Data and Assumptions
for the St. Clair - Detroit River Watershed Model

This document summarizes data and assumptions that have been 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 summary was developed to help explain the team's modeling process and provide an opportunity for feedback and discussion. You can read more about the watershed modeling project here: http://graham.umich.edu/project/assessing-detroit-river-nutrient-loads-lake-erie

Data sources and assumptions have been summarized for each of the following model requirements, in this order:

Landscape Data

1. Topography
- Produced by other sources; minimal processing

2. Soil
- Produced by other sources; minimal processing

3. Land Use and Land Cover
- Produced by other sources; minimal processing

Agricultural Practices

4. Crop Rotations
- Based on multiple year land use data

5. Mineral Fertilizer Application
- Based on fertilizer sales at county or provincial scale

6. Manure Application
- Based on livestock census data at county level

7. Tillage
- Based on county level reports of tillage practices

8. Tile Drain Implementation
- Based on tile drainage location map or soil properties

Other Model Inputs

9. Industrial and Municipal Point Sources
- Monthly reported values

10. Reservoirs
- Includes three reservoirs in Upper Thames River watershed

11. Calibration and validation locations
- Determined based on availability of flow and water quality data

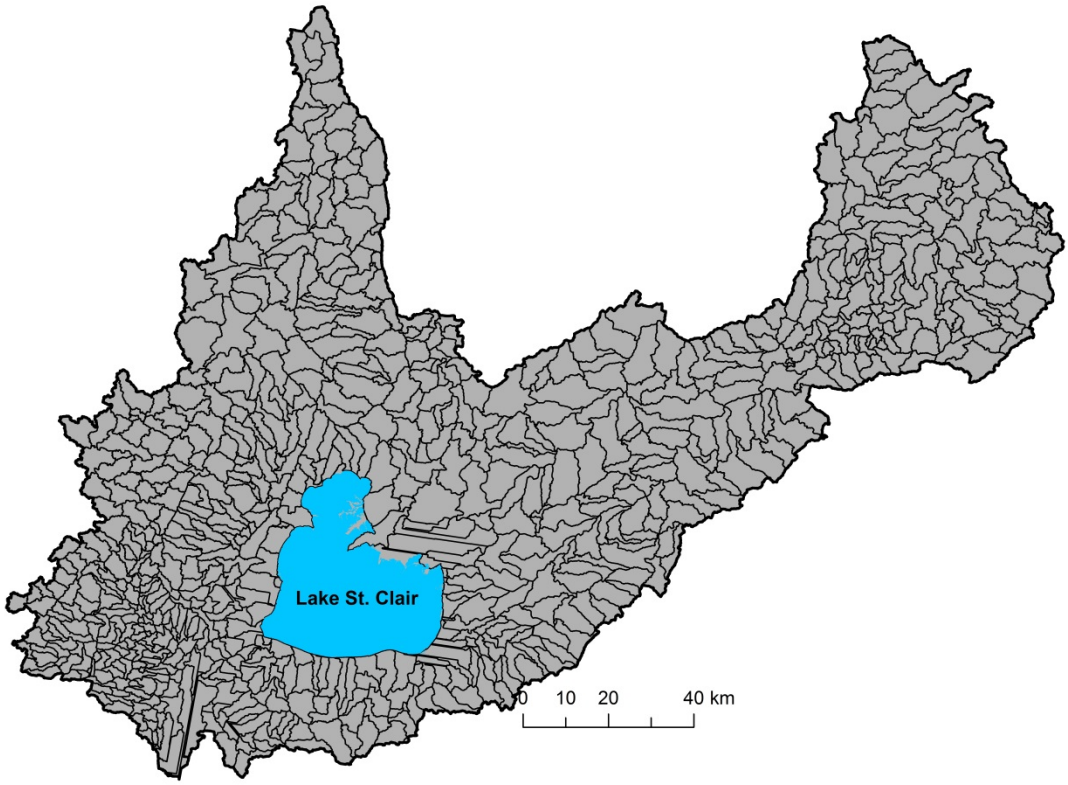
1. Topography

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 above) were created with average areas of ~ 24km^2 by applying a threshold and manually inserting additional outlets.
    - 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.

2. 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 is downloaded as shape files 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

3. 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.

4. Crop Rotations

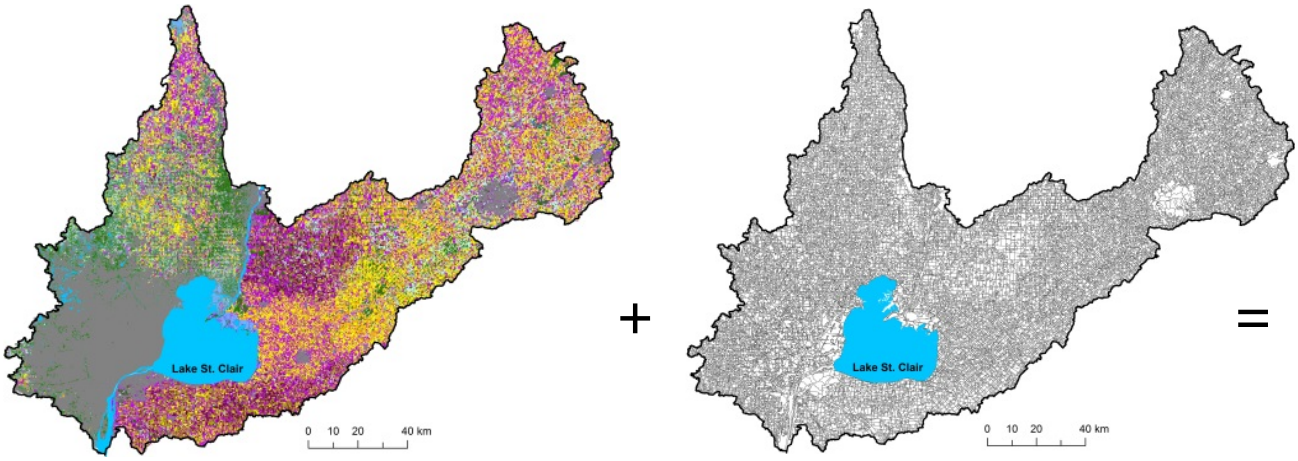
Sources:

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

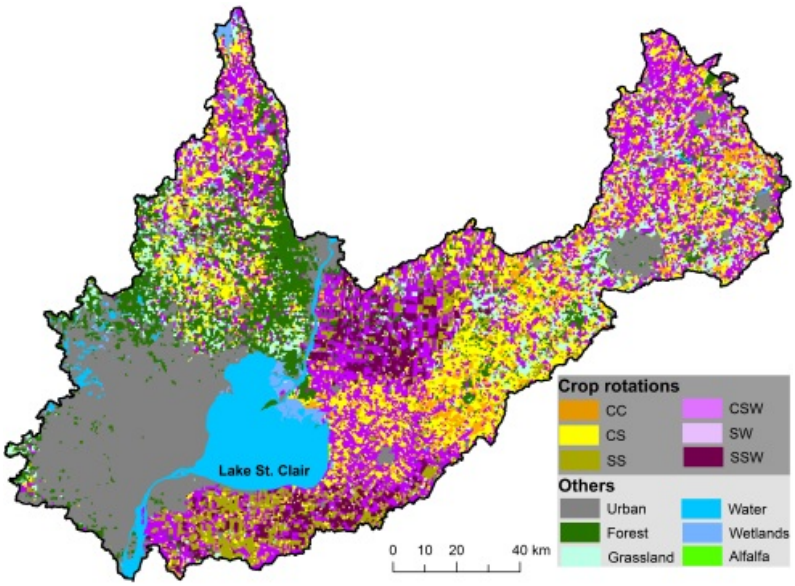
Processes:

- 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.

Grid Rotations **HRU Boundaries**



HRU Rotations



5. 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)
- US side
    - 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.
- Canada side
    - A similar process was followed for Canadian agricultural lands except that currently we only have one value for the entire province. While we are attempting to retrieve data at a smaller spatial scale, we are currently using this one value.
        - 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.

Table: County nitrogen (N) and phosphorous (P) fertilizer application rates

County	Annual Average (kg/ha)	
	N	P
Lapeer	53.9	6.7
Macomb	51.4	6.4
Oakland	59.9	7.5
St. Clair	45.6	5.7
Sanilac	61.4	7.7
Washtenaw	70.9	8.9
Wayne	58.5	7.3
Elgin	62.7	14.9
Essex	62.7	14.9
Huron	62.7	14.9
Kent	62.7	14.9
Lambton	62.7	14.9
Middlesex	62.7	14.9
Oxford	62.7	14.9
Perth	62.7	14.9

- Moreover, crop specific ranges of fertilizer application rates (tables below) were estimated for the watershed depending on which county the HRU is located and/or the type of rotation.

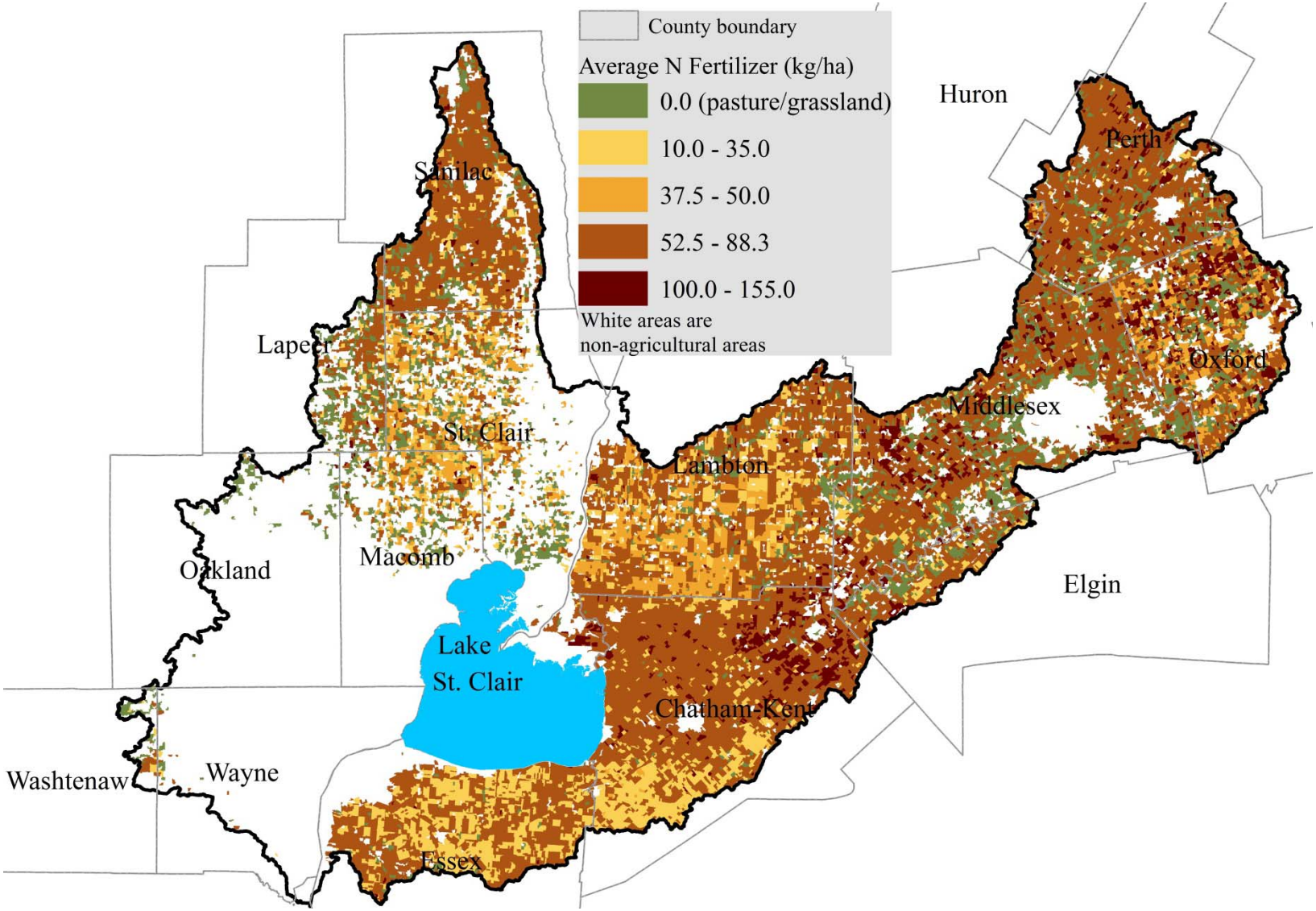
Table: Ranges of nitrogen (N) and phosphorous (P) application rates for each crop

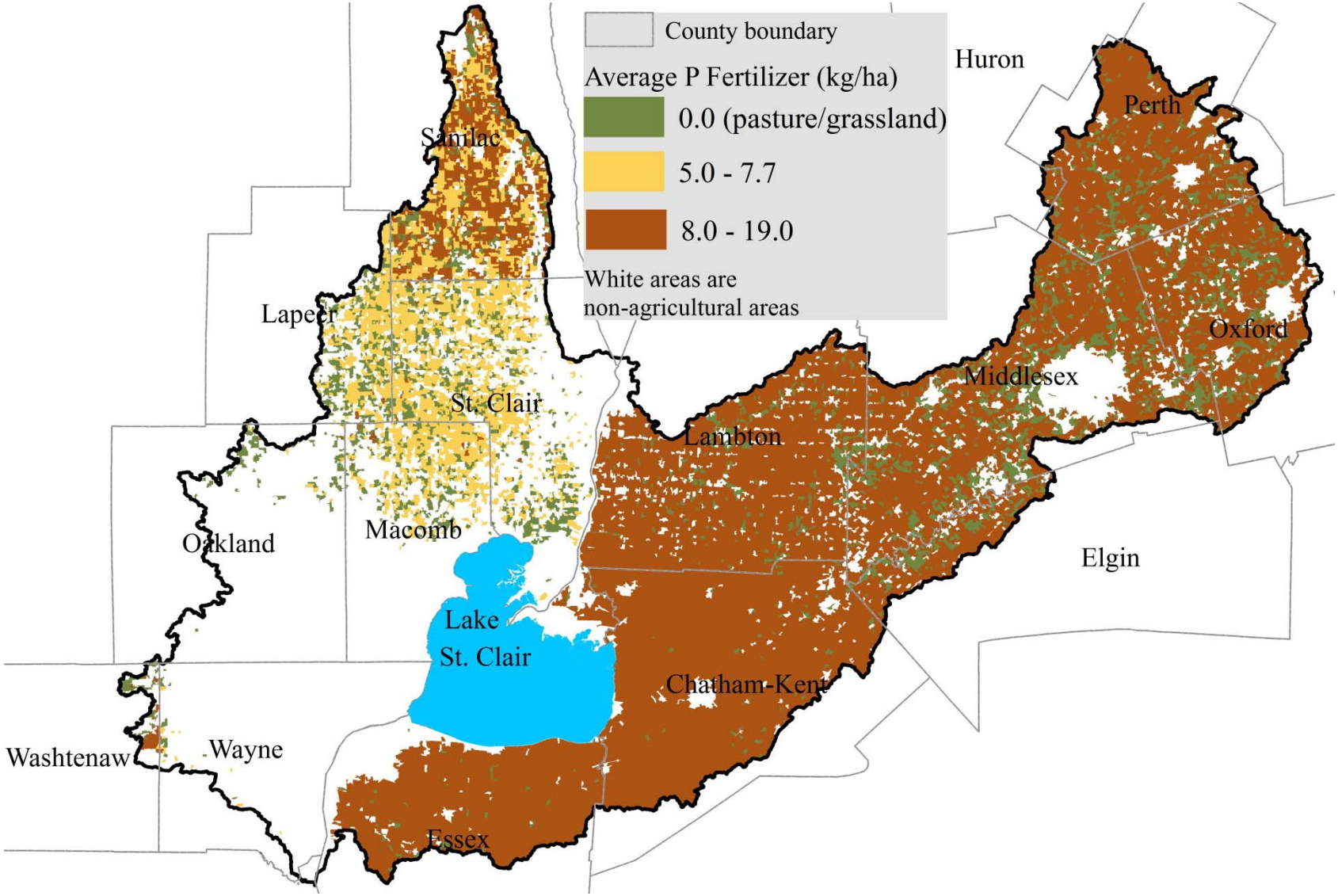
Crop type	N application rate (kg/ha)	P application rate (kg/ha)
Corn	85 - 155	6 - 19
Soybeans	10 - 35	5 - 14
Winer wheat	65 - 100	6 - 17

Table: County nitrogen (N) and phosphorous (P) fertilizer application rates for each crop and rotation

County	Country	Fertilize application rates per county per crop and rotation (kg/ha)							
		Corn after Corn		Corn after other crop		Soybeans		Winter wheat	
		N	P	N	P	N	P	N	P
Lapeer	U.S.	115	8	95	7	15	6	70	8
Macomb	U.S.	110	8	90	7	10	6	85	7
Oakland	U.S.	100	9	85	8	10	6	65	8
St. Clair	U.S.	100	8	85	6	10	5	65	6
Sanilac	U.S.	125	10	105	8	15	6	70	10
Washtenaw	U.S.	-	-	125	10	30	8	95	10
Wayne	U.S.	-	-	125	8	25	7	95	8
Elgin	Canada	125	17	110	16	10	14	70	15
Essex	Canada	155	19	130	17	35	14	100	17
Huron	Canada	100	18	85	15	10	13	65	15
Kent	Canada	135	17	110	16	10	14	70	15
Lambton	Canada	145	19	120	16	25	14	80	16
Middlesex	Canada	105	18	95	16	15	13	65	15
Oxford	Canada	100	18	85	15	10	13	65	15
Perth	Canada	120	19	95	15	10	14	70	15

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




County boundary
Average P Fertilizer (kg/ha)
0.0 (pasture/grassland)
5.0 - 7.7
8.0 - 19.0
White areas are
non-agricultural areas
Huron
Perth
Sanilac
Lapeer
Oxford
Middlesex
St. Clair
Lambton
Macomb
Oakland
Elgin
Lake
St. Clair
Chatham-Kent
Washtenaw
Wayne
Essex

6. 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 Input/Output documentation manual page 610 (Table below). As a result, the total mass of dry manure produced for each livestock type per county was calculated using these standards.

Table: Fresh manure production and characteristics per 1000 kg live animal mass per day (from ASAE, 1998)

Table A-13: Fresh manure production and characteristics per 1000 kg live animal mass per day (from ASAE, 1998a)

			Animal Type‡										
Parameter			Dairy	Beef	Veal	Swine	Sheep	Goat	Horse	Layer	Broiler	Turkey	Duck
Total Manure	kg†	mean	86	58	62	84	40	41	51	64	85	47	110
		std dev	17	17	24	24	11	8.6	7.2	19	13	13	**
Total Solids	kg	mean	**12**	**8.5**	**5.2**	**11**	**11**	**13**	**15**	**16**	**22**	**12**	**31**
		std dev	2.7	2.6	2.1	6.3	3.5	1.0	4.4	4.3	1.4	3.4	15
Total Kjeldahl nitrogen¶	kg	mean	**0.45**	**0.34**	**0.27**	**0.52**	**0.42**	**0.45**	**0.30**	**0.84**	**1.1**	**0.62**	**1.5**
		std dev	0.096	0.073	0.045	0.21	0.11	0.12	0.063	0.22	0.24	0.13	0.54
Ammonia nitrogen	kg	mean	**0.079**	**0.086**	**0.12**	**0.29**	**	**	**	**0.21**	**	**0.080**	**
		std dev	0.083	0.052	0.016	0.10	**	**	**	0.18	**	0.018	**
Total phosphorus	kg	mean	**0.094**	**0.092**	**0.066**	**0.18**	**0.087**	**0.11**	**0.071**	**0.30**	**0.30**	**0.23**	**0.54**
		std dev	0.024	0.027	0.011	0.10	0.030	0.016	0.026	0.081	0.053	0.093	0.21
Ortho-phosphorus	kg	mean	**0.061**	**0.030**	**	**0.12**	**0.032**	**	**0.019**	**0.092**	**	**	**0.25**
		std dev	0.0058	**	**	**	0.014	**	0.0071	0.016	**	**	**

** Data not found.
† All values wet basis.
‡ Typical live animal masses for which manure values represent are: dairy, 640 kg; beef, 360 kg; veal, 91 kg; swine, 61 kg; sheep, 27 kg; goat, 64 kg; horse, 450 kg; layer, 1.8 kg; broiler, 0.9 kg; turkey, 6.8 kg; and duck, 1.4 kg.
¶ All nutrient values are given in elemental form.

Source: Arnold et al. 2013

- 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?
    - At the moment, 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.

Table: Rate of manure applied in each county per livestock type

County	Manure applied on crop lands (kg/ha)							
	Dairy	Beef	Swine	Sheep	Goats	Broilers	Layer	Turkeys
Lapeer	195.22	13.66	2.67	1.89	1.22	0.27	0.73	0.05
Macomb	162.08	14.56	2.43	0.59	0.94	0.43	1.14	0.03
Oakland	671.75	50.32	34.61	54.18	31.09	13.41	47.31	2.79
St. Clair	85.09	7.72	0.38	0.64	1.25	0.28	0.53	0.10
Sanilac	397.16	13.17	5.31	0.32	0.71	0.09	0.23	0.02
Washtenaw	181.28	10.95	17.78	11.98	2.76	0.90	1.40	0.13
Wayne	130.25	7.87	21.54	19.74	21.49	4.65	11.17	2.52
Elgin	176.42	12.80	159.20	2.38	0.00	0.00	81.44	20.02
Essex	28.66	1.64	18.09	1.30	0.00	0.00	16.34	4.64
Huron	276.96	39.90	481.19	5.76	0.00	0.00	217.13	51.58
Kent	22.67	3.67	99.00	0.84	0.00	0.00	8.32	3.85
Lambton	78.35	10.90	222.12	1.38	0.00	0.00	68.32	12.49
Middlesex	195.12	17.20	270.28	2.61	0.00	0.00	123.03	67.52
Perth	626.71	32.00	558.92	4.69	0.00	0.00	218.57	4.98
Oxford	680.36	23.98	597.92	3.64	0.00	0.00	195.61	101.69
	Manure applied on pasture lands (kg/ha)							
Lapeer	42.71	194.81	1.71	2.43	1.57	0.01	0.02	0.08
Macomb	65.70	384.64	2.88	1.42	2.25	0.02	0.05	0.07
Oakland	21.07	102.86	3.17	10.02	5.75	0.05	0.17	0.61
St. Clair	34.28	202.70	0.44	1.52	2.97	0.01	0.02	0.28
Sanilac	609.30	1317.10	23.78	2.86	6.45	0.02	0.04	0.16
Washtenaw	40.90	160.93	11.71	15.93	3.67	0.02	0.04	0.21
Wayne	11.84	46.57	5.72	10.58	11.52	0.05	0.12	1.59
Elgin	153.18	439.18	119.09	10.51	0.00	0.00	18.17	12.68
Essex	289.98	656.47	157.67	67.05	0.00	0.00	42.48	34.26
Huron	334.73	1904.97	501.06	35.37	0.00	0.00	67.43	45.48
Kent	357.28	2287.10	1344.06	67.39	0.00	0.00	33.70	44.23
Lambton	205.64	1130.36	502.29	18.38	0.00	0.00	46.08	23.92
Middlesex	169.24	589.32	201.99	11.49	0.00	0.00	27.42	42.73
Oxford	641.72	893.32	485.91	17.43	0.00	0.00	47.41	69.97
Perth	605.97	1222.42	465.62	23.02	0.00	0.00	54.31	3.51

    - There is some information about portions of crop/pasture lands that received manure in a county. Hence, distributing manure in a certain percentage of crop/pasture land in a county will be considered after preliminary result assessment.

- How do we apply manure?
    - Currently, manure is assumed to be spread on lands.
        - There are other methods we are considering, such as, inject/incorporate in to soil in croplands, naturally spread by grazing animals in pasture lands, etc., however we do not have good data on this aspect.
- SWAT changes manure application rates in to nutrients using the following values of nutrient fractions in manures.

Table: Nutrient fractions for various types of manure in SWAT

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

Values in bold italics are estimated (see section A.4.2)

Source: Arnold et al. 2013

Table: Nutrient equivalents of applied manure in SWAT (sample)

County	Manure applied on crop lands (kg/ha)								Nutrient equivalent (kg/ha)			
	Dairy	Beef	Swine	Sheep	Goat	Broiler	Layer	Turkey	MinN	MinP	Org-N	Org-P
Lapeer	195.22	13.66	2.67	1.89	1.22	0.27	0.73	0.05	1.6	1.1	6.6	0.7
Macomb	162.08	14.56	2.43	0.59	0.94	0.43	1.14	0.03	1.4	0.9	5.6	0.6
Oakland	671.75	50.32	34.61	54.18	31.09	13.41	47.31	2.79	8.0	4.5	27.6	3.8
St. Clair	85.09	7.72	0.38	0.64	1.25	0.28	0.53	0.10	0.7	0.5	3.0	0.3
Sanilac	397.16	13.17	5.31	0.32	0.71	0.09	0.23	0.02	3.1	2.1	12.9	1.3
Washtenaw	181.28	10.95	17.78	11.98	2.76	0.90	1.40	0.13	2.1	1.2	6.8	0.8
Wayne	130.25	7.87	21.54	19.74	21.49	4.65	11.17	2.52	2.3	1.1	6.4	1.0
Essex	28.66	1.64	18.09	1.30	0.00	0.00	16.34	4.64	1.0	0.5	2.2	0.5
Elgin	176.42	12.80	159.20	2.38	0.00	0.00	81.44	20.02	6.7	3.2	13.4	2.8
Huron	276.96	39.90	481.19	5.76	0.00	0.00	217.13	51.58	18.1	8.3	31.0	7.2
Kent	22.67	3.67	99.00	0.84	0.00	0.00	8.32	3.85	2.9	1.3	3.4	0.8
Lambton	78.35	10.90	222.12	1.38	0.00	0.00	68.32	12.49	7.4	3.3	10.7	2.5
Middlesex	195.12	17.20	270.28	2.61	0.00	0.00	123.03	67.52	10.7	5.0	20.3	4.7
Oxford	680.36	23.98	597.92	3.64	0.00	0.00	195.61	101.69	23.9	11.6	46.9	9.4
Perth	626.71	32.00	558.92	4.69	0.00	0.00	218.57	4.98	22.2	10.8	41.2	7.8

7. Tillage

Source:

- 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.
    - The proportions calculated here (tables below) were assumed to be the same for every year

Table: Percentages of tillage practices in the **US** part of the watershed (**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

Table: Percentages of tillage practices in the **Canadian** part of the watershed

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. For example, HRUs with continuous corn rotation are assumed to have conventional tillage.
        - Conservation and no-till practices are assigned more on HRUs with more crops in rotation

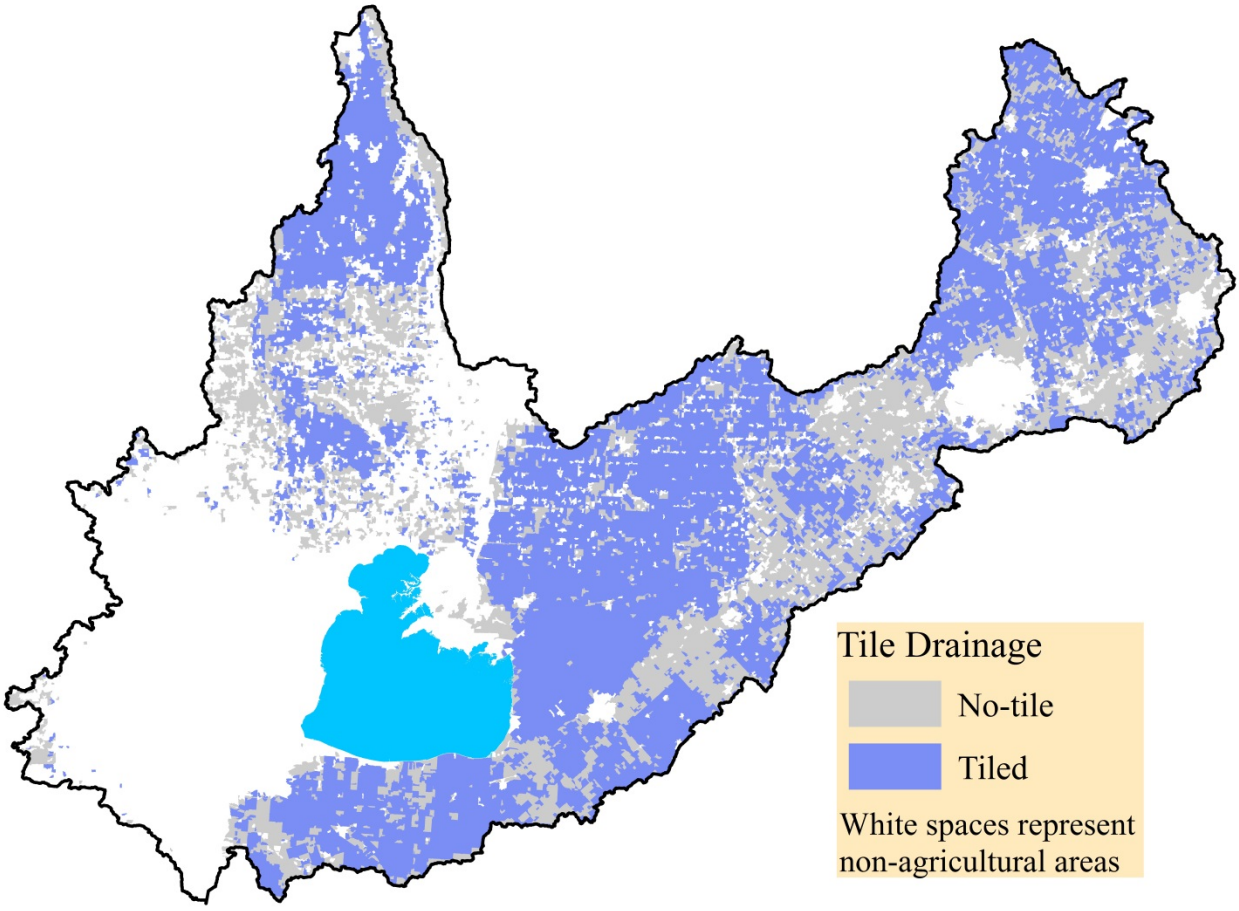
8. Tile Drain Implementation

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.



- Typical values for tile pipe diameter (76 to 152mm), installation depth (900-1200mm) and spacing (10 to 40m) for this region are considered for the model.

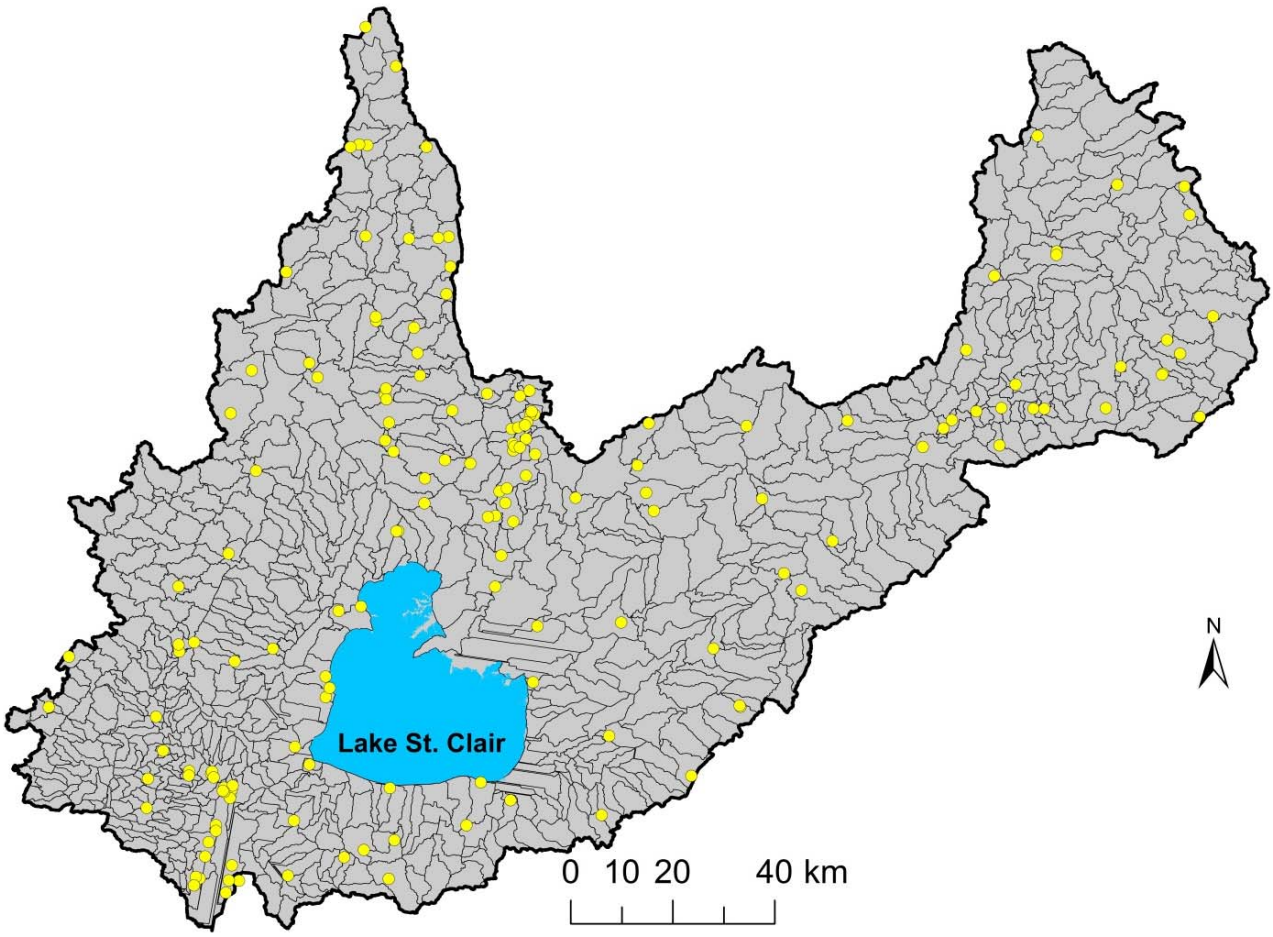
9. Industrial and Municipal Point Sources

Sources:

- EPA DMR for US (https://cfpub.epa.gov/dmr/)
- MISA for Canada (https://www.ontario.ca/data/industrial-wastewater-discharges)
- Personal communication

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.



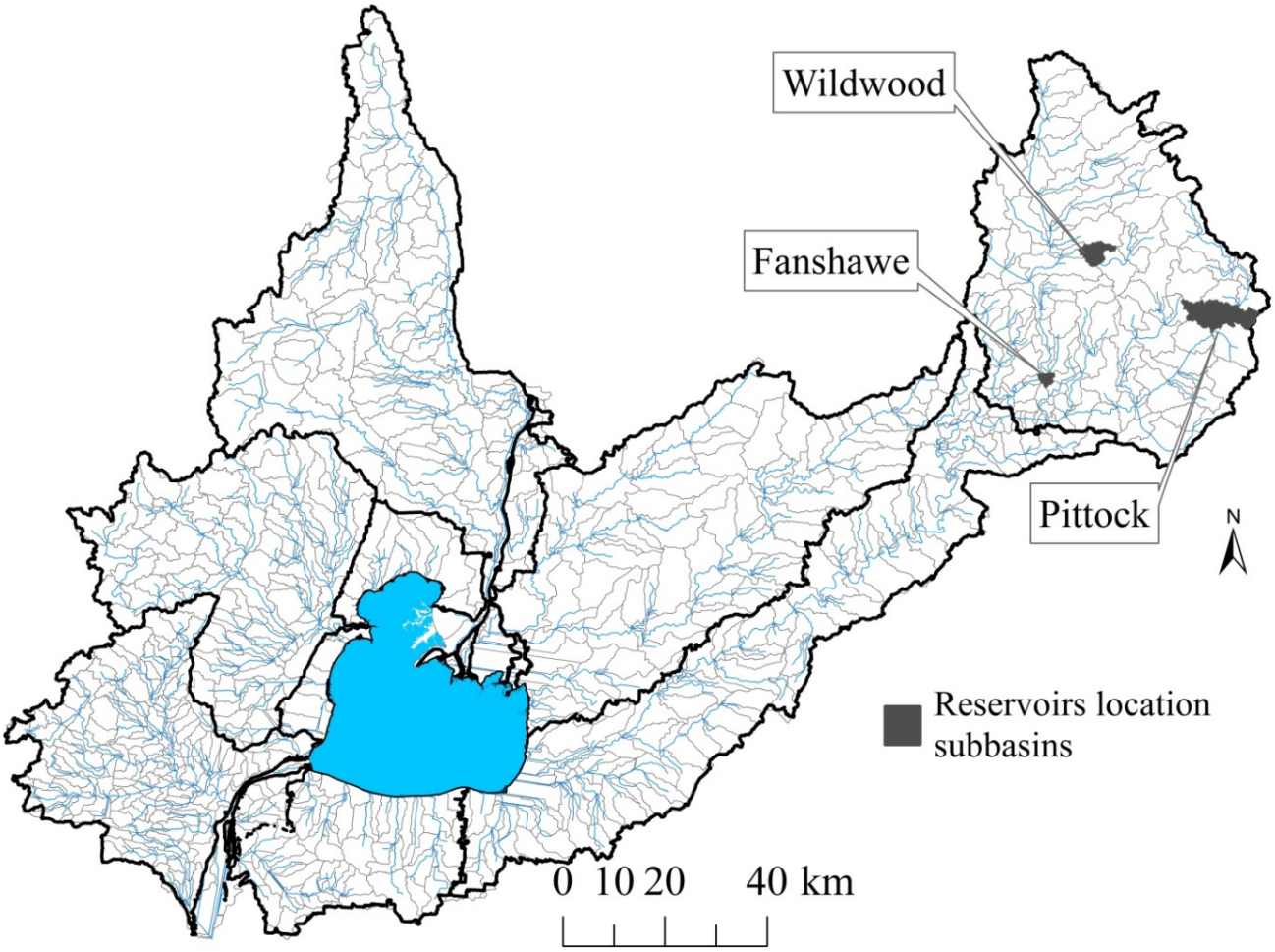
10. Reservoirs

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

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.



11. Calibration/validation locations and data

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
- Individual email communications)

Processes/assumption:

- 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.
    - A couple of calibration/validation processes may be required for water quality
        - Calibrate/validate based only on observed samples and let the model (SWAT) estimate the values for the other dates
            - This method is being used currently
        - Estimate daily, monthly and annual water quality values using estimation methods (e.g., WRTDS – Weighted Regression on Time Discharge, and Season) and calibrate the model based on these values
            - If the above calibration processes fails to satisfy model evaluation criteria, it may be necessary to use this method for calibration, at least at monthly and annual time steps.