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Impact of Impervious Surfaces on Water Quality by Measurement of Macroinvertebrates in Rock Island and Moline, Illinois

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Abstract

Streams have been degrading in quality since the introduction of impervious surfaces. Water concentrations have been altered as sediment and other pollutants have been introduced from severe erosion from runoff. As the water continues to change, the biotic integrity becomes disturbed. More specifically, aquatic invertebrate populations begin to change. More organisms that can tolerate poor quality streams are thriving as organisms that can only tolerate high quality streams are beginning to run thin. This study strives to find a spatial relationship between impervious surfaces around Rock Island and Moline, Illinois and the water quality within the streams by looking at aquatic invertebrate samples. It also hopes to find a correlation between population density and species richness from the samples collected. The results showed that a majority of the streams had poor quality (33 sites out of 42) and a decrease in richness of each site correlated with an increase in population density around it (p-value of 0.0192).

Chapter One-Introduction

Since the 1950s, a pattern began to develop as an increasing amount of people began to move into the cities. The sudden formation of big cities began and city populations skyrocketed to the millions. In the world all together, in 1950 the percentage of urban population was at 29.4. As the years passed and the calendars' hit 2010 the percentage had risen to a 51.6 percent. It is now predicted that the population will continue to rise to be 67.2 percent by the year 2050 (Benton and Short). But with this increase in desire for urban living comes a necessity to develop more. Whether the city grows up or out, there are several different changes that are associated with rapid urbanization. These changes include: land-use (ecosystem) changes, ecosystem fragmentation, increased resource use, water and air quality decreases, increased global climate change, in turn effecting public health (Benton and Short). So how exactly are streams and the organisms within it being affected by degradation that is occurring both within the city limits and adjacent? Are the areas of high impervious surfaces creating streams that are unusable and even harmful?

When there are a high percentage of impervious surfaces within the city there is a large amount of water running downhill from the point it first hit. As the water continues to run downslope it begins to pick up debris and other contaminants that pollute adjacent areas and more importantly in the several locations that streams begin to form. The continuous movement of debris into streams creates a great deal of disorder and therefore an imbalance in the system. When there is an imbalance then there are further altercations that begin to form. Organisms in general have a certain tolerance to their environment (Stevenson 2007). When a stream is in a stage of imbalance, these organisms are incapable of thriving or even surviving. One might ask, well what is the importance of having invertebrates within a stream? Although a disruption in the amount of aquatic invertebrates in a stream seems relatively small scale, there is further disruption in other systems. Without macro invertebrates there is a decrease in terrestrial organisms that may be feeding upon them. Without terrestrial organisms then there isn't control of plantings (Molles 2010). Biological Condition is assessed by both habitat quality and water quality (Stevenson 2007). Aquatic invertebrates are used as direct indicator of water quality (Stevenson 2007). By calculating aquatic invertebrates richness and tolerances, one can evaluate the overall water quality at that stream site (Hauer 2007).

The Mississippi River is one of the largest river systems in the entire world by measures of habitat diversity, size, and productivity. The overall Mississippi River Watershed includes 31 states covering over 1.2 million square miles (National Park Services). This leaves the Mississippi as an important system globally and locally. The Upper Mississippi drains completely into the river basin and is a great contributor to the degree of cutoff and degradation that occurs within the delta. So it is essential that the Upper channels are maintained in order to preserve systems below. By testing invertebrate samples over 13 watersheds in Rock Island and Moline, Illinois that drain into the Mississippi River and the Rock River, a direct tributary of the Mississippi River (seen in Figure 1.1), a determination of true stream health may be able to be found.

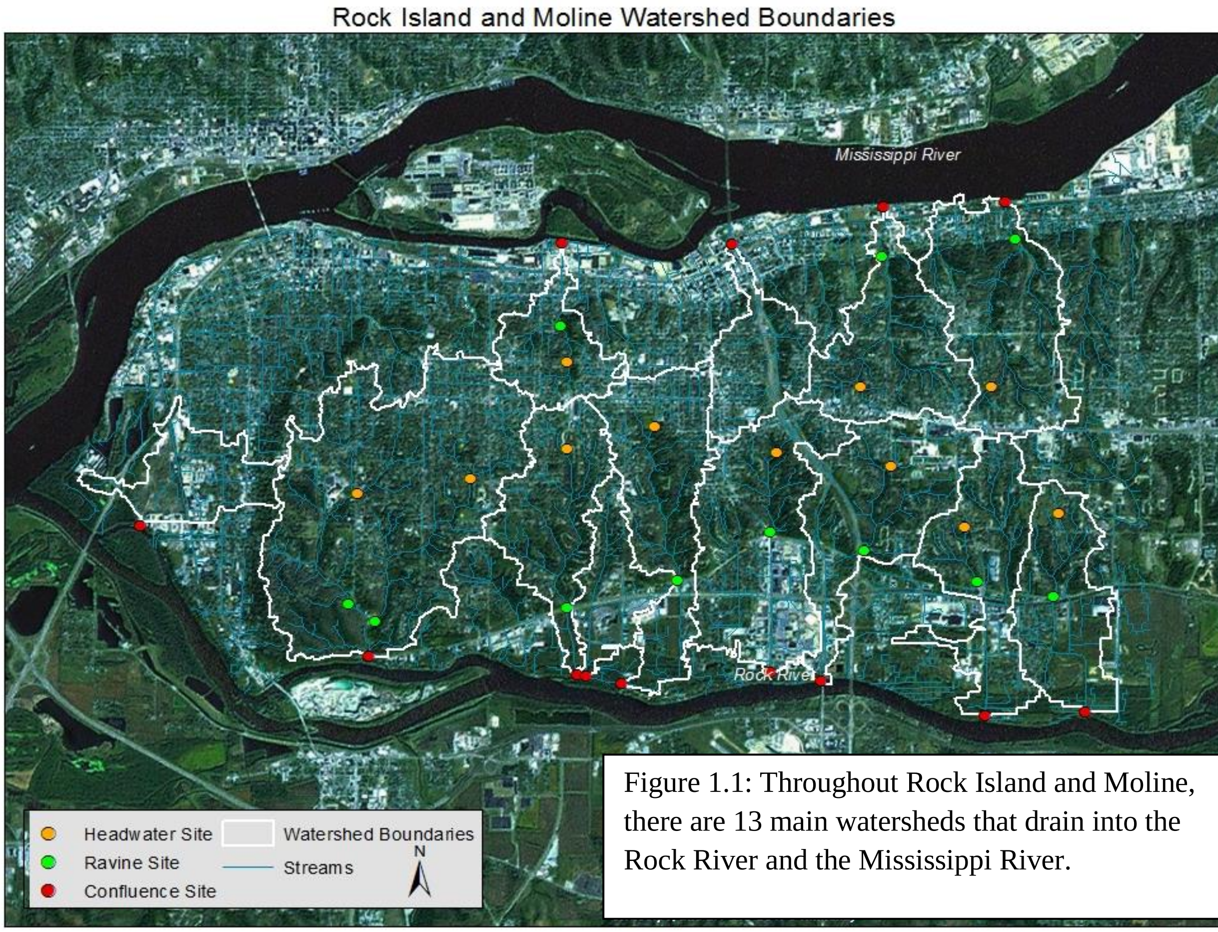

Figure 1.1: Throughout Rock Island and Moline, there are 13 main watersheds that drain into the Rock River and the Mississippi River.

The purpose of this study is to try and find a spatial relationship between the amount of impervious surfaces in the watersheds of the Upper Mississippi River and decreased water quality by looking at aquatic invertebrates. This study hopes to answer the following questions:

What is the overall quality of the streams in Rock Island and Moline using aquatic invertebrates?

How are the areas of high impervious surfaces affecting the invertebrate populations within the streams?

Chapter Two-Background

As the world's population continues to increase, cities are experiencing pressure to expand and accommodate. The United Nations Statistics Division found that in the United States there is an overall 0.9 percent increase in annual population growth predicted within the next three years (United Nations 2012). They also stated that in 2012, 82.6 percent of the population was living within developed areas (United Nations 2012). The problem that has evolved from development is the environmental impact, especially with water quality in streams. Therefore examining the water quality as a whole watershed is a very important aspect to the environmental study of water systems.

In general, a watershed is an area of land whose water drains to a common point or stream (Pennington 2010). Because watersheds are a large area, keeping a high quality watershed is a very important concern of ecologists and other communities. The water that is held within a watershed includes both above ground water systems and groundwater that has been infiltrated. Water that has infiltrated under the soil has a great effect on the biotic and abiotic components of the land which are overall very important aspects to watershed health (Pennington 2010). Naturally, water is draining downslope because of the relief, or slope. This means that processes that are acting at the higher altitudes of a watershed have control of the features represented in lower areas (Allen 2008). When there is a disturbance or alteration made within the higher altitudesin a watershed, the areas downslope will bear that affect also, and sometimes in higher quantities. This is why it is very important to try and keep the headwater streams of a watershed in a high quality state. Because of the connectivity between altitudes it is very important to look at the entire watershed.

The importance in emphasizing both above ground and below ground flows comes into play when examining alterations in ground cover. One of the main reasons why the development is seen negatively is because of the effect it has on the rate of runoff (Randolph 2012). When a natural area is cut down and developed on, there is an increased amount of impervious surfaces. This creates a decline in the amount of surface water that infiltrates into the soil. The rate of runoff goes from 10 percent when there is a natural ground cover to 55 percent when replaced with an impervious surface (Figure 1.2). This data is important to keep in perspective considering the rate of runoff has several consequences down the watershed. One study showed that increased development and urbanization lead to worsening water quality downslope (Astaraie-Imuni 2012). What aspects of stream quality are necessarily being affected?

With increased runoff comes increased erosion (Randolph 2012). When runoff increases, a disturbance occurs within the stream system. As a result, material like soil begins to break off and enter into the streams. Stream bank erosion increases the amount of sediment load found in aquatic systems. As sediment load is altered, it affects the overall ecology of a stream (Pennington 2010). When a stream gets filled up with sediment it changes the aspects of the water, such as nutrient concentrations, that make it possible for organisms to thrive. Along with the sediments, other pollutants are introduced into the stream. These sediments and pollutants include the fonutrients (phosphorus and nitrogen), chemical toxic substances, microbiological pathogens, oxygen-depleting organisms, and heat (Pennington 2010). All of these can have a large impact on the overall quality of a stream.

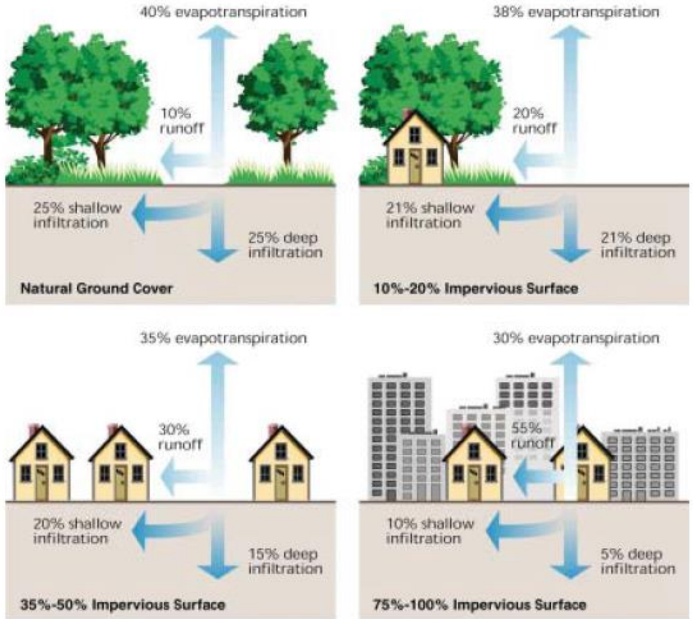

Figure 1.2: As an area becomes more developed the infiltration rate decreases which overall increases the rate of runoff (River Action).

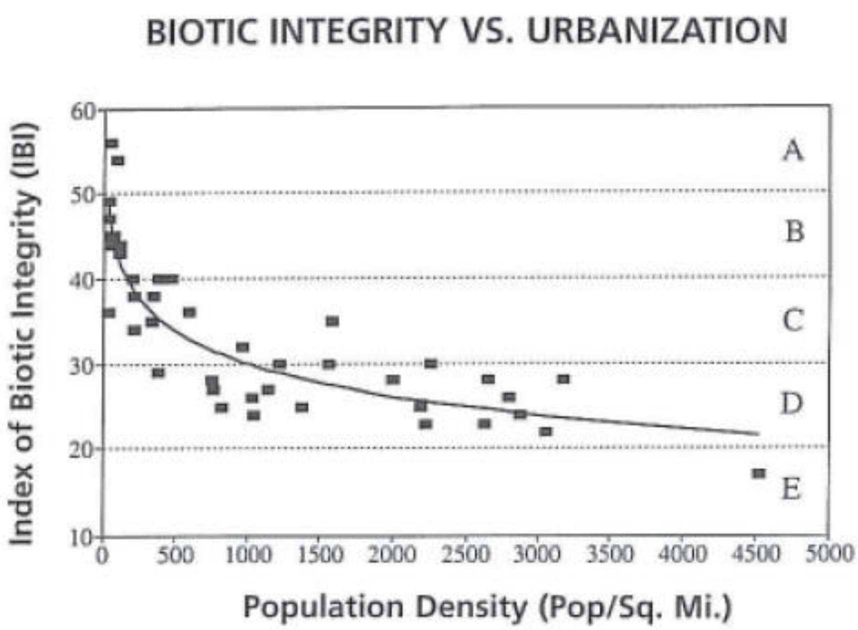

Figure 1.3: When land is developed on then there is an increase in population density. Research has found that there is an inverse correlation between density of the population of humans and the abundance and diversity of organisms (River Action).

When streams become contaminated by pollutants and the water concentrations become imbalanced, it impacts the biotic life within it. In a general sense, the overall biotic integrity decreases when there is an increase in development and population (Figure 1.3). Biotic integrity can be defined as the overall abundance and diversity of biotic life within a system. A high biotic integrity is essential to have within a stream. Only the most harsh, temporary, or grossly populated environments don't contain some sort of representative of organisms (Hauer 2007).

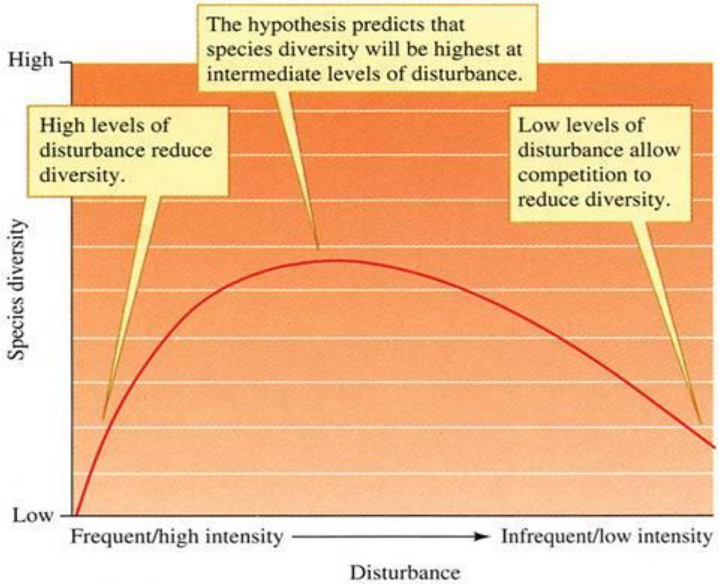

Figure 1.4: The intermediate disturbance hypothesis explains that species diversity decreases with both extremes of disturbance (Molles 2010).

The measurement of water system imbalances is important to analyze because in order for certain species to exist within a stream, there has to be a certain equilibrium. There needs to be a particular balance between pH, specific conductance, dissolved oxygen, temperature, sediment load, as well as other factors. Once the measurements start to alter, the organisms will not be able to survive and they will either die or migrate elsewhere. One way to help understand the significance of changed water measurements is to look at the intermediate disturbance hypothesis and examine the curve. The intermediate disturbance hypothesis shows the intermediate levels of disturbance that promote higher levels of diversity (Molles 2010). A particular balance between extremes is important when looking at water systems and their biotic life. This model tries to show how disturbances within a system overall effect diversity of species (Figure 1.4). This hypothesis gives a better overall understanding of how important equilibrium within a water system is as well as a need to decrease any disturbances. For example, if a stream were to have too low of a pH, only certain organisms would be able to tolerate those levels. If the stream's pH is too high, once again only a few organisms will be able to tolerate that. If the pH were to be relatively in the middle, more organisms would be capable of surviving. Any changes in the balance effect whether or not biotic life is capable of surviving.

When analyzing disturbances, there are certain organisms that are completely affected by only a slight change within a stream system while other organisms aren't as affected. Any of these organisms can be referred to as indicator species (Pennington 2010). If these species are absent it can be a signal that there has been an environmental change within the stream. Further, if there is an organism that can handle great changes within the system it can be an indicator of increased disturbance. One specific group of organisms that can be observed as indicators of environmental conditions are aquatic macroinvertebrates. These aquatic invertebrates include aquatic insects, mollusks, and more. Macroinvertebrates are an important factor within a stream community because they are an essential link in food webs between fish and organic matter (Hauer 2007). Organisms that were examined as being important to measuring aquatic quality are organisms that are dependent on the water source for part of their life cycle. There are 13 orders of aquatic insects within North America, but only five of these are strictly aquatic species (Hauer 2007). The group of insects that live strictly in aquatic ecosystems include Odonata, Plecoptera, Ephemeroptera, Trichoptera, and Megaloptera. Macroinvertebrates which are primarily terrestrial but spend a part of their lifecycle under water are Coleopeterans and Dipterans. These organisms are therefore able to be a reference for aquatic conditions.

As previously mentioned, organisms have a certain tolerance to their surroundings. Macroinvertebrates follow this rule. Each insect has a particular tolerance score that expresses its overall susceptibility to water quality issues (Hauer 2007). The organisms that have a higher tolerance are given a high tolerance score being an indicator that the water system is of low quality. Organisms that have a low tolerance score are expected to be found in streams that are of low quality (Hauer 2007). When organisms' tolerance scores are observed, an equation can translate those tolerances into an overall water quality assessment. By taking the tolerance scores of each organism collected in a stream and multiplying that by the species richness (total number and diversity of organisms within a stream) an overall Family Biotic Index (FBI) can be obtained (Hauer 2007). The Family Biotic Index gives an overall interpretation of how the water system is based on a scale from very poor to excellent. By using this system, the macroinvertebrates within a stream can give vital information as to how the stream system is doing. And further, if continued samples and measurements are taken, a conclusion as to whether the water quality is improving or degrading can be made.

All environmental changes within a system create great issues across the watershed. When one aspect of the watershed is altered it causes further problems downslope and especially in streams. When land use alters and is built near streams there is a decreased amount of infiltration creating a larger and more powerful rate of runoff. As the runoff progresses down the watershed, erosion begins to occur more frequently. When there is an increase in erosion there is then an increase in the sediment entering into the stream. When these sediments continue to filter into the stream it alters the concentration of nutrients. Once the nutrient concentrations are altered, there is a decrease in abundance and diversity of biotic life and more specifically aquatic invertebrates. It is essential that insects are taken into consideration when examining the health of a stream because they are critical for the future health of a stream, plus, they serve as a quick and easy biological assessment of water quality.

Chapter Three-Methodology

This study aimed to test for spatial associations between percent impervious surfaces, water quality, population densities, and invertebrate richness within stream systems in Rock Island and Moline, Illinois. In order to test the ecological quality status, there were a lot of samples that needed to be collected and hundreds of samples that were identified. I used the methodology used by Hauer and Lamberti in their experiment of using macro invertebrates as biotic indicators of environmental quality (2007).

The first step was to establish which watersheds were going to be tested by using Geographic Information Systems (GIS), a technique often used by Geographers to work with mapping. Then to determine where my sites were going to be, I crossed road maps layer and a streams layer to try and obtain easy access to each point. I also determined to do a headwater, ravine, and confluence site to obtain samples throughout the entire watershed. Population density and percent impervious surfaces layers were also obtained in order to determine each sites surrounding density and imperviousness. This information would be used later for analyses.

Figure 1.5: Dip nets are commonly used to collect aquatic invertebrates within shallow bodies of water.

At each one of the sites, I collected numerous samples using a dip net which are commonly shaped like the letter “D.” The way these nets were used was to take the straight edge and bump it across the substrate (Figure 1.5). Once it is lifted up, water filtered through and the invertebrates would remain within the net. The invertebrates were put into an alcohol solution in order for preservation while being taken to the lab.

Once in the lab, all of the samples were identified to their family level. When the family was determined, the species tolerances scores were determined. This measurement showed their ability to withstand water systems that are off balance or of low quality. Once each invertebrate was identified and given a score, the overall site richness was calculated. The total number of organisms within the sample and also the diversity of organisms would determine the richness. By the end of each sample, the following measurements were established: taxa richness (total number of organisms and diversity of organisms) and tolerance score (Hauer 2007). When these parameters were found, the Family Biotic Index was determined by multiplying the richness in the sample with the tolerance scores. The resulting number was then referenced to the Family Biotic Index chart which establishes the relationships between Index score and water quality (Figure 1.6).

Family Biotic Index	Water Quality
0.00-3.75	Excellent
3.76-4.25	Very Good
4.26-5.00	Good
5.01-5.75	Fair
5.76-6.50	Poor
7.26-10.00	Very Poor

Figure 1.6: By multiplying the tolerance scores of organisms and the overall diversity of the samples found, the water quality of that stream may be determined (Hauer 2007).

Some of the data collected was converted into graphs in order to give a visual representation of the data at different points. The best fit line was established allowing for the R constant to be found by analyzing the slope. The data being examined was then ran through JMP, a statistical software produced by SAS. This allowed for a p-value to be determined. An analysis of the ravine, confluence, and headwater parameters were ran through NOVA software to determine whether or not there was a statistical difference throughout the watershed.

Chapter Four-Results

Invertebrate samples were collected in the field and brought back to lab where they were classified to the family level. Throughout the samples, 35 different families were identified. Not only were the samples identified but the total number collected at each site was recorded. Overall, there were 1,889 samples that were identified. There were some families that did represent a great number of the final organism count. This included the following: Ceratopogonidae with 48 samples, Baetidae with 53 samples, Physidae with 147 samples, Corixidae with 170 samples, and Chironomidae with 499 samples. Once the number of organisms was collected, the tolerance scores of each of the invertebrates were taken. These scores ranged from 1 to 10. The invertebrates that had low tolerances (1-3) had a total of 3 different families over 5 invertebrates. Invertebrates that had medium tolerances (4-7) had a total of 21 families over 1343 invertebrates. The invertebrates that had high tolerances (8-10) had a total of 11 families over 459 invertebrates. The total number of each family found at one site was multiplied by the tolerance score. After this was complete they were divided by the total number organisms found at that site and this established the Family Biotic Index for each site. This in turn gave the water quality. Overall, no sites were excellent, 2 sites were very good, 7 were good, 3 were fair, 11 were fairly poor, 13 were poor, and 6 were very poor. In a condensed manner, 30 out of the 52 sites tested for having bad water quality conditions.

Confluence, ravine, and headwater sites were imputed through NOVA software and no significant statistical differences were found.

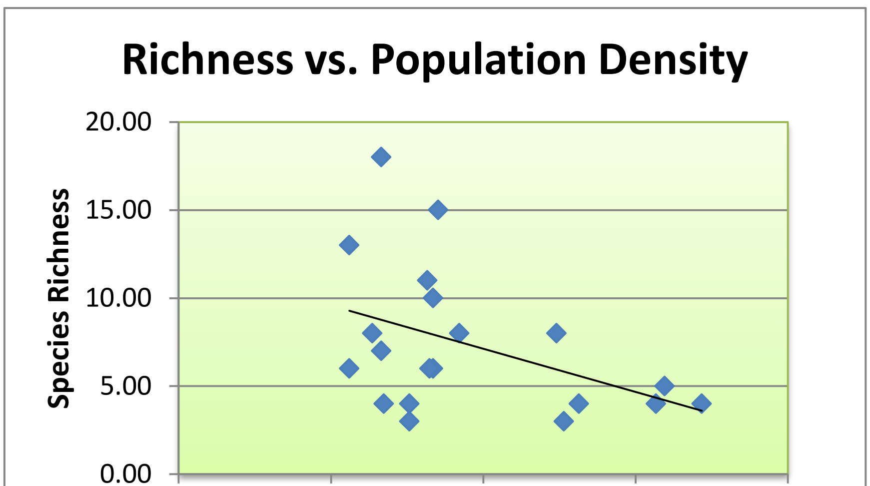

Figure 1.7: By analyzing the effect of population density on species richness, a determination can be made as to population's effect on biotic life.

The overall richness of a site was also collected. This is a number that explains how diverse a site is. When comparing the richness of each site versus the percent impervious surfaces, no statistical differences were found. Once a cross examination was given between population densities and invertebrate richness, the r-value was determined to be 0.2584 making the p-value 0.0192 which is less than 0.05 making the data statistically significant (Figure 1.7).

<u>Chapter Five- Conclusion</u>

Both the tolerances scores and the overall water quality assessment found from the Family Biotic Index equation showed that the streams were weighted more towards being lower quality. The next larger number were found within the neutral zones, but it is important to remember that water quality is computed by both the individual organisms tolerance but also the overall diversity of the site. Once tolerance scores are compiled and crossed with diversity and richness, it is clear that the water quality across the streams draining into the Mississippi River are severely lacking. There are several exceptions but there were 30 streams that had water quality ranges within the “poor” parameter. For areas that are supposed to be for recreational use and further becoming a part of the Mississippi River where we obtain our drinking water, there seems to be a large quality issue. I believe that there are many way that Rock Island and Moline citizens can work to better our streams.

One way to better the streams is to expand the buffer around them and make them “greener.” Stream banks, consisting of biotic life referred to as a riparian buffer, become stressed when there is an increased amount of pressure from high water flows. The pressure then emphasizes the importance of there being vegetation surrounding a stream and not a cemented zone. When a riparian buffer is present it contributes the following features that serve to increase the rare qualities found within ecosystems: roots stabilize banks by preventing slumping of materials, branches and trunks create habitat diversity, shade prevents warming, in-fall of vegetation and invertebrates effecting the overall food web (Allen 2008). Having a riparian buffer is important to the stream because the different vegetation and roots that are stabilizing the bank serve as a microhabitat for organisms and it overall decreases erosion. When an area is developed on, the length of the buffer and the vegetation needs to increase in order to balance out the amount of impervious surfaces being added. The reason for this is because natural covering of the riparian buffers slows down runoff creating a longer time for water to infiltrate into the soil. With increased infiltration there will be decreased erosion and increased stream quality (Allen 2008). Therefore the importance of increasing riparian buffers to balance off high runoff from impervious surfaces is of high concern.

Within the city limits, where natural ground cover will not be completely converted to its original state, there needs to be implementations of storm water management practices, called best management practices (BMPs). The purpose of these management practices is to decrease the percentage of impervious surfaces and increase natural vegetation. Although it is unrealistic to expect that all runoff can be eliminated through these practices, BMPs can be used to minimize the impacts that impervious surfaces are having on water quality further down in the watershed since they slow down runoff and increase infiltration. BMPs include these different practices: bio-retention cells, bioswales, pervious surfaces or block modular pavement systems, rain gardens, roof top gardens, sand filter systems, and native grasses. Overall adding such practices and making the appropriate changes around the streams will increase the water quality and restore the biotic integrity to them.

Works Cited

Allen, J.D., and M.M. Castillo. 2008. *Stream Ecology: Structure and Function of Running Waters.* Dordrecht, The Neverlands: Springer.

Aroviita, J., H. Myrka, and H. Hamalainen. 2010. River bioassessment and the preservation of threatened species: towards acceptable biological quality criteria. *Ecological Indicators*. 10(4): 789-95.

Astaraie-Imuni, M., Z. Kapelan, G. fu, and D. Butler. 2012. Assessing the combined effects of urbanization and climate change on the river quality in an integrated urban water system in the UK. *Journal of Environmental Mangement*. 112: 1-9.

Benton-Short L. and J.R. Short. 2013. *Cities and Nature*. New York, New York: routledge Taylor & Francis Group.

Hauer, F.R. and V.H. Resh. 2007. "Macroinvertebrates." *Methods in Stream Ecology*. Burling, MA: Elsevier Inc.

Liu, Y., S. Yang, and J. Chen. 2012. Modeling environmental impacts of urban expansion: a systematic method for dealing with uncertainties. *Environmental Science & Technology*. 46(15): 8236-8243.

Miserendino, M.L., R. Casaux, M. Archangelsky, C.Y. Di Prinzio, C. Brand, and A.M. Kutschker. 2011. Assessing land-use effects on water quality, in-stream habitat, riparian ecosystems and biodiversity in Patagonian northwest streams. *Science of the Total Environment*. 409(3): 612-624.

Molles, M.C. 2010. *Ecology: Concepts and Applications*. New York, NY: McGraw Hill.

National Park Services. 2013. *Mississippi River Facts.* www.nps.gov/miss/riverfacts.htm (Last accessed 14 January 2014).

Pennington, K.L, and T.V. Cech. 2010. *Introduction to Water Resources and Environmental Issues*. Cambridge, UK: Cambridge University Press.

Randolph, J. 2012. *Environmental Land Use Planning and Management.* Washington, DC: Island Press.

River Action. 2013. http://www.riveraction.org/ (Last accessed 26 January 2014).

Stevenson, R.J., and S.L. Rollins. 2007. “Biological assessments with benthic algae” *Methods in Stream Ecology*. Burlington, MA: Elsevier Inc.

United Nations Statistics Division. 2012. *Population growth & distribution.* http://unstats.un.org/unsd/demographic/products/dyb/dyb2011.htm. (Last accessed 18 April 2013).