6-2022

Sewage and Pathogen Contamination in Urban Streams in Schenectady in the Lower Mohawk Watershed

Joanna Wright
Union College - Schenectady, NY

Sewage and pathogen contamination in urban streams in Schenectady in the lower Mohawk Watershed

by
Joanna Wright

****

Submitted in partial fulfillment of the requirements for the degree of
Bachelor of Science in the Geosciences
Union College
June 2022

ABSTRACT

Wright, Joanna Grace, 2022. Sewage and pathogen contamination in urban streams in Schenectady in the lower Mohawk Watershed. Unpublished BS thesis, Geosciences, Union College.

Urban streams are becoming increasingly polluted by anthropogenic activity, and in Schenectady (NY) two primary stressors include poor wastewater infrastructure and road salt use. Urban streams in Schenectady include Mill Creek and Cowhorn Creek that empty into the Binnekill (feeder to the Mohawk), and the Hans Groot Kill that empty directly into the Mohawk River. These streams were sampled to evaluate water quality and analyzed for pathogens. This study is primarily focused on fecal indicator bacteria (FIB) *Enterococcus,* which is an EPA-approved method of determining surface water quality and it is an established indicator of sewage in waterways. The average pathogen values in the Hans Groot Kill and Binnekill exceeded EPA guidance for *Enterococcus*, often by several orders of magnitude. In the fall of 2021, the majority of samples failed the EPA's criteria for contact with surface waters including those from the Binnekill (74% failure, n=11), the Hans Groot Kill (100% failure, n=32), and the Mohawk River (54% failure, n=43). Geometric means for the Binnekill, Hans Groot Kill, and Mohawk River were 267 MPN/100 mL, 2223 MPN/100 mL, and 223 MPN/100 mL, respectively, all exceeding the EPA's guidance of 33 MPN/100 mL. High pathogen loads occur during rainfall events when contaminants are mobilized. However, *Enterococcus* levels in the Hans Groot Kill remain high even during dry or low-flow periods, indicating a base-level contamination that occurs in all weather conditions, almost certainly due to impaired infrastructure (broken pipes). During extreme weather events, Union College is impacted by failing sewer systems, as was the case twice in the fall of 2021, when sewer overflows on campus spilled untreated wastewater directly into the Hans Groot Kill. At low base flow, the urban creeks have elevated levels of nitrate, sulfate, chloride, and sodium that may indicate loads from contaminated groundwater. This is especially apparent in elevated levels of sodium and chloride, which probably come from road salt that temporarily resides in groundwater but is released and measurable at base flow. Elevated levels of sodium, chloride, nitrate, and phosphate are particularly problematic. The high dissolved ion loads as well as high pathogen levels in these water bodies indicates the acute leaking of sewer pipes in Schenectady due to aging infrastructure and/or illegally connected pipes. Monitoring of these waters must continue to inform plans for improved sewage handling that need to be implemented to remediate contamination in the Mohawk Watershed.

ACKNOWLEDGEMENTS

I would like to pay special respect to those who made this project happen. Thank you to my friends and colleagues who expressed interest in my thesis and leant support as I concluded this research. I must also express gratitude to fellow thesis student Cam Ragland, who assisted with collecting samples, analyzing data, and staying motivated. I would like to thank the Union College Geosciences Department faculty who assisted with several steps along this process, including Mason Stahl and Matt Manon. Finally, I would like to express my deepest thanks to my thesis advisor, John Garver, for introducing me to this ongoing project, guiding me through my thesis, and cultivating my passion for water quality.

Table of Contents

FIGURES

TABLES

APPENDICES

INTRODUCTION

The Mohawk River is an historically significant river with both rural and urban tributaries that feed into the Hudson River. Since before the first European colonizers arrived in the Schenectady area, the Mohawk River has been used for transportation of goods and commerce and thus a number of river-lining communities sprung up along the river, including Schenectady. Although the commercial and shipping days of the Mohawk are largely past, the Mohawk River is still valued for its fishing, its beauty, and its historic charm. Ensuring the health and quality of the Mohawk's waters is crucial for fostering a new phase of river use that includes drinking water resources and recreation. One area of concern and interest is how urban creeks and streams may impact the river. In the Schenectady area, the Mohawk Watershed includes tributaries such as the Hans Groot Kill, the Binnekill, Cowhorn and Mill Creeks, and the Alplaus Kill watershed (Fig. 1). Many of the creeks in the Schenectady area have seen alterations in natural hydrology due to the urban footprint. Schenectady saw major expansion between 1900-1930, and thus its urban infrastructure is aging. This means that sanitary sewers, stormwater sewers, and drinking water pipes are nearing the limit of their useful life.

A relatively simple way to approach water quality is by the use of physical water quality parameters. These parameters include temperature, pH, salinity, total dissolved solids, and more. These parameters help researchers and planners monitor basic water quality and can capture one-time pollution (such as chemical spills, floods, or drought inputs) as well as extended, long-term pollution such as contaminated groundwater or constantly leaking sewage infrastructure (Olds et al., 2018). Fresh water tends to be lower in ionic concentrations than salt water, so parameters such as salinity, total dissolved solids, and specific conductance can be used to assess water quality. However, continually elevated ionic loading of nitrate, phosphate, sodium, and chloride can hint at a much larger sewage infrastructure issue.

Water quality can also be monitored with the use of pathogens. Fecal indicator bacteria (FIB) such as *E. coli, Enterococcus,* fecal coliforms, or total coliform bacteria can be monitored to determine water quality (Boehm and Sassoubre, 2014). While *E. coli* can cause serious human illness, *Enterococcus* is a natural bacteria of the human gut and typically causes little harm to humans on its own (Byappanahalli et al., 2012). Although *Enterococcus* naturally occurs in other animals (cows, horses, dogs, etc.), the concentrated presence of *Enterococcus* in the human intestinal tract makes it a good predictor of human sewage in water. The presence of

Enterococcus suggests the presence of other harmful pathogens such as *E. coli* or the parasite *Giardia*, even though *Enterococcus* on its own does not pose a risk to human health. The U.S. Environmental Protection Agency (EPA) has set guidance of safe bacterial limits (both *E. coli* and *Enterococcus*) that can be used to issue advisories at beaches and recreational waters (U.S. EPA, 2012)[1]. States do have some control over these limits, but the EPA instructs individual states to implement the rules.

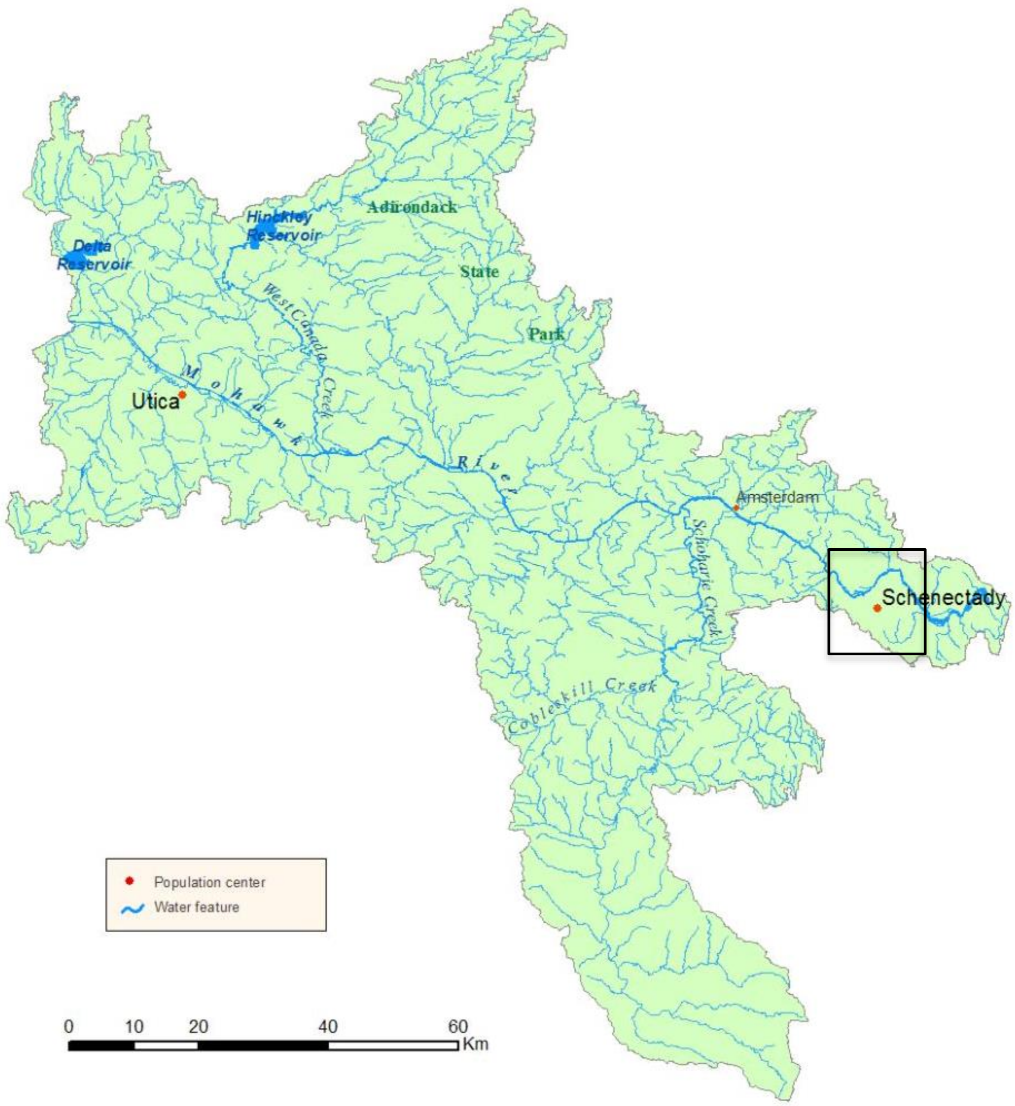

Figure 1. Detailed map of the Mohawk Watershed in eastern New York State. Schenectady is denoted by a red dot. Black box marks the study area. The Mohawk River flows from the northwest to southeast. Figure from New York State Department of Environmental Conservation.

[1] https://www.epa.gov/sites/default/files/2015-10/documents/rwqc2012.pdf

The EPA began setting guidance for recreational water in the 1980's, following the Clean Water Act (CWA), an act meant to make the United State's waters clean and swimmable (U.S. EPA, 2012). The CWA, at the federal level, guides the EPA to research and set limits on bacterial loads to keep waters safe. At the state level, the EPA instructs states and their own Departments of Environmental Conservation (DEC) to set individual limits of bacteria in order to alert public beaches and recreational waters of water pollution. The Fecal Indicator Bacteria or FIB (either *E. coli* or *Enterococcus*) are enumerated to determine if bacteria in water is above or below the beach action value (BAV). Following this rather complex system, the federal government and individual state governments, under the CWA, aim to implement measures that will protect public health.

Urban areas have sewage systems that can be problematic, especially as they age (Sercu et al., 2011). Some sewage systems are nearly a century old and increasing populations have put increased strain on the systems. Urban areas typically see elevated levels of pathogens in surface water, and outdated infrastructure only worsens this predicament (Sercu et al., 2011). Cities in the Northeast typically handle their sewage and stormwater in primarily two ways: combined sewer overflows (CSO's) and municipal separate storm sewer systems (MS4's). Where MS4's completely separate sewage from stormwater, the older CSO systems allow for untreated stormwater and wastewater to discharge directly into surface waters during high rainfall events. The EPA is phasing out CSO systems, as they contain untreated sewage that pollutes our waterways. However, the transition from a CSO to MS4 can be a complicated, costly, and lengthy process.

As climate continues changing, precipitation in the Northeast, including the Schenectady area, will continue to increase (Garver, 2021b). Larger rainfall events have already become more common, especially from large tropical storms in the summer and early fall. Storms are becoming bigger and more frequent, and our sewer systems must be able to handle these changing climatic conditions. Urban systems need to handle stormwater without polluting surface waters; outdated systems already struggle, and pressures from climate change are pushing these systems past their breaking point. As these extreme events change and become more common, we must adapt and improve our sewage infrastructure (Garver, 2021b).

A senior thesis at Union College by Eva Willard-Bauer (2021) studied the pathogens in the Hans Groot Kill (HGK), the urban stream that runs through Union College's campus (Willard-Bauer, 2021). The project determined the severe contamination of the HGK by *Enterococcus*, both in dry weather and in wet weather. The continuously high levels of FIB in the HGK were interpreted to indicate sewage infrastructure failure (leaking pipes and/or illicit discharges) polluting the Hans Groot Kill and the Mohawk Watershed, as well as a major health hazard to the public (Willard-Bauer, 2021).

Creeks in Schenectady are not limited to just the Hans Groot Kill and the Binnekill. Other creeks include Cowhorn Creek and Mill Creek, both of which have been completely buried under the city in pipes. The Cowhorn Creek briefly is exposed in Vale Cemetery, and it includes a small pond in the cemetery. Although the Cowhorn Creek and Mill Creek still flow today, they flow underground in buried pipes beneath State Street and Erie Boulevard. Streams in Niskayuna, to the east of Schenectady, drain to the east but include streams such as Lisha Kill. Most streams in this large area are at least partially covered by pipes or culvert, but eventually drain into the Mohawk River.

Some groups in the Mohawk Watershed aim to protect and monitor water quality, such as Riverkeeper and partners. Riverkeeper started as the Hudson River Fisherman's Association, but today they aim to protect and restore water quality in the Hudson River from source to sea. Riverkeeper and academic partners at SUNY Cobleskill and SUNY Poly (Utica) have monitored water quality since 2015 in the Mohawk Watershed with *Enterococcus*, sampling sites including Lock 8, the Schenectady wastewater treatment plant, Rexford Bridge, and the Vischer Ferry Dam (Fig. 2).

In this project, monitoring of the Hans Groot Kill was continued, as well as new sites in the Binnekill (another small urban creek) and the Mohawk River. Samples were collected in what turned out to be a relatively wet fall of 2021 from September through November. The FIB used was *Enterococcus*, along with other physical water quality parameters and ionic concentrations. These data were collected to analyze and address water quality in the urban streams of Schenectady and the impact they have on water quality in the Mohawk River.

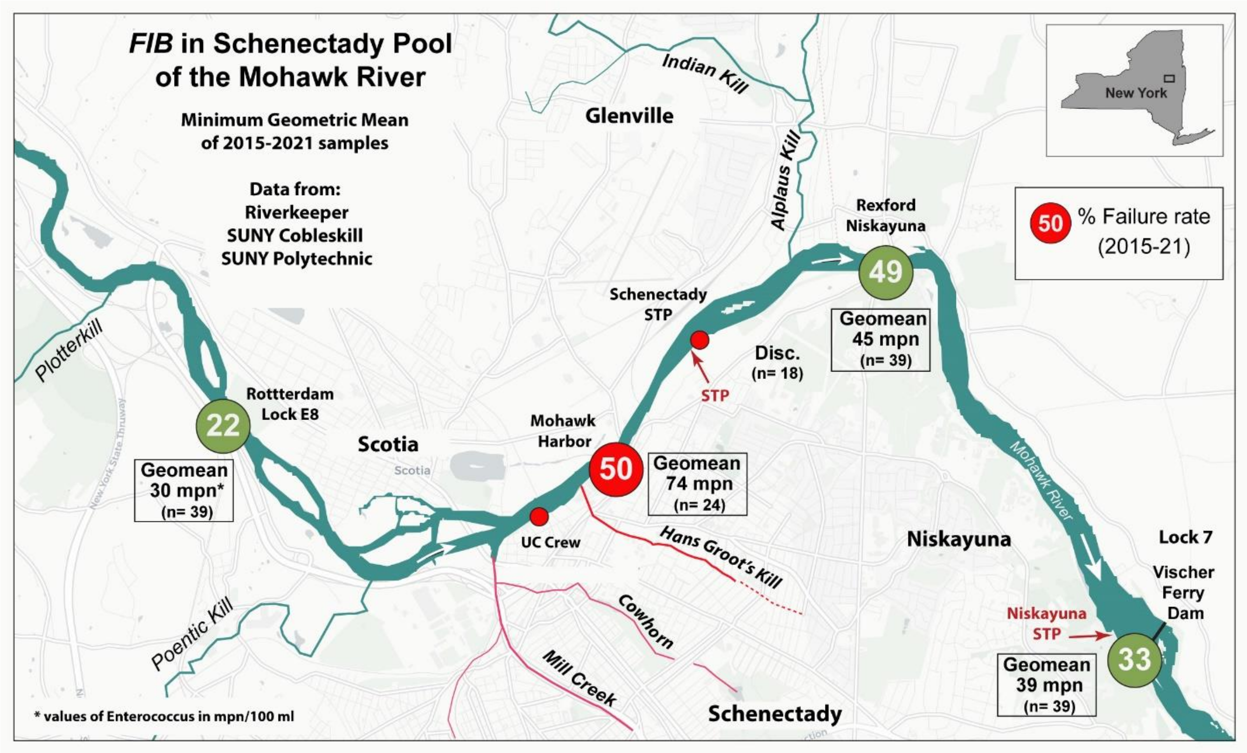

Figure 2. Failure rates at Riverkeeper sampling location on the Mohawk River. Locations, from left to right, include Lock 8, the Schenectady wastewater treatment plant, Rexford Bridge, and Vischer Ferry Dam.

BACKGROUND

This thesis involves an investigation of pathogens in urban creeks in the Schenectady area and how they may affect the Mohawk River. Most of the contamination is presumably from sewage contamination due to impaired infrastructure. Water samples were collected to analyze fecal indicator bacteria (*Enterococcus*), and other water quality parameters were also measured. This background section reviews and explores several important components of this thesis.

Urban Stream Syndrome

Urban stream syndrome indicates the key features that reflect high flows and impaired aquatic conditions (Walsh et al., 2005). Walsh and colleagues defined Urban Stream Syndrome as streams that have a "…flashier hydrograph, elevated concentrations of nutrients and contaminants, altered channel morphology, and reduced biotic richness, with increased dominance of tolerant species" (2005). Society has fundamentally changed the natural hydrology of the majority, if not all, of the urban streams in the Mohawk watershed. As buildings, roads, parking lots, and other infrastructure have been built, the land available to naturally filter water

into has declined. When rain events occur, there is a much greater overland flow and stormwater runoff, which flows directly into the nearest stream, causing an extremely ‘flashy’ hydrograph, which records the changing water level (Walsh et al., 2005). Flashy hydrographs have very high peaks that occur much closer to the rain event, and thus there is very little lag time between rainfall and stream discharge. The flow in streams increases dramatically with precipitation events, which can cause accelerated erosion along river and stream channels. This situation results in bank erosion and changes in channel morphology.

Pollution can cause major damage to the aquatic environment from both surface pollution and leaking sewage pipes. As rainfall flows overland, surface pollution can become incorporated into the flow and transported in streams. When rain overwhelms sanitary and stormwater sewer systems, sewage overflow may become a major issue, unless the sewer systems are new and do not leak (Andonie, 2019). One issue is that sewage pipes may leak (due to age) or they may overflow. Sewage exfiltration can occur when old pipes crack and leak (Wolf et al., 2012; Sercu et al., 2011). As many communities, including Schenectady, have not dealt with current leakages and infrastructure failures, it is worrying to think of the future of our cities and our water quality. Although climate change impacts different regions of the United States in different ways, the Northeast is receiving more precipitation: as precipitation increases, what does this mean for the future of sewage leaks, water quality, and human health?

Water Resources and Drinking Water in the lower Mohawk River

Sewage exfiltration from sanitary sewer lines increases pathogen levels in groundwater and streams and the overall effect is to increase nutrient loads in surface waters (Nguyen and Venohr, 2021). Nutrients such as nitrogen and phosphorus are two main ingredients in agricultural fertilizers, which are typically limiting reagents in crops, but they are both also common nutrients in sewage in urban settings (Nguyen and Venohr, 2021). When these nutrients enter aquatic ecosystems, they can severely degrade stream health. Algae blooms occur in water under these conditions: excess nutrients, warm temperatures, and still waters (Cheng et al., 2019)—these algal blooms can then fix carbon in the water column. Some algae in algal blooms contain cyanobacterias, which produce harmful toxins that then cause harm on their own (Pelley, 2016). When algae blooms die off, a large drop in dissolved oxygen in the water occurs with the decay of the algal bloom. This eutrophication of the water upsets the ecosystem and can be fatal to many sensitive species (Cheng et al., 2019).

When this nutrient flux occurs, algal blooms can wreak havoc on the river ecosystem (Cheng et al., 2019). In many rivers, slight increases in these nutrients occur with rainfall events as surface runoff and potential stormwater enters the system. In streams such as the Hans Groot Kill, a constant release of nutrients, likely from exfiltration of sewage, has undoubtedly damaged the ecosystem. When these smaller tributaries drain to the main stem of the Mohawk River, constant influxes of nutrients also damage this larger ecosystem. Not only is exfiltrating sewage increasing pathogen levels, but it also increases nutrient loading, harmful algal blooms (HABs), and eutrophication (Pelley, 2016). This situation is important for the downstream communities of Colonie and Cohoes that take their raw water for drinking from the Mohawk River.

Chlorine is used to disinfect municipal drinking water, but this can result in by-products that are harmful to human health (Clark and Sivaganesan, 1998). Chlorine is used globally as a disinfectant, but other forms of disinfectant may be supplementary or primary (ozone, chlorine dioxide, or chloramine) (Richardson et al., 2000). Disinfectants are reactive (most with carbon in the raw water source), and any form of water disinfection leads to the formation of disinfection by-products (DBPs). Most DBPs are regulated in New York State (especially HAA5 and TTHM). Many DBPs are known to be carcinogenic and/or genotoxic and have been associated with bladder cancer (Evlampidou et al., 2020).

The formation of DBPs depends on water quality parameters such as water temperature and pH, as well as the conditions under which the disinfectants were added, such as time, dose, and concentration (Liang and Singer, 2003). Two groups of DBPs are regulated. Total trihalomethanes (TTHMs) are a group of chemicals that form when chlorine (or other chemical disinfectants) are used to clean drinking water. High levels of TTHMs can be dangerous in drinking water and display a relationship to cancers such as bladder cancer and birth defects (Evlampidou et al., 2020; Backer et al., 2000). Haloacetic acids (HAAs, sometimes called HAA5 or HAA9 depending on how many are included) are of increasing concern as DBPs in drinking water (Backer et al., 2000). Improving water quality, water sources, and disinfection measures could decrease the risk of bladder cancer and birth abnormalities.

Municipal Sewer Systems

Cities with poorly designed sewer and stormwater pipes may experience elevated levels of pollution in their surface waters and groundwater (Howard et al., 2006). Two main systems of stormwater and sewage pipes are employed in the United States; the Combined Sewer Overflow

(CSO) and the Municipal Separate Storm Sewer System (MS4). With CSO systems, pipes transport all wastewater (and runoff from streets) to a treatment facility. During rainfall events, however, rainwater combined with raw sewage may exceed the capacity of the sewer system, which is designed to discharge this excess flow directly into nearby water bodies. CSO systems are widely being phased out by the EPA because they are inferior. The MS4 system, in theory, has completely separate pipes for sewage and stormwater and they should not ever mix.

Some cities such as New York City and Albany, New York still rely upon the CSO system (Farnham et al., 2017). Although the CSO system is being phased out nationally in favor of the MS4's, CSO systems still exist in a significant way. As human population and waste increases in cities, it becomes more and more important to address sewage and how it is handled. This becomes especially important in a changing climate where there may be more intense rainfall in the Northeast (Calderon et al., 2017; Garver, 2021b).

In practice, even cities with a MS4 system experience elevated FIB levels in their surface waters during rainfall events, and some municipalities set wet-weather limits for MS4 discharges (Dunn and Burchmore, 2006). This situation can happen both intentionally and unintentionally, whether from old, leaking pipes, incorrect connections, illicit dumping, or intentional dumping (spilling). No matter the cause, cities on the MS4 such as Schenectady may still see elevated FIB (i.e. *Enterococcus)* levels during rain events, despite having made the transition from a CSO to an MS4 (in 2008). Contamination in dry weather conditions in MS4 communities suggests a larger issue, perhaps because this contamination is caused by aging infrastructure as sewage exfiltrates from broken pipes into storm drains or surface waters (Sercu et al., 2011).

Untreated sewage released into waterways, intentionally or unintentionally, is a major way pathogens and nutrients are introduced to the environment (Olds et al., 2018). Humans can be exposed to these pathogens through both recreational use and drinking water. In the Mohawk watershed, several towns (such as Colonie and Cohoes) take raw water for municipal drinking water from the Mohawk River. Although Schenectady uses a wellfield, towns that drink from surface water presumably need to spend more money to treat increasingly contaminated river water. The release of sewage into surface waters may be due to sewage exfiltration from broken pipes, or overflows from failing sewage systems (Olds et al., 2018).

Municipal sewers and gastrointestinal illness in Schenectady

There have been several recent gastrointestinal outbreaks on the Union College campus in Schenectady that may be related to failing water infrastructure. In the fall of 2020, the first major event of such illness spread throughout the College and city. After a water main break in the city, dozens of cases of *Giardiensis* were reported, both on Union College's campus and in the city (Garver, 2020). Another case of gastrointestinal illness among Union College students and staff occurred in the fall of 2021, which may also be related to sewage and public health. Although the facts and numbers were not entirely clear, three major events happened in the 2021 event. First, there was a rainfall event of >2" of rain over a two-day period (23-24 September 2021). Second, there was a sanitary sewer overflow on campus the morning of September 24, with sewer water flowing from the pipe into the stormwater drain, which dumps directly in the Hans Groot Kill (Fig. 3). Third, there were dozens of cases of some gastrointestinal illness reported by the end of the following week. Collecting data for sudden events such as this gastrointestinal outbreak are essentially impossible to retrieve, as any potential contaminants or pathogens in the water would have left by the time students started getting sick. However, the timeline of this sequence of events may suggest the potential for compromised drinking water in the brief period after the sewer overflow. Although there is a degree of uncertainty about these cases, there could indeed be a connection between these events.

Figure 3. Photograph of sanitary sewer overflow morning of 24 September 2021. This overflowing sewage went directly into stormwater pipes that then emptied into the Hans Groot Kill. Photograph courtesy of Professor Kurt Hollocher of the Geosciences Department.

Fecal Indicator Bacteria and Enterococcus

To assess water quality in streams, rivers, or municipal water supplies, different methods of detecting fecal bacteria can be employed. While physical water parameters can be measured with the help of specific instruments, several methods to test for pathogens in water have recently been developed. One method to test contaminants in the environment is the use of Fecal Indicator Bacteria (FIB) such as total coliform bacteria, fecal coliform bacteria, and also the specific bacteria *Escherichia coli* (*E. coli*) and *Enterococcus*. *Enterococcus* live in the intestinal system of warm-blooded animals, and most species are harmless to humans (McBride et al., 2007). As well as reducing water quality, the presence of pathogens in water can be detrimental to the natural ecosystem in waters. By understanding sources of FIB, we can begin to implement control measures to improve water quality.

Enterococcus is used as an indicator for sewage in surface waters, as *Enterococci* are found in high numbers in human fecal matter (Boehm and Sassoubre, 2014). Because some *Enterococci* live in water, soil, and plants, there are natural levels of *Enterococcus* in surface waters (Byappanahalli et al., 2012). Understanding how *Enterococcus* and FIB in general are related to water impairment is of incredible importance for both human and environmental health. Furthermore, we can use FIB to understand the quality of city infrastructure and human health (Zhou et al., 2020). High levels of FIB in surface waters can be attributed to many things: poor sewage systems (such as the combined sewer overflow), wet weather runoff, illegal connections to the sanitary sewer, illegal discharge into streams, failing/poorly placed septic systems, poor wastewater treatment plants, farm animals, wildlife, pets, and more (Packman, 2014).

Several factors in natural surface waters can affect the fate of *Enterococcus* and other FIB (Byappanahalli et al., 2012). Sunlight, for example, has been shown to be associated with a decrease in FIB over time (Packman, 2014). FIB prefer warm water, and temperature can be a key factor in bacteria growth. Water turbidity is important for two reasons; the first being that sunlight does not pass through turbid water as easily, and second that the sediment in turbid water bodies provides a space for bacterial/microbial attachment (Suter et al., 2011).

One factor that has increasingly been recognized as a source of elevated FIB and *Enterococcus* is sediment (Packman, 2014). Sediments, whether entrained in a water column, resting on the bottom of a stream, or accumulated in pipes, provide a perfect habitat for many microorganisms and pathogens, including *Enterococcus* (Suter et al., 2011). There is evidence that FIB such as

Enterococcus can survive in sediments in levels 100 to 1,000 times higher than the overlying waters (Haller et al., 2009). During wet weather, sediment in pipes can discharge into streams, and sediment resting on the bottom of streams can get entrained in the water as discharge increases—both can result in high bacteria levels in the water. Sediment containing high levels of organic material, nutrients, and small grain size display an increased growth rate and lower decay rates for FIB (Haller et al., 2009).

Because sunlight causes *Enterococcus* deactivation, both depth and turbidity of the water column are important to understand this bacteria and its abundance (Suter et al., 2011; Myers and Juhl, 2020). Turbidity in particular is important, and this varies greatly depending on weather conditions; wet weather will create a much more turbid environment than a period of dry weather. During wet weather, not only will greater runoff and seepage increase *Enterococcus* levels, but particle-associated *Enterococcus* levels will also increase as stream turbidity increases (Myers and Juhl, 2020).

In recent years, relatively easy ways to enumerate *Enterococcus* in particular have been developed (Schang et al., 2016). Because of the ease of measurements, *Enterococcus* is typically used as a threshold analysis for recreational water use. In fact, the Environmental Protection Agency (EPA) published "water quality criteria" in the Clean Water Act (CWA) based on the most recent scientific information, and the EPA now recommends using either *E. coli* or *Enterococcus* for water quality assessment. In 1986, the EPA published *EPA's Ambient Water Quality Criteria for Bacteria – 1986*, which is now known as "the 1986 criteria". Published in this document are the EPA's recommendations for recreational waters. Today, the EPA regulation for *Enterococcus* in recreational waters is 33 colony forming units (cfu) per 100 mL of freshwater (or 35 *Enterococci* cfu/100 mL for marine water) for a month-long average (EPA, 2012). For a single grab-sample, the *Enterococcus* value must be below 60 cfu/100mL (EPA, 2012). The Environmental Protection Agency (EPA) has spent time redefining initial guidelines set in the first CWA, published in 1972.

The 2012 Recreational Water Quality Criteria (RWQC) was developed from the 1986 criteria and based on the association between concentration of FIB and gastrointestinal (GI) illnesses (EPA, 2012). In the 1960's the U.S. Public Health Service recommended fecal coliform bacteria as the main FIB for use in recreational waters. In the 1970's, *E. coli* and *Enterococcus* were studied to evaluate their possible uses as FIB, and it was concluded that *Enterococcus* are a good predictor

of FIB and therefore GI illnesses in both fresh and marine recreational waters, and *E. coli* is a good predictor of GI illness in only fresh waters (EPA, 2012).

Enterococcus has recently developed as an approach to determining water quality in surface waters, in part because *Enterococcus* is resistant to chlorine, which is important in streams affected by the urban stream syndrome. *E. coli* is not resistant to chlorine, so discharges from wastewater treatment plants (WWTP) may have little or no *E. coli*, especially if the discharges are disinfected prior to release. On the other hand, *Enterococcus* can survive the chlorination process from WWTP and will be found in the clean wastewater effluent that leaves the water treatment facilities (Ferguson et al., 2013).

One way that states can help address impaired waters is to calculate a total maximum daily load (TMDL), and then limit the amount of a pollutant that can enter a water body in order to meet EPA water quality standards. A TMDL determines this limit based on an equation that accounts for the total wasteload allocations (point-source), total load allocations (nonpoint-source), and a margin of error. TMDLs can be developed for several different pollutants, or one TMDL can be developed for multiple pollutants[2]. The scope or scale of TMDLs have not been defined by the CWA or EPA, so states have a range of possibilities when it comes to setting TMDLs. However, states must develop TMDLs for waters on their EPA Section 303(d) list of impaired waters. The EPA receives a report of TMDLs for states and accepts or rejects the plans based on regulations set in the CWA. TMDL wasteload allocations are then implemented by the EPA's National Pollutant Discharge Elimination System (NPDES) permits under CWA section 402[3].

As of 2019, the New York State DEC (NYSDEC) was in the process of developing a TMDL for the entire Mohawk Watershed to tackle phosphorus pollution (and algae blooms) and protect surface waters (Conine et al., 2019). Grab samples and the Hudson River monitoring network (HRECOS) were used to measure physical parameters, nutrient loads, algal blooms, and DBPs throughout an entire year to better understand contaminant dynamics in the Mohawk Watershed and help to progress and implement a TMDL plan to address phosphorus loading in the Mohawk River (Conine et al., 2019; Schnore et al., 2019).

[2] https://www.epa.gov/tmdl/overview-total-maximum-daily-loads-tmdls
[3] https://www.epa.gov/sites/default/files/2015-10/documents/rwqc2012.pdf

Identifying failing water infrastructure is extremely important and perhaps the best way to address water quality issues. Studies must be done to identify where the problems are: once problems are identified, they must be addressed and solved for the sake of the community. Not only does raw sewage contaminate surface waters and streams, but it has the potential to infiltrate the groundwater/local aquifer, which other communities may be using as their primary source of drinking water (Sercu et al., 2011). While some aquifers may replenish faster than others, other aquifers replenish over the course of thousands or hundreds of thousands of years, and any contaminants we add to the system today may be around for a long time.

Physical Water Quality Parameters

Several methods and parameters can be employed to discover concentrations of dissolved ions, pH, and more in bodies of water. Conductivity, for example, is related to the concentration of ions in water, which come from dissolved salts and inorganic compounds such as alkalis, chlorides, sulfides, and carbonate compounds. Distilled or deionized water have extremely low concentrations of ions, whereas brines or saltwater will have much higher concentrations. Conductivity, measured in this project by a YSI Multiparameter instrument, is measured in micro siemens/centimeter (μS/cm). Specific conductance is the conductivity measurement corrected to 25^{o} Celsius and is the standard method for reporting conductivity (Fondriest, 2014).

Total dissolved solids (TDS) combine the sum of all ions that are smaller than 2 μm, including electrolytes to make up salinity values, and are reported in mg/L. Some states and regions use a maximum TDS value for water quality rather than conductivity. An excess of TDS can have adverse effects on fish and their eggs (Fondriest, 2014).

Conductivity is a useful water quality parameter that is directly related to TDS. Generally, conductivities will have a fairly constant baseline value which can be compared to measurements taken during events of significant change (such as floods, droughts, and pollution). A sewage leak or an agricultural spill will result in an addition of nitrate, phosphate, and chloride ions, and conductivity will increase. Conductivity is also dependent on water temperature, as ionic mobility increases with warmer temperatures; conductivities may be different during the day and at night, which is why the standardized specific conductance (SPC) gives a more useful value (Fondriest, 2014).

Salinity is generally defined as the concentration of all dissolved salts in water, meaning salinity is directly related to conductivity (Fondriest, 2014). Practical salinity is derived from the

conductivity measurement, which compares specific conductance to a salinity standard. Salinity measurements are unitless, but often are notated by ‘practical salinity units (psu)’ but can change based on procedure and application. Ions such as chloride, sodium, and magnesium make up the majority of ions in seawater and are present in smaller amounts in freshwater.

Geologic units also contribute to water parameters such as geochemistry and salinity, as is the case with the bedrock underneath the Mohawk River. In this project, salinity is recorded in parts per thousand (ppt). The historical calculation of salinity was based on chloride concentration, but was only applicable for seawater, estuaries, and brackish water. Absolute salinity is a new and highly accurate method which is consistent with the thermodynamic state of the system; this method requires more complex calculations but has highly accurate and useful information. Salinity is quite important, as it affects the dissolved oxygen (DO) solubility– the higher the salinity, the lower the DO concentration. Additionally, organisms adapt to specific salinity levels, and if salinity ranges above or below that level, aquatic species can be rapidly killed due to changes in DO concentrations, osmosis regulation, and TDS toxicity (Fondriest, 2014).

Using several of these water quality parameters can give researchers an understanding of the water and potential pollution sources beyond pathogens. Floods, droughts, agriculture, human sewage, or chemical leaks all impact water quality, and will be shown in the physical water quality parameters. Monitoring these parameters helps us understand how systems work and how they respond to changes in the environment.

Major Ions. A further understanding of water quality comes from several dissolved ions, especially those that are linked with human waste and products. Four ions are a major focus in this water quality study: nitrate, phosphate, chloride, and fluoride.

Nitrogen (N) is a vital element when it comes to nutrient loading in bodies of water. Found in high amounts in agricultural fertilizers as well as human waste, nitrogen is one of two major limiting nutrients for plants (the other being phosphorus) (Mattson, 1980 and Verhoeven et al., 1996). If wastewater treatment plants do not specifically remove nitrogen, or if sewer pipes are faulty and leak, nitrogen can enter the environment in high concentrations[4]. There are two main health issues related to nitrate in drinking water: infant methaemoglobinaemia (blue baby syndrome) and cancers (like of the digestive track). However, many people believe that methaemoglobinaemia is linked to pathogens in water, not nitrate (Grizetti et al., 2011). Nitrate (NO_3^-) is a common and

[4] https://www.usgs.gov/special-topics/water-science-school/science/nitrogen-and-water

problematic ion. The EPA set a maximum contaminant level of 10 mg/L of nitrate in drinking water and levels over 30 ppm can be harmful to organisms in the aquatic environment.

Phosphorus (P) is also a limiting nutrient (especially in surface waters) and is common in agricultural fertilizers and sewage. It, along with nitrogen, is the main cause of eutrophication in surface waters. The addition of phosphorus to surface water increases microbial growth (Miettinen et al., 1997). Too much phosphorus in waters (along with the correct climate/weather conditions) often results in algae blooms and growth of aquatic plants, which results in eutrophication. Some algal blooms produce toxins which are harmful to both human and animal health[5]. The most common form of phosphorus is phosphate (PO_4^-), which can be measured by ion chromatography.

On their own, phosphates are not toxic to humans or most animals unless they occur at very high levels, meaning the main risk of high levels of phosphates is for aquatic life (Rosales et al., 2020). Unstable, fluctuating water quality due to nutrient inputs is detrimental to the ability of aquatic species to live and reproduce correctly, especially for sensitive species. If enough species at the base of the aquatic food chain are impacted, all other species will be impacted as well. Imbalance in ecosystems does not promote a stable habitat, and species may be impacted for decades (Worm et al., 2006).

Increase of nitrogen and phosphorus in waters is the main cause of eutrophication because of their importance as limiting nutrients (Grizetti et al., 2011). With large influxes of nitrogen and phosphorus into streams, major algal blooms can occur with the right weather conditions. These algae can be toxic to humans and other animals or can become toxic as they begin to decay. Another significant impact from these algae blooms is the process of eutrophication, where water bodies become anoxic due to the decomposition of these organisms (Ngatia et al., 2019). These anoxic conditions are extremely harmful to aquatic species, especially sensitive species that require a specific oxygen range. In fact, this eutrophication can contribute to a selection toward fast-growing and more tolerant species, which changes the natural species in the water and alters the native biodiversity (Grizetti et al., 2011). The ability for humans and animals to use a river or lake decreases if eutrophication becomes more frequent, which has implications for our recreation and drinking water resources. Native biodiversity is crucial for overall ecosystem health, as well as human wellness and economies.

[5] https://www.epa.gov/national-aquatic-resource-surveys/indicators-phosphorus

Chlorine (Cl) is an important element that occurs as a common anion which affects water quality, and it needs careful consideration in urban streams because of the damage it can cause to aquatic organisms. High amounts of salt (NaCl) are added to roads in the winter in the Northeast (especially in New York State) for de-icing, and as a result significant chloride (and sodium) enters the environment. When chloride is added to roads by using road salt, it easily dissolves and enters soil, surface water, and groundwater through hydrogeological processes (Siegel, 2007). Dilution occurs with rain or snowmelt, but water and soils near roads still see a much higher concentration of Cl (Findlay and Kelly, 2011). Chloride is not relatively toxic to human health, but sodium, which is associated with chloride in road salt, is linked with hypertension which can cause cardiac disease, renal disease, strokes, and more (Siegel, 2007).

The element chlorine (Cl) is used around the world as a disinfectant in drinking water as it kills most parasites, bacteria, and viruses. Chlorine levels up to 4 mg/L in drinking water is considered safe, according to the CDC[6]. While chlorine is used in small doses to disinfect drinking water, the increased concentrations found in waters today is harmful to ecosystems and humans alike. Note that most municipal water has chlorine added for disinfection, and therefore part of the chlorine in sewage is from disinfection, and not road de-icing.

Although aquatic species require chloride to regulate internal physiological processes, these chloride concentrations must be steady concentrations to which the organism adapted. Fluctuating chloride concentrations (or high levels) can affect the survival, growth, and reproduction of aquatic species (Szklarek et al., 2022). Tolerance to salt varies greatly between species; some species can survive greater salt concentrations and fluctuations in concentrations, while others can only tolerate very specific concentrations.

If vegetation health or abundance declines, soil and waters become more vulnerable to other contaminants without a good vegetative buffer. While the sodium cation (Na^+) from NaCl is the most important in relation to human health and wellbeing, chloride is primarily a concern for organisms in the aquatic environment.

Fluoride occurs naturally in waters, soils, and air, and like chlorine, it is added to municipal water supplies (Harrison, 2005). Inside the human body, fluorides are absorbed into the blood, and eventually collect in areas with high calcium such as bones and teeth (Ali et al., 2016). In general, the addition of fluoride to drinking water strengthens teeth enamel and thus helps fight off

[6] https://www.cdc.gov/healthywater/drinking/public/water_disinfection.html.

bacteria[7]. However, the accumulation of fluoride in teeth and bones, especially in children under age 8, can lead to fluorosis, a disease which targets teeth, bones, and joints. Fluorosis is related to the total quantity of ingested fluoride, which has raised some concerns as to the levels of fluoride in drinking water (Ayoob and Gupta, 2006). Regardless of these affects, fluoride can be used as a tracer for municipal water.

Salinity and Salinization

The addition of salt to our roads in recent decades has severely impacted watersheds and water quality (Szlarek et al., 2022). The liberal application of road salt (NaCl) to roads in the Northeast and New York State in general is detrimental to watersheds, as it is one of the most widely used aquatic contaminants statewide (Godwin et al., 2003; Kelly et al., 2019). Although salt has important de-icing properties which make it a vital resource in the winter, the subsequent year-round salinization of surface waters and groundwater is of huge concern. The overuse of road salt in general is detrimental, but the storage facilities for salt also have the potential to become major contamination sites (Garver, 2021a) as salt dissolves when left outdoors and leaches into the ground.

Salt in New York is incredibly cheap, thanks to large salt deposits in Upstate New York, which allows New York to purchase salt for approximately $60 a ton, or about 19 cents per ounce (Garver, 2021a). A study done by researchers at the Cary Institute found that approximately 90% of the Na^+ and Cl^- in streams comes from road salt (Kelly et al., 2019). This study from the Cary Institute also determined the long-term use (and increased use) of road salt has already resulted in the salinization of groundwater, which is nearly impossible to remove once it has entered this system (Kelly et al., 2019). Because groundwater is a major source of water in New York State, the addition of salt has implications for the quality of drinking water. The implementation of better salt management practices to reduce the use of salt is an important step to improve long-term environmental and hydrological conditions.

Precipitation in a Changing Climate

It’s well-known that the climate is changing, and in the Northeast these changes have been reflected by increased precipitation, mainly due to Atlantic-tracking storms in the summer months (Garver and Cockburn, 2011; Caney, 2015). Increased precipitation is resulting in bigger, more

[7] https://www.medicalnewstoday.com/articles/154164#takeaway

severe, and more frequent flood events, meaning cities need to be prepared for these larger events. Changes to frontal systems that control precipitation in Upstate New York (such as normal continental systems, Lake Effect from the Great Lakes, and tropical storms) are increasing overall precipitation events (Huang et al., 2017). Tropical storms are causing the biggest change of hydrology in the Mohawk Watershed, as they can result in large amounts of rainfall in a very short time, such as Hurricane Irene in 2011 or Hurricane Ida in 2021 (Garver and Cockburn, 2011). The increase in precipitation in the Mohawk Watershed is greatest in the summer (NOAA's "Climate at a Glance" tool). Flooding and rainfall events are becoming bigger, more severe, and more frequent as precipitation systems change (Garver and Cockburn, 2011; Huang et al., 2017). In fact, the fall of 2021, when this study was conducted, was an exceptionally wet fall that resulted in relatively high discharge in the Mohawk and tributaries (Fig. 4).

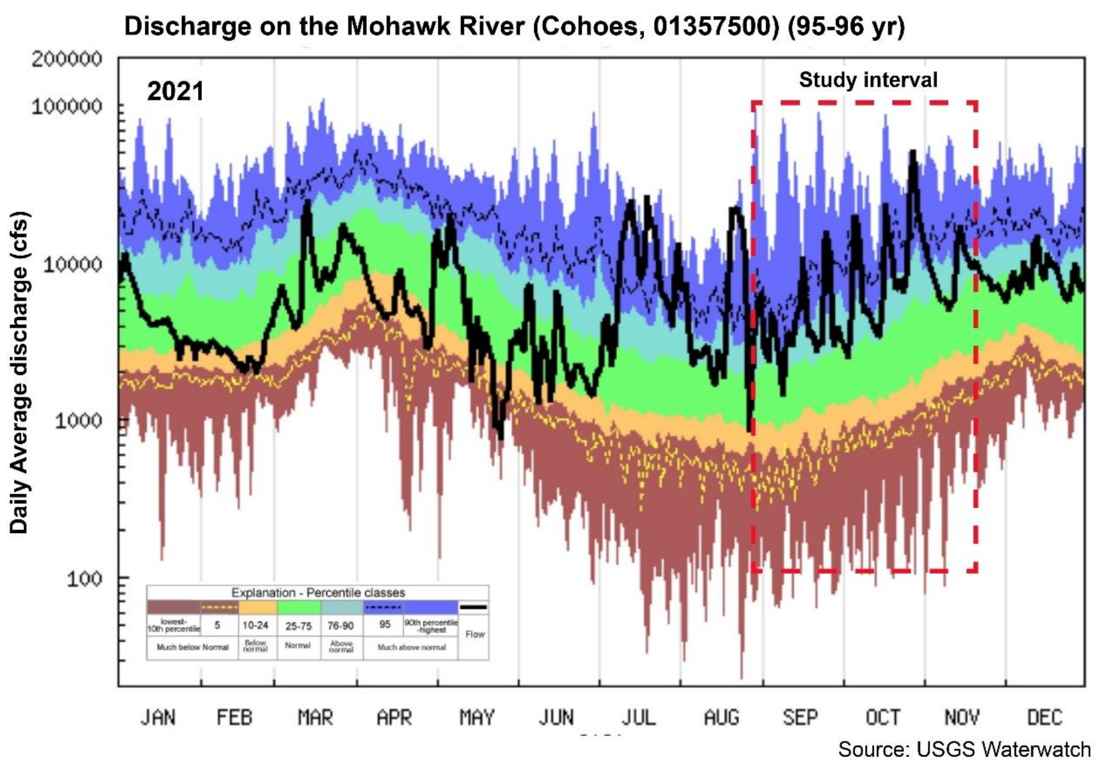

Figure 4. Discharge on the Mohawk River in 2021 (black line). Dark blue background shows the 90th percentile, or wet conditions. Bright green shows the 25th-75th percentile, or normal conditions. Red dashed box shows the study interval from September to November 2021. Graph modified from USGS Waterwatch.

This increase in precipitation has major implications for city infrastructure in the Northeast. The development of water (and wastewater) infrastructure has shown major improvements to public

health, and a decrease in environmental pollution (Hughes et al., 2021). However, when exposed to stressors such as poor construction materials or a heavy rainfall event, these systems can fail and lead to an increased pathogen burden in surface water. With the onset of more rainfall in the Northeast due to climate change, water contamination due to failing sewage infrastructure will likely increase in frequency and severity (Olds et al., 2018). In fact, the EPA estimates that roughly 850 billion gallons of raw sewage is discharged annually into waterways by CSO's, and up to 10 billion gallons from separated sewer systems (USEPA, 2004). With increased urbanization and increased rainfall, sewer systems are under stress and are becoming more vulnerable to leaks or complete failure (Olds et al., 2018).

Previous Work

Although water quality and water supplies are of importance and interest to municipalities and states, smaller water bodies are not always monitored closely. In the Mohawk Watershed, the environmental organization Riverkeeper is dedicated to protecting the Hudson River and its tributaries, which includes the Mohawk River. Since 2015, Riverkeeper and partners have sampled the Mohawk River at several locations in the study area for *Enterococcus* (Fig. 2). Their results show that in the Schenectady Pool (between Lock 7 and Lock 8), the Mohawk Harbor site has the poorest water quality with a geometric mean of 74 MPN/100 ml, and this location fails to meet the EPA BAV 50% of the time. The site's *Enterococcus* values are about twice that of the site at Lock 8 (30 MPN/100 mL), which fails to meet the BAV only roughly 22% of the time (Fig. 2). This water (Lock 8) is representative of the input to the Schenectady Pool, and thus there appears to be a decrease in water quality as the Mohawk flows through the Schenectady area.

Eva Willard-Bauer completed her Union College thesis in the spring of 2021 on the pathogen contamination in the Hans Groot Kill (Willard-Bauer et al., 2020; Willard-Bauer, 2021). She repeatedly sampled seven sites along the length of the exposed part of the HGK. In her thesis, she concluded that the levels of *Enterococcus* in the Hans Groot Kill exceeded the EPA's guidance for FIB in 254 out of 255 samples (i.e. 99% failure rate) taken in the creek, and values typically exceeded the EPA's recommended value by several orders of magnitude. These elevated pathogen levels were attributed to leaking or illegally connected sewer pipes. Willard-Bauer's findings attracted municipal attention and started a potentially lengthy (and expensive) remediation process in the City of Schenectady and with the NYS DEC. Water tests in April 2021 by the City used environmental DNA (eDNA) to determine the presence of human DNA in the Hans Groot Kill, suggesting the contamination is largely due to sewage from humans.

METHODS

Sampling for this thesis project involved the determination of suitable sample sites for water quality testing. At each site, water samples were taken and physical water quality parameters were measured using a Yellow Springs Instrument (YSI) probe. Water was then analyzed for pathogens (*Enterococcus*) and major ions, using the IDEXX system and a Dionex ion chromatograph, respectively.

Field Collection

Sampling for this project began in September 2021. In the lab before sampling, instruments and materials were organized. A bag with latex gloves, Whirl-Pak bags®, freezer packs, and storage bags was prepared every week. The YSI handheld multiparameter probe was calibrated before sampling. At every sample site, multiparameter data were collected and later added to a spreadsheet. Sterile gloves were worn to label the Whirl-Pak bags and collect water samples, which were then tied shut and kept cool with ice packs in a cooler during the sampling process. Field sampling took roughly two hours, and occurred roughly once a week, but more frequently with rainfall events.

In the lab, IDEXX plastic Quantitrays® were labeled with each site number, the date, time of collection and incubation, and dilution percentage. Sterile glass bottles were filled with deionized water to the predetermined dilution percentage (50-90%). Most samples were diluted by 90% (10 mL collected water sample and 90 mL deionized water). A blank sample was prepared as a control, using 100 mL of pure deionized water. Using a pipette, the correct amount of each sample was added to the sterile bottles with deionized water, so as to be 100 mL total. Each sample was then fed with Enterolert®, the proprietary Defined Substrate Technology nutrient indicator used to detect *Enterococcus*. The bottles were shaken until the food fully dissolved and were then added to their labeled IDEXX tray. Trays were sealed with a sealer, and then put in the incubator at 41˚C. Twenty-four hours later, sample trays were removed from the incubator and read under an ultraviolet light in a dark room. Illuminated wells were marked with a Sharpie® and then totaled. The maximum probable number (MPN) per 100 mL is determined from IDEXX tables. Dilution had to be accounted for, and MPN/100 mL numbers were multiplied depending on the dilution percent (e.g., x10 for 90% dilution, or x5 for 50% dilution).

The sites sampled are as follows (Fig. 5). The Binnekill was sampled initially at one location, BK-1, but changed to BK-2 halfway through the fall to a second outfall when low-river conditions

permitted (Fig. 6-8). The Binnekill locations posed the biggest problem for access, as the two outfalls were both only accessible with difficulty. Both are down a hill through thickets, and during high-flow events on the Mohawk, water backs up to the outfall. BK-1 was sampled in a pool at the base of the outfall, and BK-2 was sampled directly in the mouth of the outfall. BK-3 was sampled only once when low river conditions permitted and was on a muddy bank where BK-1 and BK-2 converged (and thus may also contain Mohawk water) (see Fig. 7).

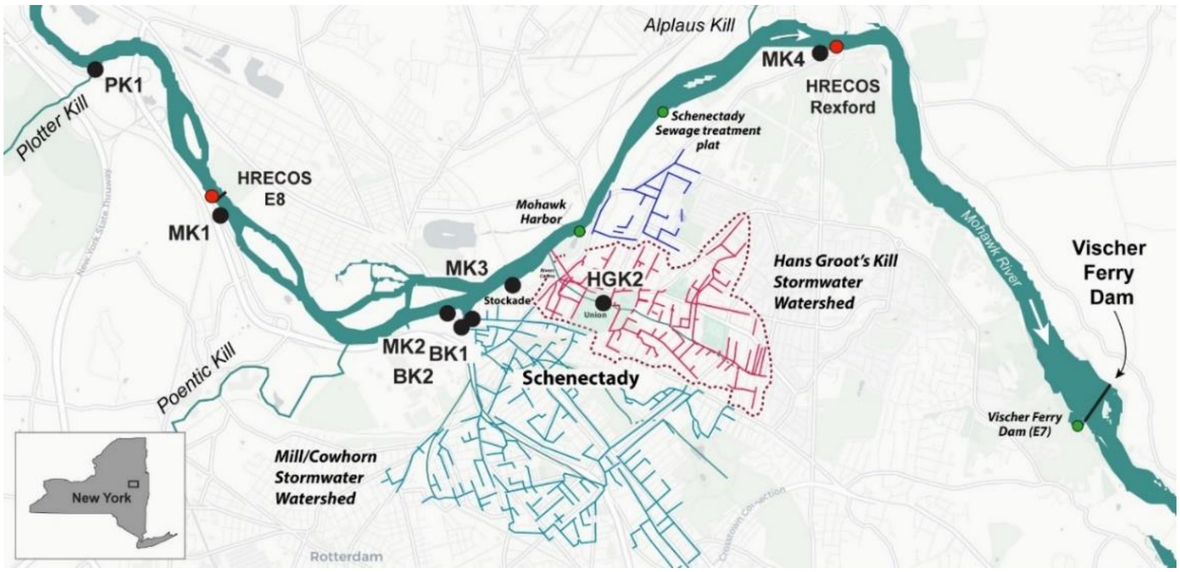

Figure 5. Map showing all sampling location in the lower Mohawk Watershed in the Schenectady pool, which is between Lock 7 and Lock 8.

Figure 6. Map showing Binnekill sampling locations. BK-1 and BK-2 were sampled from outfalls, and BK-3 was only sampled once from a muddy bank at low-flow conditions.

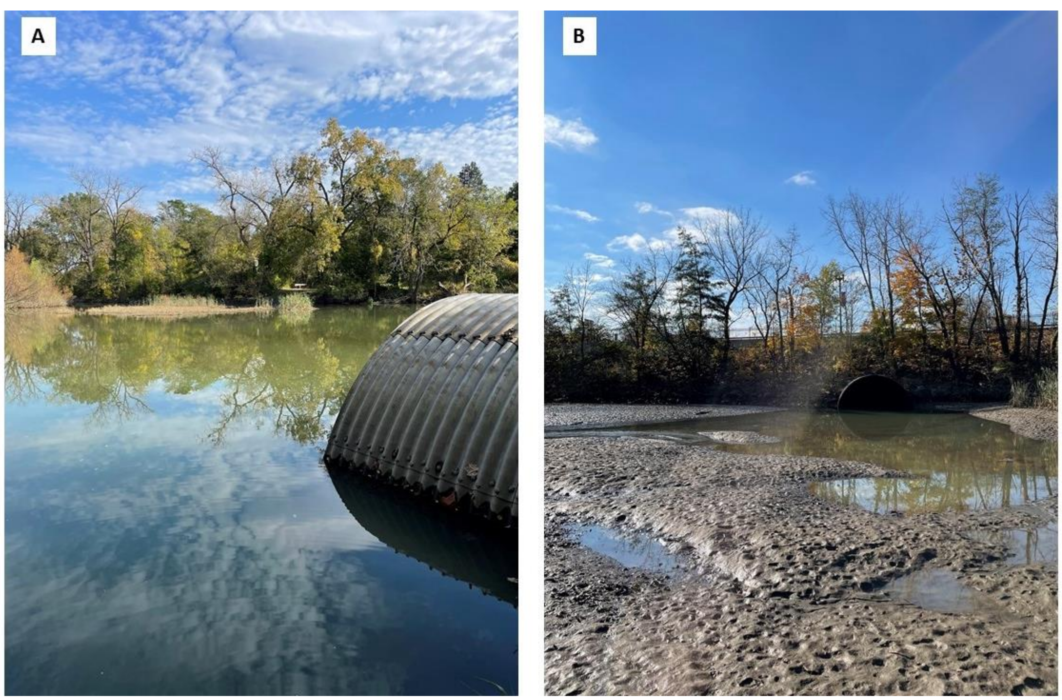

Figure 7. Images showing location BK-2. (A) Shows the outfall of BK-2 from the side, and (B) looks directly at the outfall of BK-2 at low-flow conditions.

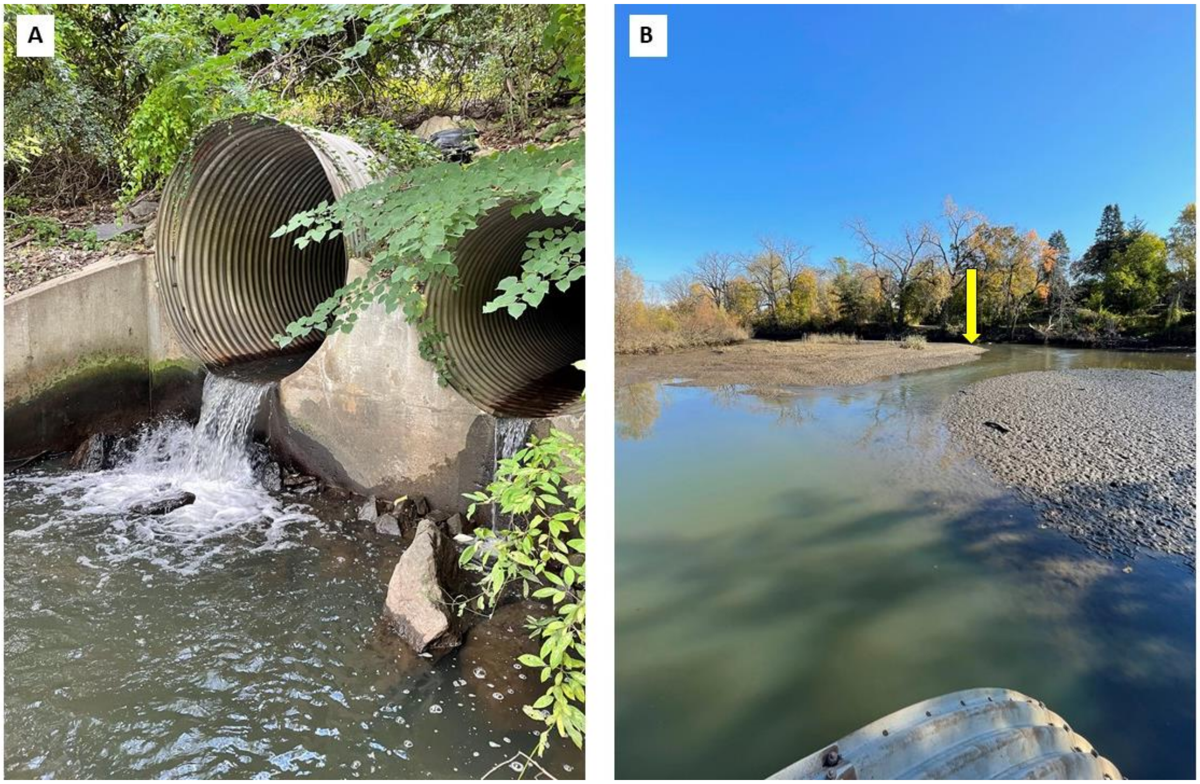

Figure 8. (A) Shows the outfall from BK-1. The pool at the base of the outfall was sampled. (B) The arrow shows the location of BK-3 from on top of the BK-2 outfall, where flows from BK-1 and BK-2 converge.

The Hans Groot Kill was sampled at HGK-1 but primarily HGK-2 from a previous study (Willard-Bauer, 2021): both sites are in Jackson's Gardens on the Union College Campus (Fig. 9). Four locations on the Mohawk River were sampled, labeled MK-1, MK-2, MK-3, and MK-4. Sampling location MK-1 is at Lock 8 upstream of Schenectady, MK-2 is at Gateway Park, MK-3 is at the Union College crew dock, and MK-4 is at the Rexford Bridge (Fig. 10-12). The Plotterkill was sampled several times, but the data were not analyzed for this project.

Figure 9. Both pictures depict the HGK-2 location under high-flow conditions. (A) Depicts the typical HGK-2 location with water overflowing the banks of the small channel. (B) Shows the pipe transporting the Hans Groot Kill under a road, approximately 20 m upstream of sample location HGK-2.

Figure 10. (A) Shows the MK-1 sampling location. The cement structure on the left is infrastructure for the channel of Lock 8. (B) Depicts MK-2 at Gateway Park in Schenectady under high-flow conditions, where the Mohawk River is flooding the adjacent floodplain.

Figure 11. Both photographs taken from MK-3 at the Union College crew dock in the Stockade. (A) Shows the dock on the Mohawk River, and (B) shows the Amtrak bridge crossing the river just downstream of the dock.

Figure 12. Location MK-4 at the Rexford Bridge. (A) Shows the view looking upstream (to the west). (B) Debris and mud deposited on the riverbanks at MK-4 after a large rainfall event.

Enterococcus

During the fall of 2021, water samples were collected from six locations on three different streams in the Mohawk Watershed. Four sample locations were on the Mohawk River. The Binnekill and the Hans Groot Kill each had one main sampling location. After collection and lab preparation, samples and blanks were sealed in IDEXX Quantitrays® and incubated within approximately 2 hours of collection at 41˚C for 24 hours (Fig. 13). Samples and blanks were read and counted under a UV light after 24 hours (Fig. 14). After lab preparation, empty vials were put in the autoclave in order to kill bacteria and sterilize the vials. Once read, sample trays were autoclaved to kill bacteria and were then discarded.

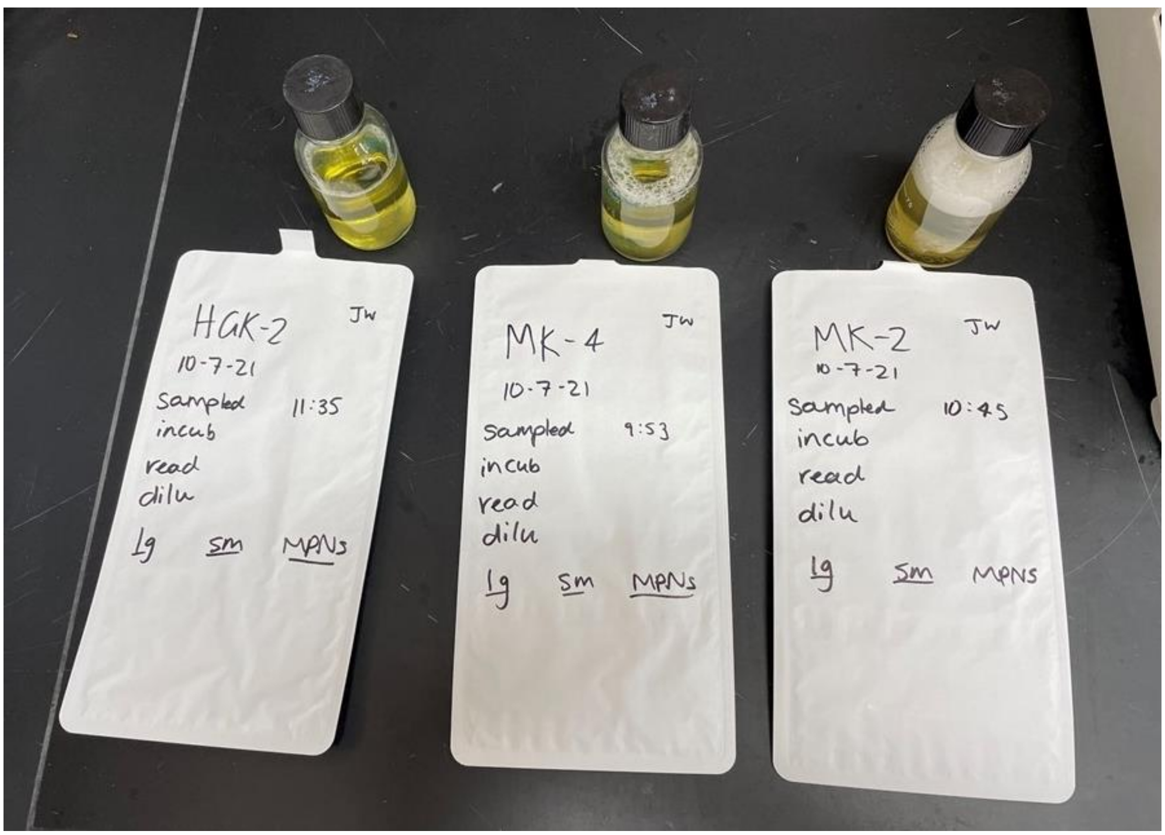

Figure 13. Image of labeled IDEXX trays. Samples fed with Enterolert are in vials.

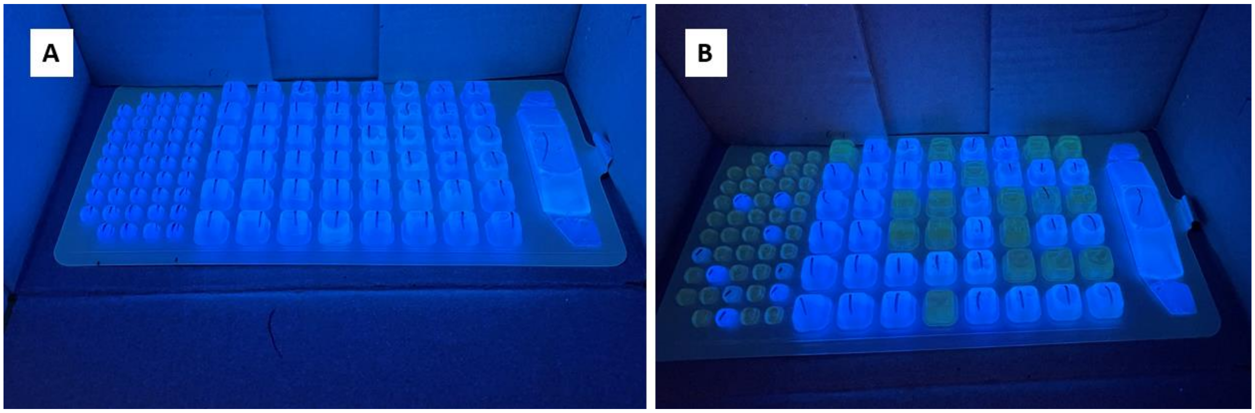

Figure 14. Photograph of IDEXX *Enterococcus* Quantitray under a UV light, 24 hours post-incubation. (A) Sample is fully saturated, with all 49 large wells and all 48 small wells glowing, indicating a value of 2419.6 MPN/100 mL. Since the sample was diluted 90%, the actual MPN correlates to a value of 24,196 MPN/100 mL. Glowing wells are marked with a black line. (B) Shows a sample that is not fully saturated. Glowing wells are marked with a black line.

Physical Water Quality Parameters (YSI)

At each sample location, a multiparameter digital water quality meter from YSI Inc. was employed to record several different water quality parameters. The Professional Plus Multiparameter Instrument from Yellow Springs Instruments (YSI) was employed to collect data. Three probes on the instrument allowed it to collect temperature, pressure, dissolved oxygen, specific conductance, conductivity, total dissolved solids, salinity, and pH.

Ion Chromatography

Ion concentrations from collected samples were analyzed at Union College using Dionex Ion Chromatographs (ICS-2100, anions; DX-500, cations). Anions were diluted with an AS19 column using potassium hydroxide as the eluent. Cations were diluted with a CS16 column and methanesulfonic acid. Multi-ion standards were prepared by pipetting standardized volumes of single ion standards to analyze for F, ClO_2^-, Cl^-, NO_2^-, ClO_3^-, Br^-, NO_3^-, SO_4^{2-}, PO_4^{2-}, and Li^+, Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}, and Sr^{2+}. Four dilutions of this standard (1:1, 1:2, 1:5, and 1:10) were prepared to calibrate the chromatograph over an order of magnitude in concentration. Check standards of 1 and 10 ppm were prepared from ultrapure multi-ion stock solutions to evaluate for accuracy. When check standards are within the calibration range, values are matched on average at 5% and always within ± 10%.

Rainfall Data

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 are collected every 15 minutes. The weather station records parameters such as temperature, humidity, pressure, wind speed and direction, and rainfall.

Turbidity Data

The turbidity data for this study were taken from the Hudson River Environmental Conditions Observing System (HRECOS) monitoring network. Sensors along the Mohawk and Hudson Rivers record water quality and weather data every 15 minutes. Sensors collect meteorological data such as air temperature, precipitation, humidity, barometric pressure, wind speed and direction, and more. Hydrologic parameters include data such as water temperature, gage height, specific conductance, dissolved oxygen, pH, turbidity, salinity, and more. For this study only turbidity was used.

Land Use Data

The land use data used for this study comes from the website modelmywatershed.org, which uses map data from ESRI. The website is an initiative of the Stroud Water Research Center. Basemaps are compiled from several sources, such as the U.S. Geological Survey (USGS), U.S. Environmental Protection Agency (EPA), U.S. National Park Service (NPS), and others.

RESULTS

Land Use

As expected, the land in this study area is primarily developed, with four types of developed space (open, low intensity, medium intensity, and high intensity) totaling 98.81% of the total space in the area (Fig. 15). Mixed forest contributes the next highest percent of land use at 0.76%. A table of exact percentages can be found in Appendix A.

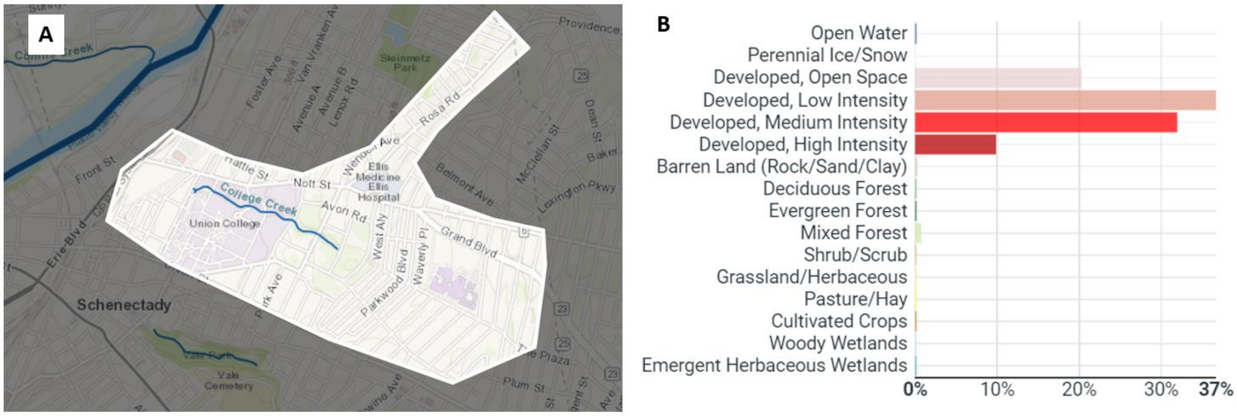

Figure 15. (A) Approximate area of the Hans Groot Kill drainage basin. (B) Associated land use data (in percent) of the Hans Groot Kill drainage basin.

Water Quality Parameters

Water quality parameters varied drastically between the Binnekill, the Hans Groot Kill, and the Mohawk. In general, specific conductance, conductivity, total dissolved solids, and salinity were higher in the Binnekill and Hans Groot Kill than in the Mohawk River. Dissolved oxygen concentration did not fluctuate greatly between any location or over time. Water quality parameters such as SPC are incredibly useful in water quality analyses, as they indicate dissolved ions in the water. All water quality parameter data follows below for the Binnekill. Specific conductance, conductivity, total dissolved solids, and salinity all varied between the three Binnekill locations, although BK-2 had the highest values of specific conductance and conductivity. BK-2 and BK-3 both had the highest total dissolved solids and salinity, at 715 mg/L and 0.55 ppt for both, respectively. Note that BK-3 was only sampled once (Table 1).

Table 1. Physical water quality parameters from BK-1, BK-2, and BK-3.

Site BK-1				Latitude/Longitude: 42°48'56.75"N 73°57'03.01"W					
	Temp (ºC)	mmHg	DO%	DO (mg/L)	SPC (mS/cm)	Cond (mS/cm)	TDS (mg/L)	Salinity (ppt)	pH
9/16/2021	19.9	762.5	101.0	9.1	370.8	335.0	241.2	0.18	7.43
9/21/2021	19.7	763.8	92.0	8.4	328.1	295.1	213.2	0.16	7.64
9/30/2021	17.1	758.2	89.0	8.6	498.4	423.1	323.7	0.24	7.86
10/7/2021	16.2	764.1	91.0	8.9	558.7	464.8	363.4	0.27	7.63
10/14/2021	16.9	754.7	90.0	8.7	987.0	834.0	643.5	0.49	7.83
Site BK-2				Latitude/Longitude: 42°48'58.23"N 73°57'06.02"W					
10/21/2021	14.5	754.5	87.0	8.8	1,105.0	883.0	715.0	0.55	7.82
10/27/2021	13	752.1	87	9.2	483.2	372.1	313.95	0.23	7.80
10/28/2021	12.8	756.1	83.0	8.8	684.0	525.0	442.0	0.3	7.66
11/4/2021	10.8	765.2	89.0	9.9	1,087.0	791.0	708.5	0.54	7.52
11/11/2021	11.0	763.1	88.0	9.6	1,083.0	793.0	702.0	0.54	7.46
Site BK-3				Latitude/Longitude: 42°48'59.31"N 73°57'03.68"W					
11/4/2021	11.6	765.1	87.0	9.4	1,104.0	821.0	715.0	0.55	7.01

The Hans Groot Kill was sampled in two locations for this study, named HGK-1 and HGK-2. HGK-1 was mainly sampled during various class trips and was not the primary Hans Groot Kill study location, and the data are similar between the two locations (Table 2). The Hans Groot Kill was sampled primarily at HGK-2 on the Union College campus. Dissolved oxygen did not have a significant variability. Specific conductance ranged to as great as 1,223 µS/cm on 10/24/2021. Conductivity ranged to as high as 990 µS/cm on 10/21/2021 (Table 2). These parameters, especially SPC and TDS, were useful to indicate baseline contamination in the Hans Groot Kill, especially when compared to values from the Mohawk River.

Table 2. Water quality parameters from locations HGK-1 and HGK-2.

Site HGK-1				Latitude/Longitude: 42°49'10.44"N 73°55'46.23"W					
	Temp (°C)	mmHg	DO%	DO (mg/L)	SPC (mS/cm)	Cond (mS/cm)	TDS (mg/L)	Salinity (ppt)	pH
9/13/2021	19.2	755.4	99	9.1	293.3	260.3	190.45	0.14	7.63
9/14/2021	18.0	755.7	87.0	8.3	311.6	270.2	202.8	0.15	7.45
9/15/2021	20.1	750.8	91.0	8.1	404.2	367.3	262.6	0.19	8.12
9/16/2021	19.6	760.2	81.0	7.4	380.2	341.1	247.0	0.18	8.01
10/19/2021	14.0	751.7	99.0	10.1	1,079.0	851.0	702.0	0.54	8.04
Site HGK-2				Latitude/Longitude: 42°49'07.60"N 73°55'38.53"W					
9/13/2021	19.0	755.3	95.0	8.8	306.3	270.8	198.9	0.15	7.39
9/14/2021	17.7	755.4	86.0	8.2	320.4	276.0	208.0	0.15	7.20
9/16/2021	18.7	760.6	95.0	8.9	351.3	308.8	228.2	0.17	7.85
9/21/2021	17.4	761.8	95.0	9.1	436.4	373.0	283.4	0.21	7.93
9/30/2021	14.9	756.5	93.0	9.4	569.4	459.4	369.9	0.28	8.08
10/4/2021	16.8	754.9	98.0	9.5	113.9	96.1	74.1	0.05	6.78
10/5/2021	16.6	760.8	95.0	9.3	470.7	395.4	306.2	0.23	8.02
10/7/2021	16.1	762.1	91.0	9.0	929.0	771.0	604.5	0.46	8.14
10/11/2021	16.9	756.3	91.0	8.7	1,074.0	908.0	695.5	0.54	8.10
10/12/2021	17.1	755.1	96.0	9.1	1,006.0	854.0	656.5	0.50	8.19
10/14/2021	17.1	753.3	90.0	8.6	1,170.0	993.0	760.5	0.58	8.01
10/16/2021	18.5	743.7	87.0	8.1	939.0	823.0	611.0	0.46	8.03
10/17/2021	16.3	747.3	96.0	9.4	859.0	716.0	559.0	0.42	7.79
10/21/2021	15.4	752.5	95.0	9.4	1,211.0	990.0	786.5	0.61	8.23
10/24/2021	12.9	757.3	94.0	9.9	1,223.0	941.0	793.0	0.61	8.13
10/27/2021	14.3	751.3	96	9.8	917	731	598	0.45	8.01
10/28/2021	13.3	754.0	93.0	9.7	1,040.0	808.0	676.0	0.52	8.22
11/4/2021	10.1	762.5	97.0	10.9	1,177.0	841.0	767.0	0.59	8.06
11/11/2021	9.8	761.0	100.0	11.3	1,187.0	843.0	773.5	0.59	8.28
11/12/2021	11.8	750	100	10.9	150.4	112.6	97.5	0.07	7.6
11/12/2021	9.7	749.7	86	9.6	249.8	178.3	162.5	0.12	7.33
11/12/2021	9.7	749.7	73	8.3	300.6	213.5	196.3	0.14	7.49
11/12/2021	11	749.6	78	8.6	364.2	267.3	237.3	0.18	7.92
11/18/2021	10.9	752.5	95	10.5	878	642	572	0.43	8.19

The Mohawk River was sampled at four locations. Values such as specific conductance, conductivity, total dissolved solids, and salinity were all generally lower at all Mohawk sample locations than in both the Binnekill and the Hans Groot Kill. Values were very similar across all four Mohawk River sample locations for all water quality parameter values (Table 3).

Table 3. Water quality parameters from all MK sampling locations.

Site MK-1				Latitude/Longitude: 42°49'36.84"N 73°59'23.06"W					
	Temp (ºC)	mmHg	DO%	DO (mg/L)	SPC (mS/cm)	Cond (mS/cm)	TDS (mg/L)	Salinity (ppt)	pH
9/16/2021	20.3	762.4	95.0	8.5	217.5	196.1	139.8	0.10	7.89
9/21/2021	20.6	763.5	97.0	8.7	207.6	190.1	135.2	0.10	7.86
9/30/2021	18.1	758.2	93.0	8.8	205.4	178.3	133.3	0.10	8.04
10/7/2021	15.9	764.0	100.0	9.9	235.0	194.3	152.8	0.11	7.87
10/14/2021	17.3	754.9	100.0	9.6	265.3	226.5	172.3	0.13	7.95
10/24/2021	13.0	758.4	102.0	10.8	313.3	241.4	203.5	0.15	8.20
10/28/2021	11.7	755.9	97.0	10.5	209.4	156.3	135.9	0.1	8.04
11/4/2021	8.6	764.6	101.0	11.7	260.1	178.5	169.0	0.12	7.93
11/11/2021	7.9	762.8	105.0	12.5	282.2	190.2	183.3	0.14	7.88

Site MK-2				Latitude/Longitude: 42°49'04.29"N 73°57'06.94"W					
9/16/2021	20.4	762.5	106.0	9.5	218.3	199.3	141.7	0.10	7.62
9/21/2021	21.2	763.8	100.0	8.8	206.9	192.1	134.6	0.10	7.85
9/30/2021	17.9	758.2	90.0	8.6	211.7	182.9	137.8	0.10	8.13
10/7/2021	16.0	764.1	95.0	9.4	263.4	218.0	171.0	0.13	7.78
10/27/2021	12.7	752.3	79.0	8.3	529.2	404.9	343.9	0.3	7.36
10/28/2021	12	756.2	92	9.9	342.5	257.2	222.3	0.16	7.70
10/14/2021	17.9	754.8	97.0	9.2	281.5	243.6	183.3	0.13	7.93
10/14/2021	17.9	754.8	97.0	9.2	281.5	243.6	183.3	0.13	7.93

Site MK-3				Latitude/Longitude: 42°49'15.55"N 73°56'38.92"W					
9/16/2021	20.5	762.4	104.0	9.3	215.1	196.8	139.8	0.10	7.75
9/21/2021	20.7	764.0	98.0	8.8	194.7	178.8	126.8	0.09	7.53
9/30/2021	17.8	758.4	95.0	9.0	208.2	179.8	135.2	0.10	7.95
10/4/2021	16.9	756.5	103.0	10.0	233.2	197.0	151.5	0.11	7.57
10/5/2021	16.1	762.2	101.0	9.9	240.5	199.8	155.7	0.11	7.90
10/7/2021	15.9	764.2	100.0	9.9	244.6	201.9	159.3	0.12	7.61
10/11/2021	17.0	758.0	97.0	9.3	245.1	207.5	159.3	0.12	7.42
10/12/2021	17.2	757.0	109.0	10.2	249.6	212.2	161.8	0.12	8.02
10/14/2021	17.2	754.7	98.0	9.4	272.8	232.1	177.5	0.13	7.66
10/16/2021	17.8	744.5	96.0	9.1	259.1	223.3	168.4	0.12	7.77
10/17/2021	16.8	749.3	105.0	10.2	269.8	227.3	175.5	0.13	7.08
10/21/2021	13.9	754.5	103.0	10.6	307.3	241.9	199.6	0.15	8.14
10/24/2021	12.8	758.4	100.0	10.6	328.1	251.8	213.2	0.16	8.20
10/26/2021	11.8	745.2	92.0	9.9	282.9	211.5	184.0	0.1	7.95
10/28/2021	11.8	756.2	93	10.1	213.2	159.5	138.45	0.1	7.72
11/4/2021	8.4	765.0	99.0	11.6	275.1	188.0	178.8	0.13	7.30
11/11/2021	8.0	763.7	102.0	12.0	296.9	200.3	193.1	0.14	7.49
11/18/2021	6.4	754	104	12.8	263.5	169.9	171	0.13	8.01

Site MK-4				Latitude/Longitude: 42°50'58.38"N 73°53'24.54"W					
9/21/2021	21.4	764.1	91.0	8.0	192.6	179.4	125.5	0.09	7.26
9/30/2021	17.9	758.3	89.0	8.4	222.2	192.3	144.3	0.11	7.95
10/7/2021	15.8	764.3	100.0	9.9	237.6	195.8	154.7	0.11	7.34
10/14/2021	17.0	754.7	94.0	9.1	268.6	227.6	174.9	0.13	7.34
10/28/2021	11.9	756.3	96	10.4	206.9	155.2	134.55	0.1	7.36
11/4/2021	8.4	765.0	96.0	11.2	271.8	185.8	176.8	0.13	6.53
11/11/2021	8.3	763.7	104.0	12.2	304.7	207.3	198.3	0.15	7.22

A table with the average specific conductance, conductivity, total dissolved solids, and salinity was assembled to define the differences more clearly between each sample location (Table 4). As BK-3 was only sampled once, the averages are just the values from one sampling trip. Save for BK-3, BK-2 has the highest SPC, conductivity, TDS, and salinity (Table 4). HGK-2 has the second highest SPC, conductivity, TDS, and salinity. Overall, the four Mohawk River locations are similar.

Table 4. Average specific conductance, conductivity, total dissolved solids, and salinity for all sample locations. Note that BK-3 was only sampled once.

Site	n	Avg SPC (mS/cm)	Avg Cond (mS/cm)	Avg TDS (mg/L)	Avg SAL (ppt)
BK-1	5	548.6	470.4	357.0	0.27
BK-2	5	888.4	672.8	576.3	0.44
BK-3	1	1,104.0	821.0	715.0	0.55
HGK-1	5	493.7	418.0	321.0	0.24
HGK-2	24	718.5	575.5	467.3	0.4
MK-1	9	244.0	194.6	158.3	0.1
MK-2	8	291.9	242.7	189.7	0.1
MK-3	18	255.5	204.4	166.0	0.1
MK-4	7	243.5	191.9	158.4	0.1

Dissolved Ions

Values from ion chromatography can be extremely useful as a proxy to determine preliminary pollution in water bodies. An increase in ions such as sodium, calcium, and chloride can be useful signs of a larger pollution problem in the water. Levels of major ions (SO_4, NO_3, Cl, Ca, Mg, K, and Na) were highest in the Binnekill and HGK (Table 5). Ion chromatograph data for the Hans Groot Kill appear similar to values from the Binnekill, with high values of sodium, magnesium, calcium, chloride, and sulfate (Table 6). Ionic loads in the Mohawk River had the lowest totals than the Binnekill or Hans Groot Kill (Table 7).

Table 5. Ion chromatograph data for BK-1, BK-2, and BK-3. Cations are Li-Sr: Anions are F to PO_4.

BK-1	Li	Na	NH4	K	Mg	Ca	Sr	F	Cl	NO2	Br	NO3	SO4	PO4
10/7/2021	-	99.8	0.04	2.41	11.3	75.4	0.1	0.23	152	0.06	0.04	4.01	25.5	0.05
10/14/2021	-	124	0.04	2.43	13.4	83	0.24	0.27	206	0.07	0.05	3.21	29.8	-
BK-2														
10/21/2021	-	122	0.28	3.63	14.5	102	0.17	0.09	192	0.16	0.06	14.2	37.9	0.01
10/27/2021	-	51.8	0.04	2.28	7.22	47.4	0.1	0.11	76.8	0.03	0.02	2.91	15.3	0.07
10/28/2021	-	85.5	0.12	2.74	11.1	73.1	0.18	0.17	129	0.07	0.04	5.53	26.1	0.05
11/4/2021	-	125	0.42	3.65	14.7	101	0.24	0.1	194	0.14	0.06	14.2	38.2	-
BK-3														
11/4/2021	-	121	0.64	3.53	14.7	103	0.17	0.11	198	0.15	0.07	14.3	37.8	-

Table 6. Ion chromatograph data for HGK-1 and HGK-2. Cations are Li-Sr: Anions are F to PO_4.

HGK-1	Li	Na	NH4	K	Mg	Ca	Sr	F	Cl	NO2	Br	NO3	SO4	PO4
9/24/2021	-	81	0.39	3.32	12	66	0.08	0.19	91.5	0.11	0.04	8.08	39.4	0.35
10/19/2021	-	135	-	2.66	18.8	91.5	0.25	0.24	183	0.04	0.14	6.47	46.2	0.32
HGK-2														
9/16/2021	-	107	-	2.36	13.9	70.6	-	0.17	143	0.01	0.05	4.59	34.4	0.24
9/24/2021	-	79.6	0.19	3.29	12	65	0.07	0.17	88.3	0.09	0.04	7.65	39.5	0.31
10/4/2021	-	10.3	-	1.11	1.64	12.3	-	0.02	11.4	0.01	-	0.43	3.2	0.18
10/5/2021	-	83.1	-	2.74	13	68.1	-	0.15	94.5	0.03	0.04	4.49	32	0.24
10/7/2021	0.01	147	-	2.6	19.5	97	0.15	0.2	191	0.02	0.08	6.05	48.3	0.28
10/14/2021	0.01	166	0.32	2.91	20.6	94.9	0.29	0.26	246	0.09	0.09	4.91	51.3	0.5
10/16/2021	-	111	0.21	3.27	15.5	74.3	0.18	0.23	165	0.06	0.57	2.89	36.5	0.51
10/17/2021	-	93.6	0.07	2.96	15.6	76.6	0.19	0.17	114	0.02	0.11	4.92	35.8	0.26
10/21/2021	-	148	-	2.51	19.9	92.4	0.18	0.24	219	0.02	0.11	5.27	47.6	0.33
10/24/2021	0.01	161	0.14	2.91	20.7	97.2	0.32	0.25	229	0.1	0.08	5.39	51.2	0.36
10/27/2021	-	105	-	2.69	16.7	81.3	0.23	0.16	126	0.02	0.04	5.52	41.2	0.21
10/28/2021	-	128	-	2.48	18.6	89.2	0.29	0.18	156	0.02	0.05	5.86	44.4	0.23
11/4/2021	0.01	152	0.19	2.52	20.9	96.3	0.32	0.22	214	0.03	0.07	5.29	48.9	0.31

Table 7. Ion chromatograph data for all MK sampling locations. Cations are Li-Sr: Anions are F to PO_4.

MK-1	Li	Na	NH4	K	Mg	Ca	Sr	F	Cl	NO2	Br	NO3	SO4	PO4
9/16/2021	-	16.9	-	1.7	6.43	37.5	-	0.05	23.7	0.01	0.01	2.35	16.8	0.1
10/7/2021	-	12	-	1.54	5.09	33.2	0.06	0.05	16.4	0.01	0.01	1.65	11.2	0.06
10/14/2021	-	13.1	0.04	1.37	5.26	34.4	0.14	0.04	18.5	0.02	0.01	1.43	11.9	0.06
10/24/2021	-	15.9	0.03	1.62	7.02	41.8	0.13	0.05	21.3	0.01	0.01	1.9	13.5	0.06
10/28/2021	-	10	0.01	1.56	4.11	29.1	0.09	0.04	11.3	-	-	1.19	6.67	0.03
11/4/2021	-	14.5	0.01	1.14	5.54	34.5	0.08	0.04	16.9	0.01	0.01	1.99	10.6	0.04
MK-2														
9/16/2021	-	21.9	0.01	1.76	6.66	40.1	-	0.06	31.7	0.02	0.01	2.74	17.3	0.09
10/7/2021	-	16.7	0.01	1.61	5.46	36.1	0.08	0.05	23.6	0.01	0.01	1.98	12.2	0.06
10/27/2021	-	57.6	0.07	2.46	7.93	54.6	0.09	0.1	85.5	0.05	0.03	4.86	18.4	0.06
10/28/2021	-	29.4	0.02	1.99	5.85	41.5	0.04	0.06	42.3	0.02	0.01	3.2	12.6	0.04
10/14/2021	-	15	0.01	1.61	5.56	35.9	0.14	0.04	21.3	0.01	0.01	1.23	12	0.01
10/14/2021	-	15.7	0.01	1.55	5.52	36	0.08	0.05	25.5	0.01	0.01	1.35	12.4	0.02
MK-3														
9/16/2021	-	17.1	-	1.71	6.42	37.5	0.12	0.05	23.9	0.01	0.01	2.42	16.5	0.1
9/24/2021	-	17.2	-	1.75	6.68	39.6	0.16	0.05	24	0.01	0.01	2.61	16.4	0.07
10/4/2021	-	16.9	0.01	1.39	6.04	37	-	0.05	23.8	0.01	0.01	2.11	14.2	0.06
10/5/2021	-	14.8	-	1.55	5.48	35.2	-	0.04	20.5	0.01	0.01	1.43	11.7	0.06
10/7/2021	-	14.2	-	1.56	5.28	34.7	0.08	0.05	19.6	0.01	0.01	1.8	11.8	0.06
10/14/2021	-	15.2	0.02	1.57	5.55	35.4	0.14	0.04	20.1	0.01	0.01	1.46	12	0.04
10/16/2021	-	24.5	0.06	1.48	6.41	38.2	0.14	0.04	19.8	0.01	0.01	1.3	11	0.04
10/17/2021	-	12.9	0.01	2.33	5.75	34	0.15	0.05	20.2	-	0.01	1.49	11.5	0.08
10/21/2021	-	19.2	0.01	1.99	6.92	42.3	0.09	0.05	21.6	0.01	0.01	1.73	12.4	0.05
10/24/2021	-	16.9	0.03	1.69	7.02	42.3	0.19	0.05	24.7	0.01	0.01	2.3	14.2	0.03
10/26/2021	-	14.3	-	1.76	6.04	35.3	0.09	0.06	33.1	0.01	0.02	1.89	13.6	0.08
10/28/2021	-	8.99	-	1.56	3.99	28.7	0.05	0.04	11.5	-	0.01	1.3	6.55	0.04
11/4/2021	-	14.8	0.01	1.2	5.61	35.6	0.08	0.04	19.6	0.01	0.01	2.17	11	0.04
MK-4														
10/7/2021	-	13.2	0.01	1.51	5.32	34.3	0.09	0.05	17.8	0.01	0.01	1.58	12.2	0.05
10/14/2021	-	14.5	0.04	1.71	5.51	34.6	0.14	0.04	19.9	0.01	0.01	1.38	11.8	0.05
10/28/2021	-	8.22	0.01	1.57	3.79	27.8	0.01	0.04	11.3	-	0.01	1.18	6.72	0.03
11/4/2021	-	13.3	0.02	1.17	5.73	35.7	0.14	0.04	18.8	0.01	0.01	1.92	11.2	0.03

Other relationships such as nitrate-phosphate, chloride-calcium, or sodium-chloride can help reveal sources of dissolved ions in water. Knowing the general relationships of ions in municipal drinking water and municipal wastewater helps to explain potential sources of contaminants (Fig. 16-17). High values of both sodium and chloride would be expected for salt-contaminated water, as these two ions make up salt (Fig. 18). Fluorine (and chlorine) are added to municipal drinking water to help with disinfection, and high fluorine values are reflected in the municipal drinking water (Fig. 19).

Some ions that dominate in the larger Mohawk River are not necessarily in the small and urban tributaries (BK and HGK). Likewise, the number of total ions differs between the large river and the smaller urban creeks. While the Mohawk River has a high percent of calcium out of all major ions analyzed (roughly 35-48%), the BK and HGK have much lower calcium values (around 20%) (Fig. 16). However, the specific conductance values are much higher in the BK and the HGK, with values between 400-1200 μS/cm. Specific conductance in the Mohawk River averages around 250 μS/cm (Fig. 16). Although Ca values are much higher in the Mohawk River, the smaller urban creeks have a much greater ability to conduct ions. BK and HGK are Ca-poor due to other ions being much more common.

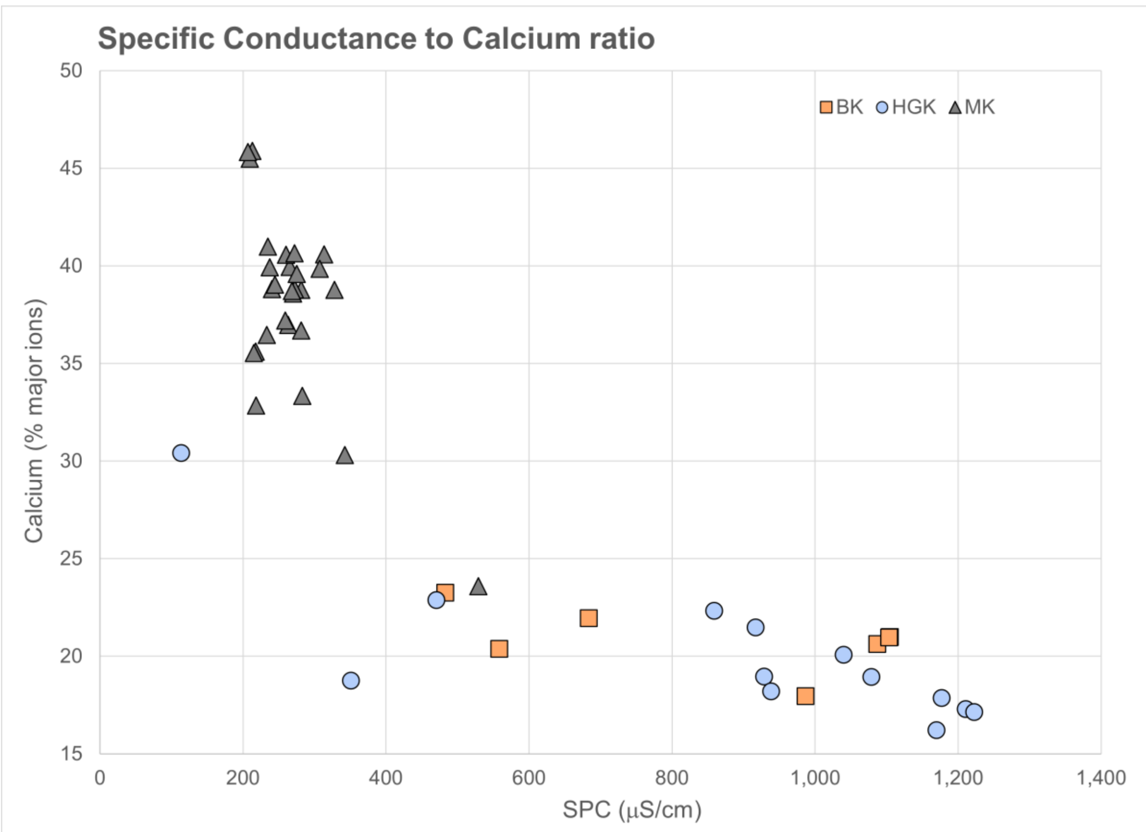

Figure 16. Relationship of specific conductance to percent calcium of major ions (major ions used are SO_4, NO_3, Cl, Ca, Mg, K, and Na). The Mohawk receives a much greater calcium input than BK or HGK, but a lower SPC than both BK and HGK. The BK and HGK are more sensitive to urban inputs (SPC), while the MK shows greater input from bedrock.

While the Mohawk River is dominated by Ca, the Binnekill and Hans Groot Kill are dominated by other ions, especially chlorine (Fig. 17). A large fraction of major ions in small urban creeks are

chlorine (30-45%), compared to the lower chlorine values in the Mohawk (~20-25%). Although rain causes dilution, the overall differences between dissolved ions in the BK and HGK versus the Mohawk are still quite apparent. Because the percentages of calcium and chloride are so vastly different between the waters, these two dissolved ions can be used to differentiate source waters in almost all flow conditions.

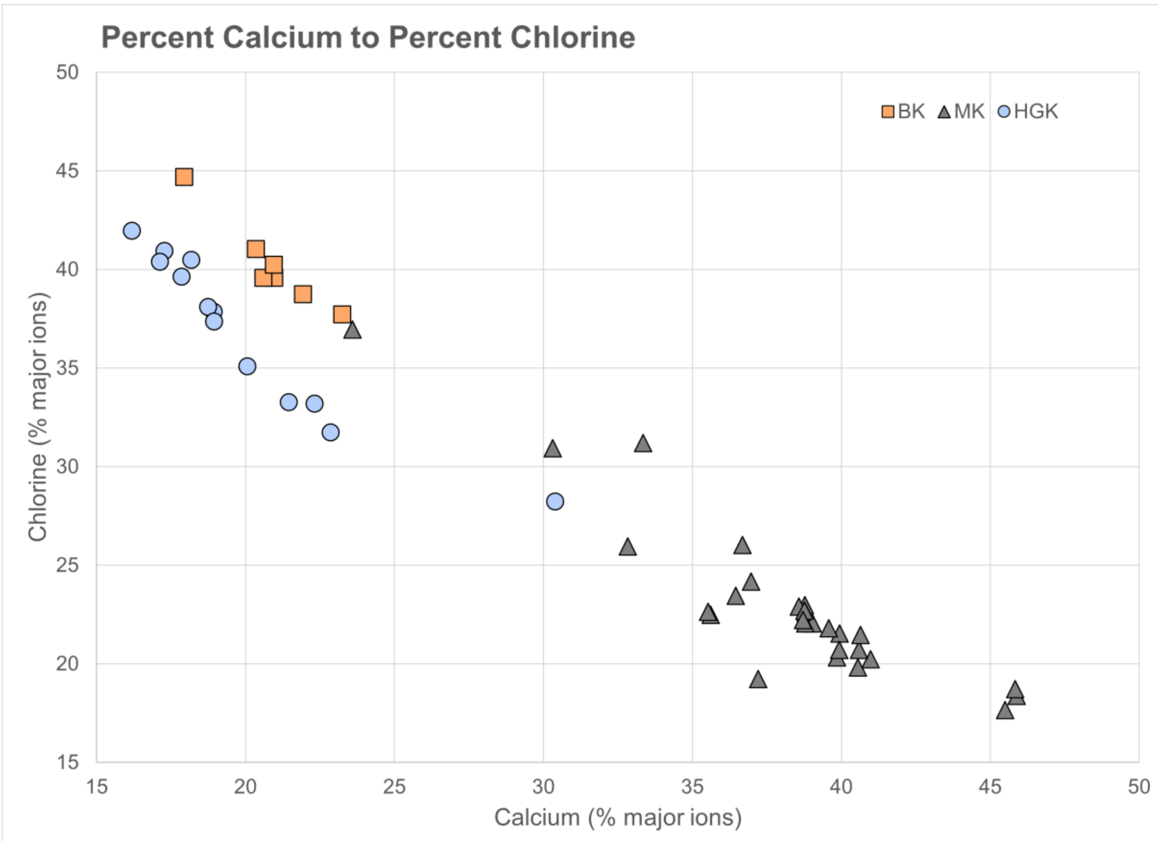

Figure 17. Calcium percent of major ions to percent chlorine of major ions (major ions used are SO_4, NO_3, Cl, Ca, Mg, K, and Na). The MK sources have higher calcium but lower chlorine, and BK and HGK have lower calcium but much higher chlorine.

Sodium and chloride in surface waters in the Northeast are highly correlated due to the input from road salt. In our sample locations in the lower Mohawk Watershed, BK and HGK tend to have higher Na and Cl than in the Mohawk. Na and Cl covary in urban streams in a significant way, but each appears distinctive (the lines in Fig. 18). These values are strongly affected by dilution during high-flow and are more concentrated at low-flow. Cl values between 100-250 ppm are common in urban creeks, while Cl in the large Mohawk River only has approximately 25 ppm. Likewise, Na

values in the BK and HGK are between roughly 80-160 ppm, and in the MK the values are around 18 ppm (Fig. 18).

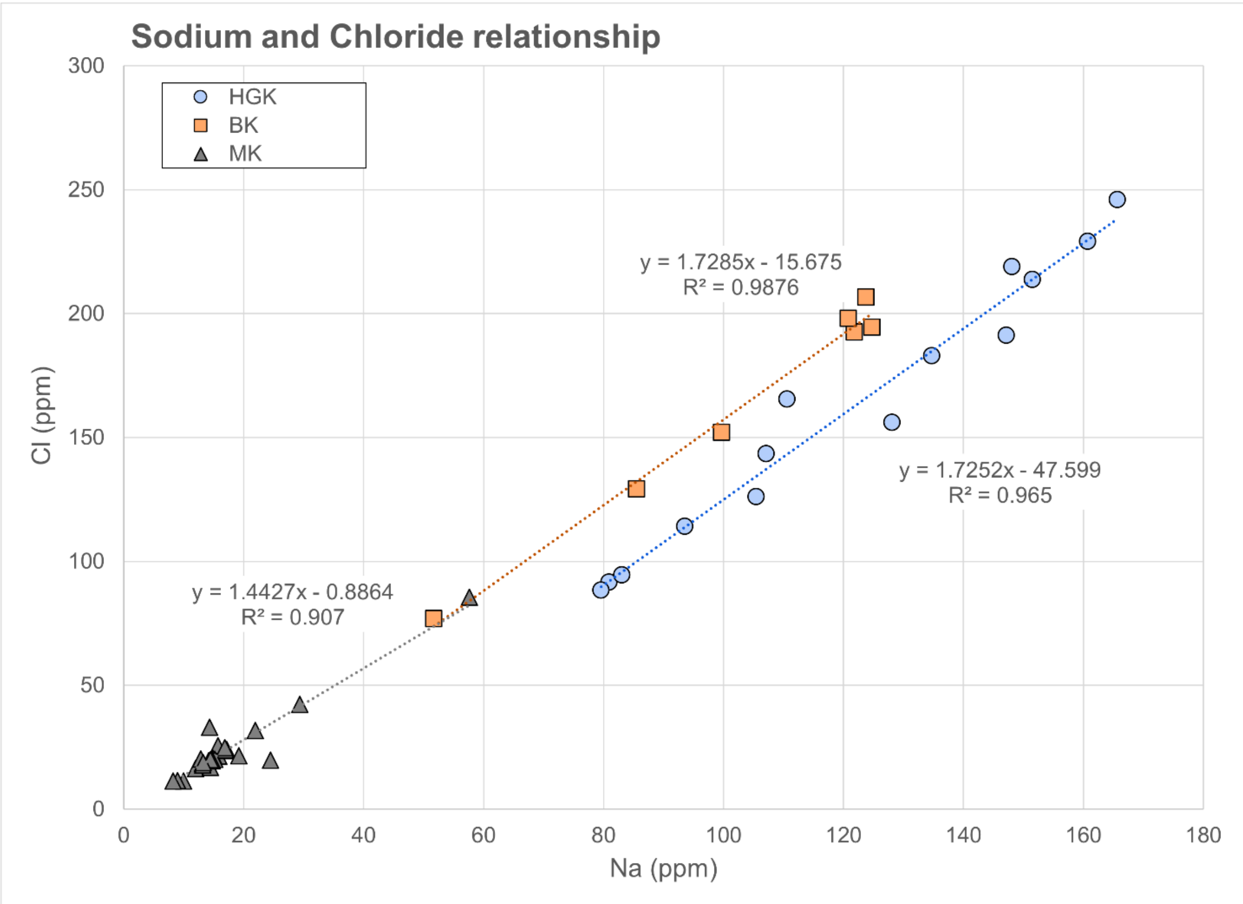

Figure 18. Relationship of sodium to chloride. Gray line serves as best fit for MK data, orange line corresponds to BK data, and blue line relates to HGK data. One data point was removed from the HGK data to better fit the trendline.

Some elements tend to behave similarly in the natural environment. As F and Cl are both halogens, they should both behave in the same way and can often be substituted for each other. Even in the monitored setting of municipal drinking water, F and Cl are typically both added during the disinfection process. If municipal drinking water were leaking, we would expect Cl to be higher than it is, as Cl^- and F^- would covary together; an increase in Cl^- would also mean a great increase in F^-. However, values in the collected water samples are too low in F^- for municipal water to leak into the surface water in a significant way (Fig. 19). The inputs of F and Cl we see in our samples are likely due to some combination of wastewater and road salt, not from municipal drinking water (Kelly et al., 2010).

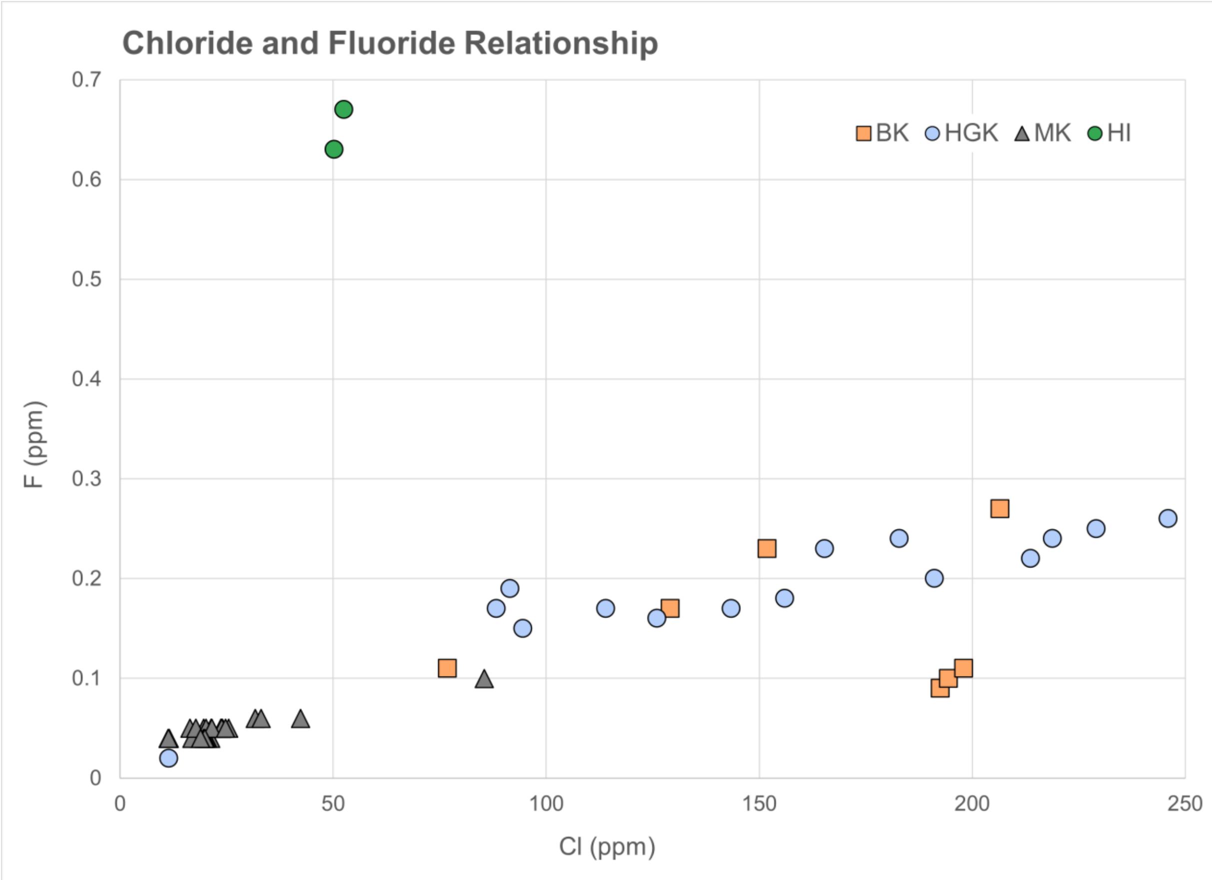

Figure 19. Relationship of Cl to F for the BK, HGK, and MK. Values from municipal drinking water (Hickok Dorm on Union Campus) were also collected and are shown by the green circles.

Excess phosphate and nitrate both have impacts on water quality and aquatic ecosystems. An increase from any normal value leaves the environment susceptible to algal blooms and eutrophication. Both the Binnekill and Hans Groot Kill have higher phosphate and nitrate values than the Mohawk. The Mohawk has a phosphate value of less than 0.1 ppm. Although the Binnekill is in the same range for phosphate, the Hans Groot Kill has phosphate values largely between 0.2-0.5 ppm (Fig. 20). Nitrate values in both the BK and HGK are higher than in the Mohawk.

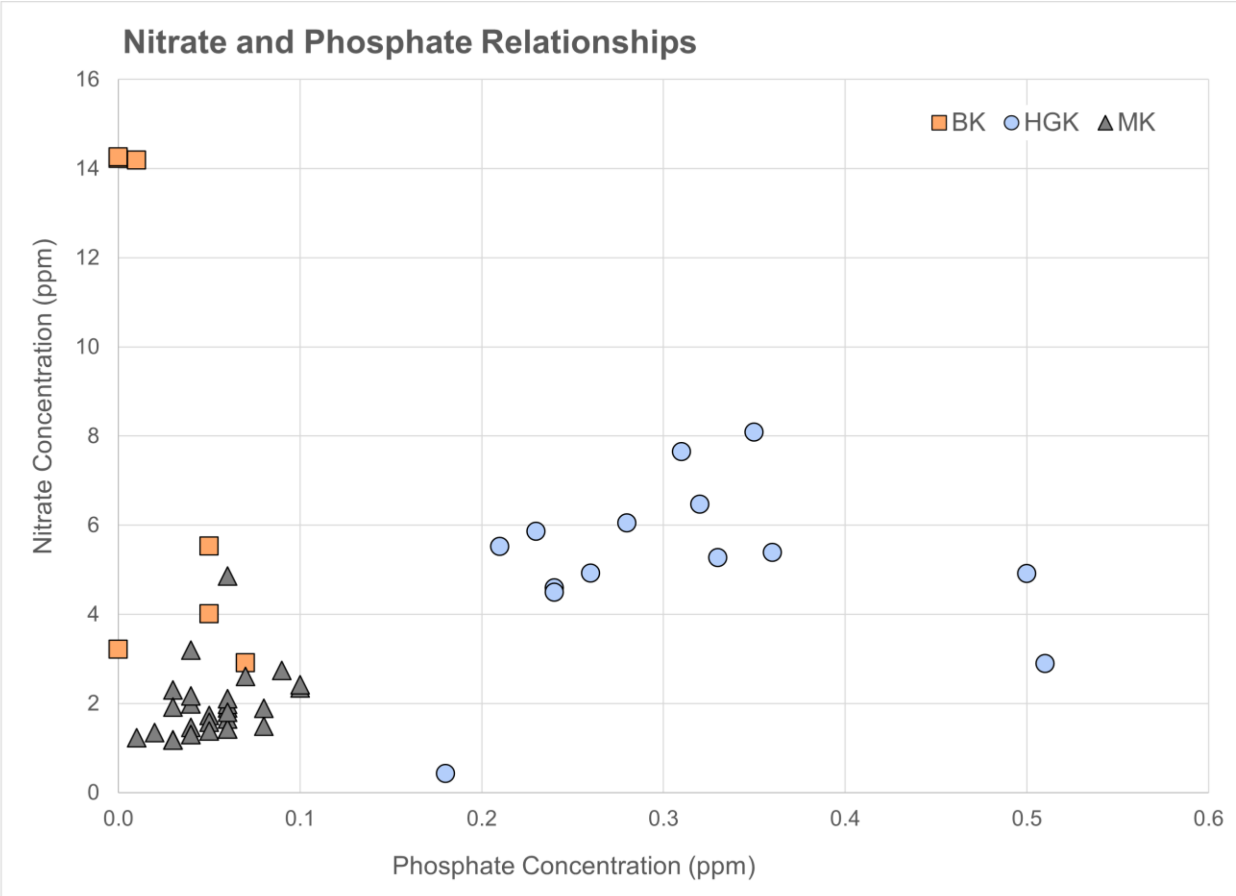

Figure 20. Concentration of phosphate to concentration of nitrate, both in ppm. The Mohawk sources have low phosphate and low nitrate. BK shows low phosphate but high nitrate, and HGK displays higher nitrate than MK, and much greater phosphate than either MK or BK.

Enterococcus

Evidence for the 'urban stream syndrome' can be demonstrated in all sample locations, but the Hans Groot Kill and the Binnekill appear to be especially distinctive due to the presence and quantity of the fecal indicator bacteria *Enterococcus.* Overall, 86 individual *Enterococcus* samples were taken: 11 from the Binnekill, 32 from the Hans Groot Kill, and 43 from the Mohawk River. It is important to note that among the 86 total samples, only 23 total were below the EPA-recommended BAV of 60 MPN/100 mL for individual samples (mostly in the Mohawk). The rest of the samples, or the 73% majority, failed to meet the EPA-recommended BAV. *Enterococcus* values ranged greatly between sample locations but were generally highest in the Hans Groot Kill (Table 8). *Enterococcus* in BK-1 were not as high as in BK-2, although were still above the BAV (Table 9). BK-3 was only sampled once. Full tables of *Enterococcus* sampling details can be found in Appendix B-C.

Table 8. Geometric means and averages of *Enterococcus* for all sample locations. Note that HGK-1 and HGK-2 contained saturated samples, meaning the average MPN and the geometric mean are the minimum averages.

Site	n	Avg MPN	Geo. Mean
BK-1	5	160	95
BK-2	5	2395	861
BK-3	1	134	134
HGK-1*	7	5548	1398
HGK-2*	25	11940	2531
MK-1	9	720	116
MK-2	8	3034	860
MK-3	19	2286	262
MK-4	7	458	62

* contains saturated samples

Table 9. Enterococcus values and rainfall totals for sampling location BK-1, BK-2, and BK-3.

BK-1	Time Collected	Actual MPN	6 hr rain	12 hr rain	24 hr rain	48 hr rain
9/16/2021	11:46	209	0	0.02	0.45	0.45
9/21/2021	12:06	30	0	0	0	0
9/30/2021	11:40	52	0	0	0	0
10/7/2021	10:29	455	0	0.01	0.01	0.09
10/14/2021	10:34	52	0	0	0	0
BK-2						
10/21/2021	11:04	172	0	0	0	0
10/27/2021	17:12	8704	0	0	0.13	1.54
10/28/2021	11:30	2098	0	0	0	0.35
11/4/2021	11:20	185	0	0	0	0
11/11/2021	11:21	816	0	0	0	0.09
BK-3						
11/4/2021	11:03	134	0	0	0	0

The total previous rainfall and *Enterococcus* relationship in the Binnekill has a positive correlation, with the 48-hour rainfall and pathogen relationship having the highest R^2 value of 0.92, meaning as rainfall increases so does the pathogen level. Low-high flow values were commonly above 100 MPN/100 mL (Fig. 21).

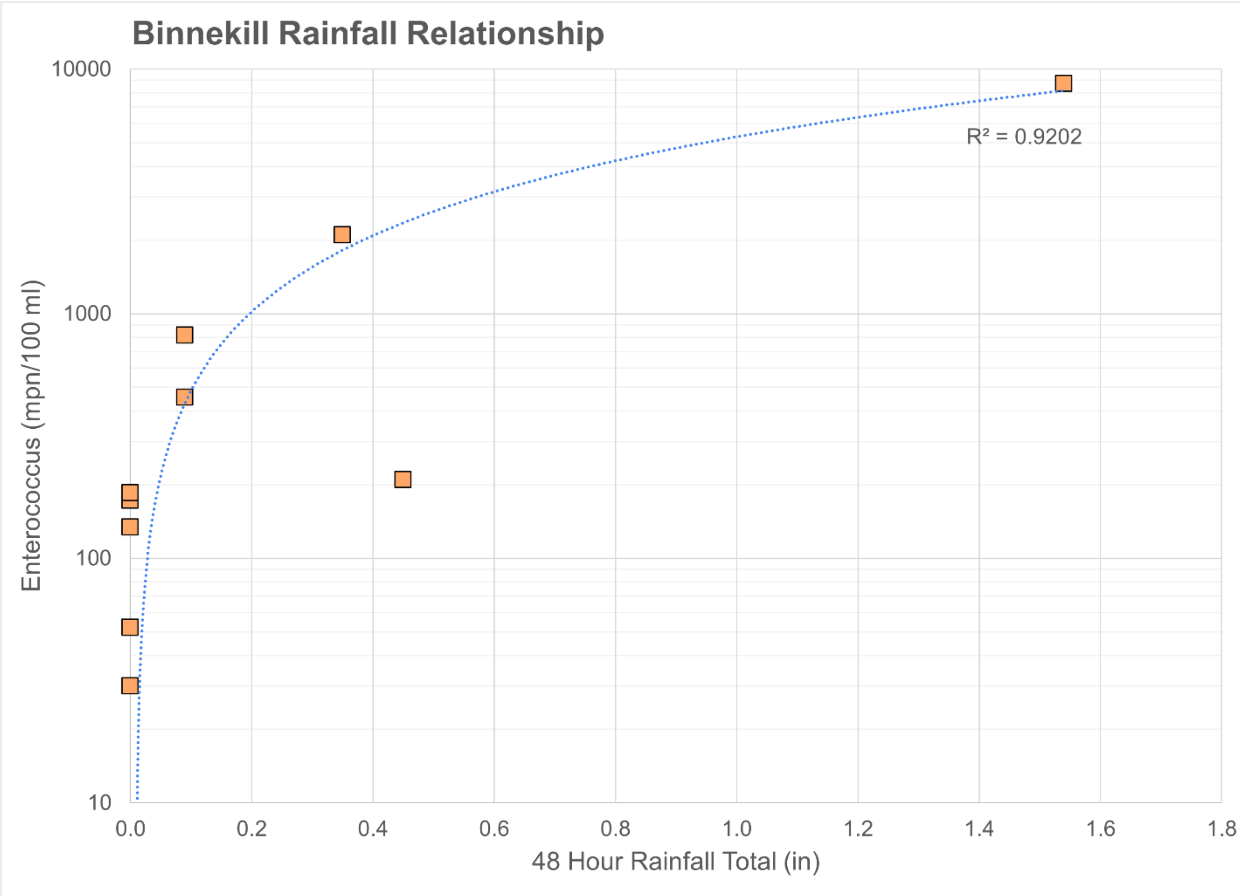

Figure 21. Relationship between 48-hour rainfall and *Enterococcus* at all BK locations. The 48-hour rainfall is the best fit of all rainfall intervals. Note that even during low rainfall events, *Enterococcus* levels tend to be high.

Enterococcus values in the Hans Groot Kill were higher, on average, than any other sample location (Table 8). The average *Enterococcus* value and geometric mean in HGK-1 were 5548 MPN/100 mL and 1398 MPN/100 mL, respectively, but ranged above 24,196 (Table 8 and Table 10). Some of the samples were fully saturated, so these averages are minimum values. The average MPN and geometric mean in HGK-2 were 11,940 MPN/100 mL and 2531 MPN/100 mL, respectively, although values ranged above 48,392 (Tables 8, 10). Of the 32 total samples taken from the HGK, none of them had an MPN that was below the BAV of 60 MPN/100 mL (100% of samples fail to meet the EPA BAV in HGK). The lowest value recorded was 108 MPN/100 mL.

Table 10. Enterococcus values and rainfall totals for sampling locations HGK-1 and HGK-2.

HGK-1	Time Collected	Actual MPN	6 hr rain	12 hr rain	24 hr rain	48 hr rain
9/13/2021	13:35	12033	0	0.66	0.84	0.84
9/14/2021	12:50	428	0	0	0	0.84
9/15/2021	14:35	624	0.01	0.01	0.01	0.01
9/16/2021	15:05	443	0	0	0.39	0.45
9/24/2021	12:42	24196	0	1.44	2.53	2.54
10/19/2021	13:37	640	0	0	0.01	0.02
10/20/2021	14:10	473	0	0	0	0.01
HGK-2						
9/13/2021	13:25	14136	0	0.66	0.84	0.84
9/14/2021	12:40	583	0	0	0	0.84
9/16/2021	12:44	1314	0	0.02	0.45	0.45
9/21/2021	13:23	305	0	0	0	0
9/24/2021	12:38	24196	0	1.44	2.53	2.54
9/30/2021	13:05	197	0	0	0	0
10/4/2021	12:31	24196	0.37	0.9	1.05	1.07
10/5/2021	12:06	10462	0.02	0.18	0.82	1.77
10/7/2021	11:35	108.1	0	0.01	0.01	0.09
10/10/2021	15:35	878	0	0	0	0
10/11/2021	15:38	262	0	0	0	0
10/12/2021	15:35	1633	0	0	0	0
10/14/2021	11:42	441	0.01	0.01	0.01	0.01
10/17/2021	13:14	12997	0	0	1.44	1.84
10/21/2021	11:33	583	0	0	0	0
10/24/2021	15:24	1162	0	0	0	0
10/27/2021	18:02	1920	0	0	0.12	1.54
10/28/2021	12:34	1071	0	0	0	0.28
11/4/2021	12:29	7270	0	0	0	0
11/11/2021	12:23	990	0	0	0	0.09
11/12/2021	12:31	48,392	0.83	1	1	1
11/12/2021	14:06	48,392	0.16	1.03	1.03	1.03
11/12/2021	15:06	48,392	0.05	1.03	1.03	1.03
11/12/2021	16:15	48,392	0	1.03	1.03	1.03
11/18/2021	9:54	238	0	0	0	0

The *Enterococcus* and rainfall relationship have a positive correlation in the Hans Groot Kill, with an R^2 value of 0.7294. The rainfall total (out of 6-hour, 12-hour, 24-hour, or 48-hour cumulative rainfall) with the highest correlation was 12-hour rainfall (Fig. 22).

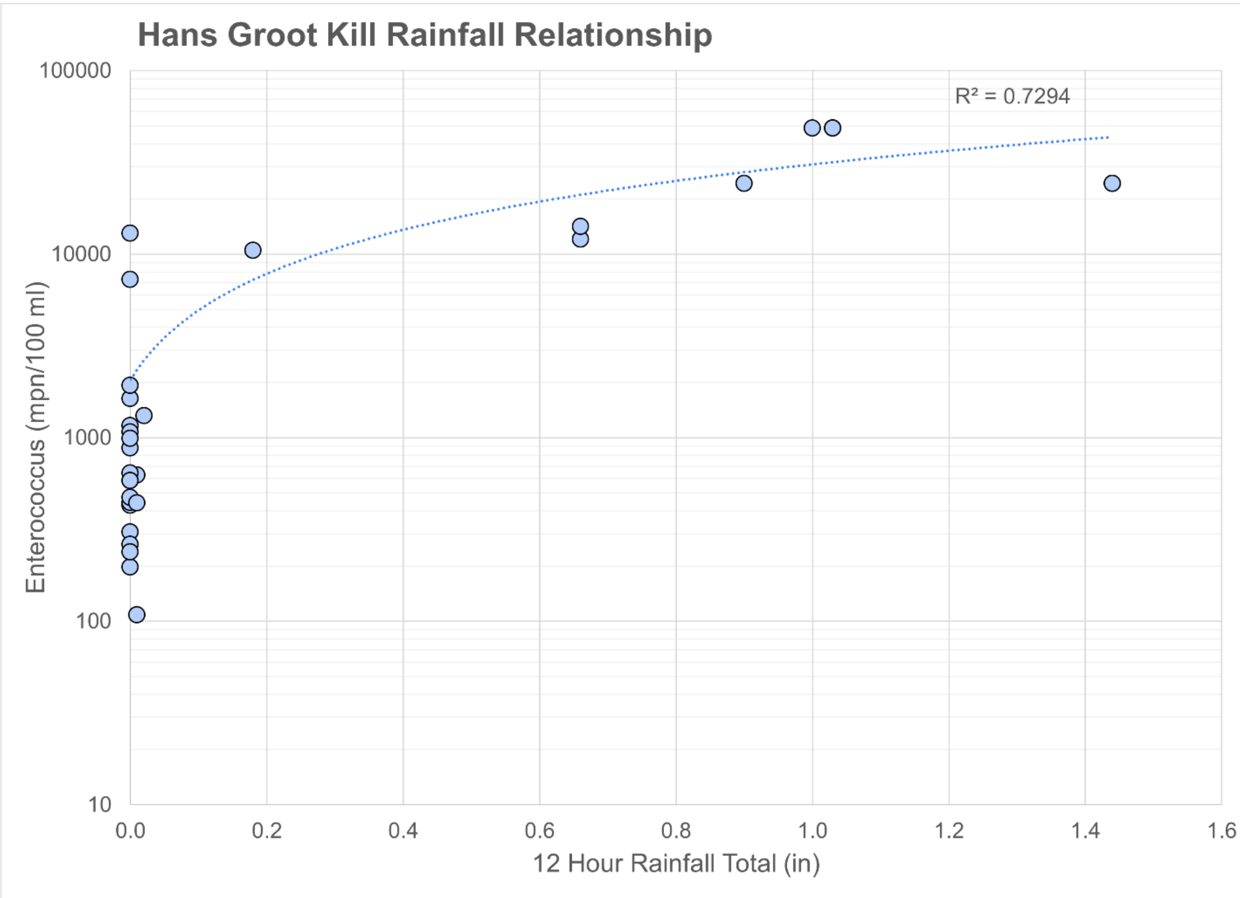

Figure 22. Relationship of 12-hour rainfall to *Enterococcus* in both Hans Groot Kill sampling locations, with an R^2 of 0.7294. Note that the *Enterococcus* values are on a log scale. The 12-hour rainfall had the highest R^2 out of 6-hour, 12-hour, 24-hour, and 48-hour rainfall totals. Notably, the HGK has elevated *Enterococcus* levels even during low rainfall events.

Enterococcus values in the Mohawk River tended to be lower than in the Binnekill or Hans Groot Kill, but of the 43 total Mohawk River samples, only 20 (46.5%) were below the BAV (i.e. 53.5% failed to meet EPA BAV criteria). It is difficult to deduce clear trends from these data because the sites were not all sampled simultaneously. All samples have a geometric mean for the fall of 2021 that exceeds the EPA BAV. MK-4 had the lowest average *Enterococcus* value at 458 MPN/100 mL (Table 8). The geometric mean at MK-4 is 62 MPN/100 mL, which is above the BAV (Table 11). The samples with the worst water quality appear to be MK-2 (Gateway Park/SUNY

Schenectady) and MK-3 (Union College crew dock in the Stockade): both adjacent to the downtown area.

An analysis of the water quality in the Mohawk before, at, and downstream of Schenectady is not easily done with this data set. All four sample sites were simultaneously sampled five times, and only two of those times were during high-flow rainfall events (Fig. 23). In both cases the highest values were at either MK-2 or MK-3. The difference was greatest on 28 October when the *Enterococcus* values at Gateway Park (3076 MPN/100 ml) and the Stockade (3654 MPN/100 ml) were nearly twice that of Lock 8 (water entering the Schenectady Pool).

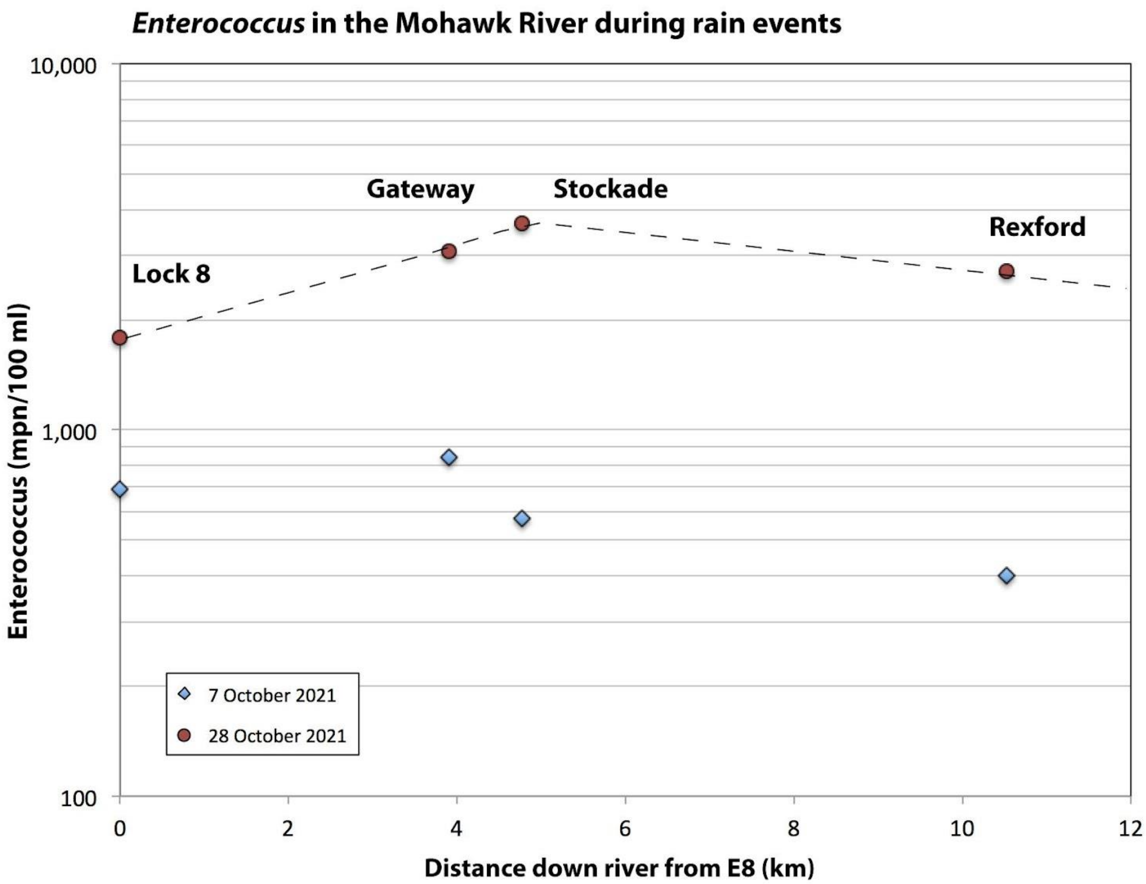

Figure 23. *Enterococcus* in the Mohawk at all four sites during two high-flow (rainfall) events.

Table 11. Enterococcus values and rainfall totals for all Mohawk River sampling locations.

MK-1	Time Collected	Actual MPN	6 hr rain	12 hr rain	24 hr rain	48 hr rain
9/16/2021	11:04	3784	0	0.04	0.45	0.45
9/21/2021	12:54	30	0	0	0	0
9/30/2021	12:26	10	0	0	0	0
10/7/2021	11:10	689	0.01	0.01	0.01	0.01
10/14/2021	11:17	41	0.01	0.01	0.01	0.01
10/24/2021	16:10	17	0	0	0	0
10/28/2021	11:57	1785	0	0	0	0.33
11/4/2021	12:02	74	0	0	0	0.09
11/11/2021	11:53	51	0	0	0	0.09
MK-2						
9/16/2021	11:18	5794	0	0.04	0.45	0.45
9/21/2021	12:26	10	0	0	0	0
9/30/2021	12:00	31	0	0	0	0
10/7/2021	10:45	845	0	0	0.13	1.54
10/27/2021	17:26	9222	0	0	0.13	1.54
10/28/2021	11:18	3076	0	0	0	0.35
10/14/2021	10:48	2382	0.01	0.01	0.01	0.01
10/14/2021	10:49	2909	0.01	0.01	0.01	0.01
MK-3						
9/16/2021	12:09	5794	0	0.02	0.45	0.45
9/21/2021	11:46	0	0	0	0	0
9/24/2021	12:36	4611	0	1.44	2.53	2.54
9/30/2021	11:22	10	0	0	0	0
10/4/2021	13:26	884	0.53	1.05	1.25	1.27
10/5/2021	11:52	2495	0.02	0.18	0.82	1.77
10/7/2021	10:15	573	0	0	0	0
10/10/2021	15:05	0	0	0	0	0
10/11/2021	14:57	10	0	0	0	0
10/12/2021	14:45	22	0	0	0	0
10/14/2021	10:17	10	0	0	0	0
10/17/2021	12:26	19863	0	0	1.44	1.84
10/21/2021	10:38	86	0	0	0	0
10/24/2021	15:39	17	0	0	0	0
10/26/2021	11:40	5172	0.41	1.19	1.2	2.04
10/28/2021	11:04	3654	0	0	0	0.37
11/4/2021	10:32	85	0	0	0	0.09
11/11/2021	10:55	30	0	0	0	0.09
11/18/2021	9:39	122	0	0	0	0
MK-4						
9/21/2021	11:19	10	0	0	0	0
9/30/2021	11:02	0	0	0	0	0
10/7/2021	9:53	399	0	0	0	0
10/14/2021	9:57	10	0	0	0	0
10/28/2021	10:43	2723	0	0	0	0.44
11/4/2021	10:14	52	0	0	0	0.09
11/11/2021	10:30	10	0	0	0	0.09

The rainfall and *Enterococcus* relationships at all Mohawk locations had positive correlations, with varying coefficients of determination (R^2 value) (Fig. 24-27). MK-4 had the highest R^2 value, at 0.8942. The rainfall total (between 6-hour, 12-hour, 24-hour, and 48-hour) with the highest R^2 correlation was used in each respectively graph to calculate the R^2 value.

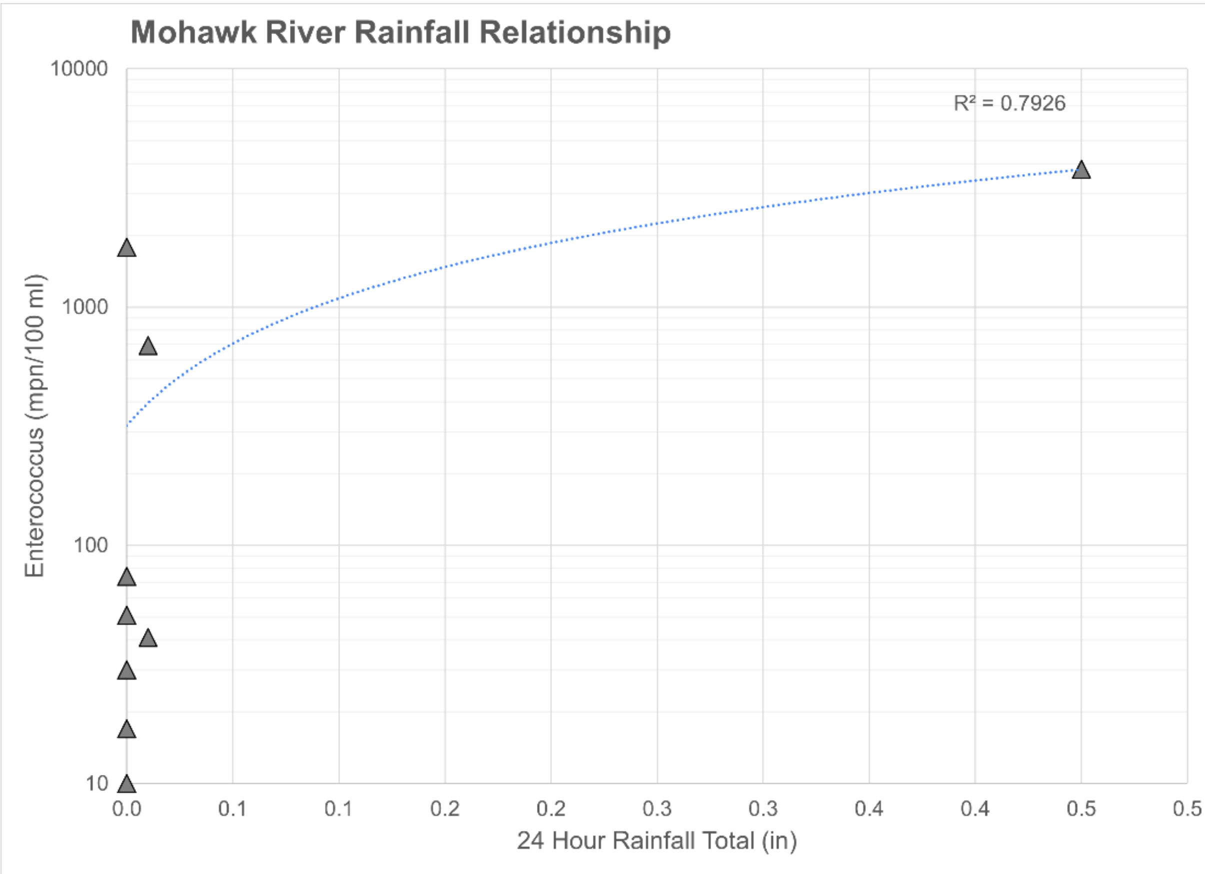

Figure 24. The 24-hour rainfall total and *Enterococcus* relation at MK-1, with *Enterococcus* on a log scale. The R^2 value with 24-hour rainfall is 0.7926, the highest relationship between 6-hour, 12-hour, 24-hour, and 48-hour rainfall.

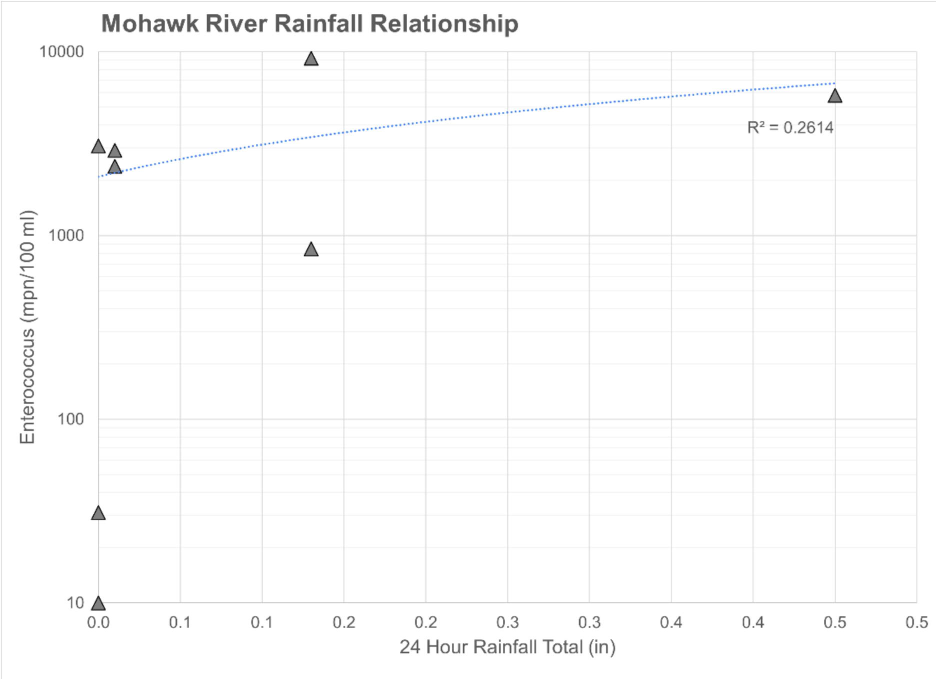

Figure 25. The 24-hour rainfall total and *Enterococcus* relation at MK-2, with *Enterococcus* on a log scale. The R^2 value with 24-hour rainfall is 0.2614, the highest relationship between 6-hour, 12-hour, 24-hour, and 48-hour rainfall.

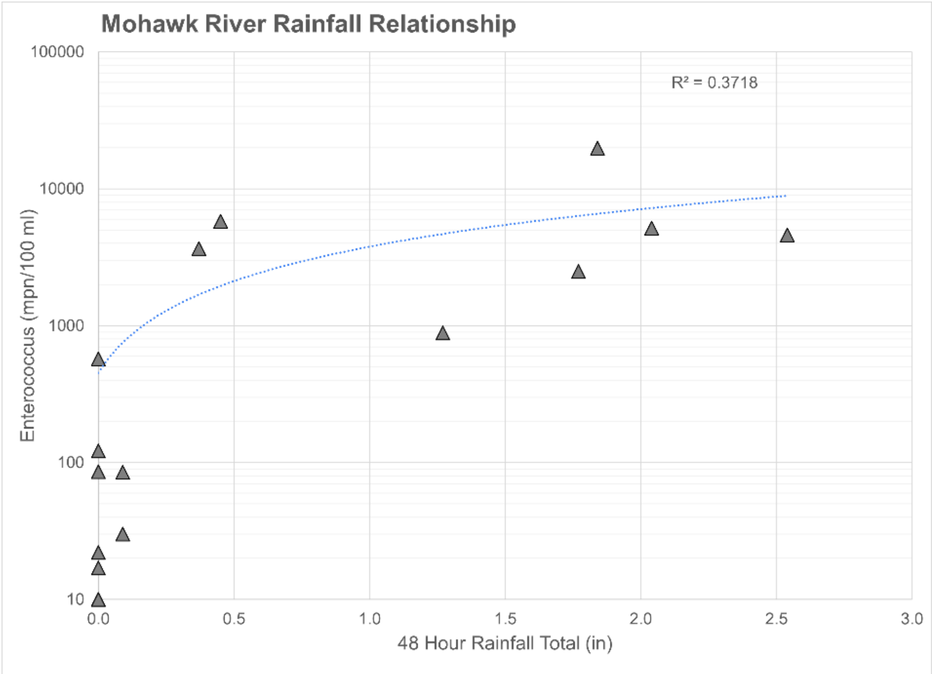

Figure 26. The 48-hour rainfall total and *Enterococcus* relation at MK-3, with *Enterococcus* on a log scale. The R^2 value with 48-hour rainfall is 0.3718, the highest relationship between 6-hour, 12-hour, 24-hour, and 48-hour rainfall.

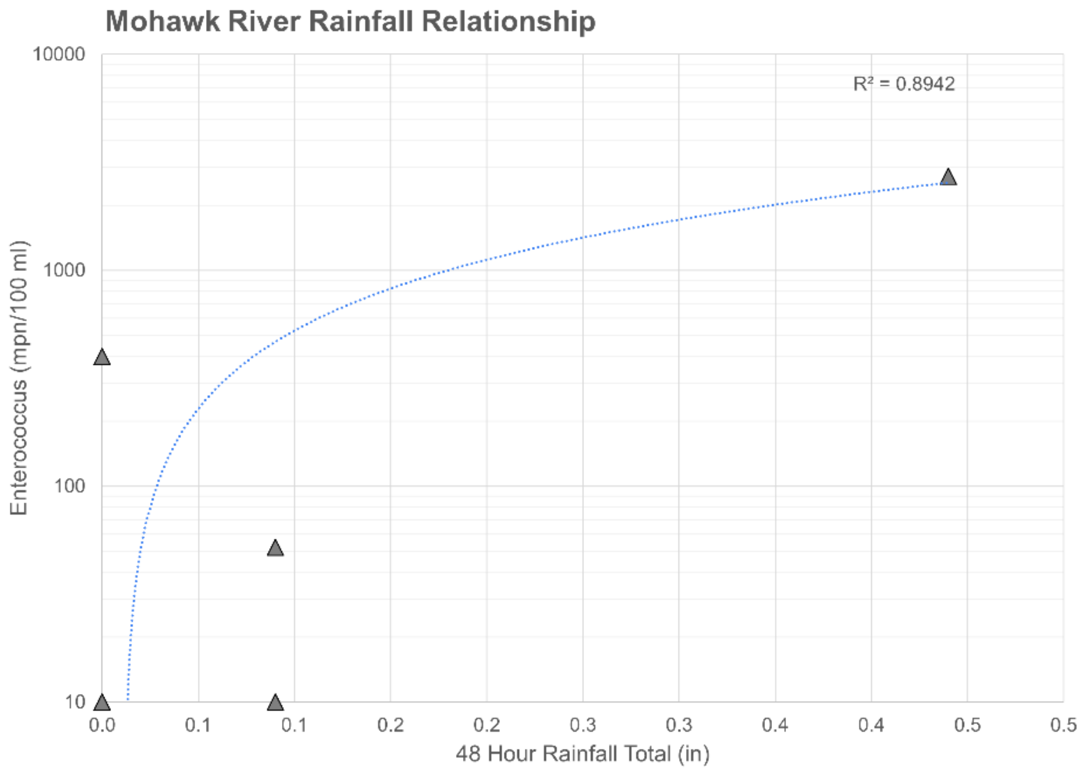

Figure 27. The 48-hour rainfall total and *Enterococcus* relation at MK-4, with *Enterococcus* on a log scale. The R^2 value with 48-hour rainfall is 0.8942, the highest relationship between 6-hour, 12-hour, 24-hour, and 48-hour rainfall.

Turbidity

Turbidity data were collected from the HRECOS website to determine the effects of turbidity on *Enterococcus* and water quality in general. Turbidity data are collected every 15 minutes and values increase with rainfall events. However, in late fall when the locks from the Erie Canal are removed, huge amounts of sediment are mobilized as an influx of water rushes through the system and disturbs the sediment on the river bottom. Thus there is natural turbidity associated with rainfall, and a 'mechanical' turbidity due to canal operations. This lock removal let us study *Enterococcus* response to the huge turbidity event and test whether bacteria attached to sediment are significant. In 2021, lock removal occurred around 10/28/2021, and it unfortunately occurred during a rainfall event, but it was the second largest turbidity event of the year, behind a large storm in the summer. Unfortunately, the rain around the same time as the lock removal means that some of the turbidity may be a response to rainfall as well as the lock removal. In this regard, the experiment has more than one variable.

Enterococcus values were plotted on top of a turbidity graph from September through November to show the fluxes of *Enterococcus* in response to turbidity changes (Fig. 28). Turbidity was also plotted against *Enterococcus* to show the general relationship (Fig. 29). Five data points, in a rough cluster, were clear outliers from the trend and were thus plotted in different colors (Fig. 29). It was found that these five data points came from the two-day period on the 27th and 28th of October 2021 during the lock removal, and the *Enterococcus* values are about 3.7 times lower than predicted from the turbidity-*Enterococcus* relationship in other samples.

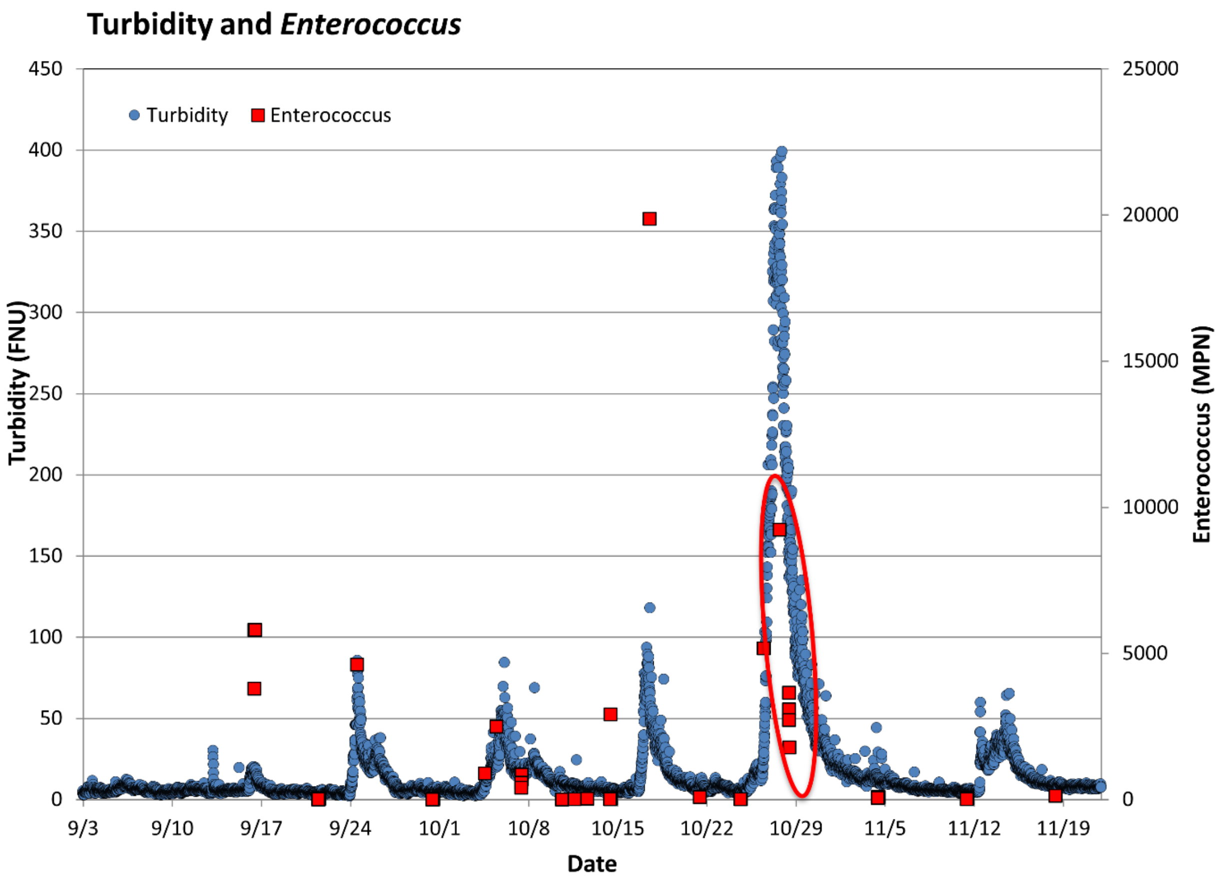

Figure 28. *Enterococcus* values in red squares plotted on top of blue turbidity points. Turbidity is plotted on the primary Y-axis, and Enterococcus on the secondary Y-axis. Generally, *Enterococcus* values increased following turbidity events. However, five *Enterococcus* values around the 10/28/2021 turbidity event, shown in the red oval, were not as high as expected.

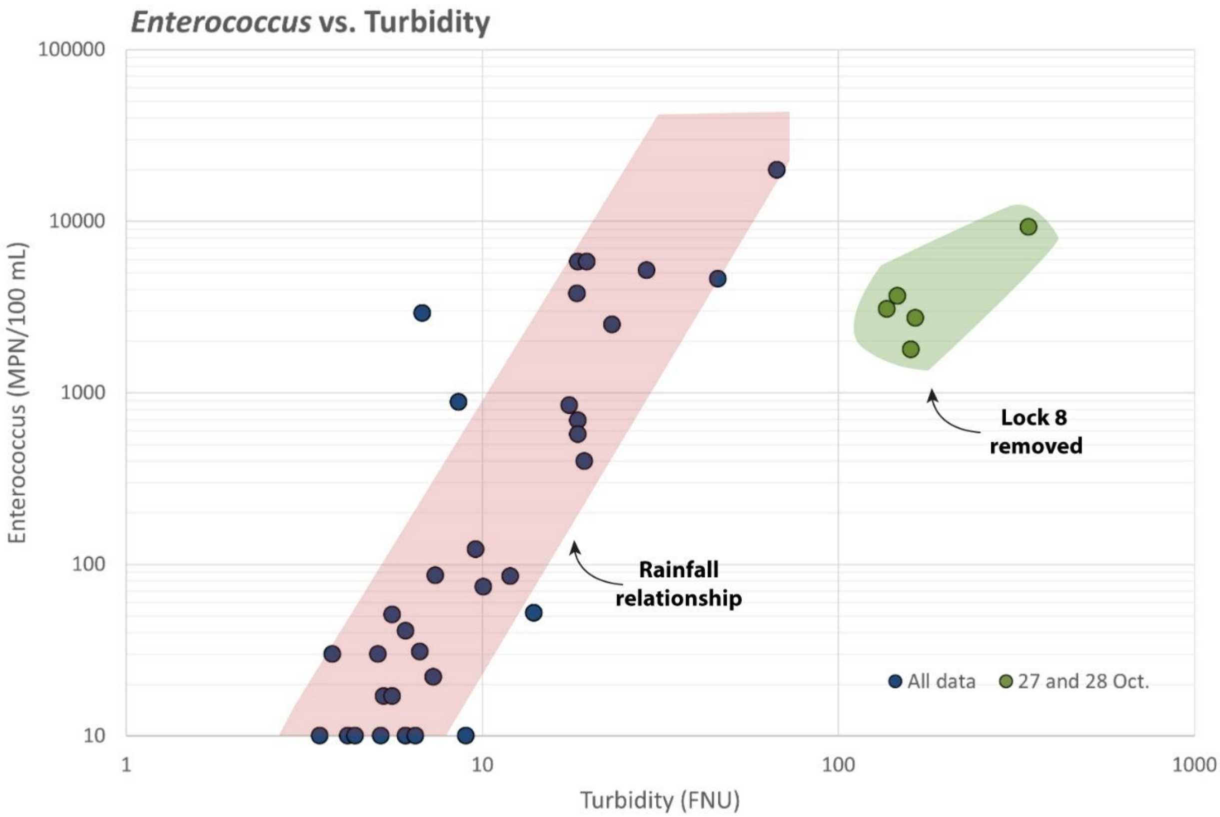

Figure 29. Turbidity from Rexford and Enterococcus for all MK locations. Blue circles show all data save for the 5 outliers in a cluster, shown by green circles. These 5 outliers all came from a two-day period, the 27th and 28th of October 2021.

DISCUSSION

The data from water sampling in the urban tributaries to the Mohawk in the Schenectady area indicate significant impairment of surface water at both high- and low-flow conditions. Contaminants are shown through pathogen sampling, water quality parameters, and dissolved ions. Data from the multiparameter (YSI) water quality sampling exhibit high levels of dissolved ions in water pathways. Major ions, such as calcium, sodium, chloride, and magnesium enter water mostly due to human activity and contamination. This contamination comes from road salt, agriculture, and most notably, human sewage.

Enterococcus values in this project varied between location and tended to depend on recent precipitation, but other trends became evident over the course of this study. *Enterococcus* in the Hans Groot Kill is generally at least an order of magnitude higher than that of the Mohawk River. High pathogens in the Hans Groot Kill occurred during both high-flow events and low-flow events; even in dry conditions, pathogen levels were still high. High-flow conditions show elevated

Enterococcus levels in all water bodies, indicating an influx of pathogens washing into water during rain events. The Hans Groot Kill especially has a significant difference between high-flow and low-flow pathogen values. Overburdened and old sewer systems leak more sewage into water bodies (through stormwater sewers, illicit connections, or infiltration) more quickly during rainfall events. If leakage only occurred during rain events, we would expect *Enterococcus* and other pathogens to be high only with rainfall. However, the consistently high levels of *Enterococcus* (at least in the BK and HGK) probably means sewage exfiltration constantly occurs from the old pipes of Schenectady.

These high levels during all flow conditions are almost certainly related to sewage leaking out of old sewer infrastructure and infiltrating the Hans Groot Kill and other streams in Schenectady. Although the city of Schenectady is technically on the MS4 sewer system, remnants of the CSO system are probably still in place. An issue may be that old overflow pipes were never completely blocked off in the transition from being a CSO to MS4 community. The sewer system in Schenectady is decades old and likely leaks already, and improper closure of the CSO system only further contributes to the ongoing sewage pollution.

The elevated specific conductance in primarily the Binnekill and the Hans Groot Kill indicates considerable dissolved ions are common, especially at low water (base flow). The Na-Cl relationship and *Enterococcus* levels indicate that the major source of pollution comes from the over-use of road salt and the outdated sewage handling systems in place in the urban setting of Schenectady. The constant high levels of dissolved ions in these samples supports a hypothesis of a long-term sewage issue in Schenectady. Human populations and urban areas create large amounts of nutrient-rich wastewater that seriously impacts surface waters when incorrectly managed. Anthropogenic sources of N and P occur at rates 10-20 times higher than natural, forest sources (Fisher et al., 2006). Although fertilizer also inputs N and P into water bodies, the study area in this thesis is highly urbanized and nutrient inputs primarily come from human wastewater.

Chloride, Fluoride, and Sodium

Relationships between sodium and chloride or chloride and fluoride can help us understand sources of contamination. We can assume that chloride and sodium covary as a direct result of dissolution of road salt. Chlorine and fluorine are both halogens, and as such they too may covary if substitution occurs. A source of fluoride is municipal drinking water supplies because it is added for health reasons. If water has high Cl but low F, the input likely comes from road salt, because

F is uncommon in NaCl. Municipal drinking water should have both high F and Cl as they are both added to water during the disinfection process but should have low sodium, as this may react out. The Binnekill and Hans Groot Kill have high chloride and high sodium, but generally have low fluoride. The Cl-F graph includes two data points taken from Schenectady municipal drinking water (Fig. 19). If municipal drinking water were leaking into water bodies, fluoride values would trend toward higher F values in a mix between surface water and municipal drinking water (Fig. 19). However, it is clear that chloride enhancement is much more significant.

The data collected came from the fall (September to November), well before any snowfall and heavy road salt use, and yet Na and Cl are still high. Because these inputs are high before heavy salt use, salt contamination in these water bodies comes from groundwater, which is a much broader issue than point-source pollution in just the Schenectady area.

Some dissolved ions do not always indicate high pathogen contamination. The Mohawk River has high calcium values, even though the correlated *Enterococcus* levels are not nearly as high as in the Binnekill or the HGK. This high calcium in the Mohawk River is attributed to the bedrock that contains a significant number of carbonates. The smaller creeks are more sensitive to urban inputs than the large Mohawk River, so calcium in the Binnekill and HGK are much lower than in the Mohawk (Fig. 17). Other ions such as chlorine, nitrogen, and phosphorus are found in much higher amounts in both human sewage and road salt.

Turbidity and Enterococcus

Turbidity is related to *Enterococcus* values and this relationship can be explored on the Mohawk River where turbidity is constantly monitored by the HRECOS network, which has a station at Lock 8 and the Rexford Bridge. *Enterococcus* can either be free-floating or attached to silt and clay particles (Myers and Juhl, 2020). Lock 8, part of the Erie Canal, is a removable lock that is withdrawn at the end of the navigation season. The timing of the canal lock removal near the end of the sampling period in the fall of 2021 allowed a brief look at the impacts of lock removal on turbidity and pathogen levels. Five *Enterococcus* samples were taken immediately following the lock removal on the 27^{th} and 28^{th} of October 2021. These samples appeared to have lower *Enterococcus* values than expected (Fig. 27-28). A trendline and its equation were calculated from the relationship between *Enterococcus* and turbidity. The equation is as follows:

EQ 1: $$y = 3524.5 * \ln(x) - 6514$$

Using the actual recorded values of turbidity as the x-value in EQ 1 let us calculate the predicted *Enterococcus* value for that given turbidity. With this equation, the misfit of the five outlier data points from the 27th and 28th of October was, on average, 3.7 times lower than the predicted *Enterococcus* value for the level of turbidity on those days. Hence these lower-than-expected pathogen levels means that the mobilized sediment during lock removal is probably related to 'clean' sediment (little attached *Enterococcus*), which is not unexpected given the generally lower *Enterococcus* levels upstream at Lock 8 (the presumed source of much of the turbidity). Although the lock removal every fall produces major turbidity events, the sediment that enters the Schenectady Pool may be relatively clean and thus does not have a large detrimental impact on water quality. However, this may not be the case downstream from the Schenectady Pool.

CONCLUSION

Surface water in Schenectady and in the Mohawk Watershed is impaired and contains high levels of the fecal indicator bacteria *Enterococcus*. While levels are highest during and shortly after large rainfall events, continuously elevated bacteria levels in smaller tributaries to the Mohawk River suggests a systematic problem. A previous study on the HGK has demonstrated elevated levels of *Enterococcus,* especially during rainfall events, and this paper furthers our understanding of the contamination in the HGK, as well as in the Binnekill and Mohawk River (Willard-Bauer et al., 2020; Willard-Bauer, 2021). The Hans Groot Kill is a public health hazard.

The elevated *Enterococcus* paired with high dissolved ions indicates a serious, ongoing problem with Schenectady's sewage infrastructure. As of the winter of 2022, serious action has not been taken regarding this concern. In 2020, signs were placed along the Hans Groot Kill on Union College's campus, but not on areas of the creek in residential neighborhoods. The outdated and failing sewage infrastructure must be addressed if stakeholders want to see cleaner, pathogen-free waters. Future testing of these surface waters needs to continue in order to monitor responses of the systems due to environmental factors such as rainfall and specific point sources. Continued monitoring provides the clearest evidence of pollution in Schenectady's waters and is the only concrete way to see if water quality is improving or deteriorating. Microbial source tracking or studies with environmental DNA would be useful to provide exact sources of pathogens in water bodies, but the link to sewage is all but certain. Most importantly, stakeholders and city leaders must take steps to repair pipes and fix the sewage issue in Schenectady in hopes of

remediating the sewage currently leaking into the Binnekill, Hans Groot Kill, and the Mohawk River.

The ongoing pathogen and nutrient loading in the Mohawk River must be addressed, and strategies such as ongoing TMDL efforts are a strong start. This non-point source pollution may have an important effect on water quality in the Mohawk River and the larger Mohawk Watershed. Efforts to reduce phosphorus in the Mohawk Watershed may help reduce overall contaminants and sewage pollution in the watershed by targeting specific pollutants.

The sewer system in the city of Schenectady is not prepared for the future. If predictions continue on the current trends, the Northeast will see larger and more frequent rainfall events which will continue to overwhelm this already over-burdened system. Base levels of contamination in dry weather will continue to increase in both the small creeks and the Mohawk River unless major action is taken regarding sewage handling. Pathogen levels after large rainfall events will continue to increase, making our rivers unsuitable for swimming or even fishing. Downstream communities that rely on the Mohawk River as a source for municipal water will continue to have added expenses to clean the river water for use. Schenectady must take immediate steps with the help of the NYSDEC to ameliorate water quality in the Mohawk Watershed.

REFERENCES

Ali, S., Thakur, S.K., Sarkar, A. and Shekhar, S., 2016. Worldwide contamination of water by fluoride. *Environmental chemistry letters*, *14*(3), pp.291-315.

Andonie, E.M., 2019. Investigating the Urban Stream Syndrome in the Schenectady-Schoharie Region of Upstate New York. https://digitalworks.union.edu/cgi/viewcontent.cgi?article=3295&context=theses

Ayoob, S. and Gupta, A.K., 2006. Fluoride in drinking water: a review on the status and stress effects. *Critical reviews in environmental science and technology*, *36*(6), pp.433-487. https://www.tandfonline.com/doi/pdf/10.1080/10643380600678112

Backer, L.C., Ashley, D.L., Bonin, M.A., Cardinali, F.L., Kieszak, S.M. and Wooten, J.V., 2000. Household exposures to drinking water disinfection by-products: whole blood trihalomethane levels. *Journal of Exposure Science & Environmental Epidemiology*, *10*(4), pp.321-326.

Boehm, A.B. and Sassoubre, L.M., 2014. Enterococci as indicators of environmental fecal contamination. https://www.ncbi.nlm.nih.gov/books/NBK190421/

Byappanahalli, M.N., Nevers, M.B., Korajkic, A., Staley, Z.R. and Harwood, V.J., 2012. Enterococci in the environment. *Microbiology and Molecular Biology Reviews*, *76*(4), pp.685-706.

Calderon, M.R., Baldigo, B.P., Smith, A.J. and Endreny, T.A., 2017. Effects of extreme floods on macroinvertebrate assemblages in tributaries to the Mohawk River, New York, USA. *River Research and Applications*, *33*(7), pp.1060-1070.

Caney, S., 2015. Climate change. In *The Routledge handbook of global ethics* (pp. 384-398). Routledge.

Cheng, B., Xia, R., Zhang, Y., Yang, Z., Hu, S., Guo, F. and Ma, S., 2019. Characterization and causes analysis for algae blooms in large river system. *Sustainable Cities and Society*, *51*, p.101707.

Clark, R.M. and Sivaganesan, M., 1998. Predicting chlorine residuals and formation of TTHMs in drinking water. *Journal of environmental engineering*, *124*(12), pp.1203-1210.

Conine, A., Schnore, M., Smith, Z., Lemly, G., Stoll, C., and Smith, A., 2019. *Characterization of disinfection by-product formation potential in Mohawk River source waters to support TMDL implemention.* Mohawk Watershed Symposium, 22 March 2019, Union College.

Dunn, A.D. and Burchmore, D.W., 2006. Regulating Municipal Separate Storm Sewer Systems. *Nat. Resources & Env't*, *21*, p.3.

Evlampidou, I., Font-Ribera, L., Rojas-Rueda, D., Gracia-Lavedan, E., Costet, N., Pearce, N., Vineis, P., Jaakkola, J.J., Delloye, F., Makris, K.C. and Stephanou, E.G., 2020. Trihalomethanes in drinking water and bladder cancer burden in the European

Union. *Environmental health perspectives*, *128*(1), p.017001. https://ehp.niehs.nih.gov/doi/pdf/10.1289/EHP4495?utm_source=Klix.ba&utm_medium=Clanak

Farnham, D.J., Gibson, R.A., Hsueh, D.Y., McGillis, W.R., Culligan, P.J., Zain, N. and Buchanan, R., 2017. Citizen science-based water quality monitoring: Constructing a large database to characterize the impacts of combined sewer overflow in New York City. *Science of the Total Environment*, *580*, pp.168-177.

Ferguson, D.M., Griffith, J.F., McGee, C.D., Weisberg, S.B. and Hagedorn, C., 2013. Comparison of Enterococcus species diversity in marine water and wastewater using Enterolert and EPA Method 1600. *Journal of environmental and public health*, *2013*.

Findlay, S.E. and Kelly, V.R., 2011. Emerging indirect and long-term road salt effects on ecosystems. *Annals of the New York Academy of Sciences*, *1223*(1), pp.58-68.

Fisher, T.R., Hagy, J.I.D., Boynton, W.R. and Williams, M.R., 2006. Cultural eutrophication in the Choptank and Patuxent estuaries of Chesapeake Bay. *Limnology and Oceanography*, *51*(1part2), pp.435-447. https://aslopubs.onlinelibrary.wiley.com/doi/pdf/10.4319/lo.2006.51.1_part_2.0435

Fondriest Environmental, Inc. “Conductivity, Salinity and Total Dissolved Solids.” Fundamentals of Environmental Measurements. 3 Mar 2014. Web. <https://www.fondriest.com/environmental-measurements/parameters/water-quality/conductivity-salinity-tds/ >.

Garver, J.I. 2020. Giardia outbreak in the Mohawk Watershed: Thirty-two students at Union College diagnosed. *Notes from a Watershed – The Mohawk River*. Mohawk.substack.com

Garver, J.I., 2021a. 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.

Garver, J.I. 2021b. Extreme Rainfall in the Northeast: It's raining a lot and our wastewater system is bursting at the seams. The resulting sewage overflows are impairing our waterways. *Notes from a Watershed – The Mohawk River*. Mohawk.substack.com

Garver, J.I. and Cockburn, J.M.H., 2011, March. Changes in the Hydrology of the Mohawk Watershed and implications for watershed management. In *Mohawk Watershed Symposium* (pp. 16-21). https://www.researchgate.net/profile/John-Garver

Godwin, K.S., Hafner, S.D. and Buff, M.F., 2003. Long-term trends in sodium and chloride in the Mohawk River, New York: the effect of fifty years of road-salt application. *Environmental pollution*, *124*(2), pp.273-281.

Grizzetti, B., Bouraoui, F., Billen, G., van Grinsven, H., Cardoso, A.C., Thieu, V., Garnier, J., Curtis, C., Howarth, R.W. and Johnes, P., 2011. Nitrogen as a threat to European water quality. https://centaur.reading.ac.uk/20869/1/28387ena_c17.pdf

Haller, L., Amedegnato, E., Poté, J. and Wildi, W., 2009. Influence of freshwater sediment characteristics on persistence of fecal indicator bacteria. Water, Air, and Soil Pollution, 203(1), pp.217-227. https://link.springer.com/article/10.1007/s11270-009-0005-0

Harrison, P.T., 2005. Fluoride in water: a UK perspective. *Journal of fluorine chemistry*, *126*(11-12), pp.1448-1456.

Howard, G., Jahnel, J., Frimmel, F.H., McChesney, D., Reed, B., Schijven, J. and Braun-Howland, E., 2006. Human excreta and sanitation: potential hazards and information needs. *Protecting groundwater for health: managing the quality of drinking-water sources*, pp.275-308.

Huang, H., Winter, J.M., Osterberg, E.C., Horton, R.M. and Beckage, B., 2017. Total and extreme precipitation changes over the northeastern United States. *Journal of Hydrometeorology*, *18*(6), pp.1783-1798. https://journals.ametsoc.org/view/journals/hydr/18/6/jhm-d-16-0195_1.xml?tab_body=pdf

Hughes, J., Cowper-Heays, K., Olesson, E., Bell, R. and Stroombergen, A., 2021. Impacts and implications of climate change on wastewater systems: A New Zealand perspective. *Climate Risk Management*, *31*, p.100262. https://www.sciencedirect.com/science/article/pii/S2212096320300528#b0670

Kelly, V.R., Findlay, S.E., Hamilton, S.K., Lovett, G.M. and 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), pp.1-9. https://link.springer.com/article/10.1007/s11270-018-4060-2

Kelly, W.R., Panno, S.V., Hackley, K.C., Hwang, H.H., Martinsek, A.T. and Markus, M., 2010. Using chloride and other ions to trace sewage and road salt in the Illinois Waterway. *Applied Geochemistry*, *25*(5), pp.661-673.

Liang, L. and Singer, P.C., 2003. Factors influencing the formation and relative distribution of haloacetic acids and trihalomethanes in drinking water. *Environmental science & technology*, *37*(13), pp.2920-2928. https://pubs.acs.org/doi/pdf/10.1021/es026230q

Mattson Jr, W.J., 1980. Herbivory in relation to plant nitrogen content. *Annual review of ecology and systematics*, *11*(1), pp.119-161.

McBride, S.M., Fischetti, V.A., LeBlanc, D.J., Moellering Jr, R.C. and Gilmore, M.S., 2007. Genetic diversity among Enterococcus faecalis. *PloS one*, *2*(7), p.e582.

Miettinen, I.T., Vartiainen, T. and Martikainen, P.J., 1997. Phosphorus and bacterial growth in drinking water. *Applied and environmental microbiology*, *63*(8), pp.3242-3245. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC168622/pdf/633242.pdf

Myers, E.M. and Juhl, A.R., 2020. Particle association of Enterococcus sp. increases growth rates and simulated persistence in water columns of varying light attenuation and turbulent diffusivity. *Water Research*, *186*, p.116140.

Ngatia, L., Grace III, J.M., Moriasi, D. and Taylor, R., 2019. Nitrogen and phosphorus eutrophication in marine ecosystems. *Monitoring of marine pollution*, pp.1-17.

Nguyen, H.H. and Venohr, M., 2021. Harmonized assessment of nutrient pollution from urban systems including losses from sewer exfiltration: a case study in Germany. *Environmental Science and Pollution Research*, *28*(45), pp.63878-63893.

Olds, H.T., Corsi, S.R., Dila, D.K., Halmo, K.M., Bootsma, M.J. and McLellan, S.L., 2018. High levels of sewage contamination released from urban areas after storm events: A quantitative survey with sewage specific bacterial indicators. *PLoS medicine*, *15*(7), p.e1002614. https://journals.plos.org/plosmedicine/article?id=10.1371/journal.pmed.1002614

Packman, A., 2014. *Pathogens in Urban Stormwater Systems*. UWRRC Technical Committee Report.

Pelley, J., 2016. Taming toxic algae blooms. *ACS Central Science*, *2* (5), 270-273.

Richardson, S.D., Thruston, A.D., Caughran, T.V., Chen, P.H., Collette, T.W., Schenck, K.M., Lykins, B.W., Rav-Acha, C. and Glezer, V., 2000. Identification of new drinking water disinfection by-products from ozone, chlorine dioxide, chloramine, and chlorine. *Water, air, and soil pollution*, *123*(1), pp.95-102.

Rosales, E., Del Olmo, G., Calero Preciado, C. and Douterelo, I., 2020. Phosphate dosing in drinking water distribution systems promotes changes in biofilm structure and functional genetic diversity. *Frontiers in microbiology*, *11*, p.3226. https://www.frontiersin.org/articles/10.3389/fmicb.2020.599091/full

Schang, C., Henry, R., Kolotelo, P.A., Prosser, T., Crosbie, N., Grant, T., Cottam, D., O'Brien, P., Coutts, S., Deletic, A. and McCarthy, D.T., 2016. Evaluation of techniques for measuring microbial hazards in bathing waters: A comparative study. *PloS one*, *11*(5), p.e0155848.

Schnore, M., Smith, A.J., Duffy, B., Stainbrook, K., Stoll, C., Smith, Z., 2019. *Phosphorus monitoring prioritization in Mohawk River basin sub-watersheds using LENS.* Mohawk Watershed Symposium, 22 March 2019, Union College.

Sercu B, Van De Werfhorst LC, Murray JLS, Holden PA, 2011. Sewage exfiltration as a source of storm drain contamination during dry weather in urban watersheds. Environ Sci Technol. 2011; 45: 7151–7157. Pmid:21786744 https://pubs.acs.org/doi/pdf/10.1021/es200981k

Siegel, L., 2007. Hazard identification for human and ecological effects of sodium chloride road salt. *State of New Hampshire Department of Environmental Services.*

Suter, E.A., Juhl, A.R. and O'Mullan, G.D., 2011. Particle association of Enterococcus and total bacteria in the lower Hudson River estuary, USA.

Szklarek, S., Górecka, A. and Wojtal-Frankiewicz, A., 2022. The effects of road salt on freshwater ecosystems and solutions for mitigating chloride pollution-A review. *Science of The Total Environment*, *805*, p.150289.

U.S. EPA 2012. Recreational Water Quality Criteria.

U.S. EPA 2004. Report to congress impacts and control of CSOs and SSOs.

Verhoeven, J.T.A., Koerselman, W. and Meuleman, A.F.M., 1996. Nitrogen-or phosphorus-limited growth in herbaceous, wet vegetation: relations with atmospheric inputs and management regimes. *Trends in Ecology & Evolution*, *11*(12), pp.494-497.

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

Willard-Bauer, E., 2021. Pathogen contamination in the Hans Groot Kill, Schenectady, NY.

Willard-Bauer, E., Smith, J.A., Garver, J.I., Goldman, D. and Newcomer, B., 2020, March. Enterococci levels in the Hans Groot Kill and Mohawk River, Schenectady, NY. In *Mohawk Watershed Symposium 2020* (p. 63).

Wolf, L., Zwiener, C. and Zemann, M., 2012. Tracking artificial sweeteners and pharmaceuticals introduced into urban groundwater by leaking sewer networks. *Science of the Total Environment*, *430*, pp.8-19.

Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., Jackson, J.B., Lotze, H.K., Micheli, F., Palumbi, S.R. and Sala, E., 2006. Impacts of biodiversity loss on ocean ecosystem services. *science*, *314*(5800), pp.787-790.

Zhou, X., Willems, R.J., Friedrich, A.W., Rossen, J.W. and Bathoorn, E., 2020. Enterococcus faecium: from microbiological insights to practical recommendations for infection control and diagnostics. *Antimicrobial Resistance & Infection Control*, *9*(1), pp.1-13.

APPENDIX

Appendix A. All land use area data for the approximate Hans Groot Kill drainage basin.

Type	NLCD Code	Area (km^2)	Coverage (%)	Active River Area
Open Water	11	0	0	0
Perennial Ice/Snow	12	0	0	0
Developed, Open Space	21	0.65	20.29	0.03
Developed, Low Intensity	22	1.17	36.7	0.07
Developed, Medium Intensity	23	1.02	31.96	0.14
Developed, High Intensity	24	0.31	9.86	0.1
Barren Land (Rock/Sand/Clay)	31	0.01	0.28	0
Deciduous Forest	41	0	0.03	0
Evergreen Forest	42	0	0.08	0
Mixed Forest	43	0.02	0.76	0
Shrub/Scrub	52	0	0	0
Grassland/Herbaceous	71	0	0	0
Pasture/Hay	81	0	0.03	0
Cultivated Crops	82	0	0	0
Woody Wetlands	90	0	0	0
Emergent Herbaceous Wetlands	95	0	0	0
Total		**3.18**	**100**	**0.33**

Appendix B. All *Enterococcus* data for the Binnekill and Hans Groot Kill.

Date Collected	Sample Name	Time Collected	Incubated	Read	Concentration	Large Units	Small Units	Apparent MPN	Actual MPN
9/16/2021	BK-1	11:46	13:41	17:30	0.1	14	4	20.9	209
9/21/2021	BK-1	12:06	14:11	15:03	0.1	2	1	3	30
9/30/2021	BK-1	11:40	13:57	14:26	0.1	5	0	5.2	52
10/7/2021	BK-1	10:29	12:41	13:51	0.1	30	1	45.5	455
10/14/2021	BK-1	10:34	12:44	12:48	0.1	4	1	5.2	52
10/21/2021	BK-2	11:04	12:09	13:37	0.05	8	0	8.6	172
10/27/2021	BK-2	17:12	18:54	19:25	0.05	49	24	435.2	8704
10/28/2021	BK-2	11:30	14:22	14:43	0.1	48	14	209.8	2098
11/4/2021	BK-2	11:20	13:06	13:28	0.1	14	2	18.5	185
11/11/2021	BK-2	11:21	13:21	13:27	0.1	38	7	81.6	816
11/4/2021	BK-3	11:03	13:10	13:26	0.1	11	1	13.4	134
9/13/2021	HGK-1	13:35	14:32	14:32	0.1	49	42	1203.3	12033
9/14/2021	HGK-1	12:50	13:20	14:00	0.1	26	5	42.8	428
9/15/2021	HGK-1	14:35	15:00	15:05	0.1	35	3	62.4	624
9/16/2021	HGK-1	15:05	15:35	15:35	0.1	26	6	44.3	443
9/24/2021	HGK-1	12:42	13:25	13:25	0.1	49	48	2419.6	24196
10/19/2021	HGK-1	13:37	13:59	14:25	0.1	30	12	64	640
10/20/2021	HGK-1	14:10	14:22		0.1	28	5	47.3	473
9/13/2021	HGK-2	13:25	14:25	14:37	0.1	49	43	1413.6	14136
9/14/2021	HGK-2	12:40	13:20	14:00	0.1	33	5	58.3	583
9/16/2021	HGK-2	12:44	13:39	17:42	0.1	45	9	131.4	1314
9/21/2021	HGK-2	13:23	14:06	14:53	0.1	21	3	30.5	305
9/24/2021	HGK-2	12:38	13:15	13:27	0.1	49	48	2419.6	24196
9/30/2021	HGK-2	13:05	13:58	14:27	0.1	14	3	19.7	197
10/4/2021	HGK-2	12:31	15:33	15:37	0.1	49	47	2419.6	24196
10/5/2021	HGK-2	12:06	12:38	13:05	0.1	49	39	1046.2	10462
10/7/2021	HGK-2	11:35	12:37	13:55	0.1	43	7	108.1	108.1
10/10/2021	HGK-2	15:35	16:23	14:30	0.1	42	2	87.8	878
10/11/2021	HGK-2	15:38	16:00	14:30	0.1	20	1	26.2	262
10/12/2021	HGK-2	15:35	16:05	18:00	0.5	49	35	816.4	1633
10/14/2021	HGK-2	11:42	12:39	12:43	0.1	28	3	44.1	441
10/17/2021	HGK-2	13:14	14:01	14:54	0.1	49	42	1299.7	12997
10/21/2021	HGK-2	11:33	12:12	13:35	0.1	33	4	58.3	583
10/24/2021	HGK-2	15:24	17:11	17:56	0.1	45	5	116.2	1162
10/27/2021	HGK-2	18:02	18:52	19:28	0.05	43	3	96	1920
10/28/2021	HGK-2	12:34	14:20	14:47	0.1	41	11	107.1	1071
11/4/2021	HGK-2	12:29	13:05	13:30	0.1	49	33	727	7270
11/11/2021	HGK-2	12:23	13:16	13:29	0.05	31	2	49.5	990
11/12/2021	HGK-2	12:31	13:06	13:21	0.05	49	48	2419.6	48,392
11/12/2021	HGK-2	14:06	16:45	16:40	0.05	49	48	2419.6	48,392
11/12/2021	HGK-2	15:06	16:45	17:40	0.05	49	48	2419.6	48,392
11/12/2021	HGK-2	16:15	16:45	18:40	0.05	49	48	2419.6	48,392
11/18/2021	HGK-2	9:54	10:14	9:46	0.1	16	4	23.8	238

Appendix C. *Enterococcus* data for all Mohawk River locations.

Date Collected	Sample Name	Time Collected	Incubated	Read	Concentration	Large Units	Small Units	Apparent MPN	Actual MPN
9/16/2021	MK-1	11:04	13:29	17:34	0.1	48	27	378.4	3784
9/21/2021	MK-1	12:54	14:08	14:59	0.1	1	2	3	30
9/30/2021	MK-1	12:26	13:59	14:20	0.1	1	0	1	10
10/7/2021	MK-1	11:10	12:40	13:52	0.1	34	8	68.9	689
10/14/2021	MK-1	11:17	12:41	12:54	0.1	4	0	4.1	41
10/24/2021	MK-1	16:10	17:13	17:58	0.5	8	0	8.6	17
10/28/2021	MK-1	11:57	14:21	14:45	0.1	47	13	178.5	1785
11/4/2021	MK-1	12:02	13:04	13:29	0.1	6	1	7.4	74
11/11/2021	MK-1	11:53	13:17	13:28	0.1	2	3	5.1	51
9/16/2021	MK-2	11:18	13:32	17:39	0.1	49	29	579.4	5794
9/21/2021	MK-2	12:26	14:07	14:57	0.1	1	0	1	10
9/30/2021	MK-2	12:00	13:56	14:22	0.1	3	0	3.1	31
10/7/2021	MK-2	10:45	12:43	13:46	0.1	36	12	84.5	845
10/27/2021	MK-2	17:26	18:56	19:20	0.05	49	25	461.1	9222
10/28/2021	MK-2	11:18	14:24	14:40	0.1	49	18	307.6	3076
10/14/2021	MK-2-A	10:48	12:43	12:50	0.1	48	17	238.2	2382
10/14/2021	MK-2-B	10:49	12:42	12:52	0.1	49	17	290.9	2909
9/16/2021	MK-3	12:09	13:38	17:45	0.1	49	29	579.4	5794
9/21/2021	MK-3	11:46	14:12	15:05	0.1	0	0	0	0
9/24/2021	MK-3	12:36	13:36	13:28	0.1	49	25	461.1	4611
9/30/2021	MK-3	11:22	14:01	14:24	0.1	1	0	1	10
10/4/2021	MK-3	13:26	15:35	15:35	0.1	39	8	88.4	884
10/5/2021	MK-3	11:52	12:36	12:55	0.1	47	22	249.5	2495
10/7/2021	MK-3	10:15	12:38	13:54	0.1	32	5	57.3	573
10/10/2021	MK-3	15:05	16:25	14:30	0.2	0	0	0	0
10/11/2021	MK-3	14:57	16:38	14:30	0.5	5	0	5.2	10
10/12/2021	MK-3	14:45	16:34	18:06	0.5	10	0	11	22
10/14/2021	MK-3	10:17	12:45	12:47	0.1	0	1	1	10
10/17/2021	MK-3	12:26	13:59	14:59	0.1	49	46	1986.3	19863
10/21/2021	MK-3	10:38	12:11	13:34	0.1	8	0	8.6	86
10/24/2021	MK-3	15:39	17:12	17:57	0.5	8	0	8.6	17
10/26/2021	MK-3	11:40	13:02	12:46	0.1	49	27	517.2	5172
10/28/2021	MK-3	11:04	14:25	14:38	0.1	49	21	365.4	3654
11/4/2021	MK-3	10:32	13:07	13:25	0.1	7	1	8.5	85
11/11/2021	MK-3	10:55	13:19	13:26	0.1	1	2	3	30
11/18/2021	MK-3	9:39	10:15	9:46	0.1	11	0	12.2	122
9/21/2021	MK-4	11:19	14:10	15:01	0.1	1	0	1	10
9/30/2021	MK-4	11:02	14:02	14:25	0.1	0	0	0	0
10/7/2021	MK-4	9:53	12:42	13:49	0.1	26	3	39.9	399
10/14/2021	MK-4	9:57	12:46	12:46	0.1	1	0	1	10
10/28/2021	MK-4	10:43	14:23	14:42	0.1	48	20	272.3	2723
11/4/2021	MK-4	10:14	13:08	13:24	0.1	5	0	5.2	52
11/11/2021	MK-4	10:30	13:18	13:24	0.1	1	0	1	10