Water Quality Analysis of Streams in the City of Lynchburg
By: The Class

Introduction:

When monitoring water quality it is important to know what to look at to help determine if the stream is healthy. The four assessments/tests that are important to use are chemistry, macroinvertebrates, fish, and physical condition. Chemistries are used to check the effects pollution has on the present condition of the stream. Macroinvertebrates and fish tell what the water quality was like before the pollution affected the stream. The effects pollution has on the macros and fish will not be seen for a couple weeks, months, and even years after the pollution was present. This is why looking at macros and fish is important; because it shows what the quality of water was like in the past. The physical quality of the stream shows the effect pollution has had on the stream years ago. All these tests and metrics help make an accurate assessment of the quality of the stream.

Water chemistry measurements and analyses are useful in assessing the condition of a freshwater system. A variety of measurements such as conductivity, pH, dissolved oxygen, and temperature can be taken on site with the use of a probe or similar instrument. Water samples can also be transferred from the sampling site to the laboratory to measure for the concentrations of nutrients such as nitrate and total phosphorous. Although these nutrients are necessary in freshwater streams and rivers, excess amounts can lead to eutrophication and be an indicator of anthropogenic pollution (Cech 2010). Water chemistry measurements are useful in evaluating the condition of a stream; however, the chemistry of a stream or river is subject to change in a very brief span of time (Shahady 2015). Heavy precipitation events can temporarily influence a stream's chemistry and may lead to increased nutrient loads, higher conductivity, or a decrease in pH. It is difficult to obtain an overall conclusion of a stream's water quality based solely on water chemistry data; however, compiled data over a duration of months or years may be used in conjunction with other metrics to assess the overall health of a stream.

Macroinvertebrate sampling is another key aspect of monitoring water quality. Macroinvertebrates (macros) are small insects like beetles and mayflies. Similar to how the chemical analysis reflects the past hours of the stream, macros reflect the previous weeks, months, or in some cases a year. They are collected using D-nets or kick nets in or along the riffles. These areas are highly oxygenated which makes a representative sample of macros easier to obtain. Several different indices can be used to analyze the macros. The first is FBI, or family biotic index. This is based on the different sensitivities of different families to pollution. The scale ranks organisms from highly sensitive to highly tolerant on an eleven point scale (Shahady 2015). Another index is the Ephemeroptera, Plecoptera, and Trichoptera index. This describes the number of families of mayflies, stoneflies, and caddisflies respectively. These particular macros are known to be indication of good, clean water. The percent model affinity index compares the found macroinvertebrates to a theoretical model of a perfect stream. Some pros to using macros as an indicator are the quantitative data regarding what is actually living in the stream. Some macros thrive more easily in bad conditions than others. If no pollution sensitive macros are found, then you can ascertain that the water is not or has not recently been pollution-free. A downside to this method is the difficulty in classifying organisms down to their family. If only one index was used, it has a chance of skewing results. Utilizing multiple indices allows for a more accurate assessment of stream health (Ogren and Huckins 2014). The time scale reflected by this method is also relatively short.

Fish can be a very useful tool for monitoring water quality. Fish can be particularly useful as they help illustrate the biological diversity, or loss of it in degraded waterways (Ganasan and Hughes 1998). For this project fish data was analyzed through the use of an Index of Biotic Integrity (IBI). Fish are counted and identified in the field, then the data is input into the computer where the metric is calculated. Fish measurements although the can be very useful, have a lag time (Shahady 2015). Fish can take years to decades to adjust to disturbances in the water. In this sense they allow a research to gain a deeper understanding of the past and how certain disturbances can affect fish populations and water quality. Finally, this data best serves its purpose when used in conjunction with other metrics and over long periods of time, as this illustrates the most in depth analysis of the stream's health.

Understanding the benefits of each of the water quality parameters aid in determining the general health of a stream. The physical quality indices such as the USM and Rosgen model show the physical health of a river but any major change in the physical quality of a river tends to take decades to manifest themselves. Knowledge of more intermediate indices become useful such as the fish IBI where fish population changes due to a change in water quality can take months to years to manifest themselves rather than decades. Another short to intermediate scale would be the macroinvertebrate indices: EPT, PMA, IBI and FBI. Changes in macroinvertebrate populations tend to take weeks to months to manifest themselves and all these indices individually look into different aspects as to how these populations are changing. When these indices are used together they can give a more detailed picture as to how the macroinvertebrate populations are changing. The most immediate scale is chemistry of the water which can take hours to days to show any changes. These parameters come together by covering the physical, chemical and biotic status of the stream and are used together to give an overall assessment of stream quality.

The general purpose of this study was to evaluate the water qualities in all of the streams in the Blackwater Creek watershed and compare the water quality findings with each different stream. Because all of these streams flow through the City of Lynchburg and into the James River, it is important to know what is having the most impacts on water quality, and where these impacts are mostly coming from. With the amount of urban sprawl and construction going on in Lynchburg and surrounding counties, we expect the water quality to be declining in most of the streams that were sampled. We expect the worse water qualities to be found in the streams that flow through the highly urbanized areas of Lynchburg, and the better water qualities to be found in stream in the least populated areas of Lynchburg and the surrounding counties. Because these streams eventually enter the James River, any deficiencies in water quality can affect the water qualities in the James River and Chesapeake Bay watershed area. Therefore, our goal was to evaluate water qualities at different streams and find out what is negatively impacting water qualities, and inform city and county officials on what they can do to reduce the impacts of water pollution.

Discussion:

In order to fully comprehend the spatial analysis results of the Lynchburg watershed, each individual stream should be compared according to its position in the system. This will be done in order of which they appear in the system, starting with Rockcastle Creek flowing down eventually into Blackwater Creek's Hollins Mill.

Rockcastle Creek is the first section that begins the eventual flow downstream into the main section of Blackwater Creek; Hollins Mill. This creek first drains into Dreaming Creek to be later joined by Tomahawk Creek to create Hollins Mill. Out of the three supplemented rivers, Rockcastle is by far the most polluted. This is evident when the chemistries are compared. Rockcastle has the highest average temperature, pH, and conductivity. This suggests that recent pollution has decreased the quality of the stream substantially (EPA, 2015). On average, Rockcastle has the lowest EPT, PMA, and IBI for macros which implies that the stream has poor water quality (Mandaville, 2002). The fish IBI shows a stream that is fair. However, this is mostly likely due to the longer lag time regarding fish parameters. This means that the stream was once better than it is, but only slightly better.

Further downstream, Rockcastle Creek flows and eventually transforms into Dreaming Creek. This section of the watershed had the highest average nitrate concentration of 0.81 ppm, the same level as Tomahawk Creek. However, Dreaming Creek had the lowest concentration of total phosphorous (0.08 ppm), which is the limiting nutrient (Shahady, 2011). In regard to the macroinvertebrate indices, Dreaming Creek had the second lowest IBI and PMA values. On the contrary, the average fish IBI value was highest for Dreaming Creek. This suggests that the pollution occurred months ago and is travelling up the parameters. Chemical parameters have began to recover, macroinvertebrates are now feeling the effects, and fish have yet to react to it.

Dreaming Creek is then later combined with a neighboring creek called Tomahawk Creek. Of all the sites tested in this study Tomahawk Creek had the highest average temperature (16.7°F) and the highest levels of NO3, tied with Dreaming (0.81ppm). These are indications that the water quality of Tomahawk Creek is declining. Tomahawk Creek ranks in the worst three for the following metrics: conductivity, FBI, EPT, PMA, and both IBIs. The level of pH seems to be insignificant and although dissolved oxygen and total phosphorus levels of Tomahawk are better than most sites, the metrics still represent that the river has been impacted. Tomahawk will soon meet the fate of Rock Castle if nothing is done. All this pollution from these three streams affect one another, and then combine to create a huge impact on Hollins Mill. However, these streams are not the only contributors to the lower Blackwater Creek. Ivy Creek flows into Hollins Mill as well and adds its water quality to that of the previous three. The first section of Ivy Creek, just like Rockcastle, flows down into and affects the different sections downstream. This section is called Upper Ivy Creek at Chaffin Farm.

Chaffin Farm is located in the Upper Ivy Creek subwatershed area which are the headwaters of Ivy Creek itself. Because this location is in a rural setting, water qualities would most likely better than other sites tested downstream in this aspect. However, because a farm is located on both sides of this stream at this location, agriculture may be the contributing factor to water pollution for Ivy Creek because chemicals and livestock waste can easily enter the stream through groundwater and runoff. The data supporting the water quality mostly indicates stream degradation based on the declining trends of the parameters. Even though there are some parameters that show good water qualities, there are more parameters showing degrading water qualities. Major concerns for this stream are chemistries, especially total phosphorus and E. coli. This year, Chaffin Farm had the highest average E. coli value (784.8 cfu) out of all of the other streams sampled. Chaffin farm also had the highest total phosphorus value for this year (0.56mg/L) out of all other streams as well as the highest average total phosphorus values (0.28mg/L) for this site for all of the years this location was sampled (2004-2016). Even though this area is in a rural area of the Blackwater Creek Watershed, the surrounding farm is most likely the contributing factor of giving this location the worst chemistry measurements as well as E. coli from livestock. Therefore agriculture is the contributing factor to water pollution in all of the Upper Ivy Creek subwatershed area.

Chaffin Farm then later extends into Hooper Road, which then becomes the section called Middle Ivy Creek. Through all parameters, Middle Ivy Creek seems to be relatively healthy compared to the other streams in this study. It has the second lowest conductivity measure (52), the highest level of IBI for fish (36.30), and the second highest level of EPT (7.00). Though most of its parameters indicate excellent health, the creek is at risk due to its position in the watershed. Upper Ivy Creek flows directly into Middle Ivy Creek and with it carries all its heavy phosphorus pollution, E. coli bacteria, and sediment run off causing high conductivity.
Middle Ivy Creek then eventually flows down into Peaks View Park, which is also known as Lower Ivy Creek. When all data points are put together and compared, two chemistries and one indice stand out when comparing average Spatial data: total average phosphorus (7.40) and average dissolved oxygen levels (87%), as well as average index of biotic integrity for fish (4.8). This suggests that the section is being heavily impacted from either upstream or on site.
Together with Rockcastle, Dreaming, and Tomahawk, Ivy Creek then flows to create the main section of Blackwater Creek: Hollins Mill. In terms of the water chemistries, Hollins Mill had the 4th highest conductivity (137.08 μs/cm) compared to Rock Castle Creek (223.05 μs/cm) , Dreaming Creek (159.32 μs/cm) and Tomahawk Creek (157.59 μs/cm). Peaks View Park and Hollins Mill Dam have the same nitrate values (0.6 and 0.59 pmm respectively. The mean total phosphorus shows that Hollins Mill Dam had the third highest total phosphorus values (0.11ppm) after Judith Creek (0.22 ppm) and Chaffin Farm (0.28ppm) in Upper Ivy Creek. The average E.coli values showed that Hollins Mill Dam (480.95) had the third highest after Chaffin Farm (784.8) and Peaks View Park (570.25) in upper and middle Ivy Creek. EPT values from Hollins Mill Dam (7.6) appear to be significantly higher than those of the upper Blackwater Creek streams (1.6-3.4) and quite similar to those in middle and lower Ivy Creek (7.9 and 7.6 respectively). The mean PMA show Hollins Mill, Chaffin Farms, Hooper Road, Peaks View Park and Judith Creek having the highest PMA values (above 50) and Rock Castle Creek with a significantly lower PMA (below 10).This pollution and degradation in Hollins Mill is a results of the streams upstream.

Though the previous streams make up the major watershed, another creek was added to the study to compare its health to the relative health of Blackwater. Judith Creek is relatively new to this study. Added in 2015, there are only two data points. This will lead to some skewed averages. In addition, it is only sampled once along its length, not in several locations as the Ivy Creek and Blackwater systems are. Judith Creek has the highest quality water, consistently scoring near the top for each of the indices and chemical indicators. Judith has the best FBI (3.34 – the only 'excellent' rating) score. Other high-ranking scores for this creek include the PMA (2nd best – 64.6), temperature (2nd best – 13.53C), and conductivity (3rd best – 63.5). The Judith system is easily affected by runoff, as indicated by the disparity in the 2015 testing results. This stream must be protected or it will start to decline.

As with the spatial analysis, the temporal study will order the creeks in order they appear in the watershed. However, this research will focus more on their individual trends rather than their effects on neighboring streams. These results will reveal the impacts of pollution and runoff that have been impacting the streams for the past twelve years. The first creek analyzed is that of Rockcastle Creek.

The water chemistries suggest the water quality is poor at the present time, and the water quality in the past was between fair and poor. There has been no significant improvement of Rockcastle water quality. The EPT and the IBIs suggest the water quality is continuing to get worse. The data suggests that water quality was once fair, in 2004, but a decrease in species diversity and low numbers suggest the water quality is getting worse. We can deduce, based on the location and data of the stream, that the urbanization and continued development is severely impacting the water quality of the stream. The stream has changed overtime. It has continued to get worse, and if there are no measures taken, Rockcastle Creek will lose its ability to serve as a stream.

The next stream analyzed is that of Dreaming Creek, which is in turn affected by the downward trend of Rockcastle. In this creek, water chemistry is not alarming, but should continue to be monitored because nitrate levels are slightly high (greater than 1 ppm) and there is a significant decrease in dissolved oxygen. The fish population present indicates poor water quality (Fish IBI 2011-2016 R2 value is 0.92). However, there is a time lag for the fish populations to respond to water quality. Temporal data indicates that the stream has experienced significantly negative impacts in recent past years. In regard to time scale, Dreaming Creek has improved but should be closely monitored to assure that the site does not deteriorate or regress to poor water quality.

The following creek is Tomahawk Creek, whose trend reveals the complicated impact history of the stream. The data for Tomahawk Creek present an overall trend that the water was once subject to pollution, was given some time to recover, and is now subject to pollution again. The IBI of fish has been decreasing since 2009, suggesting that the river was polluted in the past, due to the lag time in fish metrics. The macroinvertebrates suggest that the water quality is good, reflecting the recover time the creek was given. However, the water chemistries which suggest that the river is in fair to poor condition suggest the river is currently being disturbed.

Next is that of Upper Ivy Creek, sampled at Chaffin Farms. Overall, the data supporting the water quality seems to show stream degradation based on the declining trends of most parameters. Even though there are some parameters that show good water qualities, there are more parameters showing degrading water qualities. The parameters showing good water qualities are not listed because they do not support the conclusion. Major concerns for this stream are chemistries, especially total phosphorus and E. coli. Even though this area is rural, with not many people, the only factor contributing to these bad parameters is agriculture. Poor farming techniques such as allowing livestock to enter streams, and excessive doses of fertilizers, pesticides, and herbicides can significantly contribute to water pollution. Waste from livestock directly enters stream when allowing livestock to enter the stream, and indirectly enters streams through groundwater and runoff (engineering.perdue.edu). Agricultural chemicals also enter streams through groundwater and runoff. Therefore agriculture is the contributing factor to water pollution in all of the Upper Ivy Creek subwatershed area as well as everything downstream in Ivy Creek, including Blackwater Creek itself.

The creek then continues into Middle Ivy Creek, whose trend shows that its good health will not last. Though most parameters in the spatial analysis indicated good water quality, the temporal analysis revealed that the water quality is at risk for a heavy decline. Total phosphorus, FBI, and conductivity increased significantly while dissolved oxygen and PMA decreased substantially over the past four years. Conductivity and total phosphorus had significant r squared values of .5044 and .3796. Fish IBI showed no significant trend due to the longer lag-time regarding its reactions of decreased water quality. To reverse this current trend of nutrient pollution, it is necessary to monitor the stream and Upper Ivy Creek to find the source of runoff and limit it.

The following stream section is that of Lower Ivy Creek. The most prominent collections with an r-squared value of approximately 0.3 or higher for the Peaks View Park (the sampling site for the creek) sampling coincide with the Spatial data. Dissolved Oxygen levels within this site are rapidly declining from the first sample in 2004 (108.00) to the sample in 2016 (80.30); Total Phosphorus for this site has been increasing significantly over the past twelve year span. (From a low 0.04 in 2004, to a much higher 0.33 in 2016.); Though the fish populations have fluctuated during some years to produce higher IBI values (such as in 2005 and 2013), there has more frequently been notable drops (such as in 2006, 2009-2010, and 2015-2016) in populations and IBI values.

The last, and perhaps the most concerning section regarding the trend of the Blackwater Creek watershed is that of Hollins Mill. With the macroinvertebrate indices used, there is an increasing overall trend in the EPT and PMA macroinvertebrates but the data for this year shows a decrease and this should be monitored closely in the future. EPT index numbers tend to decrease significantly with an increase of sedimentation in streams (Studinski et al. 2012). The water chemistries hint at increasing sedimentation causing the conductivity to increase significantly since 2002. The chemistries also show sharp increasing trends for the total phosphorus and nitrogen concentrations at Hollins Mill Dam, which also hint at runoff from fertilizer or other sources of manure such as farms upstream. The chemistries also show a decreasing trend in the concentration of dissolved oxygen from 2002 to present which also coincides with the increased conductivity and phosphorus and nitrate concentrations. This trend is revealing a declining water quality and should be monitored and corrected as soon as possible.

Lastly, Judith Creek's trend was analyzed as a comparison to monitor its trends according to its present fair health. As previously mentioned, Judith Creek is too new to the study to rely on any linear regression. This process only works with many different data points. The fact that the data for this stream only exists across two years means that all r-squared values will equal 1, which indicates perfect correlation. This will be diluted in future years as more data is added. The most that can be ascertained with the current data temporally is the severe impact of rain on Judith Creek. Temperature (15.83-11.23 C) and conductivity (70-57 µs/cm) decreased in 2016, a year sampled in the absence of rain. This indicates that the rainwater was running into the stream with a higher sediment load and at a much warmer temperature. This warmer water from the rainy 2015 data carried significantly less dissolved oxygen (59.10-87.70 % saturation), making it harder to sustain life. There was also a significant spike in total phosphorus in 2015 when compared to 2016 (0.35-0.09 ppm). Figure 1, below outlines the rivers tested in this study and the water quality associated with each, based off the data mentioned above.

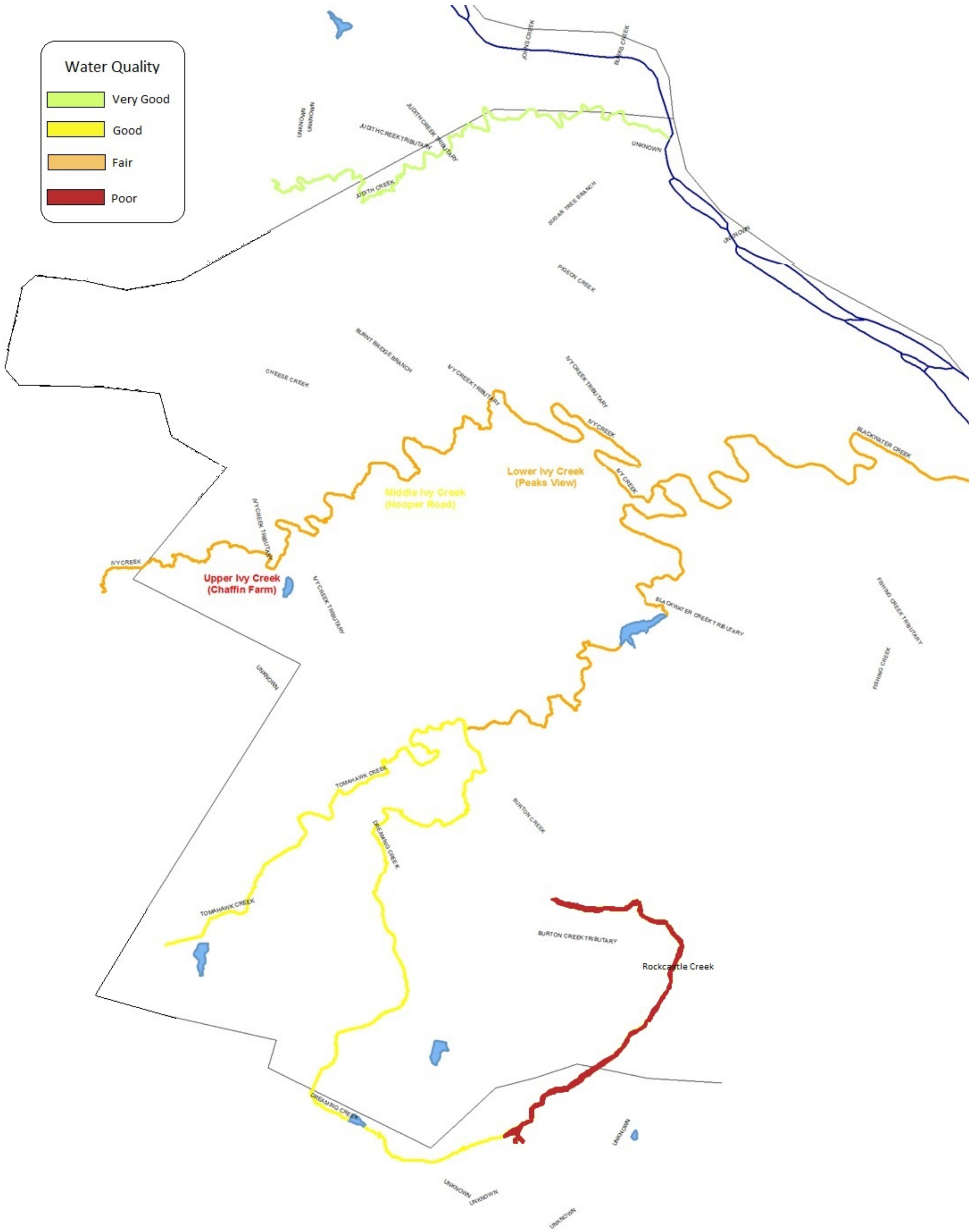

Figure 1. Map of all streams tested in the study and water quality associated with each.

Both spatial and temporal data suggests that most of the watersheds are currently experiencing a downward trend. Upper Ivy Creek, Rockcastle, and Hollins Mill, are already feeling major effects of nutrient pollution and sediment runoff. This will only spread later on to the remaining streams who are on the brink of poor water quality. To save the water quality of each of these streams, it is necessary to first handle those upstream, who flow and directly affect those further downstream. Judith Creek must be maintained at its current state so that the focus may be placed on improving the stressed and declining states of the other streams. Maintaining the quality is a cheaper and more effective process than rehabilitation.

In order to reverse the overall declining health of these sites, the sources of pollution must be found and restricted. In addition, best management practices must be put in place for future construction projects that will contribute to the urbanization of Lynchburg and surrounding areas. Impervious surfaces in high density residential and commercialized areas prohibit groundwater infiltration and contribute to increased amount of water that has come into contact with anthropogenic pollutants and subsequently flows into freshwater streams and rivers (Cho et al. 2009). By looking again to temporal and spatial data, it can be determined where best management practices will be most effective when implemented. Locating the initial point of decline within the trend lines will aid in the restoration and revival of overall water quality.

Limitations of this study could include: yearly weather patterns, inaccuracy of data collection (such as including people who are not as knowledgeable on methods, problematic collection, etc.), absent information, data calculation errors, delayed or nonexistent understanding of information, etcetera. The information that is provided throughout this paper, leads to the conclusion that each site is affected negatively or positively by the site(s) preceding it as well as its ecological location. Keeping in mind the exception of the Judith site, which is affected solely by its surroundings and ecological location. Data suggests that these sites continue to fluctuate yearly, though the average water qualities are overall in a steady decline.

References:

Cech, Thomas. 2010. Principals of Water Resources: History, Development, Management, and Policy. John Wiley & Sons. Hoboken, New Jersey.

Cho, J., Barone V., & Mostaghimi, S. 2009. Simulation of land use impacts on groundwater levels and streamflow in a virginia watershed. Agricultural Water Management, (1), 1.

Frankenberger, Jane. "E. Coli and Indiana Lakes and Streams." Safe Water Publications, n.d. Web. 01 May 2016.

Ganasan, V., & Hughes, R. M. (1998). Application of an index of biological integrity (IBI) to fish assemblages of the rivers Khan and Kshipra (madhya pradesh), India. Freshwater Biology, 40(2), 367.

Mandaville, S. M. (2002). Benthic Macroinvertebrates in FreshwatersTaxa Tolerance Values, Metrics, and Protocols. Halifax, England: Soil & Water Conservation Society of Metro Halifax.

Ogren, S. A. and Huckins, C. J. 2014. Evaluation of suitability and comparability of stream assessment indices using macroinvertebrate data sets from the Northern Lakes and Forests Ecoregion. Ecological Indicators 40:117-126.

Shahady, T. D. (2011). Applied Freshwater Stream Ecology. Virginia Beach, VA: Academx Publishing Services.

Shahady, TD. (2015). Applied freshwater stream ecology (4^{th} Ed.) Lynchburg, VA: Academx Publishing Services, Inc.

Studinski, J., Hartman, K., Niles, J., & Keyser, P. (2012). The effects of riparian forest disturbance on stream temperature, sedimentation, and morphology. Hydrobiologia, 686(1), 107-117.

United States Environmental Protection Agency. (2015, September). Indicators used in the National Aquatic Resource Surveys. Retrieved April, 2016.

United States Environmental Protection Agency. (2016, March) "The Sources and Solutions: Agriculture." *EPA*. Environmental Protection Agency, 1 Mar. 2016. Web. 01 May 2016.