Supplemental Information for the Final Report

Watershed Assessment of Detroit River Phosphorus Loads to Lake Erie

Produced by the University of Michigan Water Center and available at:
myumi.ch/detroit-river

May 2019

Sections

Section 1. Summary of Advisory Group Meetings and Consultations

Advisory Group Meetings

This table outlines project advisory group meetings and provides examples of how the project team acted on feedback the group provided the meeting.

Date	Meeting	Purpose	Examples of how team acted on advisory group feedback
March – June, 2016	Phone interviews with each advisory group member	Documented areas of expertise, topics of interest and potential concerns related to project and process.	• We prepared a comparison between Maumee and Detroit River. • We developed maps and tables explaining data sources, data resolution, monitoring points and frequencies.
May 5, 2016	In person kick-off meeting in Detroit, MI	Group identified their highest priority questions to guide research plans and raised questions.	• We decided to use a finer resolution for modeling. • We pursued additional data and consults to better capture GLWA sewershed dynamics.
June 29 and July 12, 2016	Advisory group conference calls	Group reviewed the team's assessment of how their questions could or could not be addressed through this project. Group identified related projects and data sources.	• We developed guide to how forms of P are modeled in SWAT. • We engaged Canadian researchers doing similar work. • We engaged a social scientist to help analyze stakeholder interests and concerns.
January 18 – 19, 2017	Annual In-person advisory group meeting in Windsor, Ontario	Group reviewed modeling approach and model set-up decisions. Small groups brainstormed specific scenarios to address for urban and agricultural areas.	• We developed a document outlining all agricultural management decisions used in baseline model set-up. • We decided to focus urban modeling on issues related to green infrastructure type and placement, CSOs and system-wide flow controls.
July 13, 2017	Advisory group conference call	Group reviewed updates on urban sources as well as SWAT and SWMM modeling	• We reported loads for treated and untreated CSOs separately. • We improved calculations of runoff contributions in combined sewer areas.
October 5, 2017	Advisory group conference call	Group reviewed results for Lake St. Clair and ranked practices to test through initial scenario runs.	• Lake St. Clair and mass balance modeling expanded to assess long term patterns of retention (source/sink). • We focused on two specific GI practices of interest to group - permeable pavement and bioretention cells.

Date	Meeting	Purpose	Examples of how team acted on advisory group feedback
March 15 –16, 2018	Annual In-person Advisory group meeting in Windsor, Ontario	Group reviewed initial results and provided feedback on information needs related to current policy context, and brainstormed ways to build more complex scenarios.	● We improved data visualizations. ● We made controlled drainage scenarios more realistic. ● We added scenarios about wetlands and urban trees. ● We showed scenario results at a wider range of practice adoption rates.
August 9, 2018	Advisory group conference call	Group reviewed recent urban modeling results and discussed proposed products, applications and audiences	● We decided to estimate costs for BMP scenarios. ● We developed CSO basin factsheets.
October 11, 2018	Advisory group conference call	Group reviewed recent modeling results for watershed and Lake St Clair and discussed how to best share results to maximize benefit to policy.	● We improved terminology and messaging for mass balance results. ● We improved documentation of baseline model decisions. ● We panned briefings for MI DAP team and Annex 4 groups.
November 27 – 28, 2018	Annual In-person Advisory group meeting in Ann Arbor, MI	Group reviewed final results and discussed how to best present and explain findings.	● As requested, we provided a table of load estimates and concentrations for different sources. ● We more deliberately assessed long term trends for loads and separated different components of Lake Huron load. ● We added additional context in final report about background and implications for Lake Erie.
April 8, 2019	Advisory group conference call	Group provided feedback on draft copy of final project report.	● We shared an overview of written feedback provided to date. ● We found ways to clarify how numbers are reported. ● Group offered ideas for creating shorter, targeted summaries and presenting to additional groups.

Issue-Specific Consultation Meetings

We organized a number of smaller meetings to solicit input about specific topics. Each included a few advisory group members as well as others with specific expertise and experience relative to the topic being discussed. This list does not include one-on-one conversations nor invited presentations that were not designed to be feedback opportunities.

Date	Meeting description	Key outcomes from meeting
October 19, 2016	Conference call with researchers working on Lake St. Clair water quality topics	• New connections formed between NOAA and Canadian researchers to advance HAB forecasting • Identified data sharing opportunities to improve Lake St. Clair and mass balance modeling
December 12, 2016	Conference call with modelers working in agricultural watersheds	• Explored potential collaboration opportunities • Identified new sources of data for Ontario ag practices
May 3, 2017	Consultation with MDEQ about CSO and point source data, Lansing MI	• We developed clearer diagrams of wet and dry weather discharge pathways from plant and improved calculations of US urban loads from GLWA facility and CSO basins. • Improved our interpretations of state and federal point source reports
May 3, 2017	Consultation with Michigan's Domestic Action Plan team, Lansing MI	• We began separating treated and untreated CSO volumes and loads in all future graphs. • We improved runoff calculations in urban areas. • We explored ways to model wetland restoration/construction in SWAT.
May 3, 2017	Consultation with Michigan agricultural experts, Lansing MI	• Group confirmed that most baseline assumptions of ag practices were reasonable. • Farm Bureau decided to conduct survey about tillage practices to provide more current data for model.
July 10, 2017	Consultation with agricultural experts, Woodstock, Ontario	• Group confirmed that most baseline assumptions of ag practices in Ontario were reasonable. • OMAFRA provided more accurate specifications for tile drainage in Ontario. • OMAFRA provided more accurate estimates of placement and rate of manure application from permitted livestock operations.
July 10, 2017	Consultation with modelers working in agricultural watersheds, Woodstock, Ontario	• Participants shared what they were learning about agricultural BMPs, including adoption rates, impacts for P loss pathways, and cost estimates.
October 3, 2017	Consultation with MDEQ and GLWA re: urban P loads	• Group confirmed GLWA facility load estimates were reasonable. • GLWA followed up and shared detailed data about discharge from facility.

Date	Meeting description	Key outcomes from meeting
October 11, 2017	Tour of the Great Lakes Water Authority Water Resource Recovery Facility in Detroit	● We learned more about how wet and dry weather flows are handled at basins and treatment plant. ● We learned more about operational changes that led to P reductions, as well as planned updates.
October 12, 2017	Consultation with TNC and Detroit Future Cities	● We learned more about GI planning efforts and key questions. ● We received data layers about vacant land to use in maps and modeling.
September 17, 2018	Consultation with agricultural experts, Lansing MI	● We conducted additional analyses to help explain differences between P loss from crop lands in the US and Canada. ● We refined explanations for bundled scenario results.
November 26, 2018	Project briefing for Michigan's Domestic Action Team	● Shared results and discussed implications for targets and planning. ● We learned more about sediment issues in southeastern corner of Lake Huron.
April 3, 2019	Project briefing for Annex 4 Adaptive Management Subcommittee	● Shared results related to load estimates, the role of Lake St. Clair and the Lake Huron contributions ● We learned more about about factors that could lead to resuspension of sediment and improved clarity of terminology.
April 3, 2019	Consultation with agricultural experts, Lansing MI	● Group offered suggestions for adding context to discussion about BMP effectiveness in report. ● Group identified points needing clarification in report.

Section 2. Data and methods for urban load assessment

Data Sources

This table outlines the sources and details for data used in urban sources assessment load calculations (Chapter 4 of the project report).

Urban Study Area	Data source	Source type	Data location	Data type	Temporal resolution
Michigan	Great Lakes Water Authority	Point source	Regular dry-weather outfall from the WRRF (49B) Wet-weather outfalls from the WRRF (49A and 50A)	Discharge Total phosphorus concentration	Daily
	Great Lakes Water Authority	CSO	All outfalls from GLWA RTBs and S/D facilities (n=7)	Discharge Total phosphorus concentration	Daily
	EPA Enforcement and Compliance History Online[1]	Point source	All (n=9) point source outfalls except the WRRF	Discharge Total phosphorus concentration	Monthly average
	EPA Enforcement and Compliance History Online	CSO	All treated CSO outfalls except those operated by GLWA (n=16)	Total phosphorus concentration	Monthly average
	MDEQ CSO/SSO Database[2]	CSO	All treated CSO outfalls except those operated by GLWA (n=16)	Discharge	Event-based
	MiWaters[3]	CSO	All (n=102) CSO outfalls	Outfall locations Treatment level	NA
Windsor and London	Ministry of the Environment and Climate Change[4]	Point Source	All (n=9) point source outfalls	Discharge	Monthly total
	Ministry of the Environment and Climate Change	Point Source	All (n=9) point source outfalls	Total phosphorus concentration	Monthly average
	Ministry of the Environment and Climate Change	Point source (wet weather discharge)	Seven bypass outfalls	Discharge	Monthly total

1. https://echo.epa.gov/resources/general-info/loading-tool-modernization
2. MDEQ CSO/SSO database was available at http://www.deq.state.mi.us/csosso/ at time of study. This database has since moved to the MiWaters database (link below).
3. https://miwaters.deq.state.mi.us
4. https://www.ontario.ca/data/industrial-wastewater-discharges

List of Point Sources

The table lists the point sources that are permitted to discharge phosphorus in our three urban study areas - southeast Michigan urban areas, and London and Windsor in Ontario.

Urban study area		Facility ID	Facility Name
Michigan	1	MI0002313	US Steel Corporation Great Lakes Works
	2	MI0021156	Wyandotte Wastewater Treatment Plant
	3	MI0021164	City of Trenton Wastewater Treatment Plant
	4	MI0022802	Great Lakes Water Authority Water Resource Recovery Facility
	5	MI0023647	City of Mount Clemens Wastewater Treatment Plant
	6	MI0023825	Oakland County - Pontiac Wastewater Treatment Plant
	7	MI0024287	Oakland County - Walled Lake/Novi Wastewater Treatment Plant
	8	MI0024295	Warren Wastewater Treatment Plant
	9	MI0038105	Wyandotte Electric Plant
	10	MI0056235	Dearborn Industrial Generation Plant
London	1	M120000836	Pottersburg Water Pollution Control Plant
	2	M120000845	Vauxhall Water Pollution Control Plant
	3	M120000854	Oxford Water Pollution Control Plant
	4	M120000863	Greenway Water Pollution Control Plant
	5	M120000872	Adelaide Water Pollution Control Plant
Windsor	1	M0000020107	Ford Motor Company of Canada, Windsor Casting and Engine Plants
	2	M0000020107	K+S Windsor Salt Ltd. – Evaporator Plant
	3	M120001096	Little River Water Pollution Control Plant
	4	M120001103	Lou Romano Water Reclamation Plant

CSO Outfalls in Michigan Urban Study Area

This table lists the Michigan urban study area CSO outfalls that had events between water years 2013-2016 according to data compiled from the MDEQ online CSO/SSO database available at http://www.deq.state.mi.us/csosso/ at the time of study. Between the time analyses were conducted and publication of this report, this database was relocated to miwaters.deq.state.mi.us. Total TP loads, volumes, and number of events are sums for the period 2013-2016. There are 23 treated CSO outfalls and 79 untreated outfalls. There are additional CSO outfalls in the study area, but they did not have discharge events during the study period and so are not included here.

Count	NPDES ID	Outfall Number	Treated or untreated?	TP (kg)	Total volume (MG)	Number of events
1	MI0022802	101	Treated	18,616.3	6,520.4	62
2	MI0022802	104	Treated	93,297.8	26,535.1	68
3	MI0022802	105	Treated	1,277.8	164.6	7
4	MI0022802	106	Treated	1,234.1	290.2	44
5	MI0022802	107	Treated	12,342.1	4,457.8	51
6	MI0022802	108	Treated	43.7	18.1	20
7	MI0022802	109	Treated	904.9	507.4	22
8	MI0022802	11	Untreated	148.6	31.4	15
9	MI0022802	12	Untreated	3,377.5	713.8	12
10	MI0022802	16	Untreated	337.9	71.4	30
11	MI0022802	17	Untreated	4.1	0.9	3
12	MI0022802	18	Untreated	1.8	0.4	2
13	MI0022802	19	Untreated	458.1	96.8	20
14	MI0022802	20	Untreated	33.9	7.2	5
15	MI0022802	21	Untreated	273.2	57.7	13
16	MI0022802	22	Untreated	1,141.0	241.1	22
17	MI0022802	23	Untreated	190.4	40.2	2
18	MI0022802	25	Untreated	1,984.2	419.3	15
19	MI0022802	26	Untreated	347.5	73.4	9
20	MI0022802	27	Untreated	174.4	36.9	4
21	MI0022802	28	Untreated	95.4	20.2	10
22	MI0022802	29	Untreated	1.8	0.4	1
23	MI0022802	30	Untreated	2.6	0.5	1
24	MI0022802	31	Untreated	1,431.4	302.5	15
25	MI0022802	32	Untreated	5.7	1.2	1
26	MI0022802	33	Untreated	152.4	32.2	20
27	MI0022802	34	Untreated	0.4	0.1	1
28	MI0022802	37	Untreated	8.3	1.8	1
29	MI0022802	38	Untreated	3,460.1	731.2	8
30	MI0022802	39	Untreated	17.4	3.7	2
31	MI0022802	40	Untreated	162.3	34.3	3
32	MI0022802	42	Untreated	29.7	6.3	1
33	MI0022802	43	Untreated	0.0	0.0	1
34	MI0022802	44	Untreated	20.3	4.3	2
35	MI0022802	46	Untreated	1.4	0.3	3
36	MI0022802	5	Untreated	566.5	119.7	9
37	MI0022802	54	Untreated	4,998.4	1,056.4	5

Count	NPDES ID	Outfall Number	Treated or untreated?	TP (kg)	Total volume (MG)	Number of events
38	MI0022802	59	Untreated	1,210.0	255.7	30
39	MI0022802	6	Untreated	7.3	1.6	1
40	MI0022802	60	Untreated	355.5	75.1	2
41	MI0022802	61	Untreated	2,837.9	599.8	19
42	MI0022802	62	Untreated	62.4	13.2	14
43	MI0022802	63	Untreated	4.4	0.9	23
44	MI0022802	64	Untreated	1,779.9	376.2	32
45	MI0022802	65	Untreated	1,319.5	278.9	17
46	MI0022802	66	Untreated	25.8	5.5	9
47	MI0022802	67	Untreated	58.1	12.3	16
48	MI0022802	68	Untreated	13.8	2.9	7
49	MI0022802	69	Untreated	37.3	7.9	4
50	MI0022802	7	Untreated	574.2	121.4	39
51	MI0022802	72	Untreated	49.7	10.5	10
52	MI0022802	74	Untreated	2,182.2	461.2	19
53	MI0022802	75	Untreated	37.0	7.8	9
54	MI0022802	77	Untreated	27.1	5.7	2
55	MI0022802	79	Untreated	243.3	51.4	11
56	MI0022802	8	Untreated	71.3	15.1	2
57	MI0022802	9	Untreated	2,450.9	518.0	30
58	MI0023647	3	Treated	466.5	130.3	10
59	MI0025453	1	Treated	3,127.0	1,020.6	28
60	MI0025500	1	Treated	3,078.9	1,612.0	55
61	MI0025534	101	Treated	75.5	50.8	8
62	MI0025542	1	Untreated	435.9	92.1	191
63	MI0025542	106	Treated	233.0	89.3	10
64	MI0025542	108	Treated	228.8	104.6	5
65	MI0025542	117	Treated	3,328.8	963.4	39
66	MI0025542	13	Untreated	3,515.6	743.0	191
67	MI0025542	14	Untreated	2,875.2	607.6	108
68	MI0025542	15	Untreated	0.2	0.0	1
69	MI0025542	16	Untreated	234.5	49.6	3
70	MI0025542	17	Untreated	45.0	9.5	1
71	MI0025542	2	Untreated	26.1	5.5	88
72	MI0025542	3	Untreated	1,576.2	333.1	191
73	MI0025542	4	Untreated	902.1	190.6	108
74	MI0025542	5	Untreated	95.1	20.1	53
75	MI0025585	1	Treated	1,240.2	680.7	29
76	MI0025585	2	Treated	210.8	118.5	3
77	MI0026115	1	Treated	11,006.2	5,981.2	30
78	MI0028819	101	Treated	211.1	91.0	22
79	MI0036072	1	Treated	15,575.9	4,078.3	83
80	MI0036072	2	Untreated	4,294.7	907.6	41
81	MI0037427	103	Treated	109.7	91.9	15
82	MI0048046	102	Treated	92.3	62.1	9

Count	NPDES ID	Outfall Number	Treated or untreated?	TP (kg)	Total volume (MG)	Number of events
83	MI0051462	L41	Untreated	691.5	146.1	61
84	MI0051462	L42	Untreated	55.4	11.7	5
85	MI0051471	1	Treated	229.8	110.5	22
86	MI0051471	10	Untreated	925.9	195.7	60
87	MI0051471	9	Untreated	149.5	31.6	12
88	MI0051471	L46	Untreated	240.9	50.9	12
89	MI0051489	1	Treated	71.5	41.7	10
90	MI0051489	L43	Untreated	78.7	16.6	14
91	MI0051489	M13	Untreated	63.5	13.4	13
92	MI0051489	M14	Untreated	48.9	10.3	12
93	MI0051489	U1	Untreated	40.9	8.6	9
94	MI0051535	1	Treated	32.7	14.9	8
95	MI0051535	U10	Untreated	110.6	23.4	4
96	MI0051535	U11	Untreated	75.5	16.0	6
97	MI0051535	U2	Untreated	18.1	3.8	3
98	MI0051535	U3	Untreated	64.2	13.6	8
99	MI0051535	U4	Untreated	0.5	0.1	1
100	MI0051535	U5	Untreated	143.3	30.3	5
101	MI0051535	U9	Untreated	188.8	39.9	4
102	MI0051829	45A	Untreated	166.4	35.2	29

Section 3. Data and Model Set-up for Soil & Water Assessment Tool (SWAT)

This section summarizes data and model set-up assumptions that were used to develop a Soil and Water Assessment Tool (SWAT) model for the St. Clair – Detroit River System watershed. This transboundary watershed covers an area of 19,040 km^2, of which 40% is in MI, US and the other 60% in Ontario, Canada. About half of the watershed is agricultural and the rest is urban, forest, grassland, waterbody, or wetlands.

This model was based on SWAT 2012 revision 635, with some modifications to enable more fine scale resolution for model input data, as described by articles by Kalcic (2016) and Teshager (2015). Additional modeling details, including calibration and validation results as well as methods for scenario analyses, are provided in two journal articles and the associated online supplemental information. In press and published articles are accessible on the project website: www.myumi.ch/detroit-river

- Dagnew, A., Scavia, D., Wang, Y., Muenich, R., Long, C., Kalcic, M. 2019a. Modeling Flow, Nutrient and Sediment Delivery from a Large International Watershed using a Field-Scale SWAT model. Journal of the American Water Resources Association, in press.
- Dagnew, A., Scavia, D., Wang, Y., Muenich, R., Kalcic., M. 2019b. Modeling phosphorus reduction strategies from the international St. Clair-Detroit River system watershed. Journal of Great Lakes Research, in press.

Topics Covered in this Section *(click section title to jump to the section)*

Landscape Data

Back to top of section

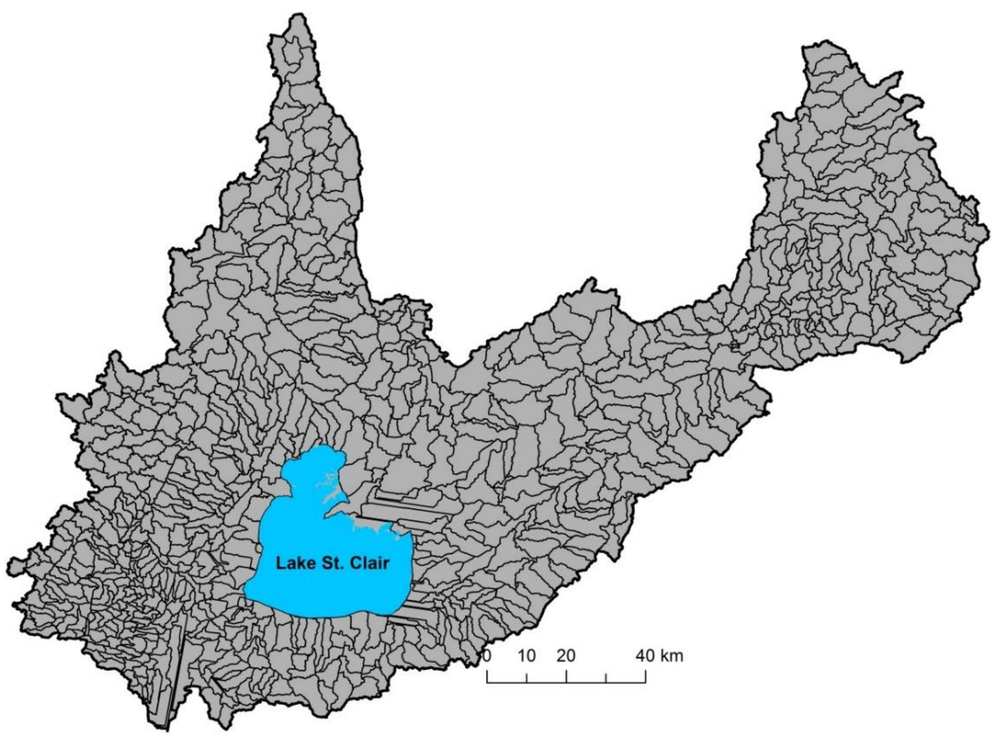
Topography

Sources:

- Digital Elevation Model (DEM) - 30m x 30m resolution
- USGS- The National Map (https://viewer.nationalmap.gov/basic/)

Processes:

- Based on the DEM, SWAT divides the watershed into subwatersheds (subbasins) as shown below based on either a stream area threshold, or burned-in stream locations.
- For this project, 800 subbasins (figure below) were created with average areas of ~ 24km^2 by applying a stream threshold and manually inserting additional outlets. These subbasins are the smallest resolution possible for extracting modeling results.
    - The size of the subbasins, which depends on the threshold value used and the location and number outlets inserted manually, is determined based on the following premises.
        - Potential model comparisons with other studies in the area.
        - The potential need of smaller subbasins in urban areas for better representation and scenario analysis.
        - Once the model is developed, it is always possible to aggregate results at larger scale than the model subbasins. However, if results are needed at a scale smaller than a subbasin in the model, the model may need to be re-setup. Hence, the sizes of subbasins were kept relatively small in this model setup.



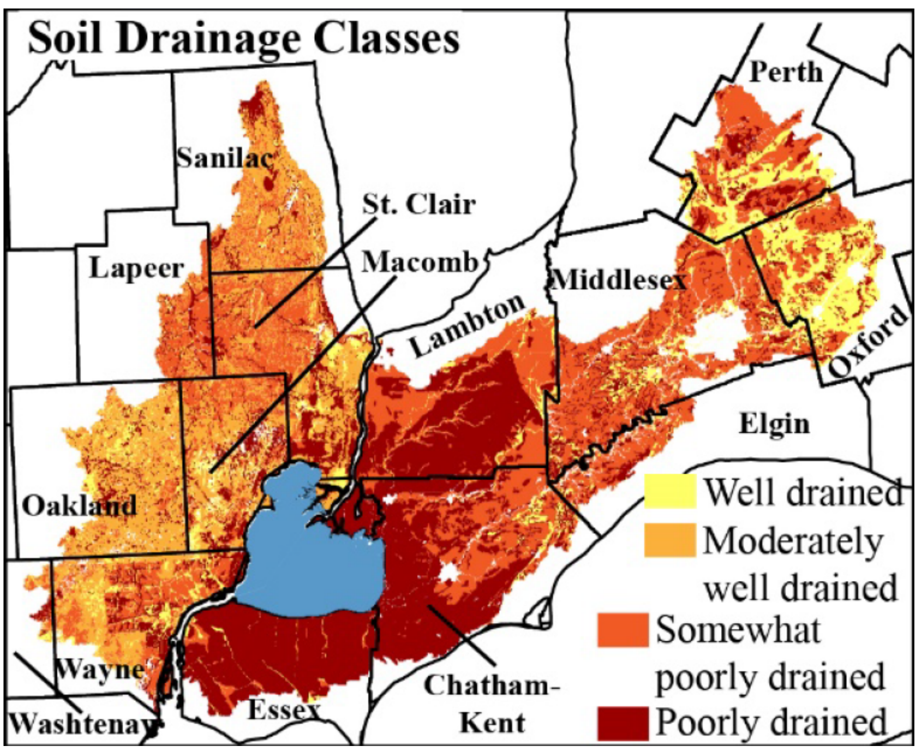
Soil

Sources:

- USDA-NRCS's SSURGO data for the US side (https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx)
- AAFC's Soil Landscape of Canada version 3.2 for the Canadian side (http://sis.agr.gc.ca/cansis/nsdb/slc/v3.2/index.html)

Processes:

- Soil data were downloaded as shapefiles from the respective sources.
- Data from the two countries were merged and the shape file was converted to 30m x 30m raster data to match the LULC and DEM data resolution.
- The resulting soil data and HRU boundaries were then used to extract dominant soil type for each HRU.
    - The dominant soil type is the soil type that covers the largest area of all the soil types with in the HRU boundary.
- The SWAT SSURGO database which currently contains only US soils was then updated to include Canadian soil data for the watershed.
    - Some of Canadian soil parameters were calculated to match SWAT-required inputs. (For more details, see Table 1 in Dagnew et al. 2019a)



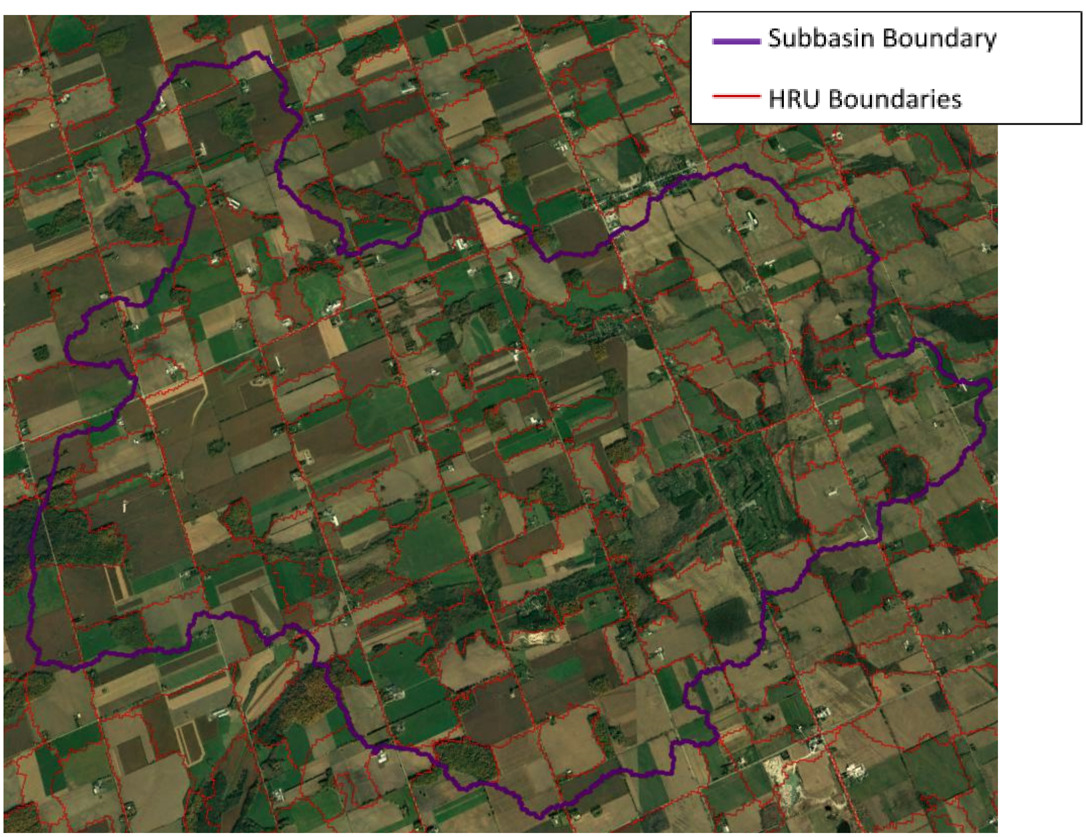
Land Use and Land Cover

Sources:

- NASS Crop Data Layer for US side of the watershed (2011-2015) (https://nassgeodata.gmu.edu/CropScape/)
- Government of Canada Annual Crop Inventory for Canada side of the watershed (2011-2015) (http://open.canada.ca/data/en/dataset/ba2645d5-4458-414d-b196-6303ac06c1c9)

Processes:

- Data from the two countries were merged to generate land use land cover (LULC) data at 30 m x 30 m resolution for St. Clair-Detroit River watershed for years 2011 - 2015.
- Canadian crop code numbers were changed to their US equivalent
- Creating HRU (Hydrologic Response Unit) boundaries which are the smallest spatial units of modeling in SWAT:
  - In this model, each subbasin is divided into HRUs which are homogeneous areas of land use, soil and slope.
    - While HRUs are usually percentage areas of a subbasin in standard SWAT model, in this project, the road network and 2015 LULC data were used to pre-determine HRUs with unique boundaries (see Teshager et al. 2016 for details). This process was adapted to ease certain input data processing, such as rotation, tile drainage, manure application, etc.
  - Subsequently, 27,751 HRUs with unique boundaries were created for this project. The average area for the HRUs is 69ha. A sample of HRUs in a subbasin overlaid on a satellite data is shown in the figure below to demonstrate how HRUs look compared to actual fields or farms.



Agricultural Practices

Back to top of section

Crop Rotations

Sources:

- Land cover and land use data, as described above.

Processes:

- Determining crop rotations in each HRU
    - The 2011-2015 LULC data was used to generate crop rotations for each 30mX30m grids by overlaying each year to determine pixel-by-pixel rotations. This rotation data was then overlaid by the HRU boundaries to extract the dominant rotation for each HRU.
    - For specific information on crop rotations by county and subwatershed, see supporting information for Dagnew et al 2019a.
    - Distribution of estimated crop rotations is shown in map below.
      Crop codes: C= corn, S= soybeans, W = winter wheat

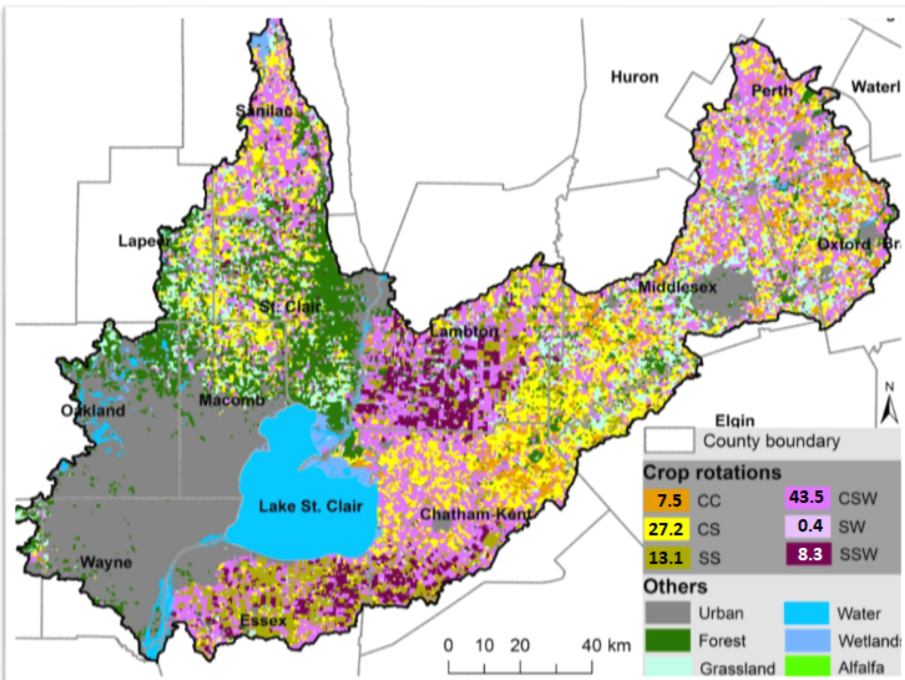


Table shows the percentage of cropland area covered with the different types of crop rotations divided between US and Canada (C= corn, S= soybeans, W = winter wheat). Taken from Dagnew et al. 2019a

Crop rotation	% cropland area Canada	US	Overall
CC	8.4	1.6	7.1
CS*	25.4	35.5	27.3
SS	13.5	13.1	13.4
CSW**	42.8	45.4	43.3
SW	0.4	0.3	0.4
SSW	9.5	4.1	8.5
Total	100.0	100.0	100.0

*Includes both CS and SC rotations
**Includes CSW or SWC or WCS rotations

Mineral Fertilizer Application

Sources:

- International Plant Nutrition Institute (IPNI) Nutrient Use Geographic Information System (NuGIS) has county level nutrient estimates for the US side (http://nugis.ipni.net/About%20NuGIS/)
- Fertilizer Canada has provincial level estimates for the Canadian side (http://www5.statcan.gc.ca/cansim/a29?lang=eng&groupid=001&p2=17)

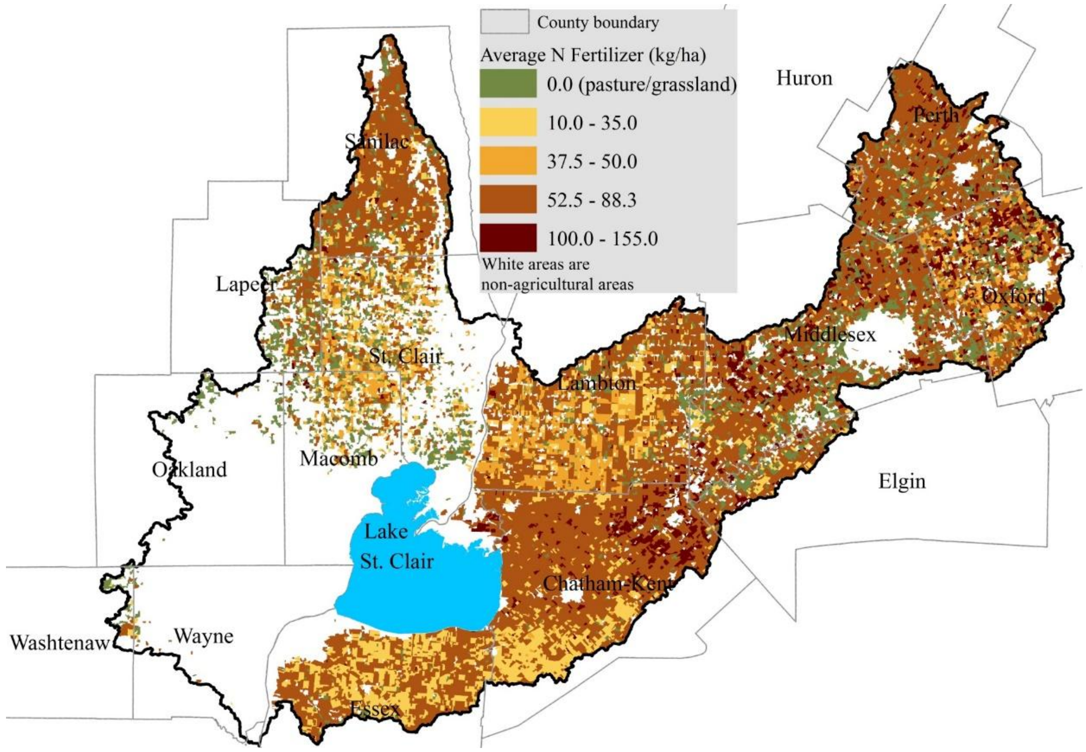
Processes/Assumptions:

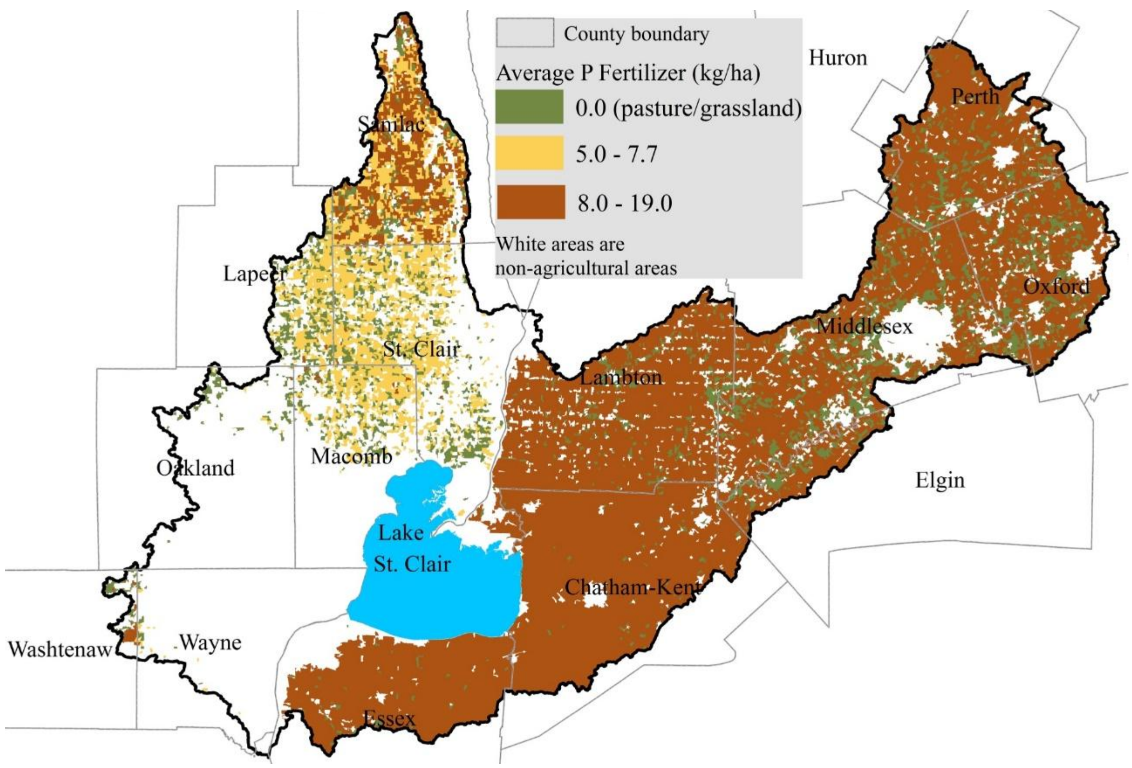
- Counties from both countries that are crossed by the watershed boundary were identified (7 in MI, US and 8 in ON, Canada)
- Michigan
  - The total cropland areas in each county were calculated.
  - The total cropland areas of each county and cropland areas in each county within the boundary of the watershed were identified.
  - Ratios of cropland areas of each county in the watershed to the total cropland areas in the county were calculated.
  - The total amount of fertilizer applied in each county was then multiplied by these ratios to calculate the total amount of fertilizer applied in each county with in the watershed.
  - Finally, fertilizer application rates for corn, soybeans and winter wheat were assumed based on estimated state values from USDA-ERS (https://data.ers.usda.gov/reports.aspx?ID=46940). These rates were scaled to better match the total amount of fertilizer applied in each county within the watershed.
- Ontario
  - A similar process was followed for Canadian agricultural lands except that currently we only have one value for the entire province.
    - Total Ontario fertilizer amount was multiplied by the ratio of cropland area in the Canadian side of the watershed to the total cropland area of Ontario.
    - The resulting value was then distributed to each county in the watershed based on areas of cropland in each county with in the watershed.
    - Rates are then estimated for each crop type and adjusted to match the total fertilizer amount in each county in the watershed.
- Even though reports show the occurrence of fertilizer application on some pasture/grasslands, we assumed no fertilizer application on pasture/grassland.
- Accordingly, the following are nitrogen and phosphorous average fertilizer application rates for each county calculated based on reported nutrient values.

The table below shows the ranges of nitrogen and phosphorus fertilizer application rates in the baseline model for each region of US (shaded) and Canadian sub-watersheds (taken from Dagnew et al. 2019b)

Sub-watershed name	Cropland Area (% sub-watershed)	Nitrogen fertilizer application rate (kg/ha)			Phosphorus fertilizer application rate (kg/ha)		
		Corn	Soybeans	Winter wheat	Corn	Soybeans	Winter wheat
St. Clair	50	84.0 - 125.9	9.5 - 16.4	62.2 - 89.7	5.9 - 10.1	4.8 - 6.5	5.7 - 10.9
Clinton	10	82.5 - 112.7	9.5 - 14.7	62.2 - 89.7	5.9 - 8.8	4.8 - 6.3	5.7 - 7.8
Detroit	2	118.8 - 122.5	23.8 - 29.4	90.3 - 93.1	7.6 - 9.8	6.7 - 7.8	7.6 - 9.8
Lake St. Clair	9	84.0 - 107.8	9.5 - 10.9	62.2 - 89.7	6.0 - 7.8	4.8 - 6.1	6.0 - 7.4
Sydenham	82	132.0 - 168.1	3.7 - 4.5	82.3 - 93.5	23.2 - 44.8	7.4 - 11.3	19.4 - 22.0
Thames	75	127.4 - 173.8	3.6 - 4.9	82.3 - 93.5	22.8 - 44.8	9.1 - 13.7	18.3 - 24.4
Essex	79	128.3 - 154.3	3.8 - 4.0	80.9 - 85.0	23.8 - 33.9	7.6 - 8.0	17.1 - 18.0

The following two figures show the distribution of estimated average fertilizer application rates at HRU level for nitrogen and phosphorous, respectively.





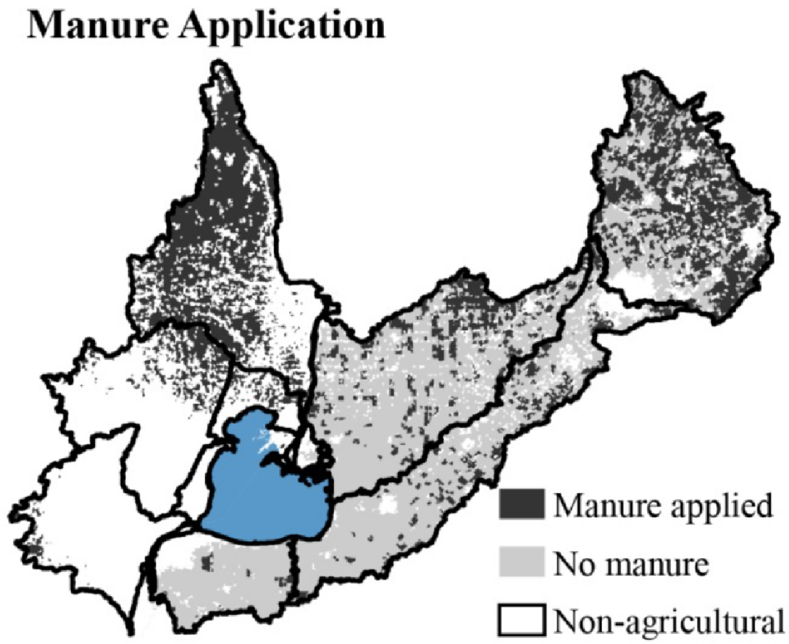
Manure Application

Sources:

- USDA-NASS 2012 census county level animal counts (https://quickstats.nass.usda.gov/?source_desc=CENSUS)
- OMAFRA, Agriculture and Strategic Policy Branch, 2011 county level census (http://www.omafra.gov.on.ca/english/stats/county/index.html)

Processes/assumptions:

- Livestock (dairy, beef, swine, sheep, goat, broiler, layer, turkey) counts for all 15 counties of the watershed were downloaded from their respective sources and compiled.
- Depending on the type of livestock, the amount of dry manure produced per livestock is calculated using a standard manure production values per 1000 kg live animal and typical live animal masses provided in SWAT 2012 Input/Output documentation manual (Appendix A, page 610, available here: https://swat.tamu.edu/docs/). As a result, the total mass of dry manure produced for each livestock type per county was calculated using these standards, for both US and Canada portions of study area.
- The amount of manure from each livestock type in each county was then divided in to recoverable and non-recoverable portion using Kellogg et al. (2000) values.
    - Recoverable manure by definition is manure available for land application. Hence, this portion of the manure was assumed to be applied in cropland areas.
    - The non-recoverable portion was assumed to be applied in pasture lands.
- Ratios of cropland/pasture areas of each county in the watershed to the total cropland/pasture areas in the county were calculated.
- The total amount of recoverable manure in each county was then multiplied by these ratios to calculate the amount of manure available for cropland/pasture in each county with in the watershed.
    - Manure produced in a county was assumed to end up either in a cropland or pasture area within the county.
    - The same amount of manure is applied each year
- Where do we apply manure?
    - For Ontario, spatial distribution of manure application was provided by OMAFRA (K. McKague, personal communication, 12/2017) as locations (points) of animal farms and field areas that receive manure from each animal farm without explicit indication of which field(s).
    - For Michigan, recoverable and non-recoverable portions of the manure are applied uniformly on all crop lands and pasture lands, respectively, in a county as shown below. Because of this assumption and the overall lower numbers of livestock, solid manure application rates in the US were lower (85-670 6 kg/ha for dairy, 8-50 kg/ha for Beef and 1-35 kg/ha for swine) than in Canada (345-1082 kg/ha for dairy, 261-695 kg/ha for Beef and 667-1556 kg/ha for swine).



- How do we apply manure?
  - Fertilizer and manure were assumed to be broadcasted on the surface and incorporated through tillage practices for all crops and were applied in spring before planting of corn and soybeans.
  - SWAT changes manure application rates into nutrients using the following values of nutrient fractions in manures (See table below and SWAT 2012 Input/Output, Appendix A, page 610, available here: https://swat.tamu.edu/docs/).

Name	Name Code	Min-N	Min-P	Org-N	Org-P	NH_3-N/ Min N
Dairy-Fresh Manure	DAIRY-FR	0.007	0.005	0.031	0.003	0.990
Beef-Fresh Manure	BEEF-FR	0.010	0.004	0.030	0.007	0.990
Veal-Fresh Manure	VEAL-FR	0.023	***0.006***	0.029	***0.007***	0.990
Swine-Fresh Manure	SWINE-FR	0.026	0.011	0.021	0.005	0.990
Sheep-Fresh Manure	SHEEP-FR	***0.014***	0.003	***0.024***	0.005	0.990
Goat-Fresh Manure	GOAT-FR	***0.013***	***0.003***	***0.022***	***0.005***	0.990
Horse-Fresh Manure	HORSE-FR	***0.006***	0.001	***0.014***	0.003	0.990
Layer-Fresh Manure	LAYER-FR	0.013	0.006	0.040	0.013	0.990
Broiler-Fresh Manure	BROIL-FR	***0.010***	***0.004***	***0.040***	***0.010***	0.990
Turkey-Fresh Manure	TURK-FR	0.007	***0.003***	0.045	***0.016***	0.990
Duck-Fresh Manure	DUCK-FR	***0.023***	0.008	***0.025***	0.009	0.990

Tillage

Sources:

- USGS tillage practices aggregated by HUC8 per crop type for 2004 (https://water.usgs.gov/lookup/getgislist)
- Statistics Canada 2011, county/sub-county level tillage practices (http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=0040205&p2=33)

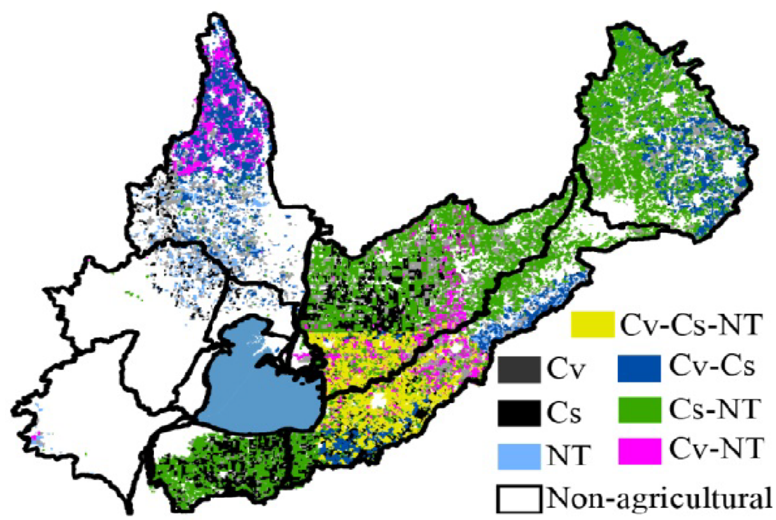
Processes/assumptions:

- For the US side, proportions of each tillage practices (conventional, conservation and no-till) in each county for each crop type were estimated based on HUC8 tillage practice from USGS. For the Canadian side the same proportions were calculated from county level data.
- In partnership with Farm Bureau, we conducted a small survey of member farmers about their tillage practices. This data set confirmed the use of the more comprehensive USGS dataset.
- The proportions calculated here (tables below) were assumed to be the same for every year

Tables below shows percentages of tillage practices in the US part of the watershed (top) and Canadian side (bottom), and map shows the distribution. (**NT**=No-till, **Cs**=Conservation tillage, **Cv**=Conventional tillage)

County	Corn			Soybeans			Winter wheat		
	NT	Cs	Cv	NT	Cs	Cv	NT	Cs	Cv
Lapeer	10.4	31.1	58.5	23.4	32.0	44.6	19.6	29.6	50.8
Macomb	12.9	50.7	36.4	39.0	25.3	35.7	38.9	39.7	21.4
Oakland	19.7	46.2	34.1	48.9	22.7	28.4	48.7	39.3	12.0
Sanilac	10.2	28.5	61.4	21.3	32.9	45.8	17.0	27.9	55.1
St. Clair	11.0	31.2	57.7	23.4	32.1	44.5	19.7	27.8	52.5
Washtenaw	37.2	28.3	34.6	65.5	19.7	14.8	64.1	27.3	8.6
Wayne	32.8	32.1	35.2	59.8	21.1	19.1	58.6	28.1	13.3

County	NT	Cs	Cv
Elgin	23.8	37.4	38.8
Essex	57.1	19.9	23.1
Huron	34.1	43.7	22.2
Kent	40.1	27.8	32.1
Lambton	47.0	30.5	22.5
Middlesex	39.8	35.0	25.3
Oxford	25.3	41.9	32.8
Perth	27.9	48.9	23.2



- Tillage practices in each county were assigned to each HRU's crop type or crop rotation to match the proportions calculated above.
  - The distribution of tillage practice within a county is random. However, the following were taken into account:
    - Corn fields were assumed to have more conventional than other tillage practices, e.g., HRUs with continuous corn rotation are assumed to have conventional tillage.
    - Conservation and no-till practices are assigned more frequently on HRUs with more crops in rotation.

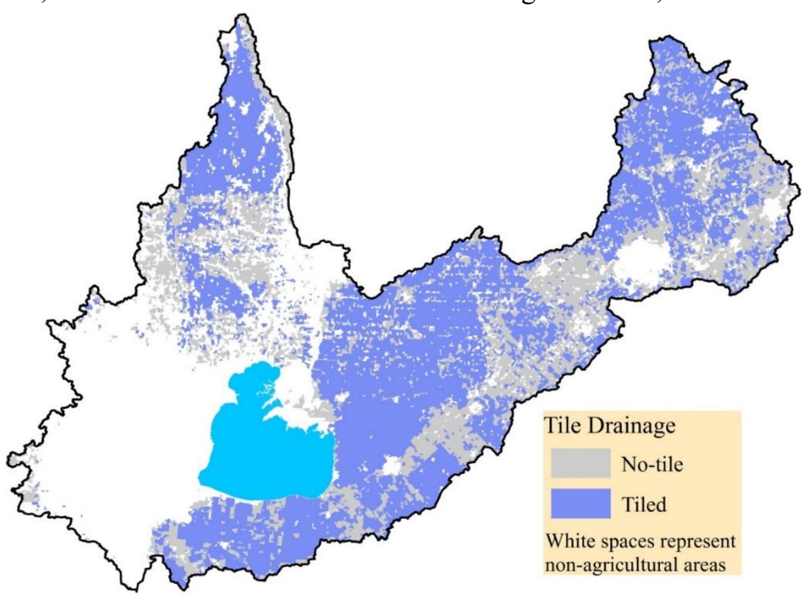
Tile Drain Implementation

Sources:

- Estimated based on soil type for US side
- OMAFRA tile drain layer for Canadian side (https://www.ontario.ca/data/tile-drainage-area)

Processes/Assumptions:

- There was no recent and explicit tile drain data for the US side of the watershed. Hence, SSURGO soil data was used to estimate potential tile drained areas.
  - Agricultural HRUs with poorly and very poorly drained soil types were assumed to have tile drainage systems in the US side of the watershed.
- For the Canadian side, the tile drainage layer from OMAFRA was overlaid by the HRU boundaries.
  - If the area of HRU covered by tile drainage layer is greater than or equal to half of the HRU area, that HRU is assumed to have tile drainage installed, otherwise no-tile is assumed.



- Due to lack of additional information, U.S. tile drainage systems were implemented with uniform depth and spacing but were varied based on soil types in Canada based on advisory group feedback and guidance from K McKague, OMAFRA). The tables below outline the tile specifications used in SWAT (left) (from Dagnew et al. 2019b) and the fraction of cropland with tile drainage systems (Dagenew et al. 2019a).

	Parameter	Soil types		
		Clayey	*Loamy*	*Sandy*
US	***Depth (mm)***	1000	1000	1000
	Spacing (m)	20	20	20
Canada	***Depth (mm)***	650	750	900
	Spacing (m)	8	12	15

HUC8/Tertiary name	Tiled area	
	% total area	% agricultural area
St. Clair (SC)	37	59
Clinton (CL)	8	46
Detroit (DR)	1	16
Lake St. Clair	5	29
U.S. total	**18**	**55**
Upper Thames (UT)	54	62
Lower Thames (LT)	49	55
Thames total	51	59
Sydenham (SY)	69	77
Essex	58	72
Canada total	**58**	**67**
Watershed total	**42**	**64**

Other Model Inputs

Back to top of section

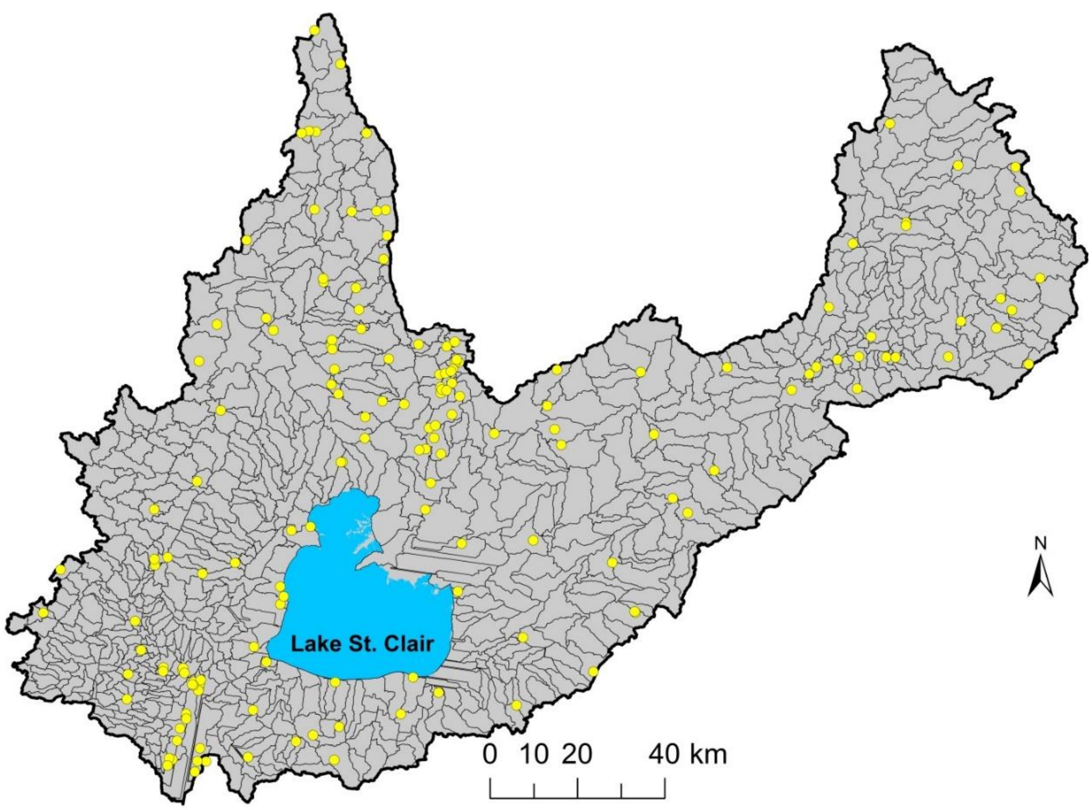
Industrial and Municipal Point Sources

Sources:

- US: EPA Discharge Monitoring Reports for US (https://cfpub.epa.gov/dmr/)
- Canada: OMECC's database for industrial wastewater discharges, as required by Effluent Monitoring and Effluent Limits and Municipal (EMEL/MISA) Regulations (https://www.ontario.ca/data/industrial-wastewater-discharges)
- Personal communication from advisory group, especially staff at Great Lakes Water Authority Water Resources Recovery Facility

Processes/assumptions:

- Monthly point source loads were available for years 2008 to 2015 for US and 2004 to 2014 for Canada.
  - The available data was extended to the years 2001-2015. Missing data for a certain month of a year were filled with average values from
    - The same month in other years where there is observation, if available.
    - If there is no data for the same month in other years, estimation was made based on values from other months.
  - Since no point source data had DRP measurements, only TP, we assumed that 47% of TP was DRP. This number comes from data at Toledo WWTP and Detroit WWTP.
  - The point source data also includes combined sewer overflow data. Point source locations are shown in map below.



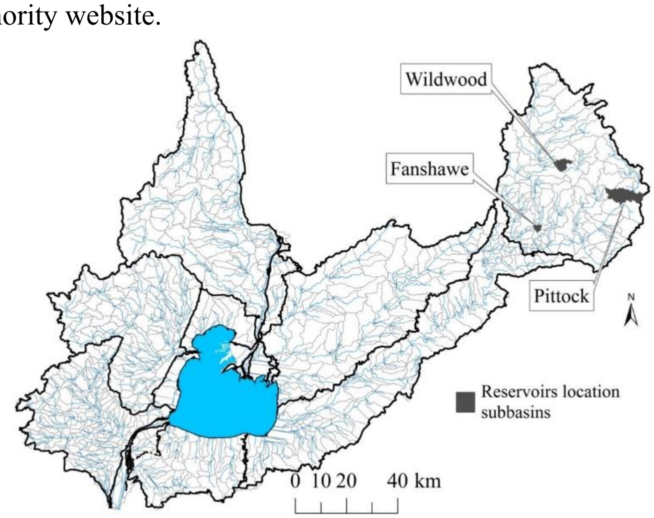
Reservoirs

Sources:

- Government of Canada (https://ec.gc.ca/rhc-wsc/default.asp?lang=En&n=9018B5EC-1)
- Upper Thames River Conservation Authority (http://thamesriver.on.ca/watershed-health/surfacewater-groundwater-studies/)
    - Three reservoirs in upper Thames River (Fanshawe, Pittock, and Wildwood) were considered following advisory group recommendation during the Jan. 19, 2017 meeting.
    - There are three reports (2005, 2006, and 2015) where data is extracted to determine reservoir properties.
    - Additional data was requested and obtained from the Authority
- Personal communications to confirm specifications

Processes/assumptions:

- Elevation-area-volume relationship
    - For Fanshawe reservoir this was obtained from documents available in Upper Thames River Conservation Authority website
    - For Pittock and Wildwood reservoirs, the information was obtained through the same organization via personal communication.
        - This information is important to determine the surface areas and volumes of reservoirs during operations at principal spillway and emergency spillway that are required for model development.
- Daily flow records are available at the Fanshawe reservoir outlet from Government of Canada Water Office website.
    - Similar data was obtained from Upper Thames River Authority personal contact for the other two reservoirs, Pittock and Wildwood.
- Information about the reservoir water quality is extracted from the three reports mentioned above.
    - SWAT required nitrogen and phosphorous settling rate and initial concentrations in reservoirs.
        - While the initial concentration won't be important as the model is set to have a warm-up period (a period to establish watershed specific properties such this) before the actual simulation is performed, average concentrations reported are used.
        - Settling rates were estimated based on sample nutrient report and whether a reservoir is a source or a sink for nutrients.
            - A reservoir is determined to be a sink or a source based on observations extracted in the three reports available at Upper Thames River Conservation Authority website.



Calibration and Validation Process

Back to top of section

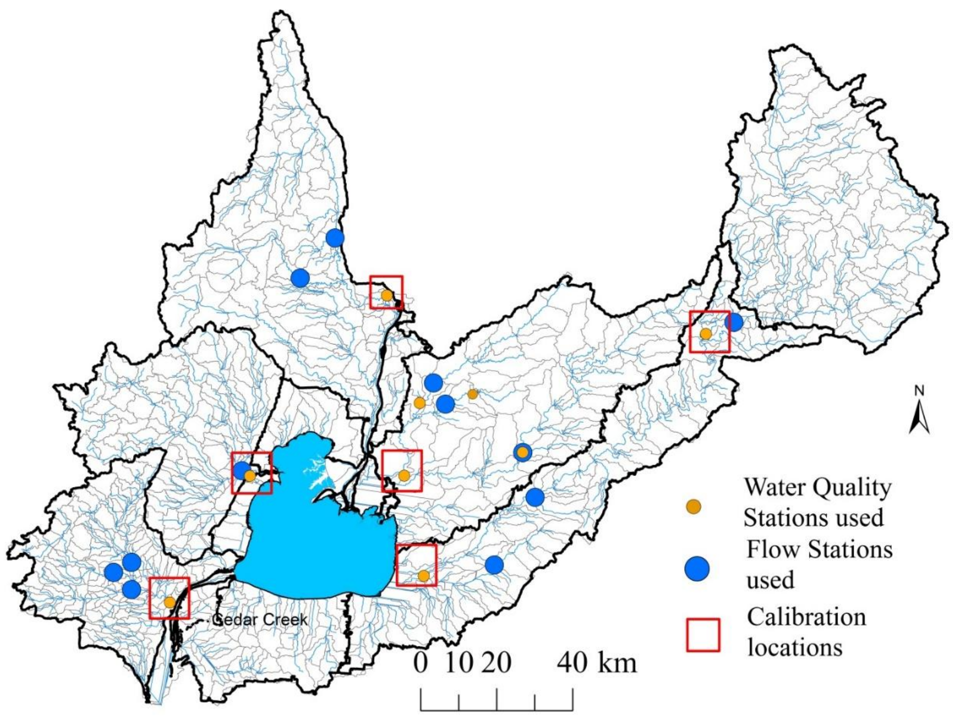
Data Sources

Sources:

- USGS and Water Quality Portal for US flow and water quality data, respectively (https://waterdata.usgs.gov/nwis, https://www.waterqualitydata.us/)
- Government of Canada and PWQMN for Canada flow and water quality data, respectively https://ec.gc.ca/rhc-wsc/default.asp?lang=En&n=9018B5EC-1 , https://www.ontario.ca/data/provincial-stream-water-quality-monitoring-network

Processes/assumptions:

- Daily flow data is available for the required period (2001-2015) for the most part. In cases where data is missing, it was estimated from flow-water level relationships if water level is available or from upstream stations.
  - The blue dots in the figure below indicate flow stations utilized to generate flow data at the calibration/validation locations (red rectangle).
- A number of sample water quality data (sediment, TP, DRP, NO3 and TN) available from multiple stations (orange dots in the figure below) range from 4 to 32 samples per years for years 2001 – 2015.



Calibration/Validation Locations:

Calibration/validation was performed at the outlets of each major streams of HUC8/Tertiary watersheds as shown in figure above. These locations were selected mainly due to the fact that they are the most downstream stations in each major streams which have water quality observations with in a predetermined simulation period (2001-2015). Flow data for most of these locations were calculated using area ratio from upstream flow gauging station(s).

Simulation Periods

- **Warm-up:** The warm-up simulation period is the time after which the model eliminates biases due to initial conditions. While there is no strict rule on how long a warm up period should be, at least 1 year is recommended in SWAT modeling practices. Generally, the longer the warm up period the better in terms of model accuracy. In this specific study a warm-up period of **2 years** was used.

- **Calibration:** is the process of fitting observations with model outputs by changing relevant model parameters. There are hundreds of parameters in SWAT model, however, modeling experience and/or initial sensitivity analysis could help focus on important parameters during calibration processes. In this study, years **2007-2015** were selected as a calibration period.

- **Validation:** is a process of demonstrating how well the calibrated model predicts observations for periods different from the calibration period without changing model parameters further. A validation period of **2001-2006** was used in this project.

While it is a common practice to use earlier years for calibration and later years for validation, the above periods were chosen for this project to capture the most recent years better in the model and most importantly most of water quality samples were collected in the later years of the simulation period.

Calibration/Validation Time Steps

Flow:

- Complete daily values of flow for most of the calibration/validation periods were available. Some missing values were filled with either linear interpolation or long-term average values or stage-discharge relationship depending on the number of missing values.
- Flow was calibrated/validated at **Daily, Monthly** and **Annual** time steps simultaneously

Water quality:

- In this project total suspended sediment (TSS), total phosphorus (TP), total nitrogen (TN), dissolved reactive phosphorus (DRP) and nitrate (NO^3) were considered for calibration.
- The following table shows the number of daily water quality sample data available at each location within the simulation period (2001-2015) and used for calibration/validation at daily time steps.

River Name	Number of sample points				
	TSS	**TP**	**TN**	**DRP**	**NO^3**
Upper Thames	109	113	115	111	112
Black	48	68	53	66	37
Sydenham	281	310	313	312	311
Clinton	152	257	233	257	156
Lower Thames	243	268	269	266	266
Rouge	67	68	60	68	68

- Given limited number of water quality samples, dividing them into calibration and validation would further reduce the number of samples for comparison and statistical calculations. Hence, once the model is calibrated and validated for flow, the entire water quality sample data is compared to the corresponding values from the model without dividing them into calibration and validation period. Hence, parameters were adjusted to fit the entire observed water quality dataset.

Additional Details

Further information about the calibration and validation process, including model performance statistics, simulated load estimates, and an explanation of scenario analyses are all available in two papers and their online supporting materials that were written by Awoke Dagnew (2019a and 2019b) and listed below in the reference section.

References for SWAT Set-up

Dagnew, A., Scavia, D., Wang, Y., Muenich, R., Long, C., Kalcic, M. 2019a. Modeling Flow, Nutrient and Sediment Delivery from a Large International Watershed using a Field-Scale SWAT model. Journal of the American Water Resources Association, in press.

Dagnew, A., Scavia, D., Wang, Y., Muenich, R., Kalcic., M. 2019b. Modeling phosphorus reduction strategies from the international St. Clair-Detroit River system watershed. Journal of Great Lakes Research, in press.

Kalcic, M.M., Chaubey, I., Frankenberger, J., 2015. Defining Soil and Water Assessment Tool (SWAT) hydrologic response units (HRUs) by field boundaries. Biol Eng 8, 12.

Kellogg, R.L., Lander, C.H., Moffitt, D.C., Gollehon, N., 2000. Manure nutrients relative to the capacity of cropland and pastureland to assimilate nutrients: spatial and temporal trends for the United States. Proc. Water Environ. Fed. 2000 (16), 18–157.

Teshager, A.D., Gassman, P.W., Secchi, S., Schoof, J.T., Misgna, G., 2016. Modeling 28 Agricultural Watersheds with the Soil and Water Assessment Tool (SWAT): Calibration 29 and Validation with a Novel Procedure for Spatially Explicit HRUs. Environmental 30 Management 57, 894–911.

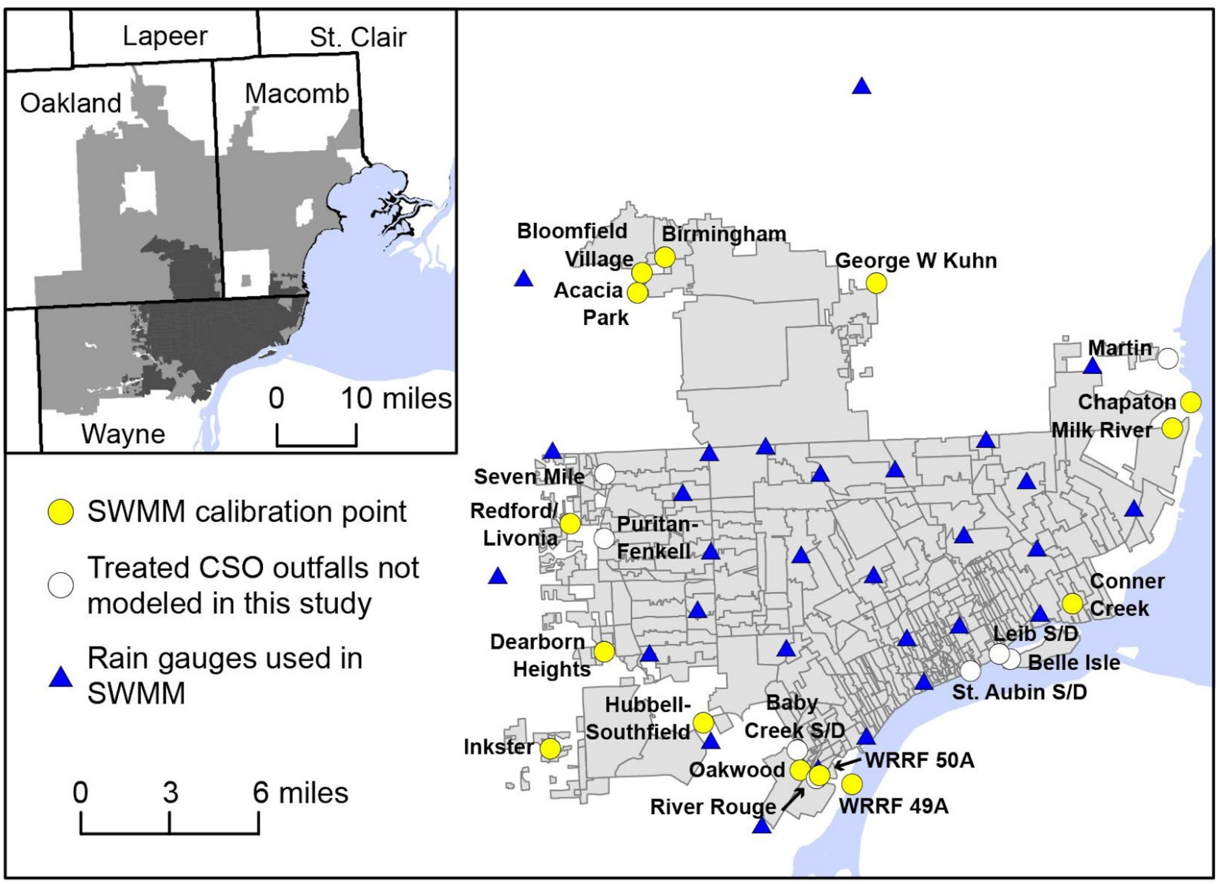
Back to top of section

Section 4. Storm Water Management Model (SWMM) details

Model Overview

A Storm Water Management Model (SWMM) was developed for the service area of the Great Lakes Water Authority's Water Resource Recovery Facility (GLWA WRRF) (See map below). This physically-based model routes rainfall inputs across a network of pipes, CSO basins, and other assets. GLWA provided a model for use in this project, and we updated and calibrated it using new sensor data, also shared by GLWA. The model was calibrated for volume at 14 outfalls (Figure 1) and at the intake to the WRRF. Model calibration procedure and results are described in:

- Hu, Y., Scavia, D., and Kerkez, B., 2018, *Are all data useful? Inferring causality to predict flows across sewer and drainage systems using directed information and boosted regression trees*, Water Research, 145, p. 697-706.

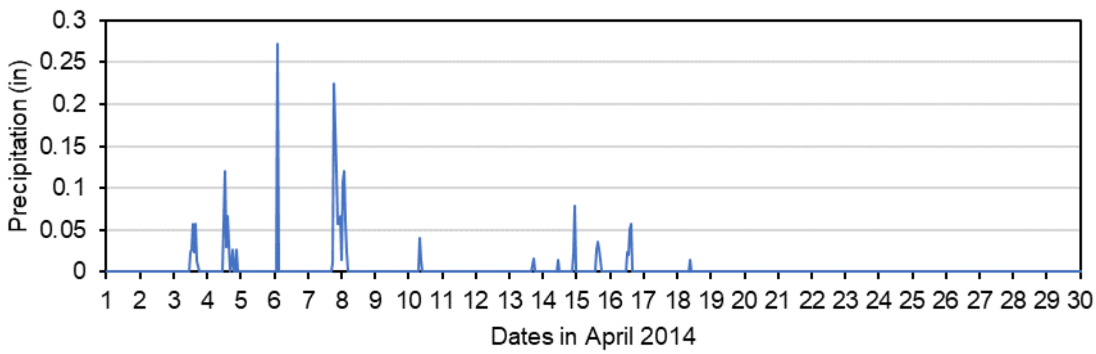


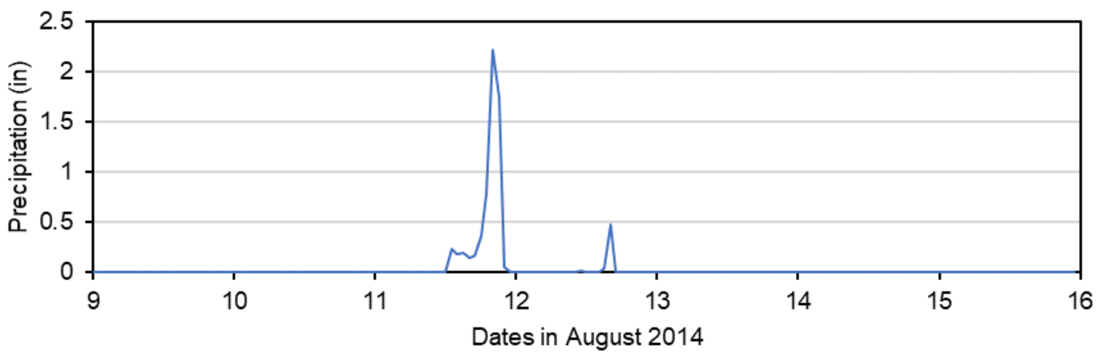
SWWM Area Map. Corner inset: GLWA sewer service area with the separated sewer area in light gray and the combined sewer area in dark gray. Main map: Combined sewer area modeled by SWMM with subcatchments delineated. Yellow circles are the 14 points where the SWMM was calibrated including 12 retention treatment basins (RTBs) and the two wet weather outfalls at the WRRF. White circles are other treated CSO outfalls that were not modeled in this study. Triangles are rain gauges used for analyses.

Scenario Analyses

Rainfall

Two rainfall simulations were used to drive SWMM: a "normal" rainfall event and an "extreme" rainfall event (figure below). The normal rainfall event was based on the month-long period April 1-30, 2014, when about 2 inches of rain fell. The extreme rainfall event was based on the August 11-13, 2014 event, when over 6.5 inches of rain fell. We simulated rainfall evenly over the system (Figure 1) to generate comparable results for all RTBs.





The two graphs above show hourly rainfall used for regular rain scenario (top). Hourly rainfall used for extreme rain scenario (bottom). Note the different scales on both the y-axes and x-axes.

Disconnection analysis

We calculated the impact of the disconnected subcatchment *i* on the CSO volume reduction from the individual outfall *j* (R_{ij} from Equation 1) and from the system's total CSO volume (R_{i_tot} from Equation 2) as a percentage of the baseline CSO discharge volume. The analysis was carried out for each of the 402 subcatchments.

$$R_{ij} = 1 - \frac{D_{ij}}{D_j}, i = 1, \ldots, 402, \qquad (1)$$

$$R_{i\_tot} = 1 - \frac{D_i}{D_{tot}}, i = 1, \ldots, 402, \qquad (2)$$

D_j is the baseline CSO discharge volume from the individual outfall j.

D_{tot} is the baseline discharge for the entire system.

D_{ij} is the CSO discharge volume from the individual outfall j when the ith subcatchment is disconnected from the system.

D_i is the CSO discharge volume from the whole system when the ith subcatchment is disconnected from the sewer system.

R_{ij} and R_{i_tot} were normalized based on the impervious area of subcatchment i.

Baseline volumes

Percent reductions of CSO in the SWMM scenarios are based on the baseline volumes in the table below. These are the discharge volumes generated by the calibrated model when the normal rain event and extreme rain event were modeled.

This table lists the baseline CSO discharge volumes from calibrated outfalls for normal and extreme rainfall events.

Outfall	Normal rain event baseline discharge (millions of gallons)	Extreme rain event baseline discharge (millions of gallons)
Acacia Park RTB	2.14	37
Birmingham RTB	0	36.7
Bloomfield Village RTB	0	57.9
George W Kuhn RTB	0	106
Redford Township RTB	0	14.7
Inkster RTB	0.65	19.3
Dearborn Heights RTB	0	23.9
Milk River RTB	0	80.4
Chapaton RTB	0	70.5
Conner Creek RTB	0	368.4
Hubbell-Southfield RTB	30.3	134.2
Oakwood RTB	30.9	43.7
WRRF 49A	708.3	905.8
WRRF 50A	265.3	813.3
System total	1038	2712

Green infrastructure analysis

We tested two types of green infrastructure in SWMM: bioretention cells and permeable pavement. Table below contains the model parameter settings used for each GI implementation. Each of the GI designs was equipped with underdrains to comply with local soil conditions. The underdrain designs are a common practice that allows the GI to drain before the next storm event, since current soils do not allow for full infiltration.

This table outlines the parameter settings of bioretention cell and permeable pavement in SWMM

Parameters		Bioretention Cell	Permeable Pavement
Surface	Berm Height (in)	0	0
	Surface Roughness (Manning's n)	0.1	0.1
	Surface Slope (percent)	5.0	1
Pavement	Thickness (in)		5
	Void Ratio		0.15
	Permeability (in/hr)		10
Soil	Thickness (in)	30	
	Porosity	0.5	
	Conductivity (in/hr)	5.0	
	Suction Head (in)	2.0	
Storage	Thickness (in)	15	20
	Void Ratio	0.75	0.75
	Seepage Rate (in/hr)	0.01	0.15
Drain	Flow Coefficient	5.0	5.0
	Offset Height (in)	6	6

Maximum treatment ratio of Bioretention Cell is 1:10, indicating one unit area of Bioretention Cell can treat the runoff from 10 units of the impervious area.

Maximum treatment ratio of Permeable Pavement is 1:5.

This supplemental information and the project report, *Watershed Assessment of Detroit River Nutrient Loads to Lake Erie*, were produced by the University of Michigan Water Center.

The full project report and links to associated journal articles can be found here: www.myumi.ch/detroit-river