Investigation of Poor Stream Function in the Fishing Creek Watershed

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“We don’t see things as they are, we see them as we are.” – Anais Nin
Executive Summary

The North Carolina Ecosystem Enhancement Program (NCEEP) is a state and federal government program formed between the North Carolina Department of Natural Resources (NCDENR), the North Carolina Department of Transportation (NCDOT) and the U.S. Army Corps of Engineers (USACE). The goal of this collaborative program is to install a watershed planning framework that pre-emptively identifies and implements local projects aimed at restoring and protecting key watershed functions.

During the watershed assessment phase of the Fishing Creek Local Watershed Plan (LWP), created in 2012, the Fishing Creek watershed and its subwatersheds including Fishing Creek and tributaries of Coon Creek and Jordan Creek were identified as potential hotspots of poor water quality and limited stream function.

A clear understanding of stressors and impacts in the Fishing Creek Watershed can assist an enthusiastic local community in identifying, funding, and implementing best management practices to improve the stream system in their own backyards. Stakeholders have expressed concern about the wastewater treatment plant, urban development, conservation easements, protection of endangered plant and animal species, agricultural practices and stormwater. As such, our study takes a multifaceted approach to identify problem areas to and make recommendations for future environmental monitoring.

Using the existing data and information gathered from a number of sources, we re-assessed areas of the Fishing Creek Watershed, with a particular focus on 303 (d) listed waters near the city of Oxford. To conduct our water quality analysis, we employed a 5-pronged approach that included GIS-based models, field evaluations, acute larval toxicity tests, community engagement and a risk assessment. Together, these components provide a holistic understanding of Fishing Creek, Coon Creek and Jordan Creek as well as the surrounding community.

The first section of this report provides a GIS-based analysis focused on pollutant load and conservation priority. Pollution Load (PLOAD) Model, a simplified model that focuses on nonpoint source (NPS) pollution, was used to estimate the pollution level for each subwatershed in our study area. For our conservation priority analysis, a self-developed python tool was used to rank subwatersheds based on their relative importance to a drinking water source.

The second section provides a detailed account of our field observations and subsequent analysis. Specific locations at each sample site were chosen based on proximity to a desired potential hotspot pollution point and access to the stream. We were particularly interested in water quality downstream of the wastewater treatment plant, near Highway 85, and near the emerging industry around Oxford. On three different days we gathered water samples and measured basic water quality parameters.
The third section describes how each of our samples was tested for their acute toxicity and ability to serve as the medium for growth of early life stage fishes. We decided to conduct a preliminary screening test to simply answer the question: “Are our stream samples of sufficient quality to allow for the normal development, growth and survival of Japanese medaka (Oryzias latipes) hatchlings over an acute 96-hour duration?”

The fourth section entails a community survey and audio piece. This survey seeks to complement the other aspects of our research with everyday observations and to assess the public's knowledge and perceptions of water quality in Granville County. Our audio piece also helps to highlight the background of Granville in terms of the natural history of nearby streams, people and industry.

The fifth and last section of the report assesses the potential impact of metals in Oxford Wastewater Treatment Plant effluent on the ecology of Fishing Creek. Using EPA guidelines for ecological risk assessment, we modeled environmental metal concentrations, evaluated potential toxic effects and characterized risk.

Our report makes the following conclusions:

• Geospatial analysis with PLOAD model shows exceedances of total phosphorus and total nitrogen in certain urban and agricultural areas, which may negatively impact downstream water quality.
• Conservation priority analysis indicates that downstream Fishing Creek and Coon Creek are potential conservation areas due to high density of riparian forests, which protect water quality.
• Acute toxicity tests suggest that stream water is generally sufficient to support medaka hatchlings.
• Community surveys reveal a high level of citizen concern, yet limited knowledge and awareness about local streams.
• Risk assessment of metal concentrations in municipal wastewater treatment plant effluent discharging into Fishing Creek indicates a potential risk to aquatic life from copper and zinc.
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Introduction

The North Carolina Ecosystem Enhancement Program (NCEEP), created in July of 2003, is a state and federal government program formed between the North Carolina Department of Natural Resources (NCDENR), the North Carolina Department of Transportation (NCDOT) and the U.S. Army Corps of Engineers (USACE). The goal of this collaborative program is to install a watershed planning framework that pre-emptively identifies and implements local projects aimed at restoring and protecting key watershed functions. NCEEP identified a number of subwatersheds near Oxford, NC that were in need of a Local Watershed Plan. In 2007, preliminary results from 135 stream field evaluations, 32 wetland sites and modeling were conducted by WK Dickson (NCDENR 2012) and elements of this identified ideal areas for stream restoration and preservation opportunities. During the watershed assessment phase of the Fishing Creek Local Watershed Plan (LWP), WK Dickson identified the Fishing Creek watershed and its subwatersheds including Fishing Creek and its tributaries of Coon Creek and Jordan Creek as hotspots of particular interest.

Following this report, project scientists and stakeholders (particularly from the Antioch Community) documented poor stream conditions in lower Coon Creek. According to anecdotal accounts (and to a lesser degree, historic aerial imagery), this part of the watershed had been very clean with abundant fish and wildlife until recent decades (Chien-Hale, 2015). Evidence collected during the LWP assessment suggested that upstream disturbance from road building and neighborhood development may have been responsible for rapid sedimentation in lower Coon Creek. Additionally habitat fragmentation both upstream and downstream may have been responsible for habitat loss and the associated disconnection from source biological populations (NCDENR 2012). The degree to which toxicants or other water quality stressors impacted lower Coon Creek watershed functions was not determined. A clear understanding of stressors and impacts in this locality can assist an enthusiastic local community in identifying, funding, and implementing particular best management practices to improve the stream system in their own backyards (NCDENR 2012).

Stakeholders are primarily concerned with the wastewater treatment plant, urban development, conservation easements, protection of endangered plant and animal species, agricultural practices and stormwater. Concerns raised by stakeholders include sewage at the Oxford wastewater treatment plant or sewage lifts stations. As a result, Oxford recently upgraded their wastewater treatment to mitigate the programs associated with spills from leaky sewer lines and failing lift stations (NCDENR, 2012). As such, the concerns on current water quality in our study mainly are
focused on three aspects: 303 (d) waters located immediately downstream of the wastewater treatment plant, the expansion of urban lands with decreasing forests and existence of a highly erodible soil series in the upstream area. According to EPA, 303 (d) listed waters are impaired or threatened waters which failed to meet water quality regulations. Total Maximum Daily Loads (TMDL) must be designated by local government or organizations to improve water quality. In our study area, about 3.18 km of stream are listed under 303 (d) based on datasets released on February 2014. The 303 (d) listed waters are located immediately downstream of the wastewater treatment plant (WWTP), resulting in heightened community concerns regarding WWTP effluent (Appendix A1). Acute larval toxicity tests and a risk assessment part were conducted to address these concerns.

Moreover, land cover in our study area has been altered significantly in recent years. Land cover type changes can be seen from the graph below (Figure 1). About 9.93% of the watershed was listed as developed land in 1992. The percentage keeps increasing and almost doubled in 2011. Over the same time, the percentage of forest and wetlands dropped significantly (by 15%) due to increased urban development. Forest and wetlands are considered buffers that benefit and maintain higher water quality. Thus, the recent changes in land cover may have had negative impacts. A detailed breakdown of each land cover type in 1992 and 2011 as well as the land use type distribution can be seen in Appendix from A2 to A4.

![Figure 1. Land Cover Type Change (1992 to 2011)](image)

Upstream highly erodible soils bring concern to stream sedimentation. Such soils are defined based on the K factors for the different soil series as described in the NRCS soil surveys (2012). The
Georgeville and Herndon series represent the most significant erodible soils in the watershed and are predominantly located in the headwaters of Coon Creek and Jordan Creeks. Detailed locations can be seen in Appendix A5.

The Fishing Creek Watershed area is under evaluation by the water quality team of Duke University, Nicholas School of the Environment Granville County Cluster. Our group of graduate student investigators is conducting a five-pronged analysis to further examine these initial 2012 LWP findings (NCDENR 2012). Elements of this analysis are: GIS-based analysis, site selection and water sample collection, acute larval toxicity testing on medaka fish hatchlings, community engagement, and a risk assessment. With these tools, this group aims to examine the presence and extent of water quality degradation of Coon-, Fishing- and Jordan Creeks. These three creeks are all contained within the Fishing Creek watershed, located in Granville County. Our study area, the Fishing Creek Watershed covers about 12160 hectares completely contained within Granville County, North Carolina, seen in Figure 2 below.

Collectively we seek to investigate the chemical, hydrologic, structural, and spatial components that contribute to the current conditions of Coon Creek, parts of Fishing Creek and Jordan Creek. Conclusions will help bolster the 2012 LWP findings and document the current water quality stressors present, ultimately assisting the local community in identifying, funding, and implementing best management practices to improve their stream systems.
Figure 2. Study Area
Section 1: GIS Analysis

Geographic information system (GIS) is known as an effective tool in analyzing water quality issues. To further analyze the water quality concerns mentioned above, Pollution Load (PLOAD) Model, a GIS based model which focused on nonpoint source (NPS) pollution was used to estimate the pollution level for each subwatershed in this case. As part of the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) toolset developed by EPA to assist in watershed management and TMDL development, PLOAD Model is a simplified GIS-based tool developed by CH2MHILL to generate annual basis pollution loads from mixed land use types for each subwatershed (Edwards, C. et al., 2001). With less data requirements and vivid results mapping, PLOAD Model has been widely used to estimate NPS problems worldwide. Its high efficiency has been proven by various NPS pollution control projects in U.S., Korea and China (Endreny, T. A. et al., 2003; Lee, K. S. et al, 2008; Shen, Z. et al., 2011).

To serve as the basis of future urban planning and conservation decision making, we also conduct a conservation priority analysis by developing a python-based GIS tool. This tool is used to rank subwatersheds based on their relative importance to a drinking water source. In this case, subwatersheds with strong ability to maintain and improve water quality are considered as areas with highest values and should be considered as conservation priority areas. Subwatersheds vulnerable to pollutants originated from NPS would also be selected for future strategy development.

Methods

Data source

Relevant datasets were collected from various sources to serve as a background information section. These included PLOAD Model analysis and conservation priority analysis. The data sources of this project are listed as below:

1. Background information section
   - **Land use**: Land Cover/Land Use Raster (2011 and 1992 Edition)
   - **Streams**: National Hydrography Dataset (NHD), Flowline (USGS National Map Viewer)
   - **Waterbodies**: National Hydrography Dataset (NHD), Waterbodies (USGS National Map Viewer)
   - **303(d) Listed Waters**: NHDPlus Indexed Dataset (EPA)
   - **Wetlands**: Wetlands (National Wetland Inventory)
**Soils Type:** SSURGO data (USDA NRCS website)

**Roads:** Transportation (USGS National Map Viewer)

**Incorporated Place and County Boundary:** Boundaries (USGS National Map Viewer)

2. **PLOAD Model analysis**

   **Land use:** Land Cover/Land Use Raster (NLCD 2006)

   **Subwatershed Data:** Delineated by using SWAT Model Watershed Delineation Function. 1 arc-second (30m) NED data are retrieved from USGS National Map Viewer to meet the SWAT Model Watershed Delineation Function’s input data requirements.

3. **Conservation priority analysis**

   **Land use:** Land Cover/Land Use Raster (2011 Edition)

   **Streams:** National Hydrography Dataset (NHD), Flowline (USGS National Map Viewer)

   **Ponds:** National Hydrography Dataset (NHD), Waterbodies (USGS National Map Viewer)

   **Wetlands:** Wetlands (National Wetland Inventory)

   **Soil:** SSURGO data (SSURGO Data Downloader)

   **DEM:** 1 arc-second (30m) NED data (USGS National Map Viewer)

   **Roads:** Transportation (USGS National Map Viewer)

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**PLOAD Model analysis**

PLOAD Model was used to estimate the loading of TSS, TN and TP in each subwatershed in Fishing Creek watershed on an annual average basis by using Event Mean Concentrations (EMCs) method. EMCs represent constant pollutant loading value for each landuse type in stormwater runoff. Thus, PLOAD Model takes EMCs values and land use layer as two critical factors to generate the pollutant loading for each subwatershed (Edwards, C. et al., 2001).

The EMCs used in this case were derived from analysis conducted by CH2M HILL in 2002 focused on nutrient overloading problem in Cary, NC for similar weather and hydrologic conditions (CH2M HILL, 2002).
Table 1a. EMCs Used in Fishing Creek Watershed

<table>
<thead>
<tr>
<th>VALUE</th>
<th>LANDUSE</th>
<th>TSS (mg/L)</th>
<th>TN (mg/L)</th>
<th>TP (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Open Water</td>
<td>20</td>
<td>0.6</td>
<td>0.1</td>
</tr>
<tr>
<td>21</td>
<td>Developed, Open Space</td>
<td>40</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>22</td>
<td>Developed, Low Intensity</td>
<td>50</td>
<td>1.2</td>
<td>0.4</td>
</tr>
<tr>
<td>23</td>
<td>Developed, Medium Intensity</td>
<td>80</td>
<td>2.1</td>
<td>0.6</td>
</tr>
<tr>
<td>34</td>
<td>Developed, High Intensity</td>
<td>170</td>
<td>3.2</td>
<td>0.6</td>
</tr>
<tr>
<td>31</td>
<td>Barren Land</td>
<td>80</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>41</td>
<td>Deciduous Forest</td>
<td>60</td>
<td>0.9</td>
<td>0.4</td>
</tr>
<tr>
<td>42</td>
<td>Evergreen Forest</td>
<td>60</td>
<td>0.9</td>
<td>0.4</td>
</tr>
<tr>
<td>43</td>
<td>Mixed Forest</td>
<td>60</td>
<td>0.9</td>
<td>0.4</td>
</tr>
<tr>
<td>52</td>
<td>Shrub/Scrub</td>
<td>60</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>71</td>
<td>Herbaceous</td>
<td>60</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>81</td>
<td>Hay/Pasture</td>
<td>60</td>
<td>1</td>
<td>2.1</td>
</tr>
<tr>
<td>82</td>
<td>Cultivated Crops</td>
<td>500</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>90</td>
<td>Woody Wetlands</td>
<td>80</td>
<td>1.1</td>
<td>0.2</td>
</tr>
<tr>
<td>95</td>
<td>Emergent Herbaceous Wetlands</td>
<td>100</td>
<td>1.1</td>
<td>0.2</td>
</tr>
</tbody>
</table>

The pollutant load for each subwatershed is estimated in pounds per acre (lb/acre). Observed data from USGS Station O0310000 and O0600000 should be used to conduct a calibration. However, data retrieved from USGS were very limited and cannot be treated as annual average value as required by calibration. Without complete calibration, the values of results are used to provide the pollutant-loading trend and highlight those areas with severe water quality problems.

Conservation Priority Analysis

Slope, land use types, proximity to streams, ponds and wetlands, soil and forest between roads and stream water are taken into consideration to select subwatersheds with highest conservation value in protecting drinking water sources. Components in each layer are scored based on their impacts on water quality. High score was assigned to positive impacts while low score was assigned to negative or neutral impacts. Subwatersheds were ranked by their average scores, and those with high scores were selected as priority conservation areas. Scores derived and used in our calculations are discussed in following sections.
The script of this tool is attached in Appendix B1.

Figure 1a. Workflow of Conservation Priority Analysis Tool.

1. Score

1) Landuse/Landcover

Forest and Wetland are important in maintaining water quality. They are effective in trapping and intercepting nutrients and sediments originating from non-point pollution source, such as crop land. Thus, high scores were assigned to forest and wetland while lower score was assigned to crop land. The final score for different landuse types in Fishing Creek Watershed can be seen as Table 1b below.

Table 1b. Score for different landuse types

<table>
<thead>
<tr>
<th>Landuse Type</th>
<th>Water/Ice</th>
<th>Open Land</th>
<th>Developed</th>
<th>Bare Land</th>
<th>Forest/Wetland</th>
<th>Shrub</th>
<th>Herbaceous</th>
<th>Hay/Pasture</th>
<th>Crop Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

2) Streams, ponds and wetlands

According to Hawes and Smith’s study (2005), riparian buffer with 16 to 164 feet width is effective in removing nitrogen and phosphorous. Buffer with 49 to 328 feet width is effective in
removing pesticides. For biocontaminants, 30 feet buffer may be helpful. Thus, threshold for proximity to streams, ponds and wetlands were set as 30 feet (10 meters), 164 feet (50 meters) and 328 feet (100 feet). Usually, proximity between 10 meters and 50 meters receives the highest score. The final scores for different proximity to streams, ponds or wetlands in Fishing Creek Watershed can be seen as Table 1c below.

Table 1c. Score for proximity to streams, ponds or wetlands

<table>
<thead>
<tr>
<th>Proximity to streams, ponds or wetlands</th>
<th>&lt;10 meters</th>
<th>&gt;10 meters and &lt; 50 meters</th>
<th>&gt;50 meters and &lt; 100 meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>7</td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>

3) Soil

Soil with high permeability provides greater flow filtration and traps more pollutants (Hawes, E. et al, 2005). In contrast, soil with low permeability usually has little filtration effect. However, based on Hawes and Smith’s study (2005), soil made up of sand may drain water rapidly, which makes the roots of vegetation unable to effectively trap pollutants. Thus, the highest score was given to the soil with medium high permeability. Soil permeabilities were decided by hydrologic soil type. Soil can be classified as “A”, “B”, “C”, “D” and mixed types such as “A/D”. “A” is the soil with highest permeability while “D” is soil with lowest permeability (NRCS, U. 2012). The final score for different soil permeability in Fishing Creek Watershed can be seen in Table 1d below.

Table 1d. Score for soil permeability

<table>
<thead>
<tr>
<th>Soil Permeability</th>
<th>High Permeability</th>
<th>Medium High Permeability</th>
<th>Medium Low Permeability</th>
<th>Low Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>3</td>
<td>10</td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>

4) Slope

According to Keith’s study (2010), steep slopes would bring some negative effects to water quality. Steep slope may shorten the time for roots to trap pollutants since the flow velocity increases. Thus, steeper slopes received lower scores.

Table 1e. Score for slope

<table>
<thead>
<tr>
<th>Slope (Degree)</th>
<th>&lt;10</th>
<th>&gt;10 and &lt;25</th>
<th>&gt;25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>10</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

5) Water-Forest-Roads (Gregory, P. E., 2007)
Forests between roads and streams are important in maintaining water quality. Forests can be treated as an effective barrier to protect streams from pollutants originated from roads. In this case, forests within 60 meters of streams and roads are selected. They were considered as the buffer forests. All these forests were given high scores. In this case, all the Water-Forest-Roads are assigned 10 as score.

2. Weight

In this case, we gave ponds and wetlands a lower weight as 0.5 since these two layers usually have huge overlapping areas. The rest layers are weighted equally as 1. Therefore, the highest score of Fishing Creek Watershed Land is 60 while the lowest score is 0.

Results

PLOAD Model analysis

Figure below indicates the trend of pollutant loading.

![Figure 1b. Pollutant loading trend of Study Area (Full Maps can be found in Appendix B2 to B4.)](image)

For total suspended solids, high loading areas include Coon Creek, Jordan Creek Hachers Run and especially upper stream of Fishing Creek and Urban Area. To discuss total nitrogen and total phosphorus overloading problem, we would take Tar Pamlico Stormwater Rule (NCDENR, 2001) as
a reference. For TN, the results ranged from 0.45 to 4.97 pounds per acre while the threshold provided by Tar Pamlico Stormwater Rule is 4 pounds per acre. The only exceeding subwatershed located at western part of Oxford City, which can easily be seen from Figure 1b. Compared to TN, TP overloading problem is much more severe. The threshold for TP loading is only 0.6 pounds per acre while the TP results range from 0.3 pounds per acre to 1.3 pounds per acre. TP overloading may arise in upper Coon Creek, Jordan Creek, Hatchers Run, upper Fishing Creek and urban areas.

*Conservation Priority Analysis Results*

![Conservation Priority Score for Subwatersheds in Fishing Creek Watershed](image)

**Figure 1c.** Results of conservation priority analysis
The conservation priority score for Fishing Creek Watershed ranged from 0 to 60 with a mean of 28.64. Results indicated that downstream of Coon Creek, downstream of Fishing Creek, upstream of Jordan Creek are the subwatersheds with highest scores and would be considered as priority conservation areas. Trends showing the lower ranked conservation watersheds included the central part of the watershed, Hatcher's Run and urban areas. Those areas were relatively vulnerable to pollutants and were characterized by low ability to maintain water quality.

**Discussion**

*Pollution sources*

PLOAD Model results indicated that most subwatersheds with high pollutant loading were located near city of Oxford. Potential pollution sources included: sentiment from highly erodible soil in upstream, irrigation flow from farm land and the effluent from the wastewater treatment plant (WWTP). However, the likely possible pollutant source is stormwater runoff from Oxford City. Flowing over impervious surfaces, stormwater runoff from city of Oxford may contain debris, chemicals, sediments and other pollutants and bring them to surrounding subwatersheds, which results in the high loads of TN, TP and TSS. And based on the results from conservation priority analysis, the ability for those subwatersheds to protect themselves from pollutants is very limited. Strategies must be developed to prevent pollutants and increase water quality. Considering main pollution sources discussed above, developing stormwater management strategies would be effective and necessary.

*Stormwater management strategies*

According to EPA’s Stormwater Management Actions, Best Practices and Techniques were widely used nationwide (EPA, 2013) and could be applied in this case. To better combine techniques with existing buildings, public space and urban planning, we focused on rain gardens, green parking and permeable paver techniques.

Rain garden’s retention ability on some nutrient is proved by Dietz’s study (2007) showing that TKN, NH₃–N were well retained, by over 70 percent. Davis et al (2009) assessed bioretention technology and strongly supported the use of this approach for: suspended solids, heavy metals and used oil. These substances appeared to be removed efficiently by bioretention technology, i.e., rain garden in this case.
According to EPA’s definition (2012) green parking uses the combination of techniques to reduce its potential negative impacts on environment. In further review, this appears to be attracting attention worldwide and designs, some using innovative products included: Zhao’s (2007) green parking garage combined with greening interlaced as courses between solid parking garage structure to increase the parking space while maintaining permeable greening area; Ahn (2012) developed an artificial greening system which can be installed inside structures of parking lots to drain and treat stormwater; Ohashi (2014) focused on greening material installed on parking lot thereby providing more shadow and reduced temperature.

For permeable pavers, Dietz (2007) proved they were effective in trapping all the measured pollutants, including TSS, NO$_3$–N, NH$_3$–N, TKN, TP, Cu, Pb and Zn. Brattebo and Booth (2003) claimed that permeable pavers were effective in filtrating water since almost no surface runoff was observed after a storm event in their study. Water quality improved significantly after infiltration by reducing copper and zinc concentration as well as removing motor oil.

Since the efficiency and reliability have been proved by study and research, strategies may be developed that integrate these three and other promising techniques as solutions for the overloading problem surrounding city of Oxford. Permeable pavers and rain gardens could be built in open spaces or planning areas to give runoffs a thorough filtration after storm events. And stormwater runoff in parking lot could be conveyed by artificial greening system to nearest permeable pavers or rain garden.

**Limitations**

While the PLOAD Model works great in providing the pollutant loading trend and highlighting the area with severe water quality problem, it does have several limitations as discussed below.

- **No time components.** Generally, PLOAD is only available for generating annual average basis results. Without time components input, PLOAD Model works as a single-event model and fails to reflect seasonal change or daily change as might be expected in individual rain events.
- **Credibility of EMCs values.** The determination of EMCs values is completely based on personal experience and literature review. Under most circumstances, researchers do not have specific project experience focused on EMCs values, which may lower the credibility of their PLOAD results.
• Difficulty in calibration. Since PLOAD Model generates average annual basis results, we usually use annual average observed data to conduct calibration. However, available continuous water quality data from monitoring stations are very limited. Most water quality data for TN, TP and TSS are non-continuous and vary significantly from season to season. The annual average observed data derived from those water quality data are invalid and cannot be used to conduct calibration.

Limitations of the self-developed Conservation Priority Tool can be seen as below:

• The determinations of score and the weight of each input layer is highly dependent on personal experience. Though default score and weight for each input layer have been provided, users still need to make some adjustment to meet the requirements of different projects. Different from PLOAD Model, there is no literature available to serve as a reference in this case, which brings more concerns on this tool’s credibility.

• Not user friendly. It is hard for beginners to use a GIS tool with more than 40 inputs. A separate tool which focused on layer inputs may be developed to solve this problem.
Section 2: Site Selection and Water Sample Collection

Methods

Seven sample sites were strategically chosen, identified to be areas of probable water quality deterioration. Marshall Floyd, a longtime resident of the Antioch Community, accompanied our team. Specific locations at each sample site were chosen based on proximity to a desired potential hotspot pollution point and access to the stream. We were particularly interested in stream quality downstream from the wastewater treatment plant, near Highway 85, and near the emerging industry around Oxford.

On October 15, 2014, January 11, 2015, and January 15, 2015 the water quality cluster at Duke University collected field samples surrounding the Antioch Community in Granville County, North Carolina. The October sample was collected during a fall dry period. The following two samples were collected during the winter. The January 15th sample was taken immediately following a rain event. We collected water samples from seven distinct sites (Table 2a), identified to be potential toxicity hotspots (Figure 2a).

Upon arrival at a site, GPS coordinates were recorded using GPS Trimble so that samples could be collected from as near to the exact place as possible each time. Important information such as: date, time of collection, weather, water temperature, conductivity, dissolved oxygen content, and any major observations of the surrounding area were recorded (Appendix C1). At each of these sites we collected 6 samples of 50 mL each. Each container was carefully rinsed with stream water before water collection. We collected 50 mL by placing the container just under the water subsurface, attempting to avoid sediment collection as much as possible. Containers were filled to the rim obviating headspace, capped to prevent release of any volatile substances, and then placed in a wet ice cooler for transport to the laboratory. Upon arriving at the laboratory, samples were stored in a dark storage room at 4°C until use.

Water samples from 1/11/15 and 1/14/15 were used in acute toxicity testing. They were also sent to Duke University’s River Center to be analyzed for ammonium, phosphate and nitrate levels. While samples should be analyzed within 24 hours, our water samples were held for several weeks before analysis. The location of each site is provided in Table 2a below.
## Sample Site Locations

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Description</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PE</td>
<td>Post-effluent</td>
<td>-78.5875</td>
<td>36.2712</td>
</tr>
<tr>
<td>2</td>
<td>PI</td>
<td>Pre-industrial</td>
<td>-78.5639</td>
<td>36.3145</td>
</tr>
<tr>
<td>3</td>
<td>WW</td>
<td>Wastewater</td>
<td>-78.5911</td>
<td>36.2769</td>
</tr>
<tr>
<td>4</td>
<td>FC</td>
<td>Fishing Creek</td>
<td>-78.5807</td>
<td>36.2556</td>
</tr>
<tr>
<td>5</td>
<td>HW</td>
<td>Highway</td>
<td>-78.5670</td>
<td>36.3026</td>
</tr>
<tr>
<td>6</td>
<td>JC</td>
<td>Jordan Creek</td>
<td>-78.5717</td>
<td>36.3211</td>
</tr>
<tr>
<td>7</td>
<td>PRE</td>
<td>Pre-effluent</td>
<td>-78.5911</td>
<td>36.2770</td>
</tr>
</tbody>
</table>

**Table 2a.** Each of the identifying characteristics for collection sites are provided along with latitude and longitude.

A map of the collection stations is shown in Figure 2a below. The map also provides a view of the three streams of interest—Jordan, Coon and Fishing Creeks. The map highlights these local streams proximity to Highway 85 and the outfall of the effluent from the City of Oxford WWTP. Our particular stretch of interest, the 303 (d) listed waters are denoted in red. Hachers (or “Hatchers”) Run is another local stream. Although not identified as a likely area of water quality deterioration, it has been included in this map for reference.
Figure 2a. Sampling Sites
Results

Site Selection and Water Sample Collection

Observations are recorded in Figure 2b and Figure 2c. Observed dissolved oxygen levels did not fall below 7.28 mg/L. Conductivity values ranged from 52.4 to 459 µs.

Ammonium, phosphate, and nitrate levels, analyzed by staff at Duke University’s River Center, are seen below. However, only nitrate was above the detection limit and this was consistent in all samples.

River Center Analysis Results

<table>
<thead>
<tr>
<th>Site</th>
<th>Date</th>
<th>NH4-N (mg/L)</th>
<th>PO4-P (mg/L)</th>
<th>NO3-N (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE</td>
<td>1/11/15</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
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<tr>
<td>PI</td>
<td>1/11/15</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.418</td>
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<tr>
<td>WW</td>
<td>1/11/15</td>
<td>&lt;0.01</td>
<td>0.0121</td>
<td>1.85</td>
</tr>
<tr>
<td>FC</td>
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<td>&lt;0.01</td>
<td>&lt;0.01</td>
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<tr>
<td>HW</td>
<td>1/11/15</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.47</td>
</tr>
<tr>
<td>JO</td>
<td>1/11/15</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.538</td>
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<tr>
<td>PRE</td>
<td>1/11/15</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.746</td>
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</table>

<table>
<thead>
<tr>
<th>Site</th>
<th>Date</th>
<th>NH4-N (mg/L)</th>
<th>PO4-P (mg/L)</th>
<th>NO3-N (mg/L)</th>
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</thead>
<tbody>
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<td>&lt;0.01</td>
<td>1.09</td>
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<tr>
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<td>1/14/15</td>
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<td>0.0104</td>
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<tr>
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<td>&lt;0.01</td>
<td>4.15</td>
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<tr>
<td>FC</td>
<td>1/14/15</td>
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<td>&lt;0.01</td>
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<td>&lt;0.01</td>
<td>0.403</td>
</tr>
<tr>
<td>JC</td>
<td>1/14/15</td>
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<td>&lt;0.01</td>
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<tr>
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<td>1/14/15</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.589</td>
</tr>
</tbody>
</table>

Table 2b and 2c. NH4, PO4 and NO3 levels measured on collection dates 1/11/15 and 1/14/15

Discussion

Streams typically vary in dissolved oxygen levels depending on external factors such as temperature, altitude, turbidity, and seasonality. Low dissolved oxygen levels can result in a harm or death to aquatic animals such as fish (EPA 2012a). According to the EPA, long periods of DO below 5 mg/L can harm larval life stages for many fish and shellfish species (EPA 2000b). Field observations from the 7 field sites over 3 different days did not record DO levels lower than 7.28 mg/L.

Conductivity measures the ability of water to pass an electrical current. Conductivity can vary depending upon temperature and the presence of various ions in water. The conductivity of rivers in the United States generally ranges from 50 to 1500 µs/cm, well within our data range from 52.4 to 459 µs (EPA 2012c).

Ammonium (NH4), nitrate (NO3) and phosphate (PO4) levels were low or non-detectable. Nitrate was detected in all samples, ranging from 0.262 to 4.15 mg/L, well below the maximum contaminant level goal (MCLG) of 10 mg/l for drinking water set by the EPA (EPA 2010d). Nearly
all phosphate levels were undetectable with the exception of 0.0121 mg/L at the WW site on 1/11 and 0.0104 mg/l at the PI on 1/14 (Table 2b and 2c). The EPA states that phosphate should not exceed .05 mg/l if streams discharge into a lake or reservoir. Surface waters with phosphate levels between .01 and .03 mg/l tend to resist formation of algal blooms (NCSU). This statement was confirmed by our observations at sites noted for detectable phosphate. All samples were below the level of detection for ammonium.

Typically, the hold-time for water samples should no be more than 24 hours. In our case, samples were stored in the fridge for a few weeks. This longer hold time could have contributed to the fact that ammonium and phosphate values were largely below the level of detection. So while informative, these values may not accurately represent the constituents in the water, especially considering the results from the PLOAD model.
Section 3: Acute Larval Toxicity Tests

Methods

Samples were tested for their acute toxicity and ability to serve as the medium for growth of early life stage fishes. Streams in the Fishing Creek watershed are known to contain various macro and micro invertebrates, including freshwater mussels, which make up the food web for larger animals (NCDENR, 2012). Another reason to inspect biota within the sampling sites is the fact that fish provide an important means of attachment of early life stage freshwater clams. These forms often attach to gill surfaces providing an optimal site for development prior to their dropping into the water and attaching to substrates (Neves and Widlak, 1987). Due to the potential toxicity of our specific locations, we decided to conduct a preliminary screening test to simply answer the question: “Are our stream samples of sufficient quality to allow for the normal development, growth and survival of Japanese medaka (Oryzias latipes) hatchlings over an acute 96-hour duration?” To answer this question, we used the Hinton Lab’s established colony of small medaka aquarium fish and modified established methods from the United States Environmental Protection Agency’s (EPA) Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms and Fish Early-Life Stage Toxicity Test Duke Institutional Animal Care & Use Committee (IACUC) protocol numbers: A062-15-02 and A031-15-01. The design for our acute larval toxicity tests was developed in part from Galus (2013) who exposed fertilized embryos to low and high treatment concentrations. Survivors were assessed for major developmental abnormalities such as spinal cord deformations, pericardial edema, yolk sac edema, and stunted growth (Galus, 2013). The 2006 Zha study also influenced our experimental design. In that study, embryos were used and exposed to a range of effluent concentrations at <4h after fertilization. Our hatchlings were accordingly exposed to 100% effluent and the individuals were monitored daily for 96 hrs.

Duke University’s Intuional Animal Care and Use Committee has approved the animal care of the Hinton orange-red medaka breeding colony (DUIACUC A062-15-02 and A031-15-01). Adult fish are typically maintained in closed recirculating water conditions at approximately 24°C under a 14:10 light: dark cycle. Adult fish are fed dry food daily (Pentair Aquatic Eco-Systems, Otohime B1 diet, 200-360 microns, T2360) and artemia nauplii (Pentair Aquatic Eco-Systems, 90% Great Lakes Strain [GSL], BS90). Embryos are collected approximately 30-60 minutes after morning feedings, cleaned and separated, and maintained in Petri dishes in a 26°C incubator until hatch. This species of
fish is commonly used in the laboratory because of their sensitivity to toxicants, and high tolerance for salinity and temperature changes. They also have a transparent chorion, high fecundity, and they undergo rapidly development (Iwamatsu, 1994).

For our tests, we carefully transferred medaka hatchlings 24-48 hours post-hatch into six-well micro-titer plates for all seven samples, from each of the individual collection trips. Five of the six wells, each with a total capacity of 16.8 mL, were filled with 5 mL total solution used for test. Three wells contained “treatment” or sample water. The remaining two wells contained embryo-rearing medium (ERM-control) made from diluted 0.3% w/v of artificial seawater.

A total of 10 medaka hatchlings were added to each of the wells. During the test, daily replacement of 4 mL of treatment and control water was conducted and each fish was fed a single brine shrimp daily, following the first 48 hours of the test. Plates were maintained in an incubation tray heater set to 28.6°C. Hatchlings were observed daily for major developmental abnormalities and survival. Mortality was denoted by no reaction to gentle prodding. Dead fish were immediately removed from the well (EPA 2002a).

Following the toxicity tests, we compiled the data for each of the sample site locations, for each of the three sampling days, according to EPA protocol (EPA 2002a). A test “passes” if survival in both the control and treatments equals or exceeds 90% (EPA 2002). The test “fails” if survival in the treatment wells proved significantly different from the control survival rate. One-tailed t-tests were calculated to generate p-values that gave us some additional insight about whether or not surrogate stream organisms, i.e. medaka hatchlings, may be impacted by wastewater and industrial effluent in the streams surrounding the Antioch Community. The test effects were also intended to indicate what might be in the water—metals, ECs, etc.

**Results**

In the lab, we implemented comparison of means t-tests to examine water quality in stream waters within the Fishing Creek watershed. Through our analysis we aimed to determine whether survival rates within the control were greater than the survival rates of medaka in the treatment. We analyzed water quality data from field data collected on October 15th, 2014, January 11th, 2015 and January 14th, 2015. As seen in the Appendix, our raw data is heavily skewed, with survival rates hovering around 100%.
We are interested in whether the treatment data survival (%) mean is significantly less than the survival (%) mean of the control. Stream water at six out of seven sample locations in these streams is of sufficient quality to support medaka fish hatchlings for a 96-hour period (p > 0.05) with no major developmental abnormalities. One location, the Fishing-Coon confluence site has a p-value of 0.05 indicating that the mean of the control may be significantly greater than the mean of the treatment (Table 3a).

T-Test, Survival Rate
- Ho: There is no significant difference between the means of survival in the control and survival in the treatment
- Ha: There is a significant difference between the means of survival in the control and survival in the treatment at the 5% or 0.05 significant level.

T-Rest Results

<table>
<thead>
<tr>
<th>Site</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE</td>
<td>0.13</td>
</tr>
<tr>
<td>PI</td>
<td>0.38</td>
</tr>
<tr>
<td>WW</td>
<td>0.16</td>
</tr>
<tr>
<td>FC</td>
<td>0.05</td>
</tr>
<tr>
<td>HW</td>
<td>0.14</td>
</tr>
<tr>
<td>JC</td>
<td>0.12</td>
</tr>
<tr>
<td>PRE</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Table 3a. Level of significance at each of the seven sample locations

Discussion

According to our one tailed t-test of survivability, six out of seven of our sample locations were of sufficient water quality to support the growth and development of medaka hatchlings over an acute duration (Appendix D). Fishing-Coon confluence was not sufficient as indicated by the significant p-value of 0.05. While this could be a result of experimental error, this was also our most downstream sample. Also, if you look at Appendix D4, it is clear that the survival rate of hatchlings drops significantly in 1/14 sample following the first day of treatment. The 1/14 water samples were collected immediately following a rain event, perhaps causing an influx of pollutants to discharge into surface waters or into the streams near Oxford.

According to EPA’s WET method (EPA 2000b), in order for test results to acceptable, survival of the control fish used, in this case, medaka, must equal or exceed 90%. It must be noted
that this is not true for all of our tests (Appendix D), and according to EPA guidelines, results should be deemed invalid and tests be repeated (EPA 2002a).

A number of external factors could also affect the results from the acute toxicity tests. Factors that could affect success (survivability) include: the experience of the investigator, the age of the fish and the quality of the test organisms could have also varied from well to well. Hatchlings were transferred to six-well micro-titer plates, 24-28 hours post-hatch. While we tried to be consistent, there were occasional discrepancies in the ages of the fish used in the tests by one day or two days. Temperature was carefully controlled per animal protocol (EPA 2002a).

Advantages of our acute larval toxicity tests methods included: ease of testing, use of minimal additional equipment and relatively short time. These tests provided a measure of instantaneous toxicity, not masked by dilution methods. However, because the samples are collected infrequently and over such a short period of time, they may not necessarily be representative of the stream water on a day-to-day basis (EPA 2002a). These tests also fail to give any specific details as to the actual toxicants present in the water, but merely just serve as a screening tool (EPA 2002a).

The EPA often uses these tests as means to control discharge of contaminants into surface waters and to provide a warning sign of major water quality degradation. These tests, while an important indicator test, are often used in conjunction with a number of other monitoring tools (EPA 2002a).

Future tests and quantitative analyses are warranted to provide an estimate of the degree and types of toxicity. Importantly, conducting toxicity tests would enable us to determine how individuals grown and behave in such water. More chronic tests could be performed in which the relative abundance of appropriate nutrition could be assessed. Also, actual exploration of streams at various sites for type and abundance of macro invertebrates and/or micro-invertebrates would be informative. Finally, autopsies of selected fish might prove to indicate the relative health of individuals.
Section 4: Community Survey and Audio Component

Methods

In addition to assessing the water quality at our chosen sites, we also sought Institutional Review Approval for a community survey, thereby involving the local community as an active part of the stream evaluation process. The stream condition survey contained questions (Appendix F1) to complement the other aspects of our research with everyday observations and to assess the public's knowledge and perceptions on water quality in Granville County. Our academic advisor, David Hinton, primarily distributed the surveys through well-connected members of the community that have attended meetings of the Granville County Environmental Affairs Committee or have served on the local Antioch Fire Department. Respondents were encouraged to inform us of their displeasure with stream quality and related attributes in the Antioch Community of North Carolina. In addition, County commissioners, whose districts include areas of the watershed under analysis, were asked to distribute questionnaires to residents. Completed surveys were returned by mail to the Hinton Lab mailbox located in Environment Hall, Nicholas School of the Environment, Duke University. Respondents were permitted to skip questions, or respond with multiple answers if desired. Using survey responses, we are able to infer community trends that can be used to guide environmental managers and local community members in implementing the most effective water resources management strategies going forward.

An audio piece documenting the historical evolution of the Granville area was also created to complement this community survey. Key members of the Granville County community including Neil Gresham, Tony Santangello, Joel Ostby, David Hinton, Marshall Floyd, Frank McKay and Paul Westfall were interviewed. These members have shared the Fishing Creek watershed for many years. The audio piece highlights the background of Granville in terms of the natural history of nearby streams, people, and industry. It also touches upon potential water quality issues going forward.

Results

52 members of the community responded to our stream quality survey. Respondents were permitted to skip questions, or respond with multiple answers if desired. Survey respondents are 54% female and 46% male (Appendix E1). 48% of these of these respondents are between the ages of 60-69 with 88% of the total being above the age of 60 (Appendix E4). 86% identify as African American
(Appendix E2). Nearly all, or 96%, have lived in Granville County for more than ten years, with most of these respondents having lived in Granville Country their entire life (Appendix E3). 84% either strongly agree or agree that access to clean drinking water is a right (Appendix E6). Over 90% of people are on well water. Most people drink water from both faucet and bottled sources. If people were unsure of where their water was coming from, they were more likely to drink bottled water. 34% had no opinion one-way or the other (Appendix E7). Around 80%, the majority of people, reported living within one mile of a stream (Appendix E9). Of these, more than 62% of these lived near Coon Creek and 38% lived along Fishing Creek. Along Coon Creek, a majority of residents reported seeing foam floating on surface water either a few times a year or once every couple of years. Litter being carried by a stream was most commonly observed more than a few times a year. Flooding was witnessed only a few times a year (Appendix E10). In comparison, folks living along Fishing Creek do not seem to have consistent observations. In general, people do not have an opinion regarding foam sightings—some residents report seeing foam floating on surface waters more than a few times a year, while other residents never observed foam. Litter is generally seen every time people are near a stream. Most people never observe the flooding of Fishing Creek (Appendix E11).

56% of respondents believed that stream quality in Oxford has degraded somewhat to greatly over time (Appendix E5). Similarly, 47% believed that water quality in Granville County has declined in the time respondents have lived in or worked in the area (Appendix E8).

The audio piece can be listened to at https://soundcloud.com/miranda_ch/final-piece2.

Discussion

Results from the survey indicate that water quality in the streams of Granville County is generally perceived as good. However, there are clear concerns about protecting local streams, as water quality is perceived to have decreased over time. Very few people drink directly from their well, there are worries about litter, coal ash, and the leachate being processed at the wastewater treatment center. There are also obvious distinctions in responses between local streams such as Coon Creek and Fishing Creek. It was also striking how few people noted the value the streams brought to their lives.

While informative, there were some inherent biases in the survey. The city of Oxford has a population of 8,695 people and median age is 41.4 years old, as compared to North Carolina’s median age of 45.5 years. 44% of the city population is white, 51% is African American and 5% falls under
“other” (City-Data). As such, it is clear that the 52 responses to our survey is slightly biased towards an older African American group that is not necessarily representative of the greater population of Oxford, NC (Idcide). However, they may be more reflective of the Antioch Community. Survey methods--including “distributing to known leaders of the community” may have also contributed to inherent biases in our results. This may have also added to the quality of the responses, as most respondents have observed these streams over most, if not nearly all, of their lives.
Section 5: Ecological Risk Assessment of Metals in Oxford Wastewater Treatment Plant Effluent

Introduction

Two reports released in 2005 and 2007 from the North Carolina Department of Natural Resources (NCDENR) documented poor water quality in Fishing Creek, fueling concern among citizens and governing bodies about effluent discharges into Fishing Creek from the City of Oxford’s municipal wastewater treatment plant (WWTP) (NCDENR 2005, NCDENR 2007). The release of these reports coincided with a large renovation of the WWTP’s infrastructure and pretreatment techniques, which improved the WWTP’s compliance status with state and national discharge regulations (City of Oxford 2013). Water quality in Fishing Creek has not been reassessed since these improvements to the WWTP, and concern persists about the potential for effluent to adversely impact the ecology of Fishing Creek despite greater regulatory compliance by the WWTP.

An ecological risk assessment utilizes data from environmental measurements and the scientific literature to quantitatively determine the risk of adverse effects posed by a given human activity to living organisms (EPA 2015). As described in the EPA’s Framework for Ecological Risk Assessment, an ecological risk assessment consists of three phases: problem formulation, analysis, and risk characterization. Problem formulation includes identification of the environmental values to be protected and development of a conceptual model of how exposures may occur and affect living organisms. The analysis phase consists of two components: characterization of environmental exposures to stressors and characterization of effects. Risk characterization integrates exposures and effects from the analysis phase to determine the degree to which a risk is present (EPA 2015). Throughout the risk assessment, uncertainties are communicated, and where necessary, conservative assumptions are made to provide adequate protection of living organisms. Risk assessment should serve as a basis for environmental decision-making and can be used to identify threatened resources and areas where further data collection is needed (EPA 2015).

Problem Formulation

Facility Description

The city of Oxford’s WWTP in Granville County, NC processes a combination of industrial, commercial, and domestic wastewater. It is permitted by the North Carolina Department of Environment and Natural Resources (NCDENR) to discharge 3.5 million gallons per day (MGD) of
effluent into Fishing Creek. The WWTP’s current flow scheme includes mechanical screening, influent pumps, aerated grit chambers, a three stage oxidation ditch featuring anaerobic, anoxic and aerobic zones to facilitate the removal of nutrients from the treated discharge waters, three secondary clarifiers that operate in parallel, a traveling bridge tertiary filter to meet total suspended solids and BOD limits, UV disinfection chambers for the removal of disease causing organisms, and mechanical aeration (City of Oxford 2014).

Under the National Discharge and Pollution System (NPDES), NCDENR enforces water quality limits and sampling/monitoring requirements for wastewater effluent. Twenty-seven constituents, including 11 metals, are tested in the wastewater effluent at various frequencies throughout the year (Table 5b). As required by the NPDES permit, effluent samples are collected at days and times that are representative of typical discharge for a given time period, and are collected at specified monitoring points before the effluent joins with the stream (NPDES 2010). Monitoring results are summarized for each month and presented to the NC DENR Division of Water Quality in a monthly Discharge Monitoring Report (DMR).

Until it was renovated in 2006, the Oxford WWTP was frequently cited for NPDES compliance issues, including sanitary sewer overflows, exceedances of permit limits for various constituents (particularly selenium and fecal coliform), and failures of the quarterly whole effluent toxicity (WET) test (which entails the exposure of living aquatic organisms to wastewater effluent to assess acute toxicity) (NCDENR 2007; EPA 2014b). The 2006 renovations to the WWTP’s infrastructure and pretreatment techniques drastically improved its NPDES compliance record, with 100% compliance reported in 2013 (City of Oxford 2014).

Stream and Watershed Description

Oxford WWTP effluent is discharged into the headwaters of Fishing Creek, approximately 10 meters below its confluence with Foundry Creek (Figure 2). In 1998, the upper portion of Fishing Creek to its confluence with Coon Creek (Figure 2) was added to North Carolina’s Impaired Waters List, also known as the 303(d) report, due to biological monitoring data indicating poor stream function. The lower portion of Fishing Creek, which drains into the Tar River, was added to the list in 2000 for similar reasons (NCDENR 2005). Fishing Creek remains on the 2014 303(d) list due to exceedances of the NCDENR water quality standard for zinc (50 µ/L) in samples collected in 2012 (NCDENR 2014a). Biological monitoring data is no longer listed as a parameter of interest on the
In order for Fishing Creek to be removed from North Carolina’s 303(d) list, monitoring data showing compliance with zinc state water quality standards would be required (NCDENR 2014a).

NCDENR’s Division of Water Quality collected ambient water quality data from downstream Fishing Creek between June 24, 1968 and March 2, 2004; measurements of ten metals in the samples began in 1991 (NCDENR 2005). In 2005, NCDENR released an analysis of this water quality data in a report entitled “Summary of Existing Water Quality Data in Fishing Creek, Granville County”. Of the ten metals that were measured in the samples, copper, lead, and zinc were found to occasionally exceed EPA ambient water quality standards. Summary statistics on these values for the component metals are provided in Table 5a.

Table 5a. Metal concentrations in Fishing Creek (NCDENR 2005)

<table>
<thead>
<tr>
<th>Metal</th>
<th>N</th>
<th>Mean (µg/L)</th>
<th>S.E. (µg/L)</th>
<th>Median (µg/L)</th>
<th>Min (µg/L)</th>
<th>Max (µg/L)</th>
<th>EPA Criteria* (µg/L)</th>
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<tbody>
<tr>
<td>Copper</td>
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<td>0.38</td>
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<td>38</td>
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</tr>
<tr>
<td>Lead</td>
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<td>0.125</td>
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<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Zinc</td>
<td>96</td>
<td>30.30</td>
<td>3.03</td>
<td>20</td>
<td>10</td>
<td>200</td>
<td>33</td>
</tr>
</tbody>
</table>

*based on assumed hardness of 25 mg/L

In 2007, NCDENR’s Division of Water Quality released a report entitled “Fishing Creek Water Quality Study in support of NC Ecosystem Enhancement Program Local Watershed Plan Development”. The Division of Water Quality collected data for this report at 29 sites in the Fishing Creek watershed between September 2005 and November 2006 (NCDENR 2007). At a Fishing Creek sample site directly below the WWTP outfall, elevated specific conductance, nutrients, and metals were recorded (NCDENR 2007). Zinc concentrations exceeded EPA criteria in all samples taken at this site (n=7; range = 37 - 240 µg/L; median = 180 µg/L). Copper concentrations also exceeded EPA criteria (n=6; range = 2.2 – 10 µg/L; median not reported). Lead was not detected in any of the samples. At a sampling site directly upstream of the WWTP outfall, metal concentrations were primarily below the method detection limit, with a few exceptions of copper and zinc showing reportable but low concentrations (NCDENR 2007).

In the 2007 Water Quality Study, a habitat score of 66 out of 100 (with 100 indicating exceptional habitat) was assigned to the Fishing Creek sampling site below the WWTP outfall. The habitat score considers several physical factors including canopy cover, bank stability, riparian zone width, instream habitat, and hydrological features such as pools and riffles (NCDENR 2005;
The monitoring site above the WWTP outfall received a score of 67 out of 100, indicating no significant difference in physical habitat between locations (NCDENR 2005).

Unfortunately, there has been neither a follow-up to NCDENR’s 2007 Fishing Creek Water Quality Study nor any additional water quality data collection by NCDENR. Therefore, it is difficult to assess whether the 2006 improvements to the WWTP have translated to improved conditions in Fishing Creek.

The ecology of Fishing Creek is not well documented. NCDENR’s Department of Water Quality collected benthic macroinvertebrate samples in June 1989 at locations upstream and downstream of the WWTP outfall. Twenty-seven total species were identified at the upstream location, while only 16 were identified at the downstream location (NCDENR 2005). Both sites were given a bio-classification ranking of “poor” due in part to the absence of EPT (Ephemeroptera + Plecoptera + Trichoptera) species, which act as strong water quality indicators due to their sensitivity to pollution. The upstream site was resampled in 1990 and classified as “fair” due to an increased number of total and EPT species. The downstream site was not resampled (NCDENR 2005).

According to the Local Watershed Plan prepared for Fishing Creek by NCDENR’s Ecosystem Enhancement Program in 2012, endangered freshwater mussels and the herbaceous aquatic plant Harperella (Ptilimnium nodosum) have been identified in Granville County streams (NCDENR 2012b). The Watershed Plan suggests that Fishing Creek might provide suitable habitat for endangered mussel recruitment, given that the 2006 updates to the Oxford WWTP improved the quality of effluent discharging into the stream. In particular, the WWTP replaced chlorination, which is known to adversely impact mussel habitat, with ultraviolet (UV) treatment as a means of eliminating potentially-disease causing organisms from the effluent (NCDENR 2012b). Because UV treatment relies on electromagnetic energy rather than chemical inputs to disinfect wastewater, it does not leave a chemical trace in the resulting wastewater and is a preferable option for protecting habitat downstream of the WWTP outflow.

The flow rate of Fishing Creek near the WWTP outfall is not monitored. However, Oxford’s WWTP NPDES permit states that the summer 7Q10 (the lowest consecutive 7-day flow over a 10 year period) for Fishing Creek at the WWTP discharge site is 0.05 cubic feet per second (CFS). According to staff at NCDENR’s Division of Water Resources, this number was mostly likely calculated when the WWTP began operation in 1981 using a gauged North Carolina stream with similar characteristics (e.g. land use, drainage area, topography) as a surrogate. Under the WWTP’s
NPDES permit, the concentration of effluent in Fishing Creek is permitted to be 98.5% of flow
during low flow (assuming 7Q10 = 0.05 cfs), which translates into Fishing Creek’s permitted
discharge rate of 3.5 MGD. The greatest ecological risk to Fishing Creek from metals in WWTP
effluent would be expected to occur during low flow, when dilution of the effluent by the receiving
stream in minimal.

Solid Waste Landfill Leachate Processing

In July of 2013, the city of Oxford signed an agreement with Granville County to accept, treat,
and dispose of up to 35,000 gallons per day of leachate discharges from the Oxford Municipal Solid
Waste Landfill (OMSWL) (Granville County 2013). In practice, the volume of leachate transported
to the WWTP on a daily basis fluctuates with rainfall, with drier days producing substantially less
leachate. The agreement followed the NCDENR Division of Waste Management’s approval in 2012
of the expansion of the OMSWL from 29 acres to 398 acres. The expanded landfill facility, which
has a gross capacity of approximately 16,886,000 cubic yards, is considered state-of-the-art and
includes composite baseliner and leachate collection systems (NCDENR Permit 2012a). It has an
expected operating life of 87 years (NCDENR Permit 2012a).

Leachate is a water-based solution formed from the percolation of rainwater through landfills
(Kjeldsen et al., 2002). Due to a combination of chemical, microbial, and physical processes,
leachate contains high concentrations of certain contaminants leached from waste materials (Kjeldsen
et al., 2002). In a review of the literature on solid waste landfills receiving municipal, commercial,
and/or industrial waste (excluding chemical waste), Kjeldsen et al. (2002) found that leachate
compositions are relatively similar among landfills due to anaerobic conditions fostered by the
biodegradation of organic content and the compaction of waste layers (Kjeldsen et al., 2002). The
authors suggest that leachate can be characterized by four classes of contaminants: dissolved organic
matter (quantified as Chemical Oxygen Demand or Total Organic Carbon), inorganic macro
components (ions such as calcium, magnesium, sodium, potassium, ammonium, iron, manganese,
chloride, sulfate, and hydrogen carbonate), heavy metals (cadmium, chromium, copper, lead, nickel,
and zinc), and xenobiotic organic compounds (household chemicals such as aromatic hydrocarbons,
phenols, chlorinated aliphatics, pesticides, and plasticizers). Other compounds including borate,
sulfide, arsenate, selenate, barium, lithium, mercury, and cobalt are considered of secondary
importance, as they are typically detected at only very low concentrations (Kjeldsen et al., 2002).
Despite these general characteristics, the composition of landfill leachate can vary depending on the stage of decomposition, the age of the landfill, and seasonal patterns. When waste is deposited into a landfill, it typically undergoes four stages of decomposition: 1) initial aerobic phase, 2) anaerobic acid phase, 3) initial methanogenic phase, and 4) stable methanogenic phase (Kjeldsen et al., 2002). In active landfills with a steady influx of waste, it is common for leachate composition to vary with the stage of decomposition, resulting in different compositions of leachates throughout the landfill (Kjeldsen et al., 2002). Kulikowska and Klimiuk (2006) analyzed temporal changes in municipal landfill leachate quality in a Polish landfill to assess the effect of landfill age on leachate quality. The principal components in the leachate were organic content and ammonia. During four years of observations, the concentration of organic compounds decreased by nearly 70%, whereas the concentration of ammonia nearly quadrupled over the same time period. Variations in other indices, including several inorganic macro compounds and heavy metals, depended on seasonal changes rather than landfill age (Kulikowska and Klimiuk 2006).

OMSWL leachate is periodically analyzed for dozens of contaminants from the four aforementioned classes of leachate contaminants (dissolved organic matter, inorganic macro components, heavy metals, and some xenobiotic organic compounds such as poly aromatic hydrocarbons). Most of the tested constituents fall below the limit of detection. However, several metals, including, copper, nickel and zinc, are frequently detected in the leachate. In a conversation with the authors, the Oxford WWTP Superintendent, Dennis Wilson, indicated that he does not currently believe that the leachate is jeopardizing the WWTP’s ability to meet water quality criteria for its effluent, but he is concerned about future impacts on WWTP effluent if the aging of the OMSWL worsens leachate quality. Mr. Wilson emphasized that constant monitoring of contaminants in the leachate and WWTP effluent is necessary to ensure that the processing of leachate by the WWTP does not pose a compliance or ecological risk.

**Sludge Reuse and Proposal for Wastewater Reuse**

Sludge is an organic-rich byproduct of the wastewater treatment process. Oxford WWTP sludge is batched and aerated for 30 days in diffused air digesters before removal by a contracted sludge hauler, who applies it to permitted agricultural sites in Granville County (City of Oxford 2012). In 2012, 3.7 million gallons of sludge from the Oxford WWTP were land applied (City of Oxford 2012). Information about where the sludge is applied is not publically available.
The City of Oxford is currently considering reclaiming Oxford WWTP effluent for non-potable uses, such as irrigation of public parks and non-edible agricultural crops. Reclaimed water is a widely used alternative to conventional water supplies, and can play a crucial role in sustainable water systems (EPA 2012a). However, use of reclaimed water may pose an environmental or human health risk if not properly regulated and monitored. According to U.S. EPA Water Reuse Guidelines (2012), protection of public health is achieved by 1) reducing or eliminating concentrations of pathogenic bacteria, parasites, and enteric viruses in reclaimed water; 2) controlling chemical constituents in reclaimed water, and 3) limiting public exposure to reclaimed water through dermal contact, inhalation, and ingestion. The most crucial treatment objective, according to the EPA, is pathogen inactivation in order to eliminate the spread of infectious agents.

Unfortunately, current state regulations of water reuse are not based on rigorous risk assessment, and therefore it is unlikely that water reuse regulations properly account for all potential hazards (NRC 2012). Whereas pathogenic contaminants are more tightly monitored and regulated in wastewater reclamation projects, many chemical contaminants, including metals, may be overlooked (EPA 2012a). UV disinfection used by the Oxford WWTP is effective at inactivating most viruses, spores, and cysts through its ability to penetrate cell walls, which destroys the cell’s ability to reproduce (EPA 1999b). Dissolved metals, on the other hand, can absorb UV radiation, but are not removed or transformed by it (EPA 1999b).

The NRC reported in 2012 that there is no epidemiological evidence of a link between reclaimed water use and adverse human health effects in the United States (NRC 2012). The potential environmental effects of reclaimed water use are less understood, however. When treated wastewater is reused for irrigation, terrestrial species can be directly exposed to treated soils. In addition, chemical contaminants may accumulate in plants, and in turn expose terrestrial animals (Salgot et al., 2003).

Risk Assessment Purpose

This risk assessment makes use of metal monitoring data from Oxford WWTP effluent collected between January 2012 and December 2014. Data was compiled from monthly DMRs provided by the Oxford WWTP. The number of values for each metal reflects sampling frequency requirements in the WWTP’s NPDES permit (Table 5b).
The aquatic toxicity of metals has been extensively studied, with known effects including growth inhibition, impaired reproduction, tissue damage, genotoxicity, and mortality (EPA 2011). Metals are naturally occurring in the environment, and some metals are essential nutrients at low doses (EPA 2011). Environmental conditions including pH, redox potential, and hardness can impact the solubility of metals (EPA 2011). In general, however, metals are considered very mobile in the environment (EPA 2011). To determine the potential risk posed by metals in Oxford WWTP effluent, this risk assessment seeks to answer three questions:

a) Do metals in the WWTP effluent pose a significant aquatic risk to Fishing Creek?

b) Will use of reclaimed WWTP effluent for irrigation pose a significant terrestrial risk?

c) Have there been changes in metal concentrations in effluent since the WWTP began accepting leachate in July 2013?

Metal concentrations in Fishing Creek will be calculated using estimated stream discharge. Concentrations will then be compared to EPA and NCDENR water quality standards. In the terrestrial environment, no dilution of the effluent will be assumed. Because neither the EPA nor NCDENR have terrestrial standards in place, toxicity data from the literature will be used to determine terrestrial risk. Regression analysis will be used to understand changes in metal concentrations in Fishing Creek.

Human health risk will not be considered in this risk assessment because the assessed metals are considered trace nutrients. Therefore, the low levels of human exposure to Oxford WWTP effluent through recreation in Fishing Creek or contact with reused water are not expected to present any hazard. While Fishing Creek does discharge into the Tar River, which is used for municipal drinking water in downstream communities, numerous uncertainties, including background metal concentrations in the Tar River and metal removal by drinking water treatment processes, prohibit any link between Oxford WWTP effluent and human health risk from drinking water. The ecological and human health risks of Oxford WWTP sludge reuse will also not be considered because neither the Oxford WWTP nor the city of Oxford are responsible for monitoring chemical constituents in the sludge. Although outside the scope of this risk assessment, future studies may consider evaluating the potential human and ecological health risks of sludge application in Granville County.
### Table 5b. Water quality parameters measured in Oxford WWTP effluent

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Number of Tests Required per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Rate</td>
<td>365</td>
</tr>
<tr>
<td>Temp</td>
<td>365</td>
</tr>
<tr>
<td>pH</td>
<td>365</td>
</tr>
<tr>
<td>Biochemical Oxygen Demand</td>
<td>260</td>
</tr>
<tr>
<td>Ammonia</td>
<td>260</td>
</tr>
<tr>
<td>Total Suspended Solids</td>
<td>260</td>
</tr>
<tr>
<td>Fecal Coliform</td>
<td>260</td>
</tr>
<tr>
<td>Dissolved Oxygen</td>
<td>260</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>12</td>
</tr>
<tr>
<td>Total Phosphorous</td>
<td>12</td>
</tr>
<tr>
<td>Total Kjehldahl Nitrogen</td>
<td>52</td>
</tr>
<tr>
<td>Oil &amp; Grease</td>
<td>4</td>
</tr>
<tr>
<td>Nitrate/Nitrite</td>
<td>52</td>
</tr>
<tr>
<td>Cyanide</td>
<td>52</td>
</tr>
<tr>
<td>Cadmium</td>
<td>12</td>
</tr>
<tr>
<td>Chromium</td>
<td>4</td>
</tr>
<tr>
<td>Copper</td>
<td>24</td>
</tr>
<tr>
<td>Nickel</td>
<td>4</td>
</tr>
<tr>
<td>Lead</td>
<td>4</td>
</tr>
<tr>
<td>Mercury</td>
<td>52</td>
</tr>
<tr>
<td>Zinc</td>
<td>24</td>
</tr>
<tr>
<td>Silver</td>
<td>4</td>
</tr>
<tr>
<td>Arsenic</td>
<td>4</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>4</td>
</tr>
<tr>
<td>Selenium</td>
<td>52</td>
</tr>
<tr>
<td>Hardness</td>
<td>12</td>
</tr>
<tr>
<td>Whole Effluent Toxicity</td>
<td>4</td>
</tr>
</tbody>
</table>

### Analysis: Exposure Assessment

**Effluent Data**

Of the 11 metals measured in Oxford WWTP effluent, only chromium (Cr), copper (Cu), nickel (Ni), and zinc (Zn) were detected at concentrations above the method detection limit (MDL) at a sufficient rate to justify analysis (at least 70%). For these four constituents, the common practice of replacing values below the MDL with the MDL divided by the square route of two was used (EPA 2003). Table 5c summarizes chromium, copper, nickel, and zinc concentrations measured in grab samples of Oxford WWTP effluent from January 2012 to December 2014.
Table 5c. Total metal (dissolved + suspended) concentrations in Oxford WWTP effluent from January 2012 – December 2014.

<table>
<thead>
<tr>
<th></th>
<th>Cr</th>
<th>Cu</th>
<th>Ni</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean (µg/L)</strong></td>
<td>2.26</td>
<td>7</td>
<td>2.75</td>
<td>162</td>
</tr>
<tr>
<td><strong>Standard Deviation (µg/L)</strong></td>
<td>1.35</td>
<td>3</td>
<td>3.85</td>
<td>62</td>
</tr>
<tr>
<td><strong>Median (µg/L)</strong></td>
<td>2.70</td>
<td>6</td>
<td>2.25</td>
<td>159</td>
</tr>
<tr>
<td><strong>95th Percentile (µg/L)</strong></td>
<td>3.68</td>
<td>10</td>
<td>3.87</td>
<td>271</td>
</tr>
<tr>
<td><strong>Max (µg/L)</strong></td>
<td>4.70</td>
<td>29</td>
<td>24.00</td>
<td>310</td>
</tr>
<tr>
<td><strong>MDL (µg/L)</strong></td>
<td>0.200</td>
<td>N/A</td>
<td>0.020</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Total number</strong></td>
<td>13</td>
<td>80</td>
<td>34</td>
<td>79</td>
</tr>
<tr>
<td><strong>Number of values below MDL</strong></td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Estimated Low Flow Concentrations

To calculate the concentration of metals in Fishing Creek, we conservatively assumed 7Q10 flow conditions, referring to the lowest 7-day consecutive flow in a 10-year period. According to the Oxford WWTP’s NCDENR permit, the 7Q10 flow in Fishing Creek is 0.05 cfs (1.42 L/s). Metal concentrations in the stream water were calculated according to equation 1:

\[
C_{FC} = \frac{C_E \times F_E}{F_{FC} + F_E}
\]

Where \( C_{FC} \) = concentration in Fishing Creek, \( C_E \) = concentration in effluent, \( F_E \) = Flow rate of effluent, \( F_{FC} \) = flow rate of Fishing Creek

Daily effluent flow rate measurements were available from the Oxford WWTP. Each value for \( C_{FC} \) was calculated using the \( F_E \) recorded on the day that the \( C_E \) was taken. It was assumed that WWTP effluent was the only source of metals to Fishing Creek (i.e. no background concentrations in the stream water). Metal concentrations in Fishing Creek assuming constant 7Q10 flow are presented in Table 5d.

Table 5d. Estimated metals concentrations in Fishing Creek using 7Q10 flow (low flow)

<table>
<thead>
<tr>
<th></th>
<th>Zn</th>
<th>Ni</th>
<th>Cu</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average (µg/L)</strong></td>
<td>155.42</td>
<td>2.66</td>
<td>6.43</td>
<td>2.17</td>
</tr>
<tr>
<td><strong>Standard Deviation (µg/L)</strong></td>
<td>61.05</td>
<td>3.69</td>
<td>3.37</td>
<td>1.36</td>
</tr>
<tr>
<td><strong>Median (µg/L)</strong></td>
<td>154.34</td>
<td>2.19</td>
<td>6.01</td>
<td>2.59</td>
</tr>
<tr>
<td><strong>95th Percentile (µg/L)</strong></td>
<td>272.76</td>
<td>6.51</td>
<td>9.71</td>
<td>4.57</td>
</tr>
<tr>
<td><strong>Maximum (µg/L)</strong></td>
<td>302.58</td>
<td>23.01</td>
<td>28.24</td>
<td>4.57</td>
</tr>
</tbody>
</table>
Estimated Daily Flow Concentrations

7Q10 flow is, by definition, a rare (once in ten year) occurrence. To better characterize the aquatic risk to Fishing Creek from WWTP effluent discharges, more complete flow data is preferable. Unfortunately, there are no flow gauges at or near the Oxford WWTP effluent discharge site in Fishing Creek. Therefore, as a surrogate for Fishing Creek, we used flow data from USGS site 02086624 Knap of Reeds Creek Near Butler, NC. This site was considered the best option for a surrogate because a) it is located in Granville County, approximately 17 miles from Fishing Creek b) it has a drainage area of 43 square miles, similar to Fishing Creek’s 46.95 square miles, and c) it has daily flow data available.

To estimate metal concentrations in Fishing Creek using ten years (March 2005-March 2015) of stream flow data from Knap of Reeds Creek, Monte Carlo simulation was performed with Crystal Ball® 2000 Professional Edition in Microsoft Excel. Briefly, best-fit theoretical distributions were assigned to stream flow data (lognormal), daily effluent flow data (lognormal), and metal concentrations (Zi = beta, Ni = lognormal, Cu = maximum-extreme, Cr = custom). Then, numbers were randomly drawn from the theoretical distributions to calculate stream metal concentrations according to equation 1. This process was repeated 10,000 times, and the results are summarized in Table 5e.

Table 5e. Estimated metal concentrations in Fishing Creek using Reeds Creek flow data and Monte Carlo analysis

<table>
<thead>
<tr>
<th></th>
<th>Cr</th>
<th>Cu</th>
<th>Ni</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (µg/L)</td>
<td>0.34</td>
<td>0.9</td>
<td>0.57</td>
<td>25.83</td>
</tr>
<tr>
<td>Standard Deviation (µg/L)</td>
<td>0.54</td>
<td>1.29</td>
<td>2.01</td>
<td>34.59</td>
</tr>
<tr>
<td>Median (µg/L)</td>
<td>0.11</td>
<td>0.39</td>
<td>0.11</td>
<td>11.44</td>
</tr>
<tr>
<td>95th Percentile (µg/L)</td>
<td>1.51</td>
<td>3.57</td>
<td>2.39</td>
<td>102.6</td>
</tr>
<tr>
<td>Maximum (µg/L)</td>
<td>4.15</td>
<td>18.24</td>
<td>76.78</td>
<td>271.05</td>
</tr>
</tbody>
</table>

Terrestrial Exposure

To estimate terrestrial exposures from wastewater reuse in parks or agricultural fields, we conservatively assumed that no dilution of the effluent occurs. This scenario assumes that wildlife exposure occurs through organisms ingesting effluent from puddles accumulated in fields or impermeable surfaces. Furthermore, we made a very conservative assumption that the effluent would be the organism’s only source of drinking water, and that the metal concentration in the effluent
would be the 95th percentile value (Table 5c). If such worst-case scenario exposure estimates fall below the values required to cause toxicity, it can be concluded that the given exposure route poses a minimal risk.

Ingested doses of copper and zinc were calculated for two representative species (mallard duck and mouse) using water ingestion rates and body weights from the EPA’s Wildlife Exposure Factors Handbook. Exposures were not calculated for chromium or nickel because effluent concentrations were far below EPA and NCDENR thresholds (see following section). Daily doses, shown in Table 5f, were calculated as:

\[
\text{Dose} = \left( \frac{\text{95th percentile concentration} \times \text{water ingestion rate} \times \text{body weight}}{1000} \right)
\]

<table>
<thead>
<tr>
<th>Metal</th>
<th>95th Percentile Concentration (µg/L)</th>
<th>Species</th>
<th>Water Ingestion Rate (ml/g bw-day)</th>
<th>Body Weight (g)</th>
<th>Dose (ug/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>9.68</td>
<td>Mallard Duck</td>
<td>0.06</td>
<td>1100</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mouse</td>
<td>0.2</td>
<td>21</td>
<td>0.04</td>
</tr>
<tr>
<td>Zn</td>
<td>271</td>
<td>Mallard Duck</td>
<td>0.06</td>
<td>1100</td>
<td>17.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mouse</td>
<td>0.2</td>
<td>21</td>
<td>1.14</td>
</tr>
</tbody>
</table>

**Limitations**

Lack of data on flow rates and background metal concentrations in Fishing Creek are sources of uncertainty in this risk assessment. While Knap of Reeds Creek is a strong surrogate for Fishing Creek flow data due to its proximity to Fishing Creek and similar drainage area, differences in land cover between the two areas may contribute to different flow conditions. Data on metal concentrations upstream of the Oxford WWTP discharge location in Fishing Creek would allow for a better characterization of aquatic risk in Fishing Creek. Nonetheless, focusing this risk assessment on the effluent data is valuable because it allows us to determine whether the effluent in itself poses a risk.

**Analysis: Effects Assessment**

*Ambient Surface Water Criteria*

North Carolina surface water quality criteria for total chromium, copper, nickel, and zinc are listed in Table 5g (NCDENR 2013). Under the Clean Water Act, North Carolina is delegated the
authority to establish state water quality standards protective of human health and the environment. The NC Environmental Management Commission (EMC) is responsible for developing these standards using available health and environmental toxicity data. Every three years, the EMC reviews surface water quality standards to assess and implement revisions if and where necessary (NCDENR 2014b).

NCDENR does not regulate zinc and copper in effluent unless the WWTP fails its quarterly Whole Effluent Toxicity (WET) tests, in which case zinc and copper limits are written into the NPDES permit for the WWTP. Because the Oxford WWTP consistently passes its WET tests, the Oxford WWTP NPDES permit does not impose limits on zinc and copper in effluent. Chromium and nickel limits are also not written into the NPDES permit. For these two metals, limits are not imposed unless effluent sampling data indicates exceedances of the estimated NPDES permit limit (Table 5g). These estimated permit limits are calculated by NCDENR using water quality criteria, receiving stream summer 7Q10, NPDES flow limit, total suspended solids, and hardness (NCDENR Calculator 2010). For chromium, both effluent monitoring data and surface water criteria refer to total chromium (chromium-3 and chromium-6), whereas the estimated NPDES permit limit distinguishes between redox states. The reason behind this discrepancy is not clear.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Surface Water Criteria (µg/L)</th>
<th>Estimated NPDES Permit Limit: Chronic (µg/L)</th>
<th>Estimated NPDES Permit Limit: Acute (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc</td>
<td>50</td>
<td>127.9</td>
<td>126.7</td>
</tr>
<tr>
<td>Nickel</td>
<td>88</td>
<td>37.6</td>
<td>337.9</td>
</tr>
<tr>
<td>Copper</td>
<td>7</td>
<td>8</td>
<td>10.6</td>
</tr>
<tr>
<td>Chromium</td>
<td>50</td>
<td>118.8 (Cr III)</td>
<td>912.3 (Cr III)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11.1 (Cr VI)</td>
<td>16.1 (Cr VI)</td>
</tr>
</tbody>
</table>

Table 5g. NCDENR (2013) Surface Water Criteria and estimated NPDES permit limits

EPA surface water criteria for aquatic life are listed in Table 5h (EPA 2014a). Unlike NCDENR criteria, EPA criteria are for dissolved metals. To convert dissolved criteria to total recoverable criteria, we divided the dissolved criteria by EPA conversion factors (Table 5h; EPA 1999a). Acute criteria are considered a one-hour average maximum concentration, and chronic criteria are considered a four-day average concentration limit (EPA 2014a). Zinc criteria are hardness dependent; chronic values were calculated as $e^{(0.8473[\ln(\text{hardness})]+0.8604)}$ and acute values were calculated
as $e^{(0.8473[\ln(\text{hardness})]+0.7614)}$ (EPA 1987). Because North Carolina streams have low hardness (USGS 2013), NCDER’s default value of 25 mg/L CaCO$_3$ was assumed.

EPA criteria are designed to protect aquatic life on a national basis (EPA 1992). According to the EPA, criteria are designed to “protect aquatic communities by protecting most species and their uses [i.e. consumption by humans and wildlife] most of the time, but not necessarily all of the time”. In addition, the EPA asserts “aquatic communities can tolerate some stress and occasional adverse effects on a few species”. To develop aquatic criteria, the EPA requires toxicity data from eight specified families representing a wide spectrum of aquatic life. The organisms tested are considered representative species and do not have to be present in a given water body (EPA 1992).

**Table 5h. EPA Surface Water Criteria (2014)**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Dissolved: Chronic (µg/L)</th>
<th>Dissolved: Acute (µg/L)</th>
<th>Conversion Factor: Chronic</th>
<th>Conversion Factor: Acute</th>
<th>Total: Chronic (µg/L)</th>
<th>Total: Acute (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc</td>
<td>33</td>
<td>33</td>
<td>0.986</td>
<td>0.978</td>
<td>33.482</td>
<td>33.482</td>
</tr>
<tr>
<td>Nickel</td>
<td>52</td>
<td>470</td>
<td>0.997</td>
<td>0.998</td>
<td>52.156</td>
<td>470.942</td>
</tr>
<tr>
<td>Copper</td>
<td>1.45</td>
<td>2.337</td>
<td>0.96</td>
<td>0.96</td>
<td>1.510</td>
<td>2.434</td>
</tr>
<tr>
<td>Chromium III</td>
<td>74</td>
<td>570</td>
<td>0.86</td>
<td>0.316</td>
<td>86.047</td>
<td>1803.797</td>
</tr>
<tr>
<td>Chromium VI</td>
<td>11</td>
<td>16</td>
<td>0.962</td>
<td>0.982</td>
<td>11.435</td>
<td>16.293</td>
</tr>
</tbody>
</table>

The freshwater criterion for this metal is expressed as a function of hardness (mg/L) in the water column. The value given here corresponds to a hardness of 25 mg/L.

**Oxford WWTP Whole Effluent Toxicity Tests**

The Oxford WWTP conducts quarterly chronic WET tests. As stated by the NPDES permit, effluent discharge, at a concentration of 90%, shall not cause observable inhibition of reproduction or significant mortality to *Ceriodaphnia dubia*. The Oxford WWTP effluent did not fail any of its WET tests during the time period of this risk assessment.

To supplement the toxicity data gathered by the Oxford WWTP, we conducted acute WET tests on laboratory Japanese Medaka fish. In addition, we tested the toxicity of water up and downstream of the WWTP outfall into Fishing Creek using WET test procedures. Tests were conducted three times between November 2014 and January 2014. No significant mortality was observed in any of the samples (see Section 3 for detailed results).
**Zinc Toxicity**

The bioavailability, and thereby toxicity, of zinc is strongly dependent on the aquatic chemistry of the stream. In particular, zinc bioavailability is hardness dependent, with high hardness associated with lower bioavailability. This is because calcium and magnesium, which are characteristic of hard waters, are divalent and compete with zinc (also divalent) for uptake and binding by organisms. In addition, hard water is typically associated with higher alkalinity, which causes precipitation of insoluble zinc carbonate and hydroxide compounds that cannot be sorbed by many species (EPA 1987). Therefore, in the low-hardness environments of North Carolina streams, organisms would be expected to readily uptake zinc.

The EPA standards for zinc have been criticized for failing to accurately predict acute and chronic freshwater toxicity over a range of zinc bioavailabilities (DeForest and Genderen 2012). Because the EPA zinc standards were developed in 1995, they do not comprehensively represent the range of species in the zinc toxicity database, which has nearly doubled in size in the last two decades (DeForest and Genderen 2012). In addition, the criteria do not account for multiple water chemistry factors that influence metal bioavailability and toxicity, including dissolved organic carbon (DOC), pH, alkalinity, and major ion concentrations (DeForest and Genderen 2012). The biotic ligand model (BLM), which accounts for these factors and the wider range of toxicity data, has been proposed as a superior method of deriving water quality criteria that are site or region specific. Unfortunately, without additional water chemistry data for Fishing Creek, we are unable to apply the BLM in this risk assessment, and must rely on the EPA and NCDENR criteria.

At low doses, zinc is a nutrient in aquatic organisms, supporting membrane stability and the metabolism of proteins and nucleic acids (WHO 2001). At elevated doses, zinc can cause both acute and chronic toxicity. For example, studies have observed mortality in freshwater fish between 0.066-26 mg/L and in freshwater invertebrates between 0.07-575 mg/L (WHO 2001). Chronic toxicity includes reproductive, biochemical, physiological, and behavioral effects in a range of aquatic species (WHO 2001).

Neither the EPA nor NCDENR have terrestrial criteria for zinc. There are, however, a limited number of terrestrial toxicity studies in the literature (examples provided in Table 5i). Effect concentrations were normalized to bodyweight for the mallard duck (1100g; EPA 1993) and for the mouse (21g; EPA 1993).

**Table 5i.** Zinc toxicity values for representative terrestrial species
Copper Toxicity

Like zinc, the bioavailability of copper is strongly dependent on the aquatic chemistry of the stream. The EPA standard for copper, which was revised in 2007, utilizes the BLM model to account for copper bioavailability as a function of pH, alkalinity, DOC, hardness (EPA 2012b). Unfortunately, because water chemistry data are not available for Fishing Creek, we assumed default values to calculate the EPA copper criteria for this risk assessment.

At low doses, copper is essential for normal growth and metabolism in aquatic species (Eisler 1998). The acute toxicity of copper in aquatic organisms is well studied in the literature. Lethal Dose 50 (LD50) values have been recorded between 2.37 µg/L for Daphnia pulicaria to 107,860 µg/L for Notemigonus crysoleucas (EPA 2007). The chronic toxicity of copper, however, is less studied, and therefore the EPA chronic criterion is calculated using the acute to chronic ratio rather than values from the literature. The limited literature on aquatic copper chronic toxicity shows effects on reproduction and long-term survival (EPA 2007).

Examples of terrestrial toxicity values from the literature are presented in Table 5j. Neither the EPA nor NCDENR have terrestrial toxicity criteria for copper.

### Table 5j. Copper toxicity values for representative terrestrial species

<table>
<thead>
<tr>
<th>Species</th>
<th>Effect Concentration</th>
<th>Effect Class</th>
<th>Endpoint</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouse</td>
<td>96 µg/day</td>
<td>Chronic value</td>
<td>Decreased growth and survival</td>
<td>ATSDR 1990 in Eisler 1998</td>
</tr>
<tr>
<td>Earthworm</td>
<td>56,000 µg/kg soil</td>
<td>NOAEL</td>
<td>Growth and reproduction</td>
<td>van Gestel et al. 1991 in Eisler 1998</td>
</tr>
</tbody>
</table>
Chromium and Nickel Toxicity

As shown in the following section, chromium and nickel values in the oxford WWTP fall below EPA and NCDENR criteria. Therefore, the toxicity of these two metals is discussed only briefly.

The toxicity of chromium is dependent on its redox state (hexavalent is considered a more potent toxin than trivalent chromium); unfortunately, chromium monitoring data from the Oxford WWTP does not distinguish between redox states. Hexavalent chromium is associated with reduced survival and fecundity and abnormal movement patterns in invertebrates, as well as reduced growth in freshwater fish (Eisler 1986). Similar effects have been observed from trivalent chromium at substantially higher doses (Eisler 1986).

The toxic effects of nickel in aquatic organisms include reduced survival and growth in invertebrates and freshwater fish (EPA 1980).

Limitations

There is a substantial amount of uncertainty associated with this effects assessment. Because chromium toxicity is highly dependent on the redox state of chromium, it is difficult to assess the potential toxicity of total chromium as measured by the Oxford WWTP. For the other metals, lack of water chemistry data from Fishing Creek prohibits the use of biotic ligand models (BLMs) to calculate site-specific water quality criteria. In addition, terrestrial toxicity data is scarce in the publish literature; few species and toxicity endpoints have been evaluated, which limits our ability to assess terrestrial risk from effluent reuse.

Risk Characterization

Aquatic Risk in Fishing Creek

Comparisons of surface water criteria with estimated metal concentrations in Fishing Creek using the 7Q10 and Monte Carlo methods reveal that copper and zinc are likely to pose an aquatic risk to Fishing Creek (Figure 5a). The median copper concentration estimated by the 7Q10 method (6.01 µg/L) exceeds EPA standards but not the NCDENR standard. The 7Q10 95th percentile concentration (9.71 µg/L) exceeds both standards. Copper concentrations estimated with Monte Carlo exceed the EPA standard 20% of the time and exceed the NCDENR standard less than 5% of the time. For zinc, the median concentration estimated by the 7Q10 method (154.34 µg/L) exceeds
both EPA and NCDENR standards. Zinc concentrations estimated with Monte Carlo exceed the EPA standard 25% of the time and exceed the NCDENR standard 18% of the time.

**Figure 5a.** Estimated metal distributions. Dashed lines represent NCDENR surface water criteria and solid lines represent EPA surface water criteria

<table>
<thead>
<tr>
<th>Chromium (ug/L)</th>
<th>Copper (ug/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Chromium Graph" /></td>
<td><img src="image2" alt="Copper Graph" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nickel (ug/L)</th>
<th>Zinc (ug/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3" alt="Nickel Graph" /></td>
<td><img src="image4" alt="Zinc Graph" /></td>
</tr>
</tbody>
</table>

**Terrestrial Risk**

Comparisons of effect concentrations with worst-case scenario estimated doses for terrestrial species indicate a very low risk associated with effluent reuse (Table 5k). Unfortunately, our confidence in this conclusion is low due to lack of terrestrial toxicity data, particularly pertaining to chronic effects. In addition, it is difficult to estimate potential zinc and copper concentrations in soil from irrigation with wastewater, as the partitioning of metals from the dissolved state to soil is dependent on soil chemistry and kinetics (EPA 1996). Therefore, we cannot estimate risk to plants and soil-dwelling species such as earthworms. As wastewater reuse becomes an increasingly common practice throughout the U.S., more attention should be given to potential risks posed to plants and wildlife.
Table 5k. Comparison of worst case scenario exposure estimates and effect concentrations for representative terrestrial species

<table>
<thead>
<tr>
<th>Metal</th>
<th>Species</th>
<th>Estimated Dose (µg/day)</th>
<th>Effect Concentration (µg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>Mallard Duck</td>
<td>0.64</td>
<td>108,000</td>
</tr>
<tr>
<td></td>
<td>Mouse</td>
<td>0.04</td>
<td>320</td>
</tr>
<tr>
<td>Zi</td>
<td>Mallard Duck</td>
<td>17.89</td>
<td>Data not available</td>
</tr>
<tr>
<td></td>
<td>Mouse</td>
<td>1.14</td>
<td>96</td>
</tr>
</tbody>
</table>

Leachate

Multivariate regression analysis was used to determine whether concentrations of Cu, Ni, and Zn in Oxford WWTP effluent have changed since the plant began accepting leachate from the SWL in July 2013. Due to the limited number of measurements of Cr, a t-test comparing pre-leachate conditions to leachate conditions was used in the place of regression. For the regressions, the full model was metal concentration as a function of leachate, days since data collection initiated, pH, and discharge flow rate. Data were evaluated for normality using the Shapiro-Wilkes test and visual inspection. Ni and Zn were normally distributed, but Cu fit a log-normal distribution and was transformed for analyses. A value in the Ni data that was an order of magnitude higher than the other concentrations (possibly due to data entry error) was removed.

The t-test for Cr and the regressions for Cu, Ni, and Zn did not show a relationship between leachate processing and metal concentrations (p > 0.10).

There was a significant relationship between temperature and Zn concentrations, with a 1° increase in temperature associated with a decrease in Zn concentration of 5 µg/L (p<0.001; r² = 0.1334). None of the other metals showed a relationship with temperature.

Recommendations

Elevated concentrations of copper and zinc in Oxford WWTP effluent require the attention of the WWTP and the City of Oxford. Monitoring of these metals in Fishing Creek may be useful to more accurately characterize risks to aquatic species. Measurements of water chemistry parameters such as pH and hardness will also be useful for determining site-specific toxicity standards using BLM methods. In addition, the WWTP may consider identifying the sources of metals in the wastewater in order to reduce concentrations in influent. Industry is most likely to be responsible for zinc inputs, whereas copper may be released through corrosion of plumbing (EPA 2012b).

Future measurements of chromium in the wastewater effluent should distinguish between redox states in order to facilitate comparisons with EPA surface water criteria.
While solid waste landfill leachate has not caused an increase in metal concentrations in Oxford WWTP effluent, continual monitoring of the leachate is recommended. In addition, the potential impacts of other contaminants, such as abiotic organic compounds, in the leachate should be considered.
Conclusion

Through our research, we identified where these stressors in stream quality changes occur and how the improvement of Coon Creek can lead to an increased quality of water in the receiving Fishing Creek and Tar River. Results of the research include: Conservation priority analysis indicates that downstream Fishing Creek and Coon Creek are potential conservation areas. Acute toxicity tests suggest that stream water is generally sufficient to support medaka fish (however these are not resident organisms and the test was conducted on life stages that have recently or have not yet ceased gaining their nutrition from their yolk sac and therefore tell us nothing about the nutrient status for resident fish). Community surveys reveal a high level of citizen concern, yet limited knowledge and awareness about local streams. Risk assessment of metal concentrations in municipal wastewater treatment plant effluent discharging into Fishing Creek indicates a potential risk to aquatic life from copper and zinc. Given the limited industry, infrastructure, and environmental data collection in Granville County, our work serves as a foundation for future water quality studies. Working with the other Granville County Group partners, we have developed a well-defined community plan for securing improvements on the stream and for communication of events that may have impacts for the future.

Acknowledgements

We would like to thank Dr. David E. Hinton, Melissa Chernick, Marshall Floyd and Nancy Daly for all of your help, advice, and accessibility throughout this project.
Work Cited

Introduction


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Section 1: GIS Analysis


Keith, A. K. GIS-BASED ANALYSIS OF POTENTIAL WATER INFILTRATION IN THE DOG RIVER WATERSHED, MOBILE, AL.


Section 2: Site Selection and Water Sample Collection
EPA (United States Environmental Protection Agency). 2012a. 5.2 Dissolved Oxygen and Biochemical Oxygen Demand. http://water.epa.gov/type/rsl/monitoring/vms52.cfm


Section 3: Larval Acute Toxicity Tests


Section 4: Community Survey and Audio Component


Section 5: Risk Assessment


Granville County. (2013). Leachate Disposal Agreement.


NCDENR. (2005). *Summary of Existing Water Quality Data Fishing Creek, Granville County*.


NCDENR. (2012b). *Fishing Creek Local Watershed Plan*.

NCDENR. (2013). Surface Water Criteria Table.


NPDES. (2010). Oxford Wastewater Treatment Plant Permit to Discharge Wastewater Under the National Pollutant Discharge Elimination System.


Appendices

Appendix A1. 303 (d) Listed waters in study area

Flowline and 303(d) Listed Waters in Fishing Creek Watershed

Map and data produced by Granville County Cluster, Stream Function Team, Duke University NSOE, 2014

Legend

- 303(d) Listed Waters
- Flowlines
  - Coon Creek
  - Fishing Creek
  - Hachers Run
  - Jordan Creek
  - Wetlands
  - Incorporate Place
  - Watershed Boundary

Granville

Vance

Miles
### Appendix A2. Land use distribution (1992)

<table>
<thead>
<tr>
<th>Land Cover Type</th>
<th>Area (Ha)</th>
<th>Percent of Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Water</td>
<td>100.26</td>
<td>0.82%</td>
</tr>
<tr>
<td>Low Intensity Residential</td>
<td>715.05</td>
<td>5.88%</td>
</tr>
<tr>
<td>High Intensity Residential</td>
<td>145.26</td>
<td>1.19%</td>
</tr>
<tr>
<td>Commercial/Industrial/Transportation</td>
<td>347.22</td>
<td>2.85%</td>
</tr>
<tr>
<td>Bare Rock/Sand/Clay</td>
<td>37.62</td>
<td>0.31%</td>
</tr>
<tr>
<td>Deciduous Forest</td>
<td>4265.28</td>
<td>35.06%</td>
</tr>
<tr>
<td>Evergreen Forest</td>
<td>2070.36</td>
<td>17.02%</td>
</tr>
<tr>
<td>Mixed Forest</td>
<td>1367.91</td>
<td>11.24%</td>
</tr>
<tr>
<td>Hay/Pasture</td>
<td>1745.55</td>
<td>14.35%</td>
</tr>
<tr>
<td>Commercial/Industrial/Transportation</td>
<td>347.22</td>
<td>2.85%</td>
</tr>
<tr>
<td>Bare Rock/Sand/Clay</td>
<td>37.62</td>
<td>0.31%</td>
</tr>
<tr>
<td>Deciduous Forest</td>
<td>4265.28</td>
<td>35.06%</td>
</tr>
<tr>
<td>Evergreen Forest</td>
<td>2070.36</td>
<td>17.02%</td>
</tr>
<tr>
<td>Mixed Forest</td>
<td>1367.91</td>
<td>11.24%</td>
</tr>
<tr>
<td>Hay/Pasture</td>
<td>1745.55</td>
<td>14.35%</td>
</tr>
<tr>
<td>Cultivated Crops</td>
<td>1094.49</td>
<td>9.00%</td>
</tr>
<tr>
<td>Urban/Recreational Grasses</td>
<td>57.87</td>
<td>0.48%</td>
</tr>
<tr>
<td>Woody Wetlands</td>
<td>188.01</td>
<td>1.55%</td>
</tr>
<tr>
<td>Emergent Herbaceuous Wetlands</td>
<td>30.15</td>
<td>0.25%</td>
</tr>
</tbody>
</table>

### Appendix A3. Land use distribution (2011)

<table>
<thead>
<tr>
<th>Land Cover Type</th>
<th>Area (Ha)</th>
<th>Percent of Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Water</td>
<td>91.89</td>
<td>0.76%</td>
</tr>
<tr>
<td>Developed, Open Space</td>
<td>1325.88</td>
<td>10.91%</td>
</tr>
<tr>
<td>Developed, Low Intensity</td>
<td>474.21</td>
<td>3.90%</td>
</tr>
<tr>
<td>Developed, Medium Intensity</td>
<td>209.97</td>
<td>1.73%</td>
</tr>
<tr>
<td>Developed, High Intensity</td>
<td>118.8</td>
<td>0.98%</td>
</tr>
<tr>
<td>Barren Land</td>
<td>21.96</td>
<td>0.18%</td>
</tr>
<tr>
<td>Deciduous Forest</td>
<td>3629.79</td>
<td>29.87%</td>
</tr>
<tr>
<td>Evergreen Forest</td>
<td>1606.23</td>
<td>13.22%</td>
</tr>
<tr>
<td>Mixed Forest</td>
<td>661.23</td>
<td>5.44%</td>
</tr>
<tr>
<td>Shrub/Scrub</td>
<td>441.36</td>
<td>3.63%</td>
</tr>
<tr>
<td>Herbaceuous</td>
<td>988.2</td>
<td>8.13%</td>
</tr>
<tr>
<td>Hay/Pasture</td>
<td>2268.36</td>
<td>18.67%</td>
</tr>
<tr>
<td>Cultivated Crops</td>
<td>156.51</td>
<td>1.29%</td>
</tr>
<tr>
<td>Woody Wetlands</td>
<td>154.8</td>
<td>1.27%</td>
</tr>
<tr>
<td>Emergent Herbaceuous Wetlands</td>
<td>1.98</td>
<td>0.02%</td>
</tr>
</tbody>
</table>

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Appendix A4. Land use distribution in study area

Fishing Creek Watershed Landuse/Landcover Type

Map and data produced by Granville County Cluster, Stream Function Team, Duke University NSOE, 2014
Appendix B1. Conservation Priority Script

Script of Conservation Priority Tool
# Conservation Priority Analysis

# Import system modules
import arcpy, sys

# Check out any necessary licenses
arcpy.CheckOutExtension("spatial")

from arcpy import env
from arcpy.sa import *

# Set workspace
# Set workspace by users.
wspace = arcpy.GetParameterAsText(0)
env.workspace = wspace
# Set Extent
wextent = arcpy.GetParameterAsText(1)
env.extent = wextent
env.overwriteOutput = True
# Set Cell Size
csize = arcpy.GetParameterAsText(2)
env.cellSize = csize
# Set Mask - Optional
msk = arcpy.GetParameterAsText(3)
if msk == None:
    del msk
else:
    env.mask = msk

# Set Variables
# Input Layers
lulc = arcpy.GetParameterAsText(4)
streams = arcpy.GetParameterAsText(5)
ponds = arcpy.GetParameterAsText(6)
wetlands = arcpy.GetParameterAsText(7)
soil = arcpy.GetParameterAsText(8)
DEM = arcpy.GetParameterAsText(9)
roads = arcpy.GetParameterAsText(10)
# Set Scores
# lulc
Swaterice = arcpy.GetParameterAsText(11)
SDevOpen = arcpy.GetParameterAsText(12)
SDevLand = arcpy.GetParameterAsText(13)
SBarLand = arcpy.GetParameterAsText(14)
SForWet = arcpy.GetParameterAsText(15)
SShrub = arcpy.GetParameterAsText(16)
SHerb = arcpy.GetParameterAsText(17)
Shay = arcpy.GetParameterAsText(18)
Scrop = arcpy.GetParameterAsText(19)
# Proximity to Stream, ponds and wetlands
S10 = arcpy.GetParameterAsText(20)
S50 = arcpy.GetParameterAsText(21)
S100 = arcpy.GetParameterAsText(22)
# Soil
SA = arcpy.GetParameterAsText(23)
SB = arcpy.GetParameterAsText(24)
SC = arcpy.GetParameterAsText(25)
SD = arcpy.GetParameterAsText(26)
# Slope
Ss10 = arcpy.GetParameterAsText(27)
Ss25 = arcpy.GetParameterAsText(28)
Ss25m = arcpy.GetParameterAsText(29)
# Water-Forest-Road
WFR = arcpy.GetParameterAsText(30)
# Input Weights
lulcw = arcpy.GetParameterAsText(31)
streampw = arcpy.GetParameterAsText(32)
pondsw = arcpy.GetParameterAsText(33)
wetlandsw = arcpy.GetParameterAsText(34)
soilw = arcpy.GetParameterAsText(35)
slopew = arcpy.GetParameterAsText(36)
WFRw = arcpy.GetParameterAsText(37)
# Output location
outresult = arcpy.GetParameterAsText(38)

# Execute
# Score lulc
outrec1 = Reclassify(lulc, "value".
RemapRange([[11,12, int(Swaterice)],[21,21, int(SDevOpen)],[22,24, int(SDevLand)],[31,31, int(SBarLand)],[41,43, int(SForWet)],[51,52, int(Sshrub)],[71,74, int(Sherb)],[81,82, int(Scrop)],[90,95, int(SForWet)]])
outrec1.save("score_lulc")

# Score Streams, ponds and wetlands
layerList = [streams, ponds, wetlands]
counter = 0
for layer in layerList:
    counter = counter + 1
    outEucDistance = EucDistance(layer)
    outEucDistance.save("dis" + str(counter))
    outrec2 = Reclassify("dis" + str(counter), "value".
RemapRange([[0,10, int(S10)],[10,50, int(S50)],[50,100, int(S100)]])
    outrec2.save("rec1" + str(counter))
    outcon1 = Con(Raster("rec1" + str(counter)) > 100, 0, "rec1" + str(counter)) # Distance bigger than 100 meters, set as 0
    outcon1.save("score_" + str(counter))
    arcpy.Delete_management("dis" + str(counter))
    arcpy.Delete_management("rec1" + str(counter))

# Score Soil
arcpy.PolygonToRaster_conversion(soil, "hydgrpdcd", "rastersoil")
outrec3 = Reclassify("rastersoil", "hydgrpdcd", RemapValue(["A", int(SA)],["B", int(SB)],["C", int(SC)],["D", int(SD)],["", int(SD)],["A/D", int(SD)],["B/D", int(SD)],["C/D", int(SD)])
outrec3.save("score_soil")

# Score Slope
outslope = Slope(DEM, "DEGREE")
outcon4 = Reclassify("slope", "value".
RemapRange([[0,10, int(Ss10)],[10,25, int(Ss25)],[25,360, int(Ss25m)]])
outcon4.save("score_slope")

# Water-Forest-Road
attExtract = ExtractByAttributes(lulc, "VALUE = 41 OR VALUE = 42 OR VALUE = 43")
attExtract.save("Forest")
arcpy.RasterToPolygon_conversion("Forest", "For_poly", "VALUE")
# Buffer streams and roads
arcpy.Buffer_analysis(streams, "str_buffer", "60 meters", "NONE")
arcpy.Buffer_analysis(roads, "roads_buffer", "60 meters", "NONE")
# Find forests within buffered area
arcpy.Clip_analysis("For_poly.shp", "str_buffer.shp", "WFR1_poly")
arcpy.Clip_analysis("For_poly.shp", "roads_buffer.shp", "WFR2_poly")
MergeList = ["WFR1_poly.shp", "WFR2_poly.shp"]
arcpy.Merge_management(MergeList, "WFR_poly.shp")
arcpy.PolygonToRaster_conversion("WFR_poly.shp", "FID", "WFR")
# Prepare for raster calculator, set nodata as 0
outcon = Con(IsNull("WFR"),0,int(WFR))
outcon.save("score_WFR")

# Delete Extra Files
arcpy.Delete_management("Forest")
arcpy.Delete_management("For_poly.shp")
arcpy.Delete_management("str_buffer.shp")
arcpy.Delete_management("roads_buffer.shp")
arcpy.Delete_management("WFR1_poly.shp")
arcpy.Delete_management("WFR2_poly.shp")
arcpy.Delete_management("WFR_poly.shp")
arcpy.Delete_management("WFR")

# Raster Calculator
# Add Scores Together
x = Raster("score_lulc")*float(lulcw)+Raster("score_1")*float(streampw)+Raster("score_3")*float(pondsw)+Raster("score_2")*float(wetlandsw)+Raster("score_soil")*float(soilw)+Raster("score_slope")*float(slopew)+Raster("score_WFR")*float(WFRw)
x.save(outresult)

# Display result
import arcpy.mapping
# get the map document
mxd = arcpy.mapping.MapDocument("CURRENT")
# get the data frame
df = arcpy.mapping.ListDataFrames(mxd,"*")[0]
# create a new layer
newlayer = arcpy.mapping.Layer(outresult)
# add the layer to the map at the bottom of the TOC in data frame 0
arcpy.mapping.AddLayer(df, newlayer,"AUTO_ARRANGE")
# Refresh things
arcpy.RefreshActiveView()
arcpy.RefreshTOC()
Appendix B2. TSS loads for each subwatershed (lb/acre)
Appendix B3. TN loads for each subwatershed (lb/acre)
Appendix B4. TP loads for each subwatershed (lb/acre)
## Appendix C1. Site Selection and Water Sample Collection Field Observations

<table>
<thead>
<tr>
<th>Site</th>
<th>Abbreviation</th>
<th>Date</th>
<th>Time</th>
<th>Observations</th>
<th>Conductivity (μS/cm)</th>
<th>Temperature (cond, degrees C)</th>
<th>DO (%)</th>
<th>DO (mg/L)</th>
<th>Temperature (DO, degrees C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Effluent</td>
<td>PE, rock near sample point</td>
<td>10/15/14</td>
<td>10:30 AM</td>
<td>moderate # of leaves, murky water, gray in shade, opaque, around 2 feet deep at sampling point, in the sun, more visibility, some litter (a little), some surfactant? (bubble are visible), almost a murky look, normal flow (according to Marshall), around 2 meters in width</td>
<td>245</td>
<td>17.3</td>
<td>75.5</td>
<td>7.55</td>
<td>16.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/11/15</td>
<td>1:00 PM</td>
<td>weather: sunny, around 50 degrees F, no recent rain</td>
<td>275</td>
<td>5.8</td>
<td>114</td>
<td>14.6</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/14/15</td>
<td>1:00 PM</td>
<td>higher flow, more blue, Ella took samples</td>
<td>146.4</td>
<td>6.1</td>
<td>101.5</td>
<td>12.74</td>
<td>5.6</td>
</tr>
<tr>
<td>Pre-Industrial</td>
<td>PI</td>
<td>10/15/14</td>
<td>2:20 PM</td>
<td>~3 1/2 m wide, ~1-2 ft deep, brown and milky look, sun shining on water, a little bit of white foam floating, sample taken nearby leaf pile</td>
<td>77.4</td>
<td>17.7</td>
<td>87.2</td>
<td>8.27</td>
<td>17.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/11/15</td>
<td>2:50 PM</td>
<td>ice and snow present, brown (light), clarity, OK visibility</td>
<td>71.8</td>
<td>2.2</td>
<td>105</td>
<td>14.75</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/14/15</td>
<td>2:00 PM</td>
<td>sediment, brown, no more snow/ice, foam</td>
<td>52.4</td>
<td>4.7</td>
<td>101.8</td>
<td>13.27</td>
<td>3.9</td>
</tr>
<tr>
<td>Wastewater Discharge</td>
<td>WW</td>
<td>10/15/14</td>
<td>12:00 PM</td>
<td>discharge point, slippery rocks, green algae</td>
<td>422</td>
<td>21.5</td>
<td>82.4</td>
<td>7.28</td>
<td>21.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/11/15</td>
<td>2:00 PM</td>
<td>wood ducks! 3 of them</td>
<td>459</td>
<td>11.7</td>
<td>103.5</td>
<td>11.61</td>
<td>11.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/14/15</td>
<td>1:30 PM</td>
<td>Ella took samples here too</td>
<td>374</td>
<td>11.9</td>
<td>85.5</td>
<td>9.6</td>
<td></td>
</tr>
<tr>
<td>Fishing Coon Confluence</td>
<td>FC</td>
<td>10/15/14</td>
<td>11:20 AM</td>
<td>more brown, some leaves, 6-7 m in width, lots of sand and sediment in sun, milky brown, in shade, murky brown, some visibility, around 2 feet deep, near a floodplain, lots of litter, tires etc.</td>
<td>121.3</td>
<td>16.6</td>
<td>81.3</td>
<td>7.79</td>
<td>16.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/11/15</td>
<td>1:30 PM</td>
<td>drier than before, pretty clear, some garbage</td>
<td>190</td>
<td>2.9</td>
<td>103.3</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/14/15</td>
<td>2:40 PM</td>
<td>road block, high flow, green (to the right) brownish (to the left)</td>
<td>85</td>
<td>4.8</td>
<td>98</td>
<td>13</td>
<td>4.1</td>
</tr>
<tr>
<td>Highway 85</td>
<td>HW</td>
<td>10/15/14</td>
<td>1:15 PM</td>
<td>under the highway, very shallow, under the highway, ~2 ft width, ~3 in deep, lots of foliage, not so much garbage, white foam</td>
<td>159.1</td>
<td>18.2</td>
<td>87.1</td>
<td>8.31</td>
<td>17.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/11/15</td>
<td>2:30 PM</td>
<td>algae (brown/orange), very noticeable, shallow, low flow, stagnant area upstream is green</td>
<td>116</td>
<td>6</td>
<td>95.4</td>
<td>12.07</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/14/15</td>
<td>1:45 PM</td>
<td>not as much algae, some foam</td>
<td>91.8</td>
<td>6.2</td>
<td>96.8</td>
<td>12.2</td>
<td>5.8</td>
</tr>
<tr>
<td>Jordan Creek</td>
<td>JC</td>
<td>10/15/14</td>
<td>2:45 PM</td>
<td>saw a fish! dark, shady, low flow (very low)</td>
<td>111</td>
<td>17.3</td>
<td>76.3</td>
<td>7.35</td>
<td>16.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/11/15</td>
<td>3:00 PM</td>
<td>more frozen, frozen foam and just foam, stagnant, greenish, murky</td>
<td>95.4</td>
<td>2.5</td>
<td>97.8</td>
<td>13.75</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/14/15</td>
<td>2:20 PM</td>
<td>Sediment, foam (pink color)</td>
<td>72.9</td>
<td>4.1</td>
<td>101</td>
<td>14</td>
<td>3.6</td>
</tr>
<tr>
<td>Pre-effluent</td>
<td>PRE</td>
<td>10/15/14</td>
<td>12:15 PM</td>
<td>Joseph, post-sample point</td>
<td>159.5</td>
<td>17.3</td>
<td>86.1</td>
<td>8.34</td>
<td>16.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/11/15</td>
<td>2:15 PM</td>
<td>bubbles and foam, greenish tint</td>
<td>163.4</td>
<td>3</td>
<td>109.6</td>
<td>14.92</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/14/15</td>
<td>1:40 PM</td>
<td>more sediment, brown color, foam upstream, higher flow</td>
<td>127.7</td>
<td>5</td>
<td>105.1</td>
<td>13</td>
<td>4.5</td>
</tr>
</tbody>
</table>
Appendix D1-D7. Acute Toxicity Results: Survival Rates at Each of the Seven Sample Locations

**Post-Effluent Point**

<table>
<thead>
<tr>
<th>Survival (%)</th>
<th>Time (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>95</td>
<td>2</td>
</tr>
<tr>
<td>90</td>
<td>3</td>
</tr>
<tr>
<td>85</td>
<td>4</td>
</tr>
</tbody>
</table>

**Pre-Industrial Site**

<table>
<thead>
<tr>
<th>Survival (%)</th>
<th>Time (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>95</td>
<td>2</td>
</tr>
<tr>
<td>90</td>
<td>3</td>
</tr>
<tr>
<td>85</td>
<td>4</td>
</tr>
</tbody>
</table>

D1.

D2.
Wastewater Discharge Point

D3.

Fishing-Coon Confluence

D4.
D5.

**Highway 85 Site**

- Survival (%) vs. Time (Days)
- 10/15 Sample (Treatment)
- 10/15 Sample (Control)
- 1/11 Sample (Treatment)
- 1/11 Sample (Control)
- 1/14 Sample (Treatment)
- 1/14 Sample (Control)

D6.

**Jordan Creek**

- Survival (%) vs. Time (Days)
- 10/15 Sample (Treatment)
- 10/15 Sample (Control)
- 1/11 Sample (Treatment)
- 1/11 Sample (Control)
- 1/14 Sample (Treatment)
- 1/14 Sample (Control)
Appendix E1-E11. Community Survey Results

E1. Male vs. Female Survey Respondents

E2. Respondent Breakdown By Race

E3. Years Lived in Granville County
E4.

Ages of Respondents

Frequency

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-39</td>
<td>2</td>
</tr>
<tr>
<td>40-49</td>
<td>1</td>
</tr>
<tr>
<td>50-59</td>
<td>3</td>
</tr>
<tr>
<td>60-69</td>
<td>25</td>
</tr>
<tr>
<td>70-79</td>
<td>13</td>
</tr>
<tr>
<td>80-89</td>
<td>4</td>
</tr>
<tr>
<td>Unknown</td>
<td>4</td>
</tr>
</tbody>
</table>

E5.

How has stream quality changed over time?

Frequency

<table>
<thead>
<tr>
<th>Option</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Don't Know</td>
<td>1</td>
</tr>
<tr>
<td>Improved Greatly</td>
<td>2</td>
</tr>
<tr>
<td>Improved Somewhat</td>
<td>6</td>
</tr>
<tr>
<td>Stayed The Same</td>
<td>11</td>
</tr>
<tr>
<td>Degraded Somewhat</td>
<td>20</td>
</tr>
<tr>
<td>Degraded Greatly</td>
<td>5</td>
</tr>
</tbody>
</table>
Access to clean drinking water is a right

- 31% Agree
- 53% Strongly Agree
- 14% Strongly Disagree
- 2% No Opinion

Water Sources and Drinking Water Habits

- Drink both water from faucet and bottled water
- Drink bottled water
- Water from faucet
- Other

E6.

E7.
Water quality in Granville County has declined in the time that respondents have lived or worked in Granville County

- Strongly Disagree: 2
- Disagree: 7
- Strongly Agree: 7
- Agree: 18
- No Opinion: 17

Do you have a stream or waterway that runs on, near, or adjacent to your land (within 1 mile)? If yes, what stream?

- Yes:
  - Coon: 20
  - Fishing: 20
  - Unknown: 0

- No: 10
How often does the stream near you flood?
How often do you see litter floating in or near the stream?
How often do you see foam in the stream?

Responses from Residents Residing Near Coon Creek

Responses From Residents Residing Near Fishing Creek

E10 and E11.
Appendix F1. Community Survey Questions

Demographic and Related Questions
1. What is your age?
2. What is your sex?
3. What race do you identify with?
4. What is your home address? (Optional: interested in proximity to sample sites)
5. What is your estimated annual income? (Optional)

General Questions
6. Are you currently a resident of Granville County?
   Yes
   No
7. If you answered yes, how many years have you lived in Granville County?
   N/A
   0-1
   2-3
   4-5
   6-10
   10+
8. Do you currently or have you worked within Granville County lines?
   Yes
   No
9. If you answered yes, how many years have you worked in Granville County?
   N/A
   0-1
   2-3
   4-5
   6-10
   10+
10. Do you live in an affordable housing unit or rent-stabilized unit?
    Yes
    No
11. What efforts do you see Granville County making to provide a clean environment for residents?
12. Are you on well or city water?
    City
    Well
    I am not sure
13. What water do you drink?
    Water from faucet
    Bottled water
    Both
    Other
14. Do you have a stream or waterway that runs on, near, or adjacent to your land (within 1 mile)?
    Yes
    No
15. If yes, what is the name of this stream? (Refer to map below)

The following three questions are about wildlife and critters that you may have seen near a stream, particularly Fishing, Coon, or Jordan Creek.

16. What kinds of wildlife or critters do you see near the stream (insect, birds, fish etc.)?
17. Does this change from season-to-season?
18. Have your observations changed over the years?

The next questions are about the stream that you identified in question 15. If you answered “no” to question 14, you may skip to question 25.

19. If you do live near a stream, how often does it flood?
    Never
    Once every couple of years
    A few times a year
    More than a few times a year
Every time you are near a stream

20. How often do you see litter floating in or near your stream?
   Never
   Once every couple of years
   A few times a year
   More than a few times a year
   Every time you are near a stream

21. How often do you see foam in your stream?
   Never
   Once every couple of years
   A few times a year
   More than a few times a year
   Every time you are near a stream

22. How clear is the stream water near your home?
   Very cloudy
   Moderately cloudy
   Relatively clear
   Very clear

23. What value does this stream bring to you?

24. In your opinion, how accessible are the access points to public recreation areas in your city?
   Not accessible
   Moderately accessible
   Very accessible
   Not sure

Perception Questions
The following questions are designed to provide us with an understanding of how the general public perceives certain issues. Please respond to the extent that you agree with the following statements.

25. Water quality in Granville County has declined in the time that I’ve lived or worked herein Granville County (if applicable).
   Strongly Disagree
   Disagree
   No Opinion
   Agree
   Strongly Agree

26. Access to clean drinking water for people is a right.
   Strongly Disagree
   Disagree
   No Opinion
   Agree
   Strongly Agree

27. Stream quality has___ over time?
   Improved greatly
   Improved somewhat
   Stayed the same
   Degraded somewhat
   Degraded greatly