# Assessment of Stormwater Runoff and the Health of their Surrounding Outfall Ecosystems in Mackinaw City

Clare Kucera

University of Michigan Biological Station

EEB 381 General Ecology

August 15, 2016

Shannon Pelini

## Abstract

During precipitation events, stormwater runoff flows over impermeable surfaces. This runoff picks up pollutants which flow into bodies of water and degrade ecosystems. We preformed this study to create a stormwater assessment of Mackinaw City that determines the concentrations of pollutants within stormwater runoff and the health of the surrounding ecosystems of its outfall. We wanted to know what best management practices and land uses were present within the city and to make suggestions to create healthier outfall ecosystems in the future. We created a map using ArcGIS to identify the outfall sites and discovered that the area we sampled in the city had approximately 45% cover of impermeable surfaces. We performed chemical analyses and tested the overall composition of the water at the outfalls. We found elevated levels of chloride, nitrate, total phosphorus, and sulfate at our sites. We found correlations between temperature and nitrate, longitude and nitrate, dissolved oxygen and nitrate, longitude and temperature, and HBI and macroinvertebrate species richness. We sampled macroinvertebrates and used the Hilsenhoff Biotic Index to assign a pollution tolerance level to each invertebrate family to understand the level of pollution in an area. We found that most macroinvertebrate species we sampled were highly tolerant to pollution. Overall, these results suggest that there is evidence for degraded ecosystems at each of our sample sites due to anthropogenic factors. Understanding the effects of pollution from stormwater is important to determine what may be the sources and what types of best management practices would help the health of the aquatic ecosystems for the future.

I grant the Regents of the University of Michigan the non-exclusive right to retain, reproduce, and distribute my paper, titled in electronic formats and at no cost throughout the world.

The University of Michigan may make and keep more than one copy of the Paper for purposes of security, backup, preservation and access, and may migrate the Paper to any medium or format for the purpose of preservation and access in the future.

Signed,

Clare Kucera

Clare Kucera

# ASSESSMENT OF STORMWATER RUNOFF AND THE HEALTH OF THEIR SURROUNDING OUTFALL ECOSYSTEMS IN MACKINAW CITY

## Abstract

During precipitation events, stormwater runoff flows over impermeable surfaces such as roads, sidewalks, and parking lots. This run-off picks up pollutants such as dirt, fertilizers, and other toxins which flow into bodies of water and degrade ecosystems. We preformed this study to create a stormwater assessment of Mackinaw City that determines the concentrations of pollutants within stormwater run-off and the health of the surrounding ecosystems of its outfall. We wanted to know what best management practices and land uses were present within the city and to make suggestions to create healthier outfall ecosystems in the future. We created a map using ArcGIS to identify the outfall sites and define the different areas of the city that are highly impermeable. We discovered that the area we sampled in the city had approximately 45% cover of impermeable surfaces. We collected water samples and performed chemical analyses on organic pollutants as well as tested the overall composition of the water at the outfalls. We found elevated levels of chloride, nitrate, total phosphorus, and sulfate at some of our outfall sites. We also found correlations between temperature and nitrate, longitude and nitrate, dissolved oxygen and nitrate, longitude and temperature, and HBI and macroinvertebrate species richness. We sampled macroinvertebrates at each site and used the Hilsenhoff Biotic Index to assign a pollution tolerance level to each invertebrate family to understand the level of pollution in an area. We found that most macroinvertebrate species at the outfalls we sampled were highly tolerant to pollution. Overall, these results suggest that there is evidence for degraded ecosystems at each of our sample sites due to anthropogenic factors. Understanding the effects of pollution from stormwater is important to determine what may be the sources and what types of best management practices would help the health of the aquatic ecosystems for the future.

## Introduction

Stormwater runoff regularly flows over impermeable surfaces such as roads, sidewalks, and parking lots. Impermeable surfaces increase the amount and force of stormwater because the water cannot be infiltrated or absorbed into the ground. This run-off picks up pollutants such as dirt, fertilizers, and other toxins. Stormwater runoff tends to flow either on land or in human-made storm drains that ultimately empty out into the nearest bodies of water. The runoff transfers these pollutants from urban areas into lakes, streams, and wetlands. There are best management practices (BMPs) to reduce stormwater runoff and the uptake of pollutants which include rain gardens, stormwater wetlands or ponds, pervious pavements, filter strips, and other surface runoff treatment methods (Simonsen, 2004).

One major source of pollution that is typical for urban as well as agricultural areas comes from nutrients. These nutrients are in the form of phosphates and nitrates used in fertilizers, septic systems, and sewage treatment plants (Falconer, 2005). Elevated concentrations of phosphates and nitrates in a body of water can cause toxic algal blooms that negatively affect human health and ecosystems (Dolah, 2000). The blooms are able to produce dangerous toxins that can sicken aquatic fauna and humans. Human consumption and exposure to the toxins produced by cyanobacterial algae can cause organ failure, poisoning syndromes, other physiological disorders, and skin irritation (Zang & Dickman, 1999).

Toxic algal blooms not only negatively affect humans, but can severely degrade freshwater ecosystems as well. Increased levels of algal biomass can be measured by chlorophyll concentrations. Water with high levels of nutrients may have high concentrations of chlorophyll due to the excess amounts of algae from eutrophication. Eutrophication is the process by which humans cause massive algal blooms from nutrient run-off that blocks sunlight and kills underwater plants. Bacteria then break down the plants and use the remaining oxygen to create hypoxic to anoxic dead zones where little to no organisms can survive (Falconer, 2005).

Macroinvertebrates are also an indicator of the level of pollution in an ecosystem (Merritt & Cummins, 2006). The Hilsenhoff Biotic Index (HBI) estimates the overall tolerance of the community in a sampled area. The relative abundance of invertebrate taxonomic groups are weighted and assigned a tolerance number that indicates their known sensitivity to organic pollutants. The number of specimens and tolerance values are calculated to produce an HBI that describes the degree of organic pollution in an area (Hilsenhoff, 1988).

Our purpose of this study is to create a stormwater assessment of Mackinaw City. We wanted to determine the concentrations of pollutants within stormwater run-off and the health of the surrounding ecosystems of its outfall as a result of land use and best management practices. We wanted to perform an assessment of Mackinaw City because it is urbanized and experiences substantial tourism and population increases during the summer months. We hypothesized there would be evidence of degraded ecosystems from the chemical and composition analyses of the stormwater and macroinvertebrate sampling at the outfall sites due to anthropogenic forces within Mackinaw. We would like to develop a model that illustrates impermeable surfaces and storm drainage areas into Lake Huron and Lake Michigan from Mackinaw City to reinforce our presumed connection of imperviousness and ecosystem health. We want to use our model and results to suggest best management practices for the city to improve the health of its aquatic ecosystems.

## Methods

We walked along the shoreline of Mackinaw City to preform general reconnaissance to locate and identify different types of stormwater outfall drains. After our initial observations, we obtained a map of the outfalls from the supervisor of the Mackinaw City Water Department, Pat Rivera. We validated that the six sites we sampled and took coordinates from were legitimate outfalls; any point where stormwater discharges into an area. We used ArcGIS and the National Land Cover Database of 2011 to map stormwater outfalls and estimate percent cover of impermeable surfaces for Mackinaw City.

We measured the depth, temperature, pH, turbidity, conductivity and dissolved oxygen at each outfall site in Mackinaw City by placing the hydro lab into the flowing storm water. We used a manta 2 sub3 model of the hydro lab to collect our data following a rain event so that the stormwater would be either physically flowing out of its outfall or pooling in the area. The information we obtained from the hydro lab tells us the depth, temperature, pH, turbidity, conductivity and dissolved oxygen of the water so we can understand how that specific freshwater ecosystem functions. Depth give us an overview of how the outfall is shaped. Temperature, pH, turbidity, conductivity, and dissolved oxygen levels that are too high or low can suggest that the health of the ecosystem is impaired or abnormal and can limit the amount of life that live in the area.

Next, we took 120cc samples of the flowing or pooled stormwater in acid washed bottles at each outfall site in Mackinaw City after a rain event. We filtered the water samples through a millipore filter. The water samples were tested in the chemistry lab for organics that included chloride, nitrate, total nitrogen, phosphate, total phosphorous, sulfate, and chlorophyll-a. These concentrations revealed if nutrient levels are higher than normal due to anthropogenic forces. The chlorophyll also gives us an idea of how much primary productivity there is in each of the freshwater ecosystems (Bergey, 2006).

We sampled for macroinvertebrates at three sites because they were the only outfalls with an existing water column. We used a dip net to scoop samples from the water and sediments into the netting. We collected samples until a substantial amount of material was observed after 1-3 minutes. We placed the samples into a large sorting pan. We searched each tray for invertebrates for a total designated time of 30 minutes (Brauns, Garcia, Walz & Pusch, 2007). We put any invertebrates we found into approximately 75% ethanol and returned to the lab to count and identify their taxonomic families. After their identification, we calculated their Hilsenhoff Biotic Index number to get a quantitative degree of organic pollution for each site (Hilsenhoff, 1988).

Finally, we performed a regression analysis to see if there were any correlations between our chemical analyses, water composition, and macroinvertebrate sampling data that we took at Mackinaw City. These correlations can reveal how the pollutants affect each other and where their sources may be.

## Results

We sampled six outfall sites in Mackinaw City. One outfall was located west of the Mackinaw Bridge and the other five sites were located east of the bridge (Fig1). We observed that each outfall implemented some sort of best management practice which is a technique used to treat, prevent or reduce water pollution from runoff (Simonsen, 2004). Each site except for East Site 5, had either a small or large amount of pooling that was not directly connected to the lake. East Site 1 and East Site 4 had plants growing in the ponded areas as well. East Site 2 and West Site 1 just had stormwater ponds with sediment and no flora in the area. East Site 5 deposited stormwater directly into the lake after being filtered through a stormwater pond that was located further inland (Table 1).

We also calculated the percent imperviousness of Mackinaw City using ArcGIS software. Within the city limits of Mackinaw, approximately 18% cover is impermeable surfaces. Within our urban sampling area of the city, approximately 45% cover is impermeable surfaces (Fig 2). A low 0 – 25% impervious cover accounted for 32% of the city. A 26 – 50% impervious cover was 20% of the city. A 51 – 75% impervious cover was 28% of the city. A high 76 – 100% impervious cover was 20% of the city.

Our chemical analyses revealed that some of the outfall water was polluted. The standard concentration level of chloride that is definitive for a healthy ecosystem is 50mg/L and lower (Napgal, Levy, & MacDonald, 2003). East Site 5 had 81.183mg/L of chloride and West Site 1 had 79.328mg/L of chloride (Fig 3). Even though chlorophyll-a concentrations were within the normal limits of 7ug/L, there were still elevated concentrations of nutrients. We observed two sites that had greater than normal nitrate levels of 1mg/L. East Site 1 had 1.219mg/L and West Site 1 had 2.166mg/L (Fig 4). East Site 1 and East Site 5 had higher than the standard amount of total phosphorus which is .30mg/L for a healthy ecosystem (Oram, 2014). East Site 1 had .117mg/L and East Site 5 had .0376mg/L (Fig 5). East Site 5 had sulfate concentrations of 146.35mg/L which is significantly greater than the maximum concentration of 30mg/L before ecosystem health is degraded (Filpansick, 2014) (Fig 6).

We also observed some correlations between pollutants, overall stormwater composition, and the presence of invertebrate species which we analyzed by preforming regressions. Temperature (˚C) and nitrate (mg/L) had a significant negative correlation at a 95% confidence level (R^2 = .891, B = -.944, t = -.5720, p = .005) (Fig 7). Longitude (˚W) and nitrate (mg/L) had a significant negative correlation at a 95% confidence level (R^2= 0.705, B= -0.840, t = -3.090, p = 0.037) (Fig 8). Dissolved oxygen (mg/l) and nitrate (mg/L) had a significant positive correlation at the 95% confidence level (R^2= .730, B=.855, t = 3.292, p = .03) (Fig 9). Longitude (˚W) and temperature (˚C) had a significant positive correlation at 90% confidence level (R^2= 0.538, B=0.734, t =2.159, p = 0.097) (Fig 10). HBI Index and macroinvertebrate species richness had a significant negative correlation at the 90% confidence level (R^2 = 0.987, B = -0.993, t = -8.657, p = 0.073) (Fig 11).

We sampled macroinvertebrates at West Site 1, East Site 2, and East Site 4. At West Site 1 there were six families identified with tolerance values ranging from 5 – 8, 58 total specimens, and an HBI of 6.534. This HBI indicates that the water quality is poor with very substantial pollution likely. At East Site 2 there were four families identified with 122 specimens recorded. The tolerance values ranged from 2 – 7 with a HBI of 6.81 which indicates poor water quality with very substantial pollution likely. At East Site 4 there were three families identified with tolerance value ranges between 7 -8 and 20 specimens recorded. The HBI was 7.35 which indicates the water pollution is very poor with severe organic pollution likely.

## Discussion

Our results supported our hypothesis that we observed degrees of health impairment at each site. East Site 5 and West Site 1 had higher than natural levels of the pollutant, chloride. This pollutant primarily comes from road salts, which suggests that during the winter months the chloride concentrations in the water may be significantly higher and can stay within the aquatic ecosystems for long periods of time. Chloride has a direct relation to imperviousness because salts are applied directly to the roads. Any precipitation can easily move these pollutants to the nearest body of water or wetland (Napgal, Levy, & MacDonald, 2003). According to figure 2, East Site 5 has high rates of impermeability near its outfall as well. Pervious payments would be the best management practice to reduce this pollutant from the aquatic systems at the outfalls since chloride is usually applied directly to roads.

East Site 1 and West Site 1 also had slightly greater than normal nitrate levels. This reveals that there is an anthropogenic force adding nitrate into the ecosystem that is not just from decomposing plants and animal wastes (Oram, 2014). West Site 1 does not have very high impervious rates, but is in a residential area which may be adding nitrates from lawn fertilizers to the ecosystem. East Site 1 had the greatest excess of total phosphorus and East Site 5 had slightly elevated levels of total phosphorus concentrations as well. Both were located within high ranges of impermeability. East Site 1 is located adjacent to a tourist center which is most likely adding lawn fertilizers to beautify their property and cause phosphorus to runoff into the outfall. Phosphorus tends to be the limiting nutrient in most aquatic systems. Small concentrations cause significant plant growth and have a large effect on the surrounding ecosystem. It can accelerate the process of eutrophication, leaving the area subjected to toxic algal growth. While chlorophyll concentrations have not yet reached unhealthy concentrations, it is likely that the eutrophication process has started at some of these sites due to the elevated nutrient levels we observed. While these sites employ pond management practices, it would improve ecosystem health to add more vegetation to the area as well as along its flow path to allow more nutrients in the stormwater to be infiltrated and filtered before it even reaches the outfall.

East Site 3 was an anomaly with massive amounts of sulfate concentrations. It was located near a construction site and the ferry parking lot which results it a highly impermeable area. This high volume of vehicle traffic is likely to cause the massive amount of sulfate pollution in the area compared to other sites. Large quantities of sulfate are released from vehicle exhaust and the combustion of fossil fuels which are emitted from the massive construction machinery (Filpansick, 2014). Since the construction is occurring at the outfall site, it is difficult to control the runoff pollution from best management practices. The most efficient way to limit this pollution is from the point source itself; to end the massive combustion of fossil fuels from construction machinery and automobiles.

The correlations we found between water quality parameters proved to be interesting as well. Temperature and nitrate had a significant negative correlation. Runoff from parking lots and other impervious surfaces is a form of thermal pollution. Water that flows off these high albedo surfaces absorb much of their heat and transfer it to a nearby body of water which elevates the temperature of the area. High temperatures in aquatic ecosystems causes advection and vertical mixing which increases the rate of nutrient uptake by phytoplankton at the surface. This lowers nitrate concentrations significantly (Oram, 2014). Longitude and temperature had a significant positive correlation. As the sites moved father east the temperatures increased, which suggests that imperviousness is greater to increase heat at these outfalls. Longitude and nitrate had a significant negative correlation as well. As the sites moved farther east there were smaller concentrations of nitrates. This suggests that the anthropogenic forces that introduce nitrates into the ecosystems are greater further west. Also, previous regressions suggest that the further east the sites are, temperature may be increasing which lowers nitrate concentrations. In order to lower this heat pollution, it would be best to employ filter strips. Filter strips are gently sloping, vegetated areas adjacent to roads. They would lessen the impact of the intense areas of imperviousness surrounding all of the east outfalls. Filter strips reduce impacts of the flow and velocity of stormwater which helps improve water quality and cools it down before it reaches the outfall (Simonsen, 2004).

Dissolved oxygen and nitrate also had a significant positive correlation. Nitrates are an oxidized form of nitrogen that plants use to establish the growth of aquatic plants. Therefore, nitrates increase with dissolved oxygen which supports that a normal range of nitrates is healthy for aquatic plant production in an ecosystem. Too much nitrates may cause an overabundance of plant growth while too little from increasing temperature may limit healthy aquatic plants.

HBI and macroinvertebrate species richness had a significant negative correlation. A higher HBI calculation infers a more polluted ecosystem. Therefore, the number of different macroinvertebrate species in an ecosystem decreases as HBI increases. The presence of certain macroinvertebrates provided interesting evidence of the health quality of West Site 1, East Site 2, and East Site 4. Each sample site indicated impaired ecosystems with very substantial to severe organic pollution which is much more extreme than our chemical analyses and water composition tests suggested. Therefore, it is possible that the best management practices of outfall ponds have been implemented more recently but the invertebrates have not had the time to recover. It can also suggest that pollution varies seasonably and the HBI could decrease as tourism comes to an end when there are less physical human disturbances.

There were various limitations to our study. First, there was a lack of precipitation events during our data collection phase of the project. Precipitation is essential to cause run-off which we needed to preform our chemical and compositional analyses of the stormwater. We were able to obtain water samples several hours after one rain event but it was not ideal to only sample the outfalls once. If we waited too long after a rain event, the sites that had stormwater retention would dry up very quickly. There were also many documented outfalls that were difficult to find and located below the lake water column which made it impossible for us to collect data. As a result of a very dry and hot summer, we were only able to sample stormwater at six sites once each and collect macroinvertebrates at three sites which lowered our sample size much more than we intended. It took about a week for our water samples to be analyzed in the chemistry lab as well, which limited our time even further to collect data. We were also unable to determine the flow paths of the stormwater into specific outfalls. This limited us to only speculate how much runoff there was and where the runoff and pollution were coming from. Finally, the impervious estimation of ArcGIS was misaligned which made our estimations of percent impervious cover slightly less accurate.

Overall, we found elevated levels of chloride, nitrate, total phosphorus, and sulfate at some of our outfall sites. We also found correlations between temperature and nitrate, longitude and nitrate, dissolved oxygen and nitrate, longitude and temperature, and HBI and macroinvertebrate species richness that indicated the ecosystems are impaired. For the future, it may be advantageous to the health of Lake Michigan and Lake Huron to implement a greater number of best management practices with the ones we had already observed at our six sites. The current stormwater ponds at the sites helped slow the flow of runoff by creating pooling, but were still not successful at filtering out pollutants and keeping the outfall area from eventually flowing into the lake. Therefore, pairing other best management practices with the stormwater ponds would be an ideal way to manage the aquatic systems in the future. Rain gardens, pervious pavements, and filter strips would be functional at all of these sites and within the city, although some may be more costly than others. Even if implementing specific best management practices are not possible, it is important to add any green or pervious layer that is possible in order help infiltrate the runoff in the massively urban, Mackinaw City. More importantly, decreasing pollution altogether is essential to improving aquatic ecosystems. Excess fertilizers and chemicals put into the ground are not always necessary. Ultimately, it would be beneficial to educate the public on the negative effects of stormwater runoff in order to stop the pollution problem at its source and to ensure the health of the aquatic systems at Mackinaw City and other urban areas.

Figures and Tables

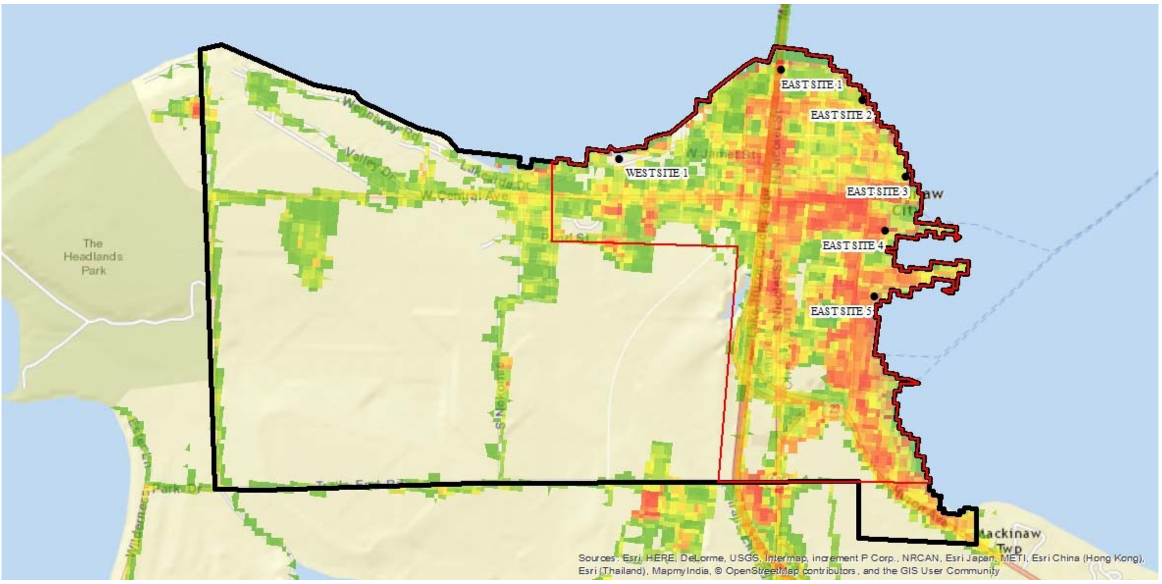
*Table 1 – The locations and descriptions of each outfall we sampled from in Mackinaw City*

| Sites | Latitude ˚N | Longitude ˚W | Pipe Description | Outfall Area Description |
|---|---|---|---|---|
| East Site 1 | 45.78808 | -84.7319 | Large concrete | Water pooling into a grassy area that did not flow directly into the lake |
| East Site 2 | 45.78655 | -84.726 | Small plastic | Sandy with a little gravel and a large pooled area with lots of algae growth that was not connected to the lake |
| East Site 3 | 45.78267 | -84.7229 | Large concrete | Rocky area with minimal pooling that extended over the beach into the lake |
| East Site 4 | 45.77992 | -84.7244 | Large concrete | Water pooling in a fern-filled area close to the marina water that is connected to the lake |
| East Site 5 | 45.77661 | -84.7252 | Large corrugated metal | On a hotel beach that drains from a pond within the city directly into the lake |
| West Site 1 | 45.78358 | -84.7437 | Large concrete | Water pooling into a sandy area with large rocks that drains across the beach directly into the lake |

*Figure 1 – Map of the locations of each outfall we sampled from in Mackinaw City*

Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

*Figure 2 – The range of imperviousness of Mackinaw City (green low, red high)*



Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

*Figure 3 – The concentrations of chloride within the stormwater at each site compared to the maximum concentrations of chloride in healthy ecosystems*

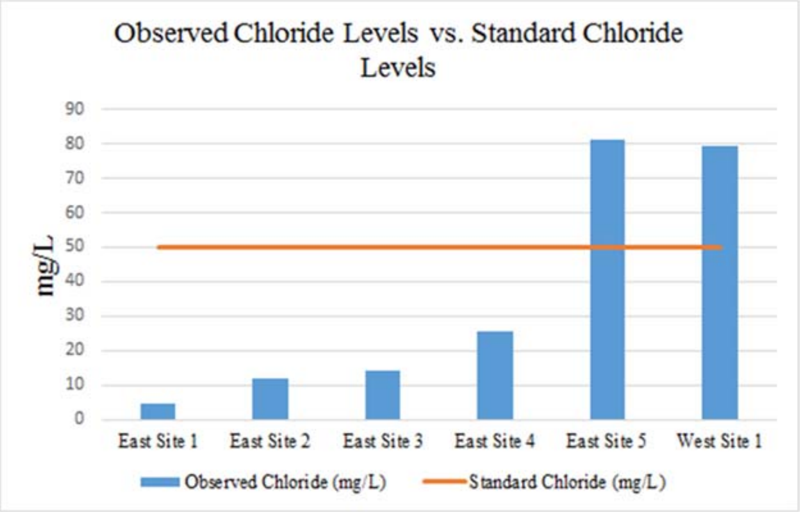


*Figure 4 – The concentrations of nitrate within the stormwater at each site compared to the maximum concentrations of nitrate in healthy ecosystems*

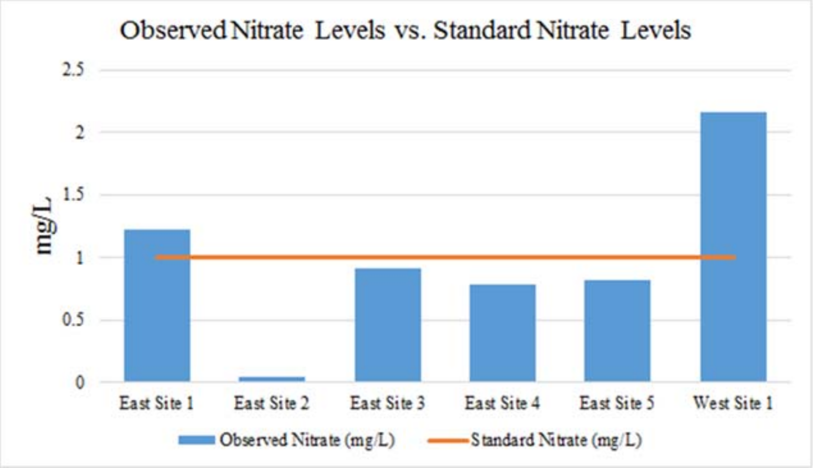


*Figure 5 – The concentrations of total phosphate within the stormwater at each site compared to the maximum concentrations of total phosphate in healthy ecosystems*

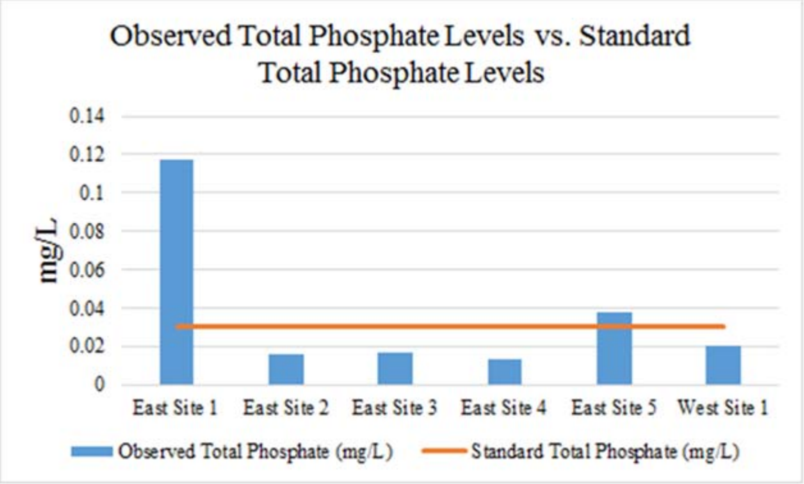


*Figure 6 – The concentrations of nitrate within the stormwater at each site compared to the maximum concentrations of nitrate in healthy ecosystems*

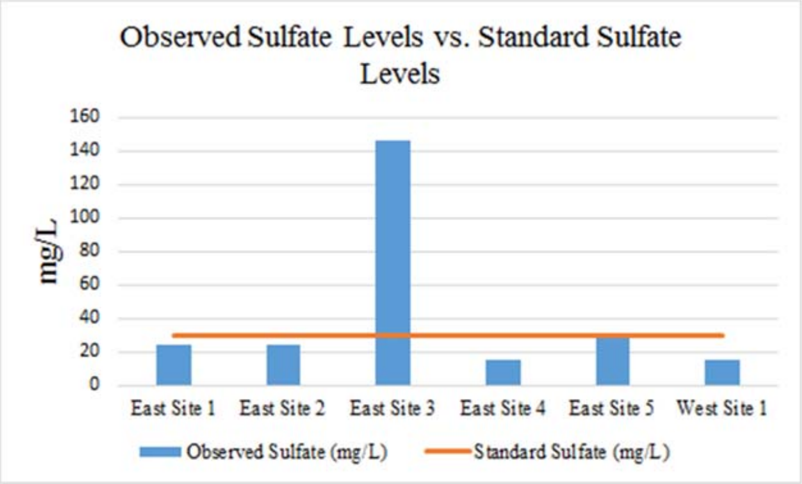


*Figure 7 – The regression of temperature against nitrate concentrations within the stormwater at each site*

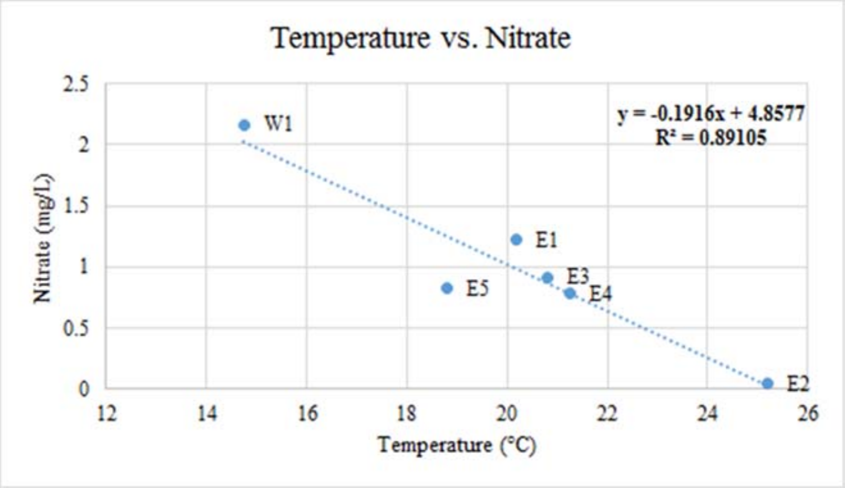


*Figure 8 – The regression of longitude against nitrate concentrations within the stormwater at each site*

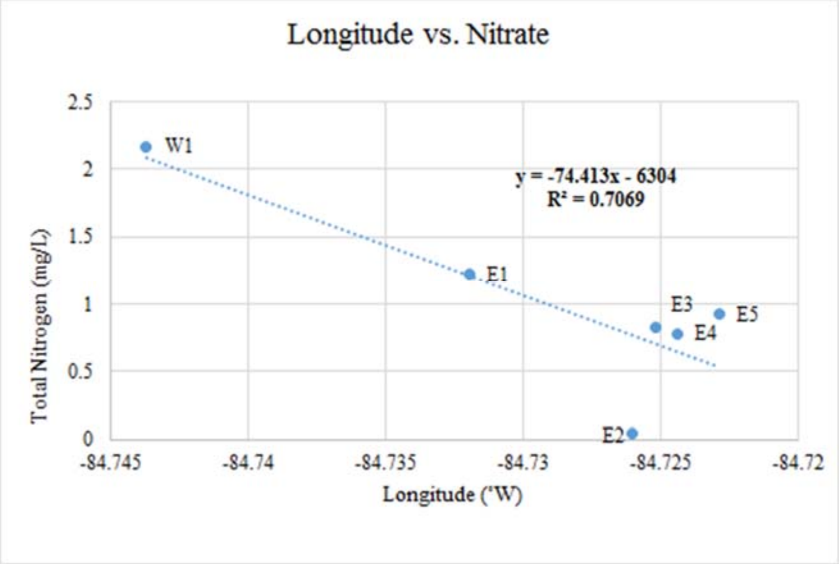


*Figure 9 – The regression of dissolved oxygen concentrations against nitrate concentrations within the stormwater at each site*

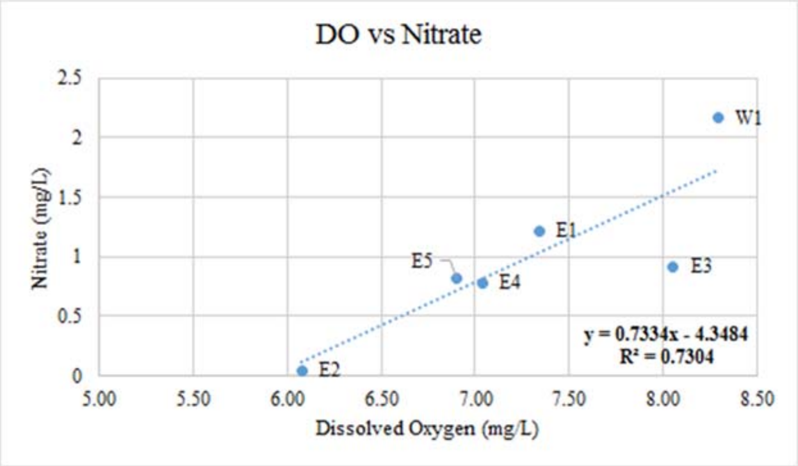


*Figure 10 – The regression of longitude against temperature within the stormwater at each site*

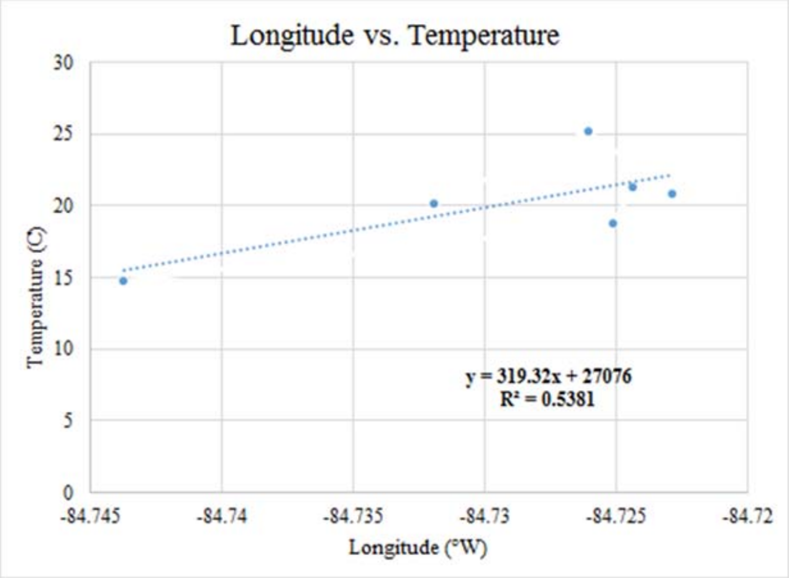
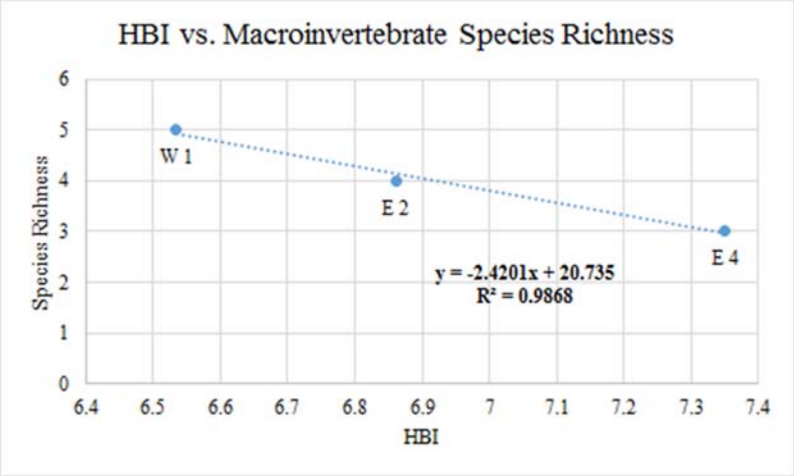


*Figure 11 – The regression of the Hilsenhoff Biotic Index against macroinvertebrate species richness within the stormwater at each site*



## Citations

Bergey, E. A. (2006). A review of methods for measuring the surface area of stream substrates. Oklahoma Biological Survey and Department of Zoology, University of Oklahoma, Norman.

Brauns, M., Garcia, X., Walz, N., and Pusch, M.T. (2007). Effects of human shoreline development on littoral macroinvertebrates in lowland lakes. *Journal of Applied Ecology, 44*, 2-4.

Claucherty, M.  (2014). Duncan-grass bays watershed management plan. Tip of the Mitt Watershed Council.

Dolah, V. (2000). Marine algal toxins: origins, health effects, and their increased occurrence. *National Institute of Environmental Health Science, 108,* 137-139.

Falconer, I. R. (2005). Health risk assessment of cyanobacterial toxins in drinking water. *Environmental Research and Public Health, 2,* 43-50.

Filpansick, P. (2014). 2014 Forest Lake Water Quality Review. Lake Pro Incorporated, Swartz Creek.

Hilsenhoff, W.L. (1988). Rapid field assessment of organic pollution with a family-level biotic index. Department of Entomology, University of Wisconsin, Madison.

Merrit, R. W. and Cummins, K. W. (2006). Trophic relationships of macroinvertebrates. Departments of Entomology and Fisheries and Wildlife, Michigan State University, East Lansing.

Napgal, N.K., Levy, D. A. and MacDonald, D. D. (2003). Ambient water quality guidelines for chloride. New Hampshire Department of Environmental Services, Concord.

Oram, B. (2014). Phosphates in the Environment. Water Research Watershed Center, Dallas.

Simonsen, J. (2004). Best management practices. U.S. Department of the Interior Bureau of Land Management.

Zhang, F. and Dickman, M. (1999). Mid-ocean exchange of container vessel ballast water. *Marine Ecology Progress Series, 176,* 243-251.