Effects of Roadway Runoff on the Water Quality of the Codorus Creek Watershed

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Abstract

This study is to serve as a model for future, intensive studies into the effect roadway runoff has on the water quality of the Codorus Creek watershed. This runoff is known to contain nonpoint source pollutants that are picked up and transported during rain and snowmelt events. Roadways specifically may contain high levels of heavy metals and hydrocarbons transported by vehicles and deposited as they travel. Preliminary samplings of runoff water at 3 sites was conducted for 5 separate rainfall events (August 28, September 5, September 8, September 11, and November 16) and were tested for the following: lead, zinc, pH, hydrocarbons, turbidity, and total suspended solids. These samples were analyzed and the results compared with the EPA’s National Recommended Water Quality Criteria and similar studies on the effects of roadway runoff in other locations. While further, more thorough investigation is necessary to verify my results, it appears that there is a slight correlation between the concentrations of pollutants associated with roadway runoff and the level of vehicular traffic experienced by each roadway.

Introduction

Pollution can enter our watersheds through fairly obvious channels such as pipes, sewers, and treatment plants. There are also less obvious means that pollution can enter our streams and rivers, referred to as nonpoint source pollution. The term “nonpoint source pollution” is generally defined as “a contributory factor to water pollution that cannot be traced to a specific spot; for example, pollution that results from
water runoff from urban areas, construction sites, agricultural and silvicultural operations, and so forth. This pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, or seepage that carries and deposits both natural and man-made pollutants into watersheds.

The most common nonpoint source pollutants are sediment and nutrients. Other common nonpoint source pollutants include pesticides, pathogens (bacteria and viruses), salts, oil, grease, toxic chemicals and heavy metals. These pollutants can be found in a variety of sources, such as agricultural, mining-related, and for the purpose of this paper, highway facilities. Table 1 shows some of the major contributors to roadway runoff pollution and the specific sources from which they arise.

Highway nonpoint source pollution is created when chemicals, debris, fertilizers and automotive oils are washed off roadways and bridges during rainstorms and carried as runoff to streams, rivers, lakes and bays. Approximately 46% of U.S. vehicles leak hazardous fluids, such as: crankcase oil; transmission, hydraulic, and brake fluid; and antifreeze, as can be visibly seen by oil spots on roads/parking lots. Most everyone in the U.S. has seen at one time the rainbow sheen from an oil puddle at some close proximity to a roadway, indicative of this type of pollution. It is estimated that at least 30% of oils used in vehicles are either burned in the engine or lost in drips and leaks. Each year in the U.S., about 180 million gallons of used oil are disposed of improperly onto the ground or into sewers. To put this into perspective, that is 16 times the amount spilled by the Exxon Valdez. The proximity of urban and suburban areas to
major highways allows for runoff containing any number of these pollutants from vehicular travel

<table>
<thead>
<tr>
<th>Sources of Pollution in Highway Runoff</th>
</tr>
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<tbody>
<tr>
<td><strong>Pollutant</strong></td>
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<tr>
<td>Sedimentation</td>
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<tr>
<td>Nutrients</td>
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<tr>
<td>Heavy Metals</td>
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<tr>
<td>Hydrocarbons</td>
</tr>
</tbody>
</table>

Table 1. Typical pollutants found in runoff from roads and highways. Adapted from Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.
As shown in Table 1, heavy metals are found in roadway runoff; zinc, copper, and lead are the three most common heavy metals found in this type of runoff and account for approximately 90% of the total metals in road runoff. It is important to note that lead levels have been steadily declining since leaded gasoline was discontinued. Iron is another common metal and can be attributed to factors such as rust on the vehicles and steel structures including bridges and guiderails. As zinc and lead are common indicators of roadway runoff pollution, I decided to test for these metals.

The concentration of hydrogen ions dissolved in water is commonly expressed in terms of the pH scale. Low pH corresponds to high hydrogen ion concentration, and vice versa. When the environment lies under a pH of 7 (acidic), there is a high enough level of H+ ions to occupy many of the negatively charged surfaces of clay and organic matter. This in turn allows less space for the metals to bind to the organic matter, leaving more metals to remain soluble. As pH is a major factor in the behavior of metals in stream water, I chose to document these values as well.

Turbidity is a measure of water clarity and is caused by roadway runoff as well as soil erosion, eroding stream banks, and water discharge. When there is more material suspended in the water, there is a decrease in the passage of light through the water. These materials can include clay, silt, sand, algae, plankton, and microbes, among others. These materials are typically in the size range of 0.004 mm (clay) to 1.0 mm (sand). The suspended particles absorb heat from the sunlight, making turbid waters
become warmer, and so reducing the concentration of oxygen in the water (oxygen dissolves better in colder water). The suspended particles also scatter the light, thus decreasing the photosynthetic activity of plants and algae, which contributes to lowering the oxygen concentration even more. Heavy metals are also affected; the particles aid in the attachment of metals and other organic compounds and pesticides. As turbidity is tied to roadway runoff and the reaction of heavy metals I have also analyzed the collected samples for this parameter.

Turbidity is closed tied with another parameter, total suspended solids or TSS. The greater the amount of total suspended solids in the water, the murkier it appears and the higher the measured turbidity. While turbidity measures the amount of light scattered from a sample, the TSS test measures an actual weight of material per volume of water. This difference becomes important when trying to calculate total quantities of material within or entering a stream. Such calculations are possible with TSS values but not with turbidity readings.

Perhaps the most important indicator of roadway runoff in a water body is total petroleum hydrocarbons, or TPH. Petroleum hydrocarbons are directly and unilaterally linked to vehicles. For example, engine coolants and antifreeze containing ethylene glycol and propylene glycol can be toxic and contribute to water quality impairments. Oil, grease, and other hydrocarbons related to vehicle use and maintenance can also contribute to runoff. Their sources can be: disposal of used oil and other fluids on the
ground or into storm drains, spills of gasoline or oil, and leaks of oil and other fluids from vehicles. The Codorus Creek, located in York County, PA, is a tributary of the Susquehanna River and is comprised of a 278 square mile drainage area. It contains 447 miles of streams, is home to approximately 220,000 residents, and has a wide diversity of land uses including agricultural, forest, residential, commercial, and industrial. The watershed is comprised of three primary drainages: East Branch Codorus, South Branch Codorus and West Branch Codorus. The water quality of the Codorus has been heavily studied over the past few decades and it has been determined that out of the 447 miles of streams, only 46% of those assessed meet water quality standards. Nonpoint source pollution factors attributed include: stream bank, channel erosion, and sedimentation, which is responsible for more than half of the degraded streams. Although information is available for less than half of the Codorus Creek's streams and tributaries, many of those are considered eutrophic (high in nutrients and low in dissolved oxygen). The Susquehanna River, which feeds into the Chesapeake Bay, accounts for about 20% of the total phosphorus and 39% of the total nitrogen loadings of the Bay, of which nonpoint sources of pollution generate the majority of these.

The South Branch Codorus is geographically located between the Mason-Dixon Line and Seven Valleys, PA (see Figure 1.). The total drainage area here is roughly 74,880 acres and the streams here total 68.05 miles in length. The length of roads
housed in this sub-watershed total 162.35 miles. The land use here breaks down into the following:

- Commercial/Industrial/Transportation: 37 acres
- Deciduous Forest: 5,472.86 acres
- Emergent Herbaceous Wetland: 21.62 acres
- Evergreen Forest: 336.41 acres
- High Intensity Residential: 10.47 acres
- Low Intensity Residential: 334.92 acres
- Mixed Forest: 450.11 acres
- Pasture/Hay: 12,517.14 acres
- Row Crops: 2,449.63 acres
- Water: 56.33 acres
- Woody Wetland: 44.53 acres

Closely associated with the land use is the zoning of this sub-watershed, which is detailed as follows:

- Agricultural: 15,523.9 acres
- Business: 42.25 acres
- Commercial: 85.49 acres
- Commercial/Industrial: 9.19 acres
Conservation/Open Space: 2,762.89 acres

Industrial: 202.41 acres

Mixed Use: 150.45 acres

Residential: 1,360.53 acres

Residential (Rural/Low Density/Open Space): 1,090.98 acres

Village Center: 505.5 acres

Figure 1. Map of South Branch Codorus Creek Watershed

Courtesy of DEP, Codorus Creek Nonpoint Source Pollution Control Watershed Implementation Plan, York County, Pennsylvania.
Previous studies of the Codorus have concluded that the watershed lacks riparian zones, or buffers that consist of vegetated or forested strips of land, that help reduce erosion and trap runoff, pollution, and sediment before they can enter the water body. The buffers that are intact are often too narrow to offer any real benefit and most of them are not forested; instead, they contain vegetation that cannot contribute in stabilizing the stream’s banks. This is significant because when roadway runoff exists, the lack of riparian zones allow more of the pollution associated with it to enter the water body.

Studies have been performed in various locations worldwide to determine the impact roadway nonpoint source pollution has on the water quality of neighboring watersheds, though this has never been researched in any area of the Codorus watershed. As seen in Figure 2, this watershed contains numerous roadways, and most of the major routes directly border banks of the Codorus and streams branching from the mainstem. The purpose of this study is to obtain preliminary findings that support my hypothesis, that there is a direct relationship between roadway runoff and increased pollution into adjacent bodies of water. I expect that more heavily traveled roadways contribute higher levels of pollution associated with runoff from vehicles, specifically total petroleum hydrocarbons and heavy metals. I also expect that the levels of total suspended solids, turbidity, and pH will all increase as a result of the pollution from the runoff. I anticipate that these levels of pollutants become less prevalent directly proportional to the decrease in vehicular traffic the roadway pavement encounters. This study serves to gain an understanding of the effect roadway runoff
has in this area for use in future, more intensive water quality studies.

Figure 2. Major roadways in the Codorus Watershed

Methods

The three sites I chose for this study differ in the nature of their locations; site 1 in Glen Rock Borough is located adjacent to a primary roadway, State Route 216/Glen Rock Road; site 2 is a secondary roadway also in Glen Rock Borough, Rockville Road; site 3 is adjacent to the parking lot of the Glen Rock Mill Inn (see Figure 3). The sites were chosen to study the effects of roadway runoff of 3 different intensities of vehicular travel.
Figure 3. Approximation of sampling site locations (courtesy of Google Maps)

All three sites are located on the South Branch Codorus and this drainage area was chosen because its primary land use is agriculture (about 80%)⁶. Agricultural activities that cause nonpoint source pollution include the following: poorly
located/managed animal feeding operations; overgrazing; plowing too often or at inappropriate times; and improper, excessive, or poorly timed application of pesticides, irrigation water, and fertilizer. These resulting pollutants include sediment, nutrients (nitrogen and phosphorus in particular), pathogens, pesticides, ammonia, and salts. The parameters I’ve chosen for this study are not typically linked to agricultural activities and therefore cannot be attributed to these practices.

The water samples were collected from three distinct sites and were tested for turbidity, heavy metals (including lead and zinc), total suspended solids (TSS), pH, and hydrocarbons (total petroleum hydrocarbons). These parameters were chosen because they are directly related to roadway runoff pollution. The lack of runoff from additional nonpoint sources other than agriculture (such as industrial or urban) enables me to rule out other factors that may contribute to the test results.

The samples were collected during rainfall runoff events and I ended my study with 5 sampling events analyzed. Water was collected using the grab method at each of the three sites; they were collected from a roadway culvert pipe for site #1 and site #2 and from pavement runoff from the parking lot at site #3. Lancaster Laboratories was contracted to perform the specific tests and they delivered a cooler via courier to my residence for each sampling event. These coolers contained the bottles used to collect each sample with appropriate preservatives included for each test requested. The following containers and preservatives were used to collect the samples for each individual site: 3 – 40 mL glass vials for TPH-GRO preserved with hydrochloric acid; 1
– 500 mL plastic bottle (no preservative needed) for total suspended solids/pH/turbidity; and 1 – 500 mL plastic bottle preserved with nitric acid for lead and zinc.

Figure 4. Packed cooler of samples taken on 9/5/11.

Additionally, these coolers were also used to store and transport the samples to the lab for testing. They contained bubble wrap, foam dividers, and bags for ice as needed for safe transportation to the lab. Per their testing procedures, aqueous samples needed to be submitted within 48 hours of collection and must be submitted chilled (with wet ice) so that the temperature upon arrival to the lab is 4 degrees Celsius (+ or – 2 degrees Celsius). I hand-delivered the samples to the lab for each event within 24 hours of collection to: Lancaster Laboratories, 2425 New Holland Pike, Lancaster, PA 17605 for analysis. The samples included an external chain of custody which detailed the analyses needed, collection date/time/location, type of sample (i.e. grab), types of preservatives for each sample, total number of sample containers, and my identifying information. This laboratory utilized the following methods for analyzing the samples and details of the specific testing procedures are as follows:

**pH:** Standard method 20 4500 H/B
• pH was determined electrometrically using a glass electrode in combination with a reference electrode

**Turbidity: EPA 180.1 (1993)**

• Turbidity is measured in NTU: Nephelometric Turbidity Units. The instrument used for measuring it is called nephelometer, which measures the intensity of light scattered at 90 degrees as a beam of light passes through a water sample.

**Total Suspended Solids: Standard method 20 2540 D**

• TSS is measured with a gravimetric device which works by pouring a carefully measured volume of water through a pre-weighed filter of a specified pore size, then weighing the filter again after drying to remove all water.

**Lead and Zinc: SW-846 6010B**

• All heavy metal analyses were determined by inductively coupled argon plasma (ICP), where argon plasma is used as the ionization source and a mass spectrometer is used to separate the ions produced.

**TPH-GRO (water C6-C10): SW-846 8015B**

• For the purposes of my study and my sites selected, I chose to analyze for TPH-GRO, which are the gasoline range organics (also known as purgeable
hydrocarbons). The roads and parking lot involved in this study are traveled primarily by gasoline-powered vehicles as opposed to diesel. This test measures the total hydrocarbon values for organics found in gasoline, which consists of C$_6$-C$_{10}$ (or 2-methyl pentane to 1,2,4-trimethyl benzene). These are measured by purge-and-trap gas chromatography (GC) analysis using a flame ionization detector (FID).

Additionally, field blanks were utilized for each procedure for quality assurance purposes. Lancaster Labs supplied electronic spreadsheets with the raw data results, accessible via a web-based program. This data was then analyzed using GraphPad Instat statistical program and those results reported in the following section. It should be noted that Lancaster Labs requires prior permission to be named in connection with reporting and that permission was obtained during my initial consultation with the business development department.

Summary water quality characteristics for runoff samples will be presented as median event mean concentrations for all 5 events and standard deviation for each site. There is a possibility that some constituents may be present in levels lower than that of the detection limits of the equipment used; in such cases, the value of the detection limit was assigned and used for analysis. I have also quantified these findings against: EPA’s National Recommended Water Quality Criteria, published pursuant to Section 304(a) of the Clean Water Act (CWA) and provide guidance for states and tribes to use in adopting water quality standards; values found for roadways traveled by less than
30,000 vehicles per day from a study by Driscoll et al.⁸; and a study conducted by Barrett et al.³. These comparisons will serve as an evaluation of the effects roadway runoff has on the quality of water in the Codorus Creek. More importantly, this process will serve as model which individuals can use in the future to perform in-depth analysis of the effects of roadway runoff in this watershed.

**Results**

GraphPad InStat was used to input all values reported by Lancaster Labs and calculate reported values; the level of significance for all data is 5%. Table 2 summarizes the median event mean concentrations of each parameter found at all 3 testing sites. Standard deviations are also given for each. There is no significant difference in the quantities of heavy metals found between sites. pH values are also similar among the sites selected. Most notable are the values for turbidity and TSS; the primary roadway (site #1) showed far greater quantities of TSS but the turbidity measurement was far greater for the parking lot (site #3). TPH-GRO was detected in low levels in both the primary roadway and the parking lot.

For all analysis performed by Lancaster Labs, the following limits of quantitation (smallest amount of analyte which can be reliably determined) apply for each of these tests:

- TPH-GRO: 0.0500 mg/L
- Lead: 0.0150 mg/L
- Zinc: 0.0200 mg/L
- Turbidity: 0.30 NTU (nephelometric turbidity units)
- TSS: 30.0 mg/L

As stated previously, for constituents that were reported by Lancaster Labs as possibly present in levels lower than that of the detection limits of the equipment used, the value of the detection limit was assigned and used for analysis. Every site had two or more samples that showed this value for TPH-GRO. Sites #1 and #2 had three or more samples of zinc that resulted in this analysis, and site #2 and #3 had all 5 sample sets demonstrate this value for both lead and TSS.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SITE #1, PRIMARY ROAD</th>
<th>SITE #2, SECONDARY ROAD</th>
<th>SITE #3, PARKING LOT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lead (mg/L)</strong></td>
<td>0.0158</td>
<td>0.0150</td>
<td>0.0150</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>8.38</td>
<td>8.08</td>
<td></td>
</tr>
<tr>
<td><strong>TSS (mg/L)</strong></td>
<td>60.48</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td><strong>Turbidity (NTU)</strong></td>
<td>10.36</td>
<td>3.08</td>
<td>32.90</td>
</tr>
<tr>
<td><strong>TPH (mg/L)</strong></td>
<td>0.0530</td>
<td>0.0500</td>
<td>0.0554</td>
</tr>
<tr>
<td><strong>Zinc (mg/L)</strong></td>
<td>0.0222</td>
<td>0.0200</td>
<td>0.0309</td>
</tr>
</tbody>
</table>

Table 2. Median event mean concentrations (MC) of constituents of highway runoff, with standard deviation (SD) given for each.
In order to determine any significance in these values in terms of indicators of roadway pollution, these values were compared with the most recent EPA National Recommended Water Quality Criteria as well as a study performed by Driscoll et al.\(^8\). Shown below in table 3, I have two separate values listed for the EPA standards; the first value (EPA CMC\(^A\)) is the Criteria Maximum Concentration, the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect. The second value, EPA CCC\(^B\) or the Criterion Continuous Concentration, is the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect\(^8\). This second value is most significant here, as the measurements calculated reflected concentrations that were present for an extended period of time. TSS and turbidity are not included in the EPA’s National Water Quality Criteria and TPH-GRO consists of various hydrocarbons, none of which have concentrations accepted by the EPA. The pH values all fell within acceptable limits, as did the levels of zinc in the samples collected. Most noted here are the concentrations of lead in comparison to the EPA’s CCC limits; all three sites are above this recommended value.

The value listed from the Driscoll et al. study is one cited by numerous sources with regards to roadway runoff pollution studies. They found very consistent average values for runoff pollution from roadways that have less than 30,000 vehicles travel it daily versus roadways that have more than 30,000 vehicles traveled daily. All three
sites I selected fall into this first group, with less than 30,000 vehicles daily.

Comparison to these values result in the following:

- **Lead:** All three sites have values less than those found in this study
- **TSS:** Slightly less but comparable values for site #2 and #3; I found a much greater concentration from site #1 than expected
- **Zinc:** All sites had a lower concentration than expected
- **pH, turbidity, and TPH:** Were not reported in this study

Finally, I chose to compare these same median calculations to a similar study done in Texas by Barrett et al.\(^3\). This study was what initially inspired me to conduct an investigative analysis into the Codorus and it seemed logical to contrast our results. They also sampled water from a primary roadway and a secondary roadway; additionally, values were obtained from a major highway, which are not reported since I did not test a similar roadway. Again, their study only quantified lead, TSS, and zinc. This table can be interpreted as follows:

- **Lead:** Values are comparable
- **TSS:** Barrett et al.\(^3\) found a much larger quantity from their primary road study than reflected in my analysis; however, my analysis showed a significantly larger amount of TSS in my secondary road site when compared to their study
- Zinc: Very little variation and thus comparable

Site #3, the paved asphalt parking lot of the Glen Rock Mill Inn, showed elevated values for TPH, zinc, and turbidity, more so than even the primary road in this study.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SITE #1, PRIMARY ROAD</th>
<th>SITE #2, SECONDARY ROAD</th>
<th>SITE #3, PARKING LOT</th>
<th>EPA CMC&lt;sup&gt;A&lt;/sup&gt;</th>
<th>EPA CCC&lt;sup&gt;B&lt;/sup&gt;</th>
<th>&lt;30,000 VEHICLES/DAY (DRISCOLL et al. 1990)</th>
</tr>
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<tbody>
<tr>
<td>Lead (mg/L)</td>
<td>0.0158</td>
<td>0.0150</td>
<td>0.0150</td>
<td>0.0650</td>
<td>0.0025</td>
<td>0.0800</td>
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<td>pH</td>
<td>8.38</td>
<td>7.48</td>
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<tr>
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<td>Zinc (mg/L)</td>
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<td>0.1200</td>
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</table>

Table 3. Comparison of Median EMC’s with EPA National Recommended Water Quality Criteria<sup>11</sup> and values from a study by Driscoll et al.<sup>8</sup>.

The CMC and CCC are just two of the six parts of an aquatic life criterion; the other four parts are the acute averaging period, chronic averaging period, acute frequency of allowed exceedence, and chronic frequency of allowed exceedence. Because 304(a) aquatic life criteria are national guidance, they are intended to be protective of the vast majority of the aquatic communities in the United States<sup>11</sup>. 

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<sup>11</sup>
<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SITE #1, PRIMARY ROAD (BARRETT et al. 1995)</th>
<th>PRIMARY ROAD (BARRETT et al. 1995)</th>
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<th>SITE #3, PARKING LOT</th>
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<td>TPH (mg/L)</td>
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Table 4. Comparison of Median EMC’s with Barrett et al. study, *Characterization of Highway Runoff in Austin, Texas, Area*.

Discussion

I expected to find a significant increase in all parameters tested for site #1, the primary roadway in Glen Rock, than in the secondary roadway (site #2). The increases I found were less than I expected, and in some cases very slight, but do support my overall hypothesis given the limited data sets. I also expected levels of pollutants from the secondary roadway to be elevated in comparison to the parking lot. This was not the case; while fewer vehicles pass through this parking lot on a daily basis, the
vehicles that do encounter the pavement are in contact with it for extended periods of time. The increased amount of time these vehicles are stationary in the parking lot may allow more runoff to make contact with the pavement and therefore allow more pollutants in the runoff to enter the creek.

As my cursory findings show that the parking lot exhibits more roadway runoff than the secondary road, I would expect an increase in levels of pollutants. My findings are inconclusive when analyzed for lead and TSS; however, the concentrations of zinc, TPH, and values for turbidity are all elevated and in support of this hypothesis. pH also seems to increase with relation to other pollutants in the water body.

Lead seems to be a particular concern from my findings; all of the sites evaluated had water containing levels of lead above what is recommended by the EPA for ambient water quality. The interesting finding here is that these concentrations are still less than what was found in the Driscoll et al. study and both their findings and Barrett et al. are also above the EPA recommended value. Otherwise, the EPA recommendations, though limited in their spectrum, are all met for all studies investigated.

When compared to the Driscoll et al. findings, the South Branch Codorus actually has less zinc and lead. My TSS findings are comparable with this study as well; while the levels found in water samples from the secondary roadway and parking lot had smaller concentrations, the primary roadway off of Route 216 had a substantially higher amount.
Comparison to the Barrett et al. study yielded similar results. My TSS concentrations are in the range reported in this analysis, and the lead and zinc values are within reasonably similar amounts. A larger sample size is needed to accurately characterize these concentrations however; generally, at least 15-20 are the recommended minimum.

As previously stated, the value for turbidity is vastly higher for site #3, the parking lot, than for the other two sites studied. By contrast, the concentration of TSS is not higher; TSS is highest in site #1. Further investigation is necessary in order to determine the cause of this; it could be as a result of contamination of the parking lot sample or the particles in this sample could have been so minute as to not have been detectable by the testing equipment.

The limits of quantitation should also be considered when discussing these results. There were a significant number of samples that had little to no levels of lead, zinc, TSS, and TPH-GRO, and thus were reported as the value of this smallest detection limit. This could alter the results, as it is possible that the actual concentrations in the samples were much smaller than this limit. Further, more in-depth studies of the Codorus is needed in order to determine what effects, if any, these values had on the overall analysis of all three sampling sites.
Conclusion

While my cursory studies have shown slight evidence of a direct correlation between increased pollutants in water bodies with roadway runoff, additional testing is necessary in order to further evaluate the relationship. I was able to collect samples from five storm events; ideally, at least 15 should be collected and analyzed for more reliable results. Additionally, there is initial evidence of a relationship between the amount of roadway runoff pollutants and the extent to which the roads are traveled by vehicles when analyzing my data from the primary and secondary roadways. This should also be further studied with a more thorough evaluation of these sites in order to provide more solid evidence to support these findings.

Along with sampling more rainfall events, I would also recommend expanding the testing parameters to include: iron, copper, cadmium, chromium, nickel, manganese, cyanide, calcium, sodium, chloride, and sulphates. Other petroleum tests could also be performed, such as TPH-DRO (diesel range organics) and oil and grease. This would expand the understanding of the relationship between roadway runoff and petroleum pollution. These tests may also show petroleum compounds prevalent in this area that are not reported in the TPH-GRO analysis. I was unable to perform these tests due to the expenses involved, but as they are also indicators of roadway runoff pollution it would be useful to test for and compare to the studies referenced in this paper.

I would also recommend testing more parking lot sites to compare with the Glen Rock Mill Inn site. It would be useful to determine if other parking lots display higher
levels of pollutants than my secondary site, thus supporting my findings that parking lots may allow higher levels of runoff pollution to enter the watershed than minor roadways. I was unable to find any studies previously performed that tested the effects of parking lot runoff, so additional research done in this watershed could serve as a basis for advanced analysis and future studies.

Further research into the effects of roadway runoff on the South Branch Codorus will serve to better comprehend the correlations found in this study. Additional factors could also be considered, such as analyzing the velocity of runoff. A larger sample and data set can be subjected to more intensive statistical analysis and therefore expand this understanding and serve as a foundation for future research on the subject.
References


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