6-2022

Sewer System Infrastructure and Stressors on Water Quality in Streams within the Alplaus Watershed in Upstate NY

Camryn Ragland
Union College - Schenectady, NY

Sewer System Infrastructure and Stressors on Water Quality in Streams within the Alplaus Watershed in Upstate NY

By

Camryn J. Ragland

****

Submitted in partial fulfillment

of the requirements for Honors in the

Environmental Science, Policy, & Engineering Program

UNION COLLEGE

June 2022

ABSTRACT

RAGLAND, CAMRYN J. Sewer System Infrastructure and Stressors on Water Quality in Streams within the Alplaus Watershed in Upstate NY. Environmental Science, Policy, and Engineering Program, June 2022.

ADVISOR: John Garver

Healthy aquatic ecosystems require clean water, but many creeks and streams may be impaired by human activity. This study is focused on surface water quality of the Alplaus, and Indian Kill streams located within the Alplaus Watershed in Schenectady and Saratoga Counties (NY). The primary goal of this study is to understand the extent of water quality impairment within the Alplaus and Indian Kill using a range of indicators to understand the impacts of failing infrastructure and stressors to surface water. Sixty-five water samples were collected in the fall of 2021 from six locations in the Alplaus and Indian Kill and they were taken during periods of low- and high-flow. Samples were measured for fecal indicator bacteria (FIB) *Enterococcus*, dissolved ions, and physical water quality parameters. At high flow, samples show elevated levels of FIB and Phosphate. Single sample *Enterococcus* levels exceeded the EPA Beach Advisory Value (BAV = 60 mpn/100 mL) in 93% of samples (61/65) from both low- and high-flow conditions. The geometric means at low flow for the Alplaus and Indian Kill are 180 and 100 mpn/100 mL, respectively. The geometric means at high flow for the Alplaus and Indian Kill are 14,652 and 21,291 mpn/100 mL, respectively. The two highest recorded *Enterococcus* values were after periods of high rainfall along the Mayfair Creek, a tributary to the Indian Kill in an urban setting. During low flow (or baseflow) high levels of nitrate, sodium, and chloride indicates input from contaminated groundwater, especially in the suburban/urban setting of the Mayfair area in the town of Glenville (Indian Kill). The Alplaus and Indian Kill streams are fed by groundwater discharge during low flow, indicating there is contamination of the groundwater. Low flow concentrations of chloride and nitrate were three and four times higher than high flow in the Alplaus Watershed respectively. Through increased urbanization and aging infrastructure, it appears that surface water quality in streams and rivers has been impaired by sewage from leaky pipes or failing septic systems and chemical pollutants such as road salt. Local areas with chronic contamination have a large number of septic systems, most presumably 60–70-year-old, and are a likely suspect of water quality impairment to groundwater that is especially apparent in the Indian Kill.

ACKNOWLEDGEMENTS

I would like to express my greatest thanks to all my friends, family, and colleagues who have pushed me to pursue my passions and make this research possible. First, I would like to thank Dr. Jeff Schell from Sea Education Association for introducing me to research on Fecal Indicator Bacteria and stimulating my love of fieldwork. I am so thankful to the Union College Environmental Science, Policy, and Engineering Program and the Geosciences Department for their endless support throughout this project. I would specifically like to thank Matt Manon for his guidance in using lab instruments and Mason Stahl for inspiring my passion for hydrology and assisting in my analysis. To Jodie Wright, my partner in water quality studies, thank you for always being by my side. Finally, my most sincere thanks go to my thesis advisor John Garver. Your passion for this project and water quality improvements constantly inspires me and push me to be a better scientist. Thanks to your guidance and immense knowledge we pushed the limits of what I thought possible for this project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Surface water quality is essential for the health of aquatic ecosystems, drinking water, hydropower, recreation, and a host of other economic and ecosystem services (U.S. EPA, 2012). Surface water bodies provide a system of transport for dissolved and suspended solids, pollutants, and other anthropogenic impacts on natural hydrology. All streams and rivers contain a different composition of hydrologic features and water chemistry based on local geology, land use, and human impacts such as infrastructure and sewage systems. This thesis aims to understand water quality in the Alplaus Watershed. Our primary goal is to identify areas of water quality impairment to potentially inform future remediation efforts. The Alplaus Watershed is a tributary to the lower section of the Mohawk River that runs through Schenectady County, NY. The Mohawk River is the largest tributary to the Hudson River, which water supplies resources to over 600,000 New Yorkers[1].

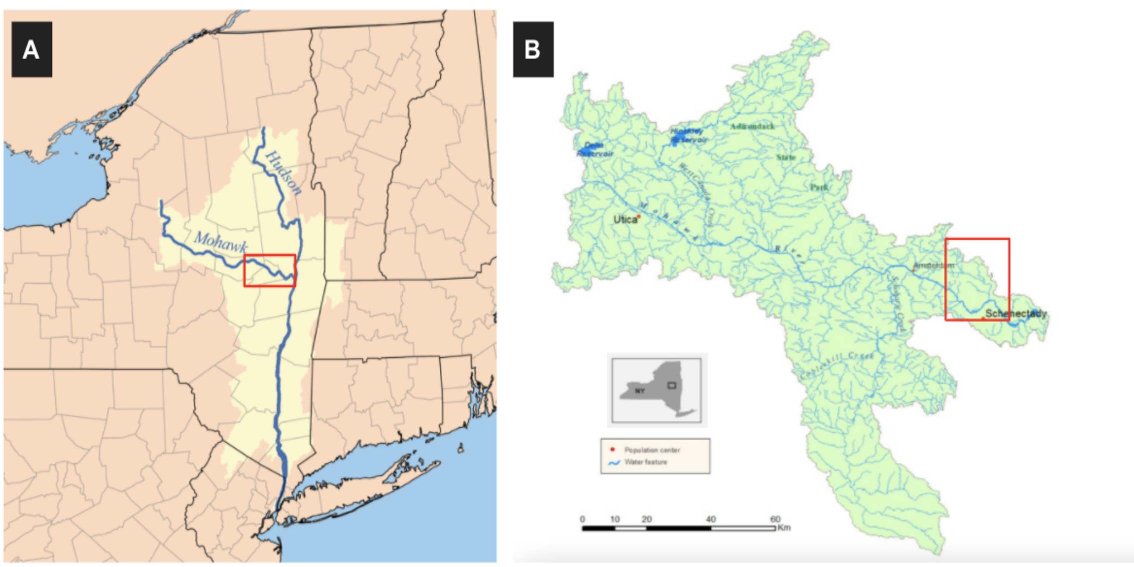


Figure 1: A) Map of the greater Mohawk-Hudson Watershed, where the box surrounds the lower Mohawk River. B) The entire Mohawk Watershed with a red box showing the approximate location of the Alplaus Watershed, which is the local area of this study.

The Alplaus Watershed is a tributary to the Mohawk, making it a potential contributor of high loads of nutrients and other pollutants into the Mohawk River. The Alplaus watershed (Figure 1 B) is of importance because of its connection to the Mohawk River and the role it may be playing in impairing water downstream in the Mohawk. Starting January 1, 2022, the NYS DEC is beginning a TMDL or Total Maximum Daily Load for phosphorus in the Mohawk, and the contribution of pollutants from tributaries is important in understanding the total flux of nutrients. A TMDL is essentially a “pollution diet” where a

[1] Mohawk River Watershed Management Plan – Published by the Mohawk River Watershed Coalition, March 2015

municipality is required to create and implement a plan to reduce a specific pollutant that is over the safe threshold for the water body to maintain healthy ecosystems. Thus, understanding the extent of the contamination present in the Alplaus Watershed may prove to be essential for moving forward with how to reduce the total phosphorus load in the Mohawk River.

The most recent reports of aquatic ecosystem health and water quality in the Alplaus and Indian Kill, the two primary streams within the Alplaus Watershed, were NYSDEC Stream Biomonitoring Unit Rapid Assessment Survey (RAS) Reports published in 2005, and 2000 respectively. In these reports, the Alplaus Kill was found to be “slightly impacted”, and the Indian Kill “slightly to moderately impacted”. There have been no conclusive and comprehensive studies conducted on these water bodies since.

One important way of evaluating water quality is to analyze for fecal indicator bacteria (FIB) such as *Enterococcus* or *E. coli,* which exist in the gut of warm-blooded animals. The U.S. EPA recognizes FIB as a method of recognizing water quality impairment in surface water bodies, as they are commonly introduced into the environment through fecal matter (U.S. EPA, 2012). Most FIB are harmless to humans, however, their presence in surface water bodies often indicates the presence of other pathogens that are harmful to humans. FIB can be introduced into the environment from a variety of sources including, but not limited to, leaking septic tanks, wildlife, livestock, combined sewer overflows (CSOs), and failing Municipal Separate Storm Sewer System (MS4s) acting as CSOs (Gordon et al., 2013, Cho et al., 2020).

Proper management of sewage and stormwater systems is essential for reducing pollutant load in surface water bodies. Two common sewage and stormwater systems used by municipalities are Combined Sewer Overflow Systems (CSOs) and Municipal Separate Storm Sewer Systems (MS4s). CSOs are inclusive systems that source rainfall-runoff and stormwater discharge. MS4s are systems that have separate drainage methods for stormwater and sewage. In MS4s, polluted stormwater runoff is transported through the MS4 system and the discharged, untreated, local water bodies. The implementation of an MS4 system by a municipality requires many stages and permits, along with yearly reporting of the progress of stormwater outfall monitoring for illicit discharges. The Town of Glenville follows an MS4 stormwater and sewage management plan.

The type of wastewater treatment, septic system or municipal, from a given building is important in understanding pollution sources that directly or indirectly into the environment. A septic system is a wastewater treatment structure located underground. Septic tanks partially treat the wastewater, then slowly release the effluent through perforated pipes into the soil (Tamang, 2020). If a septic system is functioning properly, it will remove nutrients, bacteria, and other pollutants from the wastewater. However, septic systems can often fail, especially in older homes or buildings, causing high levels of sewage and

pollutants to enter the soil, groundwater, and surface water (Tamang, 2020). Municipal sewage pipes or sanitary sewers, exist underground leaving the potential for old leaking pipes to interact with both groundwater and surface water bodies.

This thesis will discuss the importance of consistent sampling to fill a gap in the understanding of water quality in the Alplaus Watershed. A broad and rich dataset collected over a period of two months in the fall of 2021 is presented in this report to close the gap in the understanding of water quality in the Alplaus and Indian Kill streams. *Enterococcus* was measured to determine the extent of contamination from fecal sources such as sewage overflows, animal waste, or runoff from agricultural fields. Salinity indicators, such as specific conductance (SPC), sodium, and chloride, were measured to understand the impacts of road salt on surface water bodies. The nutrients Nitrate (NO_3) and Phosphate (PO_4) were used to understand broadly non-point source pollution related to failing septic systems, agricultural runoff, treated sewage, and impairment from stormwater outfalls. The combination of all pollution indicators used in this analysis present a better understanding of human impacts on the surface water bodies within the Alplaus Watershed.

The sampling sites looked at in this thesis contain a number of urban streams (Indian Kill), with both rural or mixed land use (Alplaus Kill). The Alplaus Watershed comprises a wide range of land uses, making identifying point source and nonpoint source pollution challenging. Point source pollution is the inflow of a pollutant that can be attributed to a particular source such as a wastewater treatment plant, to leaking municipal sewage pipe. Nonpoint source pollution is the cumulative input of diffuse pollutant inflow from a broad range of sources. Water quality impairment signals from areas with high developed land and agricultural land indicate a potential difference in the source area. Understanding the land use for the watersheds analyzed in this thesis may narrow the scope of nonpoint source pollution possibilities.

The collection of samples for this thesis was done simultaneously with a parallel study on pathogens and water quality in the Mohawk River and urban creeks in the Schenectady area (Wright, 2022). The broad range of contaminant indicators used in this thesis represents the complexities involved in understanding pollution sources in this study area, thus emphasizing the urgency in identifying consistent offenders in pollution inputs.

BACKGROUND

The Mohawk Watershed and Tributaries Water Quality

The Mohawk River Watershed is the largest tributary to the Hudson River with an area of 3,460 square miles and this accounts for 25% of the Hudson River watershed (MRWC, 2015). Over 600,000 New Yorkers live within the Mohawk watershed's 170 municipalities. The entire watershed includes 6,656 miles of freshwater tributaries including rivers, streams, and canals (MRWC, 2015). The Mohawk River is an important common resource among stakeholders within the watershed for recreation, commercial, and industrial uses (NYSDEC, 2018). Ensuring the health, specifically water quality and supply, of the Mohawk River is essential for the maintenance of local ecosystems and community engagements.

Water quality and TMDL

In the past ten years, many stakeholder groups across the Mohawk Watershed have become involved in actions related to maintaining water quality and the health of the watershed. In 2015, the Mohawk Watershed Basin Action Agenda published a progress report detailing actions taken regarding environmental sustainability and flood hazard risk reduction. Most recently, the progress report published by the New York State Department of Environmental Conservation (NYSDEC) in 2018 is an updated version of this prior report. In 2015, the NYSDEC conducted an analysis of pollutant load to better understand their sources and loads in the Mohawk River. In accordance with the US EPA Clean Water Act, states are required to monitor ambient water quality to limit the exceedance of any particular pollutant. Results from this analysis indicated that around 60% of the phosphorus present in the Mohawk Watershed is coming from point source entry points such as sewage treatment facilities (Smith & Nystrom, 2017). An additional 21% of the phosphorus was attributed to non-point source agricultural practices and the remaining 19% estimated from a combination of land, septic fields, and natural sources.

Riverkeeper, an environmental group based in the Hudson Watershed, published a water quality report on the Mohawk River from 2015-2020 (Riverkeeper, 2020). This report highlights important water quality impairment issues including *Enterococcus* and phosphorus, that are described further in this thesis. Riverkeeper started coordinated FIB testing in 2015.

The exceedance of water quality impairment thresholds identified in these analysis of the Mohawk Watershed has led the NYSDEC to develop a Total Maximum Daily Load (TMDL) plan to reduce the overload of total phosphorus in the Mohawk Watershed. A NYSDEC enforced TMDL plan to reduce the amount of total phosphorus present in the Mohawk River went into effect on January 1, 2022. A TMDL is a calculation of a pollutant threshold in a particular waterbody that is needed to meet in order to maintain a water quality standard (U.S. EPA, 2021). A TMDL is the sum of three waste-related input criteria. These criteria include waste allocations from point sources, load allocations from nonpoint

sources and background input, and a margin of safety related to the determined overloaded pollutant (EPA, 2021). A TMDL is meant to characterize the relationship between pollution sources and waterbody conditions to create maximum pollution loads that a waterbody is then required to adhere to (EPA, 2021). Water quality issues in the Mohawk River have triggered the need for a TMDL because of violations of total phosphorus levels identified above the limit for impaired waters listed in Section 303(d) of the NYSDEC list of impaired waters. According to the U.S. Clean Water Act, the NYSDEC is required to implement this plan to clean up the pollution in the Mohawk Watershed. This TMDL plan requires compliance from all municipalities within the Mohawk Watershed. Tributaries to the Mohawk will play a major role in the effectiveness of this plan to reduce waste inputs into the Mohawk River.

The Alplaus Watershed Physical Hydrology

The Alplaus Watershed is in Schenectady and Saratoga counties in New York State. he Alplaus Kill is the largest stream in the Alplaus Watershed and spans 108 total km in length. Four streams comprise most of the watershed, these include the Alplaus Kill, Indian Kill, Crabb Kill, and La Rue Creek. The total length of streamflow systems in the Alplaus Watershed is 195 km, spanning across the total watershed area of 144 km^2 (ggSURGO, 2016; NLCD, 2019). The confluence of the Alplaus with the Mohawk River is in the village of Alplaus. The Indian Kill is a tributary to the Alplaus Kill, extending approximately 38 km west in the town of Glenville. A focus on the Indian Kill was selected primarily because of its mixed land uses, spanning through the most developed areas of Glenville and the Indian Kill Nature Preserve. Most of the watershed is present in the towns of Glenville and Charlton, NY. A broad range of land uses is present across the watershed including mixed forests, woody wetlands, and developed areas being the most common (NLCD, 2019). Additionally, the majority of the hydrologic soil groups in the Alplaus Watershed are Medium/Very Slow infiltration (gSSURGO, 2016). The size and range of developments across the Alplaus Watershed make it an important area of study for contamination in surface waters as it relates to pollution in the Mohawk River.

Sewage and Pathogens in Surface Water

Fecal Indicator Bacteria

Pathogens from sewage are the number one cause of water quality impairment in urbanized areas (Clary et al., 2014). A pathogen is any type of organism - mainly bacteria, viruses or parasites - that can cause diseases. Pathogen presence has implications for recreational and environmental conditions and additionally, human health impacts. Common pathogens used to monitor water quality include *Enterococcus*, *Escherichia coli* (*E. coli),* Total Coliform, and Fecal Coliform. The transport and fate of FIB in surface waters is determined by a variety of factors including, but not limited to: growth and decay, colonization, and attachment to sediments (Clary et al., 2014). Environmental or secondary sources of

FIB are also high contributors to a more persistent flow of pollutants into subsequent watersheds (Clary et al., 2014).

Sediments both in storm pipes and on streambeds provide the perfect environment for FIB growth. Stormwater discharge pipes are cold and dark, allowing for high microorganism production. Sediments transported through these pipes in large flow events contain high levels of FIB that can drain into surface water. The ideal environment for FIB is in surface water bodies with the least number of environmental stressors, and these include increased sunlight (Boehm et al., 2009), salinity (Anderson et al., 2005), and water treatments such as chlorine (Berg et al., 1978, Tree et al., 2003).

Different FIB have been used to evaluate water quality. In the late 1970's and early 1980's the EPA determined that *Enterococci* are good predictors of GI illnesses in marine and fresh recreational waters, and *E. coli* are good predictors of GI illnesses in fresh waters (Cabelli et al., 1983; Dufour, 1984). This result was published in the EPA's Ambient Water Quality Criteria for Bacteria – 1984, which defined standards for FIB levels in marine and surface water. These criteria recommend 33 *Enterococci* cfu per 100 mL in fresh water and 35 *Enterococci* cfu per 100 mL in marine water and 126 *E. coli* cfu per 100 mL in recreational fresh waters (U.S. EPA, 1986). The EPA has since published a new Recreational Water Quality Criteria (RWQC) in 2012, which are summarized in the following table.

Criteria Elements	**Estimated Illness Rate (NGI): 36 per 1,000 primary contact recreators**		OR	**Estimated Illness Rate (NGI): 32 per 1,000 primary contact recreators**	
	Magnitude			**Magnitude**	
Indicator	GM (cfu/100 mL)[a]	STV (cfu/100 mL)[a]		GM (cfu/100 mL)[a]	STV (cfu/100 mL)[a]
Enterococci – marine and fresh	35	130		30	110
OR					
E. coli – fresh	126	410		100	320
Duration and Frequency: The waterbody GM should not be greater than the selected GM magnitude in any 30-day interval. There should not be greater than a ten percent excursion frequency of the selected STV magnitude in the same 30-day interval.					

Table 1: The U.S. EPA's most updated standard showing the geometric mean (GM) and statistical threshold values (STV) for suggested fecal indicator bacteria (U.S. EPA, 2012).

The current EPA FIB standards presented in the table above define the statistical threshold value (STV) and geometric mean (GM) for *Enterococcus* and *E. coli,* the two FIB that are common practice for water quality impairment identification. The GM is a calculation used for FIB to get the average concentration over a period of time. Unlike the arithmetic mean, the GM tends to reduce the effect of very high and very low values. The GM is helpful for understanding FIB concentrations, because

concentrations from a single sample may vary several orders of magnitude anywhere from 10 to 10,000 cfu/100 mL. The STV is a calculation that approximates the 90th percentile of the water quality distribution and is intended to be a value that should not be exceeded by more than 10% of the samples used to calculate the GM (U.S. EPA, 2012).

In 2017, the EPA performed a 5-year review of the 2012 RWQC and decided to not revise the criteria (U.S. EPA, 2017). However, this review did recognize many areas of further research and analysis that added to the previous criteria. The 2012 RWQC has defined how marine and surface waters are tested to assess their risk for human health. High *Enterococcus* levels pose a threat to human health in that it is a source of gastrointestinal diseases. While the EPA recognizes *Enterococcus* for marine or freshwater sampling and *E. coli* for freshwater sampling, the NYSDEC does not recognize *Enterococcus* usage as standard practice for water quality sampling.

Enterococcus

Enterococcus is a naturally occurring bacteria present in the intestinal tracts of humans and animals as well as environments including water, soil, and plants (Cho et al., 2020). The EPA recognizes wildlife as an important non-point source of FIB, but they suggest beavers, deer, geese, ducks and herons are examples of potential sources (Clary et al., 2014). *Enterococcus* can also occur in high concentrations in sediment. Over time bacteria accumulates and can resurface in high volumes during high flow conditions when discharge is elevated.

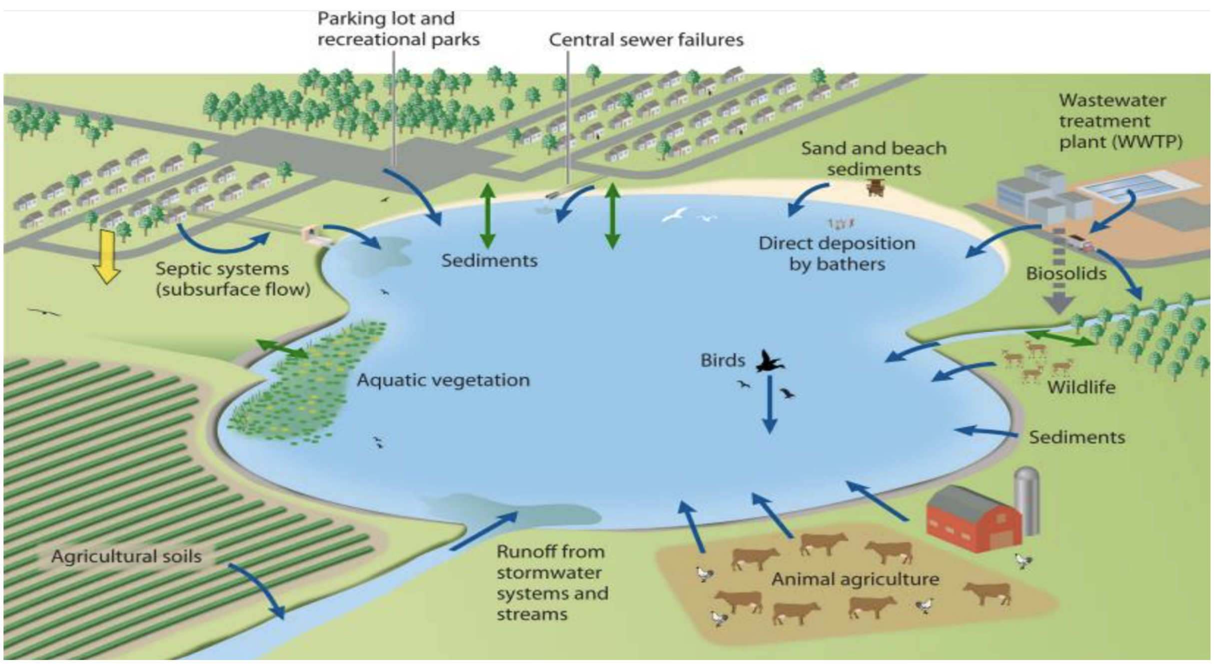


Figure 2: Sources of Enterococcus in the environment. Blue arrows show the sources and green arrows indicate fluxes where there is potential for exchange of Enterococcus between sinks (Byappanahalli et al., 2012).

Enterococcus is commonly used as an indicator bacterium in marine and surface waters to identify pathogens from sewage that may be present in surface water. It is important to note that most strains of enterococci and *E. coli* do not cause human illness (that is, they are not human pathogens); rather, they indicate the presence of fecal contamination (U.S. EPA, 2012). The presence of *Enterococcus* does not always indicate sewage, and there is a complex relationship between non-point source contributions to the environment and levels of measured *Enterococcus* in common sinks (Figure 3). Important sources of Enterococcus in the environment, not from direct human input, include domestic animals such as cattle or swine, wildlife such as birds and deer, and high bacteria can also be present in sediment and aquatic vegetation (Byappanahalli et al., 2012).

Enterococcus is a bacteria present in the environment through natural sinks and sources, because it naturally exists in all warm-blooded animals. *Enterococcus* species can be found as commensal bacteria in accordance with microbial aiding of digestion and degradation of food (Pillay et al., 2018). Outside of the intestinal tract, *Enterococcus* is widely adaptable to natural environments and is able to colonize in various habitats from hospitals to human guts to plants and soils (Hammerum, 2012). When *Enterococcus* is identified outside of the gut of humans or animals, it is considered a fecal indicator bacteria and human pathogen (Pilay et al., 2018).

Currently, the EPA RWQC is based on previous studies relating FIB concentrations in surface waters to gastrointestinal diseases in swimmers (Cabelli, 1983). However, recent studies have shown that FIB levels and gastroenteritis are not correlated from nonpoint source pollution such as storm or sewage water (Gordon et al., 2013). Because of this, the EPA has suggested that water quality monitoring be accompanied by quantitative PCR (qPCR) as a part of the 2012 RWQC report (U.S. EPA, 2012). Since 2012, many methods of microbial source tracking (MST) have emerged to evaluate the source of FIB in recreational waters.

An increase in runoff in urban areas, likely from high precipitation events, increases the concentration of FIB in surface waters threatening public and aquatic health during wet weather conditions (Cho et al., 2010; Chong et al, 2011). PCR methods of MST have indicated high levels of human sewage contamination during wet weather events that may be attributed to sanitary sewer overflows (SSOs) (Chong et al., 2011).

Human Health Impacts

Enterococci are commonly associated with human and animal feces, thus their presence can be predictive of human health risks from exposure to polluted recreational waters (Byappanahalli et al.,

2012). It is important to recognize that the bacteria *Enterococcus* itself is not the cause of human health impairment, but rather the waterborne pathogens that co-exist in its presence are of concern.

Enterococcus can be present in the environment at high levels from nonpoint source environmental origins, not directly related to sewage inputs. A study where marine water bathers were exposed to waters with high microbe concentrations with no known point sources found that bathers had an increased risk of gastrointestinal illness, respiratory illness, and skin illness (Fleisher et al., 2010). A dose-related relationship has been found between increasing *Enterococcus* concentrations and skin illnesses (Fleisher et al., 2010). Additionally, there was a casual dose-related increase of human health risks as FIB concentrations increase in a broad view of FIB and illness correlations (Prüss, 1998). *Enterococcus* was subsequently identified as the the most correlated indicator for human health outcomes from marine and freshwater, and *E. coli* was well correlated for just fresh water (Prüss, 1998).

Microbial Source Tracking

The wide range of potential environmental non-point sources and anthropogenic point sources related to high FIB inputs in surface waters, make it challenging to understand where the source of FIB. Knowledge of the source of FIB is typically important for water quality remediation efforts such as TMDL (Byappanahalli et al., 2012). Microbial source tracking (MST) aims to identify the origin of pathogens in recreational waters where they may pose a danger to swimmers or environmental quality. MST typically uses library-independent gene targeting methods such as qPCR. Identifying the HF183 gene during the qPCR process means the bacteria can be attributed to human sewage. MST is typically used in addition to FIB testing to determine which warm-blooded animals are the pathogen source. Once an area is determined to be contaminated through FIB sampling, MST is often the next step in understanding where this impairment is coming from and how it can be repaired.

Water Quality Parameters

Physical water quality measurements of surface water temperature, total dissolved solids (TDS), and acidity/alkalinity (pH) can be important factors in understanding surface water quality variability (Poudel et al., 2013). The decomposition of inorganic materials in surface waters can be good indicators of water quality impairment especially in areas with mixed land uses including agricultural (Poudel et al., 2013) and residential areas (Poudel and Jeong, 2009). Surface water quality parameters change depending on daily, seasonal or annual variations dependent on agricultural activities, degradation of streamside vegetation, or rainfall events (Poudel et al., 2013; Praus, 2007). Indicators for salinity (conductivity or specific conductance) can be indicative of road salt in water from de-icing reclamation plants or treated sewage (Jackson et al., 2008). Physical parameters are easily accessible to study using water quality probes such as a varieties of YSI (Yellow Springs Instruments) probes that are commonly used in the methods of surface water quality studies (Mei et al., 2011; Schveitzer et al., 2013; Tanrıverdi

et al., 2010). YSI probe attachments allow easy access to physical parameters such as temperature, pH, TDS, conductivity, SPC, salinity, and additional dissolved ions such as nitrate and phosphorus.

Dissolved ions in surface water and groundwater interactions

Major dissolved ions in streams are variable dependent on bedrock type, population density, annual precipitation and average stream temperature (Peters, 1984). Dissolved ions in surface waters primarily include concentrations of sodium, potassium, magnesium, calcium, chloride, sulfate, fluoride, nitrate, or phosphate. These ions have a variety of natural environmental and anthropogenic sources and sinks. The three major of these sources include rocks and soil surrounding the drainage basin, atmospheric deposition, and anthropogenic activities (Peters, 1984).

In urban watersheds or watersheds with mixed and variable land uses, engineered headwaters and urban infrastructure additionally are sources of dissolved ions (Kaushal & Belt, 2012). A very important predictor of dissolved ion concentrations in streams is annual precipitations (Peters, 1984). The amount of precipitation in a stream can be indicative of its flow conditions. After an extreme precipitation event, flow will be high and during a dry period of no precipitation flow will typically be much lower and the stream will thus be at baseflow conditions.

The combination of mixed land uses, especially at the interface of urban and rural land use in watersheds where septic systems commonly occur in high concentrations and this complicates groundwater flow paths, and dissolved ion contamination of surface and groundwater systems. The urbanization of a watershed plays an important role in flow of groundwater resources, which recharge urban streams (Kaushal & Belt, 2012). The contamination of groundwater and their related recharged streams are directly influenced by the system of stormwater drains, sanitary sewer lines, potable water pipes, and septic inputs within the watershed boundaries (Kaushal & Belt, 2012). Urban watersheds impact groundwater flow systems because of the network of pipes that are typically present at depths in which they interact with the water table. Typically at the interface between urban and rural watershed boundaries, there is a a higher density of septic sewer systems present that can release nitrogen below the water table, where it is then transmitted to groundwater and upstream surface headwaters (Kaushal et al., 2011). The inclusion of septic systems in urban-rural watersheds complicate ground and surface water contamination because the individual systems may deteriorate over time at different rates than more streamlined and efficent sanitary sewer lines (Kaushal & Belt, 2012).

While ideally all underground pipe systems are operating independently, groundwater flow below the subsurface complicates exchange between sanitary sewer, storm, and potable water pipes and recharge to surface water bodies (Kaushal & Belt, 2012). The three main pipe systems present in urban stream areas—storm drains, sanitary sewers, and potable water pipes—may have very different leakage

patterns, directly impacting ecosystem functions through contamination (Kaushal & Belt, 2012). Drinking water pipes under high pressure have a leakage rate of around 20 to 30 percent (Garcia-Fresca, 2007). Fluoride is often added to drinking water in the United States, so its presence in surface water, specifically more urban streams with mixed networks of stormwater and sewer pipes indicates that the pipes may be leaking. The presence of fluoride in surface waters may be indicative of leaks from wastewater and potable drinking water pipes (Kaushal & Belt, 2012). While dissolved ions like fluoride have a signature for anthropogenic inputs, calcium can be used to understand weathering from limestone and shale bedrock input from groundwater recharge (Horan, 2019).

Threats to water quality

Septic Treatment Systems

Septic systems are onsite wastewater treatment systems that are used to treat domestic wastewater (Tamang, 2020). Conventional septic systems include a septic tank and drain field that are primarily designed to filter for solids, pathogens, and other pollutants from domestic wastewater (Tamang, 2020). Often at the interface between urban and rural watershed boundaries, there is a higher density of septic sewer systems present that can release nitrogen below the water table, where it is then transmitted to groundwater and upstream surface headwaters (Kaushal et al., 2011). The inclusion of septic systems in urban-rural watersheds complicate ground and surface water contamination because the individual systems may deteriorate over time at different rates than more streamlined sanitary sewer lines (Kaushal & Belt, 2012).

Concentrations of the nutrients Nitrogen (N) and Phosphorous (P) can be used in some occasions to identify leaking septic systems (Tamang, 2020). Nitrogen can be more complicated because it can exist in many forms in the environment. Through the process of nitrification, microbes in the soil convert NH_4^+ into nitrite (NO_2) and nitrate (NO_3) (Tamang, 2020). In this study only Nitrate is important because of its connection to eutrophication in surface waters impairing aquatic organisms. Additionally, P can be available in many forms in the environment. Of the major forms of Phosphorus, Phosphate was collected for this study because it is a form of P that is readily available for uptake by plants, bacteria, and phytoplankton so it can be of concern for water quality impairment and eutrophication (Tamang, 2020).

Sewage and Stormwater Management Systems

Lack of proper waste disposal systems and untreated sewage in waterways has the potential for detrimental effects of human and environmental health. And it causes eutrophication in rivers and lakes from high nutrient loads (Rechenberg et al., 2006). As cities continue to expand, urban stormwater encounters an increase of impervious surfaces that carry biological and chemical pollutants into local waterways (Zgheib, 2012). Degrading infrastructure, sewer overflows, agricultural and residential runoff,

and illicit discharges are all noted as positive sources of fecal contamination in watershed systems (Green et al., 2019). Urban streams are a mixing pot for a host of contamination sources. This contamination typically can be attributed to wastewater disposal systems such as combined sewer overflows (CSOs), municipal separate storm sewage systems (MS4s), and septic onsite wastewater treatment structures.

CSOs are inclusive systems that source rainfall runoff and stormwater discharge. In high rainfall events, flow in CSO systems can exceed the capacity of wastewater treatment plants (WWTPs) and untreated sewage and stormwater are subsequently released into downstream waters (Phillips et al., 2012). Over 700 cities in the US use CSOs for stormwater and sewage management. They are most commonly on the east coast, Great Lakes, and Pacific Northwest (Phillips et al., 2012). The main problem surrounding CSO infrastructure is overspilling in high flow events. Included in the sanitary overflows that occur at high flow is untreated human and industrial waste, toxic materials, and debris. CSO discharges can be contributors to water quality impairment in watersheds. Other issues related to CSO overflow include the exposure of humans to untreated sewage and sewer overflows that back up in highly populated areas (U.S. EPA, 2016).

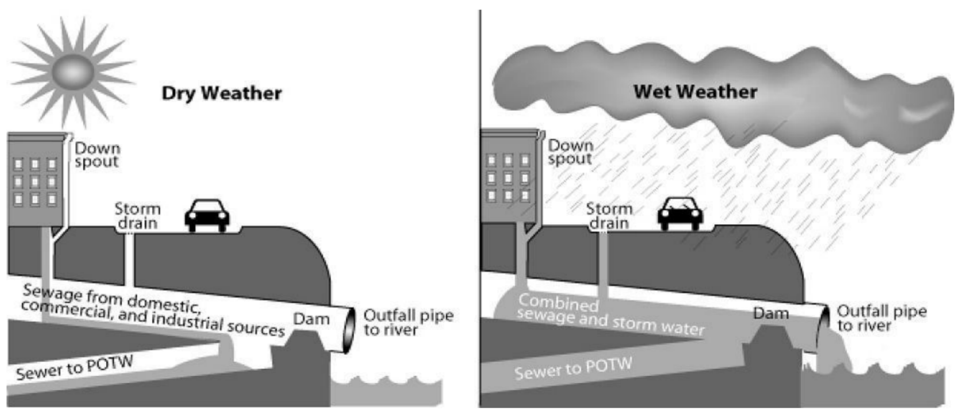


Figure 3: The impacts of wet weather overloads in CSO outfalls. During dry weather conditions, sewage flows to publicly owned treatment works (POTW) and during wet weather conditions sewage flows into rivers (U.S. EPA, 2016).

Municipal separate storm sewage systems (MS4) present an alternative that is designed to eliminate spikes in fecal discharge in high flow events. MS4s operate under the conditions that stormwater is kept separate from sewage and pollution is prevented in any released discharge. Municipalities who are seeking to engage in an MS4 plan are required to create a stormwater management program (SWMP) to control regulation practices and reduce pollutants entering waterways through discharge.

In 1987, MS4s were added to the Clean Water Act section 402(p) as the permitting standard for sewer and storm water (Pierce et al., 2020). Watersheds with MS4s may use total maximum daily load (TMDL) to address impairments and understand pollutant loads. Under MS4 guidelines, cities are supposed to reduce pollutants to the maximum extent possible (MEP). This reduction can often be challenging to measure, as many sources contribute to pollutant concentrations in urban areas. High variability in pollutant concentrations is measured seasonally and is commonly dependent on the intensity of rainfall events.

MS4 pollution sources range from industrial failures, leaky sanitary sewers, irrigation overflow, to livestock release into stormwater. This wide range of non point source pollution makes it challenging to regulate and monitor pollutants consistently (Zgheib, 2012). Additionally, the combination of many pipes (such as sanitary sewer lines) underground in MS4 systems lead to many opportunities for failure in the infrastructure. The pipes can often be inefficient due to aging, poor initial laying and construction, land movements, external load from traffic, and the presence of tree roots among many other pressures (D'Aniello et al., 2021). Existing failed CSOs can contribute to high pollutant concentrations, as older infrastructure may not be able to handle high flow rates. When flow is above the maximum available amount for treatment, sanitary and stormwater may mix (Clary et al., 2014).

The Town of Glenville MS4

Currently, the Town of Glenville operates under an MS4 system, meaning it is required to have a plan in place for monitoring stormwater outfalls and pollution prevention into surface streams and rivers. Over the past few decades, the US EPA has been facilitating the transition from Combined Sewer Overflows (CSO) to Municipal Separate Stormwater Sewer Systems (MS4). This is because CSOs spill sewage into rivers during rainfall events, but a MS4 system, in theory, keeps stormwater and sanitary sewage separate. In 2003, the Town of Glenville submitted the required Notice of Intent and was authorized as an MS4 under the State Pollutant Discharge Elimination Permit Program's (SPDES) General Permit. Previously, the Town operated under a CSO stormwater management system. The general permit requires operators of small MS4s to develop, implement, and enforce a stormwater management program (SWMP) that is intended to reduce the discharge of pollutants into surface waters to the maximum extent possible to protect water quality (Town of Glenville, 2019). The SWMP is required under the MS4 program to report its updates of adherence to the six following goals each year:

1. Public Education and Outreach
2. Public Participation and Involvement
3. Illicit Discharge Detection and Elimination
4. Construction Site Runoff Control
5. Post-Construction StormWater Management

6. Pollution Prevention and Good Housekeeping

As part of these goals, The Town of Glenville is required to detail the water bodies (streams) within its municipality that receive stormwater discharge: among these water bodies are the Alplaus Kill and the Indian Kill. The Town of Glenville SWMP considers the Alplaus and Indian Kill as "stressed (minor impacts) by urban/storm runoff and hydrological modification" (Town of Glenville, 2019). The methods for determining this minor impact is not discussed in the SWMP. Additionally, there is noted concern for potential contamination in the Mohawk River due to contaminants such as phosphorus, pathogens, and salts (Town of Glenville, 2019).

The Town of Glenville SWMP lists its plans to accomplish and effectively achieve the six goals listed above through best management practices (BMPs). In the section listed as *MCM 3 – Illicit Discharge Detection and Elimination (IDDE),* the SWMP details how it plans on dealing with the inevitable presence of illicit discharges from failing infrastructure. The first control measure in this plan is to inspect 20% of the storm water outfalls for IDDE per year. Thus, this plan requires all outfalls to be inspected on a 5 year rotating basis. The Illicit Discharge Detection and Elimination Manual by the EPA published in 2004 is cited as the guidelines for town employees to determine illicit discharges. The goal from this section in the SWMP is to identify illicit discharges before they reach surface water such as the Alplaus or Indian Kill. However, no use of quantitative measures to evaluate water quality (i.e. analyses for fecal indicator bacteria, nitrogen, or phosphorus) is listed as a method for determining illicit discharge in outfalls.

In accordance with the MS4 General Permit, the Town of Glenville is required to submit an annual report following up on their actions and findings regarding the six criteria for MS4 listed above. The MS4 report reporting on the adherence to the SWMP BMPs was published for the 2021 calendar year, and according to this report there were no sanitary sewer overflows identified (Town of Glenville, 2021).

Urban Stream Syndrome

Urban stream syndrome is defined as the impacts that urbanization has on watersheds. Typical symptoms include increased flooding and erosion, reduced biodiversity, and elevated concentrations of nutrients and contaminants (Andonie, 2019). Streams play an important role in urban areas for promoting diversity in fauna and carrying out biologic and geologic processes (Walsh et al., 2005). Urban stream syndrome is measured based on stream impairment that can be identified by a variety of physical features, including pollutants and sewage. FIB in urban streams is diagnostic of impairment to waterways by sewage. Anthropogenic sources of FIB are typically leaky sanitary sewers due to faulty or aging infrastructure. Elevated levels of FIB are common in cities, as there are many environmental and anthropogenic sources that contribute.

The Hans Groot Kill (HGK), a tributary to the Mohawk River that runs through the Union College campus in Schenectady, and it has been identified as having Urban Stream Syndrome (Willard-Bauer et al., 2020). The HGK is in a highly urbanized and industrialized area with a host of nonpoint source pollution contributors. Willard-Bauer et al., 2020 used *Enterococcus* to determine the level of stream impairment. Adjacent stormwater systems and leaky sewage pipes were thought to be major contributors to the sewage contamination.

Road Salt

The chemistry of freshwater streams is being rapidly altered in urbanized areas as major changes in land use are leading to an increase in road salts used in winter months. Excessive salt pollution has the potential to threaten soil, lake, and coastal systems (Pecher, 2019). As the demand for roads to be cleared faster and more efficiently in the winter is increasing, so is the road salt usage. Cold weather states have become dependent on road salts to deice roads and ensure safety during dangerous winter conditions. Road salts reduce accident rates on average 87% and 78% on two-lane and multilane highways, respectively (Kuemmel & Hanbali, 1992). As road salts have proven to continually be effective, its usage has increased. In the 2017/18 winter season, nearly 22 million metric tons of road salt was applied for de-icing in the USA (USGS, 2018). The major sources of road salt pollution are from the dissolved ions in sodium chloride (NaCl). Increased chloride values in freshwater streams and rivers are directly related to road salt contamination. Typical Cl concentrations from natural sources in surface freshwater ecosystems are <20 mg/L (Hintz & Relyea, 2019). Among surface water systems, Cl contamination from road salts can range from 6 to 13,500 mg/L in ponds next to salt-storage facilities (Hintz & Relyea, 2019, Ohno, 1990).

Seasonal and temporal variations occur in chloride concentrations in area watersheds. Kelly et al., 2019 observed a consistent and noteworthy trend in Na^+ and Cl^- concentrations, where the ions increase toward the end of winter, plateau then increase once again at the end of the summer months. The dataset used in this study used a 32 yearlong analysis on hydrology in rural, southeastern NY. This bimodal, annual trend indicates that salt entering streams in the summer is from groundwater discharge during baseflow conditions (Kelly et al., 2019). A dataset of over 20 years, in United States watersheds shows that groundwater released during base flow in summer months is the contributor to high Cl concentrations (Corsi et al., 2015). Increasing baseflow overtime not only accounts for yearly inputs of salts into watersheds but is a cumulation of many years' increase.

Road salt in the aquatic environment has a broad range of ecological impacts including reduced abundance and growth of sensitive species and altered community structures (Hintz & Relyea, 2019). The residence time of Cl in freshwater watersheds may be 20 to 30 years, indicating that a maintained level of high road salt use will continue to affect aquatic ecosystems because groundwater is a significant

resource (Gutchess et al., 2016). Two direct impacts of increased salt levels are aquatic biota and drinking water quality (Corsi et al., 2010). Additionally, road salt contamination alters nutrient and carbon cycling in watershed ecosystems leading to a host of chemical and biological impacts (Hintz & Relyea, 2019). As road salt cycles through streams, it often settles in sediments, contributing to excess contamination. These contaminated sediments can increase microbial mats in the sediment-water interface that lead to a decrease in surface water pH, accompanied by an increase in exchangeable cations (Ca_2^+, Mg_2^+, K^+, Na^+), Fe(II), and Mn(II), which may increase primary production and anaerobic respiration (Hintz & Relyea, 2019).

The impacts of increasing urbanization and road salt use in New York state is contributing to high amounts of salinity in the Mohawk Watershed. A combination of areas of large impervious surfaces and dynamic runoff slowly have increased the salinity load in the Mohawk Watershed with the increase of road salt being used during the winter months. Additionally, these changes in flow patterns may be resulting in shifts in groundwater recharge patterns and coincide with increasing nutrient loads. The Alplaus Kill watershed is home to a diverse community of aquatic biota (NYSDEC, 2000; NYSDEC, 2005), and this increasing contamination is posing a threat to aquatic health.

Climate Change and Extreme Precipitation

The climate has changed in measurable ways in the past few decades and this change has important implications for water quality like driving increased levels of sewage into the environment. Greenhouse gas emissions from anthropogenic activities have caused irreversible changes in the global climate (IPCC, 2018). Climate change is expected to heavily impact global water quality and availability. The impacts of climate change are broad and catastrophic, some of which include changing precipitation patterns, water quality impacts, and increased flooding. Most of New York State has warmed 3° F in the last century (U.S. EPA, 2017).

There has been a dramatic increase in precipitation in the Northeast (NSF, 2017). In the next 50 years, the number of “100-year” storms is projected to increase while the return period between large storm fall events is expected to decrease in NY state (Garver, 2021). The effects of climate change will be increasing extreme rainfall events, increasing runoff from storm events, possibly exceeding the capacity of what stormwater and sewage systems in urban and suburban areas can handle (Garver, 2021). The current infrastructure in place in many areas of eastern NY was not built to handle the increased frequency and magnitude of high rainfall events. Rainfall events that exceed infrastructure capacity put stress on stormwater systems at risk of failure. When the current threshold of infrastructure stormwater management is reached, increased flooding over impervious surfaces in urban areas carries higher loads of contaminants into adjacent surface water bodies (Clary et al., 2014). These surface waters may be

utilized for recreation or as a source for drinking water, additionally, the runoff is harming aquatic ecosystems. As rainfall frequency increases, so does the possibility of higher contamination from stormwater overflows in surface waters (Powers et al., 2021).

CSOs and faulty MS4s will continue to input mixed sewage and stormwater into surface water bodies at higher loads if there is no efforts to adapt sewage systems for the effects of climate change. Increased water quality impairment due to high loads of nutrient runoff from non-point source pollution in larger amounts is likely as extreme rainfall events become more frequent.

Cities that follow an MS4 plan are less likely to see the impacts of mixing sewage and stormwater in surface water bodies (Clary et al., 2014). The Town of Glenville is an MS4 system, so in theory there should be no problem with the mixing of sewage and stormwater if the infrastructure is able to handle extreme rainfall loads adequately. However, there is a possibility of stormwater overflow, where an MS4 system acts as a CSO, causing unforeseen and unmonitored damage to surface water quality. In this case, every possible action needs to be taken to resolve such an issue. In the case of a sanitary sewer overflow (SSO), the MS4 municipality is required to treat the spill as any other illicit discharge event and report appropriately with correct clean-up procedures (NACWA, 2018).

Extreme precipitation events should be monitored by agencies controlling sewage and stormwater systems (esp. CSOs). However, even in municipalities with MS4s, extreme precipitation events should be taken seriously and the possibility of a SSO should be considered, especially with the impending impacts of climate change in New York state. MS4 and CSO outfalls should be monitored more often in the days following extreme rainfall events to identify potential areas of high contamination inflow to surface water bodies. Reducing illicit discharge (IDDE) to the maximum extent possible (MEP) is essential for maintaining a high standard of water quality as extreme precipitation events become more frequent, and the current infrastructure is not being shifted to adapt to changes.

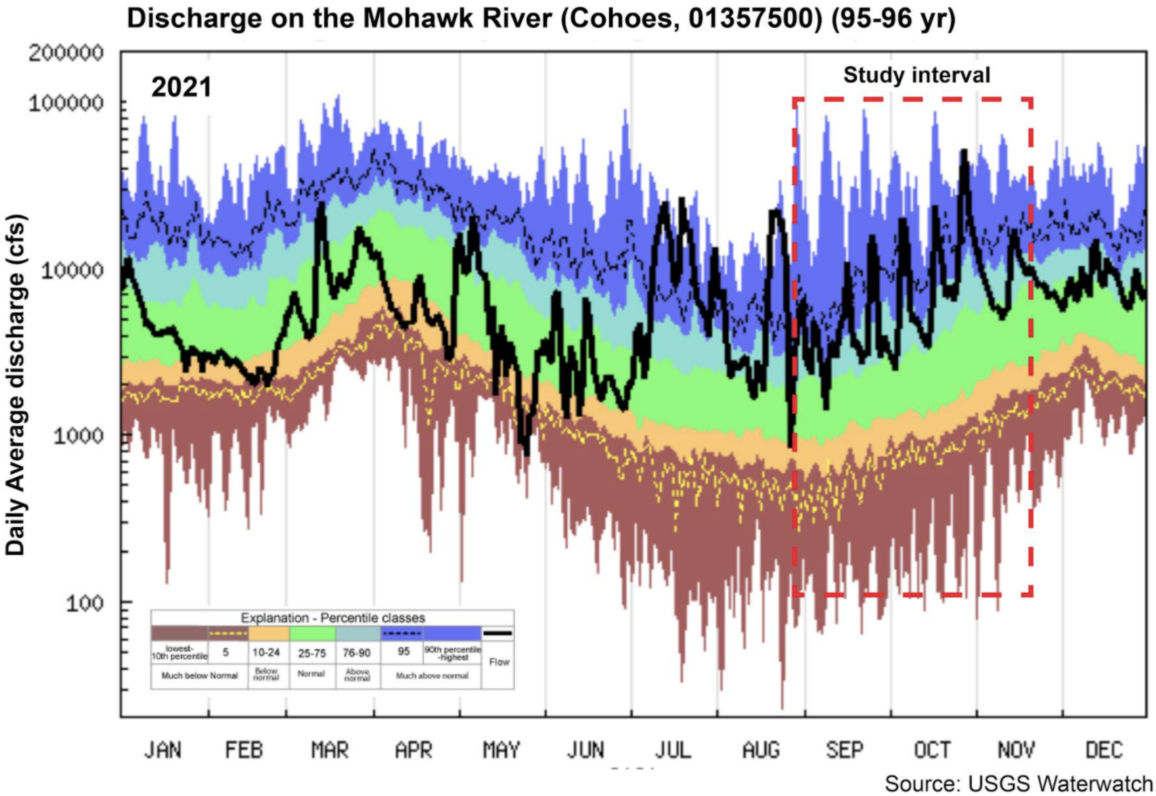


Figure 4: Discharge on the Mohawk River measured at Cohoes. The black line represents discharge measured in 2021. The purple shaded area represents the 90th percentile of the total 95 years of measured discharge. The red dotted box comprises the discharge measured during the sampling period compared to historical discharge measurements.

The sampling period for this thesis was during a period of high rainfall (Figure 4). During the time period of September to November of 2021 discharge in the Mohawk River in Schenectady was almost consistently within the 90th percentile of the past 95 years. There were many extreme rainfall events, and as climate change continues to impact New York State, extreme rainfall periods as seen in the fall of 2021 will become more common.

PREVIOUS RESEARCH

Union College Water Quality Studies

Previous work by Union College students and faculty provides a framework for understanding local streams in the lower part of the Mohawk Watershed in the context of water quality impairment.

Specifically, Willard-Bauer (2021) and Horan (2019) have recently investigated the role of urban development, water quality, and local hydrology in the Mohawk Watershed. However, neither of these studies are directly in the Alplaus Watershed.

Willard-Bauer (2021) details contamination in the Hans Groot Kill (HGK), an urban stream that flows through the Union College campus and General Electric (GE) Realty plot. The research aimed to evaluate contamination in the HGK using the determination of *Enterococci*. The HGK presents a classic case of Urban Stream Syndrome based on its high level of contamination and proximity to urbanized areas. Results from Willard-Bauer (2021) showed that *Enterococci* levels exceeded EPA regulatory levels in all but one of the 255 samples collected in the HGK. While the HGK is a case of extreme contamination, its proximity to the Alplaus Watershed makes it relevant in understanding the extent of local water impairment. Researchers in the Geology Department at Union College have been sampling the HGK at a variety of sites on a relatively consistent basis for the past 2 years to understand the extent of its contamination. From this long-term sampling, the Union research group has been able to gain a bigger picture understanding of the way *Enterococcus* behaves in highly contaminated waters, providing a comprehensive background for this thesis.

Horan (2019) used physical hydrology and flow characteristics to understand the water quality of six rivers in upstate NY, several in the Mohawk Watershed. This report specifically highlights the impacts that road salt has in surface and groundwater systems. Measurements of Na and Cl concentrations were higher than historic measurements taken by the USGS on the same streams. Elevated Na and Cl concentrations were typically found during baseflow conditions when rainfall has been low and the streams are being fed by groundwater discharge. Baseflow conditions in these streams indicate low precipitation, and high recharge from groundwater. High Na and Cl concentrations under baseflow conditions indicate a level of groundwater contamination.

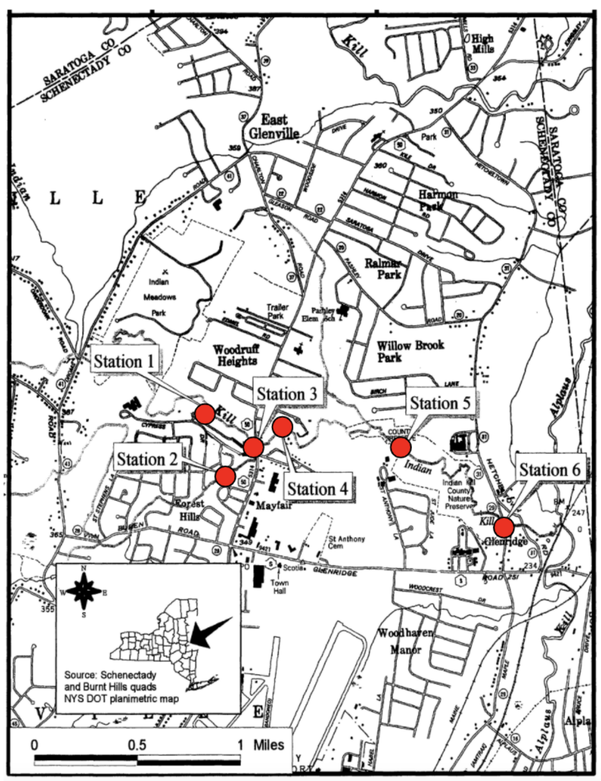
DEC Stream Biomonitoring Unit Rapid Assessment Survey (RAS) Reports

Understanding the water quality of the Alplaus Kill is crucial in identifying the pollutant load of the entire Alplaus Watershed into the Mohawk River. There are major gaps identified in water quality monitoring in the Alplaus Watershed. No conclusive reports have been published detailing water quality parameters, specifically fecal indicator bacteria and water chemistry in the Alplaus Watershed. The only reports to date published on the Alplaus and Indian Kill were Stream Biomonitoring Unit Rapid Assessment Survey (RAS) reports done by the NYSDEC, published in 2005[2] and 2000[3], respectively. These reports are both over fifteen years old, and thus these analyses may not fully represent the current water quality of these water bodies. A full analysis of the contaminant load in the Alplaus Watershed is

[2] Alplaus Kill RAS Report https://www.dec.ny.gov/lands/77842.html
[3] Indian Kill RAS Report https://www.dec.ny.gov/lands/77842.html

necessary for understanding how much is needed to be reduced to comply with the Mohawk River TMDL that is currently being enacted.

In 2000 and 2005, the NY State Department of Environmental Conservation (NYSDEC) conducted biological assessments to categorize water quality on the Indian Kill (IK) and Alplaus Kill (AP) respectively. The goal of these reports was to assess overall water quality and establish a baseline for comparison of future studies in these areas. The water quality assessment used a variety of biological species indicators. For both studies, the streams were assessed by looking at abundance and diversity of macroinvertebrates and community parameters. The community parameters used species richness, biotic index, EPT (*Ephemeroptera*, *Plecoptera*, *Trichoptera*) richness, and percent model affinity to understand water quality. Benthic macroinvertebrates are used as a water quality indicator because their presence and abundance is indicative of a niche environment they have adapted to live in. Variable conditions that change macroinvertebrate communities include habitat, flow source, flow regime, temperature, and most importantly water quality. The following stream assessments use these biological parameters to get a broader understanding of watershed health in the Schenectady and Saratoga County areas.



STATION	LOCATION
01	Mayfair 100 meters below footbridge at Hickory La. 2.4 miles above the mouth latitude/longitude: 42°52'39"; 73°56'03"
02	Mayfair 5 meters above Bigwood Rd bridge 2.3 miles above the mouth latitude/longitude: 42°52'25"; 73°56'00"
03	Mayfair 5 meters below Rte 50 bridge 2.1 miles above the mouth latitude/longitude: 42°52'31"; 73°55'48"
04	Glenville 200 meters below Mayfair Plaza trib, off Mayfair Rd 2.0 miles above the mouth latitude/longitude: 42°52'32"; 73°55'41"
05	Glenridge behind Woodlin Club 1.2 miles above the mouth latitude/longitude: 42°52'32"; 73°55'03"
06	Glenville above culvert at Maple Ave 0.3 miles above the mouth latitude/longitude: 42°52'13"; 73°54'23"

Figure 5: Map of the sampling locations along the Indian Kill completed for the NYSDEC RAS Report in 2000.

For the NYSDEC assessment, six sampling sites were established along the Indian Kill to monitor water quality by using kick samples on 29 August 2000 (Figure 5). The assessment resulted in three notable conclusions about water quality along the Indian Kill. Based on the impairment scale presented in the report, it was found that water quality ranged from good to poor, however, all sites along the main branch of the stream (stations 1 and 3-6) all had good water quality. Additionally, another scale was used ranking water quality 1 to 4, where one was non-impacted and 4 was severely impacted. Station 2 (Mayfair Creek) had a low ranking of 3 (out of 4), which would indicate it is moderately impacted. This low ranking reflects poor water quality and this result indicates that species richness and biotic indices are all in the low range. Water quality in these areas is often limited to fish propagation, but water quality is low enough to limit fish survival.

The 2000 report showed that contamination in Mayfair Creek was identified as stemming from the south branch of the Indian Kill, where nonpoint source runoff and septic inputs were contaminating the Mayfair Creek (a tributary to the Indian Kill). It is notable that the Mayfair Creek is an upstream tributary of the Indian Kill, so while water quality was considered poor in this area, the rest of the Indian Kill had good water quality. The macroinvertebrate samples from the Indian Kill indicate that there may have been many sources of nonpoint source pollution throughout the entire system. The Mayfair Plaza discharge was most notably identified as the impacting stressor on the stream. All stations sampled on the IK showed conclusive similarities regarding nonpoint, most likely agricultural, nutrient inputs.

Biological assessment along the Alplaus Kill was completed in 2005. This study showed that all seven studied locations had water quality that was rated as slightly impacted, with nutrient enrichment being the primary factor of impairment. The segments were designated as “slightly impacted” and ranked 2 out of 4. Overall trends show that the best water quality was found farthest upstream and it progressively deteriorated closer to the mouth at the Mohawk River (below the confluence with the Indian Kill). Along with water quality analysis, the report summarized land use along the Alplaus to better understand nonpoint sources. Total forested area increased upstream, while total residential area increased downstream.

Glenville Outfall Study

In the winter of 2020, Leah Marsh assisted the town of Glenville in implementing an outfall monitoring program through Union College’s Environmental Policy internship course. As a part of this unpublished study, she tested 12 outfalls once in February 2020 around Glenville for heavy metals and *Enterococcus*. Marsh used the same methods for sampling *Enterococcus* as used in this thesis (i.e. IDEXX Enterolert done in the Geology Department at Union College), but she only sampled once per outfall in the winter. Marsh’s work highlighted the problem of *Enterococcus* contamination in Glenville and a need for more consistent water quality monitoring. Outfalls and contaminated streams in Glenville are

present on public and private properties.

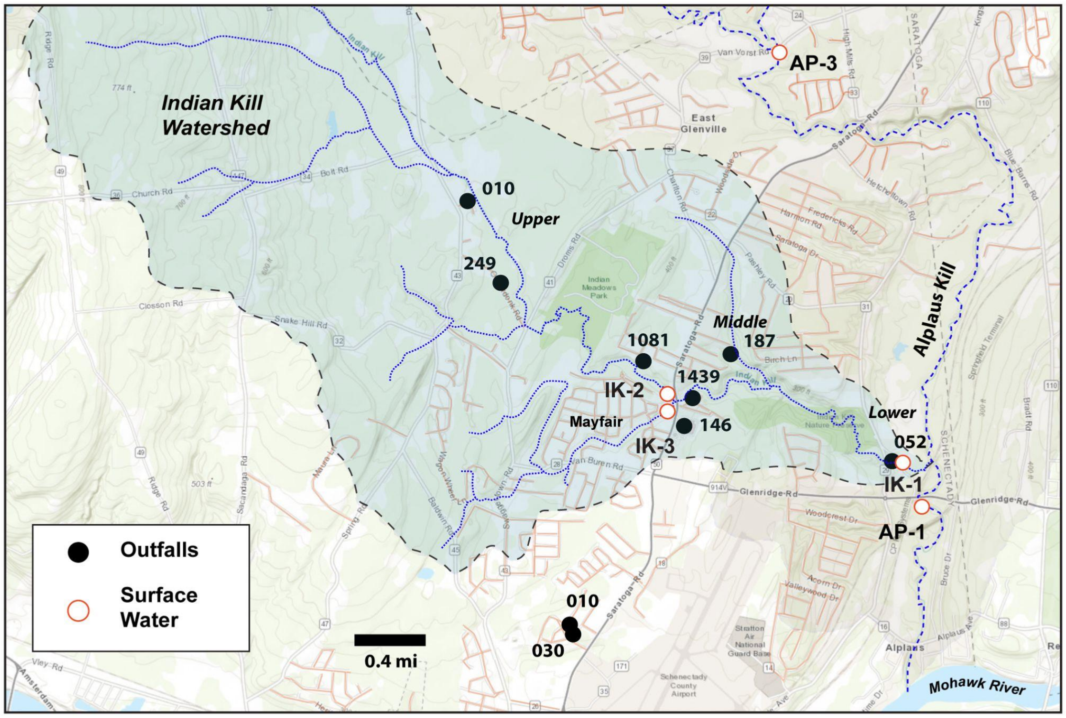


Figure 6: The *Enterococci* concentrations (mpn per 100 mL) at outfalls (stormwater pipes that empty into surface waters) sampled by Marsh in February 2020, shown with the sampling sites used in this thesis. Values above 130 MPN/100 ml are above the EPA STV for single samples.

Enterococci from Glenville outfalls - 27 February 2020 (Marsh study)

Locaiton	Latitude	Longitude	#	Incubation Start	Incubation End	# Large wells	# Small wells	Entero (MPN/100 ml)
Lower Indian Kill								
Maple	42°52'12.4"N	73°54'22.7"W	1	18:45	18:07	5	0	**52**
Middle Indian Kill								
Church	42°52'30.7"N	73°55'48.1"W	2	18:09	17:52	12	1	**146**
Bigwood	42°52'24.7"N	73°55'58.6"W	3	17:55	17:54	45	12	**1439**
Englehart	42°52'44.6"N	73°56'03.7"W	4	18:17	17:58	43	7	**1081**
Stottle	42°52'45.8"N	73°55'28.9"W	5	18:38	18:06	15	1	**187**
Upper Indian Kill								
Schlensker	42°53'33.3"N	73°57'11.9"W	6	18:28	18:02	1	0	**10**
Onderdonk	42°53'08.2"N	73°57'01.0"W	7	18:33	18:03	20	0	**249**
Kromme Kill								
Joyous	42°51'18.6"N	73°56'34.7"W	8	18:23	17:59	1	0	**10**
Miracle #2	42°51'18.6"N	73°56'34.7"W	9	17:49	18:01	2	1	**30**
Heritage	42°49'42.9"N	73°56'14.8"W	10	17:45	17:49	40	1	**762**

Note: All samples diluted 90% in dionized water

Table 2: *Enterococci* concentrations taken at the 12 outfall sites used in Marsh's study. All samples were collected on February 27, 2020. All samples were diluted 90%. (Not on map: location of Heritage to the south near Collins Lake, east of Scotia).

Marsh's sampling concluded that the highest *Enterococcus* was in the Middle Indian Kill, at the Bigwood and Englehart outfalls, presenting 1439 and 1084 mpn per 100 mL respectively. The Bigwood outfall is directly downstream from the confluence of Mayfair Creek and the main stem of the Indian Kill. Thus, in this report, Marsh was able to identify hotspots of potential contamination related to possible sewage entering the Indian Kill.

The Town of Glenville has been continuing outfall monitoring as it relates to stormwater management and they completed outfall monitoring surveys in 2005, 2018, 2020, and 2021. Most recently in the 2021 report, 24 out of 70 total outfalls were surveyed for a variety of characteristics, mostly including categorical information that was identified from a visual assessment. A few of these characteristics included "Flow Description", "Odor/ Severity", "Illicit Discharge Detection", "Temperature", and "Abnormal Vegetation". The criteria listed in the outfall monitoring report do not, however, test the effluent discharge for any quantitative water quality parameters that could enumerate impairment.

The Mohawk River Watershed Management Plan

The Mohawk River Watershed Management Plan, published in March 2015 by the Soil & Water Conservation District (SWCD), assessed water quality in the Mohawk sub watersheds with a rating system that ranked the Alplaus Kill as a mid-scoring sub watershed[4]. Scoring criteria considered individual water quality, habitat, and land use scores to create a total assessment score. In discussing this score, it is noted that:

> *"The Alplaus Kill has low water quality with percent impairment of water bodies in the range of 40–60%. The water use most affected by the poor water quality is aquatic life. Of note for the Alplaus Kill is that 40–60% of the area has groundwater resources… the Alplaus Kill, where the percent aquatic life impaired is relatively high at 60–80%. Throughout these sub watersheds, the percent of intolerant fish ranges from 5–20%, and endangered species have been observed."*

Additionally, The Mohawk River Watershed Management Plan recognized impaired water bodies in the Alplaus Kill sub watershed as Collins Lake and Mariaville Lake. Both water bodies were listed on the 2012 NYS Compendium of Impaired Waters {303(d) List} due to phosphorus contamination.

[4] Mohawk River Watershed Management Plan – Published by the Mohawk River Watershed Coalition, March 2015

METHODS

Selected Sites and Collection

Sample collection in the fall of 2021 was centered on sites in the Alplaus Watershed, including the Indian Kill sub-watershed. Six sites were selected along the Alplaus Kill and Indian Kill Watersheds for consistent water quality sampling during the fall of 2021 (Sept. 16 - Nov. 17). Sampling sites were chosen based on land cover, ease of accessibility to the streams, and location in the watershed. A combination of rural (AP-2, AP-3) and suburban (IK-2, IK-1) and urban areas (IK-3) and mixed (AP-1) were picked as sampling locations. A total of 65 samples were taken at the six sampling locations.

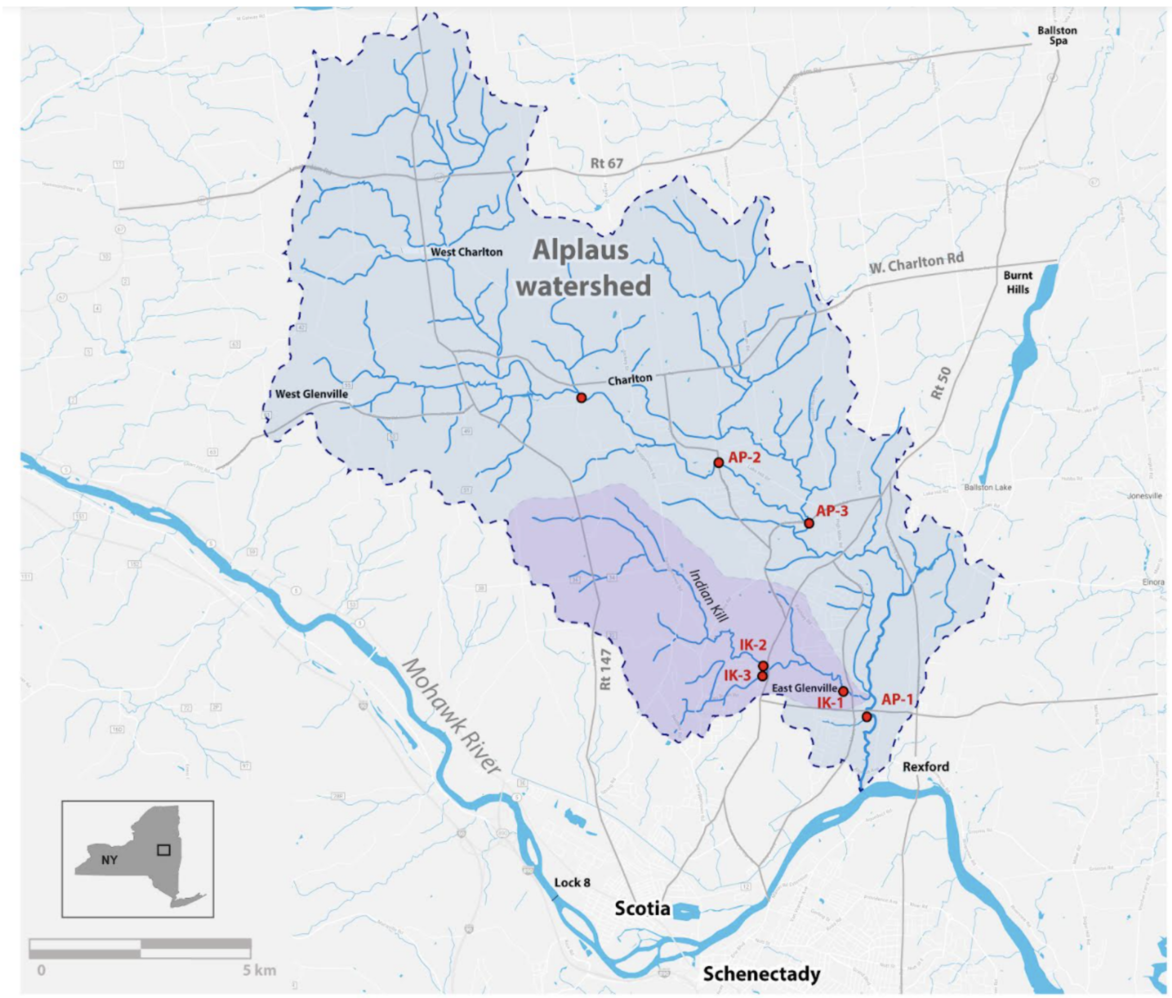


Figure 7: The entire Alplaus Watershed with sampling locations used in this thesis shown by red circles. The blue dashed line shows the boundaries of the Alplaus Watershed, and the purple area is the Indian Kill watershed.

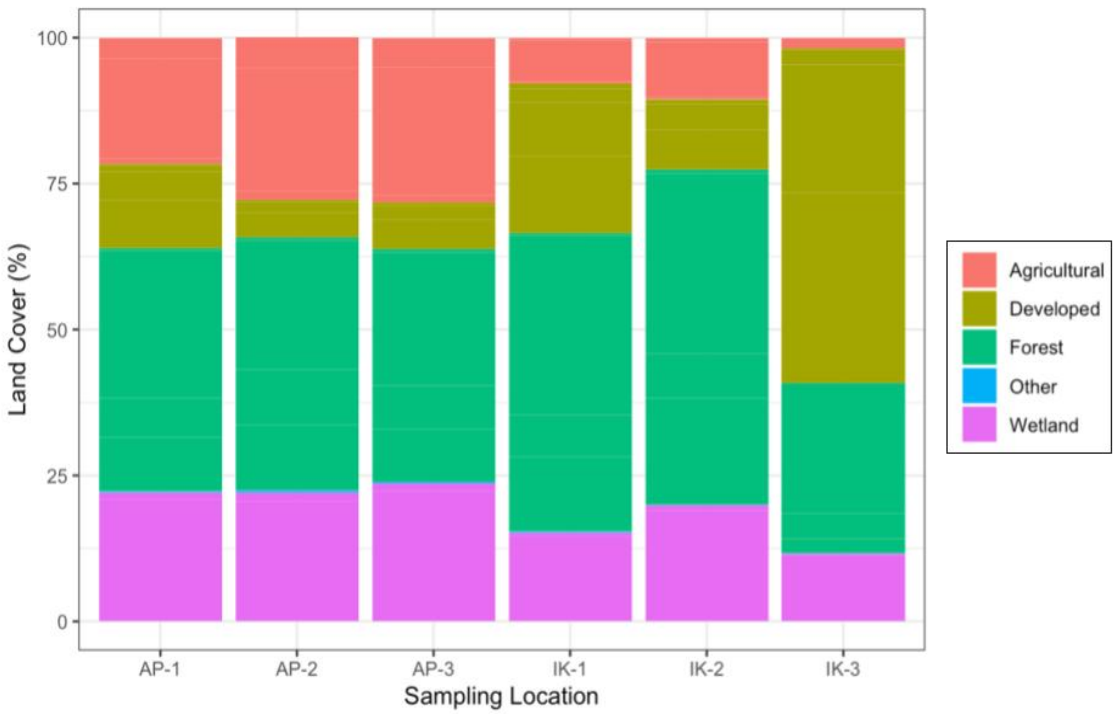


Figure 8: Land cover composition of the delineated watersheds from sampling locations. Land cover data for each watershed was determined using data from the National Land Cover Database (2019).

Site Code	Agricultural	Developed	Forest	Wetland	Other
AP-1	23	15	42	22	0.3
AP-2	28	7	43	22	0.4
AP-3	28	8	40	24	0.3
IK-1	8	26	51	15	0.3
IK-2	11	12	58	20	0.2
IK-3	2	57	29	12	0.0

Table 3: Land cover percentage of delineated watersheds from each sampling location. Land cover data for each watershed was determined using data from the National Land Cover Database (2019).

Site Code	Stream Name	Descriptive Location	Latitude	Longitude
AP-1	Alplaus Kill	Alplaus Kill Nature Center	42.866279	-73.902466
AP-2	Alplaus Kill	Under bridge near 271 Stage Rd Ballston Lake, NY	42.916632	-73.944061
AP-3	Alplaus Kill	Under bridge near 964 Van Vorst Rd Glenville, NY	42.904954	-73.918531
IK-1	Indian Kill	Indian Kill Nature Preserve Glenville, NY	42.871683	-73.909038
IK-2	Indian Kill	East Glenville Community Church	42.875628	-73.930499
IK-3	Indian Kill (Mayfair Creek)	Base of hill near 309 Saratoga Rd, Schenectady, NY	42.874596	-73.930558

Table 4: The Locations of all sampling sites in this study.

Site Code	Area of the drainage basin to sampling location (km^2)	Active river length in drainage basin (km)
AP-1	141.65	50.57
AP-2	66.39	23.47
AP-3	97.57	34.94
IK-1	21.51	8.44
IK-2	13.11	5.88
IK-3	4.10	1.45

Table 5: The lengths and area of the delineated watersheds for each sampling location. Note that for IK-3, the watershed was not delineated, but rather an estimated drainage basin was drawn based on a DEM map.

Alplaus Kill Sampling Locations

Figure 9: Sampling Locations along the Alplaus Kill located in Glenville and Ballston Lake, NY.

Figure 10: Photos of all three sampling locations along the Alplaus Kill (top left to bottom right). AP-1 A is at the Alplaus Kill Nature Area when the stage was relatively low. AP-1 B shows AP-1 just after a large precipitation event when the stage was relatively high. AP-2 A shows the sampling location just below Stage Rd at low flow. AP-2 B is a picture of the same location just after a large precipitation event. AP-3 A is taken under the bridge on Van Vorst Rd. AP-3 B shows the same location, but the stage is elevated, where it is not possible to go under the bridge.

Indian Kill Sampling Locations

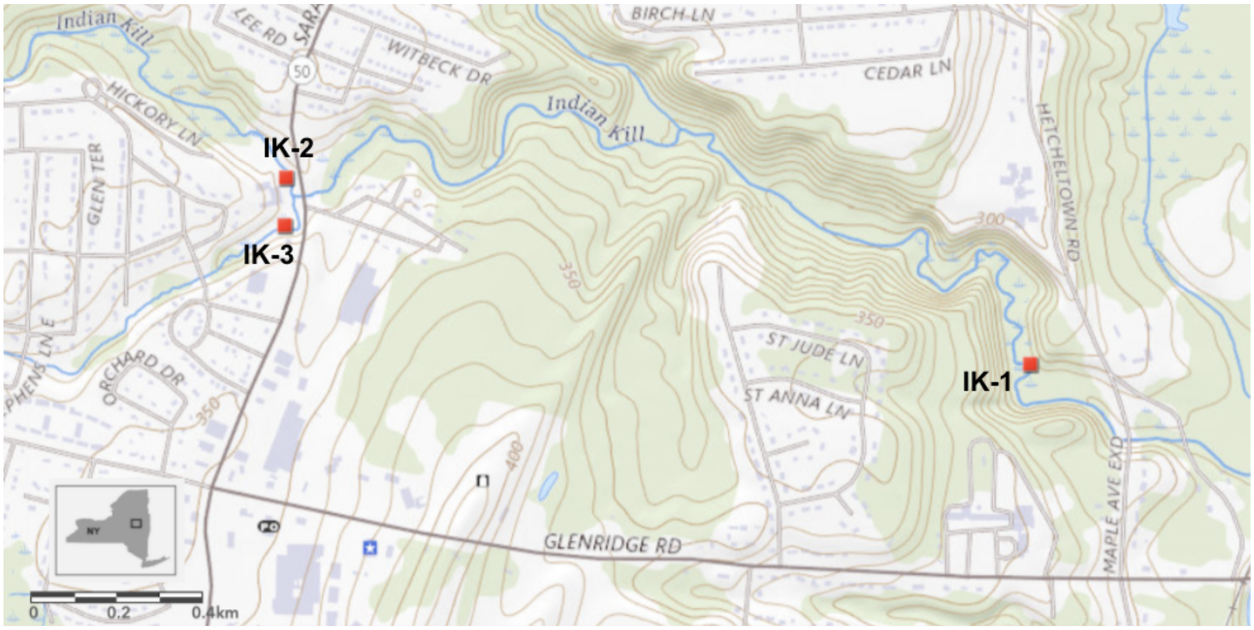


Figure 11: The sampling locations along the Indian Kill located in Glenville, NY.

Figure 12: Photos of all three sampling locations along the Indian Kill (top left to bottom right). IK-1 A is just downstream of the walking bridge in the Indian Kill Nature Preserve. IK-1 B shows the Indian Kill just after a large precipitation event flowing through the dam under the walking bridge in the Indian Kill Nature Preserve. IK-2 A shows the Indian Kill after a large precipitation event flowing through the tunnel located below the driveway to the East Glenville Community Church. IK-2 B is the Indian Kill at low flow, taken at the base of the hill in front of the East Glenville Community Church. IK-3 A is the sampling location of IK-3 at low flow. IK-3 B shows the Mayfair Creek flowing toward the IK-3 sampling location.

Figure 13: The pipe located upstream of the IK-3 sampling location that directly drains into the Mayfair Creek at low and high flow conditions. A) An image of the pipe draining during low flow conditions. B) the pipe location relative to the IK-3 sampling location. It is up a steep hill, draining into the sampling location. C) IK-3 pipe flow during high flow conditions.

Basic Water Quality parameters

When collecting samples, the YSI multiparameter water quality meter was used to collect metadata. These parameters include temperature (°C), air pressure (mmHg), dissolved oxygen percent (%), dissolved oxygen concentration(mg/l), specific conductance (µS/cm), conductivity (µS/cm), total dissolved solids (mg/L), salinity (ppt), and pH (pH units).

Enterococcus Methodology

Samples were taken approximately once per week over a period of ten weeks, with additional samples taken in periods of significant rainfall or prolonged dry periods. To take a sample, a Whirl-Pak® bag was secured to the end of a pole and placed in the stream to gather flowing surface water. Septic technique was used, so rubber gloves for taking all samples in the field. The Whirl-Pak® bag was then secured and placed on ice in a handheld cooler to transport before processing of the sample in the lab.

The water samples were then processed in the lab using the EPA-Approved Enterolert IDEXX method. To begin the process, DI water and collected water samples were measured for an appropriate dilution that was combined to reach 100 mL of total water. The dilutions used in this study ranged from 0 to 95 mL DI water added to the sample. The sample was then pipetted into a sterile, 100 ml bottle with one Enterolet package and the sample was then mixed. All glassware and pipette tips were autoclaved prior to use. The bottle was then capped and shaken and poured into a Quanti-Tray. The tray is placed in the Quanti-Tray sealer to secure the contents and disperse it appropriately across the 51 wells in the tray. The sample is then incubated at exactly 41° C in a Binder incubator for 24 hours. After incubation, the Quanti-Tray is removed from the incubator and the wells are counted for fluorescence when exposed to a 6–watt, 365 nm, UV light. Blue fluorescence indicates that the well is positive for *Enterococcus.* The number of illuminated blue wells is then recorded and converted using the IDEXX table to get the

apparent MPN value. The actual MPN value is then found by the apparent mpn by (1/the dilution factor). After reading the samples, they were autoclaved and then destroyed.

Ion Chromatography

A 15 mL aliquot was taken from the Whirl-Pak® bag and put into a Falcon® tube for analysis by Ion Chromatography. The Falcon® tube was then refrigerated with other samples until at least thirty samples had been collected for processing on the Ion Chromatograph. Dionex® Ion Chromatographs (ICS-2100, anions; DX-500, cations) were used to analyze ion concentrations. Anions were eluted with an AS19 column using potassium hydroxide as the eluent and the cations using a CS16 column and methane sulfonic acid. Multi-ion standards were prepared by pipetting appropriate volumes from single ion standards to analyze for the anions (F, ClO_2^-, Cl^-, NO_2^-, ClO_3^-, Br^-, NO_3^-, SO_4^{2-}, PO_4^{2-}), and the cations (Li^+, Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}, Sr^{2+}, respectively). From these standards, four dilutions are made to calibrate the ion chromatographs (1:2, 1:5, and 1:10). To assure the accuracy of the standards, check standards 1 and 10 ppm ultrapure multi-ion stock solutions were prepared and analyzed at the same time as unknowns. Once the check standards are within the range of calibration, the values are matched to the created standards for anions and cations on average at 5% and always within ± 10%. The multi-ion standards, check standards, and blank DI samples are all placed in their respective ion chromatographs along with the water samples.

Rainfall

Weather data for the fall of 2021 were recorded by a Davis Instruments Vantage Pro2 Plus weather station at Union College, monitored by the Geosciences Department. Rainfall data measurements are collected every 15 minutes. The Union College weather station collects additional parameters such as temperature, humidity, pressure, wind speed, wind direction. Of all these parameters, only rainfall was used for calculations and analysis in this report. The 12-, 24-, and 48-hour rainfall totals prior to sample collection were calculated.

Land Cover

The land cover data used in this thesis comes from the Multi-Resolution Land Characteristics (MRLC) consortium, which is a group of federal agencies. The data set used for analyses was the National Land Cover Dataset (NLCD). The data were plotted, manipulated, and downloaded using the website modelmywatershed.org. The data were simplified into four categories: agricultural, developed, forest, wetlands, and other. Additionally, the data were downloaded into R Studio for further analyses and comparison to collected water quality samples. Using digital elevation model (DEM) base maps on modelmywatershed.org, shapefiles for the watershed drainage basin of each sampling location, except IK-3, were delineated. Because IK-3 is located off the main body of the Indian Kill on the Mayfair Creek,

the stream resolution network was not high enough to detect the watershed location from this point. To accompany this, an estimated watershed was drawn on modelmywatershed.org.

RESULTS

Enterococcus Concentrations

The geometric means (GM) for all sampling sites (AP-1, AP-2, AP-3, IK-1, IK-2, IK-3) during the sampling period present in this study (Sept. 16 - Nov. 17, 2021) are above the EPA recommended standard for freshwater. Single sample *Enterococcus* levels exceeded the Beach Advisory Value (BAV = 60 mpn/100 ml) in 93% of samples (61/65). The two highest recorded *Enterococcus* values were recorded on Oct. 26 and Nov. 12, 2021, both at IK-3. On both days, the maximum number of grids was reached on the sampling Quanti Tray with a dilution of 95% (hence the sample was saturated, and the value is a minimum concentration), thus the sample had >48,392 mpn/100 ml. Because both the Indian Kill and Alplaus Kill had saturated samples, which are a minimum concentration, the calculated Geometric Means are minimum Geometric Means (mGM).

Site Code	Enterococcus Geometric Mean
AP-1	1,695
AP-2	663
AP-3	666
Alplaus Kill total average	1075
IK-1	982
IK-2	879
IK-3	837
Indian Kill total average	900

Table 6: The geometric means of all 37 samples at the Alplaus Kill (AP-1, AP-2, AP-3). Below is the geometric means of all 25 samples at the Indian Kill (IK-1, IK-2, IK-3). The Alplaus Kill and Indian Kill total averages are geometric means of all samples taken at the respective stream.

The GM for all *Enterococcus* samples in the Alplaus Kill (GM = 1075 mpn per 100 mL) is higher than in the Indian Kill (GM = 900 mpn per 100 mL). The GM highest at an individual site was 1695 mpn per 100 mL, recorded at AP-1 (which is downstream from the confluence of the Indian Kill). The

geometric means for the remaining sites are as follows: AP-2 = 663, AP-3 = 667, IK-1 = 983, IK-2 = 880, IK-3 = 838 mpn per 100 mL.

Bacteria-Rainfall Effect

Concentrations of *Enterococcus* were found to be significantly different when sampled during wet and dry conditions at all sampling locations. First, all data from both the Alplaus and the Indian Kill were evaluated together. When the data are plotted there is a clear distinction between low and high rainfall events. The geometric mean of low rainfall values (<0.1 in) is 113 mpn/100 mL, and the geometric mean of high rainfall values (>0.1 in) is 18,230 mpn per 100 mL. Correlation of rainfall totals in different time intervals when pathogen loads were determined to understand the response of sewage loading to rainfall events.

Site Code	Low Flow	High Flow
AP-1	123	18,036
AP-2	57	14,306
AP-3	84	8,927
IK-1	209	21,609
IK-2	212	15,237
IK-3	217	48,392

Table 7: *Enterococcus* geometric means of all samples at the Alplaus and Indian Kill, separated by low flow and high flow, based on their respective rainfall relationship.

	12 Hour Rainfall	24 Hour Rainfall	48 Hour Rainfall
Alplaus Kill	0.6574	0.7215	0.7983
Indian Kill	0.7744	0.5043	0.5738

Table 8: The R^2 values calculated for the best fit rainfall relationship based on a least-squares regression analysis with rainfall (in) and *Enterococcus* concentrations (mpn per 100 mL). The values highlighted in yellow are the rainfall values chosen to represent the Alplaus Kill (48 hour) and Indian Kill (12 hour), respectively.

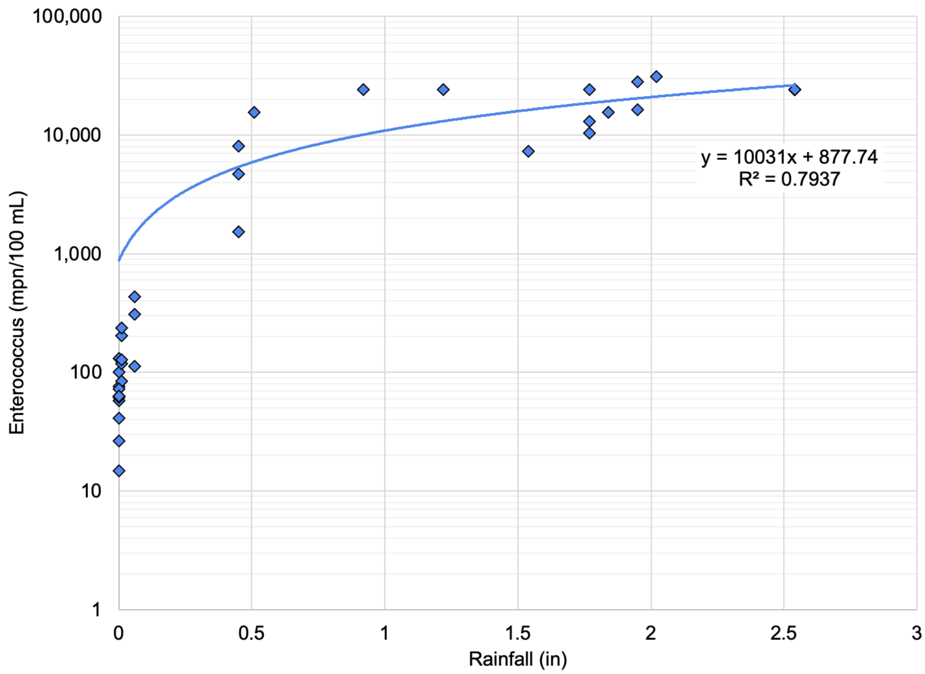


Figure 14: 48-hour rainfall versus *Enterococcus* concentrations in the Alplaus Kill. The y axis is shown using a log10 scale. A least-squares linear trendline was fit for all points. The equation and R^2 are displayed next to the trendline.

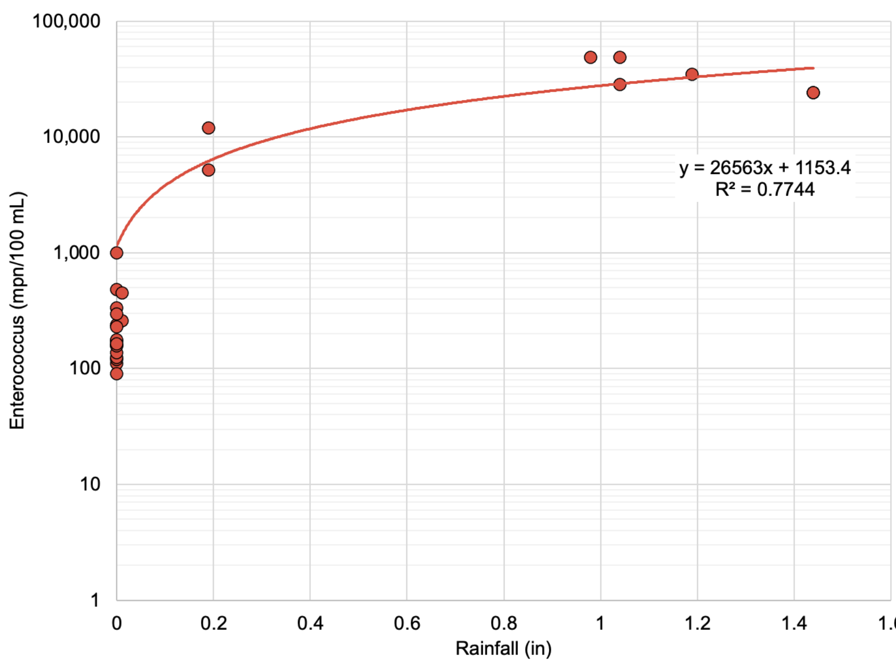


Figure 15: 12-hour rainfall versus *Enterococcus* concentrations in the Indian Kill. The y axis is shown using a log10 scale. A least-squares linear trendline was fit for all points. The equation and R^2 are displayed next to the trendline.

Rainfall totals were used for 12-, 24-, and 48-hour intervals, and these were compared to pathogen concentrations. This process was done for both the Alplaus Kill and the Indian Kill. The 48 Hour rainfall total most closely accounts for the variance to the *Enterococcus* load in the Alplaus Kill (R^2 = 0.7983) using a linear least-squares analysis (Figure 9). The 12-Hour rainfall most closely accounts for the variance in the *Enterococcus* load in the Indian Kill (R^2 = 0.7744) (Figure 10). *Enterococcus* concentrations when sampled during dry conditions in the Alplaus Kill (GM = 84 mpn per 100 mL) were much lower than the Indian Kill (GM = 213 mpn per 100 mL), and hence the Indian Kill has a higher base level of FIB. The two highest reported *Enterococcus* counts were sampled at IK-3 on Oct. 26 and Nov. 12, 2021, during the two largest rainfall events recorded (12-hour rain = 0.98 and 1.04, respectively). The only samples with *Enterococcus* concentrations below the EPA standards were measured in the Alplaus Kill headwaters at AP-2 and AP-3 during prolonged dry periods of no rainfall where no rain had occurred in at least the 48 hours prior.

Dissolved Ion Interactions

Dissolved Ions measured in water samples presented trends based on high and low flow during sampling periods. Significant relationships were found between salinity indicators increase during low flow conditions, and phosphate during high flow conditions.

Chloride in the Alplaus and Indian Kill

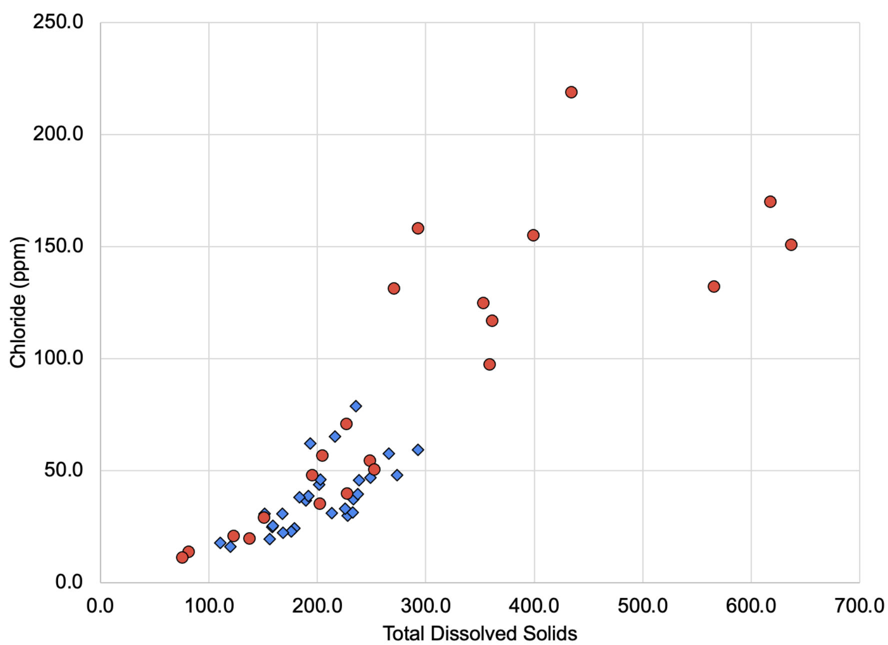


Figure 16: The amount of total dissolved solids measured versus the Cl concentrations in the Alplaus and Indian Kill.

The highest total dissolved solids (TDS) and chloride (Cl) concentrations are seen at the Indian Kill (Figure 11). The Alplaus Kill and Indian Kill follow similar trends of increasing TDS and Cl concentrations until TDS reaches around 300 mg/L and Cl reaches 70 ppm. This point seems to be a threshold for Alplaus Kill concentrations of both salinity indicators. The Indian Kill, however, displays a different trend, where over this threshold TDS and Cl concentrations are much higher and more variable than Alplaus Kill concentrations (Figure 11). As Cl concentrations are increasing, so are TDS concentrations indicating that there is a higher overall influx of ions into the Indian Kill at this point. Chloride is known to exist with the dissolved ions sodium, fluoride, and nitrate depending on its source area.

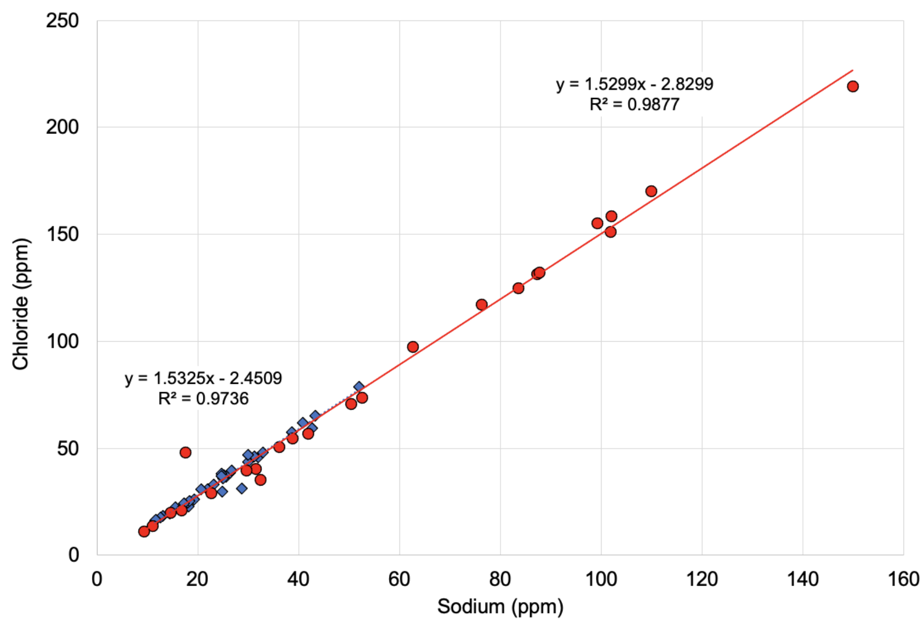


Figure 17: Sodium (Na) concentrations versus Chloride (Cl) concentrations in the Alplaus and Indian Kill. Blue diamond's indicate samples taken along the Alplaus Kill and red circles represent samples taken along the Indian Kill. Linear trend lines were fit for the Alplaus and Indian Kill, respectively. The equation and R^2 are displayed next to their respective trendline.

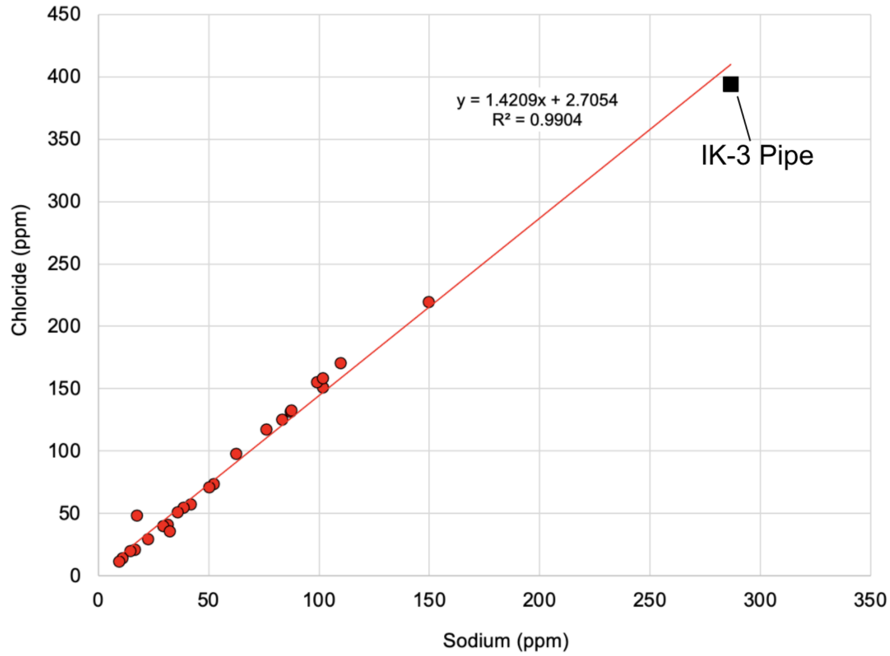


Figure 18: Sodium (Na) concentrations versus Chloride (Cl) concentrations in the Indian Kill. The black square was taken at the IK-3 pipe and a linear trend line was fit for all points. The equation and R^2 are displayed next to the trend line.

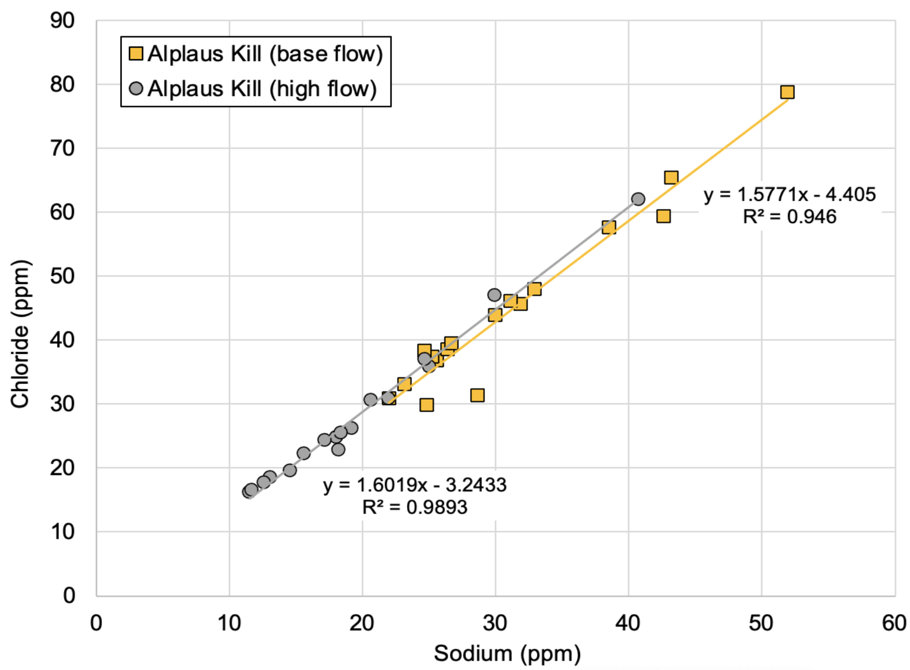


Figure 19: Na vs Cl at the Alplaus Kill at base flow and high flow. Linear trend lines were fit for the base flow and high flow, respectively. The equation and R^2 are displayed next to their respective trendline.

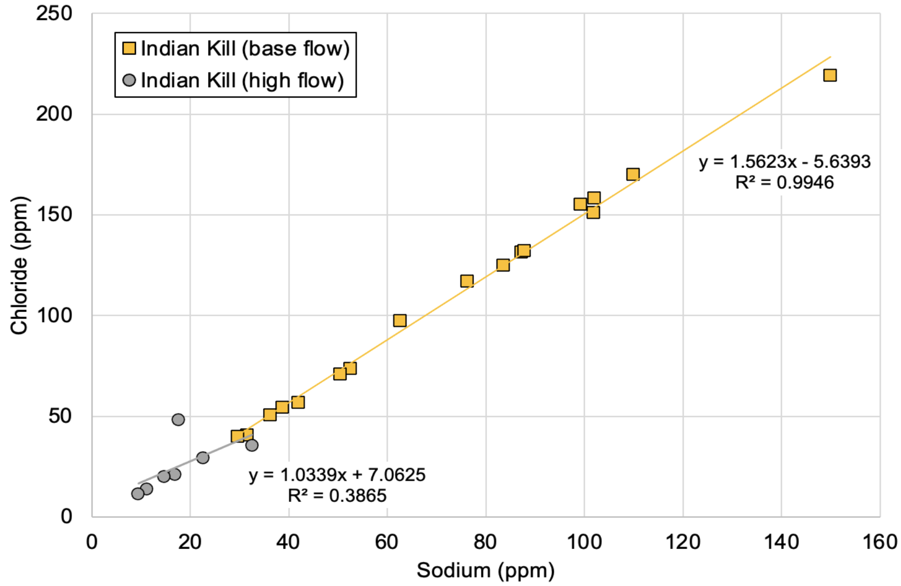


Figure 20: Na vs Cl at the Indian Kill at base flow and high flow. Linear trend lines were fit for the base flow and high flow, respectively. The equation and R^2 are displayed next to their respective trendline.

Na and Cl concentrations show clear linear relationships in both the Alplaus and Indian Kill (Figure 12). While the relationships seen are similar, the Alplaus Kill consistently has lower Na and Cl concentrations relative to the Indian Kill. Additionally, the Indian Kill presents a much broader range of Na and Cl concentrations, which can be explained by the flow present at the time of sampling (Figures 14 & 15).

The flow type in both streams can be indicative of the Na and Cl presence at the time of sampling (Figures 14 & 15). There is a distinct difference between baseflow and high flow concentrations of Na and Cl at the Indian Kill (Figure 15). At the Alplaus Kill, more overlap is seen between base flow and high flow samples taken, however, the data all still follow a linearly increasing trend. The wider range of Na and Cl concentrations seen in the Indian Kill may be explained by the sample taken from the IK-3 pipe.

A linear trend is seen when the Na and Cl concentrations taken at IK-3 pipe are fit along with all other Indian Kill data (Figure 13). The IK-3 pipe sample presents an end-member relationship, where a highly concentrated ratio of the samples taken along the Indian Kill is seen. The linear trendline fits with the IK-3 pipe sample and all Indian Kill samples has an R^2 of 0.99.

Na and Cl concentrations present equal ratios expected in the Alplaus and Indian Kill (Figure 12). Parts per million (ppm) is a mass per volume (mg/L) method of measuring constituents in water samples. This does not take into account the molar weight of Na and Cl. The mass of Na is 23 amu and the mass of Cl is 35 amu. The expected ratio of Na to Cl is 1.54. The slope of the linear trendline equations

presents a similar ratio of 1.53 for both the Alplaus Kill and Indian Kill. While this ratio is expected for an equal 1:1 relationship, Cl has many other sources related to varied pollutant source indicators that can be described by F and NO_3.

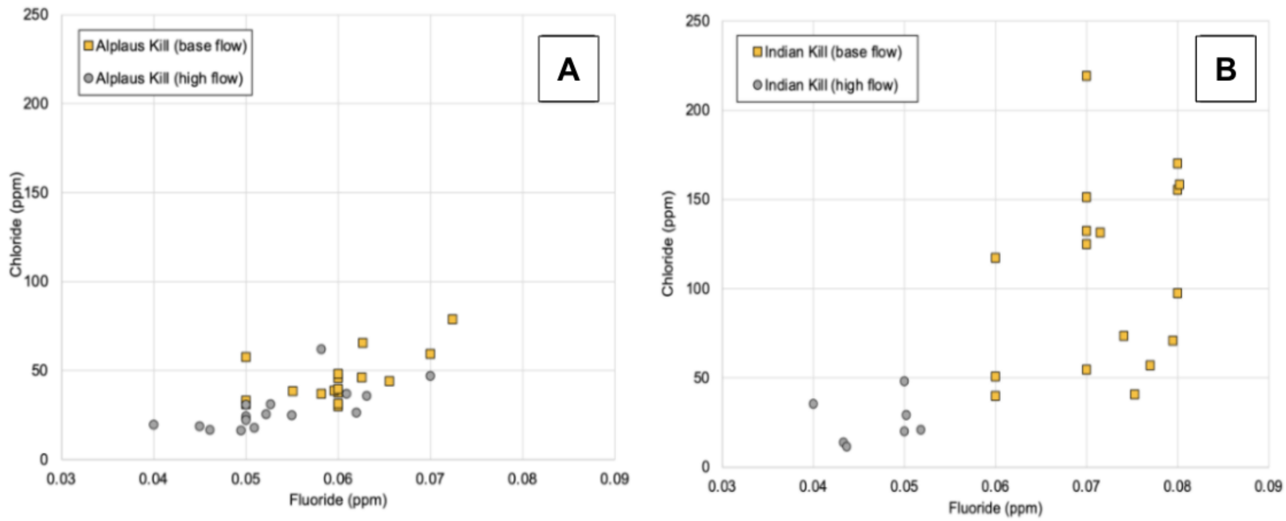


Figure 21: Cl and F concentrations in the Alplaus and Indian Kill at high flow and base flow.

Fluoride concentrations are increasingly high relative to high chloride concentrations seen in the Indian Kill. At baseflow, elevated Cl and F concentrations are seen in the Indian Kill (Figure 16). In the Alplaus Kill, there is little difference in trends between Cl and F concentrations at base flow compared to high flow. The Indian Kill presents a clear difference between Cl and F concentrations dependent on the level of flow. When F concentrations exceed 0.06 ppm, Cl concentrations are similarly increasing. High levels of Cl and F concentrations at base flow in the Indian Kill may indicate a source that is contributing excess Cl into surface waters. Because F concentrations are so low relative to Cl concentrations, it is likely that very little Cl can be attributed to Cl and F sources. However, the clear division between low flow and high flow conditions in the Indian Kill may indicate that there is some similar source. Additionally, relationships between Cl and NO_3 may describe elevated Cl concentrations in the Indian Kill during base-flow conditions.

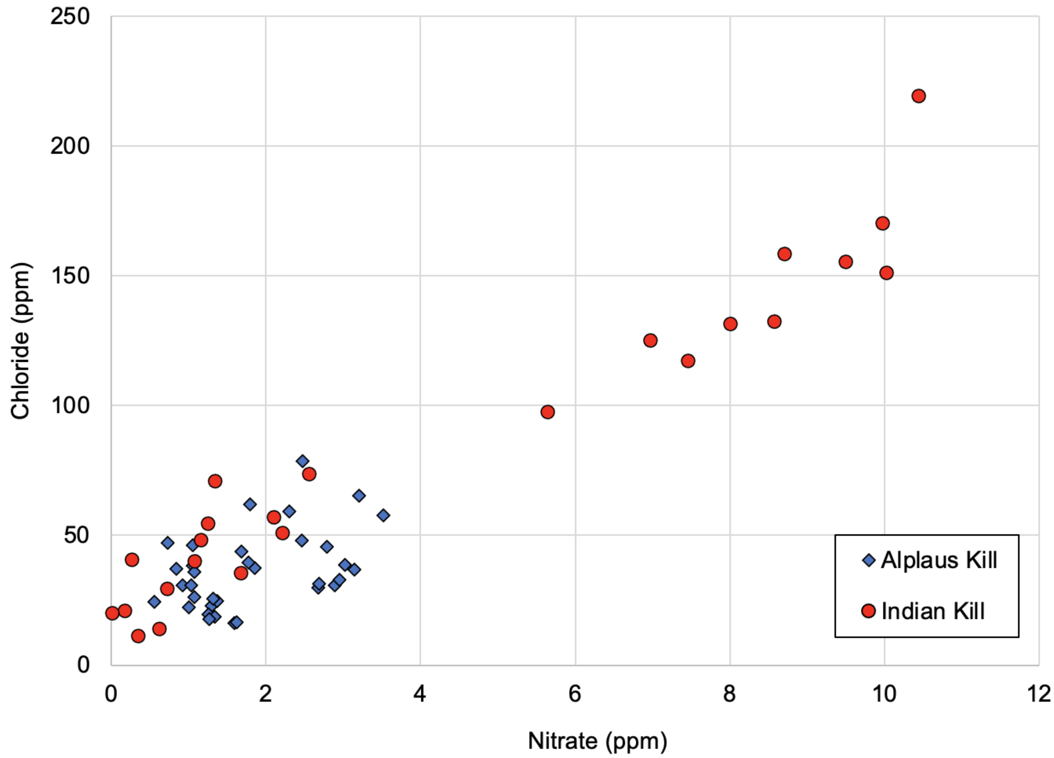


Figure 22: Chloride (Cl) and nitrate (NO_3) concentrations at the Alplaus and Indian Kill.

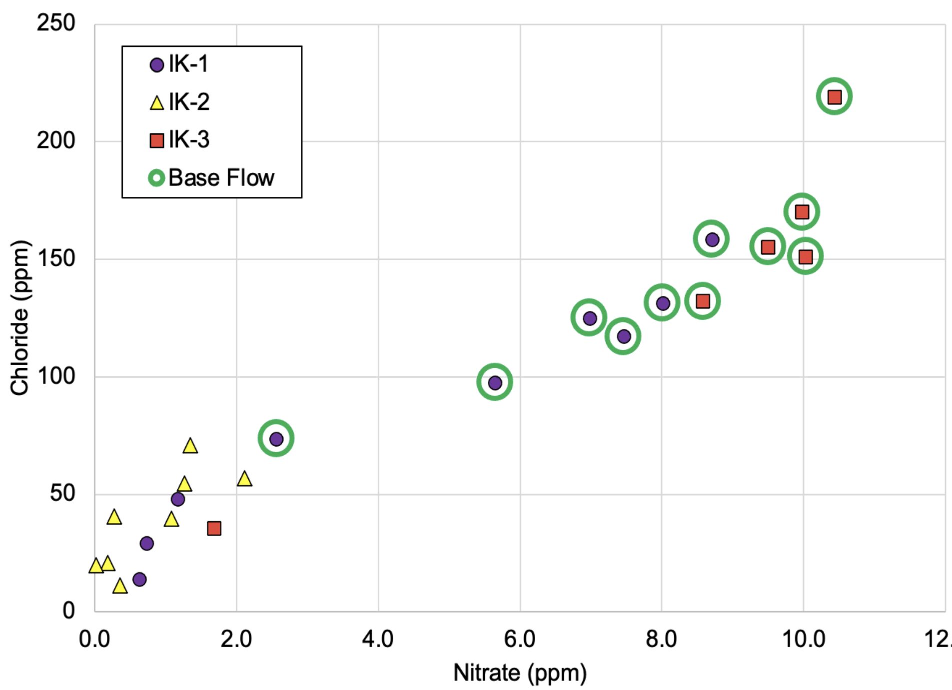


Figure 23: Chloride (Cl) and nitrate (NO_3) concentrations at the Indian Kill. The sampling locations are divided and the legend on the graph indicates the respective shapes and colors. Points with a green circle were sampled during base flow conditions at IK-1 and IK-3 (12 hr rainfall < 0.1 in).

While the Alplaus Kill has consistently relatively low NO_3 and Cl concentrations, the Indian Kill shows a linear trend. This trend could indicate that Cl and NO_3 are coming from the same source in the Indian Kill (Figure 17). There is large variability in the Cl and NO_3 concentrations between sites measured along the Indian Kill (Figure 18). This variability is also relative to the flow conditions at IK-1 and IK-3. Cl and NO_3 concentrations at IK-2 do not fluctuate based on flow conditions. IK-1 and IK-3 present the largest range and variability of Cl and NO_3 concentrations. The positive linear relationship at all Indian Kill sampling locations indicates there may be similar sources of Cl and NO_3 entering the Indian Kill. Elevated levels of Cl and NO_3 are entering IK-1 and IK-3 during base-flow conditions.

Nitrate in the Alplaus and Indian Kill

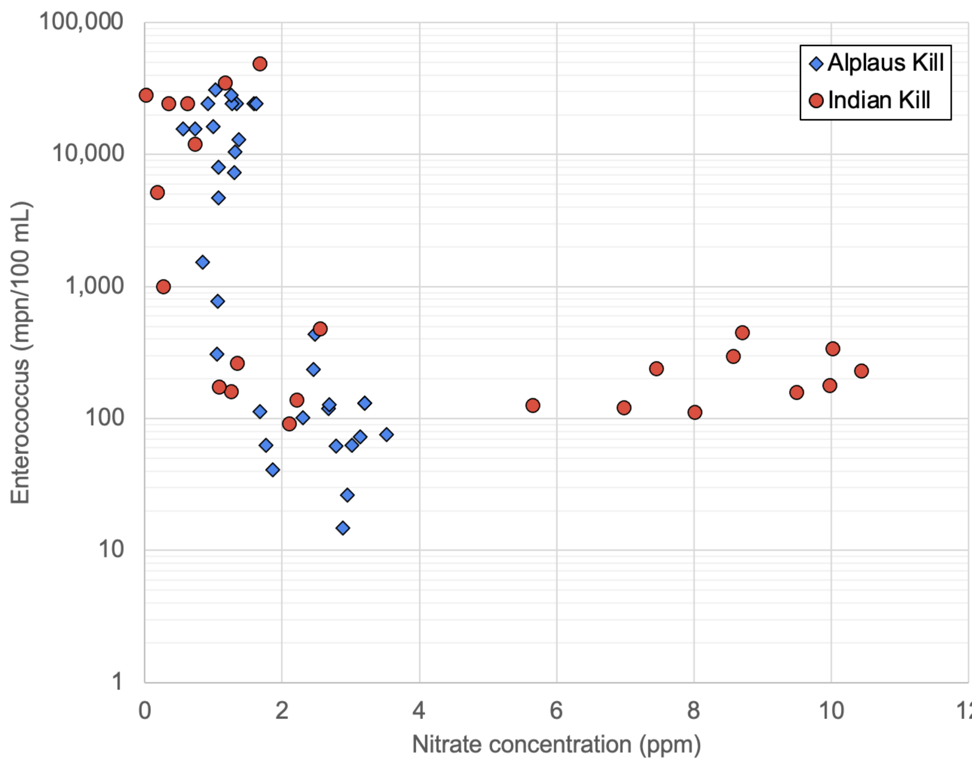


Figure 24: Nitrate concentrations versus Enterococcus. Blue diamond's indicate samples taken along the Alplaus Kill and red circles represent samples taken along the Indian Kill.

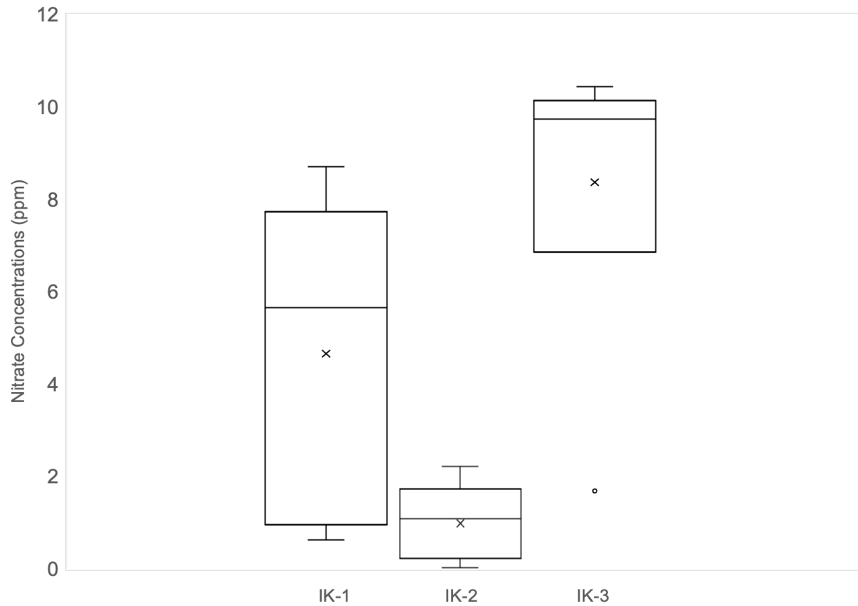


Figure 25: Nitrate concentrations at IK-3 were significantly higher than IK-1 and IK-2 (ANOVA, p = 0.00015). All measured points are shown, and the mean for each location is marked by an X.

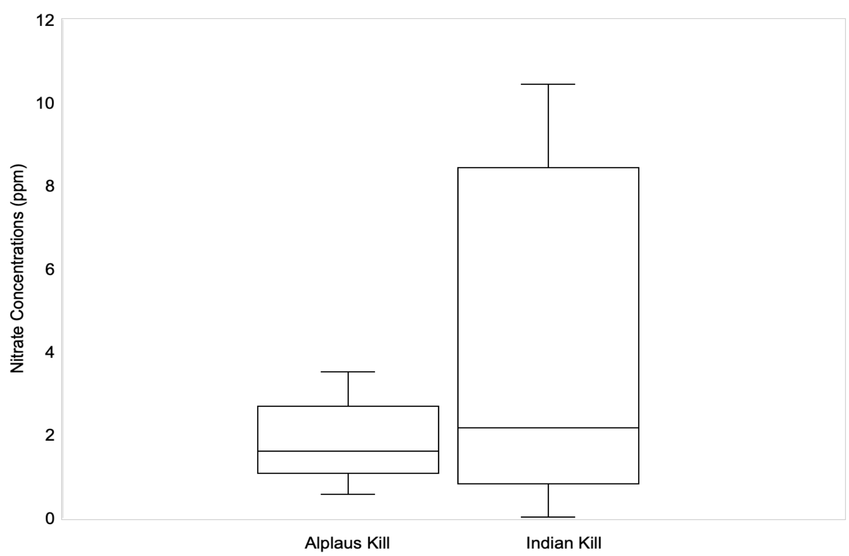


Figure 26: Indian Kill Nitrate concentrations (μ =4.21 ppm, Median = 2.16 ppm) are significantly higher than the Alplaus Kill (μ = 1.82 ppm, Median = 1.61 ppm) (ANOVA, p = 0.0013).

Indian Kill nitrate concentrations (μ = 4.21 ppm) were found to be significantly higher than the Alplaus Kill (μ = 1.82 ppm) (ANOVA, p = 0.0013). Within the sites of the Indian Kill (IK-1, IK-2, IK-3), there is a significant variance in nitrate concentrations (ANOVA, p = 0.00015). IK-3 has the highest overall nitrate concentrations (μ = 8.37, σ = 3.33), followed by IK-1 (μ = 4.66, σ = 3.36) and IK-2 has the lowest

nitrate concentrations (μ = 0.98, σ = 0.83). An analysis of nitrate concentrations in the Indian Kill and Alplaus Kill indicates that there are many high single sample values and variations in the Indian Kill.

Phosphate in the Alplaus and Indian Kill

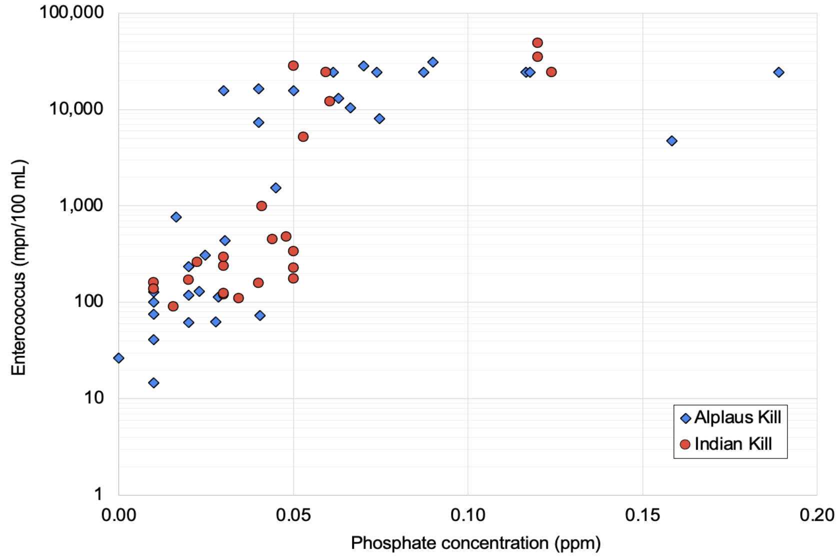


Figure 27: Phosphate and *Enterococcus* concentrations. Blue diamonds indicate samples taken along the Alplaus Kill and red circles represent samples taken along the Indian Kill.

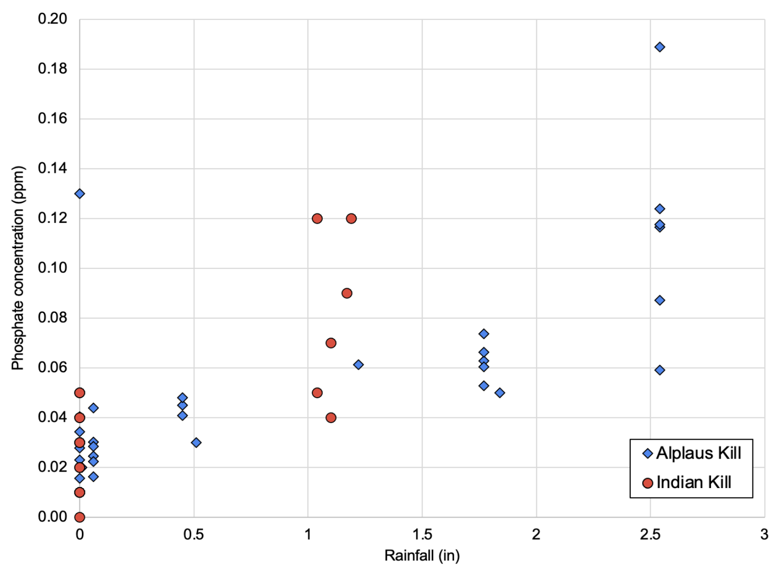


Figure 28: Rainfall (12 for Indian Kill and 48 for Alplaus Kill) vs phosphate concentrations (ppm). Blue diamonds indicate samples taken along the Alplaus Kill and red circles represent samples taken along the Indian Kill.

While there is not a statistically significant linear relationship between phosphate concentrations and *Enterococcus* concentrations (R^2 = 0.45), when there are high *Enterococcus* concentrations, phosphate concentrations are much more variable and typically higher. With the knowledge that *Enterococcus* concentrations are at their highest during high precipitation events, it is also likely that phosphate concentrations increase during high precipitation events. Samples taken in the Alplaus Kill have much higher variation in phosphate concentrations when *Enterococcus* is elevated. Of the 26 samples taken with phosphate concentrations greater than or equal to the EPA acceptable threshold (0.05 ppm), 80 percent of them were sampled when *Enterococcus* concentrations were above 1,000 mpn/100 mL when the flow was high after a precipitation event. This relationship indicates that when rainfall is high, both *Enterococcus* and phosphate concentrations are likely to be elevated. When rainfall is greater than 0.1" it is likely that phosphate concentrations will subsequently increase.

Water Quality and Land Cover

Enterococci and Land Cover

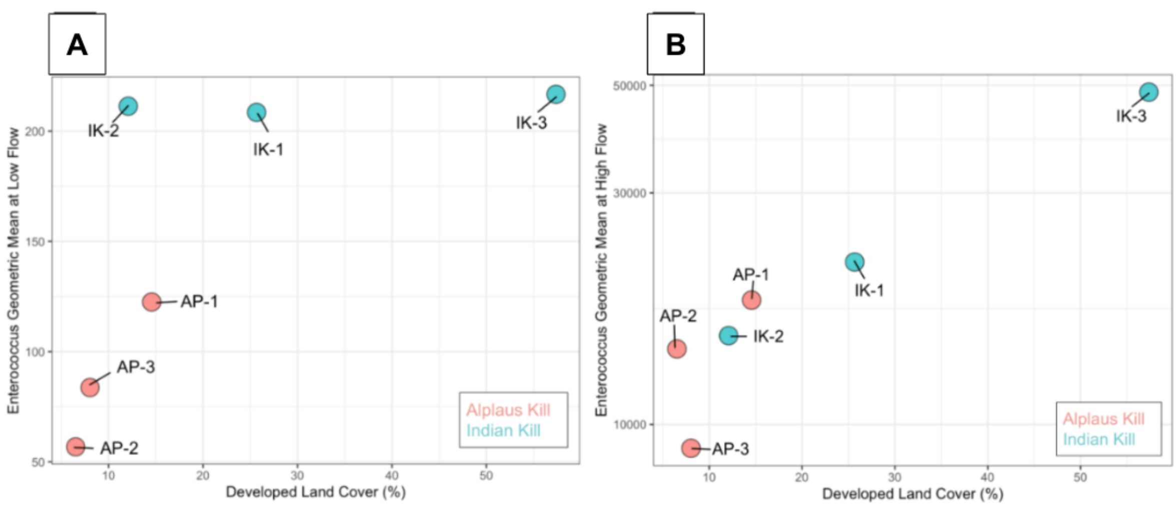


Figure 29: The percent of developed land cover versus the geometric mean of *Enterococcus*

The highest concentrations of *Enterococcus* at both low and high flow are at IK-3, where developed land cover is the highest of all sampling locations. At low flow, there is variance in the developed land cover and *Enterococcus* relationship, however, the Indian Kill is consistently at a higher base level of *Enterococcus.* As rainfall increases in both streams, there tends to be more of a correlation between developed land cover and *Enterococcus.* The lowest geometric mean concentrations of *Enterococcus* at high flow are seen in the sampling locations that have the lowest developed land cover. This relationship could indicate urban sources of *Enterococcus* entering surface waters such as stormwater and sewage runoff or septic system failure (Byappanahalli et al., 2012).

Dissolved Ions and Land Cover

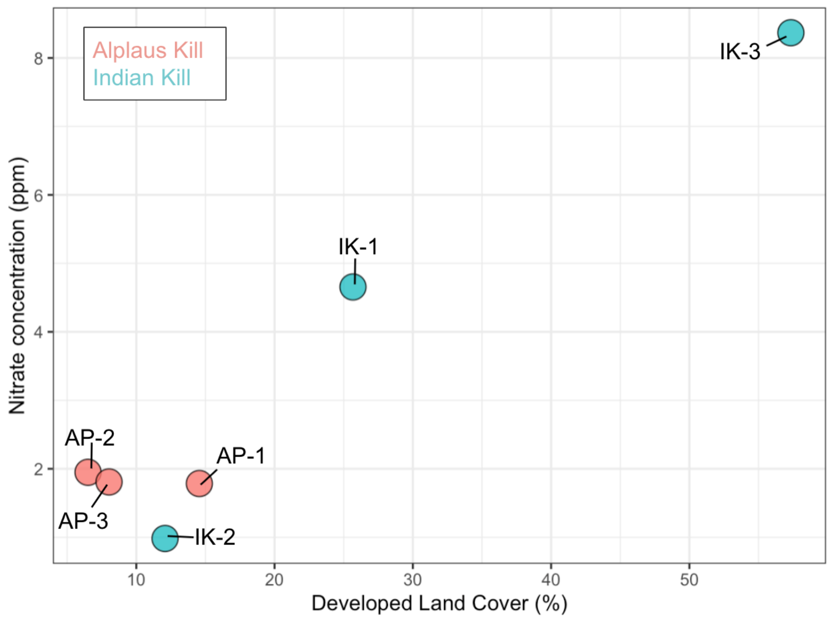


Figure 30: Total mean nitrate concentrations modern versus the percent of the drainage area that is classified as developed land.

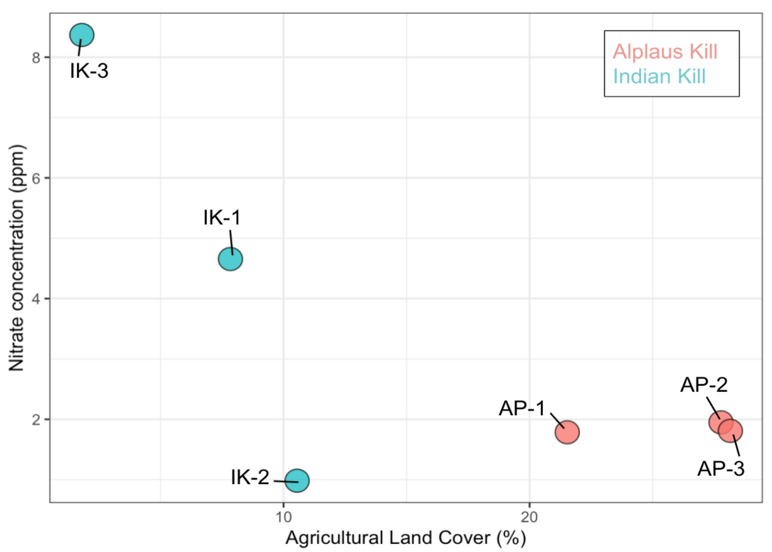


Figure 31: Total mean nitrate concentrations modern versus the percent of the drainage area that is classified as agricultural land.

Nitrate concentrations are at their highest in the location with the highest developed land area (IK-3), and at their lowest in the locations with the most agricultural land (AP-2, AP-3). This indicates that there may be a relationship between more developed or urban areas and higher nitrate concentrations. Though nitrate in surface waters can often be a byproduct of agricultural fertilizers, the trends seen in this study indicate that agricultural-related inputs do not play a significant role in large increases in nitrate concentrations. In the Indian Kill, there is a relatively clear and substantial increase in nitrate

concentrations, as developed land cover increases. The two sampling locations, IK-2 and IK-3, meet upstream of IK-1. Figure 26 shows that IK-1 is a mix of both the high nitrate concentrations at IK-3 and the low concentrations at IK-2.

Ionic Composition Percentages

The ions with the typical highest overall concentration measured using the ion chromatograph on water samples were calcium (Ca), chloride (Cl), and sodium (Na). There was a wide variation as to which of these three ions was present in the highest quantities based on the stream sampled, and the amount of recent rainfall.

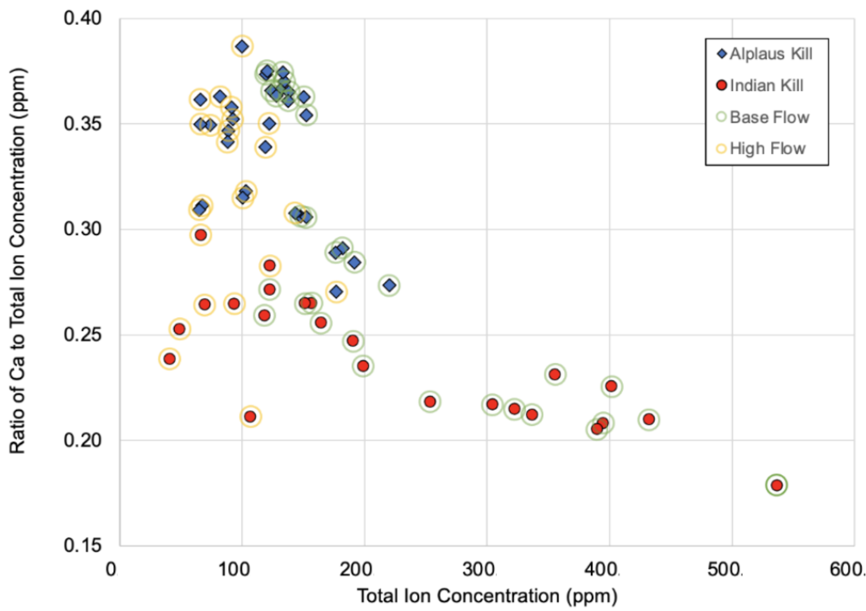


Figure 32: The ratio of calcium (Ca) in the total ionic composition versus the total ionic concentration. The blue diamond's represent the Alplaus Kill and the red circles represent the Indian Kill. The green outlines indicate there has been < 0.1 in of rainfall in the most recent 48- or 12-hour periods for the Alplaus and Indian Kill, respectively.

The relationships seen above indicate that the lowest amount of relative Ca is present in the Indian Kill when the stream is in base flow conditions and the highest amount of relative Ca is present when total ion concentrations are at their lowest in the Alplaus Kill when flow is high. In both streams, the relative Cal composition tends to be at its highest when flow is also high. The highest total ion concentrations are seen in the Indian Kill at baseflow; however, these samples also contain the lowest relative Ca concentrations. At high flow, total ion concentrations are at their lowest, but the concentrations of Ca do not fall similarly. At low flow in the Indian Kill, Ca does not dominate the total ion composition, thus other primary dissolved ions are present in higher compositions.

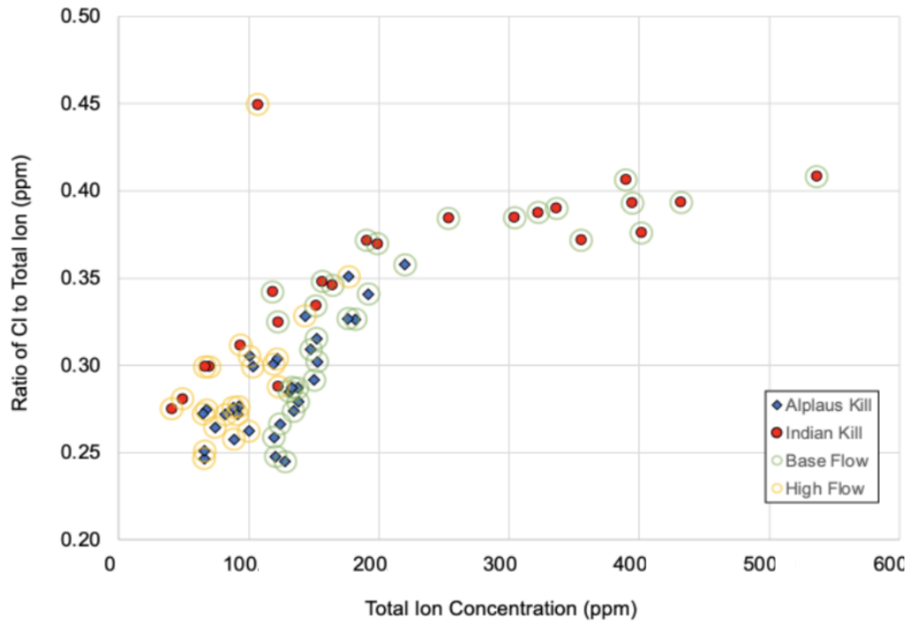


Figure 33: The ratio of chloride (Cl) in the total ionic composition versus the total ionic concentration. The blue diamond's represent the Alplaus Kill and the red circles represent the Indian Kill. The green outlines indicate there has been < 0.1 in of rainfall in the most recent 48- or 12-hour periods for the Alplaus and Indian Kill, respectively.

Chloride concentrations are at their highest in the Indian Kill during base-flow conditions. The opposite relationship is seen in the ratio of calcium to the total ionic concentration (Figure 32). This finding indicates that the primary dissolved ion in the Indian Kill at base flow is Cl. When the Alplaus Kill is at baseflow, the percentage of Cl increases in the total ionic composition. At baseflow in the Alplaus Kill, the Cl concentration remains low in respect to the relatively low total ion concentrations. The one exception to these general trends is the point, where the Cl ratio is 45 percent of the total ion concentration in the Indian Kill at high flow. This sample was collected at IK-1 on October 26, 2021, when the 12-hour rainfall measured at 1.19 inches.

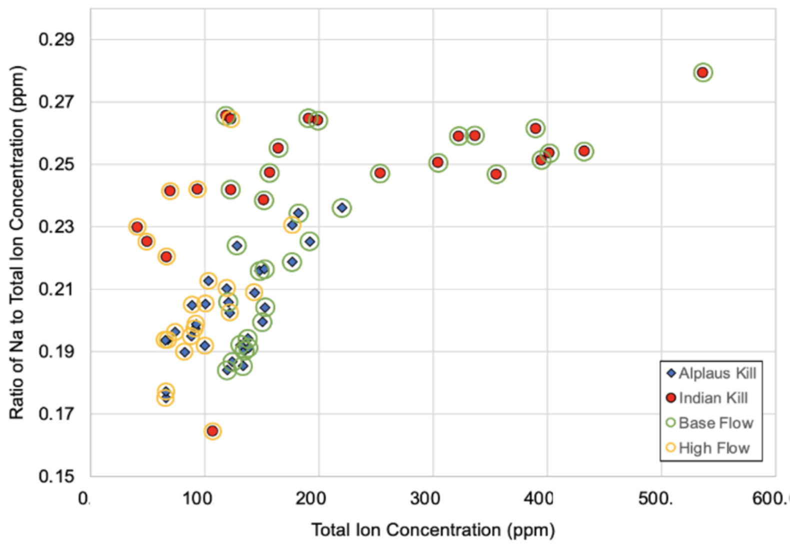


Figure 34: The ratio of sodium (Na) in the total ionic composition versus the total ionic concentration. The blue diamond's represent the Alplaus Kill and the red circles represent the Indian Kill. The green outlines indicate there has been < 0.1 in of rainfall in the most recent 48- or 12-hour periods for the Alplaus and Indian Kill, respectively.

Sodium (Na) concentrations are elevated along with Cl levels in the Indian Kill at baseflow, indicating that it is likely groundwater contamination from road salt. In the Alplaus Kill, the same relationship of increasing Na and Cl concentrations as total ionic concentrations is seen at base flow indicating that equal relative concentrations of Na and Cl are entering the stream from the same source. Relative Na concentrations are typically higher in the Indian Kill compared to the Alplaus Kill. Additionally, Na concentrations are typically lower during periods of high flow.

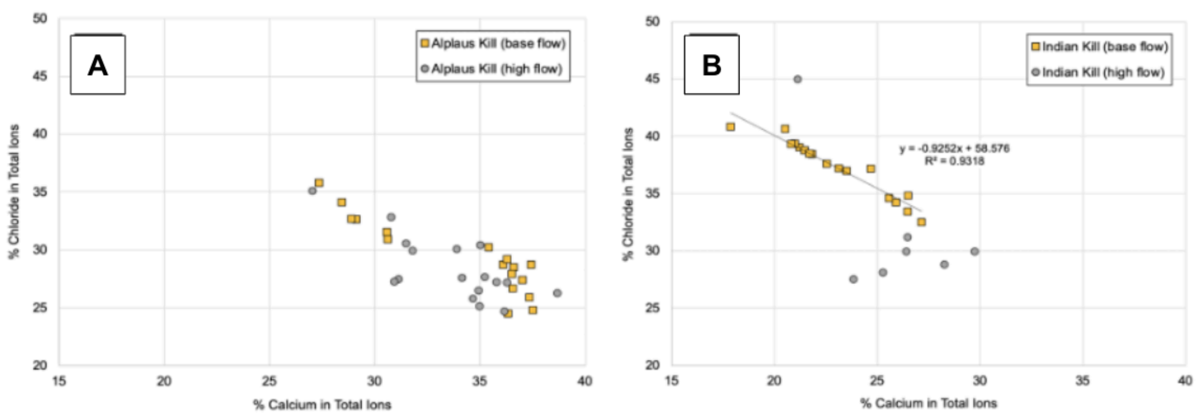


Figure 35: The ratio of chloride (Cl) in the total ionic composition versus the ratio of calcium (Ca) in the total ionic composition. The data are colored by the amount of flow, indicated by rainfall. The yellow squares indicate there has been < 0.1 in of rainfall in the most recent 48- or 12-hour periods for the Alplaus and Indian Kill, respectively. The gray circles indicate > 0.1 in of respective rainfall.

The Alplaus Kill typically contains higher calcium concentrations, while the Indian Kill typically has higher chloride concentrations. In the Alplaus Kill, there is little distinction between trends in calcium and chloride concentrations between baseflow and high flow conditions. In the Indian Kill, there is a clear negative, a linear trend seen at base flow conditions ($R^2 = 0.93$). As the amount of calcium increases, the chloride concentration decreases. Concentrations of calcium and chloride at high flow in the Indian Kill do not follow this relationship. This finding indicates that the entry of calcium and chloride at an equal ratio is likely related to groundwater recharge. An exception to this trend is seen at a singular point sampled at IK-1 at high flow, where the chloride concentration measured is the largest percent composition of the total ionic concentration.

Water Quality Results in Compliance with U.S. EPA Standards

Contaminant	Threshold Value for fresh surface waters	Source
Enterococcus	35 (mpn/100 mL)	U.S. EPA 2012 RWQC
Phosphate	0.05 (ppm)	Litke, 1999 (USGS)
Nitrate	10 (ppm)	U.S. EPA 2002
Chloride	230 (ppm)	U.S. EPA 1988

Table 9: The threshold value for contaminants surface waters that is enforced by the EPA/DEC.

Site Code	GeoMean Total *Enterococcus* (mpn/100 mL)	GeoMean Low flow *Enterococcus* (mpn/100 mL)	GeoMean High flow *Enterococcus* (mpn/100 mL)	Mean Phosphate (ppm)	Mean Nitrate (ppm)	Mean Chloride (ppm)
AP-1	1,695 (n = 19)	123 (n = 9)	18,036 (n = 10)	0.05	1.78	43
AP-2	663 (n = 9)	57 (n = 5)	14,307 (n = 4)	0.06	1.95	29.5
AP-3	666 (n = 9)	84 (n = 5)	8,928 (n = 4)	0.05	1.80	32.2
IK-1	982 (n = 9)	210 (n = 5)	21,609 (n = 4)	0.05	4.66	88.2
IK-2	789 (n = 9)	211 (n = 5)	15,238 (n = 4)	0.04	0.98	40.56
IK-3	837 (n = 8)	217 (n = 6)	48,392 (n = 2)	0.10	8.40	143.8

Table 10: The listed values are the geometric means for *Enterococcus* at low and high flow, and the mean phosphate, nitrate, and chloride concentrations. The values that are highlighted in yellow exceed the EPA regulatory threshold values listed above

DISCUSSION

Contamination in the Alplaus Watershed

High *Enterococcus* concentrations at low- and high-flow stream conditions indicate that the Alplaus Watershed is likely contaminated with sewage, potentially from stormwater runoff mixing or leaking septic systems. The large number of septic systems in the watershed is a likely cause of water quality impairment primarily seen in the Indian Kill, but present in the Alplaus Kill, impact because the two systems are connected.

The main indicator of sewage in surface water in this study is the fecal indicator bacteria (FIB) *Enterococcus.* The presence of *Enterococcus* at consistently high levels during rainfall events indicates that there are sources of sewage that are entering the streams. The dynamic range of *Enterococcus* values based on rainfall is also indicative of contaminated stormwater. All the highest *Enterococcus* values were from samples collected during high rainfall events (> 0.1 in), and the rainfall-runoff relationship is clear (Figures 13 & 14).

No previous long-term study of *Enterococcus* at these sampling sites or equivalent locations on the same streams has been conducted. The dataset in this thesis was collected during a period with a high amount of precipitation, some of which were extreme rainfall events (24-hour > 2"). The *Enterococcus* results most likely reflect this in their concentrations at high flow. The results present a large and variable range of *Enterococcus* concentrations that are highly dependent on rainfall.

In extreme precipitation events, overflow appears to be occurring and this is causing sewage and stormwater to mix, and this mixing results in high fecal loads (*Enterococcus)* into the watershed. According to the Town of Glenville SWMP, the Alplaus and Indian Kill are predicted to be receiving only minor impacts by urban/storm runoff. However, given the level of *Enterococcus* that is consistently present in these two streams, the impairment appears to be significant. While the source of the *Enterococcus* has not been directly determined, it is possible that a fault in the infrastructure is contributing to high levels of pathogens in surface waters.

The combination of sanitary sewer, stormwater, and potable water pipes below the subsurface may exfiltrate and the flow may be creating a "karst-like" network of groundwater flow mixed with

contamination to surface water recharge that is seen primarily in base flow conditions (Kaushal & Belt, 2012; Figure 22). This failing infrastructure is a primary cause of the water quality impairment seen at baseflow conditions. As pipes continue to degrade over time and the effects of extreme weather and climate change increase, the threat to water quality impairment within the more urbanized area of the Alplaus Watershed increases.

Long-term slow degradation of septic systems may also be contributing to groundwater contamination that is recharging surface waters during base-flow conditions. High nitrate concentrations at baseflow conditions may be attributed to long-term contamination of groundwater from leaking septic systems present within the watershed boundaries, especially in the Mayfair Creek[5] at IK-3 (Kaushal et al., 2011). Higher fluoride concentrations in IK-3 may be indicative of leaking potable pipes in the subsurface entering through groundwater recharge (Kaushal & Belt, 2012).

The broad range of contamination in the Alplaus and Indian Kill at both low and high flow conditions indicates that the impact of potentially failing infrastructure and broad-spectrum nonpoint source pollution needs to be re-evaluated. These streams hold great potential for human recreation and thriving aquatic ecosystems, however, at their current state, the lower reaches of the Alplaus and Indian Kill are not likely to support healthy aquatic communities.

The results presented in this thesis highlight the importance of consistent and broad-spectrum water quality sampling in mixed land use watersheds to understand surface water contamination. It additionally highlights the need for water quality measurements to be taken during stormwater outfall monitoring studies. While the Town of Glenville SWMP is sufficient in complying with MS4 guidelines, methods of illicit discharge monitoring need to be improved in order to identify point sources for high levels of contamination at high and low flow periods. The potential of leaking septic systems needs to be addressed to resolve high contamination within the Alplaus Watershed. The most recent Town of Glenville Comprehensive Plan, published in 2017, states that one of the long-term goals related to water resource improvement is to expand sanitary sewer systems and reduce the use of septic systems draining into the Indian Kill watershed (Town of Glenville, 2017). The data in this report support this assessment and this issue should be addressed as soon as possible.

Water quality impairment is seen in both high and low flow stream conditions; however, the contaminants vary widely based on the amount of precipitation present. At high flow conditions, *Enterococcus* and phosphate are present and at low flow conditions, nitrate, sodium, chloride, and

[5] The Mayfair area of Glenville has municipal water supply, but it relies on individual septic systems to handle wastewater.

fluoride are seen at higher concentrations. Based on this broad understanding of contaminant presence, we can narrow down source areas, and thus present different remediation options based on rainfall.

Water Quality Impairment at High Flow

Alplaus Kill *Enterococci*

Concentrations of *Enterococcus* measured at AP-1 represent the high variance dependent on rainfall seen throughout the Alplaus Watershed. This sampling location is important because it shows the total contamination load entering the Mohawk River. This was the sentinel site for this study, and the most samples were taken at this location. This is the lowest site in the watershed and thus it represents virtually the entire watershed and all tributaries (including the Indian Kill) just upstream with the confluence with the Mohawk River. The range of *Enterococcus* values varied widely from 58 to 31,062 mpn/100 mL. The low flow and high flow geometric means at AP-1 were 123 and 18,036 mpn/ 100 mL, respectively. At AP-1, a clear pattern exists with *Enterococcus* increasing with increased stream flow. Out of the 19 samples taken at AP-1 over the sampling period, only one of these samples was recorded below the EPA acceptable limit (BAV = 60 mpn/100 mL) for freshwater *Enterococcus* concentrations, thus in the sampling interval this site failed to meet the EPA BAV 95% of the time, and failure occurs even at low flow. This result implies that there may be a range of sources of fecal contaminants entering the watershed, and as seen in the discussion below, these sources of FIB appear to be from both the upper Alplaus and the Indian Kill.

Sample sites AP-2 and AP-3 are the most rural sampling sites. Despite its more remote setting AP-2 still reached a maximum *Enterococcus* concentration of 28,272 mpn/100 ml. While low-flow concentrations were some of the lowest sampled, high-flow events did have high *Enterococcus* concentrations. Sample Site AP-3 has the best water quality of any site studied. This site is at the confluence of the main portion of the Alplaus Kill and the La Rue Creek, and it consistently proved to have the lowest *Enterococcus* concentrations compared to all other sampling locations, not unexpected given the more rural setting in the area. The large amount of pasture and forested area and low number of developed areas upstream of AP-3 are probable contributors to the low *Enterococcus* concentrations.

Intense Rainfall Events and Sources

On September 24, 2021, an extreme rainfall event occurred (24 hr rain = 2.54 in). All samples taken (AP-1, AP-2, AP-3, IK-1, IK-2) saturated the Quanti-Tray at 24,196 mpn per 100 mL. The ability to understand these results to their maximum capacity is reduced because of the saturation, however, this was the highest recorded value for AP-3. In this case, the highest value recorded at AP-3 is comparable to some of the highest values recorded at sites with the most developed areas such as AP-1.

On 5 October 2021 after a high rainfall event (48 hr rain = 1.77 in) out of all sample sites taken (AP-1, AP-2, AP-3, IK-1, IK-2) AP-2 was the second-highest recorded *Entero*coccus sample (*Enterococcus* = 12,997 mpn/100 ml). In areas where impervious surfaces and developed areas are relatively low, *Enterococcus* values can still be high when rainfall is high. Land use upstream of AP-2 indicates much of this part of the watershed is rural, and thus septic systems and livestock (horses, cows) are the most likely source of fecal contamination. Thus, microbial source tracking (MST) may be useful in future work to resolve sources of fecal contamination in this setting.

Livestock can contribute to fecal loads in rural watersheds (Byappanahalli, 2012). This part of the watershed has a large population of cows and horses in the sampling area relative to other sample sites along the Alplaus Kill, and these animals may be contributors to the pathogen and fecal matter in this area. Based on the analysis done in this report, however, it is not possible to identify specific sources (i.e. no Microbial Source Testing or MST has been conducted here). Nonetheless, the distinctive rainfall-*Enterococcus* relationship was recognized at AP-3, like other sites (both urban and rural).

The sites along the Alplaus Kill have a very wide range of *Enterococcus* values. The implications of these results and understanding source patterns are challenging because of the broad range of land use in the areas, but still relatively comparable *Enterococcus* concentrations. These results do, however, show that the *Enterococcus* load in the Alplaus Kill is at its highest 48 hours after large rain events. All areas of the Alplaus Kill sampled in this study reach high levels of *Enterococcus* in the 48-hour period after an extreme rainfall event. The exact source of this bacteria is unknown, but it is likely attributed to sewage contamination, and domestic farm animals such as horses or cows (especially AP-2 and AP-3), and farther downstream (AP-1) it is likely that the levels reflect a mix of both the rural signal (Livestock, septic) and the urban signal (septic, outfalls) (Layton et al., 2010). Regardless of the source, and how the pathogens are entering the watershed, these high concentrations of *Enterococcus* pose a threat to human health and water quality in the Alplaus Watershed.

Indian Kill *Enterococci*

All sampling locations along the Indian Kill had very high geometric means of *Enterococcus* at both low and high flow. The Indian Kill is a relatively small watershed but it has a significant urban footprint, which may be directly related to high pathogen levels. Of the 25 samples taken at the three Indian Kill locations, none of them were below the EPA BAV, and thus these samples failed to meet the EPA BAV 100% of the time. IK-3 (Mayfair Creek) was identified as having the highest consistent *Enterococcus* concentrations at both low and high flow, and thus this segment is clearly impaired.

Enterococcus concentrations at IK-1, the sentinel site for the Indian Kill, indicate severe contamination of the entire Indian Kill. Samples at IK-1 were taken just above the confluence of the Indian

Kill and Alplaus Kill. The lowest *Enterococcus* single sample value sampled at IK-1 was twice the EPA BAV for single samples (120 mpn/100 mL). The highest *Enterococcus* value measured at IK-1 was the highest unsaturated sample taken in this study at 34,658 mpn/100 mL. Thus, stormwater and sewage flowing into the Alplaus, and Indian Kill are not mutually exclusive and can be seen by high relative *Enterococcus* values at AP-1 and IK-1.

Enterococcus values enumerated at IK-2 had the lowest concentrations in the Indian Kill, and this site is the tributary that captures the headwaters of the Indian Kill before it enters the more urban area of Glenville. Nine total samples were collected at this site over the sampling period, and the geometric mean of the low flow was 210 mpn/100 mL and at high flow it was 15,238 mpn/100 mL.

Sample site IK-3 (Mayfair) has the poorest water quality in this study. This site presented the highest variability in *Enterococcus* values dependent on rainfall, with consistently high loads of pathogens. The geometric mean for IK-3 at low flow was 217 mpn/100 ml and minimum geometric mean at high flow was >48,392 mpn/100 mL. This site was identified midway through the study, and thus it has the lowest number of total samples (n=8), and two of these samples were taken during high flow events. The *Enterococcus* values were saturated, so they represent a minimum value.

It was initially thought that high pathogen concentrations at IK-3 may have been related to an unidentified outfall pipe located just uphill of the creek near the confluence with the main branch of the Indian Kill. However, simultaneous pathogen sampling of the pipe and creek at high flow and low flow indicate that the source is not from the pipe, but from a source or sources farther upstream. At low flow sampling the pipe had 10 mpn/100 mL, while the adjacent creek was 336 mpn/100 mL. At high-flow sampling, the pipe was 2,613 mpn/100 mL, while the creek was >48,392 mpn/100 mL. Note that the pipe is not uncontaminated (2,613 mpn/100 ml is still a high value), but there appears to be an even more significant source upstream. Mayfair Creek, which is IK-3, has been identified as contaminated in the DEC Stream Biomonitoring Unit Rapid Assessment Survey Report, published in 2000. The results from the *Enterococcus* concentrations in this study confirmed this area is still contaminated. These recent results indicate that the public should not be in contact with these waters even at low flow.

Alplaus and Indian Kill *Enterococci*

The concentrations of *Enterococcus* in this thesis indicate it is possible that illicit discharge of sewage is entering the Alplaus or Indian Kill through failing infrastructure such as leaking septic systems or overflowing stormwater outfalls. Measuring outfalls on a five-year rotating basis seems to be insufficient in identifying areas of impairment stemming from stormwater outfalls. It is likely that surface water impairment, especially in wet weather, is related to the overflow capacity of stormwater and sewage

water. The patterns seen between *Enterococcus* and rainfall in both streams indicate a potential common source of non-point source contamination.

While the Indian Kill presents a higher pathogen load relative to the Alplaus Kill, the *Enterococcus* geometric means of IK-1 and AP-1 indicate that not all contamination at AP-1 can be attributed to the Indian Kill. A mixing model can be used to understand the relationship between contamination in the Alplaus Kill and Indian Kill by using the area of the drainage basins of both streams. The Indian Kill contributes 15 percent of the total drainage basin area to AP-1, thus if the Indian Kill was the sole contributor to contamination at AP-1, there would be an expected *Enterococcus* low flow geometric mean of 91 mpn/100 mL. The actual low flow geometric mean at AP-1 was 123 mpn/100 mL, which is 35% higher than the expected geometric mean. This simple calculation indicates that there is likely contamination entering the Alplaus Kill entering below the AP-2,-3 and above AP-1. Land use maps indicate that there is considerable urban area (suburban development with septic systems) adjacent to the Alplaus just upstream of the confluence with the Indian Kill, and thus these areas should be investigated.

***Enterococci* and Phosphate**

The results of all sampling patterns in the Alplaus and Indian Kill indicate that when there are high levels of *Enterococcus,* there are high levels of phosphate. The EPA standard of safe phosphate levels in surface waters is 0.05 ppm (U.S. EPA, 1986). All samples taken that exceeded the 0.05 ppm also exceeded the EPA single sample threshold (BAV = 60 mpn/100 mL). It is likely that high levels of phosphate in surface waters can be a prediction of elevated *Enterococcus* levels. This is significant because it is possible that *Enterococcus* will clarify source areas of contamination related to the Mohawk River TMDL.

The current TMDL in the Mohawk River is aimed at the removal of phosphorus in the Mohawk Watershed to improve water quality. It is possible that the source of phosphate and *Enterococcus* indicated in this study are similar. Additionally, *Enterococcus* may be indicative of sanitary sewer overflows (SSOs) and the presence of phosphate could be from broad-spectrum runoff over agricultural land and impervious surfaces or leaking septic systems. The combination of the two pollutants in high concentrations in the same water samples may be a result of stormwater and sewage mixing during high flow events. It is highly likely that failing infrastructure in extreme precipitation events are contributing to the presence of high Enterococcus and phosphate during high flow.

Because of the relationship seen between *Enterococcus* and phosphate, the possibility of using *Enterococcus* to guide decisions related to the Mohawk TMDL. Currently, the NYSDEC uses Total Coliform (TC) and Fecal Coliform (FC), and these fecal indicators may also do a good job at predicting

phosphate levels in our surface streams. The use of FIB and phosphate relationships should be explored further to understand the total phosphorus load within the Mohawk Watershed and the role that sewage in total contamination.

Water Quality Impairment at Baseflow

Urban-Related Contamination Signals

Measurements of nitrate indicate greater impairment during baseflow of the Indian Kill as opposed to all other sites. All measured values of NO_3 were below the EPA standard (10 ppm, U.S. EPA, 2012) except two samples measured at IK-3 (the most urban site) at low flow and one sample measured from the outfall above IK-3 measured at low flow. In the Alplaus Kill, nitrate concentrations are consistently low (max = 3.5 ppm measured at AP-1). However, the Indian Kill presents a more complex relationship with higher nitrate loads at low-flow settings, and of the three sites, IK-3 has consistently high nitrate concentrations (Figure 24). The one sample taken at high flow measuring nitrate at IK-3 contained a much lower concentration (1.68 ppm) than the typical undiluted low flow concentrations measured IK-3 (median = 9.74 ppm. Because IK-3 is the most urban site in this study, the dynamics between urban sources of nitrate in periods of baseflow, or minimal precipitation need to be explored to better understand source areas in the Alplaus Watershed.

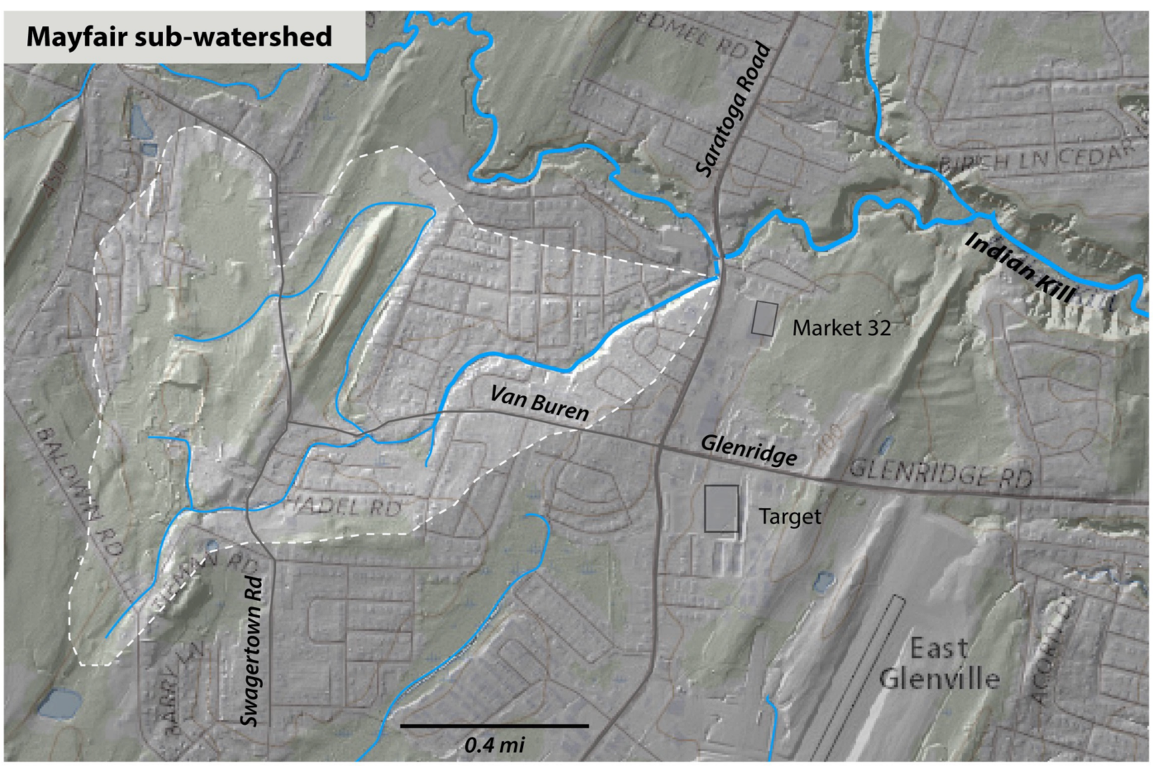


Figure 36: The drainage basin of the Mayfair Creek to IK-3 sampling location.

High nitrate concentrations during low-flow or baseflow conditions can be attributed to urban activities (Hur et al., 2006). Mayfair Creek, part of the Indian Kill, is a small stream that transects this developed area and joins the main body of the Indian Kill at the IK-3 sampling point. The 1 km^2 area directly upstream of IK-3, has 87% developed land (NLCD, 2019). This area is a combination of high-, medium-, and low-density developments that include primarily residential homes and a few business establishments. Any high levels of contamination that are detected at this sampling location are likely a result of nonpoint source pollution from the suburban developments in the local watershed. The outfall sampled above IK-3 showed high nitrate concentrations at low flow indicating that this pipe may be a source of extreme contamination into the Indian Kill. While the density of developed land cover alone could be causing high pollution loads in the Indian Kill, the combination of many septic systems attached to these homes complicated point source identification.

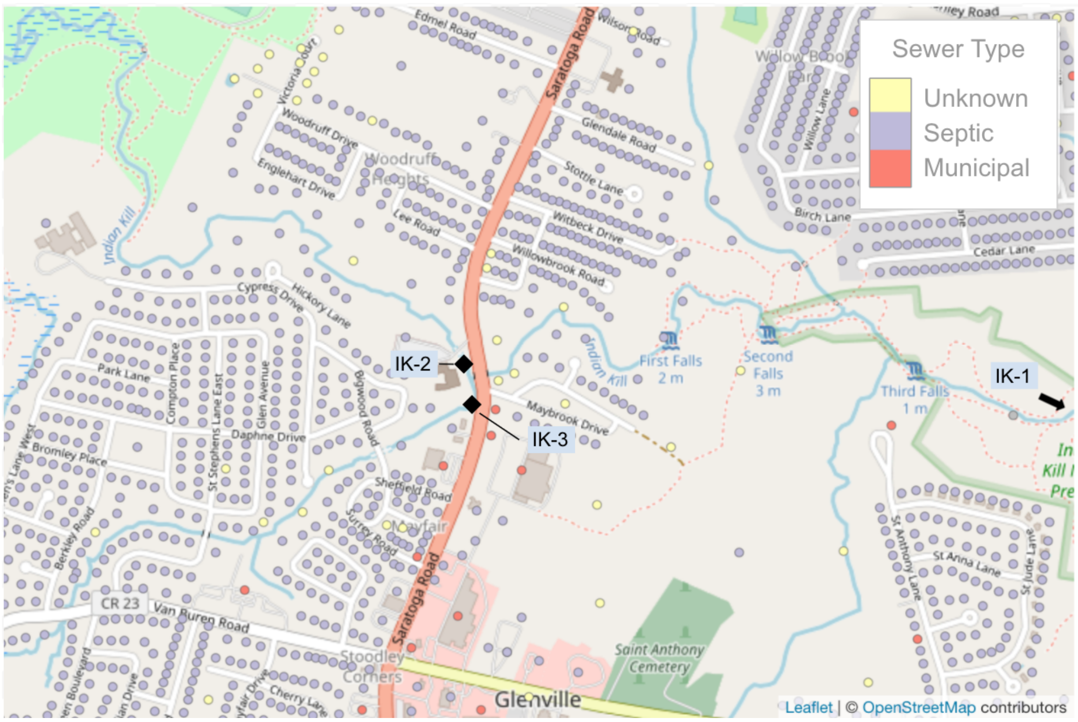


Figure 37: Sewer types within a localized area of the Indian Kill watershed. Plot created from data from NY Tax Parcels, 2020.

The high number of septic sewer systems in the Indian Kill watershed are likely a high contributor to contamination seen in the Indian Kill. Septic systems are monitored less frequently and typically are installed for longer periods of time than municipal sewer systems (Tamang, 2020). Because of this, there is much more opportunity for septic systems to leak or fail unknowingly. During rain events, septic systems can overflow which then results in the release of septic effluent directly to the subsurface, or to surface water bodies through stormwater runoff (Withers et al., 2014).

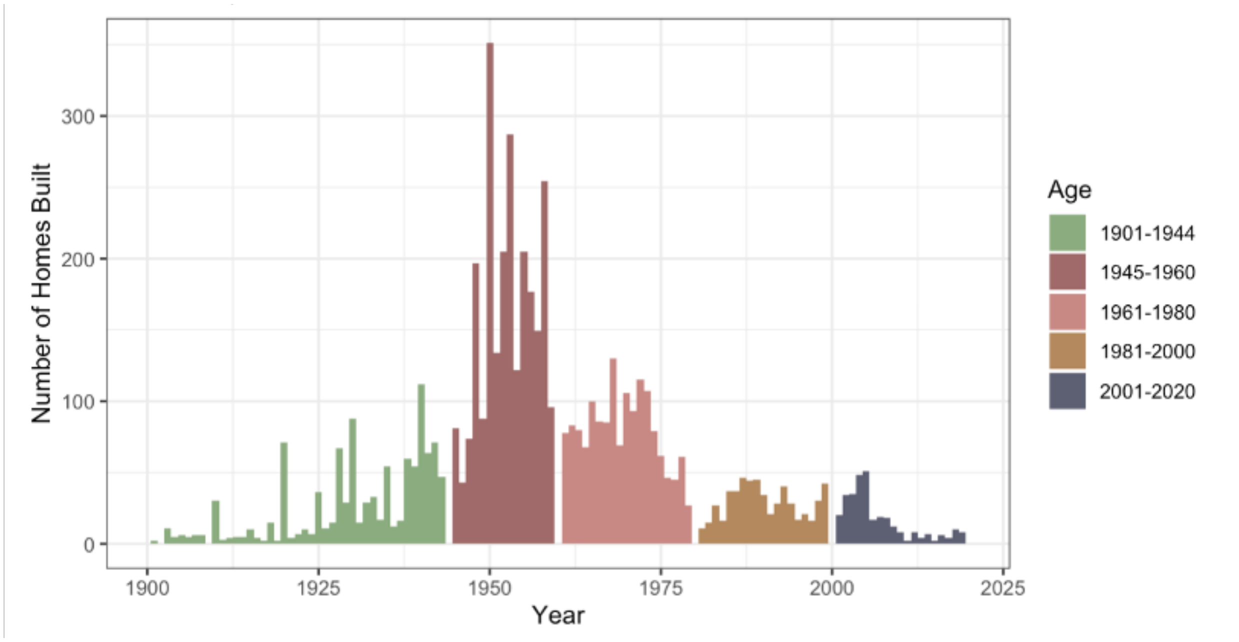


Figure 38: Histogram of the ages of homes in Glenville, NY with onsite wastewater treatment (septic) systems (plot created from data from NY Tax Parcels, 2020).

The age of the septic systems in the Glenville area is almost certainly playing a role in the increased degradation and failure that is contributing to high contaminant loads. Of the 6,127 total septic systems located within Glenville, 40% of these were initially built in the post-war boom between 1945 and 1960. Failure of septic systems is typically only recorded when there is an obvious water quality or odor problem reported. Typically, septic system failure rates are only collected from field performance surveys on randomly selected sites (Withers et al., 2014). Because of a lack of septic system efficiency monitoring, it is not possible to attribute contamination to direct sources, however, the high concentration of old homes with septic systems indicates that this lack of monitoring may be resulting in water quality impairment. The relatively high rate of nitrate contamination seen at low flow in the Indian Kill indicates that there may be groundwater contamination of nitrate or leaking septic systems that have slowly, and over a long period of time been loading nutrients into the surface water as the groundwater recharges the streams.

High levels of chloride is also recognized at base flow conditions, primarily at IK-1 and IK-3, indicating that both chloride and nitrate may both be stemming from groundwater contamination (Figure 22). High chloride concentrations entering at baseflow in conditions, when streams are being fed by groundwater discharge, is likely due to the lasting impacts of road salt. If road salt application ended, it may still take decades to fully flush (Horan, 2019). As discussed above, similar patterns of high nitrate concentrations occur in the Indian Kill. It is possible that long-term failing septic systems have been polluting groundwater in the same fashion as road salt. Nitrate enrichment of groundwater is often related

to the density of septic systems within a given watershed (Gill et al. 2009; Katz et al. 2011). Because the Alplaus Kill does not see the same signals of high nitrate and chloride concentrations (Figure 21), it is likely that the source of the contamination is due to urban development and associated activities of those homes. The smaller surface area and higher development cover in the Indian Kill watershed creates a more concentrated area for nitrate loading in both groundwater and surface water.

CONCLUSIONS

The Alplaus and Indian Kill are contaminated with a variety of pollutants at baseflow and high flow conditions. The dataset presented in this thesis highlights the complexities surrounding when and how much contaminants are present in these streams. Additionally, the range of direct and indirect sources complicate the process of remediation. The level of contamination present in some of the sites is unsafe for humans interacting with these waters and aquatic ecosystems that live in them.

At high flow, the Alplaus and Indian Kill are severely contaminated with *Enterococcus* and elevated levels of phosphate. These findings directly relate to the Mohawk River TMDL which is aimed at reducing phosphorus to improve water quality. This TMDL is especially important for those communities in the lower Mohawk River that rely on the river for municipal drinking water (i.e. the towns of Colonie and Cohoes). The source of *Enterococcus* is likely overflowing stormwater pipes, which may have sewage and septic systems that are potentially mixing in the subsurface. It is likely that the phosphate measured in this study is coming from the same source, because phosphate concentrations are elevated at high flow as well.

At low flow, contaminated groundwater is likely recharging the Indian Kill with nitrate, chloride, sodium, and fluoride which can be related to the long-term septic system leakage and road salt contamination. The issue of old septic system leakage in the Indian Kill, especially in the Mayfair area, needs to be addressed to reduce water quality impairment within the Indian Kill watershed. The Town of Glenville has recognized this is a problem, but the data presented in this report indicate that the problem still exists (Town of Glenville, 2017).

Long-term solutions need to be put in place to improve surface water quality within the Alplaus Watershed. To reduce chloride contamination and related groundwater recharge throughout the year, the municipalities within the Alplaus Watershed should reevaluate using salt in moderation or explore other alternatives to de-icing in the winter (Kelly et al., 2019). Stormwater outfalls should be monitored on a more consistent basis and include water quality testing in the Town of Glenville to properly identify point sources of contamination to water bodies.

Perhaps the most significant mitigation would be the eventual transition from widespread septic to an integrated sanitary sewer network for Glenville. The Town of Glenville should look at increasing the

reach of the municipal sanitary sewage system to areas within the Indian Kill Watershed, especially the Mayfair housing development along the Mayfair Creek. Leaking septic, municipal and potable water pipes need to be monitored for leaking and groundwater contamination during high flow conditions. These solutions presented are not simple, however, they need to be addressed in order to reduce the magnitude of water quality impairment within the Alplaus and Indian Kill.

REFERENCES

Anderson, K. L., Whitlock, J. E., & Harwood, V. J. (2005). Persistence and differential survival of fecal indicator bacteria in subtropical waters and sediments. *Applied and environmental microbiology*, *71*(6), 3041-3048.

Andonie, Elizabeth Marie, "Investigating the Urban Stream Syndrome in the Schenectady-Schoharie Region of Upstate New York" (2019). Honors Theses. 2264. https://digitalworks.union.edu/theses/2264

Berg, G., Dahling, D. R., Brown, G. A., & Berman, D. (1978). Validity of fecal coliforms, total coliforms, and fecal streptococci as indicators of viruses in chlorinated primary sewage effluents. *Applied and environmental microbiology*, *36*(6), 880-884.

Boehm, A. B., Yamahara, K. M., Love, D. C., Peterson, B. M., McNeill, K., & Nelson, K. L. (2009). Covariation and photoinactivation of traditional and novel indicator organisms and human viruses at a sewage-impacted marine beach. *Environmental science & technology*, *43*(21), 8046-8052.

Byappanahalli, M. N., Nevers, M. B., Korajkic, A., Staley, Z. R., & Harwood, V. J. (2012). Enterococci in the environment. *Microbiology and Molecular Biology Reviews, 76*(4), 685-706. doi:10.1128/mmbr.00023-12

Cabelli, V.J. (1983) Health Effects Criteria for Marine Recreational Waters. Research Triangle Park, NC: U.S.E.P. Agency.

Cho, K. H., Cha, S. M., Kang, J., Lee, S. W., Park, Y., Kim, J., & Kim, J. H. (2010). Meteorological effects on the levels of fecal indicator bacteria in an urban stream: A modeling approach. *Water Research, 44*(7), 2189-2202. doi:10.1016/j.watres.2009.12.051

Cho, S., Jackson, C., & Frye, J. (2020). The prevalence and antimicrobial resistance phenotypes of salmonella , escherichia coli and enterococcus sp. in surface water. *Letters in Applied Microbiology, 71*(1), 3-25. doi:10.1111/lam.13301

Chong, M. N., Aryal, R., Sidhu, J., Tang, J., Toze, S., & Gardner, T. (2011). Urban stormwater quality monitoring: From sampling to water quality analysis. *2011 Seventh International Conference on Intelligent Sensors, Sensor Networks and Information Processing*. doi:10.1109/issnip.2011.6146598

Clary, J., Pitt, R., & Sheets, B. (2014). Pathogens in Urban Stormwater Systems. *UWRRC Technical Committee Report,* 0-298.

Corsi, S. R., De Cicco, L. A., Lutz, M. A., & Hirsch, R. M. (2015). River chloride trends in snow-affected urban watersheds: Increasing concentrations outpace urban growth rate and are common among

all seasons. *Science of The Total Environment, 508*, 488-497. doi:10.1016/j.scitotenv.2014.12.012

Corsi, S. R., Graczyk, D. J., Geis, S. W., Booth, N. L., & Richards, K. D. (2010). A fresh look at road salt: Aquatic toxicity and water-quality impacts on local, regional, and National Scales. *Environmental Science & Technology, 44*(19), 7376-7382. doi:10.1021/es101333u

Dufour, A.P. (1984) Health Effects Criteria for Fresh Recreational. Cincinnati, OH: U.S.E.P. Agency.

D'Aniello, A., Cimorelli, L., & Pianese, D. (2021). Leaking pipes and the urban karst: A pipe scale numerical investigation on water leaks flow paths in the Subsurface. *Journal of Hydrology, 603*, 126847. doi:10.1016/j.jhydrol.2021.126847

Fleisher, J. M., Fleming, L. E., Solo-Gabriele, H. M., Kish, J. K., Sinigalliano, C. D., Plano, L., . . . Backer, L. C. (2010). The Beaches Study: Health effects and exposures from non-point source microbial contaminants in subtropical recreational marine waters. *International Journal of Epidemiology, 39*(5), 1291-1298. doi:10.1093/ije/dyq084

Garcia-Fresca (2007) Urban-enhanced groundwater recharge: review and case study of Austin, Texas, USA. Urban groundwater—meeting the challenge, Selected papers from the 32nd International Geological Congress (IGC), Florence, Italy, August 2004. Howard KW (ed). Taylor & Francis/Balkema, Netherlands, pp. 3–18.

Garver, J.I., 2021. Notes from a Watershed – The Mohawk River. Exploring the intersection of surface water hydrology, dams, ecology, and society. Unpublished reader for GEO 160 “Living with the Mohawk River,” Union College, Schenectady NY. 223 p.

Gill, L. W., O'luanaigh, N., Johnston, P. M., Misstear, B. D. R., & O'suilleabhain, C. (2009). Nutrient loading on subsoils from on-site wastewater effluent, comparing septic tank and secondary treatment systems. *Water Research*, *43*(10), 2739-2749.

Gordon, K. V., Brownell, M., Wang, S. Y., Lepo, J. E., Mott, J., Nathaniel, R., . . . Harwood, V. J. (2013). Relationship of human-associated microbial source tracking markers with enterococci in Gulf of Mexico Waters. *Water Research, 47*(3), 996-1004. doi:10.1016/j.watres.2012.10.032

Green, H., Weller, D., Johnson, S., & Michalenko, E. (2019). Microbial Source-tracking reveals origins of fecal contamination in a recovering watershed. *Water, 11*(10), 2162. doi:10.3390/w11102162

Gridded Soil Survey Geographic (gSSURGO). (2016). Database for the Conterminous United States. United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). Obtained from the USDA Geospatial Data Gateway.

Gutchess, K., Jin, L., Lautz, L., Shaw, S. B., Zhou, X., & Lu, Z. (2016). Chloride sources in urban and rural headwater catchments, Central New York. *Science of The Total Environment, 565*, 462-472. doi:10.1016/j.scitotenv.2016.04.181

Hammerum, A. (2012). Enterococci of animal origin and their significance for public health. *Clinical Microbiology and Infection, 18*(7), 619-625. doi:10.1111/j.1469-0691.2012.03829.x

Hintz, W. D., & Relyea, R. A. (2019). A review of the species, community, and ecosystem impacts of road salt salinization in Fresh Waters. *Freshwater Biology, 64*(6), 1081-1097. doi:10.1111/fwb.13286

Horan, C. 2019 "Characterizing the Waters of 6 Rivers in Upstate New York With a Focus on Physical Hydrology and Controls on Water Quality" (2019). *Honors Theses*, Union College, Schenectady NY

Hur, J., Schlautman, M. A., Karanfil, T., Smink, J., Song, H., Klaine, S. J., & Hayes, J. C. (2006). Influence of drought and municipal sewage effluents on the baseflow water chemistry of an Upper Piedmont River. *Environmental Monitoring and Assessment, 132*(1-3), 171-187. doi:10.1007/s10661-006-9513-1

IPCC, 2018: Summary for Policymakers. In: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (eds.)]. In Press.

Jackson, P. R., García, C. M., Oberg, K. A., Johnson, K. K., & García, M. H. (2008). Density currents in the Chicago River: Characterization, effects on water quality, and potential sources. *Science of The Total Environment, 401*(1-3), 130-143. doi:10.1016/j.scitotenv.2008.04.011

Katz, B. G., Eberts, S. M., & Kauffman, L. J. (2011). Using Cl/Br ratios and other indicators to assess potential impacts on groundwater quality from septic systems: a review and examples from principal aquifers in the United States. *Journal of Hydrology*, *397*(3-4), 151-166.

Kaushal, S. S., & Belt, K. T. (2012). The Urban Watershed Continuum: Evolving Spatial and temporal dimensions. *Urban Ecosystems, 15*(2), 409-435. doi:10.1007/s11252-012-0226-7

Kaushal, S. S., Groffman, P. M., Band, L. E., Elliott, E. M., Shields, C. A., & Kendall, C. (2011). Tracking nonpoint source nitrogen pollution in human-impacted watersheds. *Environmental Science & Technology, 45*(19), 8225-8232. doi:10.1021/es200779e

Kuemmel, D. A., & Hanbali, R. M. (1992). Accident analysis of ice control operations. (Ed D.O.C.E. Engineering). Marquette University

Kelly, V. R., Findlay, S. E., Hamilton, S. K., Lovett, G. M., & Weathers, K. C. (2019). Seasonal and long-term dynamics in stream water sodium chloride concentrations and the effectiveness of Road Salt Best Management Practices. *Water, Air, & Soil Pollution, 230*(1). doi:10.1007/s11270-018-4060-2

Layton, B.A., Walters, S.P., Lam, L.H. and Boehm, A.B. (2010) Enterococcus species distribution among human and animal hosts using multiplex PCR. J Appl Microbiol 109, 539–547.

Litke, D. W. (1999). *Review of phosphorus control measures in the United States and their effects on water quality* (Vol. 99, No. 4007). US Department of the Interior, US Geological Survey.

Mei, K., Zhu, Y., Liao, L., Dahlgren, R., Shang, X., & Zhang, M. (2011). Optimizing water quality monitoring networks using continuous longitudinal monitoring data: a case study of Wen-Rui Tang River, Wenzhou, China. *Journal of Environmental Monitoring*, *13*(10), 2755-2762.

NACWA. (2018). MS4 Storm Permitting Guide. Retrieved March 30, 2022, from https://www.nacwa.org/docs/default-source/news-publications/white-papers/2018-03-07permittingguide.pdf?sfvrsn=29e1f761_4

National land cover dataset (NLCD). (2019) [Map]. Multi-Resolution Land Characteristics Consortium (U.S.). [Research Triangle Park, NC] :[Multi-Resolution Land Characteristics Consortium].

Newton, R. J., & McClary, J. S. (2019). The flux and impact of wastewater infrastructure microorganisms on human and Ecosystem Health. *Current Opinion in Biotechnology, 57*, 145-150. doi:10.1016/j.copbio.2019.03.015

NSF. (2017). Projected precipitation increases are bad news for water quality. Retrieved March 30, 2022, from https://nsf.gov/news/news_summ.jsp?cntn_id=242494#:~:text=Increased%20precipitation%20from%20a%20changing,Science%20and%20Venkatramani%20Balaji%20of

NY Tax Parcels. (2021). Saratoga and Schenectady Counties Tax Parcel Centroid Points, SHAPE. Retrieved from http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1300

Ohno, T. (1990). Levels of total cyanide and NaCl in surface waters adjacent to road salt storage facilities. Environmental Pollution, 67, 123– 132. https://doi.org/10.1016/0269-7491(90)90077-p

Pecher, W. T., Al Madadha, M. E., DasSarma, P., Ekulona, F., Schott, E. J., Crowe, K., . . . DasSarma, S. (2019). Effects of road salt on microbial communities: Halophiles as biomarkers of road salt pollution. *PLOS ONE, 14*(9). doi:10.1371/journal.pone.0221355

Peters, N. E. (1984). Evaluation of environmental factors affecting yields of major dissolved ions of streams in the United States. *U.S. GEOLOGICAL SURVEY WATER-SUPPLY, PAPER 2228*. doi:10.3133/wsp2228

Phillips, P. J., Chalmers, A. T., Gray, J. L., Kolpin, D. W., Foreman, W. T., & Wall, G. R. (2012). Combined sewer overflows: An environmental source of hormones and wastewater micropollutants. *Environmental Science & Technology, 46*(10), 5336-5343. doi:10.1021/es3001294

Pierce, G., Gmoser-Daskalakis, K., Jessup, K., Grant, S. B., Mehring, A., Winfrey, B., . . . Levin, L. (2020). University stormwater management within urban environmental regulatory regimes: Barriers to progressivity or opportunities to innovate? *Environmental Management, 67*(1), 12-25. doi:10.1007/s00267-020-01377-3

Pillay, S., Zishiri, O. T., & Adeleke, M. A. (2018). Prevalence of virulence genes in Enterococcus species isolated from companion animals and Livestock. *Onderstepoort Journal of Veterinary Research, 85*(1). doi:10.4102/ojvr.v85i1.1583

Poudel, D. D., Lee, T., Srinivasan, R., Abbaspour, K., & Jeong, C. Y. (2013). Assessment of seasonal and spatial variation of surface water quality, identification of factors associated with water quality variability, and the modeling of critical nonpoint source pollution areas in an agricultural watershed. *Journal of Soil and Water Conservation, 68*(3), 155-171. doi:10.2489/jswc.68.3.155

Poudel, D., & Jeong, C. (2009). Manual composite sampling in edge-of-field surface runoff for assessing nonpoint source pollution from agricultural lands and residential areas. *Journal of Soil and Water Conservation, 64*(5), 324-335. doi:10.2489/jswc.64.5.324

Powers, N.C., Pinnell, L.J., Wallgren, H.R., Turner, J.W. (2021). Water Quality Dynamics in Response to Rainfall along an Estuarine Ecocline. *ACS ES&T Water, 1* (6), 1503-1514. DOI: 10.1021/acsestwater.1c00051

Praus, P. (2007). Urban water quality evaluation using multivariate analysis. *Acta montanistica slovaca*, *12*(2), 150-158.

Prüss, A. (1998). Review of Epidemiological Studies on health effects from exposure to recreational water. *International Journal of Epidemiology, 27*(1), 1-9. doi:10.1093/ije/27.1.1

Rechenburg, A., Koch, C., Claßen, T., & Kistemann, T. (2006). Impact of sewage treatment plants and combined sewer overflow basins on the microbiological quality of Surface Water. *Water Science and Technology, 54*(3), 95-99. doi:10.2166/wst.2006.454

Riverkeeper. (2020). MOHAWK RIVER Water Quality Monitoring Results 2015-2020. Retrieved February 10, 2022, from https://www.riverkeeper.org/wp-content/uploads/2021/08/2020-Entero-Report-CATSKILL.pdf

Schveitzer, R., Arantes, R., Costódio, P. F. S., do Espírito Santo, C. M., Arana, L. V., Seiffert, W. Q., & Andreatta, E. R. (2013). Effect of different biofloc levels on microbial activity, water quality and

performance of Litopenaeus vannamei in a tank system operated with no water exchange. *Aquacultural Engineering*, *56*, 59-70.

Smith, A.J., Nystrom, E. (2017). Enhanced Water Quality Monitoring in Support of Modeling Efforts in the Mohawk River Watershed. *Proceedings of the 2017 Mohawk Watershed Symposium*, 61-62.

Tamang, A., (2020). "Quantification of septic system contribution to nutrient loads in surface waters" Electronic Thesis and Dissertation Repository. 6885. https://ir.lib.uwo.ca/etd/6885

Tanrıverdi, Ç., Alp, A., Demirkıran, A. R., & Üçkardeş, F. (2010). Assessment of surface water quality of the Ceyhan River basin, Turkey. *Environmental Monitoring and Assessment*, *167*(1), 175-184.

Town of Glenville. (2017). Town of Glenville Comprehensive Plan. Retrieved March 06, 2022, from https://www.townofglenville.org/sites/g/files/vyhlif3161/f/uploads/updated_plan_10-23-17.pdf

Town of Glenville. (2019). Town of Glenville Schenectady County, NY Stormwater Management Program Plan. Retrieved March 6, 2022, from https://www.townofglenville.org/sites/g/files/vyhlif3161/f/uploads/11.4.19_draft.pdf

Town of Glenville. (2021). MS4 Annual Report. https://www.townofglenville.org/sites/g/files/vyhlif3161/f/uploads/2021_ms4_annual_report.pdf.

Tree, J. A., Adams, M. R., & Lees, D. N. (2003). Chlorination of indicator bacteria and viruses in primary sewage effluent. *Applied and environmental microbiology*, *69*(4), 2038-2043.

U.S. EPA (1986) EPA's Ambient Water Quality Criteria for Bacteria – 1986. U.S. Environmental Protection Agency: Washington, DC. EPA 440/5-84-002.

U.S. EPA. (1988). Ambient Water Quality Criteria for Chloride. *United States Environmental Protection Agency, Office of Water Regulations and Standards Criteria and Standards Division, PB88-175 047*.

U.S. EPA. (2004). Illicit Discharge Detection and Elimination. *Office of Water and Wastewater U.S. Environmental Protection Agency*.

U.S. EPA (2012) Recreational Water Quality Criteria. Washington, DC: Office of Water, U.S.EPA. https://www.epa.gov/sites/default/files/2015-10/documents/rwqc2012.pdf

U.S. EPA. (2016). Combined Sewer Overflows into the Great Lakes Basin. *U.S. Environmental Protection Agency, Office of Wastewater Management*.

U.S. EPA. (2017). 2017 Five-Year Review of the 2012 Recreational Water Quality Criteria. *U.S. Environmental Protection Agency: Washington, DC, EPA 823 -R*(18), 001st ser.

U.S. EPA. (2021, September 20). Overview of Total Maximum Daily Loads (TMDLs). Retrieved February 10, 2022, from https://www.epa.gov/tmdl/overview-total-maximum-daily-loads-tmdls#1

U. S. Geological Survey. (2018). *Mineral commodity summaries 2018*. Report. Reston, VA, USA: U. S. Geological Survey; 2018. 200p. 10.3133/70194932

Walsh, C.J., Roy, A.H., Feminella, J.W., Cottingham, P.D., Groffman, P.M., Morgan II, R.P. (2005). The urban stream syndrome: current knowledge and the search for a cure. The North American Benthological Society, 24(3): 706-723. https://www.journals.uchicago.edu/doi/pdf/10.1899/04-028.1

Willard-Bauer, E., Smith, JA, Garver, JI, Goldman, D., Newcomer, B. 2020. Enterococci levels in the Hans Groot Kill and Mohawk River, Schenectady NY. In Garver, J.I., Smith, J.A., and Rodak, C. 2020. Proceedings of the 2020 Mohawk Watershed Symposium, Union College, Schenectady, NY, March 20, 2020, v. 12, p. 63-68

Willard-Bauer, E. 2021 "Pathogen contamination in the Hans Groot Kill, Schenectady, NY" (2021). *Thesis*, Union College, Schenectady NY

Withers, P. J., Jordan, P., May, L., Jarvie, H. P., & Deal, N. E. (2014). Do septic tank systems pose a hidden threat to water quality?. Frontiers in Ecology and the Environment, 12(2), 123-130.

Zgheib, S., Moilleron, R., & Chebbo, G. (2012). Priority pollutants in urban stormwater: Part 1 – case of separate storm sewers. *Water Research, 46*(20), 6683-6692. doi:10.1016/j.watres.2011.12.012

APPENDICES

Appendix A: Enterococcus measured at the Alplaus and Indian Kill (Sept 16 - Nov 17 2021)

i. *Enterococcus* Measured at AP-1

Date Collected	Time Collected	Time Incubated	Time Read	Unk. Conc	Large Cells	Small Cells	Apparent MPN	Actual MPN/100 mL
16 September 2021	14:52	17:01	17:15	0.3	49	48	2419.6	8,065
23 September 2021	10:49	13:56	15:24	1.0	49	24	435.2	435
24 September 2021	9:41	13:38	13:21	0.1	49	48	2419.6	24,196
24 September 2021	11:09	13:37	13:20	0.1	49	48	2419.6	24,196
28 September 2021	12:05	12:35	12:03	0.1	17	0	20.3	203
30 September 2021	9:39	12:10	12:39	0.3	25	4	39.3	131
4 October 2021	1:09	3:34	3:39	0.1	49	48	2419.6	24,196
5 October 2021	10:27	12:35	12:46	0.1	49	47	2419.6	24,196
12 October 2021	15:10	16:36	18:07	0.5	20	3	28.8	58
16 October 2021	12:42	13:19	14:05	0.1	49	44	1553.1	15,531
17 October 2021	12:08	14:00	14:57	0.1	49	44	1553.1	15,531
20 October 2021	10:58	13:00	13:12	0.5	43	10	117.8	236
24 October 2021	13:37	17:09	17:51	0.5	32	1	50.4	101
26 October 2021	10:57	13:00	12:43	0.05	49	44	1553.1	31,062
27 October 2021	16:38	18:55	19:22	0.05	49	21	9:36	7,308

3 November 2021	8:02	10:42	12:39	0.3	14	2	12:00	62
9 November 2021	8:40	12:15	13:30	0.5	25	3	37.9	76
12 November 2021	11:37	13:02	13:27	0.05	49	41	1203.3	24,066
17 November 2021	11:03	15:02	15:02	0.5	27	3	42	84

ii. *Enterococcus* Measured at AP-2

Date Collected	Time Collected	Time Incubated	Time Read	Unk. Conc	Large Cells	Small Cells	Apparent MPN	Actual MPN/100 mL
16 September 2021	15:44	17:01	17:27	0.3	49	44	1413.6	4,712
24 September 2021	12:07	13:39	13:20	0.1	49	48	2419.6	24,196
30 September 2021	10:10	12:11	12:40	0.3	18	1	21.8	73
5 October 2021	11:13	12:42	1:09	0.1	49	42	1,299.7	12,997
12 October 2021	10:50	12:40	12:08	0.1	2	2	4.1	41
20 October 2021	11:55	13:02	13:21	0.5	34	3	59.4	119
26 October 2021	10:21	12:57	12:40	0.050	49	43	1413.6	28,272
9 November 2021	9:40	12:15	13:40	0.500	6	1	7.4	15

iii. *Enterococcus* Measured at AP-3

Date Collected	Time Collected	Time Incubated	Time Read	Unk. Conc	Large Cells	Small Cells	Apparent MPN	Actual MPN/100 mL
16 September 2021	16:00	16:59	17:22	0.3	47	25	461.1	1,537
23 September 2021	12:26	13:53	15:32	1.0	49	18	307.6	308
24 September 2021	12:17	13:30	13:25	0.1	49	48	2419.6	24,196
30 September 2021	10:23	12:14	12:41	0.3	16	0	18.9	63
5 October 2021	11:25	12:37	12:59	0.1	49	39	1,046.2	10,462
12 October 2021	11:04	12:35	12:07	0.1	5	1	6.3	63
20 October 2021	11:42	13:01	13:25	0.5	36	2	63.7	127
26 October 2021	10:37	12:58	12:42	0.050	49	35	816.4	16,328
9 November 2021	9:53	12:15	13;39	0.500	10	2	13.2	26

iv. *Enterococcus* Measured at IK-1

Date Collected	Time Collected	Time Incubated	Time Read	Unk. Conc	Large Cells	Small Cells	Apparent MPN	Actual MPN/100 mL
23 September 2021	11:09	13:58	15:36	1.0	49	26	448.4	448
24 September 2021	11:22	13:37	13:22	0.1	49	48	2419.6	24,196
30 September 2021	9:43	12:09	12:43	0.3	21	5	33.2	111

5 October 2021	10:42	12:43	1:12	0.1	49	41	1203.3	12,033
12 October 2021	10:15	12:34	12:05	0.1	9	2	12	120
20 October 2021	11:08	12:57	13:27:00	0.5	35	3	62.4	125
26 October 2021	11:20	13:01	12:45	0.050	49	45	927.7	34,658
9 November 2021	8:54	12:15	13:42	0.500	44	8	118.7	237

v. *Enterococcus* Measured at IK-2

Date Collected	Time Collected	Time Incubated	Time Read	Unk. Conc	Large Cells	Small Cells	Apparent MPN	Actual MPN/100 mL
16 September 2021	15:27	17:00	17:30	0.3	48	22	298.7	996
23 September 2021	11:23	13:49	15:38	1.0	48	19	260.3	260
24 September 2021	11:48	13:40	13:21	0.1	49	48	2419.6	24,196
30 September 2021	9:57	12:13	12:45	0.3	15	8	27.2	91
5 October 2021	10:58	12:40	1:03	0.1	49	27	517.2	5,172
12 October 2021	10:35	12:39	12:14	0.1	13	1	16	160
20 October 2021	11:22	12:58	13:30	0.5	39	7	86	172
26 October 2021	10:05	12:54	12:36	0.050	49	43	14:24	28,272
9 November 2021	9:25	12:15	13:44	0.500	34	8	68.9	138

vi. *Enterococcus* Measured at IK-3

Date Collected	Time Collected	Time Incubated	Time Read	Unk. Conc	Large Cells	Small Cells	Apparent MPN	Actual MPN/100 mL
20 October 2021	12:00	13:00	13:32	0.5	45	13	148.3	297
24 October 2021	14:00	17:10	17:53	0.5	38	10	88.6	177
26 October 2021	9:52	12:52	12:35	0.050	49	48	14:24	48,392
3 November 2021	8:14	10:42	12:37	0.300	28	5	7:12	158
9 November 2021	9:17	12:15	13:41	0.500	43	9	114.5	229
12 November 2021	11:56	13:05	13:24	0.050	49	48	2419.6	48,392
17 November 2021	11:17	15:02	15:02	0.500	39	5	81.3	163

vii. *Enterococcus* Measured at IK-3 Pipe

Date Collected	Time Collected	Time Incubated	Time Read	Unk. Conc	Large Cells	Small Cells	Apparent MPN	Actual MPN/100 mL
12 October 2021	11:25	12:36	12:10	0.1	1	0	1	10
12 November 2021	11:53	13:03	13:26	0.100	49	15	261.3	2,613

Appendix B: YSI Data collected at the Alplaus and Indian Kill (Sept 16 - Nov 17 2021)

i. YSI Data Collected at AP-1

Date Collected	Temp (ºC)	mmHg	DO%	DO (mg/L)	SPC	Cond	TDS	Salinity	pH	Weather (ºF, conditions)
23 September 2021	19.4	753.9	98.0	9.0	361.9	323.2	235.3	0.17	7.98	79, cloudy
24 September 2021	17.4	755.4	99.0	9.5	170.0	145.4	110.5	0.08	7.55	72, clear
30 September 2021	13.4	758.2	98	10.2	332.8	259	216.45	0.16	7.34	57, cloudy
4 October 2021	15.1	756.4	104	10.5	305.4	247.8	193.25	0.15	7.33	55, raining
5 October 2021	14.3	761.8	99.0	10.1	257.7	205.2	167.7	0.12	7.71	56, sprinkling
12 October 2021	16.9	756.7	107.0	10.4	421.4	356.4	274.3	0.20	8.32	68, sunny
16 October 2021	17.6	744.7	99.0	9.4	382.8	328.9	249.0	0.18	8.08	68, sunny
17 October 2021	14.4	749.2	95.0	9.7	275.0	219.3	178.8	0.13	6.66	57, cloudy
20 October 2021	11.9	754.5	124.0	13.3	420.9	315.9	273.7	0.20	8.17	65, sunny
24 October 2021	10.2	758.6	112.0	12.6	449.8	322.6	292.5	0.22	7.72	55, sunny
26 October 2021	10.8	745.0	91.0	10.0	233.1	169.9	151.5	0.11	7.58	48, raining
27 October 2021	11.7	751.6	106.0	11.5	271.2	202.4	176.2	0.13	8.30	52, cloudy
3 November 2021	6.2	760.5	105.0	13.0	367.4	235.2	238.6	0.18	7.61	43, cloudy
9 November 2021	4.9	758.5	100.0	12.8	408.9	251.9	265.8	0.29	7.70	40, sunny
12 November 2021	12.0	747.7	119.0	12.8	162.6	122.3	106.0	0.08	8.05	40, raining

17 November 2021	4.4	762.4	116.0	15.0	322.1	195.3	209.3	0.15	7.56	43, sunny

ii. YSI Data Collected at AP-2

Date Collected	Temp (ºC)	mmHg	DO%	DO (mg/L)	SPC	Cond	TDS	Salinity	pH	Weather (ºF, conditions)
23 September 2021	19.5	750.0	109.0	10.0	309.5	277.1	201.5	0.15	8.18	79, cloudy
24 September 2021	17.4	751.6	101.0	9.7	183.7	157.0	119.6	0.09	7.43	72, clear
30 September 2021	13.2	754.5	113	11.9	290.8	225.2	189.15	0.14	8.02	57, cloudy
5 October 2021	14.1	758.4	96.0	9.8	244.5	193.7	158.6	0.12	7.73	56, sprinkling
12 October 2021	13.8	755.5	101.0	10.40	358.70	282.2	233.35	0.17	7.93	68, sunny
20 October 2021	11.9	750.6	102.0	11.0	351.1	263.2	228.2	0.17	8.10	65, sunny
26 October 2021	10.5	742.4	93.0	10.3	240.0	170.7	156.0	0.11	7.49	48, raining
9 November 2021	4.9	754.1	102.0	13.0	335.6	207.0	213.4	0.16	7.75	40, sunny

iii. YSI Data Collected at AP-3

Date Collected	Temp (ºC)	mmHg	DO%	DO (mg/L)	SPC	Cond	TDS	Salinity	pH	Weather (ºF, conditions)
23 September 2021	19.8	750.5	100.0	9.8	311.9	281.0	202.8	0.15	8.10	79, cloudy
30 September 2021	13.5	755.1	112	11.7	295.4	230.5	191.75	0.14	7.98	57, cloudy
5 October 2021	14.2	759.0	96.0	9.9	245.2	194.5	159.3	0.12	7.81	56, sprinkling

12 October 2021	14.3	756.1	134.0	13.7	364.7	290.2	237.3	0.18	8.13	68, sunny
20 October 2021	11.9	751.2	100.0	10.8	358.2	268.6	232.7	0.17	8.06	65, sunny
26 October 2021	10.5	742.7	89.0	10.0	259.0	187.3	168.3	0.12	7.55	48, raining
9 November 2021	5.1	754.6	97.0	12.3	346.6	215.1	225.6	0.17	7.88	40, sunny

iv. YSI Data Collected at IK-1

Date Collected	**Temp (ºC)**	**mmHg**	**DO%**	**DO (mg/L)**	**SPC**	**Cond**	**TDS**	**Salinity**	**pH**	**Weather (ºF, conditions)**
23 September 2021	18.6	753.3	93.0	8.7	450.1	323.2	292.5	0.22	8.07	79, cloudy
24 September 2021	17.4	755.1	98.0	9.4	125.2	107.1	81.3	0.06	7.36	72, clear
30 September 2021	13.1	758.0	109.0	11.4	415.7	312.5	270.4	0.20	7.76	57, cloudy
5 October 2021	14.3	761.7	99.0	10.2	231.6	184.4	150.8	0.11	7.69	56, sprinkling
12 October 2021	13.9	759.1	116.0	12.0	543.0	427.0	353.0	0.26	8.11	68, sunny
20 October 2021	12.4	754.1	97.0	10.3	551.9	418.9	358.8	0.27	7.95	65, sunny
26 October 2021	10.7	745.7	89.0	9.9	299.9	217.0	195.0	0.14	7.64	48, raining
9 November 2021	5.9	758.1	97.0	12.1	555.6	352.8	361.4	0.27	7.81	40, sunny

v. YSI Data Collected at IK-2

Date Collected	**Temp (ºC)**	**mmHg**	**DO%**	**DO (mg/L)**	**SPC**	**Cond**	**TDS**	**Salinity**	**pH**	**Weather (ºF, conditions)**

23 September 2021	19.6	751.1	84.0	7.6	349.1	312.9	226.8	0.17	7.97	79, cloudy
24 September 2021	17.5	752.7	100.0	9.6	116.0	99.3	75.4	0.05	7.41	72, clear
30 September 2021	13.5	755.6	118	12.3	315.1	246.2	204.75	0.15	7.85	57, cloudy
5 October 2021	14.3	759.4	93.0	9.5	189.2	150.4	122.9	0.09	7.55	56, sprinkling
12 October 2021	14.1	756.7	121.0	12.4	381.9	302.6	248.3	0.18	7.99	68, sunny
20 October 2021	12.4	751.8	96.0	10.2	350.1	265.9	227.5	0.17	8.01	65, sunny
26 October 2021	10.6	743.7	90.0	10.0	210.8	152.7	137.2	0.10	7.36	48, raining
9 November 2021	5.1	755.4	93.0	11.8	388.1	240.5	252.2	0.19	7.89	40, sunny

vi. YSI Data Collected at IK-3

Date Collected	Temp (ºC)	mmHg	DO%	DO (mg/L)	SPC	Cond	TDS	Salinity	pH	Weather (ºF, conditions)
12 October 2021	14.6	756.4	92.0	9.3	978.0	783.0	637.0	0.49	7.89	68, sunny
20 October 2021	13.2	751.6	92.0	9.6	871.0	675.0	565.5	0.43	7.91	65, sunny
24 October 2021	11.3	755.9	97.0	10.6	945.0	697.0	617.5	0.47	7.88	55, sunny
26 October 2021	11.1	743.7	95.0	10.4	310.0	228.7	202.2	0.15	7.43	48, raining
3 November 2021	8.1	757.7	104.0	12.2	613.8	416.2	399.1	0.30	7.69	43, cloudy
9 November 2021	8.0	755.3	89.0	10.5	668.2	451.7	434.2	0.33	7.94	40, sunny
12 November 2021	9.0	750.7	94.0	10.9	456.9	317.3	297.1	0.22	7.43	40, raining

17 November 2021	7.1	759.4	95.0	11.5	539.9	355.2	355.2	0.26	7.78	43, sunny

vi. YSI Data Collected at IK-3

Date Collected	Temp (ºC)	mmHg	DO%	DO (mg/L)	SPC	Cond	TDS	Salinity	pH	Weather (ºF, conditions)
12 November 2021	11.1	747.9	87.0	9.5	276.1	203.0	179.4	0.13	7.68	40, raining

Appendix C: Ion Chromatograph Data collected at the Alplaus and Indian Kill (Sept 16 - Nov 17 2021)

i. Ion Chromatograph Data Collected at AP-1

Date Collected	Li	Na	NH_4	K	Mg	Ca	Sr	F	Cl	NO_2	Br	NO_3	SO_4	PO_4
16 September 2021	0.00	25.04		2.88	7.90	40.36		0.06	35.8	0.01	0.02	1.07	5.85	0.07
23 September 2021	0.00	51.92		2.47	11.70	60.17		0.07	78.7	0.02	0.02	2.48	12.39	0.03
24 September 2021	0.00	13.08	0.01	4.47	4.18	21.01		0.05	18.5	0.01	0.00	1.33	4.74	0.09
24 September 2021	0.00	12.61		4.26	4.13	20.14		0.05	17.7	0.01	0.01	1.27	4.72	0.19
28 September 2021														
30 September 2021	0.00	43.22		2.27	10.83	54.54		0.06	65.4	0.01	0.02	3.21	12.26	0.02
4 October 2021	0.00	40.74		3.28	9.88	47.79		0.06	62.0	0.01	0.02	1.80	11.09	0.06

5 October 2021	0.00	21.92		3.06	6.91	32.79		0.05	30.9	0.00	0.01	0.92	6.50	0.07
12 October 2021														
16 October 2021	0.0006	29.92	0.02	3.95	9.64	44.08	0.11	0.07	47.02	0.01	0.02	0.73	7.63	0.03
17 October 2021	0.0002	17.17	0	3.77	6.66	30.08	0.07	0.05	24.3	0	0.01	0.56	5.37	0.05
20 October 2021	0.0006	32.94	n.a.	2.53	9.92	46.53	0.05	0.06	48	0.01	0.02	2.46	9.67	0.02
24 October 2021	0.0009	42.65	n.a.	2.25	11.14	52.99	0.07	0.07	59.39	0.01	0.02	2.3	11.07	0.01
26 October 2021	0.0003	20.64	n.a.	3.03	6.97	31.66	n.a.	0.05	30.69	0	0.02	1.03	6.36	0.09
27 October 2021	0.0003	18.19	n.a.	2.58	6.72	30.78	0.07	0.05	22.87	0	0.01	1.3	6.16	0.04
3 November 2021	0.0006	31.91	n.a.	1.97	9.66	45.26	0.11	0.06	45.68	0.01	0.02	2.79	10.32	0.02
9 November 2021	0.0008	38.56	n.a.	1.8	10.82	50.93	0.11	0.05	57.58	0.01	0.02	3.52	12.84	0.01

ii. Ion Chromatograph Data Collected at AP-2

Date Collected	Li	Na	NH_4	K	Mg	Ca	Sr	F	Cl	NO_2	Br	NO_3	SO_4	PO_4
16 September 2021	0.00	19.19	0.00	2.45	7.06	38.67		0.06	26.2	0.02	0.02	1.07	5.06	0.16
23 September 2021	0.00	29.98		2.16	10.27	54.53	0.09	0.07	43.8	0.01	0.01	1.68	7.64	0.03
24 September 2021	0.00	11.51	0.02	3.70	4.60	23.75		0.05	16.2	0.01	0.01	1.59	4.14	0.12
30 September 2021	0.00	25.59		1.88	9.42	49.80	0.06	0.06	36.8	0.01	0.02	3.14	7.67	0.04
5 October 2021	0.00	18.00		2.72	6.43	32.65		0.06	24.8	0.00	0.01	1.37	5.12	0.06

12 October 2021	0.0007	25.22	n.a.	1.85	9.49	48.03	0.08	0.06	37.4	0.01	0.02	1.86	7.20	0.01
20 October 2021	0.0006	24.82	0.01	2.2	8.84	45.22	0.11	0.06	29.87	0.01	0.01	2.68	6.69	0.02
26 October 2021	0.0002	14.53	n.a.	3.06	5.55	25.86	0.01	0.04	19.58	0	0.01	1.26	4.05	0.07
9 November 2021	0.0006	21.99	n.a.	1.47	9.04	44.62	0.1	0.05	30.91	0	0.01	2.89	8.35	0.01

iii. Ion Chromatograph Data Collected at AP-3

Date Collected	Li	Na	NH_4	K	Mg	Ca	Sr	F	Cl	NO_2	Br	NO_3	SO_4	PO_4
16 September 2021	0.00	24.68		2.44	8.90	42.70	0.04	0.06	37.0	0.00	0.01	0.85	5.18	0.05
23 September 2021	0.00	31.15		2.19	10.42	54.04	0.07	0.06	46.1	0.00	0.01	1.05	7.47	0.02
24 September 2021	0.00	11.69	0.02	4.00	4.57	23.09	0.02	0.05	16.6	0.01	0.01	1.63	4.23	0.12
30 September 2021	0.00	26.42		1.93	9.64	50.46	0.04	0.06	38.6	0.01	0.01	3.02	7.99	0.03
5 October 2021	0.00	18.36		2.83	6.48	32.52		0.05	25.5	0.00	0.01	1.31	5.17	0.07
12 October 2021	0.001	26.71	0.02	2.01	9.97	49.65	0.13	0.06	39.5	0.01	0.01	1.77	7.73	
20 October 2021	0.0008	28.65	n.a.	2.22	9.45	46.47	0.06	0.06	31.33	0.01	0.02	2.69	6.97	0.01
26 October 2021	0.0003	15.58	n.a.	2.73	6.03	29.78	0.05	0.05	22.3	n.a.	0.01	1	4.48	0.04
9 November 2021	0.0006	23.14	n.a.	1.49	9.23	45.32	0.06	0.05	33.02	0	0.02	2.95	8.65	0

iv. Ion Chromatograph Data Collected at IK-1

Date Collected	Li	Na	NH_4	K	Mg	Ca	Sr	F	Cl	NO_2	Br	NO_3	SO_4	PO_4
16 September 2021	0.00	52.52		2.56	9.24	46.78		0.07	73.6	0.01	0.04	2.56	11.53	0.05
23 September 2021	0.00	101.95		2.70	12.95	80.01		0.08	158.4	0.02	0.04	8.71	24.92	0.04
24 September 2021	0.00	11.07		3.45	2.76	12.42	0.01	0.04	13.8	0.00	0.01	0.63	4.89	0.06
30 September 2021	0.00	87.26		2.68	12.26	71.40		0.07	131.3	0.01	0.04	8.01	23.53	0.03
5 October 2021	0.00	22.63		2.85	5.46	24.76		0.05	29.1	0.00	0.02	0.73	7.81	0.06
12 October 2021	0.0016	83.53	n.a.	2.65	12.69	69.25	0.16	0.07	124.93	0.01	0.04	6.98	22.08	0.03
20 October 2021	0.0007	62.65	n.a.	2.63	10.71	55.34	0.08	0.08	97.45	0.02	0.04	5.65	18.85	0.03
26 October 2021	0.0001	17.57	n.a.	2.64	5.09	22.57	n.a.	0.05	48.02	0.01	0.02	1.17	9.58	0.12
9 November 2021	0.0015	76.25	n.a.	2.26	12.32	66.03	0.13	0.06	117.12	0.01	0.04	7.46	22.66	0.03

v. Ion Chromatograph Data Collected at IK-2

Date Collected	Li	Na	NH_4	K	Mg	Ca	Sr	F	Cl	NO_2	Br	NO_3	SO_4	PO_4

16 September 2021	0.00	31.45		2.39	7.31	30.68		0.08	40.5	0.00	0.03	0.27	5.63	0.04
23 September 2021	0.00	50.48		2.29	10.52	47.09	0.06	0.08	70.9	0.01	0.04	1.35	7.87	0.02
24 September 2021	0.00	9.40		3.25	2.52	9.75	0.01	0.04	11.2	0.00	0.01	0.35	4.17	0.12
30 September 2021	0.00	41.93		2.34	9.65	42.01		0.08	56.8	0.00	0.04	2.11	9.29	0.02
5 October 2021	0.00	16.79		2.87	4.68	18.38		0.05	20.8	0.00	0.02	0.18	5.73	0.05
12 October 2021	0.0006	38.73	n.a.	2.23	9.86	41.49	0.1	0.07	54.5	0.00	0.03	1.26	8.32	0.01
20 October 2021	0.0004	29.63	0.01	2.48	8.45	33.25	0.08	0.06	39.79	0	0.03	1.08	7.6	0.02
26 October 2021	0.0002	14.62	0	3.01	5.23	19.73	0.04	0.05	19.85	0	0.02	0.02	3.73	0.05
9 November 2021	0.0006	36.15	n.a.	1.8	9.95	40.13	0.02	0.06	50.64	0	0.04	2.22	10.51	0.01

vi. Ion Chromatograph Data Collected at IK-3

Date Collected	Li	Na	NH_4	K	Mg	Ca	Sr	F	Cl	NO_2	Br	NO_3	SO_4	PO_4
12 October 2021	0.0016	101.9	n.a.	2.77	15.47	90.60	0.13	0.07	151.0	0.04	0.05	10.03	29.62	0.05
20 October 2021	0.0016	87.74	n.a.	2.71	14.42	82.19	0.18	0.07	132.14	0.03	0.05	8.58	27.26	0.03
24 October 2021	0.0021	109.87	n.a.	2.86	15.51	90.68	0.16	0.08	170.06	0.03	0.05	9.98	32.89	0.05
26 October 2021	0.0006	32.47	0.02	2.65	6.84	34.7	0.07	0.04	35.34	0	0.01	1.68	8.84	0.12
3 November 2021	0.0012	99.25	n.a.	2.62	14.22	82.17	0.16	0.08	155.17	0.02	0.05	9.5	31.44	0.04
9 November 2021	0.0015	149.89	n.a.	3.06	15.4	95.85	0.18	0.07	219.05	0.02	0.05	10.44	42.46	0.05

vii. Ion Chromatograph Data Collected at IK-3 Pipe

Date Collected	Li	Na	NH_4	K	Mg	Ca	Sr	F	Cl	NO_2	Br	NO_3	SO_4	PO_4
12 October 2021	0.0004	286.66	n.a.	4.4	15.20	115.09	0.13	0.11	394.0	0.01	0.08	12.68	69.47	0.13

Appendix D: Rainfall Data (in) Collected at The Union Weather Station (Sept 16 - Nov 17 2021)

i. Rainfall Data Collected at Union College Weather Station and calculated for 12-, 24-, and 48-hour averages

Date Collected	12 Hour	24 Hour	48 Hour
16 September 2021	0	0.39	0.45
23 September 2021	0.01	0.01	0.06
24 September 2021	2.33	2.53	2.54
28 September 2021	0	0	0.01
30 September 2021	0	0	0
4 October 2021	0.78	1.35	1.22
5 October 2021	0.19	0.74	1.77
12 October 2021	0	0	0
16 October 2021	0.01	0.4	0.51
17 October 2021	0	1.44	1.84
20 October 2021	0	0	0.01
24 October 2021	0	0	0
26 October 2021	1.17	1.18	2.02
27 October 2021	0	0.14	1.54
3 November 2021	0	0	0
12 November 2021	0.92	0.92	0.92
17 November 202 1	0	0	0.01