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Christmas Brook: Naughty or Nice?

An Evaluation of Local Water Quality

By Becky Davies, Sam Denton-Schneider and Ben Swimm

ENVI 102, Professor Dethier

Monday and Wednesday Labs

Experiment Performed March - May 2006

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Abstract

Since the extension of the Williamstown sewer system in the mid 1990s, Christmas Brook has experienced improved health from reduced fecal contamination. However, the stream exhibits the effects of large amounts of road salt, and runoff from fertilizer at recreational facilities. Increases in chloride and calcium concentrations point to additional input sources.

Index of Graphics

Introduction

As the landscape of Williamstown, Massachusetts changes, the benefits of improved recreational facilities, local attractions, and residential development obscure human effects upon the environment. Degradation of the natural environment threatens the health of plant and animal species, including humans, and can affect environmental quality outside of Williamstown. Waterways originating in and flowing through Williamstown illustrate the effects of human influence upon environmental health, as they receive point and nonpoint source pollution from a variety of residential, commercial, and industrial zones. Christmas Brook, a first order stream that develops into a second order stream as it flows north towards downtown Williamstown, models how human influences affect stream health, and demonstrates the importance of reducing human impact upon the natural environment (Appendix 1).

Serving as the headwaters for the Hudson River Drainage Basin ("Hudson"), the small streams and wetlands that originate at high elevations in the Berkshire Mountains of Williamstown and the surrounding northwest region capture water that travels hundreds of miles, draining into rivers like the Green River, which first joins the Hoosic River as it runs northwest into Vermont, and eventually flows westward into the Hudson River and south out the New York Harbor ("The Hudson River", Appendix 2). Covering approx. 5000 sq. ft (Power), Christmas Brook contributes a relatively negligible amount of water to the drainage basin, yet it represents hundreds of streams that cumulatively form larger rivers. Hence, upstream contamination accrues in downstream waters, thereby exporting the effects of environmental disturbance.

Locally, Christmas Brook forms from intermittent runoff from the east side of Stone Hill and the northeastern side of Mount Swimm, the lower peak east of Stone Hill (Appendix 3). Dubbed "Phoebe's Brook," this branch flows northward through wetland areas and beneath Gale

Road before merging with another branch to become a second order stream. Along with seasonal tributaries, the two main branches constitute the Christmas Brook drainage basin, which provides a valuable aquifer for groundwater collection, especially for private wells (Taylor). Water draining into the basin off Stone Hill runs over quartzite bedrock, which has a high resistance to weatherization and low acid neutralizing capacity (Appendix 4). However water draining from Mount Swimm passes over marble, which has greater capacity to neutralize acidic rain before it reaches Christmas Brook. The west branch of Christmas Brook also lies in quartzite. Downstream, marble serves as the dominant bedrock (Dethier).

The first developed site Christmas Brook encounters along the west branch is Pine Cobble School (Appendix 4). Replacing Highcroft School in the mid 1990s, the Pine Cobble campus contains athletic fields, schools buildings, a pool, and parking lots ("Campus"). Christmas Brook passes through a ravine west of the school, receiving runoff coming down the slope. Potential runoff includes lawn and field treatments, road treatments such as road salt, and wastewater.

Along the east branch, which runs during periods of higher water, the brook lies down slope from the Buxton School and the Clark Art Institute (Appendix 4). The Buxton School arrived at its present site in 1947, and presumably contributes similar inputs as Pine Cobble School ("About"). The Clark Art Institute originated in 1952 but expanded in 1973, adding a second building closer to the stream site. The Institute plans to remodel and expand its facilities and grounds in the near future, which could add construction residue runoff to the current and future landscape and parking lot inputs ("Construction").

Municipal wastewater leakages from these three sites and from neighboring residential areas greatly concern the health of Christmas Brook. Before the mid 1990s, residences relied on private septic tanks rather than town sewers (Appendix 5). Leaking sewage, the septic tanks contaminated Christmas Brook with high levels of fecal matter that degraded the stream environment. The polluted water threatened groundwater drawn from private wells where city water was unavailable, such as at Buxton School (Appendix 6). Since then, the city has extended its sewer system to reach local residences, presumably removing fecal contamination (Dethier).

Damaging effects from other sources, such as road salt, could continue to pose a threat. Paved surfaces at the schools, museum, houses, and city roads receive salt to melt snow, which then flows into Christmas Brook. Though the concentration of road salt peaks during winter, lingering effects remain as the wetlands try to absorb excess nutrients.

As the two branches merge beside Gale Road, Christmas Brook continues into the Taconic Golf Course.

Figures 1 & 2: Phoebe's Brook as it passes from under Gale Road (Left) and the West Branch of Christmas Brook before it merges with Phoebe's Brook (Right)

First opened in 1896, the golf course has had ample time to alter the surrounding environment ("Taconic"). Visibly, the golf course's manicured greens compromise the natural wetlands that they cover (Appendix 7).

Figure 3: The Taconic Golf Course
http://www.golfclubatlas.com/taconic1.html

Figure 4: Christmas Brook at the 18th Hole

The resulting loss of organic matter and aquatic life could alter stream water chemistry and the stream's ability to absorb inputs. Though less immediately apparent, the effects of fertilizers and chemicals used to treat the golf course also threaten Christmas Brook, which receives the runoff from applied substances. In the spring and fall, the golf course receives ammonium sulfate based fertilizer, in addition to a slow-release potassium bulk spread applied in late June. Every three weeks the course receives soluble urea nitrogen. Annually, the course receives 2.5 lbs of potassium and nitrogen per square foot from fertilizer, plus trace amounts of phosphorous. In the past, the golf club used a natural organic fertilizer, but found that it easily ran off, burdening the brook and requiring additional fertilizer. Maintenance also requires preventative fungicides applied in rotation so as to prevent plant resistance. The fungicides include Dacono, Banner Maxx, Chipco 26GT, Touche, Subdue Maxx and Bayleton. Groundskeepers apply insecticides such as Merit and Scimitar once a year when necessary, but have not done so this year. Lastly, the golf course receives spot treatments of herbicide, in concentrations as low as five to six ounces for 10 to 15 acres of treatment (Lemme). Planned additions of 200 yards of golfing greens this winter will eliminate nearby plant life and trees, and potentially increase runoff into Christmas Brook, furthering affecting stream health.

After passing through the golf course, Christmas Brook enters Williams College property, bordering recently renovated athletic fields from 2004 and nearby facilities buildings (Senecal).

Figure 5: Lamb Field, a turf field constructed in 2004

The removal of a baseball diamond in close proximity to the stream (map) potentially reduces chemical inputs to Christmas Brook, since the new turf field in its place requires no chemical maintenance. However, the stream still borders a parking lot and resides near a football field that receives 1250 lbs of fertilizer—containing vast amounts of nitrogen—in the late fall, polymer coated slow-release fertilizer in the spring, and fungicides in the summer, including Chipco GT, Bayleton, and Subdue Maxx (Fitzgerald). Runoff or groundwater saturation can drain these chemicals from the fields into Christmas Brook. Aside from field applications, human activity at the site results in the accumulation of inorganic waste such as plastic bags and broken bottles in Christmas Brook.

Figures 6 & 7: Christmas Brook pollution is evidence of human activity at the Weston Athletic Field Complex

Passing under Latham Street south of downtown Williamstown, Christmas Brook flows eastward through pipes beneath the street before joining the Green River, which continues to the

Hoosic River. While the downstream effects remain important, the local consequences of stream pollution present more significant concerns. Organisms that live in the immediate vicinity of polluted streams and rely on the wetland habitat or the local aquifer will suffer from water contamination. Christmas Brook accommodates an abundance of plant and animal species, sustaining wetlands, aquatic life, and human life, and contributing to the aesthetic appeal of the area. By measuring various indices of stream health including pH, ANC, coliform, cation and anion concentrations, turbidity, and aquatic indicator species at different points along Christmas Brook, we aim to determine the health of the stream. Using data from upstream on both branches, the point of merger, the middle of the golf course, the end of the golf course at the 18^{th} hole, and just before the stream runs beneath Latham Street (Appendix 7), we can compare current data to historical data to assess whether new sewer systems have improved stream health, or if Christmas Brook exhibits further degradation from human activity.

Based on the history of Christmas Brook, we hypothesize that the stream water quality will have improved since the sewer system installation. In the absence of sewage contamination, we expect to find a decrease in nitrate, sulfate, and coliform count at upstream sites in comparison to historic levels. Though we have no historical data on phosphate, we expect to find little or no phosphate as well. Cleaned of sewage contamination, we anticipate a greater contrast between the health of Christmas Brook upstream versus downstream. In particular, we hypothesize that we will find a rise in contamination from road salt due to increased road salt use in recent years (Dethier). Additionally, we expect a disparity in upstream and downstream water quality due to runoff from the golf course and athletic fields. Specifically, we expect higher levels of nitrate, sulfate and potassium from fertilizer in the stream at the 18^{th} hole and at Latham Street.

Experimental

Water samples for coliform analysis and preliminary chemical testing were collected 15 April 2006. Samples tested for pH and ANC were collected 19 April 2006. Additional samples for chemical (anion and cation) analysis were collected 19 April, 2 May, and 11 May 2006.

Diluted and non-diluted 100 ml samples from three sampling sites were tested for coliform by filtering the samples through a .45 micrometer filter membrane using a vacuum filtering apparatus. The gridded filter membrane was then placed on a nutrient pad covered in either blue (fecal) or red (total) nutrient broth. Both raw and 10 fold dilutions were used for each sample, and both fecal and total coliform were tested for all sites. All samples were incubated for 24 hours at 35 degrees C (total coliform) or 44.5 degrees C (fecal coliform) and then counted.

Water pH of three sites was tested in the field and in the lab. Both devices were passivated and standardized with pH 4 and pH 7 buffer solutions. The lab pH-meter was a glass electrode meter, while the field meter had a metal tip. The acid neutralizing capacity of 50 mL of water from three sites was also calculated using glass electrode pH meters and Hach titrators containing either .16 N or 1.6 N H_2SO_4 (Sulfuric acid). Acid was added for the sample to reach a pH of 4.5, and ANC calculated by multiplying the number of digits by either 0.2 or 2.0, depending on the concentration of acid used. Final ANC was given in Standard Alkalinity, $CaCO_3$ mg/L. Conductivity was measured in the lab in μs/L, though we used a field measuring device.

Anions in solution—F^-, Cl^-, NO_3^-, PO_4^{-3}, and SO_4^{-2} were measured using an Ion Chromatograph. The presence of chemicals in the form of cations was measured through atomic absorption spectroscopy (Na^+ and K^+) and atomic absorption spectroscopy (Mg^{+2} and Ca^{+2}).

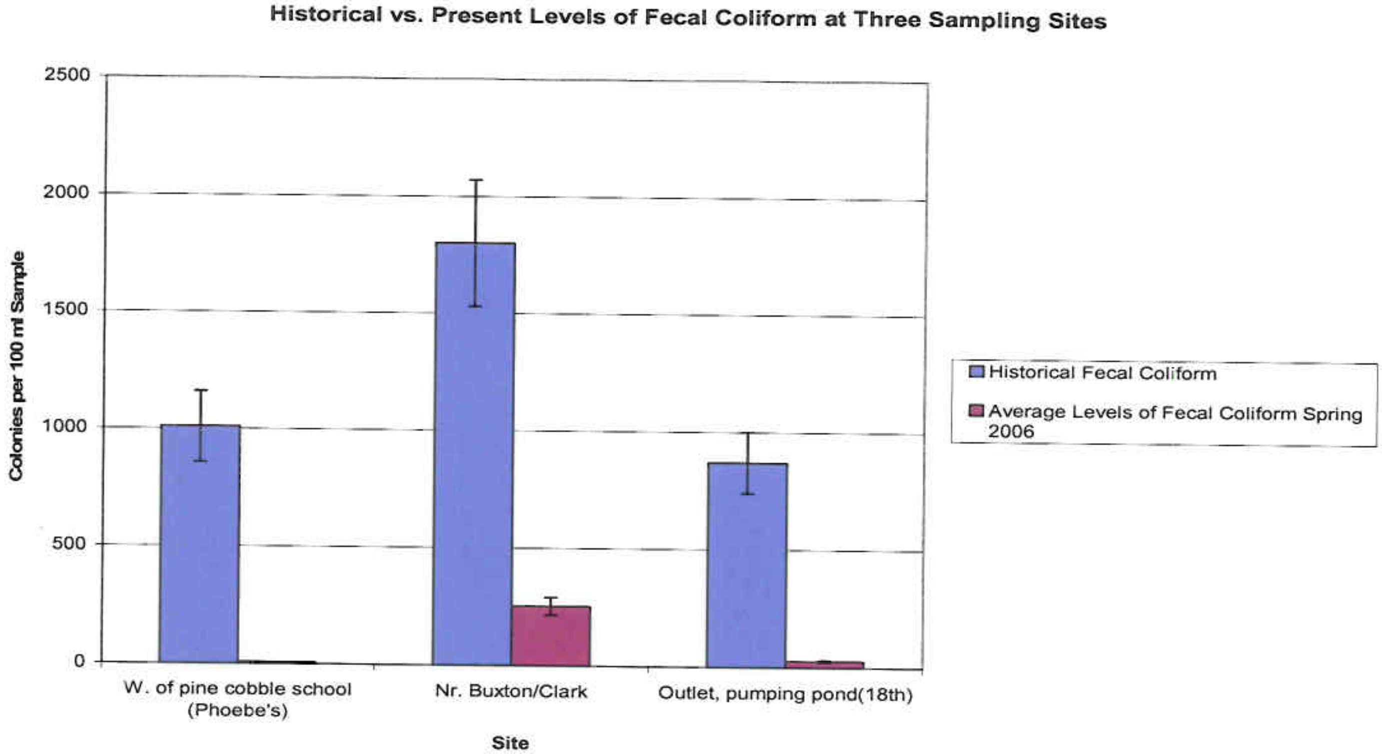
Aquatic invertebrates were sampled at three sites for ten minutes at each site. We then used a microscope to count and classify the invertebrates into six orders: plecoptera, tricoptera, diptera, odonata, ephemeroptera, and coleoptera. We used our data to compile a biotic index for each site. To calculate our biotic index values we used E.D. King's (1999) reference table with pollution values for each order of aquatic invertebrates (Appendix 8). A higher value signified poor water quality. Since there were numerous families within each order of aquatic invertebrates, we averaged the pollution tolerance values for each family within an order to obtain an average value for each order. We then used the average pollution tolerance values to calculate the biotic index of each site (Calculation 1).

For complete lab techniques reference the ES 102 Lab Manual (ES102).

Results

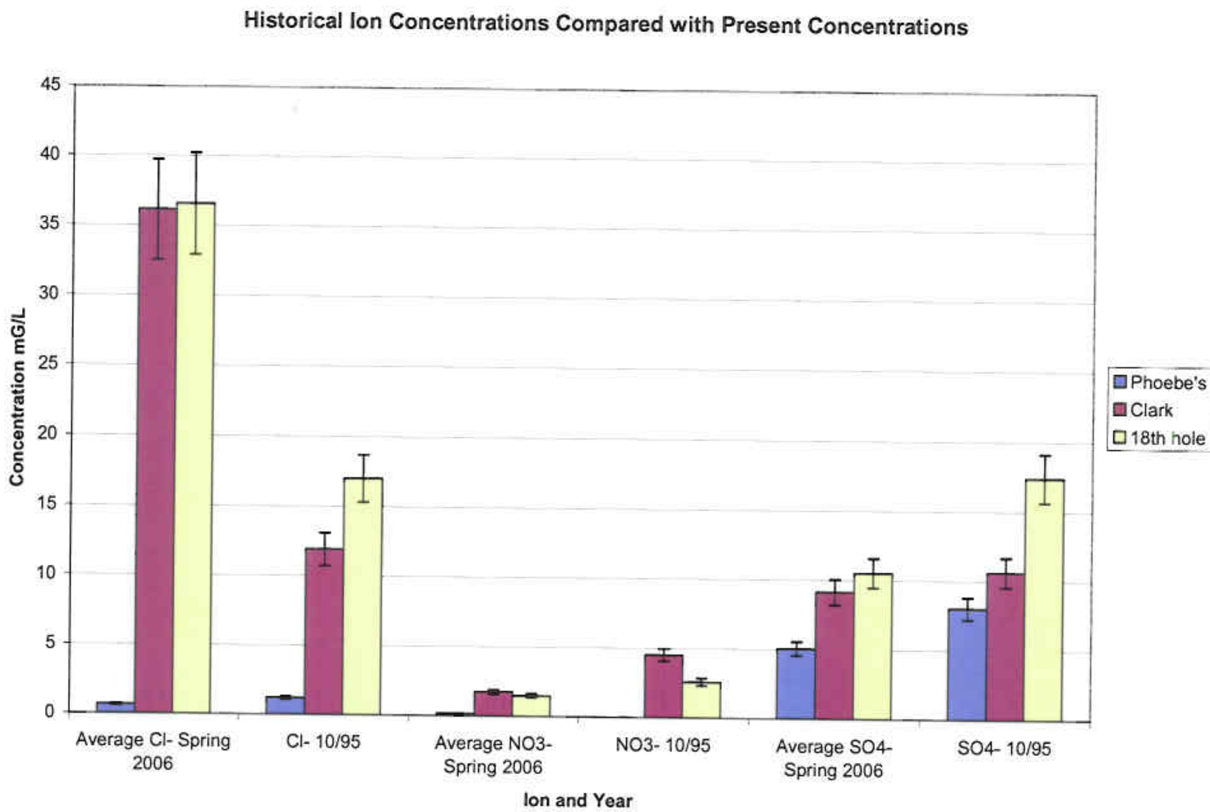
Our data revealed a significant drop in fecal coliform contamination at the three sites sampled in October 1995 before the construction of the sewer. Fecal bacteria levels in 1995 reached 1800 colonies per 100ml sample at the "Clark" sampling site, where the average level is now 250 colonies per 100ml sample. In addition, this number may be affected by a single high sample which may have been contaminated; when compared to the average of two other sites, 250 fecal coliform appears unusually large. The average number of fecal coliform colonies found in samples at upper Phoebe's Brook was 7 colonies per 100ml, compared to 1010 in 1995. At the 18th hole of the Taconic Golf Course fecal coliform levels dropped to 28, compared to 870 in 1995 (Figure 8). Human error accounted for plus or minus 15%.

Figure 8



Ion chromotography tests also exhibited decreases in sulfate and nitrate since 1995. In 1995, nitrate concentrations were 0mg/L at Phoebe's Brook, 4.53 mg/L at the Clark sampling site, and 2.59 mg/L at the 18^{th} hole, while in 2006 concentrations fell to 0.16, 1.73, and 1.49 mg/L, respectively. Similarly, concentrations of sulfate dropped by 3.0mg/L at Phoebe's Brook, 1.46mg/L at Clark, 6.9mgL at the 18^{th} hole since 1995. An opposite trend, however, appeared in the relationship between historical and present levels of chloride. While chloride levels at Phoebe's, Clark, and 18^{th} hole were 1.2, 11.9, and 17.0 mg/L in 1995, they averaged 0.66, 36.1, and 36.6 mg/L in 2006 (Figure 9).

Figure 9



Assuming that the chloride levels found at the Phoebe's Brook site represent background levels, we can evaluate the current health of the watershed. According to these values of under 1 mg/L, all other tested sites indicated human impact in the form of some input of chloride into the watershed. Levels of chloride at each sampling site correspond to the distance of the site from the headwaters of Phoebe's Brook, with concentrations rising further from the headwaters where contamination can arise from roads, residential areas, and the golf course (Figure 10).

Other ions echo this trend. For example, as Phoebe's Brook progresses further from the original source, levels of sodium and calcium increase precipitously. Calcium concentrations, rise from 8 mg/L in Phoebe's Brook water source to over 20 mg/L in the golf course, 1.5 km away, and as high 50-80 mg/L at Latham St (Figure 11). Sodium ions concentrations also increase dramatically downstream. At Phoebe's Brook the average concentration of sodium is 0.4 mg/L, while the concentration of sodium is 23 mg/L in the golf course and about 16 mg/L at Latham Street (Figure 12).

Figure 10

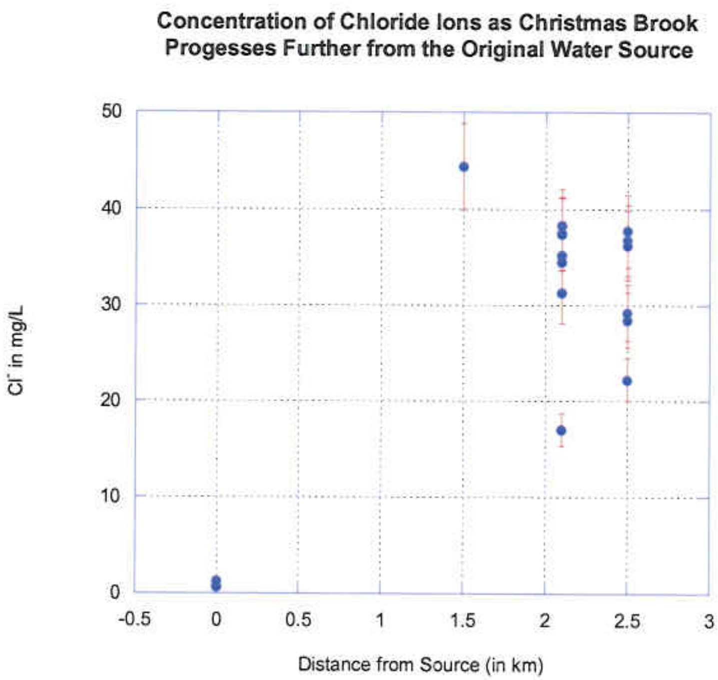


Figure 11

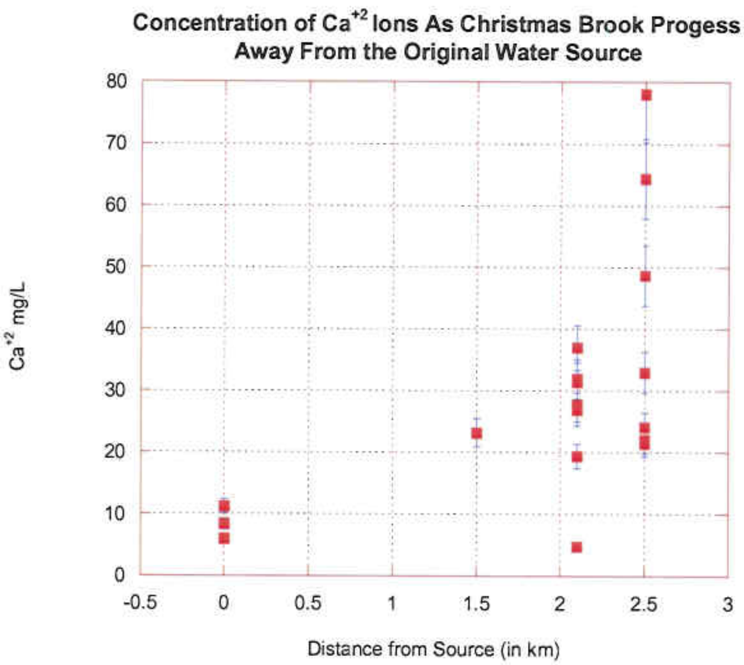


Figure 12

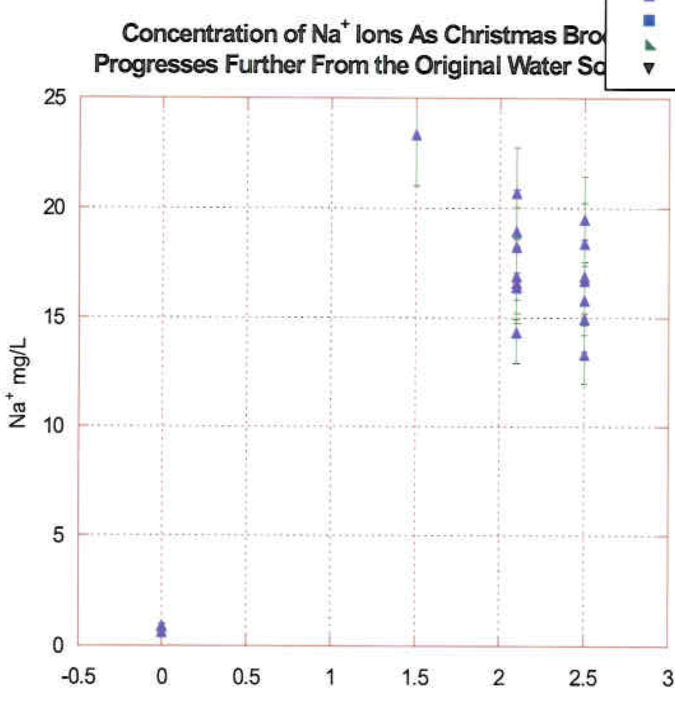
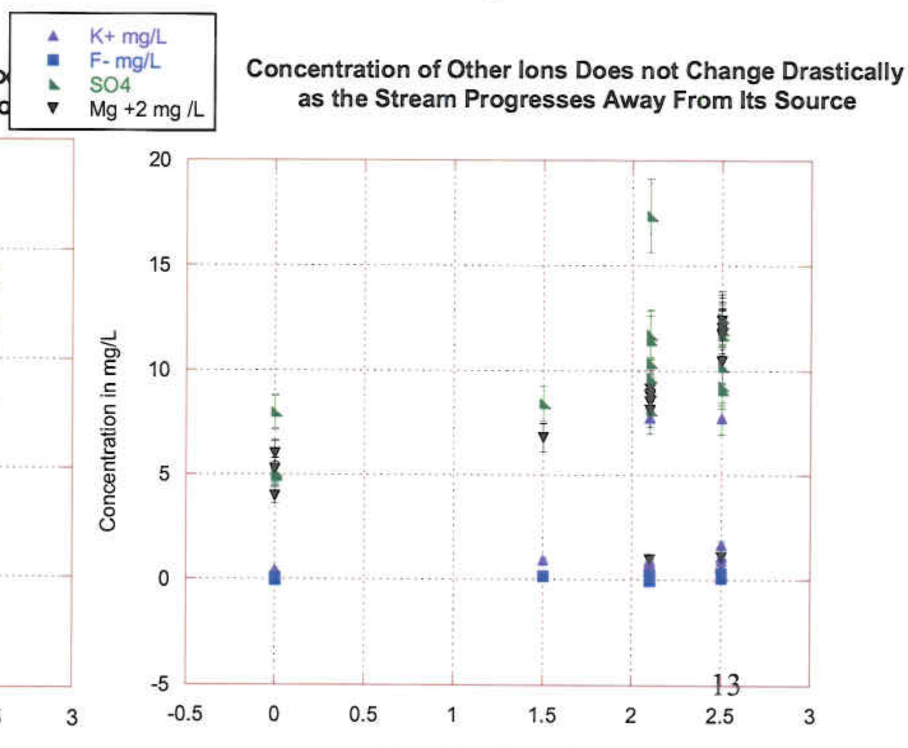


Figure 13

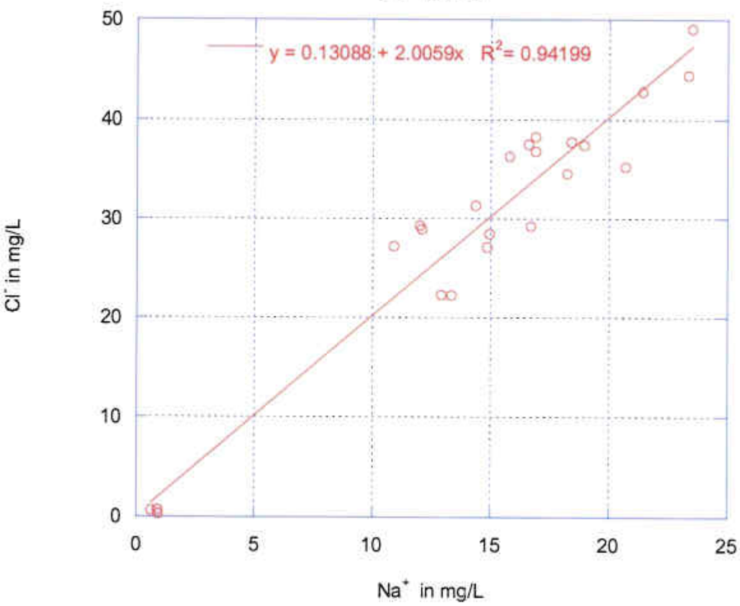


However, other ions, most notably K^+, F^-, SO_4^-, and Mg^{+2}, do not indicate the same trend (Figure 13). Though the concentration of some of these ions appears to increase steadily as the stream progresses, they never rise far above background levels.

The presence of chloride above 1-2 mg/L, often used as an anthropogenic indicator of human impact, correlates with the presence of sodium ions, pointing to a common source in road salt (Figure 14). If road salt fully explained the correlation, however, we would see a slope in the correlation graph of approximately 1.5. The slope of the graph is 2, indicating an additional source of chloride contamination. Though potassium and magnesium chloride are possible sources, concentrations of these ions do not correlate strongly to chloride levels (Appendix, Figures 15 and 16).

Figure 14

Na^+ vs. Cl^-



Between four site samples, conductivity increases as the stream progresses away from the original water source (Figure 17). Conductivity relates to the presence of ions (Appendix, Figure 18), and the levels of ions are higher at Latham, the 18th Hole, and Clark than they are upstream at Phoebe's Brook.

Figure 17

Acid Neutralizing Capacity with Rising Levels of Ca+2 (Calcium Carbonate?)

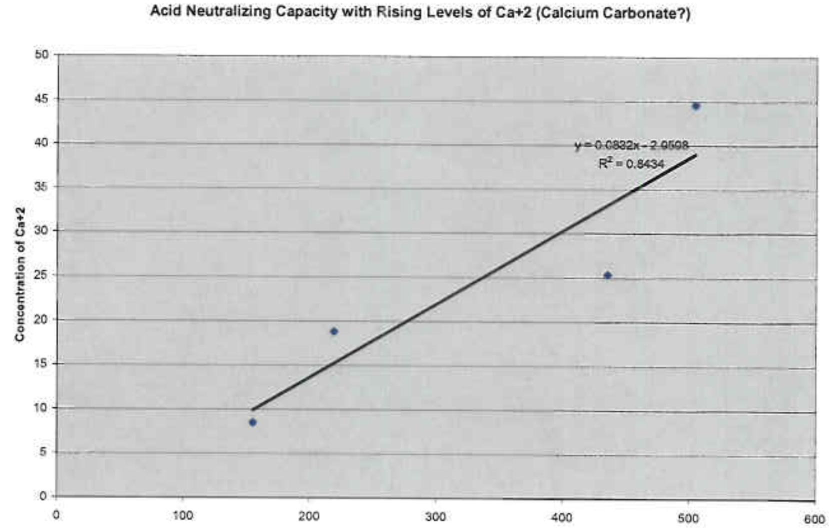
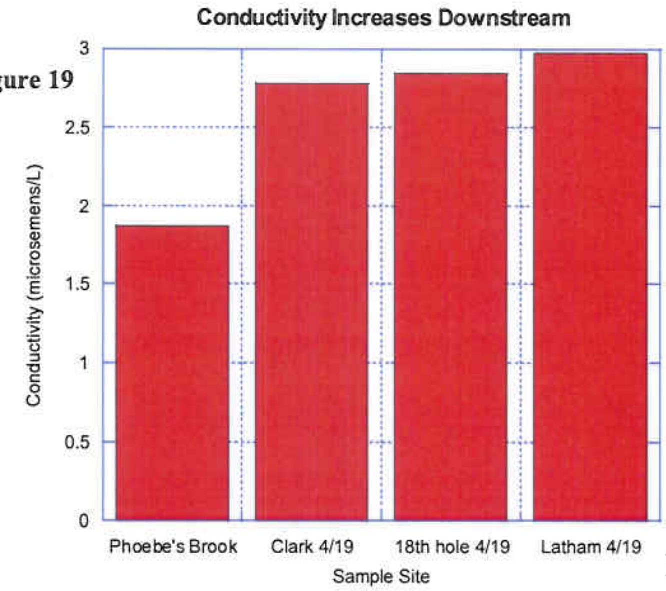


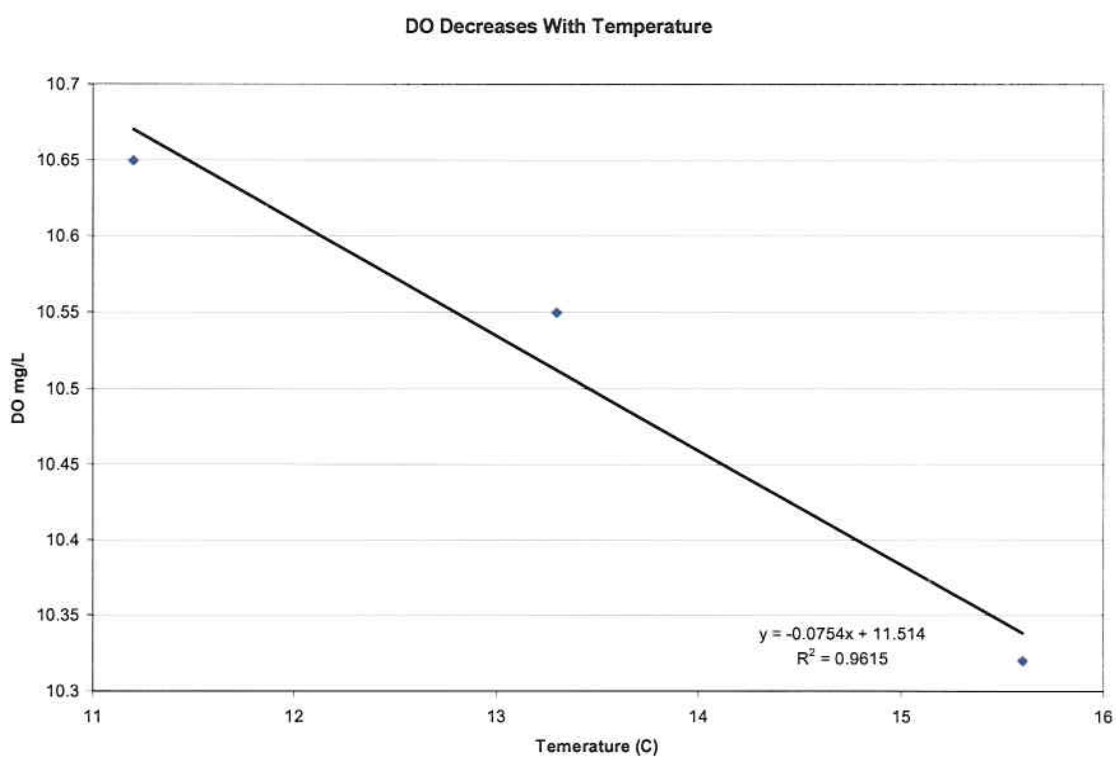
Figure 19



Levels of ions, especially calcium ions, also correlate with the pH and acid neutralizing capacity of different sites. Where pH and ANC are low, calcium ions are few compared to the sites with high pH and ANC. For example, Phoebe's Brook has an ANC of 155 $CaCO_3$ mg/L and an average calcium concentration of 8.6 mg/L, while Latham Street, has an ANC of 504 $CaCO_3$ mg/L and an average calcium ion concentration of 44.6 mg/L. Calcium concentrations at sites between these two extremes reflected corresponding ANC values (Figure 19).

As the temperature at each site decreased, we observed a trend of higher dissolved oxygen. The R-squared value of .9615 indicates the close correlation between DO and temperature (Figure 20).

Figure 20

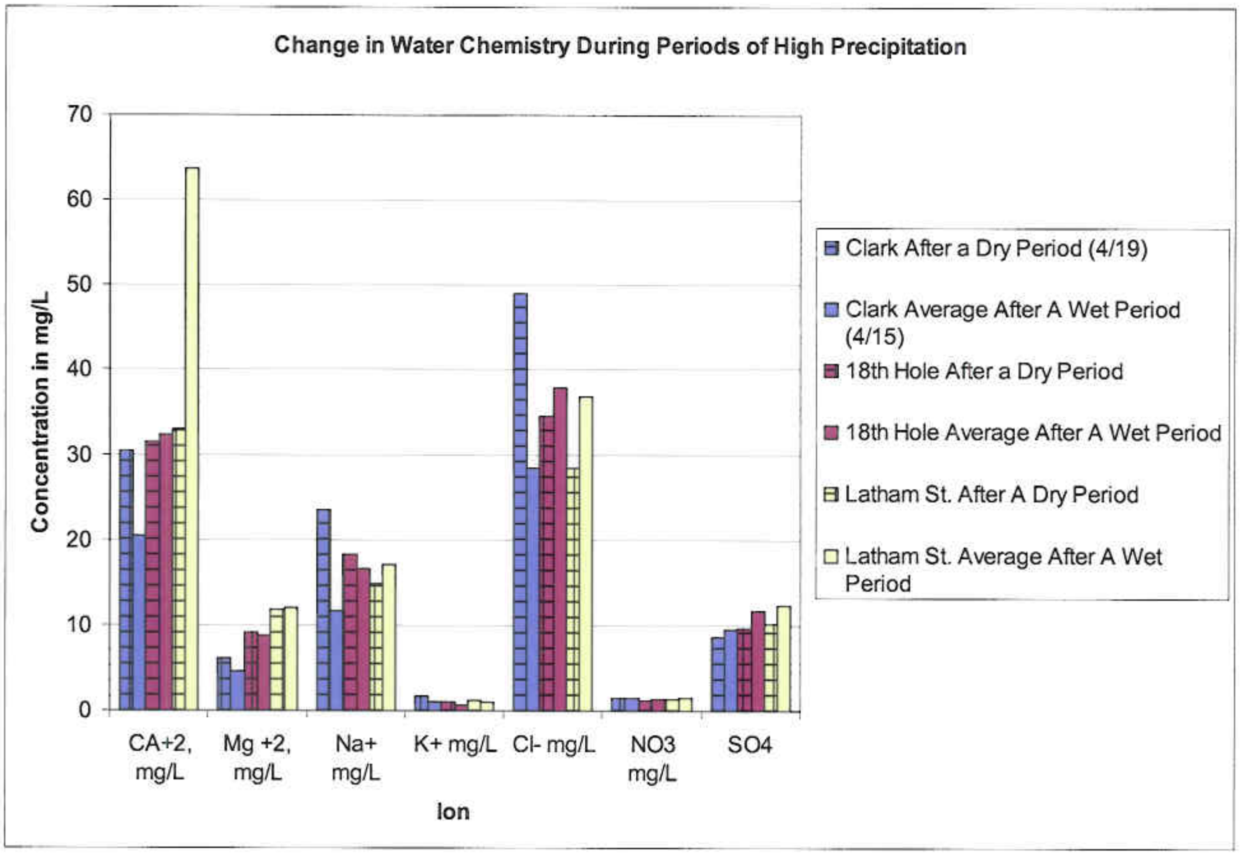


At the Clark sampling site, the site furthest upstream that we tested for aquatic invertebrates, we found concentrations of tricoptera and diptera that were two to three times the concentrations of odonata and plecoptera. The site contained over 40% tricoptera, and approximately 30% diptera, despite other water quality indicators that suggest that the site is in good health (Appendix, Figure 21). The Clark's biotic index value of 2.07 points to "some disturbance or organic enrichment" and earns a "good" water quality rating (Appendix, Figure 22). At the 18^{th} hole, our sample consisted of 63% diptera and 31% tricoptera minority (Figure 21). The diptera population indicates poor water quality, leading to a biotic index value of 2.56 and a "fair" rating (Figure 22). Contrary to the 18^{th} hole, the species at Latham consisted of primarily tricoptera and only a small fraction of diptera, 17% (Figure 21). Interestingly, Latham's biotic index value is 2.09, corresponding to a water quality rating of "good" (Figure 22), despite Latham's location furthest downstream.

With increased precipitation we observe higher levels of water discharge. Data from the Birch Brook Watershed in Hopkins Forest characterizes this trend (Figure 23). Also, with increased precipitation and discharge, the concentrations of ions within the stream to change, as sediment and other substances are washed into the stream or diluted by rainwater. This relationship allows us to assume that precipitation leads to higher levels of discharge, which may result in dilution or other effects on the chemistry of Christmas Brook.

Ion concentrations tended to decrease after rainfall upstream, but increased after rainfall at the 18^{th} hole and Latham sites (Figure 24).

Figure 24



At the Clark, the furthest upstream site tested after precipitation, chloride, calcium, and sodium concentrations dropped dramatically with increasing levels of precipitation, while the concentration of other ions remained approximately constant (Figure 25).

Figure 25

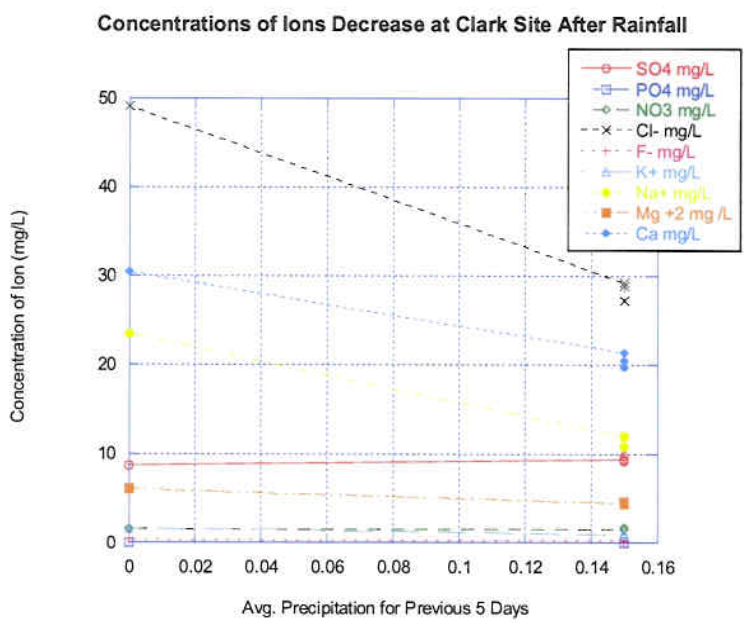
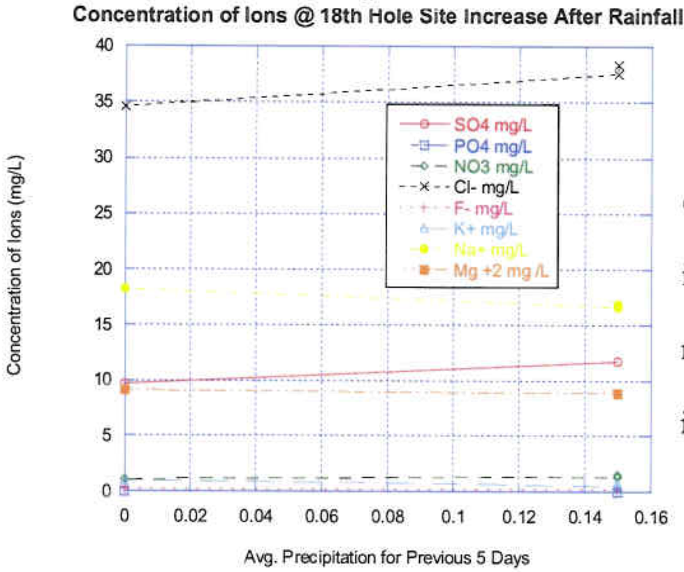


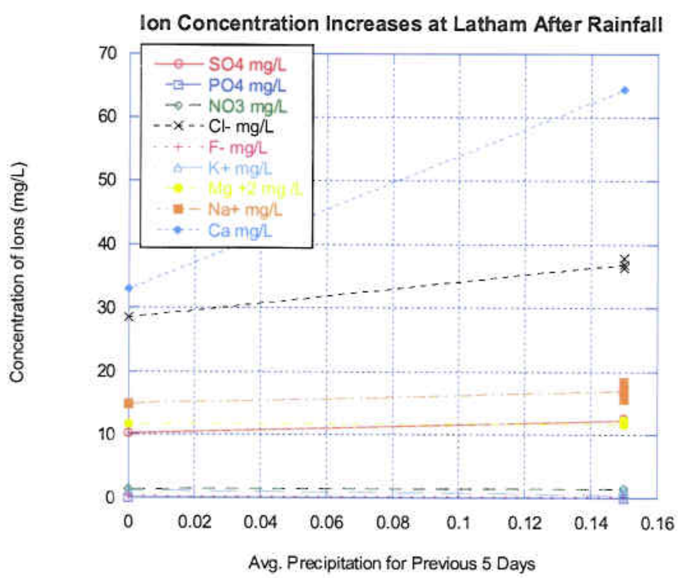
Figure 26



At the 18th hole, the concentration of every ion except sodium stayed constant or increased after precipitation (Figure 26). Most notably, the concentrations of chloride and sulfate increased while the concentration of sodium marginally decreased.

At Latham Street, the concentration of nearly every ion increased or remained the same (Figure 27). Calcium and chloride increased substantially, while sulfate and sodium levels rose less (Figure 27).

Figure 27



Sources of Error

When counting aquatic indicator specimens, human error included failure to capture and count all of the various aquatic invertebrates. Inability to see smaller organisms could have skewed our biotic index. Also, seasonal variation accounts for a degree of experimental error.

By late spring, many of the aquatic invertebrates may have already hatched and left their respective sites. If those intolerant to pollution have departed, our biotic index values were high and the water quality is actually better then calculated.

Human error arises in coliform counting when many colonies are present. We counted a quarter of the Petri dish and multiplied that number by four. Although counted by the same person to ensuring consistency, human discretion limits accuracy. Also, bacteria were randomly distributed throughout the sample and the Petri dish, thus counting only a quarter of one sample dish does not ensure accuracy. Before we analyzed the coliform samples, human error in the form of getting dirt in our samples may have affected our data.

For conductivity and DO tests, if we used a different meter on different days the results for conductivity and DO may have been imprecise. Also, the conductivity meters assume a constant elevation, yet the sample sites vary in elevation. Seasonal variation again factors in our results, causing differences in ion concentration. We sampled during the spring when roads may retain winter road salt, whereas our historical data was measured in the fall when road salt is less abundant, if existent at all. Sampling on different days and at different times may have affected our temperature and thus DO data. Samples taken in the afternoon are likely to be warmer than those taken in the morning or evening, causing lower DO measurements. Wildlife activity also could have affected our samples. In one test of Phoebe's Brook we identified phosphate, which is generally indicative of sewage and likely to be absorbed by the environment, yet when we tested the same site later we found no phosphate. We attributed the phosphate to animal feces.

In the lab, AAS and AES tests contained a 10% error margin due to possible non-uniformity in the standard solutions, and dilution errors. An error of one drop in dilution can affect AAS, AES, and ion chromatography data significantly. Lastly, by assuming precipitation and discharge data from Birch Brook matches that of Christmas Brook, we neglected variation between the two sites and watersheds.

Discussion

The fact that fecal coliform levels have drastically dropped from 1995 to the present supports our hypothesis that the quality of Christmas Brook has improved since the construction of a sewer line in the surrounding areas (Figure 8). Though we found some fecal coliform in our present-day samples, we attribute them to natural wildlife activity rather than human fecal contamination. Because the historical samples were taken at a different time of year (October) than the present ones, the levels of fecal coliform in the samples cannot be entirely accurately compared. October stream water is most likely warmer and fosters greater bacterial growth, and coliform have all summer to multiply and inhabit the stream. We would expect early spring coliform levels to be lower than autumn levels, but the difference seen between the coliform found in our present data and in the historical data was so great that we believe it cannot be attributed to only seasonal fluctuation. Therefore, we believe that the improved low levels of fecal coliform indicate that the health of the stream has improved since the extension of the sewer to areas around Christmas Brook. Decreases in the levels of sulfate and nitrate between 1995 and 2006 also support our hypothesis of improved stream quality since the installation of a sewer (Figure 9). These ions often indicate nutrient rich environments, and the decrease in their levels over time may show the elimination of a human "fertilizer" source.

Though historical data shows drastically lower levels of chloride at the Clark and 18th hole sites, this may be due to seasonal chemical differences from anthropogenic sources. Since we took samples in March and April, road salt still lingered in the environment and entered the stream in runoff, in contrast to October after months since salting. Also, certain Williamstown citizens have testified that the volume of road salt used by the town has increased threefold in recent years (Dethier). Finally, Phoebe's Brook, which would be unaffected by roads or road salt, still shows decreased levels of chloride from 1995 to 2006, supporting that the level of contamination potentially caused by the lack of a sewer system has decreased since the installation of the system.

Though the sewer system has reduced contamination from fecal coliform and some chemicals, other aspects of stream health indicate that the sewer has not mitigated all issues of contamination. Samples downstream of the relatively untainted Phoebe's Brook site show higher levels of chloride, sodium, and calcium ions (Figures 10-12). An expected source of both chloride and sodium is NaCl in the form of road salt. As mentioned earlier, all chloride contamination could be accounted for if the ratio between sodium and chloride were around 1.5. We instead found a ratio of 2.0, and therefore believe that there exists an additional source of chloride contamination (Figure 14). We know that $MgCl_2$ and KCl are both commonly used as water softeners in the area, but our data shows little to no correlation between magnesium, potassium, and chloride. Perhaps these small correlations can account for the "extra" chloride, but some unknown source of chloride probably contaminates Christmas Brook (Figures 15 and 16, located at the end of the report).

Calcium ions also increase drastically as the stream progresses away from its original water source (Figure 11). This was unexpected, and could be due to a variety of factors. First, the area of Stone Hill upon which Phoebe's Brook originates is geologically composed of mostly quartzite, a mineral which weathers very slowly and would deposit only small amounts of calcium into the stream. Downstream, however, Christmas Brook crosses areas of marble, which weathers much easier and is probably a significant source of calcium ions in the form of calcium carbonate (Appendix 4). This geologic difference, though it may account for a rise in calcium concentration from the slopes of Stone Hill to the low-lying areas below, does not account for the increase of calcium ions seen between sites such as the Clark, the 18th hole, and Latham Street. One possible source of calcium ions is the "liming" of the Taconic Golf Course. Many New England farmers must lime their fields to help neutralize the acid deposition that plagues the area. Though Kent Lemme at the golf course did not explicitly tell us of any calcium compounds added to the fairways, perhaps the liming process is an engrained part of golf course care. Another possible source of this calcium is a high level of calcium in Williamstown tap water in general. The pond in the golf course pumps water from a well in order to irrigate the course, and perhaps this water is high in calcium, which would eventually leech back into Christmas Brook, especially with high levels or rainfall. Additionally, leakages from the town water system could contribute excess calcium. We cannot confirm these hypotheses, but are aware that some unknown source of calcium feeds into Christmas Brook.

Though we expected to see a drastic increase in the levels of potassium, nitrate, and sulfate as Christmas Brook ran through the Taconic Golf Course because the course uses nitrogen, potassium, and sulfate fertilizers, these compounds did not increase far above background levels (Lemme; Figure 13). The absence of potassium in our water samples can be explained by the season; the golf course is not treated with slow release potassium bulk spread until late June. However, the course has already been received urea nitrogen and ammonium sulfate. These results show that the golf course, an expected major source of chemicals going into the stream, either fertilizes in lower amounts or is more efficient at containing fertilizers than predicted. In either case, the input of contaminants by the golf course (except of calcium, perhaps) is much less of a threat to water quality than road salt.

Our conductivity data also supports our earlier assertion that Christmas Brook becomes more contaminated as it moves away from the original source. Because conductivity relates to the amount of ions in solution (Appendix Figure 18), a conductivity reading can actually be used as a fairly accurate approximation of contamination. Advantages of this method include that the site can be sampled in the field and accurately by a highly reliable field instrument. Conductivity readings do not, however, reveal which ions are present, and therefore are not useful in determining whether anthropogenic or natural sources contribute ions. For example, Latham Street's high conductivity does not necessarily make it the most contaminated site. If we look closely at the site, we see that a large part of its ion "contamination" is due to calcium, an ion that does not necessarily indicate human activity and may actually help the stream become healthier by neutralizing acids (Figure 19).

The location of the Clark site explains its low biotic index value. Upstream, there are fewer anthropogenic sources of pollution, plus there are fewer upstream sources of pollution to contaminate it. We would expect to find more aquatic invertebrates intolerant of pollution, indicating higher water quality. This conjecture was corroborated by our data showing Clark to have the lowest levels of conductivity (Figure 17). The poorer water quality indicated by a high BI number at the 18th hole may be explained by the site's location next to the fairway, which receives runoff from grass covered by fertilizer in the fall and spring. The fertilizer may contaminate the water, thus explaining the high diptera population.

The "fair" water quality rating at the 18th hole may also relate to the site's function as a repository for stream pollution. Upstream inputs settle in a pond above the point where we sampled. While in the pond, it is likely that the water collects runoff from the golf course, including the fertilizer. Our poor biotic index value for the 18^{th} hole site was supported by data showing the 18^{th} hole to have high levels of conductivity (Figure 17). The stagnant water could also provide a good habitat for certain species of invertebrates which usually indicate poor water quality. Also, it is important to keep in mind that while diptera are extremely tolerant to pollution, that does not necessarily mean that they are only found in polluted water.

One reason for "good" water quality at our Latham site may be increased dilution as stream order increases, although we didn't find this in our data concerning ion pollution relative to location (Figure 17). Instead, the brook may wash contaminants downstream, especially after precipitation, as shown in our data concerning ion concentration before and after precipitation (Figure 27). The high tricoptera value could have been a temporal aberration, since the biotic index value for the site improved its water quality rating significantly. Our data also reveals that Latham, like the 18^{th} hole, accumulates pollution, having the highest levels of conductivity, which confirms our suspicion that the large number of tricoptera found on the specific day we sampled skewed our data (Figure 17). Also, we found the banks of the site at Latham littered with organic and inorganic matter, including leaf packs, algae, and trash. The solid matter may serve as a trap to collects other organic matter, which may further increase the conductivity and the density of aquatic invertebrates indicative of pollution at the site.

The reduction in ion concentrations after rainfall at the Clark sampling site may be due to the isolated nature of the site. Of all the sites sampled after precipitation, it is the most removed from human contact and the furthest upstream (Appendix 4). This means it is least affected by humans and suffers from fewer anthropogenic input sources. Many of its inputs are likely related to native animals, such as fecal contamination, that may be deterred from entering the river in periods of high rainfall. Thus, the rain may reduce inputs into the stream while diluting it, lowering ion concentrations. This trend was most evident in the large decreases in chloride, calcium, and sodium concentrations. We can attribute this to the fact that chloride, sodium, and calcium are mostly human inputs that come from road salt and water softener, most significantly calcium chloride. Since the Clark site is generally removed from human contact compared to the other sites sampled for ion concentration before and after precipitation, we would expect the concentration of the ions to decrease after rainfall because of the lack of human inputs washed into the brook, and the cleansing effects of the rain water pushing ions downstream. Thus, dilution of the brook has a large affect on decreasing the concentration of ions.

The increase in the concentration of most ions at the 18^{th} hole is telling. Although the sodium concentration decreased slightly, it may have decreased because of dilution from precipitation. The increase in sulfate may be due to the fact that an ammonium sulfate fertilizer is applied to the golf course in the spring, and the rain may have washed fertilizer into the brook. Increased runoff could also explain the rise in chloride from various undetermined sources, possibly golf course chemicals, or city water system leakages.

We observed the largest increase in ion concentrations at Latham. Most notable are the increases in calcium and chloride, while sodium increased slightly. Since these are human inputs, Latham's proximity to human activity supports such increases. We can also assume that the Latham site accumulates upstream pollution. Its downstream location and abundance of solid matter makes it vulnerable to pollution collection, especially after rainfall creates runoff. It is important to realize that almost all runoff from the Christmas Brook area will eventually end up at this site. All other ions, including sulfate, remained relatively constant in concentration between Latham and the 18^{th} hole before and after rainfall, indicating that the Latham site does not receive significant amounts of direct inputs of sulfate and other ions. Our knowledge about the golf course fertilizer confirms that sulfate is an input unique to the golf course.

Conclusion

Using various indicators of water quality including physical, chemical and biological analyses, we assert that the extension of the Williamstown sewer system has improved the health of Christmas Brook by halting the flow of fecal and septic system contamination into the stream, substantiating our hypothesis. However, the accumulation of contaminants in Christmas Brook as it progresses north indicates continued human impact. Increases in road salt and additional anthropogenic sources of chloride and calcium continue to burden the stream and alter the water chemistry. Though seasonal variation in natural and human activity affects measurements, the data consistently indicates inorganic inputs into Christmas Brook.

Our hypotheses proved partially correct. Although the sewer system improved the stream, while increased road salt runoff proved detrimental, evidence of degradation from golf course inputs into Christmas Brook is weaker than expected—though still significant, especially after periods of precipitation. Additionally, disparities between upstream and downstream sites consistently illustrate the accumulation of pollution as the stream progresses.

Such accumulation suggests broader implications for the health of waters further downstream, such as the Green River, the Hoosic River, and ultimately, the Hudson River. If changes in the health of Christmas Brook model regional trends, increases in detrimental human activities partially negate improvements in water quality management. Both for local residents and habitats dependent on the Christmas Brook drainage basin and for remote members of the Hudson River Drainage Basin, attempts to revive polluted waters must address all input sources if we expect the holistic improvement of our watershed.

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Becky Davies

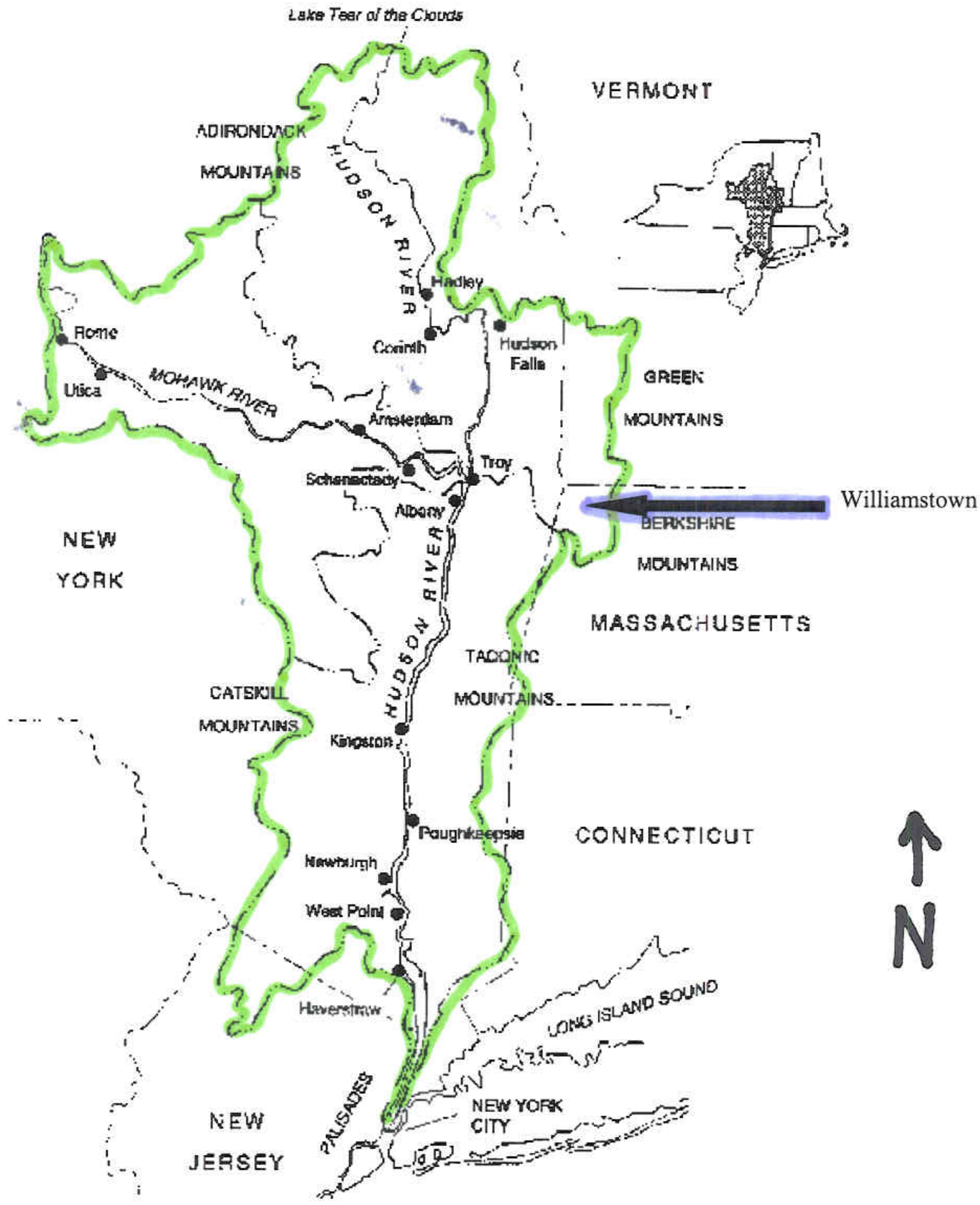
Ben Swimm

Sam Denton-Schneider

Map 1: Satellite View of Christmas Brook

The headwaters of Christmas Brook form in less densely populated areas before traveling past sites with high human activity.

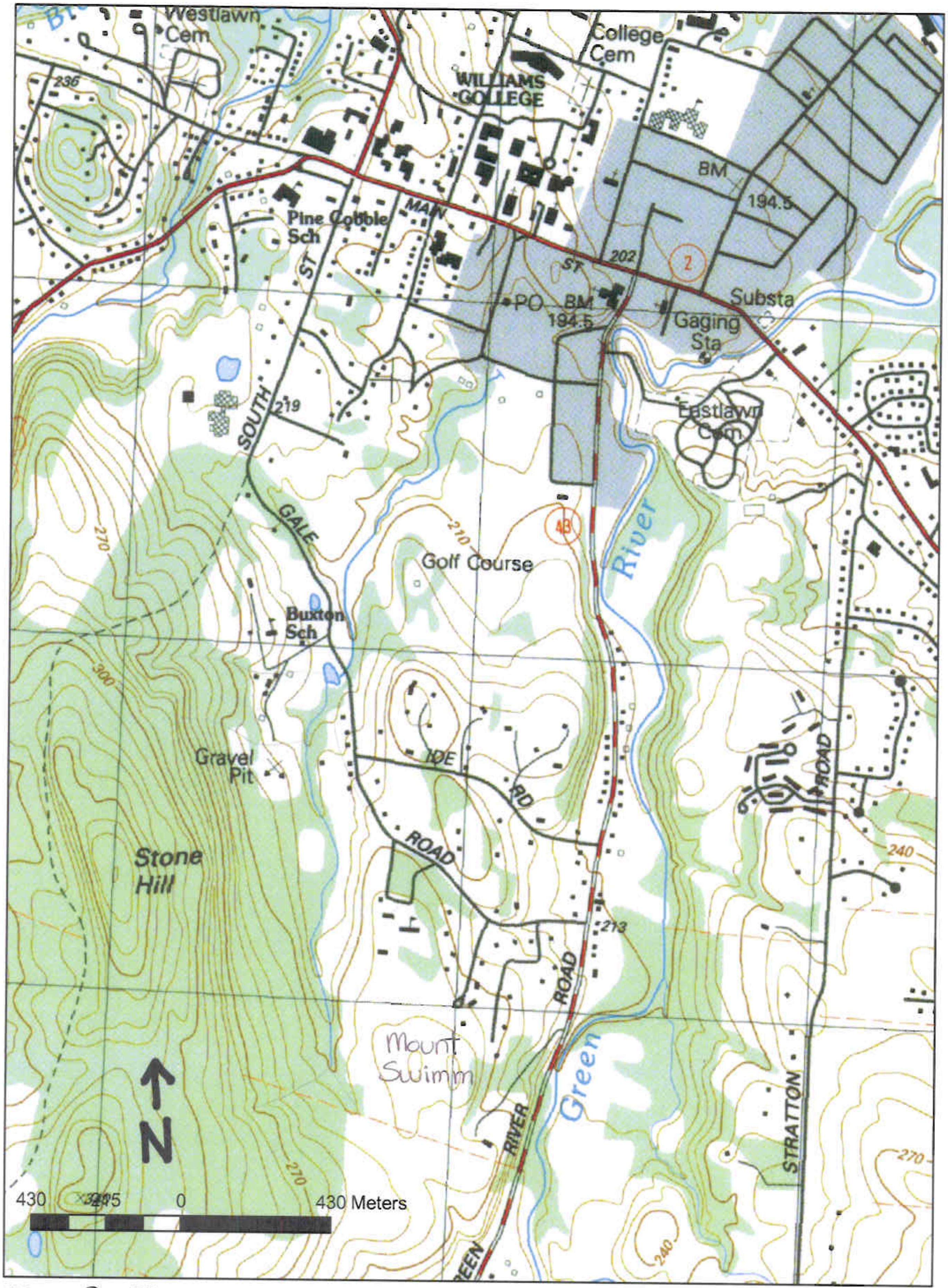
Appendix 1



Map 2: Hudson River Drainage Basin
Water falling on the Berkshire Mountains in NW Massachusetts will ultimately arrive at the New York Harbor.

Source: http://www.epa.gov/OWOW/info/WaterEventsNews/images/hudsnmap.gif

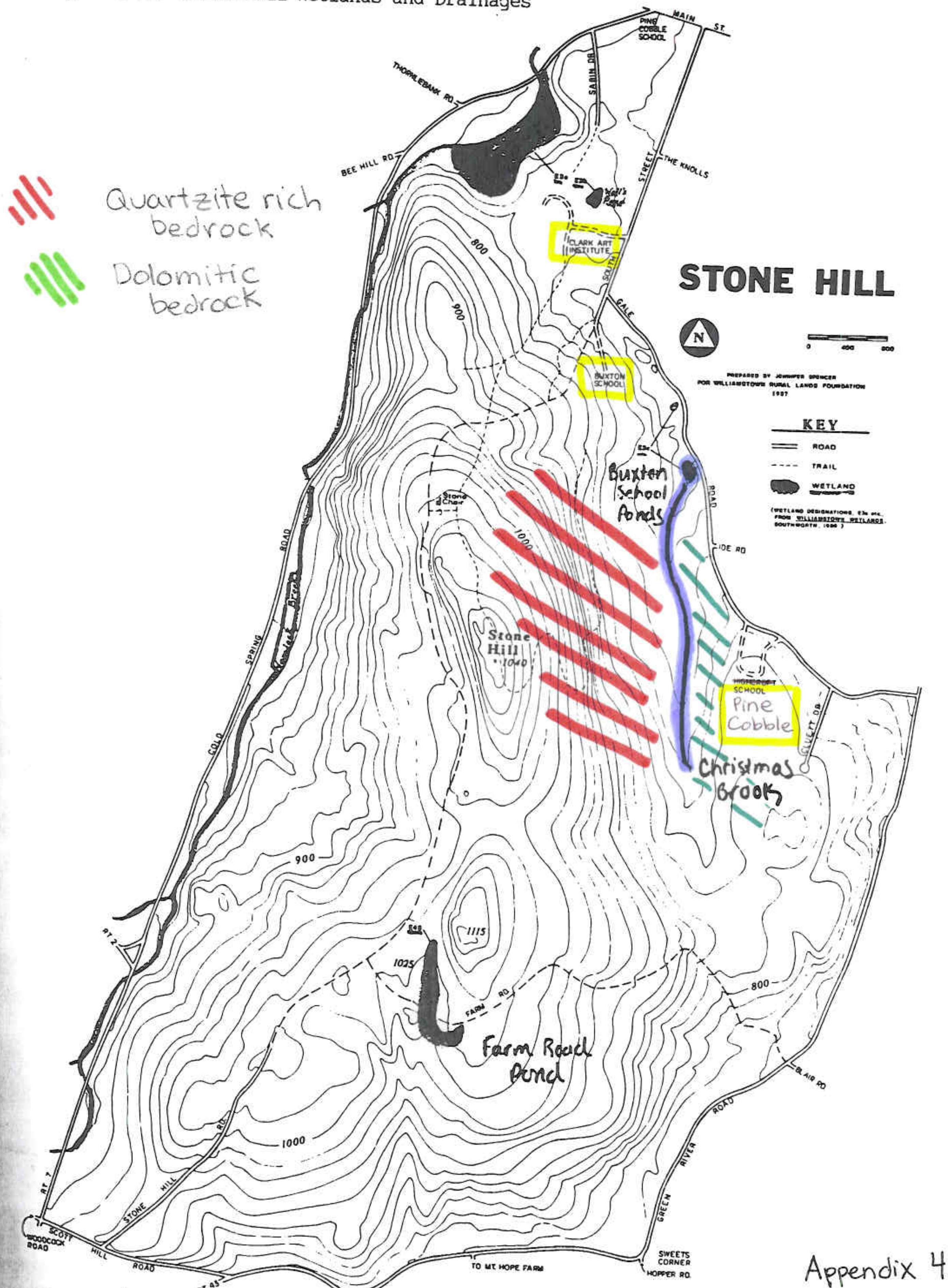
Appendix 2



Map 3: Topography of Christmas Brook
"Phoebe's Brook," the main branch of Christmas Brook, drains the west side of Stone Hill and the east side of Mount Swimm.

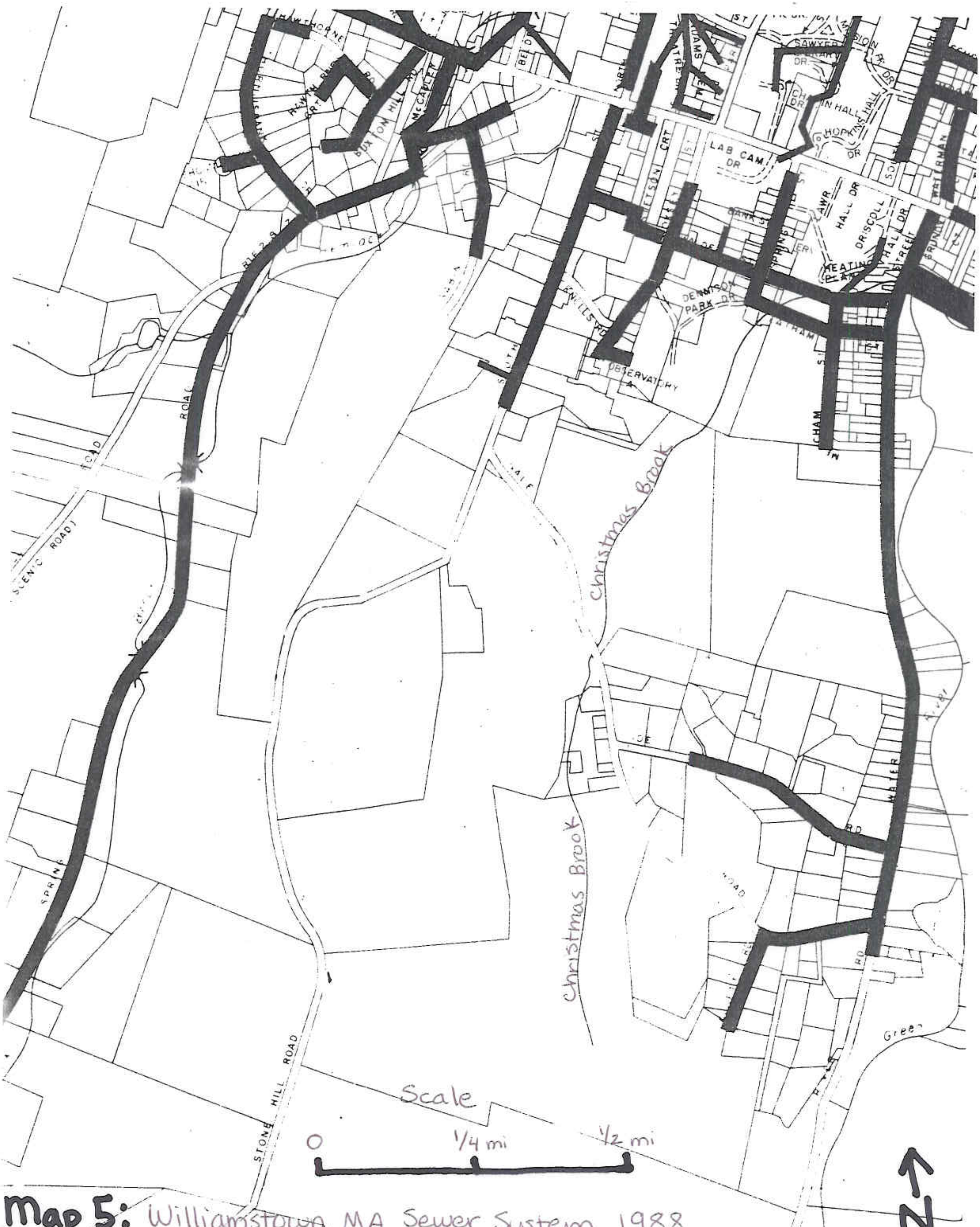
Appendix 3

[redacted] Stone Hill Wetlands and Drainages



Appendix 4

Map 4: Upstream Christmas Brook Bedrock and Local sites
Water drains from quartzite rich bedrock in the west and more dolomitic bedrock in the east.

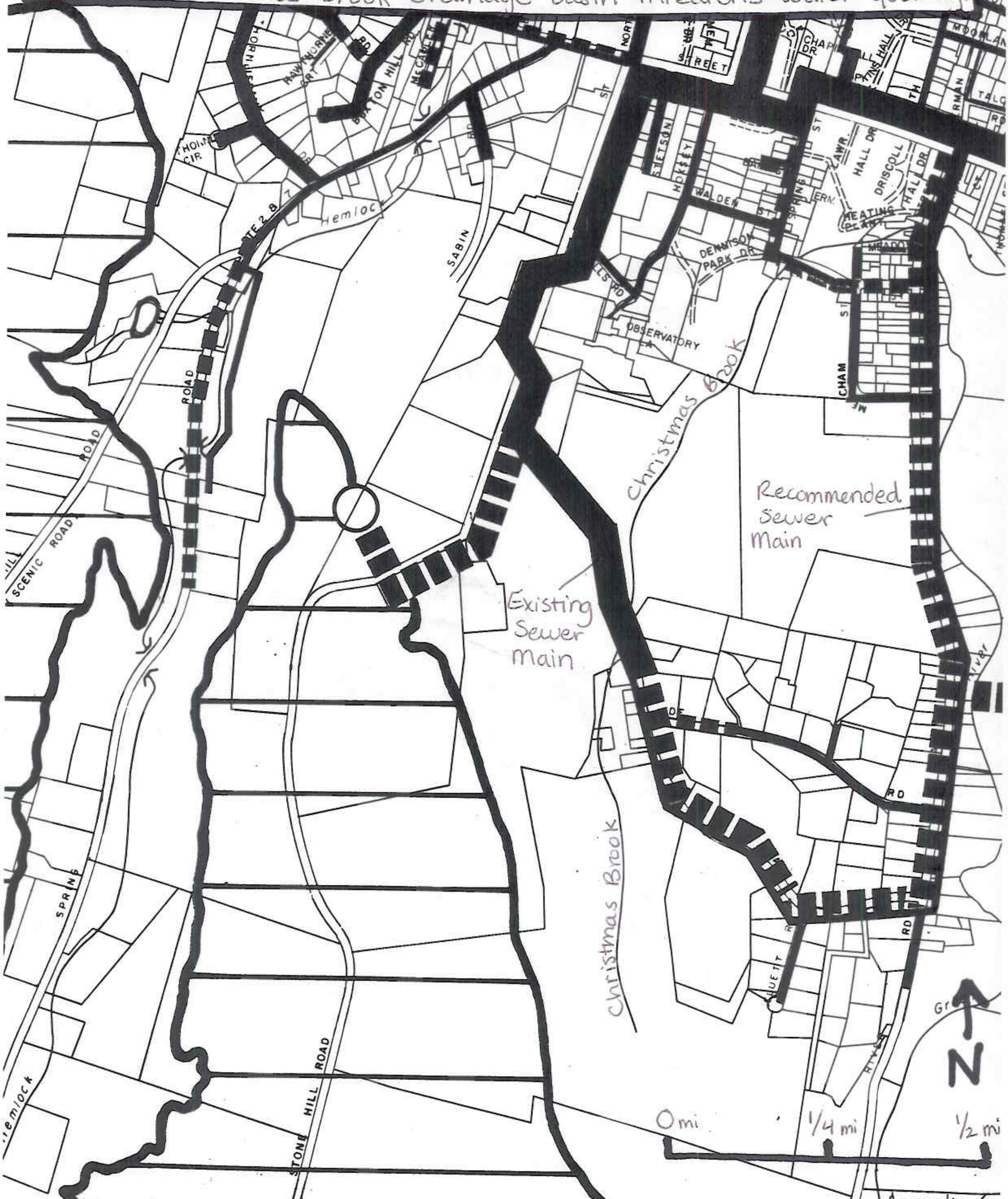


Map 5: Williamstown, MA Sewer System, 1988
Before the mid 1990s, the sewer system did not serve residents near Christmas Brook.

Appendix 5

Map 6: Williamstown, MA Water System, 1988

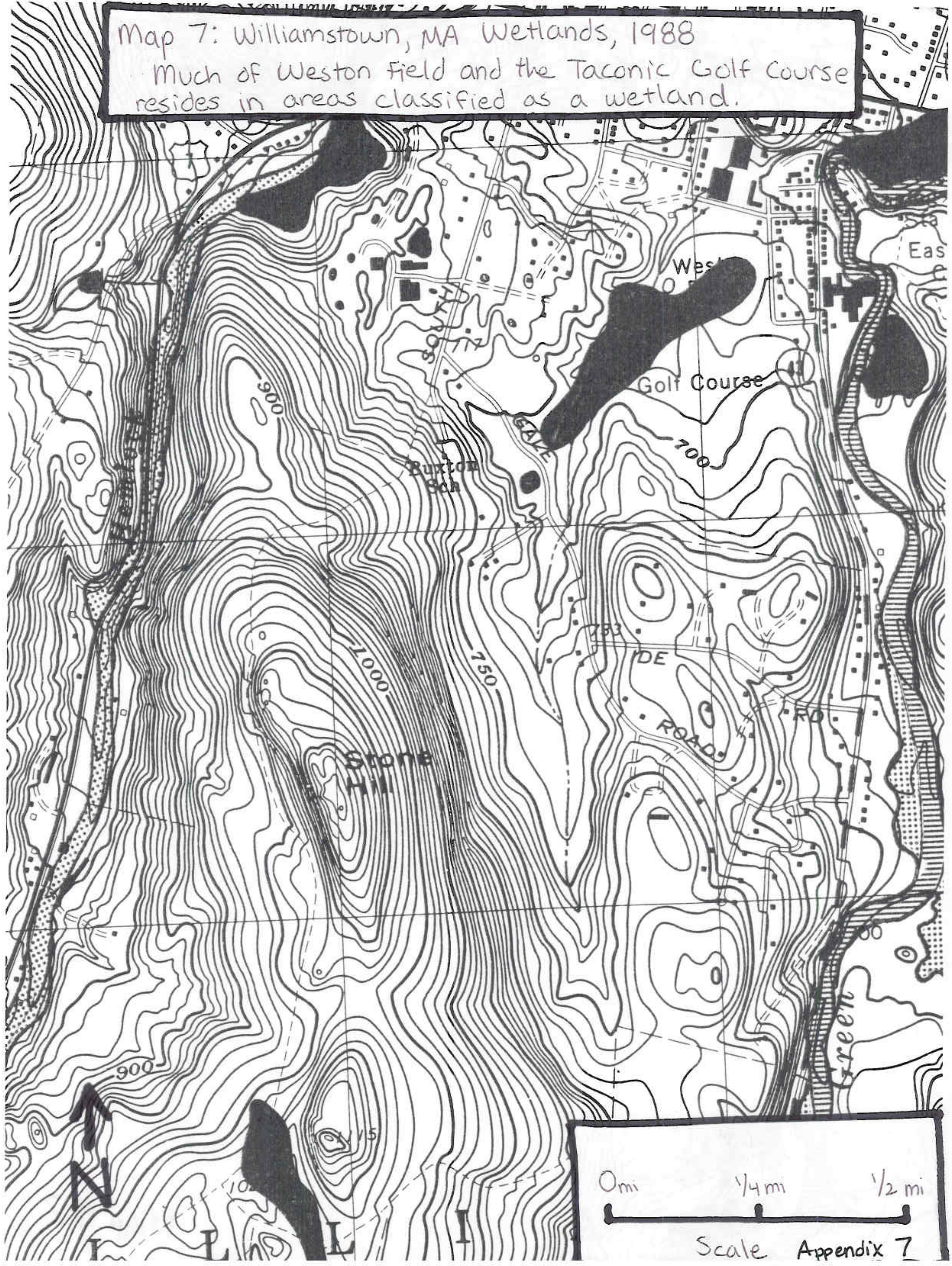
For the residents relying on private wells, the contamination of the Christmas Brook drainage basin threatens water quality.



Appendix 6

Map 7: Williamstown, MA Wetlands, 1988

Much of Weston Field and the Taconic Golf Course resides in areas classified as a wetland.



Appendix 7

Calculation 1: Biotic Index Calculation

$$\text{Biotic Index} = \frac{\sum (\text{number of aquatic invertebrates of an order})(\text{average pollution tolerance value for order})}{\text{Total \# of aquatic invertebrates}}$$

Ex. 18th Hole

$$\frac{\sum 5(1.93) + 10(2.875) + 1(2.5)}{16} = 2.556$$

Figure 15

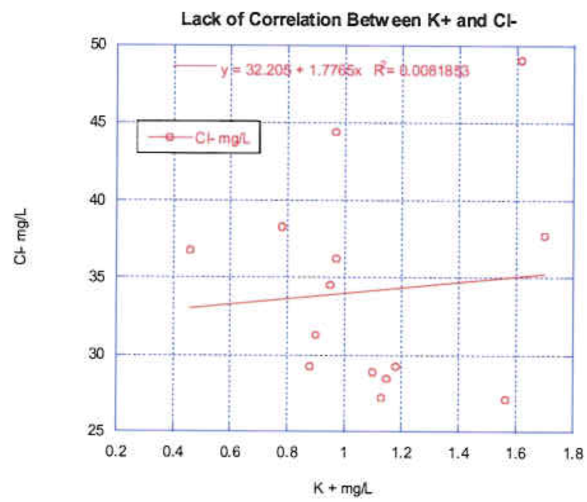
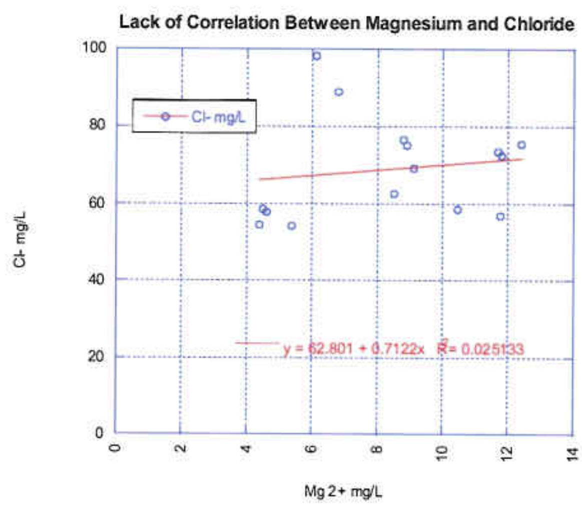


Figure 16



Appendix 8

Figure 18

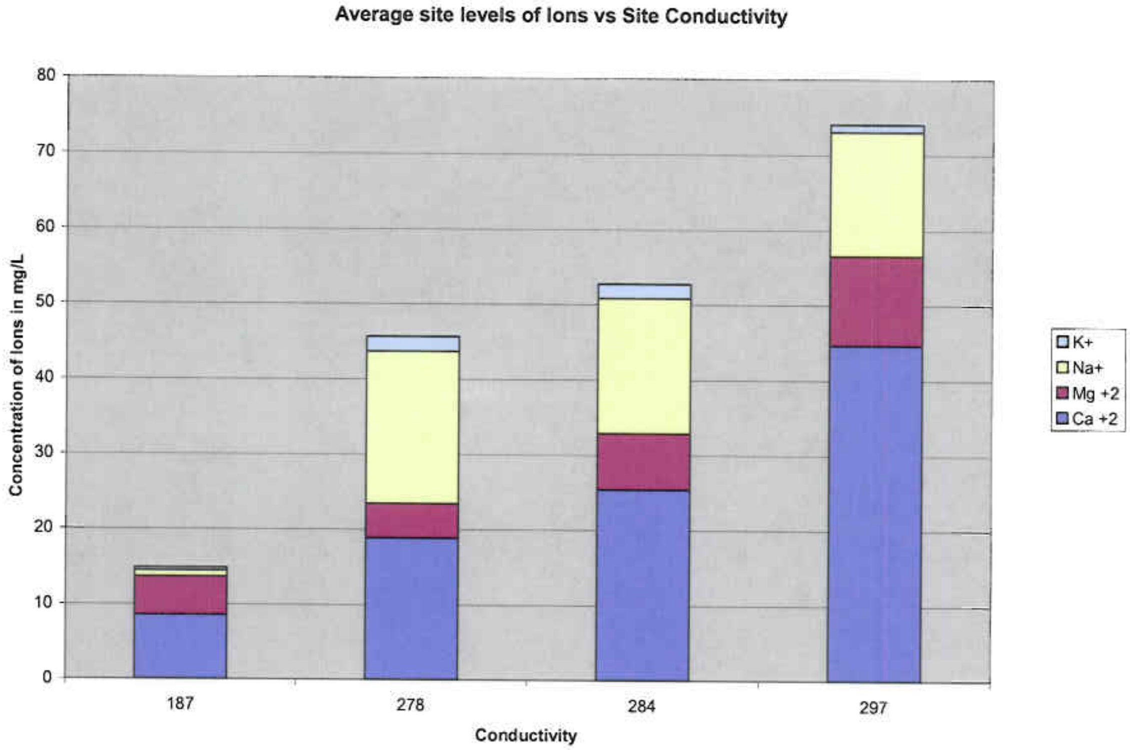
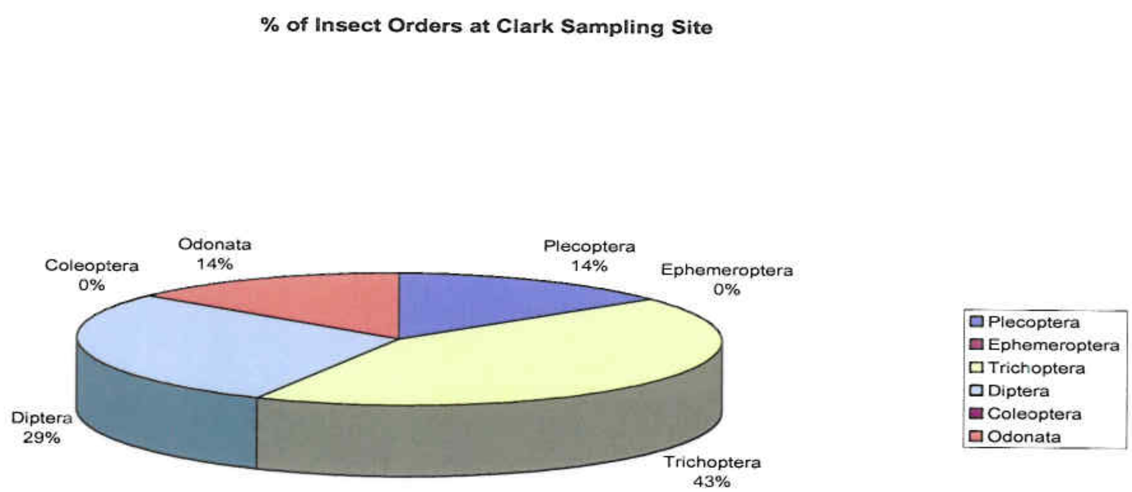
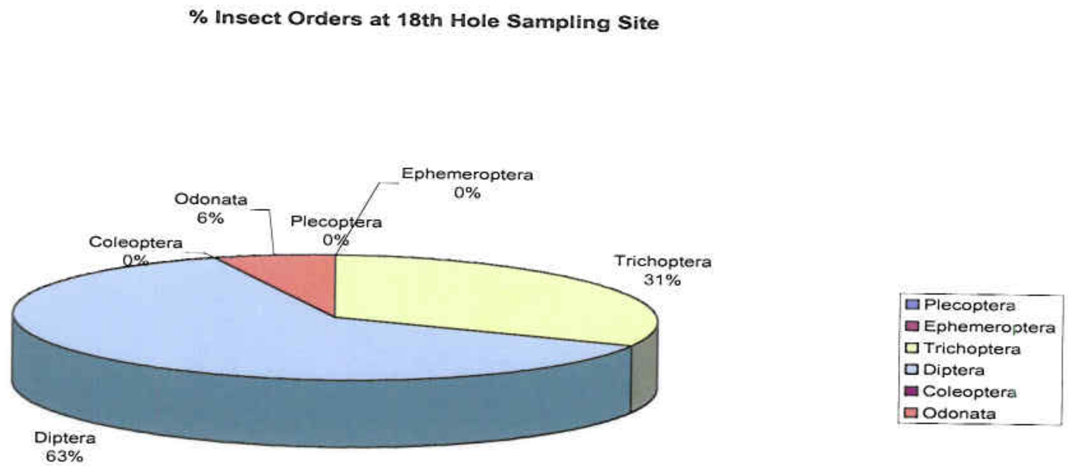


Figure 21



Appendix 9


% Insect Orders at 18th Hole Sampling Site
Ephemeroptera 0%
Odonata 6%
Plecoptera 0%
Coleoptera 0%
Trichoptera 31%
Diptera 63%
Plecoptera
Ephemeroptera
Trichoptera
Diptera
Coleoptera
Odonata

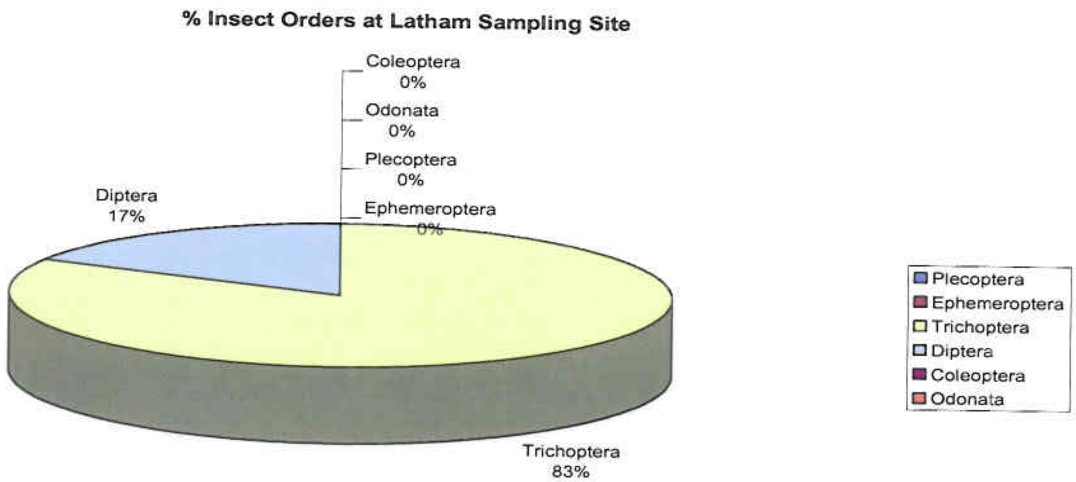

% Insect Orders at Latham Sampling Site
Coleoptera 0%
Odonata 0%
Plecoptera 0%
Ephemeroptera 0%
Diptera 17%
Trichoptera 83%
Plecoptera
Ephemeroptera
Trichoptera
Diptera
Coleoptera
Odonata

Figure 22

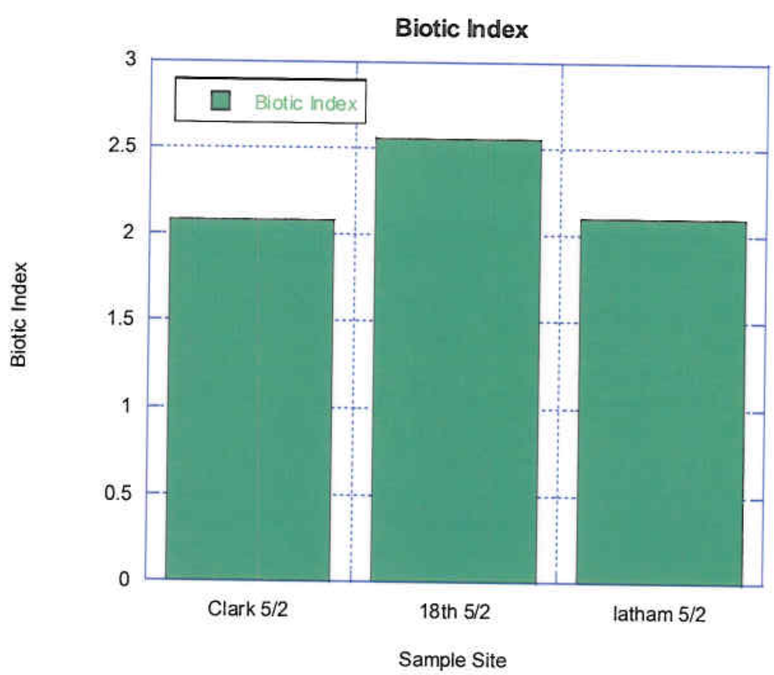
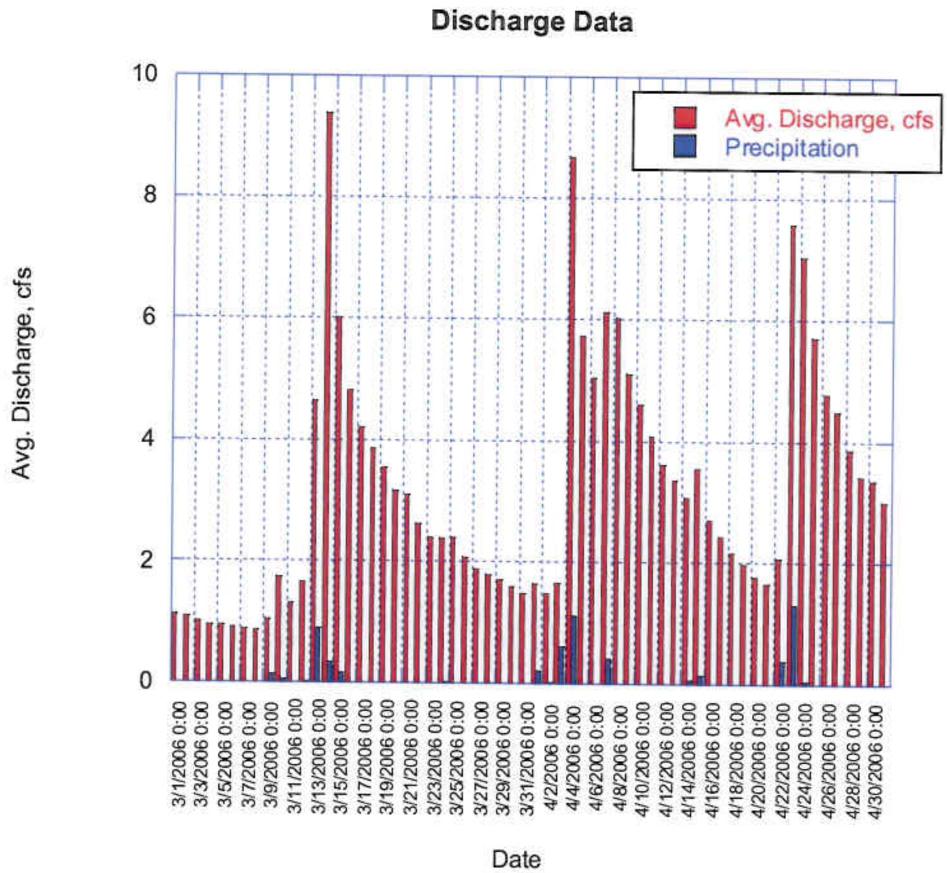

Biotic Index
Biotic Index
3
2.5
2
1.5
1
0.5
0
Biotic Index
Clark 5/2
18th 5/2
latham 5/2
Sample Site

Figure 23



Appendix 11

Appendix 12

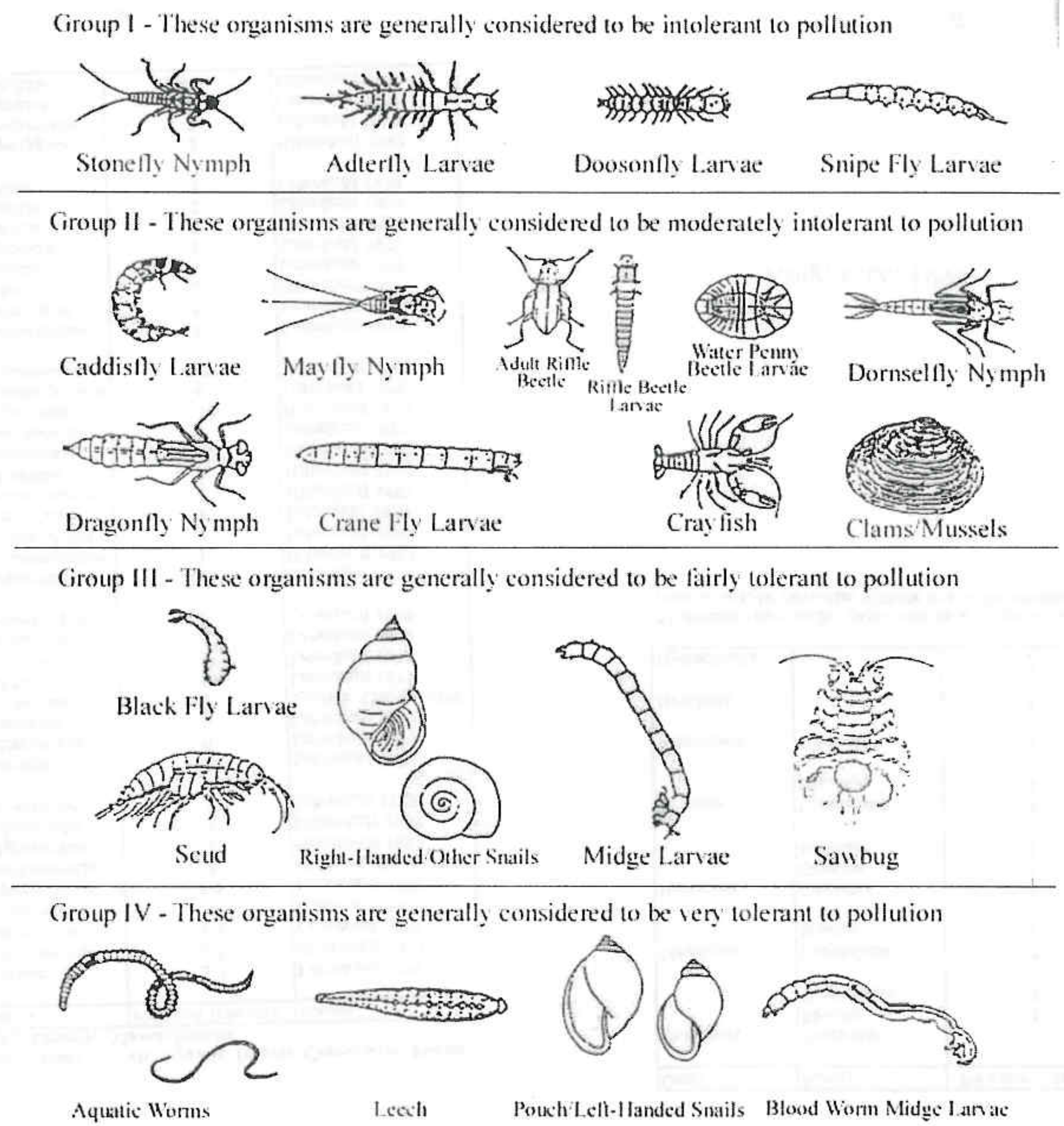


Figure 7: Field Identification Reference Sheet
Organisms divided into their respective taxa groups

Appendix 12

APPENDIX 2

Pollution Tolerance Values for all Aquatic Insects Commonly Found Northern Berkshire County, Massachusetts

Order	Family	Pollution Tolerance	Source
Ephemeroptera (med, 1.66)	Baetidae	2.5	Lehmkuhl 1979
	Ephemerellidae	0.5	Hilsenhoff 1977
	Ephemeridae	1.5	Lehmkuhl 1979
	Heptageniidae	1	Hilsenhoff 1977
	Leptophlebiidae	1.5	Hilsenhoff 1982
	Neophemeridae	2	Hubbard, Peters 1978
	Oligoneuriidae	2	Hilsenhoff 1982
	Siphlonuridae	2	Hilsenhoff 1977
	Tricorythidae	2	Lehmkuhl 1979
Plecoptera (good, .5)	Capniidae	0	Lehmkuhl 1979
	Chloroperlidae	0	Lehmkuhl 1979
	Leuctridae	0	Lehmkuhl 1979
	Peltoperlidae	2	Surdick, Gaufin 1978
	Perlidae	0	Lehmkuhl 1979
	Perlodidae	0	Lehmkuhl 1979
	Pteronarcidae	1	Lehmkuhl 1979
	Taeniopterigidae	1	Lehmkuhl 1979
Trichoptera (med, 1.93)	Brachycentridae	0.5	Lehmkuhl 1979
	Glossosomatidae	1	Hilsenhoff 1982
	Hydropsychidae	4	Lehmkuhl 1979
	Hydroptilidae	3	Lehmkuhl 1979
	Lepidostomatidae	2	Hilsenhoff 1982
	Leptoceridae	2	Hilsenhoff 1982
	Limnephilidae	1.5	Hilsenhoff 1982
	Philopotamidae	0	Lehmkuhl 1979
	Phryganeidae	1.75	Hilsenhoff 1982
	Polycentropodidae	4	Lehmkuhl 1979
	Psychomyiidae	1.5	Hilsenhoff 1982
Diptera (2.875)	Ceratopogonidae	3	Lehmkuhl 1979
	Chironomidae	5	Lehmkuhl 1979
	Dixidae	2	Hilsenhoff 1977
	Empididae	4	Lehmkuhl 1979
	Rhagionidae	2	Lehmkuhl 1979
	Simuliidae	3	Hilsenhoff 1988*
	Tabanidae	2	Lehmkuhl 1979
	Tipulidae	2	Lehmkuhl 1979
Odonata (2.5)	Calopterygidae	2	Hilsenhoff 1982
	Coenagrionidae	3	Lehmkuhl 1979
	Gomphidae	0.5	Lehmkuhl 1979
	Libellulidae	4.5	Hilsenhoff 1987*

Order	Family	Pollution Tolerance	Source
Coleoptera (2.33)	Dytiscidae	1	Hilsenhoff 1977
	Elmidae	2	Lehmkuhl 1979
	Psephenidae	2	Lehmkuhl 1979
Megaloptera	Corydalidae	2	Hilsenhoff 1982
	Sialidae	2	Hilsenhoff 1982
Hemiptera	Corixidae	4	Lehmkuhl 1979
	Gerridae	3	Lehmkuhl 1979
	Veliidae	3	Lehmkuhl 1979
Physidae	Lymnaeidae	3	Plafkin et al.1989
	Physidae	4	Plafkin et al.1989
Amphipoda	Talitridae	4	Hilsenhoff 1982
Hirudinea		5	Plafkin et al.1989
Hydrachnidia		2	Plafkin et al 1989

*Tolerance values in this paper were on a ten-point scale so they were adjusted to a five-point scale to be consistant with the rest of the tolerance values.

King, E.D., 1999

Sample Site	Turbidity (centigram/50mL)	Residue Color	pH	ANC (units?)	Conductivity (units?)
Clark Upstream 5/11					
Phoebe's Brook	negligible		6.61	155	187
Phoebe's Brook 5/11 #1					
Phoebe's Brook 5/11 #2					
W. of pine cobble school (Phoebe's)					
Clark 1C	"	Lightest, faintly tinted yellow/tan			
Clark 2C	"	"			
Clark 3C 4/15?	"	"			
Clark 4/19			7.34	219	278
Clark 5/11					
Clark Christmas 3/13					
Nr. Buxton/Clark					
18th hole 1B	"	Darkest tan/yellow of the sites			
18th hole 2B	"	"			
18th hole 3B	"	"			
18th hole 4/19			7.65	435	284
18th 5/11					
Christmas @18th hole					
Outlet, pumping pond(18th)					
Latham 1A	"	Medium shade,but variance:			
Latham 2A	"	lightest OF ALL SAMPLES			
Latham 3A	"	almost as dark as B samples			
Latham 4/19			7.95	504	297
Latham 5/11					
Christmas@ Latham					
Upstream 5/2					
Clark 5/2					
in course 5/2					
18th 5/2					
latham 5/2					

D.O.	Temp. (°C)	CA+2, mg/L	Mg +2, mg/L	Na+ mg/L	K+ mg/L	F- mg/L	Cl- mg/L	NO3 mg/L	PO4 mg/L	SO4	Total Coliform
		14.44	4.84	12.92	1.046	0.1138	22.283	1.1342	0	6.298	
		6	6	0.646	0.316	0	0.6468	0.2622	0.8363	5.0421	113
		11.28	5.24	0.931	0.469	0.1004	0.6699	0.1119	0	5.1277	
		8.39	3.97	0.898	0.453	0.0982	0.6578	0.12	0	4.9479	
							1.2	0		8	
		19.7	4.6	12.1	1.1	0.2195	28.87	1.73	0	9.78	1760
		20.5	4.4	10.9	1.13	0.1772	27.2	1.5	0	9.19	388
		21.4	4.5	12	0.88	0.1985	29.24	1.52	0	9.39	412
10.65	11.2	30.43	6.12	23.51	1.618	0.35	49.043	1.559	0	8.6981	
		19.27	6.46	21.43	1.909	0.1211	42.769	1.3134	0	8.6493	
		1.85	1.19	41.3	5.32	0.00	39.7	2.78	0.00	9.16	900
							11.9	4.53		10.6	
		37	8.8	16.9	0.78	0.1903	38.25	1.49	0	11.74	970
		31.9	8.9	16.6	0.5	0.1849	37.46	1.31	0	11.71	444
		27.8	8.9	16.4	0.56	0	---	1.26	0	11.47	436
10.32	15.6	31.43	9.12	18.23	0.951	0.27	34.509	1.1087	0	9.6915	
		19.4	8.12	18.94	0.964	0.1149	37.382	0.4112	0	8.132	
		4.78	0.986	20.7	7.77	0.19	35.2	3.37	0.00	10.4	580
							17	2.59		17.4	
		78.1	12.4	18.4	1.7	0.2025	37.7	1.59	0	12.55	650
		64.4	11.8	15.8	0.97	0.195	36.22	1.57	0	11.97	336
		48.7	11.7	16.9	0.46	0.1887	36.75	1.51	0	12.28	328
10.55	13.3	32.98	11.77	14.96	1.148	0.34	28.436	1.38	0	10.2127	
		21.49	12.06	13.33	0.601	0.1178	22.224	1.2166	0	9.1073	
		22.1	1.09	19.5	7.75	0.17	70.3	3.63	0.00	11.7	278
		10.72	3.157	0.937	0.331	0	0.2533	0.4093	0	4.3583	
		21.95	5.38	14.84	1.565	0.2138	27.074	1.1761	0	8.3309	
		23.17	6.79	23.35	0.969	0.1954	44.388	0.4379	0	8.4325	
		26.96	8.51	14.36	0.9	0.1837	31.26	0.9702	0	8.9966	
		24.05	10.45	16.7	1.181	0.1994	29.219	1.4731	0	9.2812	

Fecal Coliform 1995	Fecal Coliform 2006	Plecoptera	Ephemeroptera	Trichoptera	Diptera	Coleoptera	Odonata
	7						
1010	7						
	30	1	0	3	2	0	1
	31						
	700						
1800	253.6666667						
	20	0	0	5	10	0	1
	12						
	52						
870	28						
	10	0	0	19	4	0	0
	20						
	64						

Appendix 15