

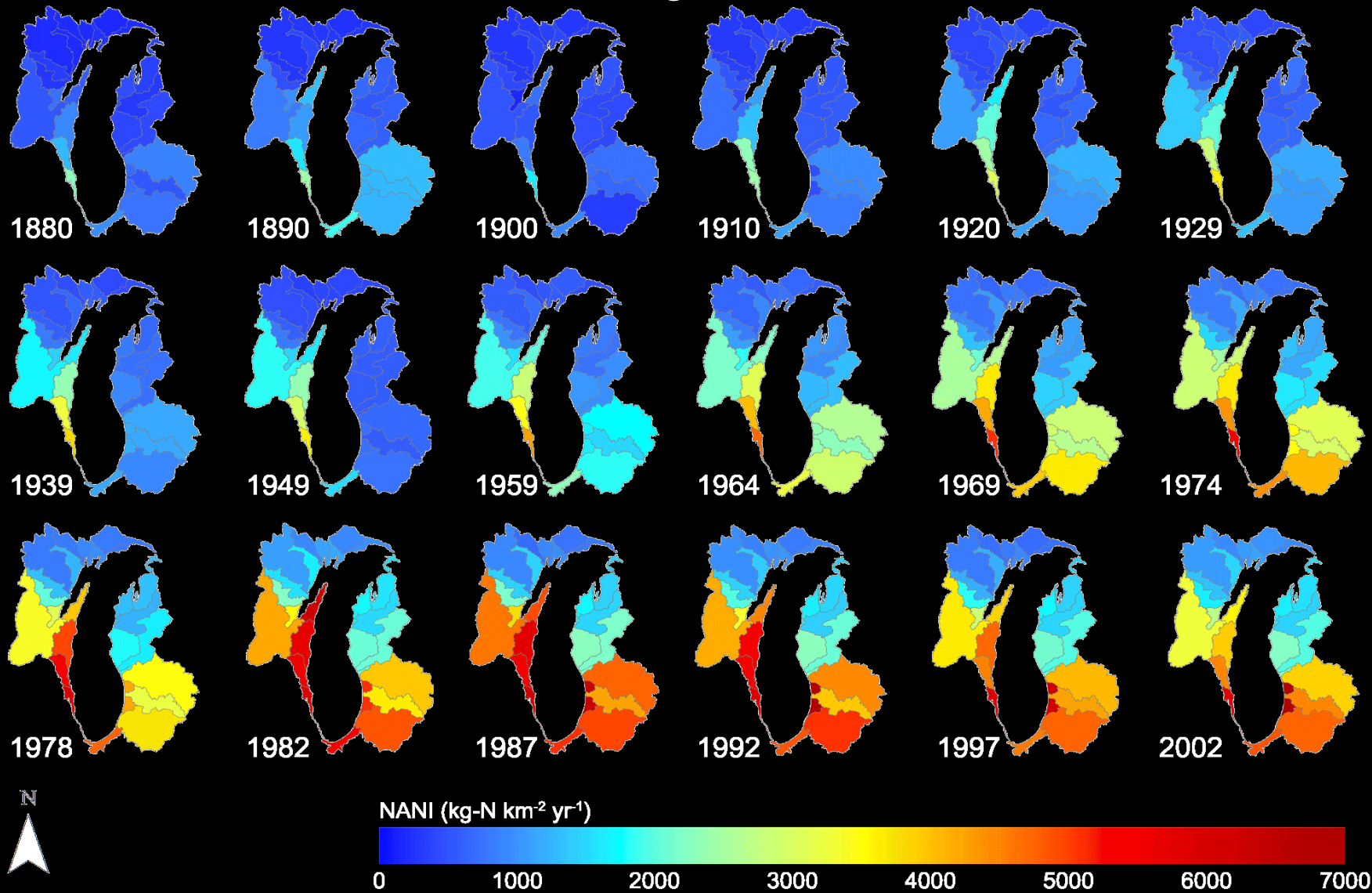
Spatial and Temporal Variation in Phosphorus Budgets for 24 Lake Michigan and Lake Erie Watersheds

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Watershed Budget Approach

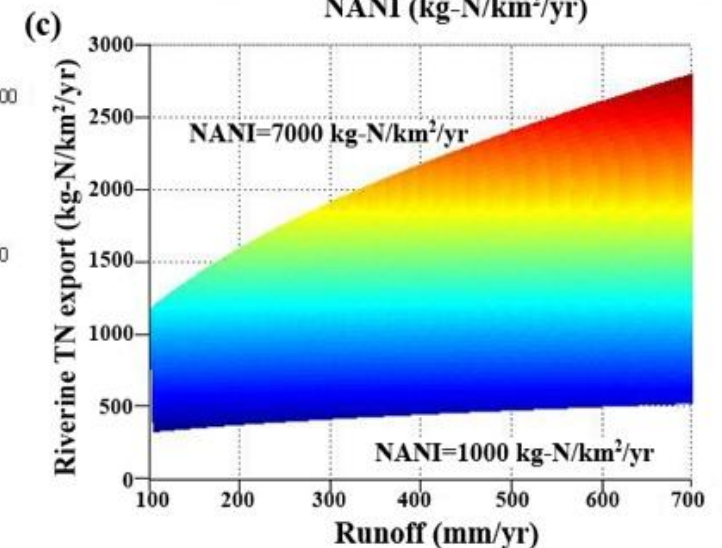
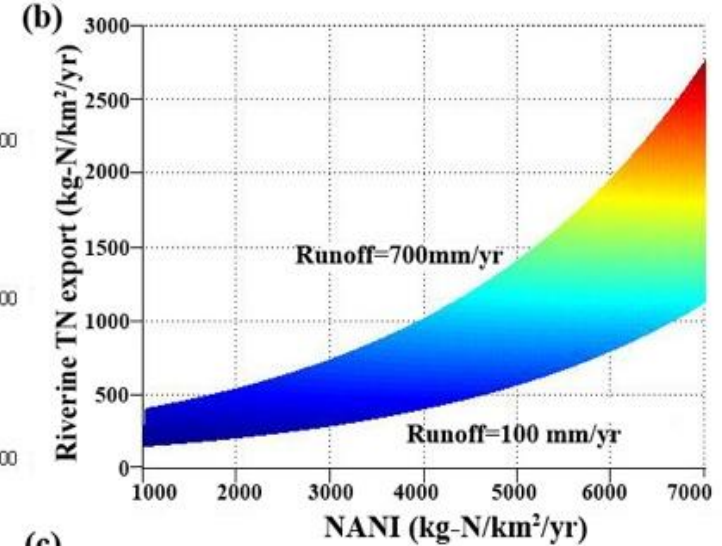
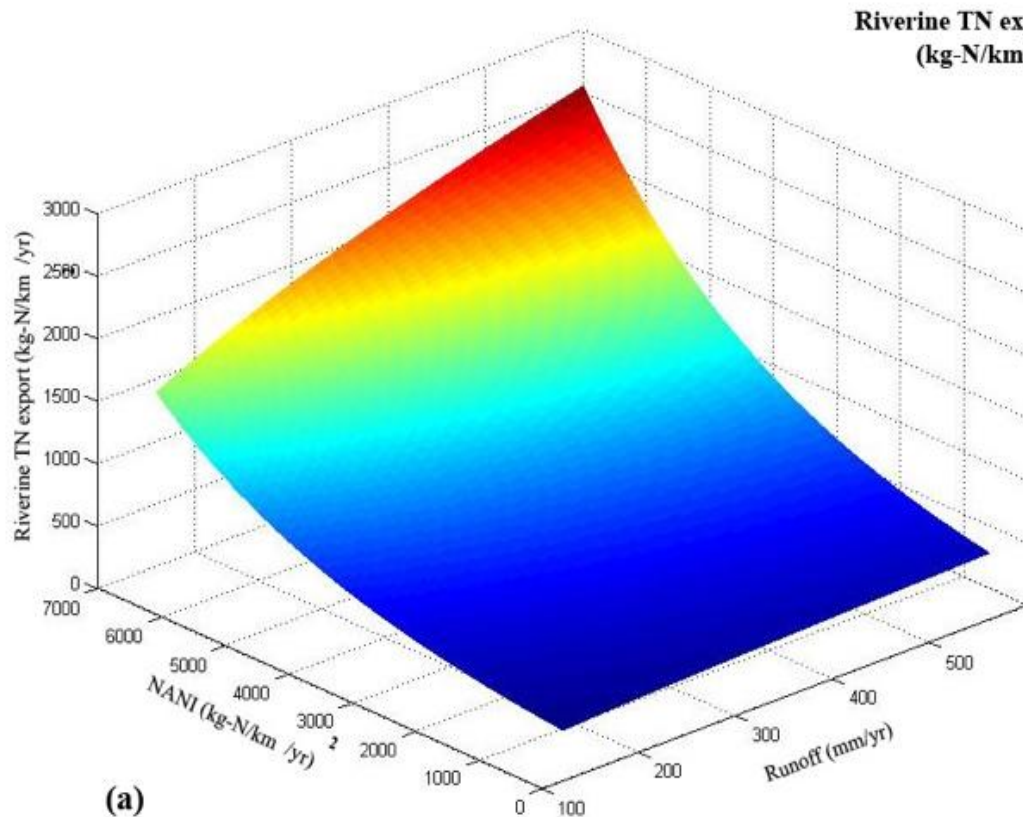
- Quantify all source inputs of N or P to a watershed
 - Useful for comparing total inputs and relative contribution by source, across space and time
- Quantify statistical relationship between total inputs and river export
 - Estimate of fractional export of nutrient
 - Useful for forecasting and backcasting
- Many examples for Nitrogen (Howarth, Boyer, others), rarely undertaken for Phosphorus

Trends in anthropogenic N inputs (kg-N km⁻² yr⁻¹) for the 25 lake Michigan from 1880 to 2002

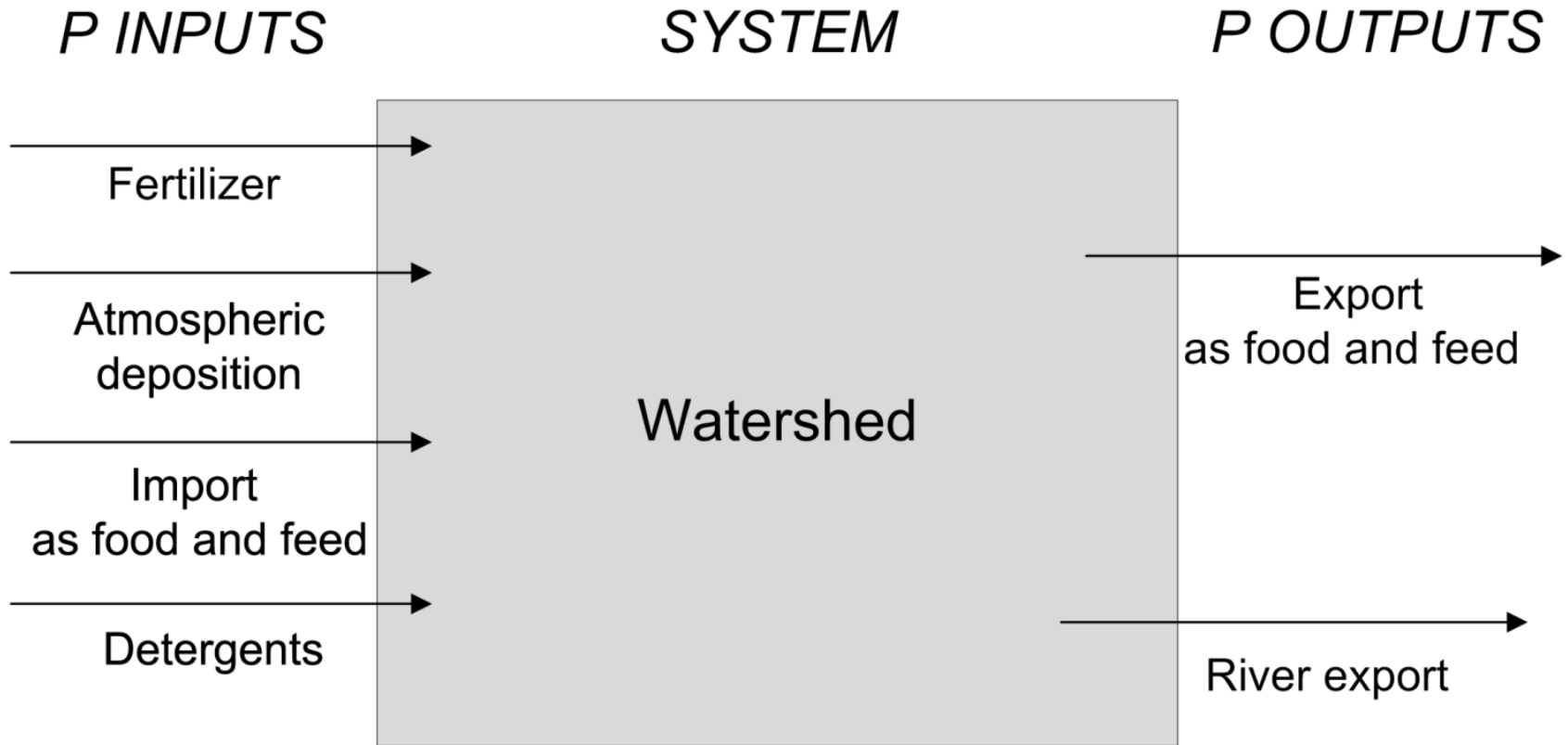


Dependency of riverine TN export on NANI and water discharge
estimated using a panel regression model
(Han et al. , *ES&T* 43(6), 2009)

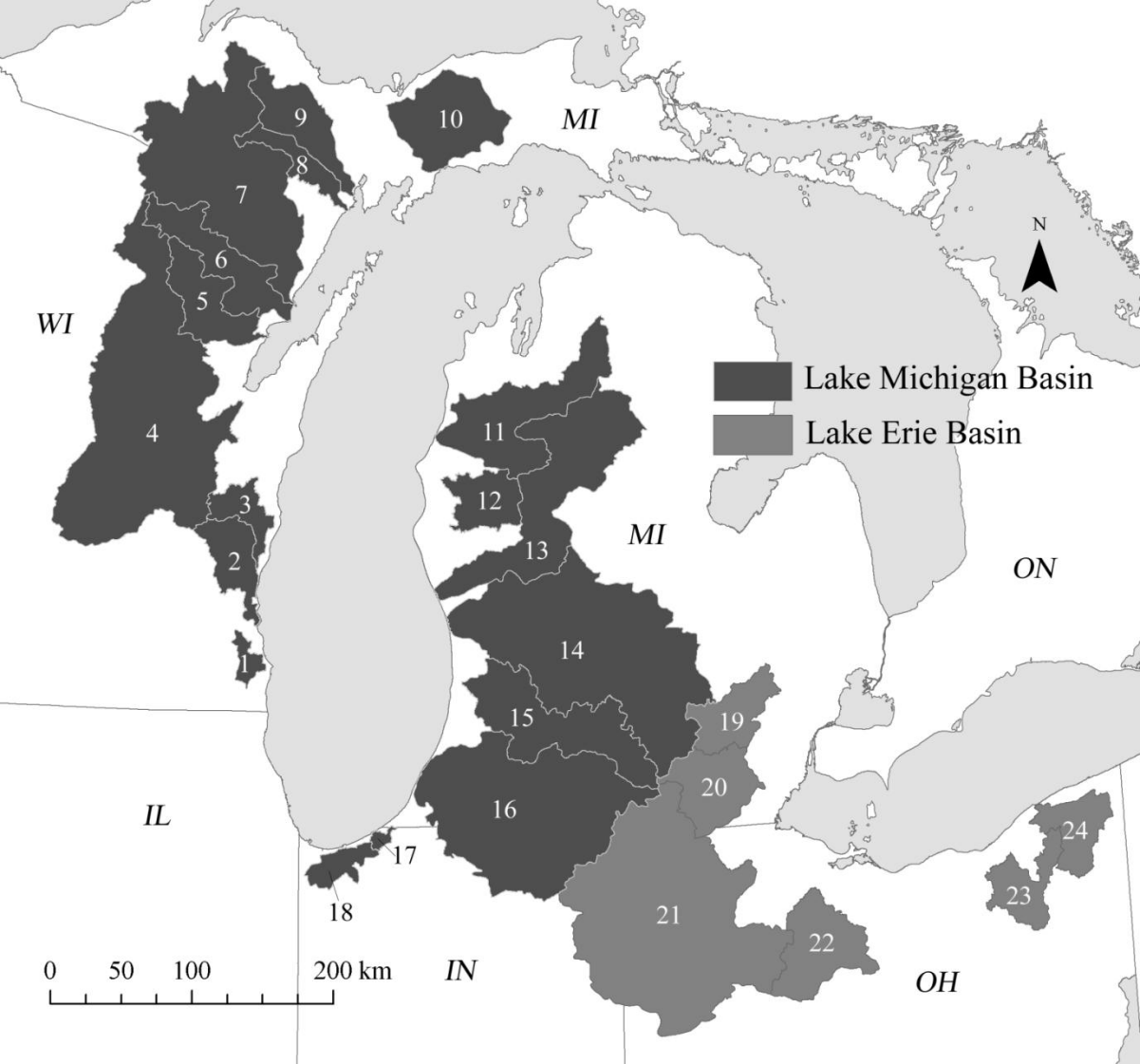
$$TN = 11.65 \times \text{Waterdischarge}^{0.46} \times \exp(3.49 \times 10^{-4} \times \text{NANI})$$



Conceptual diagram for phosphorus budget including inputs, system, and outputs



Locations and areas of the 18 Lake Michigan watersheds and 6 Lake Erie watersheds . Numbers are used to identify watersheds in tabular reporting.



Complete NAPI budgets for each watershed averaged across 5 agricultural census years (1974, 1978, 1982, 1987, 1992).

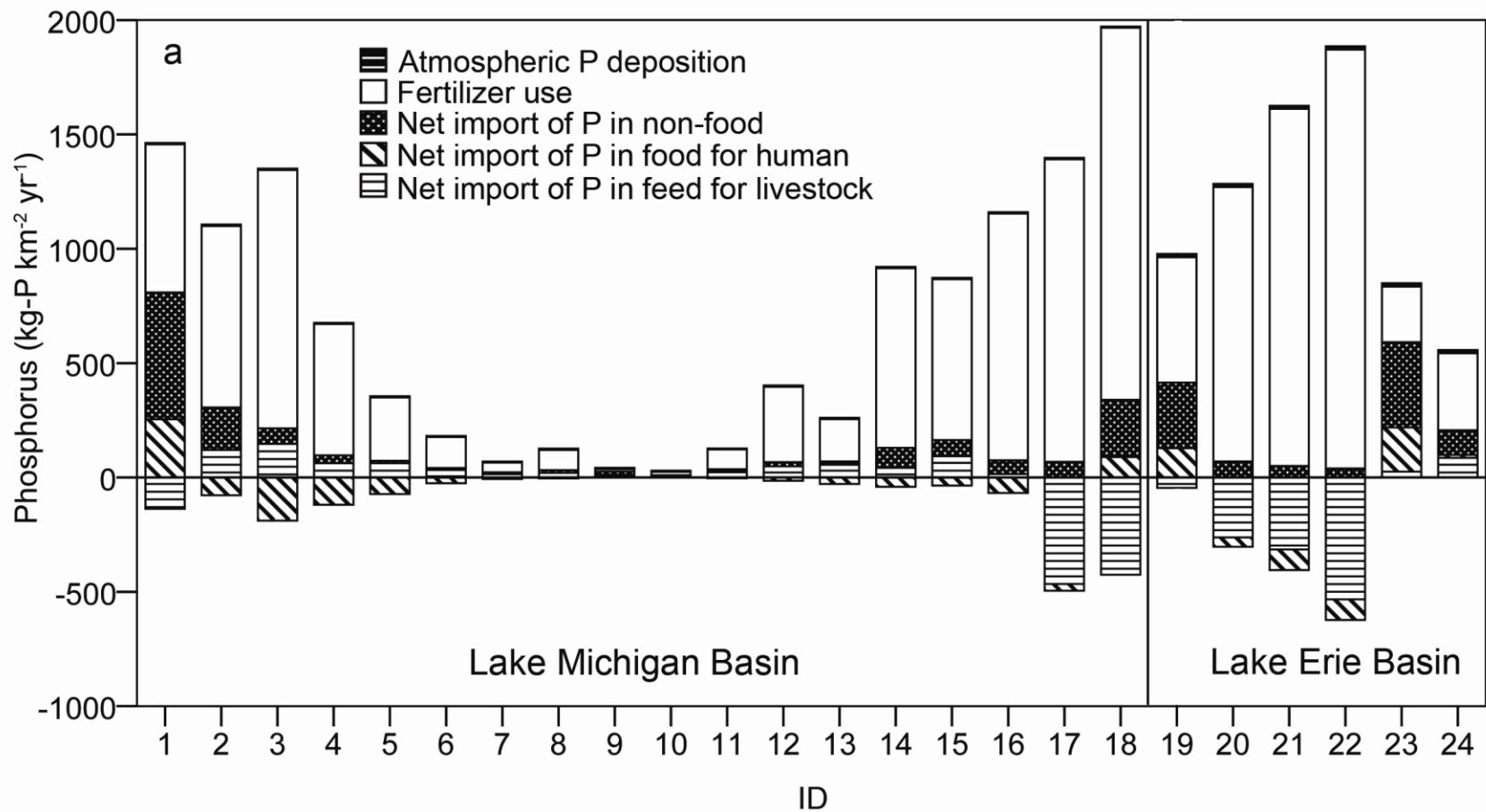
All units in kg-P km⁻² yr⁻¹.

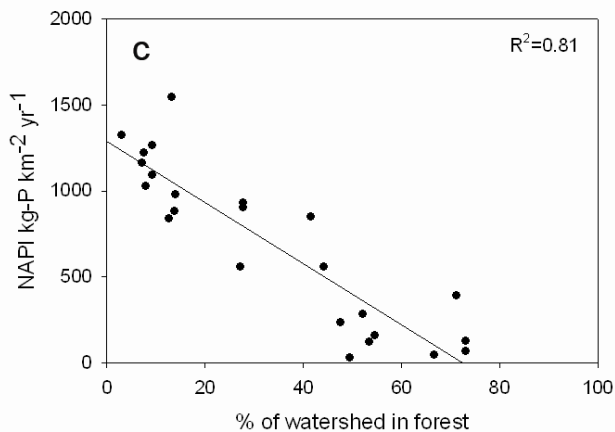
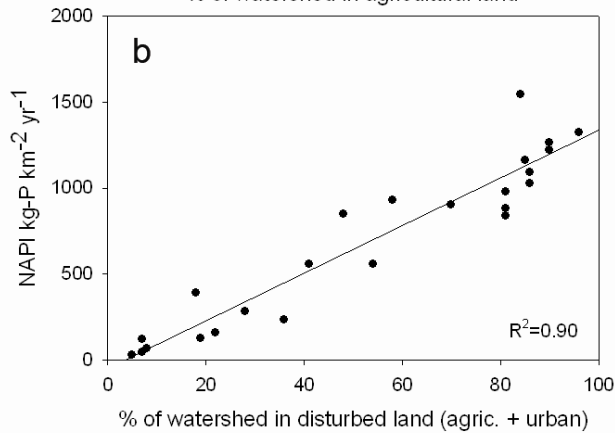
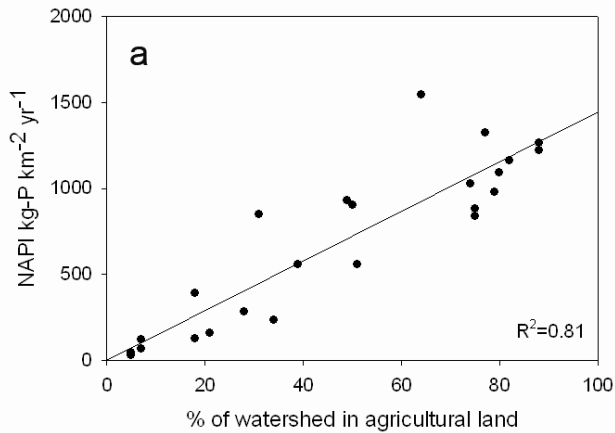
Lake Erie

Key	Watershed name	Atmos. dep.	Fert.	Net import in food	Net import in feed	Detergent	NAPI	Manure	Crop export
19	Huron	14	548	128	-46	182	826	121	269
20	Raisin	14	1203	-42	-262	45	959	160	623
21	Maumee	14	1460	-90	-315	43	1112	154	875
22	Sandusky	14	1858	-89	-533	42	1291	116	908
23	Cuyahoga	15	244	194	25	648	1125	94	124
24	Grand (OH)	15	336	13	85	117	566	176	154
<i>Avg. area-weighted</i>		<i>6</i>	<i>1310</i>	<i>-42</i>	<i>-265</i>	<i>99</i>	<i>1112</i>	<i>145</i>	<i>710</i>

Lake Michigan

Key	Watershed name	Atmos. dep.	Fert.	Net import in food	Net import in feed	Detergent	NAPI	Manure	Crop export
1	Root	6	648	254	-137	415	1186	194	459
2	Milwaukee	6	793	-78	120	92	934	558	605
3	Sheboygan	6	1130	-189	146	62	1156	678	708
4	Fox	6	574	-119	62	25	548	391	449
5	Oconto	6	277	-72	62	8	280	236	225
6	Peshtigo	6	136	-25	33	6	155	97	88
7	Menominee	6	42	-7	14	6	61	39	36
8	Ford	6	88	-4	20	8	117	42	36
9	Escanaba	6	10	6	6	9	36	9	7
10	Manistique	6	14	1	6	2	28	8	7
11	Manistee	6	85	-4	23	9	119	44	41
12	Pere- Marq.	6	329	-14	49	10	380	88	96
13	Muskegon	6	184	-29	56	9	226	125	122
14	Grand (MI)	6	786	-41	42	55	848	234	425
15	Kalamazoo	6	704	-36	93	45	812	200	391
16	St. Joseph	6	1068	-68	15	35	1056	243	662
17	Trail Creek	6	1323	-30	-465	35	869	165	802
18	Burns Ditch	6	1626	89	-426	142	1438	87	637
<i>Avg. area-weighted</i>									
	<i>(LM)</i>	6	501	-50	38	31	558	204	314



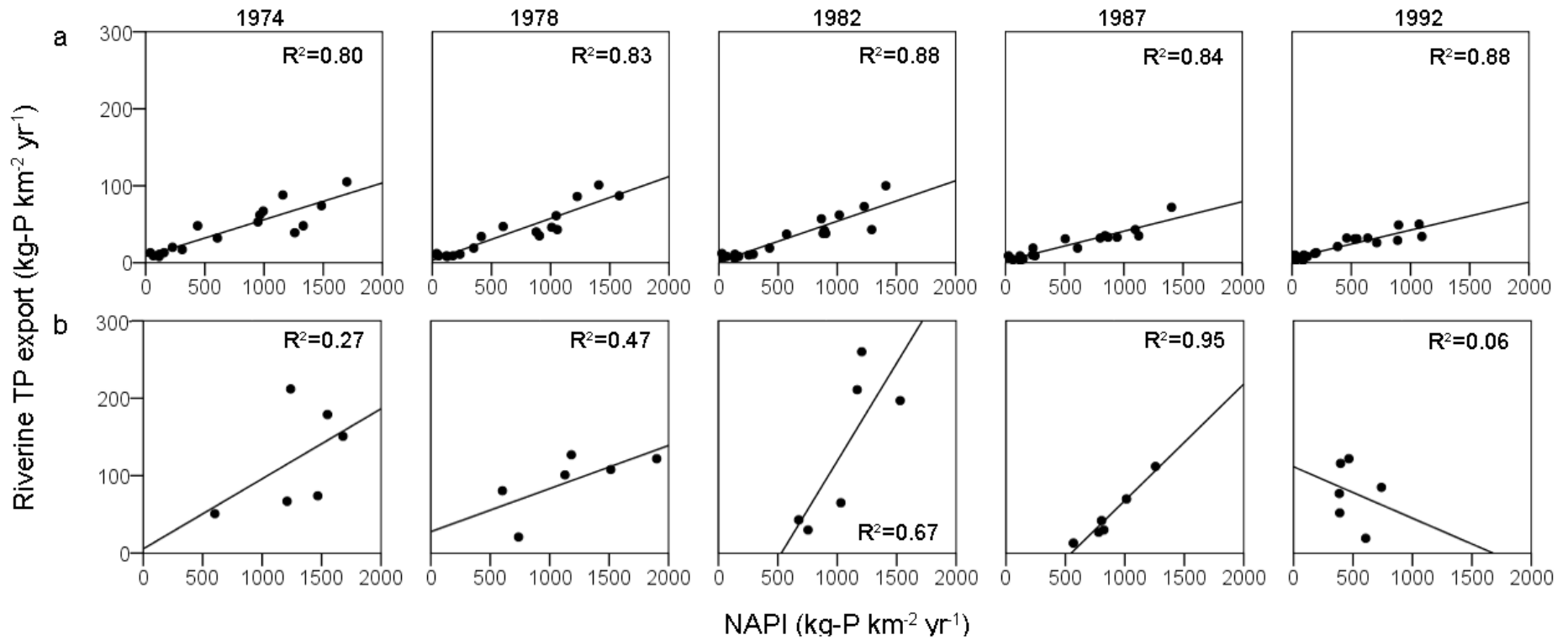


Phosphorus inputs to the 24 LM and LE watersheds are strongly related to land use:

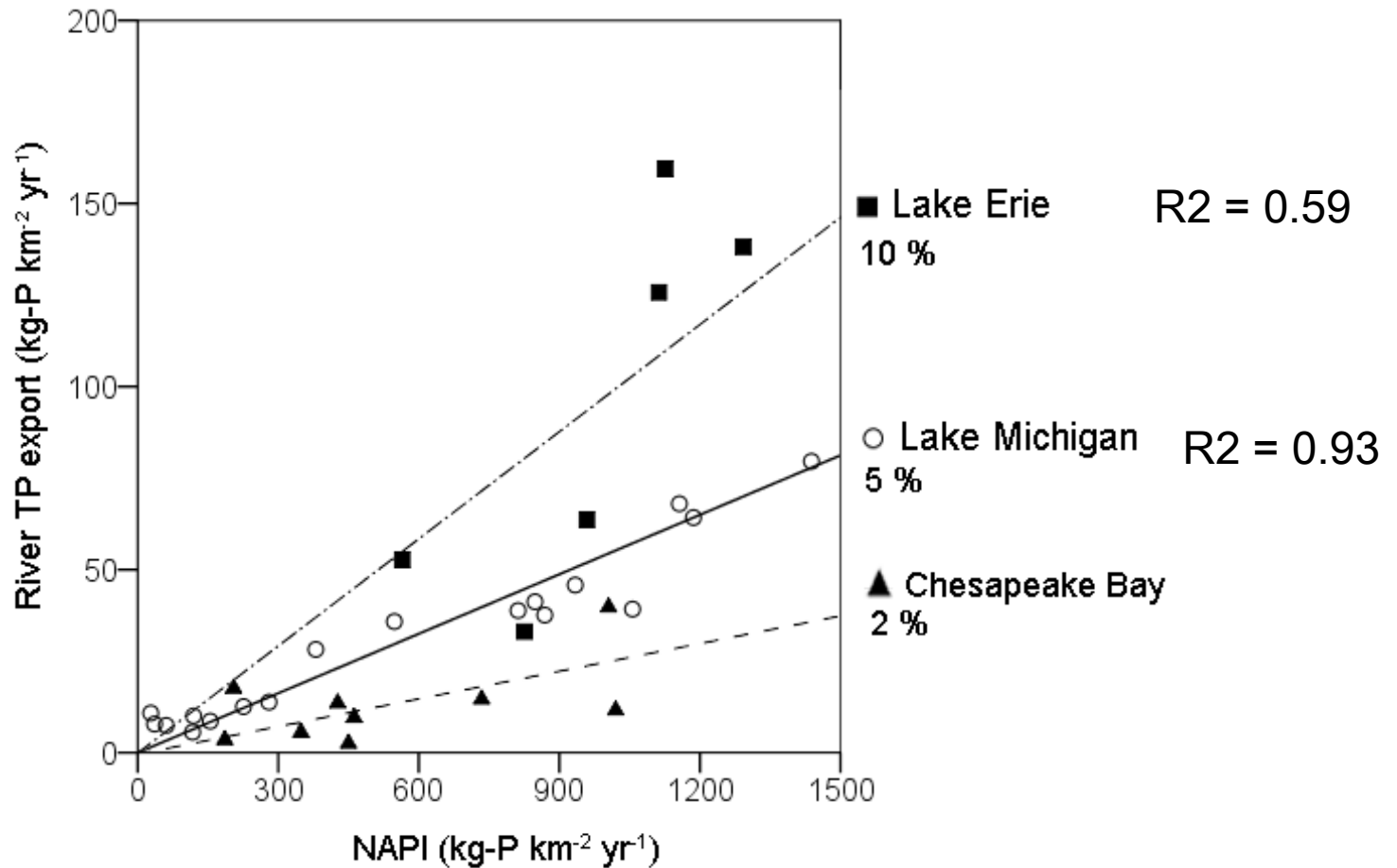
(a) positive relationship with land in agriculture

(b) positive relationship with land in agriculture and urban use combined

(c) negative relationship with forested land



Total phosphorus (TP) export by rivers is positively related to NAPI for Lake Michigan (top) and Lake Erie (bottom) watersheds across the 5 agricultural census years



The relationship between river total phosphorus export and NAPI appears to differ regionally for individual watersheds of the Lake Erie, Lake Michigan and Chesapeake Bay basins. Chesapeake Bay data from Russell et al. (2009) for 9 primarily forested watersheds.

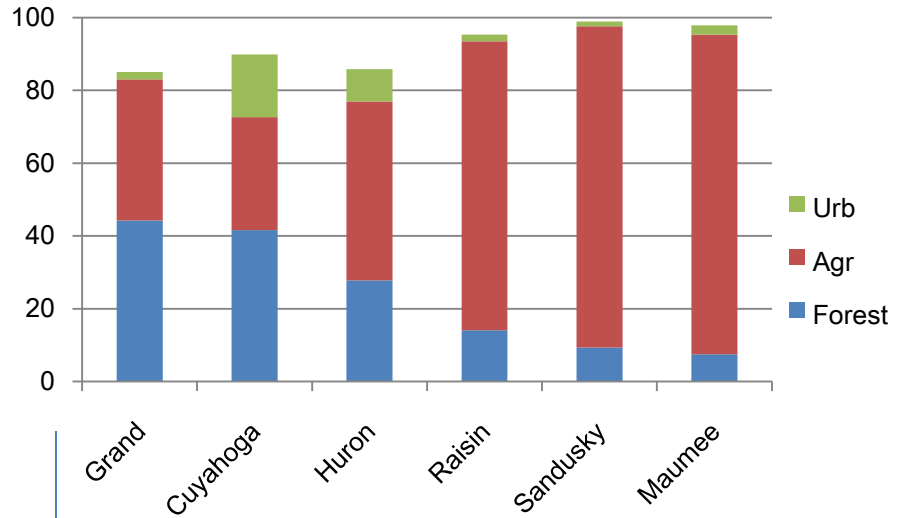
A linear regression was used to fit the data for the three basins without intercepts to allow comparison of fractional delivery among regions.

Why regional differences?

- Land use
 - Chesapeake Bay forested land > LM > LE
 - LE fertilizer use 3X LM on average
 - LM manure application > LE
- Soils
 - More loam, sand and gravel in LM, more clay in LE
- Hydrology
 - Higher precip in LE watersheds exports more P
- Other?
 - Legacy effects, shift to no-till.....

Watershed I and cover

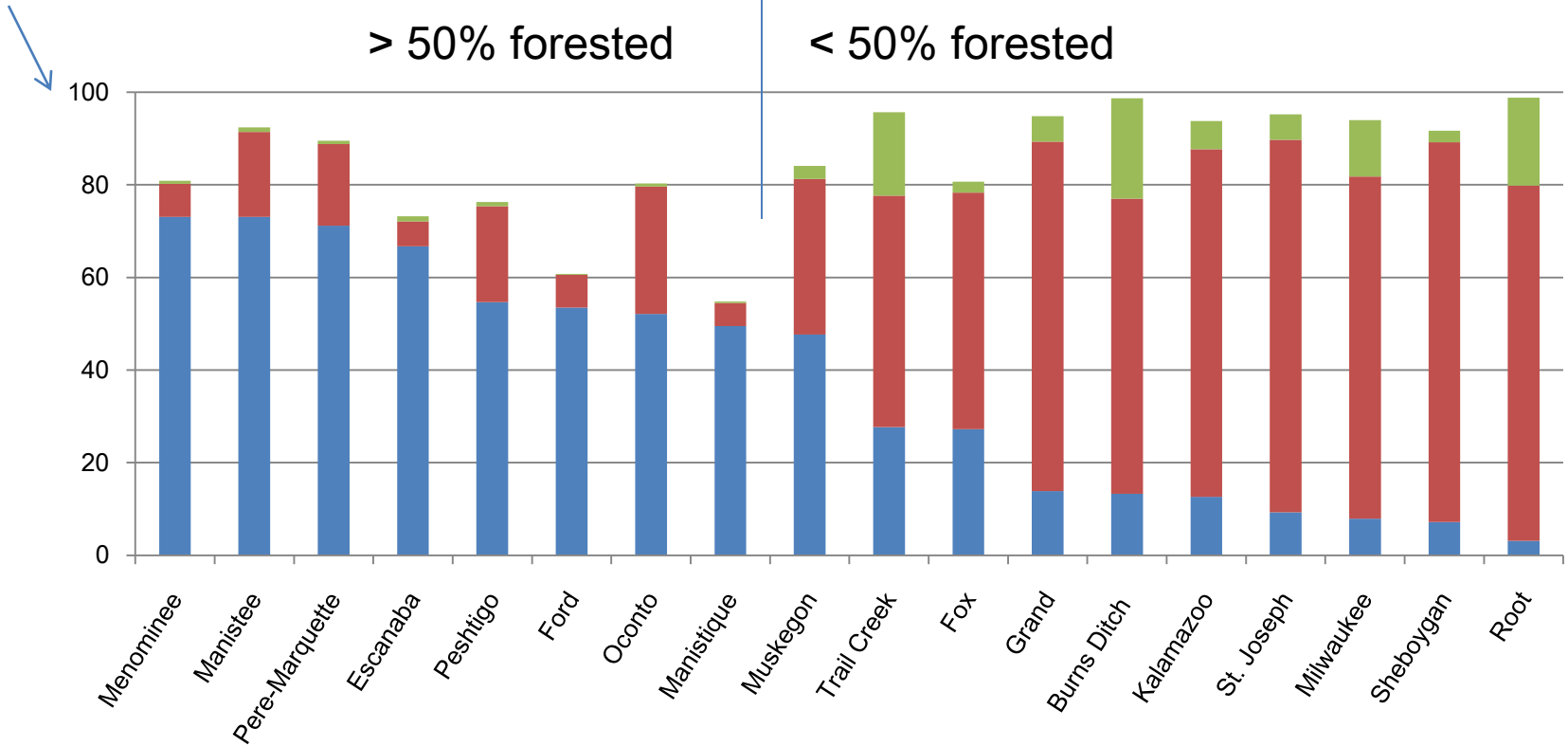
Lake Erie watersheds →



Lake Michigan watersheds

> 50% forested

< 50% forested



Acknowledgements

- Dave Dolan for river P concentrations
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- NOAA award NA07OAR432000 (Ecofore)