Water quality of streams in the Deer Creek Watershed

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Introduction

Stream ecosystems in urban environments face many challenges. Fertilizer from lawns and gardens can be washed into streams and cause algae to flourish, choking out other organisms (Bryan et al. 1997). Storm runoff from hot roads and parking lots can raise urban stream temperatures (Pluhowski 1970). Sewage spills and feces from geese, pigeons, deer, and domestic pets can cause fecal coliform bacteria counts for urban runoff to be twenty to forty times higher than the public health standards for swimming (University of Wisconsin 1997). The Deer Creek Watershed lies in a heavily urbanized area. This study aims to monitor the water quality of the streams in this watershed, comparing them to a stream that runs through a forested reserve approximately 20 miles west of Deer Creek.

Fertilizer runoff can result in mass fish kills in urban streams. Two main components of chemical fertilizers are nitrogen and phosphorus. When these nutrients are over applied to lawns or crop fields, water from irrigation or rainwater can wash them into the groundwater supply and then into streams (United States Environmental Protection Agency 2010). There the nutrients fertilize algae in the stream, causing an algal bloom. This means that during the day when the algae are photosynthesizing, dissolved O_2 in the stream will be high. However, at night when the algae respire but do not photosynthesize - or if large numbers of algae die and decompose - dissolved O_2 downstream of the algal bloom will plummet (Bryan et al. 1997). Low levels of O_2 may suffocate aquatic organisms or make them vulnerable to other stressors. The overgrowth of algae due to high nutrient enrichment is known as eutrophication.

According to Goolsby et al. (2000), when spring rains carry nutrients into the Mississippi River, a 7,000-9,000 km^2 area of oxygen depleted water develops in the Gulf of Mexico each year, due to eutrophication. Goolsby et al. found that the main sources of nitrogen to the gulf are likely agricultural fields in southern Minnesota, Iowa, Illinois, Indiana, and Ohio. However, eutrophication can also be caused by fertilizer from lawns, especially when they are routinely watered. Nitrogen and phosphorus, as well as potassium, are the three main components of fertilizer used on golf courses, which are often heavily watered ("Best Management Practices for Golf Courses"). Winter et al. (2003) found that streams in operational golf courses in Ontario had higher nutrients and were more likely to be dominated by a single taxon. There are eight golf courses in the Deer Creek Watershed.

Nitrogen is present in streams in the form of nitrate (NO_3^-), very small amounts of nitrite (NO_2^-), and ammonia. About 80 percent of the nitrogen used in fertilizer is in the form of ammonia, and 20 percent is in the form of nitrate (Bryan et al. 1997). Ammonia pollution poses a unique problem for aquatic ecosystems**.** At a normal pH and temperature, the majority of the ammonia will be in the nontoxic form NH_4^+. However, if the pH of the water rises, NH_4^+ loses a hydrogen ion and becomes "unionized ammonia," NH_3. Unionized ammonia can accumulate in aquatic organisms and affect body pH and metabolism (Isenhart 2008). Ammonia is normally harmless at concentrations of 1.0 mg/L or less (Vigil 1996). Unionized ammonia is safe for fish reproduction at 0.020 mg/L or less (Levit 2010). Natural levels of nitrate vary greatly with the size, hydrology, and depth of streams but are generally 0.12-2.2 mg/L **(**United States Environmental Protection Agency 2010**)**.

Like nitrogen, phosphorus is essential for the growth of aquatic plants. Adding phosphorus to streams has been found to increase the biomass of macroalgae (algae not attached to the stream bottom) and periphyton (attached algae) (Morgan et al. 2006). Phosphorus is mainly present in streams in the form of phosphate (PO_4^{3-}). Sources of excess PO_4 in streams are fertilizer, animal manure, sewage, and lawn clippings (Missouri Department of Education et al.). Phosphorus binds readily to soil particles and can enter streams by washing in from fertilized soil that is highly saturated with it, or from eroded soil particles. While nitrogen can exit the water column through denitrification, a process in which bacteria convert it to nitrogen gas or ammonia, phosphorus has no way to be removed other than being taken up by plants (Johnson and Gregory 2009). Natural levels of PO_4 are generally 0.01-0.075 mg/L (United States Environmental Protection Agency 2010). According to Bryan et al. (1997), levels of greater than 0.1 mg/L can lead to eutrophication.

The pH of a stream is another factor that affects the health of the ecosystem, and it may cycle up and down daily. At night, aquatic plants respire CO_2 but do not use it up in photosynthesis. This CO_2 is converted to carbonic acid, making the water more acidic. When the sun rises and plants begin to photosynthesize again, they use up CO_2 from the water, and the pH increases. Therefore, the concentration of toxic unionized ammonia is highest in the late afternoon, when pH is highest (the formation of unionized ammonia also increases, to a lesser degree, with temperature, which is also greatest in the late afternoon) (Wurts 2012). Normal pH in streams ranges from 6.5 to 8.5. In addition to plant respiration, acid rain can have an effect on the pH of streams. However, the limestone that lines many of Missouri's streams acts as a buffer against drastic changes in pH (Missouri Department of Conservation et al.).

The temperature of a stream affects the metabolic and photosynthetic rates of aquatic organisms. In addition, water with a higher temperature holds less dissolved O_2 and promotes the formation of the toxic form of ammonia. Urban streams can have higher temperatures than rural streams due to thermal pollution (Pluhowski 1970). When impervious surfaces like parking lots, streets, and roofs absorb energy from the sun, they become much hotter than surrounding vegetation. Particularly during the summer, heat from these surfaces can be transferred to storm water runoff, potentially upsetting cold water ecosystems (Thompson et al. 2008).

Turbidity is a measurement of the clarity of the water of a stream, determined using a turbidity tube. High turbidity (low water clarity) decreases photosynthesis and can even cause clogging of fish gills, hindered reproduction, and limited egg survival. High turbidity can be caused by soil erosion or by the overgrowth of algae (Missouri Department of Conservation et al.).

This study compares the water chemistry of two Deer Creek tributaries to Hamilton Creek. The monitoring sites of the Deer Creek tributaries (Twomile Creek and upper Deer Creek) are located in Ladue, one of the wealthiest suburbs in St. Louis. The Deer Creek Watershed includes eight golf courses and numerous home lawns. Golf balls are routinely found washed into the creek. A lake located in the center of one golf course drains into a tributary to Deer Creek upstream from the monitoring site. Hamilton Creek flows through Rockwoods Reservation in Wildwood, Missouri. The reservation is a 1,880 acre wooded area set aside for recreation and conservation education (Missouri Department of Conservation 2012). Also upstream from the monitoring sites at Hamilton Creek are several farms and scattered houses.

The objective of this study is to determine whether the water quality factors previously discussed differ between streams in the heavily developed Deer Creek Watershed and the stream in Rockwoods Reservation. If NO_3, PO_4, and NH_3 concentrations differ between the Deer Creek and Hamilton Creek sample sites, they are predicted to be higher at the Deer Creek sites due to fertilizer runoff from lawns. If water temperature differs between the two areas, it is predicted to be higher in the Deer Creek Watershed due to runoff from impervious surfaces. Turbidity and pH are predicted not to differ significantly between the two watersheds.

Materials and Methods

Samples were collected and analyzed from each of four stream sites. The first site was at Hamilton Creek, across from the Rockwoods Reservation Office. The second location was at Hamilton Creek at the intersection of Melrose Rd. and Highway 109. The third location was at Twomile Creek near Overbrook Dr. The last sampling location was at upper Deer Creek, near Litzsinger Rd. Samples were taken one to three times per week over a three week period. They were always collected in the mornings, within two hours of each other. Samples were kept in 8-oz plastic bottles and stored in a cooler on the way to the lab.

At the time each sample was taken, the time of day, water and air temperature, and turbidity were recorded. The amount of rain in the past seven days, according to the Weather Channel's records, was also noted.

At the lab, the samples were analyzed to determine pH and concentrations of NO_3, NH_3, and PO_4. NO_3 was measured using the cadmium reduction method, in which cadmium converts NO_3 to NO_2. A second reagent produces a purple color, which is darker when more NO_2 is present. This color is then compared to other shades of purple to determine the concentration of NO_3. NH_3 concentration was measured by adding ammonia salicylate and ammonia cyanurate to the sample. These chemicals react with NH_3 to form a blue-colored compound, which can be measured using a colorimeter. This test gives the concentration of ammonia-nitrogen (NH_3-N). The amount of toxic unionized ammonia can be calculated using the pH and water temperature to find a constant on a chart. That constant is then multiplied by the mg/L of NH_3-N. The test used to measure PO_4 was conducted by adding a reagent containing ascorbic acid and ammonium molybdate, which reacts with PO_4 to form a blue compound. This blue compound can be quantified using a colorimeter.

In between samples, the plastic bottles were scrubbed with a phosphate-free detergent, rinsed three times with cold tap water, rinsed with 9% hydrochloric acid, and rinsed three times with deionized water.

ANOVAs were performed to compare each of the six water quality factors among the sites: turbidity, water temperature, PO_4, NO_3, NH_3-N, and pH. The Missouri Stream Team's monthly measurements of the NO_3 and PO_4 in these streams during the year 2012 was also analyzed to compare to the results from this study. In addition, the concentration of unionized ammonia was calculated for each measurement site. This was merely done to check for toxic amounts of unionized ammonia; no comparisons were made among the sites in regards to unionized ammonia.

Results

NO_3 was relatively low in all four streams. In fact, every NO_3 measurement taken was recorded as less than 0.25 mg/L (the lowest measurement provided by the test kit). NO_3 measurements taken by the Missouri Stream Team throughout 2012 also showed no significant difference among the streams, according to an ANOVA test (see figure 1).

Figure 1. Monthly NO_3 concentration in Hamilton, Deer, and Twomile Creeks during the year 2012, as measured by the Missouri Stream Team. An ANOVA test revealed that there is no significant difference between mean NO_3 measurements among the creeks (p-value = 0.16).

PO_4 in Twomile Creek was significantly higher than in the other streams (see figure 2). Measurements taken by the Missouri Stream Team in 2012 show that Twomile Creek appears to routinely have higher PO_4 than Deer or Hamilton Creeks (see figure 3). However, an ANOVA and Tukey's post hoc tests revealed that PO_4 measurements in Twomile Creek were significantly higher than in Hamilton Creek but not Deer Creek. NH_3-N, turbidity, and pH measurements did not differ significantly among the creeks (p-values 0.47, 0.42, and 0.67, respectively). The only site that had a toxic amount of unionized ammonia (over 0.020 mg/L) was Deer Creek, with an unionized ammonia measurement of 0.037 mg/L. This measurement was recorded on a day when Deer Creek had the highest water temperature recorded in this study.

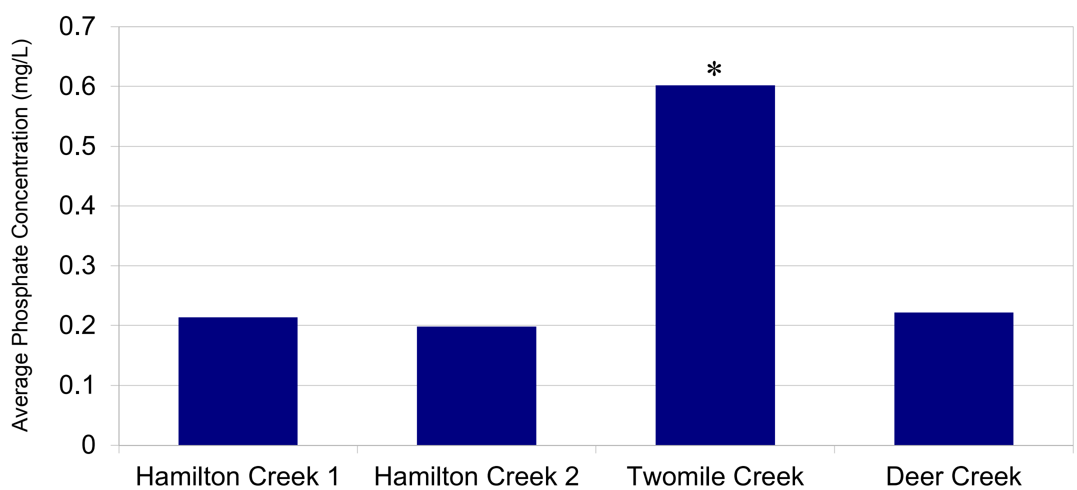

Figure 2. Average PO_4 concentration at creek sites from July through August, 2013. * marks an average that was determined significantly higher than the rest, using an ANOVA and Tukey's post hoc tests.

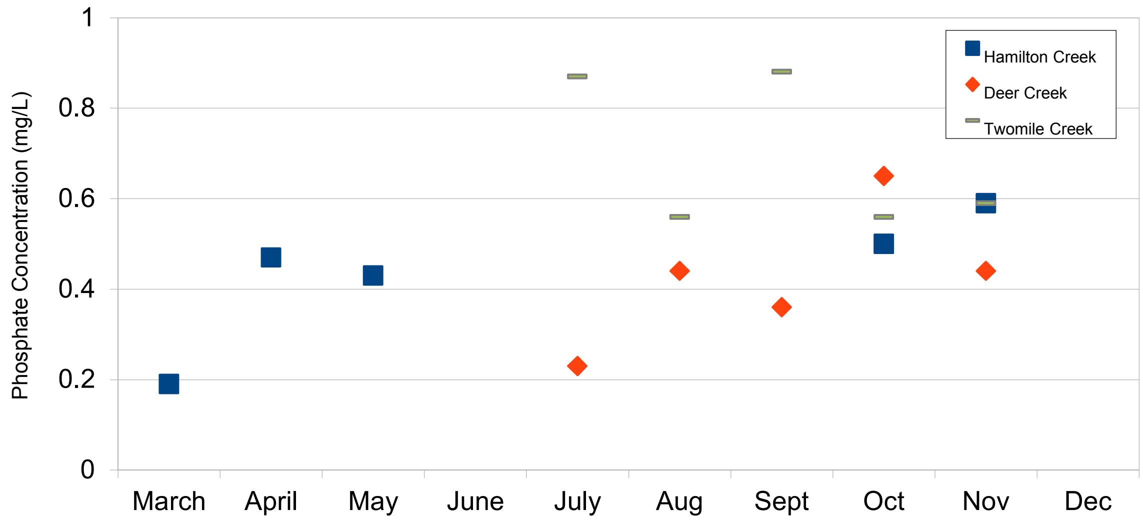

Figure 3. Monthly PO_4 concentration in Hamilton, Deer, and Twomile Creeks during the year 2012, measured by the Missouri Stream Team.

Average water temperature in Deer and Twomile Creeks was significantly higher than that in Hamilton Creek (see figure 4). The average temperatures of the two warmer streams were approximately 8° C higher than Hamilton Creek, even though air temperature did not differ significantly among the sites (see figure 5). However, the mean air temperature did increase slightly in the order that the sites were measured, meaning that the first site visited in the morning had the lowest mean air temperature, and the last one visited had the highest.

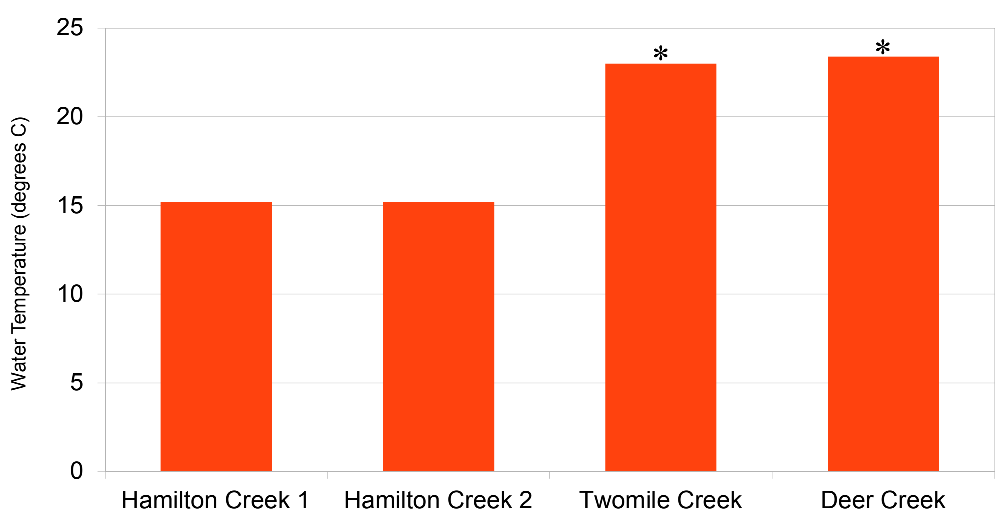

Figure 4. Average water temperature of creek sites from July through August, 2013. * indicates that an ANOVA and Tukey's post hoc tests found that Twomile and Deer Creeks had significantly higher average temperatures than Hamilton Creek.

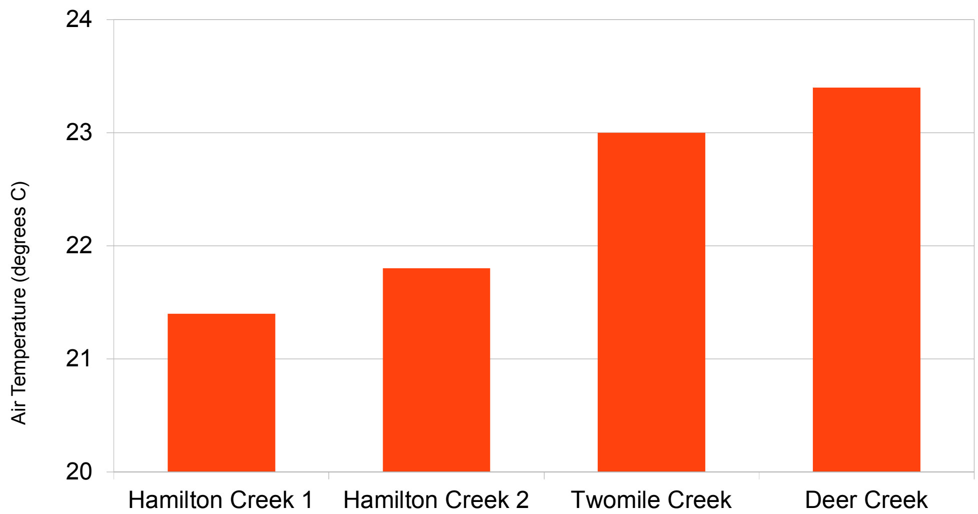

Figure 5. Average air temperature of creek sites from July through August, 2013. Data was collected in the morning, starting with Hamilton Creek site 1, then site 2, then Twomile Creek, and ending with Deer Creek. An ANOVA test indicated that there is no significant difference between the means (p-value = 0.63).

Discussion

Because PO_4 was higher in Twomile Creek but NO_3 was the same among all creeks, it is hypothesized that nitrogen acts as a limiting nutrient to algae in Deer and Twomile Creeks. If any nitrogen entered the creek as fertilizer runoff, aquatic plants may have sequestered it before it could be detected in the water column. Johnson and Gregory (2009) found that 50 percent of nitrogen input into a stream was taken up by aquatic and riparian organisms within 650 feet of the site where it was added. Some nitrogen may also be released into the air and some converted to ammonia in the process of denitrification. PO_4, however, remains in streams until it is taken up by aquatic plants. Phosphorus is normally the limiting nutrient in streams, used up by plants before nitrogen, but in the case at Deer and Twomile Creeks, it would appear that nitrogen is scarcer and is being used up first. Because Hamilton Creek receives little fertilizer runoff, both of these nutrients would be relatively limited. The “limiting nutrient” may go back and forth between the two.

Twomile Creek may have had higher phosphorus than Deer Creek because more algae were dying in Twomile Creek, returning phosphorus to the water column. This could be due to the fact that Twomile Creek was at a more advanced stage of receiving nutrient pollution. The Twomile monitoring site was located closer to a golf course than any of the Deer Creek sites.

It is possible that if this study were conducted in the spring, spring rains may have washed higher amounts of nutrients into Deer and Twomile Creek. However, every monitoring site on all monitoring days had received at least some rain in the past seven days. In addition, the lawns that would have drained fertilizer into the streams were probably routinely irrigated.

Both Deer Creek and Twomile Creek had higher average water temperatures than Hamilton Creek. This may be due to the greater number of parking lots and roads in the Deer Creek Watershed. Thompson et al. (2008) found that the temperature of asphalt decreased an average of 12.3° C over 60 minutes during simulated rainfall. Pluhowski (1970) found that on Long Island, runoff from urban areas raised stream temperatures by as much as 8° C. Runoff from hot surfaces may have directly raised the temperatures of Deer and Twomile Creeks, or it could have been stored as warm groundwater before it entered the streams. Other factors that could have influenced water temperature could be the width and depth of the streams. The Hamilton and Twomile sites had similar width and depth. The Deer Creek site was slightly deeper, which should promote cooler water temperatures. However, there are areas upstream from the Deer Creek site that are wider, shallower, and unshaded.

The findings of this study indicate that the temperature of streams in the Deer Creek Watershed may be higher than normal due to the impacts of urbanization. Dissolved O_2 and unionized ammonia should be routinely monitored in these streams, because they depend on water temperature. Dissolved O_2 should be measured just before dawn, as it drops during the night when plants are taking in O_2 through respiration but not photosynthesizing. Unionized ammonia should be recorded in the late afternoon, when pH and temperature - and therefore unionized ammonia - will be highest (Wurts 2012).

NO_3 and PO_4 should also be routinely monitored in Deer Creek, particularly during spring rains. The soil on all golf courses in the watershed should be tested for nitrogen and phosphorus. Only when one of these nutrients is lacking should fertilizer with that nutrient be applied. Excess nutrients will not only cause eutrophication in stream ecosystems in the Deer Creek Watershed. NO_3 and PO_4 that are not taken up by plants or removed through denitrification will be washed into the River Des Peres, which flows into the Mississippi. According to Goolsby et al. (2000), nitrogen from the Mississippi River Basin is believed to be partly responsible for the massive oxygen depleted zone that develops annually in the Gulf of Mexico. Stream pollution does not only impact ecosystems in the immediate area; it can have an effect on a global scale.

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