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Assessing the impact of a constructed wetland biome on the ecosystem health of Cedar Run

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ASSESSING THE IMPACT OF A CONSTRUCTED WETLAND BIOME ON THE ECOSYSTEM HEALTH OF CEDAR RUN

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Accepted by the faculty of the Department of Integrated Science and Technology, James Madison University, in partial fulfillment of the requirements for the Honors Program.

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PUBLIC PRESENTATION

This work is accepted for presentation, in part or in full, at ISAT/CS Room 148 on April 15th, 2016.

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Abstract

A wetlands ecosystem is defined as "an area saturated by surface or groundwater at a frequency or duration sufficient to support...a prevalence of vegetation typically adapted for life in saturated soil conditions" (Batzer and Sharitz, 2007). Wetlands serve as biofilters and thus have been used to treat sewage and wastewater, as well as to restore the health of polluted water systems. Solly Walker and Lorinda Palin, owners of a certified natural and biodynamic farm called Avalon Acres located in Broadway, Virginia, constructed a wetland two years ago, using the stream, Cedar Run, that flows through their property. Pollution from agricultural activity in the watershed upstream of Avalon Acres has compromised the health of the ecosystem. Ultimately, Solly and Lorinda would like to restore the health of the stream ecosystem, provide a safe habitat for native plant and animal species, and help to mitigate ecological destruction taking place downstream. The purpose of this project is to assess the impact that the constructed wetlands has had on water and soil quality. Stream water quality data, such as nitrate, phosphate and coliform levels, dissolved oxygen concentration, pH and conductivity, were collected over the course of 11 months. Soil carbon data and results from plant and macroinvertebrate sampling were also used to analyze the influence of the wetlands on the ecosystem. Consistently high levels of nitrates and phosphates were found indicating impairment of the stream. Due to the limited time and scope of the project, and the relatively recent introduction of the wetlands, no definitive conclusions can be made regarding the impact of the wetlands on water and soil quality. However, there were lower levels of pollutants in sites within the wetland area than sites outside of the wetland in the stream, which indicates that the wetland is having an effect. This research project establishes a baseline for further investigation into the impact of the wetlands at Avalon Acres Farm over the coming years.

Introduction

Avalon Acres is a biodynamic farm located near the historic downtown district of Broadway, Virginia. Lorinda and Solly are the owners and operators of the farm. On the farm they grow a variety of produce and raise chickens and sheep. They sell their produce, tinctures, teas and other products at the Harrisonburg Farmers Market throughout most of the year, excluding the winter months (late November through March). A perennial stream, called Cedar Run Creek, part of the Cedar Run Watershed, runs through the property. Most of the land in Cedar Run's watershed is used for agriculture such as cattle and sheep, poultry houses, and hay and agricultural fields. Unsustainably managed agricultural practices have polluted Cedar Run with surface runoff containing excess loads of sediment, fertilizer, and animal waste, which has compromised the health of the ecosystem. This polluted water runs into the North Fork of the Shenandoah River, connects with the Potomac River and eventually flows into the Chesapeake Bay, where there are a variety of ecological problems such as excessive eutrophication, habitat destruction and species loss. Solly and Lorinda, with the help of student volunteers from James Madison University, dredged out land alongside the stream and planted wetlands species such as cat tail, watercress, marshmallow, milkweed and blue flag. Their goal in dredging out the land was to divert the flow of water flow so that it would run through the constructed wetlands areas - designed to mimic the native wetlands of the Shenandoah Valley - and through wetlands plant species that are excellent at capturing nutrients from the water. As development has occurred in the valley, many wetland plant and animal species were wiped out or forced to migrate from the area. Ultimately, Solly and Lorinda would like to restore the health of the stream ecosystem and provide a safe habitat for native plant and animal species to live in.

The purpose of this project is to assess the impact that the wetlands has had on water and soil quality, and the overall ecosystem. Stream water quality metrics such as nutrient and coliform levels, dissolved oxygen concentration, pH, conductivity and macroinvertebrate sampling data will be used to analyze this impact. In addition, soil carbon content and the presence of plant species will also help analyze the influence of the wetlands on the ecosystem. Freshwater ecosystems, such as wetlands and streams, are complex and require multiple testing metrics to determine their overall health.

Chapter 1: Project Overview

1.1 Avalon Acres Farm

The research project was conducted at Avalon Acres Farm, located in Broadway, VA about 15 miles NorthWest of Harrisonburg. The farm is owned by Lorinda Palin and Solly Walker (shown in the picture below). They sell a variety of produce at the Harrisonburg Farmers Market and engage with the JMU community for scientific and agricultural pursuits.

Figure 1: Solly Walker (left) and Lorinda Palin (right) at the Harrisonburg Farmers Market.

Photo credit: Thomas Vasilopoulos

Avalon Acres is certified natural and the owners use biodynamic practices to enrich the land and the crops they produce. Solly and Lorinda act as stewards with their efforts to restore the land and ensure that everything lives in harmony on their farm. There is a stream, called Cedar Run, which runs through the property. With help from volunteers from James Madison University, the two owners constructed a wetland by dredging the land alongside the stream and redirecting the flow of water. In constructing the wetland, Lorinda and Solly sought out to restore the native habitat and improve the health of the stream, which is ecologically impaired largely due to agricultural activity in the watershed upstream of Avalon Acres Farm.

1.2 Goals and Objectives

The goals and objectives of this research project, which tie in to the intentions that Solly and Lorinda had when they chose to construct the wetland, are to determine the condition of the Cedar Run Stream ecosystem, then assess the impact that the wetland has had on water and soil quality by collecting various datum over the last 11 months.

Below is a map of the wetland and the farm (Figure 2). The blue line represents Cedar Run Stream, which runs south to north from site 1 on the right towards site 4 on the far left. Water from the stream feeds the wetland, which is roughly outlined in green. The house and barn are positioned on a hill that has a slightly higher elevation than the wetland down below. The yellow stars, located both inside and outside of the wetland, indicate the seven spots chosen for water sampling and testing throughout the course of the project.

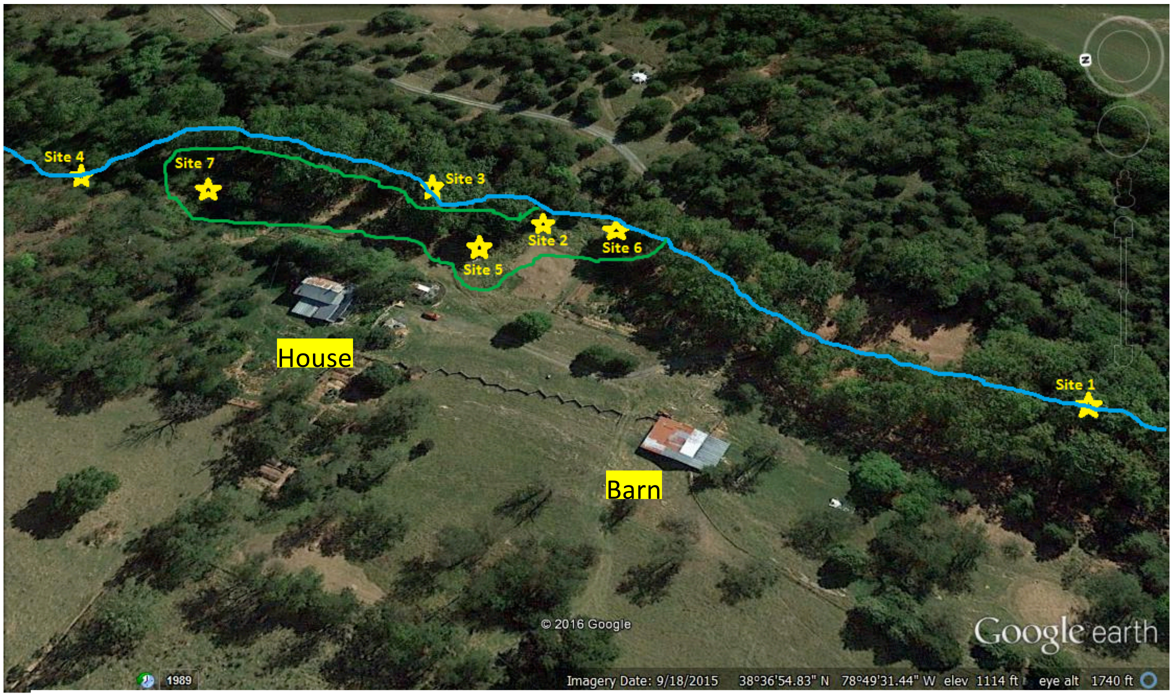


Figure 2: Map of Avalon Acres Property (image from Google Earth)

Cedar run connects with the North Fork of the Shenandoah River, which connects with the Potomac River and then flows into the Chesapeake Bay and finally the Atlantic Ocean. The Chesapeake Bay watershed is 64,000 square miles and spans 6 states: New York, Pennsylvania, Maryland, Delaware, West Virginia and Virginia (Chesapeake Bay Program). Due to the massive size of the watershed, water quality issues in any one the streams, tributaries or rivers that flows into the bay will have an impact on the Chesapeake Bay ecosystem. Systems thinking is a holistic approach to understanding ecological systems, such as a wetland or a bay, which focuses on the way in which all the individual biotic and abiotic components interrelate to form a healthy and functional ecosystem. Using the lens of systems thinking, is possible to understand, for example, how agricultural runoff and the subsequent ecological degradation that occurs, in a stream such as Cedar Run, can have an impact 180 miles away in the bay and even affect aquatic life in Atlantic ocean off the Maryland coastline.

1.3 What is a wetland? What can wetlands do?

A wetland ecosystem is defined as "an area saturated by surface or groundwater at a frequency or duration sufficient to support...a prevalence of vegetation typically adapted for life in saturated soil conditions" (Batzer and Sharitz, 2007). The diagram below (Figure 3, page 12) explains the physical, chemical and biological processes that take place in wetlands. It shows the wetlands functioning as a system with each part of the ecosystem performing different functions. It depicts agricultural runoff making its way into the wetland, the cycling of nutrients like nitrogen and phosphorous, and the uptake of nutrients by plants. The ecosystem services provided by wetlands will be explained in greater detail in the following chapter of this report. The ecological benefit of wetlands, along with other information about wetlands, will be discussed in greater depth in the following sections.

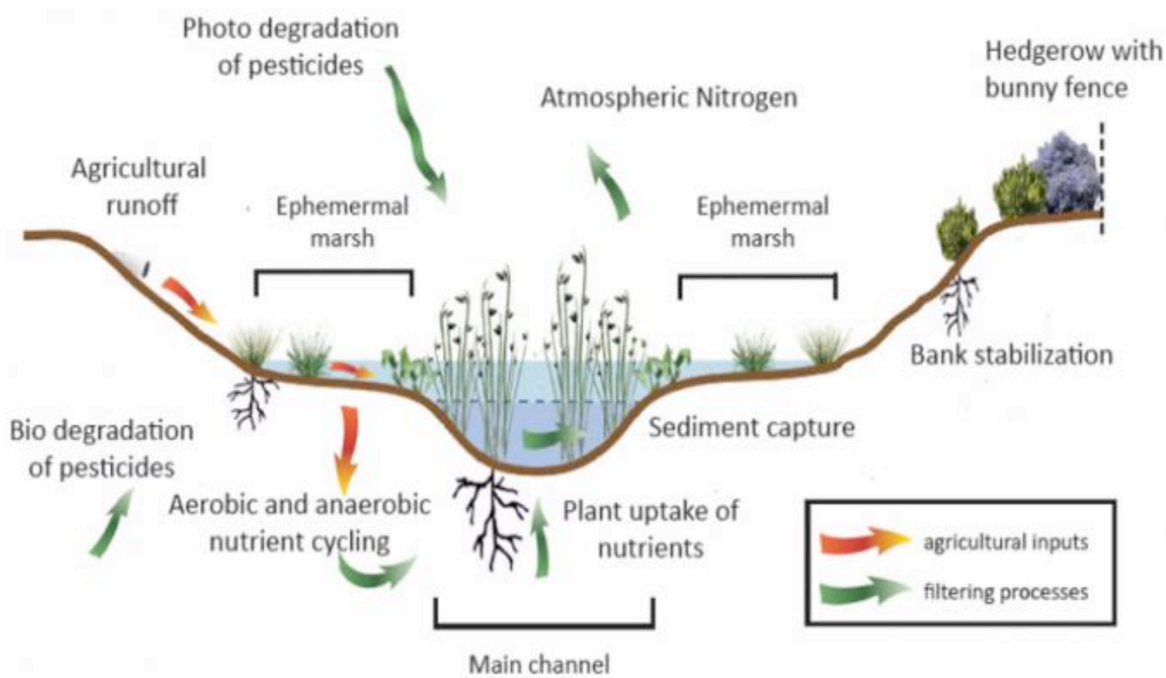


Figure 3: Diagram of ecosystem services offered by wetlands.

Image from: Central Coast Wetlands Group

Chapter 2: Background and Information on Wetlands

2.1 Loss of Wetlands

A study in 1998 by Constanza et al estimated the economic values of services provided per hectare of the world's ecosystems and determined wetlands and swamps/floodplains to be the highest valued ecosystems. Wetlands provide numerous ecosystem services including water supply, food production, flood attenuation and biofiltering which improves water quality (Batzer, 2007). The ecosystem functions that wetlands provide were not always known and wetlands used to be viewed as wastelands. In the 19th and early 20th century wetlands were regularly drained and filled for agricultural or urban development. By the 1970s, almost half of the wetlands in the United States had been destroyed (Figure 4); this was not limited to just the US, wetlands around the world have

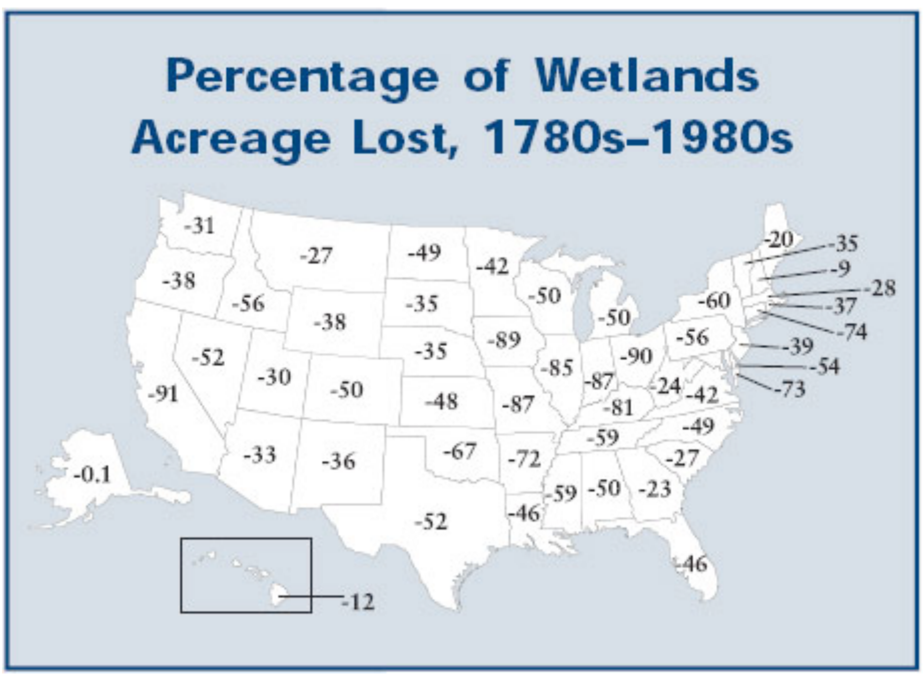


Figure 4: EPA map of wetlands loss per state from 1780s-1980s.

been destroyed (DeLaney, 1995). By the end of the 20^{th} century, the knowledge of wetlands function became more widespread and efforts to restore and enhance wetlands have become popular. Now there are policies such as “No Net Loss” which state that if a wetland is destroyed for development an equal area must be restored in the same watershed. The EPA provides user guides outlining the planning, implementation, and monitoring of wetlands to ensure their functions and ecosystem is fully restored (EPA, 2015).

2.2 Wetlands Functions and Ecosystem Services

Wetlands can dramatically shape the landscape around them. They increase biodiversity by providing ecosystems for both terrestrial and aquatic species. They attenuate flooding events and reduce streambank erosion, as well as providing for food production and recreational activities. Wetlands also improve many aspects of water quality, which is the main focus of this report. This includes nutrient uptake, removal of pathogens, improved dissolved oxygen levels, reduced turbidity, and removal of metals (DeLaney, 1995). The cumulative effect of development and corrective measures applied to water-bodies has reduced the ability of many watersheds to absorb water, detain sediments, and remove nutrients, leading to degradation of freshwater ecosystems. Nonpoint source pollution from agricultural and urban runoff is the largest source of pollution in surface waters and causes further damage to vulnerable ecosystems that are incapable of handling the excessive inputs from nutrient and sediment erosion (Obarska-Pempkowiak, 2015). Restoring and creating wetland ecosystems provides watersheds with biofilters and nutrient sinks to improve water quality, biodiversity, and lessen damages from flooding events.

2.2.1 Particulate Settling

One of the main functions that wetlands provide is particulate settling. As the water from the stream channel enters the wetlands it spreads out into the larger area which causes a reduction in flow velocity. This reduced speed allows suspended particulates and sediments to settle out of the water column and become deposited in the wetlands (Maynard, 2009). The clarity of the water in streams that exits the wetland will be improved, which is beneficial to native species of fish, in this region include the Small Mouth Bass or Red-Breasted Sunfish, which rely on their eyesight to hunt (Behnke, 2002). This is also important for the submerged aquatic vegetation in the wetlands. Particulate settling reduces the clogging of downstream waterways, which is important to support recreational and navigational uses. Any toxins and nutrients attached to the sediments will be deposited in the wetlands which are more capable of diluting or using the excess loads. From the literature review, it was found that wetlands can remove 88-91% of total suspended solids (Maynard, 2009).

2.2.2 Nutrient Cycling and Uptake

One of the main sources of pollution from agricultural runoff, which the main pollutant in Cedar Run stream, is fertilizer containing chicken litter with high levels of nitrogen and phosphorus. Through nutrient cycling and uptake, wetlands are able to remove nitrogen and phosphorus from streams. Phosphorus cannot move on its own in water but attaches to sediments and is runoff from fields into streams during rain events so the particulate settling function deposits phosphorus into wetlands soils (Maynard, 2009). Wetlands are a highly productive area able to support a variety of submerged aquatic vegetation that cannot become established in stream channels. This productivity uptakes and uses the excess nutrients, removing them completely from the streams. Wetlands can remove up to 88% of phosphorus depending on factors such as surface area, age, and types of vegetation present (Braskerud, 2005). Nitrogen can move on its' own through water and runs off from fields into streams or infiltrates into groundwater. Wetlands are still able to remove nitrogen because of the long retention time of water; when the nitrogen is held stable in one location for a period of time, wetlands bacteria are able to facilitate denitrification. This involves the bacteria removing oxygen from the nitrate compound which frees nitrogen on its own as a gas that is released into the atmosphere. Nitrogen that does not go through this process can be taken up by vegetation as well (DeLaney, 1995).

2.2.3 Dissolved Oxygen/Biological Oxygen Demand

Wetlands improve dissolved oxygen levels of downstream waters by reducing the biological oxygen demand. Organic matter settles out of the water column as well as sediments and then decomposes in the wetlands. As microorganisms decompose organic matter, they use dissolved oxygen for their respiration. Excess loads of organic matter in streams can cause depleted dissolved oxygen levels and subsequent dead zones in streams. The larger area of wetlands and the greater volume of water is more capable of handling high loads of organic matter. This takes stress off downstream ecosystems and improves the aquatic habitat (Batzer, 2007).

2.2.4 Pathogen Removal

Pathogens, such as *E. coli*, are also filtered by wetlands. *E. coli* is a particularly dangerous pathogen in streams because it is mammalian based so it can infect humans. *E. coli* cannot reproduce in water outside of the host organism and the levels degrade over time out of an organism so a high level directly indicates cattle have access to the stream relatively close. Wetlands are able to remove pathogens by providing exposure to direct sunlight which causes photo-degradation that kills organisms. When the pathogens become trapped in the wetlands they have a prolonged time out of the host organism that they cannot survive for long. Wetlands typically have a lower pH than streams that pathogens cannot tolerate for long. Wetlands also have a diverse protozoan community that will consume some pathogens. From the literature review, it was found that wetlands can reduce *E. coli* by 95.5% and total coliform by 74.4% (Karimi, 2014).

2.3 Small Riparian Wetlands

Not all wetlands function in exactly the same way and the wetland studied in this report is a small riparian wetland. This type of wetlands can be implemented throughout upper watersheds as a National Resource Conservation Service (NRCS) Best Management Practice (BMP) to remediate nonpoint source pollution. Small, riparian wetlands are best suited to improve water quality and reduce erosion of smaller streams in the upper watershed. Multiple systems implemented throughout the stream channels will be most effective to reduce flood volume and velocity of normal, annual flood events. These function to filter sediments and nutrients from the stream and reduce erosion by slowing the peak and flood flows. Agricultural pollution is best filtered through small wetlands since most agricultural practices tend to be located in the upland watershed area. Forested wetlands downstream from urban areas can remove metals such as lead that entered the stream in runoff. These small, riparian wetlands are not as suited for wildlife habitat because of their size and the flow of water is more highly variable. During periods of low rainfall and uneven fluctuations in water these can regularly run dry, making it unsuitable habitat for populations to establish and serve as feeding grounds for larger predators. However, the benthic aquatic ecosystems of the streams will benifit from the reduction in sediment erosion and nutrient loads. The habitat of the larger streams these tributaries feed into will be improved from this filtration and wetlands in the lower regions are less likely to be washed out as a result of the reduction in flood and peak flows (De Laney, 1995).

Chapter 3: Experimental Protocol

3.1 Water Quality Metrics

As depicted in the wetland map that was displayed previously in the paper, data was collected from seven sites located in the stream and in the wetland (Figure 2). A variety of water quality metrics were used to assess the impact of the wetland on the ecosystem. Using a WTW Meter, conductivity, which is a measure of the ion concentration in the water, dissolved oxygen (DO), which is a measure of the oxygen present in the water, temperature and pH were measured. Measurements were taken at each of the seven sites.

Water samples were also collected from each site and were brought back to the JMU Integrated Science and Technology Environment Lab for chemistry testing. A device called the Vernier probe was used to quantify the presence of nitrates in the water; a LaMotte Kit and Spectrometer were used to measure the amount of phosphates in the water. Phosphates and nitrates are measured in milligrams per liter or parts per million (ppm), which are interchangeable units.

3.2 Other Metrics

Other metrics were also used to measure water quality such as turbidity, which is the measure of the sediment being carried by the stream, flow rate in feet per second, soil carbon, coliform levels, and macroinvertebrate and plant surveys. The photo below shows one of the instruments used to measure coliform (Figure 5).

Figure 5: IDEXX Colilert Test Instrument

3.3 Seven Testing Sites

As mentioned previously, data was collected over the course of 11 months from sites located both inside the wetland and in the stream adjacent to the wetland. The following seven subsections explain the sites, and why they were choses, in greater detail.

3.3.1 Site 1

Site 1 is close to the southernmost boundary of Avalon Acres Farm. It marks the point where the stream enters the property. Casey, one of the two researchers who conducted this project, is shown using the WTW meter to take water quality data. This site was chosen as a control to compare water quality data from sites at the end of the farm with this site, at the beginning of the farm.

Figure 6: Site 1 at the south end of the farm

3.3.2 Site 2

Site 2 marks the beginning of the wetland. The flow rate is extremely slow and the stream is shallow so water here is retained in the wetland for a long period of time. Thomas is shown here measuring stream pH using the WTW meter. The Watercress depicted in this image was later picked and sold at the Harrisonburg Farmers Market by the two owners. Watercress uptakes nutrients from the water, such as nitrogen, which improves water quality and also stimulates plant growth.

Figure 7: Site 2 located at the beginning of the wetland.

3.3.3 Site 3

Site 3 is part of the stream, located outside of the wetland, therefore water here does not benefit from wetlands ecosystem services, such as the uptake of nutrients by plants. The image was taken in November (Figure 8, page 21).

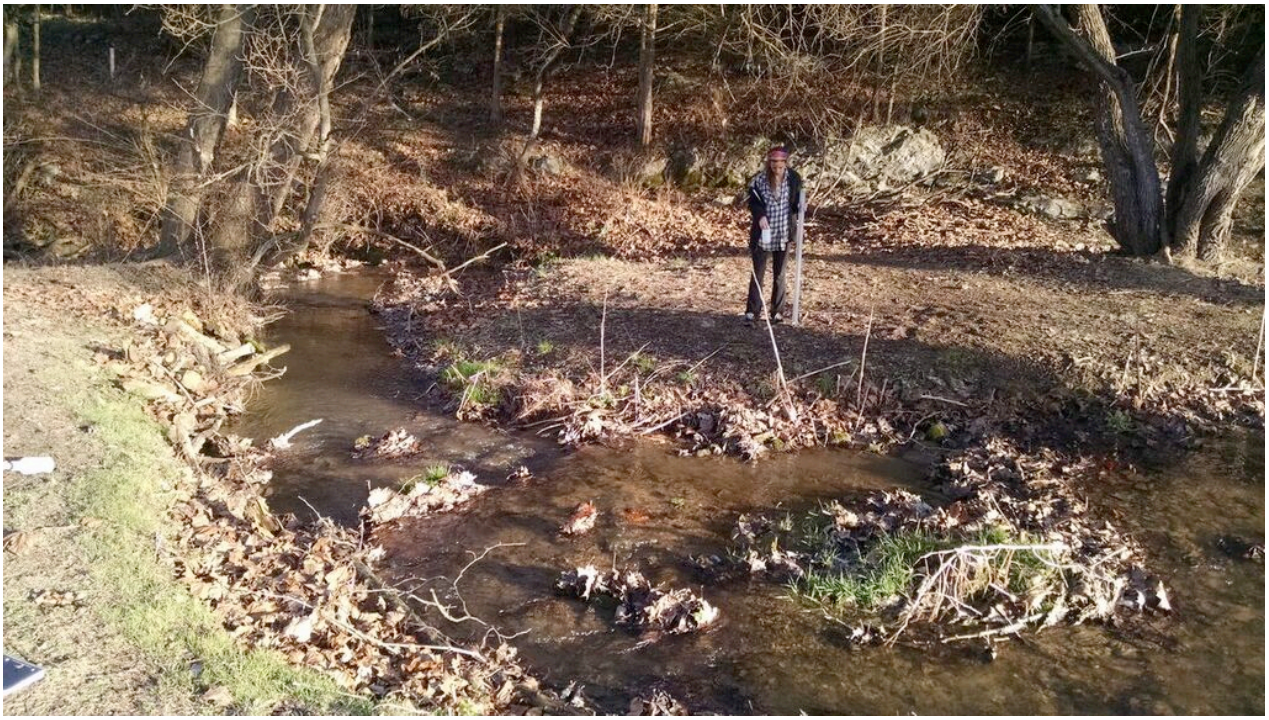


Figure 8: Site 3, located outside of the wetland in the stream

3.3.4 Site 4

Site 4 marks the end of the property, at its northernmost part, and is the point at which the wetland reconnects with the stream as water spills down a small waterfall back into the primary flow path. This picture was taken in January; there was a storm event that occurred not long before this snapshot which resulted in 8+ inches of snowfall. The water level is higher than normal in due to snow melt (Figure 9, page 21).

Figure 9: Site 4 at the north end of the farm

3.3.5 Site 5

Site 5 is located within the wetland. Water flows through certain wetland plant species, such as Cattail and Blue Flag. These plants remediate pollution in the water by performing ecosystem services.

Figure 10: Site 5, located in the heart of the wetland

3.3.6 Site 6

Site 6 is a seep, which is an underground spring that has more than one exit point. The seep is useful as a comparison for water quality because water from the seep has a different source than water in the wetland and in the stream. This site was added months into the data acquisition process, as the water table was not high enough to cause the underground spring to flow until the temperature started to increase in late winter (Figure 11, page 23).

Figure 11: Site 6, a seep discovered midway through the project

3.3.7 Site 7

Site 7 marks the end of the wetland area (Figure 12, page 23). It formed over the winter via the continuous flow of water over the soil and the streambed is already becoming established. Ten feet north of the image shown below is where the water from the wetland reconnects.

Figure 12: Site 7, also at the north end of the farm just before the wetland flow reenters the main stream channel.

Chapter 4: Data & Results

4.1 Watershed Land Use Survey

A watershed and land use survey was performed to determine the ways in which the land in the Cedar Run watershed is being used. It was discovered that the majority of land is dedicated to agricultural purposes. There were poultry houses, cattle farms and hay fields. When farmers apply chicken manure to their fields as fertilizer, the waste is broken down aerobically, meaning with the presence of oxygen, and is converted from ammonia into nitrates. During storm events, these chemical nitrates runoff into the stream. For this reason, constructing a riparian buffer, and employing other NRCS BMP's, is important to prevent pollution of streams and rivers.

It was discovered that on most farms, there was typically either a small riparian buffer or no buffer present between streams and pastureland. The diagram below explains how a buffer should look with various layers of foliage - trees, grasses and managed forest - protecting the stream and the riparian zone. These measures deter erosion and prevent pollution from entering the stream.

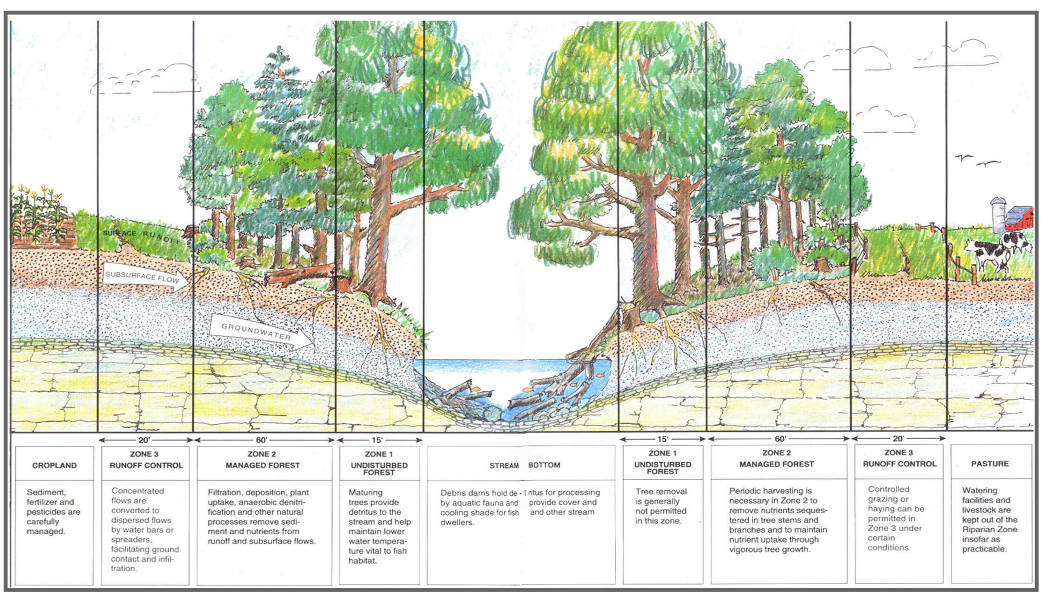


Figure 13: Image depicting an ideal Riparian Buffer Zone.

Source: Central Coast Wetlands Group

During the land use survey it was also discovered that cattle on farms had direct access to streams, which explains the presence of *E. Coli* in the water and the poor condition of the streambank. *E. coli* is a mammalian gut bacteria that does not reproduce in water, so it must come from an animal. It was also discovered that there were bare sloping fields with no cover crops to prevent erosion during the winter months.

4.2 Macro-invertebrate Survey

In order to assess the water quality of Cedar Run Stream, a macroinvertebrate survey was performed. Different species have different tolerances to pollution levels, temperature and pH, therefore the presence of certain species will indicate the health and condition of the stream. In order to perform a macroinvertebrate survey, a net is placed in the water until there are a sufficient quantity of aquatic insects trapped inside. Then the insects are counted and separated based on species and placed in separate pools of water in an ice-cube tray or a similar piece of equipment. Based on the S*ave Our Streams Macroinvertebrate Index Value*, a score less than 8 indicates that the stream has unacceptable ecological conditions, a score between 8 and 14 indicates partially acceptable ecological conditions, and a score greater than 14 indicates acceptable ecological conditions.

Two surveys were conducted: one on May 1st, 2015 and the other on October 14th, 2015. Based on survey results, a value of 11 was determined on May 1st and a value of 10 was determined on October 14th. As indicated by calculated Macroinvertebrate Index Values, Cedar

Run Stream is slightly impaired, but not completely impaired and can still support a variety of aquatic faunal species.

4.3 Plant Survey

In addition to surveying macroinvertebrates, plant transections were also performed and wetland plant species were collected and identified. As previously mentioned, certain wetland species are excellent at taking up nutrients, like nitrogen and phosphorous, from the water and using them for growth.

Table 1: Plant species located in the Avalon Acres wetland

Wetland Plant Species
Marsh Mallow
Watercress
Cat Tail
Blue Flag
Wild Astor
Button Bush

As indicated in the table above, some wetland plant species that were discovered were Marsh Mallow, Watercress, Cattail, Blue Flag, Wild Astor and Buttonbush. All of these species were intentionally planted by Lorinda and Solly, the farm owners, to improve water quality.

4.4 Soil Carbon

Soil organic carbon (SOC) is the amount of carbon stored in the soil from organic matter in various stages of decomposition. Soil carbon is a measure of the fertility of soils; a soil depleted of its carbon cannot support the growth of new life. To measure the soil carbon in soil at Avalon Acres, a soil carbon burnout test was performed. Soil samples were collected from each site along the banks of the stream or wetlands using a soil sampling tube and were brought back to the lab. There, the initial weight of each sample was determined using a mass balance and then the samples were placed in an oven at 90˚C for an hour to remove the moisture in the soil. The weight of each dried sample was recorded again using a mass balance and then the samples were placed in an oven for an hour at 700˚C to burn out all of the organic matter in the soil. The samples were weighed again and the difference between these two weights is the amount of organic matter in the soil, 45% of which is soil carbon. Healthy soils typically have at least 3-5% soil carbon but since wetlands act as a sink for organic matter and are a highly productive area they tend to have a higher level of soil carbon. The results for soil carbon at each site in Avalon Acres is shown in Table 2.

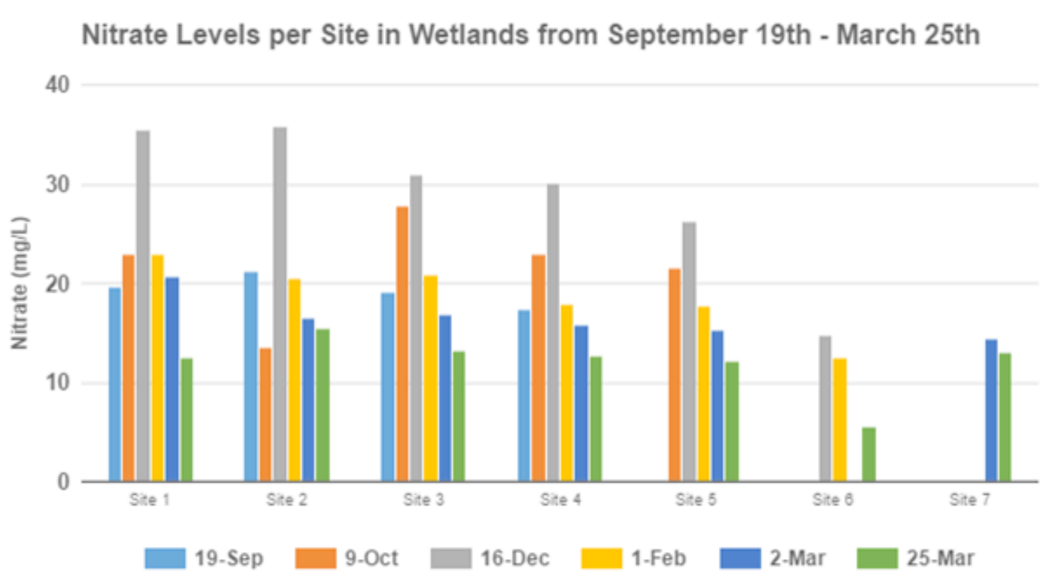
Table 2: Soil Carbon Data across seven sites

Soil Carbon	
Site 1	7.72%
Site 2	8.54%

Site 3	10.42%
Site 4	7.91%
Site 5	9.83%
Site 6	11.23%
Site 7	9.25%

The carbon content ranged from about 8-11% which is typical of an established wetlands but since the wetlands at Avalon Acres is only a few years old it is not the sole contributor of healthy soil carbon levels. Sustainable practices performed by Lorinda and Solly over the years has kept their land very fertile with a high soil organic carbon percentage.

4.5 Nitrates



<u>Figure 14:</u> Bar chart of nitrate levels per site for each testing day.

The nitrate levels at the different sites were measured six times throughout the course of the project. This was performed by collecting water samples and taking them to the environmental laboratory where a Vernier sensor was used to measure the nitrate concentration. This concentration was expected to be high due to the agricultural activity in the watershed and we hoped to see downward trend throughout the wetlands as an indicator of plant species up taking nitrogen as well as denitrification by wetlands bacteria. The results from the testing are shown in Figure 14. The average nitrate value was 19.58 mg/L, which is extremely high considering the natural level of nitrates in freshwater streams is <1 mg/L and the drinking water quality standard is <10 mg/L. Site 5 could only be tested for nitrates five times instead of six because in September there was not enough water running through the wetlands to allow testing at the time. Site 6, the seep, was only tested three times because its presence was not observed until later in the project in December and on March 2nd the wetlands was too flooded with water for an accurate sample to be taken. Site 7 did not form until later in the project when the wetlands had consistent enough flow to allow that site to establish so samples were only taken in March. A downward trend throughout the sites was determined, indicating the wetlands is removing nitrogen from the water that flows through it. However, the wetlands does not have a large impact on the stream as a whole because the percentage of the overall flow from the stream into the wetlands is small, an estimated 5% (estimate is variable and not based on hard data). This is indicated by the levels of nitrate at Site 4, which is the part of the stream after the wetlands recombines with Cedar Run before it exits Avalon Acres property. Site 4 does not show a considerable change from sites 1-3 but sites 5 and 7 in the heart of the wetland show reduced nitrate values.

December 15th, the grey bar, consistently has the highest levels of nitrate of all the days of testing. Since nitrate can move on its own through water, we referred to a hydrograph of the flow discharge over time made by the USGS of the closest monitoring station to Avalon, Cootes Store, shown in Figure 15. Around December 15th, the midpoint between November and January, there was a spike in discharge indicating a storm or heavy rain event. The flow moving through the wetland that day was possibly the highest we had yet seen. This indicated that the storm event washed off excess nitrates from agricultural fields, which were carried into the stream, causing the highest recorded nitrate value of the entire project at 35 mg/L at site one.

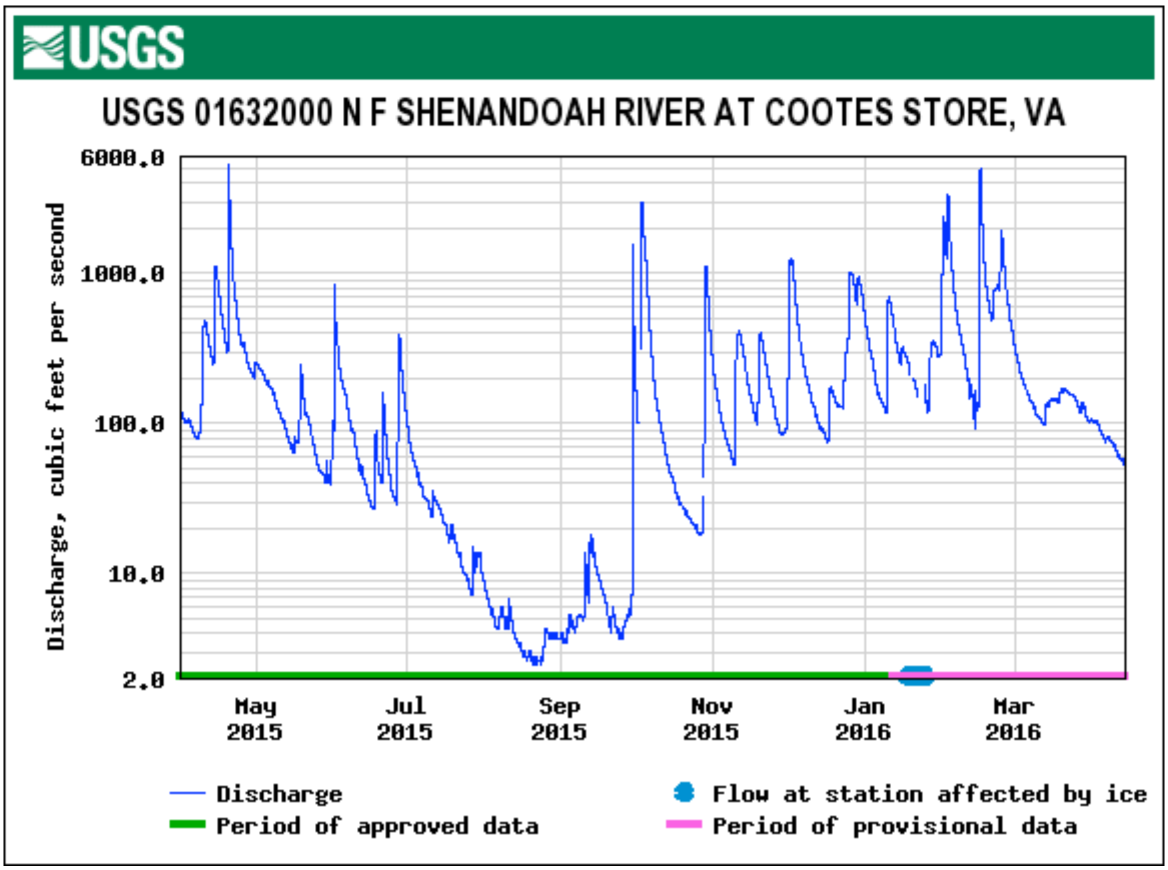


Figure 15: USGS hydrograph of Shenandoah River at Cootes Store May 2015 - April 2016.

4.6 Phosphates

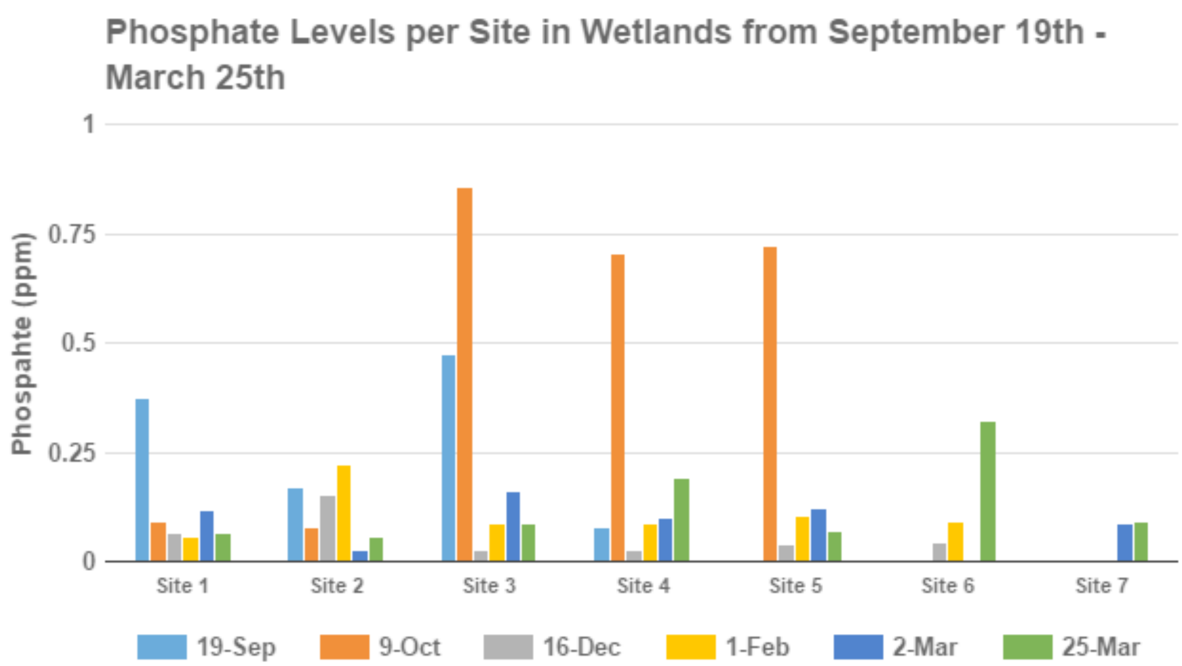


Figure 16: Bar chart of phosphate levels per site for each testing day.

The phosphate levels were measured at the same time as nitrates and were determined using a LaMotte Kit and spectrometer. The LaMotte kit has phosphoric acid and a phosphate reducing reagent that allows the phosphate level to be picked up by a spectrometer, set to wavelength 635 nanometer, as absorbance. The absorbance level is then entered in the equation,

$$Phosphate = Abs/0.3952$$

to determine the phosphate level in ppm. The levels of phosphate were also expected to be high due to agricultural activity, specifically runoff from poultry houses. The results from the phosphate testing are shown in Figure 16_. The phosphate results were highly variable, most likely due to uncertainty and variability among the testing instruments, particularly the spectrometer. Multiple trials were conducted using three samples from each site to prepare with the LaMotte kit and several different spectrometers to test the absorbance at the same time. Different spectrometers set to the same wavelength and blank would record different levels of absorbance for the same sample, which should have come out identical. The phosphate data was highly variable and did not follow a consistent trend, as can be seen in Figure _. The average phosphate value was determined to be 0.194 ppm, which is higher than the healthy limit for streams. The natural level of phosphate in freshwater streams is below 0.1 ppm; levels higher than 0.1 ppm can have detrimental ecosystem impacts such as algal blooms and depletion of dissolved oxygen.

Poultry houses are the main contributor of phosphorus runoff and there are an estimated 16 poultry houses in Cedar Runs watershed of 2.34 mi^2, which gives a poultry house density of 6.8 houses/mi^2. This density was compared to a fellow ISAT student Sonja Long's graduate thesis, which calculated the poultry house densities throughout Rockingham County. The density of Cedar Run was actually greater than any of the densities Long studied; her highest was 5.55 houses/mi^2. However, this was in the Muddy Creek watershed of 25 mi^2 having a total of 138 poultry houses (Long, 2006). Cedar Run is not receiving the largest input of phosphate pollution in Rockingham County but it is receiving a dangerously high level for its small area.

4.7 WTW Metrics

As mentioned earlier in the report, the WTW Meter is the device that was used to measure conductivity, temperature, pH and dissolved oxygen at each of the seven sites in the stream and in the wetland. Across all the data that was collected, pH values ranged from 7.31 to 8.4. This falls within the healthy pH range for streams which is between 6.5 and 8.5. For dissolved oxygen measurements, a range of 8.49 to 10.86 mg/L. Anything above 7 mg/L is considered healthy so these measurements indicate a healthy oxygen concentration in the water.

Conductivity is a measure of the stream's ability to pass an electrical current; it's the measure of the concentration of dissolved ions being carried by the stream. Conductivity values ranged from 577 to 749 µs/cm, which is above the healthy limit of 500 µs/cm. This is partially because of high levels of nitrates and phosphates in the water, which were discovered during testing, and partially because of the innate hardness of the water due to the karst limestone topography.

4.8 Pathogens

Coliform and *E. coli* levels were measured at three points over the course of the project. These bacterium are measured in MPN, which is the Most Probable Number of colony-forming bacteria. Healthy levels of these bacteria in streams are below 235 MPN. As demonstrated in the table below, consistently high levels of coliform were discovered and there was a noticeable spike on April 1st. This is most likely because farmers are required to stop spreading manure for the winter months and they are allowed to start again in mid-March. Through precipitation and runoff, nutrients from manure make their way into the stream. No conclusive trend was discovered showing a reduction in pathogen levels before and after the wetland, partly because *E. Coli* does not survive long outside the gut of an animal.

Table 3: Coliform and E. coli levels

	Coliform (MPN)	**E. Coli (MPN)**
October 9th	410.6 - 2419.6	-
March 2nd	428 - 808	41 - 213
April 1st	1616 - 2359	10 - 85

Chapter 5: Conclusions - The Larger Picture

In conclusion, consistently high levels of nitrates and variable levels of phosphates were found in both the stream and the wetland. The wetland constructed by Lorinda and Solly at Avalon Acres Farm is not large enough to improve water quality for the entire stream, but water that ran through the wetland did display a marked decrease in pollutant levels compared to water that did not pass through it, indicating its effectiveness. The Avalon Acres wetland must be part of a larger collective effort to improve water quality in the Shenandoah Valley if there is to be drastic improvement in ecological conditions. Through research and data collected over the course of this research project, a baseline for further investigation into the impact of the wetland on the ecosystem health of Cedar Run has been established.

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