Master of Public Health

Integrative Learning Experience Report

WATER QUALITY SURVEILLANCE OF THE LOWER GOOSE CREEK WATERSHED IN LOUDOUN COUNTY, VIRGINIA

by

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submitted in partial fulfillment of the requirements for the degree

MASTER OF PUBLIC HEALTH

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Abstract

Environmental sources of drinking water require routine water quality surveillance to ensure consumer safety; water treatment plants do not protect the water quality of people who swim in streams and rivers, nor do they protect people whose water comes from private wells. While contaminants in water range from natural to man-made, chemical to bacterial, in Loudoun County, Virginia, the main contaminant for waterways is fecal coliform bacteria: *Escherichia coli*. The Goose Creek and its aquifer provide drinking water to thousands of people via wells, and because it is also a designated Scenic River, the community has the right to freely recreate in the Goose Creek. This Applied Practice Experience consisted of water quality monitoring of the Lower Goose Creek Watershed from December 2020 to January 2021, measuring temperature, nutrients (nitrate, ammonia, orthophosphate), turbidity, dissolved oxygen, conductivity, pH, and the concentration of *E. coli* at thirteen sampling sites. Because the Goose Creek and some of its tributaries are considered impaired for fecal bacteria, routine monitoring, whether performed by government agencies or local stakeholders, is crucial for assessing and improving water quality.

Subject Keywords: Water quality monitoring, fecal contamination, Goose Creek, Loudoun County, *Escherichia coli*

Table of Contents

List of Figures

List of Tables

Chapter 1 - Introduction to Water Quality of the Goose Creek

National Water Quality Management

Preservation of water quality involves combined efforts by the United States (US) Environmental Protection Agency (EPA), US Geological Survey (USGS), and individual state departments (e.g., Virginia Department of Environmental Quality, Kansas Department of Health and the Environment, etc.). Contamination of drinking water comes from the environment, animals, and humans.[1] Environmental contaminants include an array of chemical pollutants, and other animal-derived contaminants are deemed primarily nonpoint source pollutants, such as feces.[1] Human-derived contaminants are more wide reaching: wastewater, pathogens, heavy metals, nitrates, pesticides, and pharmaceuticals. Each pollutant needs to be monitored and managed in order to prevent disease in humans and animals. The US population accesses water through water and wastewater plants and distributions systems, or through private wells; however, private wells are not included in the EPA's Safe Water Drinking Act (SWDA), further emphasizing the need for routine monitoring of environmental water quality. For example, a 2001 USGS report discussing enteric viral and microbial contamination in groundwater in Maryland found that shallow wells close to livestock operations were vulnerable to pathogenic contamination, with 11% of samples testing positive for the presence of viral RNA and 15% for bacterial DNA.[2] The presence of not only bacteria, but also viruses, amplifies the need for routine surveillance of groundwater quality and prevention of contamination.

Pollutant Management

While each state has its own method for managing water quality, the EPA and USGS provide guidelines and regulations for national water quality monitoring. For example, the National Pollutant Discharge Elimination program is overseen by the EPA through the Clean Water Act, and responds to water pollution by regulation of point source discharging into waterways. The EPA defines point source as any "discernible, confined and discrete conveyance, such as a pipe, ditch, channel, tunnel conduit, discrete fissure, or container."[3] A permit is needed for discharging pollutants through a point source, if they are not going into a municipal sanitary sewer system.[4] The permit can either be individual or general, where an individual permit is for a single discharger, while a general permit will cover multiple dischargers

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[1] Polluted runoff as a result of rainfall or snowmelt moving over the ground, carrying and ultimately depositing pollutants into waterways. See "Sources of Pollution," below.

that produce similar pollutants. Stormwater discharge (from stormwater, snow, and surface run-off and drainage) are excluded from the program. The USGS conducts routine water quality monitoring through the National Water Quality Assessment (NAWQA). This ongoing assessment examines both groundwater and surface water quality on a national scale. Hydrologic studies are crucial for assessing groundwater quality as about 50% of the US population obtains their drinking water from groundwater.[5] The data is collected at hundreds of sites across the country, measuring physical and chemical parameters including pH, conductivity, temperature, and dissolved oxygen. The data is then organized into the National Water Information System NWIS), delivering historical and current water conditions across the US.[6]

Challenges of Water Quality in Loudoun County, Virginia

Goose Creek

The Scenic Rivers Program is listed under the recreational planning for the Virginia Department of Conservation and Recreation.[7] The Code of Virginia defines a scenic river as “a river or section or portion of a river… that possesses superior natural and scenic beauty, fish and wildlife, and historic, recreational, geologic, cultural, and other assets”.[8] This program was established in 1970 to protect and preserve valuable waterways in the state, recognizing their importance to local citizen stakeholders. The Goose Creek is one such valuable waterway, as 48 miles of the river’s 53.9 miles are designated as scenic.[9] The river stretches from its headwaters near Linden, Virginia to its mouth at the Potomac River, in Leesburg, Virginia. It travels through two counties, Fauquier and Loudoun, and comprises the primary waterway of the Goose Creek Watershed. The watershed can be subdivided further into the Upper Goose Creek Watershed (UGCW) and the Lower Goose Creek Watershed (LGCW; see Figure 1.1**),** Hydrologic Unit Code 10: 0207000807 (Figure 1.2). Major tributaries of LGCW include the North Fork of the Goose Creek, Little River, Sycolin Creek, and Tuscarora Creek.[10] According to the Goose Creek Organization’s 2017-2020 Report Card, the Goose Creek fails in regards to recreational health due to bacterial impairment found at public access sites.[11] This failure is counterproductive to the designation as a scenic river, as the designated uses such as swimming, recreation, fish consumption, and public water supply use are not able to be safely supported.[12]

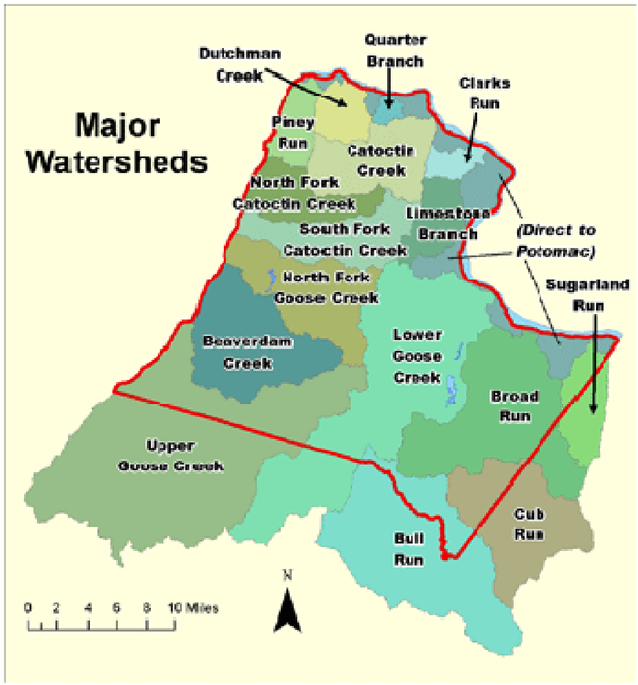

Figure 1.1 Major watersheds of Loudoun County, Virginia, with Lower Goose Creek located in the center of the county, stretching south into Fauquier County.[13]

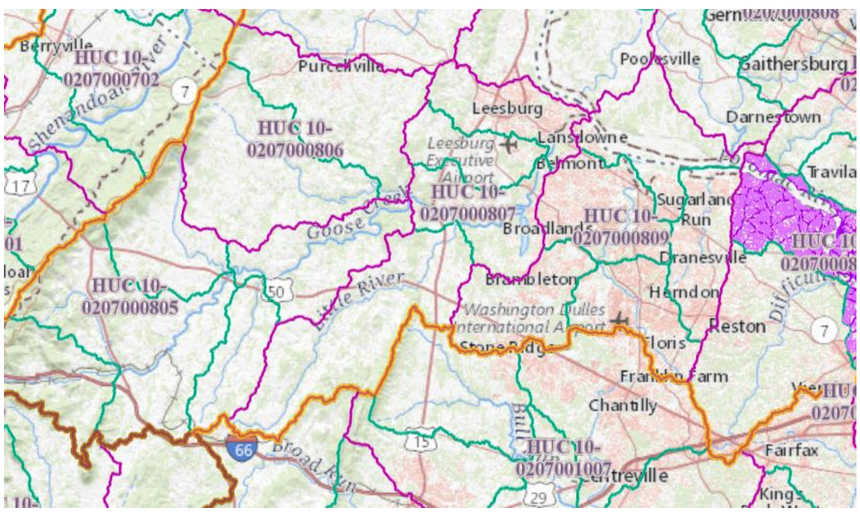

Figure 1.2. HUC10 – 0207000807 – the Lower Goose Creek Watershed (center).[14]

According to the 2008 Loudoun County Comprehensive Watershed Management Plan, “Bacteria seem to be the most significant water quality issue for Loudoun County waters” (pg 4-11).[15] Water quality surveillance of the Goose Creek from 1999-2001 by the Virginia Department of Environmental Quality (DEQ) resulted in the classification of impairment for the Goose Creek and multiple tributaries, as fecal coliform bacteria concentrations exceeded Virginia’s water quality surveillance standards at the time. The DEQ and Virginia Department of Conservation and Recreation (DCR) then developed a total maximum daily load (TMDL) for bacteria, published in 2003.[10] A TMDL is a calculation that considers the maximum amount of a pollutant a waterbody can receive and still meet water quality standards. It incorporates the sum of a Waste Load Allocation (WLA - point source pollutants), Load Allocation (LA - nonpoint source pollutant), and a Margin of Safety (MOS). The equation may be expressed as follows (TMDL, 2003):

$$TMDL = \Sigma WLA + \Sigma LA + MOS$$

To respond to the impaired status and the development of a TMDL, stakeholders, such as the DEQ, develop an implementation plan (IP). The bacteria TMDL covers the entire Goose Creek Watershed; however, the IP covers only the upstream portion of the watershed, the UGCW, and not the LGCW. The approach “back then” was to only develop an IP for a portion of the TMDL. Reasons for this decision included stakeholder interest as well as the thought that by focusing on a smaller area, best management practices would be better implemented. The current stance on developing IPs now focuses on taking a “larger scope” approach, due to funding shortages, time, and experience. However, an IP is voluntary; only a TMDL is mandated by federal legislation in the event of an impaired waterway (personal communication with Sarah Sivers, DEQ Water Quality Planning Team Lead; 1/5/21).

Major tributaries of the Goose Creek were also placed on the bacteria TMDL priority list as they were also considered to be impaired by fecal coliform bacteria: North Fork of the Goose Creek, Little River, and Sycolin Creek (but not Tuscarora Creek), in addition to other tributaries not pertinent to this review. As mentioned, the IP covers only the UGCW; therefore, the tributaries listed above are not part of an implementation plan. Due to the age of the TMDL (published in 2003), compared with the regularly updated implementation plan (published in 2018 and updated in 2019), much of the data yielded from the TMDL is out of date, while a majority of current monitoring data focuses on the UGCW. The only in-depth water quality assessment covering the LGCW after establishment of the TMDL is a 2005 Loudoun Watershed Watch report.[16]

When the TMDL was published in 2003, Loudoun County was (and still is) on track for massive development and population growth, though it was still considered mostly rural where the author’s sampling ultimately occurred. The county population in 2003 was 220,090; as of 2019, it had nearly doubled to 413,538.[17] Consequently, housing developments have increased in number, as have industrial and data centers, resulting in increased fecal contamination, increased runoff from impervious surfaces, and increased erosion.

Sources of Pollution in Virginia Waterways

The terms point source and nonpoint source are used to describe origins of pollution, specifically fecal coliforms such as *E. coli* . Point sources of fecal coliform bacteria are managed by the DEQ through Virginia Pollutant Discharge Elimination System (VPDES) permits, as an extension of the EPA's NPDES program.[10] Point sources of fecal contamination include all municipal and industrial plants that treat human waste as well as private residences with VPDES permits for discharge. Nonpoint source pollution includes failing septic systems, biosolids applications, uncontrolled discharges (e.g., straight pipes), pets, livestock, and wildlife. Point sources and septic systems within 50 feet of surface water can directly contribute to fecal contamination.[10] Industrialization increases nonpoint source pollution because pavement, an impervious surface, prevents permeation of water into the ground. Consequently, stormwater from the streets runs off into waterways with greater volume and velocity, dumping pollutants such as bacteria, nutrients, and sediment.[18] Greater stream flow is associated with increased concentrations of bacteria, contributing to nonpoint source runoff during rain events.[12] Without identifying the source, it is not possible to discern the origin of the fecal contamination, for example, whether it is coming from pasture runoff or from failing residential septic systems.

Livestock waste from pastures represented the primary nonpoint source of fecal coliform bacteria for the watershed, and nonpoint sources overall appear to contribute to the "vast majority" of fecal coliform bacteria in the watershed.[19] While cattle (beef and dairy) are declining in number in Loudoun County, the county now has one of the largest horse populations in the state (possibly second only to neighboring Fauquier county).[20] Regardless, as of 2018 there were still 14,000 head of cattle in the county,[21] and cattle are the primary reservoir for shiga toxin-producing *E. coli* (STEC). Water contaminated with cattle feces is a common source of STEC infection in humans.[22]

Drinking Water

Not only is the Goose Creek protected for recreational use, it also serves as a source of drinking water. Prior to 2019, the Goose Creek provided water to citizens of the Leesburg municipality, but its reservoir is now used as an emergency water source (personal communication, Elvia Castro, Customer Relations, Loudoun Water 1/14/21). Loudoun Water now has a Potomac River water supply, with withdrawn water pumped through a six-mile pipeline to the newly built Trap Rock Water Treatment Facility, with exhausted quarries serving as reservoirs for the pumped water prior to treatment.[23] The purpose for this change in supply stems from an ever-increasing demand for water in Loudoun County, as the current water demand is approximately 50 million gallons per day, with demand projected to increase to 90 million gallons per day by 2040.[23]

Perhaps more importantly in the context of the Goose Creek and its drinking water quality, the LGCW has a robust aquifer that provides drinking water for 5,557 people through wells.[24] The 2018 Water Resources Monitoring Data Summary produced by Loudoun County government states that there are “more than 19,000 active individual water supply wells throughout Loudoun County,” up from 15,950 in 2016, and that groundwater is the “primary source of drinking water for the majority of residents in western Loudoun”.[25] According to the data summary, the county has a “network” of 19 monitoring wells for long term tracking of groundwater levels and quality. Curiously, the Groundwater Standards (Section 190) and Water Quality Criteria for Groundwater (Section 230) were repealed from the Virginia Administrative Code (Chapter 260. Water Quality Standards) in 2004.[26] Looking at the 1997 Virginia Register of Regulations, it appears that, initially, groundwater quality criteria carried the same regulatory limitations as surface water criteria, but because the quality can “vary greatly from area to area,” enforceable standards were not mandatory. The EPA does have a Ground Water Rule that serves to improve drinking water quality from ground water, but it only applies to public water systems.[27]

The Virginia Department of Health (VDH) has a well water program, covered under the Private Well Regulations (12VAC5-630), requiring newly constructed wells to pass drinking water quality standards (including bacteriological testing).[28] The VDH recommends annual well testing for bacteria and nitrates. According to Virginia’s Private Well Regulations, however, well inspections and testing are not required for a property transfer (e.g., home sale), putting buyers at risk.[28] Overall, there is scant data analysis regarding the LGCW aquifer’s bacteriological quality. While the Loudoun County monitoring data summary annually includes statistics on groundwater chemistry parameters (e.g., nitrates), there has been no analysis of groundwater bacterial parameters by the county. Records for private well testing are maintained by the Loudoun County Health Department, and are available to the public.[28]

According to the monitoring data summary for Loudoun County’s water resources, improper installation or maintenance of on-site wastewater treatment systems (OWTSs), also termed septic systems, are the biggest risks for groundwater pollution.[25] In Loudoun County, there are approximately 17,377 “active” OWTSs, and they are typically used on properties that also have private water wells, putting consumers directly at risk of drinking water contamination if either the OWTS or well is not maintained properly.

Legislation and the Value of Citizen Science Programs

Prior to 2021, the Virginia DEQ criteria for *E. coli* in freshwater were described as follows[29]:

> When appropriate, the monthly geometric mean standard of 126 per 100 ml (*E. coli*) for freshwater… applies when a minimum of four weekly samples are collected during any calendar month. The *E. coli*/enterococci maximum standard of 235 per 100 ml (*E. coli* in freshwater) applies when a minimum of four weekly samples per month are not available to calculate a geometric mean. Where data are not sufficient to calculate a monthly geometric mean, at least two exceedances and >10.5% of the total samples taken during the assessment period exceeding the single sample maximum [SSM] bacteria standard for primary contact recreation is impaired.

In contrast, the current criteria under the Virginia Administrative Code are described as follows[30]:

> *E. coli* bacteria shall not exceed a geometric mean of 126 counts/100ml and shall not have greater than a 10% excursion frequency of a statistical threshold value (STV) of 410 counts/100 ml, both in an assessment period of up to 90 days… In VPDES discharges to freshwater, bacteria in effluent requiring disinfection shall not exceed a monthly geometric mean of *E. coli* bacteria of 126 counts/100ml.

The difference between the old and new criteria is the incorporation of the statistical threshold value (STV), which the Virginia DEQ called a "totally new concept," replacing the single sample maximum (SSM).[31] Both the geometric mean and the STV must now be assessed when determining that a waterway can support recreational use. Another way to explain the updated criteria is that violation of either the geometric mean or the STV results in an impairment designation. Further changes are in place for the *2022 Water Quality Assessment Guidance Manual*, which the DEQ finalized on May 27, 2021. Within the proposed 2022 manual, a minimum sample size of 10 samples for up to 90 days will be required to calculate a geometric mean. The purpose of this sampling change was to "reduce the likelihood of listing a waterbody as impaired when it is not".[31] The impetus for changing and updating criteria and standards regularly comes from the Clean Water Act, which requires the EPA to periodically update their recommended criteria.[32] As explained during the 2019 Virginia Citizens for Water Quality Summit, the criteria (i.e., the geometric mean, SSM, and STV) are selected from different points in a distribution of risk, where the acceptable risk of gastrointestinal illness from recreational swimming is 36 in 10,000 people. In the 2020 criteria, the value of 126

CFU/100mL corresponds to the 50th percentile (geometric mean), while 235 CFU/100mL (the SSM value) is the 75th percentile (Figure 1.3). The updated criteria use the STV, which at 410 CFU/100mL, is the 90th percentile. The EPA determined that the SSM does not accurately reflect health risk, resulting in the introduction of the STV. As DEQ explained during the 2019 water quality summit, the updated criteria are more stringent because they are "less forgiving" of closely spaced, high exposure events; however, they are also "more forgiving" of sporadic, high exposure events "as long as they don't cluster together in time".

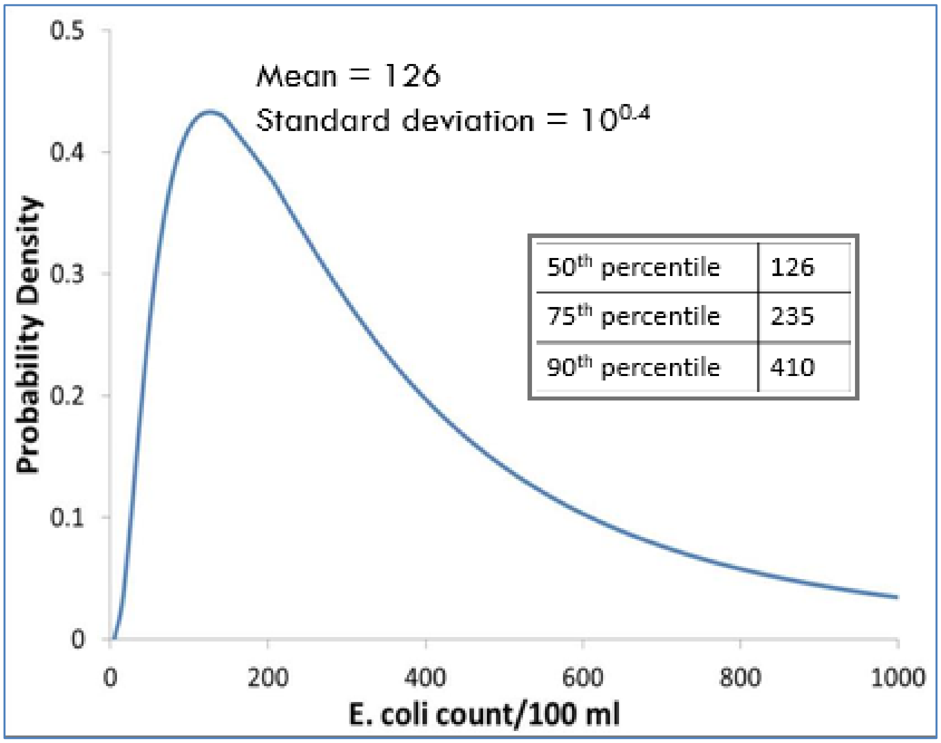

Figure 1.3. Theoretical 30-day *E. coli* distribution conferring an acceptable illness risk.[31]

This legislation serves to protect primary contact, recreational uses in surface water (e.g., swimming), which is applicable to the Goose Creek as a scenic river. The standards also apply to the Goose Creek's tributaries, as they run through rural and suburban communities, where livestock and households have access to the water; these tributaries can potentially carry fecal contamination into the Goose Creek. Note that while the DEQ monitors surface waters statewide and conducts water quality assessments to determine whether a waterway is impaired (as defined by the federal Clean Water Act), it is the VDH that issues and lifts public recreational water advisories. However, this regulation is restricted to coastal beach monitoring and is funded by the EPA. No federal program exists for inland waterbodies, highlighting the need for so-called "citizen science monitoring" as a form of public health and awareness in recreational swimming. Citizen science monitoring is an encouraged program outlined by the DEQ, through the Virginia Citizen Water Quality Monitoring Program Methods Manual.[33]

Common Waterborne Pathogens and Contaminants

Historically, government agencies evaluated bacterial impairment by measuring fecal coliforms. In 2002, DEQ standards changed in response to EPA criteria updates, and *Escherichia coli* is now the primary indicator for bacterial impairment of freshwater, as it is more indicative of water quality problems resulting from fecal contamination.[15] The EPA has determined that the IDEXX Colilert-18 test is a suitable method for the detection of fecal coliforms (i.e., *E. coli*) in water.[34] The tests measures *E. coli* in colony forming units (CFU) per 100mL, or the number of viable *E. coli* cells in a sample per 100mL.

Fecal coliforms, or more specifically *E. coli*, are not inherently pathogenic; however, people who consume high levels of *E. coli* in contaminated water have an increased risk of illness as a consequence. *E. coli* are gram negative, rod shaped, facultative anaerobic bacteria, normally found in the digestive tracks of animals and passed along with feces. The bacterium's association with fecal matter explains why it is used as an indicator for measuring fecal contamination. *E. coli* O157:H7 is of particular public health concern, as it a cause of foodborne and waterborne illness and potentially death.[25] To understand the relationship between coliforms and *E. coli*, see Figure 1.4.

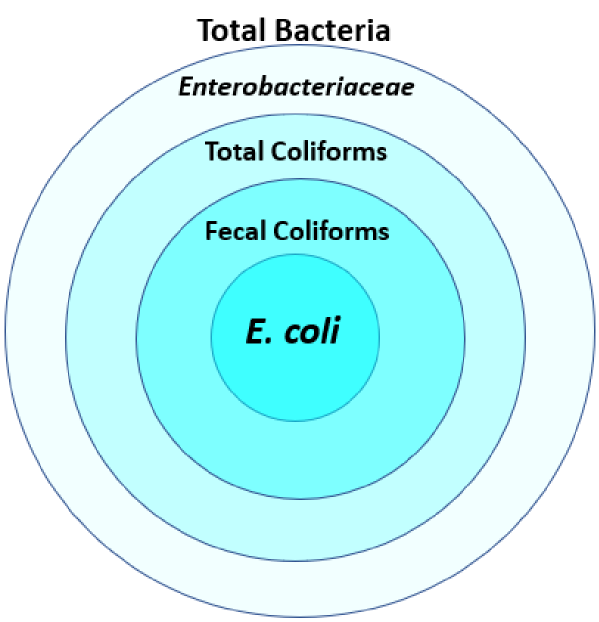

Figure 1.4. The relationship between *E. coli* and coliforms.

In addition to *E. coli, Enterococcus* is another microbiological criterion for fecal indicator bacteria, and both are included in state and federal surface water quality standards, as greater concentrations of these bacteria are associated with greater risk of exposure to pathogenic bacteria in contaminated waterways.[36, 37] Fecal indicator bacteria are a pathogen screening tool because they do not replicate outside of the intestinal tract, so the concentration of bacteria measured is directly correlated with the degree of fecal contamination and risk to public health.[37] DEQ typically only monitors for *Enterococcus* at salt or brackish water sites.[33] Exposure to pathogens in recreational water occurs through dermal contact, ingestion, and inhalation, necessitating routine water quality surveillance for waterways where people have access (e.g., the Goose Creek). Infrequently, other bacteria are implicated in cases of waterborne illness: *Salmonella* spp., *Vibrio cholerae*, *Leptospira interrogans*, *Shigella* spp., *Campylobacter* spp., and *Clostridium perfringens*, which have a seasonal pattern of summer outbreaks.[37] Viruses associated with fecal contamination of water include Enteroviruses, Hepatitis A, Hepatitis E, and Rotaviruses, while pathogenic protozoa include *Cryptosporidium* oocysts, *Giardia lamblia* cysts, and *Naegleria fowleri*.[1,37]

Agency and Preceptor This Field Experience

The Virginia Cooperative Extension (VCE) is an educational outreach program of Virginia's land-grant universities—Virginia Tech and Virginia State University—as part of the USDA's National Institute for Food and Agriculture.[38] Extension offices are located in each county, with the author's Applied Practice Experience taking place at the Loudoun County VCE office. The extension office in Loudoun County offers programs and resources covering a wide range of public health and agriculture related topics. Specific to water quality, the Loudoun County office offers annual well water testing clinics for private well owners, advises the public on best management practices for their properties, and generally strives to increase the area of land (and water) that is certified to meet EPA standards for TMDLs.

The author's preceptor, James Hilleary, is the Unit Coordinator and Extension Agent for the VCE office in Loudoun County. When asked how he came to be involved in public health and the VCE, James said:

> Why did I become an animal science extension agent employed by Virginia Cooperative Extension (VCE)? Because the job's requirements, the department's demands, and the time of hiring matched my life's interests, skills, experiences very well. It wasn't because I grew up on a farm; I grew up in suburban Arlington, Virginia. As a high-school education student attending Virginia's larger land-grant university, I sat in class with

students who were preparing to return home to the family farm. I envied what I imagined they were inheriting: livestock, open spaces, and working outside.

More than two decades and four children later, it was time for our family to retire from the Army. I knew that somewhere along the way that I lost my patience for teaching teenagers but I had learned about the principles of andragogy. If I was going to teach, I would devote my time and intellect to helping adults. The local county extension agent introduced me to VCE and the role of an animal science extension agent. It was then that I decided which career would lead to my second retirement—one that included livestock, open spaces, and working outside.

I returned to school for a graduate degree in agriculture extension education and raised my hand to be the contracted farm-manager who would restore a failed community farm as an education farm. Both initiatives required three years. In the interim, to increase my farm experience I also accepted part-time jobs working for Virginia Tech as farm-mentor coordinator. In 2013, the full-time position of animal science extension agent and department director in Loudoun County, opened. Loudoun's population was increasing and its demographics were changing faster than any could have imagined even ten years previously. Success in this job would mean accepting the changes to date and planning for more change while helping others with similar life stories experience livestock, open spaces, and working outside.

Chapter 2 - Learning Objectives and Project Description

Learning Objectives

The author's APE sought to achieve the following learning objectives:

- Understand and communicate to the public the importance of preserving water quality
- Understand and describe the nature of the relationships between physico-chemical parameters and *E. coli* enumeration in the Lower Goose Creek Watershed
- Become more conversant about surface water and groundwater quality
- Understand the role of legislation and government in Virginia for mobilizing water quality surveillance

Project Description

In November 2020, the author reached an agreement with her preceptor that she would conduct an independent project on water quality monitoring in the Lower Goose Creek Watershed (LGCW) in Loudoun County, Virginia from December 2020 to January 2021. In November, she also provided a project proposal during the Loudoun Soil and Water Conservation District's monthly meeting, obtaining their approval and support for her project. The water quality of the Goose Creek and its watershed needs to be monitored because of its designation as a scenic river, in order to support designated uses such as swimming, recreation, fish consumption, and public water supply use.[12] Impairment of the watershed by fecal coliform bacteria additionally supports the need for water quality monitoring.

The author's sampling sites came from a 2005 Loudoun Watershed Watch report that had a table of previously sampled sites within the LGCW. Initially, there were thirteen sample sites targeted for monitoring; however, two more sites were added at a later point in time (see Figure 2.1 for site locations). The site IDs provide information about the order in which they were sampled, the waterway being sampled, and their location relative to other sites on that particular waterway. For example, 001.TC.01 was the first site sampled; it was located on the Tuscarora Creek (TC), and it is the most upstream Tuscarora Creek site (respective to Goose Creek). On the other hand, 011.TC.03 was the 11th site sampled and was also on the Tuscarora Creek, but it was the most downstream of the three Tuscarora Creek samples. See Appendix A for a complete list of sampling sites, their coordinates, and their corresponding county or state site IDs. It was important that one of the sample sites was located at a USGS gage station, which for this project was USGS Gage 01644000 (site 007.GC.01). The gage provides data for water discharge, streamflow, and other field measurements.

Figure 2.1. Aerial view of the Lower Goose Creek Watershed in Loudoun County, Virginia, with sample site IDs labeled and corresponding to order of sampling and waterway.[39]

In addition to the Tuscarora Creek and Goose Creek (denoted as GC for site ID), the author also sampled the North Fork of the Goose Creek (NFGC) and Little River (LR), both of which are tributaries of the Goose Creek, while Hungry Run (HR) is a tributary of Little River.

Karen Andersen, lab director for the Friends of the Shenandoah River, accompanied the author for each sampling event. There were four sampling events: December 21, 2020; December 28, 2020; January 5, 2021; and January 12, 2021. Once they reached a site, they would walk to the bank and fill out a site evaluation form, recording any unusual odors or colors, in addition to the general appearance of the waterway and bank (human litter, foam, natural debris, erosion, etc.). They would also notate whether there were any wildlife or signs or wildlife, as well as water level and flow. Upon entering the water, they would measure water temperature, dissolved oxygen (DO), conductivity, and pH, using meters with probes attached, according to the manufacturer's protocol.[40] They recorded all information on a site evaluation form. Once these steps were completed, they would collect two water samples in plastic bottles, with a third sample collected using an IDEXX Colilert-18 water container. They would face upstream when collecting the water to avoid accidentally collecting disturbed sediment as a consequence of wading in the water. They used the water from one plastic bottle to measure turbidity at the lab that evening, while they stored the other water sample on ice and transferred it to a freezer at the lab, for chemical analysis of nitrate, orthophosphate, and ammonia at a later point in time. Water temperature, dissolved oxygen, pH, nitrogen (nitrate and ammonia), phosphorous (orthophosphate), and fecal coliforms (*E. coli*) are listed in the Virginia Administrative Code for surface water.[41]

The water sample analysis took place at the Friends of the Shenandoah River laboratory at Shenandoah University, in Winchester, Virginia. This lab is DEQ level III and EPA certified, following quality assurance and control measures that allow data produced in the lab to be submitted to DEQ. They used the LaMotte 2020t turbidity meter to measure turbidity (in nephelometric turbidity units – NTU) according to the manufacturer's protocol.[42] Nitrate, orthophosphate, and ammonia were measured via mass spectroscopy, using the Lachat QuickChem Flow Injection Analysis System, also according to the manufacturer's protocol, and the parameters were measured in parts per million (ppm).[43]

E. coli Assessment

They used the IDEXX Colilert-18 and Quanti-Tray Test Method for the detection of fecal coliforms in the water, an EPA approved method of fecal coliform detection.[34] The water collection containers contained sodium thiosulfate to neutralize any chlorine that might have been present in the water. This method of analysis uses a chromogenic nutrient indicator, ortho-nitrophenyl-ß-D-galactopyranoside (ONPG). This indicator causes water samples containing fecal coliforms to turn yellow, as the fecal bacteria contain ß-D-galactosidase, which hydrolyzes the ONPG, causing the yellow color in the sample when incubated at 44.5ºC after a period of incubation (anywhere from 18-22 hours; samples were incubated for 19 hours). The presence or absence of *E. coli* is visualized under UV light, where the number of positive wells (wells that fluoresced under UV light) are added together, and compared to the most probable number (MPN) table to obtain a value (MPN/100mL, equivalent to CFU/100mL). Enumeration of *E. coli* was performed according to the IDEXX Colilert-18 manual.[34] At each sampling event, they would include one water sample that contained sterile, deionized water as a control sample. They would also perform either a split or a duplicate of one field water sample, for quality assurance purposes.

As explained above, two additional sites were added to the original thirteen. One of the two added sites occurred during the third sampling event. At ones of the sites, the author realized that the body of water they were sampling from was a stagnant tributary of Sycolin Creek, not the Sycolin Creek itself (as a tributary of the Goose Creek), which was farther north (by about 100 yards) from where they had sampled during the previous two times. This stagnant tributary continuously feeds into Sycolin Creek farther downstream from where they sampled, but the origin of the tributary was difficult to discern due to the way the road over Sycolin Creek had been constructed. Multiple large culverts were placed on the creek to allow for subsurface flow under the road, then asphalt filled in all the gaps, eliminating the origins of the stagnant tributary (which presumably has a subsurface origin from Sycolin Creek), but results in flooding over the road each time it rains as a consequence. Regardless, the author had to adjust the sampling site IDs to reflect this distinction, creating a new site ID for the tributary that they had sampled from during the first two events. The second site was also added during the third sampling event, and occurred while they were driving through a heavily industrial portion of the county, containing quarries, asphalt contractors, petroleum and concrete suppliers, and energy plants. While driving through this area, they noticed another unnamed tributary of Sycolin Creek where the water color was bright orange! They submitted an online report to the Loudoun Express Request, and 48 hours later, most of the discoloration had subsided (though the water was still turbid due to erosion coming in from a smaller tributary). The data from this project contributes to water quality surveillance through Total Maximum Daily Load (TMDL) performance monitoring and pollution identification.

The results from the APE appear in the next chapter. The next chapter also includes a reflection and discussion regarding the field experience.

Chapter 3 - Noteworthy Findings, Reflections, and Future Research Questions

Noteworthy Findings

See the Complete Results in Appendix B.

Temperature

The lowest temperature recorded was 1.30°C (January 12, 2021) at the North Fork of the Goose Creek. The highest temperature recorded was 7.30°C (December 21, 2020) at one of the sampling locations on Tuscarora Creek. This temperature range is normal for the time of year when compared to USGS gage station records.[44] All sites on January 12, 2021 had ice on the bank of the waterway, and at one location the waterway had a layer of ice that we had to break through in order to access the water.

Nutrients

The lowest nitrate value recorded was 0.44 ppm, while the highest was 1.77 ppm. The lowest orthophosphate measurement was less than or equal to 0.01 ppm, while the highest was 0.02 ppm. The lowest ammonia measurement was also less than or equal to 0.01 ppm, while the highest measurement was 0.05 ppm, which occurred at a single site. The Lachat system does not reliably measure values lower than 0.01 ppm, so any readings that were 0.00 ppm we manually changed to 0.01 ppm, and noted that the measurement was less than or equal to 0.01 ppm. These values are all within DEQ surface water quality standards.

Turbidity and Conductivity

Turbidity ranged from 1.13 NTU to 12.90 NTU, with a mean of 5.55NTU, excluding the site opportunistically sampled twice. At the site where the author opportunistically sampled due to the glaring orange discoloration of the water, the turbidity measured 168 NTRU (Figure 3.1). The turbidity was 27.70 NTU the next time the author sampled the site. As for the daily discharge at the gage station during the sampling period, it started at 450 ft^3/s on December 21, 2020, spiked to nearly 6000 ft^3/s on December 25, 2021, and then declined to below 300 ft^3/s by January 12, 2021.[6] There was also a general decline in turbidity throughout the sampling period. Conductivity ranged from 91 to 670 μS/cm, with an average value of 228 μS/cm.

While turbidity and conductivity are not included in the Administrative Code, these parameters were still included in this project because they are useful indicators and are listed in the Virginia Citizen Water Quality Monitoring Program Methods Manual.[33] Turbidity is used as an indicator of runoff or discharge effects from construction, agricultural practices, logging, waste discharges, and erosion in general. Turbidity also often increases during and just after rainfall, especially where there are impervious surfaces (e.g., rooftops, pavement, and parking lots), exacerbating the volume and velocity of stream flow and eroding stream banks. The turbidity of the water affects sunlight reaching submerged aquatic vegetation, reducing photosynthesis and production of dissolved oxygen.[33] Conductivity is useful for water quality monitoring as it can indicate discharge or pollution over time. For example, a septic tank failure would cause an increase in conductivity due to the presence of chloride, phosphate, and nitrate. Rainfall and oil cause a decrease in conductivity.

Schwartz et al. (2000) determined that there was an association between drinking water quality based on turbidity and gastrointestinal illness for elderly (65 and older) residents in Philadelphia, with water coming from nonprotected sources that were treated by city water treatment.[45] As the USGS highlights, “high turbidity can promote regrowth of pathogens in the water, leading to waterborne disease outbreaks… The particles of turbidity provide shelter for microbes by reducing their exposure to attack by disinfectants. Microbial attachment to particulate material has been considered to aid in microbe survival.”[46]

Figure 3.1. Turbid waterway; orange effluent from construction upstream.

Dissolved Oxygen

Dissolved oxygen (DO) ranged from 3.65 mg/L to 15.31 mg/L, with an average value of 12.13 mg/L. The stagnant tributary of the Sycolin Creek yielded the lowest DO value of 3.65 mg/L. According to the Virginia Administrative Code's criteria for surface water, nontidal waters in Virginia that have a DO value of less than 4.0 mg/L, or a daily average of 5.0 mg/L, are considered impaired.[41] The mean at this site for DO (based on three samples) was 7.06 mg/L. The concentration of dissolved oxygen is inversely related to water temperature, and rapidly moving water contains more oxygen than stagnant water.[47] Bacteria in the water also consume oxygen. It appears that in 2017, the DEQ stopped measuring dissolved oxygen at the sampling sites.

Low DO can be an indicator of excessive algal growth, which can cause hypoxia (characterized as less than 3 mg/L) over time as the oxygen depletes, resulting in algal death and ultimately decomposition via bacteria, impacting the water quality.[33] The site that had the recorded DO value of 3.65 mg/L also had algal growth on rocks in the water, in spite of the presence of ice on the surface of the water. Nutrients, namely nitrogen and phosphorus, are necessary for biological processes in waterways and contribute to eutrophication and decreased DO. Nitrogen in particular is influenced by human influences and sources: wastewater runoff, failing septic systems, stormwater runoff, fertilizer runoff, and agricultural wastes. Thus, elevated nutrient levels in the water can be indicative of fecal contamination from both human and animal sources. Phosphorus can exist in multiple forms in the water, and it can bind to soil particles and minerals, resulting in lower levels in the water. If DO reaches an anoxic state, phosphorus will be released in the water, causing algal blooms and negatively impacting water quality.[33] This scenario is dangerous not only to the aquatic systems in the waterways, but also to humans who recreate in the water.

pH

pH ranged from 7.00 to 7.98, with an average value of 7.48. According to the Virginia Administrative Code's criteria for surface water, pH within 6.0-9.0 is acceptable for water quality.[41]

E. coli

The overall range for *E. coli* concentration was from 24.10 to 1,299.70 CFU/100mL, using the IDEXX Colilert-18 test method. The author applied the criteria for impairment listed in the Virginia Administrative Code prior to 2021; these criteria included the monthly geometric mean standard of 126 CFU/100 mL (*E. coli*) for freshwater, or two exceedances of the *E. coli* single sample maximum standard of 235 CFU/100 mL, to indicate impairment of the sampled segment.

Tuscarora Creek had three sampling sites, with *E. coli* values ranging from 40.2 to 172.3 CFU/100mL.The geometric mean at each site, from most upstream to most downstream, was 83.75, 66.70, and 92.40 CFU/100mL. Therefore, no site was considered impaired for fecal coliform bacteria, which is in line with the 2003 TMDL.

Sycolin Creek had four sampling sites, with *E. coli* values ranging from 38.9 to 1,299.7 CFU/100mL. The most upstream site had the highest value recorded during the entire sampling period: 1,299.70 CFU/100mL, measured on December 21, 2020, although it declined to 98.70 CFU/100mL by January 12, 2021 (which was also the driest sampling event). The geometric mean at this site was 484.0 CFU/100mL. The next site downstream also had a peak on December 21, 2020, of 1,119.90 CFU/100mL, declining to a low of 38.90 on January 12, 2021. The geometric mean at this site was 355.42 CFU/100mL. The third and fourth sites, continuing downstream towards the Goose Creek, had maxima of 105.0 and 461.10 CFU/100mL, respectively. Respectively, the geometric mean at these sites were 77.70 and 221.58 CFU/100mL. Based on these results, the third site did not exceed standards for *E. coli* criteria; however, the results at the other three sites indicate impairment for fecal coliform bacteria as the geometric means (with $n \geq 4$) were greater than 126 CFU/100mL.

Little River consisted of two sampling sites, one upstream and one downstream of Hungry Run, which was also sampled. The *E. coli* concentrations from these sites ranged from 90.90 to 224.70 CFU/100mL. The upstream Little River site had a geometric mean of 155.23 CFU/100mL for *E. coli* , while the site downstream of Hungry Run had a geometric mean of 140.88 CFU/100mL. The geometric mean for the *E. coli* concentrations at Hungry Run was 142.83. Because the geometric means, each calculated from four weekly samples, were greater than 126 CFU/100mL, the sampled segments from both Hungry Run and Little River were considered impaired for fecal coliform bacteria.

Finally, there were two sampling locations on the Goose Creek itself, one of which was located at the USGS gage station, and there was a single sampling site on the North Fork of the Goose Creek (NFGC). *E. coli* concentrations at the Goose Creek sites ranged from 34.5 to 816.4 CFU/100mL, while the NFGC concentrations ranged from 81.3 to 222.4 CFU/100mL. The geometric mean at the gage station was 339.70 CFU/100mL, while the geometric mean at the downstream site (closest to the Potomac River) was 143.40 CFU/100mL. The geometric mean at the NFGC was 145.23 CFU/100mL. Thus, the geometric mean at each site was greater than 126 CFU/100mL, indicating impairment for fecal coliform bacteria.

As previously discussed in Chapter 1, measuring either (a) two exceedances of the *E. coli* SSM standard of 235 CFU/100 mL or (b) a geometric mean greater than 126 CFU/100mL indicate fecal bacterial impairment of that waterway segment. The updated legislation, however, which goes into effect this year, requires 10 samples over a 90-day period for calculation of an STV and geometric mean.

On two occasions, both of which came from the same sampling site (but on different days), there was exceptional fluorescence upon visualization of the IDEXX Colilert-18 incubation trays under UV light (Figure 3.2), possibly due to the presence of laundry detergent in the water. According to the EPA, optical brighteners added to detergent could cause cross-reactivity with the IDEXX test, as they also fluoresce under UV light.[48]

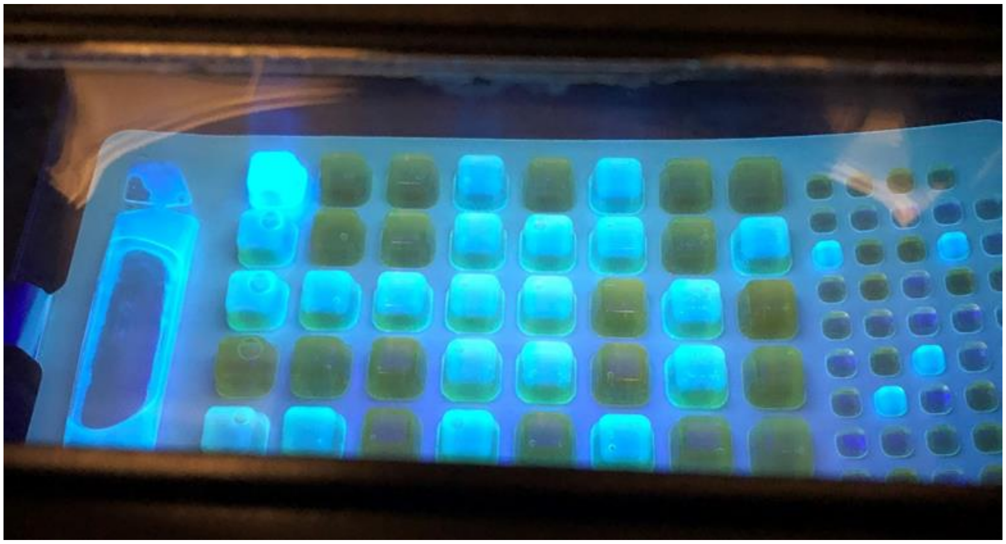

Figure 3.2. Suspect laundry detergent cross-reactivity (top left corner) with *E. coli* visualization under UV light using the IDEXX Colilert-18 and Quanti-Tray Test Method.

Ecological Findings

Each site had signs of deer, as evidenced by hoofprints. Although there is a large deer population, the estimated contribution to measured fecal contamination is likely minimal. According to the 2005 report on the LGCW, overall wildlife contributions to fecal contamination are likely small, and wildlife fecal reductions would not noticeably assist in meeting water quality standards.[16] At the site on the North Fork of the Goose Creek (site 003.NFGC.01), there were signs of beaver activity (Figure 3.3).

Figure 3.3. Evidence of beaver activity on the North Fork of the Goose Creek

The coldest sampling day was January 12, 2021, requiring the author to break through ice to sample water at the stagnant tributary at Sycolin Creek (discussed above). Despite the temperature, green algae were still growing underneath the ice (Figure 3.4).

Figure 3.4. Green algae underneath a layer of ice.

Reflections

(Note: The ILE document will now turn to a first-person narrative. The author and her major advisor decided to do this for the sake of indicating personal growth through reflections, the project portfolio, discerned future research questions, and the competencies acquired.)

The Value of Organizational Categorization and Nomenclature

I was familiar with the concept of using sample identification from previous research projects, so when planning my APE, I automatically knew that each site would have an ID and that I would keep a spreadsheet with site ID, location, coordinates, date, etc., for the sake of organization and easy analysis of data. When developing the site IDs, I used Karen Andersen's method of labeling sites, where the waterway and location relative to other sites (that is, its location upstream or downstream) are included in the name. I could have used DEQ or Loudoun County sample IDs rather than developing my own, but as discussed, we added more sites over time, necessitating the creation of new site IDs. We wanted to be consistent in the naming for all sites, but doing so introduced even more names for a single site, and there is no database allowing for easy comparison of names. Indeed, some sites have IDs established by Loudoun

County government, DEQ, and other non-governmental local organizations (e.g., Save Our Streams, etc.), and my project created yet another site ID!

Having an Excel spreadsheet (with all available ID codes) reduced the time required in analyzing the data, which was connected to my sampling sites. I could quickly organize and reorganize the data depending on the subject, calculate equations (such as the geometric mean) easily and with low risk for human error, and share the data through E-mail. Organization of data was necessary for preventing errors and being efficient.

The Threat of Urbanization in Water Quality Surveillance

Urbanization, in the form of construction for buildings and roads, leads to problems for water quality surveillance. One problem includes reduced accessibility to historical sample sites. When visiting sites listed in the 2005 LWW report for use as my sampling sites, I had to assess whether Karen Andersen and I could safely park our two vehicles, safely walk down to the sampling site for wading, and avoid trespassing on private property. An alternative to wading into the waterway was lowering a bucket down from a bridge or overpass, but there is obviously additional risk due to vehicles speeding across the bridge. Since 2005, Virginia roadways have expanded, both in numbers of lanes and traffic volume (which also increased our risk when the only available parking was on the shoulder of a road). As discussed, active construction prevented us from sampling at one site on Tuscarora Creek during the last two sampling events. Both entrance points of the creek were completely blocked off and bulldozers were working in the water and on the bank, which would have affected the measurements collected from that site (for example, turbidity would have been artificially elevated). Elsewhere, urbanization did elevate the turbidity (as seen in Figure 3.1), with the extension of a roadway upstream. We also documented the presence of oil and human litter in the water and on the banks. On a related note, we debated not sampling from one site on the Little River, because upstream there was active construction on a historic dam (Figure 3.5). Problems plagued this construction site, including bank erosion, improperly placed sediment booms, broken bottles (and other litter), and confusion as to who was in charge of this project, namely, who was in charge of ensuring that the trash produced would be cleaned up!

Figure 3.5. Construction at Aldie Mill Historic Dam.

Historical Events Involving Contaminated Water in Virginia

Lest we forget history (and lest we leave out one of my major professor's passions), it must be remembered that Virginia was home to some of the earliest water-related public health events in pre-Revolutionary America. Jamestown settlers during the "Starving Time" (1609-10) suffered from an epidemic of illnesses, including dysentery and typhoid, decimating hundreds of people.[49] These diseases were associated with fecal contamination of drinking water, exacerbated by salt toxicity from high salinity levels in the groundwater.[50] Fecal contamination of the water supply occurred due to the proximity of latrines to the James River. Even today, the very aquifers that were used by the colonists still have an elevated fecal coliform count, though now the fecal contribution is from the resident Canada goose population (see Figure 3.6).[50]

Figure 3.6. Jamestown site, location of waterborne illness circa 1609, courtesy of Justin Kastner.

E. coli

The results from the APE demonstrated an association between *E. coli* concentrations and precipitation. As discussed in the turbidity results, there was a peak in stream flow around December 25, 2020, which corresponded to snowmelt from a snowstorm on December 16, 2020 that yielded 3-6 inches in the area.[51] There was minimal precipitation during sampling in January. Monitoring at all times of the year is important for the sake of public health, not only because the Goose Creek is distinctively designated a Scenic River, but also because it is considered impaired due to fecal bacterial loads. As James Beckley explained at a Virginia Citizens for Water Quality Summit (2012),

> Fecal bacteria [are] the largest impairment source of streams in Virginia, [and] high levels of fecal bacteria and sewage in waterbodies increase the risk of illness, [with] sewage (leaking sewer lines, septic systems, straight pipes) as the largest or second [largest] source of fecal bacteria in nearly any given waterbody.[35]

As discussed above, the methods of calculation and the parameter values for determining surface water impairment are constantly changing.

Given the small sample size for each site, statistically comparing *E. coli* geometric means to the Goose Creek flow rates or to recent precipitation levels would not be practical, especially since the geometric mean will no longer be the sole method required for determining water quality. As a general statement, *E. coli* concentrations were highest on days where precipitation had occurred within 48 hours of sampling, or where there was active snow melt and runoff.

Further complications in evaluating data arose when reading the latest reports on water quality for the LGCW and Goose Creek. The most recent Water Resources Monitoring Data Summary report for Loudoun County is from 2019, but the most recent publicly available report is from 2016.[52] In order to access the 2019 report, I completed a formal Freedom of Information Act request.[2] The *E. coli* criteria for impairment in these reports are now out of date, making the data difficult to interpret in the context of the recently updated criteria (using the STV and greater sample size). The 2019 summary included data from a 2018 DEQ study on surface water microbiology in the watersheds of Loudoun County.[25] The state legislation at the time determined the recreational limit for *E. coli* colonies to be 235 CFU/100mL. The results of the DEQ study showed that approximately 93% of 107 water samples analyzed were above that recreational limit, and that stream segments exceeding that value 10.5% of the time were impaired with respect to bacteria. In 2016, 86% of water samples (n = 123) analyzed were above the recreational limit of 235 CFU/100mL. What is the significance of these data then, in the context of the updated criteria, where more samples are required over a longer period of time, and with the addition of a new method of calculation (the STV) for impairment?

Project Portfolio

I organized the data from this project into an Excel spreadsheet (see Appendix B), which has since been submitted to the Virginia Department of Environmental Quality, where it will be added to an online water monitoring mapping database.[53] I also submitted the data to the Loudoun County Department of Building and Development, where it will be added to the county's online stream monitoring mapping application.[54] Per the suggestion of one county employee, I requested to have my results added to the annual Water Resources Monitoring Data Summary for Loudoun County. That request was denied, however, due to the "numerous"

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[2] The FOIA is a federal freedom of information law that requires disclosure of previously unreleased information and documents under the jurisdiction of the US government upon request, making government agencies of the executive branch more accountable and transparent.

organizations that request to have data included in the report, which would become an “overwhelming undertaking” for the county employees (Personal communication, Jim Brown, Natural Resources Division Manager, 5/15/21).

I also presented the results from this project in February 2021, at the monthly meeting for the Loudoun Soil and Water Conservation District (LSWCD), a “para-county” agency involved in nonpoint source pollution.[3] During this presentation, I outlined the objectives and results from my project, and discussed the implications of impaired surface water quality in the context of fecal contamination (see Appendix C).

I also created a handout for the Virginia Cooperative Extension’s office in Loudoun County, outlining water quality resources and assistance available to the community that are offered by federal, state, and local agencies involved in water quality: the US Department of Agriculture’s Natural Resources Conservation Service, Virginia Department of Environmental Quality, Virginia Department of Health, LSWCD, Loudoun County Virginia Cooperative Extension, and Loudoun County Department of Environmental Health (see Appendix D). The impetus for this product was to educate the public and help them decide what organization to contact for assistance or information regarding water quality. (I personally had trouble deciding which agency to contact when I had questions, given the overload of information online and because there are overlapping interagency responsibilities for a huge range of water quality topics.)

I also assisted Dr. Kastner, my major advisor, with an interactive discussion with his undergraduate students enrolled in DMP314, Environmental and Public Health, this summer. Like Virginia, Kansas waterways need routine water quality surveillance, highlighting the value in educating students as the future stewards of natural resources.

Future Research Questions

Measuring *E. coli* in a waterway is only the first step in managing fecal contamination. Determination of the actual source of contamination is arguably just as important; identification of non-point source contamination factors would allow for successful management and prevention. Microbial source tracking (MST) allows for qualitative identification of the animal source(s) that are contributing to fecal contamination in the waterways.[36]

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[3] My thanks to James Hilleary for opening the opportunity and enabling me to quickly reach nearly all stakeholders of the Goose Creek Watershed.

MST research methods can be either library-dependent or library-independent, where a "library" is a database that is temporally and geographically specific to the area.[36] Library-dependent methods, while more expensive and time consuming, allow for the detection of multiple sources that can be compared to the database. These methods can be further broken down to genotypic methods (e.g., rep-PCR and pulsed field gel electrophoresis), and phenotypic (e.g., antibiotic resistance analysis and carbon utilization). Library-independent methods can also be characterized by genotypic (e.g., host-specific PCR) and phenotypic (e.g., bacteriophage and bacterial culture). Bacteriophage analysis is the least discerning MST method, while carbon utilization is the most discerning.[36] Molecular analysis of *E. coli* in contaminated water is based on the premise that there are genetic differences (a "genetic fingerprint") among enteric bacteria in hosts that can be isolated and used to determine the host species. Phenotypic, or biochemical, methods use observable characteristics of the isolated bacteria in water samples. For example, antibiotic resistance analysis of water samples allows for host identification of *E. coli* because antibiotic treatment of a host animal may result in resistance by intestinal bacteria to that specific antibiotic.[36]

DEQ had an MST program that began in the 1990s, and, according to a 2011 EPA report, the DEQ "has since implemented a statewide MST program to support TMDL development" (Pg. 46).[36] However, when speaking to the DEQ's Water Quality Planning Team Lead, Sarah Sivers, in December 2020, I was informed that the DEQ no longer engages in this type of surveillance. DEQ then put me in contact with the Department of Environmental Services in Arlington, Virginia, as they also had an MST program; however, the assays of the laboratory they utilized were limited to detecting human and dog fecal *E. coli*. When considering Loudoun County's watershed reports (e.g., the TMDL and IP), however, livestock are likely the primary species that contribute to *E. coli* in the waterways, so it would be necessary to have assays for livestock fecal *E. coli*. Source Molecular Labs in Miami Lakes, FL also offers MST. Their assays can detect fecal contamination from "humans, dogs, cows, pigs, horses, chickens, birds, geese, gulls, ruminants (deer, elk, goats, sheep), [and] beavers."[55] Each sample submission costs $360 for the first assay, then an additional $150 per assay. Submitting a single sample and having it tested for the presence of horse, cow, human, and dog fecal *E. coli* would cost $810 ($360 + $150 + $150 + $150), which was cost-prohibitive for my APE but would be worthwhile for a future researcher to pursue.

While the Implementation Plan (IP) for the UGCW is a useful guideline for obtaining a more current understanding of the entire Goose Creek watershed, implementing identical recommended management measures for the LGCW would not be the right decision, as the two portions of the watershed are becoming increasingly different in regards to human population, land use, and development overall. The UGCW IP discussed the possibility of a regional equine composting facility. To reiterate, the UGCW and LGCW both cover Fauquier and Loudoun Counties, which have similar equine populations and both could benefit from better management of equine waste. When speaking with the Conservation Education Specialist for Fauquier County, Michael Trop, in January 2021, I learned that the idea for the regional equine composting facility was abandoned. The reasoning, he explained, was due to a number of complex challenges (e.g., covering two counties and requiring cooperation between private landowners). He did say that there are currently cost-share efforts to help individual landowners set up small-scale composting facilities. While they are also "running into issues," he expected them to ultimately be installed. Furthermore, the IP acknowledges that the recommendations of the 2003 bacteria TMDL (covering the entire Goose Creek Watershed) were not reasonable, as the document called for "near elimination of all major sources of bacteria throughout the watershed."[19] Considering that *E. coli* concentrations rapidly fluctuate to potentially unsafe levels in association with precipitation, MST offers a research strategy to narrow down the source of fecal contamination. As it is unlikely that an IP will ever be established for the LGCW, routine water quality monitoring via citizen monitoring programs as well as government oversight will remain necessary to safeguard environmental and public health.

Chapter 4 - Competencies

Student Attainment of MPH Foundational Competencies

Table 4.1 Summary of MPH Foundational Competencies

Number and Competency		Description
2.	Evidence-based Approaches to Public Health	Select quantitative and qualitative data collection methods appropriate for a given public health context
4.	Evidence-based Approaches to Public Health	Interpret results of data analysis for public health research, policy or practice
13.	Policy in Public Health	Propose strategies to identify stakeholders and build coalitions and partnerships for influencing public health outcomes
19.	Communication	Communicate audience-appropriate public health content, both in writing and through oral presentation
21.	Interprofessional Practice	Perform effectively on interprofessional teams

I attained Competencies 2, 4, and 13, through development of a data sheet that organized the results of the data from the APE. For competency 2—selection of data collection methods appropriate for a given public health context—I collected both qualitative and quantitative water quality data. Qualitative data included the color and general appearance of the water (e.g., presence or absence of foam, human litter, silt and sediment, etc.), evidence of erosion along the bank, and whether animals were observed at the monitoring site. Quantitative data included conductivity, pH, dissolved oxygen, turbidity, water temperature, *E. coli* concentrations, and chemicals (i.e., nitrate, orthophosphate, and ammonia). I then applied competency 4 by interpreting my results in light of public health (and water quality) standards, policies, and practices. Collection of data at each sampling site created a water quality "snapshot" suitable for incorporation into databases produced by Loudoun County and Virginia DEQ; the snapshots' parameters comport with the Virginia Administrative Code's surface water quality monitoring legislation. The APE parameters were also in line with the Virginia Administrative Code's criteria for water quality monitoring at the time in regards to fecal contamination (e.g., taking the geometric mean of the *E. coli* values of four samples from a single site over a 30-day period would determine whether the waterway was impaired for bacteria). As for the other parameters listed in the Administrative Code (i.e., dissolved oxygen, maximum temperature, and pH), I was able to further practice competency 4 by interpreting the results and concluding that the watershed was not impaired for other pollutants that merit production of TMDLs. I also attained competency 13—propose strategies to identify stakeholders and build coalitions and partnerships for influencing public health outcomes—during the APE. To reiterate, the APE sampling area occurred in Loudoun County; however, the entire LGCW spans across Loudoun and Fauquier County, and I had to communicate with the Fauquier County government to understand the status of the watershed, as certain reports and summaries in relation to the TMDL have not been made public. Furthermore, while my preceptor was the unit coordinator for the extension office in the county, I worked closely with the lab director (Karen Andersen) for the Friends of the Shenandoah River, whose laboratory is not even located in Loudoun County. I also routinely communicated with the Goose Creek Association and, by default, the DEQ; both organizations play a role in performing water quality monitoring of the LGCW. The list of stakeholders with whom I communicated with goes on, and I learned during the APE that a concerted, multi-stakeholder effort is needed in monitoring the LGCW (rather than piecemeal efforts by different organizations and agencies). During the APE, some of the stakeholders actually began to create a working group to establish what needs to be done to improve the health of the LGCW, given the lack of an overall coordinated IP.

My preceptor is a board member of the Loudoun Soil and Water Conservation District (LSWCD), which essentially is comprised of most of the stakeholders listed above, and more. This organization facilitates interprofessional communication for addressing soil and water issues, and conserving natural resources in the county, fulfilling competency 21—perform effectively on interprofessional teams. My project proposal and final presentation bookmarked the beginning and end of the APE, and I relied on their scientific and government-related insights on how to apply my data so that it would be useful for conserving the water quality in the LGCW. Although I independently developed this project, I required the LSWCD assistance in accessing historical data, obtaining approval on the sampling sites, having my questions answered, and understanding the procedures involved in water quality monitoring. My presentations (to the LSWCD) exercised part of competency 19 (communicating audience-appropriate public health content, both in writing and through oral presentation). For the writing aspect of competency 19, I created a handout that would communicate to the public how they can access forms, general information, and technical support for maintaining the quality of drinking water that comes from the LGCW.

In addition, I engaged in Competency 22—"systems thinking"—by developing an overall causal loop diagram; this diagram appears in my APE document on p. 11.

Student Attainment of MPH Emphasis Area Competencies

Table 4.2 MPH Emphasis Area Competencies

MPH Emphasis Area: Infectious Diseases/Zoonoses		
Number and Competency		**Description**
1	***Pathogens/pathogenic mechanisms***	Evaluate modes of disease causation of infectious agents.
2	***Host response to pathogens/immunology***	Investigate the host immune response to infection.
3	***Environmental/ecological influences***	Examine the influence of environmental and ecological forces on infectious diseases.
4	***Disease surveillance***	Analyze disease risk factors and select appropriate surveillance.
5	***Disease vectors***	Investigate the role of vectors, toxic plants and other toxins in infectious diseases.

As a concurrent DVM/MPH student, my MPH emphasis area is infectious diseases and zoonoses. In consideration of competencies 1 and 5, *E. coli*-associated illness and outbreaks are zoonotic and infectious; however, they are not vector-borne, but rather food- and water-borne. Cattle are the primary shedders for pathogenic *E. coli*, especially O157:H7. Cognizant of this risk, the APE considered not only human fecal contamination, but also livestock fecal contamination. Microbial source tracking (MST) would have been useful in narrowing down the source of the fecal contamination, but due to budget constraints, one can only speculate on the fecal sources. The site that consistently had the highest *E. coli* levels was about a half mile downstream from a few horse farms, where the pastures sloped down directly into the sampled waterway, the Sycolin Creek. From my readings on the watersheds throughout Loudoun County, cattle have directly contributed to fecal contamination in waterways, documented by cattle standing for prolonged periods in the waterway. During my project, I never saw cattle frequenting the waterways, but the risk is still present, considering the waterways cross through private cattle (and horse) pastures where fecal waste management is the responsibility of the producer. Humans are also a risk factor through human-human transmission of pathogenic *E. coli* and also through waterborne transmission, which as discussed in the literature review, can occur due to the proximity of septic tanks, private wells, and waterways.

When conducting background research, I could not find any case reports of *E. coli*-associated gastrointestinal illness associated with contaminated drinking water from the LGCW aquifer. I also could not find any associated outbreaks with recreating in the Goose Creek or its tributaries in the LGCW. When attempting to investigate the host immune response to infection (competency 2), it would then be implied that risk of illness is low, but that does not absolve government agencies from water quality monitoring. Stakeholders cannot rule out the possibility of isolated illnesses of unknown sources associated with contaminated water. Speaking from personal experience, in my youth I became ill after (foolishly) drinking untreated water from the Goose Creek.

The designation of impairment, based on the criteria established by the Virginia Administrative Code for *E. coli*, suggests that the human immune response to fecal coliforms for the general population has a threshold before there are clinical signs (additionally, infectious dose varies according to the specific pathogen). Initially, the goal of the 2003 Goose Creek Watershed TMDL was to nearly eliminate fecal contamination. Not only is that recommendation impossible due to wildlife fecal contributions and failing septic systems, it is also not necessary for preventing waterborne *E. coli* outbreaks; the concentrations of *E. coli* must only be below a certain level. Uncertainty arises as to what that level is, evidenced by the constantly changing criteria in the Virginia Administrative Code.

I addressed Competency 3 by connecting *E. coli* concentrations with other ecological parameters of the sampled waterways. For example, increased *E. coli* concentrations were associated with increased stream flow and precipitation or snow melt over the last 24 hours. Conversely, water temperature typically has an inverse association with *E. coli* concentrations, yet we were able to measure *E. coli* in water temperatures below the freezing point (albeit the *E. coli* concentrations we measured were below the SSM value for impairment). Both the natural and built environment contributed to increased risk of infectious disease from *E. coli* in the water, as mismanagement of livestock wastes directly contribute *E. coli* to surface waters, while impervious surfaces channel contaminated water directly into storm drains and waterways. Ideally, preservation of the natural ecosystem through increased use of riparian buffers (a concept recommended by the UGCW Implementation Plan) would likely mitigate risk of disease from pathogenic fecal coliforms.

For competency 4, the primary objective of my APE was to conduct surveillance of the LGCW for *E. coli*, with risk factors including failing septic systems, in addition to nonpoint source pollution like runoff livestock waste. Surveillance also involved assessing whether there were regulations in place for protecting private well owners from disease. Although newly installed wells are required to pass drinking water quality standards, legislation fails to mandate routine monitoring of wells. Additionally, there is no agency in charge of issuing recreation-related advisories for scenic rivers in the event of elevated *E. coli* levels.

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Appendix A - Sample Site ID and Coordinates

Site ID	Waterway	Latitude	Longitude	DEQ/Loudoun ID
LGCW.001.TC.01	Tuscarora Creek	39.101276	-77.573666	LOGC-205-H-2009
LGCW.002.SC.01	Sycolin Creek	39.077005	-77.606916	1ASYC007.43
LGCW.003.NFGC.01	N. Fork Goose Creek	39.038922	-77.64979	NA
LGCW.004.LR.02	Little River	38.976216	-77.65105	1ALIV-17-SOS
LGCW.005.HR.01	Hungry Run	38.965486	-77.6555707	1AHUN-17a-SOS
LGCW.006.LR.01	Little River	38.974186	-77.668135	1ALIV006.92
LGCW.007.GC.01	Goose Creek	39.018333	-77.575299	NA
LGCW.007B.GC.01	Goose Creek	39.018809	-77.577688	1AGOO011.23
LGCW.008.SC.02	Sycolin Creek	39.05538	-77.575631	1ASYC004.93
LGCW.009.SC.03	Sycolin Creek	39.061224	-77.555282	NA
LGCW.010.SC.04	Sycolin Creek	39.061668	-77.541413	1ASYC002.03
LGCW.011.TC.03	Tuscarora Creek	39.084672	-77.516675	1ATUS000.37
LGCW.012.GC.02	Goose Creek	39.085703	-77.511499	1AGOO002.38
LGCW.013.TC.02	Tuscarora Creek	39.098589	-77.546785	LOGC-207-H-2009
LGCW.014.SCT.01	Sycolin Creek Trib	39.061045	-77.55486	NA
LGCW.015	Sycolin Creek Trib	39.071673	-77.529212	NA

Appendix B - LGCW Water Quality Monitoring Results

Site ID	Sample date	*E. coli* (CFU/100mL)	Turbidity (NTU)	DO (mg/L)	Water temp (C)	Conductivity (µS/cm)	pH
LGCW.001.TC.01	1.05.2021	52.0	4.06	11.98	6.3	227	NA
LGCW.001.TC.01	12.28.2020	90.8	5.78	12.74	4.6	221	NA
LGCW.001.TC.01	12.21.2020	93.4	3.23	12.16	5.6	384	NA
LGCW.001.TC.01	1.12.2021	98.8	1.13	13.26	2.7	254	NA
LGCW.002.SC.01	1.12.2021	98.7	2.76	14.03	1.5	175	7.96
LGCW.002.SC.01	1.05.2021	102.2	3.19	12.24	5.9	167	7.70
LGCW.002.SC.01	12.28.2020	435.2	5.40	12.92	4.0	161	7.47
LGCW.002.SC.01	12.21.2020	1,299.7	3.06	12.90	4.8	189	NA
LGCW.003.NFGC.01	1.12.2021	81.3	3.67	13.63	1.3	181	7.86
LGCW.003.NFGC.01	1.05.2021	105.0	6.56	NA	NA	NA	NA
LGCW.003.NFGC.01	12.28.2020	172.2	12.90	12.69	3.5	171	7.52
LGCW.003.NFGC.01	12.21.2020	222.4	4.16	9.24	4.9	210	NA
LGCW.004.LR.02	1.12.2021	90.9	2.32	14.02	1.5	118	7.72
LGCW.004.LR.02	1.05.2021	96.0	4.34	12.55	5.7	115	7.29
LGCW.004.LR.02	12.28.2020	162.4	10.03	13.19	4.1	111	7.30
LGCW.004.LR.02	12.21.2020	214.2	3.89	6.74	5.4	127	NA
LGCW.005.HR.01	1.12.2021	118.7	1.96	14.15	1.5	92	7.52
LGCW.005.HR.01	1.05.2021	131.4	2.83	12.47	6.2	95	7.18
LGCW.005.HR.01	12.21.2020	172.7	2.49	8.32	6.4	99	NA
LGCW.005.HR.01	12.28.2020	198.9	3.99	12.76	5.1	91	7.03
LGCW.005.HR.01 **DUPLICATE**	1.12.2021	122.3	NA	NA	NA	NA	NA
LGCW.006.LR.01	1.05.2021	101.7	4.92	12.27	5.7	117	7.28
LGCW.006.LR.01	1.12.2021	128.1	2.76	13.75	1.4	121	7.62
LGCW.006.LR.01	12.28.2020	166.4	8.62	12.76	4.2	113	7.45
LGCW.006.LR.01	12.21.2020	224.7	5.00	8.33	5.6	129	NA
LGCW.007.GC.01	12.21.2020	613.1	6.13	9.35	4.9	177	NA
LGCW.007.GC.01 **SPLIT**	12.21.2020	816.4	NA	NA	NA	NA	NA
LGCW.007B.GC.01	1.12.2021	86.2	3.31	13.79	1.4	152	7.53
LGCW.007B.GC.01	1.05.2021	122.3	6.90	12.41	5.3	146	7.00
LGCW.007B.GC.01	12.28.2020	195.6	10.75	13.04	3.7	141	7.31
LGCW.007B.GC.01 **DUPLICATE**	12.28.2020	204.6	NA	NA	NA	NA	NA
LGCW.008.SC.02	1.12.2021	38.9	2.93	14.33	2.3	186	7.51
LGCW.008.SC.02	1.05.2021	119.8	5.07	12.56	5.8	171	7.19
LGCW.008.SC.02	12.28.2020	387.3	7.17	13.11	4.7	165	7.34
LGCW.008.SC.02	12.21.2020	1,119.9	5.87	NA	NA	NA	NA
LGCW.008.SC.02 **DUPLICATE**	1.05.2021	111.2	5.18	12.56	5.8	171	7.19
LGCW.009.SC.03	1.12.2021	50.4	3.50	14.71	2.6	224	7.61
LGCW.009.SC.03	1.05.2021	105.0	7.15	12.78	5.8	199	7.35
LGCW.010.SC.04	1.12.2021	51.2	3.94	14.88	2.2	227	7.72
LGCW.010.SC.04	1.05.2021	98.5	7.58	12.86	5.7	202	7.37
LGCW.010.SC.04	12.21.2020	275.5	7.28	9.98	5.8	283	NA

LGCW.010.SC.04	12.28.2020	461.1	9.24	13.34	4.6	199	7.34
LGCW.011.TC.03	1.12.2021	40.2	2.84	15.31	3.7	427	7.98
LGCW.011.TC.03	1.05.2021	69.1	5.90	12.81	6.9	384	7.52
LGCW.011.TC.03	12.28.2020	88.0	8.12	13.11	6.3	384	7.46
LGCW.011.TC.03	12.21.2020	172.3	11.50	11.16	7.2	679	NA
LGCW.012.GC.02	1.12.2021	34.5	3.60	14.55	2.7	226	7.91
LGCW.012.GC.02	1.05.2021	110.6	8.06	NA	NA	NA	NA
LGCW.012.GC.02	12.21.2020	209.8	8.59	10.18	5.8	355	NA
LGCW.012.GC.02	12.28.2020	218.7	10.31	13.78	4.2	210	7.61
LGCW.013.TC.02	12.21.2020	65.7	3.55	10.51	7.3	617	NA
LGCW.013.TC.02	12.28.2020	67.7	5.93	13.08	6.5	334	7.61
LGCW.013.TC.02	1.05.2021	NA	NA	NA	NA	NA	NA
LGCW.013.TC.02	1.12.2021	NA	NA	NA	NA	NA	NA
LGCW.014.SCT.01	1.12.2021	24.1	3.05	10.83	4.0	374	7.51
LGCW.014.SCT.01	12.28.2020	43.1	9.70	6.71	4.4	270	7.21
LGCW.014.SCT.01	12.21.2020	293.3	6.23	3.65	6.9	335	NA
LGCW.015	1.05.2021	NA	168	NA	NA	NA	NA
LGCW.015	1.12.2021	NA	27.70	NA	NA	502	NA

Appendix C - LSWCD February Meeting Presentation

Water Quality Monitoring in the Lower Goose Creek Watershed

Karen Hood

February 11th, 2021

Overview

- Introduction
- Timeline and Locations
- Results
- Discussion and Future Directions

Back in November…

- Initial presentation of this idea to LSWCD
- Worked with Jim Hilleary
  - Established objectives
- Contacted Karen Andersen (FOSR)
  - Outlining a sampling schedule
  - Laboratory space
- E-mailed David Ward a few dozen times

Timeline

- Four sampling events based on the 2020 WQA Guidance Manual:

"the monthly geometric mean standard of 126 per 100 ml (*E. coli*) for freshwater applies when a minimum of four weekly samples are collected during any calendar month"

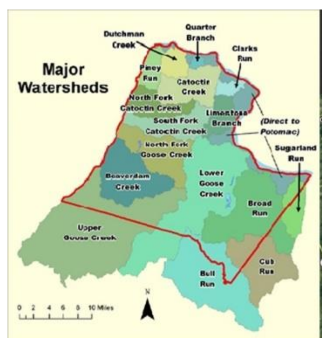
- December 21st, 2020
- December 28th, 2020
- January 5th, 2021
- January 12th, 2021

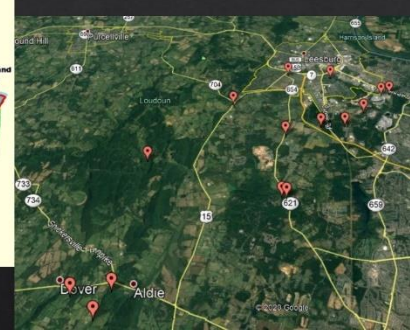
Goal: Snapshot of LGCW water quality in winter

Table A.28. Stream Monitoring Stations and Data Type for the Lower Goose Creek and Little River Watersheds.

Monitoring Sites	Water Flow	Chemical & Physical	Bacterial	Stream Habitat	Aquatic Insects
Main Stem					
– Rt. 7	USGS 1910 - 1999	DEQ 1973-2004	DEQ 1973-2004	DEQ 1996- 2004	DEQ 1996-2004
– Rt. 621	USGSS	DEQ 2001-2004	DEQ 2001-2004		
Little River					
– Rt. 15		DEQ 2001- 2002	DEQ 2001- 2002		
– Rt. 50		DEQ 1973-2002	DEQ 1973-2002	DEQ 1997-2004	DEQ 1997-2004
– Rt. 629	LSWCD 1999-2001	DEQ 2003-2004 LSWCD 1999-2001	DEQ 2003-2004 LSWCD 1999-2001		LSWCD 1999-2001
– Rt. 632	LSWCD 1999-2001	LSWCD 1999-2001	LSWCD 1999-2001		LSWCD 1999-2001
Sycolin Creek					
– Rt. 15		DEQ 1973-2000	DEQ 1973-2000		
– Rt. 652		DEQ 1973-2002	DEQ 1973-2001	LWC 2004	LWC 2004
– Rt. 621		DEQ 1973-2000	DEQ 1973-2000		
– Rt. 797		DEQ 1973-2000	DEQ 1973-2000		
Tuscarora Creek					
– Golf Course		DEQ 2003-2004	DEQ 2003-2004		
– Rt. 653		DEQ 1973-2002	DEQ 1973-2002		
– Lawson Rd.				LWC 1997-2004	LWC 1997-2004

Lower Goose Creek Watershed sites – based on a 2005 State of the Streams report for Loudoun County





Parameters

- Nutrients – orthophosphate, nitrate, ammonia
- pH
- Water temperature
- Conductivity
- Dissolved oxygen
- Turbidity
- E. coli

Parameter Results (range)

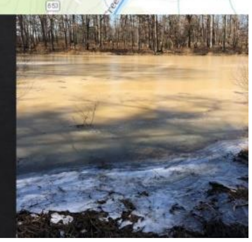
- Nutrients (PPM)
  - Nitrate: 0.44 – 1.77
  - Orthophosphate: <0.01 – 0.02
  - Ammonia: <0.01 – 0.05
- pH
  - 7.00 – 7.98
- Temperature (Celsius)
  - 1.30 – 7.30

Parameter Results (range)

- Dissolved oxygen (mg/L)
  - 6.74 - 15.31
  - Outlier: 3.65 mg/L

Parameter Results (range)

- Conductivity (µS/cm)
  - 91 - 679
- Turbidity (NTU)
  - 1.13 – 12.90
  - Outlier: 168 NTU

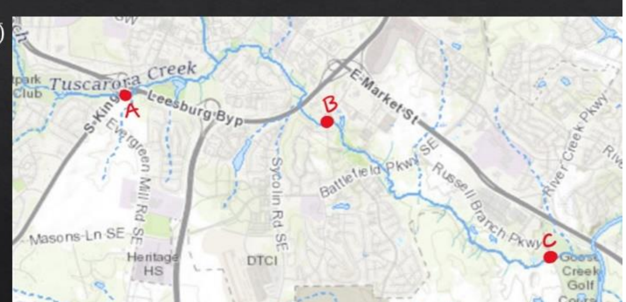


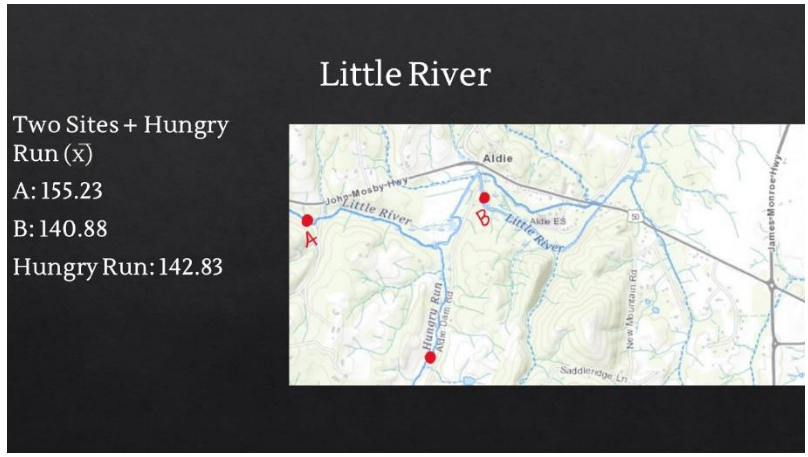
E. Coli Results (CFU/100mL)

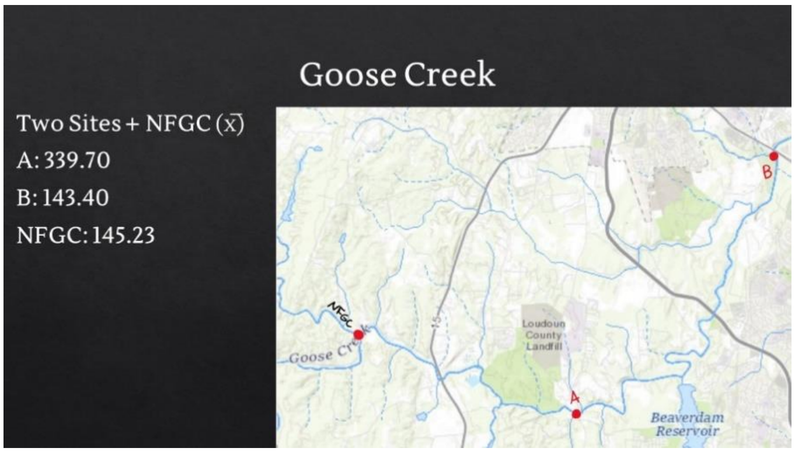
- Range: 24.10 – 1,299.70
- Overall average: 201.35

Tuscarora Creek

Three Sites ($\bar{x}$)
A: 83.75
B. 66.70
C: 92.40
Overall: 83.80







Future Directions

- Microbial source tracking
- Compare data with DEQ

Appendix D – Handout on Agencies Involved with Water Quality

Agencies Involved with Water Quality

Federal: Natural Resources Conservation Service
nrcs.usda.gov

- Provide technical resources & fact sheets for water quality monitoring & assessment for farmers & ranchers
- Provide technical & financial assistance to farmers in priority watersheds who are interested in voluntarily installing monitoring stations

State: Department of Environmental Quality
deq.virginia.gov

- Responsible for state management of surface water & groundwater resources by monitoring for pollutants & implementing clean up plans for impaired waterbodies
- Regulation of "point source" pollution through Virginia Pollutant Discharge Elimination System (VPDES) permits
- Provide training & assistance to professionals for wastewater treatment facilities

State: Department of Health
vdh.virginia.gov

- Online water well testing interpretation tool
- Provide a surveillance map & hotline (888-238-6154) for reporting Harmful Algal Blooms (HAB)
- Regulate onsite sewage treatment & disposal and private wells (in conjunction with VCE)
- **Does not issue swimming advisories for scenic rivers**

County: Soil and Water Conservation District
loudounsoilandwater.com

- Offer a $50 rebate for septic tank pump out
- Offer financial incentives & assistance to homeowners & businesses that install "best management practices" to create watershed friendly landscapes

County: Virginia Cooperative Extension
loudoun.ext.vt.edu

- Offer annual drinking water clinics for well owners
- Provide education materials & periodic workshops for soil health and erosion management

County: Department of Environmental Health
loudoun.gov/1286/Environmental-Health-Services

- Find well & septic inspection records
- Find a licensed operator for yearly septic system inspection
- Find forms & instructions for well & septic installation, repair, or abandonment
- Offer well water quality testing