# Using GIS technology to prepare and process data for groundwater modeling at Lake St. Clair Metropark

Brendan O'Leary [a], S. Mohsen Sadatiyan A. [b]

[a]. Geology Department
brendan.o'leary@wayne.edu
[b] Civil and Environmental Engineering Department
mohsen@wayne.edu

Wayne State University, Detroit, USA

Advisor: Carol J. Miller, PhD

**Key Words:** Lake St. Clair, groundwater, modeling, ArcMap, MODFLOW, GIS

**Abstract**

The groundwater flux component of the water budget for Lake St. Clair is known with much less certainty than other components of the budget (e.g. precipitation and surface water runoff). There is a need to better quantify this component of the budget due to the special role groundwater plays in a variety of hydraulic processes. For instance, groundwater flow can be a key factor in the transport of contaminants between surface and subsurface water systems. At the Lake St. Clair Metropark, which has experienced significant beach closures due to microbial contamination, it is thought that groundwater flow may be a pathway for microbial transport. Based on the importance of an improved understanding of the relation between groundwater flow and contaminant transport in that area, we created a computer model for simulating groundwater and contaminant movement under varying hydrologic conditions. In this study, two GIS based computer software were used, ArcMap and MODFLOW Flex. ArcMap created the spatial parameters for the study area and soil characteristics. MODFLOW Flex utilized this spatial information to create both a conceptual and numerical model to simulate groundwater flow. Although using two separate software programs caused some compatibility issues, each of the programs have unique strengths when combined create a detailed model. This study, which is part of the Huron to Erie Alliance for Research and Training, represents an initial study to identify the groundwater flux and related potential pollutant transport in Lake St. Clair.

# 1. Introduction

## 1.1. Background

The Laurentian Great Lakes are all hydraulically connected, but there are significant differences between the Upper Great Lakes (Superior, Huron, and Michigan) and the Lower Great Lakes (Erie and Ontario). The dominant land use of the majority of the watershed basins contributing to the Upper Lakes is rural – primarily forested or agricultural, while the land use contributing to the Lower Lakes is much more varied – including significant areas of urban and suburban use, as well as rural. The Upper Great Lakes are connected to the Lower Great Lakes by the bi-national Huron to Erie Corridor. The focus of the present investigation is the central water body of this connecting corridor, Lake St. Clair. Although this lake has significant importance to tourism, navigation, and recreation (Michigan government proclamations, 2013) for the nearly 2 million residents within a 20-mile radius of this Lake (U.S. Census Bureau, 2010) it has been severely under-studied in relation to the Great Lakes that surround it, due in part to the "Great Lakes" designation required for many funding sources. Many water budget components associated with Lake St. Clair are investigated, but there is still a large degree of uncertainty associated with groundwater flux (Winter, 1981; USGS, 2007).

While various components of the water budget (surface water flow, evaporation, precipitation, etc.) of Lake St. Clair are measured and investigated by different organizations in USA and Canada, most of the time groundwater flux is not considered a highly influential factor (Neff and Killian, 2003). Groundwater flux is not easily measured in most locations but by calculating the water budget we know the approximate value of groundwater flux for the whole lake. The difficulty with estimating the groundwater flux resides in the variability of groundwater fluxes across the entire lake and the lack of easy and accurate methods to measure groundwater fluxes at the limnetic zone. This variability can cause certain areas of the lake to have positive or negative seepage which could result in incorrect models.

Specially, for Lake St. Clair Metropark (LSCMP) seepage might cause some pollution transport that affects the operation of beach. Due to high levels of biological pollution, beach closures have occurred in past summers resulting in economic losses to the region (SEMCOP, 2013). Therefore, generating an accurate hydraulic model can give us valuable information about groundwater flow and potential pollutant movement. The objective of this study is to create and evaluate a groundwater flow model using GIS technology in the Lake St. Clair Metropark (LSCMP). The methods outlined in this paper are part of a larger study conducted by Huron to Erie Alliance for Research and Training (HEART- heartfreshwatercenter.org) to assess the overall water budget and environmental health of Lake St. Clair.

## 1.2. Study Area

This study looks specifically at the Lake St. Clair Metropark of Huron-Clinton Metropark Authority and the northern marshes adjacent to the park (Figure 1). This metropark is one of few parks along the shoreline that promote natural vegetative growth and habitat and is a major attraction for Lake St. Clair tourists and local communities. This study area is also associated with two different drainage systems, the Clinton River and St. Clair River tributaries, making it important hydraulically (Figure 2). The area of interest is defined as the Lake St. Clair Metropark combined with the northern marshes up to the Clinton River (Figure 1).

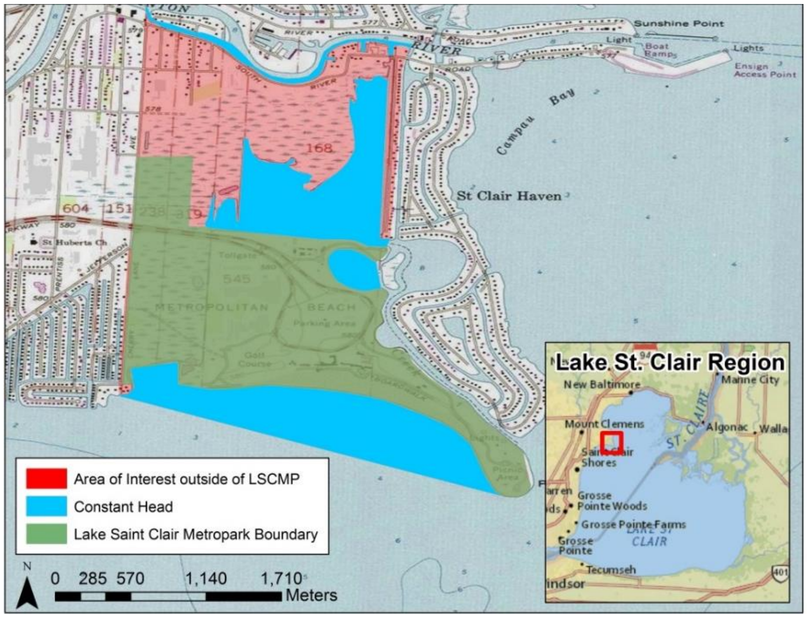


Figure 1- Map of the Lake St. Clair Metropark with surroundings. The study area is defined as the Lake St. Clair Metropark (green) combined with the red area of interest to the north of the park. Constant head boundaries for the model, defined as surface water, are also shown in this map.

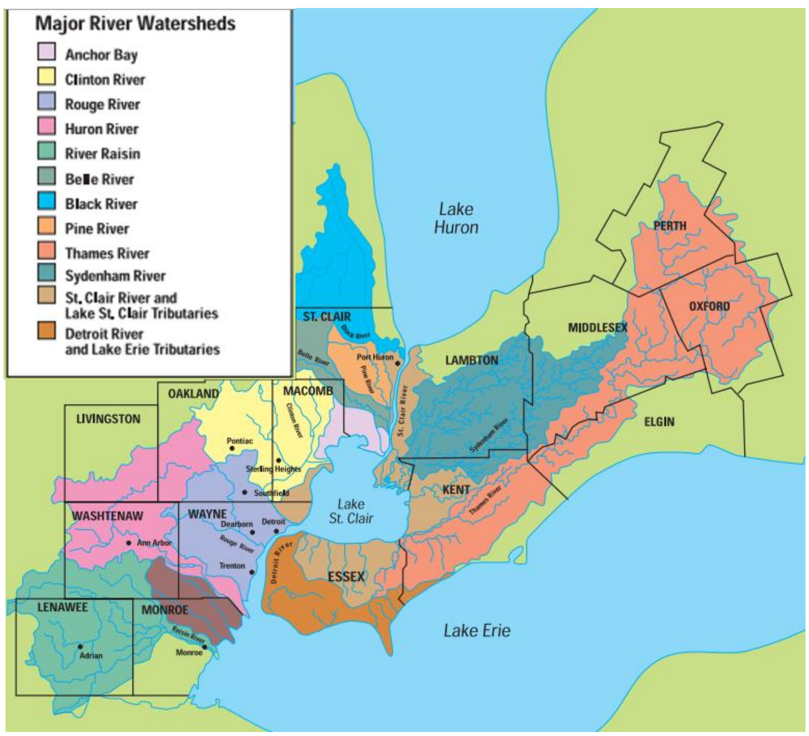


Figure 2- Major river watersheds for southeastern Michigan and southwestern Ontario (Lake St. Clair Canadian Watershed Coordination Council, 2013)

The NRCS soil survey (Larson, 1971) provided a detailed spatial understanding of the soil distribution both vertically and horizontally throughout the park (Figure 3 and Table 1). The soil survey noted two distinct classes of soils in the Metropark. These included Udorthents and Udipsamments which are typical of well drained disturbed soils near beach settings and Lamson which are typical of a fine sandy loam. Both Udorthents and Udipsamments were located throughout the groomed public areas of the Metropark, while the Lamson soils were located in the wetlands area.

Table 1- Hydraulic conductivity values for soils in the Lake St. Clair region.

| Depth (cm) | Udorthents and Udipsamments: Hydraulic Conductivity (μm/sec) | Depth (cm) | Lamson: Hydraulic Conductivity (μm/sec) |
|---|---|---|---|
| 0-20 | 9.17 | 0-80 | 9.00 |
| 20-80 | 7.76 | 80-120 | 41.52 |
| 80-120 | 3.90 | | |

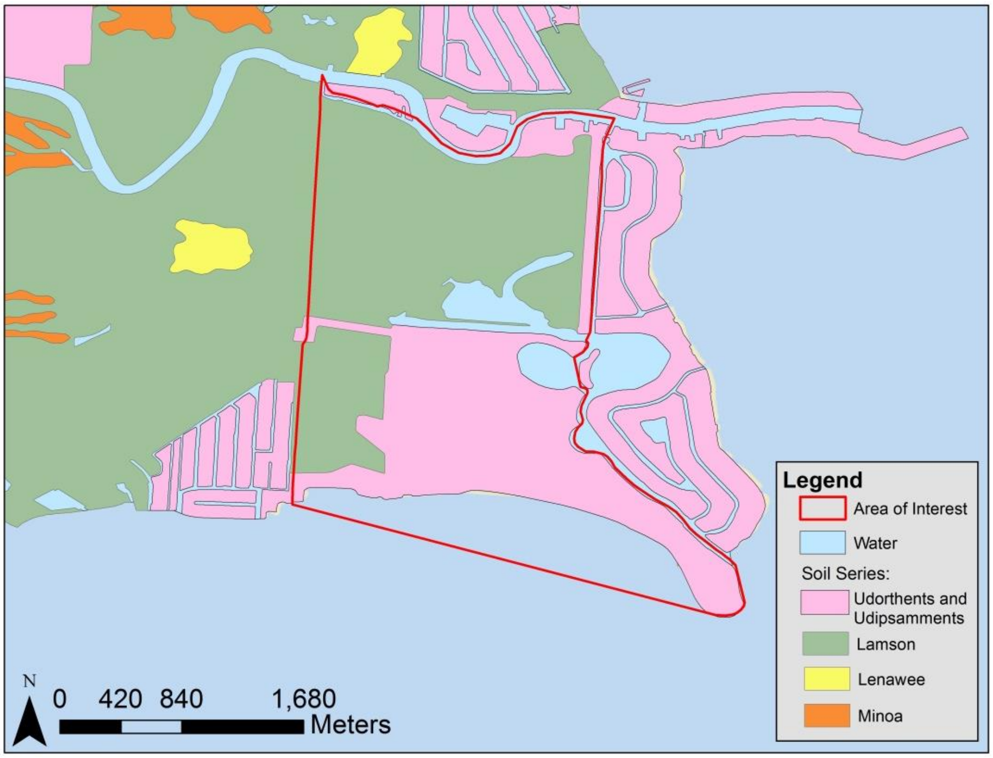


Figure 3- Map of Soil Series in the Lake St. Clair Metro Park region

## 2. Methods

Two GIS programs, ESRI ArcMap 10.0 and Visual MODFLOW Flex 2013.1, were employed to map and assess the groundwater flow at the Lake St. Clair Metro Park. ArcMap generated the spatial boundaries of the model and MODFLOW was used to simulate groundwater flow in the study area. The Universal Transverse Mercator Zone 17N with North American Datum of 1984 (NAD 1984) was the projection for the model.

## 2.1.ArcMap

ArcMap provided the spatial editing tools needed to create the spatial parameters for the groundwater flow model in MODFLOW Flex. There were 4 spatial components generated in ArcMap which include the Lake St. Clair Metropark borders, the area of interest, adjacent surface water bodies, and the discretization of the soil units in the area of interest. The area of interest, Lake St. Clair Metropark borders, and adjacent water bodies shape files were sketched manually using the editor tool and streets base map provided by ArcGIS online. The soil shapefile dataset was downloaded from the Web of Soil Survey website (websoilsurvey.sc.egov.usda.gov) run by the United State Department of Agriculture (Figure 3). The soil information was then extracted based on the area of interest shapefile.

## 2.2.MODFLOW Flex

MODFLOW Flex was used to model the hydrogeological conditions of the Lake St. Clair Metropark. MODFLOW uses a conceptual model coupled with a numerical model to solve differential equations of head distribution with numerical methods. The conceptual model creates the framework which is then discretized in the form of a grid for the numerical model. The GIS raster data and shapefiles provided the framework for the conceptual model in MODFLOW.

To create soil structure in MODFLOW, layered horizons were created that represented individual soil layers. This information can be imported in MODFLOW Flex as a cloud of points in various formats (e.g. text and grid files). The clouds of points with defined X, Y and Z values can be converted to surfaces and used as horizons.

The Digital Elevation Model (DEM) of ground surface was obtained from the national map viewer web site of U.S. geological survey (USGS, 2013). Resolution of the DEM file is 1/3 of arc-second (about 9.2 meter). The DEM data was downloaded in the format of raster file and was divided based on soil type shapefile. It was assumed that soil layers in the area of interest are parallel. To create soil layers, a constant value was subtracted from value of each cell of DEM of ground surface (that shows elevation of each point of ground surface). The subtracted constant value for each layer was equal to depth of layer. Raster files of soil layers were finally converted to text files. This information was imported in MODFLOW as text file and was used for creating surfaces. After intersecting surfaces in MODFLOW, spatial structure of soil layers that contains horizons and zones were created. In the next step, soil characteristics (e.g. hydraulic conductivity in three direction, porosity, etc.) were assigned to different soil layers. For the purposes of this study, the model used the Udorthents/ Udipsamments and Lamson soils as two discrete soil in the area of interest. Constant head boundaries, surface water adjacent to the area of interest, were defined previously in ArcMap as a shapefile which was then imported into MODFLOW FLEX (Figure 1).

The southern boundary of the model was represented as a constant-head boundary based on surface water levels of Lake St. Clair. The overall average from 1898 to 2012 was 174.986 m (GLIN, 2013). Over the past 10 years the average level was 174.897 m. On average, the lake levels varied by approximately 0.2 m per year. For this model, a constant head of 174.9 m (573.8 ft) above mean sea level was used. Also depending on the season of the simulation (winter or summer) the constant head value can be changed in a range from 174.7 to 175.1 m (573.2 to 574.5 ft) (GLIN, 2013). The eastern boundary was represented by a no-flow boundary, since existence of sheet-pile wall segregate the groundwater from surface water channels. Although if we assume that the sheet pile is not impervious to water and the groundwater can be in equilibrium with the surface water at that location. In that case, the eastern boundary can be characterized as a constant head boundary. It has the same initial condition as that as the southern boundary (equal to the lake level of Lake St. Clair). Similarly, the northern boundary considered in equilibrium with the Clinton River and represented by a constant head boundary. For the purposes of the simulation, it was assumed that the elevation of the Clinton River was higher than the elevation of Lake St. Clair. Visual observations of the Clinton River have indicated that the water surface is at an elevation lower than the ground surface elevation of its banks. Therefore, the Clinton River was represented at a water level between 573.8 and 577 feet above mean sea level. The western boundary of the model area is coincidental with Cherry Lane and Jefferson Avenue. These roads have a ditch on each side, and this ditch also considered as constant head boundary.

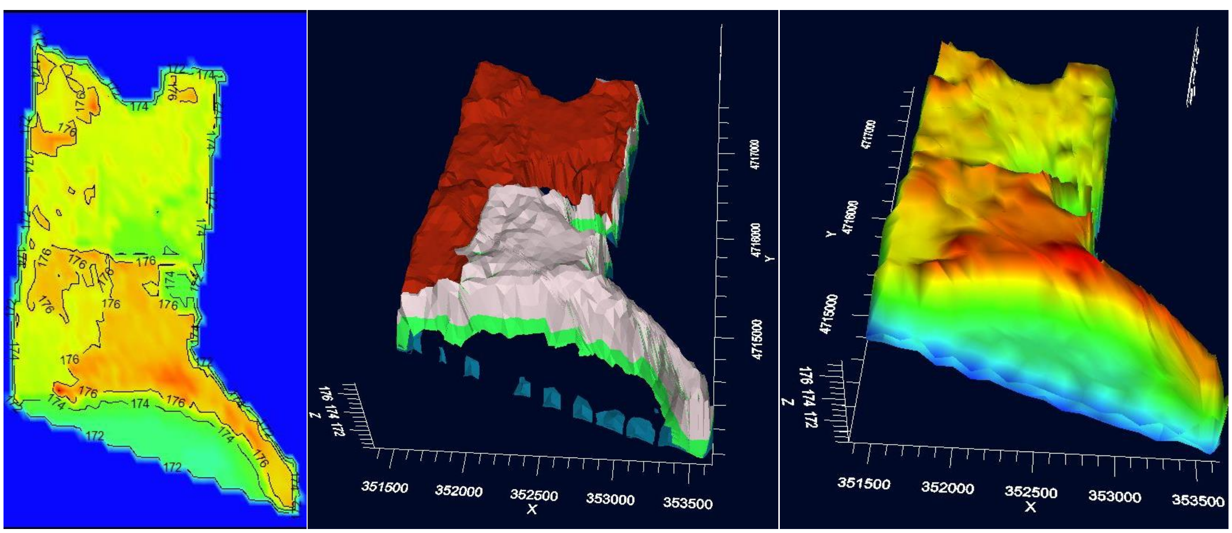


Figure 4- 2D view (left) and 3D view (middle and right) of conceptual model of LSCMP

MODFLOW Flex simulation used these constant head boundaries as boundary condition to solve differential equation of head distribution in groundwater. MODFLOW utilized the resulted head values and spatial soil information to calculate velocity and flux of groundwater in each location. Depth and other characteristics of the observation wells were imported into MODFLOW as Comma Separated Values (CSV file). By importing all above mentioned data, a conceptual model of LSCMP was created Figure 4 shows some 2D and 3D views of the conceptual groundwater model.

Finally a finite difference grid was used to convert the conceptual model to numerical model. Figure 5 shows three layers of numerical model of LSCMP. From left to right: top layer, middle layer and finally low conductivity clay layer at the bottom are shown.

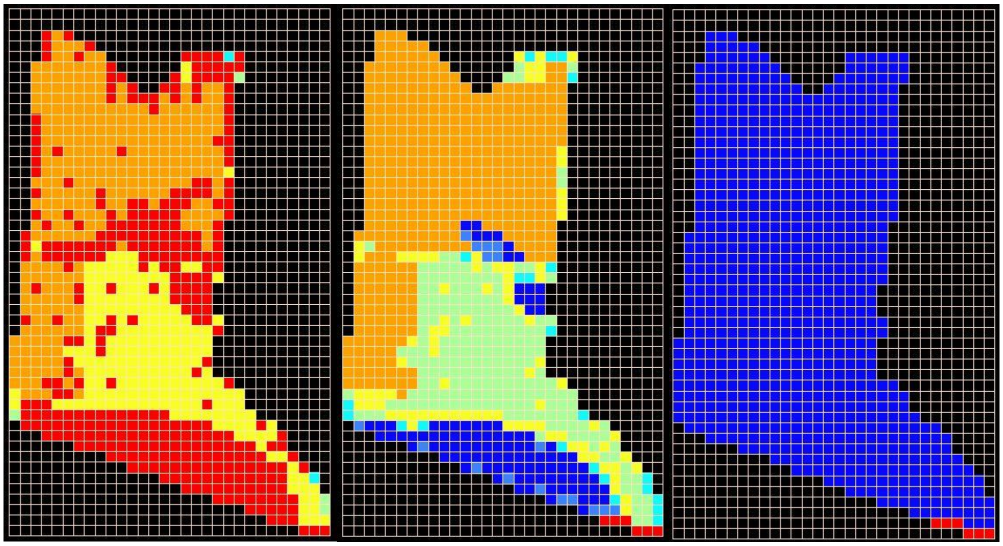

Figure 5- Three layers of LSCMP numerical model (left to right corresponds to top to bottom layers)

## 3. Result and Discussion

This paper presents the geospatial data workup of the ongoing study by HEART on groundwater activity at the Lake St. Clair Metropark. The model created provides an initial foundation for future work at this park. By creating a localized model the Lake St. Clair Metropark, we can better predict groundwater flow and potential toxins associated with the groundwater flux throughout Lake St. Clair.

This LSCMP study provides an example of how to take advantage of two separate GIS programs to create a detailed numerical model. Using ArcMap to initially create the spatial boundaries enabled MODFLOW Flex to create a detailed multilayer spatial model (Figure 5). ArcMap does have a groundwater modeling toolset under the spatial analyst toolbox but this only solves 2-D groundwater flow problems using Darcy's Law (eqn. 1)

$$Q = -k * \Delta h * A \qquad (1)$$

with Q as discharge, k as hydraulic conductivity, Δh as hydraulic head gradient – defined as change in head per unit length in the direction of flow, and *A* as area of flow. MODFLOW Flex provided a better alternative for modeling groundwater flow through its use of the 3-D groundwater flow equation as the governing equation (eqn. 2) solving for hydraulic head:

$$\frac{\partial}{\partial x} K_x \frac{\partial h}{\partial x} + \frac{\partial}{\partial y} K_y \frac{\partial h}{\partial y} + \frac{\partial}{\partial z} K_z \frac{\partial h}{\partial z} + W = S_s \frac{\partial h}{\partial t} \qquad (2)$$

with *W* as the volumetric flux per unit volume representing sources and/or sinks, $S_s$ as specific storage of the porous material, *h* as hydraulic head, and *t* as time. This provided 3-D groundwater flow in the Lake St. Clair Metropark.

Using two separate GIS programs did create some compatibility issues with one program not accepting specific formatting from the other program. For instance, the available DEM raster file could be opened by ArcMap but MODFLOW flex was not able to utilize the data directly. Most of the ArcMap files needed to be converted to suitable format for MODFLOW Flex. In addition when converting imported point cloud data (in the format of text file) to surfaces in MODFLOW Flex, it is important to select a relevant interpolation method and grid size to help create smooth and accurate surfaces that shows real soil structure.

With this new model, we hope to start and address lack of spatial understanding of the groundwater water resources associated with Lake St. Clair. There are only two water level gages between the National Oceanic and Atmospheric Administration (NOAA) and Canadian Hydrographic Service (CHS) directly on the lake and this regional monitoring approach has proven inaccurate (Neff and Killian, 2003). More small scale understanding of water flow, especially from groundwater, has the potential to decrease the margin of error in the lake wide water balance budgets.

## 4. Future Applications

The availability of high resolution GIS data (e.g. DEM, surface water shape files, and soil type information) with high performance modeling software enables engineers and scientists to create more spatially detailed models for large areas. These spatially detailed large area models can better predict the future behavior of systems. Our model, created in this study, provides a baseline for understanding groundwater flow into or out of the lake. This model can be calibrated and used for predicting future effects of groundwater movement on the water quality in Lake St. Clair.

This study represents the first groundwater study by HEART at the new LSCMP field station funded by the National Science Foundation. Future studies hope to look at other locations along the lake, specifically comparing the groundwater flow in urban areas versus agricultural areas. These groundwater models will hopefully start to create a better understanding of the groundwater/surface water flux in Lake St. Clair and how this flux plays a role in the transport of pollutants.

## 5. Acknowledgements

This study was a subset of a larger study conducted by Wayne State University’s CE 7190 Groundwater Modeling class taught by Dr. Carol Miller. Members of the class include A.M. Pruehs, F. Alighalehbabakhani, A.M. Wayne, S. Fowler, J.D. Steis, and M. Afzal. We also want to thank the Huron-Clinton Metropark Authority (HCMA) for their support with our work at the Lake St. Clair Metropark. We also want to thanks the members of HEART for their support in this study.

## 6. References

1. Environmental Systems Research Institute (ESRI) (2012). ArcMap 10.1. Redlands, California

2. Great Lake Information Network (GLIN), St. Clair River, Lake St. Clair and Detroit River Water Levels, (2013, 11) www.great-lakes.net/envt/water/levels/levels-cur/stclairwlc.html

3. Lake St. Clair Canadian Watershed Coordination Council, The Lake St. Clair Canadian Watershed Technical Report: An examination of current conditions, accessed December 4, 2013. http://www.scrca.on.ca/wp-content/uploads/2013/11/Pub-Lake-St-Clair-technical-report.pdf

4. Larson, R. L., United States. & Michigan State University. (1971). Soil survey: Macomb County, Michigan. Washington: For sale by the Supt. of Docs., U.S. Govt. Print. Off.

5. Michigan Department of technology, Management and Budget. (2013, 11) Retrieved from Geographic data library catalog: www.mcgi.state.mi.us/mgdl/

6. Michigan government proclamations, 2013. Wednesday, (July 31, 2013): Lake St. Clair Day. http://www.michigan.gov/snyder/0,4668,7-277-57577_59874-312183--,00.html. Accessed November 3, 2013.

7. Neff, B.P. and Killian, J.R., (2003), The Great Lakes Water Balance: Data Availability and Annotated Bibliography of Selected References : U.S. Geological Survey Water-Resources Investigation Report 02-4296.

8. Schlumberger Water Services (2013). Visual MODFLOW flex, Tucson, Arizona

9. SEMCOP Southeast Michigan Council of Governments. Water Quality. Accessed November 4, 2013. http://www.semcog.org/Water.aspx. 2013.

10. Thomas C. Winter, (1981), "*Uncertainties in Estimating the Water Balance of Lakes*", Water Resources Bulletin, Vol 17, NO.1, AWWA

11. U.S. Geological Survey, (2007), Scientific Investigation Report 2007-5041, pubs.usgs.gov/sir/2007/5041/section4.html

12. U.S. Geological Survey. (2013, 11). Retrieved from National Map Viewer: viewer.nationalmap.gov/viewer/

13. U.S. Census Bureau 2010, (2013, 11), www.census.gov/2010census