Watershed Assessment of Detroit River Loads to Lake Erie

Detailed overview of key findings



Fred A. and Barbara M. Erb Family Foundation
WATER CENTER
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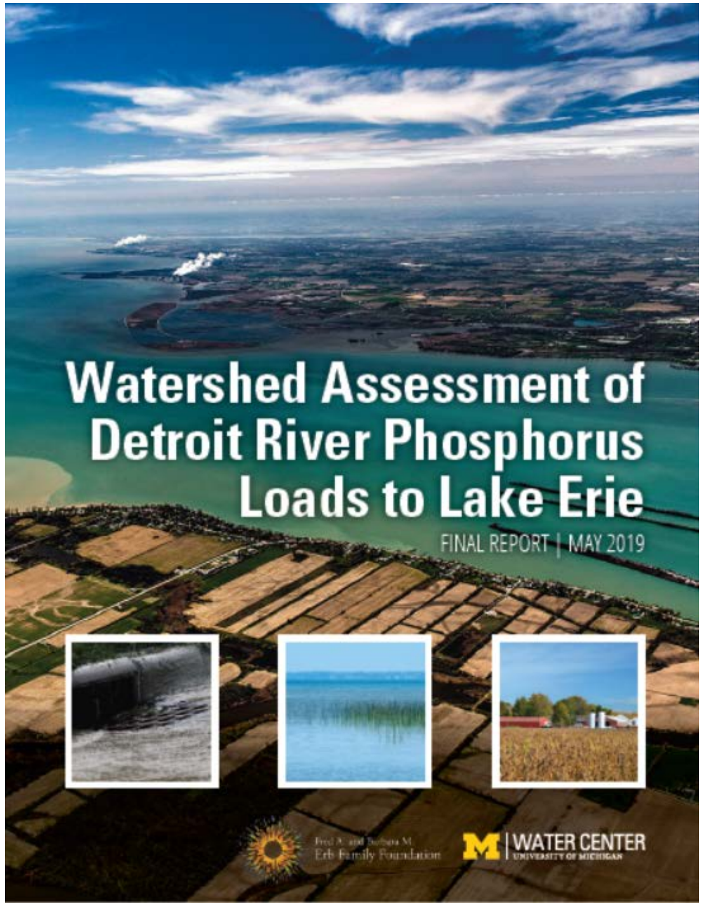
Project overview



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FUNDING: Erb Family Foundation

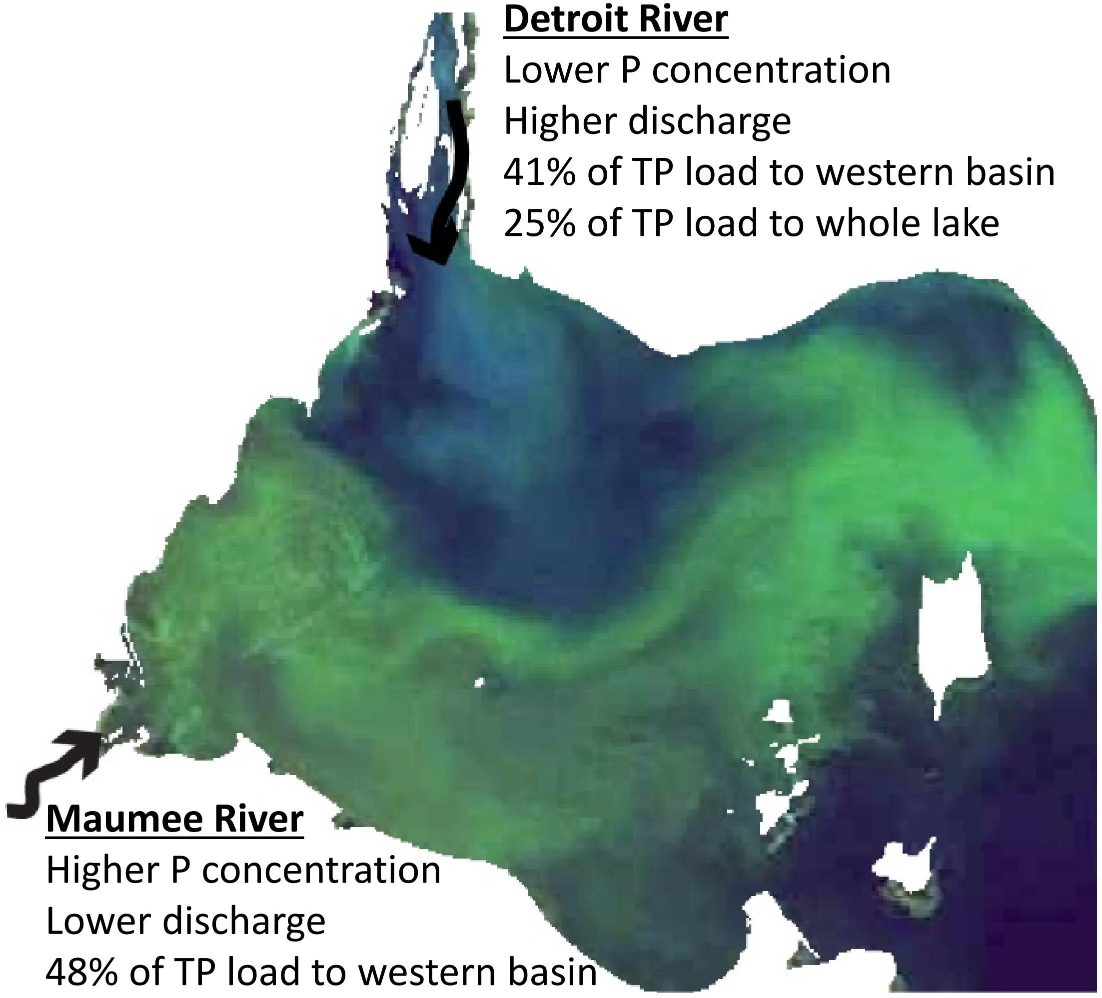
Fred A. and Barbara M. Erb Family Foundation

ADVISORY GROUP: 30 people from US and Canadian government, non-profit, industry, and academic sectors provided feedback throughout entire project

Report (released May 2019) and supporting documents available at:
myumi.ch/detroit-river

Why this study was needed

- Lake Erie Harmful Algal Blooms (HABs) and hypoxia (low oxygen) are driven by phosphorus inputs.
- US and Canada signed a revised *Great Lakes Water Quality Agreement* in 2012 that led to new loading targets and action plans to reach them.
- Targets include a 40% reduction (relative to 2008 levels) in western and central basin TP loads.
- **There has been uncertainty about the role of the Detroit River, sources of Detroit River nutrients, and managing Detroit river loads.**



TP= Total Phosphorus, which includes dissolved and particulate forms of P

Known and unknown information

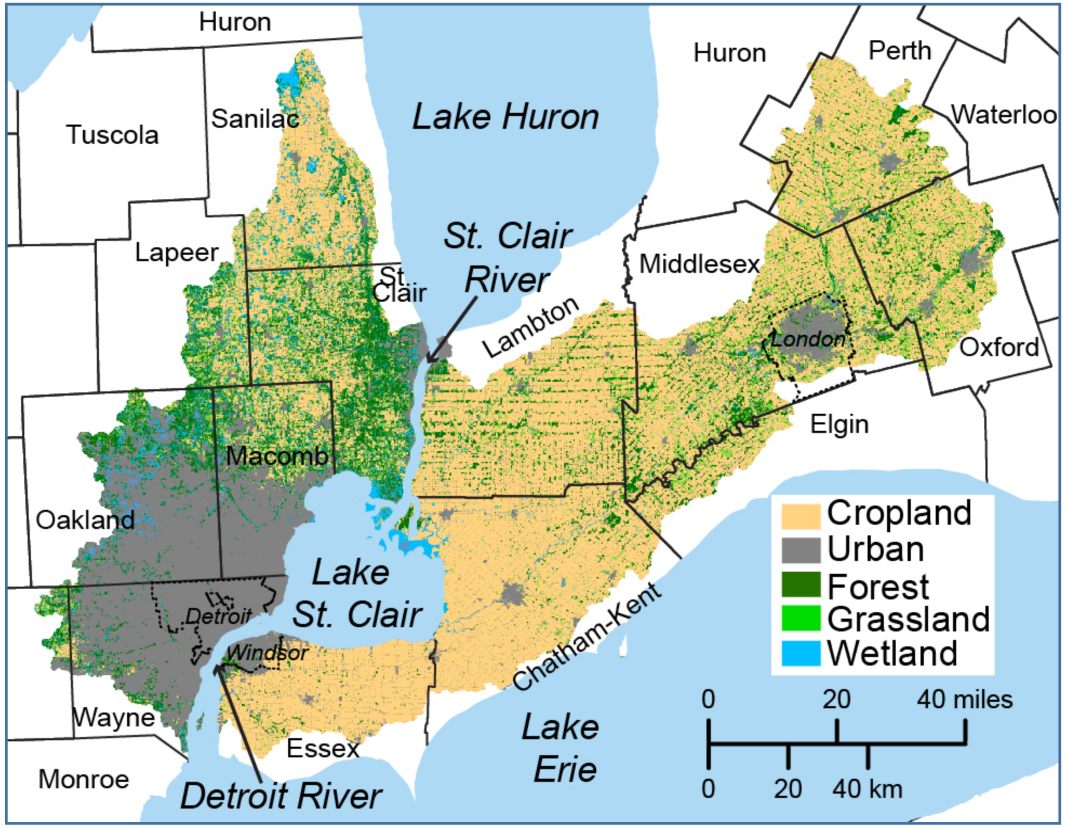
Previous studies quantified the TP and DRP loads from the Detroit River, but…

- attribution by source type and land use (e.g., point vs. nonpoint; urban loads vs. agricultural) were unclear
- trends caused by Lake Huron zebra mussels and improved wastewater treatment in Detroit on the reduction in the Detroit River load had not been articulated
- the role of Lake St. Clair as a modulator of upstream loads was not quantified
- the effects of load reduction strategies were not quantified with calibrated and validated models

Discrepancy between higher load at the bottom vs the top of the St. Clair River had been noted, but …

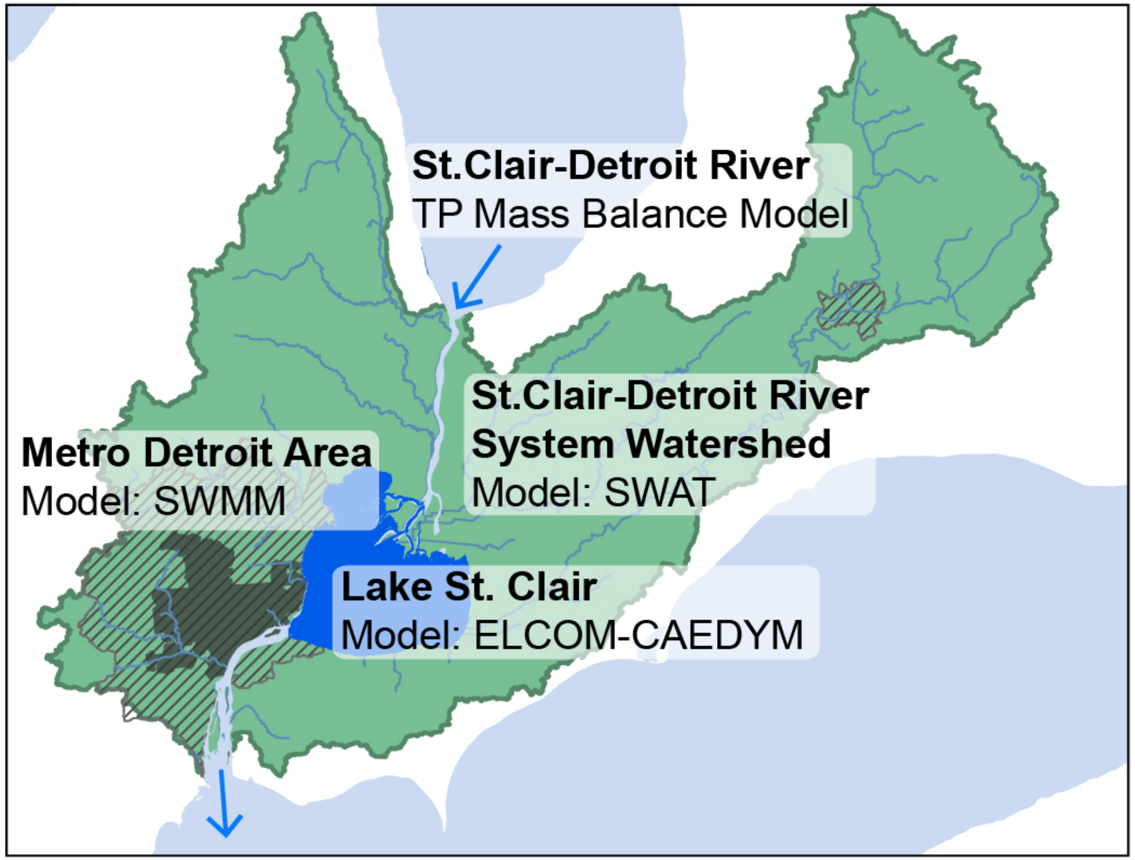
- the potential source of that unmeasured load was unknown
- the impacts of that unmeasured load on allocating load reductions was not appreciated

Study area: the St. Clair-Detroit River System



- 19,040 km^2 watershed
- ~40% in Michigan and ~60% in Ontario
- 49% cropland, 21% urban, 13% forest, 7% grassland, 7% water bodies
- 79% of the agricultural land is in Ontario
- 83% of the urban land is in Michigan
- Lake St. Clair processes water and nutrients from Lake Huron (via the St. Clair River) and its proximate 15,000 km^2 watershed

Study approach



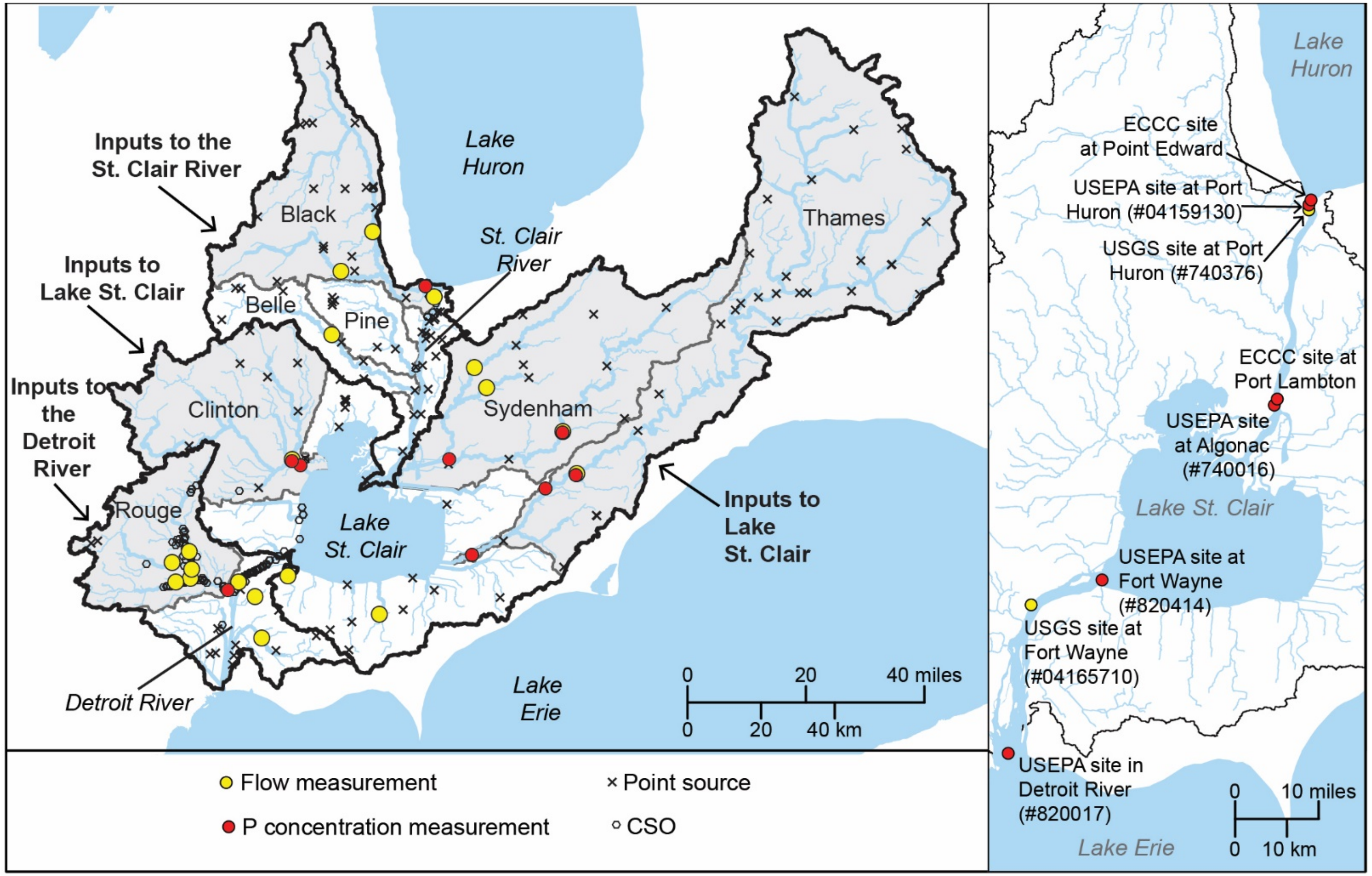
Four models were used to estimate loads and assess opportunities for load reduction

1. A total phosphorus **mass balance model** for all inputs and outputs
2. A **watershed** model simulating flow and dynamics of water, nutrients, and sediments
3. A 3D coupled hydrodynamic and ecological model of **Lake St. Clair**
4. An urban model simulating the sewer service area in the **metro Detroit area**

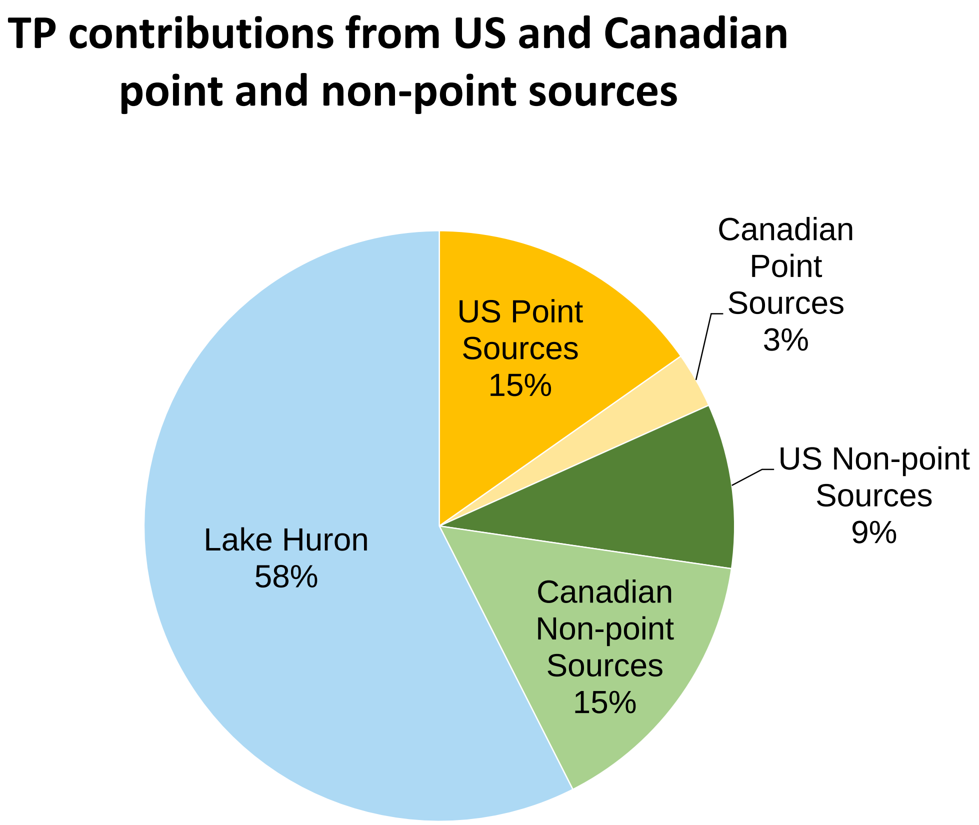
Estimating total phosphorus contributions

1. **Non-point source loads** calculated using flow and phosphorus measurements from gauge stations for each sub-watershed, direct drainage area, and Lake Huron.

2. **Point source loads** (including CSOs) calculated from EPA and MOECC data bases.



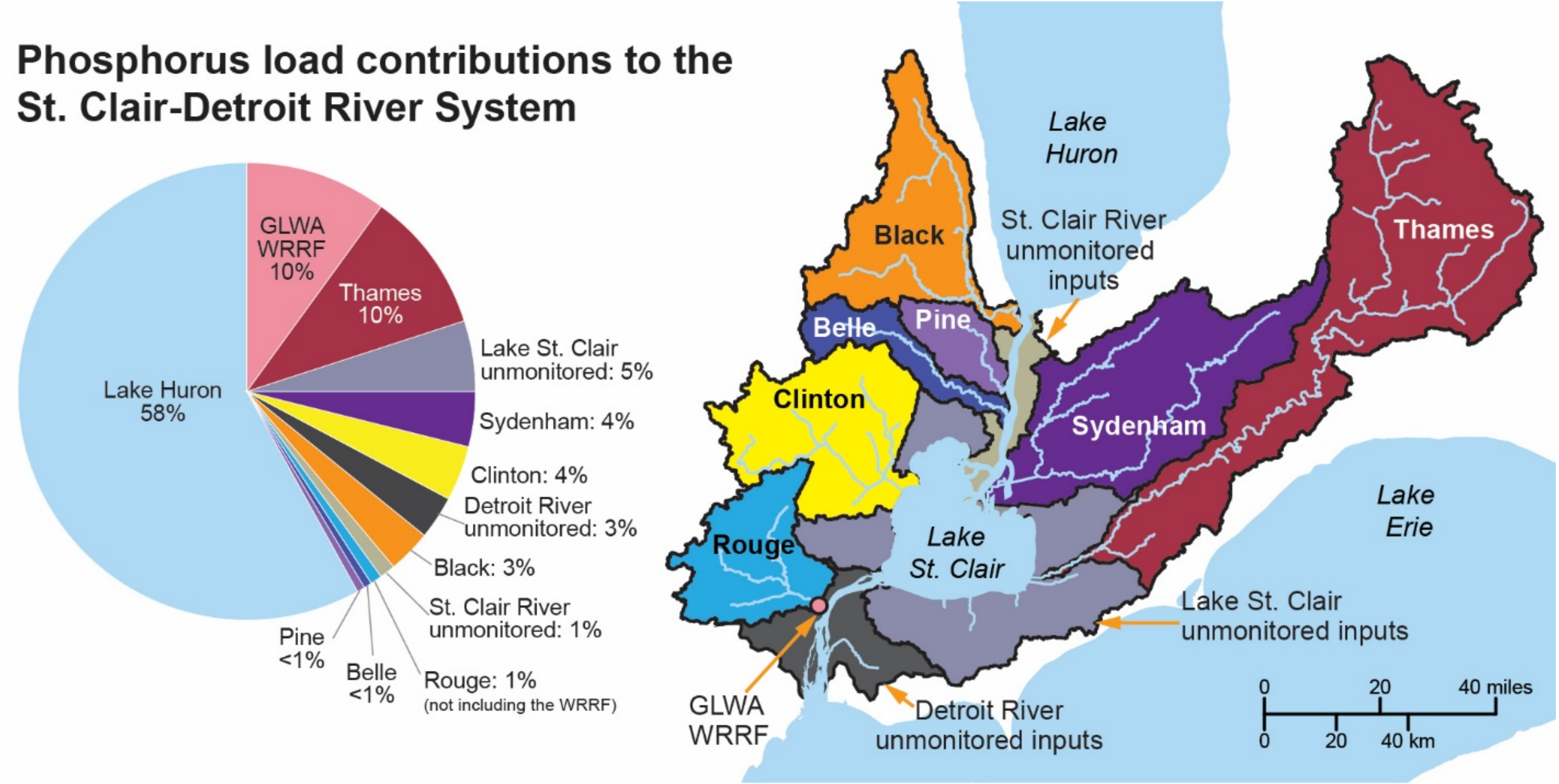
TP contributions to the St Clair-Detroit River System



- Lake Huron contributes 58% of the system's TP load.
- Point source (PS) and nonpoint source (NPS) contributions are nearly equal.
- Average annual load from US: 798 MTA
- Average annual load from Canada: 601 MTA

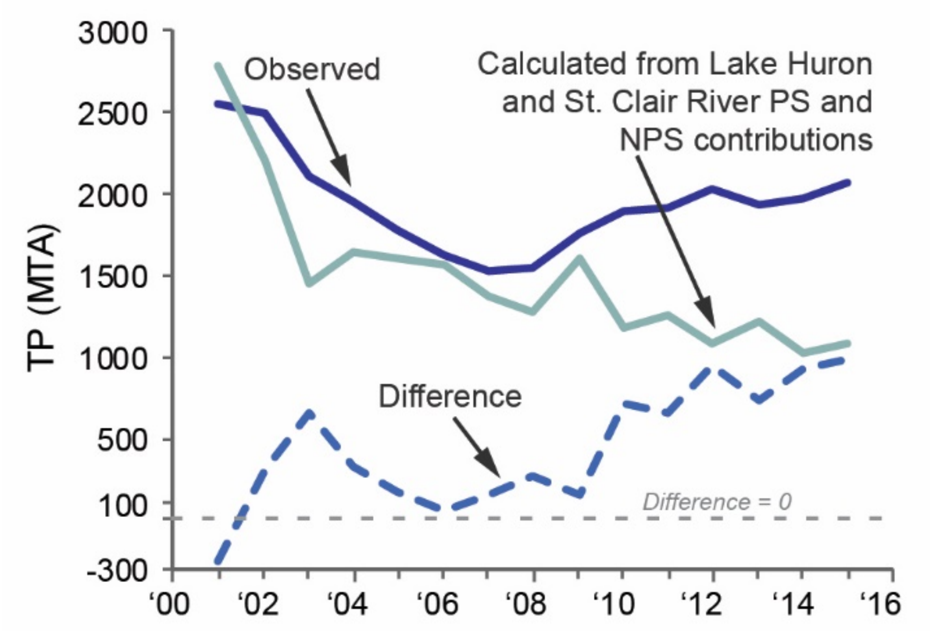
Note: This is based on average loads for a 4-year period from 2013 – 2016 and does not take into account any processing of nutrients in Lake St Clair

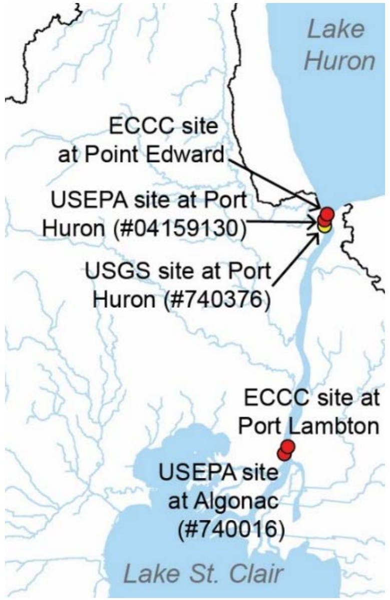
Where is phosphorus coming from?



- Pie chart shows relative contributions to the system's P inputs from largest to smallest
- Map is color coded to correspond to pie chart

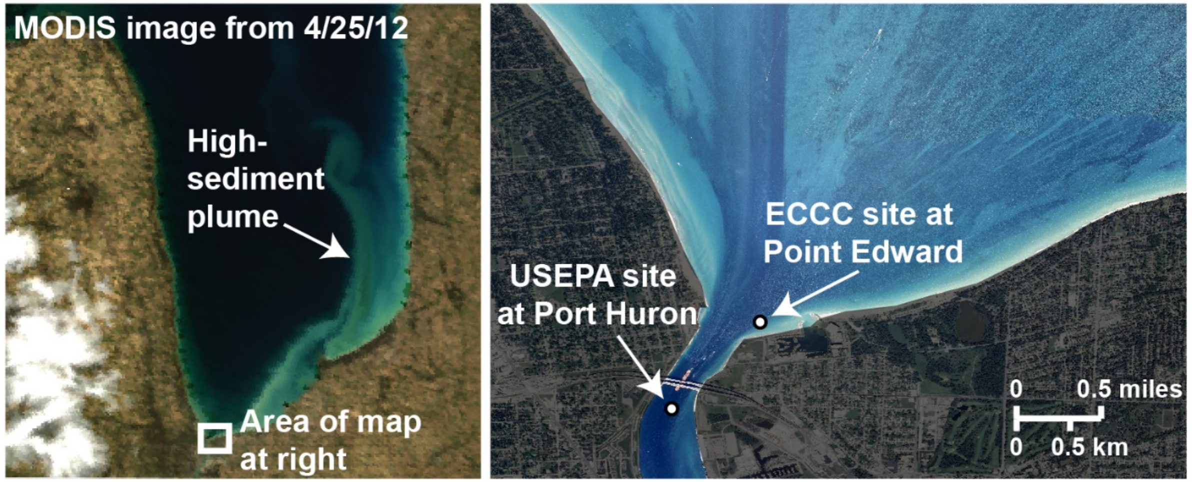
Phosphorus from Lake Huron





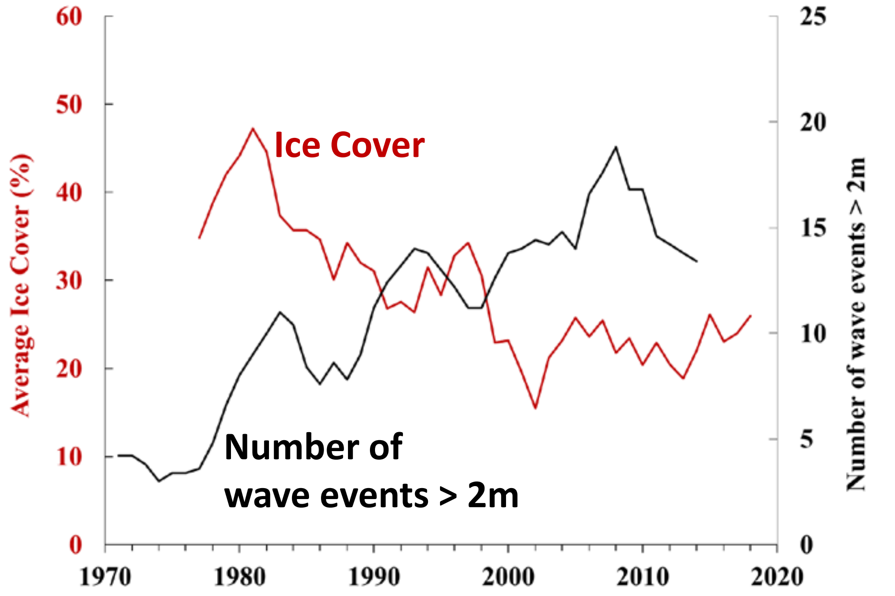
- TP inputs to Lake St. Clair measured at Algonac and Port Lambton (black line) are **greater than** the measured TP out of Lake Huron plus St. Clair River PS and NPS contributions (gray line).
- This unmeasured load was also identified by Burniston et al. (2018).

Phosphorus from Lake Huron



- This unmeasured load is likely from large sediment resuspension events in Lake Huron that evade detection at Point Edward and Point Huron monitoring sites.
- This was observed when comparing a time series of satellite imagery to sampling dates; several events per year were missed by the sampling programs.
- Load estimates could be improved by adding continuous measurements of turbidity or another parameter that could be correlated with P concentrations.

Phosphorus from Lake Huron

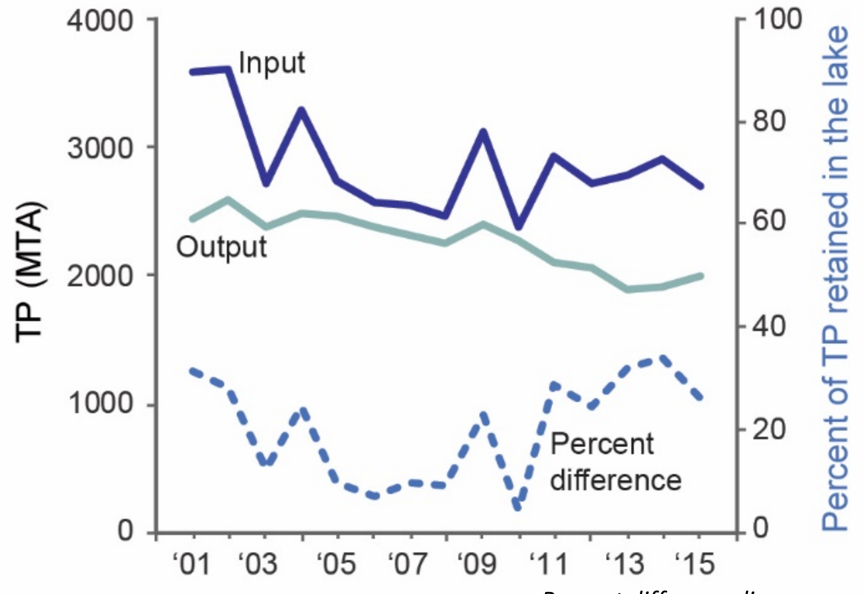


- The unmeasured load from Lake Huron has increased over time, consistent with decreased ice cover and increased storms in the lake.
- Less ice cover means storms will re-suspend sediment more easily.
- The P contribution from Lake Huron is therefore likely to continue to increase as climate warms.

Lake St. Clair is a TP sink

- On average between 2001 and 2015, Lake St. Clair retained 20% of its TP inputs (with substantial inter-annual variability).
- Sediment deposition in the 30% of lake is deeper than 5m likely contributes to the retention.
- Zebra and quagga mussels also likely contribute.
- DRP measurements are less reliable, but annual retention appears to be much lower, possibly approaching 0.

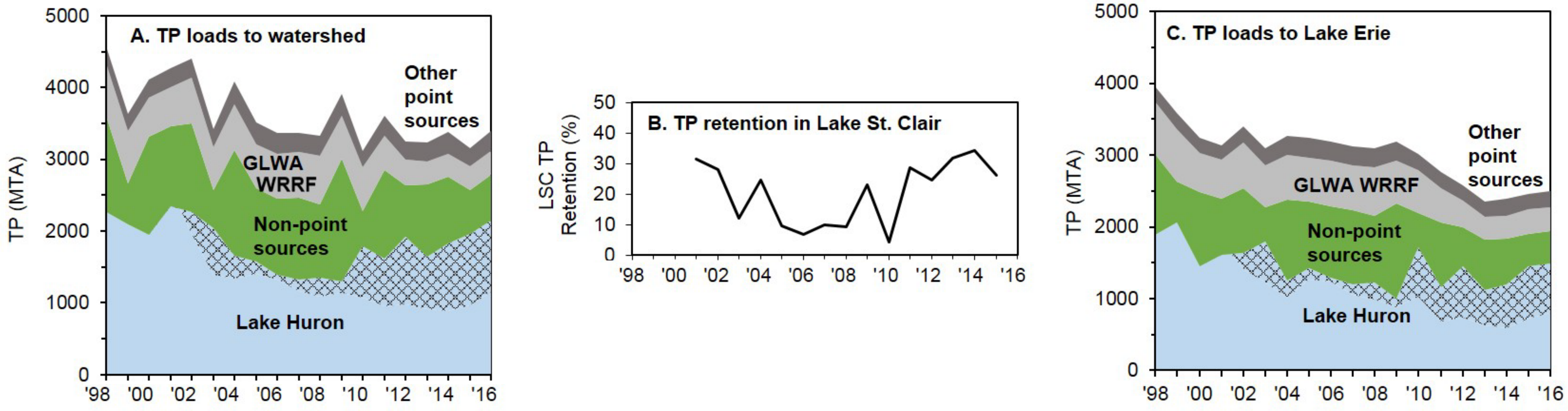
TP input to and output from Lake St. Clair annually



Percent difference line corresponds with right y-axis only, not MTA axis.

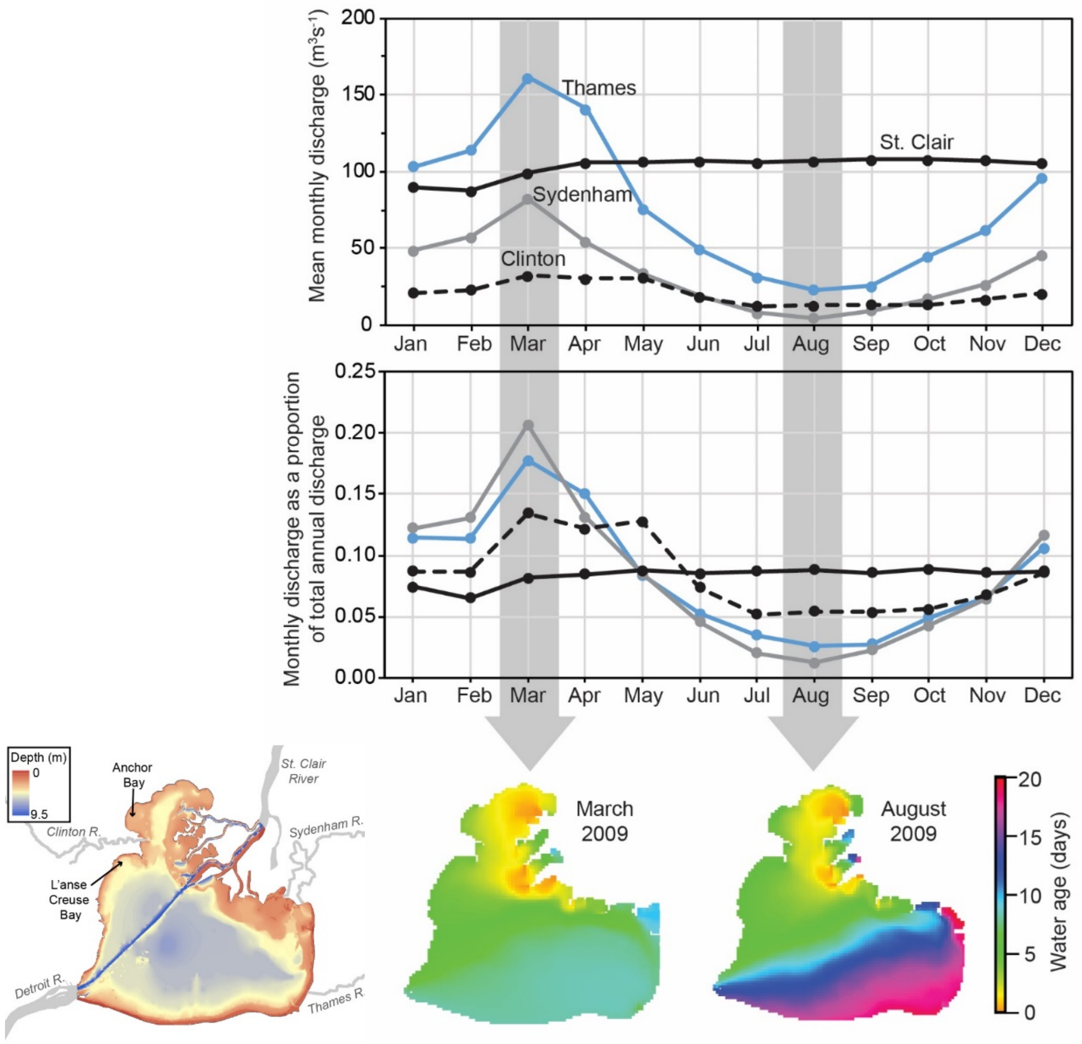
Lake St. Clair is a TP sink

- Some of the TP from sources upstream of Lake St. Clair will be retained and not reach the Detroit River or Lake Erie.
- This tends to increase the relative importance of sources below the St. Clair River.



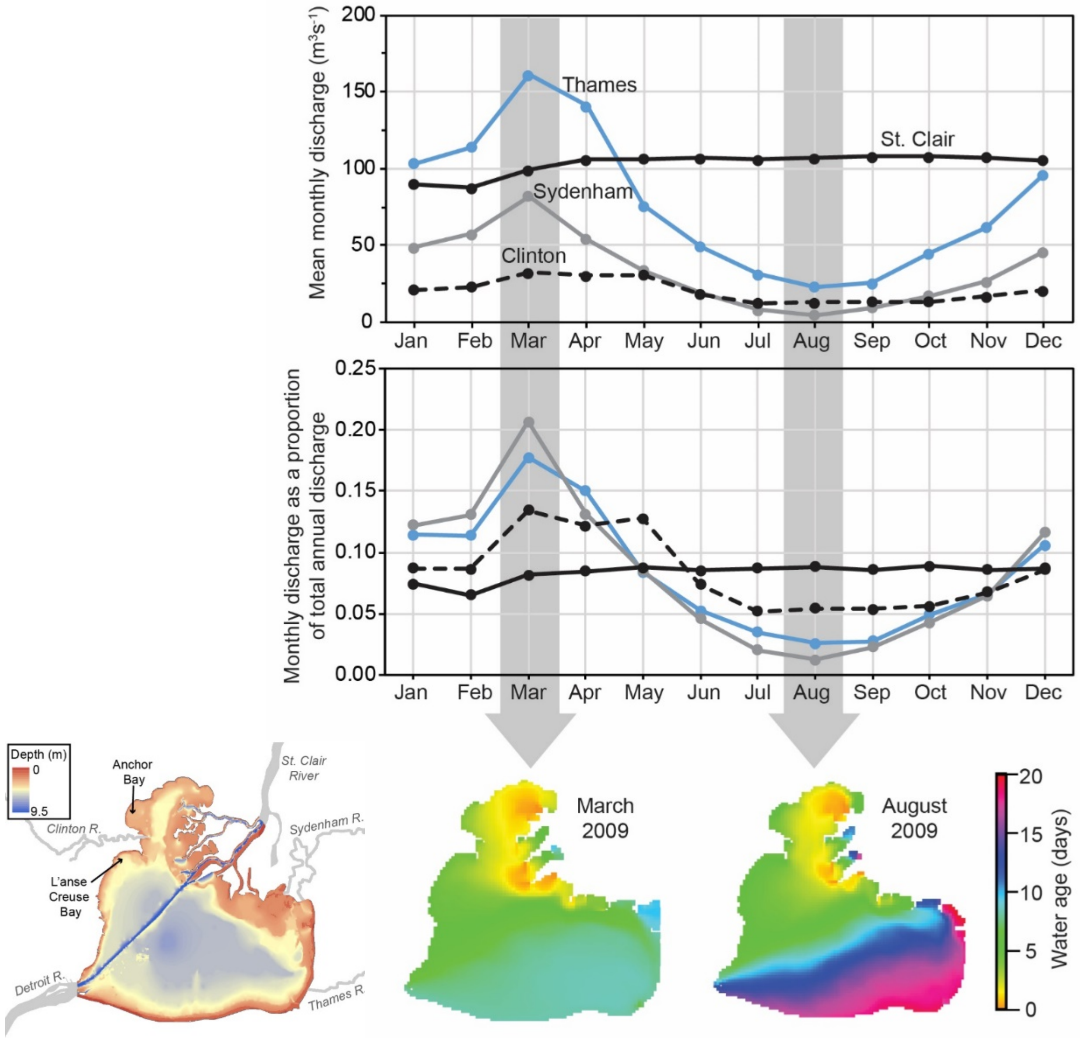
Lake St. Clair nutrient processing

- Thames River:
  - P load is largest in late winter and early spring, coinciding with shorter river water residence times → this means less retention.
  - Thames water residence time increases in summer, but most of the river's load has already entered the lake by then.
- Sydenham River:
  - River outlet is separated from the lake outlet by a basin deep enough for sediment to accumulate → this enhances particulate P retention.
- Clinton River:
  - Load is delivered more evenly throughout the year, including during the periods of higher production and settling, leading to higher retention.



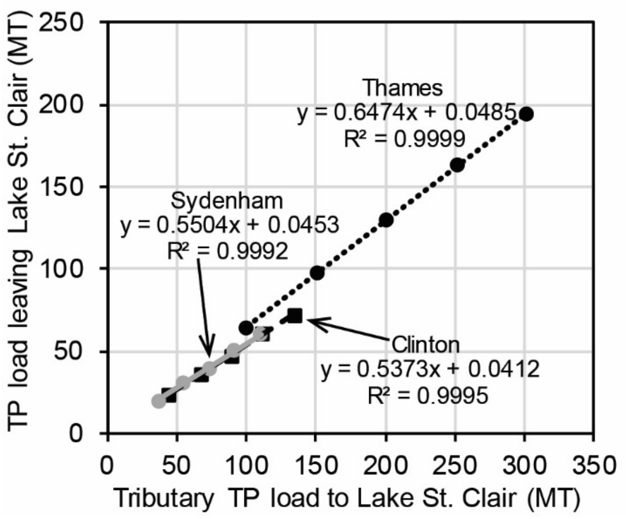
Lake St. Clair nutrient processing

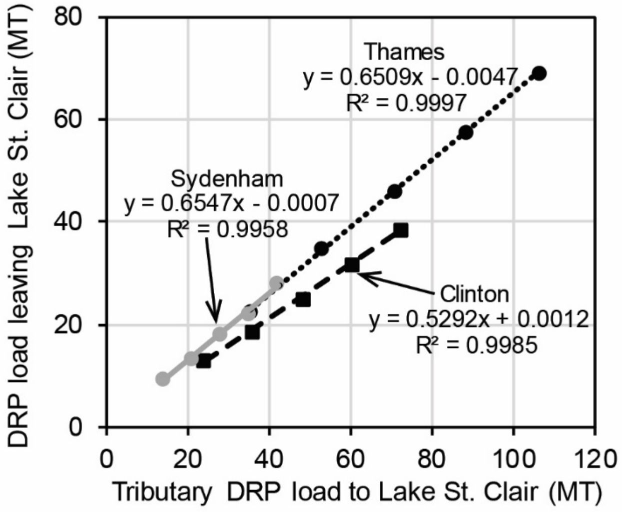
- TP loads from the Thames therefore have **lower retention rates** in the lake compared to loads from the Sydenham and Clinton, and so load reductions in the Thames watershed will results in **larger reductions** at the outlet of Lake St. Clair.
- Changes are likely to still be small compared to the overall load to the lake, though, which is dominated by the St. Clair River.



Lake St. Clair nutrient processing

- Load-response curves show how the load leaving Lake St. Clair would change if the load from one of the tributaries changed.
- The **linear responses** indicate that within the range of 50% to 150% of typical loads, the lake's **response was proportional to changes in tributary loads**.

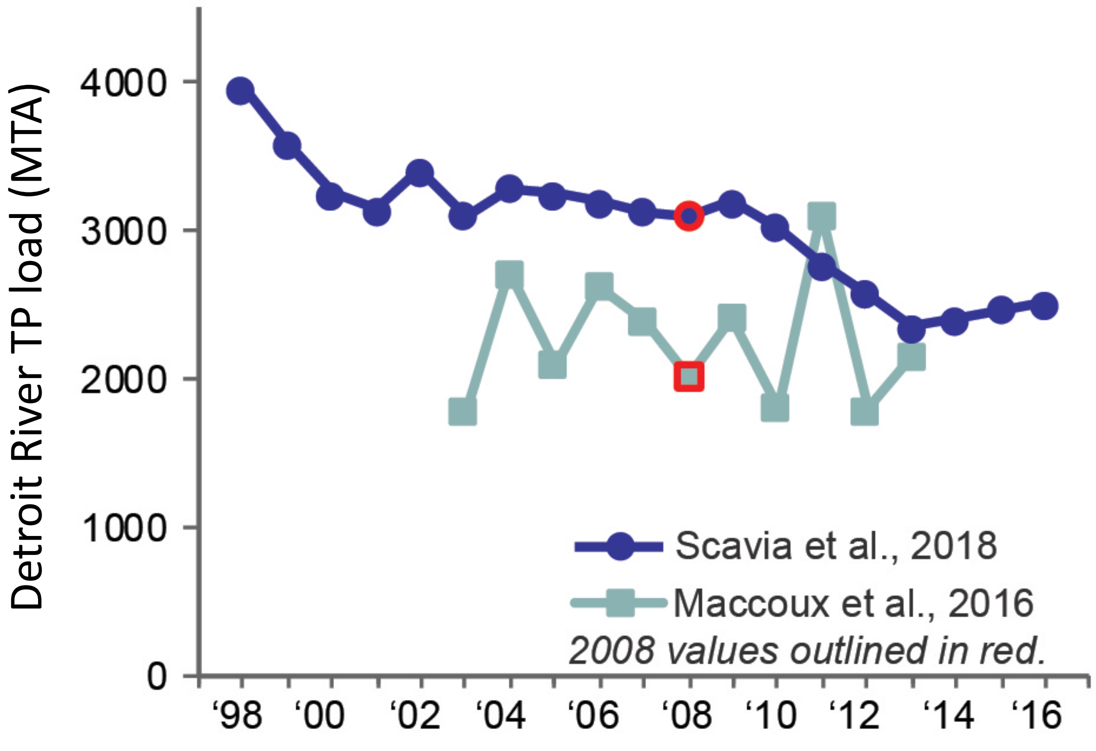




Regression intercepts were subtracted from the load leaving Lake St. Clair

- TP response curve slopes indicate that a unit **reduction in the Thames River load produces a larger reduction in the TP load leaving the lake** than do unit changes in the Sydenham or Clinton loads.
- Unit reductions in the Thames or Sydenham are more effective than the Clinton at reducing the DRP load.

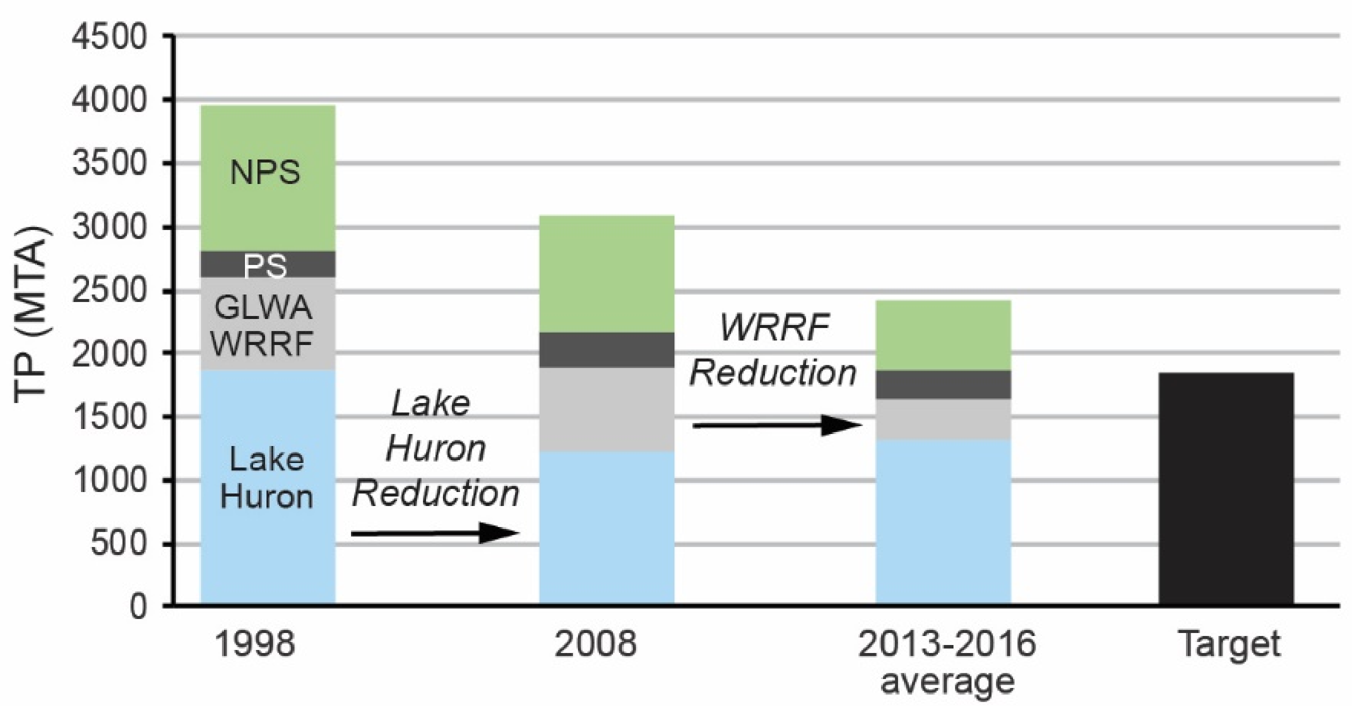
Detroit River TP loads to Lake Erie



- Retention in Lake St. Clair is accounted for when calculating Detroit River TP loads to Lake Erie.
- Our estimate for 2008 is considerably higher than what was used to set the targets (Maccoux et al. 2016).
- Maccoux et al. underestimates likely due to their of a low value for the Lake Huron load.

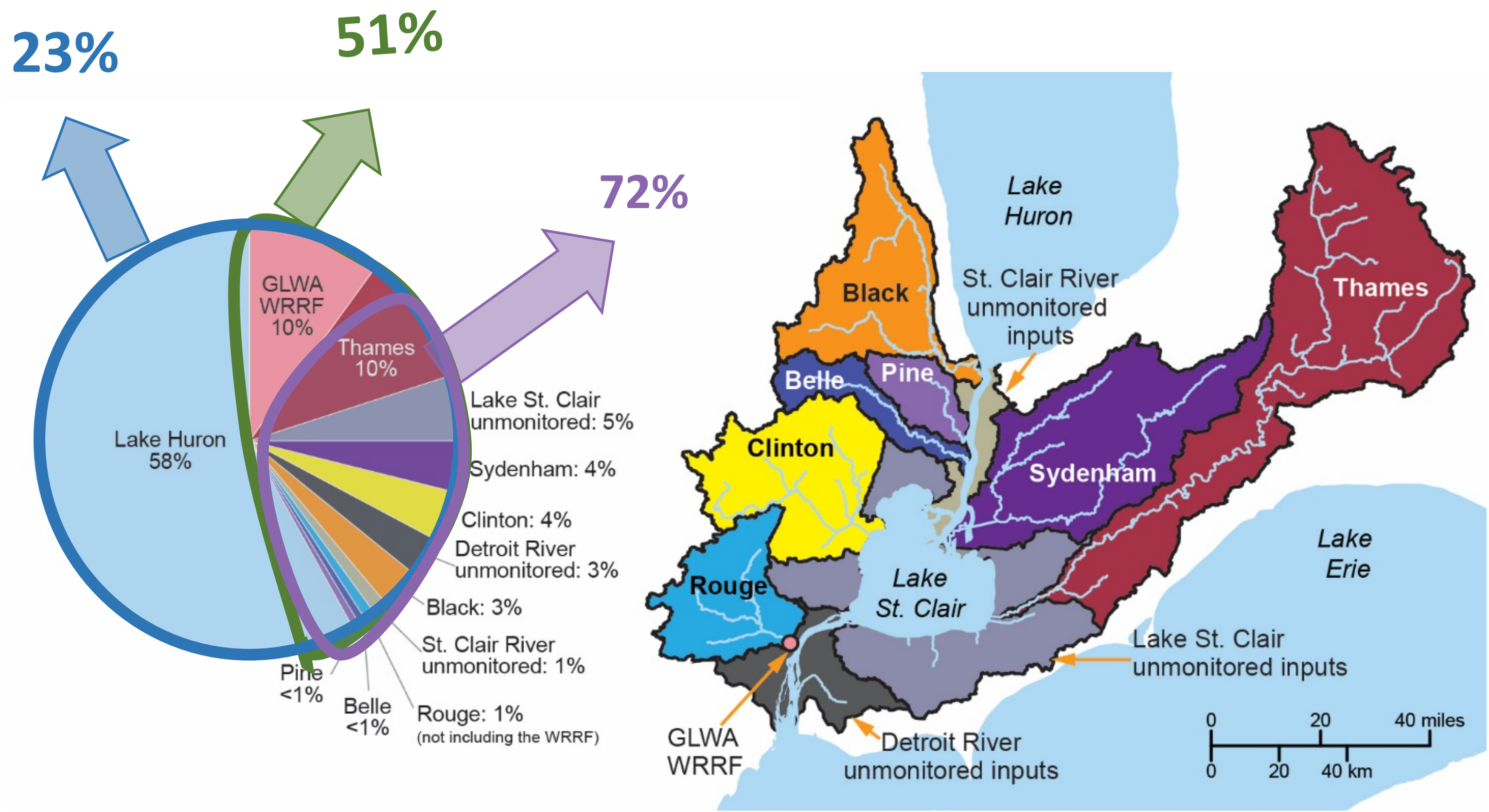
Load reduction overview

- 2008 Detroit River TP load estimate: **3,096 MTA**
- 40% reduction means target for the Detroit River is **1,858 MTA**.
- Detroit River load has already declined to **2,425 MTA** (2013-2016 average load), mostly due to decreases in the loads from Lake Huron and the WRRF.
- **567 MTA** remain to be reduced.



Note: These numbers are based on the load estimates generated by the project team and have not been adopted for official use.

Percent reduction needed to hit 40% target

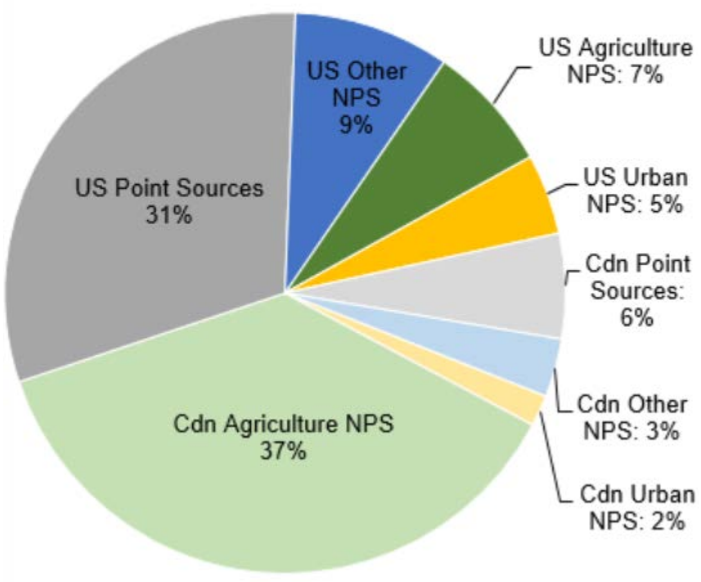


- An additional **23%** reduction from all sources is needed to meet the loading target.
- If there are no reductions to the Lake Huron load, a **51%** reduction would be required from the remaining watershed sources.
- If there are no further reductions from the GLWA WRRF **and** none from Lake Huron, a **72%** load reduction would be needed from the remaining sources.
- Reducing Lake Huron load and GLWA WRRF loads each by 10-15% leaves 40-50% to be reduced from other watershed sources (which simulations show is possible).

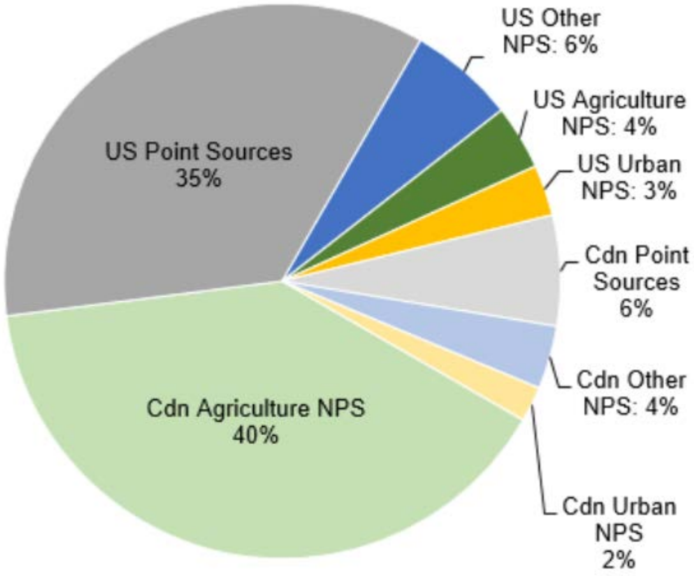
Options for reducing nonpoint sources

- Pie charts show proportion of watershed TP and DRP from point sources and nonpoint sources, with nonpoint sources subdivided by land type.
- The load from Lake Huron is not included here, and retention in Lake St. Clair is not accounted for.

Total Phosphorus



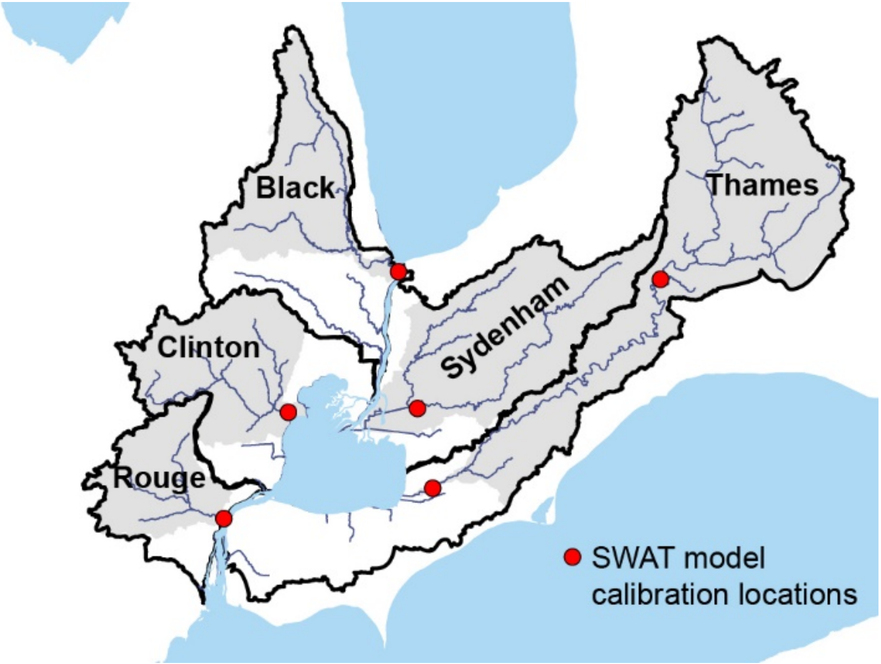
Dissolved Reactive Phosphorus



Agriculture land includes cropland and pasture. Other land includes wetlands and forests.

Options for reducing nonpoint sources

- The Soil and Watershed Assessment Tool (SWAT) was applied to the full watershed to explore options for reducing TP and DRP loads.
- Modeling units correspond to farm fields, the first time this has been done for a watershed of this size.
- Model was calibrated (2007-2015) and validated (2001-2006) at the mouths of six major tributaries
  - Neighbor watersheds with similar characteristics were assumed to respond similarly.



Options for reducing nonpoint sources

- Seven practices were studied, first one at a time and then bundled in different combinations:

Applied to all cropland

1. Reduced fertilizer application rates
2. Subsurface placement of fertilizer
3. Controlled drainage

Applied to all land including permeable urban areas

4. Cover crops
5. Wetlands
6. Filter Strips
7. Grassed waterways

Comparing single practices for agricultural watersheds

Subsurface placement of nutrients

TP: 29 – 34%

DRP: 30 – 32%

Buffer strips

covering 1.7% of field

TP: 31 – 39%

DRP: 20 – 25%

Wetlands

1% of area, draining 50% of watershed

TP: 26 - 27%

DRP: 22- 23%

Cover crops

After corn and soybeans

TP: 22- 30%

DRP: 18 – 24%

25% Reduction in nutrient application

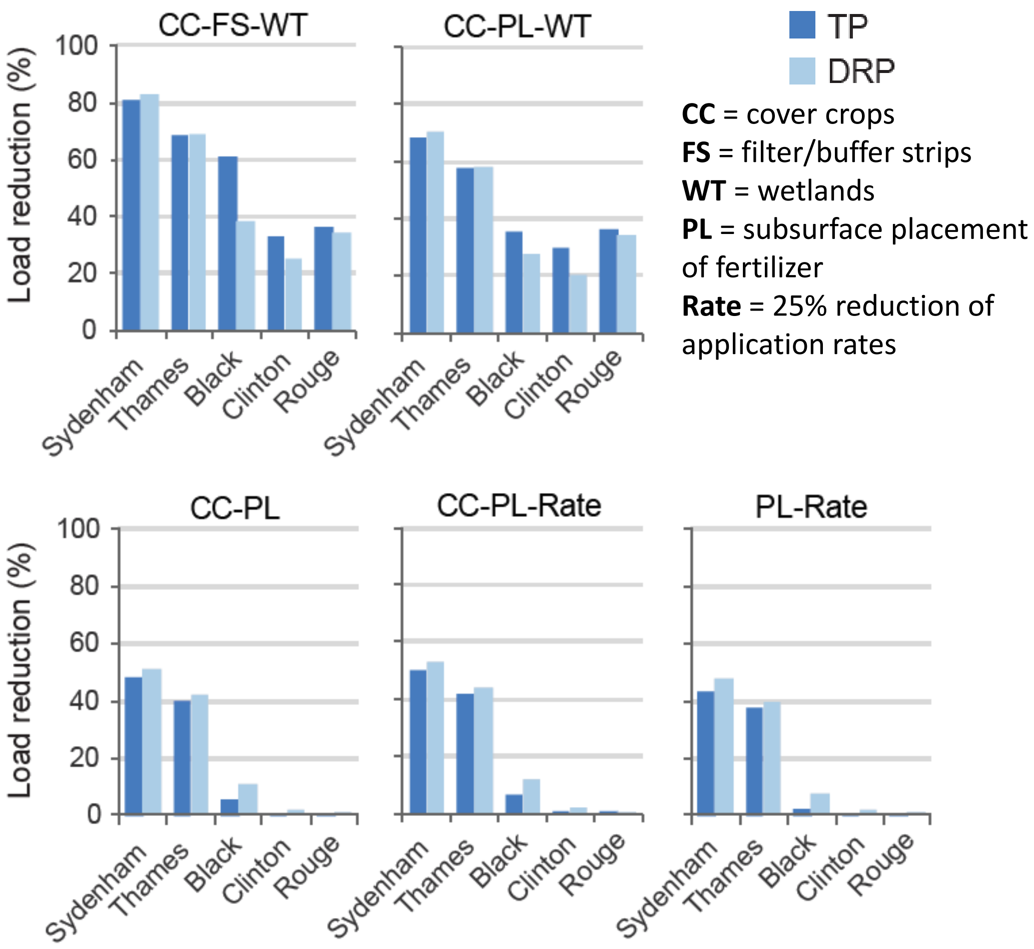
TP: 8 – 12%

DRP: 15 – 18%

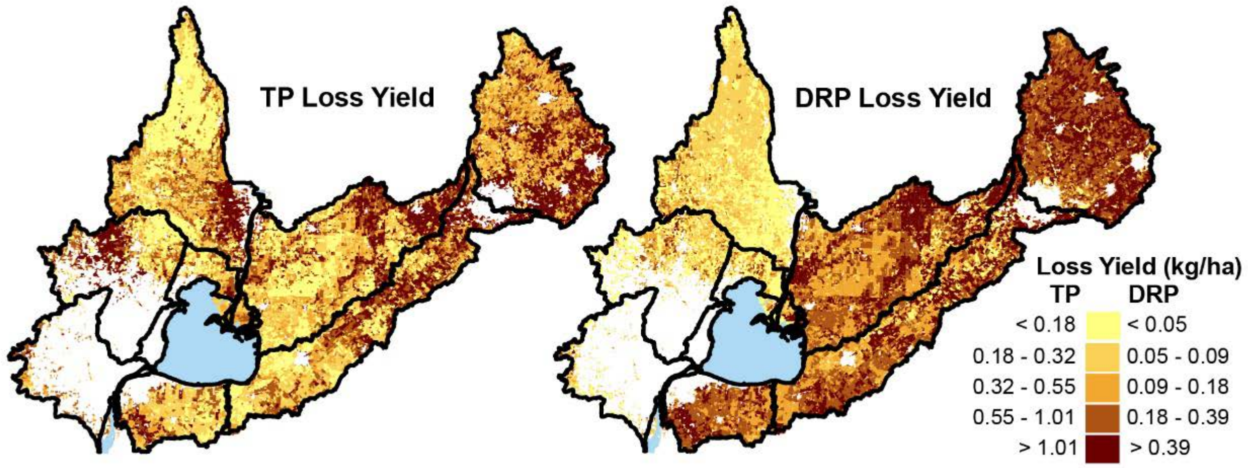
SWAT results. Percent reductions are shown for the Thames and Sydenham, assuming 100% adoption

Combining practices leads to better outcomes

- Even with 100% adoption, **none of the practices implemented alone achieved a 40% load reduction** at their subwatershed's outlet.
- **Bundling practices** works better than implementing single practices.
- Combining practices such as cover crops, filter strips, wetlands, and subsurface placement of fertilizer resulted in **TP reductions >50%.**
- CC-PL bundle performed almost as well as CC-PL-Rate, suggesting it may not be necessary to adjust application rate if cover crops and subsurface placement are implemented.



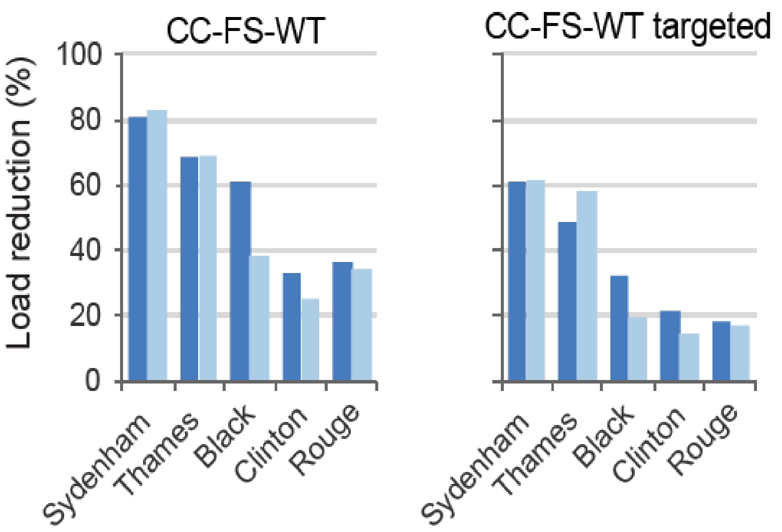
Focusing practices on high loss areas



While Ontario fertilizer application is higher and tile drain spacing is more intense …

… it is more likely that higher rainfall and different soil characteristics explain the higher loss yields compared to Michigan.

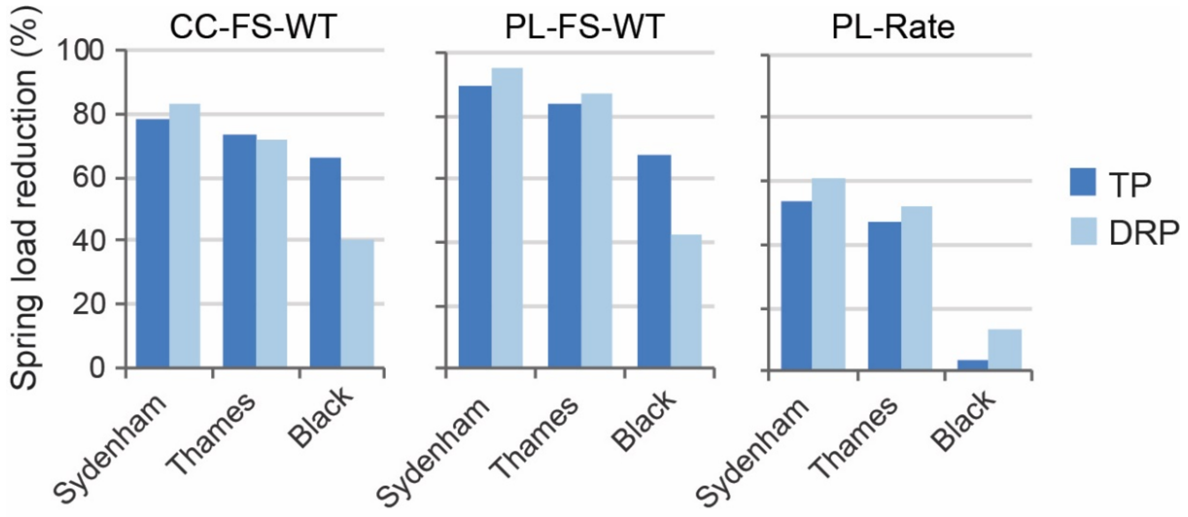
Focusing practices on land with the highest phosphorus losses (55% of total land, instead of 100%) resulted in reductions approaching those achieved by applying practices on all agricultural land.



CC = cover crops
FS = filter/buffer strips
WT = wetlands

Combined practices can reach spring load targets

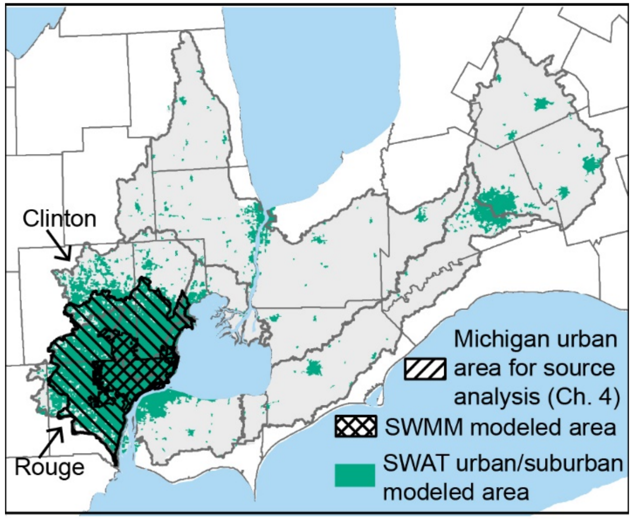
- GLWQA also calls for a 40% reduction in **spring load** from the Thames watershed (among others outside of our study area).
- Spring load reduction percentages are equal to or greater than the annual reductions for the Thames and other agricultural watersheds.
- Practices selected to address spring TP and DRP loads will also be effective for reducing annual TP.

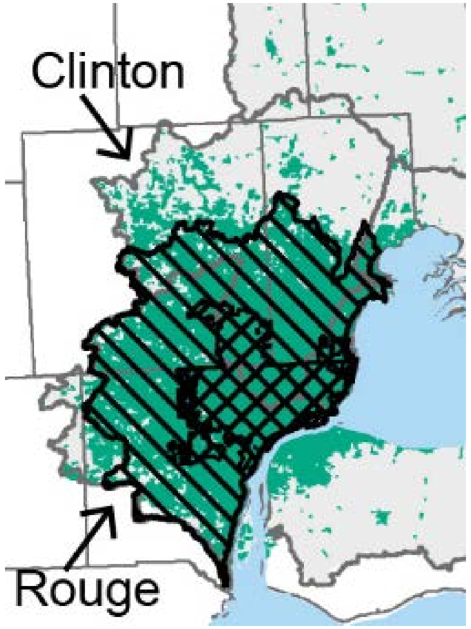


CC = cover crops; **FS** = filter/buffer strips; **WT** = wetlands;
PL = subsurface placement;
Rate = 25% reduction of application rates;

Options for reducing urban/suburban nonpoint sources

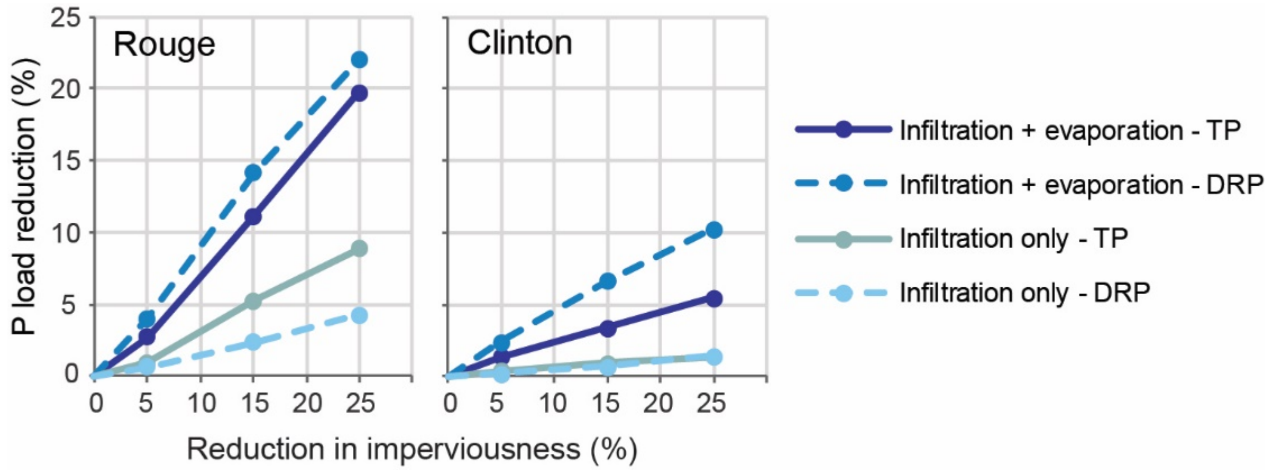
- The SWAT model was used to simulate reductions in impervious urban and suburban areas in the Rouge and Clinton watersheds.
- Scenario 1: Impervious surfaces were changed to bare pervious surfaces (e.g, permeable pavement) to increase infiltration.
- Scenario 2: Impervious surfaces were changed to vegetated pervious surfaces (e.g., rain gardens) to increase both infiltration and evaporation.





Options for reducing urban/suburban nonpoint sources

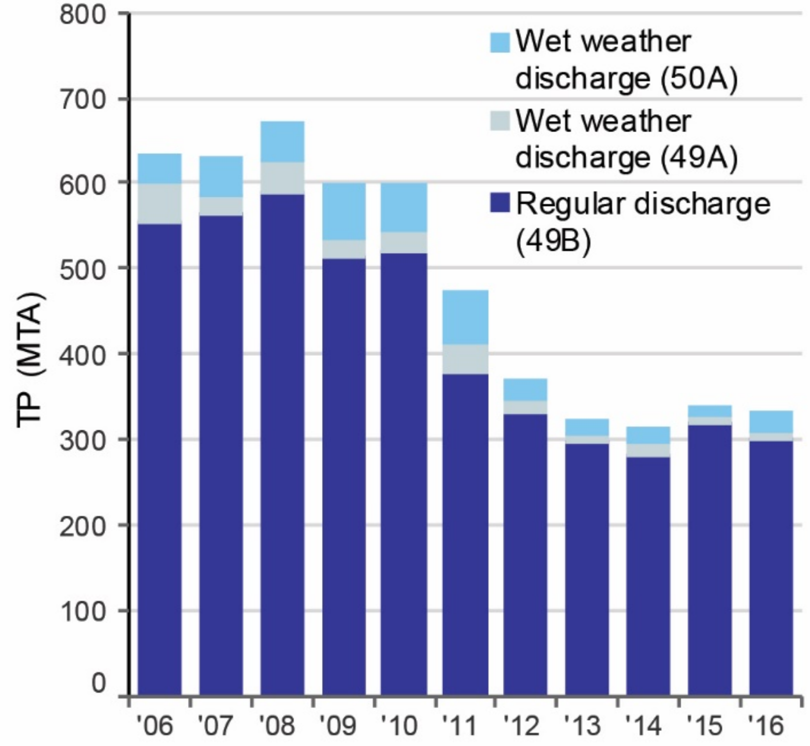
- Increasing infiltration and evaporation (by converting impervious land cover to vegetated pervious land cover) was most effective at reducing TP and DRP.
- The Rouge responded more to both scenarios than the Clinton because a higher proportion of the watershed is impervious.
- The absolute loads reduced from these watersheds are roughly equivalent, though, because the NPS TP load from the Clinton is about three times that of the Rouge.



Understanding point sources

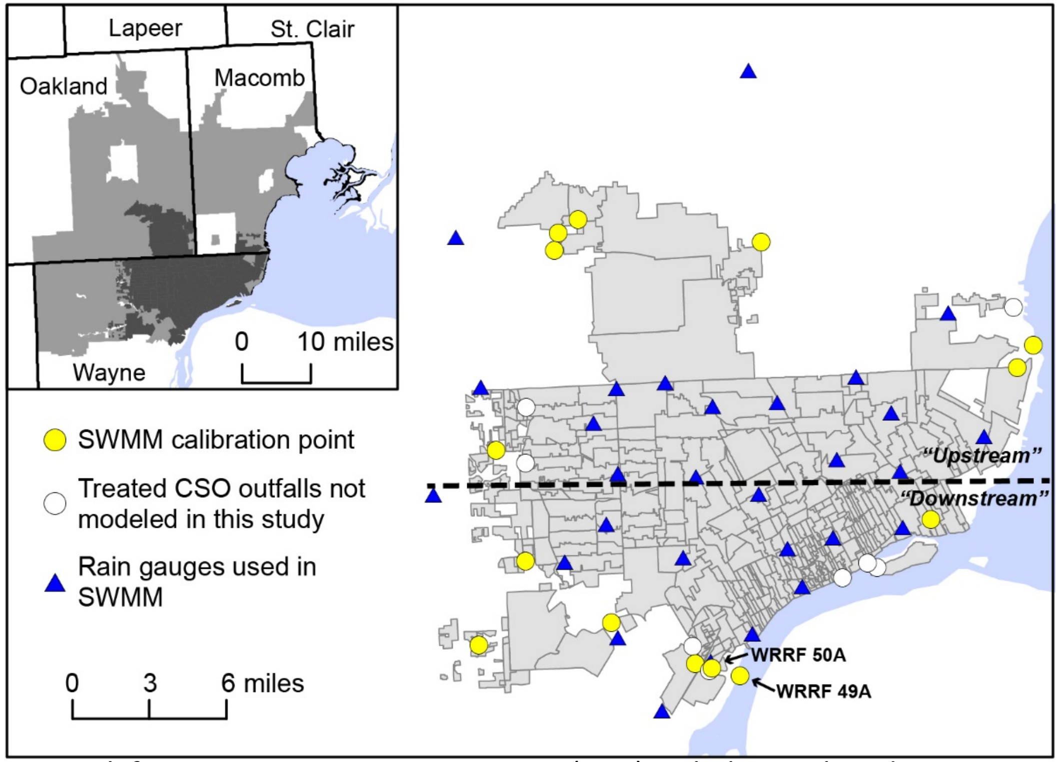
- Point sources contribute 43% of the TP watershed load, and CSOs contribute less than 4%.
- GLWA WRRF is 54% of the point source TP load and 13% of the Detroit River's load to Lake Erie.
- GLWA WRRF has already reduced its load by 51% since 2008.
- While reductions from any one of the ~150 other point sources will not have a substantial impact, collectively they could help.

Changes in the phosphorus load from the Great Lakes Water Authority Water Resource Recovery Facility (GLWA WRRF) in Detroit



Options for reducing combined sewer overflows

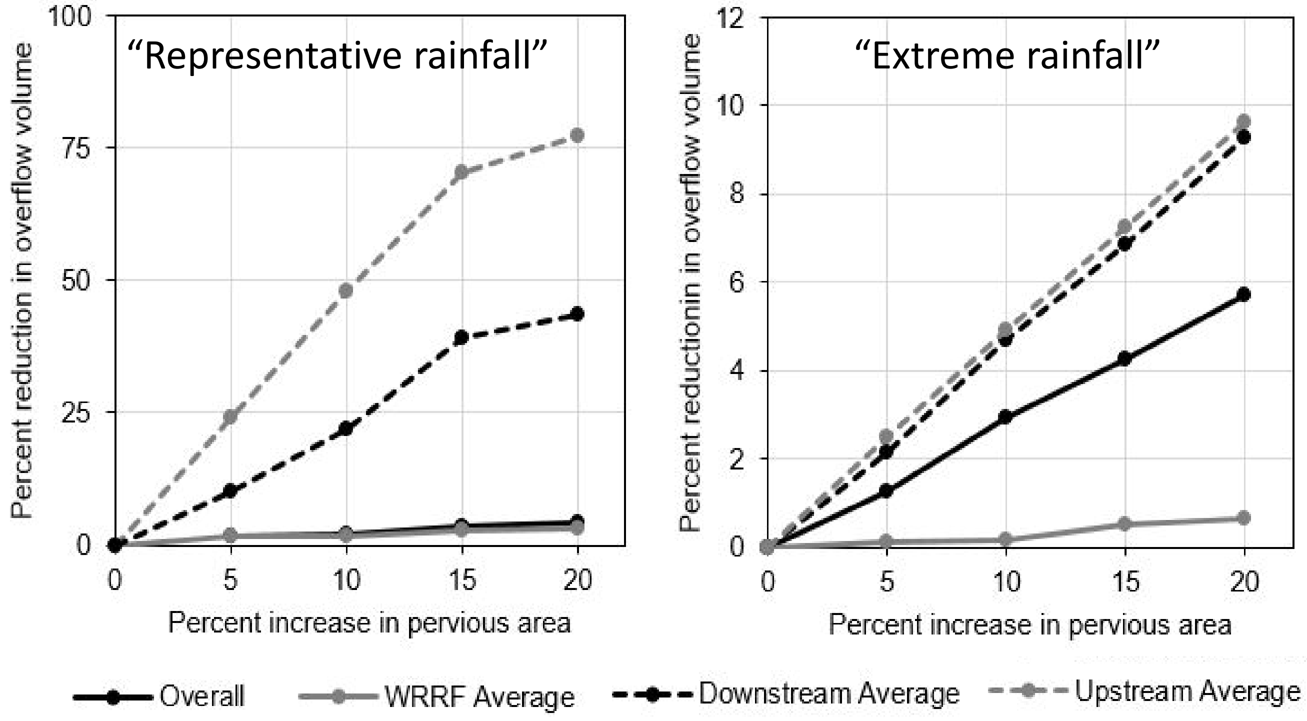
- A Storm Water Management Model (SWMM) was calibrated for volume at outfalls of 12 retention basins, two wet weather outfalls at the WRRF, and inflows to the WRRF.
- Two types of green infrastructure (bioretention cells and permeable pavement) were implemented separately in the model to examine the effects on reducing CSO volumes at the calibrated outfalls.
- Model was run with “representative rainfall” and “extreme rainfall.”
- Scenarios are not intended to provide realistic implementation goals, but rather an understanding about the range of potential impacts GI may have.



Upper left inset: GLWA sewer service area (gray) with the combined sewer area shown in dark gray.
Main map: Area modeled by SWMM, calibration points, and “upstream” vs. “downstream” separation used for depicting results (next slide).

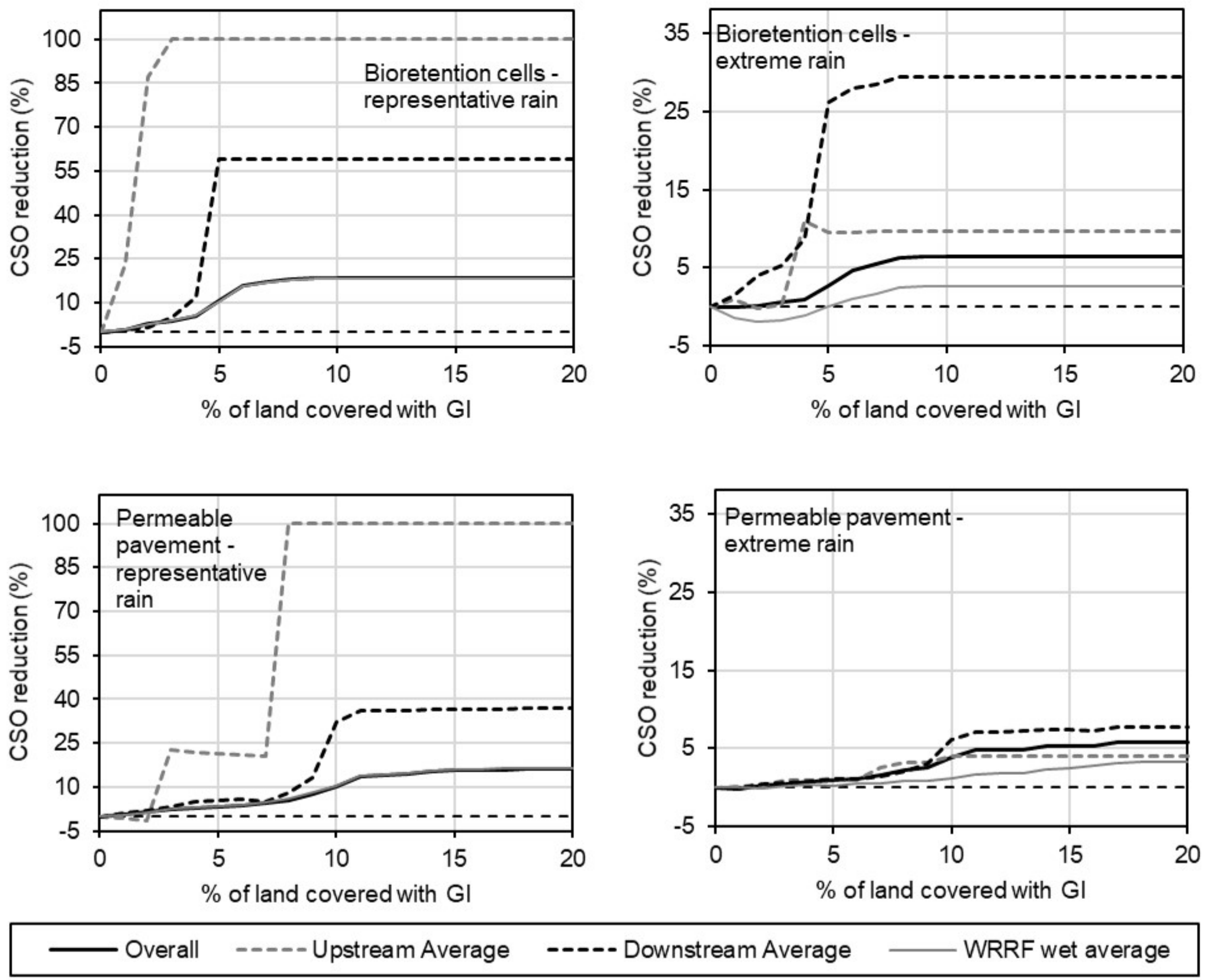
Modeling changes in impervious cover

- The fraction of pervious land cover in the combined sewer area was increased incrementally to see how much CSO volume might be reduced.
- Under representative rain conditions, increasing pervious cover substantially reduced upstream CSOs, but impacts at the WRRF and for the whole system were limited.
- Under extreme rain scenario, CSO reductions were minimal even with large increases in pervious area.



Note the different y-axes.

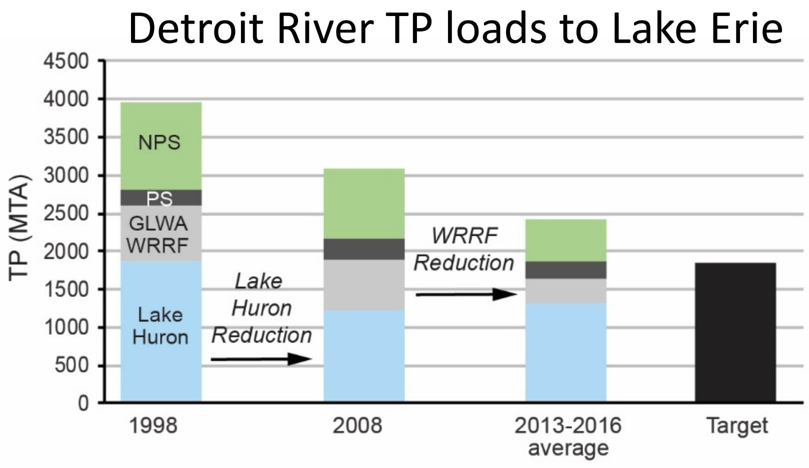
Evaluating green infrastructure impacts on CSO volume



- The coverage of each GI type was increased from 0% to 20% of the combined sewer region.
- The percent change in CSO volume at each outfall and for the entire system
- Only one upstream location had an overflow under representative rain. As such, GI showed the potential to entirely reduce overflows upstream.
- The entire system showed maximum reduction of about 6% with either GI type under extreme rain and about 15 - 20% under representative rain.

Summary of key findings: Overview of loads

- Over 50% of the Detroit River TP load comes from **Lake Huron**.
- On average, **Lake St. Clair** retains 20% of the TP that enters the lake.
- Reaching a 40% load reduction for the Detroit River requires reducing
  - **23%** of all sources (because some reduction has already occurred since 2008).
  - **51%** of watershed sources if Lake Huron is not included.
  - **72%** of sources if Lake Huron and the WRRF are not included.
- Reducing Lake Huron load and GLWA WRRF loads each by 10-15% leaves 40-50% to be reduced from other watershed sources (which simulations show is possible).



Summary of key findings: Agricultural loads

- Model simulations suggest **bundles of agricultural practices** could be used to exceed load reduction targets from individual sub-watersheds, but applying single practices alone did not.
- **Targeting agricultural practices** on just the 55% of land with the highest loss yields is nearly as effective as putting practices on 100% of land in some cases. High phosphorus loss lands need to be identified on the ground using farm- or field-level information.
- The practices that meet the annual TP targets also meet the **spring DRP targets** for the Thames River.
- Estimated loss of TP and DRP per acre showed that losses were generally higher in Canada than in the US, likely driven by higher precipitation on agricultural lands in Ontario.

Summary of key findings: Urban loads

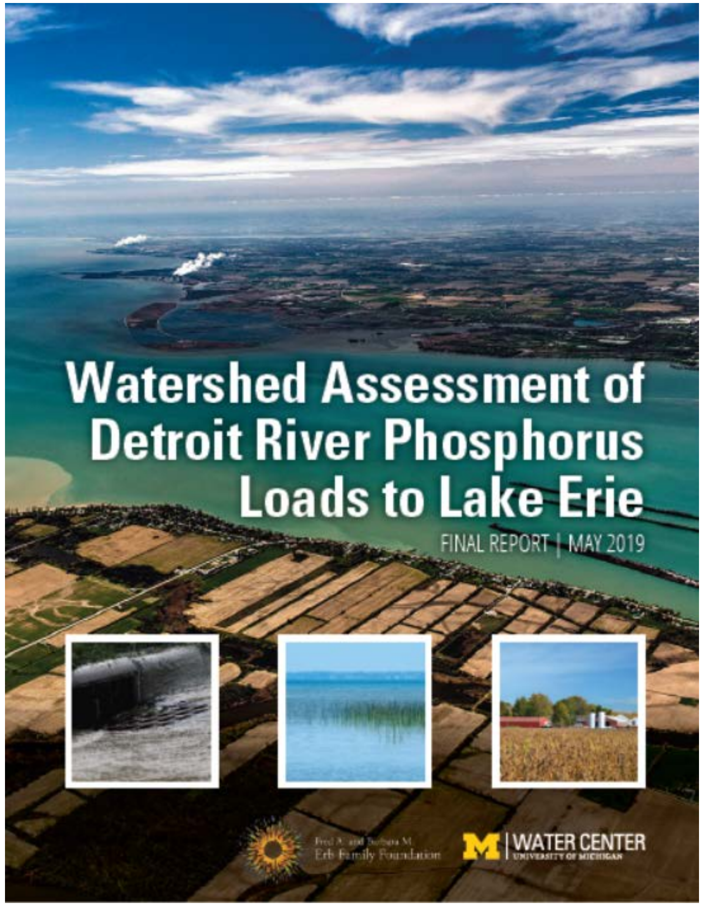
- The **WRRF in Detroit** contributes 23% of the watershed load (not including Lake Huron's contributions) and 13% of the Detroit River's load to Lake Erie, but it has already reduced it's load by 51% since 2008.

- **Increasing pervious area** in the combined sewer region showed reductions in CSO volume at upstream locations under representative rainfall conditions, but impacts downstream and for the system overall were minimal. Impacts were also minimal at all locations under extreme rainfall.

- Two types of **green infrastructure** – bioretention cells and permeable pavement – both showed potential to reduce CSO volume by 16-18% under representative rainfall, and by up to 6% under extreme rainfall. These maxima are only achieved with a high coverage of GI across the system.

- While modeling exercises may not represent realistic levels of GI implementation, they provide an understanding about the range of theoretical impacts that increasing pervious land has on CSOs.

Thank you!



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