GREAT LAKES AND WATER QUALITY

A REGIONAL PERSPECTIVE

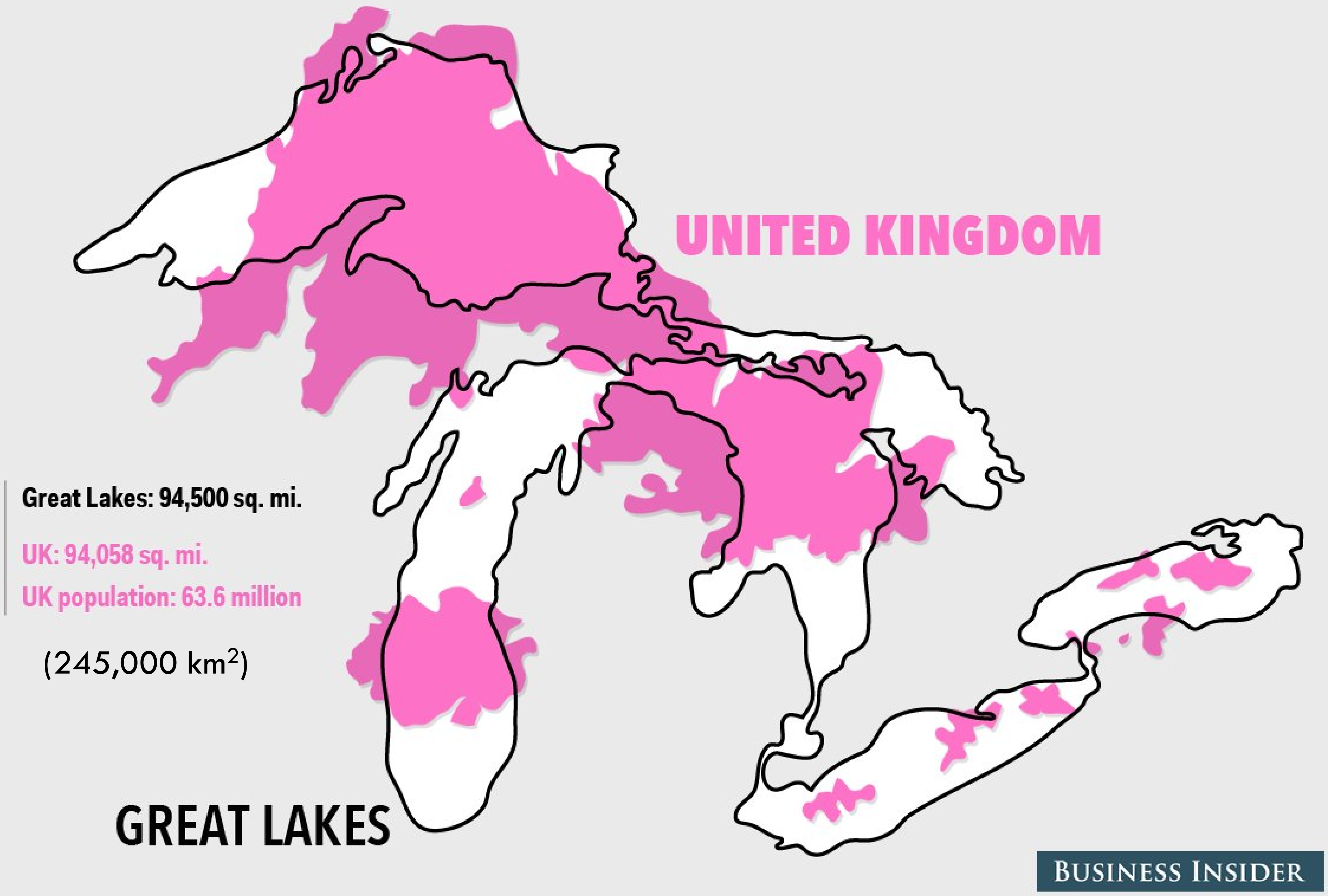
Nandita Basu & Philippe Van Cappellen

UNIVERSITY OF WATERLOO

LAURENTIAN GREAT LAKES (LGL)

- 244,106 km^2
- 22,671 km^3
- 80% North America's surface freshwater
- 17,000 km shoreline
- 214,000 ha coastal wetlands
- 170+ fish species
- 8 US States, Ontario, Indigenous Peoples
- Border Waters Treaty: 1909
- International Joint Commission (IJC)

The UK can fit inside the Great Lakes.



(245,000 km^2)

GREAT LAKES BASIN

- Gross Regional Product: ~US$ 6 trillion
- ~50% Canada's population
- 8 out of Canada's 20 largest cities
- 60% national GDP
- 25% Canada's farmland

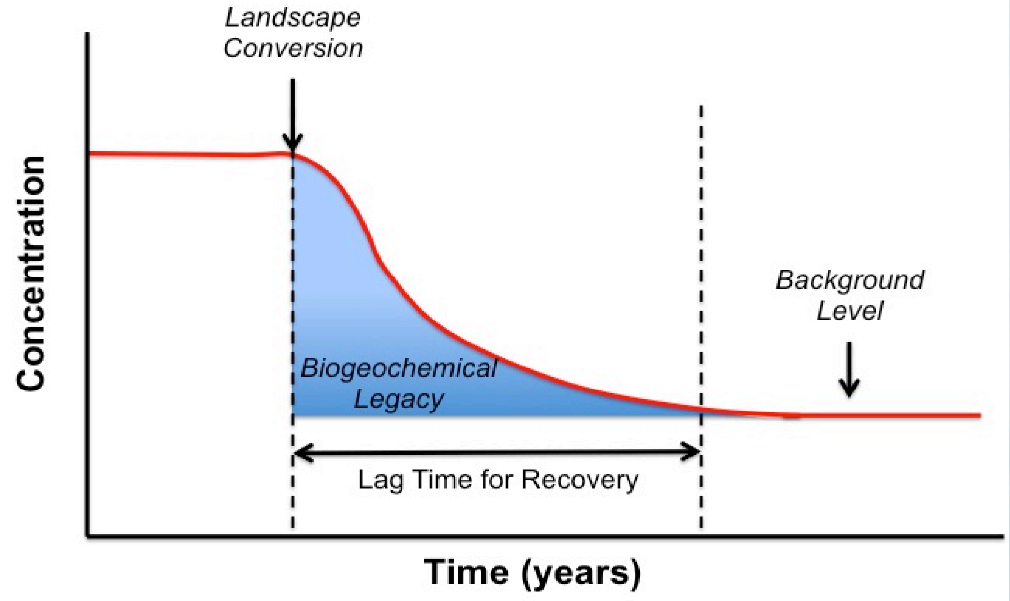
Pressures: intensive agriculture, coastal development, urban growth, climate warming, water-level changes, legacy and emerging contaminants, habitat loss, invasive species, …

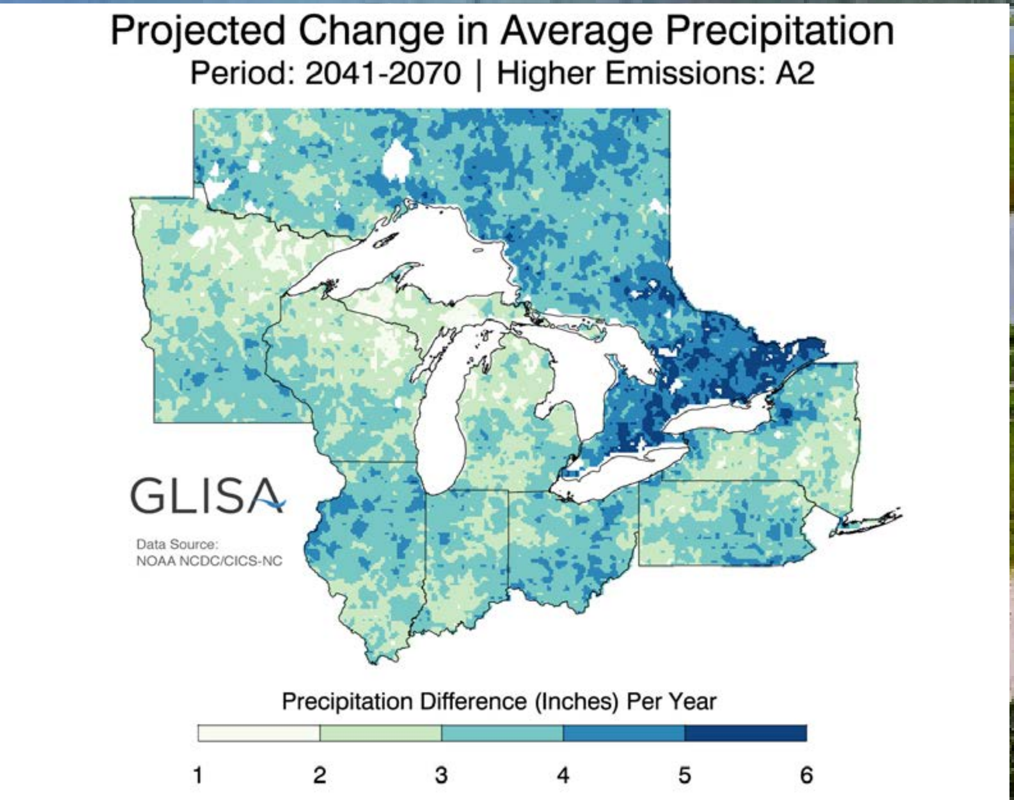
5-year fight removes less than 1% of phosphorus from Lake Winnipeg basin

Targeted action needed against nutrient causing toxic algae blooms, scientists and advocates say

By Cameron MacLean, CBC News   Posted: Sep 17, 2017 4:00 AM CT | Last Updated: Sep 17, 2017 11:02 AM CT

Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds





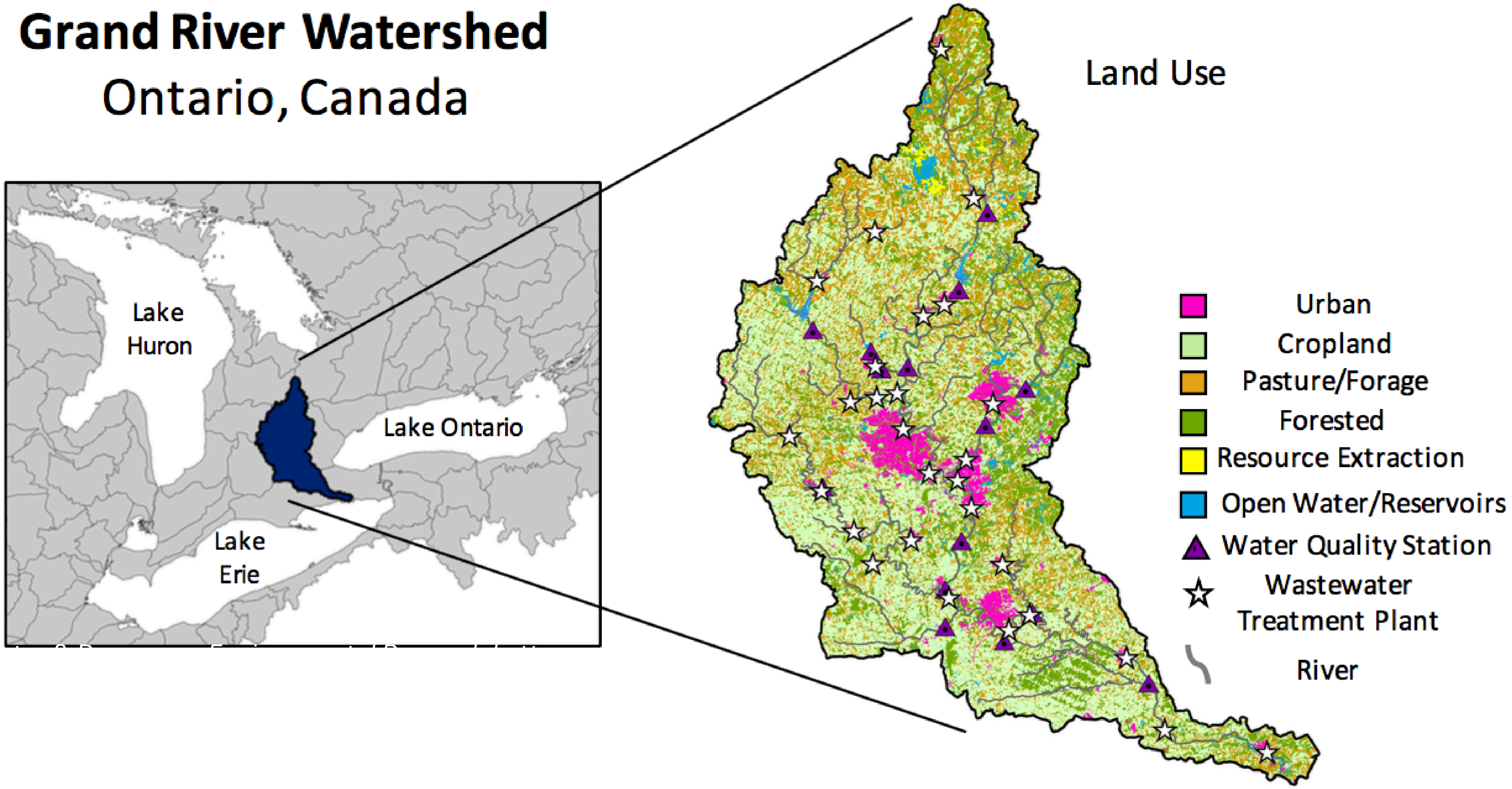
Respect Legacy

If we make changes to the landscape today, how long will it take to improve water quality?

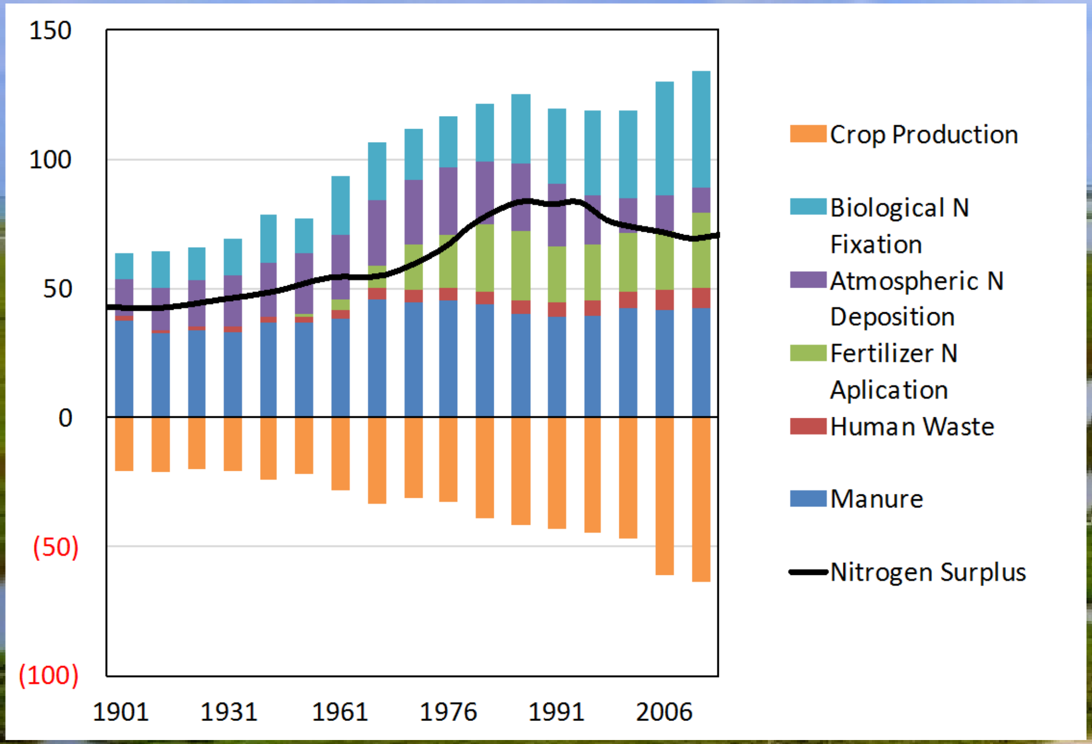
Embrace Dynamics

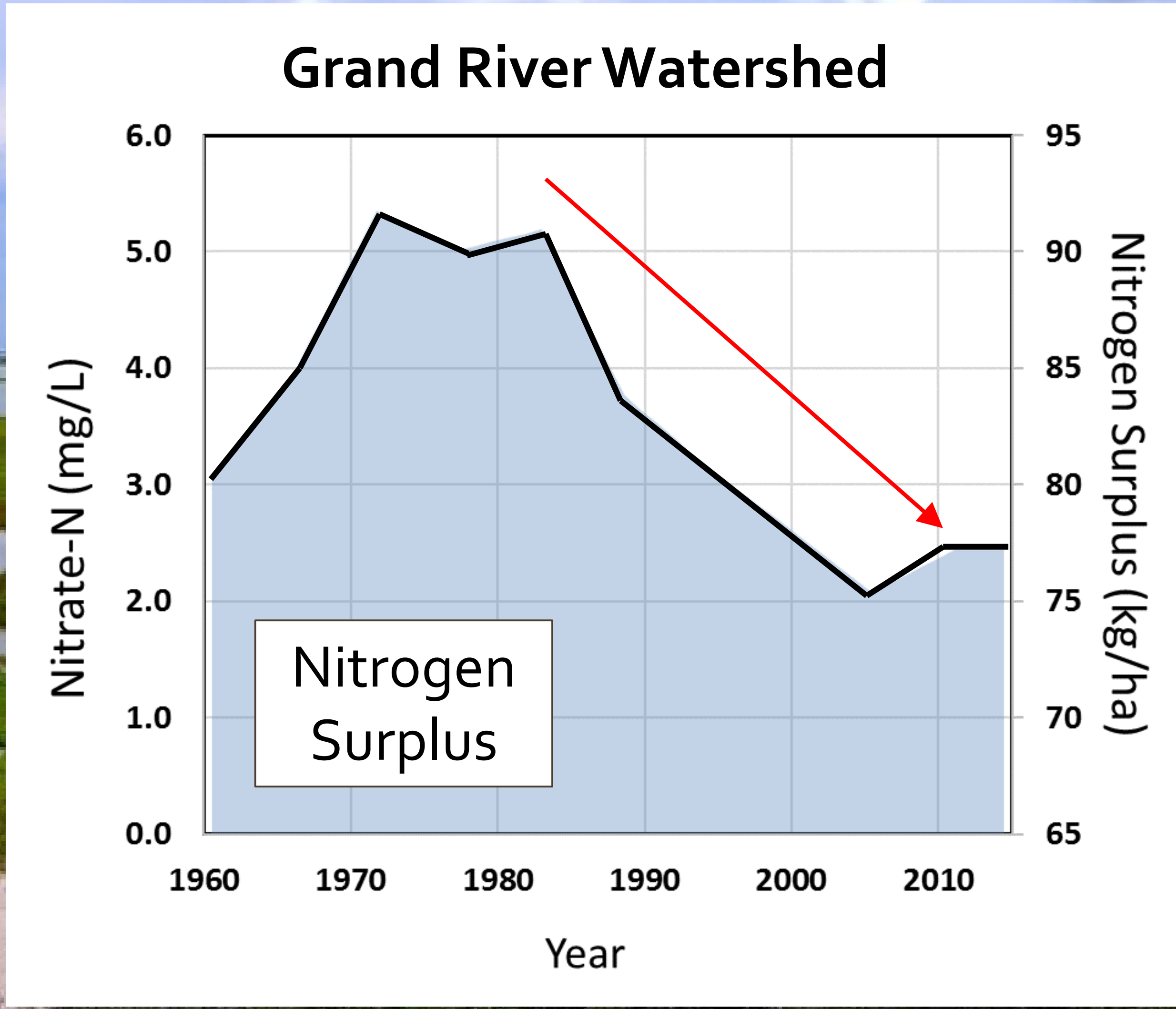
How does changing climate impact water quality risks?

Quantifying Lag Times using Measured Data



Watershed Mass Balance

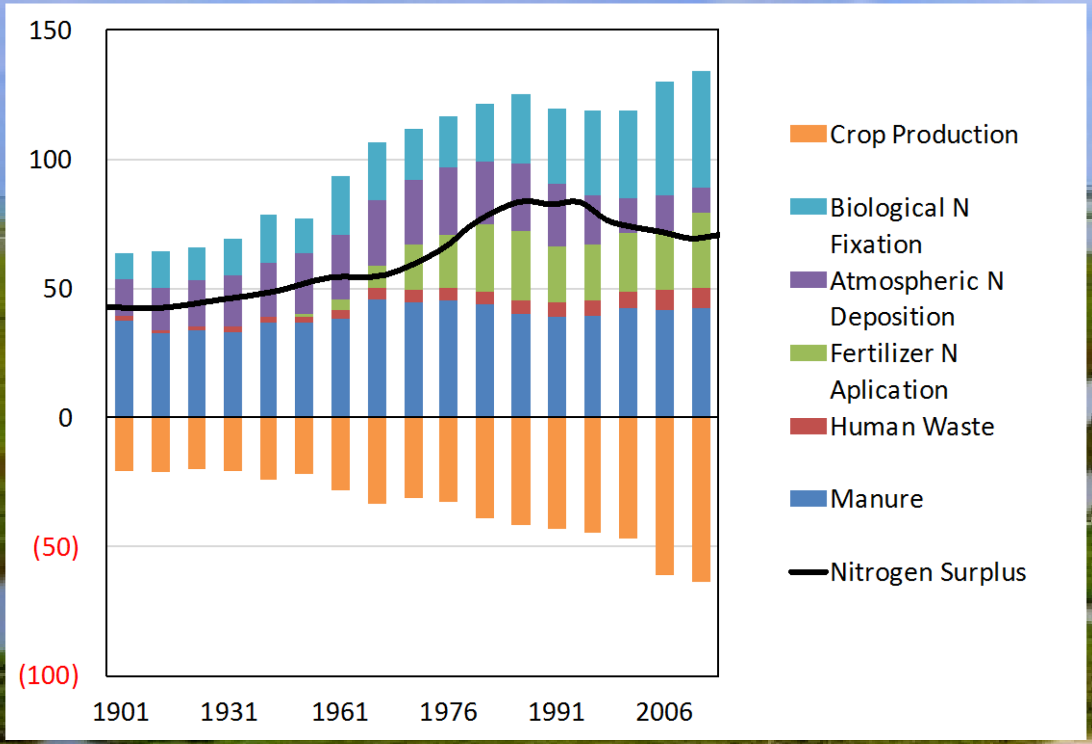


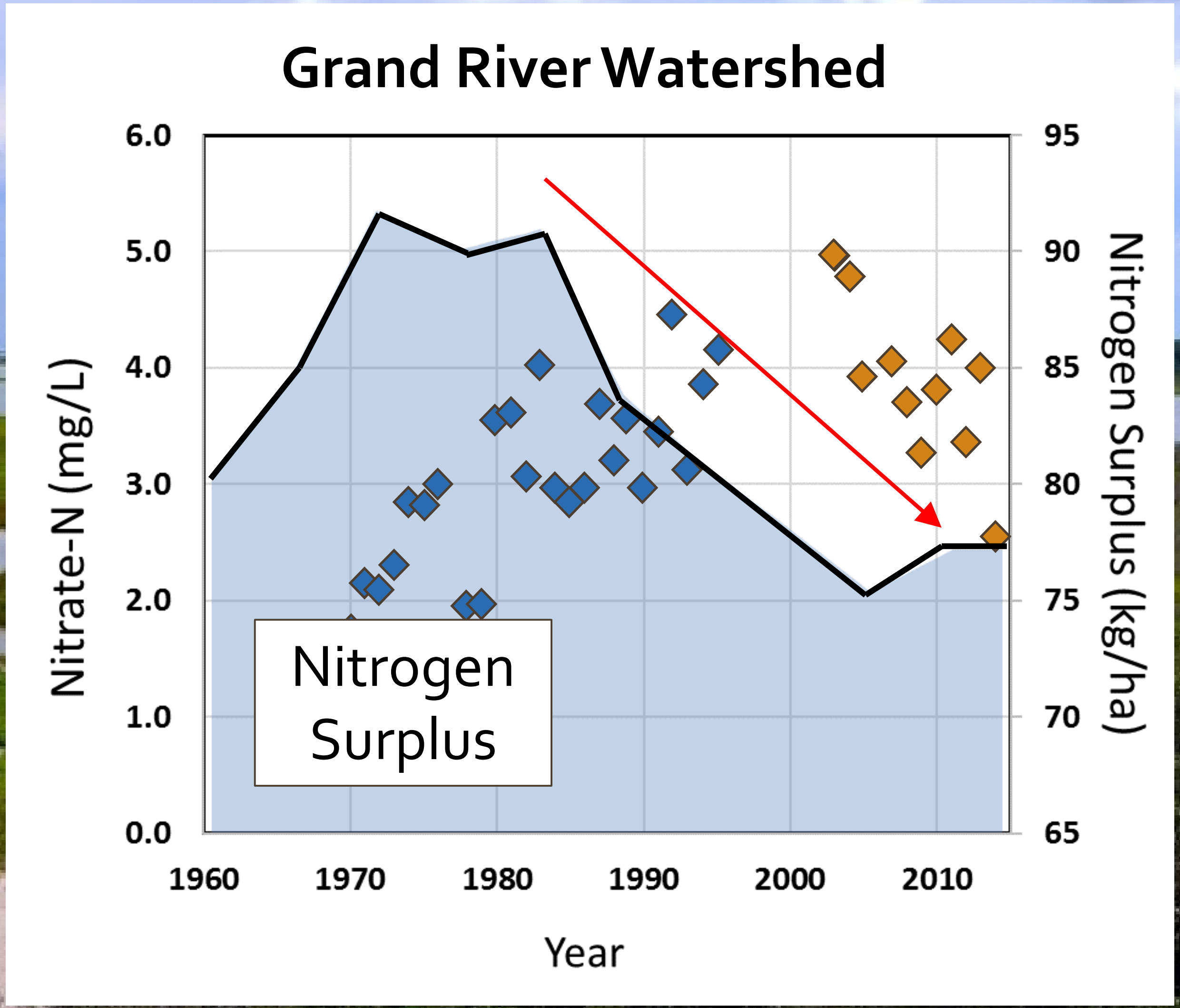


Van Meter & Basu, 2017, *Environmental Research Letters*

Time Lags in Watershed Response

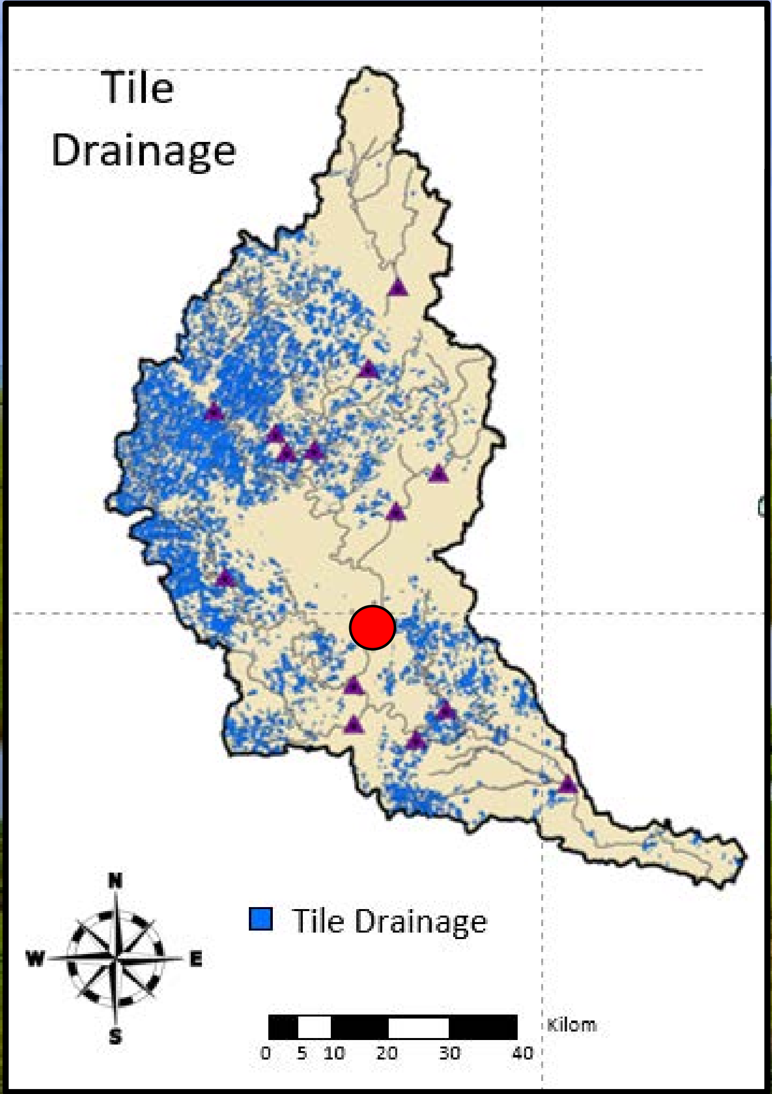
Spring Nitrate Concentrations (mg/L)

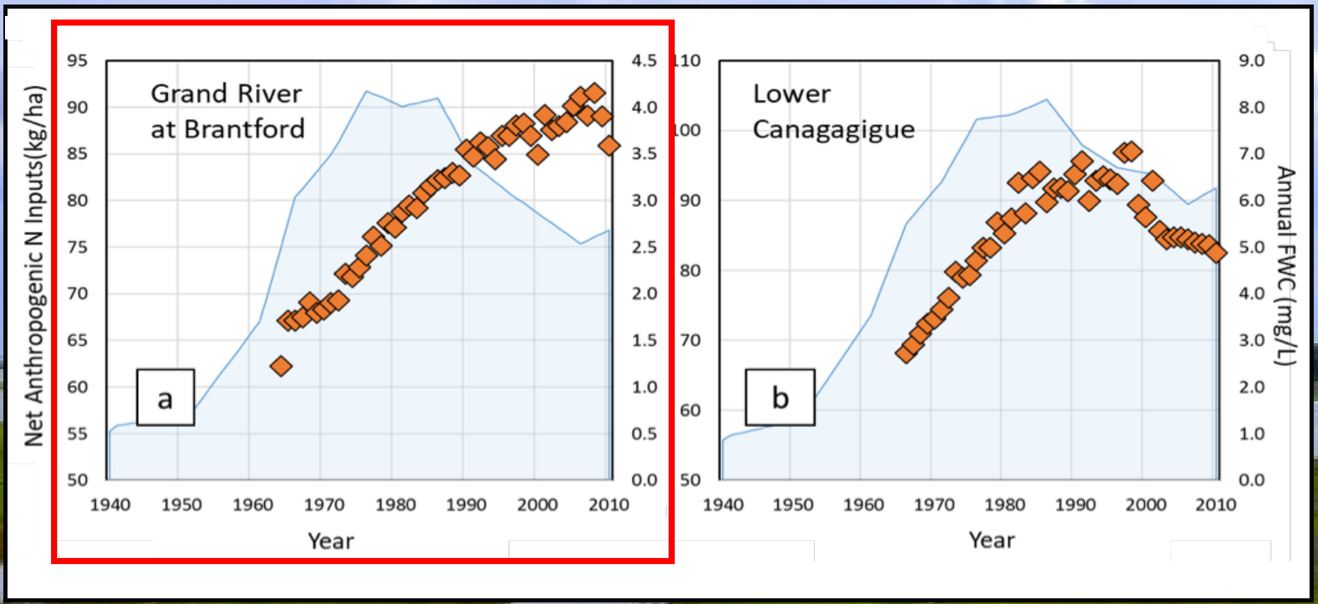




Van Meter & Basu, 2017, *ERL*

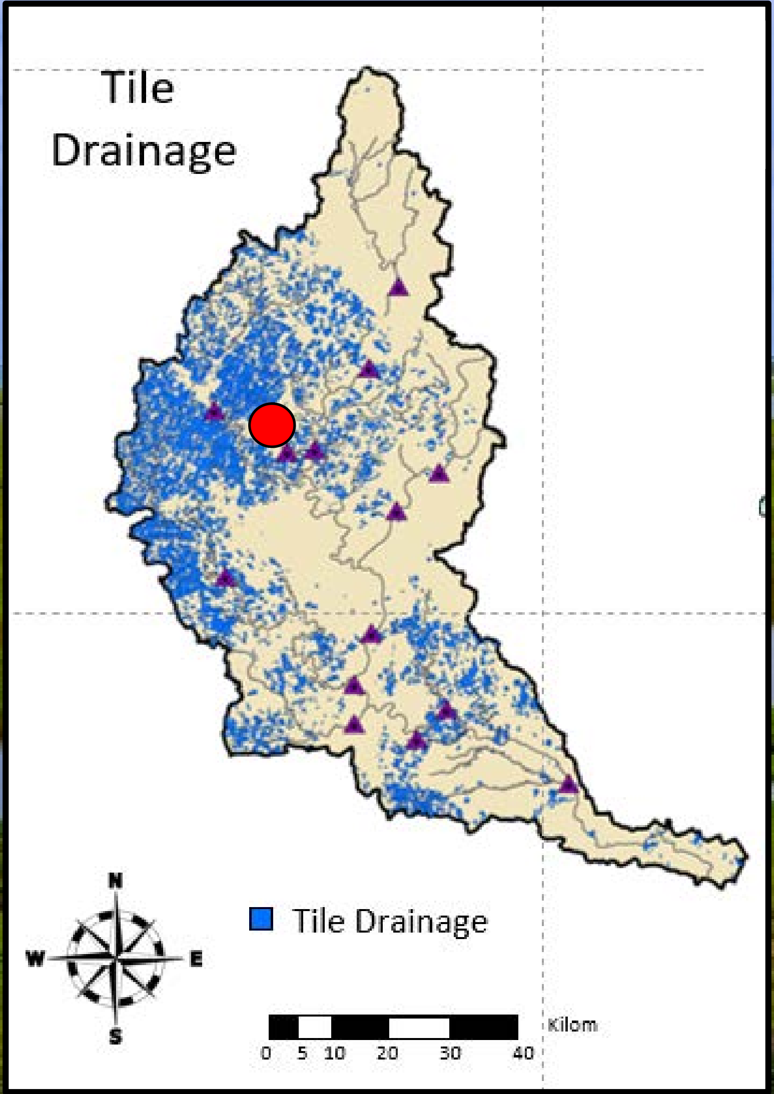
Time Lags in Watershed Response

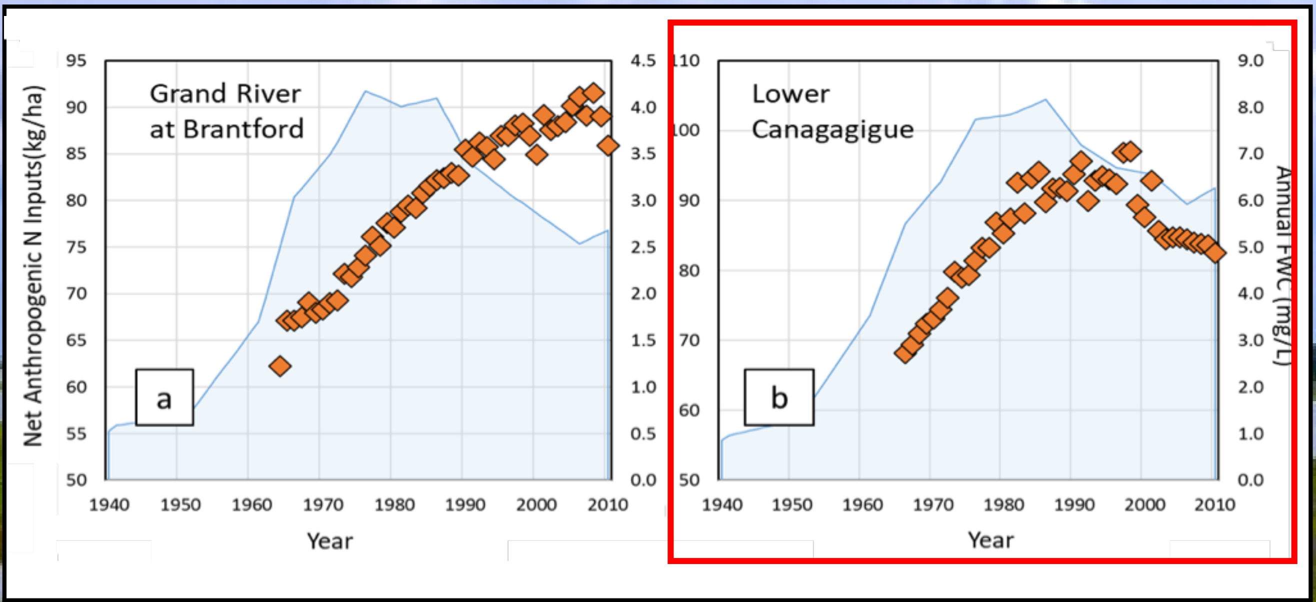




Van Meter & Basu, 2017, *ERL*

Time Lags in Watershed Response



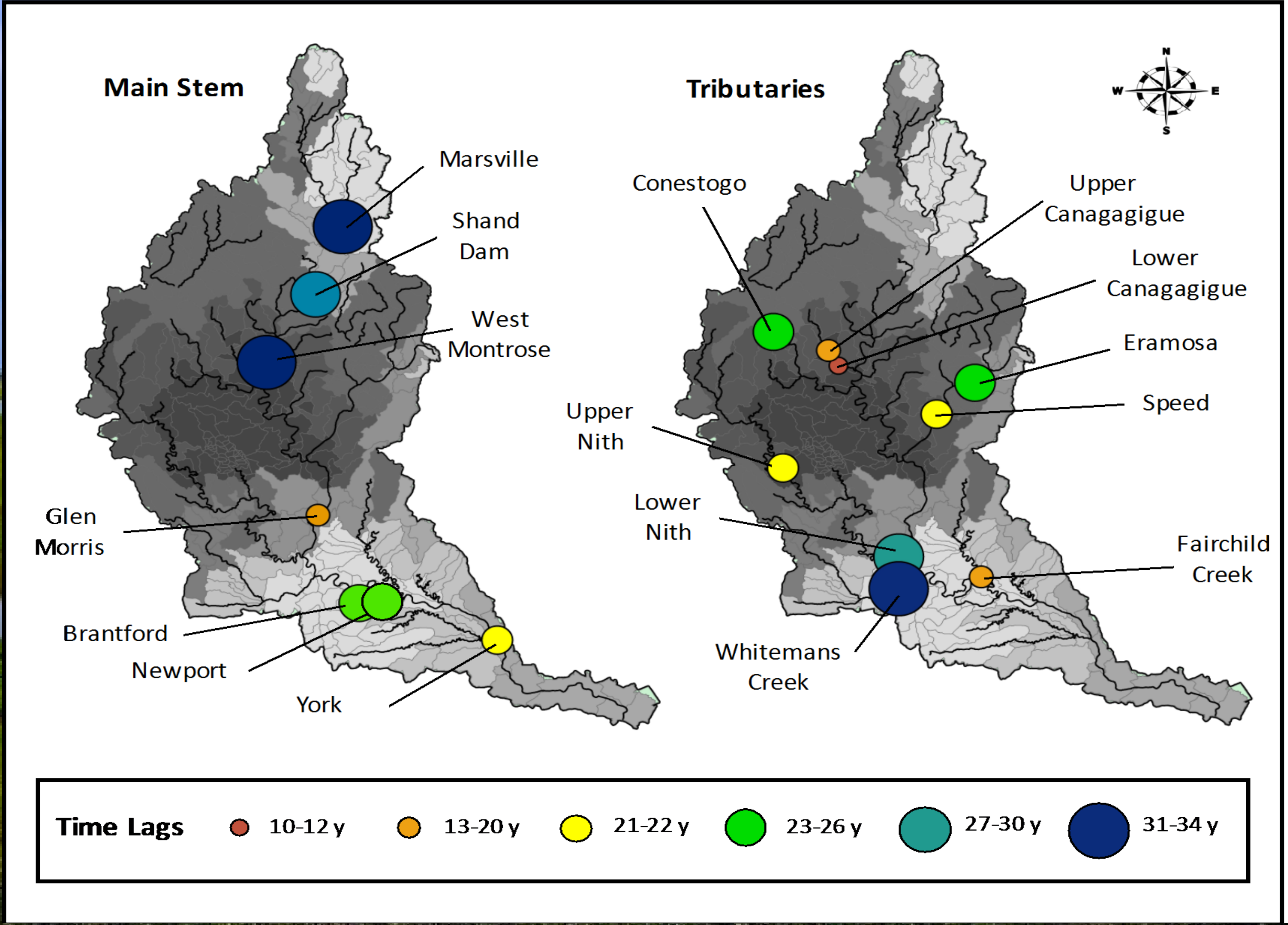


Van Meter & Basu, 2017, *ERL*

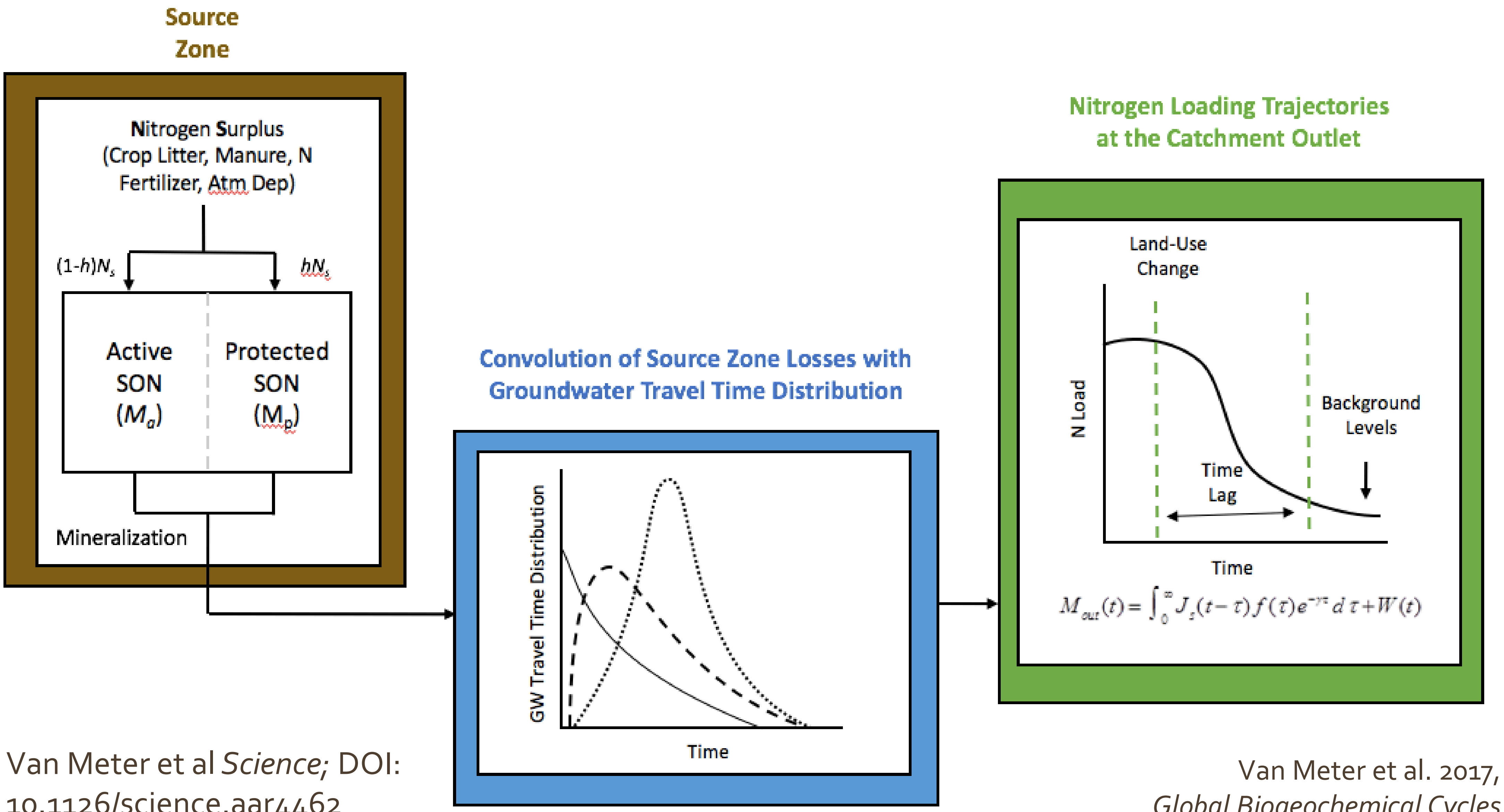
Time Lags in Watershed-Scale Nutrient Transport

An Exploration of Dominant Controls

Van Meter and Basu, Environmental Research Letters



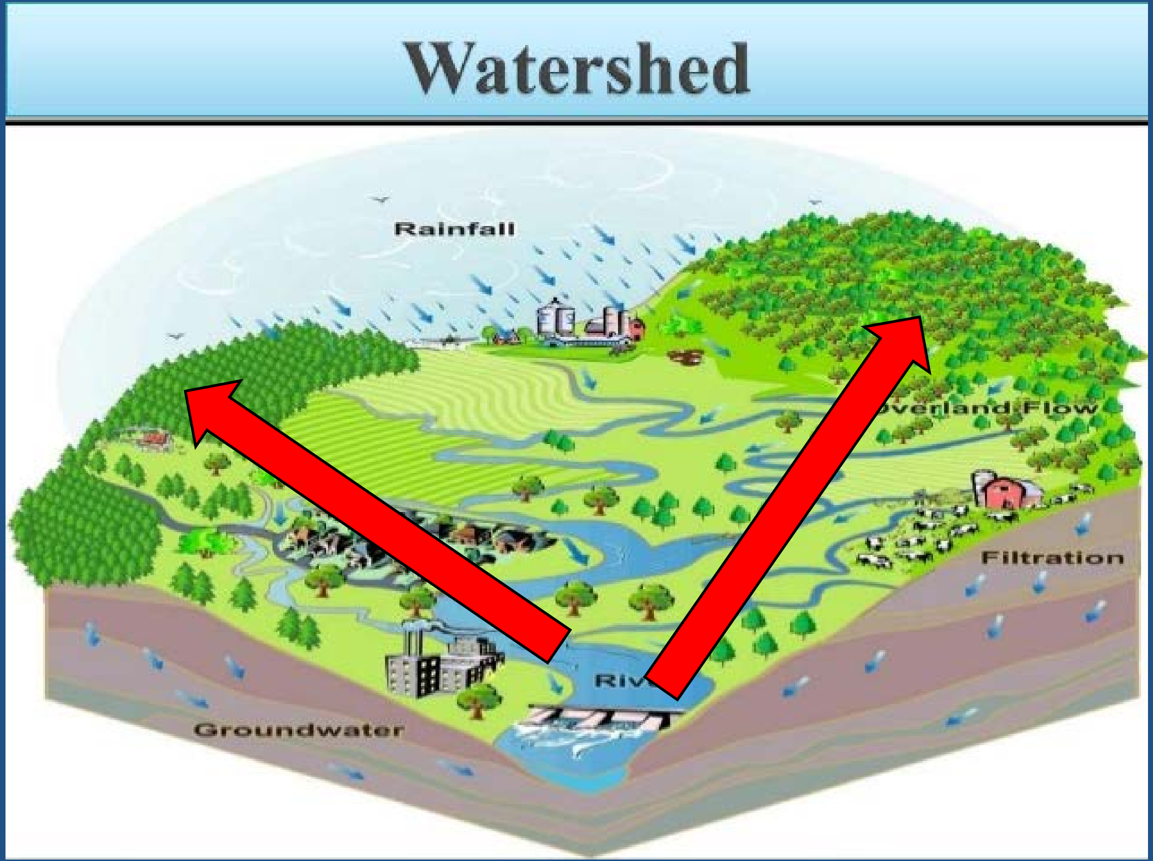
ELEMeNT (Exploration of Long-tErM Nutrient Trajectories)



Van Meter et al *Science;* DOI: 10.1126/science.aar4462

Van Meter et al. 2017, *Global Biogeochemical Cycles*

Rivers as Integrators

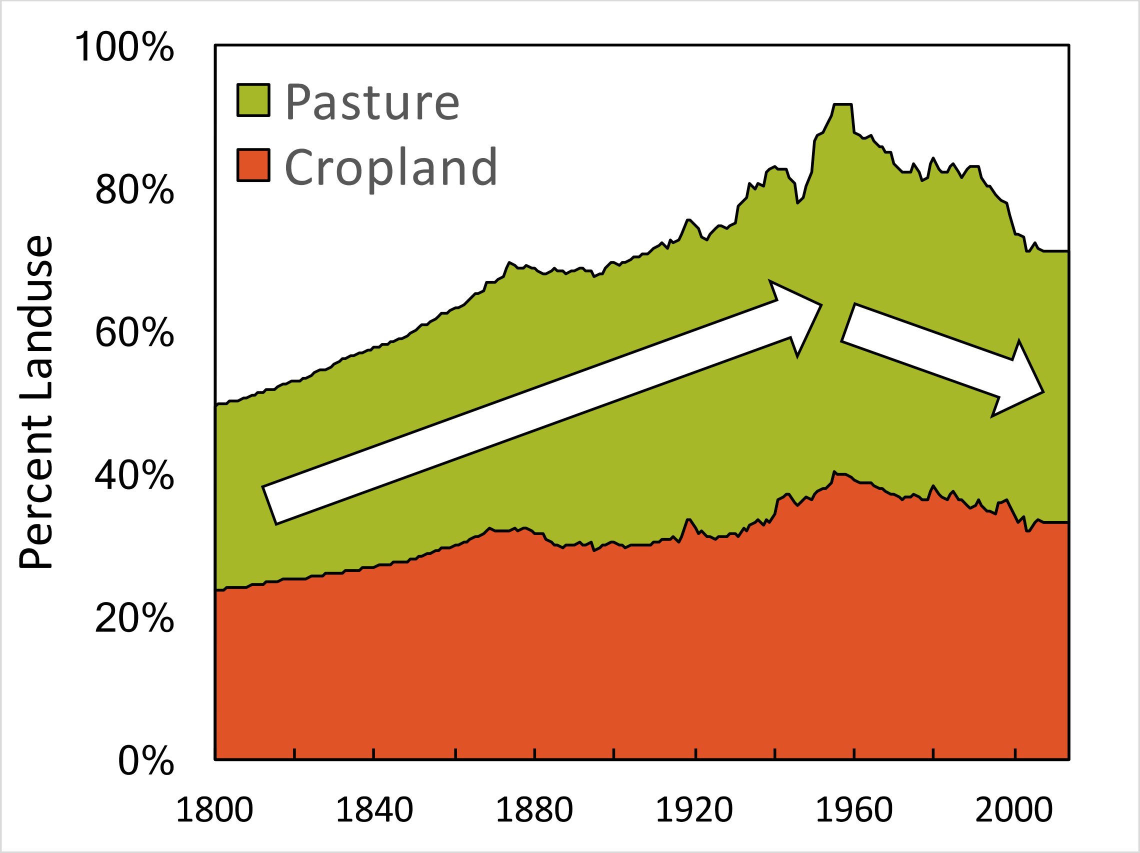


Water quality is an integrated function of all inputs, processes and pathways across the watershed

$$WQ = \int_0^{S} \begin{matrix} Nutrient\ Inputs, \\ Land\ Use, \\ Transport\ Pathways, \\ Retention\ Mechanisms \end{matrix}$$

Rivers as Integrators





Water quality is an integrated function of land use history, management history, and residence times within the catchment

$$WQ = \int_0^t \begin{matrix} \textit{input trajectories} \\ \textit{land use trajectories,} \\ \textit{soil residence times,} \\ \textit{GW travel times} \end{matrix}$$

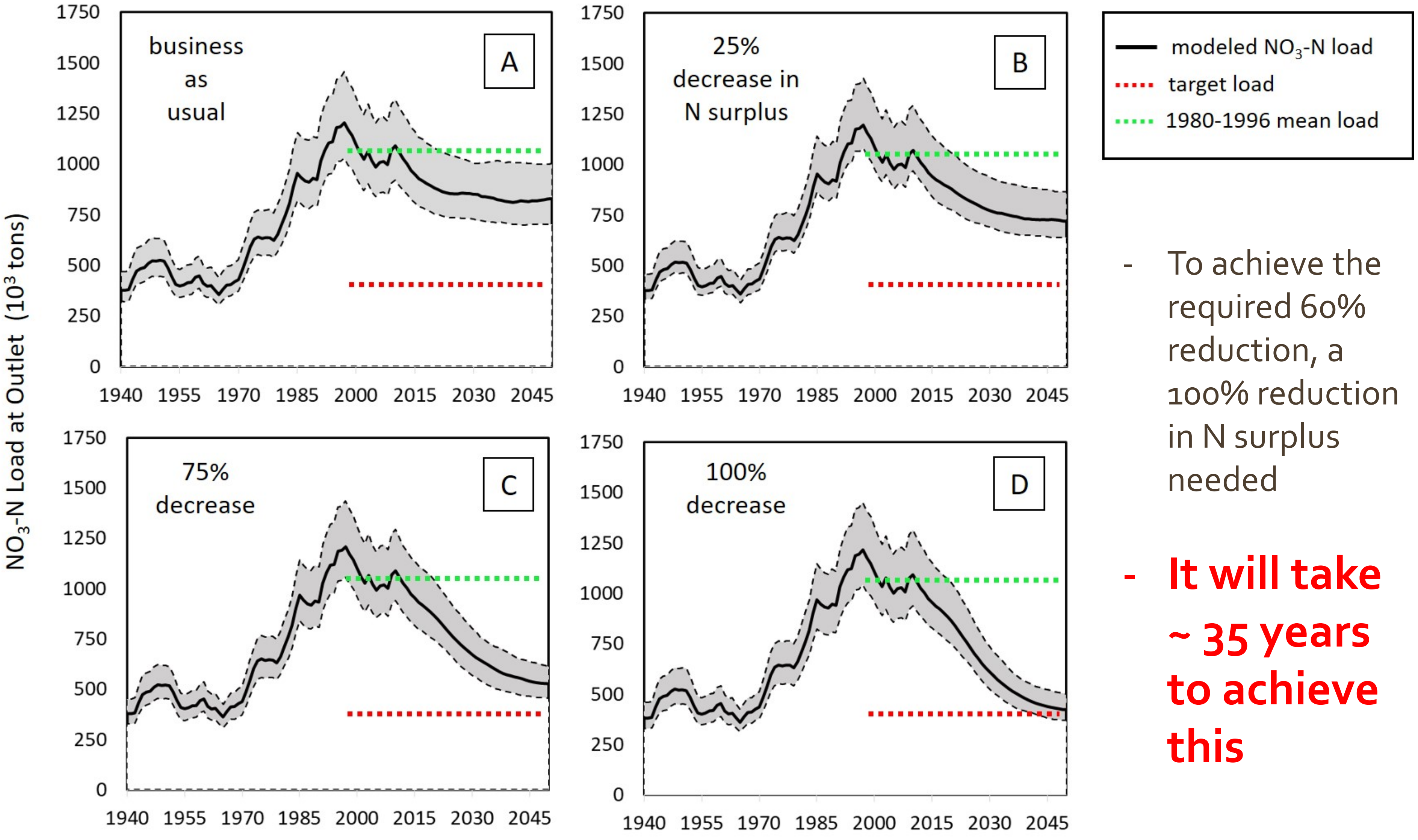
Prediction is very difficult… especially if it's about the future.

-Nils Bohr

Legacy nitrogen may prevent the achievement of water quality goals in the Gulf of Mexico

Van Meter, Van Cappellen and Basu, *Science;* DOI: 10.1126/science.aar4462

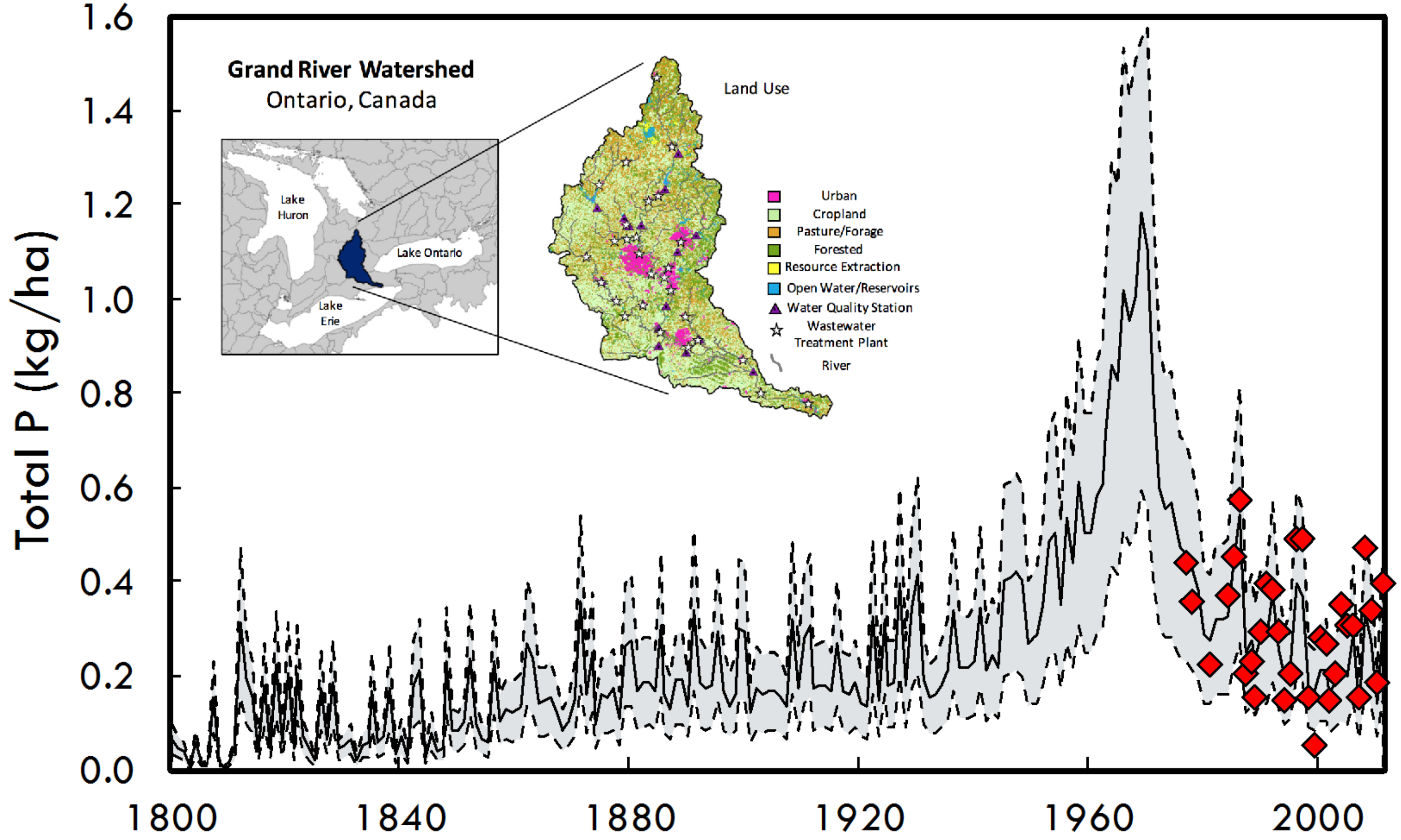
How long will it take to improve water quality in the Mississippi River Basin?



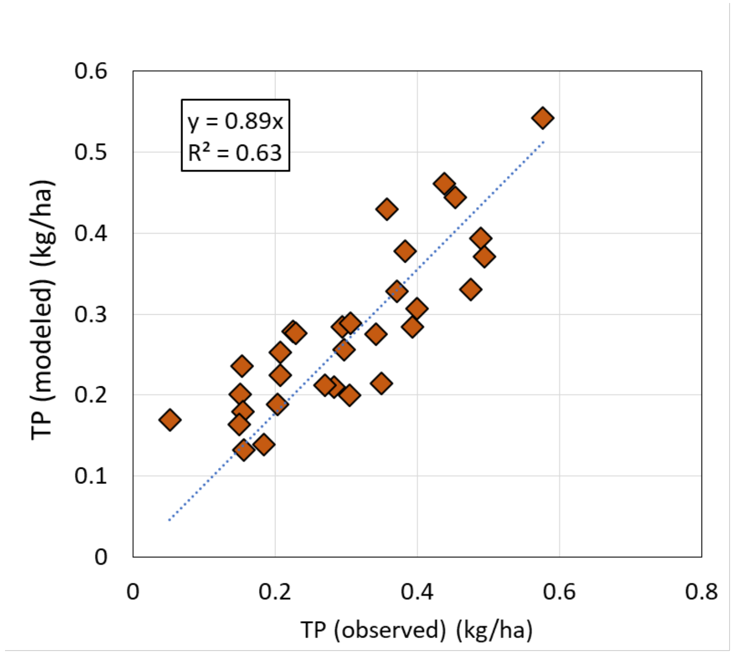
- To achieve the required 60% reduction, a 100% reduction in N surplus needed
- **It will take ~ 35 years to achieve this**

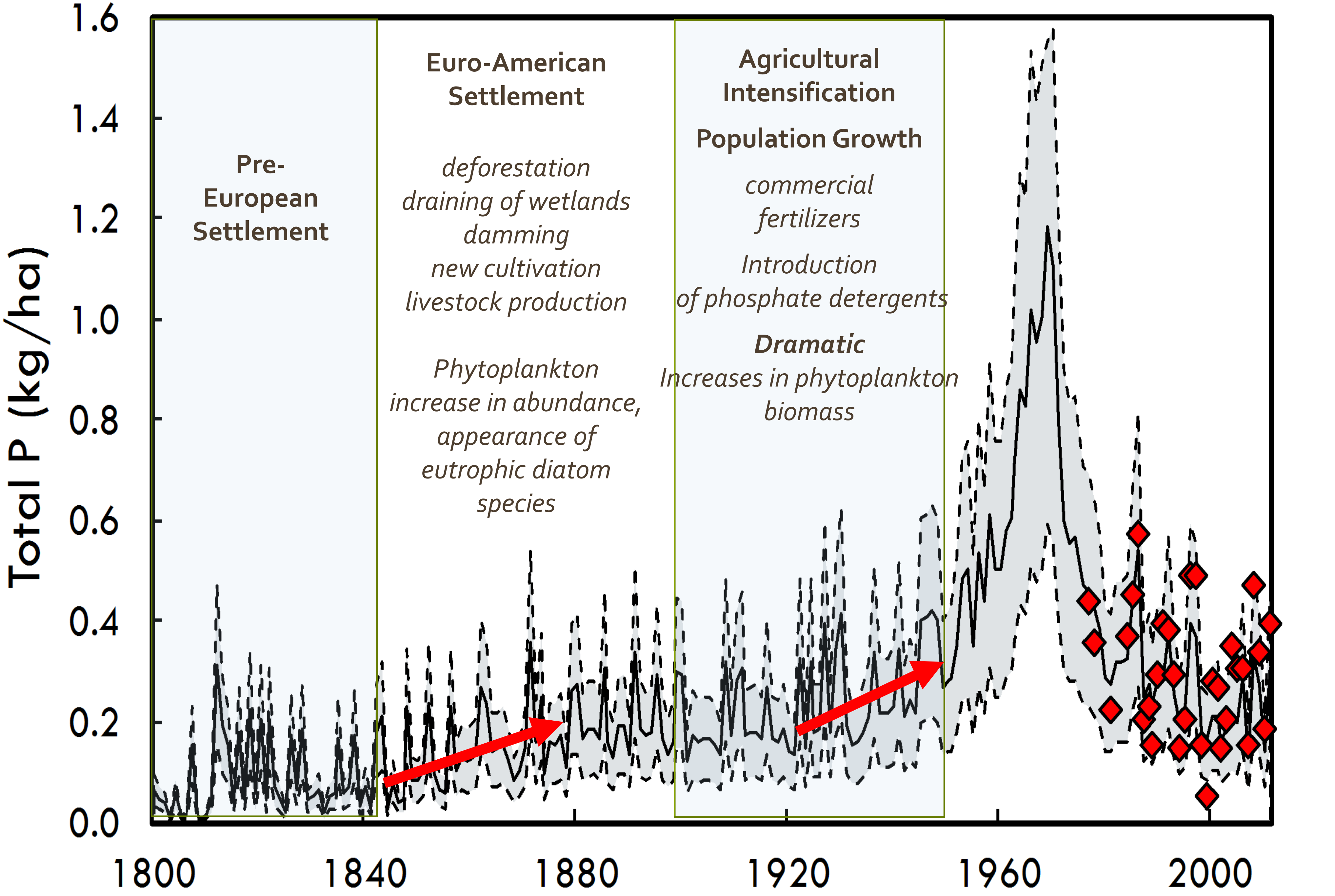
Van Meter et al., *Science*

ELEMeNT-P (**E**xploration of **L**ong-t**E**r**M** **N**utrient **T**rajectories)



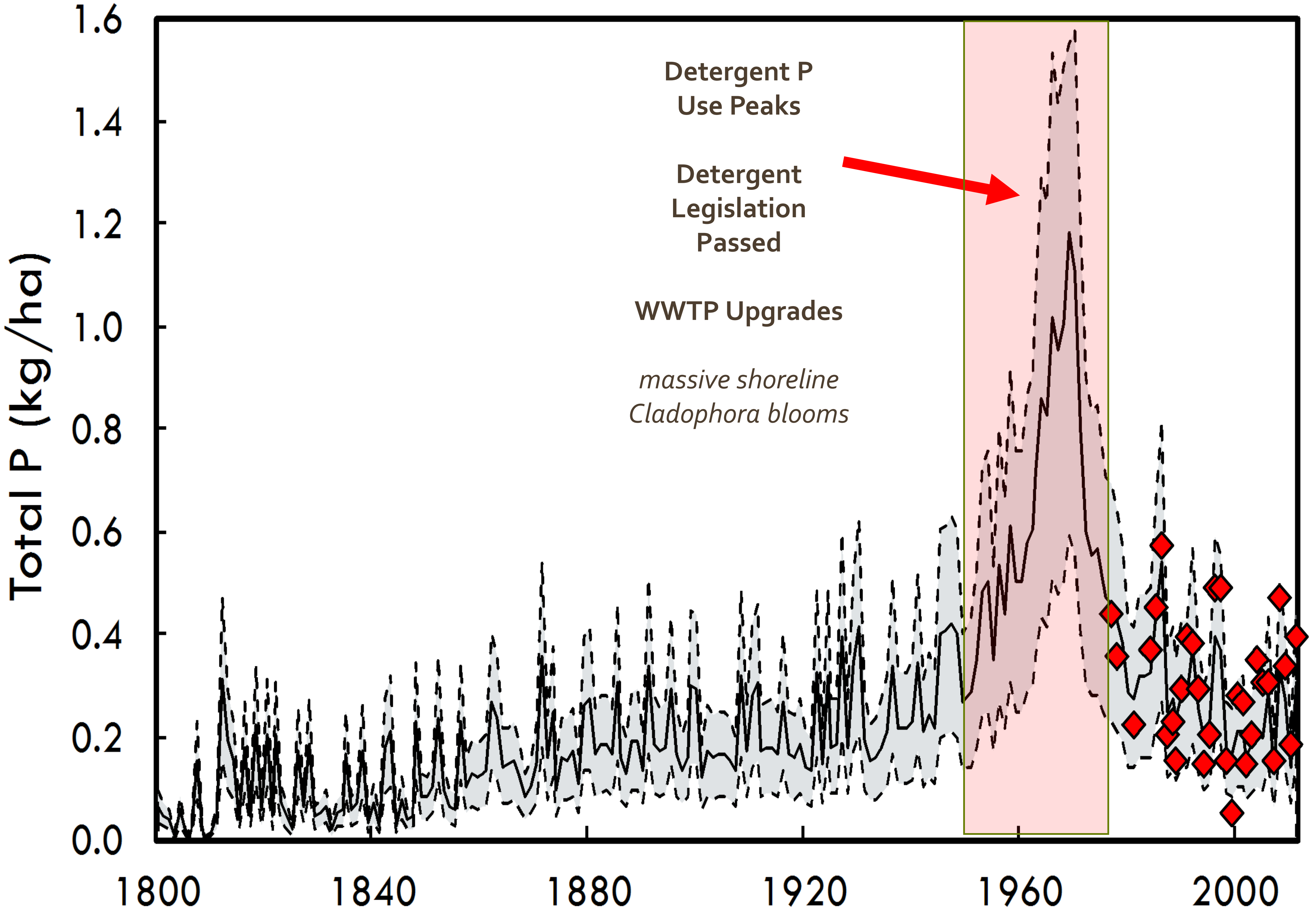
Observed vs. Modeled TP Values
1977-2011



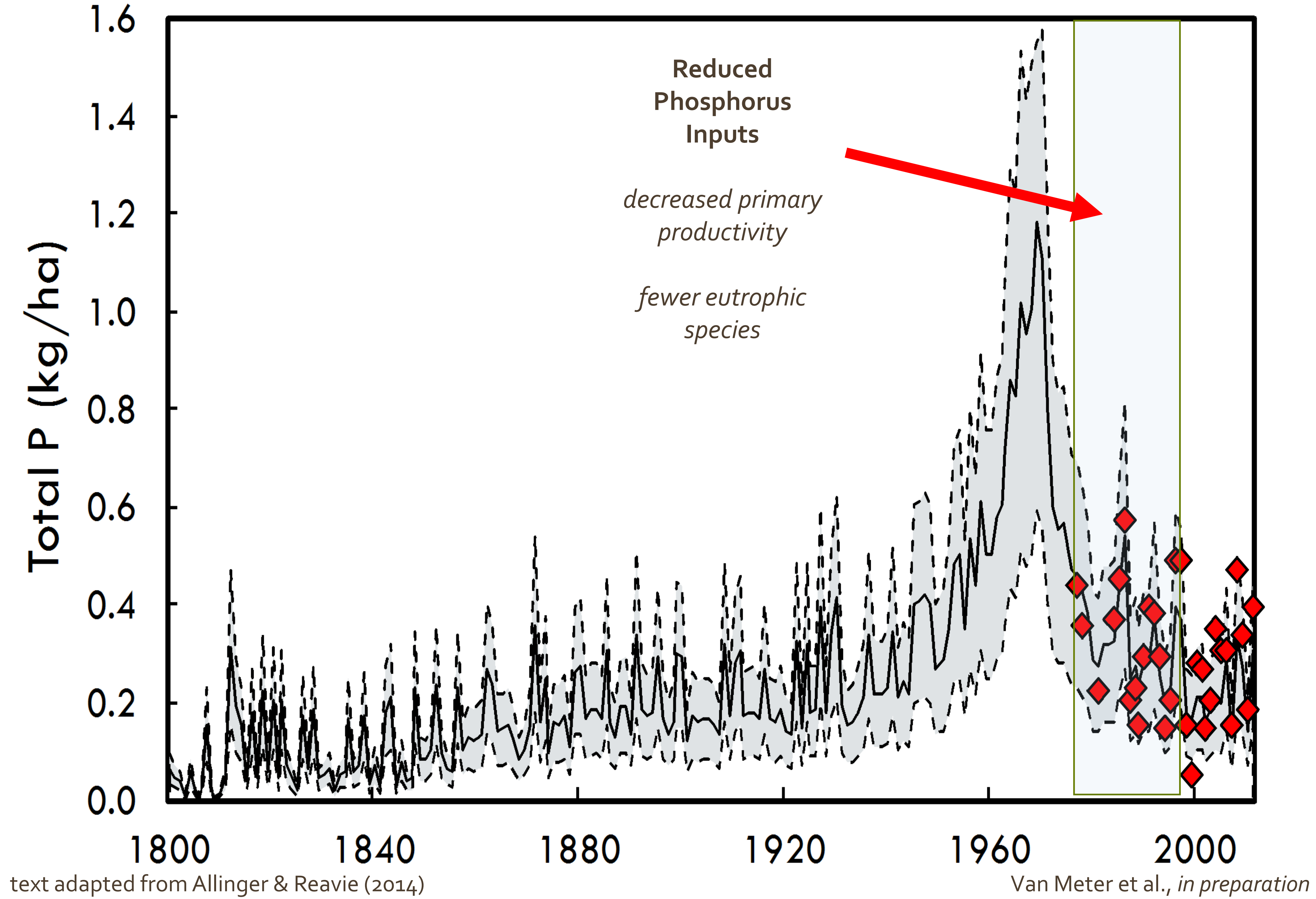


text adapted from Allinger & Reavie (2014)

Van Meter et al., *in preparation*



Total P (kg/ha)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1800
1840
1880
1920
1960
2000
Detergent P
Use Peaks
Detergent
Legislation
Passed
WWTP Upgrades
massive shoreline
Cladophora blooms


Reduced
Phosphorus
Inputs
decreased primary
productivity
fewer eutrophic
species
Total P (kg/ha)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
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1800
1840
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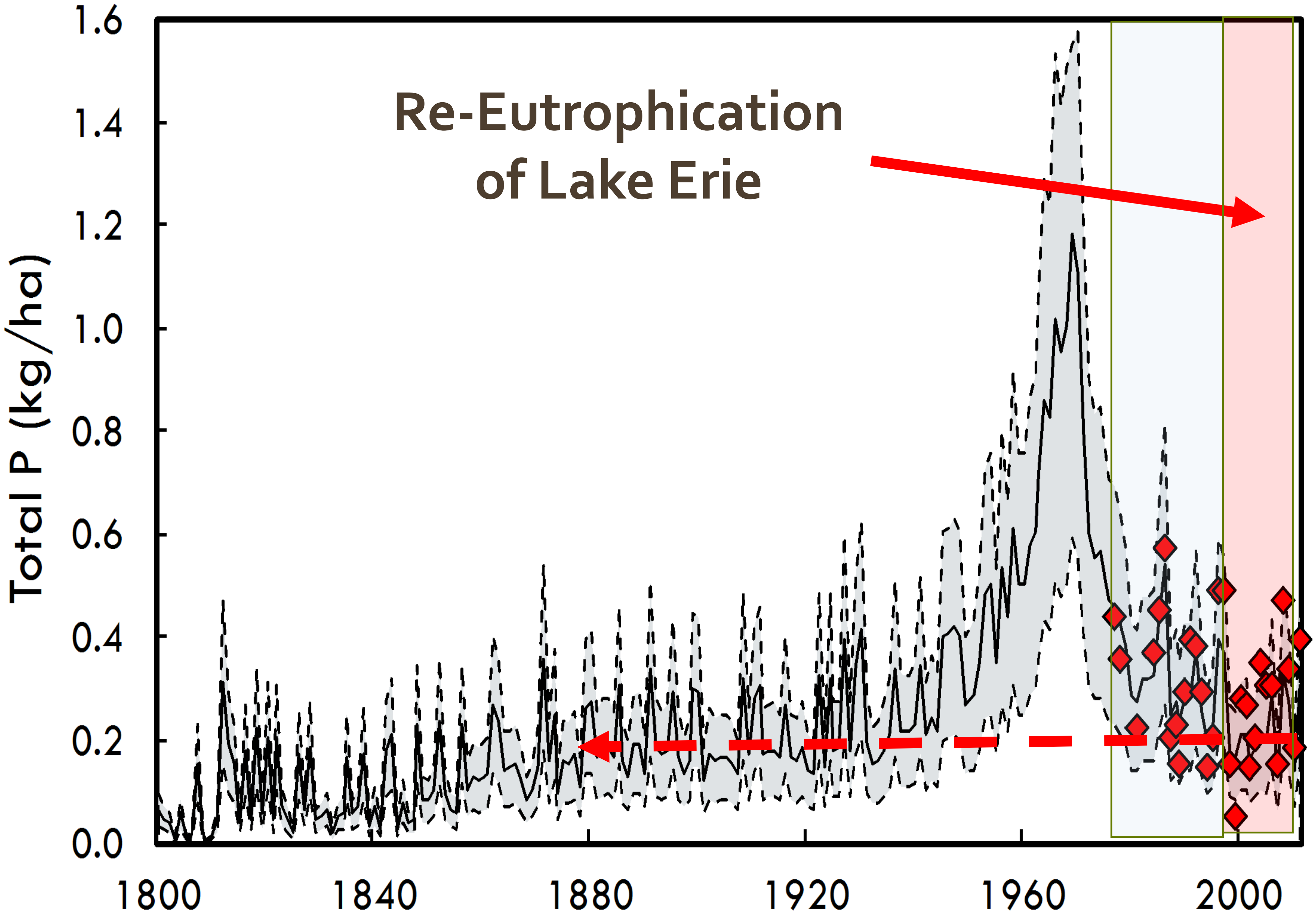
Van Meter et al., *in preparation*

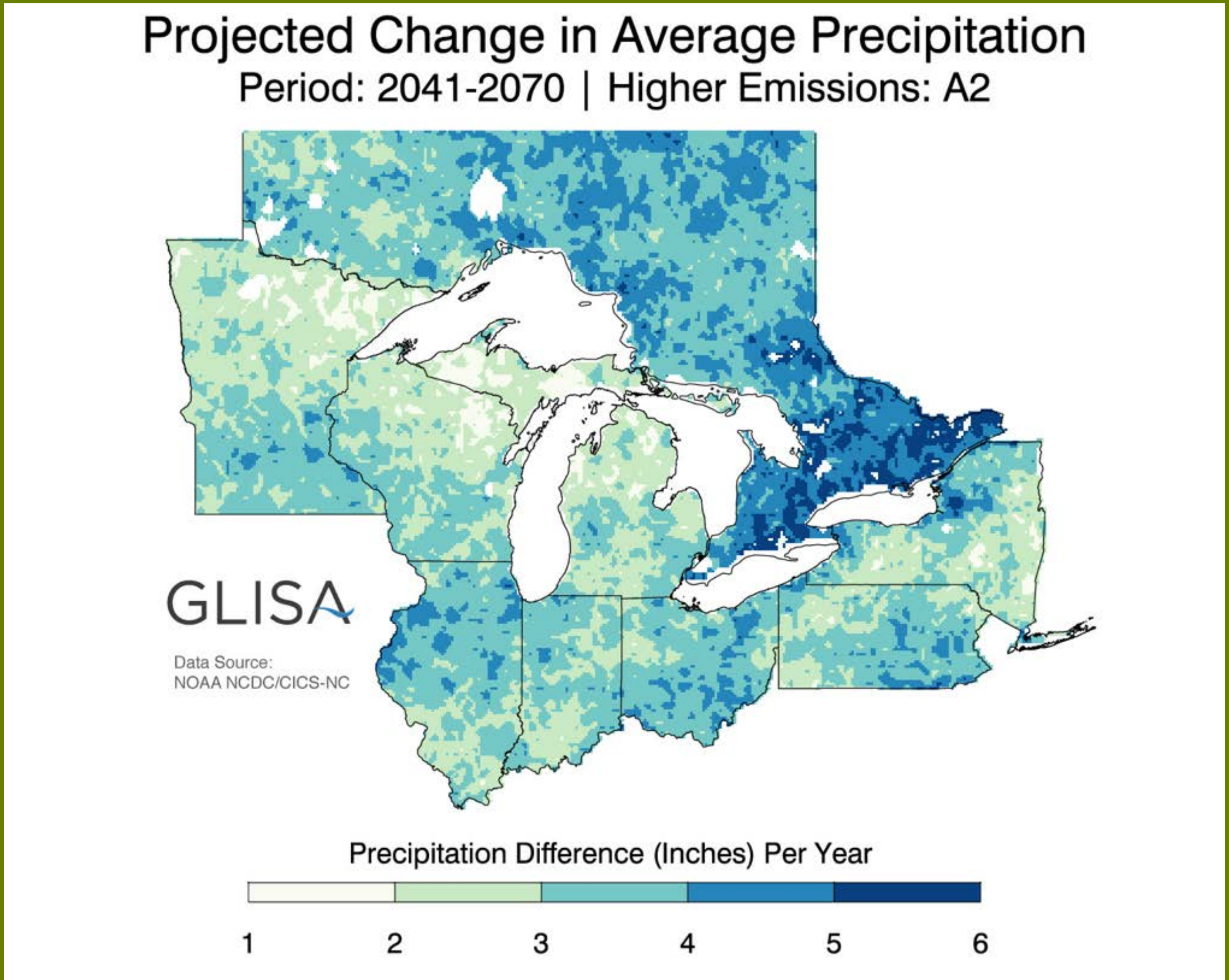


Van Meter et al., *in preparation*

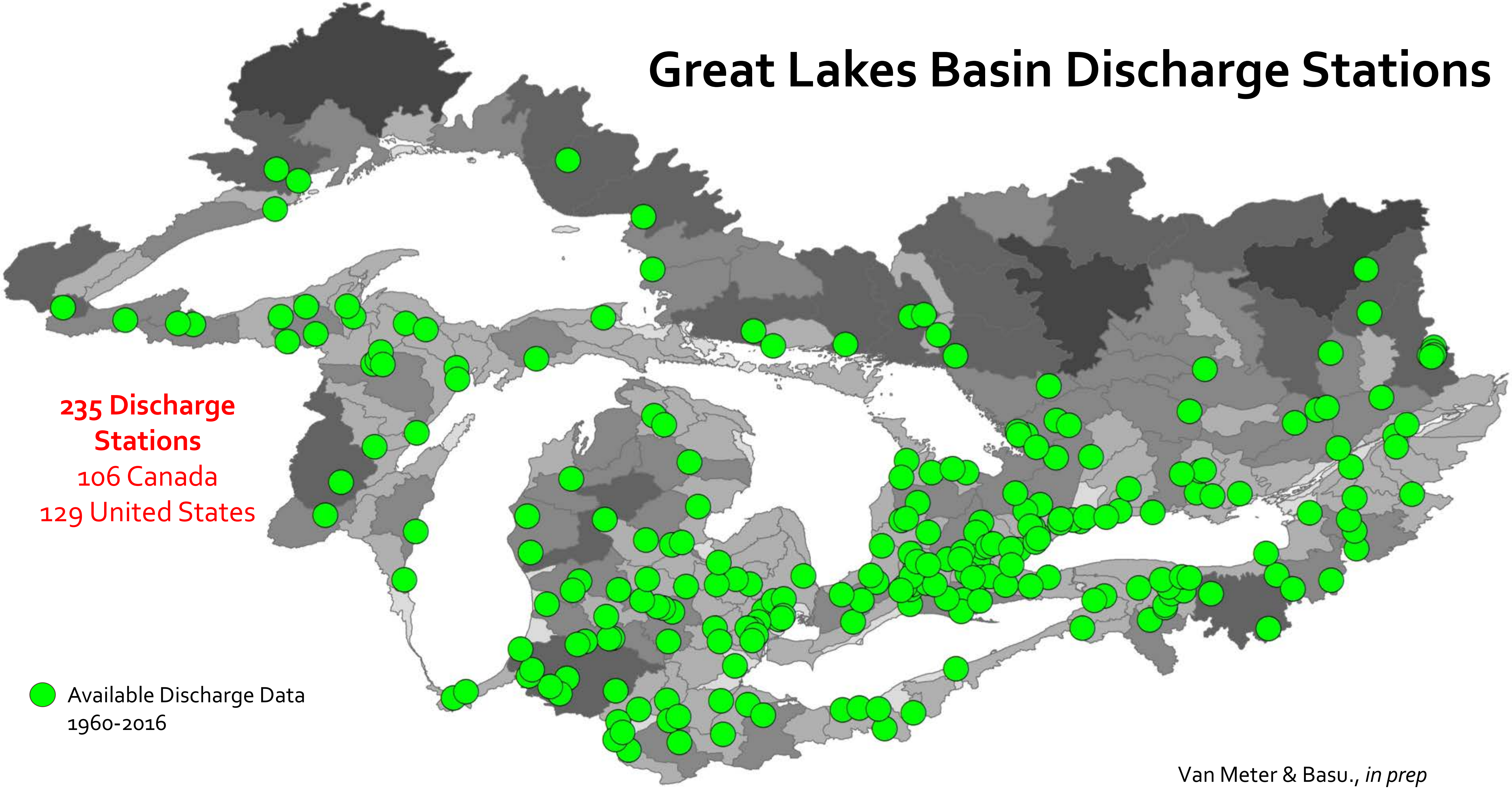
Embrace Dynamics

Are discharge patterns **changing** across the Great Lakes Basin?

Are changes in discharge driving the delivery of **bioavailable P** to the Great Lakes?

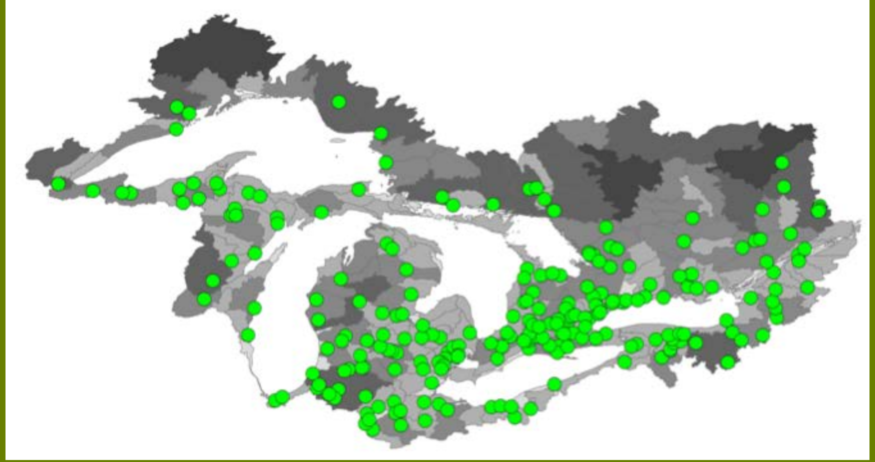


Great Lakes Basin Discharge Stations



Van Meter & Basu., *in prep*

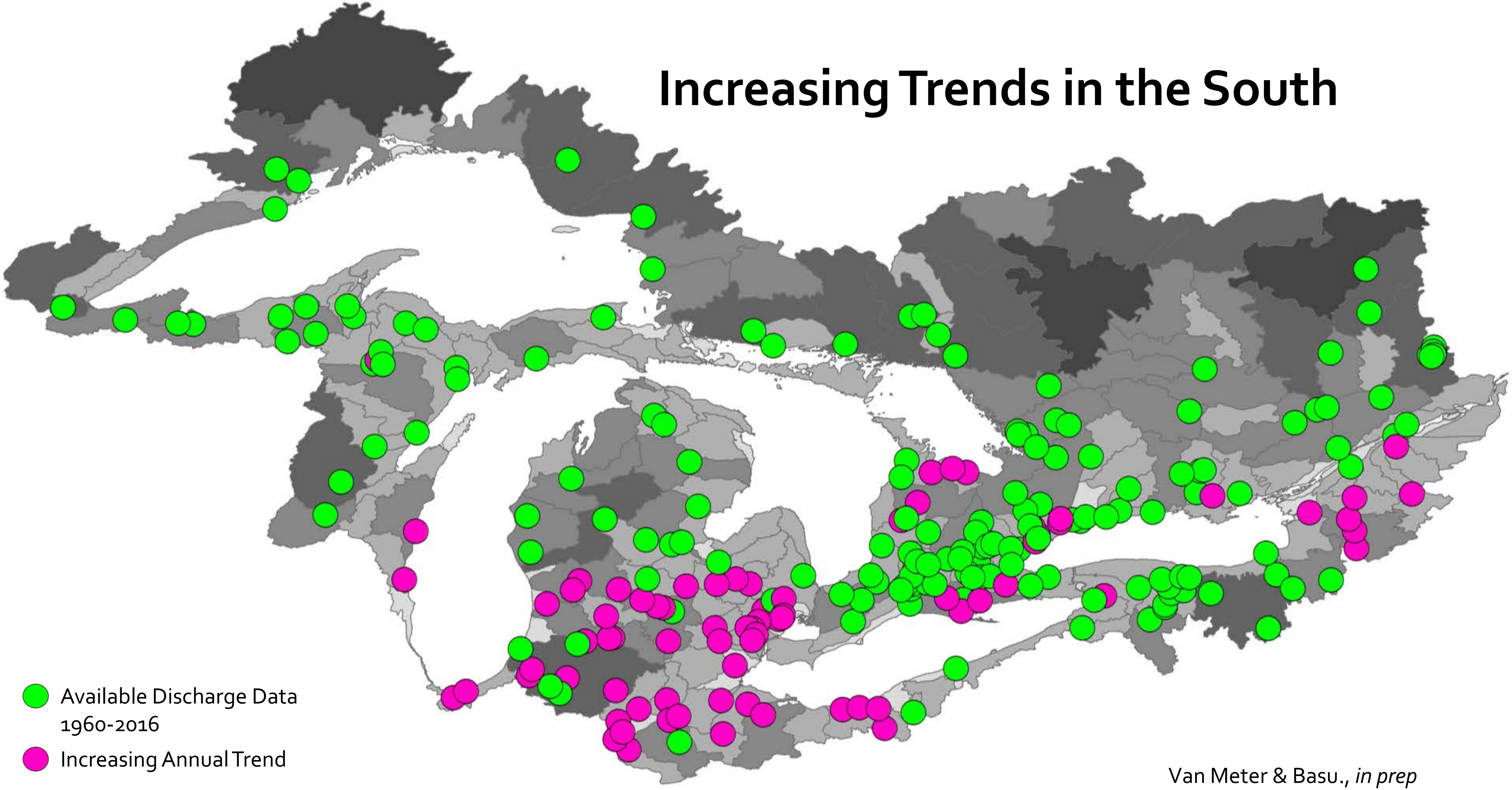
Great Lakes Discharge Stations
Trend Summary



	WIN n=232	SPR n=223	SUM n=220	FALL n=229	ANNUAL n=235
Increasing Trend					
increasing	203	108	170	169	181
significant (95% CI)	106	10	93	21	77
% increasing	46%	4%	42%	9%	33%
Decreasing Trend					
significant (95% CI)	9	19	18	9	25
% decreasing	4%	9%	8%	4%	11%
Increasing Trend, No Significant Annual Trend					
significant (95% CI)	53	1	33	3	NA
% increasing	38%	1%	23%	2%	NA

Van Meter & Basu, *in prep*

Increasing Trends in the South

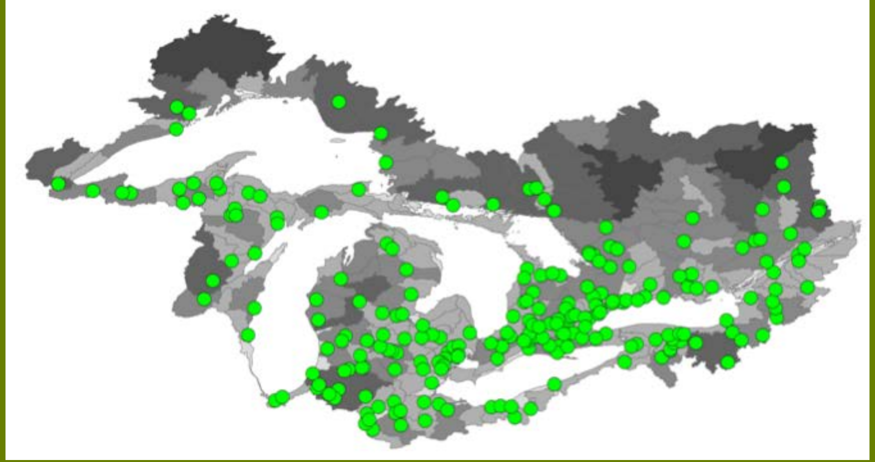


Available Discharge Data 1960-2016

Increasing Annual Trend

Van Meter & Basu., *in prep*

Great Lakes Discharge Stations
Trend Summary



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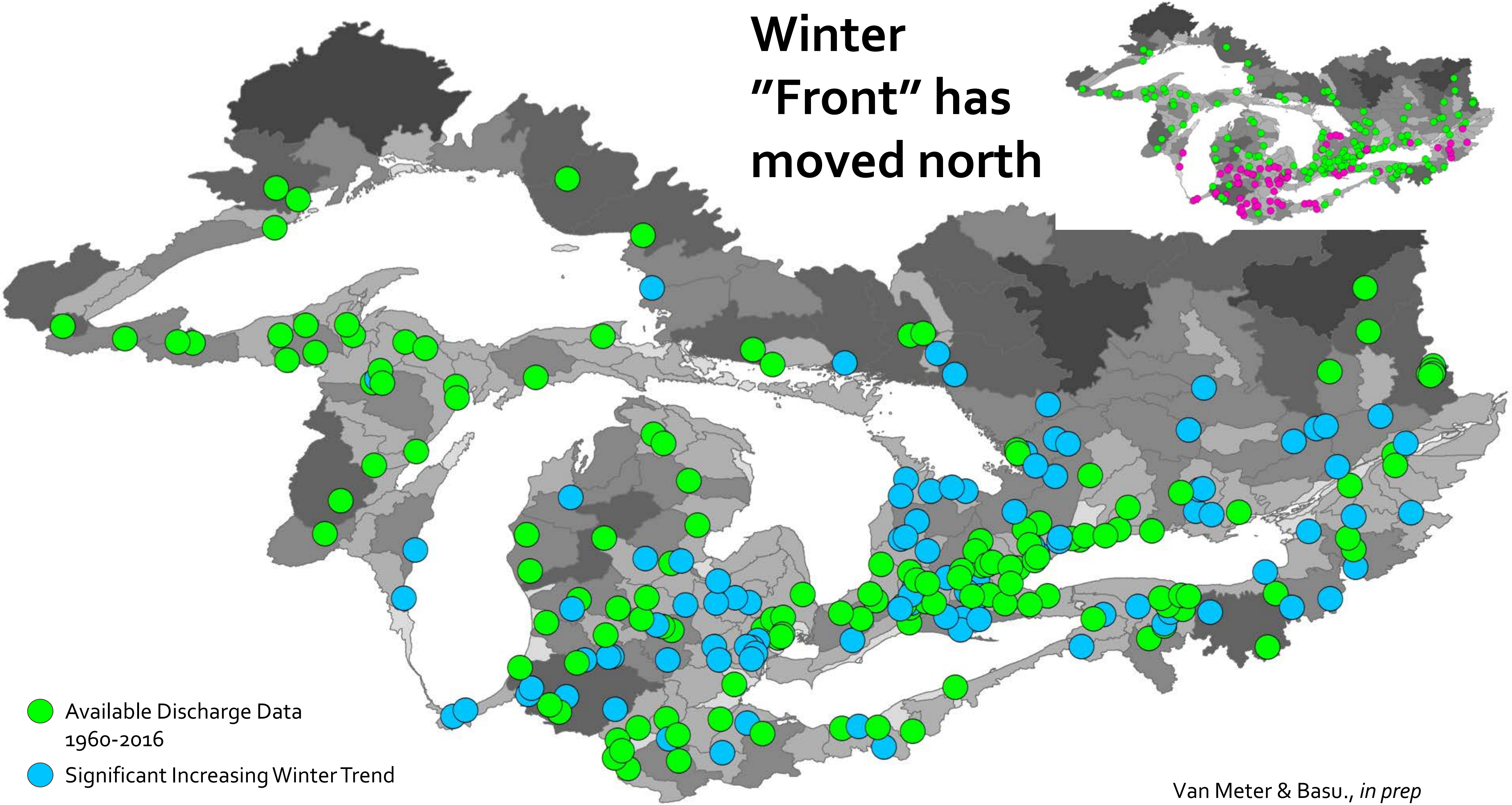
Van Meter & Basu., *in prep*

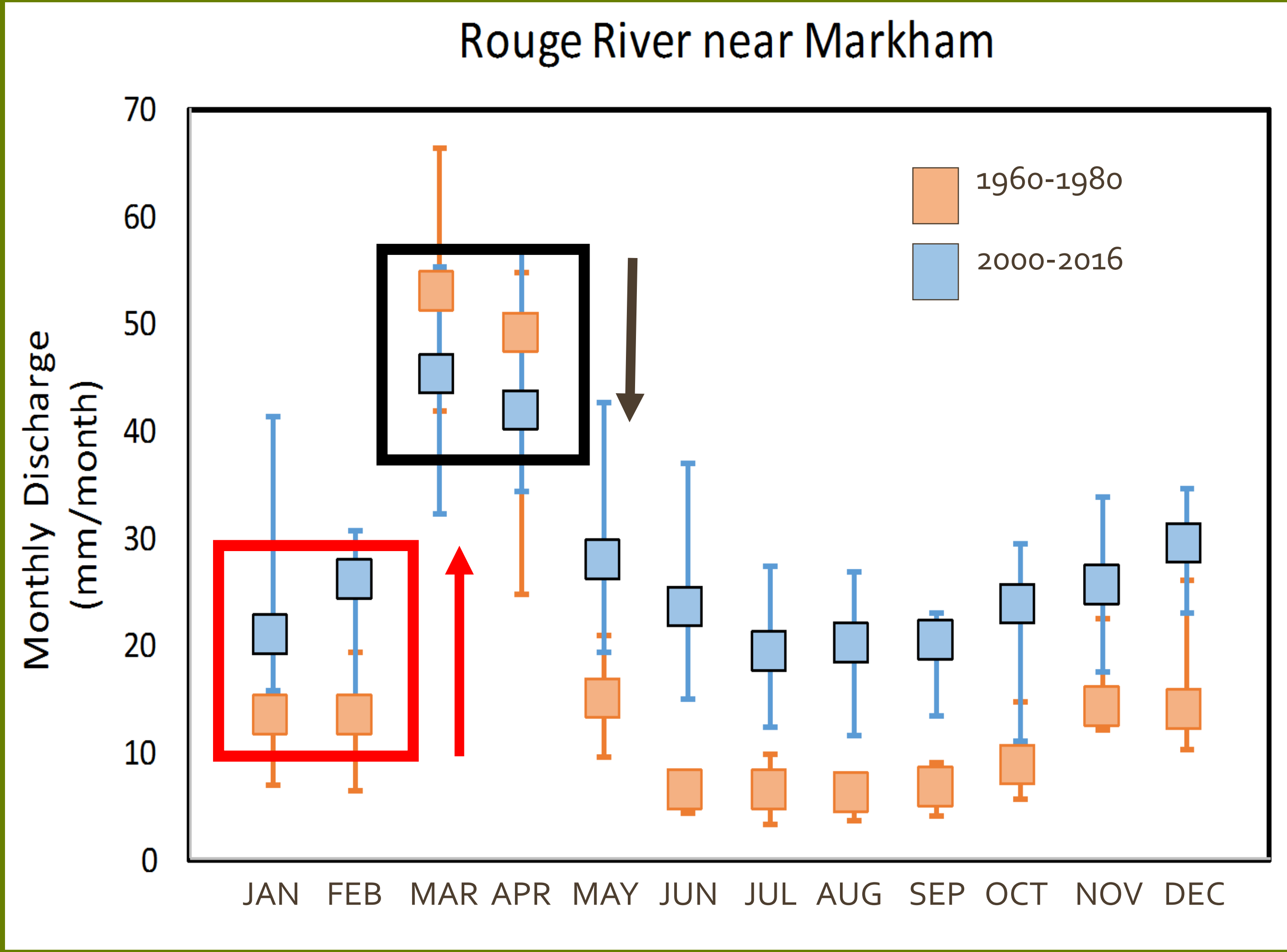
Winter "Front" has moved north

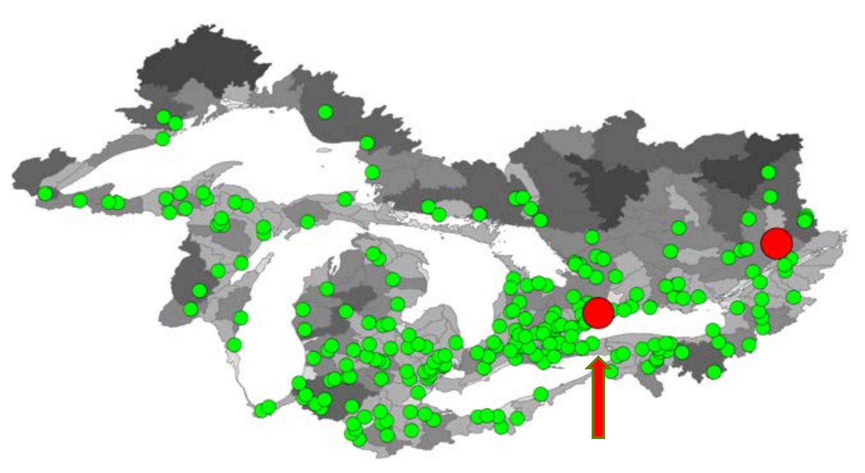


Van Meter & Basu., *in prep*

Great Lakes Discharge Stations

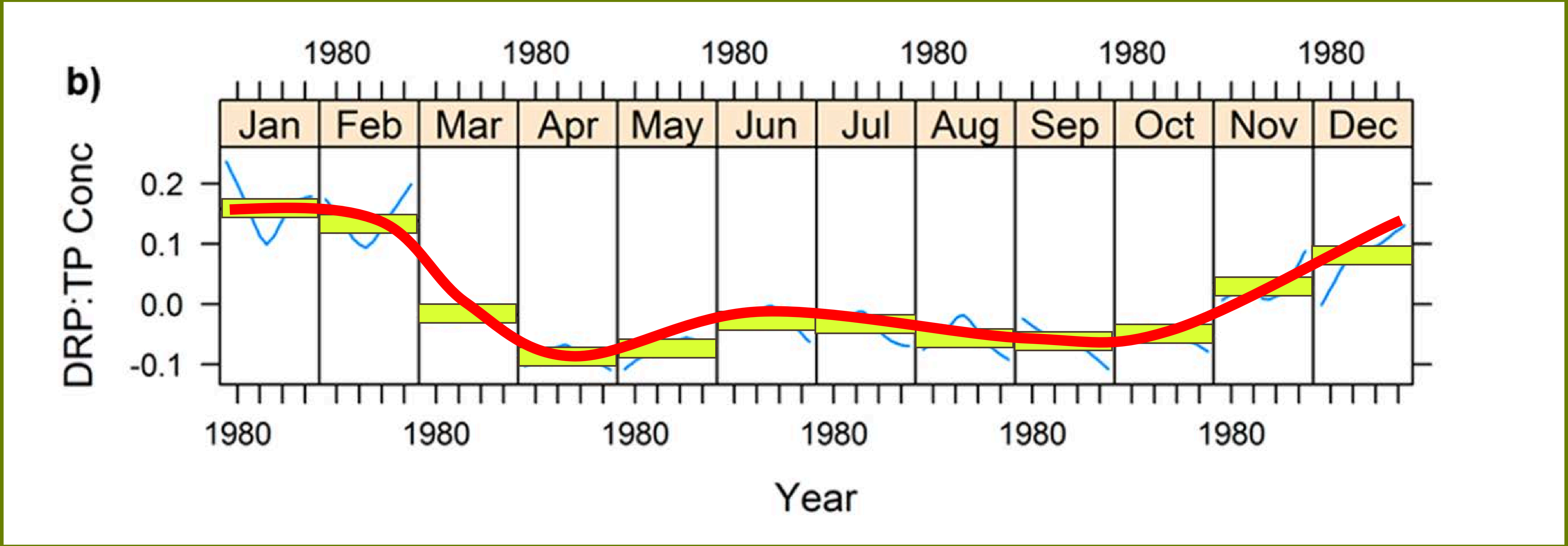
Changes in Flow Regimes

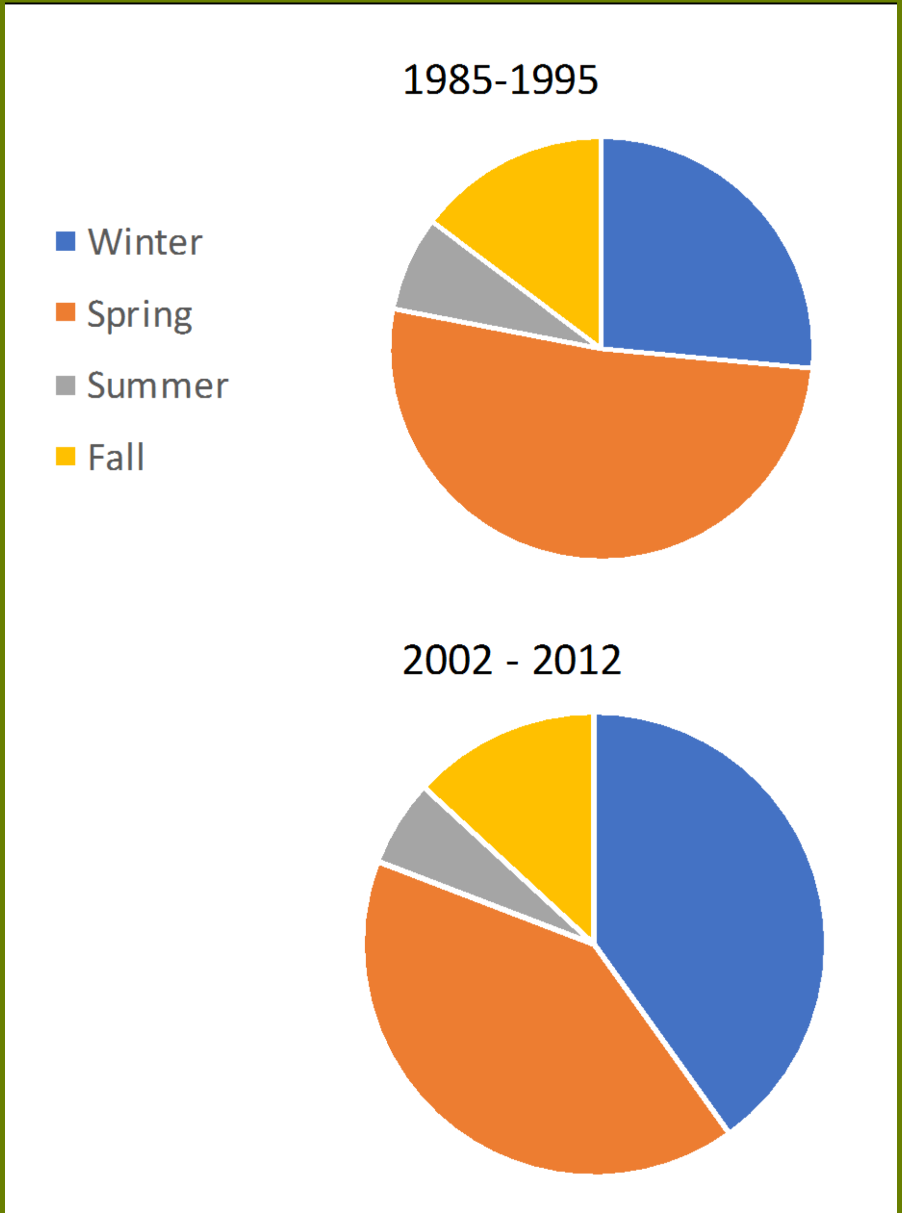





Article
pubs.acs.org/est
Environmental Science & Technology
Long-Term and Seasonal Trend Decomposition of Maumee River Nutrient Inputs to Western Lake Erie
Craig A. Stow,*,† YoonKyung Cha,‡ Laura T. Johnson,§ Remegio Confesor,§ and R. Peter Richards§

More bioavailable P in winter and now winter has higher flows





1985 – 1995

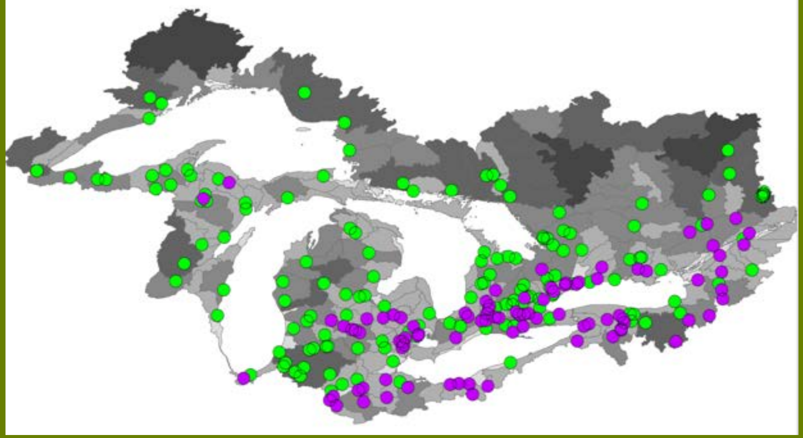
25% of SRP transported in winter

2002 – 2012

more than 40% SRP transported in winter

Climate-driven changes in discharge regimes must be taken into consideration when evaluating eutrophication risk

Increasing SRP:TP Ratios



67% of Great Lakes Basin watersheds show significant ($p<0.05$) increases in SRP:TP ratios

- *Legacies of N and P in anthropogenic catchments lead to time lags*

- *ELEMENT model to describe legacies and time lags*

- *Climate change linked to eutrophication risk*

Kimberly Van Meter, Room 1110 at 230 pm

Yuhe Liu: Past, Present, and Future: Quantification of Long-Term Phosphorus Legacies in the Grand River Watershed (Poster 14)

Mahyar Shafii: Spatio-temporal variations of landscape nitrate fluxes in agricultural catchments driven by flow pathways and nutrient transport mechanisms Wed 2:15 Rm 1105

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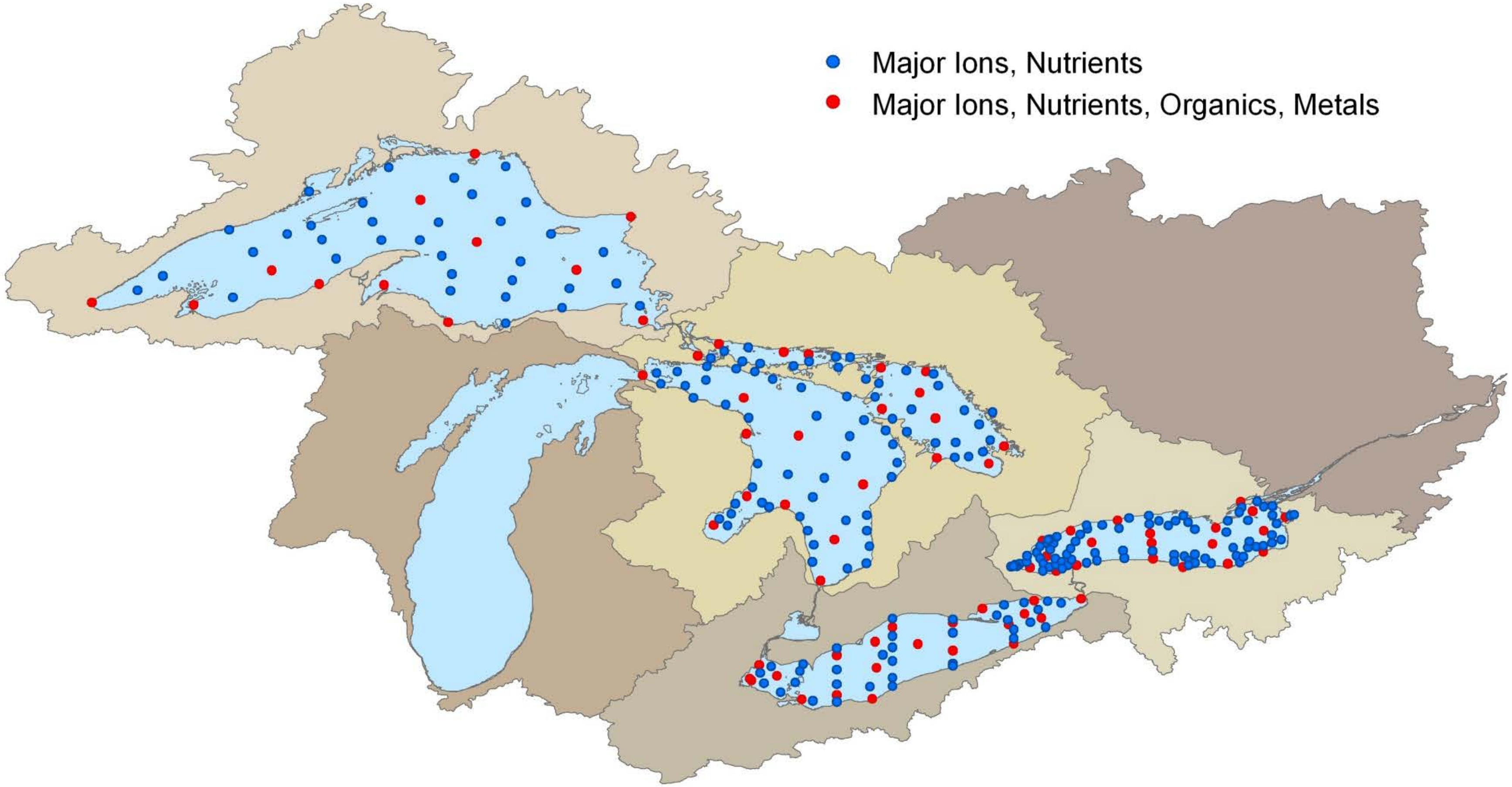
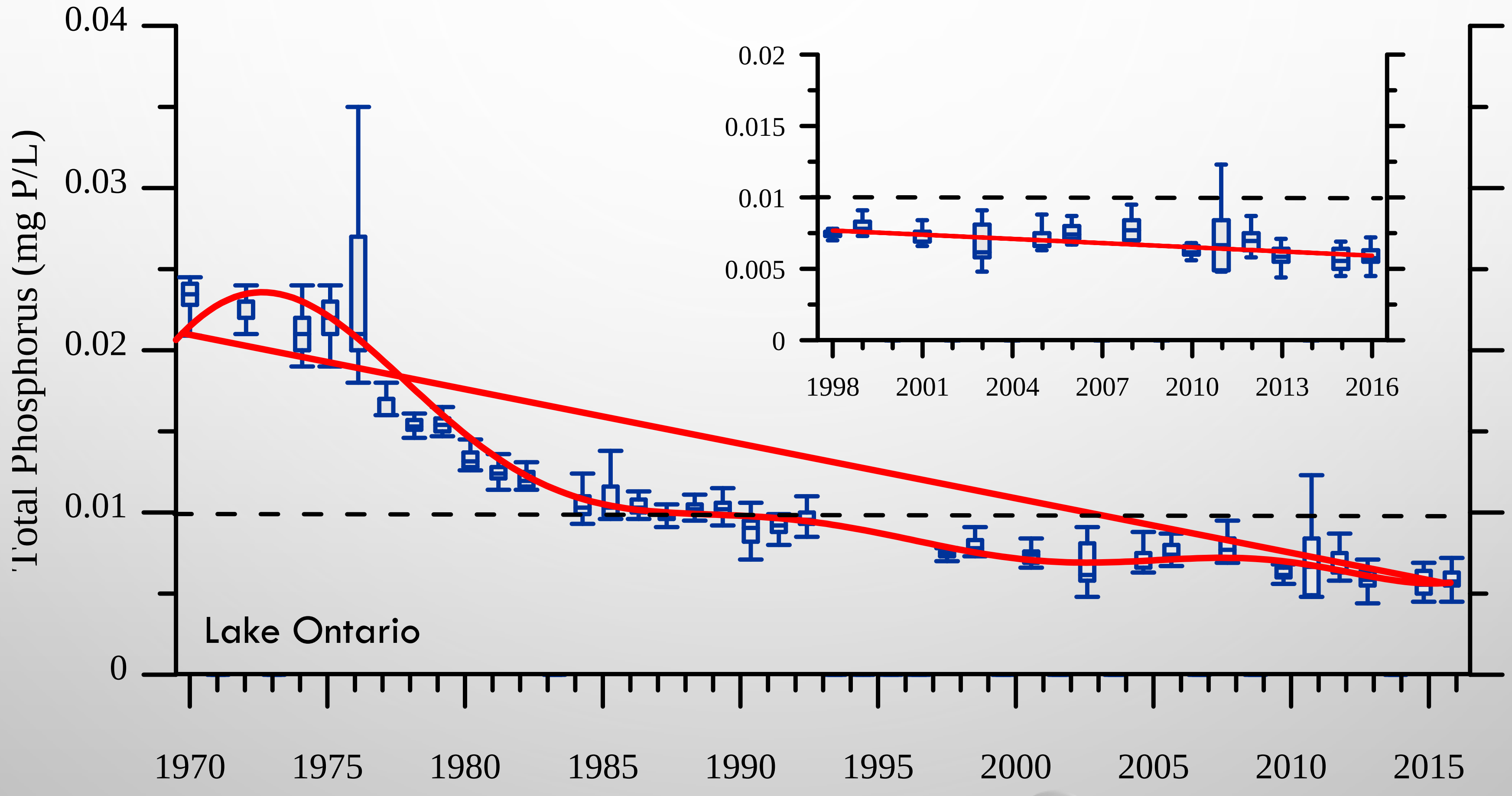
MONITORING DATA



Courtesy of A. Dove, Environment and Climate Change Canada

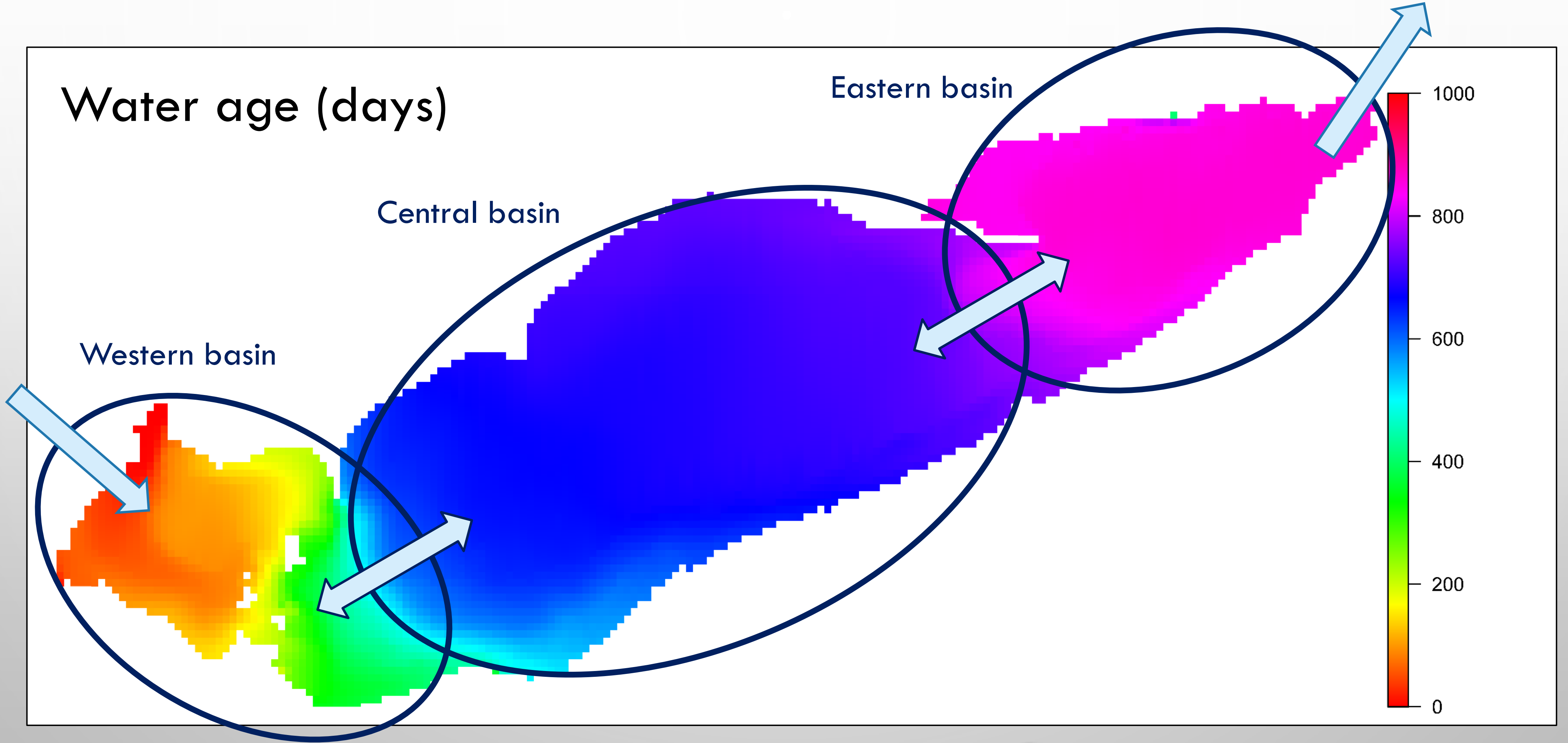
LONG-TERM WATER QUALITY



Dove A. and Chapra S.C. (2015) *Limnol. Oceanogr.* **60**, 696-721.

Western Lake Erie
September 26, 2017,
Landsat 8_Operational Land Imager (OLI)

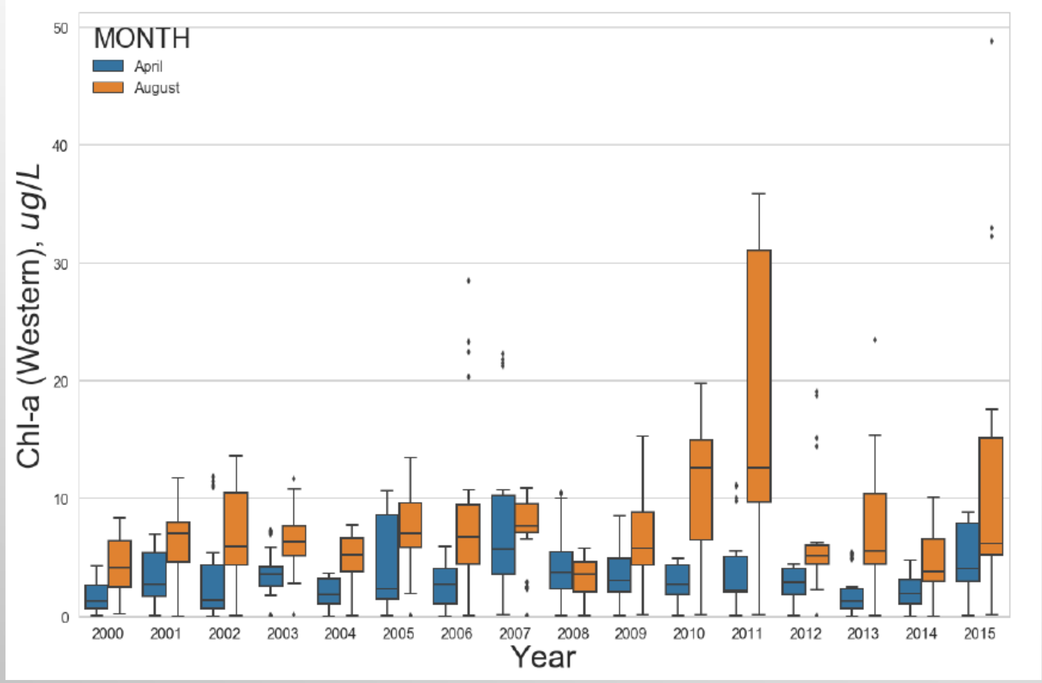
LAKE ERIE



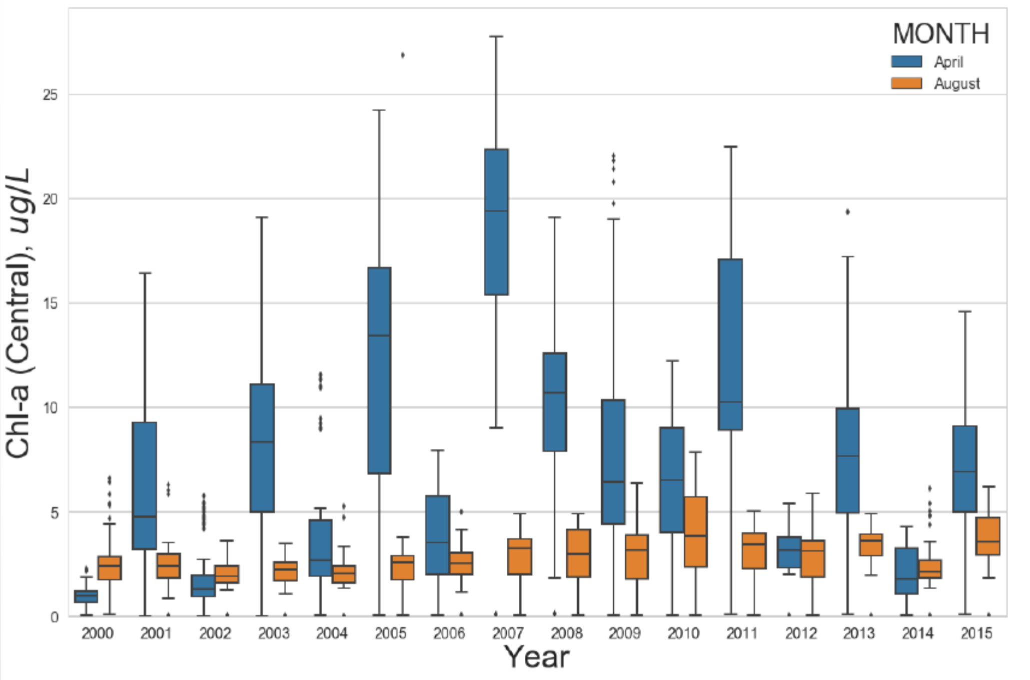
Courtesy Serghei Bocaniov, University of Waterloo

LAKE ERIE BASINS

Western basin



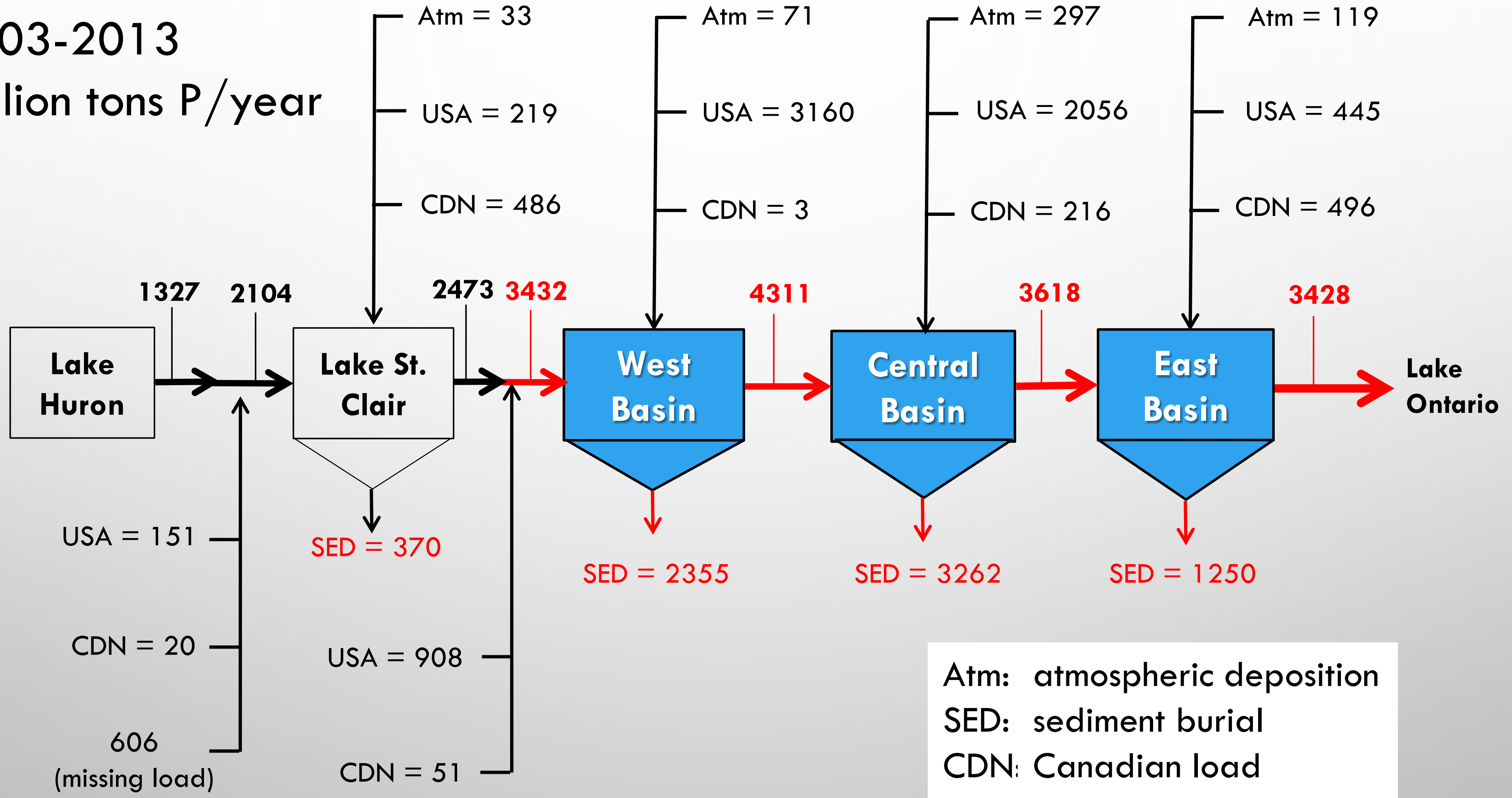
Central basin



Data compiled by Igor Markelov, University of Waterloo

LAKE ERIE: PHOSPHORUS BUDGET

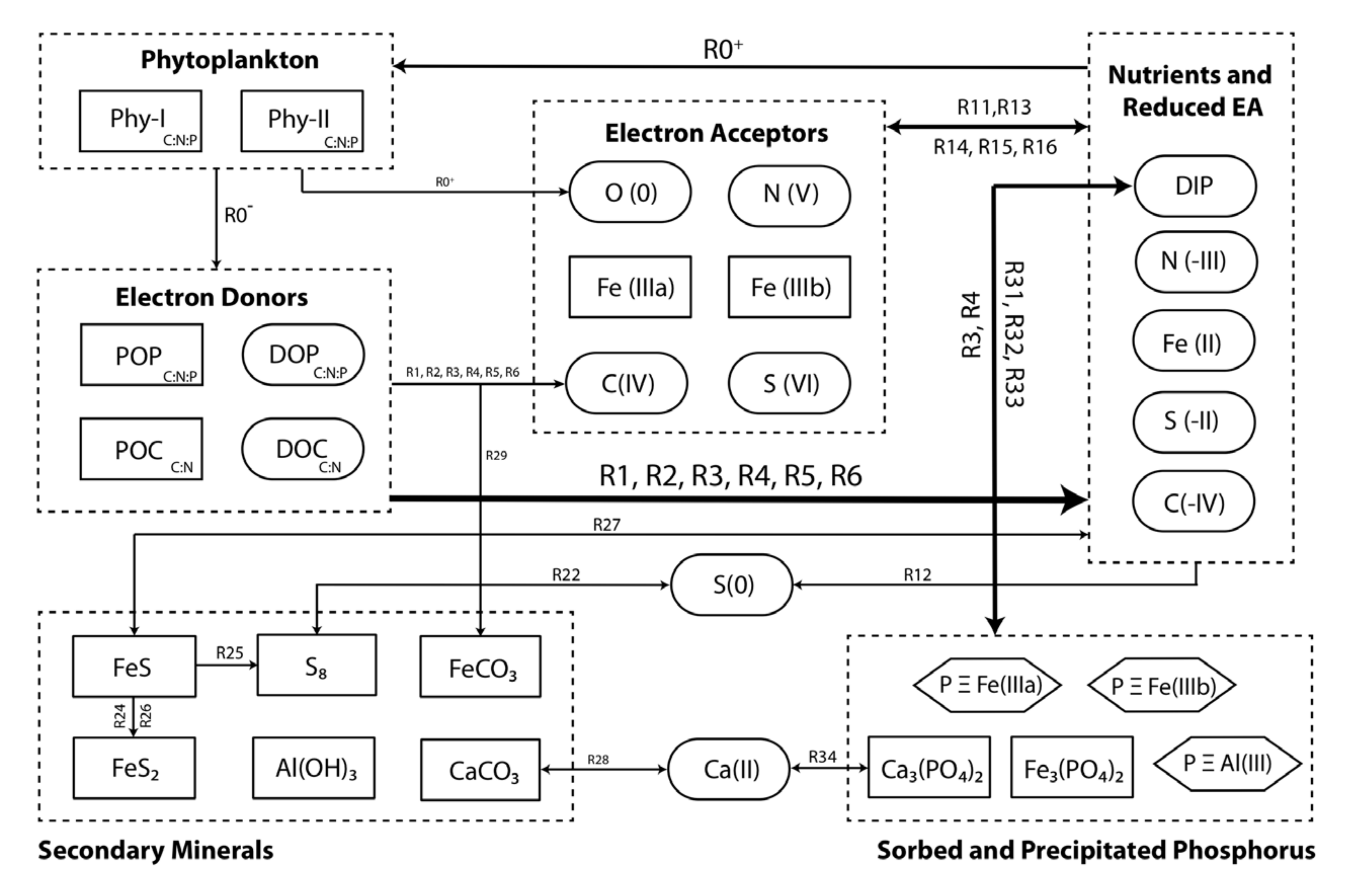
2003-2013
Million tons P/year



Atm: atmospheric deposition
SED: sediment burial
CDN: Canadian load
USA: USA load

Courtesy Serghei Bocaniov, University of Waterloo

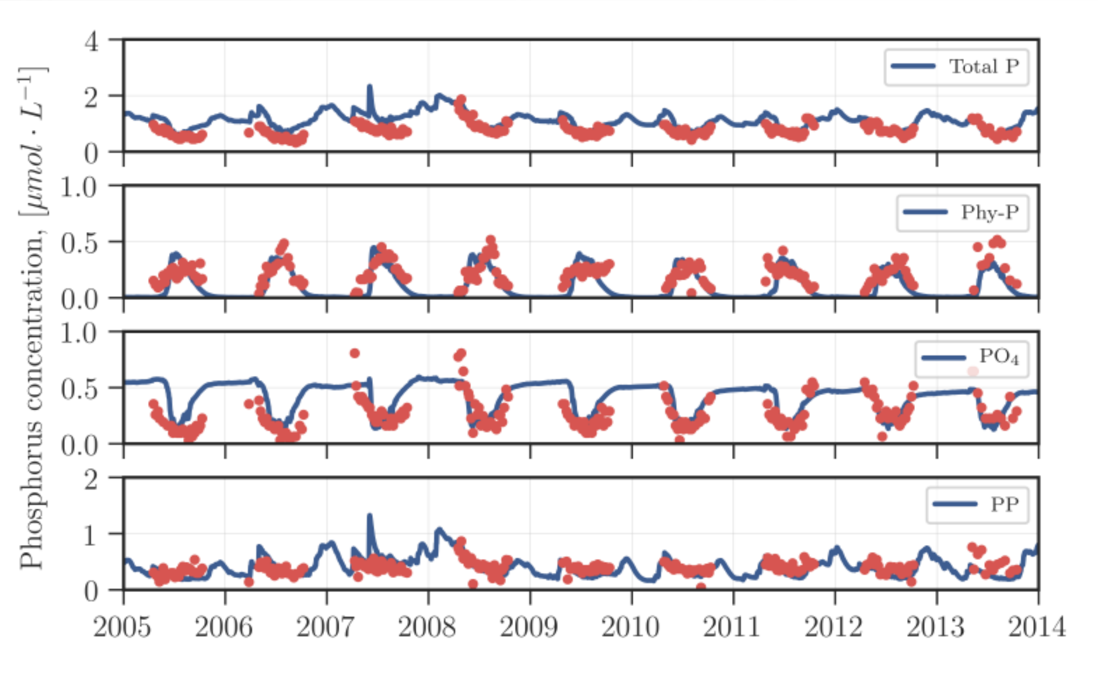
MYLAKE



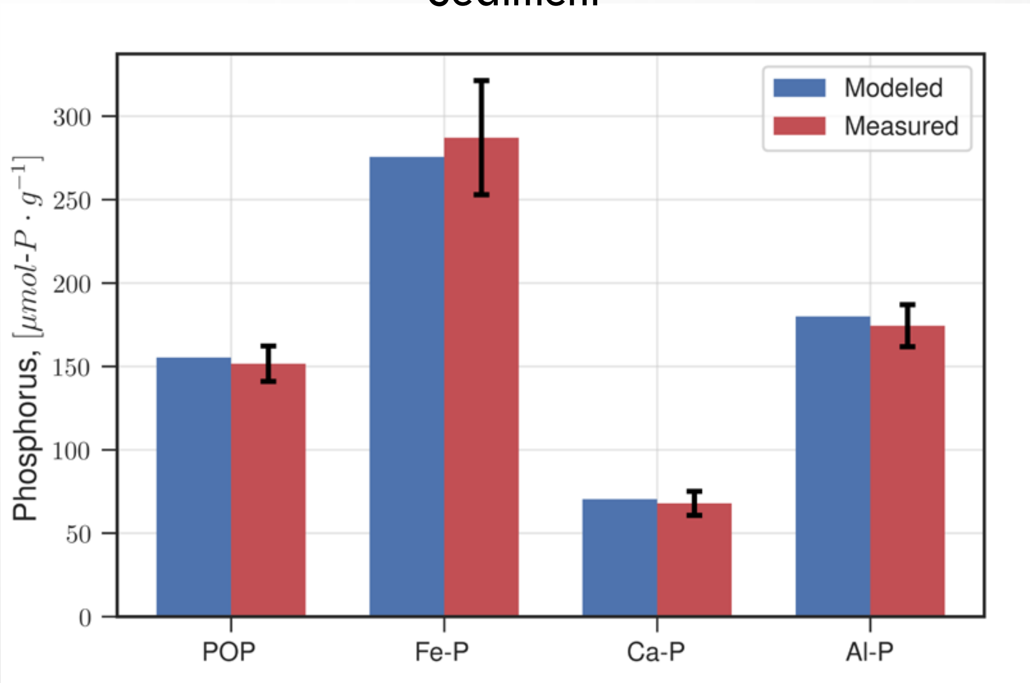
Courtesy Igor Markelov, University of Waterloo

LAKE VANSJØ (SE NORWAY)

Water column



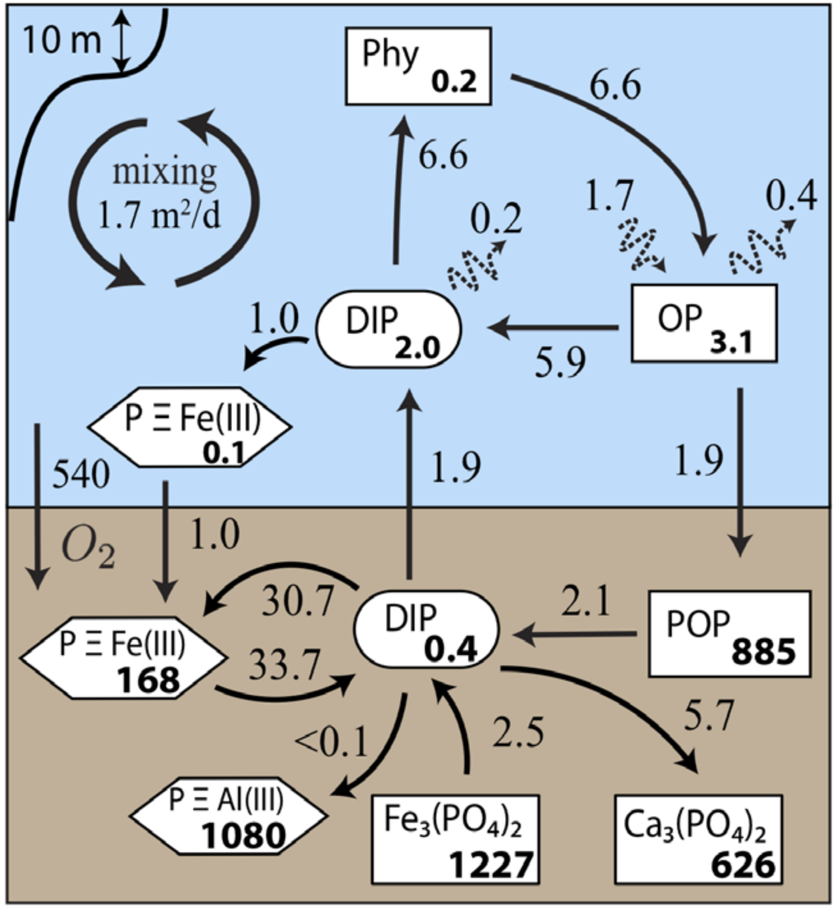
Sediment



Markelov I., Couture R.-M. and Van Cappellen P. (2018) Internal phosphorus loading, climate change and lake restoration: A coupled water column-sediment biogeochemical modeling study of Lake Vansjø, Norway. Biogeosciences, in preparation.

LAKE VANSJØ (SE NORWAY)

(1) Baseline 1995-2015



Markelov I., Couture R.-M. and Van Cappellen P. (2018) Internal phosphorus loading, climate change and lake restoration: A coupled water column-sediment biogeochemical modeling study of Lake Vansjø, Norway. Biogeosciences, in preparation.

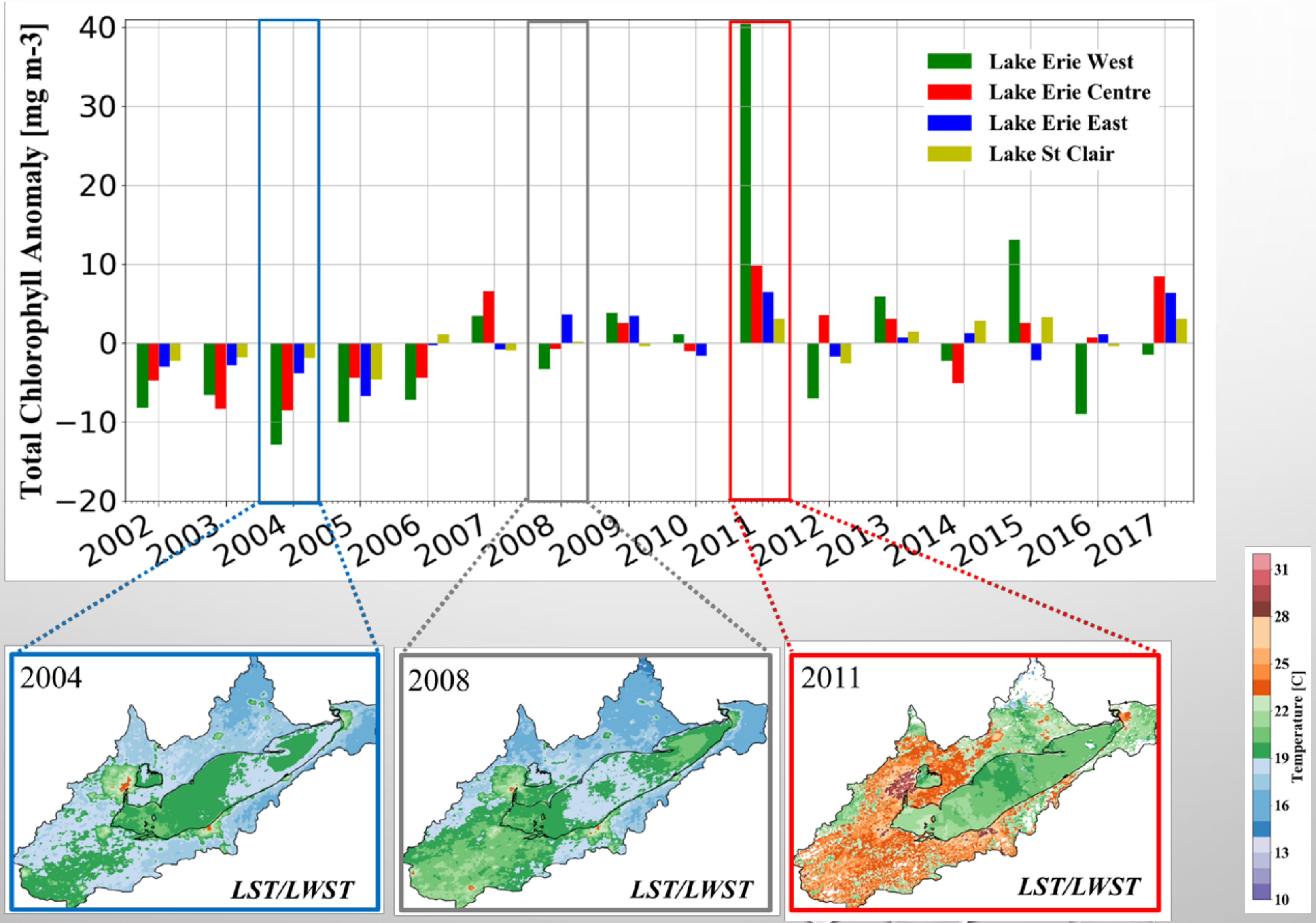
Lake Erie ice cover

March 07, 2014
MODIS

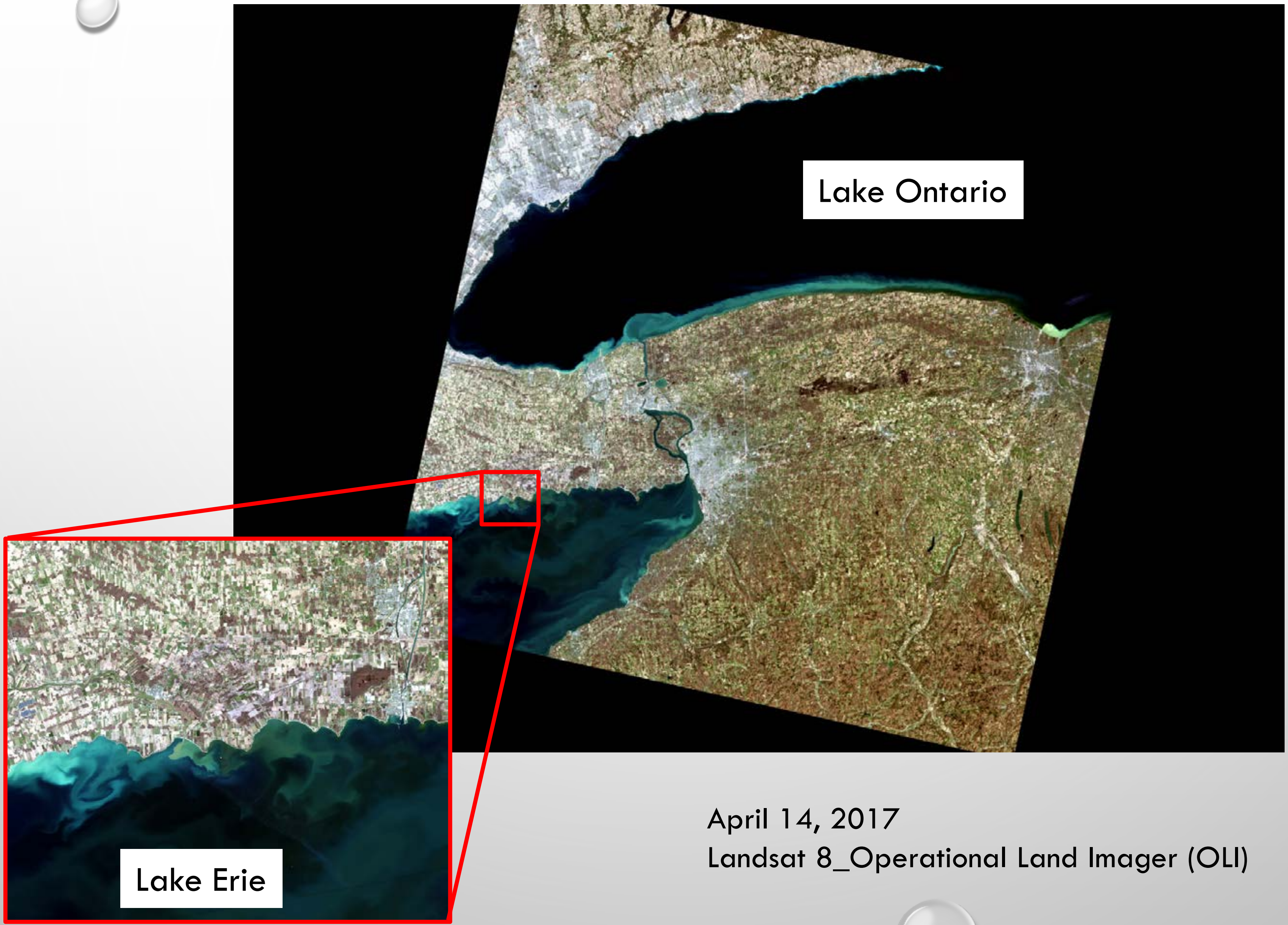
March 05, 2010
MODIS

Data retrieved by Homa Kheyrollah Pour, University of Waterloo

CLIMATE SIGNALS



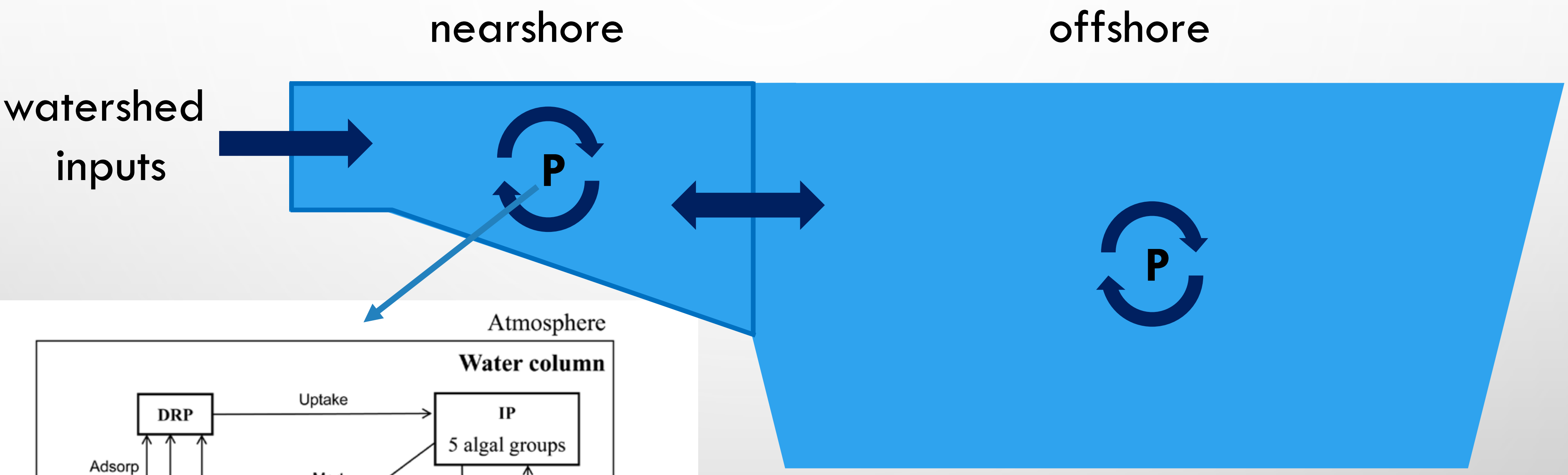
Data compiled by Homa Kheyrollah Pour, University of Waterloo

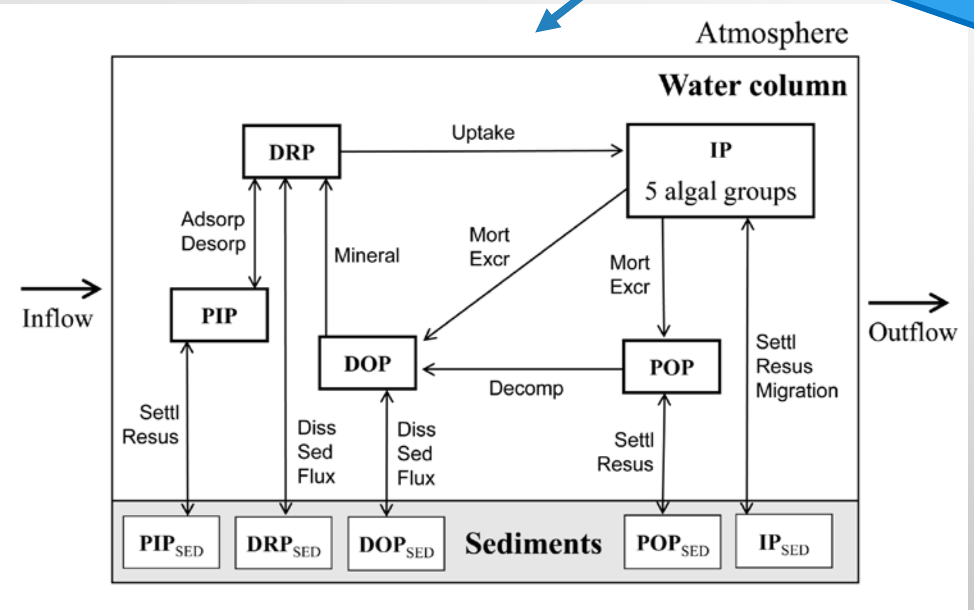


April 14, 2017
Landsat 8_Operational Land Imager (OLI)

Courtesy Homa Kheyrollah Pour, University of Waterloo

LITTORAL ZONE PROCESSES





RECAP: SOME RESEARCH PRIORITIES

- Nutrient legacies
- Climate change and eutrophication risk
- Inter-basin exchanges & internal nutrient loading
- Climate sensitivity: ice cover & temperature
- Nearshore-offshore interactions