Stormwater Monitoring and Pollutant Assessment in Mackinaw City, Michigan

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EEB 381, General Ecology
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Abstract:

Stormwater pollution has become an increasing threat due to increases in impervious surfaces, and the destruction of wetlands. Mackinaw City is a high traffic destination, located in the northern Lower Peninsula of Michigan, yet little is known about stormwater runoff in this area. In this study, we conducted stormwater monitoring to assess the concentration of pollutants entering the Great Lakes from stormwater monitoring. We quantified average impervious surfaces in the city using GIS. To conduct stormwater monitoring, we collected water samples for water chemistry from 6 sites (Chloride, sulfate, phosphorous, nitrate, chlorophyll-a) following a rain event on July 21, 2016. In addition, we measured physical parameters of the water (temperature, pH, dissolved oxygen, conductivity, and turbidity). Macroinvertebrates were also collected to indicate the degree of pollution at each outfall. Our sample area in Mackinaw City was ~45% impervious surfaces, while Mackinaw City overall was ~17% impervious surfaces. Overall, Mackinaw City showed signs of pollution that differed depending on apparent land use around each outfall. HBIs from macroinvertebrate sampling suggested the water quality was poor in three sites, and likely nutrient polluted, although water chemistry data did not support this in the sites macroinvertebrates were sampled.

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Introduction

Recent trends toward urbanization impact local ecosystems by altering the natural hydrology of an ecosystem and increasing stormwater pollution. Natural systems contain key components that define local hydrological cycles. These systems have permeable surfaces that allow runoff to infiltrate slowly through soil**.** Wetlands perform multiple ecosystem services that are often undervalued by society (Boyer & Polasky 2004); for example, wetlands act as natural sponges that store excess rainwater, organic matter, and pollutants, provide habitat, and offer recreation activities like fishing and hunting. Urbanization has caused major losses in wetland areas through commercial and residential development, and the establishment of road infrastructure (Boyer & Polasky 2004). Urban centers typically have more impermeable surfaces, like paved roads, parking lots, sidewalks, and compact soil, which prevents rainwater from percolating into the ground, disrupting natural hydrology (Arnold & Gibbons 1996). As rainwater runs along the impervious surfaces, pollutants may be carried into aquatic systems.

Pollutants from stormwater can include fertilizer, road salts, and heavy metals, among other things (Arnold & Gibbons, 2007). Stormwater can also carry sediments into aquatic ecosystems, degrading habitat for fish and macroinvertebrates (Lee et al., 2006). In northern states, road salts release chlorines with meltwater or runoff into aquatic systems and increase salinity (Marsalek 2003). Impervious surfaces, particularly asphalt or concrete, act as thermal energy sinks, transferring thermal energy into stormwater runoff, and harm aquatic biota by directly having biological impacts on organisms or influencing water quality in ways that causes biological impacts; raising water temperatures may harm cold-water fishes, alter aquatic life cycles, or reduce the storage capacity of dissolved oxygen (Van Buren et al., 2000). Stormwater may also carry and spread harmful bacteria, like *E. coli* from sewage overflows or pet waste (McLellan 2007; Stormwater).

Several methods, known as “best management practices,” are utilized to mitigate the impacts of stormwater runoff. Permeable pavement may be used in place of impervious surfaces to allow runoff to slowly infiltrate the sediment, where the sediment slowly filters out pollutants in the runoff before it entering bodies of water. Similarly, vegetation may be used as a filter: filter/buffer strips are strips of vegetation (grasses, shrubs, etc.) positioned on gently sloping land that are used to filter runoff as it passes over the strip (Line & Hunt 2009). Raingardens (or bioretention area) are shallow depressions planted with trees and/or shrubs, and covered with mulch, that allow water to percolate and may filter pollutants (Dietz & Clausen, 2005). Detention ponds, catchment basins, or pools near stormwater fallout points slow the flow of stormwater and allow sediment, nutrients, and heavy metals to drop out (Martin 1988).

Mackinaw City, Michigan is an urban center in northern Michigan with abundant impervious surfaces. Mackinaw City is located at the tip of Michigan’s Lower Peninsula on the Strait of Mackinaw. An average water flow of nearly 1900m^3 s^{-1} is transported from Lake Michigan to Lake Huron through the Strait of Mackinaw (Saylor & Sloss 1976). Excess pollution in Mackinaw City has the potential to travel throughout the northern portion of Lake Huron. In this study, we quantified percent coverages of impermeable surfaces in Mackinaw City and evaluate the impacts of stormwater runoff in the Great Lakes. We sought to assess the concentrations of pollutants in the stormwater run-off and to determine the overall health of the ecosystem surrounding outfalls as a result of land use and best management practices. We predicted pollution in runoff from each fallout would differ based on unique best management practices and local land use.

Materials and Methods

We examined stormwater in Mackinaw City, Emmet/Cheboygan County, Michigan in July and August, 2016. Using GIS and data downloads (2011 ed.) from the National Land Cover Database, we created layers for Percent Developed Imperviousness in Mackinaw City (NLCD 2006). We quantified impervious surface cover in the Mackinaw City limits and in the sample area by counting pixels in GIS with an area of 30 meter^2. Areas of 0-25% impervious, 26-50%, 51-75% and 76-100% impervious surfaces were calculated for Mackinaw City limits and the sample area.

In Mackinaw City, we mapped storm drains by walking along the Lake Michigan and Lake Huron shorelines and recording the coordinates of any outfall points (where stormwater enters the lake), and the type of drain present. We used a map, located in the Mackinaw City Master Plan, to help locate fallout points (Most el al, 2011). Mackinaw City consists of 16 drains total: 4 on the western side of I-75, and 12 on the eastern side. These points were entered into GIS and labeled as West or East.

At each outfall point, we collected macroinvertebrates, water chemistry, physical data, and chlorophyll-a. Stormwater was sampled July 21, 2016. Macroinvertebrates were collected August 4, 2016. Using dipnets, macroinvertebrates were collected near outfalls using the CABIN protocol (Environment Canada, 2012). We sampled 1m^2 areas within close proximity of the drains, then we swept the area of the quadrats with dip nets using a zig-zag motion. We transferred the contents of the dip nets into white enamel pans, then collected macroinvertebrates for a collective 30 minute effort (1 person = 30 minutes, 2 people = 15 minutes, 3 people = 10 minutes). We preserved the macroinvertebrates in ethanol to be sorted by family, which were assigned tolerance values. We calculated the degree of organic pollution of each outfall, according the Hilsenhoff Biological Index (Hilsenhoff 1988).

Physical measurements of runoff were taken from outflows if flowing water was present, and in surrounding pools if no flow was present at the outfall points. Using a Manta 3 hydrolab, we measured temperature, dissolved oxygen, pH, conductivity, and turbidity. To collect water samples for water chemistry, we filtered water with a syringe through 0.45 µm filters into acid-washed bottles. Water was analyzed for total phosphorous, total nitrogen, and chlorophyll-a.

For statistical analysis of water chemistry, physical parameter, and macroinvertebrates, we used linear regressions to find correlations. We used an alpha <.10 to determine significance.

Results

Within Mackinaw City limits, we found 17.795% impervious surfaces. Most of Mackinaw City ranged from 0-25% imperviousness (72.795% of the total area). Within the sample area, we found 45. 125% imperviousness. Most of the sample area ranged from 0-25% (32% of sample area) and 51-75% (28% of sample area) impervious surfaces (Table 1). Most impervious surfaces appeared to be located on the East (Figure 1).

During the span of this study, only one rain event occurred that allowed us to collect runoff data. Of the 16 stormwater drains present in Mackinaw City, we were only able to collect stormwater from 6 fallouts. We sampled stormwater shortly after a rain event from 6 drains on July 21, 2016 shortly after a rain even (approximately 6-8 hours following rain): 1 site from West Mackinaw, and 5 sites from East Mackinaw. All drains were large concrete structures except for East Site 2 (small plastic pipe) and East Site 5 (corrugated steel pipe). At West Side 1, a concrete storm drain fed directly into Lake Michigan. Drains on East Side 3 and 4 were similar, although in site 4, stormwater flowed through a field of vegetation whereas East Site 3 was surrounded by sand and gravel. Stormwater in East Side 1 also allowed water to pool in a ditch, surrounded by herbaceous vegetation, before entering Lake Huron. East Side 2 was a retention pond, separated from Lake Huron by a narrow beach.

Water chemistry varied between sites. East site 5 and West Side 1 had high levels of *chloride* (81.183 mg/L; 79.328 mg/L) (Figure 2a). East Site 3 had the highest concentration of *sulfate* (146.352 mg/L) among all sites (Figure 2b). East Site 1 and 5 had the highest levels of total phosphorous (50.917 ug/L; 42.662 ug/L)(Figure 2c). West Side 1 also had the highest levels of *nitrate* (2.166 mg/L), followed by East Side 1 (1.219 mg/L). It may also be important to note that East Site 2 had very low concentrations of nitrate (0.0476mg/L) (Figure 2d). East Site 1 and 2 had the highest chlorophyll-a levels (1.493ug/L; 3.166 ug/L). East site 1 had the highest TP (117.1 ug/L) and TN (1158.04 ug/L), followed by East Site 5 (37.6 ug/L; 555.22 ug/L).

Physical parameters West Side 1 had the lowest runoff temperature (14.75 °C), turbidity (3.28 NTU), and highest conductivity (782.10 μS/cm).

Macroinvertebrate samples were only taken in West Site 1, East Site 2 and 4. The greatest abundance of macroinvertebrates were located in East Site 2, although West Side 1 had the greatest macroinvertebrate richness. The HBI calculated was highest for the East Side 4 (7.35) and lowest for the West Side 1 (6.53).

Multiple linear regressions were used to test if several physical parameters or water quality predicted issues associated with stormwater runoff. We saw longitude significantly predicted temperature (positive correlation) and concentration of nitrate (negative correlation) in stormwater runoff in Mackinaw City (β=-0.734, t=2.159, $p < 0.10$; β= -0.840, t= -3.090, $p < 0.05$) (Figure 3,4). We found temperature was a significant predictor of nitrate, and displayed a negative correlation ($\beta = -0.944$, $t = -0.572$, $p<0.05$) (Figure 5). Additionally, HBI was a significant predictor of macroinvertebrate species richness ($\beta = -0.993$, $t = -8.657$, $p < 0.10$) (Figure 6).

Discussion

Mackinaw city is a large urban center found in Northern Michigan. Nearly half of the sampling area was covered by impervious surfaces. Figure 1 displays imperviousness in Mackinaw City and our sampling area, where 32% of the sampling area is covered mainly by impermeable surfaces. Natural areas like forests and wetlands with 0% imperviousness covered a large portion of Mackinaw City outside of our sampling area.

Water chemistry revealed concentrations of pollutants that were variable from site to site. Chloride levels were higher than standard accepted chloride concentrations in East Site 5 and West Site 1 (Napgal et al., 2003). Chloride primarily comes from the application of road salts. We suspect high chloride levels in West Site 1 may result from inputs of groundwater in the fallout. Ground water is typically colder, and runoff temperature at the site was much colder than the other fallouts. East Site 5 drained from a retention pond into Lake Huron. The retention pond may act as a chloride sink and store higher concentrations of chloride throughout the year. Sulfate can be used by bacteria to methylate mercury, which can bioaccumulate in fish and pose a threat to human health (Gilmour et al., 1992). Levels of sulfate were higher than the standard accepted sulfate concentrations in East Site 3 (Filpansick 2014). Sulfate may accumulate on impervious surfaces from atmospheric deposition or from car exhaust. East Site 3 was located in a high traffic area on Shepler's ferry service property. High traffic, in addition to frequent deposition from starting gasoline-fueled vehicles and atmospheric deposition of sulfate may result in a high concentrations of sulfate that are transported by stormwater. Phosphorous and nitrates are both used as fertilizers. Total phosphorous were higher than the standard accepted phosphorous concentrations in East Site 1 and 5 (Oram 2014). Nitrate was higher than the standard accepted concentration in East Site 1 and West Site 1 (Oram 2014). East Site 1 was located near Colonial Michilimackinac Park, a popular tourist attraction. We suspect large amounts of fertilizer were applied to this area, contributing to higher concentrations of nutrients. Additionally, there were large amounts of bird droppings that added to nutrient inputs at East Site 1. Conversely, East Site 2 had unusually low concentrations of nitrate. The drain in this site had the smallest diameter, which may suggest less water drains into this site. However, we may also contribute this finding, in part, to the effectiveness of the applied best management plan. Retention ponds, like the one located at East Site 2, retain runoff, allowing sedimentation to occur, and allow plants or algae to take up nutrients before the runoff enters other bodies of water. Most other drains had pooling areas before entering Lake Michigan or Lake Huron, allowing some pollutants, nutrients, and sediment to fallout.

We found longitude to be a significant predictor of stormwater runoff temperature in Mackinaw City, where temperature increased from West to East (Figure 3). This finding matches the observation that there is more imperviousness in the eastern half of Mackinaw (we did not calculate imperviousness in the east and west for a comparison because we only had one site in the west side, versus five on the east side). Impervious surfaces can increase the temperature of runoff by acting as thermal sinks, heating runoff as it flows over the surfaces. Longitude also was a significant predictor of nitrate concentrations, where concentrations decreased from West to East (Figure 4). Thus, these relationships explain why we observed a significant, negative correlation between temperature and nitrate concentrations (Figure 5). As temperature increased in runoff, we saw lower concentrations of nitrate (Figure 6). We suspect higher temperature of runoff promotes higher uptake of nitrates by plants as it flows toward drains, resulting in lower concentrations.

HBIs of macroinvertebrate sampling revealed all sites (East Side 2 & 4, West Side 1) had poor water quality, suggesting these sites are likely affected by the presence of substantial, or severe pollution (Hilsenhoff 1988). As HBI increases, we expect increased pollution, which would allow only a few, very tolerant species to exist. The findings from the HBI do not necessarily reflect the level of pollutants we found. It should be noted that the HBI may be influenced by both seasonality and precision of identification. The water quality of a stream my change depending on season; warmer months typically result in lower dissolved oxygen, meaning our results may be negatively influenced because this study took place in the mid-late summer. Additionally, the accuracy of HBI may be lost due to identifying macroinvertebrates to only family, and not species.

While we were able to assess pollutants entering the Great Lakes from Mackinaw City stormwater, evaluated the different concentration of pollutants at each site, and used macroinvertebrates as indicators of pollution, this study had several limitations. Due to limited sampling in the summer, we were only able to obtain water samples from one rain event. Additionally, we were unable to test for heavy metals, which may cause a risk for public health, In addition, the flow pathway for stormwater in Mackinaw City was not provided to us during this study, nor did we have the resources to map flow directions. Some drains in this study could drain a much larger area and contain more pollutants that are not representative of the area/land use. Additionallly, we do not know of any best management practices that occur elsewhere in the drainage system. For future studies, we recommend sampling more rain events to generate a better profile of stormwater pollutants, sampling from more fallouts, and working to create drainage maps for each outfall, with best management practices noted along the drainage pathway.

In conclusion, with growing urbanization, stormwater is a continuously growing threat to our aquatic ecosystems and can be strongly influenced by the contributions of pollutants depending on surrounding land use. A large portion of our sampling site in Mackinaw City is covered mainly by impervious surfaces, although the average imperviousness in the city limits is relatively low. Macroinvertebrates collected at each fallout indicated polluted waters, although there were several caveats.

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Appendix

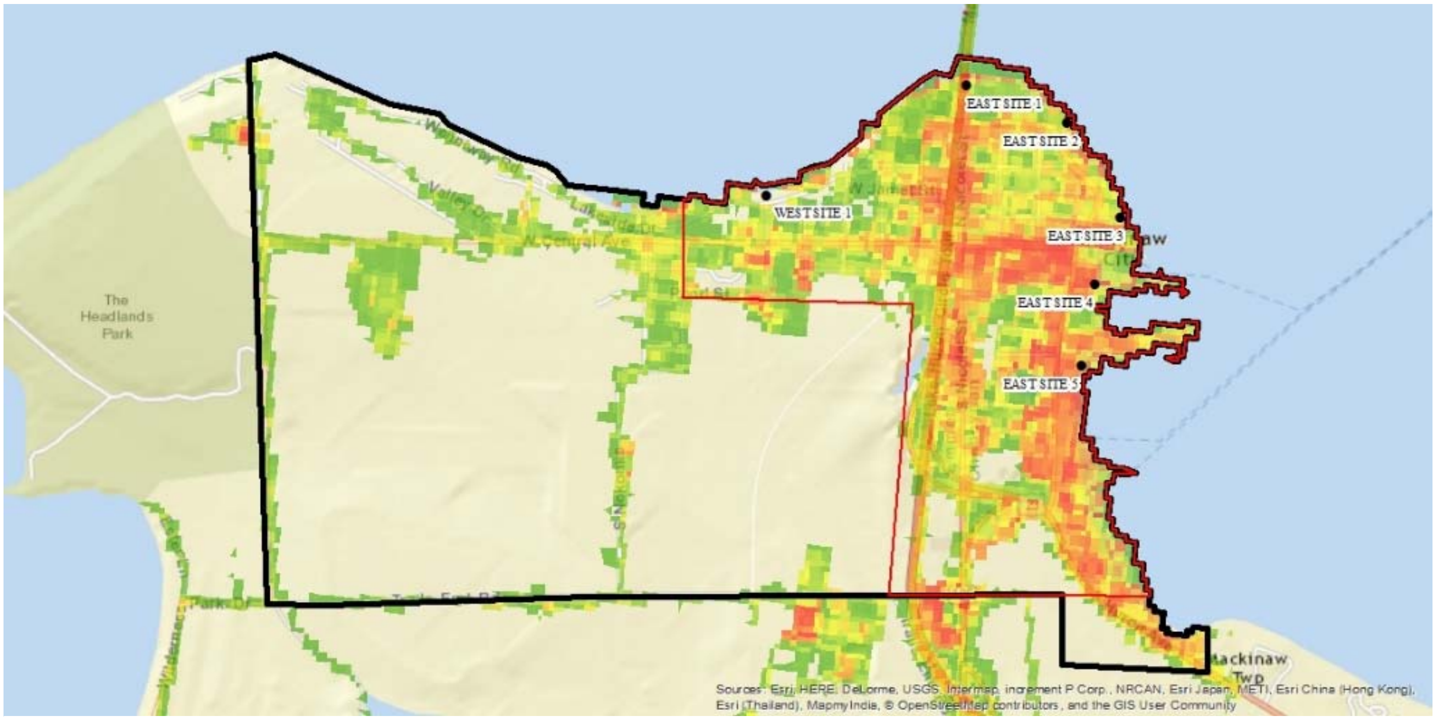

Figure 1: Map of sampling sites and imperviousness in Mackinaw City. The red line delineates sampling area, based on the storm drains found will surveying. The black line indicates the city limit. Green pixels indicate 0-25% imperviousness, moving up to red pixels indicating 76-100% imperviousness.

Table 1: Imperviousness of Mackinaw City limits and within our sample area.

City Limit: Average 17.795% Imperviousness			Sampled Area: Average 45.125% Imperviousness		
Range (% Imperviousness)	**Range Area**	**% Total Area**	**Range**	**Range Area**	**%Total Area**
0-25	347850	72%	0-25	50010	32%
26-50	47940	10%	26-50	31020	20%
51-75	49830	10%	51-75	44520	28%
76-100	36090	7%	76-100	32370	20%

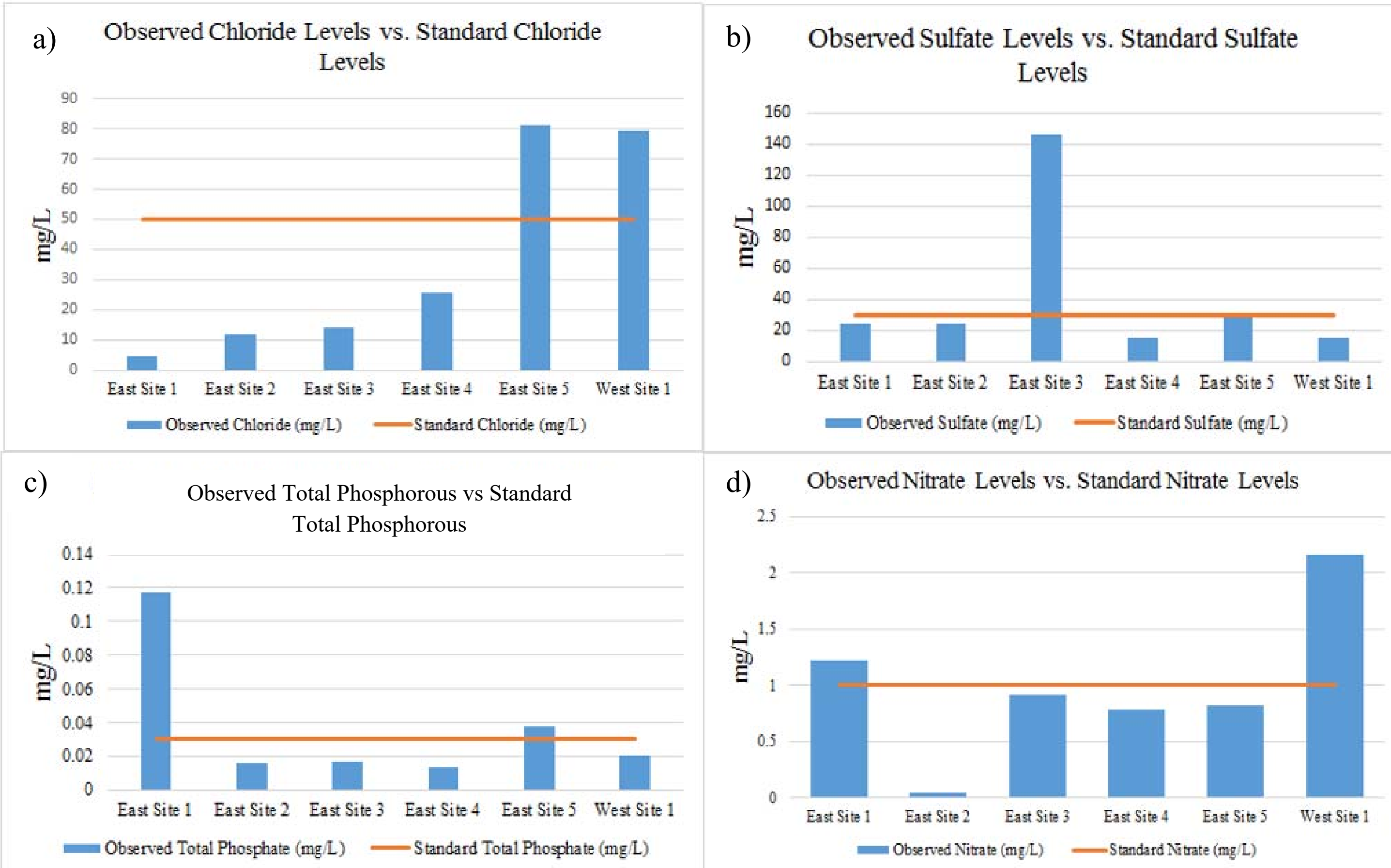

Figure 2: Bar charts of observed chloride (a), observed sulfate (b), observed phosphorous (c), and (d) observed nitrate levels in relation to standard levels: chloride, 50 mg/L (Napgal 2003); sulfate, 150 mg/L (Filpansick 2014); phosphorous, 0.30 mg/L (Oram 2014); nitrate, 1 mg/L (Oram 2014).

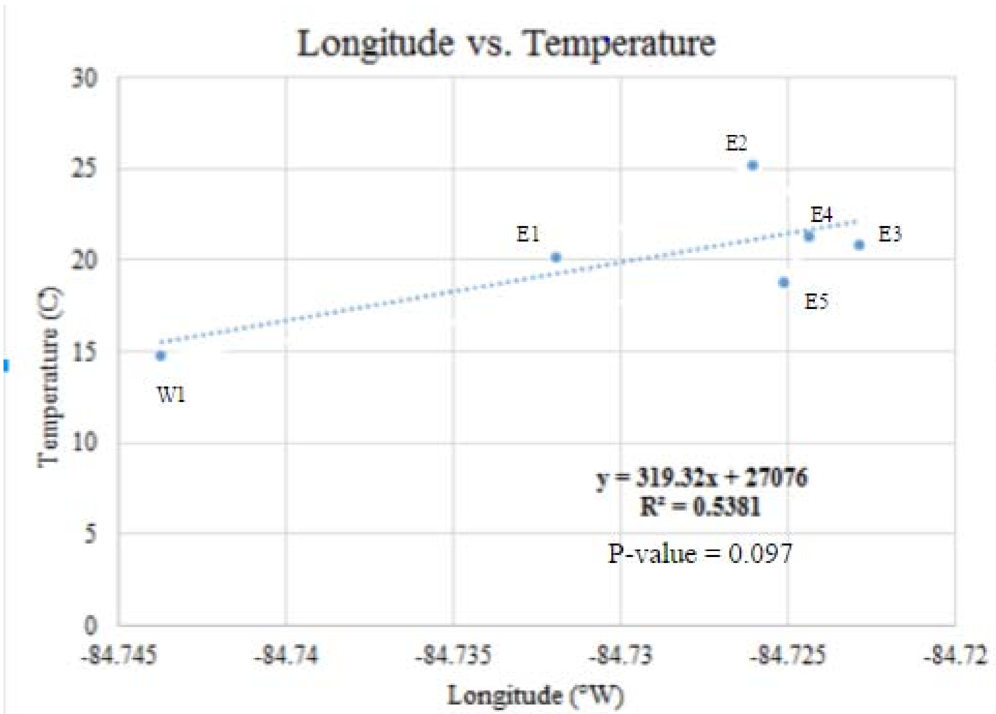

Figure 3: Scatterplot of temperature versus increasing longitude (moving from west to the east). Dots indicate position and temperature taken at each outfall.

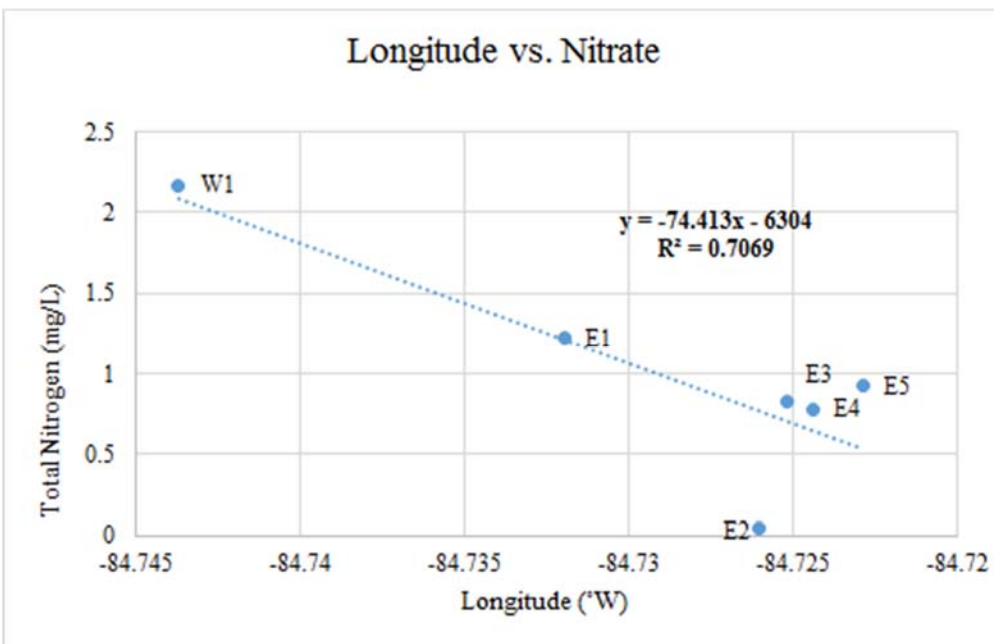

Figure 4: Scatterplot of temperature versus increasing longitude (moving from west to the east).

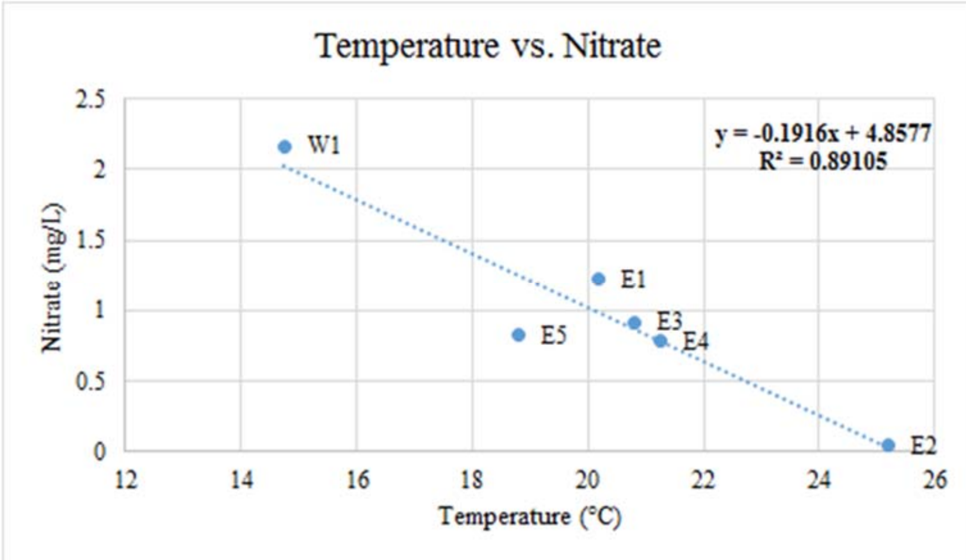

Figure 5: Scatterplot of temperature versus nitrate concentration (moving from west to the east).

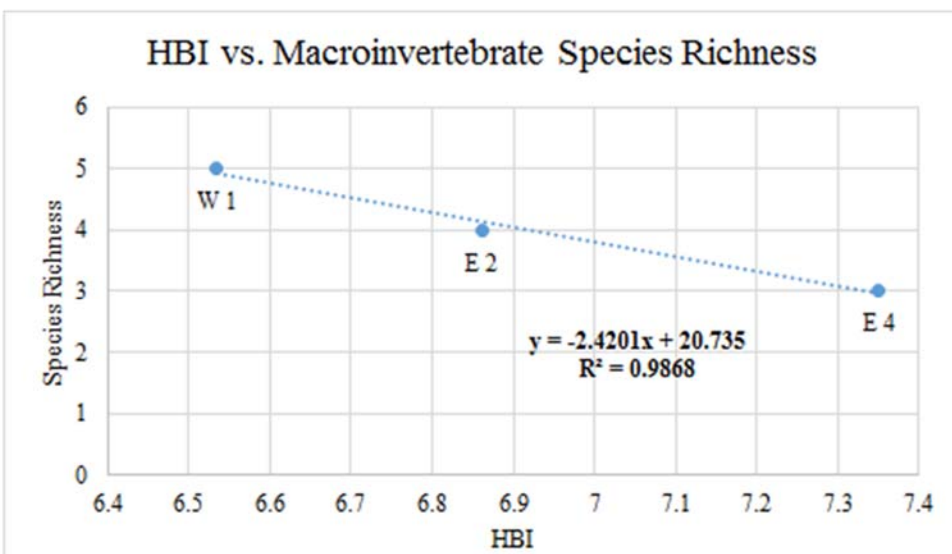

Figure 6: Scatterplot HBI versus macroinvertebrate species abundance taken at 3 sites in Mackinaw City.