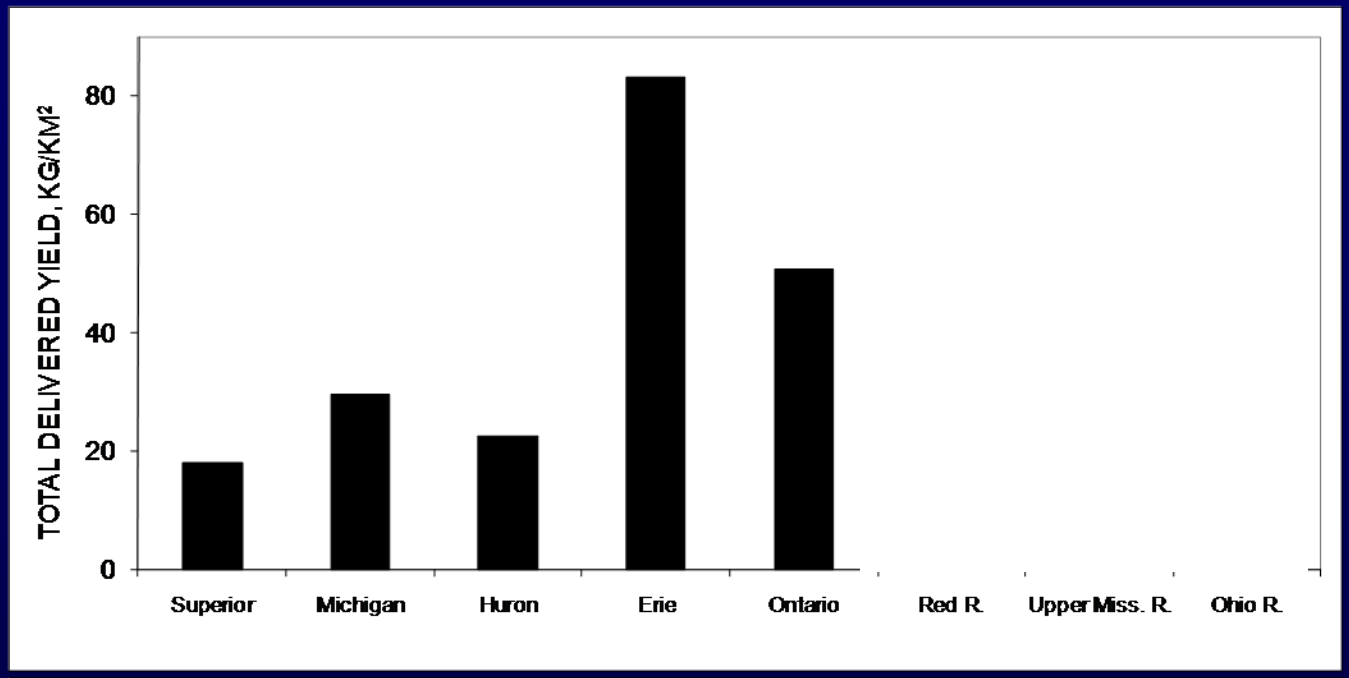
[a]Loads and yields from the U.S. part of each lake's watershed, and do not include direct atmospheric deposition.

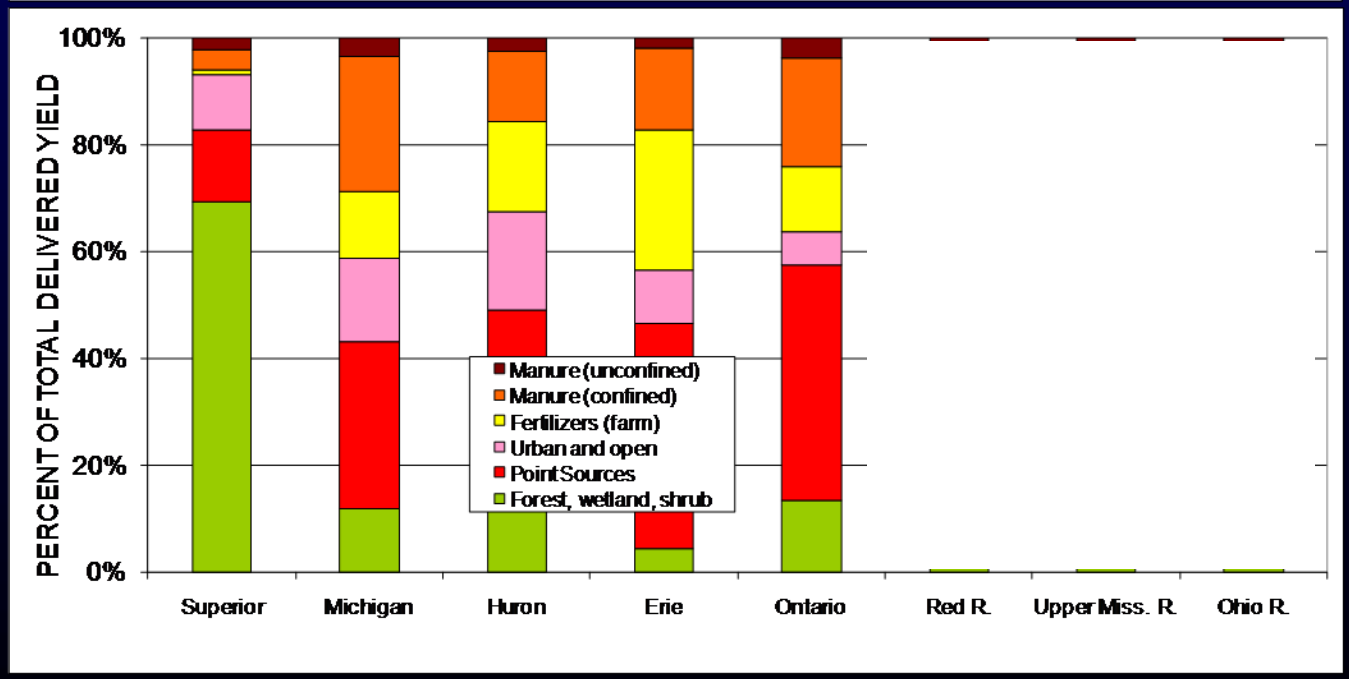

Total Phosphorus Loading to Lake Michigan
TOTAL PHOSPHORUS LOADING (TONNES/YR)
10000
8000
6000
4000
2000
0
1974
1978
1982
1986
1990
1994
1998
2002
Year
IJC annual Loads
IJC Average (1980-91)
Robertson Average (1980-1991)
Mass Balance Study
SPARROW - ca2002
Target Load (5,600)

What are the major sources to each of the Great Lakes?

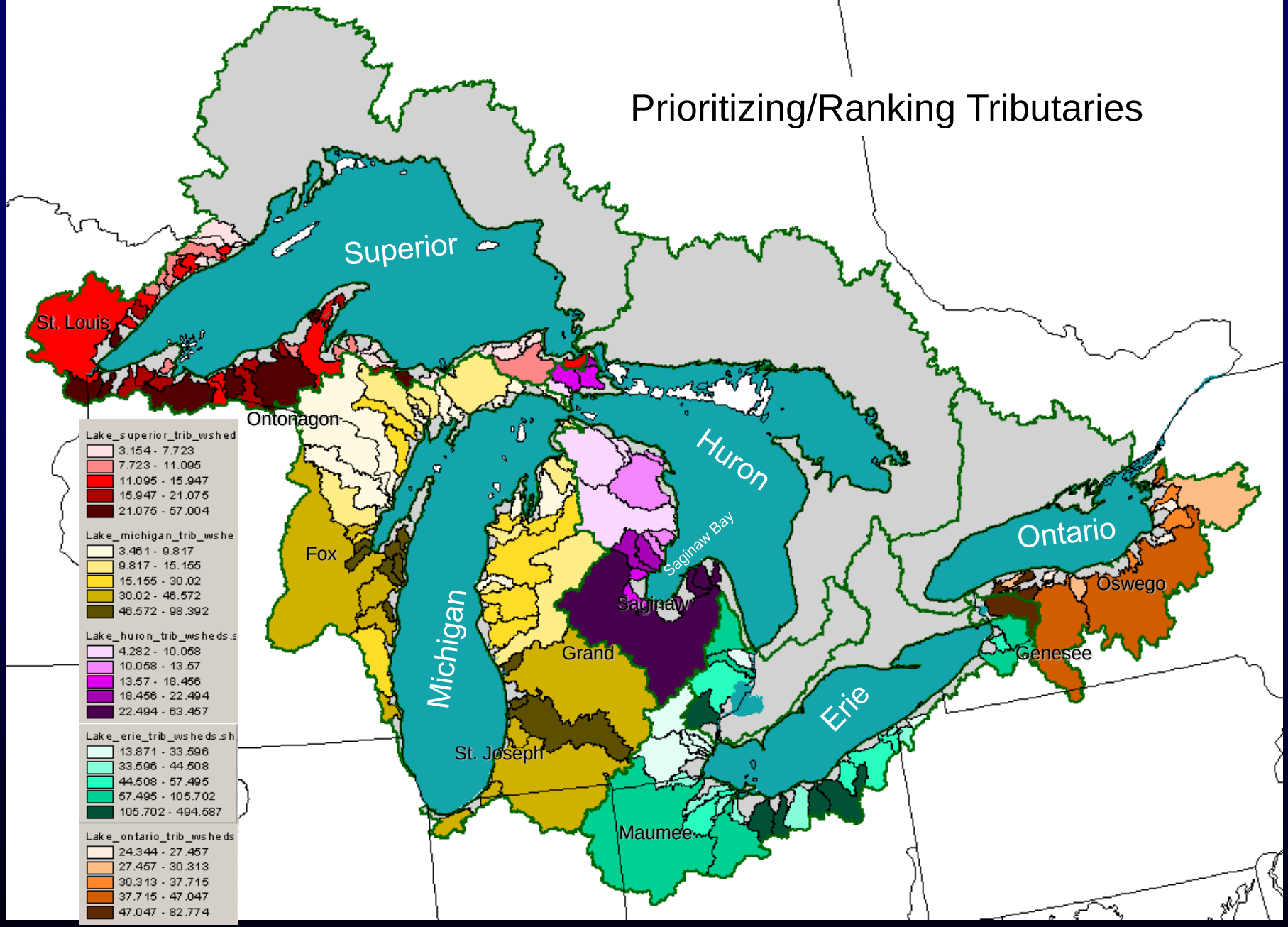


How do the yields to the Great Lakes Basins compare with each other and with those from other nearby large river basins?





Prioritizing/Ranking Tributaries



Conclusions

1. P loadings to Superior, Erie, and Huron have dropped since the 1980s. Michigan and Ontario are similar to the 1980s (but loading to Michigan is lower than in the 1970s).

2. Highest P loadings are from tribs with the largest basins, whereas highest yields are from areas with most intense agriculture and most point sources. >> Enables better prioritization of where rehabilitation efforts should be conducted.

3. Largest sources of P are from agricultural sources (~33-44%) and point sources (31-44%), except Superior where there is little of each. >> Enables better definition of what types of efforts are needed.

4. P yields to Lake Erie is similar to that from the Ohio and Upper Miss. Rivers. Yields to the other lakes is less than that from those rivers.