Effectiveness of Stream Restoration Practices in the Piedmont of North Carolina

A report for the North Carolina Department of Environment and Natural Resources

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Abstract

Stream composition, structure, and function are degraded due to anthropogenic activities such as urbanization and agriculture. Urbanization increases the amount of impervious surfaces which increase runoff of pollutants into streams. Watershed geomorphology is also altered by erosion due to increased runoff, which has compounding effects on stream function and structure when coupled with land clearing for agricultural use. Using a function based approach, North Carolina's Department of Environment and Natural Resources (NC DENR) attempt to restore degraded streams. The purpose of this study is to evaluate the effectiveness of said practices. For this study, a time continuum was created by selecting four streams, located in the North Carolina Piedmont, at different stages of the restoration process: Mud Lick Creek (0 years), Ellerbe Creek (2 years), Chapel Creek (4 years), and Sandy Creek (8 years). Two reference streams, Eno River and Duke Forest, were used as controls. Volumetric flow rate, turbidity, temperature, nutrients, dissolved oxygen, and pH were measured in each stream in order to evaluate the effectiveness of restoration efforts over time on stream function and structure. Overall structure and function were hypothesized to improve with time. The results were largely inconclusive due to error and data gathering limitations.

Introduction

Stream Ecology

Streams are bodies of concentrated flowing water that occur in low areas or channels along the land surface. They are integral parts of the landscape, carrying water and sediment from higher elevations to downstream lakes, estuaries, and oceans. Along the way, they provide life-giving water to a wide array of ecosystems, including wetlands, bogs, ponds, forests, and floodplains. Streams are categorized into three major classes: ephemeral, intermittent, and perennial, that are defined by their respective supplies of water. Ephemeral streams transport only storm water, whereas intermittent streams have a well-defined channel that contain water for part of the year and are predominantly fed by storm water. Perennial streams also have a well-defined channel but contain water year-round, are supplied with water and stormwater. In the relatively lower altitudes of the North Carolina Piedmont, perennial streams are the dominant stream type and will thus be the focus of our study.

Streams have a variety of functions all of which are interrelated. This interdependence is described as the stream functions pyramid, where the lower functions on the stream pyramid shape the higher-level functions, which in turn affect the lower-level stream functions in ways that will be explained later in the report. The base of this stream pyramid is hydrology. In this explanation of stream functions the hydrological function refers to the transportation of water from the watershed area to the channel. The next layer up on the stream pyramid is the hydraulic function of streams, which refers to the transport of water within the channel, from the channel onto the floodplain, and through the sediments of the streambed. The third level on the pyramid is geomorphology, which describes the transport of large debris and sediment that eventually create a diverse bed form. Above the geomorphological level is the physiochemical level, which refers to the temperature and oxygen regulation along with the processes that decompose and interact with organic matter and nutrients. In addition to this, the physicochemical structure of a stream also refers to the stream's ability to withstand influxes of new chemicals and nutrients entering the system. At the top of the stream functions pyramid is biology. The biological functions of a stream refer to the streams ability to support a wider variety of plant, animal, and microbial species.

As stated previously, the lower level functions of the stream shape and determine the higher-level functions. Water flow behavior from the watershed area to the channel will greatly determine how the water flows once in the channel (hydrology affecting hydraulic functions). The way in which the water flows once in the channel will clearly shape the geomorphology of the stream. The relationships between these functions continue as the geomorphology of a stream will determine the depth and flow a stream which will thus affect the aeration and temperature (deeper streams would be expected to have lower average temperatures especially in sunny conditions) which will consequently affect what aquatic species can inhabit the stream (Harman 2012).

Watershed Processes

The land area draining to a stream is called its watershed. When rain falls in a watershed, it runs off the land surface, infiltrates the soil or evaporates, forming the fundamental components of the hydrologic cycle (Harman 2012). From the standpoint of stream formation, the greatest concern is with the hydrologic processes of runoff and infiltration. Surface runoff, whereby excess water collects on the ground surface and flows over land toward watershed valleys and stream systems, is produced when rainfall exceeds the rate at which water can infiltrate the soil. Surface runoff is the process by which stream levels rise and fall during and following rainfall events (Harman 2012).

In most systems, a large portion of the water that infiltrates the soil also reaches the stream system, but by sub-surface or groundwater flow (Harman 2012). This process occurs much more slowly and steadily than surface runoff. Groundwater discharge is the main source of water that produces base flow conditions in stream channels (Harman 2012).

The hydrologic processes (precipitation, infiltration, runoff, evaporation) that occur at the watershed level influence the character and functions of streams. Small stream channels form at the higher elevations, or headwater regions, of a watershed and become progressively larger in size as the watershed size increases (i.e., moving downstream). In the headwater regions of a watershed, surface runoff concentrates and moves downhill, forming small ephemeral channels and gullies. Ephemeral channels carry only surface runoff and thus only flow for short periods of time (generally less than 24 hours) following rainfall events (Harman 2012). Moving down the watershed, ephemeral channels continue to carry water and become intermittent channels, which carry water for extended periods following rainfall events and during wet seasons. Intermittent channels carry surface runoff but also receive discharge from shallow groundwater, particularly during wet portions of the year. Farther downstream, intermittent channels give way to perennial channels, which generally flow year round. Perennial channels carry not only surface runoff, but also groundwater discharge, which maintains baseflow conditions in the stream. During drought periods, groundwater levels can drop, and perennial stream channels can stop flowing for periods of time. But in general, perennial channels maintain some permanent water level that sustains aquatic life and provides the functions that are most associated with creeks and rivers (Harman 2012).

Overview of Stream Functions

A stream and its watershed comprise a dynamic balance where the floodplain, channel and streambed evolve through natural processes that erode, transport, sort and deposit sediments (Harman 2012). Land-use changes in the watershed, channel straightening, culverts, removal of streambank vegetation, impoundments and other activities can upset this balance. As a result, adjustments in channel form often occur with changes in the watershed. A new equilibrium may eventually result, but not before the associated aquatic and terrestrial environment are altered.

Streams carry the water supplied by their watershed. The resulting hydrology and hydraulic processes provide the basic foundation for all other functions that streams provide. The relationships between precipitation, runoff, infiltration and groundwater flow determine the amount of water that the stream carries at any given time, the energy of the water to move sediment, the physicochemical processes that affect water quality, and the biological processes that the stream will support (Harman 2012). Stream channels that are connected with their floodplains attenuate flood pulses and spread nutrients and organic matter during flooding events (Harman 2012). Stream flows rise and fall with precipitation and snowmelt events, resulting in the dynamic range of flows, which defines the channel form on which many other processes and functions rely. Groundwater is both recharged and discharged along stream channels, providing another hydrologic link between the stream channel and the landscape.

The transport of water and sediment is reflected in the bed features that are formed within a stream channel. Natural streams have sequences of riffles and pools or steps and pools that maintain channel slope and stability. The riffle is a bed feature that may have gravel or larger rock particles (Harman 2012). The water depth is relatively shallow, and the slope is steeper than the average slope of the channel. At low flows, water moves faster over riffles, which removes fine sediments and provides oxygen to the stream. Riffles enter and exit meanders and control the streambed elevation. Pools are located on the outside bends of meanders between riffles. The pool has a near-flat water surface due to low relief and is much deeper than the stream’s average depth. At low flows, pools are depositional features and riffles are scour features. At high flows, however, the pool scours and the bed material deposits on the riffle. This occurs because a force applied to the streambed, called shear stress, increases with depth and slope. Depth and slope increase rapidly over the pools during large storms, increasing shear stress and causing scour (Harman 2012).

Physicochemical functions of streams include the physical and chemical processes that create baseline water chemistry, breakdown organic matter and transform nutrients (Harman 2012). It could be argued that once water reaches the channel (Hydrology and Hydraulic functions) chemical and biological processes begin to occur. Physicochemical water quality assessments include the following parameters: nutrients, dissolved oxygen, temperature, pH, conductivity and turbidity. Nutrients can be assessed rapidly in the field with test kits, but are more often measured in a laboratory. Nutrient processing is always measured as a rate and significantly contributes to the character of the stream system; therefore, these parameters are direct measures of function (Harman 2012). Dissolved oxygen, temperature, pH and conductivity are typically measured at a point in time rather than a rate over time and are considered a structural measure (Harman 2012). However, with continuous monitoring, parameters such as temperature can be considered a function. For example, the rate of change in water temperature as air temperature changes is a functional measure of thermal regulation.

Disturbances

Urbanization and agriculture are the two main anthropogenic activities that cause disturbances to stream function and composition. Rapid urbanization across the United States has resulted in increased amounts of impervious surfaces that affect stream hydrology and function. The greater the impervious coverage of a stream's watershed or drainage basin, the greater resultant impact on streams. Streams are categorized as "stressed" at 1-10% imperviousness, "impacted" at 11-25%, and "degraded" at greater than 25% (Arnold 1996). Paving the natural landscape disrupts the hydrological cycle by altering the way water is transported and stored within a watershed. Stream degradation due to agriculture is brought about by runoff and can be just as damaging to stream composition and function as urban development (Lenat 1994). Agricultural disturbances are similarly pertinent in that they, like urban disturbances, have widespread effects on stream's water quality and physical form while being just a pervasive as urbanization throughout the United States.

Urbanization and agriculture pose threats to water quality, largely because of impervious surface increasing runoff of pollutants such as sediments, nutrients, pesticides, and heavy metals. At just 10-20% impervious cover, there is a 10% increase in the amount of runoff (Arnold 1996). Imperviousness prevents natural pollutant processing in the soil by preventing infiltration and percolation of surface water (Brabec 2002). These surfaces act as pollutant-carrying fast tracks to waterways (Brabec 2002). After precipitation occurs, soil and other sediments are washed off into streams, where the sediment is then suspended in the water column and deposited on the streambed. Excess sediment clouds the water, reducing the temperature of the stream as well as the amount of sunlight that reaches aquatic plants (Lenat 1984), which reduces primary production (Wauchope 1978). Often other pollutants, such as fertilizers, pesticides, and heavy metals, are attached to soil particles and also end up in streams, which can further degrade water quality. Surface runoff also increases concentrations of nitrates and phosphates (Ryden), because farmers and homeowners apply chemical fertilizers, manure, and wastewater biosolids to fields (Willis and McDowell 2009). These substances, along with animal waste from livestock operations, get washed into streams. Organic matter, such as animal waste and leaf litter, are oxygen-demanding wastes, which decompose by aerobic bacteria that utilize free oxygen (Barnes 2002). An influx of waste materials can increase dissolved solids contents and decrease dissolved oxygen content (Leopold 1968). Anaerobic decomposition produces and releases noxious gases and compounds (Barnes

2002). The cumulative effects of repeated storm water discharges and runoff from urban and agricultural areas degrade water quality and alter the natural functioning of these systems.

Urbanization and agriculture also impacts stream morphology and hydrology. As impervious cover increases, the velocity and volume of surface runoff also increases, thereby increasing impacts from floods. During floods, storm flows are greater in volume and peak more rapidly. As flood peaks increase, there is a decrease in groundwater recharge as a result of impervious surfaces and a decrease in lag time (Leopold 1968)—this makes the stream "flashier". Agricultural run off also contains sediments, which can enter streams due to rain events. Various volumes of dumped sediment can affect the turbidity of the stream, as well as play a key role in erosion (Costa). The increased volume of water and sediment combined with the flashiness of peak charges causes the widening and straightening of stream channels (Costa). Simultaneously, this causes an increase in erosion rates. Urbanization may also affect stream temperature. In 1968, E.J. Pluhowski published a study focused on the relationship between urbanization and stream temperature. He found that in the summer, streams in more urban areas were 10-15 degrees hotter than normal (Leopold 1968). However, in the winter, urban streams were colder than normal (Leopold 1968). This temperature variation is due to increase surface area of the stream.

Stream Restoration

Stream Restoration is the process of returning a degraded stream environment to its fullest potential of function, like meeting the Environmental Protection Agency's Clean Water Act water quality standards and providing niches for native species. Stream restoration takes places when there has been clear degradation to a stream with respect to multiple environmental variables.

An assessment of the current habitat is necessary to give a base/zero point for restoration to occur on. Once a stream has been identified for restoration, restoration of that stream occurs by selecting and monitoring those variables, which dictate stream functionality. Restoration also happens in occurrence with a plan that is tailored to suit the needs of a particular stream. There are several important goals, which may be addressed. These goals are set because somewhere during development of riparian land, the variables that control the viability and function of these streams have been impaired. The streams, for the purpose of this experiment, are those that have ongoing restoration projects centered on restoring water quality, restoring terrestrial and aquatic habitats, reducing bank erosion and water sedimentation, and improving flood attenuation.

Shields (2003) asserts that initial project phases must include definitions of measurable project objectives by project stakeholders. Once individual goals have been noted, restoration planning continues by monitoring/measuring/observing those factors, which cause streams to lose their function. These factors fall under five categories: hydrologic, geomorphic, biotic, riparian vegetation and physicochemical. Hydrologic factors include discharge/flow rates and describe the movement of the water in the stream. Geomorphic factors include substrate particle size, floodplain connectivity, streambed armoring, channel geometry and other physical features. Biotic factors include species variety, sensitive species variety, fish size, and other attributes of the living things within the stream. Riparian vegetation factors include percentage of native vegetation intact, vegetation composition and size and anything pertaining to the health of the riparian barrier. Physicochemical characteristics such as water chemistry, temperature and oxygen can also significantly impact stream function (Palmer 2011). These factors contribute to the health of a stream ecosystem and their measurement can lead to an evaluation of the overall stream health. Furthermore, an evaluation of what variables need to be changed in order to achieve stream health can be accomplished.

Once monitoring and measuring the stream's features, the invested parties make a conclusion about the remaining potential of the stream and plans for the restoration of the stream are drawn up. The effectiveness of these plans are what we are testing for in our experiment to give helpful feedback to the client, North Carolina Department of Environment and Natural Resources (NCDENR 2012), in the hopes of enhancing the restoration projects to become more effective and cater to the weak points in a stream's recovery process. Plans typically take one of these two forms: structural or non-structural. Structural improvements involve building, planting or otherwise altering the physical composition of the stream habitat in order to positively impact stream functionality. Non-structural projects make use of software, metrics or otherwise non-physical methods to evaluate and address stream needs (Palmer 2011).

Authorities use dozens of techniques for restoring the ecological integrity of streams, with each technique often offering various specific solutions. Road Improvement strategies such as road removal, reduction of road drainage to streams, correction of unstable crossings and traffic reduction all serve to reduce the sediment load of streams. High levels of sediment can harm fish eggs as well as disturb habitats such as birthing pools making it difficult for aquatic life to flourish. Riparian restoration techniques such as silviculture (planting of ideal tree species while removing others) remove hardwood species and replace them with species like Conifers. Conifers provide a more stable supply of LWD (Large Woody Debris) which represent ideal sources of nutrients and contribute to habitat formation. Grazing and fencing Strategies such as the exclusion of livestock or seasonal grazing rotations help to reduce the impact of large grazers on the stream environment. Excessive grazing can destroy riparian buffers, causing significant erosion and decreased water quality. Instream Habitat restoration techniques center around LWD placement, or placement of other large, typically organic or natural objects into the stream to provide habitat formation for aquatic life. This strategy results in an increase in breeding pool frequency and depth as well as woody debris retention. Carcass placement and nutrient enrichment are techniques designed to provide aquatic life with resources necessary to their growth and health. A primary nutrient enrichment technique is to add inorganic nitrogen and phosphorus to streams; another is the distribution of fish carcasses within streams to provide organic matter for wildlife as well as vegetation (Roni 2005).

It is difficult to account for all of the variables reduce the viability of a stream. Therefore, restoration planners are aware of certain constraints, which may make it impossible for full restoration to be achieved. For instance, impervious surface cover (ISC) is any man-made surface that covers natural ground, such as asphalt or concrete, reducing drainage. High levels of ISC can lead to flash floods in streams which may prevent species recovery and underlying processes needed to maintain stream health. ISC is also associated with reduced water quality as nutrients and other effluent from man-made structures get swept up and deposited in the stream.

There are many other factors that influence a stream's properties and level of impairment. Dams or flow diversions cause flow redirection, which can result in negative impacts on habitat suitability and stream/riparian geomorphology. Agricultural land use, especially in excess, leads to excess nutrient and sediment levels in the stream from wastewater effluent. Invasive species of concern typically have a negative effect on local aquatic life but their effect varies based on species in question. Upstream water quality can reduce the ability to restore downstream segments for any length of time (Palmer 2011). It is apparent that with all of the possible variables that can majorly affect a stream, a specific combination of treatments should be applied to restore a degraded stream. The variables tested in this experiment seek to identify whether the cocktail of stream restoration treatments are fully effective.

Considerations of certain variables are very important for determining stream health and then planning for its restoration. Dissolved oxygen (DO) indicates the amount of oxygen available and can be used to reveal whether there is enough oxygen in the water column to sustain aquatic life. The power of hydrogen (pH), which is the spectrum of acidity or alkalinity of a solution, must maintain a moderate balance necessary for aquatic life. If the pH of a water body, in this case a stream, varies too far from neutral on the pH spectrum, it can seriously damage fish and other organisms. Aquatic life also requires a moderate range of temperature to thrive. Riparian barriers, which help to prevent nutrient and sediment pollution (or erosion), aid in the stabilization of a fish habitat, control flooding and establish a microbial food cycle. The geomorphology of a stream indicates past sediment pollution and channel shape. High levels of turbidity have numerous harmful effects on aquatic life as well as increasing the cost of water treatment for drinking and food purposes (MPCA 2008). Flow rates impact the presence of certain aquatic life forms and have a strong effect on dissolved oxygen and erosion. Stagnant water is prone to hypoxic events, because organisms throughout the water column need oxygen to survive but when there is little mixing within the water column, oxygen from the atmosphere cannot replenish the bottom layers of water. Fast-moving water can more readily erode stream banks, harming the riparian land surrounding a stream. Erosion impacts the sediment load of streams and impacts water quality and aquatic life.

Objective and Hypotheses

The objective of our research project was to evaluate stream restoration with respect to water quality and hydrology by investigating North Carolina Department of Environment and Natural Resources (NC DENR) restoration projects that are in different phases of the restoration processes.

With respect to water quality we hypothesized the following:

- **Hypothesis 1**: Streams in the later stages of restoration will exhibit progressively decreased turbidity, temperature, and nutrients (phosphates and nitrates) as compared to streams in earlier stages of restoration.
- **Hypothesis 2**: Streams in the later stages of restoration will exhibit progressively increased dissolved oxygen and will obtain a more neutral pH as compared to streams in earlier stages of restoration.
- **Hypothesis 3**: During elevated flow, a stream will experience increased turbidity and decreased pH levels as compared to the same stream at base flow.
- **Hypothesis 4:** During elevated flow, streams in the earlier stages of restoration will exhibit increased nutrient levels, turbidity, and a more acidic pH as compared to streams in later stages of restoration.

With respect to hydrology we hypothesized the following:

- **Hypothesis 5**: Streams in the later stages of restoration will have a lower base flow rate compared to similar streams in the earlier stages of development.

Methods

Site Selection

We considered two main factors when selecting our streams. First, we made sure that all streams within the study had a wetland riparian zone and overlapping project objectives such as improving water quality and restoring wetland functions. Second, each stream differed from the rest in terms of how much time had elapsed since restoration began

Stream 1– Mud Lick Creek: The Mud Lick Creek, located in the Cape Fear River Basin in Chatham County, was initially restored 0 years ago. The Mud Lick Creek watershed is rural and is characterized by agricultural crop and pasture lands (35%), wooded areas (60%), and low density residential development (5%). The historic and current land-use within the riparian zone is agricultural and livestock production (DENR 2013). The primary goals of the proposed restoration is to improve the aquatic habitat, greatly reduce bank erosion and sedimentation to downstream waters, improve water quality, restore terrestrial habitat and a native riparian community, and restore the natural patterns and cross-sectional dimensions of the project site that has been degraded due to livestock access, removal of riparian vegetation, and channelization and relocation (MLCMS). Stream channelization “describes any activity that moves, straightens, shortens, cuts off, diverts, or fills a stream channel, whether natural or previously altered” (EPA 2005). Stream relocation refers to the physical change in location of the stream due to either natural or anthropogenic forces.

Stream 2– Ellerbe Creek: Ellerbe Creek, located in the upper Neuse River Basin in Durham County, was initially restored 2 years ago. The drainage basin area for the site is urban and residential. Ellerbe Creek is a perennial, third- order stream in Northgate Park (DENR 2006). The projects site is predominantly a park setting with scattered, large trees, recreational grasses, and patches of upland forested areas (DENR 2011). Along the stream, the buffer area is narrow and regularly maintained; containing ornamental/planted species and invasive herbaceous species (DENR 2011). The goals of the Ellerbe Creek Stream Restoration Project are to improve water quality, enhance flood attenuation, and restore aquatic and riparian habitat (EPA 2005). The project objectives are to form a stable urban stream channel, improve the connection to the stream's floodplain, and restore the riparian buffer from park grasses and herbaceous vegetation to Piedmont Bottlomland forests to provide filtration of nutrients and organic matter inputs into the stream.

Stream 3– Chapel Creek: Chapel Creek, located in the Cape Fear River Basin in Orange County, was initially restored 4 years ago. The goals of the restoration project are to improve water quality in Chapel Creek by: (1) channel restoration of pattern, profile, and dimension for approximately 1,000 linear feet of Chapel Creek, (2) channel enhancement/stabilization for approximately 600 feet, (3) restore reach to a stable stream channel, capable of transporting flows and sediment load efficiently, (4) improve aquatic habitat by planting trees along the banks in the cleared section to increase shade and adding more sinuosity to create more pool and riffle sections, and finally (5) reduce sediment inputs to the stream from bank erosion by re-vegetating the banks.

Stream 4– Sandy Creek: Sandy Creek, located in the Cape Fear River Basin in Durham County, was initially restored 8 years ago. Sandy Creek is a wetland restoration and stream enhancement mitigation site. The project goals and objectives for this project are as follows (DENR 2011) (1) Improve water quality by incorporating log vanes within the stream channel and planting the stream buffer, (2) Improve wetland hydrology with the removal of fill material and the sludge drying beds, (3) Improve in-stream habitat with the installation of log vanes to enhance pool depths, (4) Restore wetland function with the incorporation of wetland woody and herbaceous plant species, (5) Stream enhancement of 2,461 linear feet of Sandy Creek, (6) Restoration of 3.13 acres of wetlands through the removal of fill material and the sludge drying beds to improve wetland hydrology, (7)Establishment of a 22.6 acres conservation easement.

Reference Stream 1–Duke Forest: A reference stream was chosen from Duke Forest, located in the Cape Fear River Basin in Durham County. This stream demonstrated similar composition and structure to the other four chosen streams.

Reference Stream 2–Eno River: Another reference stream was chosen from Eno River State Park located in the Cape Fear River Basin in Durham County. Similar to Reference Stream 1 from Duke Forest, this stream appeared to have similar composition and structure to the chosen four experimental streams.

Water Quality

Water quality samples were collected at three sites in each stream once during base flow conditions. We waited at least one week after a rain event to sample base flow water quality to ensure that we were sampling streams when they were being primarily fed by groundwater as opposed to surface water runoff. Sampling points during base flow conditions were determined by using a Garmin Etrex 1 to map the length of the stream, and estimated locations that were 25%, 50%, and 75% of the way down the stream. The measurements obtained at each of these three locations were averaged and used as the replicate value for each stream.

A stage sampler was deployed at each stream during base flow conditions to obtain water samples following a precipitation event. Each stage sampler consisted of a 0.5L Nalgene bottle capped with a rubber stopper containing two holes. Protruding from one hole was a U-shaped tube that provided a channel for water to enter through once water levels rose above 20 cm. The other hole had a flexible plastic tube that rose 1-m above the stage sampler and served as an exhaust vent as water entered the bottle. The stage samplers were assembled in the field and were attached to a steel pole with cable ties after driving the poles vertically into the streambed with a pile driver. For each stream, we deployed one stage sampler prior to a precipitation event. After a precipitation event, the water samples were collected from each stream and returned to the lab for further nutrient and turbidity analysis

Total nitrogen and phosphorus concentrations under were measured with a LaMotte Nitrate-nitrogen test kit model 3354-01 and a WARD'S Instant Water Quality Snap test kit for phosphate, respectively. These test kits use pre-measured reagents to induce a color change in water samples that is compared visually to standard colors. We measured turbidity (NTU), with a LaMotte 2020we turbidity meter, pH with an Accumet Excel pH Meter, dissolved Oxygen (DO) with a YSI Pro DO probe and temperature with a YSI Model 30 Probe.

Geomorphology

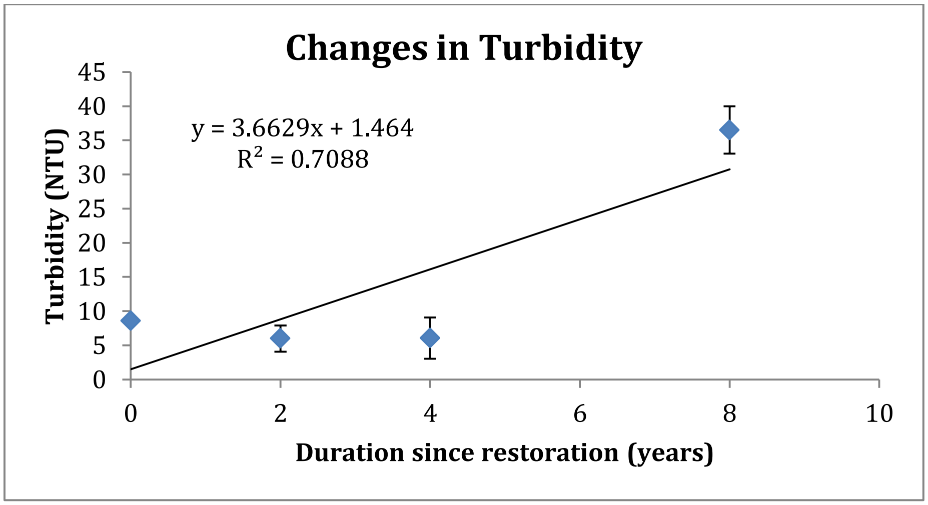
We randomly chose one site at each restored stream to map its cross-sectional change in elevation. First we randomly selected a point to serve as an elevation benchmark and drove a two foot long piece of rebar into the ground to mark the spot. We then established a survey site to deploy a leveled a tripod with a laser level affixed to its top. Lastly, we selected the two endpoints for the survey on each side of the stream that were above bankfull height. We drove a two foot long piece of rebar into the ground at each endpoint, secured the start of the measuring tape on one piece of rebar, and then extended the measuring tape over to the endpoint on the opposite side of the stream. We used a telescoping level rod to measure the elevation across the stream bed, relative to the benchmark. We took the first elevation measurement at the endpoint located on the same stream bank as the laser level and took systematic elevation measurements every two feet or when a major change in elevation occurred (e.g., edge of the bank, waters edge, etc.)

To estimate flow rate, a section of stream approximately 6 meters in length was chosen with the following characteristics: relatively straight, at least 10 centimeters deep, and have relatively little barriers restricting flow of the stream. We measured the width of the stream by stretching a measuring tape between the waters edge on both banks. We then measured water depth at five equidistant points along the width of the stream with a meter stick. Then we calculated the cross-sectional area by multiplying the width and the average depth. We then used a flowmeter to measure water velocity at each of the five equidistant points and averaged these values together. We then multiplied the cross sectional area (ft^2) by the flow rate (ft/sec) to get volumetric flow rate (ft^3/sec).

Results and Discussion

First, all base flow data was analyzed. Each stream data point represented in the below analysis is an average of three raw data points generated from the different sampling sites along each stream. Plots were generated using these averaged measurements. In order to generate one data point for the reference stream, both reference streams were averaged together for each variable tested.

Figure 1. This figure represents the changes in turbidity with respect to duration since restoration for base flow. Standard error for each data point is shown, as well as a line of best fit and the corresponding coefficient of determination.



For each variable, a regression analysis was completed which yielded a line of best fit and a corresponding coefficient of determination. An interpretation of these analyses will be conducted later in this section.

Figure 2. This figure represents the reference stream value for turbidity at base flow.

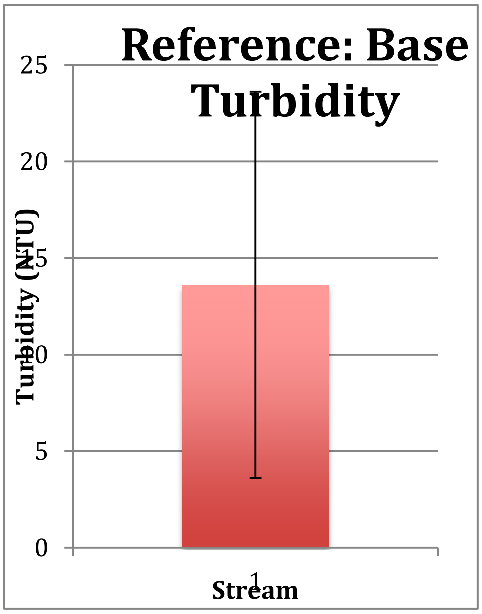


Figure 1 and **Figure 2** are indicative of the analysis that was conducted for the other test variables, the results of which will be investigated in due time.

For elevated flow the same analysis was conducted, the only exception being that the plotted data was not generated from averaged measurements because one water sample of elevated flow was collected per stream. Besides an analysis of strictly elevated flow, comparisons were drawn between select variables at base and elevated flow.

Hypothesis 1 states that streams in the later stages of restoration will exhibit progressively decreased turbidity, temperature, and nutrients (phosphates and nitrates) as compared to streams in earlier stages of restoration. Let us first examine turbidity.

According to hypothesis 1, **Figure 1** should exhibit a negative trend between the change in turbidity and the duration since restoration began. However, the hypothesis is not supported by the data. **Figure 1** demonstrates a positive linear relationship with a slope of 3.66 and an R-squared value of 0.7, denoting a moderately strong fit between the regression line and true data. The base reference stream turbidity, shown in **Figure 2**, has a value of 13.6. In looking at the data presented in **Figure 1**, the turbidity at year 8 since restoration (Sandy Creek) is quickly identified as the outlier, without which there would be a completely different trend. The turbidity at Sandy Creek is potentially so high because that stream is currently experiencing massive construction. This has nothing to do with the restoration efforts of NC DENR and should be kept in mind when evaluating the data presented.

In terms of temperature, while a negative trend was expected, an almost stable line arose around 15˚C shown below in **Figure 3**. The largest deviation from 15˚C arose from the temperature at year 2 since restoration (Ellerbe Creek), which had an average temperature of 11.1˚C rather than the approximate value of 15˚C boasted by the other three streams. The reference stream, **Figure 4**, had an averaged value of 17.6˚C, which also deviates from the 15˚C norm though not to the degree that Ellerbe Creek does.

Figure 3. This graph plots the change in temperature since restoration efforts began. The line of best fit along with the R-squared value are also on this graph.

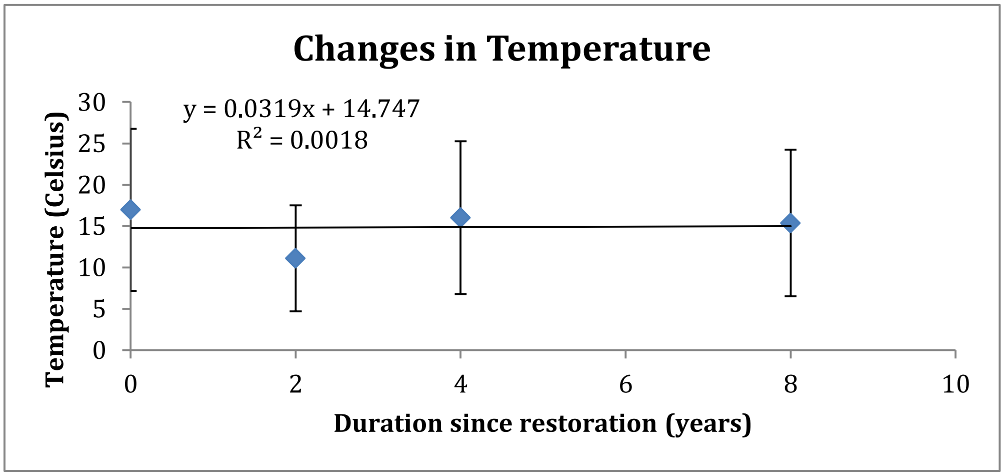
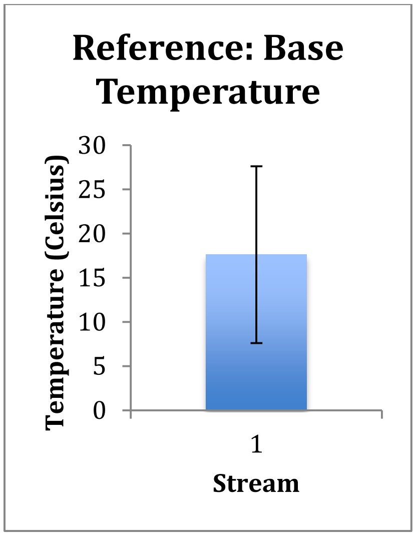


Figure 4. Reference stream value for temperature at base flow.



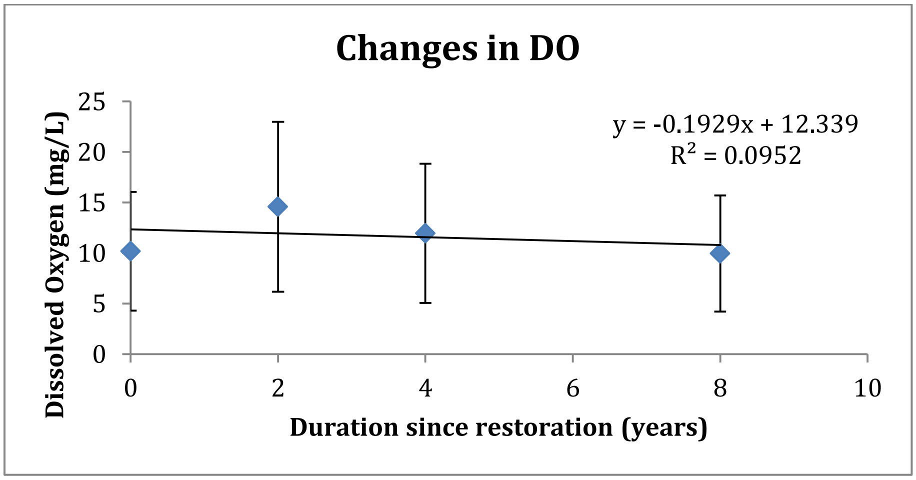
No conclusions can be drawn about nutrients due to the low sensitivity of the testing equipment. Therefore, no further discussion of nutrients will occur in examining results. **Table 1** shown below summarizes all nutrient data collected.

Table 1. This table summarizes all collected nutrient data including that from base (highlighted in blue) and elevated flows.

Stream	Years since restoration	Phosphates	Nitrates
Mud Lick Creek	0	0	0
		None	None
Ellerbe Creek	2	0	0.16
		0	0
Chapel Creek	4	0	0
		0	0
Sandy Creek	8	0	0
		0	0
Eno River	Reference	0	0
		0	0
Duke Forest	Reference	0	0
		0	0

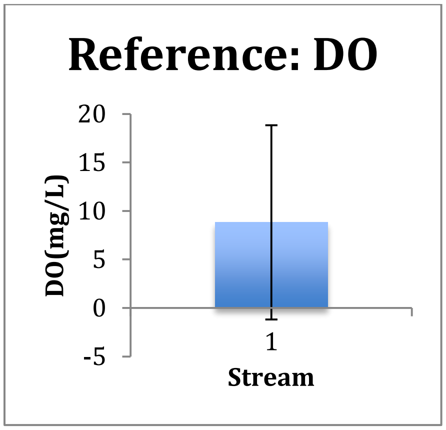
Hypothesis 2 states that streams in the later stages of restoration will exhibit progressively increased dissolved oxygen and will obtain a more neutral pH as compared to streams in earlier stages of restoration. As can be seen in **Figure 5**, the data does not support the hypothesis; rather, a slightly negative trend arises. With only a slope of -0.19, the data barely describes a trend, similar to temperature readings in **Figure 3**.

Figure 5. This plot illustrates the changes in dissolved oxygen since restoration. The line of best fit and R-squared value are also presented on the plot.



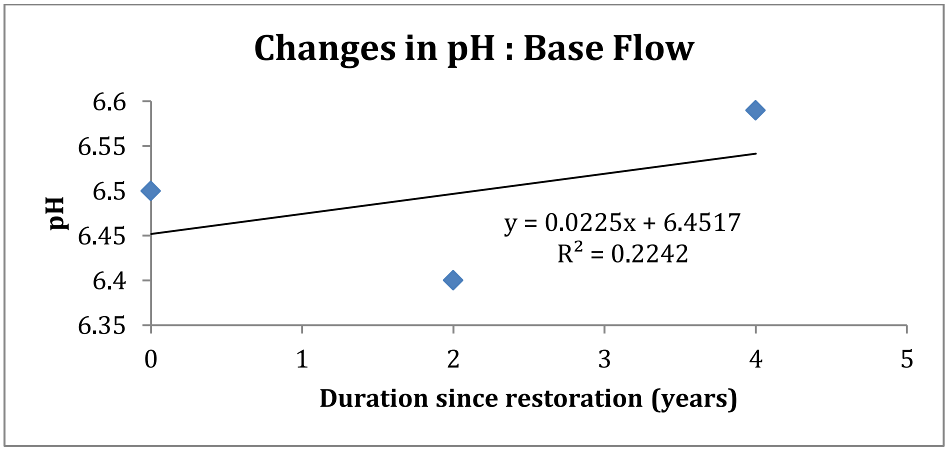
The reference stream, **Figure 6**, demonstrates a dissolved oxygen value of 8.8 mg/L, which is low, compared to the data in **Figure 5** that falls between ~10 mg/L and ~15 mg/L.

Figure 6. Reference stream for dissolved oxygen



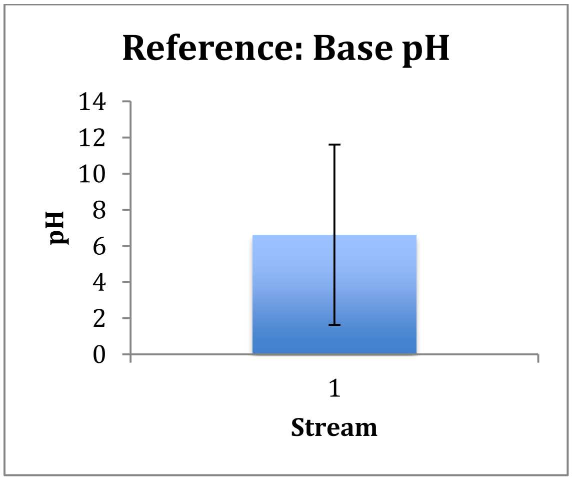
A movement towards a more neutral pH (7) was predicted in hypothesis 2 and is supported by the data, shown below in **Figure 7**.

Figure 7. This graph illustrates the changes in pH according to duration since restoration.



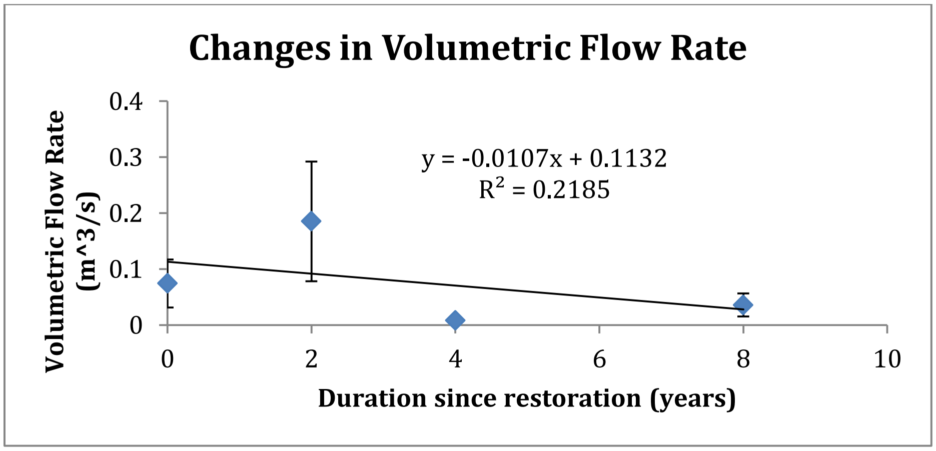
Streams generally are between a 6.5-8 on the pH scale and with the exception of Ellerbe (2 years since restoration), all streams fall within this range. The reference stream, **Figure 8**, with a pH of 6.62 also falls within this range. There are only three data points presented in **Figure 7** because pH data was not taken for Sandy Creek, which represents 8 years since restoration. The reference stream also represents data from the Eno River because pH data was not taken at Duke Forest.

Figure 8. Reference Stream for pH at Base Flow



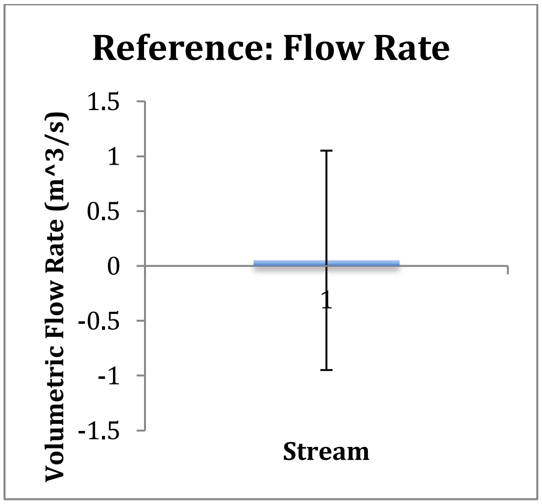
In terms of volumetric flow rate, hypothesis 3 predicted overall to see a lower base volumetric flow rate. **Figure 9** illustrates the negative trend predicted by the hypothesis. As with temperature (**Figure 3**) and dissolved oxygen (**Figure 5**), the trend is only slightly negative with a slope of -0.01 and it is challenging to draw any conclusive results from such data.

Figure 9. The changes in volumetric flow rate with respect to the number of years passed since restoration.



The reference stream had an almost nonexistent volumetric flow rate of 0.05 m^3/s. The reference stream volumetric flow rate is shown below in **Figure 10**.

Figure 10. Reference stream for volumetric flow rate



Hypothesis 4 predicts that during elevated flow, a stream will experience increased turbidity and decreased pH levels as compared to the same stream at base flow. Hypothesis 5 estimates that during elevated flow, streams in the earlier stages of restoration will exhibit increased nutrient levels, turbidity, and a more acidic pH as compared to streams in later stages of restoration. Nutrients will not be examined as stated previously.

The elevated flow turbidity data is incomplete because elevated flow for Mud Lick Creek was not taken and the elevated flow turbidity of Ellerbe Creek was recorded in different, non-convertible units. Thus, no analysis was done in accordance with hypothesis 5 to determine if the turbidity will increase during elevated flow with respect to time passed since restoration. All turbidity data is summarized in **Table 2** and a graphical comparison of the data, sans elevated flow from Mud Lick Creek and Ellerbe Creek, is depicted in **Figure 11**.

Table 2. This table is a summarization of turbidity data for base flow (highlighted in blue) and elevated flow.

Stream	Duration since restoration (years)	Turbidity
Mud Lick Creek	0	8.6 NTU
		None
Ellerbe Creek	2	5.9 NTU
		1086 AU
Chapel Creek	4	60.1 NTU
		19.8 NTU
Sandy Creek	8	36.5 NTU
		169 NTU

Eno River	Reference	9.58 NTU
		14.7 NTU
Duke Forest	Reference	16.3 NTU
		43.5 NTU

Figure 11. A graphical representation of turbidity during base flow and elevated flow

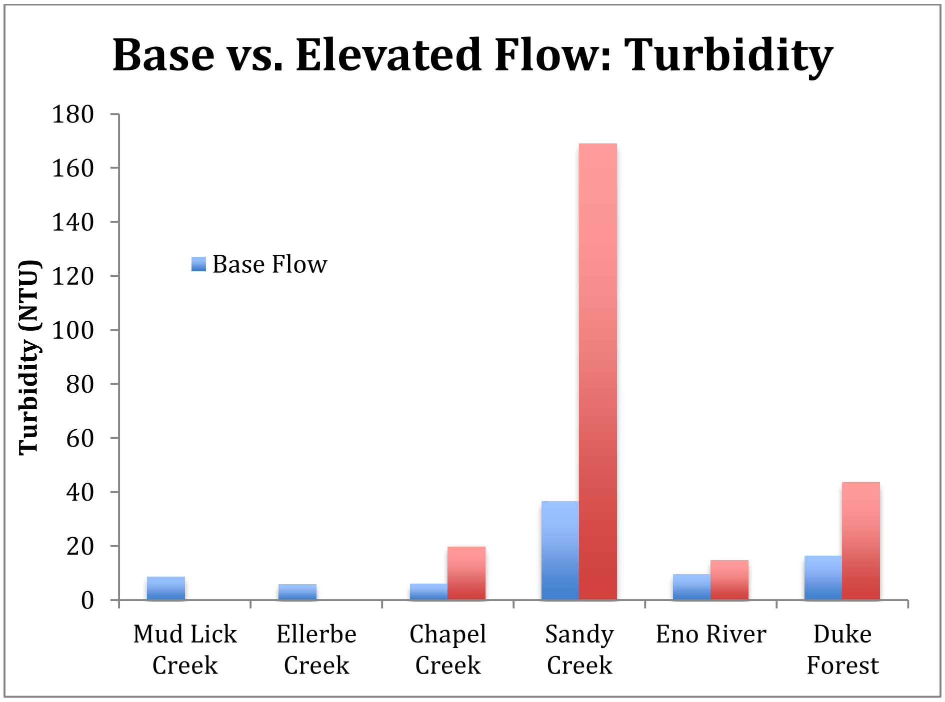
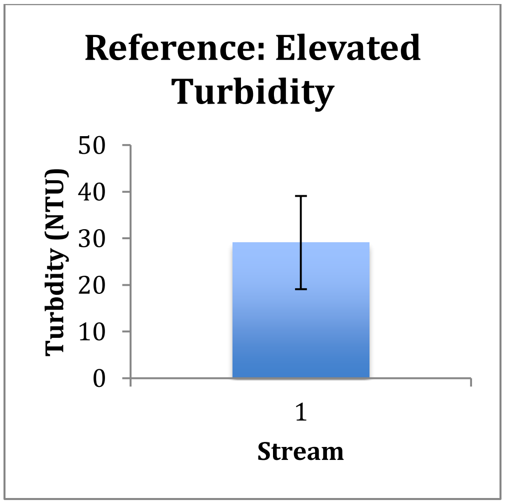
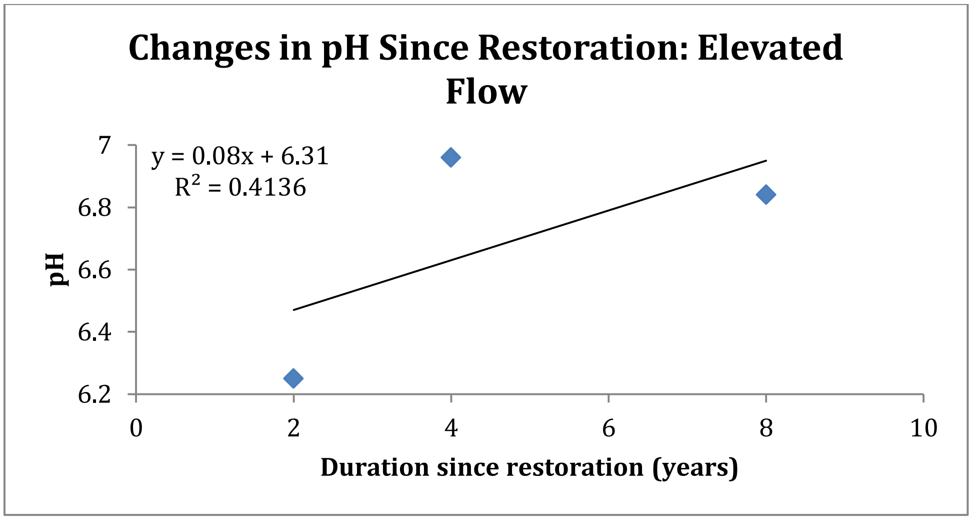


Figure 12. The reference stream for turbidity during elevated flow



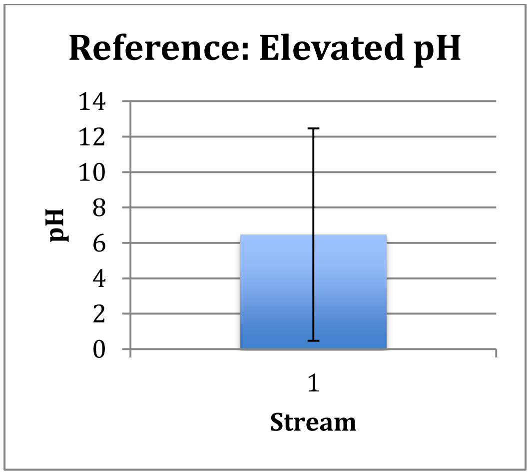
The elevated flow data for pH is more complete than the turbidity data, though pH data is missing from Duke Forest and Sandy Creek during base flow and Mud Lick Creek during elevated flow. An analysis similar to the one conducted for base flow can be seen in **Figure 13**. Hypothesis 5 predicted a more acidic pH, yet the data presents an overall trend toward a neutral pH. However, with a R squared value of 0.4, the correlation is not very strong and more data is required to draw any conclusions.

Figure 13. This figure represents the changes in pH with respect to duration since restoration for elevated flow. The line of best fit and the corresponding coefficient of determination are also shown.



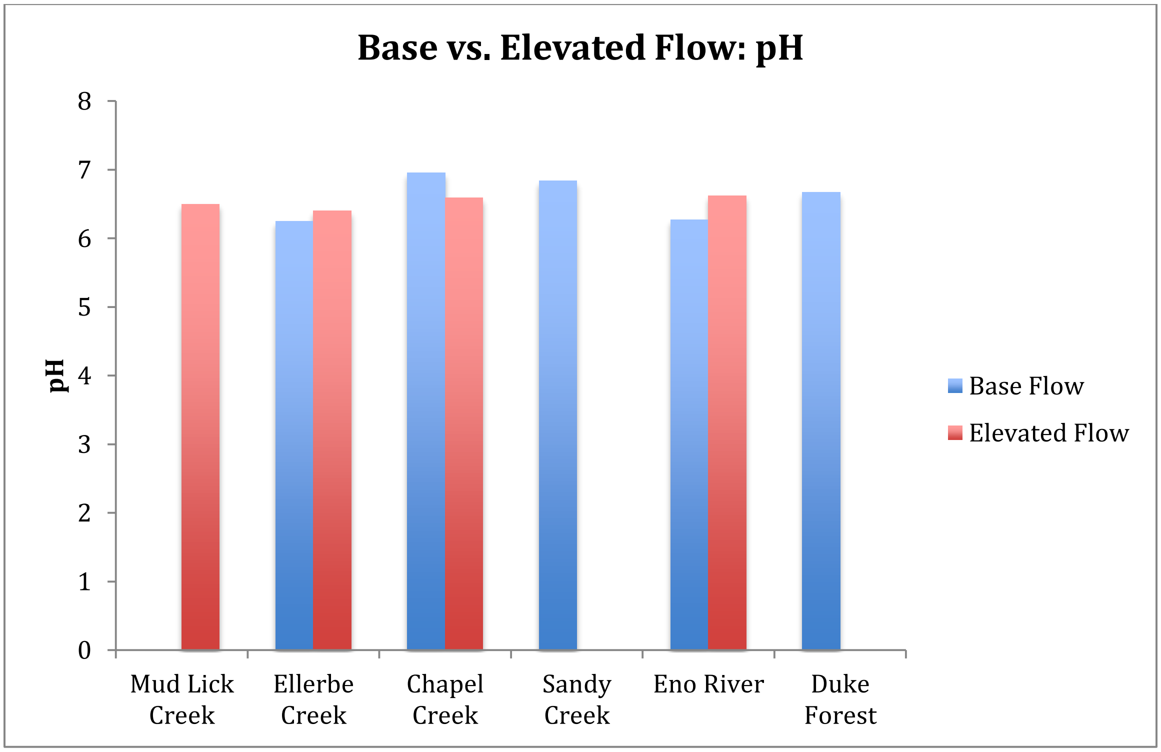
The reference stream, which as mentioned above only consists of Eno River, had a pH of 6.47, seen below in **Figure 14**.

Figure 14. Reference stream for pH during elevated flow



Finally, a comparison of pH during base and elevated flow for each stream was done. This is represented in **Figure 15**. There are few concrete conclusions that can be drawn from this comparison. It does appear that all of the recorded pH values are fairly similar, falling between 6 and 7. Of the three streams that have data for both base and elevated flow, there does not appear to be a large disparity between the pH which does not support the assertion that elevated flows will have lower pH values than base flows.

Figure 15. This plot depicts pH values of all streams during base and elevated flow.



Error and Limitations

Errors and limitations in the experiment contributed to, if not led to, inconclusive results. The first limitation was the small sample size of streams undergoing the restoration process. In this experiment, four were used though ideally ten to twenty streams would be included. This would allow for a more complete and longer continuum and would hopefully generate interesting and clear trends, something that did not occur with the current data.

Another limitation lies with the sensitivity of nitrate and phosphate testing kits. While it is possible that nitrates and phosphates were zero for every stream tested during both base and elevated flow, this seems highly improbable. This means that the testing kits likely were not accurate determiners for levels of nitrates and phosphates in the study area.

A significant error in this experiment is the incomplete and missing data. Some of this is due to limitations, though the majority lies with human error. Elevated flow from Mud Lick Creek was never collected because there were limitations in contacting and coordinating with the property owner so that the stage sampler could be retrieved.

The largest limitation to this study was logistical. In terms of time, a semester was given to complete this project, thus limiting our ability to run longer-term analyses. In terms of locality, the study was limited to streams within driving distance of the University. This limited the number of streams to draw on for sampling, thus bringing in the error of diverse restoration goals. Every stream is restored with specific functionalities in mind so when choosing sites, those goals were kept in mind. All streams were chosen with as similar functionalities and restoration goals as possible but there is still variation, which introduces error.

Conclusions

The purpose of this study was to evaluate the effectiveness of NC DENR’s stream restoration practices. By looking at water quality and geomorphology of streams in various phases of restoration, we hoped to determine whether the current stream restoration practices are having any real impacts on improving stream composition, structure, and function. Unfortunately, inconclusive results yield uncertainty. At this point in time, we can make no definitive judgment on the effectiveness of stream restoration practices. Further study is required to investigate the practices and determine their effects on restoring stream composition, structure, and functionality.

Future Studies

We view this capstone project as the foundation for future studies. This type of project requires long term monitoring, thus we envision future capstones continuing to evaluate the streams discussed in this report. Besides continual monitoring, future studies can diversify the experimental variables. In looking at the stream function pyramid, this study only focuses on two (physicochemical and geomorphology) of the five tiers. Originally, this study was to include biological factors but due to logistical constraints this did not happen. Hopefully, future capstones may build upon this initial research to encompass all five tiers of the stream function pyramid.

Future capstones may also diversify the streams examined and venture outside of the vicinity of the University. Conversely, if this capstone was to be run continuously throughout the year, then one or two long-term restoration projects could be monitored on all aspects of the stream function pyramid. If this was the case, we would be able to build a holistic picture of the stream composition, structure, and function and see how these variables were changing over time. Future capstones may also be interested in generating a database to store all collected data on these streams, which has the potential to prove useful to future restoration studies if they need specific historical data.

A cross section was also conducted for each experimental stream. This had no bearing on our experiment in terms of a testable hypothesis, rather was an effort to monitor and collect data for NC DENR per their request. **Figures 16-19** are the cross section of each of these streams. In looking at cross sections, it is possible to elucidate information on erosion and stream bank structure. For future studies it would be interesting to continue conducting such cross sections and compare the changing morphology over time.

Figure 16. Cross section for Mud Lick Creek

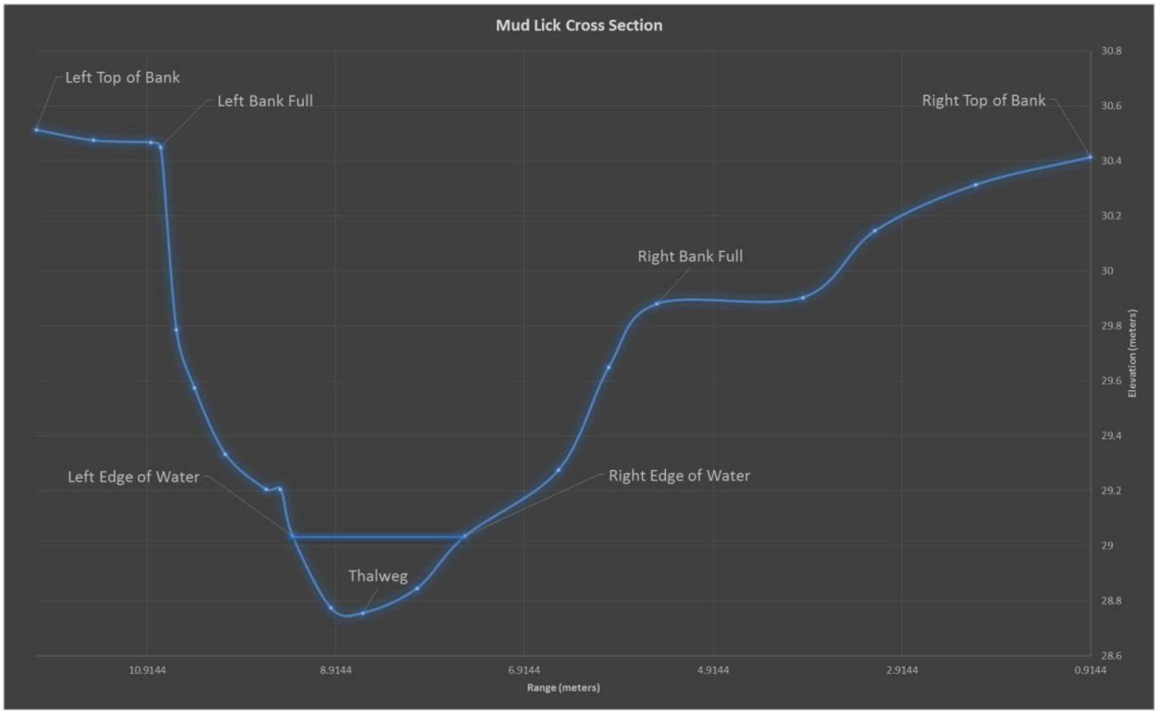


Figure 17. Cross section for Ellerbe Creek

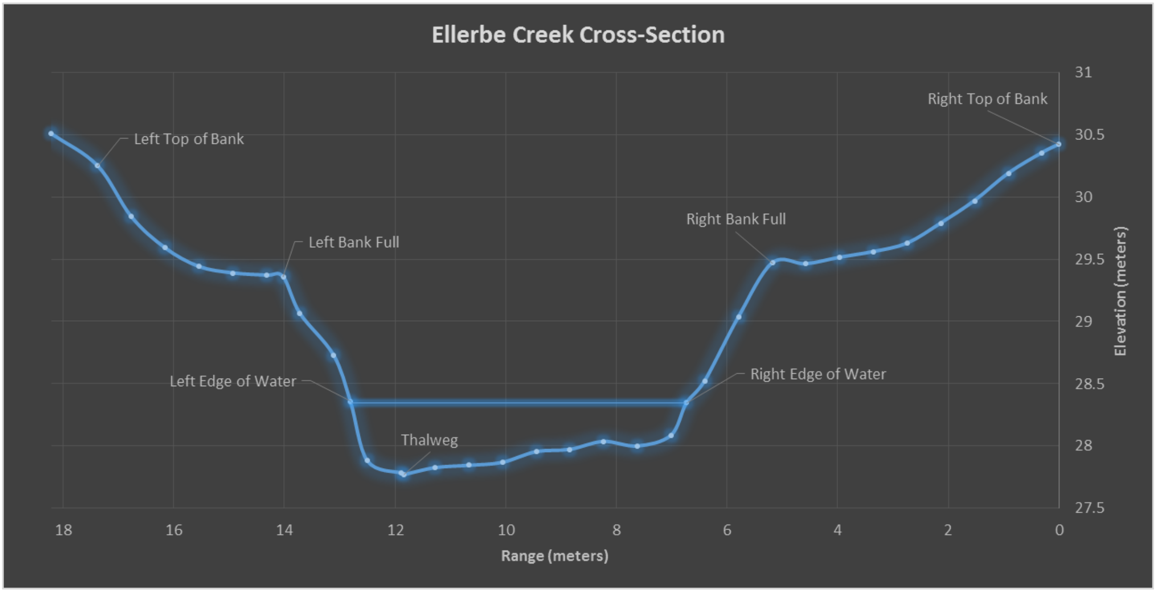


Figure 18. Cross section for Chapel Creek

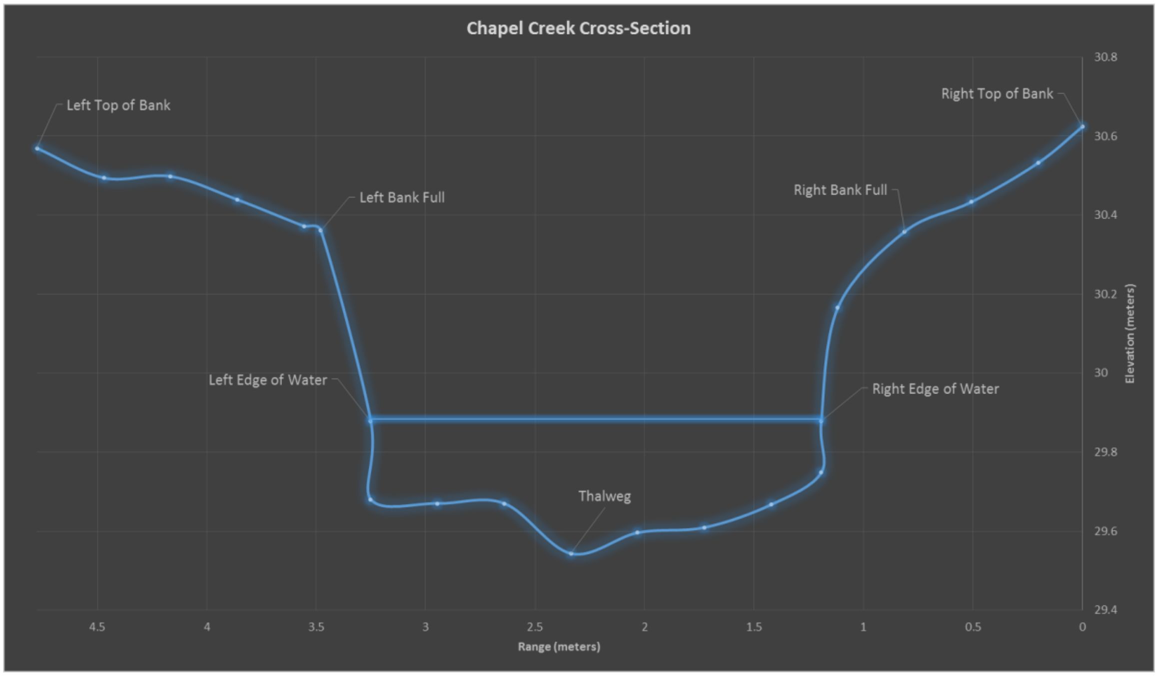
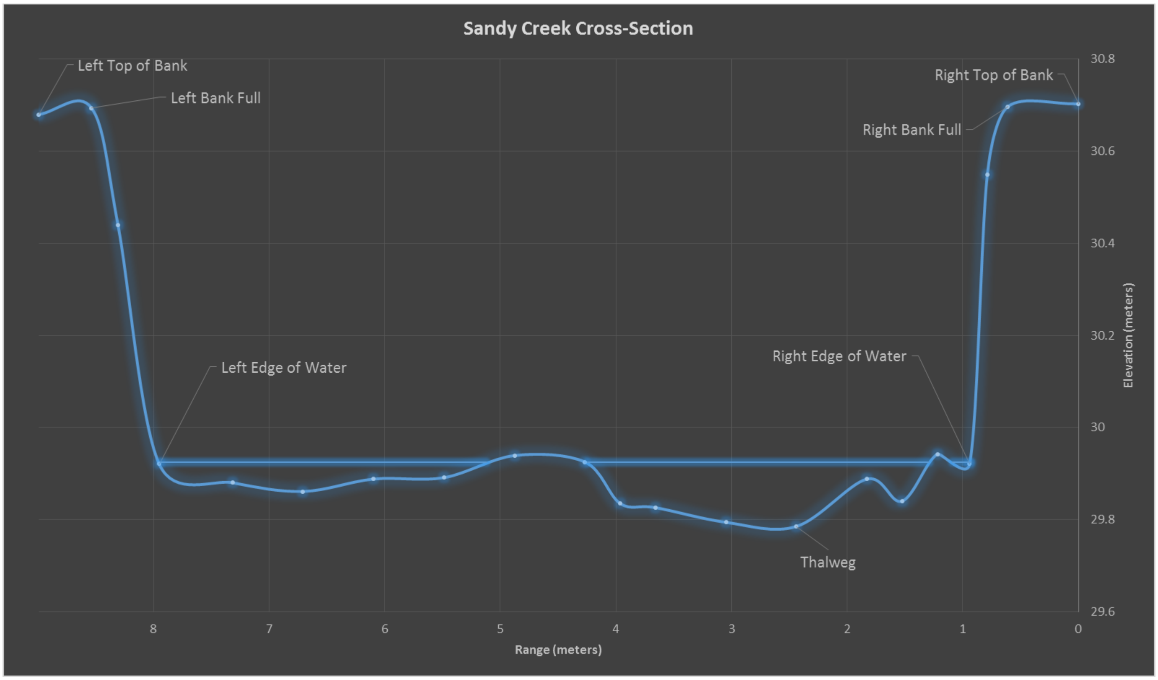


Figure 19. Cross section for Sandy Creek



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