CLEAN WATER

A LONG-TERM WATER QUALITY MONITORING NETWORK TO EVALUATE RESTORATION OF HICKORY RUN AT THE MT. CUBA CENTER

by

Matthew D. Ludington

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Science in Water Science and Policy

Fall 2018

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ACKNOWLEDGMENTS

Foremost, I would like to thank the University of Delaware Institute for Public Administration for the opportunity to undertake this research, the financial and logistical support, and the consistent help they have provided through my time at the Delaware Water Resources Center. I count myself extremely lucky for the experiences gained and lessons learned during my time as a graduate student under their tutelage.

I would like to especially thank Jerry Kauffman for his guidance throughout both my time at the Water Resources Center, as well as my studies. His knowledge, humor, and passion for water is contagious and encourages all who come in contact with him. I would like to extend these thanks to the entire staff at the WRC, who took the time to make sure I had everything I needed to succeed.

Next I would like to thank my committee members, Martha Narvaez and Dr. Carmine Balascio, for guiding me through this process and providing insight into areas I truly needed help. This was a long process and did not always follow a traditional path, and I thank them for their patience and guidance. I would also like to thank the staff at the Mt. Cuba Center, specifically George Schurter, for their continued support!

I would like to thank my family and friends, who patiently listened to all things water for what must have seemed like far too long. Their support and care truly helped me get through this process when it seemed overwhelming at times.

A special thank you to Jim and Nina Russell, who helped more than I can thank them. Their unquestioning support meant I got to finish the project on my terms, and I cannot thank them enough.

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ABSTRACT

Mt. Cuba is in the advantageous position of having planned restoration efforts developed around a stream that is healthy, stable, and largely devoid of many anthropogenic inputs so commonly seen in water bodies throughout the Mid-Atlantic. Because of this the effects of these restorative efforts can be directly observed through rigorous water quality monitoring, and reasonable connections can be drawn between ecosystem changes and their effects on potential pollutants and water quality conditions. Additionally, research has recently been published on quantifying the ecosystem services of native versus exotic plant species, and while certain information is known on how these plant species differ their effects on water quality are still unproven – an area of research acknowledged by authors as needing more study.

To take advantage of the ideal research situation baseline measurements need to be undertaken as soon as possible with a look toward more permanent measuring stations which can identify a range of water quality parameters. Beginning with the recently completed surveying and cross-sections of Hickory Run, and in combination with ongoing sampling, the ability to add flow and turbidity data for both base flow conditions as well as during storm events can begin to provide an idea as to how the stream itself is impacted over time. Because discharge and turbidity readings are widely undertaken, especially through U.S. Geological Survey efforts in the region, these readings become

immediately useful not only for comparison over time at Mt. Cuba itself but also to surrounding streams throughout the region.

On a greater scale, as climate change continues to potentially alter the ways in which ecosystems function data collection can no longer be solely focused on how anthropogenic effects have altered nature. It must begin to quantify how restorative efforts will impact these same systems. If sound decisions are to be made toward securing safe, reliable water sources for the future, then data from areas such as Mt. Cuba where there is a known history of uses, planned and documented land use and restoration, and dedicated staff and monitoring capabilities, will become invaluable. There is an opportunity not only to undertake meaningful research in a vital area but to encourage future investigation into these effects by being able to provide reliable, significant data over a long period of time.

“Like it or not, for now the Earth is where we make our stand

-Carl Sagan, *Pale Blue Dot*, 1994

Chapter 1

INTRODUCTION

1.1 Research Objectives and Scope

The objective of this research is to establish baseline water quality conditions of the Hickory Run Creek at the Mt. Cuba Center, analyze habitat and land cover conditions, and establish a long-term water quality monitoring station which, together, will be used to investigate the potential impact of native plant restoration efforts across the Mt. Cuba Center's lands.

Research has recently been published on quantifying the ecosystem services of native versus exotic plant species and while certain information is known on how these plant species differ, their effects on water quality are still unknown (McCormick et al. 2010, Aquatic 2007). The Mt. Cuba Center in the Red Clay Creek watershed in northern Delaware is implementing planned restoration efforts in the subwatershed of Hickory Run, a stream that is healthy, stable, and largely devoid of many anthropogenic inputs commonly seen in water bodies throughout the Mid-Atlantic. The effects of these restoration practices can be measured by water quality monitoring to draw connections between ecosystem changes and their effects on potential pollutants and water quality conditions.

Hickory Run Creek flows through the Mt. Cuba Center, a garden located in northern Delaware just west of the Hoopes Reservoir (Figure 1.1). It is a roughly 500-acre botanical garden dedicated to the restoration and conservation of native plants and increasing public awareness of the issue. Their show gardens are open to the public and the Center funds and implements continuing research into native plants and other related topics local to the Mid-Atlantic region.

Hickory Run Creek runs through these lands, mostly forested areas, under a train bridge, as well as 2 other roads and a small residential area. Its watershed serves as a subset of the Red Clay Creek watershed and Hickory Run joins the Red Clay 500 ft. downstream of the last monitoring site (Figure 1.2).

This research began in the late summer of 2016 and continued through the fall of 2017. Additionally, long-term monitoring equipment installed during this period is designed to last on a decadal scale so future data can continue to be collected as restorative efforts evolve and climate change exerts its influence.

1.2 Research Questions

This research hopes to address the following questions:

1. What are the characteristics and capabilities of a monitoring system that could be used to examine the effect of native plant restoration in the watershed on water quality along Hickory Run at the Mt. Cuba Center?

2. How are the habitat and land cover of the Hickory Run watershed at the Mt. Cuba Center characterized?

3. What are baseline habitat and water quality/quantity conditions in the Hickory Run watershed?

4. What are the impacts of native plant restoration in the watershed at the Mt. Cuba Center on the stream habitat and water quality/quantity of Hickory Run?

1.3 Thesis Organization

This thesis will be organized into the following chapters:

Chapter 1: Provides an overview of the research objectives and guiding questions. Discusses the scope and motivation behind the thesis objectives, as well as a brief outline of background information.

Chapter 2: Provides background on the Mt. Cuba Center. Discusses history of the center, research efforts and goals, and physical layout and properties.

Chapter 3: Outlines literature. Delves into scholarly literature based around monitoring strategies, types of equipment, and the call for longer-term data sets. Outlines water quality monitoring history. Summarizes the beginning of monitoring efforts focused around visual records, and how physical or chemical efforts began.

Chapter 4: Summarizes similar monitoring efforts at botanical and research gardens, especially regionally.

Chapter 5: Explains the methodology used to establish baseline conditions and develop a long-term monitoring station for Hickory Run Creek at the Mt. Cuba Center. Provides a more detailed description of events that led to the study. Also discusses where roadblocks and problems arose during the study.

Chapter 6: Discusses the results of the study. Baseline levels are established, as well as physical measurements describing Hickory Run Creek and analysis of incoming water quality data for specific precipitation events.

Chapter 7: Provides insight into possible future work and concludes the paper. Areas of potential future research, as well as how this current study could be applied, are suggested. Conclusion includes a summary of work.

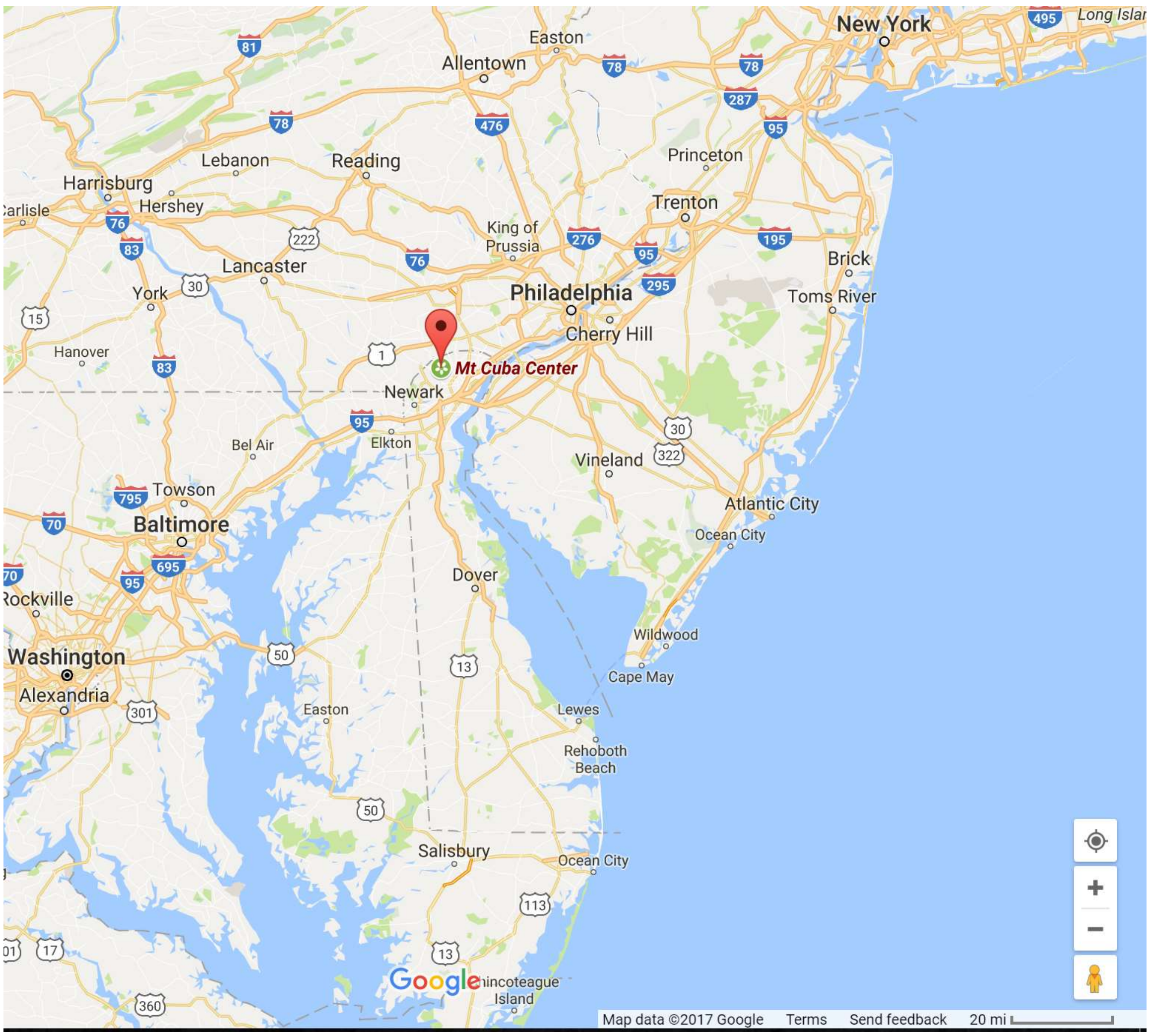

Figure 1.1 Location of Mt. Cuba Center

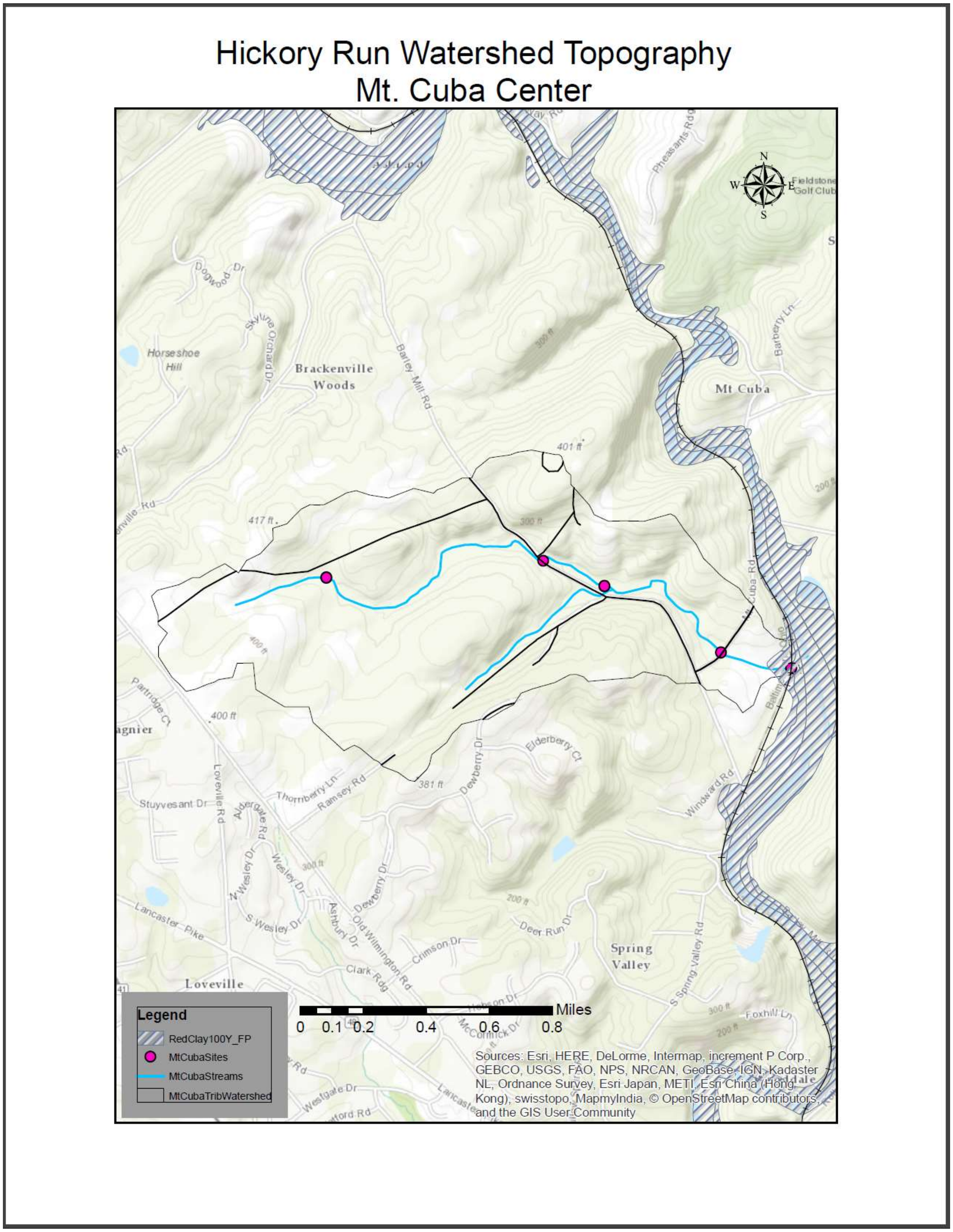

Figure 1.2 Hickory Run Watershed and Sampling Sites

Chapter 2

MT. CUBA

2.1 Mt. Cuba

The Mt. Cuba Center is a beautiful landscape that blends human interaction with a conserved, natural landscape. Pictures cannot fully encompass the feeling of leaving behind a busy, fast-paced concrete world and stepping back into the natural setting the Mt. Cuba Center works hard to preserve. Open meadows and hayfield give way to natural, wild tall grass growth which then give way to thick forests - trees whose tops seem to form a rolling green carpet when viewed from any point outside their shaded confines. Small birdfeeders dot the landscape, enticing wildlife to use the lands as they would have before human interaction, and even the railroad which runs through the land has its tracks at the bottom of a small trench so sightlines are unobstructed as you look across the grounds. It is a prime example of how modern society can exist *with* nature, instead of against it.

The Mt. Cuba Center is a 500-acre conservation and botanical garden set in the Red Clay Creek watershed. Their mission is to "inspire an appreciation for the beauty and value of native plants and a commitment to support the habitats that sustain them" (Mt. Cuba 2017). This mission began with Mr. and Mrs. Lammot du Pont Copeland, the original owners who created the Mt. Cuba Center. The Center sums this in a quote on their website:

> "I want this to be a place where people will learn to appreciate our native plants and to see how these plants can enrich their lives so that they, in turn, will become conservators of our natural habitats"
>
> -Mrs. Copeland

This founding mission serves as the basis for the Center's work and acknowledges the fact that simply observing nature is no longer enough. Understanding its role in an environment heavily impacted by anthropogenic wants and needs will be necessary to ensure that future generations have the opportunity to enjoy the natural landscape that is still available today.

The land was originally purchased in 1935 as 126.7 acres of farmland near the village of Mt. Cuba. Its original purpose was a house for the Copeland family, designed and built in the mid-1930s. In 1950 an additional 17.72 acres were purchased on surrounding land, on which the first naturalistic gardens were developed. Over the next approximately 30 years the lands expanded to their current size while work on botanical gardens began and a focus on ecology and ecological research emerged. In 1983 Mr. Copeland, the landowner, passed away, and Dr. Richard Lighty came on as the first Director of the Mt. Cuba Center. Six years later the Mt. Cuba Center formally incorporated as a foundation and a structure similar to its current state began to emerge.

A decade after incorporating, Rick Lewandowski took over as the second director of the Mt. Cuba Center in 1999. A few years later Mrs. Copeland passed away and the land moves from a residence to a full time ecological and botanical garden foundation, with what was the main house converting to office and staffing space. Throughout the early 2000s the transition to a public garden commenced and in 2002 the first native plant trial began in their cut flower garden, a topic which would become a focus of research and efforts through the Mt. Cuba Center. In 2006 the foundation offered its first education class, reaching out to inform the public through interactive and firsthand experiences.

As the 2010s began, Jeff Downing took over as Executive Director in 2012, a position which he retains today. Shortly thereafter general admission began and the Mt. Cuba Center moved into its more public role as a botanical garden, ecological research, and education center. They now offer a multitude of classes throughout the year, an Ecological Gardening Certification program, as well as access to much of the research and information gathering efforts undertaken on-site. Furthermore, extensive work has been established to move toward a native species oriented set of plants, and some of the original designs from the first gardens have been brought back using these native species.

The research currently at the Mt. Cuba Center is focused around the role of native plants throughout the Mid-Atlantic region of the United States, more specifically how they will act in the area and their impact on the environment. They refer to their living collections, or different plant groupings, as a museum would their collections. Visitors are able to walk through many of these gardens, including test gardens where research is being conducted, and experience them first-hand. This is meant to build a greater appreciation for the native species and their benefits in a hands-on, more interactive environment.

Much of the data and reports that are generated at the Mt. Cuba Center are available to the public via website or request. The Mt. Cuba Center tests specific breeds and variations of individual plants to determine which are best suited for the Mid-Atlantic climate and their reports emphasize the ecosystem services these types of plants can provide whether in a controlled garden or allowed to grow naturally over more wild landscapes. The Center continues these research initiatives by hiring post-docs and offering multiyear positions or funding research that will provide a better look into the full impact these native plants will have once brought back on a wider scale. The entire library of native plants and species that have been planted or studied at the Mt. Cuba Center is available on their website for visitors to gain more information. Part of this effort is aimed at improving home gardens' ability to thrive using these native plants and increasing their reintroduction into the surrounding area.

2.2 Regional Land Use

Land use throughout the Mid-Atlantic region will play an important role in both the incoming pollutants expected to be found in and around the Mt. Cuba Center as well as the types of parameters tested. When choosing parameters, the eventual purpose or use of data needed to be taken into consideration. Therefore, regional water issues, often associated with land use, had to be incorporated as data is often used to justify decisions or persuade decision makers.

The United States Geological Survey (USGS) Land Cover Institute (LCI) categorizes the region as partially urban, part temperate or subpolar grassland, and part tropical or sub-tropical broadleaf deciduous forest. While these categories do not specifically describe land use they provide a reference point which shows the ready availability of water throughout the region, providing a similarity to the more specific area in which the Mt. Cuba Center resides. Temperate and subpolar give a general description to the climate as well, which is seasonal, and although temperatures can fluctuate extremes both hot and cold are often avoided. Looking more closely at the LCI map it becomes clear why approaches to water management are often promoted on a watershed scale basis, where common water quality or quantity problems can be grouped to find answers that work geographically. Water availability remains high through the Eastern Seaboard, drops significantly through the middle third of the country (horizontally), and improves slightly along the west coast, but levels still do not meet those found on the eastern counterpart. The LCI map shows this intuitively through their visual representations - using greens and reds to denote heavy vegetation as well as urban development, both of which follow water patterns, and a tan or sand coloring, throughout the middle of the country.

While specific regions may experience a wide variety of water quality issues common patterns exist and land use plays a significant role in identifying these patterns. In an expanding view of the Mid-Atlantic land is most often categorized as either urban/developed, agriculture, or forested/undeveloped.

2.3 Mt. Cuba Land Use

Mt. Cuba's land use was compiled using USGS data and downloadable shapefiles defining the different regions within Hickory Run Creek's watershed. The program breaks the land use types down further to include:

- Cultivated Crops
- Deciduous Forest
- Developed, Low Intensity
- Developed, Open Space
- Evergreen Forest
- Hay/Pasture
- Herbaceous
- Mixed Forest
- Shrub/Scrub
- Woody Wetlands

While these all represent different land use types they can generally be divided into the four categories of developed/urbanized, forested, wetland, or grassland/crop land. The map and further breakdown of Mt. Cuba's land use can be found below (Figure 2.1).

Land use throughout the Hickory Run Creek watershed as well as Mt. Cuba's grounds in general is extremely undeveloped, with very little impervious ground cover. Much of the area is heavily forested, starting with the center of the watershed and expanding to the grass and croplands which tend to ring the outer areas. There is one mass of developed area, described as developed – open space, and houses the Mt. Cuba complex and administrative grounds. These are largely the houses once occupied by the DuPont family, and now have been expanded to include storage areas and living quarters for interns or other employees and volunteers who are frequently part of the staff for extended periods of time. Lastly, a point of interest is the large hay and cultivated crop field that sits just upstream of the final observation point, which is also the site of the long-term monitoring post. One of the potential upcoming projects at the Mt. Cuba Center is to convert this back to forest and native plant growth in the upcoming years, which poses a significant research opportunity for water quality impacts. Runoff from these fields both during and after this project would flow almost uninterrupted into Hickory Run Creek directly upstream of the monitoring equipment and these impacts can be charted and analyzed for a direct look at the impact of these land use changes.

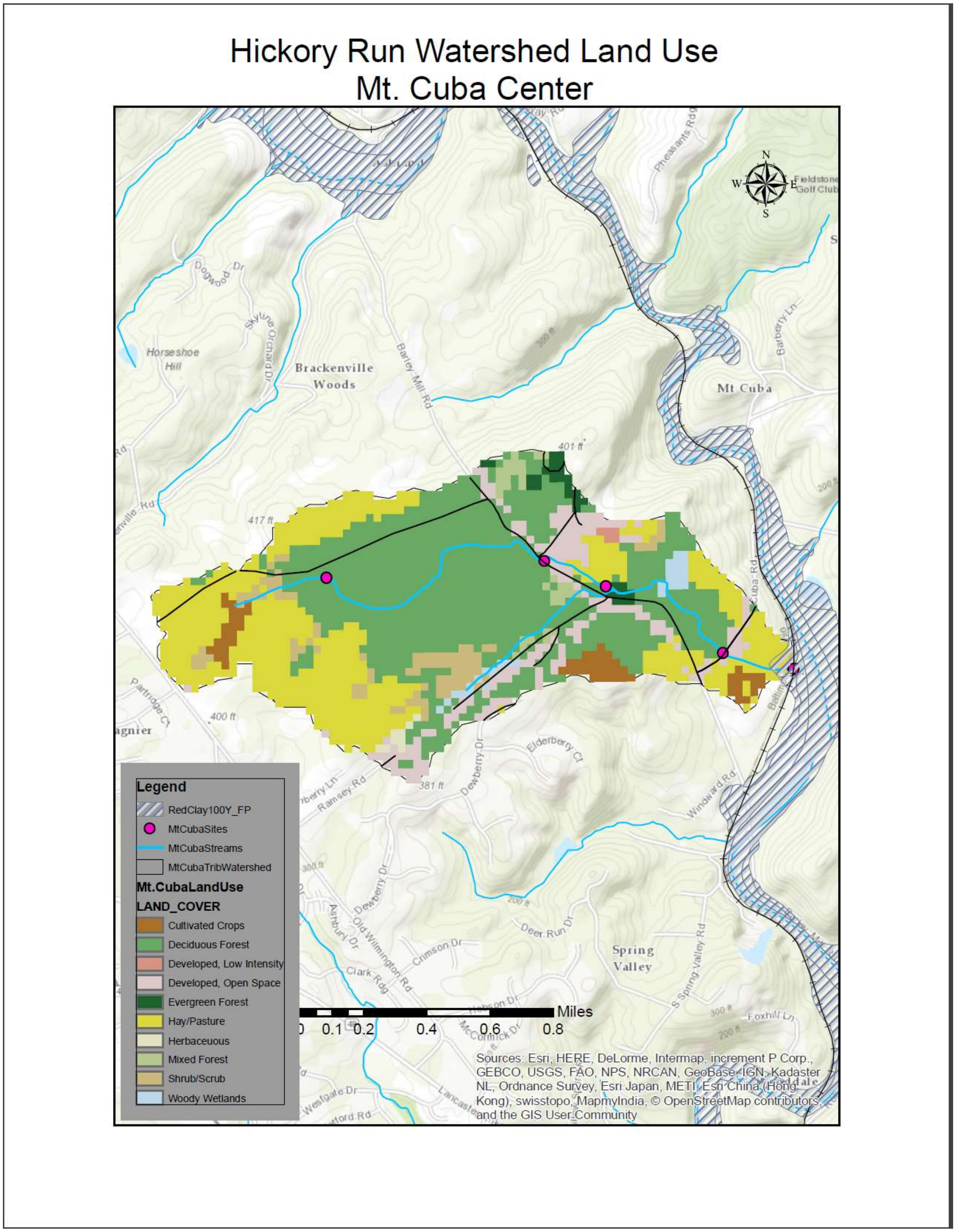

Figure 2.1 Mt. Cuba Land Use

2.4 Soil Classification

Soil classification is done under the USDA Natural Resource Conservation Service's Hydrologic Soil Groups. This divides soil types into four Hydrologic Soil Groups (HSG) which they labeled A, B, C, or D. These types are ranked by the minimum infiltration rate obtained for bare soil after prolonged wetting, which is used in determining runoff potential (U.S. Department of Agriculture 2007). These are sorted with A soils having the smallest runoff potential, and D soils with the highest. This is especially appropriate for the Mt. Cuba Center's work, as runoff is the most common avenue for potential pollutants to make their way into the water. This is also part of the TR-55 modeling system used in this project. Rate of transmission refers to the rate at which water infiltrates down into soils. These soil groups are defined below:

Group A: Sand, loamy sand, or sandy loam. "A" soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sand or gravel and have a high rate of water transmission (greater than 0.30 in/hr).

Group B: Silt loam or loam. "B" soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in/hr).

Group C: Sandy clay loam. "C" soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05-0.15 in/hr).

Group D: Clay loam, silty clay loam, sandy clay, silty clay, or clay. "D" soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr).

Using the group classifications described above, the Mt. Cuba Center has predominantly B or C type soils, with a small section of D type. This means the potential for quick runoff is in the medium range, and makes sense considering the high presence of forested land cover on the grounds. The smaller Group D region is down near the confluence with the Red Clay, and could be impacted more heavily by heavier clay particles that make their way down the Red Clay and become deposited there, or were brought down over time by Hickory Run Creek and deposited during floods in the same region (Cronshey 1986). These soil types have one of the larger effects on runoff speed and times, combined with interception from overhead leafy plants and trees. A visual representation (Figure 2.2) of these soil types can be seen below, showing the intermixing of B and C groups soils, as well as the small section of group D near the Red Clay Creek.

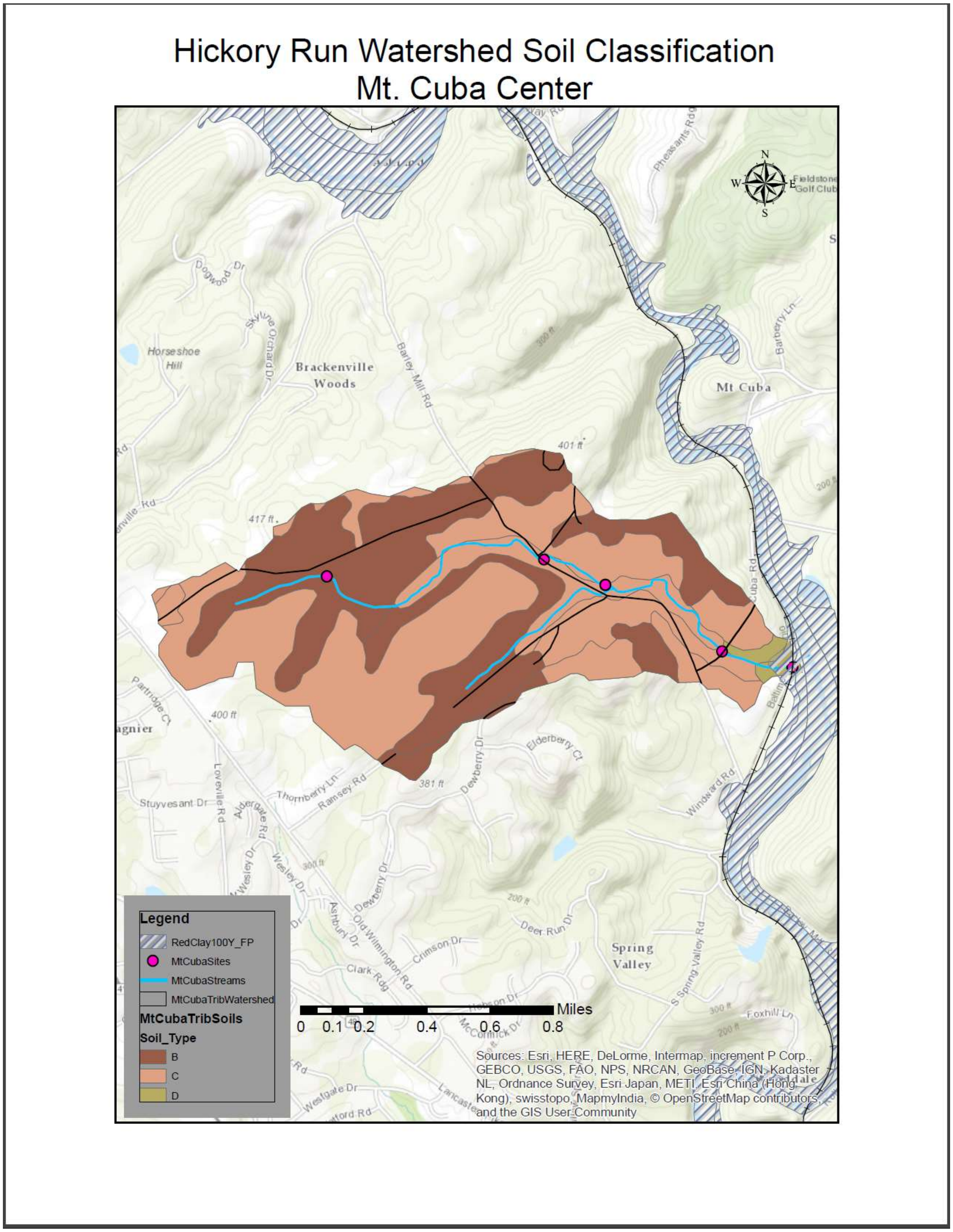

Figure 2.2 Mt. Cuba Soil Classification Map

2.5 Research

The research at the Mt. Cuba Center is focused on the role of native plants throughout the Mid-Atlantic region of the United States, more specifically how they will influence the area and their impact on the environment. They refer to their living collections, or different plant groupings, as a museum does their exhibits and visitors are able to walk through many of these gardens This includes their test gardens where research is being done which allows visitors to experience the work for themselves. This is meant to build a greater appreciation for the native species and their benefits in a hands-on, more interactive environment.

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Chapter 3

LITERATURE REVIEW

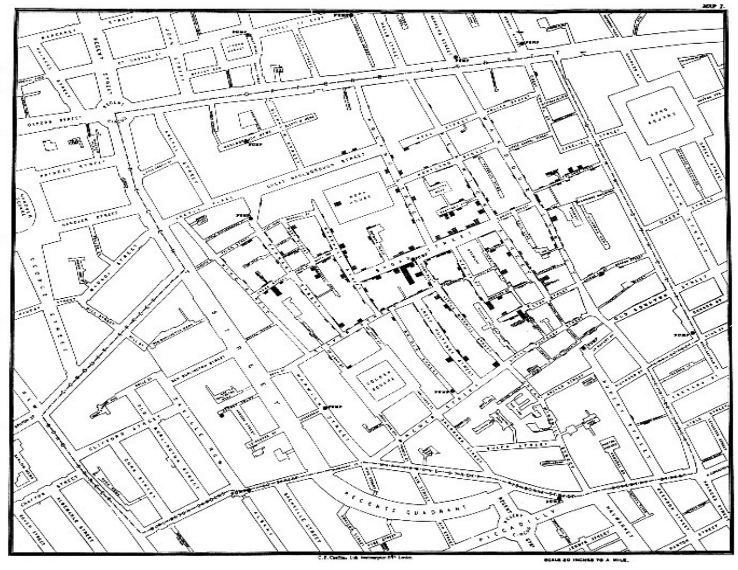
3.1 History of Water Monitoring

The history of water monitoring dates back, in a physical sense, to the Roman aqueduct systems. As one of the first truly large-scale water distribution systems there was a recognition that the availability of clean, potable water was of significant importance to a growing society. Water used to bathe in or used for waste removal was not then suitable for consumption and more pristine waters were brought in from sometimes hundreds of miles away and much further upstream. Engineers and the earliest water scientists were charged with maintaining not only the aqueducts themselves but also the cleanliness of the water they brought in, and the first form of water monitoring was born (Taylor 2012).

In a more modern sense one of the earliest examples of water monitoring was implemented to ensure water quality, and specifically to prevent the spread of disease, was John Snow's examination of the cholera outbreak throughout London during the mid-1800s. At the time, the theory of bacteria spreading disease was unknown and diseases such as cholera, or even the Black Plague, were often still attributed to "Bad Air" or other forms of transmission. Snow did not agree with this however, basing his original thought process on the fact that other environmental factors, wind, rain, etc., spread throughout regions without spreading disease and proposing that cholera must then be spread through a separate mechanism (Shiode et al. 2015).

Although Snow's instruments at the time could not directly prove a dispersal method for the cholera sickness he took samples from various water pumps throughout his area of study, including the Broad Street pump which he later famously shut off by removing the handle (Tulodziecki 2011). In addition to his samples, Snow began interviewing survivors and relatives of those killed by the disease and discovered in many cases they either got their water from the Broad Street pump, went to school/work nearby, or interacted with it in some other form. From this data and in combination with pinpointing where cases of the disease occurred Snow created what amounts to a heat map (Figure 3.1), tallying the locations and frequency at which the disease occurred. With this evidence he was able to petition the local government to disable the pump, and shortly thereafter a decline in cases began. While Snow admits that this shut-off and the decline coincided with a large exodus from the area in general, which could have also led to a decline in frequency of outbreaks, it is largely accepted that this early form of water monitoring helped reduce the spread of disease (Shiode et al. 2015). If this disease can be equated to a pollutant this example shows a strong case for one of the earliest successful examples of water quality monitoring, the goals of which hold fairly similar to the overall objective of ensuring clean water to the public today.

Figure 3.1 John Snow's 1854 Map of Cholera Outbreak and Water Pump Location (Snow 1854)



While John Snow's goal of remediating a deadly outbreak of disease essentially underlines the overall goal of all water monitoring, efforts to obtain specific water data largely began around the turn of the 19th century with the National Weather Bureau's (NWB) attempts to begin recording temperature and precipitation data. While there are many accounts of small scale operations before this, the NWB initiative was larger scale and operated on a nationwide basis. It ran on volunteers and has expanded to this day with 11,500 out of 11,800 weather stations still being volunteer run. (Firehock and West 1995).

In addition to government efforts, smaller goal or interest-driven groups were formed earlier in the 20th century and largely focused around ensuring continued fishing levels or visual water inspections. The Izaak Walton League of America was founded in 1922 as a means to begin compiling information on water chemistry and pollution and protecting the lands that surround this country's waterways. They were successful from the early stages, creating the designation of the Upper Mississippi Fish and Wildlife Refuge in 1924, and launching their first water survey initiative in 1926. The results of this survey of water chemistry findings and pollution levels was then given to the government, businesses, as well as other interest groups in an effort to raise public awareness of related issues (Firehock and West 1995).

The League, as it is often referred to now, has expanded significantly since its inception nearly a hundred years ago, but its goals have not. Its mission statement now includes a larger variety of environmental pollution and reads: “To conserve, restore, and promote the sustainable use and enjoyment of our natural resources, including soil, air, woods, waters, and wildlife” (Izaak Walton League 2018). Membership is nationwide, including a reported 43,000 members and 240 community-based chapters, largely appealing to outdoor enthusiasts and environmentalists who share a common interest in the sustainable use of the nation’s natural resources (Izaak Walton League 2018).

In another example of historical water monitoring moving toward a more modern application there was a long-held tradition in Europe of hiring a Riverkeeper or someone entrusted to watch over the health of waterways used mostly for fishing and as sources of freshwater. This tradition was adopted in the USA throughout the 20th century and earlier with one of the best organized examples in New York on the Hudson River. The Riverkeeper organization began as the Hudson River Fishermen’s Association (HRFA) in 1966 and was built out of a group of concerned fishermen along the Hudson River. Their goal was not direct water monitoring but to create an organization that would act as an advocate for the river, whose health they saw clearly beginning to decline (Riverkeeper 2017). As it expanded and more parties joined the cause, in 1986 the organization changed its name to simply Riverkeeper.

The Riverkeeper organization, and its predecessor HRFA, was the first organization to use the Rivers and Harbors Act of 1888 and the Refuse Act of 1899 to begin pinpointing polluters along the Hudson and forcing them to pay for remediation of the damage they had done (U.S. EPA 1972). Additionally, they used the little-known laws to collect bounties on finding these polluters and used the incoming funds to expand their reach (Riverkeeper 2017). They eventually purchased a boat and infrastructure to physically travel the Hudson attempting to identify unpermitted polluters and joined with other local activist efforts to have an electrical generation plant's construction halted and eventually removed (Riverkeeper 2017).

While all of these different efforts were not founded with the direct purpose of monitoring water quality, they give strong examples of the origin of water quality monitoring. In many cases monitoring programs are established to answer a set of specific questions, and the data accumulated is designed to do just that. It is often later, when this data is looked at under different circumstances or a more expansive view of water monitoring as a whole, that the true value of large quantities of data, accumulated over an extensive timeframe, is truly realized.

These examples come out of regionally-based efforts often to simply protect local waterways and while their goal was not to accumulate data for future use or analysis, they have often done just that. Where reliable data exists from previous efforts, especially dating back decades if not a century or more, comparative analysis can be made against current findings and these changes can then be analyzed to help better understand the effects inputs such as pollution, climate change, or change over time are having on a region. These types of analysis can also then be put into modeling programs to help not only predict future outcomes if a variety of actions are taken but help inform future action. The more real-world data that can be used to calibrate and validate the model, the more reliable the model output scenarios.

3.2 Current Monitoring Strategies

Where there are many considerations behind the why, when, and who and the how question in water monitoring largely depends on the organization involved, the goals of the project, and the type of water quality parameter and body of water involved. The EPA and USGS, two of the largest government organizations that handle water monitoring, have released in depth documentation on how water monitoring can be undertaken. Even within the EPA, however, there are three distinct manuals for handling streams, estuaries, and lakes. This discussion will focus on stream monitoring as the efforts at the Mt. Cuba Center focus on a flowing stream at all points except the headwaters. These could be considered a small lake, although its size in relation to the stream help justify using the stream classification.

EPA Stream Monitoring: A Methods Manual is an extensive document focused on all aspects of establishing and undertaking stream-based water quality monitoring (U.S. EPA 2017). It begins with a general understanding of the motives behind the efforts and explains the concept of a watershed, focusing on how water inputs can come from all parts of said watershed. This is especially important when the motives behind the study are to establish the impact of efforts on land. To help guide the development of a stream monitoring program, the report outlines a set of 10 questions which they recommend will help get the program started toward useful data collection. Those questions are summarized as follows, with brief descriptions of how the EPA suggests answering them, as well as how they apply to the Mt. Cuba project.

Monitoring: The first question raised within this manual is potentially the most basic: Why is the monitoring taking place? The EPA lists common reasons such as developing baseline levels, looking for water quality changes over time, or searching for water quality problems potentially associated with decision making for the water body itself.

In the case of Mt. Cuba, monitoring is taking place for a combination of the reasons listed above. The original round of research dealt with developing baseline levels, and a basic version of looking for water quality changes over time. Once the permanent equipment is installed, motivation will move to looking for water quality changes over time. With the availability of continuous 15-minute data, changes will become more apparent, and it will be possible to distinguish between long-term changes and simply outlier readings. Additionally, data will be comparable to nearby stream readings and monitoring stations and will record during large storm events which would otherwise have been unattainable by grab sampling.

Audience: The second question continues the trend of firmly establishing the basic motivations behind research by asking: Who will use the monitoring data? The EPA's common uses for water monitoring data include governmental analysts of all levels, the monitoring organizations themselves, universities or other research organizations, and the general public.

The data at the Mt. Cuba Center will likely be used in various ways for multiple audiences. The first is for dissemination through the Mt. Cuba Center to the public as part of their classes, tours, or outreach programs. This data will also be available to the University of Delaware and likely to any other research organizations or universities the Mt. Cuba Center deems appropriate. This is why data received will be transferred to Microsoft Excel after it is retrieved from the field, where it comes in the form of proprietary software both from the IQ system as well as the Campbell Scientific turbidity probe. Such data are useless for widespread dissemination unless available in a nonproprietary format. In an effort to create useful data, a working Excel file will hold retrieved data and results can therefore be published and disseminated in a much more commonly available format.

Data Usage: In addition to who will receive data, the EPA suggests the plans for said data are equally important by asking: How will the data be used? Data in general is recognized as being useful in a myriad of situations, the purpose largely dependent on the type of data, location, and audience. Top uses included scientific study/research, government water quality assessments or decision-making evidence, or as persuasion in making a decision for business or other uses.

In the case of the Mt. Cuba Center the largest use of the data will be for research purposes. The Center has a long history of sponsoring and funding individual research projects, the process and results of which are often available either on their website or on-site. If the data proves to be useful it will also likely be sent back to Universities or other research groups and could be used in a decision-making process regarding future water quality issues.

Parameters: Moving beyond the motivation behind the research, a more practical question is asked next: What parameters or conditions will be monitored? The choice of which parameters to monitor comes back to the question of the purpose behind the study. The why will have the biggest impact on the what in this case, as objectives can greatly alter the types of data needed. The EPA brings up the examples of identifying if a water body is adequate for swimming and the need for human-health related parameter monitoring such as fecal coliform bacteria or others which may directly impact humans. They also touch on whether fishability is a target question, or if a sport fishing hole is in the area. If so, dissolved oxygen, temperature, or the availability of food sources for fish should be the target parameters.

In the case of Hickory Run Creek at the Mt. Cuba Center, the goal of the study is largely to establish baseline health characteristics for the water and then begin longer-term testing to establish the impact of restorative efforts. Discharge and turbidity were chosen as strong indicators of change as they can most clearly show the effect different size storms can have, as well as the amount of total sediment moved by the incoming waters. Additionally, these two parameters are commonly measured by surrounding gages and therefore these readings will create comparable data not only to itself over time but to the larger region as a whole.

After establishing what will be measured the question of how detailed the study needs to be is raised, through: How good does the monitoring data need to be? The EPA proposes that the quality of data needs to be higher in the case of decision-making processes or in much of the research field, but if the purpose of the study is more for "overall educational aspects of stream monitoring" then it is often less important. Data quality is said to be measured in five ways, which will be examined below: Accuracy, Precision, Completeness, Representativeness, and Comparability.

In the terms of the Mt. Cuba Center project, the original set of data collected as spot sampling and cross-section/habitat assessment left a lot to interpretation and human error. While the sampling readings themselves were done by instrument, they were done on a weekly basis largely regardless of weather or recent precipitation, and being done by hand, again, had room for human error. Future data will be done by the same device, in the same spot, on a repeating basis, and given that discharge will be measured the effect of storms can be brought into the equation. This will result in much higher quality data. The quality of the Mt. Cuba Center data in the five terms from the EPA are broken down as follows.

Accuracy: The accuracy of data in this case relies heavily on the instrument being used. They have both been extensively tested and literature is available to reinforce their accuracy, as well as recalibration available if readings begin to drift. As readings will be taken from the same instrument over a long period of time, this also increases accuracy as they are directly comparable.

Precision: Precision is related more closely to the ability to reproduce the same result on the same sample. In the case of Mt. Cuba this could be proven by grab sampling the same area at the same time the equipment is taking readings, and in the beginning this will be done to ensure accurate measurements. This will happen less as times goes on, however, as the equipment is designed to be free-standing and eliminate the need for repeated visits to the testing site.

Representativeness: Similar to previous descriptors of data quality the representativeness will come once equipment is installed and up and running. There will be only one site (for the first installation at least) and while it cannot be directly representative of every spot in the stream, it is roughly 500-600 ft upstream of its confluence with the Red Clay and downstream of the vast majority of restoration work. The site was chosen largely for its accessibility while still being secluded enough to hopefully ensure the equipment's safety, but it also will get a better end result of any work upstream.

Completeness: This is often measured as the amount of data actually recorded vs. the amount expected in the original design as the EPA manual is designed for volunteer monitoring which will result in days where volunteers cannot, or do not, sample. This can also include setting standards for when data should be taken, or a minimum time between measurements even during dry periods. With the equipment staying in stream the only missed data should come from technical flaws or times when it is removed for data retrieval, cleaning, or charging.

Comparability: The parameters chosen for the Mt. Cuba Center project took into account local USGS gages and their most common parameters, with the goal that data retrieved could be easily compared to surrounding sites. While the equipment will be different the data should be largely comparable and therefore applicable to regional decisions or trends.

Methodology: From these previous questions, real decisions as to how the research should be physically conducted can begin. The first is to decide the methodology to be used, asking: Which methods should be used? The decision of which methods should be used in water sampling should be most heavily influenced by the eventual purpose of the data, as well as the quality of the data required, according to the EPA. The considerations include all types of inputs - from on-site vs. grab sampling, monitoring methodology and protocols vs. instrument-based monitoring, and the types of identification equipment used at the monitoring site.

For the Mt. Cuba Center project, a lot of methodology decision making was guided by budgetary questions and need. It was decided early on that instrument measurement would be the desired route, as the goal of the study is to establish long-term monitoring sites which would be capable of acting stand-alone well beyond the immediate future. Additionally, the cost of continued grab sampling and lab analysis would eventually dwarf the up -front cost of equipment purchase, and therefore it was decided that in-water monitoring devices would be used. There is a large amount of equipment available for these types of measurements, and therefore instruments with appropriate ranges for measuring low flow streams could be selected.

Site Location: The next question may go hand-in-hand with the methodology selection, as site specifics may influence equipment choice and vice-versa. The EPA manual addresses site selection with the question: Where are the monitoring sites? This question can be answered in many different ways or through different approaches, although in many cases real-world needs for secure, accessible monitoring sites often trump other considerations. Site location should also take into account other groups that may be monitoring the water body, representativeness of the entire watershed, and landowner permission. Lastly, the question of whether there are enough monitoring sites to adequately collect research should be handled as a derivative of the research question and goals, and will vary based on the types of inputs and how extensive the testing criteria is.

For the Mt. Cuba Center project, the monitoring site decision came down to accessibility, security, and representativeness. The majority of Hickory Run Creek is heavily forested, and for many sections surrounded by thick rose bush and other thorny plant species. To make data retrieval and maintenance realistic, a site had to be chosen where access was not out of the question. The railroad crossing where equipment is to be installed is also downstream and nearing the creek's confluence with the Red Clay Creek, and while this may be physically closer to some restoration projects than others, it will hopefully equally monitor all efforts, as they are planned throughout the 500 acres of the Mt. Cuba Center's lands. Lastly, another bridge site was originally suggested slightly further upstream but is under a larger road and has signs of graffiti and reportedly higher human traffic. Due to the cost and obvious nature of the installed equipment, it was decided to use the railroad bridge site which is far more secluded from normal everyday traffic.

Timing: Another consideration is timing, with timing referring to a variety of parameters, and asked through: When will monitoring occur? The EPA approaches this through time of day, time of the year, and frequency of sampling. The time of day is most appropriate when ensuring that parameters such as dissolved oxygen and temperature are handled under similar conditions. The time of year becomes one of the largest concerns when research goals or targets surround seasonal activities, such as swimming or with fishing patterns. Frequency of sampling could have an effect in extreme situations where depletion of macroinvertebrate or other species could be in question from over sampling, but more often this relates to ensuring that storm events are adequately monitored.

The Mt. Cuba Center monitoring effort will largely go around this question, and monitor on a consistent basis. The equipment is sensitive to extreme colds (and extreme heat, but well beyond expected temperature ranges at the site), and therefore monitoring will be undertaken throughout roughly three of the four seasons, and only require removal during periods of freezing risk.

Presentation: Moving from establishing the study, questions about data presentation begin with: How will monitoring data be arranged and presented? EPA begins by underlining the need for program coordinators to have a clear plan and objective before starting any monitoring project as these plans will be the clearest path to correctly disseminating data. Field and lab work should be double checked, and a database should be developed to store and organize all data in a cohesive, fluent manner. The EPA also recommends having any volunteer groups check with program coordinators before engaging in data management or manipulation, as specific steps may be required by agencies or funding groups.

For the Mt. Cuba Center project, data will be originally collected via in-house software which comes with the monitoring equipment, then moved into an Excel file designed to organize and store the data over a longer time period. This allows for the Mt. Cuba Center to decide what to do with their eventual mass of information, and averages over various spans of time will be available. The Mt. Cuba Center will then have the options of giving that data to whoever they choose or even to the general public in a way that is clear and concise.

Credibility: The final question from the EPA manual is in some terms a summary question, ensuring that viable answers to previous considerations are available and that the study becomes useful once completed. The EPA addresses this as: How will the program ensure that data are credible? The best way in which data are considered credible is by effectively addressing the questions above, and keeping open methodology and storage notes. Proper training for everyone involved in the project ensures tasks are completed correctly, and continual evaluation of where a program is and then correcting any flaws keeps the project running in its most efficient manner. As noted above properly documented methodology for all steps in the process, including data storage and management, are also key to ensuring data is handled correctly and that anyone using the data can clearly follow the steps by which it has been handled.

For the Mt. Cuba Center project, the beginning steps involved research, continual updating of planning, and some trial and error. These steps were documented to present a useful final product, however, and have led to step-by-step methodology for future repetition. Due to the monitoring station's long-term goals these steps will be delivered to an intern at the Mt. Cuba Center who will be responsible for collecting data throughout the year and removing/reinstalling instrumentation over the winter months.

While the range of applicability makes the EPA the most useful resource in planning a water quality monitoring site there are a plethora of scholarly articles and peer-reviewed literature on the topic, all of which offer valid options and opinions on how water monitoring should be undertaken. Many focus on specific aspects, although most adhere to the importance of a general outline similar to the one the EPA manual describes (Gangopadhyay et al. 2001, Telci et al. 2009, Madrid and Zayas 2007). For example, in their paper on determining where to most effectively monitor a series of wells through what they call Principal Component Analysis describe the key points in monitoring network design as, "To define the objectives; to select the spatial location of monitoring wells; and to ascertain the sampling frequency." These steps nearly mirror the EPA's approach, reaffirming its thoroughness.

The authors then go on to describe an idea that may help in choosing where to monitor many sources of water quality, especially if there are multiple end points or many avenues of flow. This principal component analysis applies to a situation where it is deemed cost-effective to monitor one of these avenues as a representative of the water body as a whole, and their procedure describes how to choose which of these avenues should be the final location. Their specific research is aimed at ground water levels, a water quantity evaluation, but as they acknowledge this type of monitoring involves many of the same considerations as water quality analysis. While this type of analysis does not pertain specifically to single-stream monitoring it is a concept that can be applied to streams whose access points may come from smaller branches looking to monitor a larger upstream region. Their findings represent a mathematical formula for choosing which of these downstream regions best quantifies a larger area (Gangopadhyay et al. 2001).

In similar approaches, researchers use different methods to determine where to monitor a river system when multiple sites are to be implemented. Even in these sites authors acknowledge general guidelines which appear similar to those of the EPA manual, and bring up issues such as placement, frequency, and parameters determined by early goal setting (Telci et al. 2009). To approach a multi-location monitoring system, however, contaminant transport and fate are considered more heavily. Systems on this scale can increase in size to cover entire states, as Telci et al. (2009) describe in their efforts to adequately monitor the Altamaha River network in Georgia, USA.

Other writings touch on aspects of water quality not directly aimed at freshwater stream monitoring, but whose conclusions can be applied to justify the types of work done in smaller streams and freshwater bodies. For example, the need for on-site, in-stream monitoring is highlighted by Gamayunov et al. (2001) in their paper on ocean monitoring using a submersible monitoring system, wherein they describe the flaws found from satellite monitoring for any water body except deep oceans. While satellite imagery has advanced to the point where large amounts of ground information can be derived from vast distances, in shallower waters there is often so much turbidity or other coloration that satellites or other out of water measuring instruments are insufficient. Their research focuses on chlorophyll readings, but the same can be said for discharge and turbidity readings that may be attempted from out of water, non on-site methods. In areas such as the Mt. Cuba Center the land is too heavily forested to rely on any method that is not directly in the water itself and therefore to ensure quality readings in-situ fixtures must be used.

There are multiple options for on-site monitoring, however, as not all equipment works on the same principles. Sampling systems are generally divided into three categories, in-situ, on-line, or off-line (Greenwood et al. 2006). In-situ monitoring implements a permanent, in-water system which measure the water directly, similar to the IQ and turbidity sensors implemented in Hickory Run Creek. They often rely on a nearby power source, and either store data locally or transmit through a cellular system. On-line systems sample water automatically but pull it to an out of water portable lab or other device that remains nearby, again with a standalone power source. These options allow for some pretreatment where necessary, or in complex setups allow for other chemicals to be added for more complex measurements. Results, again, are stored either locally or transmitted for further analysis. The third option, off-line monitoring, represents devices that sample periodically but can still be considered on-site monitoring if the sampling is automated, and samples are stored near the monitoring site to be collected later. These are then moved either to a nearby mobile lab, or in some cases collected and brought back to a larger lab for more in-depth testing. These three options are represented in the diagram (Figure 3.1).

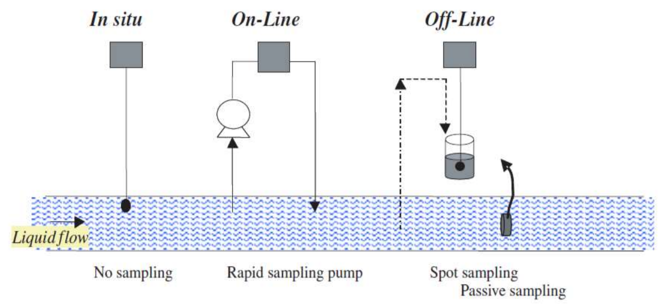


Figure 1. The main approaches to water monitoring.

Figure 3.2 Types of Water Monitoring (Greenwood et al. 2006)

Part of the decision-making process surrounding what type of monitoring to implement depends on the parameter in question, as that may determine whether in-situ, on-line, or off-line sampling is appropriate. As technology increases more and more parameters can be measured in-stream or in-situ, which is preferable for the simple fact that it eliminates storing and removing water, a phase during which errors or contamination may occur (Madrid and Zayas 2007). In-situ equipment is also often less complicated or self-contained which reduces the number of places where malfunction can occur. Many newer sensor types now rely on optical or electrical detection principles as well, reducing the need for added chemicals. While more expensive in some cases these reduce the need to keep other chemicals on-site, as well as eliminate the need to mix chemicals and then take readings, one more area in which mixing may not be exact every sample or part of the process could break down (Pellerin et al. 2016).

The parameters to be tested should stem from the goals of the study, going back to the very first steps of the EPA's monitoring guide. That is not to say the original plans for a study need to be extraordinarily rigid, however, as goals should be written to determine some measure of health or answer a question, and plans should be drawn with enough flexibility to adapt to changing needs as they arise. Successful plans will have a reevaluation step inherently built-in, during which new monitoring needs can be addressed (Davies-Colley et al. 2011). As shown using New Zealand's national water quality monitoring program as an example, successful implementation requires thorough documented steps to be followed so that changes can be made as well as justified as different groups take charge over time, or interests become involved who may question expenditures and efforts. Even in smaller-scale efforts the cost of equipment and labor may be acceptable to one group but questioned further down the line as jobs and employees change hands. Justification for monitoring is considerably easier if goals are outlined and methods are thoroughly explained. Additionally, just as emphasis must be placed on clear arguments for collecting data, the types of data collected are becoming more important and longer-term data sets are quickly becoming a necessity across all avenues of water quality research.

3.3 Long-Term Data Sets

With ever increasing impacts from climate change becoming apparent it is clear that the need for information, for reliable data, to build a foundation for future decision making is paramount. From this need the way in which this data is acquired, and the type of data, becomes all the more important. Inefficient or inadequate sample sizes can lead to a lack of information or data that describes a situation far from the reality. As the patterns and effects emerge which describe the new normal this information has to be persuasive not only in its findings, but also upon further scrutiny from peer evaluation.

A theme in the changes climate change has created is that stationarity, or the idea that what was once known about environmental systems and climatic event occurrences would hold throughout time, may not be as steadfast as once thought. When asked why long-term data sets are important, Burt et al. (2014) summarize the situation as follows: "For much of the 20th century, there was an expectation that many environmental systems (climatic, hydrological, ecological, geomorphological) has some characteristic average long-term state about which there would be small fluctuations but for which statistical stationarity could be assumed". They continue to explain that recently this idea is fading, replaced with an awareness to the possibility that change in global systems, either as a driver or independently of climate change, could be the result of land use and land management. Long-term data sets, they conclude, allow for identification of changes in the condition of environmental systems and the evaluation of the drivers for these changes.

"Stationarity is dead" (Betancourt 2008). This idea of previously predictable environmental patterns and cause/effect relationships holding to their past patterns is being upended by environmental change, and the effects that climate change in general is having, and may continue to have, on environmental interaction. As research continues to meet evolving needs in the water community its goals are beginning to shift from how anthropogenic drivers have altered natural systems to how restorative and conservative efforts will again affect these same systems. Many large research agencies are meeting this need for increased information by calling for longer-term data sets as well as decision-making and model creation that can take into account these newer, more robust amounts of information.

The beginning of long-term data acquisition began largely unintentionally with monitoring systems designed to test for drinking water quality and serve as early warning of contamination or otherwise unhealthy conditions (Burt et al. 2014). In 1854 John Snow traced the source of a cholera outbreak to a public water pump, serving as one of the earliest examples of need-based water monitoring. The continued measurements that followed, however, started to create a wealth of information that could, over an extended period of time, show trends that spot-checking or more time restricted research initiatives could not. Many environmental changes happen over geological time scales and therefore to see their true impacts data must be able to conclusively show that changes are not due to local conditions, but a larger scale driver.

The key to creating an adaptable situation which is capable of addressing current needs as well as yet unforeseen problems lies in creating a base of knowledge thorough enough to approach problems from multiple avenues. This wealth of information comes from adapting our research in two main ways: (1) moving to creating long-term data sets that incorporate information across large enough timescales that environmental change and adaptation can be observed, and not simply localized conditional responses and (2) the ways in which we develop and implement the studies that create this data must incorporate wide enough goals to account for flexibility of future uses (Davies-Colley et al. 2011).

By shifting the goals behind water monitoring design to incorporate both longer term data as well as a more encompassing area of information it becomes possible to be ready to address future problems as they arise.

To return to the idea of stationarity, Milly et al. discuss how being able to give an event or variable a probability of occurring with some degree of accurateness over a reasonable time scale, is shown to be falling by the wayside (Milly et al. 2008). For example, a 100-year storm gives a 1% chance in a given year of a said sized storm occurring. However, in recent decades these storms have been occurring more frequently and a correlation is strengthening between these storms and the perceived anthropogenic drivers of climate change (CO2 release, GHG emissions, etc.). While stationarity is not meant to be predictive on a small time-scale, even as its predictive strength breaks down as the time in question shrinks, the trend toward larger storms can be considered a separation from the predicted norm (Miley et al. 2008).

Stationarity itself gives a probability density function, or a percentage over time, chance for storm occurrences and does not say it is impossible for multiple large storms to hit within a certain time frame. As recorded data is expanded temporally, however, the argument is strengthened that these qualifications and predictions simply are not holding. This in turn gives another call for long-term data sets as only extended periods of observation can truly be relied on to either bolster the idea of storm predictions, or prove that there is some input not being taken into account - in this case the likely culprit being climate change.

The argument for expanded long-term data sets goes beyond uncertainty, however, and its support has been outlined through several points. In a 2014 article supporting this shift in research goals, Burt et al. (2014) break these down into six individual points. The first parallels some of the above ideas wherein environmental trends, cycles, or even infrequent events require longer time periods to be properly identified. The changes or processes associated with these ideas are often slow to emerge and require longer research (the authors cite >10 years) as necessary to differentiate between hydroclimatic variability and true, deeper, running change.

In the case of climate change, these time scale necessities are clear throughout published literature. Water-based publications more commonly focus on ideas such as "...may alter riparian habitats substantially in coming decades," referring to the notion that change of some sort has already begun and is expected to continue (Perry 2015). The Intergovernmental Panel on Climate Change, or IPCC, (International 2014) actually goes beyond this, giving its models and predictions through a century after publication in an effort to convey the potential thoroughness of the coming effects. These largely depend on the level of change to anthropogenic drivers (International 2014). At the very least, the IPCC's near-term predictions" are based on decadal modeling and project almost unanimously through the year 2100 (International 2014). If the goal of securing water resources for future generations is to be accomplished, then actions must be taken that are designed to fit these time frames, and not simply to address very immediate needs. To do this, longer modeling capabilities must be accomplished.

The second argument deals with longer-term data's ability to help put the findings of smaller scale research into context. As one of the largest inhibitors of longer term research is funding, it makes sense that a large proportion of projects continue until statistically significant results are reasonably expected to be found, or enough data is collected to achieve this, then they are shut down. Furthermore, a vast quantity of these projects are academic graduate level research, which often runs for approximately 2 years for a master's degree, or approximately 4-5 years for a doctoral study. Working within these societal frameworks, shorter term projects seem likely to continue, and applying their findings, which are extremely useful, can provide great insights into needed areas of research.

One of the strengths of having long-term data in this area lies in its ability to help put shorter term data, of which there is vast amounts, into the appropriate context. It becomes extremely valuable to be able to take an observed long-term variation and then zoom in on an area in particular to obtain more detailed observations.   As individual situations arise the combination of shorter-term data within the context of longer term observations allows for finding solutions that are not only immediately helpful but their effects over time are more likely to be impactful.

In a similar fashion Burt et al. (2014) third point brings up the infrequency with which rare events occur. Therefore, finding evidence, or better yet recordings, of these rare events often requires running measurements that are continuously (or on a set timer) recording. Long-term data sets are very often most effectively found through in situ monitoring, which allows for measurements before, during, and after rare events as they are occurring. This data can then be directly related to the observed after effects and effective plans of action can be constructed.

In a more real world consideration, physically getting to testing sites during these rare events is often problematic as the events tend to signify large storms or even catastrophic precipitation. For example, a common area where more research is needed is defining 100-year storms, as their occurrence is shown becoming more frequent with climate change. Traveling to testing sites to take grab samples during a storm of this magnitude would be difficult to nearly impossible due to the potential size of the storm.

Another benefit when continuous, long-term data sets are available is that it becomes possible to test previously undreamt of theories or hypotheses. Especially under the influence of climate change the issues or problems that future generations will face likely do not exist today, or at the very least are not considered severe enough to warrant heavy research and therefore are not being directly monitored. If thorough data is collected now the answers to these future hurdles may be later found in the same data.

The methods that will likely be involved in solving these issues, whether current or yet unforeseen, will almost undoubtedly use modeling in some manner - this is the author's fifth point. To more accurately model the existing world, and therefore extrapolate how decision and future actions will affect this same world, these models need the most up to date information and data possible. This is especially important at benchmark sites which could have long data histories already, or sites that are unique or specific to the types of areas in question.

The sixth point brought forward by the authors here is that monitoring, "is an essential way of discovering whether there are significant undesirable changes taking place in the natural environment" (Burt et al. 2014). While this seems obvious on the surface, its meaning can be taken further and argued that as decisions are made, especially those aimed at conserving or restoring environmental systems, the likely effects of these efforts should be examined. Some work today still goes under the pretense that reverting back to a natural state will always be beneficial, but this could be ignoring the fact that changes have already occurred, and this natural state may have changed from its previous definition. Also, decisions will likely have to be made as to whether the desired outcome is an environment devoid of anthropogenic impacts or one that will allow humans to continue their way of life as best as possible, while still allowing for natural conditions where possible. This brings environmental ethics into question and while the answers may not be entirely scientific, sound and reliable data will be needed to justify any conclusions that are drawn.

Moving through the end of the monitoring process, the question of how to deal with data, especially these massive quantities, is arguably one of the most important considerations. Without proper presentation the information becomes essentially useless to the consumer, in this case referring to decision makers or whoever else will make use of it. On the other hand, data that has been too heavily manipulated may spell a misleading story, leading to decisions which have counter-productive outcomes.

Many of the more useful tools are also the simplest, stemming from basic statistical analysis – mean, median, and range calculations. A 15-minute interval monitoring station records 96 entries/day, a number far too large to look at and compare to other days on any type of scale. A daily average, however, is one number which can be directly compared, graphed, or otherwise used to show significance and long-term trends.

For displaying the results, themselves, Boyer et al. have a useful approach that breaks up possibilities into 1-dimension, 2-dimension, and 3-dimension displays. The first 1-dimensional approach includes statistical description approaches, they mention box-and-whisker plots, 1-line graphs, or other direct number comparisons. These will be the most common tool used for Mt. Cuba in describing baseline and current conditions, as they can accurately display information visually that represent a wide area. Two-dimensional displays include maps and topographical displays, such as the ones created to show conditions at the Mt. Cuba Center. Time-series graphs are also considered 2-dimensional by Boyer et al., as time itself is used as a dimension here. These will be the best tool for showing change over time due to native plant restorative work as proving this influence will require time as a factor. Three-dimensional visualizations will not be used at this time for the Mt. Cuba Center as they involve showing change through time, often via modeling, and the modeling done for the Mt. Cuba Center is most effective in a comparative sense as opposed to a visual one.

3.4 Invasive Species

Research is beginning to emerge about the effects of invasive or non-native species on their environment and, although rarer, on water quality and quantity. Much of this is focused on invasive animal species that have begun pushing out native varieties but similar threats may exist where botanical species are concerned. McCormick et al. (2010) looked into the effects nonindigenous species can have on water quality and quantity, especially from a monetary point of view. They place this figure at over $178 billion annually with the highest amounts coming from agriculture and then sectors such as tourism, fisheries, and water supply (McCormick et al. 2010). This alone proves the need for studies such as this one being undertaken at the Mt. Cuba Center, as by better understanding the interactions between invasive plants and water quality it may become possible to make informed decisions with regards to removing/replacing invasive species to improve drinking water intake quality, or leaving them as they are.

The report also brings up interesting points with regards to how the questions surrounding invasive plants in general can be addressed. They pose the following questions, presented here as together they form a train of thought especially pertinent to how data on invasive species and water quality combined can be put to use ensuring future water availability (McCormick et al. 2010):

- What will we require our riparian water resources to produce in the coming decades?
- What are the major goods, services, and values that may be disrupted by invasive species?
- How will invasive species affect water resources and what are the associated socioeconomic effects?

- What are our future management, policy, and societal needs to mitigate or adapt to the effects of invasive species as they alter the ability of aquatic ecosystems to provide these goods, services, and values?
- How can research provide management systems and strategies for interactions between invasive species and water resources to optimize continued future production of these goods and services?
- What are the effects on native species biodiversity, and the noneconomic societal values for maintaining that biodiversity?

While broad in stature the questions approach the idea of water availability and invasive species from an anthropogenic utilitarian viewpoint and then begin to look at the ethical questions that may very well become necessary to tackle. As the climate is altered on a local and even global basis water demand will continue to rise as traditional supplies begin to at the very least change from climatic drivers, and in many cases likely begin to dwindle. As water levels are still high in places such as the Eastern United States morality now often plays a driver in moving back toward a more natural or non-human-influenced state. This is especially true with invasive species, as they very often arrive via human travel or expansion.

As water demand rises and resources become scarcer, however, this morality may begin to shift toward being anthropogenically focused as survival dictates. If significant data emerges that some invasive species filter contaminants more efficiently than their native counterparts their implementation may become necessary, if not desired, simply to keep costs of providing clean, potable water down. This is a discussion that will require reliable long-term data from efforts such as the one being undertaken at the Mt. Cuba Center, as any solution will need to be thoroughly justified.

The last source of in-depth information on invasive species comes from government resources, the EPA and their associated Aquatic Nuisance Species group (Aquatic 2017). Similar to other sources of information this focuses primarily on animal invasive species but does seem to be expanding their database of invasive plant species. The ANS reconfirms the most common pathways invasive species are spread is through human means, namely shipping/ballast water, or for plants specifically being utilized for "habitat restoration or erosion control efforts" (Aquatic 2017). This confirms that there has been use of invasive species to begin purposefully altering habitats toward anthropogenic-centered needs, which again goes back to the question of whether they may be better suited for necessary uses in some areas.

Additionally, the ANST divides the potential adverse impacts of aquatic invasive species into 3 categories – environmental effects, economic impacts, and public health. Within each of these are listed the top threats, and within all three many of these threats can be linked directly to invasive plants' effect on local water quality. The site serves as a portal for research into these areas but their main objective is clearly stopping the spread of invasive species and is centered on the most effective means of categorizing where this has already occurred, and stopping it where possible. They also link to other like-minded groups such as the University of Florida's Center for Aquatic and Invasive Plants. While these are aimed at understanding and stopping the spread of harmful invasive plants, there is a lack of data about the direct effects that invasive species have on water quality vs. native plants.

Throughout all of these sources it is clear that information exists surrounding, in a sense, the core question of how invasive plants may alter water quality but little direct research has been done to address this question. The mission statements of many botanical gardens lead to them likely benefitting from this type of knowledge, and many have the controlled circumstances needed to conduct such studies. Additionally, the beginning of research into this area, as well as plans on how to potentially address issues related to water quality, show that water quality issues are starting to emerge as likely candidates for increased study as the need for continued clean, usable water continues to rise. Lastly there is a growing library of research on invasive species and their impact on ecosystems and habitats but a lack of information on how invasive plant species directly impact water quality from an ecosystem services standpoint. This information may become vital as needs and priorities potentially alter with coming climate and water pattern changes.

Chapter 4

LOCAL BOTANICAL GARDEN REVIEW

The goal of the Mt. Cuba Center is not only to support and better understand native plants as well as the habitats that sustain them, but also to impart this knowledge onto the public. While they are an industry leader in the field and one of the foremost botanical gardens in the region there are other botanical gardens in the vicinity with similar conditions, although there is little to no effort toward monitoring their impact on local water quality.

While there is little importance put on water quality monitoring, the gardens' goals and mission statements show common themes that would benefit from undertaking water quality data. Four of these are discussed briefly below, and a geographic map is provided below to show their vicinity (Figure 4.1). The four gardens - Longwood Gardens, Winterthur, Tyler Arboretum, and Morris Arboretum, were chosen for their proximity to the Mt. Cuba Center as well as their size and scope of research. They are briefly outlined in Table 4.1 below, and described in more detail following. The map below (Figure 4.1) represents the gardens' locations visually.

Table 4.1 Botanical Garden Summary

Title	Geography	Watershed	Size of Garden	Notes
Mt. Cuba Center	Hockessin, DE (near Hoopes Reservoir)	Red Clay Creek	~500 acres (0.78mi^2)	Botanical garden focused on native plant research
Longwood Gardens	Kennett Square, PA	Bennetts Run	~1029 acres (1.609 mi^2)	On-site Ponds and lakes, extensive water management system
Winterthur	Winterthur, DE	Wilson Run	~980 acres (1.53 mi^2)	Focus is on culture and artistic expression
Tyler Arboretum	Media, PA	Dismal Run, Ridley Creek	~657 acres (1.027 mi^2)	Has 2 on-site ponds, little monitoring
Morris Arboretum	Philadelphia, PA	Wissahickon Creek	~175 acres (0.27 mi^2)	Connected to UPenn, does water quality outreach work

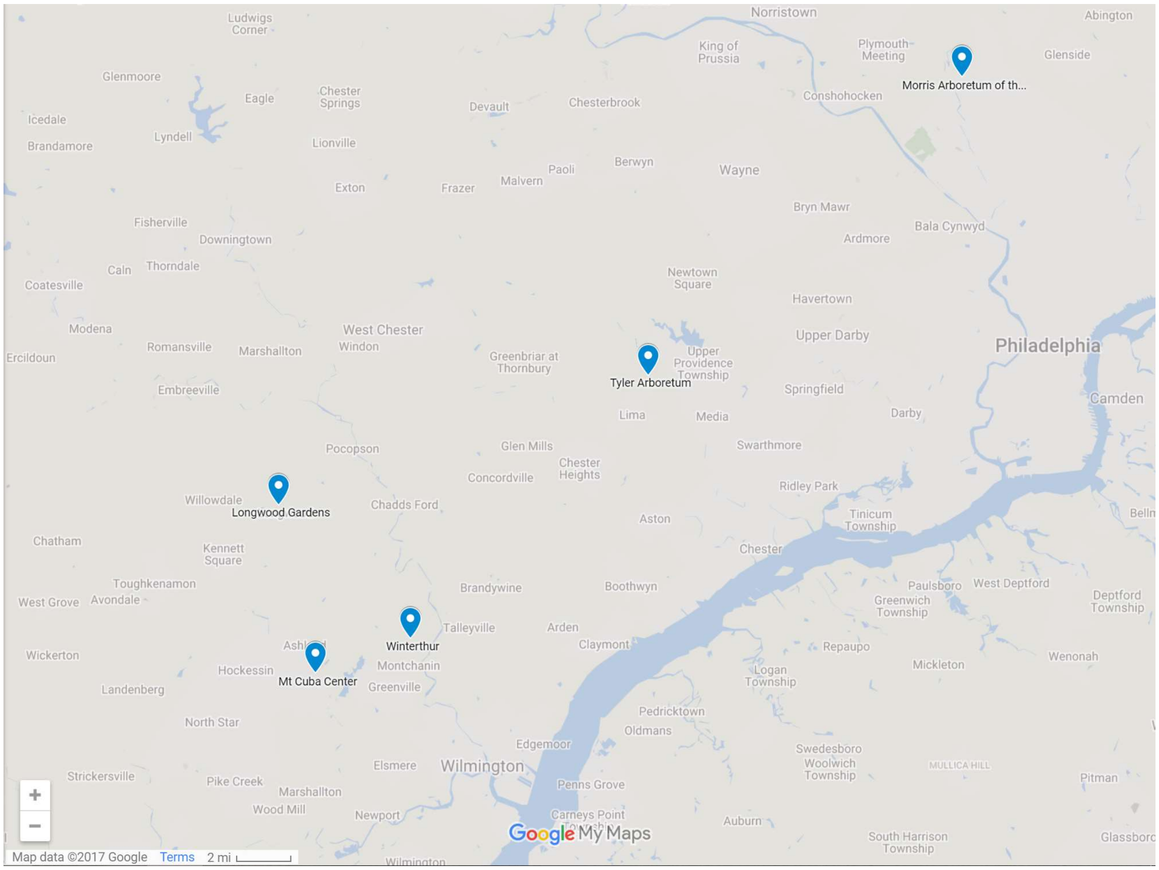


Figure 4.1 Regional Botanical Gardens

4.1 Longwood Gardens

The first of these gardens is Longwood Gardens, located in Kennett Square, PA, just north of the Mt. Cuba Center. What began in 1907 is now a popular attraction in the area with expansive gardens showcasing a variety of botanical and architectural features, namely a set of fountains that help center the garden. The land and gardens were originally owned and designed by Pierre DuPont (the DuPont name is associated with many public attractions in the area) and their design and goals remain centered around his original idea today. It was originally built as an entertainment area for visiting family and friends and while now has expanded significantly and incorporates research and sustainability initiatives in its mission statement, the same general idea of exposing visitors to awe-inspiring works of gardening and landscaping still remain (Longwood Gardens 2017).

While a large set of fountains centers Longwood Gardens land, their goals and mission statements show that their aims are in areas not pertaining to water quality. Their stated short-term (7 year) efforts are divided into 5 goals:

- Advance our mission of excellence and beauty to ensure an extraordinary guest experience
- Invest in Longwood Gardens' Staff, enhance diversity, and advance safety programs
- Preserve and advance Longwood Gardens' fiscal flexibility to achieve our mission and advance our vision
- Measure and communicate the value and impact of our mission

- Demonstrate our civic responsibility by advancing our commitment and leadership in environmental stewardship, community engagement, and accessibility (Longwood Gardens 2017)

As these show, the main focus of Longwood Gardens seems to be in creating a botanical display that is aimed at engaging the public and increasing viewership. While these are worthwhile endeavors, with specific regard to water quality monitoring there is very little attention paid. There are extensive bodies of water throughout Longwood's lands, however, which could provide a useful source of data as the water must be managed to ensure enough is available at a clean enough level to fulfill the extensive needs of the gardens. With some input a monitoring program could be developed to determine the level of pollutants that make their way into these fountains and eventually the nearby gardens enhancing Longwood's ability to accomplish their goals of a thorough guest experience, as well as advancing their commitment to environmental leadership.

4.2 Winterthur

The second regional botanical garden is simply called Winterthur and is located just 3 miles roughly northeast of the Mt. Cuba Center in Winterthur, Delaware. This nearby location provides an especially interesting possible comparison to Mt. Cuba, as many of the same conditions will persist at both sites. Winterthur was also once a DuPont estate that has since been turned into a public gathering place and exhibit. During the early 1960s Henry Francis DuPont opened his childhood home to the public in which today is one of the premier museums of American Decorative Arts focusing on American objects used or developed between 1640 and 1860. The lands themselves sprawl over 1,000 acres with the main 175-room house now established as the museum and a 60-acre naturalistic garden (Winterthur 2017).

Though Winterthur is another expansive garden its main mission and research objectives focus more on the topic of American art and culture. Without an explicit mission statement there are still research opportunities at Winterthur, and even an internal academic journal, the Winterthur Portfolio (Winterthur 2017). Again, this work is aimed at a number of subjects surrounding what they describe as American Material Life and much less on physical water or topics related to water quality. In this case the goals of Winterthur seem to focus on academic research into non-environmental topics, and therefore the smaller 60-acre gardens may not provide an appropriate setting for water quality research as their impact may be minimal. The grounds do sit adjacent to the Wilson Run Creek, however, and therefore it may be possible to examine the water quantity removed from there or elsewhere to feed the gardens, and look into areas such as how much returns to the creek, or is consumed.

4.3 Tyler Arboretum

The third of these regional botanical gardens, Tyler Arboretum, is located in Media, PA, roughly 15 miles northeast of the Mt. Cuba Center. Like other regional gardens Tyler Arboretum is focused on displaying botanical exhibits and increasing educational efforts to the surrounding public. It encompasses 650 acres in total including several historic buildings, as well as year-round indoor exhibits. The Arboretum offers classes for all ages, including outreach and educational programs focused on a range of topics related to the grounds. Their mission statement reads: “To preserve, enhance, and share our heritage, collections, and landscapes, to create and inspire stewards of the natural world" (Tyler Arboretum undated). This statement is aimed at their work on gardens and other botanical works, and there is no mention of direct research or water quality involvement.

Tyler Arboretum also offers internships, although they seem to be aimed at shorter term work and direct landscape efforts as opposed to research or graduate work. There are two options listed on the website, one for youth, and one for a part time (7.5 hrs/week) summer intern to learn how a non-profit works and how the Arboretum functions as a whole. The rest of their website does offer employment opportunities and some of the reports created on-site, although these are annual reports and not research summaries. Tyler Arboretum has at least four on-site ponds, however, and therefore there must be some sort of water control features to adequately supply their expansive grounds. While these efforts are not listed or readily shown to the public a study into their quantitative use at the very least might provide insight on ways to cut down consumptive uses, or a water quality study could show the effects of planning and gardening on such a large scale. As their stated mission is to create stewards of the natural world, this may be a prime opportunity to incorporate educational research into the gardens' effect on water quality. If internships or other opportunities are offered there may also be options to incorporate local school or universities in the effort.

4.4 Morris Arboretum

The fourth regional botanical garden or arboretum is the Morris Arboretum at the University of Pennsylvania, located in Philadelphia, PA, roughly 30 miles northeast of the Mt. Cuba Center. Because Morris Arboretum is attached to a research University their role doubles as both a research institution as well as a public outreach and display garden. Their mission is to: "Promote an understanding of the relationship between plants, people and place through programs that integrate science, art, and the humanities" (Morris Arboretum 2017).

The Morris Arboretum does research in a variety of areas which they split into botanical, horticultural, and even a forestry research clinic which lends itself to various groups looking to expand forestry initiatives, especially in urban areas. They are especially focused on the plant species which grow throughout Pennsylvania and the time periods during which they existed in the region. While their research efforts do not directly focus on water Morris Arboretum does undertake outreach and other programs throughout the community which can be focused on water quality efforts. While not water quality monitoring, they work in areas such as the Thomas Mill Ravine in a partnership with the Friends of the Wissahickon and Garden Club to restore parts of the park which are vulnerable to erosion and stream bank degradation (Morris Arboretum 2017). While not the same as monitoring the effects of botanical gardens on surrounding water quality it does prove the idea that there is a potential need for water related research in the field of research gardens.

The shared focus on local, native plant species that Morris Arboretum has with the Mt. Cuba Center provides a great opportunity to institute a similar monitoring network, assuming there are restorative efforts planed at Morris which can determine where monitoring sites should be established. If comparative measurements can be taken the noted effects of one site versus the other can be used to further prove whether the results at the Mt. Cuba Center are purely localized or can be assumed correct at other sites at least throughout the Mid-Atlantic region.

While these four regional botanical gardens and research arboretums may not address water quality research directly it is evident from consistent themes in their mission statements that there would be room for applicable efforts. Unanimously they strive for a better understanding of how the ecosystems that govern and surround their gardens function and interact, and therefore the interaction with water is a key component. Water is vital to every function of these habitats and is a primary source of influence all the way from fueling the plants through moving nutrients and energy from one section of garden to another over time. A water quality monitoring program could help provide knowledge that shows how these plants may interact and therefore provides an avenue toward potential future growth and healthier gardens themselves.

Moving beyond the immediate regional vicinity of the Mt. Cuba Center, however, there are examples of botanical and research gardens engaging in water quality research with a variety of purposes. On a broader scale, the American Public Gardens Association has even begun a template that can be followed by members (or the public, as the information is very broad and available to the general public) and aims at helping these gardens begin to implement water quality monitoring efforts. Their outline is straightforward and will be described below as it puts forth a clear, concise path from identifying a project, to putting forth goals applicable to the client, to implementation.

The American Public Gardens Association is a group dedicated to the promoting of interests for public horticulture by providing expertise, education, and networking opportunities to their members worldwide (APGA undated). As for their interest in water quality and how it relates to these gardens, they have a recently developed section entitled Water Quality and Consumption whose creation is evident by a note across the top displaying that more information and a fully developed introduction as well as a goals section is forthcoming (APGA undated). The guidelines are as follows:

- Investigate and Establish a Baseline
- Identify Stakeholders
- Data Collection/Resources
- Develop and Implement a Plan of Action
- Evaluate/Revise/Monitor and Maintain Success
- Report Communicate and Educate (APGA undated).

The guidelines are more descriptive and go into the motivation behind each but are focused around the need for efforts to be driven by a succinct goal and communicated clearly between the stakeholders and data collectors. These basic outlines seem simple but in essence represent the steps taken throughout the program at the Mt. Cuba Center from realization through the ideal end phase, which will be continuing data collection and therefore a continuation of this process.

The American Public Gardens Association's page on water quality also serves as a link to like-minded programs, starting with the Brooklyn Botanic Garden where efforts are underway to drastically reduce their exhibit's water consumption by upwards of 95% through the installation of a rain garden on-site. While this is an example of water quantity work being undertaken at a botanical garden as opposed to water quality, it shows there is enough of a predicted link to warrant the beginnings of research and other work toward water-related issues in general. Additionally, while there is not an online summary of the event Brooklyn's Botanic Garden calendar shows that in 2016 they ran an educational event entitled: "Water-Conscious Gardening: Create a Rain Garden with Native Plants" (Brooklyn Botanic Garden 2017). Operating under the assumption that native plants will thrive in local conditions, the workshop was focused on teaching the methodology behind creating an effective rain garden to collect runoff in a yard or larger space.

Aside from these projects, individual efforts have also been undertaken to evaluate the water quality on botanical garden or similar grounds. One such effort comes from the Lewis Ginter Botanical Garden in Richmond, Virginia wherein water quality testing was undertaken to establish the health of water used to irrigate display gardens. This water is taken from an on-site irrigation pond but program directors were aware of the influence runoff can have on increasing nutrient and other pollutant levels and decided to establish baseline levels for the water they were directing toward this irrigation (Stretchko 2012).

The Lewis Ginter site is comprised of an 82-acre public garden, and its on-site irrigation water is collected directly through stormwater runoff. To help ensure healthy products the owners decided to test for E. Coli, nitrogen, phosphorous, and petroleum hydrocarbons in this runoff and rate their findings against EPA and Virginia Department of Environmental Quality standards for recreational freshwater system standards. While their findings showed all levels below acceptable standards it underlies the effect that stormwater runoff is known to potentially have on water sources, as well as the unknown effects that botanical gardens can have on the grounds and runoff itself and the need to continue watching and monitoring on these sources.

Chapter 5

METHODS

The methods and procedure for establishing the long-term water monitoring stations at the Mt. Cuba Center began in late July/August 2016, and spanned through confirming the contract at the end of December 2016. It began as a conversational idea about possible future work and grew to fill a need in research coverage, culminating in a research proposal which can be found in the Appendix.

The first steps for work at the Mt. Cuba Center began with a meeting between the Water Resources Center research assistants, Director Jerry Kauffman, and Natural Lands Steward George Schurter from the Mt. Cuba Center. As a work plan was being put together to do some basic data gathering and stream analysis it became apparent the eventual goals of the Mt. Cuba Center were to get a larger picture of the health of the environment as a whole, including the state of its waters.

The next step moved onto research and understanding the goals of the Mt. Cuba Center. As research into how water monitoring efforts are undertaken began to show, the goals and motivation behind a project can have a large impact on the types of work desired. Therefore, the long-term goals of the Mt. Cuba Center had to be taken into account throughout the entire project.

In the example of the Mt. Cuba Center the history behind the lands and projects intertwines fully with their mission to further understand the impact of bringing back native vegetation to the Mid-Atlantic region. When designing this project, the proposal had to go along with these goals, and the types of data accumulated needed to be useful in furthering this understanding. This proposal can be found in the appendix.

5.1 Sample Site Locations

The first round of water research began with multiple approaches to categorizing the land and water as well as establishing baseline readings. Weekly water sampling was undertaken at five distinct locations, two of which have multiple sites (Figure 5.1). These sites were tested for conductivity and turbidity using handheld meters and a portable turbidity unit. These sites are briefly described below, with a map of the sites directly below the descriptions:

Pond: Large pond serving as headwaters for Hickory Run, water flows through a man-made drainage system into the beginning of the creek. Sampling was done in the pond itself, as well as on the outflow side of the drainage system, roughly five meters down the creek. The pond itself had very low movement, and was almost stagnant except for the outflow at times. During the late fall algae coverage approached 100%, and eutrophication was likely.

Road Underflow: Readings taken just downstream of three man-made pipes which allow flow to continue under a paved road. The pipes range roughly 6-12 inches in diameter, and flow often only came through one of the three. Very low flow area, medium gravel and large rocks prevalent on surface here. The outflow falls directly onto a grouping of large rocks, and flows down approximately two feet to the new creek bed.

House: Two sites here taken near a residential house. The creek parallels the road to an extent, and is crossed by a small foot bridge. The first site is the main channel of the creek, slightly deeper than the previous (road underflow) site, but still often a low flow with large rocks creating heavy ripples. The second site here is a very small incoming tributary, which was entirely stagnant or nearly dry during periods of low precipitation. Some readings from the tributary were also influenced by a local dog, who seemed to enjoy pushing her nose into the cool waters!

Mt. Cuba Rd. Bridge: This site was further downstream, and ran under a two lane road just off the main road. The creek is wider here, and the bridge is estimated to be 10-20ft wide. Readings were taken from the downstream side of the bridge, as it was the most accessible. Waters were calmer here, and the creek widened by multiple feet, as well as increased in depth.

Western Railroad Crossing: The last site was furthest downstream, just over 500 creek ft upstream from Hickory Run Creek's confluence with the Red Clay Creek. This site runs under a shorter bridge (about half the size of the Mt. Cuba Rd. Bridge), that holds up an active train track. Samples here were taken again from the downstream side, and at this point the water level typically has increased, and discharge has gone up with volume.

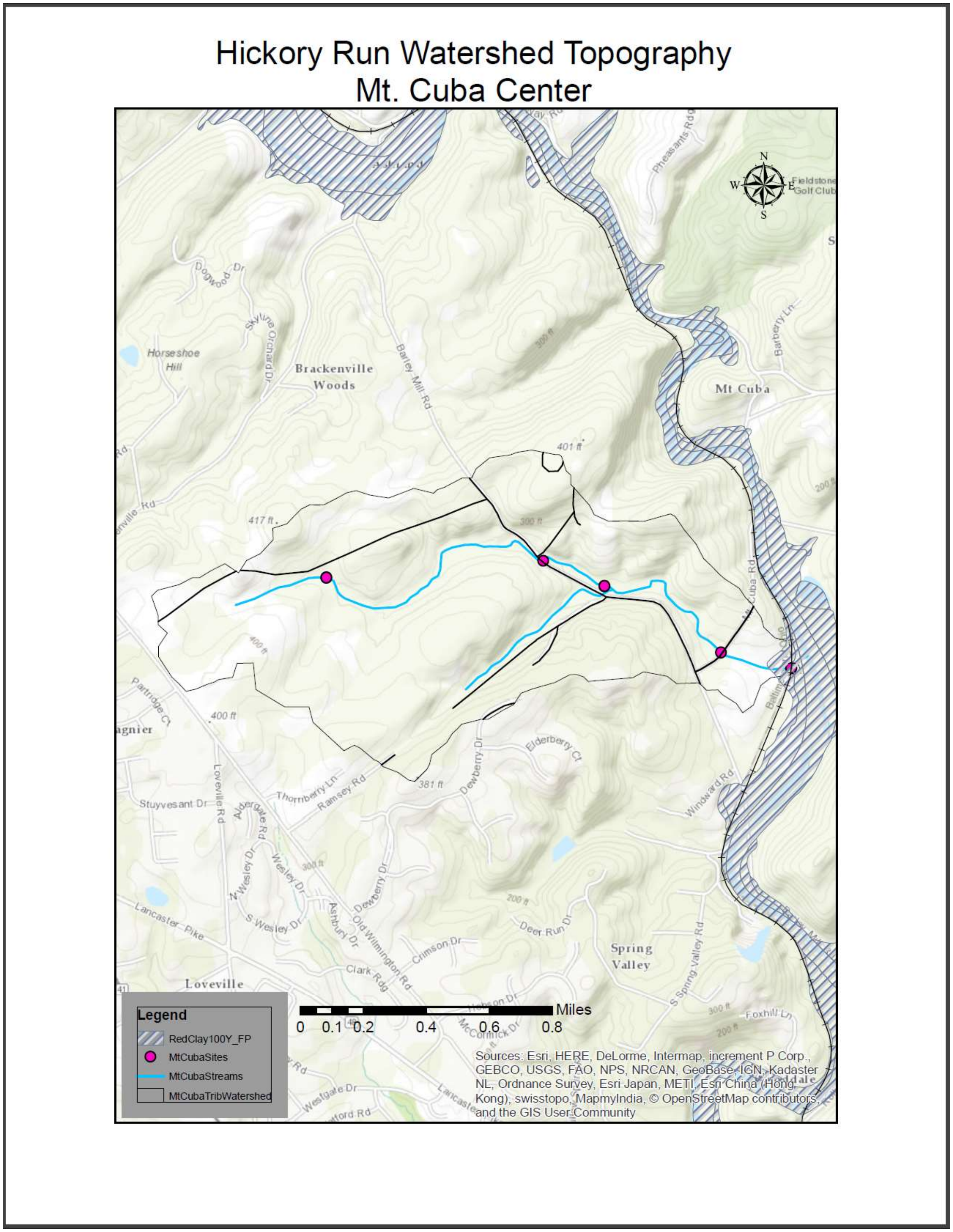


Figure 5.1 Water Sampling Sites

These sites were tested weekly when conditions permitted over the period of mid-July through December 2016. The motivation for this work was to establish baseline readings for the majority of the stream, and gain the ability to identify any large-scale changes that may occur throughout the fall. Additionally, these readings allowed for a general idea of the health of the stream and can be used in comparison with comparable readings taken from USGS and other gages in the area.

5.2 Grab Samples

This type of water monitoring is the most direct means of establishing a water quality baseline whereas the other efforts, cross-sections analysis and the bioassessment, are aimed at determining the physical conditions of the stream as well as determining the quality of the stream and surrounding area's condition. The results are analyzed in the next chapter and describe a healthy stream which shows a fairly consistent baseline across multiple months of testing.

Turbidity: The EPA (2012) describes turbidity as: "A measure of water clarity; how much the material suspended in water decreases the passage of light through the water. This suspended material can come from any number of sources, and often ranges from ~0.004 mm – 1 mm in size, or a grain of clay to a grain of sand. Generally anything larger will quickly settle in the water column and rest on the bottom. This increase in suspended material can have varying effects, starting with the physical - visual changes as sediment distorts light and color alteration, dependent upon the amount and type of suspended material. Chemical properties are also affected, such as temperature changes from suspended materials absorbing more heat, and lower levels of dissolved oxygen due to warmer water. At extremely high turbidity levels light can also be blocked to an extent wherein photosynthesis can be lowered, which in turn further decreases the dissolved oxygen content.

General sources of turbidity can really range to include any foreign input into a body of water, but the EPA identifies the most common as:

- Soil erosion
- Waste discharge
- Urban Runoff
- Eroding Stream Banks
- Large numbers of bottom feeders – stir up bottom sediments
- Excessive algal growth

While this list is far from exhaustive its wide range of potential contaminants proves a good example of how every type of land use can lead to increased levels of turbidity. Therefore, some turbidity is to be expected in every watershed, and the need to identify what levels can be considered polluted or unhealthy becomes imperative. A goal or standard for healthy waters cannot simply be set at zero – there should be a long record of data for the source, taking into account land uses and how they have changed over time, as well as climatic and natural events, before water level standards can accurately be established.

Because turbidity is a measure of nearly all sources of pollution it is widely used to track the effects these changes in land use can have on the watersheds they impact. It is also ideal for tracking these effects during transformation of a watershed, and this is one of the reasons it was chosen to be specifically tested at the Mt. Cuba Center. With their goals of slowly returning land to a more natural state, in this case referencing the replanting of native species and reducing the impact of development, the efforts to actually replant the land should be monitored as well as their long-term effects on the water to gain a complete picture. If this data is to one day be compiled and used as evidence in decision making for restoration or conservation projects, then the effects during the restoration should be considered as well as the eventual conditions.

Measuring turbidity is most often accomplished through a handheld turbidity meter, although it can also be accomplished via sampling efforts which take a sample back to a lab for further analysis. These spot checks can provide valuable information about the health of a stream at a certain point in time, and if other samples or readings are taken across a region at the same time, these levels can serve as a strong comparison of the water bodies in question. They do not, however, provide comparison across a time scale as conditions at any given point can be influenced by a large number of factors. There is also a lack of monitoring to establish what might be long-term trends vs. short-term or immediate events, such as rainfall or a natural event. If these spot checks continue long enough they may become valuable for establishing these trends, but still do not account for short-term variability as they only take a once a week reading, for example.

To account for this need, a long-term turbidity meter is being installed at the Mt. Cuba site, which will be programmed to take readings on a 15-minute interval. The goal is to establish a robust record wherein identifying trends against outliers will become fairly easy. This also allows for automated readings to be stored during extreme weather events, such as large storms or high runoff events, either during construction or from heavy precipitation.

Conductivity: The EPA (2012) defines conductivity as: "a measure of the ability of water to pass an electrical current". The conductivity of water is largely affected by the presence of inorganic dissolved solids, lending monitoring conductivity a strong baseline for measuring water quality and level of impact from surrounding land use. Organic compounds dissolved in water, such as oil, sugars, or alcohols, do not conduct electricity and therefore do not show up in conductivity readings. Many of the common sources of conductivity come from dissolved solids such as:

- Chloride
- Nitrates
- Sulfate
- Phosphate anions (ions carrying a negative charge)
- Aluminum cations (ions carrying a positive charge)
- Sodium
- Calcium
- Iron

Additionally, conductivity itself is affected by temperature. As water temperatures increase conductivity does as well. Due to this conductivity is given at levels at 25 degrees Celsius. Therefore, conductivity itself can be affected by other pollution factors, such as turbidity.

As the list of common sources shows conductivity is largely affected not only by surrounding sources of pollution but the physical circumstances surrounding the body of water. Whereas other parameters (such as turbidity or specific pollution types) are more largely affected by inputs alone, the geology of a region can have a much higher effect on local water bodies. Whereas all water sources are expected to show some erosion and absorption of materials which lead to changing turbidity, for example, the geologic structure of bedrock and surrounding inputs can create vast differences in background conductivity levels. If these are composed of inert materials such as granite then even as water erodes small pieces into the water it does not break down into ionic components, and therefore does not have a large effect on conductivity levels. In the presence of materials that ionize upon dissolving such as many clays and sedimentary rocks, however, this same process can cause drastic changes in background levels of conductivity.

This again shows the need for widespread, long-term monitoring systems to be implemented. To effectively determine the impact of surrounding areas on the conductivity of a body of water, some amount of baseline readings must be established for the area. While rock types and local geology can be identified on a large scale, the exact levels of conductivity these factors lead to within the actual body of water will vary, and therefore must be sampled and tested for. If periodic tests are taken, there may be no way to fully determine what are true baseline levels and which are more impacted by local pollutants and extreme weather events, and therefore the impact of surrounding pollution, especially anthropogenic sources, will become much harder to identify.

Monitoring conductivity is almost entirely handled by probes or other equipment. For this work a Hanna Instruments Waterproof Tester was implemented, which is a handheld sensor capable of reading pH, conductivity, total dissolved solids, oxidation reduction potential, and temperature. For the most part measuring conductivity is done by simply moving an electrical current across a set field through the sample of water in question – either in a laboratory setting or by inserting a handheld meter (as is the case for the Mt. Cuba Center) directly into the water itself.

5.3 EPA Rapid Stream Habitat Bioassessment

The next step was to perform an EPA rapid stream health assessment and cross-section analysis across the length of the river at 500ft intervals. While the water quality sampling gives an idea of the health of the water itself, these more physical measurements give an idea of the dimensions of the stream, as well as the health of the environment and habitat surrounding the water. In a general situation this becomes important as environmental inputs to water sources originate in the surrounding environment, and eventually make their way into the water body. It is increasingly important in terms of the research being undertaken at Mt. Cuba, as one of the largest goals is to better understand the impact of the restorative work being done. By performing the assessment before (or before the next phase) restoration a baseline can be established, and compared to later results.

To adequately characterize the watershed surrounding Hickory Run Creek at the Mt. Cuba Center, it is important to take into account not only the stream itself, but the habitat as a whole. The EPA Rapid Stream Bioassessment is designed to do just this, using 10 categories to put a 20-point rating scale to water quality inputs, streambed conditions, as well as the status of the immediately surrounding area. To best cover all bases, the assessment uses the categories outlined in the next paragraphs.

Epifaunal Substrate/Available Cover: The amount of available cover for epifaunal colonization and fish cover. This is described as permanent or semi-permanent (not new and very loose) snags, branches, or crags in which species can gather and survive.

Embeddedness: The extent to which the stream bed is comprised of large boulders or rocks. Higher (preferred) scores relate to lower amounts of fine particles or sand surrounding the boulders. The lower the sand levels, the larger potential for animals or plants to take root.

Velocity/Depth Regime: The stream assessment breaks this down into four distinct categories: Slow-Deep, Slow-Shallow, Fast-Deep, Fast-Shallow. Slow is generally seen as less than 0.67 mph, fast is anything greater than 1.1 mph. If all four categories can be seen near the survey spot, then the maximum score is awarded.

Sediment Deposition: This relates to the effect sediment buildup has on the general construction of the streambed. Slow-moving streams with high deposition can be affected or even eventually displaced as sediment buildup, therefore higher scores are given to less sediment with <5% of the surface being broke by island buildup taking the highest score.

Channel Flow Status: Channel flow is determined by whether the water reaches both banks of the stream, and how much of the space between is exposed substrate above the water line. The less exposed substrate, and further the water reaches toward both sides, the higher the rating.

Channel Alteration: This rating stays true to its name, with the amount of human-influenced alteration providing the rating. Little to no alteration results in the highest score, whereas high levels of channelization of alteration/embankments (often found around bridge abutments, etc.) leads to a lower one.

Frequency of Riffles (Or Bends): To determine this score the EPA gives a ratio to apply to the occurrence of riffles compared to the stream width, 7:1. If the riffles are closer together than this, a higher score is given. The less frequent the riffles are (or bends), the lower the score.

Bank Stability: This measurement, again, sticks to its name. The stability of the stream bank on both sides is rated individually on a scale of 1-10, then combined to form the score out of 20. The metric includes evidence of past erosion, current stability, and potential for future erosion or collapse.

Vegetative Protection: A measure of the vegetative cover on each bank. Scores are lowered for mowing or other human impacts, and higher scores awarded for natural plant growth and high percentage of coverage. Again here both banks are scored individually and then combined.

Riparian Vegetative Zone Width: This last measurement addresses the width of the riparian zone surrounding the stream on both sides. This is also scored as two individual banks and combined, and top points are given for >18m of riparian zone on each side. The score is reduced for human impact such as roads, mowing, parking lots, crops, etc.

These together give a more inclusive summary of the area surrounding a creek, in this case Hickory Run, than water quality sampling alone. A more holistic understanding of the area could lead to better insight into the effects of native plant restoration at the Mt. Cuba Center.

At each of the same 500-ft intervals used for the EPA Rapid Stream Bioassessment a stream cross-section was also taken to determine the dimensions of the streambed itself. In water quantity analysis these can be used in combination with depth and velocity to determine discharge (Q, ft^3/s) expressed as area (A, ft^2) multiplied by velocity (V, ft/s).

A rating curve is used in combination with depth, determined separately, and can be used to find the total 2-dimensional area of water moving down the stream at any given point.

To accomplish these cross-sections, a three-person team employs two tape measures and a level (as was used in Hickory Run), or in larger streams a measuring stick. One tape measure is pulled across the stream on a horizontal line, and the other is used to take measurements from the horizontal one to the streambed at pre-set intervals. The closer together the interval the more precise the measurement, and in this project a 1 ft interval was chosen. In the case of large depth change or drastic alteration, as determined by the team, further measurements could be taken where needed. These often included where large rocks had settled and then dropped to the streambed, or erosion played a factor. This provided a fairly detailed image of the streambed through a set protocol, but also allowed enough flexibility to be useful around an uneven landscape.

These depths were then recorded and turned into negative values when input into a Microsoft Excel database. The horizontal line was chosen at a high enough point to account for the majority of expected water levels and became a “0” reference point. Through graphing, a digital reconstruction of the shape of the stream bed was formed around this data creating a digital picture of the streambed at 500 ft intervals.

5.4 Long-Term Monitoring

Prior to equipment selection a site had to be chosen for the long-term monitoring to take place. While multiple methods of doing so were investigated, including modeling and input mapping, the decision was simplified by the need for the area to be easily accessible by foot or small car, secure and secluded enough that the threat of the equipment being stolen was minimal, and downstream of the planned restoration, as the effects would be most easily shown this way.

Piggy backing off of site selection for the grab sampling the two sites furthest downstream were presented as viable options – Mt. Cuba Rd. bridge and the W&W Railroad Crossing. Both had stable structures near which the equipment could be placed (bridge construction made of concrete or stone), were accessible, and were far enough downstream that most of the watershed sat upriver. While the Mt. Cuba Rd. bridge was more accessible, it was decided that it was too open, and graffiti and signs of other human influence showed that there were often groups of people spending time in the area – which could result in a threat to equipment left in the open. Furthermore, the stream here widened and was very shallow, at times running the risk of flow not being high enough for the sensors to function optimally.

Therefore, the W&W Railroad Crossing was selected for the monitoring site, and planning could move to the next phase. The site was accessible via a short (~0.5 mile) walk from the barns and storage facilities, or a very short drive when conditions allowed. Furthermore, it was secluded enough that the equipment would not be obvious to passerby while the presence of the railroad line and crossing bridge meant the area would remain accessible throughout future years.

When discussing the possibilities for long-term monitoring at the Mt. Cuba Center, a few different inputs went into the decision-making process. Once it was established that water quality monitoring was of interest to the Mt. Cuba Center, choosing the parameters to monitor became a primary question. The next was the need for cost-efficient, effective sensors that could be nearly standalone and require minimal man-hours once set up and running. Additionally, these sensors needed to be able to provide coverage on a consistent basis through storm and other climatic events, throughout restorative efforts, and during times when putting people out to survey really was not possible such as at night or during weekend hours.

To address this first question of which parameters to choose for a long-term monitoring program, the primary research question became a driving factor. To determine the effects of native plant restoration it became apparent that overland flow/runoff times could be directly impacted, as well as sediment levels moving downstream. These would also prove to be strong indicators of overall change to an environment, and changes would become easily visible in monitoring results. Furthermore, upon investigation into local USGS gages that could be used for comparative analysis discharge was the most common parameter measured (behind gage height, which is used as a factor in determining discharge) and turbidity was the second most common (Table 5.1). Therefore, long-term data sets taken along Hickory Run Creek could be compared to local conditions and differences in trends could help further investigate the effects of native plant restoration.

Table 5.1 Local USGS Water Gages

Site Name	Gage	Discharge	Turbidity	Temp	pH	Conductivity
Red Clay Creek						
Red Clay near Kennett Square	1479820	X	X	X		
Red Clay at Wooddale	1480000	X	X			
Red Clay near Stanton	1480015	X	X			
Red Clay trib. at Marshallton	1480017					
White Clay Creek						
White Clay Cr. near Strickersville	1478245	X	X			
White Clay Cr. at Newark	1478650	X				
White Clay Cr. near Newark	1479000	X				
Brandywine Creek						
Shellpot Cr. at Wilmington	1477800	X	X			
Brandywine Cr. at Wilmington	1481500	X	X	X	X	X
Brandywine Cr. at Chadds Ford	1481000	X	X	X	X	X

Next, ensuring that the sensors would be self-contained and require little to no constant input was a necessity to ensure data would be collected during important climatic or storm events. Additionally, while Mt. Cuba has full-time staff on site it did not make sense to redirect their efforts at constant stream water quality measurement. As a result, the equipment chosen needed a large data storage capacity as well as the ability to be powered from a unit without a grid-based power line. There was research into providing a photovoltaic cell system (solar power) to constantly charge a battery and provide power over the long-term, but the costs of this were deemed excessive and a contained battery unit was decided upon.

As the research proposal in the appendix shows, the larger cost of the two instruments became the discharge monitor, and a YSI Sontek IQ system was chosen. The largest advantage here is the IQ's self-contained design which is able to measure depth (pressure) and velocity simultaneously, determine water discharge by combining these with a user-input cross section, and then store this data internally. The five-sensor doppler system is designed to accurately report all of these parameters over a long period of time in water ranging from .5m – 5m deep. There are also internal temperature gages, and temperature is recorded at the same time as depth and discharge (YSI).

The system has very low power requirements, and 4GB of internal storage. The attached software provides easy setup and access and gives the user estimates of remaining battery life as well as storage capacity. With the battery pack that was eventually designed the system is capable of running uninterrupted from early spring until late fall when it must be removed due to freezing risk.

For a turbidity sensor, a smaller Campbell Scientific OBS3+ sensor was chosen as it provided the durability to be used on a decadal time scale, and provided options that allow the sensor to work effectively in the lower-flow Hickory Run Creek. The OBS3+ works similarly to most turbidity sensors, including the portable turbidity lab used for grab sampling, in that it is a light scatter/absorption sensor. The sensor itself is roughly cigar-shaped, with one end housing the connection port for power and data transmission, and the other tapering to a flat-sided light emitter and sensor. This light broadcasts into the surrounding water, and the sensor is used to detect turbidity levels. The OBS3+ does not have internal data storage or programming capability, however, and therefore requires a separate datalogger to accomplish these tasks.

On this end a CR300 datalogger, again from Campbell Scientific to ensure compatibility, was chosen. This choice largely came down to cost and size as the OBS3+ did not require a robust system, and a more basic datalogger served the purpose. To accompany this system Campbell Scientific provides software to not only manage and collect the data, but also program the datalogger, which powers and controls the sensor. The process here is slightly more complicated, and is handled in steps:

Wiring: the sensor and datalogger are connected via a set of small (12-gauge) wires, which allow the electrical signals that control the sensor as well as return information to do so along pre-set pathways. Once wired the system takes power from the battery to the datalogger itself which then sends it to the sensor. Diagrams for wiring are provided depending on the sensor in use, as the CR300 is compatible with multiple sensors. The diagram is shown below (Figure 5.2), and this clearly displayed set of wiring instructions means that over the years if the wiring needs to be redone whoever is doing so will be able to follow the same set of instructions.

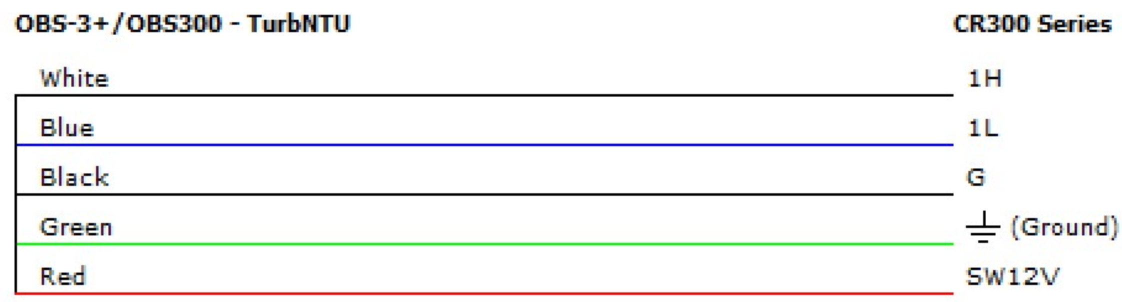


Figure 5.2 Turbidity Sensor Wiring Diagram

Programming: This is done through proprietary Campbell Scientific software which comes along with the data logger. This cuts programming down exponentially as it asks for inputs and preferences for monitoring times, intervals, and storage types, then generates the program via pre-set coding. While this is not an option for some more complicated uses, the OBS3+ turbidity monitor is being used to solely monitor turbidity levels and therefore this was a viable option. Additionally, these programs require specific calibration levels for the sensor, which was a source of issue the first time as the data was returning “0” repeatedly due to a missed coefficient.

Once successfully installed and initiated, the turbidity sensor runs similarly to the discharge meter in that it will collect and store data on a 15-minute interval until it is manually stopped in the late fall, again to avoid freezing issues. Data will be collected at the same time as the IQ system, and is done on-site via a USB connection in the same way as the IQ system.

The last part of the equipment installation was the battery pack build, which took a fair amount of time due to flood concerns and battery capacity. The original plan was to use a simple lead-acid car battery, placed inside a marine box, and stored nearby on the ground. This went by the wayside as capacity issues arose, and the potential damage of running the battery to a very low state over time. This gave way to a deep-cycle marine battery to solve this issue, which is able to be run to almost near empty and recharged without significant capacity loss. There was a brief change of plans from this as it became evident that some marine batteries vent hydrogen gas as part of their design, and therefore could not be housed in a sealed container. Non-venting deep-cycle batteries were chosen as appropriate replacements.

The next hurdle here arose as the potential, albeit rare, for high levels of flooding was brought up. The monitoring site does suffer reported extreme flooding every 5-10 years, even outside of the reported Red Clay Creek floodplain. These floods were reported by the Mt. Cuba Center staff and when no completely submergible battery box could be easily established it was determined that a sealed box would be adequate, and in the case of extreme flooding would have to be or replaced. The final setup, pictured below, involves a large industrial construction box housing 2 interstate deep-cycle 12v 42AH batteries, the CR300 datalogger, and all associated wiring. A small (~1 in) hole was drilled in the front through which the wiring was fed, and a black silicone caulk sealant was piped in to reseal the hole to restore its watertight seal.

As the project was running this threat became a reality, as a large enough storm came through to not only throw the equipment around, including the 300-lb concrete pillar, but also reshape the stream geometry and remove more than a foot of sediment in many places. With a small stroke of luck only a small cap on one of the connecting wires was broken, although the site took some re-thinking to set back up. Bent rebar is used to secure the pillar in the bed of the stream, and the excess wiring, most likely where debris caught and pulled it out of place, is secured behind natural barriers and better connected to the ground where possible in an attempt to avoid future problems. The battery and equipment box is also raised off the ground via cinderblocks and a cow step ramp to keep more of it out of standing/slow moving water should flooding occur again.

The entire site set-up can be seen below (Figure 5.3) in pictures taken directly from the site shortly after installation. The picture on the right shows the two batteries attached to the data recorder as well as outgoing wires, while the one on the left shows the cement post to attach the instruments under water during a very low flow period.

Figure 5.3 Monitoring Site Photographs

5.5 TR55 Modeling

The TR55 modeling program is designed to take into account geographic and land use variables and determine their effects on incoming rainwater and its travel time from one end of a watershed to its eventual end or confluence with the next body of water and watershed. The strength of this program lies in its ability to show the changes that will occur if land use is altered, especially in areas such as Mt. Cuba's grounds where restoration may alter land types. Therefore, current levels can be compared to new readings if, for example, a section of forest is converted to road or parking lot, or a wild field eventually is replanted into forest lands. The program also allows you to model different flood potentials depending on the users' choice. It offers 2-yr, 5-yr, 10-yr, 25-yr, 50-yr, and 100-yr flood levels (USDA 1986).

When determining health of a stream and land stability this becomes extremely important, as the speed at which water moves, both over land and through a stream, is important when determining potential erosion or impacts from runoff. If considering new construction, for example, the speed at which water moves and therefore potentially causes erosion is important for determining safe build distances from active waterways.

The first step to modeling the watershed surrounding Hickory Run Creek is to determine the types of land use inputs needed for the TR55 program. There are multiple ways of doing this, however the USGS (2017) offers a very simple program online called StreamStats. While it does not have complete information it can provide some basic answers such as watershed size, impervious cover, as well as estimating slope if necessary. These are input as numerical measurements and added to the model.

Next the land use numbers are given a rainfall distribution type, of which the entire region is Type II. This is based on rainfall frequency maps out of TPS-40, which is a national rainfall frequency atlas out of the National Oceanic and Atmospheric Administration, and the National Weather Service. These tell the TR55 modeling program how rainfall is distributed through the area and therefore how the falling precipitation will distribute itself across the watershed in question.

Lastly, the model requires total length of the stream (the watershed acreage is covered during the land use section), elevation and slope of the stream, which is accomplished using elevation maps, as well as being given a surface manning's friction coefficient (n). This coefficient comes from the values used for Manning's equation, which is used as an equation for determining the flow rate of water through open channels or areas and is represented as:

$$Q = \left(\frac{1.49}{n}\right) AR^{2/3}\sqrt{S}$$

Where:

Q	= Discharge (ft^3/s)
A	= Cross-Sectional Area (ft^2)
n	= Manning's Roughness Coefficient
R	= Hydraulic Radius (ft)
S	= Channel Slope (ft/ft)

While TR55 does not rely solely on this equation or operation, the idea of a standard coefficient for the types of land cover give the model weight. The result from all of the inputs give a predicted flow time from start to endpoint of the furthest drop of water during a storm or precipitation event while taking into account a wide range of variables.

Chapter 6

RESULTS

Before considering the following analysis, which in part involves comparison of Hickory Run to the Red Clay Creek, it is beneficial to consider why this comparison is useful and what may or may not account for differences in readings. The first consideration is that their location is close enough to eliminate most, if not all, inputs from climate and weather. The climate of Hickory Run will almost unanimously be the same as that of the Red Clay Creek even where it flows near Kennett Square, PA. Specifically, this means that precipitation levels will likely be almost identical, drought patterns will match, and temperatures which could affect flow levels will be the same. Similarly, large-scale events and seasonal weather patterns will remain the same between the two. As temperatures trend upwards or downwards, both water bodies will be affected similarly.

There are many inherent differences in the two, however, and instead of these invalidating a comparison, they should be used to investigate further how these differences could have caused differences in readings. The Red Clay Creek is larger, has a watershed considerably higher in size, and even though the Kennett Square USGS site is upstream the inputs into the creek come from a larger, more diverse area. Spills or inputs that can alter water quality may reach the Red Clay, but in no way make their presence felt in Hickory Run.

Additionally, the increased size of the Red Clay Creek means that a higher volume of water is being transported downstream. While the old adage of "the solution to pollution is dilution" has long been proven false, the idea still applies and any water quality inputs will more quickly dilute within the larger volume of the Red Clay Creek. For example, the same amount of sediment – a bucket of sand, for example, will spread out more completely in the Red Clay, and could potentially result in a lower individual turbidity reading. In Hickory Run Creek, however, that same bucket of sand has less volume to disperse and therefore as it passes the turbidity meter could likely present as a much higher turbidity reading where it blocks more of the light used to measure it.

Lastly, on this same topic the smaller volume of water, and therefore lower discharge, could result in higher variability in readings from Hickory Run as compared to the Red Clay Creek. As stated above, this lower discharge means that inputs will have a larger measurable effect on individual readings in Hickory Run as opposed to the Red Clay whereas their impact will be felt less.

6.1 Grab Samples

Turbidity: To compare the turbidity readings taken across the summer/fall/winter of 2016, the Kennett Square USGS gauge site was chosen as it is the closest Red Clay site with turbidity readings (Table 6.1). The following graphs and comparisons are based on grab samples taken from Hickory Run, and USGS turbidity readings from the same date and time. Both use formazin nephelometric units (FNU).

Additionally, the State of Delaware has water quality standards for various water quality parameters in accordance win the Clean Water Act's requirements. For turbidity there is not a set level, but the state requires that levels measured in FNU: "In all waters of the State shall not exceed natural levels by more than 10 units" (U.S. EPA 2017). This underlines the need for long-term, reliable baseline research to be undertaken in waters throughout the state, as meeting this requirement requires an understanding of where levels are during uninfluenced or baseline periods.

Table 6.1 Hickory Run Turbidity (NTUs)

Date	W&W RR	Mt. Cuba Rd.	Ramsey Rd.	Ramsey Rd Trib.	Barley Mill Rd.	Pond	Pond Outflow	Red Clay
7/22/2016	1.42	1.89	13.41	3.40	3.08	0.63	67.00	12.00
7/28/2016	1.70	3.48	16.57	2.28	2.75	2.85	51.00	1.00
8/5/2016	1.92	7.68	1.34	4.12	2.72	3.81	1.68	0.90
8/12/2016	0.95	2.84	0.85	2.40	2.41	18.60	4.33	0.20
8/19/2016		2.21	1.26	1.81	3.32			1.00
8/26/2016	1.10	3.60	0.92	1.33	3.57			1.20
9/2/2016		5.46	1.56	17.03	2.29			2.30
9/15/2016	1.07	3.94	1.44	4.75	2.37	1.76	137.00	1.40
10/7/2016	0.10		0.11	148.00	1.30			3.40
10/14/2016		0.73	0.16	14.74	6.01	5.40	1.75	3.70
11/11/2016	0.57	0.95	1.13	29.24	0.06	2.83	1.14	2.30
11/19/2016		0.61	0.20	177.00	0.56			2.50
12/2/2016	0.69	2.68	0.01	0.44	0.01	2.80	4.15	7.30
12/9/2016	0.20	0.56	0.51	0.29	0.22	2.04	2.52	3.10
Mean:	**0.97**	**2.82**	**2.82**	**29.98**	**2.19**	**4.97**	**30.06**	**3.02**
Median	**1.01**	**2.68**	**1.03**	**3.40**	**2.39**	**2.85**	**4.15**	**2.30**

As this table shows conditions along Hickory Run Creek are extremely variable, largely due to its general low-volume baseflow. As local conditions change or are affected by weather conditions particles (sediment) are kicked up and make their way downstream. Even small amounts of sediment have a large effect, as there is less overall volume for it to spread into. While dilution is not the solution – to quote the old incorrect adage again – it does play a large role in turbidity levels. As specific location notes, both the Ramsey Tributary and Pond Outflow were extremely affected by localized conditions and therefore their averages provide a skewed picture of true conditions. The Ramsey Rd. Tributary was less than a foot wide and less than 6 inches deep, as well as nearly stagnant, which meant that sediment settled easily. Therefore, any disturbance kicked all of this loose, settled sediment up and distorted readings. The Pond Outflow was just downstream of water falling down a rocky waterfall ledge, and therefore sediment is constantly being kicked up and likely transported with any type of raise in water levels, resulting in the spikes seen above.

This other side of the argument about the smaller stream, however, is that the extremely healthy conditions surrounding Hickory Run Creek mean that far fewer potential pollutants will reach the water body itself. As evidenced by the averages along the bottom of the table the general turbidity in Hickory Run Creek is very low compared to nearby Red Clay Creek. The four sites that represent moving water and are not tributaries or headwater sources, (Barley Mill Rd., Ramsey Rd., Mt. Cuba Rd., and W&W RR) all have average levels below that of the Red Clay Creek. This is including the spikes in readings, which occur sporadically but pull these average values up across the board. An inevitable flaw of spot or grab sampling, the fact that averages stay below their nearby, larger Red Clay Creek counterpart strengthens the argument that Hickory Run Creek is, overall, a very healthy body of water.

In addition to a general lower level of turbidity, it is evident from the data that turbidity drops as the creek flows downstream. From the most general approach, the pond which forms Hickory Run Creek's headwaters has an average turbidity of 4.97 FNU, as compared to the final site at the Wilmington & Western crossing of 0.97 FNU. The pond often supports near complete algal growth coverage, and is open to wildlife inputs, both of which tend toward higher levels of turbidity and which stay in the water as it begins its trip downstream. For levels to drop so significantly by the time it reaches near its confluence means that there are very few additional inputs along the way and far more turbidity and suspended sediment is lost to settling or other removal than is gained from environmental inputs.

Looking more closely, turbidity levels do increase between the Barley Mill Rd. and Ramsey Rd. sites but this is misleading due to extremely high readings (outliers) at Ramsey Rd. About 71% (10 of 14) sampling days showed a drop between the two sites, showing a very dominant downward trend as the stream flows onward. The same cannot be said for between Ramsey Rd. and the Mt. Cuba Rd. site, although here site location likely plays a larger role. All of the locations were chosen in part for accessibility, but Mt. Cuba Rd. is one which flows directly under a road bridge and therefore is subject to all of the incoming waste and particles associated with automobile traffic. An earlier site, Barley Mill Rd., also is shortly after a road crossing but there the water flows into a pipe upstream of meeting the road and is protected by these pipes until it is ~5m on the other side of the asphalt. Therefore. a slight rise at the Mt. Cuba Rd. site is expected and does not detract from a noticeable downward trend in turbidity as the creek flows onward.

The last movement of water is to the Wilmington & Western RR site where the average drops to a minute 0.97 and 100% of the readings dropped from the previous location. This is some of the strongest evidence for a healthy, low-turbidity stream, as by this point levels from the origin at the pond have dropped to less than ¼ of their original levels. There is a potential for the population of samples here coming into play, as this site was the least accessible and closed on multiple trips. However, there are still enough sample points to show a definite lowering of turbidity levels compared to any other point on the stream. The high reading at this site is also a low 1.92, showing that the spikes seen across other sampling regions seem to have dissipated. Even despite the location under a train bridge (including one reading during/directly after a train rolled by) surrounding factors seem more than capable of lowering turbidity levels to the lowest levels on the stream. This is important going into the Red Clay Creek, where any remaining turbidity will add to the existing levels.

It is also worth noting the difference between average and median, which works to better ignore the impact of large outliers whether high or low. In many cases these levels wind up being similar as they are both measures of center, although for the Ramsey Rd. Tributary and Pond Outflow sites it removes the readings that were so far outside the others they pulled the averages up significantly.

Lastly, the variability in numbers is a strong argument for the long-term, consistent monitoring that will be undertaken moving forward at Hickory Run Creek. These grab sample numbers do provide a general baseline, but due to their snapshot nature it is impossible to determine true long-term trends. As evidenced by the spikes in different readings it is clear that short-term effects are having significantly more input here than long-term trends. To truly determine the effects of restorative efforts, long-term, comprehensive data needs to be collected and compared especially during storms and other climactic events.

Conductivity: Conductivity measurements taken through the summer, fall, and early winter of 2016 are summarized below (Table 6.2). While there are no local USGS or other reliable gage readings for conductivity it is important to note that these are useful even as standalone readings in part to establish the level of local inputs, as pure water in its chemical state is not conductive and therefore all conductivity is based on foreign inputs. Conductivity levels can also be related to chloride levels, and therefore continued measurement in this area could reveal levels of human input such as road salts.

Table 6.2 Hickory Run Conductivity (μS/m)

Date	W&W RR	Mt. Cuba Rd.	Ramsey Rd.	Ramsey Rd Trib.	Barley Mill Rd.	Pond	Pond Outflow
7/22/2016	140	150	130	150	110	100	100
7/28/2016	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8/5/2016	223	227	184	211	154	122	115
8/12/2016	215	223	180	215	149	130.5	116
8/19/2016		225	194	245	162.4		
8/26/2016	232	232	192	293	163		
9/2/2016		234	162	360	252		
9/15/2016	248	254	208	513	167	118	12
10/7/2016	214		183	340	142		
10/14/2016		230	175	395	137	137	117
10/28/2016	213	223	185	356	154	125	129
11/4/2016	134	231	141	471	124	134	128
Median	**214**	**228**	**183**	**340**	**154**	**125**	**115**

As there are no direct water quality parameters designating safe, or swimmable/fishable waters for conductivity, as well as no immediate adjacent measurements to compare to, conductivity levels taken from Hickory Run Creek therefore need to be evaluated in a different manner. The first and easiest comparison is to that of deionized water, which comes in around 5.5 µS/m. While the readings from Hickory Run Creek seem comparatively high, deionized water can be considered essentially as low as possible, and therefore these numbers need context for comparison. As a note the EPA reports its numbers in micromhos instead of microsiemens although they are considered equivalent with a 1:1 conversion ratio.

This is best found by comparing to national stream averages, which the EPA reports as a group to fall anywhere between 50-1500 µS/m. Using this as a reference it becomes clear that Hickory Run fall considerably toward the low side, falling in the bottom 10% of that range (<150) for 25/65 of the readings, and the bottom 25% (<325) for 59/65 readings. While again these are spot checks with a fairly low total population of 65 readings, that large of a grouping in the lowest end of national averages describes a largely unimpacted stream with a healthy ecosystem surrounding it.

Furthermore, the EPA reports that studies of inland fresh waters indicate that streams supporting good mixed fisheries have a range between 150 and 500 µS/m (U.S. EPA 2012). Again, this is a measure of the strength of the habitat within Hickory Run Creek as well as the ecosystem surrounding it, within which water quality is high enough to support healthy fisheries. Only one of the 65 readings comes in above this level, suggesting that while the creek itself is not large enough to support large fish populations, smaller species are able to survive there, as well as macroinvertebrates. Furthermore, this healthy condition flows into the Red Clay Creek which can support larger fish populations, where these low conductivity readings will have more of an impact.

Similar to turbidity, the conductivity levels throughout Hickory Run Creek are also subject to the lack of volume in that excess inputs from nutrients or other pollutants will have a larger effect on conductivity levels simply due to the smaller water volume. With less dilution possible any input will be exaggerated, its effects creating spikes in readings. While there are some larger numbers, the majority of them come from the Ramsey Rd. tributary site, an extremely low-flow tributary that was almost stagnant, and therefore susceptible to larger fluctuation and levels due to a lack of flushing. The fact that many of the numbers remained low speaks to the health of the creek.

The last takeaway from these readings is the clear growth in levels from where they begin near the Pond through the Wilmington & Western Railroad site, where numbers are higher across all of the sampling dates. This conclusion eliminates one of the drawback of spot sampling as all of these sites were tested within a small window of time, and therefore conditions were likely almost identical. It is clear then that while Hickory Run Creek flows through heavily forested regions, there are still inputs adding to conductivity levels rising before reaching the Red Clay Creek.

This does not necessarily mean that pollution levels are high beyond natural levels, however, as some sort of input is to be expected. This presents an opportunity for more comprehensive monitoring to be able to easily identify increases in conductivity levels and therefore link them back to specific events when they occur, especially if there are steady increases over time as restoration occurs.

6.2 EPA Rapid Stream Habitat Bioassessment

The EPA Rapid Stream Habitat Bioassessment, as discussed above, is used in an effort to better connect overall habitat and environmental conditions to stream characteristics and quality. Table 6.3 summarizes the results of this assessment applied every 500 ft along Hickory Run with 3 standards applied, as the assessment rates scores 16 and above as Optimal, from 11-15 as Sub-Optimal, 6-10 as Marginal, and 1-5 as Poor.

Table 6.3 EPA Rapid Stream Bioassessment Summary

Hickory Run																	
Parameter/ Station	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Substrate	18	15	16	20	15	10	9	17	15	14	19	15	5	18	20	10	19
Embeddedness	8	17	16	17	18	17	16	18	5	10	17	13	2	17	13	15	18
Velocity	13	15	14	18	13	10	14	10	5	15	15	10	15	17	10	5	5
Sediment	3	13	16	19	20	14	15	12	20	7	13	5	17	10	8	12	17
Channel Flow	13	18	18	14	18	16	17	12	20	11	17	20	20	5	8	3	7
Channelization	20	12	20	20	20	20	20	19	15	3	18	19	20	20	20	20	20
Ripples/Bends	18	13	15	19	19	18	18	19	7	8	17		8	7	13	10	10
Bank Stability	20	9	17	20	18	18	17	14	19	20	11	17	20	18	15	15	17
Bank Vegetation	20	20	20	20	20	20	20	20	15	16	17	20	20	20	18	20	20
Riparian	20	20	20	20	20	20	20	18	16	15	15	20	20	20	20	20	19
Habitat Total	**153**	**152**	**172**	**187**	**181**	**163**	**166**	**159**	**137**	**119**	**159**	**139**	**147**	**152**	**145**	**130**	**152**

Substrate: The first parameter of the EPA Rapid Stream Habitat Bioassessment, substrate, shows that Hickory Run is, for the most part, in the Optimal to Sub-Optimal Range (Figure 6.1). This conveys an overall average to above average stream where substrate is concerned. This is likely due to the smaller stature of the stream itself, wherein much of the larger logs or other debris that make their way into the stream stay there as there is not enough water flow to physically move them downstream. It does create a vulnerability to larger storms, however, which could more easily change the makeup of the local substrate more easily. Because the stream is smaller and more easily filled with debris that may serve as breeding grounds or protection for smaller species, this debris may change storm to storm and these scores could potentially shift.

This is one of the areas very susceptible to any restoration or native plant reintroduction that may occur as the physical movement of plants and debris will undoubtedly result in more of it winding up in the water. In an extreme case it could begin to build upon itself and causing a damming effect on the water itself, although this would likely necessitate a large amount of debris to fall in a small area. If the reintroduction of native plants results in higher brush levels this could have the opposite effect, however, and this added brush or shrubs, etc. could act as a catch-all and restrict some of the debris from making its way into the water.

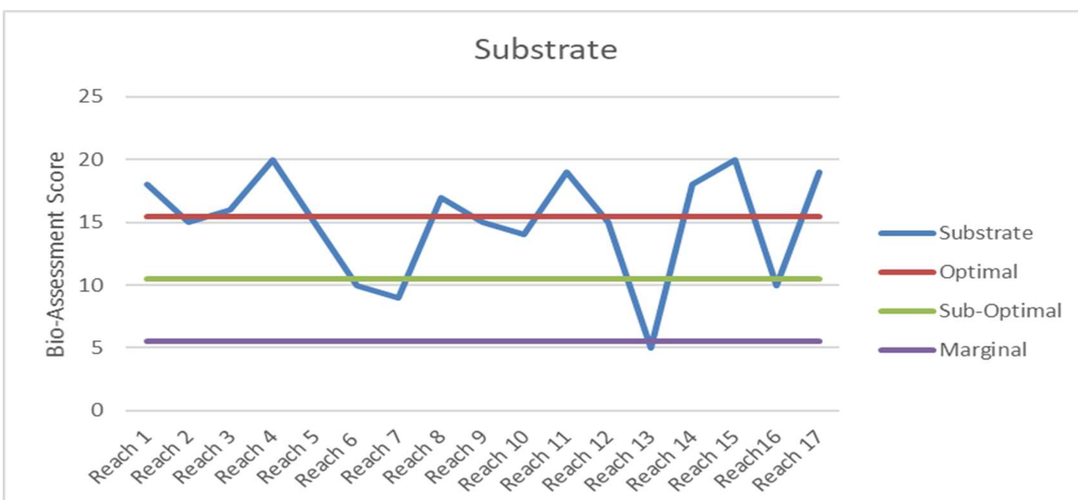


Figure 6.1 Substrate

Embeddedness: Despite individual reaches scoring poorly the embeddedness of Hickory Run Creek, as measured by the EPA's standards, is very healthy (Figure 6.2). There is a mixture of materials, with submerged vegetation, roots, and larger rocks present. Where the bottom is made of finer materials, the sand or gravel tends to be hard packed, and seemingly more stable. This is likely due to the lower flow in many areas, which would be incapable of removing sediment at a higher rate, and therefore existing levels become compacted as they settle. Additionally, as sediment is transported the largely untouched nature of the stream, which shows little channelization and is extremely bendy, could account for the build-up of what sediment exists in the few lower scoring areas as flow speeds decrease further to navigate the twisting paths.

The effect of the restorative work at the Mt. Cuba Center on this parameter is likely to be on the lower side, as much of the alteration of plant species is focused on land-based vegetation. Many of the larger species, whose roots have the size capacity to be counted in this measurement, are also likely to be left untouched and therefore their impact on the waters will remain the same. As with most categories the physical disturbance caused by restorative efforts could have an impact in the short-term as debris and sediment is flushed into the water, although larger impacts will likely be minimal.

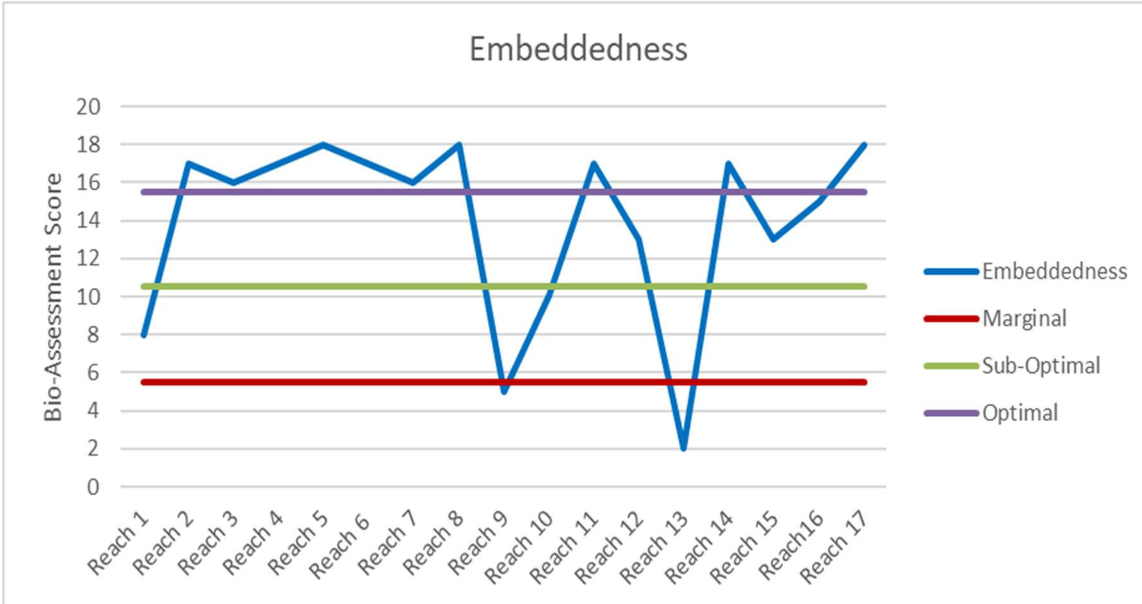


Figure 6.2 Embeddedness

Velocity: Hickory Run's velocity scores tended to be in the low to mid-range, averaging just above Suboptimal at a 12 (Figure 6.3). When examining the possible reasoning behind this the method of analysis seems to play a larger role, with scoring largely being determined by whether specific types of stream flow speeds were present. As with many of the other parameters this is likely due to the low-flow dynamic for much of the stream, as there is simply not enough water to incorporate different flow dynamics within one specific area. Additionally, as Reach 9 shows lower scores on both Embeddedness and Velocity, since stream geometry, or a higher presence of bends surrounding the site could be altering flow patterns and forming a singular movement speed in this region.

Velocity is also an area likely unaffected by restorative work undertaken at the Mt. Cuba Center. The largest limiting factor in velocity scoring was the lack of total water flow which limited the types of velocity patterns that could develop in any one area. Runoff patterns may change over time as native plants are reintroduced and invasive species removed, especially in the riparian zone surrounding the water, although the total volume of inputs will likely remain too low to significantly change these scores.

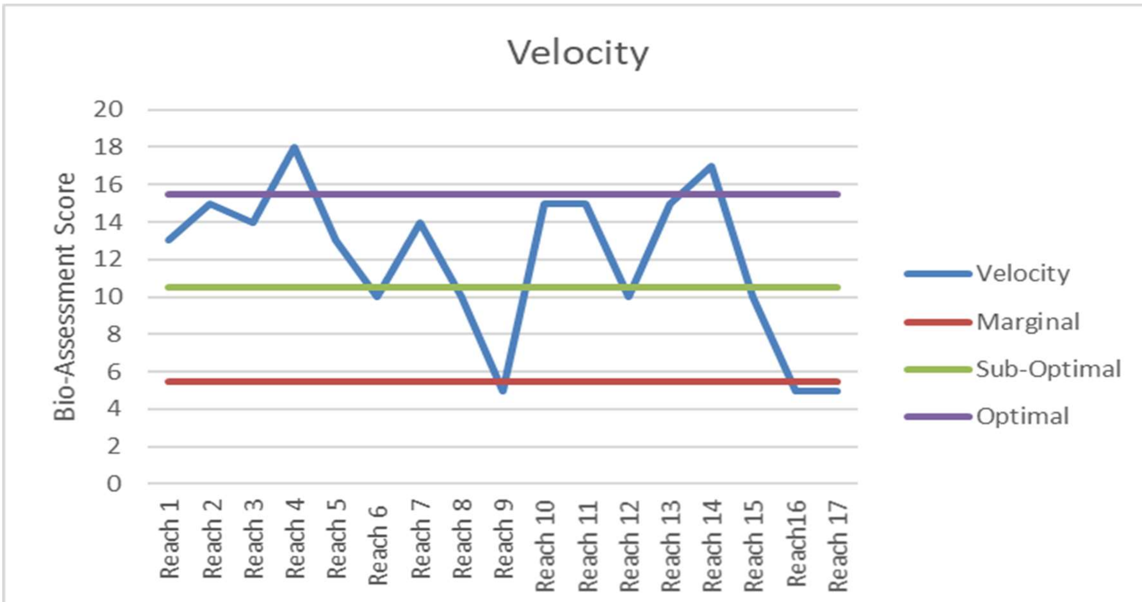


Figure 6.3 Velocity

Sediment Deposition: Sediment deposition for the Hickory Run Creek had a nearly even breakdown of scores, increasing the likelihood that this parameter was very site-specific (Figure 6.4). Similar to substrate characterization, sediment deposition adds a measurement of total surface area disturbed by islands or point sediment/sand bars. In some cases, these surface point bars could have developed around a larger object which then caught passing sediment, and may not be directly related to stream-based factors except that depth was shallow enough to allow this build-up to break the surface.

Subsurface (below water) sediment deposition was also considered and areas with lower scores, again, are likely to show where flow speeds slow and allow sediment to settle. The variability of scoring clearly visible in the graph could indicate an altering between fast and slow areas as one moves downstream with sediment being picked up in one region, dropped the next, then picked up again and repeated.

Sediment deposition is one area that may become more heavily impacted as planned restorative efforts are undertaken at the Mt. Cuba Center due to the physical disturbance leading to an increase in sediment inputs. These additional sediment levels will likely exaggerate ratings in areas which are already poor, as sediment build-up increases along barriers and existing sand/gravel banks. Short-term effects are highest over time as these sediment build-ups are eroded and moved downstream with natural erosion and deposition patterns.

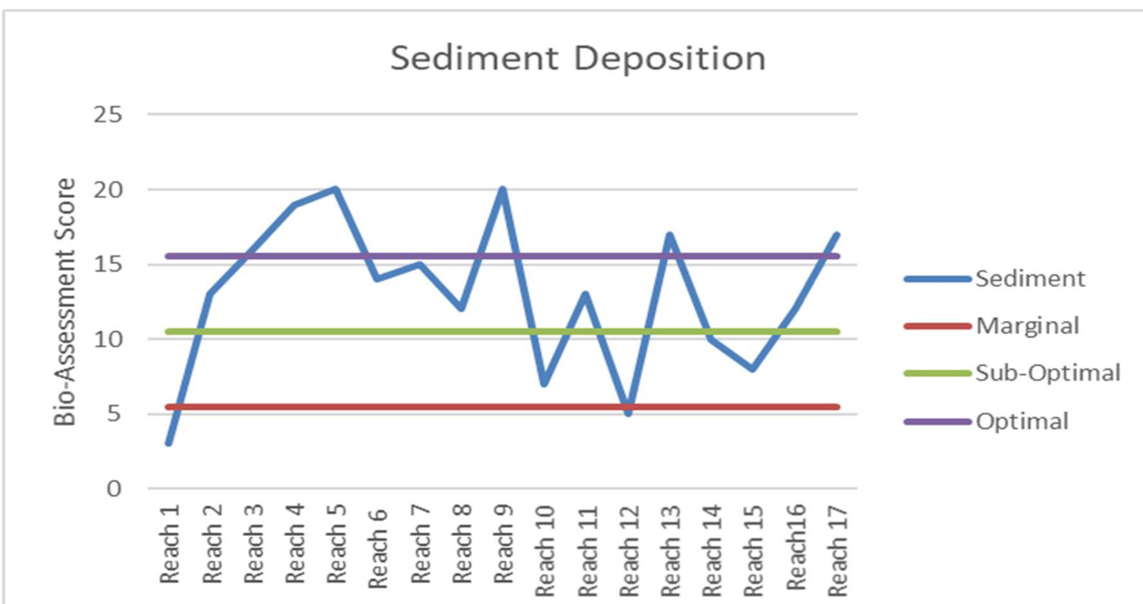


Figure 6.4 Sediment Deposition

Channel Flow Status: As the graph above indicates, the channel flow status of Hickory Run Creek is fairly strong for the beginning majority of the creek, but as one moves back toward its headwaters, the scores drop significantly (Figure 6.5). Additionally, there is a noticeable increase in slope in these reaches, lending to a faster flow rate, which also leads to lower water levels. These two inputs combined likely lead to less available water to fill the stream, and therefore the water will not reach as far across the stream (resulting in more bank exposed), as well as a likelihood that substrate or sediment build-up (sand bars) will breach the shallower surface.

Sediment input may vary as work moves locations and, similar to other parameters, buildup will be exaggerated in locations already suffering high levels. The overall pattern will remain the same, however, as water inputs will continue to increase as it moves downstream, and the slope flattens out to result in low velocities.

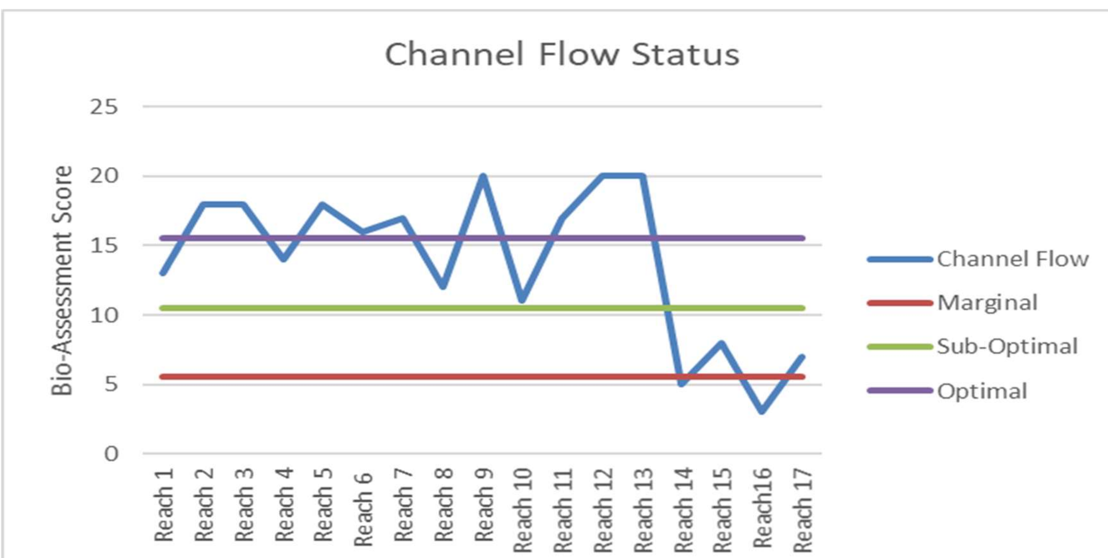


Figure 6.5 Channel Flow Status

Channelization: Channelization, also known as channel alteration, is one of the areas where Hickory Run truly benefits from running through grounds as pristine as the Mt. Cuba Center's (Figure 6.6). The two reaches that scored as sub-optimal flowed near the railroad crossing and road undercut and had light influence, but largely still held to a generally natural flow pattern. The one reach which scored poorly came near the entrance to the Mt. Cuba Center's headquarters from Barley Mill Rd. at an area which was divided into man-made levels and channeled by stacked stone and concrete to create a uniform lowering of water across four different levels. Here channelization was evident, although short-lived and soon returns to a natural flow pattern.

The amount of influence restorative work will have on channelization scores depends entirely on the type of work done, and how much, if any, alteration is undertaken on the stream itself. If the work requires rerouting the stream in any areas, or dredging to allow a new flow pattern, then influence could be high at individual reaches.

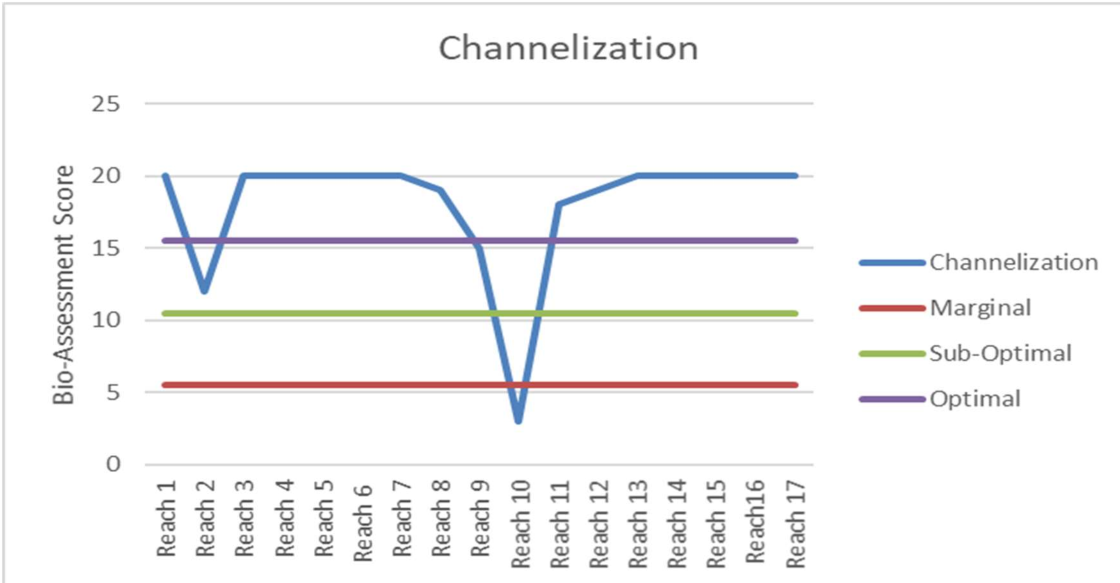


Figure 6.6 Channelization

Riffles/Bends: Riffle or bend frequency attempts to give a score to the amount Hickory Run meanders naturally through its environment, and therefore scores are very individual and likely cannot be related from one reach to the next (Figure 6.7). Geographic and landscape inputs play the largest role here, although anthropogenic channelization would also lower a score.

Because this parameter is so highly dependent upon site-specific inputs, the level to which restorative work at the Mt. Cuba Center will affect it is hard to predict beforehand. If work is heavy at one site then the score will likely change drastically, while reaches which experience little to no restoration will remain largely unchanged.

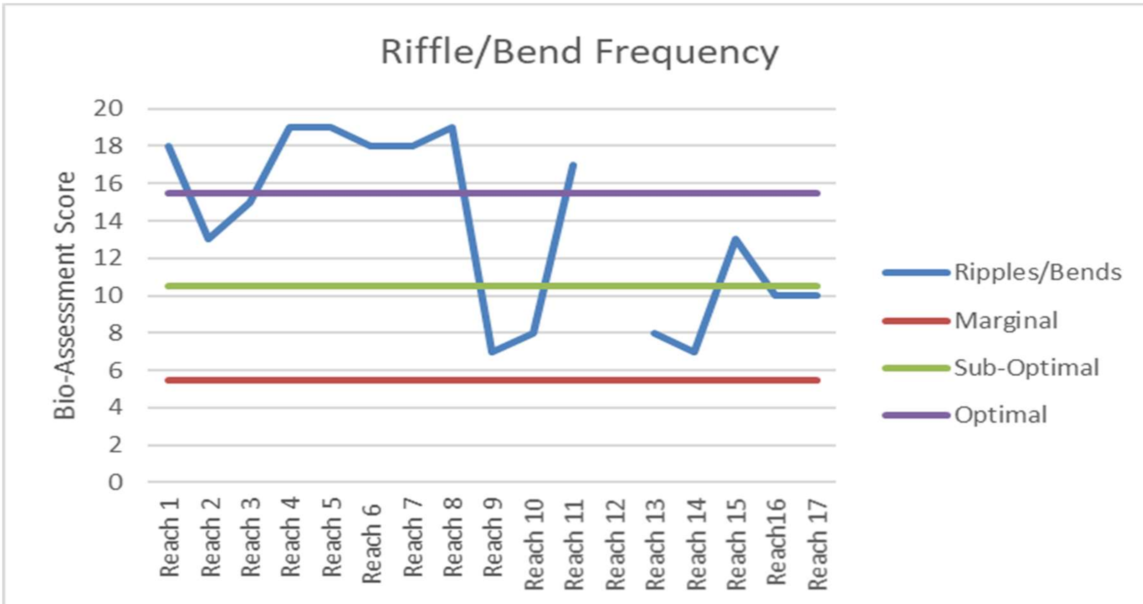


Figure 6.7 Riffle/Bend Frequency

Bank Stability: The bank stability along Hickory Run, as shown through the very high percentage of Optimal scores, is extremely strong (Figure 6.8). This is the first of the parameters where each bank is measured independently on a 0-10 scale and added together, so that one side cannot solely alter an overall rating. The most likely contributing factor to this strength is its overall low-flow compared to the bank size moving down the stream. Banks often rise 1-2 ft above observed base flow conditions, but are wide enough and gradually sloped at the bottom to allow for low impact of the water itself on the vertical sections. This is more apparent in the cross-section maps, which show how even as base flow rises during storm events, it takes a large scale storm for levels to rise beyond the gently sloping areas and physically begin impacting the more vertical banks. This is not true in all areas, however, as the two lower scores show that local conditions still play a large role here. Uprooted trees and other disturbances can, and do, cause immediate impact, and increase erosion rates against otherwise near pristine banks.

Bank stability and erosion may be impacted by the planned works across Mt. Cuba in two main ways. The first is a direct impact through the removal of invasive species that may have taken root along the banks, as with their removal comes a loss of roots which provide stability, plus the physical act of removing the plants which will undoubtedly destabilize the soil and increase the rate of erosion. If a large enough storm were to come through directly after this work was undertaken, entire bank sections could be washed away and flow patterns could be permanently altered. The second route is less direct but no less potentially impactful, and comes as runoff and flow patterns change further from the stream itself. If the input of native species, or the removal of invasive species, drastically alters ground conditions or slope it could create channelization of runoff waters, which, as they reach the stream, could begin eroding a bank from the outside in. As this occurs it will further allow stream waters access through newly lowered sections to the bank, and further raise the effects of erosion. This is a prime example of the need for long-term data in areas of restoration such as Mt. Cuba, as these effects may not be seen immediately and any trends could expose themselves over months or year-long time periods, not within immediate grab samples.

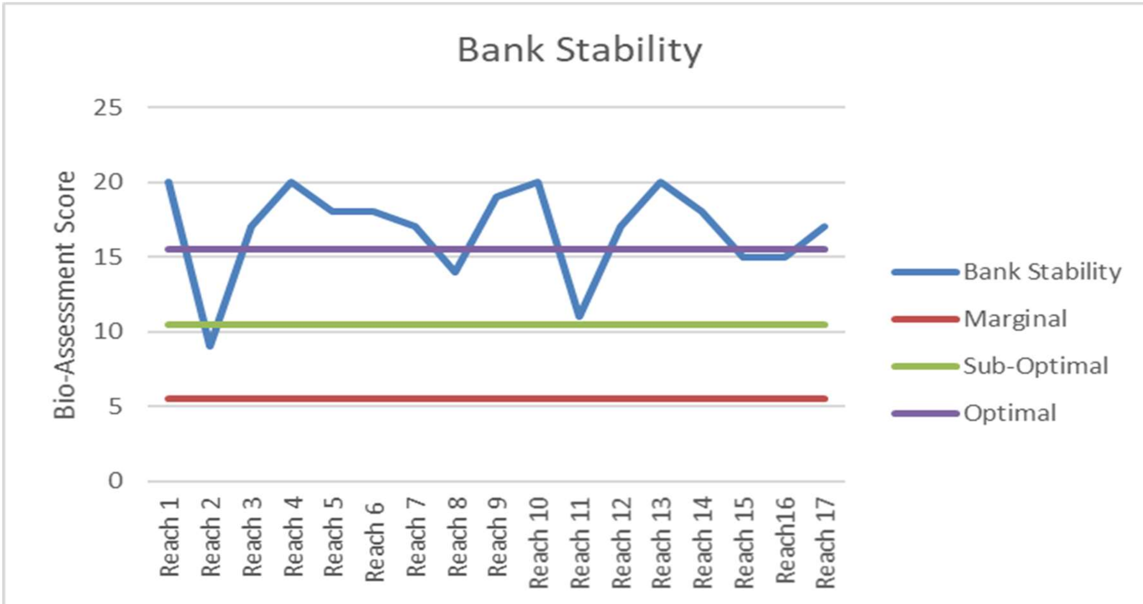


Figure 6.8 Bank Stability

Bank Vegetation: Throughout Hickory Run Creek much of the stream bank has some form of local plant growth, and this combined with a low level of water at base flow leads to strong, sturdy banks which is held up by extensive root systems (Figure 6.9). These root systems help stabilize local conditions and remove excess nutrients and potential pollutants from runoff that would otherwise wind up directly in the stream itself. These nutrients are essential for plant growth and in a sense symbolize the interconnectedness of an ecosystem as a whole. The EPA Bioassessment categorizes Optimal scores as having 90% of the bank covered in vegetation of some kind, preferably a combination of shrubs, trees, and grasses. While there was a much higher majority of grasses and small shrubs across Mt. Cuba's riparian zones, in most of the reaches there were enough larger trees and shrubs either directly on the bank or within the riparian zone to be counted as beneficial. However, the two lower scoring reaches do show the ability of local disturbances to have a large impact here. In some places larger plants had been uprooted, including trees, and their appearance along a bank can drastically lower the stability at that point. This includes the removal of their roots from the bank structure, which means the surrounding area may be collapsing.

The influence of the Mt. Cuba Center's restorative work will, as with other parameters, largely depend on location. If native plant reintroduction occurs along the riparian buffer, there is a high likelihood that the loss of existing root systems will result in a loss of bank stability long before the new plants have time to adequately establish their own roots. Additionally, the buffer these plants provide for nutrient and pollutant removal may be largely hampered by plant upheaval or removal entirely. This may be the most relevant connection to the question being asked throughout this study, as new plant species will undoubtedly have a differing impact on the ecosystem's ability to filter incoming runoff, whether more efficient or not remains to be seen. The results from ongoing water monitoring will be used directly to answer this question and hopefully lead to a better understanding of whether native species were more, less, or equally useful when it comes to nutrient and other toxin removal from runoff waters. The work itself will also be evaluated and while these effects will be seen on a more short-term scale. How waters become heavily impacted will help future planners account for these impacts when designing conservation or restoration work in similar habitats.

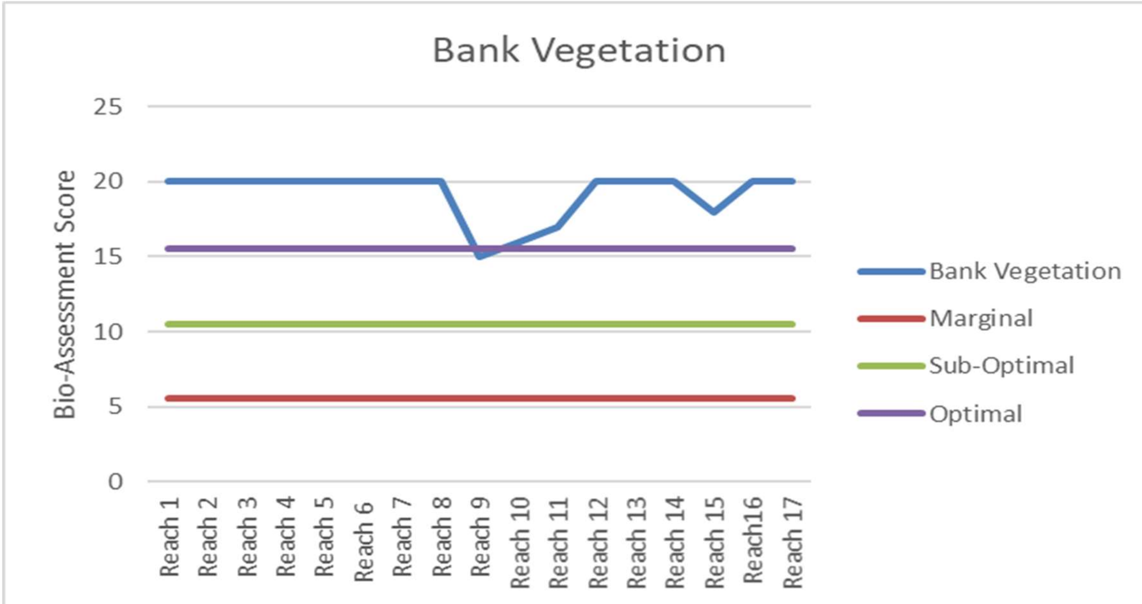


Figure 6.9 Bank Vegetation

Riparian Zone: The riparian zone parameter is judged completely on the width of a natural band of area surrounding the stream, and in an area such as Hickory Run Creek at the Mt. Cuba Center in almost all the reaches this zone was well beyond the desired 18m width (Figure 6.10). In the sections that were not scored as 20/20 it is clear through the trends on the graph that the stream leaves the confines of a heavily forested area, a human-maintained lawn area emerges, and the stream then flows up near and under Barley Mill Rd. before heading back into the forest. The lowest scores still come in around a high Suboptimal range, which puts the riparian buffer closer to 12-18m and therefore still provides some cover for the stream in all areas except where it flows directly under the road. This undercut is covered by pipes which, intentionally or not, help keep some of the pollution from reaching waters before the pipes open back up.

As far as impacts from the Mt. Cuba Center's restorative work are concerned, any felt here will be a direct impact of invasive removal or native reintroduction. This parameter measures a physical component of the land, and therefore will be largely affected if work is undertaken within this 18m zone. There is a smaller potential impact if work elsewhere changes nutrient or input availability to plants within this zone which may then be outcompeted for resources, although that will be more gradual and will likely allow time for new plants to move in. Even in this case the physical width of the riparian zone will remain intact unless building is undertaken which cuts into it, and it will still officially qualify as a buffer.

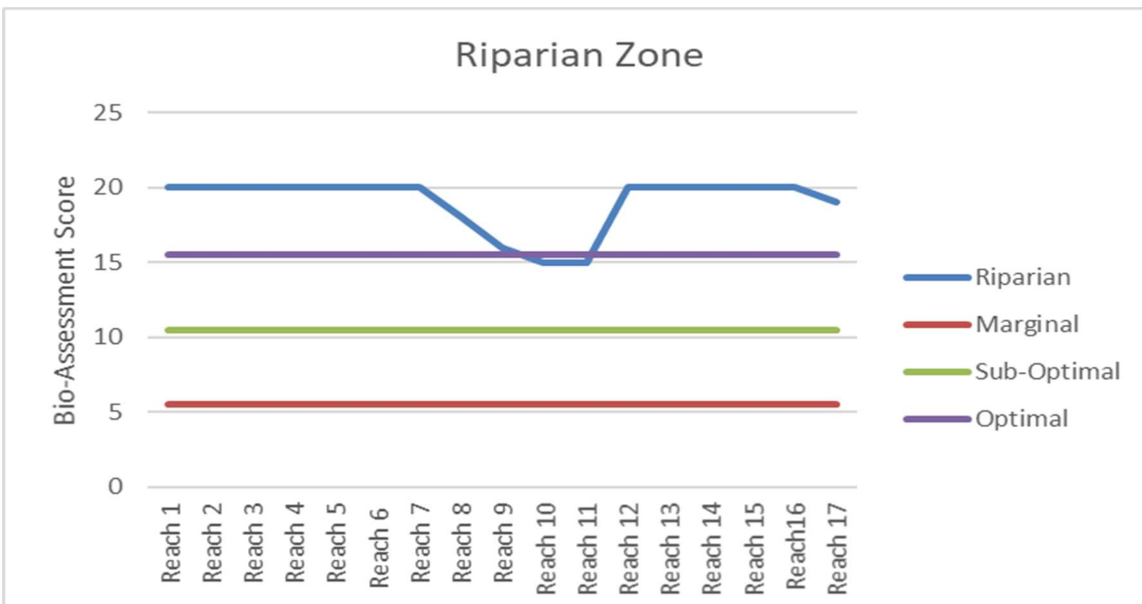


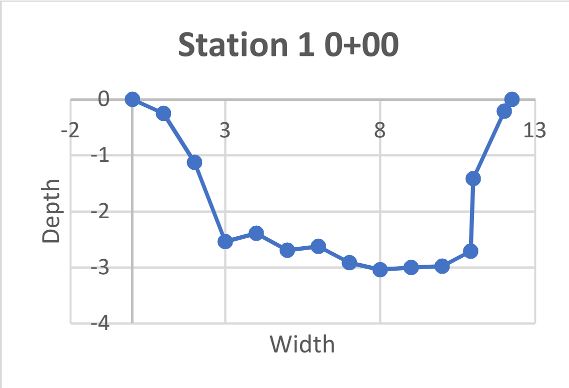
Figure 6.10 Riparian Zone

Cross-Sections: As described above, cross-sections were taken at 500ft intervals along Hickory Run Creek, and this data was then turned into 2-D renderings of the creek itself using Microsoft Excel (Figure 6.11). The strengths of these analyses are their ability to show how extremely micro-level, localized inputs have an effect on the creek itself. This analysis is strengthened by a summary of the EPA Rapid Stream Habitat Bioassessment done at that location, combining physical stream characteristics with their surrounding habitat in an easily digestible visual manner.

Additionally, a station by station breakdown of the EPA Rapid Stream Bioassessment has been included for reference against the physical cross-sections (Figure 6.12). For an in-depth analysis, three have been chosen for their unique shape or scoring, and described below to show the effect of surrounding habitat on local conditions.

While the examples below go into minute detail for individual station examples, the structure of the creek is fairly uniform with distinct bank structure at all except three or four of the stations. There are larger rocks strewn throughout the stream and many of these can be seen as explanations for the raised sections in the middle of the stream bed, which go against the common structure seen through the length of the creek.

There is a general trend that emerges from the habitat assessment, wherein the headwaters of Hickory Run Creek, or the higher numbered stations, often fall short in some of the parameters being measured. Taking these results and comparing them to the 2-dimensional cross-sections it becomes apparent that depths are generally lower in this region, and therefore smaller changes are more likely to have larger impacts. As the creek flows through more of its watershed and total volume increases these same impacts may have less of an effect, or be more easily mitigated by deeper water and larger surrounding environments. As it returns to more heavily forested areas set back from even the nearest road, scores increase, and the stream is generally considered healthier as it approaches the Red Clay Creek.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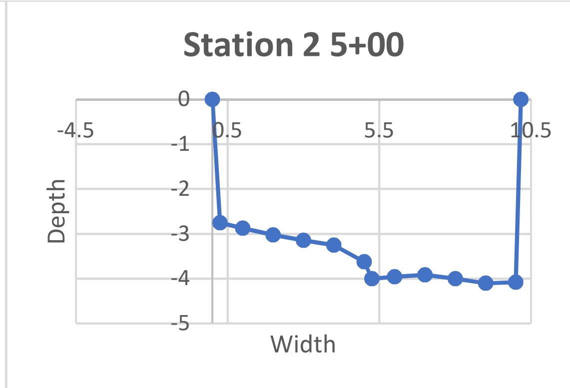
0
-1
-2
-3
-4
-2
3
8
13
Depth
Width


Station 2 5+00
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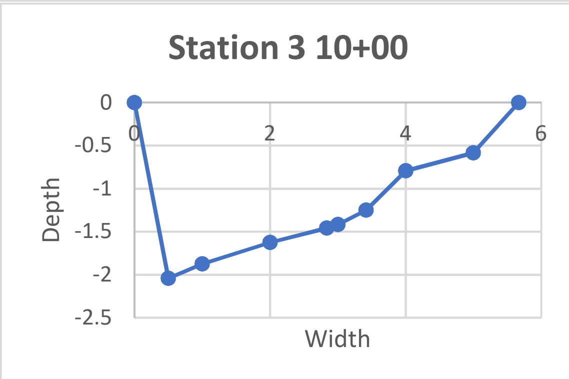
-2
-3
-4
-5
-4.5
0.5
5.5
10.5
Depth
Width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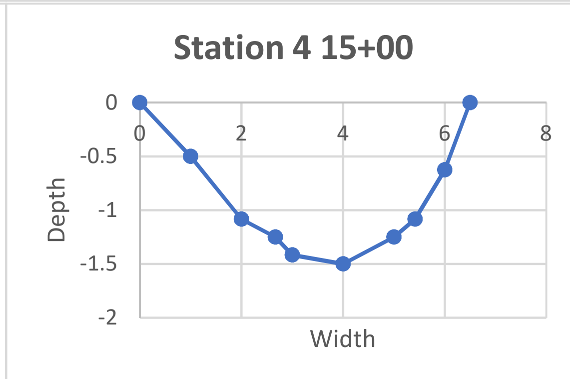
-1.5
-2
-2.5
0
2
4
6
Depth
Width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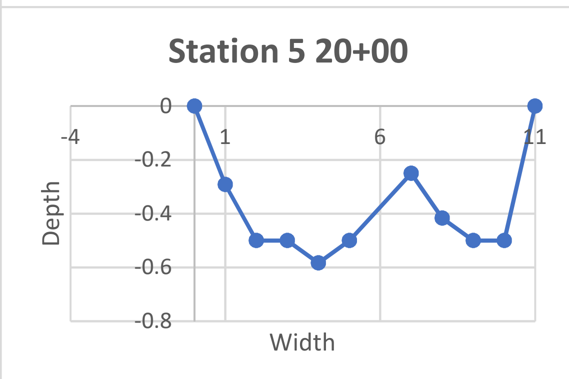
-1.5
-2
0
2
4
6
8
Depth
Width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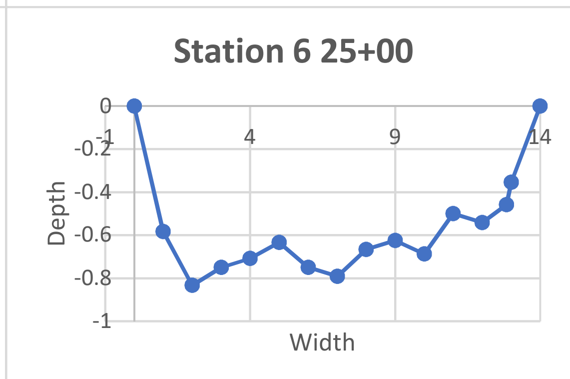
-0.4
-0.6
-0.8
-4
1
6
11
Depth
Width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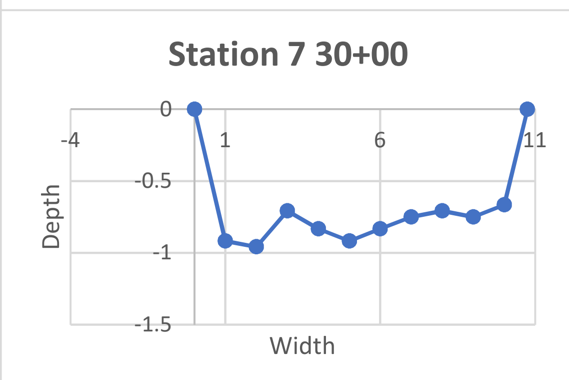
-1
-1
4
9
14
Depth
Width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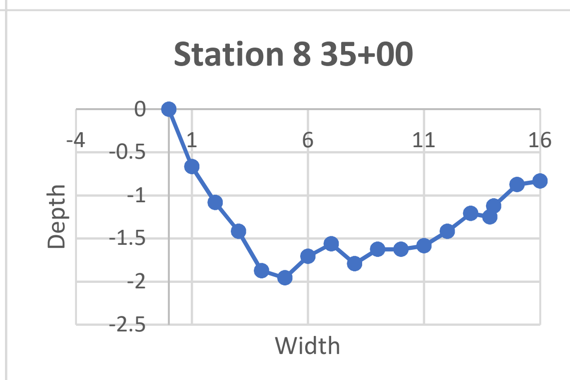
6
11
Depth
Width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-1.5
-2
-2.5
-4
1
6
11
16
Depth
Width

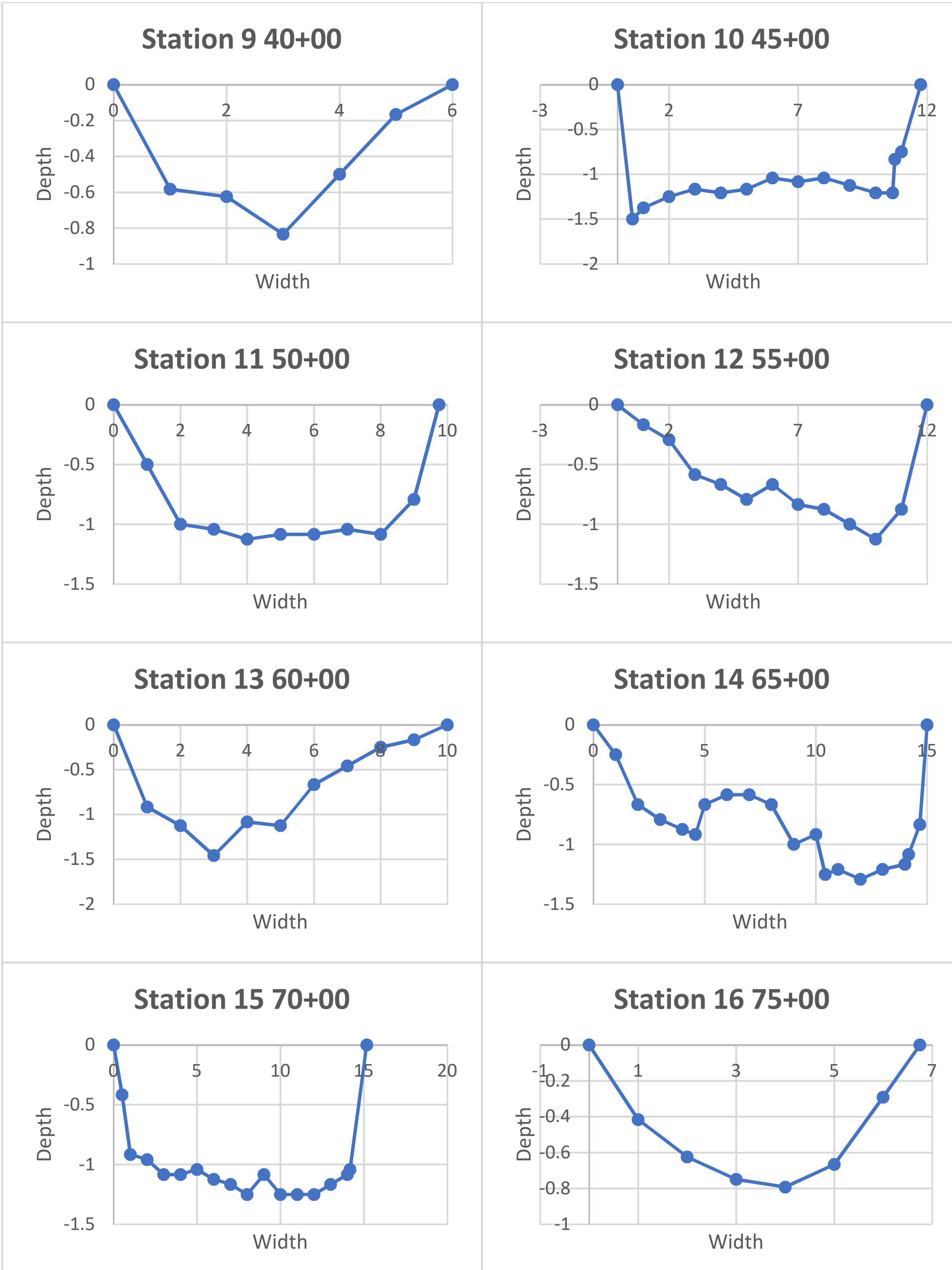
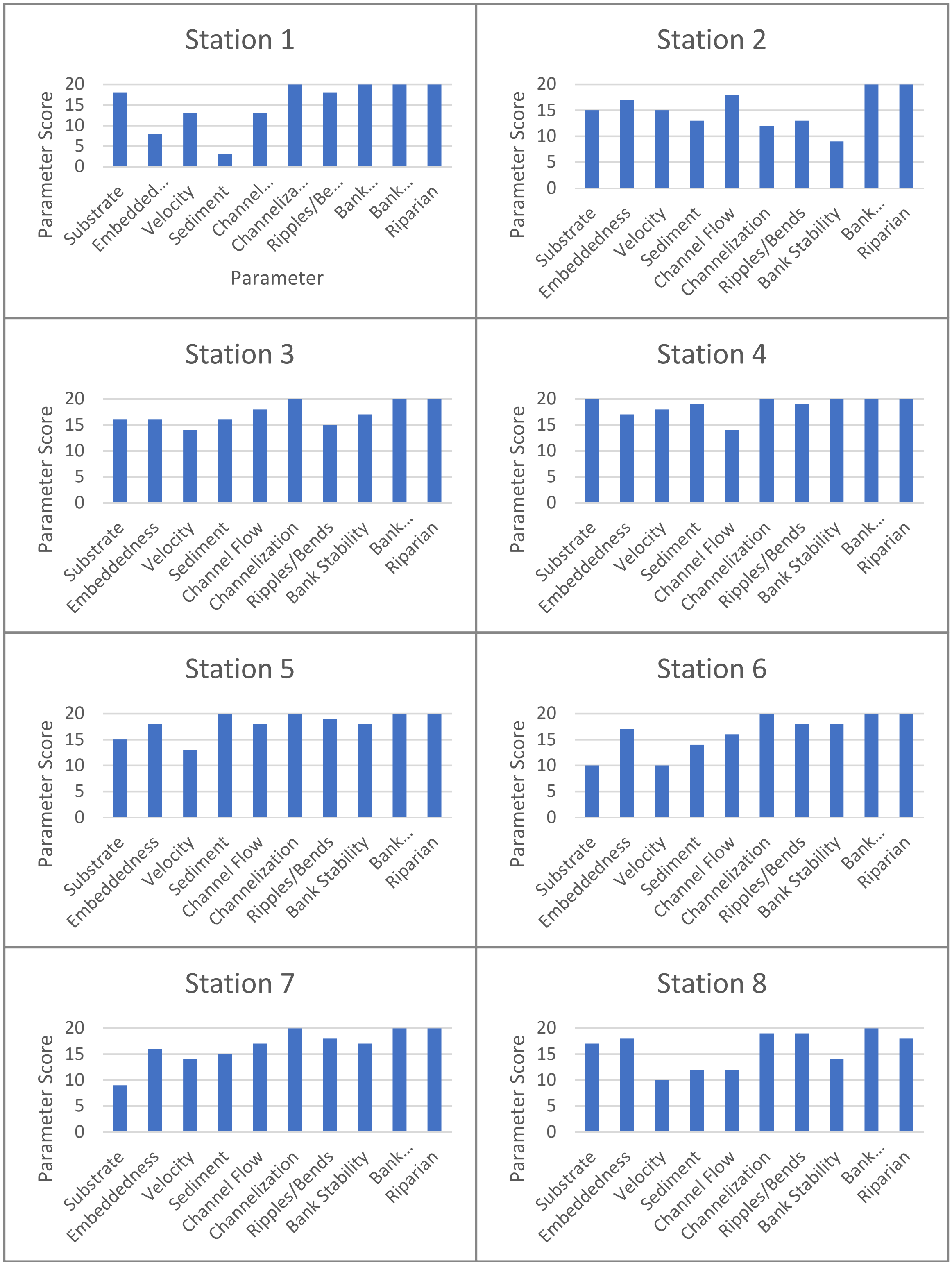


Figure 6.11 2-Dimensional Cross Sections


Station 1
Parameter Score
20
15
10
5
0
Substrate
Embedded...
Velocity
Sediment
Channel...
Channeliza...
Ripples/Be...
Bank...
Bank...
Riparian
Parameter
Station 2
Parameter Score
Substrate
Embeddedness
Velocity
Sediment
Channel Flow
Channelization
Ripples/Bends
Bank Stability
Bank...
Riparian
Station 3
Station 4
Station 5
Station 6
Station 7
Station 8

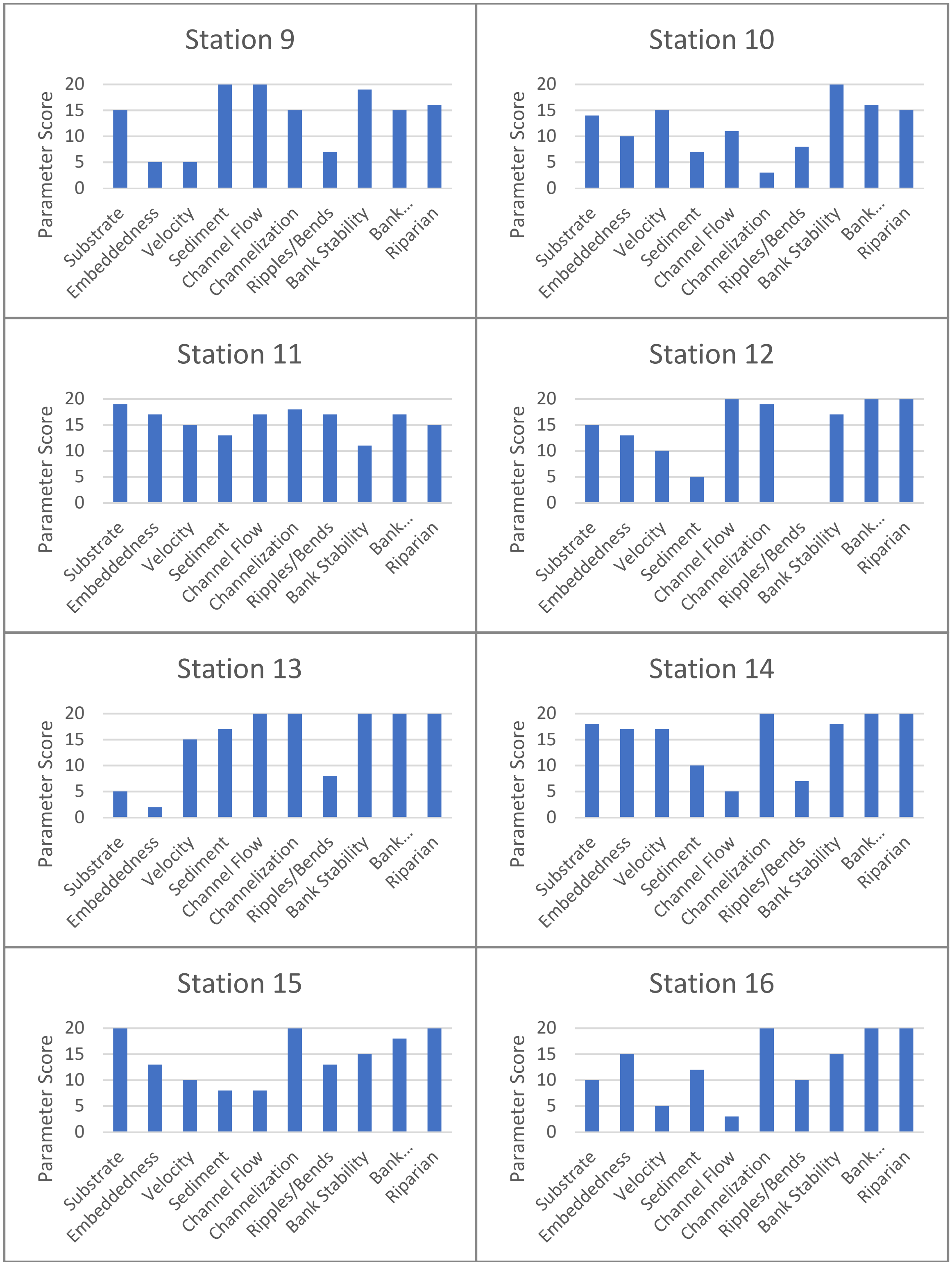


Figure 6.12 EPA Station Parameter Scores

Station 0+00: The first reach was examined directly at Hickory Run's confluence with the Red Clay Creek, and was clearly influenced by the larger creek's flow. The water flowing across Hickory Run's opening mixed with the Red Clay to create a sort of pooling effect which caused sediment to across the bottom, although slightly higher to one side (the left side on the graph). The Red Clay flow had clearly widened the opening, although both banks now are stable and have high stability thanks to vegetative growth. Embeddedness and sediment scores are lower likely due to the settling of sediment moving down the Red Clay. The velocity score is, again, affected by the faster moving waters of the Red Clay mixing with the slower moving waters of Hickory Run, and waters may not have been reaching both banks just upstream of the confluence as the effects of the Red Clay have worn off and flow is primarily coming down from Hickory Run Creek.

Station 45+00: As the creek approaches reach 10 it enters the most anthropogenically-influenced, and therefore lowest scoring, section of the stream. Channelization at this point is extremely high, as the creek has been squared away within rock walls on both sides and built in three levels as the water makes its way through constructed areas that almost represent locks moving downstream. This accounts for many of the low scores, as the hard-surfaced sides and bottom force a very small layer of sediment bottom. While one side of the stream is deeper than the other at the cross-section point the bottom was clearly man-made, in concert with the walls. There are actually a few bends just after the channelized section which gains a few points back in that category, and bank stability is the saving grace points-wise as the walls themselves are very sturdy and represent an extremely low risk of any type of erosion. While the guaranteed wide width here allows for some embedded objects its proximity to the road and inaccessibility due to no real path for fish to swim upstream keeps wildlife levels low.

Station 65+00: Reach 14 is unique in that there is a large, discernable island made out of built up sand and other sediment. As the cross-section shows there is a roughly 3' wide island that rises above the water line, and a deeper valley paralleling it leading into the other bank. This island is stable enough to have vegetative growth that has sprung up along it, whose roots likely help hold it in place against erosion that would otherwise wipe it form the surface. On the one hand this proves problematic for ensuring even, consistent flow patterns and sediment movement downstream, but it does slow flow patterns and keep sediment that may be problematic downstream in one place. This island accounts for the low channel flow and sediment scores and although there is a lack of ripples/bends in the area being surveyed, the island may help keep speeds down and lower erosion, almost like a traffic circle does on a busy road.

6.3 Long-Term Monitoring

Long-term water quality monitoring is established at the Western & Wilmington monitoring site along Hickory Run Creek and will continue during non-freezing months for the foreseeable future – aimed at a decade or more of continued research using the current equipment setup. Readings have been collected up to this point for two reasons – establishing a baseline level for current conditions, as well as a proof of concept that these pieces of equipment can be relied upon to provide strong, useful data for the coming future (Table 6.4, Table 6.5).

Table 6.4 Discharge Data Return Sample

Sample time	Area (m^2)	Depth (m)	Flow (m^3/s)	Temp. (°C)	Volume (m^3)
6/9/2017 12:09	0.36	0.11	0.01	15.80	0.58
6/9/2017 12:24	0.36	0.11	0.01	16.05	11.30
6/9/2017 12:39	0.36	0.11	0.02	16.33	27.70
6/9/2017 12:54	0.36	0.11	0.02	16.80	44.17
6/9/2017 13:09	0.36	0.11	0.02	16.97	58.19
6/9/2017 13:24	0.36	0.11	0.01	17.02	70.49
6/9/2017 13:39	0.36	0.11	0.02	17.47	82.49
6/9/2017 13:54	0.36	0.11	0	17.46	82.49
6/9/2017 14:09	0.36	0.11	0.02	17.56	91.34
6/9/2017 14:24	0.36	0.11	0.01	17.45	105.70
6/9/2017 14:39	0.36	0.11	0.02	17.46	119.66

Table 6.5 Turbidity Data Return Sample

TOA5	CR300 Mt Cuba RR Bridge	CR300	4384	CR300.Std.0 5.01	CPU: 15 Min RR Bridge CR300	Output
TIMESTAMP	RECORD	P Temp C	BattV	Turb NTU	TurbNTU	TurbNTU
TS	RN	Deg C	Volts	NTU	NTU	
2017-06-24	94	27.71	12.55	-0.14	-0.14	0.14
2017-06-24	95	28.47	12.55	-0.14	-0.14	0.14
2017-06-24	96	29.36	12.55	-0.14	-0.14	0.14
2017-06-24	97	29.75	12.55	-0.14	-0.14	0.14
2017-06-24	98	29.42	12.55	-0.14	-0.14	0.14
2017-06-24	99	29.14	12.55	-0.14	-0.14	0.14
2017-06-24	100	28.52	12.55	-0.14	-0.14	0.14

From this raw data baseline readings can begin to evolve over time and with the addition of local precipitation data comparisons can be drawn to help establish the effect of incoming water on stream conditions, as well as the long-term effect of the Mt. Cuba

Center's restorative work. This additional precipitation data comes from the Delaware Environmental Observing System (DEOS) at their Winterthur location, a nearby station to the Mt. Cuba Center monitoring site.

For the sake of providing an example data was retrieved for both parameters in question, discharge and turbidity, and precipitation data was taken to match. From there 2 storm events were chosen for which data is available across all three parameters on June 27, 2017 and September 6-7, 2017

To establish a basic idea of baseline levels an average of data across slightly more than a month, June 9 – July 13, were taken. As a note these are purely unmanaged readings, with only missed (N/A) or negative readings removed. These were taken out to due to technical failure and therefore should not be considered. While they are still representative of a relatively small sample and need to be continually updated, it is useful to measure baseline readings as follows: Discharge (1.18 cfs) and Turbidity (0.13 NTU).

To demonstrate the analytical strength of these monitoring efforts, the July 27 (Figure 6.13, Figure 6.14, Figure 6.15), and September 6-7 (Figure 6.16, Figure 6.17), storm events are represented through graphs below. Included are comparison graphs relating turbidity to precipitation levels as well as discharge to precipitation levels during the same events:

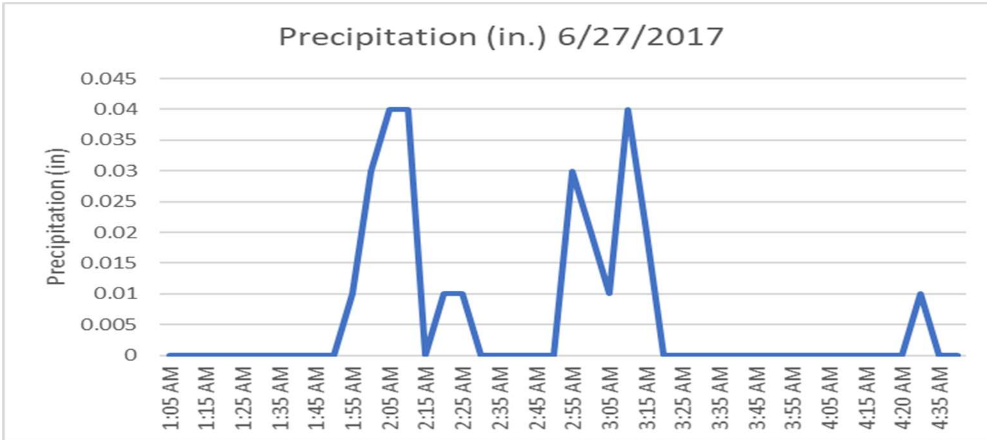


Figure 6.13 Precipitation at Winterthur (June 27, 2017)

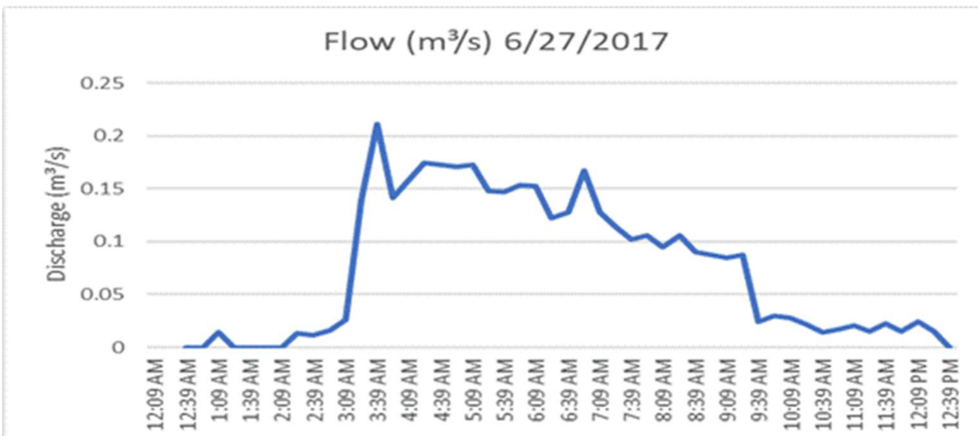


Figure 6.14 Hickory Run Discharge Readings (June 27, 2017)

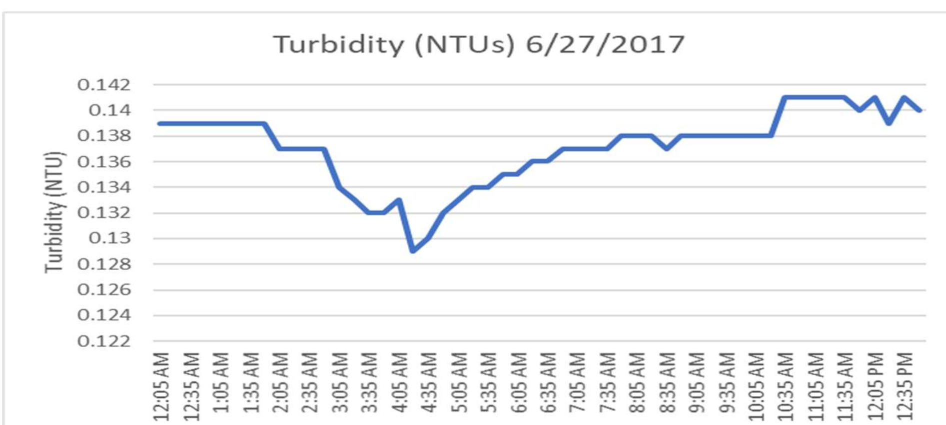


Figure 6.15 Hickory Run Turbidity Readings (June 27, 2017)

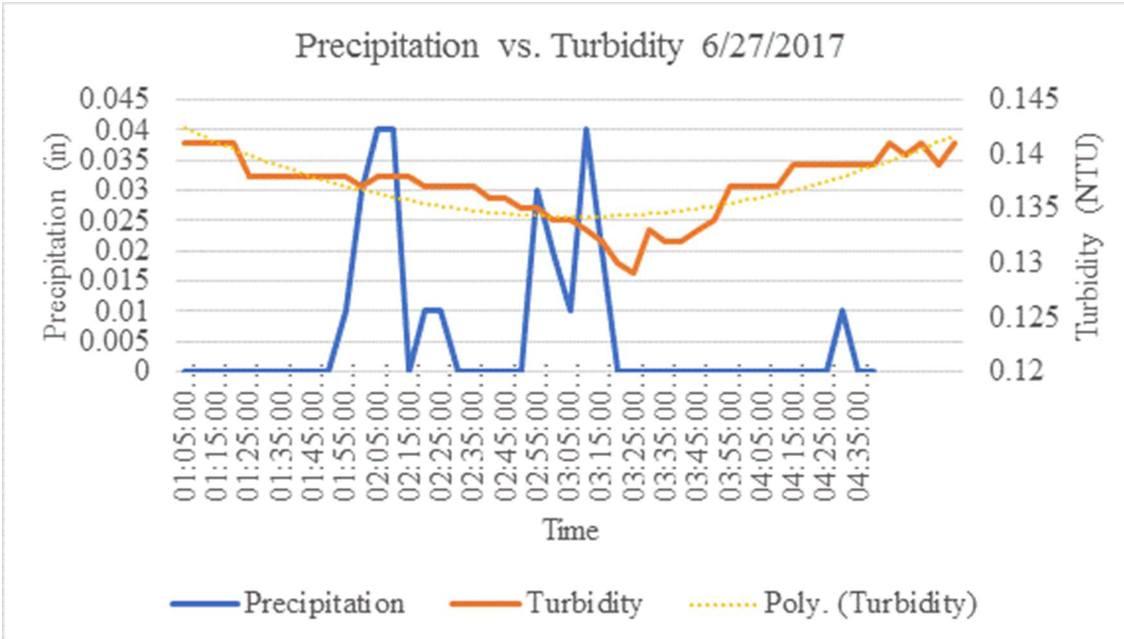


Figure 6.16 Precipitation vs. Turbidity (June 27, 2017)

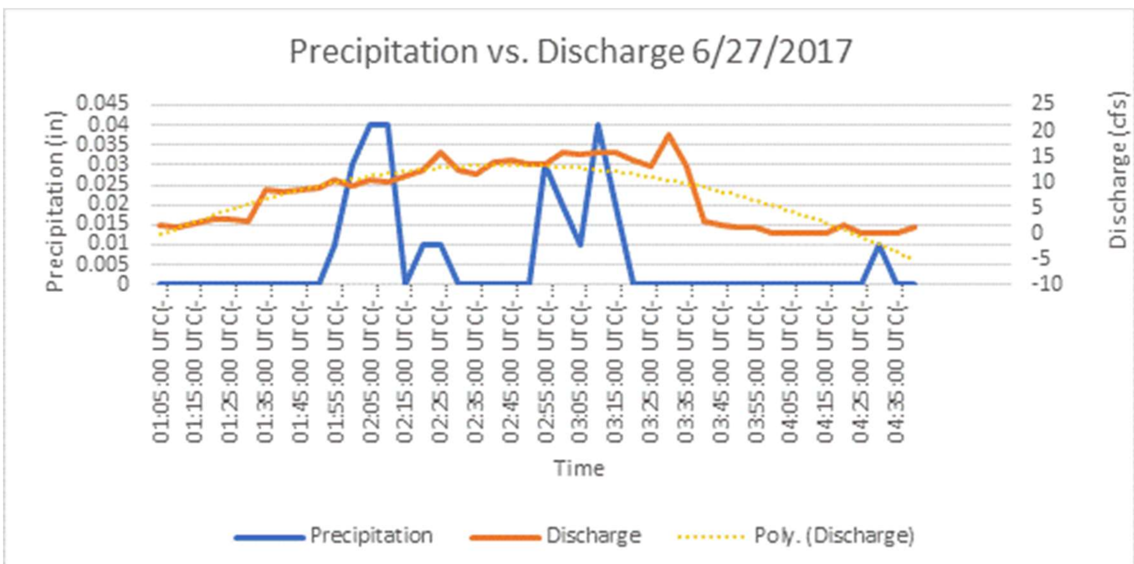


Figure 6.17 Precipitation vs. Discharge (June 27, 2017)

As the graphs show, the addition of precipitation to the normal baseflow conditions create obvious, perceptible changes. The first comparison to be made is to determine where this storm falls on the hydrograph for Hickory Run, taken from the TR-

55 model. According to this model, the peak discharge levels for various storms levels are as follows (in cubic feet/second):

2-yr   >200 cfs

10-yr   >700 cfs

100-yr >1700 cfs

For this storm event peak flow falls at 54 m^3/s (19 ft^3/s). At 19 ft^3/s, this storm does not register as even a 2-Yr storm and therefore cannot be considered a major event. While major events do present unique opportunities for study, more common storms such as this present the chance to study how the stream reacts under levels of much more numerous smaller precipitation events.

The first comparison to be drawn is between the beginning of precipitation, around 1:45AM, and the effects being seen on flow and discharge which begin to show up about the 2:39AM reading. The next is peak flow, which occurs an hour later at about 3:39AM. This again matches a storm shy of a 2-yr storm event as the hydrograph shows flows peaking roughly an hour after the event starts, and fading off for up to 9-12 hours. In this event, discharge is clearly increased for about six hours after peak flow and then tapers off for the next three hours. There are small-scale peaks along the stream's return to base flow and these line up in large part with the variable precipitation levels as time goes on, where rain was not steadily falling but appears to pick up, fall back to no precipitation, then pick back up again. The fact that this storm event falls significantly below a 2-Yr storm, yet the discharge is still affected for such a long period of time could be a marker of the largely unimpacted status of the environment surrounding the creek, wherein there is likely large levels of ground absorption and transfer from surface to groundwater, as well as low levels of surface runoff due to the smaller size of the storm. Water is retained by soils for longer in this manner, and therefore will take longer to make its way to the stream itself.

The next parameter for comparison is less straight forward, wherein turbidity levels actually drop during the storm event and come back up to baseline levels after discharge has returned to base flow. While levels are low to begin with, approximately .139 NTUs, they drop even further to approximately .129 NTUs at the lowest point, taking almost three hours to reach this peak drop, and about six more to return to baseline levels.

There are a couple possible factors explaining this drop in turbidity but to determine an actual cause will take more investigation of storms over the coming years. The first has to do with the storm itself, wherein it was not a massive downfall of rain and therefore could not have been enough to cause large disturbances that would spike turbidity levels. A high percentage of the stream and surround areas are shaded by foliage and interception of precipitation is high, leading to falling water having less impact by the time it reaches ground level. Additionally, much of the banks and surrounding area is fairly stable, so moving water will not bring with it as much sediment as it would in a less healthy area.

While these explanations would explain why increases may be smaller the reasoning behind an actual drop in turbidity levels is less clear. Again, further examination and monitoring is paramount as this could be a one-time event or an indicator of future events. For this storm, however, the drop in readings is potentially due to the incoming water being low and slow moving enough not to bring with it sediment or kick up existing sediment, while still increasing water levels overall. This returns to "dilution is the solution" usually not being a worthwhile answer, although it may be the culprit here as the total volume of water increased but measurable turbidity or suspended sediment does not. Therefore, turbidity readings would decrease where in reality water volume was simply increasing. This could lead to false assumptions about the effects of work overall on water quality and, again, should be monitored over the long-term.

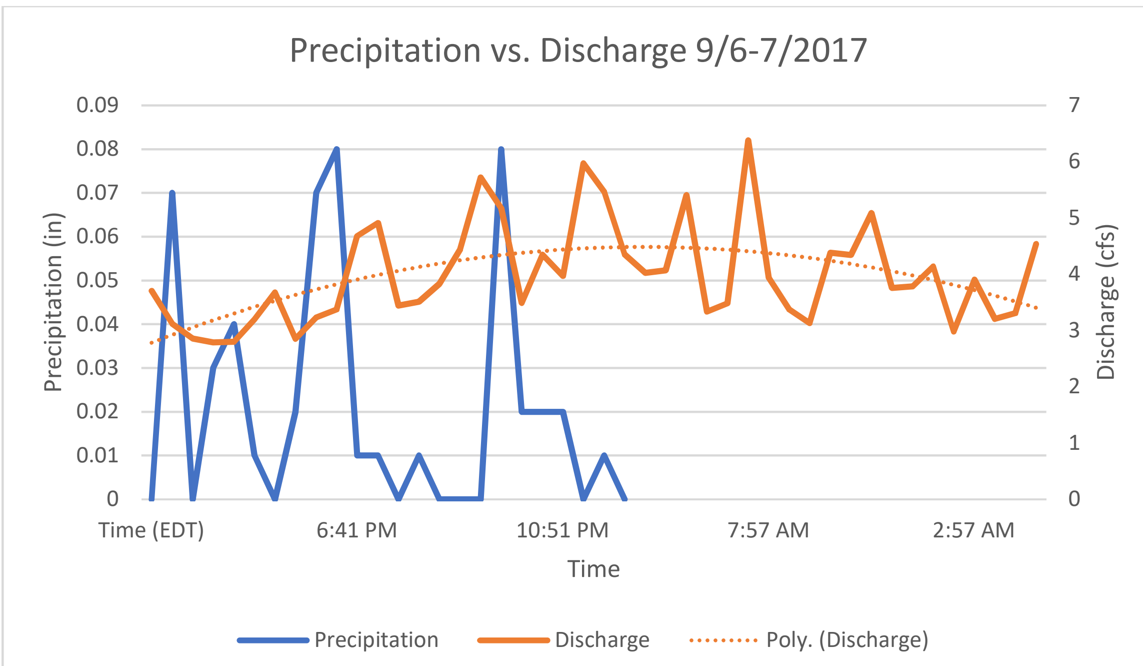


Figure 6.18 Precipitation vs. Discharge (September 6-7, 2017)

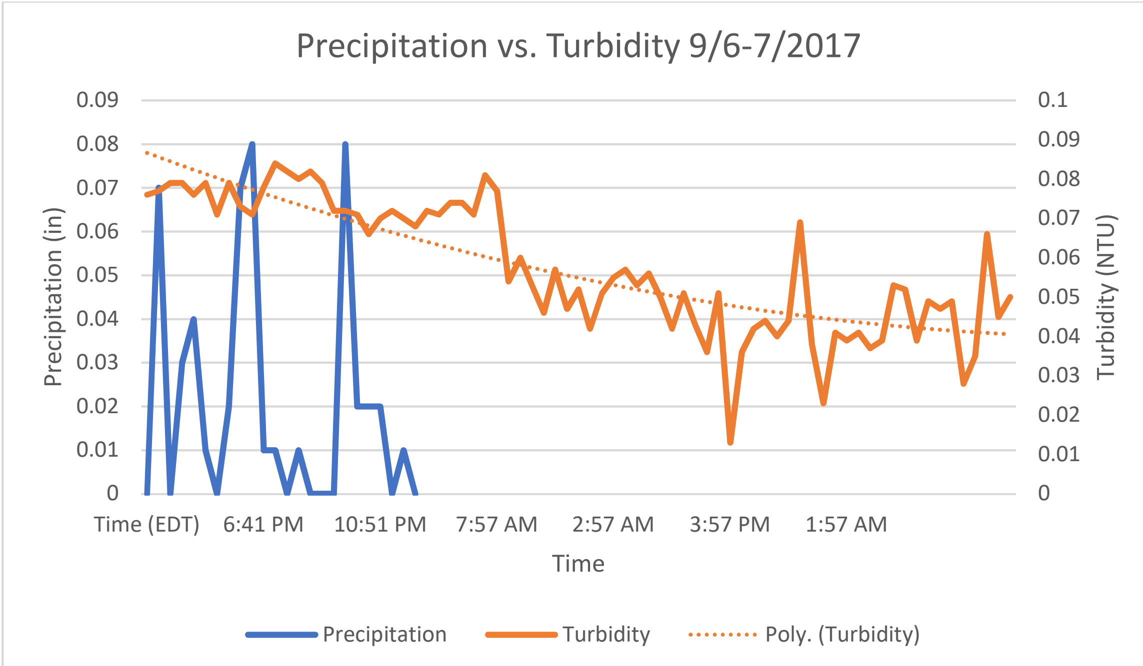


Figure 6.19 Precipitation vs. Turbidity (September 6-7, 2017)

As the comparisons above again show (Figure 6.18, Figure 6.19), small storms tend to follow a similar pattern as to their effects on Hickory Run Creek. Discharge rises and falls, returning to fairly steady rates about 12 hours after the storm has stopped and, as shown in the previous storm as well, turbidity actually drops with the increased volume of water. Running the same comparisons across storms can be telling during restoration and conservation efforts, but in this case can be used to establish baseline effects. To do this, the same parameters are measured beginning with determining storm severity. As above, the discharge levels are examined to help put this storm size in perspective:

2-Yr: >200 cfs

10-Yr: >700 cfs

100-Yr: >1700 cfs

With the peak flow from this storm even smaller than the last it is clear that this much precipitation should not appear drastically different from the July 27th event. The main difference with this storm, however, is that while flow rates did not go above the previous storm the rain fell much more heavily and in a shorter amount of time. Peak precipitation levels for the Sept 6-7th storm came in around 0.08 in. while they did not clear 0.04 in. during the July 27th storm. Despite this difference flow levels did not return to base flow for just over 12 hours, similar to the previous storm, and likely shows the general forested nature and health of the Mt. Cuba Center's lands. Water continued to flow into the stream long after the rainfall stopped, and this was would have come from the trees and absorbed groundwater.

In another similarity, turbidity follows the same pattern of dropping in levels during and directly after the precipitation, and then returning to base levels as discharge dissipates. As a standalone event this nonconventional occurrence could have been written off, but as the pattern clearly repeats its causes become more likely. As these storm events cannot be considered major, it is likely that the extra volume of water dissipates existing turbidity bringing very high amounts of input with it through runoff. Therefore, existing levels are dissipated, and turbidity levels drop in the short-term. Visual lines of best-fit are included which show these trends of discharge growing then falling, and turbidity doing the opposite, and provide an easy to digest representation of what is occurring.

Events such as this prove the strength of this type of long-term continuous monitoring, as retrieving measurements on a continuing scale for the length of a storm event, especially in bad weather, is nearly impossible. By examining results of multiple storms of varying size over a long period of time, more meaningful and predictive conclusions can be drawn as to the effects of Mt. Cuba's restorative work on water quality, and how similar efforts in other areas may have similar effects.

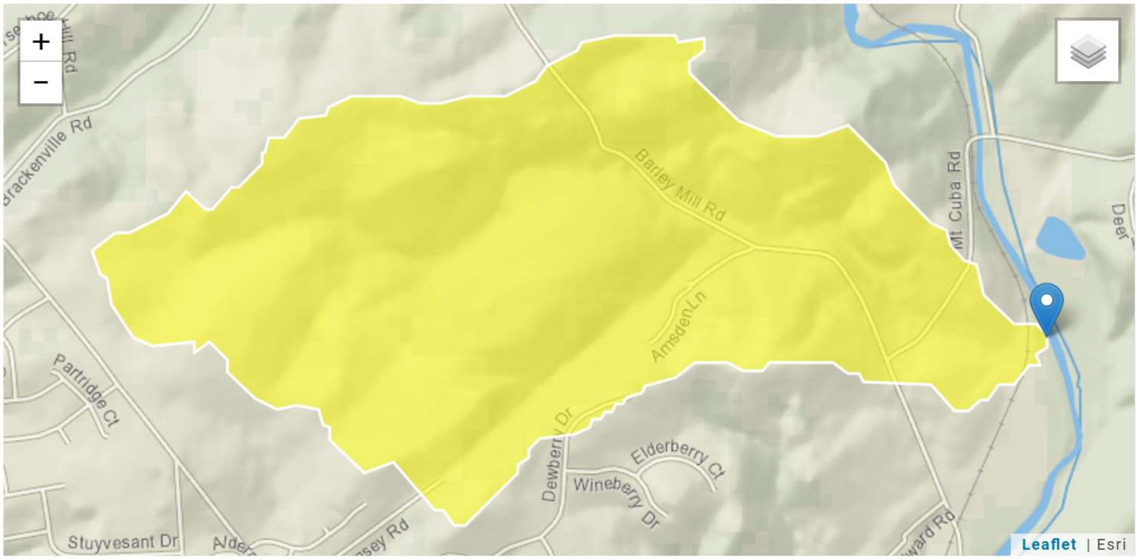
6.4 TR55 Modeling

As discussed above the TR55 modeling program is designed to take into account geographic and land use variables and determine their effects on incoming rainwater and its travel time from one end of a watershed to its eventual end or confluence with the next body of water and watershed. The strength of this program lies in its ability to show the changes that will occur if land use is altered, especially in areas such as the Mt. Cuba Center's grounds where restoration may alter land types. Therefore, current levels can be compared to new readings if, for example, a section of forest is converted to road or parking lot, or a wild field eventually is replanted into forest lands.

The first step to modeling the watershed surrounding Hickory Run Creek is to determine the types of land use inputs needed for the TR55 program. This is done through USGS StreamStats. The StreamStats results for Hickory Run Creek are shown below, as well as some of the characteristics about the watershed (Figure 6.20).

StreamStats Report

Region ID:	DE
Workspace ID:	DE20170730211948470000
Clicked Point (Latitude, Longitude):	39.78143, -75.63787
Time:	2017-07-30 21:20:38 -0400



Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
BSLDEM10M	Mean basin slope computed from 10 m DEM	13	percent
DRNAREA	Area that drains to a point on a stream	0.67	square miles
FOREST	Percentage of area covered by forest	52.8436	percent
LC11DEV	Percentage of developed (urban) land from NLCD 2011 classes 21-24	9.6	percent
LC11IMP	Average percentage of impervious area determined from NLCD 2011 impervious dataset	0.4	percent

Figure 6.20 Mt. Cuba StreamStats Report, Watershed Characteristics

Using these as a starting point, information such as soil type, length of the stream, and general area land use (to determine Manning's number) must be input. From these, however, an output giving total water in cubic feet per second, as well as total travel time from one end of the watershed to the confluence is given. Lastly this allows for accurate creation of hydrographs explaining peak flow during a large storm event of different magnitudes (Figure 6.12).

```
ML                                  mt. cuba

               New Castle Coastal Plain DMV_C County, Delaware

                       Hydrograph Peak/Peak Time Table

 Sub-Area       Peak Flow and Peak Time (hr) by Rainfall Return Period
 or Reach       2-Yr     10-Yr    100-Yr
Identifier     (cfs)     (cfs)     (cfs)
            (hr)      (hr)      (hr)
---------------------------------------------------------------------------------
SUBAREAS
Hickory Ru    209.84    693.75   1712.45
           12.14     12.12     12.12

REACHES

OUTLET        209.84    693.75   1712.45
```

Figure 6.21 TR55 Modeling Results

As these results show, while the total volume of water moving down the creek increases hugely between 2, 10, and 100 year storms the estimated travel time does not change significantly. There are multiple potential explanations for this, but one of the most likely is that between 2 and 10 year levels, the ground takes on so much water that infiltration is maximized and water makes its way as direct runoff from its landing spot to the creek itself. Whereas in smaller storms much of this could have been absorbed by the ground or nearby plant life, etc., when a certain saturation point is reached any more water moves over the ground instead bringing with it any debris or pollutants in its path.

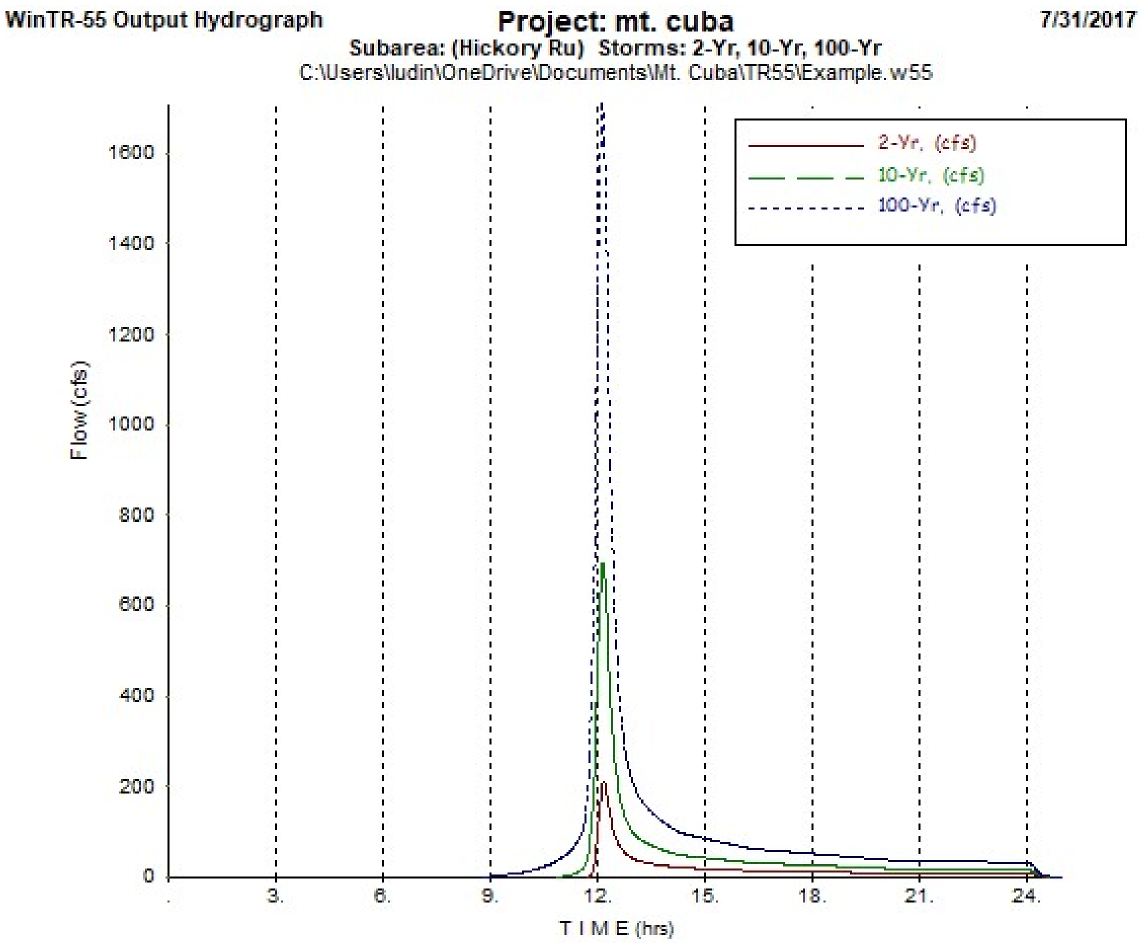


Figure 6.22 Mt. Cuba 2-Yr, 10-Yr, 100-Yr Hydrograph

Similar to the numerical output from TR55, this hydrograph (Figure 6.22), shows the difference in peak flow during a storm event of differing sizes. While the increase in volume is obvious, it is interesting that peak flows all occur at the same time. Furthermore, even with the much larger amounts of water a return to base flow happens almost along the same timeframe, and the slope (speed) at which flows return are almost identical as well. Therefore, this excess water is clearly falling on the watershed and being flushed downstream to the outlet much more quickly, and not given time to absorb into surrounding vegetation. This is to be expected, however, as again there is a point where the ground becomes saturated and more water simply runs across the top.

As mentioned in the introduction to this section the true strength of this program is its ability to input potential changes in land use, and then model their predicted effect on the water discharge rates. All of the other inputs being held equal, that type of changing means impacts can be evaluated during the decision-making process, as opposed to afterward when it has become too late to change the choice.

Chapter 7

SUMMARY OF RESEARCH

7.1 Summary of Analysis

This thesis is directed at summarizing current water quality and habitat conditions of the Hickory Run Creek at the Mt. Cuba Center, establishing a long-term monitoring network to monitor water quality for the foreseeable future, and beginning to investigate the impacts of native plant restoration on local water quality. The history of water quality monitoring is discussed, as well as some of the current thought processes and motivation behind water quality monitoring programs. An outline and background of the Mt. Cuba Center is discussed, and then the methods behind this research is delved into. Protocols for grab sampling, an EPA Rapid Stream Habitat Bioassessment, and cross-section analysis are discussed, as well as the process of developing and implementing a water quality monitoring site using YSI Sontek and Campbell Scientific equipment. Lastly, results outlining baseline conditions along Hickory Run Creek are discussed, as well as the first rounds of data which help describe current levels to be compared to future readings. In the final section of this thesis, recommendations for future work and expanded research based on the findings of this paper are discussed.

7.2 Conclusions

The findings of this thesis are meant to describe current conditions across Hickory Run Creek at the Mt. Cuba Center based on measured parameters, and use these findings to draw conclusions about the habitat as a whole. Additionally, the methods decided upon here are meant to work within the framework described here, with motivations and justifications described specific to this individual thesis and project. These may not be applicable to all projects, although the general framework may be applied to help make decisions given different inputs.

1. Baseline Conditions: Baseline conditions throughout the watershed of Hickory Run Creek are extremely healthy based on the considerations considered in this thesis. Anthropogenic inputs are minimal compared to surrounding streams and watersheds, and given the stated goals of Mt. Cuba, they are likely to stay this way for the foreseeable future. Turbidity and conductivity levels speak to low sediment transport, and therefore likely low levels of other potential pollutant inputs. Cross-section and EPA Rapid Stream Habitat Bioassessment analysis generally speak to a high-quality, uninfluenced environment with large areas of riparian buffers to help protect water quality. While soil classification warns of potential medium level runoff potential, this high level of wooded and forested grounds work to slow runoff speeds, and therefore increase ground absorption. Additionally, the TR55 modeling program will allow for future work's impacts to be readily known, and hopefully dissuade against future projects that could prove harmful to water quality. Lastly, the fact that this project was undertaken and funded cannot be ignored as it shows the Mt. Cuba Center's continued commitment to upholding healthy, natural habitats in which Hickory Run Creek resides.

2. Monitoring Network: The most effective means of establishing a long-term monitoring network along Hickory Run Creek is to install stand-alone, continuous monitoring equipment at the Wilmington & Western Railroad bridge crossing. While other sites offer various advantages this site is accessible enough to not only construct the system but to be approachable for future data retrieval and system maintenance. It also is toward the lower end of the creek, 500 ft. upstream of its confluence with the Red Clay Creek. This means nearly all work done upstream will be evident by this point, and readings will continue to catch long-term trends. Additionally, to begin monitoring these effects both stream discharge (volume of flow) as well as turbidity should be monitored. This provides a physical parameter to be monitored along the stream, so that changes in flow vs. rainfall patterns can be analyzed well into the future. It also provides a general measure of sediment input, one of the largest threats to native plant restoration which will not only monitor inputs over the long-term, but during the restoration process itself. Additionally, turbidity gages along the Red Clay Creek nearby provide a good comparison point for turbidity levels.

3. Monitoring Equipment: To begin monitoring Hickory Run Creek a YSI Sontek IQ system as well as a Campbell Scientific OBS3+ and CR300 datalogger will be used. The IQ system is designed to monitor stream discharge through a set of doppler and pressure sensors and comes with internal storage and low energy needs. It is small enough to work effectively in Hickory Run Creek at the W&W railroad site, accurate over extended periods of time, and cost-effective. The OBS3+ and associated datalogger are smaller and record turbidity alone through a light dissipation and reflection system. The sensor is cigar shaped and fits on the same piling holding the IQ system in place, making it ideal for this application. Both sensors are connected by wire to a storage box approximately 8m away which houses two Interstate Deep Cycle Marine batteries, rated as 12v ~42ah each. This box also houses the datalogger, as well as attachment accessories for both sensors. Data collection is simple, and done through associated software from both manufacturers. Data can be collected for extended periods of time, without the need for constant input from Mt. Cuba staff. Both sensors are designed to stay in-water for all parts of the year that do not risk freezing (roughly eight months out of the year). They are expected to last on a decadal time scale, and the batteries are rechargeable even after being run down to very low levels.

4. Influence of Restoration Work: While the direct influence of native vs. nonnative plants cannot be answered beyond a doubt yet, this research and thesis make it clear that the work being undertaken has created a healthy, sustainable ecosystem and body of water. Hickory Run Creek is removed from many of the common anthropogenic pollution inputs in the area, water quality and habitat surveying levels are healthy, and high levels of permeable surfaces (low levels of impermeable surfaces) creates the conclusion to this point, and highly likely into the future, restorative efforts will continue to create a healthy stream environment.

7.3 Recommendations for Future Research

While this research has effectively created a baseline assessment for Hickory Run Creek, and begun to draw conclusions about the impacts native plant restoration work is having on the water quality and habitat as a whole, there are many avenues that could strengthen these findings, and perhaps develop further insights.

1. Continuation of Current Monitoring: Common to most research efforts, continued work into the areas already being investigated is crucial for increasing knowledge levels. It is especially important here, however, as the short-term data already accrued is not adequate to identify long-term trends, which is where many of the potential impacts of the work done at the Mt. Cuba Center are likely to be seen. These effects will likely only become apparent after 5-10 years of data collection, or potentially even longer. While this seems like a huge time period, the decisions this research may help influence are questions that will have effects for generations to come, and therefore longer trends are required to make smart, informed choices.

2. Broaden sampling parameters: For future water quality monitoring efforts, it would significantly increase the usefulness of the data for more parameters to be monitored. While turbidity and discharge are important, almost essential, parameters to keep track of, there is a plethora of other options that can give more insight into how native plant restoration is affecting water quality. Some of the specific types useful to Mt. Cuba would be:

Excess nutrient runoff from both agricultural and residential use is one of the largest sources of pollution in the Mid-Atlantic, and many other, regions. Higher nutrient content often creates higher crop yields, therefore it is applied heavily onto lands that may or may not need or be able to absorb all of them before rainfall comes and washes them toward bodies of water. Plant growth along these pathways often intakes some of these nutrients for themselves, and native plants' capacity to do this is one area that is an important factor for future decision making.

Another common source of water pollution is bacteria infestations such as Enterococcus. These levels can be easily monitored, and often exist in higher levels as a sign of waste inputs from either a dumping or one-time event, or a more extended input from manure sources. These could be anthropogenic sewage waste, waste from agricultural animals or wildlife such as geese, or even just waste from neighborhood pets that is being washed into the water.

Another good indicator of water quality, pH fluctuations have become a growing source of research as climate change induces higher levels of CO^2 sequestration in water bodies, which acidifies the water. While this may not be as large a problem within the stream itself, the pond which makes up its headwaters could be sequestering rising levels, and this would show up downstream as pH levels fluctuated. This can also be an indicator of a larger one-time event which was large enough to force a change.

While this is not an exhaustive list of likely useful parameters, it does represent a good place to start. The key to future work would be to create efforts that are flexible enough to address changing needs as they arise. Whereas these may be paramount now, future events and circumstances may create the need for alternative parameters to be monitored.

3. YSI Sonde: To accomplish the goal of sustainable, adaptable future monitoring efforts the best option available now is a YSI multiparameter sonde. This is the same company who manufactured the discharge/flow meter being implemented currently, and the sonde itself allows for multiparameter monitoring, as well as the changing of these parameters at a future date. The sonde itself is a long tube, with connecting ports at one end to plug in a wide variety of water quality sensors. These sensors are purchased separately, and therefore if future needs change new sensors can be bought and plugged in without having to buy an entire new set of equipment.

To fully understand the influence of specific restoration projects, increasing the number of monitoring sites will give a better view of specific sections of the stream. If known efforts are being undertaken in one area, it may be possible to then move these sensors so readings are taken directly above and below the site, measuring water quality coming into the area, and then immediately flowing out of restorative efforts. While the current site does give a good impression of efforts on a creek-wide scale, this multi-sensor approach would like give very detailed, micro-level analysis of the potential impacts. This could also provide data on a species vs. species comparison, if different species are being introduced at different spots along the creek over the course of coming years.

In addition to increasing the number of sites, future installations would benefit from a solar power installation, as opposed to continuing to use batteries. While the batteries have plenty of power to run the IQ system and turbidity sensor, as stations expand their needs will as well. Solar power has come down in price to be equitable to the batteries, and presents the advantage of not needing to be recharged during the off-season. The potential drawback here is available sunlight, and a survey should be conducted at potential sites to decide its viability – these results should be taken into account when choosing locations.

4. Create Partnerships: One of the important aspects of data collection is getting it into the hands of those who can most effectively put it to use. The data collected here can be very useful in planning Mt. Cuba's future restoration plans as far as water quality is concerned, but those same questions are arising throughout gardens and restoration or conservation efforts across the country, or even the planet. Significant evidence as to which plants are most effective at improving water quality (whether that be through nutrient removal, sediment and bank stabilization, flood risk removal, etc.) could prove invaluable as the need to create these results grows. As discussed above the need to ensure safe, reliable water sources is only growing ever more pressing and this data could prove a huge benefit.

To this end, partnering with University and other research institutes is where Mt. Cuba should start. They often have connections to places where this data could be most useful, as well as means of sifting through large data sets to present a clean, succinct report. Organizations such as the Delaware Invasive Species Council have experts and networks established for analyzing and disseminating this type of research, and will be great allies in putting the information to its best use. Additionally, these Universities and other centers of research are often where organizations who have to make water quality and availability decisions will look first, and therefore if they can point to this research it significantly increases its impact.

From all of this research, the biggest takeaway is the opportunity to create a base of knowledge and research that is not only relevant and impactful, but potentially extremely useful as water needs continue to grow and change. Influences such as climate change and population growth will continue to stress the resources already available, and researched, clear paths toward securing future availability will come from research such as the work being done at Mt. Cuba, and now reinforced by a growing base of knowledge toward the impact restoration and native plant reintroduction could have on water quality.

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Appendix

RESEARCH PROPOSAL

Matt Ludington
1 Easton Ct. Apt. 547
Newark, DE 19711

December 22, 2016

Mr. Jeff Downing
Executive Director
Mt. Cuba Center
3120 Barley Mill Rd., Hockessin, DE 19707

Dear Mr. Downing,

I am pleased to submit this proposal as a continuation of my work at Mt. Cuba along the Hickory Run Experimental Watershed. I propose to work at Mt. Cuba Center to conduct field studies, streamflow, and water quality monitoring during 2017 along the Piedmont tributary of Barley Mill Run that flows east and joins the Red Clay Creek near Hoopes Reservoir in Ashland, Delaware. The 430-acre watershed is largely undeveloped and covered by 53% forest, 0.1% wetlands, and just 0.2% impervious cover.

The objective of the watershed-based research program is to quantify the benefits of reforestation at Mt. Cuba Center on the water quantity and water quality of Barley Mill Run. The importance of this study, methods I will use, schedule of tasks, maps and budget are attached. I hope you will consider funding this research to insure a baseline reference point that you can use in future stream restoration work.

Sincerely,

Matt Ludington

Barley Mill – Hickory Run Watershed Monitoring Plan
Mt. Cuba Center - Ashland, Delaware
December 2016

Importance

Mt. Cuba is in the advantageous position of having known, planned restoration efforts which surround around a stream that is healthy, stable, and, comparatively, largely devoid of many anthropogenic inputs so commonly seen in water bodies throughout the Mid-Atlantic. Because of this, the effects of these restorative efforts can be more easily shown through close water quality monitoring, and reasonable connections can be drawn between ecosystem changes and their effects on potential pollutants and water quality conditions. Additionally, research has recently been published on quantifying the ecosystem services of native vs. exotic plant species, and while certain information is known on how these plant species differ, their effects on water quality are still unproven – an area of research acknowledged by researchers as needing more study.

To take advantage of the situation, however, baseline measurements need to be undertaken as soon as possible, with a look toward more permanent measuring stations which can identify a range of water quality parameters. Beginning with the recently completed surveying and cross-sections of Hickory Run, and in combination with ongoing sampling, the ability to add flow and turbidity data for both base flow conditions, as well as during storm events, can begin to provide an idea as to how the stream itself is impacted over time. Because streamflow (discharge) and turbidity readings are widely undertaken, especially through USGS efforts in the region, these readings become immediately useful not only for comparison over time at Mt. Cuba itself, but also to surrounding streams throughout the region.

On a greater scale, as climate change continues to potentially alter the ways in which ecosystems function, data collection can no longer be solely focused on how anthropogenic effects have altered nature, but must begin to quantify how restorative efforts will impact these same systems. If sound decisions are to be made toward securing safe, reliable water sources for the future, then data from areas such as Mt. Cuba, where there is a known history of uses, planned and documented land use and restoration, and dedicated staff and monitoring capabilities, will become invaluable. There is an opportunity not only to undertake meaningful research in a vital area, but to encourage future investigation into these effects by being able to provide reliable, significant data over a long period of time.

Methods

The proposed work conducted at Mt. Cuba Center will characterize the Barley Mill Creek watershed according to the following field methods:

1. Characterize Watershed: Using ArcView GIS, delineate and map the Barley Mill Run watershed to include the following layers: (a) hydrology, (b) aerial photography, (c) roads/railroads, (d) topography, (e) subwatershed boundaries, (f) land use/land cover, (g) soils, (h) wetlands/hydric soils, (i) floodplain.

2. Monitoring Stations: Establish stream flow and water quality monitoring stations at the following 4 locations: (a) Barley Mill Road, (b) Ramsey Road, (c) Mt. Cuba Road, and (d) Wilmington and Western Railroad. Monitored through weekly probe sampling.

3. Stream Cross-Sections: Using a surveying rod, level, and tape measure; survey 19 stream cross sections along 9,500 linear feet at 500 foot intervals along Barley Mill Run and its tributary (near Ramsey Road) tied to mean sea level (msl) datum. Map the 100-year floodplain.

4. Stream Habitat: Record stream habitat along each 500 feet reach as optimal, sub optimal, marginal, or poor according to the following ten parameters using a 0-20 point scoring system from the EPA rapid stream bioassessment technique for steeply sloped (Piedmont) streams.

- Epifaunal Substrate
- Embeddedness (% embedded by sediment)
- Velocity/Depth Regime
- Sediment Deposition
- Channel Flow Status
- Channel Alteration
- Channel Sinuosity
- Bank stability
- Vegetative Protection
- Riparian Vegetative Zone

5. Geomorphology: Record predominant substrate along each 100 feet reach according to the Rosgen Stream Geomorphology Classification system according to the following parameters:

- Channel Width-to-Depth Ratio
- Sinuosity
- Entrenchment ratio
- Water Slope
- Substrate Composition

6. Stream flow Monitoring: Establish streamflow monitoring station suing YSI SonTek IQ system, recording on 15 or 30-minute intervals. Data will be collected from the system by hand bi-weekly, or as necessary. If necessary as a backup, establish hydraulic control sections at the roadway culverts to measure flow depth and velocity. Staff gages will be installed at each culvert to measure flow depth. Velocity will be recorded using a flow meter. Once per week and during storms over a 6-month period, record flow depth and velocity to estimate stream flow by the equation:

$Q= vA$

Where:

Q = stream flow or discharge (ft^3/sec)

v = velocity of flow (ft^2/sec)

A = cross section area of the culvert (ft^2)

7. Water Quality: At each of the 4 water quality monitoring stations over a 6-month period, sample water quality for a base (low) flow and a storm (high) flow event and transmit for analysis at the University of Delaware Agriculture Laboratory.

- Dissolved Oxygen
- Total Suspended Solids
- Turbidity, Conductivity
  - Will include in-stream turbidity sensor
- Nitrogen, Phosphorus
- Metals (Cu, Pb, ZN, Fe, Mn, Hg)

8. Soils: Characterize and map soils in the watersheds based on data from the USDA Natural Resources Conservation Service (NRCS) Soil Survey for New Castle County, Delaware.

9. Hydrogeology: Characterize and map watershed geology based on data from the Delaware Geological Survey.

10. Hydrologic Model: Develop a TR55 hydrologic model for the Barley Mill Run watershed to estimate 2-, 10-, and 100-year discharge to evaluate the benefits of reforestation and other land cover changes on the creek and also to design best management practices (BMPs) to restore the watershed and the stream. This will include the use of updated land use data as available.

11. Research Design and Field Report: Prepare a report outlining design for long-term research potential. To include site location, design, and equipment. Prepare a field report that summarizes the field work to characterize the watersheds according to the following parameters: stream cross-sections, stream habitat, biology, streamflow, water quality, geomorphology, soils, hydrogeology, wetlands, forests, hydrology, and rain garden implementation. Conduct statistical analysis of water quantity (stream flow) and water quality parameters for temporal and spatial trends.

Schedule

Task			Milestone
Commence Research			January 2017
1.	Characterize Watershed		Feb 2017
2.	Monitoring Stations		March 2017
3.	Stream Cross-Sections	Oct 2016,	March 2017
4.	Stream Habitat	Oct 2016,	March 2017
5.	Geomorphology		April 2017
6.	Stream Flow Monitoring		Sep 2016-May 2017
7.	Water Quality		Sep 2016-May 2017
8.	Soils		Jan 2017
9.	Hydrogeology		Jan 2017
10.	Hydrologic Model		Feb 2017
11.	Research Design and Field Report		June 2017

Budget

Contractor Pay	$18,000
Discharge Measurement*	
YSI SonTek IQ System	$4,820
Car Battery	$50
Marine Battery Case	$50
Turbidity Sensor*	
Campbell Scientific OBS-3+	$1,085
Connection Cables (10 m)	$200

Datalogger C.S. CR300	$400
Total	$24,605

*After the Research and Design Field Report is complete, Mt. Cuba Center will take possession of the equipment for Discharge Management and the Turbidity Sensor, for long-term monitoring.