SEDIMENT AND PHOSPHORUS CHANGES IN AN IMPAIRED STREAM BEFORE AND DURING A STREAM RESTORATION PROJECT

by

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(Under the Direction of L. Mark Risse)

ABSTRACT

Water quality impairment of the nation's streams has become a major topic of importance for both research and regulatory agencies over the past few decades. This highlighted importance has led to research on stream restoration to improve water quality impairments. For this study, monitoring of a stream in Demorest, GA began 4 months prior to construction of a stream restoration project and continued throughout the construction phase of the project until vegetation was reestablished. Manual grab samples were analyzed for suspended sediment and total phosphorus concentrations and results from pre-construction and construction time periods were compared. This study found that the construction activities added a significant amount of sediment to the stream but these changes were not sustained for long periods of time. There were no significant changes seen in total phosphorus. In-situ, bedload, substrate and cross-sectional changes during construction are also discussed.

INDEX WORDS: Sediment, Phosphorus, Stream Restoration, Natural Channel Design, Best Management Practices, Water Quality

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DEDICATION

I want to dedicate this thesis to my family and Alysondria for being behind me while I pursued this degree and for always supporting me throughout my academic career. Without everyone's love and support this would have not been possible.

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CHAPTER 1:

INTRODUCTION

The impairment and restoration of impaired streams across the nation has become an increasingly publicized and studied area in the past few decades. According to the Wadeable Stream Assessment (WSA), the U.S. Environmental Protection Agency (USEPA, 2009b) found that 42% of the U.S. stream miles were in poor condition. In 2008 the USEPA assessment found that 59% of Georgia's streams were impaired. The leading causes of these impairments were nitrogen, phosphorus, sediment and riparian disturbance (USEPA, 2009b). These impairments more than double the chances that a stream will have poor biological conditions (USEPA, 2009b) along with decreasing the overall water quality of the stream. The leading cause of these impairments comes from Nonpoint Source (NPS) Pollution, such as soil erosion from deforestation, agriculture and urbanization. There are different types of NPS pollution but NPS pollution usually involves runoff containing nutrients, pathogens, sediment, metals and pesticides (Harmel et al., 2003).

Excess sediment is one of the major causes of impairments in streams. According to the WSA almost 25% of the nation's streams have sedimentation problems. Excess sedimentation can change water flow patterns causing increased bank erosion, excess sediment build up within the stream, and increased turbidity. The sediment can also act as a carrier of nutrients like nitrogen and phosphorus along with pathogens such as fecal coliform (Kim et al., 2010). Excess sediment can also affect the aquatic organisms that live in and around the stream by making the area unsuitable for organisms to live in.

The Soque River Watershed in Habersham County Georgia experiences significant impairments from sedimentation, especially where bare soil is left unplanted in failed housing developments. The Soque River is an important regional resource that supplies roughly one sixth of the total water to Lake Lanier, the primary source of drinking water for the metropolitan area of Atlanta, GA. However, the Soque River supplies an enormous amount of sediment, with estimates of almost 50% of the total contributed sediment load into the lake (SRWA, 2010). Excess sediment flowing into these catchments can cause loss of storage capacity, decreased water quality and an added expense due to the required removal of material.

The site for this project is located in the Yellowbank Creek Tributary region of the Soque Watershed outside of Demorest, GA. The roughly 140 meters (500 feet) of first order stream selected for this restoration and research project was chosen after the owner decided to seek the help of the Soque River Watershed Association (SRWA) for a solution to the flooding problem he was having with the stream located on his property. It was decided that this property would be a good site for a Natural Channel Design (NCD) stream restoration project. This easily accessible stream would not only benefit from the restoration but the SRWA would also benefit from having a demonstration site to display the different aspects of a NCD project and to display some of the work that the SWRA is doing in the area to protect and improve the watershed. The project was funded by a $30,000 EPA 319 grant, matched funds from the SRWA and landowner and donated design from North Carolina State Cooperative Extension.

Runoff containing high concentrations of nutrients, like nitrogen and phosphorus, is another leading cause of impairments to streams. In Georgia phosphorus is a major nutrient of concern because it is the limiting nutrient in most freshwater impoundments. Although high concentrations of nitrogen and phosphorus can combine together to cause eutrophication of lakes and impoundments, in freshwater phosphorus is considered the driving variable (Flores-Lopez et al., 2010; King and Balogh, 2011). In the United States, it is estimated that about 47% of the total phosphorus that is discharged into streams is due to agricultural practices (Flores-Lopez et al., 2010). Although agricultural practices take the majority of attention, recreational areas such as golf courses and parks can also play a significant role in nutrient runoff (King and Balogh, 2011). Poultry farms are plentiful in North Georgia as is the use of poultry litter for fertilizer on agriculture fields and pasture land. If proper application rates for phosphorus are not followed an excess amount of phosphorus can accumulate in the soil and lead to NPS phosphorus loading in surrounding streams (Romeis, 2008).

The USEPA has added programs to help decrease negative effects from point and non-point pollution sources along with increasing the accountability of those who have the potential to harm the environment; however the majority of these programs are set up to monitor point source pollution. In 1972 the U.S. Government, with the creation of the Clean Water Act (CWA), gave the USEPA the authority to implement programs such as the National Pollution Discharge Elimination System (NPDES) to help control harmful discharges into waters in the country (USEPA, 2009c). The implementation of Section 404 required those that discharge dredged material into the nations waters, including wetlands, to have permits to do so and stated that they must mitigate the “unavoidable impacts" by creating a similar habitat in the same watershed (USEPA, 2009a). Every state is required by section 305(b) of the CWA to assess and describe the quality of waters in their state every two years (USEPA, 2009a). Section 303(d) of the CWA requires that each state submit a list of impaired waters in the state along with those that need Total Maximum Daily Load (TMDL) standards created. In the state of Georgia there have been 242 different TMDL's created for sediment alone according to the USEPA and Georgia Environmental Protection Division (GAEPD) (GAEPD, 2010). The combination of these programs and others has lead to improvement in water quality conditions (USEPA, 2009c). Although these programs are all helpful in protecting streams and rivers they do not necessarily address some of the problems with NPS pollution.

Best Management Practices (BMPs) are used to control NPS pollution. One BMP in particular that has been heavily researched and promoted recently is stream restoration/remediation. NCD stream restoration is one commonly used method for stream restoration. NCD stream restoration uses a methodology associated with attempting to restore a stream to a more "natural" state based on reference streams in similar geographical areas. Although there are different approaches to restoring a stream, a stream restoration can include modifying the stream in order to stabilize the banks, reconnecting the stream to the floodplain, addition of structures that aid in controlling flow and reducing sediment load along with modifying the riparian area to treat runoff before entering the stream (Doll et al., 2003). Though the methods may differ, it is the goal of any stream restoration project to improve the water quality within the stream. A study of the projects completed in the Southeastern United States showed that water quality management was the leading goal for a restoration project (Sudduth et al., 2007). One of the main reasons that NCD restoration has been such a heavily studied area in recent literature is because of the massive amount of money that has been invested in projects in the past 20 years. Since 1990 at least $15 billion has been spent on the restoration of streams and rivers in the US (Bernhardt et al., 2005).

A major focus of NCD is the restoration of riparian buffers. Riparian buffers around streams, aid in the removal of pollutants such as sediment, nitrogen and phosphorus by treating runoff from the surrounding watershed before it enters the stream (Ranganath et al., 2009; Sahu and Gu, 2009; Wenger, 1999). Riparian changes including reestablishment of vegetation on stream banks, removal of invasive species and planting new vegetation that are known to increase the reduction of pollutants before they enter the stream (Doll et al., 2003) are typically included in NCD and other restoration projects. The changes to a riparian area may have a greater impact on the water quality in a stream than the in-stream modifications themselves because of the water being treated before entering the stream. In agriculture areas where cattle are prevalent, livestock exclusion can be included in a project which helps riparian vegetation and overall water quality (Ranganath et al., 2009). All of these aspects were included in the restoration project being studied.

Despite the resources that have been spent on stream restorations efforts, there has not been an equivalent amount of effort put into the evaluating of the effectiveness of restoration projects (Ernst et al., 2010). Most permits, for mitigation projects, dictate that the stream should be monitored for 2-3 years after the project is completed in order to ensure that the construction works as intended and the stream is in a better condition than before the project. These permits, however, do not dictate by what means the monitoring must occur. There are a number of research projects that have used monitoring before and after a stream restoration project to look at the effects of the restoration project but few have monitored past one or two years after restoration (Ernst et al., 2010). According to the National River Restoration Science Synthesis (NRRSS) reports updated on March 28, 2006, of the reported stream restoration projects in Georgia only 15% contained some type of monitoring(NRRSS, 2006). Although this is ahead of the national average reported of around 10% (NRRSS, 2006), there is still a major concern that not enough emphasis is being put on the monitoring of stream restoration projects.

While research has been performed looking at the before and after effects of stream restoration, there is a lack of research data on how the contaminant loads in the stream, in this case sediment and phosphorus, change during the restoration itself. Stream restorations can require an extensive amount of construction work where soil is excavated and moved; along with changing where and how the water flows with the addition of control structures. Three leading construction methods for performing a restoration project include: "construct the new channel in the dry, pump or divert the water around the construction area or work in the active stream area (work in the wet)" (Doll et al., 2003). The method used for each project is situation dependent based on the permits obtained and general requirements with the project. With all of the methods, the main goal is to minimize the negative impacts to the stream and the surrounding area while construction is taking place. For the construction phase of this project the contractor installed a pump around system to divert as much water as possible around the construction area even though they were permitted to work in the wet. Most contractors prefer to install some kind of pump-around system because it makes working on the stream easier for equipment operators while constructing the new channel and floodplain.

For this project the stream in Demorest, GA was monitored using manual grab samples and bed load samples at up and downstream areas of the stream reach to be restored. Sampling began 4 months before construction started in order to gain information on the pre-existing conditions of the stream. Samples were also taken during the construction phase of the restoration. The construction phase was defined as beginning at the time when the equipment first began working on the site until the riparian vegetation was reestablished. This was the cut off point on quantifying the changes in sediment and phosphorus concentrations in the stream while the restoration project was taking place.

The main objective of this study was to characterize the changes in sediment and phosphorus concentrations that occur within the stream during the construction of a NCD restoration project. It was known that the sediment concentration would increase while equipment was working in the stream, but it was the goal of this research project to see how large the increase would be and if, through the duration of the construction, there would be a significant difference in the amount of sediment flowing downstream. For phosphorus, it was expected that the concentrations would follow the same pattern as the sediment given that the sediment particles in the water should add to the phosphorus concentration of the stream since the sediment particles contain phosphorus as well. It was hypothesized, however, that both the sediment and phosphorus concentrations would drop to levels equal to or less than the pre-existing conditions by the time the study concluded.

This study was not designed as a blanket study of what will occur in all restoration situations but rather a study looking into the changes that occurred for this particular restoration project and demonstrating a methodology for monitoring changes during construction of a restoration project. The results from this study will increase the knowledge of what changes occur in the stream while a NCD restoration project is occurring, along with growing the general knowledge base of what affects these NCD restorations have on streams. This knowledge will help contractors, water resource professionals and regulatory officials better understand the impact on a stream during the construction of a stream restoration project. Another benefit from studying changes during construction is that a project manager will be able to explain what changes a landowner downstream could expect while the construction project was taking place. Also the results of this project could be used to help these professionals improve the preventative measures employed in stream restoration projects currently to ensure that they have a minimal impact on the stream and downstream systems.

CHAPTER 2:

LITERATURE REVIEW

Sediment Issues

One of the leading impairments and monitored constituents in streams is sediment. The sediment itself is an impairment but the contaminants (i.e. - heavy metals, nutrients, bacteria) contained on the sediment particles can lead to other problems (Harmel et al., 2003; Kim et al., 2010; Meade et al., 1990). Although there are various causes of sedimentation one of the largest causes is stream channel erosion (Trimble, 1997). This is especially true in urbanizing watersheds where an increase in the amount of impervious surface increases stormwater runoff but decreases the sediment load in the runoff. These urban conditions lead to streams that are sediment deprived which leads to excess degradation and downstream sedimentation. In agricultural areas, especially where historically forested areas were converted to row crop agriculture, there is an excess amount of sediment runoff that causes streams in these areas to aggrade. In the United States alone, several studies have shown that the economic impacts of sedimentation are in the billions of dollars every year (Jastram et al., 2010).

Trimble (1997) monitored a highly urbanized stream near San Diego, CA where stream channel erosion was measured from 1983 to 1993. In the ten years the study was conducted the researchers found that there was a net average rate of channel erosion of 106×10^3 Mg per year (Trimble, 1997). Trimble (1997) noted that while the effects on water quality were usually the main focus, the underlying problem with erosion effects is that the stream erosion usually occurs laterally, causing loss of valuable urban real estate. Streams such as this one typically try to expand laterally (Trimble, 1997) which causes serious problems in urban areas where space is already an issue.

Row crop agriculture is the most impactful human activity that has contributed to increased sediment loads in rivers across North America (Meade et al., 1990). Unlike urbanization, agricultural practices over the years have led to an increase in sediment flowing into streams. During the 19th century, prairie grasslands and forests were converted over to crop land causing a large increase in sediment yields (Meade et al., 1990). The deep tillage of crop land and soil left bare led to conditions favorable to high levels of soil erosion. Over the past couple of decades conservation tillage practices, such as no-till agriculture, have become popular and has helped to reduce the amount of soil that is lost due to agricultural practices. In Georgia, as well as most of the Southeastern US there is a current and historical problem with sediment particularly from NPS pollution (Jackson et al., 2005).

Bedload Transport

Sediment transported in a stream can be broken up into two different categories, bedload and suspended sediment. Bedload sediment is the sediment that moves along the bed of the stream within a few millimeters of the stream bed (Meade et al., 1990). Bedload sediment usually consists of gravel sized particles or larger but there are streams in which the bedload transported is coarse sands (Charlton, 2008). The particle size of the sediment, stream power, turbulence and velocity all contribute to whether or not a sediment particle will be transported and by what means. In sand bed streams sediment can moved causing bedforms such as ripples and dunes to form on the stream bed as the sediment is transported (Charlton, 2008). In gravel and gravel-sand mixed channels, pebble clusters and transverse ribs can form (Charlton, 2008). Although bedload transport is difficult to measure (Meade et al., 1990), the use of samples such as the Helley-Smith bedload sampler (Helley and Smith, 1971) can allow researchers to measure bedload transport at a given time and place in the channel cross-section.

Suspended Load

Suspended sediment is characterized as the sediment that is supported by the flow of the river and maintained in suspension by the processes of advection and turbulent diffusion (Charlton, 2008; Meade et al., 1990). Over 17% of the streams in the US have high levels of suspended sediment (Mukundan et al., 2010). The suspended sediment is carried downstream as long as the stream exerts enough energy on the particle to keep it in suspension. Once the stream does not have the ability to keep sediment particles in suspension they will be deposited. This is usually caused by a reduction in discharge or slope, increases in cross-sectional area or boundary resistance, flow separation or obstructions in the flow. Suspended sediment is easier to measure than bedload but harder to predict because of the variables outside of the stream channel that affect suspended loads (Meade et al., 1990). The ratio of suspended load and bed load sediment varies greatly depending upon the individual river system but in general the larger the river the smaller the proportion of bedload transport as compared to suspended load (Meade et al., 1990).

Sources of suspended sediment can vary from upland erosion sources (i.e., agricultural fields and construction sites) to bank erosion (Mukundan et al., 2010). Identifying these sources is important for restoration work (Mukundan et al., 2010) because knowing where the suspended sediment originates can help in the planning of the restoration project.

Phosphorus Issues

Another of the leading impairments to streams is excess nutrient concentrations, such as phosphorus (P), caused by runoff from non-point sources. Excess nutrients, especially phosphorus, can pose serious water quality issues like eutrophication which can lead to algal blooms. Although both P and nitrogen (N) cause eutrophication, in freshwater P is considered the driving factor (Flores-Lopez et al., 2010; King and Balogh, 2011). The USEPA offers criteria that suggest a P concentration of less than 0.1 mg L^{-1} to guard against algal growth for streams not directly discharging into lakes or reservoirs while streams that do discharge into reservoirs should be less than 0.05 mg L^{-1}.

Although agricultural practices are a leading area of concern for many studying non-point source pollution, urban areas along with recreational areas, such as golf courses can also play a part in nutrient runoff (King and Balogh, 2011). King and Balogh (2011) found that the outflow of a stream running through a golf course in Minnesota had significantly higher concentrations of TP and dissolved reactive P (DRP) especially during the early growing season, usually May, when almost 45% of the P was being applied to the course.

In Georgia P is a nutrient of great concern because of the heavy use of poultry litter and other animal waste for fertilizer. Farmers using litter for fertilizer will usually apply the litter in quantities that meet the N needs of the intended crop or pasture. This practice causes an excess of P to be applied leading to a buildup in P in the soil and greater levels of P in runoff from agricultural lands. In the United States agriculture is responsible for around 47% of total P discharged into streams (Flores-Lopez et al., 2010). In a research study in the Upper Etowah River Basin of North Georgia it was found that streams in agricultural watersheds had a magnitude higher concentration of total P (TP) than streams in forested watersheds (Romeis, 2008). Romeis, 2008 concluded that dissolved reactive P concentrations observed during baseflow were well correlated to total annual P loads. The watersheds used in Romeis (2008) are very similar to the watershed containing the stream reach for this research project.

Livestock Exclusion

Part of this specific restoration project included installing a fence to exclude the livestock on the property from entering the restored stream reach. Livestock having access to stream reaches can cause stream bank erosion can be detrimental to the overall water quality in the stream (Wenger, 1999). Livestock walking in the stream can cause phosphorus enriched sediment particles to become entrained in the flow of the stream increasing the P levels in the stream (Flores-Lopez et al., 2010). Also the feces that the cows drop into and around the stream can increase nutrient and bacteria concentrations. Livestock exclusion practices include fencing around the riparian area of the stream and constructing stream crossings that don’t allow the animals to enter the stream area. These practices increase the riparian area around the stream and allow it to function as a buffer to the stream.

In a study of livestock exclusion reaches in southwestern Virginia the amount of groundcover was found to double in places where the cattle could not access the stream area (Ranganath et al., 2009). Increasing riparian cover around stream banks increases the amount of pollutants from runoff that can be treated before entering the stream, thus decreasing the concentration of pollutants in the stream and improving the water quality. Sahu and Gu (2009) discussed the changes in nutrient uptake in relation to the width of riparian buffer zone. It was found that when the riparian area was increased from 10% to 20% of the watershed area there was a large increase in nutrient uptake (Sahu and Gu, 2009), proving that even a small improvement in the riparian area around the stream can make a significant difference. Wegner, (1999) reviewed 140 articles and books to "establish a legally defensible basis for determining riparian buffer width, extent and vegetation" focusing mainly on sediment, nutrients and contaminants. Wegner, (1999) proposed three options for buffer guidelines including buffer widths from 15.2 – 30.5 m (50 – 100 ft), inclusion of adjacent wetlands and use of vegetation consisting of native forest vegetation.

A study by Flores-Lopez et al (2010) in the Catskill Mountains of New York looked at changes in soluble reactive P (SRP) amongst other contaminants before and after these livestock exclusion principles were in place. The researchers found that after construction of cattle crossings and fencing around the streams SRP concentrations declined by as much as 41% in one reach (Flores-Lopez et al., 2010). Many watershed organizations promote livestock exclusion and the Soque River Watershed group goes as far to help land owners find funding sources to install these BMPs.

Natural Channel Design

One of the most popular but criticized stream restoration methods is the natural channel design (NCD) approach (Ernst et al., 2010) which is based upon the analysis of channel forms by Rosgen (1994, 1996). The NCD approach to stream restoration uses geomorphic characteristics of the stream and nearby reference reaches to recreate stable channel dimensions, patterns and profiles (Doll et al., 2003; Ernst et al., 2010; Rosgen, 1994, 1996). Although the specific goals for a project vary, one uniform goal is to improve the water quality in the stream and to allow the stream to reach a state of dynamic equilibrium, such that the stream has the proper balance between aggradation and degradation (Ernst et al., 2010). The process of designing these projects is complex and requires understanding of many different disciplines such as fluvial geomorphology, engineering, plant science and ecology. The correct combination of these different disciplines can help form a restoration project that can be successful and effective.

Using the geomorphic approach to NCD there are eight phases (listed below) that one should go through in order to perform a restoration project (Rosgen, 2006):

1. Restoration Goals/Objectives
2. Regional and Local Relations
3. Watershed/River Assessment
4. Change Overall Management
5. Stream Restoration/NCD
6. Design Stabilization and Fisheries Enhancement Structures
7. Implementation
8. Monitoring and Maintenance Plan

Phase one is very important to any project but is especially critical for measuring the success of a project. Some of the common goals of a project are: reduce flood levels and frequency, stabilize streambanks, reduce sediment supply and land loss, improve visual values and improve fish habitat (Rosgen, 2006). Phase two of the process deals with gathering information about the geomorphic characterization, hydrology and hydraulics. The critical portion of this phase is that information on a reference reach that represents a stable stream in a similar area needs to be found. This reference reach is the basis for design decisions made later on in the restoration process.

Phase three of the process assesses the individual stream and surrounding watershed. The information gathered during this process can include but is not limited to drainage area, impervious surface, current and past land use, bankfull identification, stream flow data, stream cross sectional profile, stream planform, stream longitudinal profile and substrate analysis. (Doll et al., 2003; Rosgen, 1994, 2006). Using this data the stream is classified according to a set of guidelines according to the Rosgen Stream Classification System (Rosgen, 1994).

Phase four of the plan is one that is sometimes overlooked but nonetheless important. Rosgen (2006) suggests that this phase should include looking at a change in how the area around the stream is managed (passive restoration). If the area around the stream can be effectively managed such that the stream can stabilize itself then this is the preferred technique. If the natural recovery potential of the stream is poor and/or doesn't meet the original goals of the project then a stream restoration would be appropriate (Rosgen, 2006). This phase would particularly be useful in an urban setting where land constraints are high.

Phase five of the process is the NCD stream restoration phase. The process is iterative and requires the combination of many different factors so that the proper design is decided on. One of the first decisions that has to be made, especially in urban and incised streams, is the priority of the restoration. There are four main priorities of restoration: establish bankfull stage at the historical floodplain, create a new floodplain and stream pattern with stream bed remaining at present elevation, widen the floodplain at the existing bankfull elevation and stabilize existing streambanks in place (Doll et al., 2003). The priority selected for an individual project depends on land constraints, channel condition and the overall goals of the project. Once a priority is decided on, the variables that were collected in earlier phases are looked at and a new channel design is developed.

After the new stabilized channel is designed then the structures that are to be placed in the channel to meet the stated objectives must be designed (Phase 6) (Rosgen, 2006). These structures are used to reduce stress on the banks, enhance fish habitat and dissipate energy (Doll et al., 2003; Rosgen, 2006). Examples of these structures are root wads, log vanes, rock vanes, and J-hooks. Vane structures are essential to control flow and combined with structures like root wads, help to control erosion of the banks while vegetation is being reestablished on the stream banks and floodplain after construction. Once the channel and structure designs are finalized the implementation (Phase 7) of these plans can begin. Once construction is done, the final, yet sometimes neglected, phase is monitoring and maintenance. This is an essential phase in the project in determining the effectiveness of the project. The data from properly monitored projects can aid in understanding changes brought on by restoration and furthering the knowledge of effective and ineffective stream restoration methods (Bernhardt et al., 2005; Doll et al., 2003; Ernst et al., 2010; Rosgen, 2006).

Monitored Projects

Although the majority of stream restoration projects do not receive the proper monitoring after completion, it is important to pay attention to the monitored projects for guidance. Klein et al. (2007) conducted an extensive research project on the Lower Red River in Idaho where a section of the river was restored using the natural channel design methods. For the study, there were 17 different indicators studied in order to justify biological and ecological changes before and after construction (Klein et al., 2007). It was found in this research study that after the restoration, the proportion of fine (< 2 mm and < 6 mm) sediment had decreased significantly within the stream (Klein et al., 2007). This is a positive sign since a lowered sediment load in a stream improves the overall water quality in the stream. Restoring this reach of stream increased sinuosity by 60% and decreased the slope by 40% changing the conditions in the stream back to those similar to 1936 (Klein et al., 2007). The temperature increased slightly in the reach and was attributed to the planted vegetation not having adequate time to grow and produce shade. Overall, the results of this experiment showed promising signs in many areas but the authors are quick to point out that longer duration between restoration and experiment are essential to discovering what significant changes NCD restored streams can see.

Ernst et al. (2010) compared six stream reaches of the Catskill Mountains in New York that had been restored, following NCD guidance, from 2000-2003. The study assessed data from paired treatment and control reaches to determine what changes occurred in the NCD restoration reaches. The goals of the restoration projects in this area were to reduce the erosion of stream banks and limit the concentration of total suspended sediment (TSS) in the stream. The study showed that on average stream stability increased at the sites (Ernst et al., 2010). The water quality changes varied from site to site and were usually not significant. The authors note that the lack of statistical results could be due to the small sample size and large variability between the different sites coupled with the short time period between the study and restoration of the stream reaches.

Miller and Kochel (2010) studied 26 stream restoration efforts in North Carolina measuring the adjustments made in the channel since restoration. About 55% of the total number of cross sections in the study exhibited 20% or less change in channel capacity (Miller and Kochel, 2010). This study also examined structures placed in the stream during restoration and found that about 30% of the total number of structures placed in the viewed sites showed some kind of damage that affected their function (Miller and Kochel, 2010). There were no water quality or habitat changes discussed in the study but the study is a good contrast to the two previous studies discussed because it showed that NCD restoration is not always the best way to help improve streams. It also reiterates the fact that the current knowledge of these projects, especially after restoration, is still lacking.

This is a small sampling of various projects in different parts of the country that have been in the recent literature. In 2003 a project restoring 770 m of channel along with another 1500 m in livestock exclusion located in Pennsylvania was completed (Nagle, 2007). The study watershed showed a greatly reduced TSS loading to the stream (Nagle, 2007). Not all of the projects completed have had such success. A stream in a heavily forested area in California and another project in Pennsylvania with high bedload movement were both unsuccessful (Nagle, 2007). The success of a project depends heavily on the background conditions in the watershed and the overall design and goals of the project itself. Whatever the results of the project may be, if the correct monitoring and reporting is performed, the successful and even unsuccessful projects can be equally valuable to researchers and practitioners.

Current Issues with Restoration

Despite the amount of resources that have been spent on stream restorations efforts, there has not been an equivalent amount of effort put into the evaluation of the effectiveness of restoration projects (Ernst et al., 2010). Most permits dictate that the stream should be monitored for 2-3 years after the project is completed in order to ensure that the construction works as intended and the stream is in a better condition than before the project but they do not dictate by what means the monitoring occurs. The US Army Corp does require certain monitoring guidelines for compensatory mitigation projects (USACE et al., 2011). There are a number of research projects that have used monitoring before and after a stream restoration project to look at the effects of the restoration project but few have monitored beyond one or two years after restoration (Ernst et al., 2010). The cost of monitoring a stream long term and the lack of a regulatory obligation of the project head to monitor past a couple of years are the main reasons that there is a lack in this area. The lack of monitoring can lead to methods that are ineffective staying in use while ones that are effective being taken away and not used (Bernhardt et al., 2005; Ernst et al., 2010)

According to the National River Restoration Science Synthesis (NRRSS) reports updated on March 28, 2006, of the reported stream restoration projects in Georgia only 15% contained some type of monitoring(NRRSS, 2006). Although this is ahead of the national average reported of around 10% (NRRSS, 2006) there is still a major concern that not enough emphasis is being put on the monitoring of stream restoration projects. Of projects in the southeast that were monitored the leading reasons that the monitoring was completed were funding requirements (36%), legal requirements (33%) and academic involvement (28%) (Sudduth et al., 2007). Sudduth et al 2007 found that the leading cause for projects not being properly monitored was lack of funding. Monitoring a project to make sure that it is meeting the goals of the restoration project is one of Rosgen's (Rosgen, 2006) main phases in the stream restoration process. With 37,000 stream restoration projects occurring at a cost of $14 billion since 1990 (Bernhardt et al., 2005; Nagle, 2007), it would only make sense that a greater effort be put towards monitoring the investments that have been made.

Palmer et al., 2005 took a different approach to the problems with monitoring restorations. This was accomplished by building upon the idea of creating five criteria (listed below) for measuring a project's success, with an emphasis on the ecological perspective (Palmer et al., 2005).

1. The design of a restoration project should be based on a specified guiding image of a more dynamic, healthy river that could exist at the site.
2. The river's ecological condition must be measurably improved.
3. Only minimal follow-up maintenance is needed
4. During the construction phase, no lasting harm should be inflicted on the ecosystem
5. Both pre- and post-assessment must be completed and data made publicly available

One of the main reasons that these criteria were published was to continue the conversation on what constitutes a "successful" restoration project. Billions of dollars have been spent on restoration projects (Bernhardt et al., 2005; Nagle, 2007; Palmer et al., 2005). Most projects are implemented with the understanding that the main goal of the project is to improve the environmental conditions of the site, but at the time the Palmer et al. (2005) study was performed, there was no set of agreed upon standards for what characterizes an ecologically successful river restoration. The lack of standards for evaluating projects coupled with the lack of proper monitoring after a restoration, has hindered the advancement of truly successful restoration practices and elevated the use of unsuccessful practices (Bernhardt et al., 2005; Ernst et al., 2010; Palmer et al., 2005).

Another problem pertaining to stream restoration is site selection. Restoration sites are usually selected where it is the most convenient, not where it can do the most good for the stream and watershed (Miller and Kochel, 2010; Sudduth et al., 2007). In a study by Sudduth et al. (2007), it was found that in the southeast 49% of restoration projects were done for mitigation while the national average is about 13%. Due to mitigation laws that require no "net loss" of stream or wetlands this means that in order for contractors to impact a stream they have to mitigate their interferences elsewhere. This leads to restoration projects being done in places where the project can be easily performed, not necessarily where it is most needed. Normal farming, silviculture, and ranching activities are exempt from the permit and mitigation requirements under CWA section 404.

Mitigation permits, under section 404 of the CWA, usually require two to three years of monitoring after the project. The CWA section 404(g) authorizes individual states to assume responsibility for the 404 permitting program (Ferrey, 2010) if they so choose. To date about 20 states have exercised this power (Ferrey, 2010). In the southeast, some states have exercised this right and used it to extend monitoring requirements. The state of Georgia requires that mitigation bank owners create annual sampling reports for the first 5 years after a restoration project is completed (USACE et al., 2011). This monitoring must be continued for a minimum of 5 years after the project is determined to be functioning successfully. In North Carolina the mitigation permits require five years of monitoring (Sudduth et al., 2007). This is still a short time for monitoring considering the amount of time that it takes for a fluvial system to change.

CHAPTER 3:

METHODS & MATERIALS

Site Description

The site for this research project is located on private land just outside of Demorest, GA (83^{o} 34' 19.67"W 34^{o} 36' 25.55"N) in Habersham County (see Figure 3.1). This stream is a part of a small network of streams that make up the Soque River Watershed in North Georgia. The Soque River Watershed is unique in that the entire watershed is located within Habersham County. The watershed itself exhibits many problems with excess sedimentation impairments (SRWA, 2010).

The stream reach sampled for this project is a roughly 140 meter long section of first order stream that runs through a current livestock pasture (see Figure 3.2). The stream's headwater begins 660 meters upstream of a 15 meter long concrete box culvert that separates the headwater section from the studied reach. The stream has suffered intense bank incision that has caused the stream to lose connectivity with the once active floodplain. The bed of the stream is made up of mainly gravels (D_{50} = 6mm, Fine gravel) and coarse sands. The pasture around the stream is vegetated with a mixture of fescue, rye and other grasses. The stream banks contain some of the same types of vegetation but are also filled with trees and invasive species such as Chinese privet (Ligustrum sinense).

Before the restoration occurred the stream was not fenced and the cattle were allowed to access the stream freely. The owner of the land also historically used poultry litter to fertilize the pastures surrounding the stream. Soil samples were taken from the adjacent pastures around the stream and the existing banks on the property during restoration. Soil tests were performed by the Soil, Plant, and Water Lab at the University of Georgia (Athens, GA) using Mehlich I Extractant methods. The pasture land on both the East and West sides of the stream ranked Very High on the index scale used by the lab with the soil containing 43.14 kg/ha and 94.17 kg/ha, of Phosphorus, respectively. These tests were used to confirm high background levels of Phosphorus in the soils surrounding the stream.

The watershed for this stream is roughly 32.6 hectares and contains around 15% impervious surface (see Figure 3.3). The land cover in the watershed is predominately deciduous forest and pasture land with a few houses, buildings and other impervious surfaces. There is also a subdivision that has been built in the watershed within the past 10 years. The owners of the project site claim that since the construction began on the subdivision, the frequency of floods overtopping the banks has increased. The increased flooding and problems with bank erosion were the driving reasons behind the owners seeking help for a restoration project. Some of the measurements of the stream were made using surveyed data from the North Carolina State Cooperative Extension office in Asheville, NC. Other measurements were made using ESRI ArcGIS 9.3.1© software (ESRI, 2009) and files downloaded from the Georgia GIS Clearinghouse and obtained from the Habersham County GIS Office.

Restoration Design

An engineer from the Department of Biological and Agricultural Engineering at North Carolina State University was employed to design the plans for restoration. The plan for this stream was informed by NCD methods while taking into consideration the constraints and available materials on-site. For this particular site the main objective was to minimize the current flooding issues and the migration of banks. The new channel was designed keeping in mind the cross-sectional area of the existing channel. Another important factor in the design decision was creating an active floodplain for the stream. The stream had become disconnected from any active floodplain due to the incisions of the existing stream banks, so reconnecting the stream to a floodplain was a major priority. The fact that cattle were going to be fenced out of the stream once construction was completed was another criterion in the design. The land owner was going to continue to use the pastures on either side of the stream and didn't want to lose more pasture space than required for the appropriate restoration to take place.

As with most projects, one of the main objectives for the design of the project was the available funding. In order to minimize cost the designer opted to minimize the use of imported boulders and maximized the use of on-site materials, such as logs that were removed from the riparian area, for structures necessary to control water flowing through the channel. Since the project was not designed by the author, this information about the design was obtained from personal communication with the engineer that was in charge of the design and with the foreman working on the project.

At the conclusion of the project there was one cross-vane placed about 5 meters from the exit of the culvert, which was constructed to control flow coming from the culvert and turn it in the direction of the new channel. Further downstream a log vane was combined with a brush toe and a rock j-hook to divert water and make the next major bend in the stream. To better control water on the steep grade through the rest of the channel 3 sets of 3 log sills were constructed. Footers of the log sills were a mix between rock and brush footers. The log sills cause pools to form in the stream and lessen stream power, controlling the flow through the newly constructed channel and reducing erosion of the banks and stream bed. The brush used at the toe of the channel bank slope, not only assists with lessening erosion of the bank but also creates new habitat for fish and other organisms in the stream.

At the downstream end of the reach, banks were smoothed over using sod excavated from areas where the new floodplain was being constructed. The sod was then placed in low lying areas near sampling point 2 and tamped down using the excavator. This “chop and drop” method created the new floodplain and banks for the channel near the downstream sampling point. Pre-existing conditions in this area restricted the amount of construction work that could be performed.

Another important part of this restoration was the replanting of riparian vegetation. A mix of grasses was broadcast onto the bare banks after construction. Sloped banks were covered with matting and the remaining areas were covered with straw to minimize any erosion that could occur before the vegetation was established. The planting of native vegetation is to be coupled with the planting of live stakes and other trees conducive to good riparian health that is on schedule to take place in the late fall of 2011. This vegetation on the newly created floodplain will help to maintain a stable and healthy stream over the long term.

Biological Assessment

A biological assessment of the site was completed by Duncan Hughes of North Georgia Technical College, Clarksville location and the Soque Watershed Group. The assessment was completed according to the Macroinvertebrate Biological Assessment of

Wadeable Streams in Georgia – Standard Operating Procedures (GAEPD, 2007) and the Ecoregion 45a – Southern Inner Piedmont indices. The result from this study was a benthic macroinvertebrate index (BMI) comprised of: Plecoptera Tax, % Trichoptera, Tolerant Taxa, % Scraper and Clinger Taxa. The results from these scores are shown in Table 3.1. The BMI was calculated and the stream reach used for this research scored an index score of 56 obtaining a narrative score of “fair”.

Pre-Construction Sampling

Manual grab samples were taken bi-weekly from February 7th 2011 until June 13th 2011, the week before construction began, in order to analyze the pre-existing conditions in the stream. Due to scheduling complications and drought conditions only one storm event was able to be sampled. There were two sampling points in the studied reach of stream. The first sampling point (upstream) was located at the first riffle section after the stream exited the culvert. The second sampling point (downstream) was located in the last riffle section about 2 meters from the end of the studied reach where the studied stream joins two other small tributaries. Samples were taken using 500 milliliter acid washed Nalgene bottles that were pre-weighed before every sampling event.

The downstream sampling location was always sampled first in order to minimize any interference that could be caused from walking in the stream at the upstream sampling location. In addition to the two manual grab samples, a field blank was also made in the field by filling an empty bottle with de-ionized water for validation purposes. The samples were placed in a plastic storage container and taken back to the lab under ambient vehicle conditions. Once returning to the lab the sample containers were placed in a cool, dark holding area until further analysis could occur. A sampler, such as a DH-48 water sampler, was not used for this project because the depth of the water in the thalweg would not allow for use of such instrument.

Construction Sampling

Water sampling methods for the construction phase of the project were nearly identical to those for the pre-construction sampling. The main difference was that while the construction equipment was on the ground turbidity measurements were taken at both sampling locations. Turbidity was measured at the same time as the grab samples using a Hach 2100P field turbidimeter (Hach Company, Loveland, CO, USA). To get a correct reading, three vials were filled at each sampling location and analyzed for Nephelometric Turbidity Units (NTU) on the turbidimeter. The three readings were written down and averaged for the final NTU reading for each sampling event.

The second difference in sampling between the time periods was due to the restoration design. The design of the restoration included the installation of a rock cross-vane structure causing a pool where the original upstream sampling point was located. In order to remedy this problem and to ensure that a proper upstream sample was taken, the sampling point was moved about 3 m (10 ft) upstream from the original location. This location change allowed for a proper sample that would depict conditions of the water at the head of the stream section, which was the main focus of the upstream sampling location.

Equipment was in use on site from June 22nd 2011 until June 27th 2011. A total of 100 hourly samples were taken on these days throughout the work day which usually started at approximately 7:30 AM and lasted until as late as 7:00 PM. Sampling was spaced out after equipment ceased to be on site. Samples were taken daily from June 28th

until July 1st and bi-weekly sampling was resumed beginning on July 11th. The final sampling event for this project occurred on July 25th, 2011; marked by the reestablishment of vegetation on the stream banks and surrounding riparian area. Numerous pictures were taken throughout the entire project, but more extensively during the construction phase to track the progress of the restoration.

Suspended Solid Concentration

After phosphorus samples were taken from the manual grab samples and the samples were weighed, the remaining portion of the sample was filtered to measure the suspended solids concentration (SSC) of each sample. All lab methods and calculations were conducted under the American Society for Testing and Materials D 3977-97 (Reapproved 2007): *Standard Test Methods for Determining Sediment Concentration in Water Samples* Test Method B-Filtration (ASTM, 2007). The filter and sample pans used for filtration were dried in an oven at 105°C for 24 hours, cooled in a desiccators, then weighed to the nearest 0.0001 grams (g) for a pre-weight. The samples were then filtered, dried in an oven and weighed again for the post-weight. The net weight of sediment was divided by the net weight of the water sample and multiplied by 1,000,000 to calculate the concentration of sediment in part per million (ppm). This standard method also includes a table for correction factors used to calculate the concentration in mg/L however all of the samples for this project were below the threshold that required use of a correction factor.

For samples taken during the construction phase of the project the lab processes for SSC were altered. In order to cut down on material costs and lab time, turbidity measurements were used to estimate SSC based off of turbidity readings. All 8 of the samples that registered over 1000 NTU were filtered and analyzed for SSC since the field meter used could not read samples above 1000 NTU. The remaining samples were used to build a model using recorded turbidity measurements to estimate SSC. The first samples filtered for the model were random samples between 0-150 NTU, to ensure that the filtered samples wouldn't exceed the 10,000 ppm threshold of the ASTM standard being used to filter the grab samples. Next all samples above 100 NTU were filtered and the model was completed by filtering every third sample between 0 and 100 NTU. Models were made using the known NTU and SSC of the selected samples and transformations were made to the data until the best model was found. The chosen model was used to estimate the SSC of the remaining samples.

Bedload Sampling

While in the field, bedload samples were taken using a Helley-Smith (Helley and Smith, 1971) 6x6 inch bedload sampler. The bags for the sampler were weighed to the nearest 0.01 g before leaving the lab. Equipped with a sample bag, the sampler was placed in the stream at the same locations as were used for the manual grab samples and allowed to sit on the bed of the stream for 5 minutes. Once the adequate amount of time had passed, the sample bags were removed from the sampler and placed in a sealed plastic bag for transport to the lab under ambient vehicle conditions. During the pre-construction phase, bedload samples were taken at both sampling locations; however, during construction the removal of the upstream sampling point led to samples only being taken at the downstream sampling point. Upon returning to lab the bags were set out to dry for a minimum of 48 hours. Once the samples were dry, the weight of each bag was measured again and the net weight of the sample calculated. The bedload transport rate was calculated by taking the net weight of the sample and dividing by 300 (number of seconds in 5 minute time period). The samples were then placed in 15 mL scintillation vials and stored for future Phosphorus analysis. In total 25 samples were used for Phosphorus analysis.

Phosphorus Concentration

In order to measure for the phosphorus concentration a sub sample of each manual grab sample was taken in the lab and frozen until all of the samples had been collected. For each sample, 15 milliliters were taken from the grab sample bottle using a pipette, placed into an appropriately labeled scintillation vial and then stored in a freezer, for future analysis. A duplicate tray of scintillation vials was also created as backup in case of an error in the lab or in the case that tests for other nutrients was warranted. After the phosphorus samples were collected and the vials returned to the freezer the manual grab sample bottles were weighed for a second time to gain the total weight of the sample taken.

During handling and storage of phosphorus samples there is always the chance for the phosphorus in the samples to transform either through removal or transformation (Pierzynski, 2000). Freezing the samples helps reduce the removal of phosphorus, through sorption, onto the sample container but can cause phosphorus to change forms (Pierzynski, 2000). In order to reduce analytical and reporting error that could come from freezing, the samples for this project were analyzed for TP concentration. Upon completion of the project a total of 76 representative samples were taken to the Analytical Chemistry Lab within the University of Georgia’s Odum School of Ecology for analysis.

The samples were analyzed using perosulfate digestion following methods of Koroleff (1983) with modifications from Qualls (1989). A continuous flow colorimetric analysis was then performed on the samples following EPA Method 365.1 (1983). The detection limits of the machine were 0.02 μg/L for the water samples and those below detection limit were reported as one half the detection limit for analysis purposes.

In-situ Measurements

During each sampling event pH, temperature, dissolved oxygen (DO) and conductivity were measured using an YSI 556-MPS handheld multi-parameter instrument (YSI Incorporated, Yellow Springs, OH, USA). The instrument was placed in the thalweg of the stream and the display unit was observed until the parameters remained constant. The DO probe used with this instrument was always the last to equilibrate. In the case that the DO reading would not remain constant the reading was taken after 2 minutes in the water. The probes were rinsed with DI water between sampling events to ensure that the probes remained clean.

Discharge Calculations

Stage measurements were made in the same place in the concrete culvert during every sampling. The culvert was selected for stage measurements because its cross-sectional area would remain constant during the project whereas the cross-section of the stream could change dependent upon storm events and migration of the thalweg.

Velocity measurements were also taken in the culvert. The depth of the water in the culvert would not allow for use of a mechanical velocity meter so the “stick and leaf” method was used. A leaf was placed in the flow at the upstream edge of the culvert and allowed to flow through the culvert. The time it took for the leaf to flow the length of the culvert was taken using a stopwatch and recorded. This process was repeated three times during each sampling and an average taken to calculate the velocity. The velocity and stage measurements recorded in the field were used to calculate the water discharge in the culvert.

Survey data was used to formulate an equation (Equation 1) for the cross-sectional area of the culvert. The water discharge was calculated by multiplying this

$$\text{Equation 1: } A = 0.026774 \text{ m}^2 + (x - 0.0254)*(2.1082 \text{ m})$$

A = cross-sectional area (m^2)
x = stage measurement (m)

cross-sectional area by the velocity of the flow in the culvert and the applicable unit conversions. The stream was considered to be a small well mixed stream and also considered to maintain the same flow in and out of the reach throughout the study.

Cross-section Analysis

In order to characterize changes made to the stream channel itself, two separate surveys were taken on three different cross sections, using a total station. To ensure that the relative reference elevations were the same for both surveys, common benchmarks were created onsite. The first survey took place one week before the construction began while the second took place once sampling had been completed for the project. Data points from the two surveys were placed into Microsoft Excel © and AutoCad Civil 3D 2011 © for analysis of changes in the cross-sectional area of the stream before and after restoration. Pictures were also taken throughout the project at each cross section for a visual comparison of the changes taking place at each cross-section.

Pebble Count

A zig-zag pebble count was performed near the beginning (2/7/2011) and end (8/24/2011) of the project using the procedure described by Bevenger and King (1995). For each sampling event 100 pebbles were blindly chosen and measured along the intermediate axis (Bevenger and King, 1995). The pebbles were selected by taking small steps in the stream in a zig-zag pattern. After each step the pebble was chosen blindly by selecting the first pebble touched at the toe of the sampler's boot. The measurement was recorded and the data used to calculate the applicable percentages and a percent finer than graph created using Microsoft Excel ©.

Statistical Analysis

All of the collected data was placed into Microsoft Excel© spreadsheets for data analysis. All statistical analysis was performed on the data using Minitab 15© (Minitab Inc., State College, PA, USA). Due to the large variation in the SSC data both upstream and downstream, a t-test or ANOVA analysis was not appropriate. Instead a Wilcoxon signed rank test was used for a non-parametric comparison of the SSC for both time periods. Data from each sampling event was normalized by calculating the difference between the log of the downstream concentration and log of the upstream concentration yielding a single value for each event. The median of the pre-construction events was found and used for the comparison. The data was set up such that the null hypothesis was that the medians of the two time periods would be equal and the alternative hypothesis was that the medians were different. The p-value given by the Wilcoxon test was compared to an α=0.05 to test whether to reject the null or fail to reject the null. An ANOVA analysis was used for bedload and in-situ comparisons. Statistical analysis was not completed on TP concentration data due to the large amount of non-detects in relation to the total number of samples sent to the lab. Only descriptive statistics were used to describe TP concentration data.

Tables

Table 3.1: Raw and standardized scores used in BMI

Metric:	Plecoptera Taxa	% Trichoptera	Tolerant Taxa	% Scraper	Clinger Taxa	Index Score	Narrative Score
Raw Score	4	10	6	15	8	---	---
Standardized Score	71	32	100	38	40	56	Fair

Figures

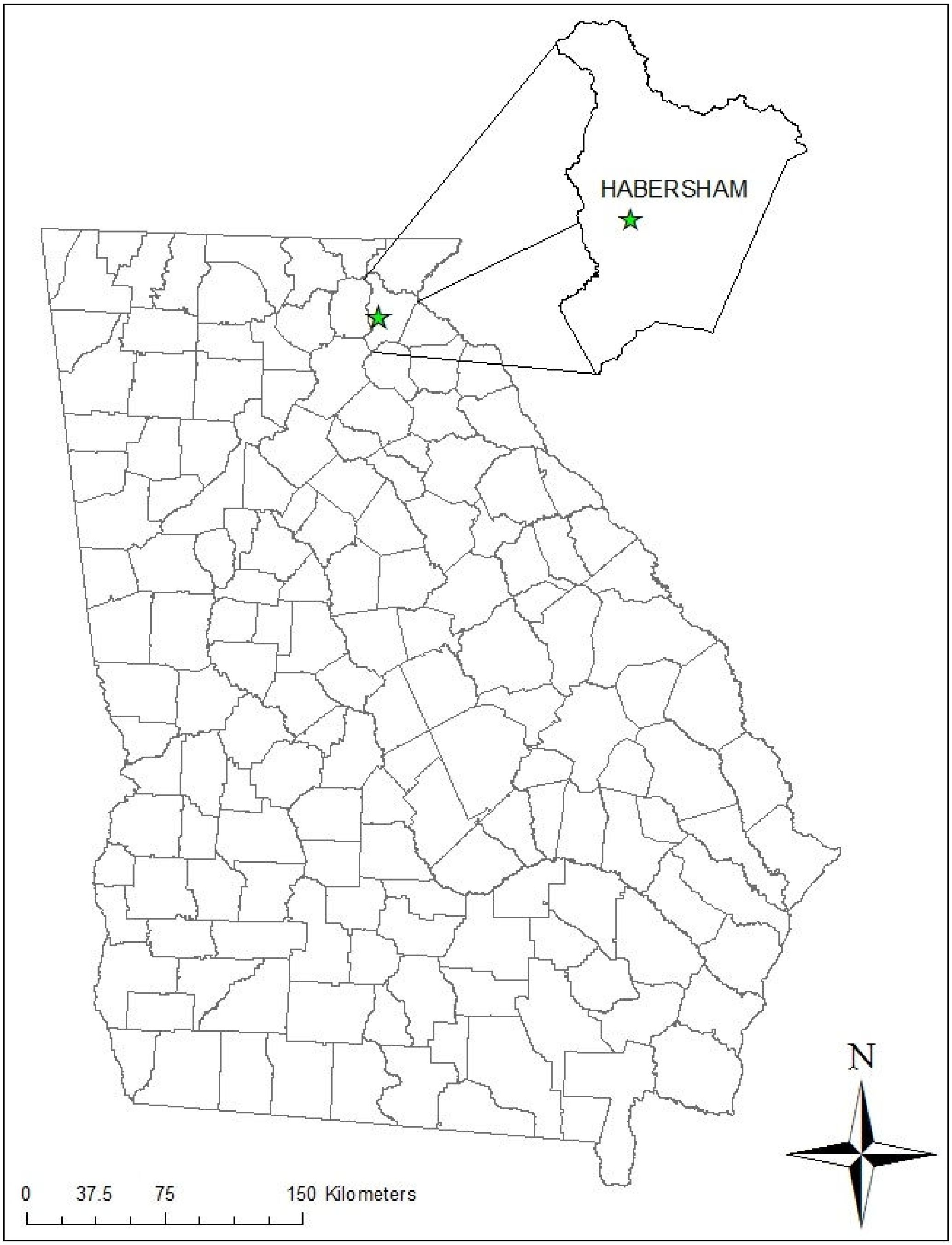

Figure 3.1 – Map of restoration site in reference to state of GA

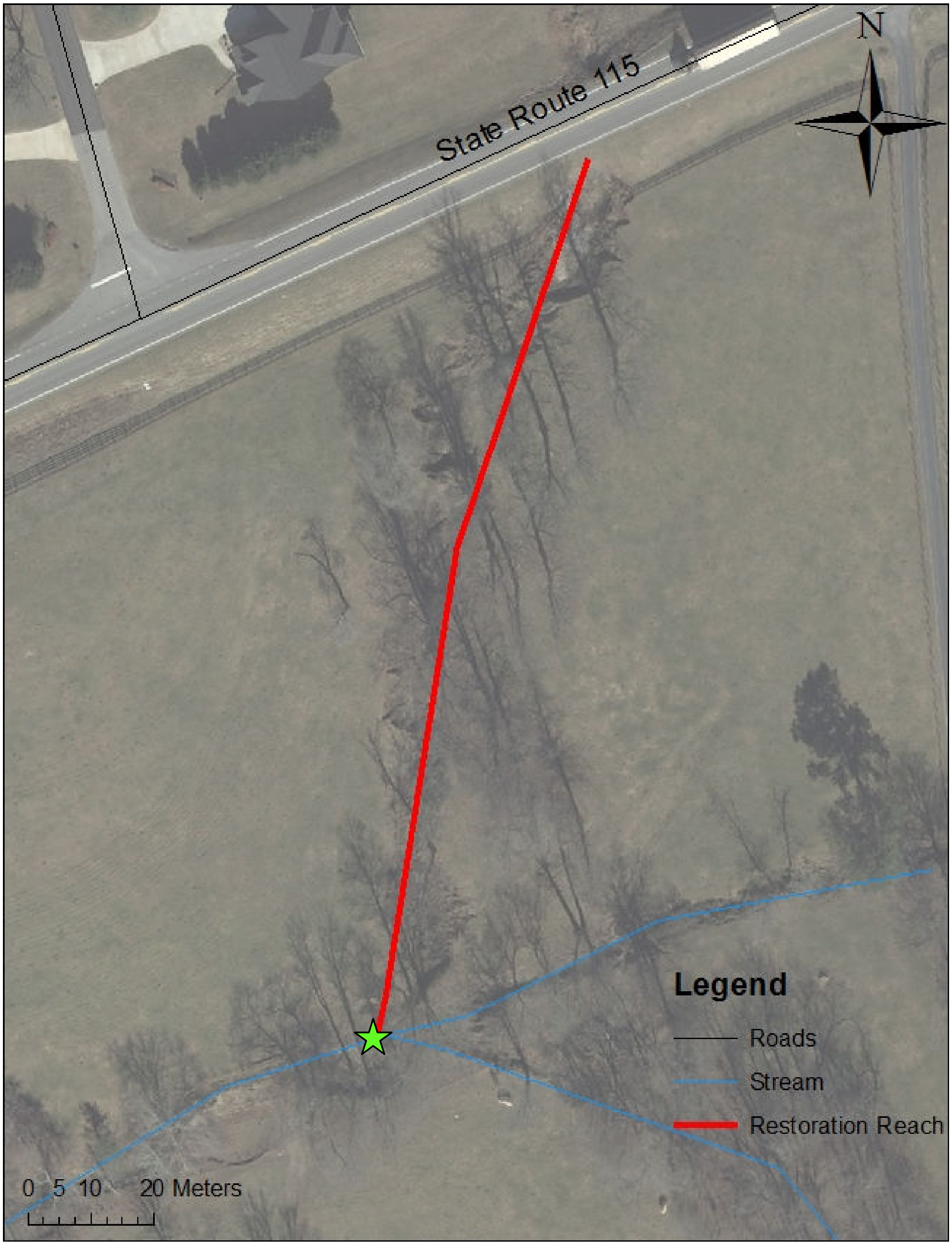

Figure 3.2 – Map with aerial photo and tributaries located on property

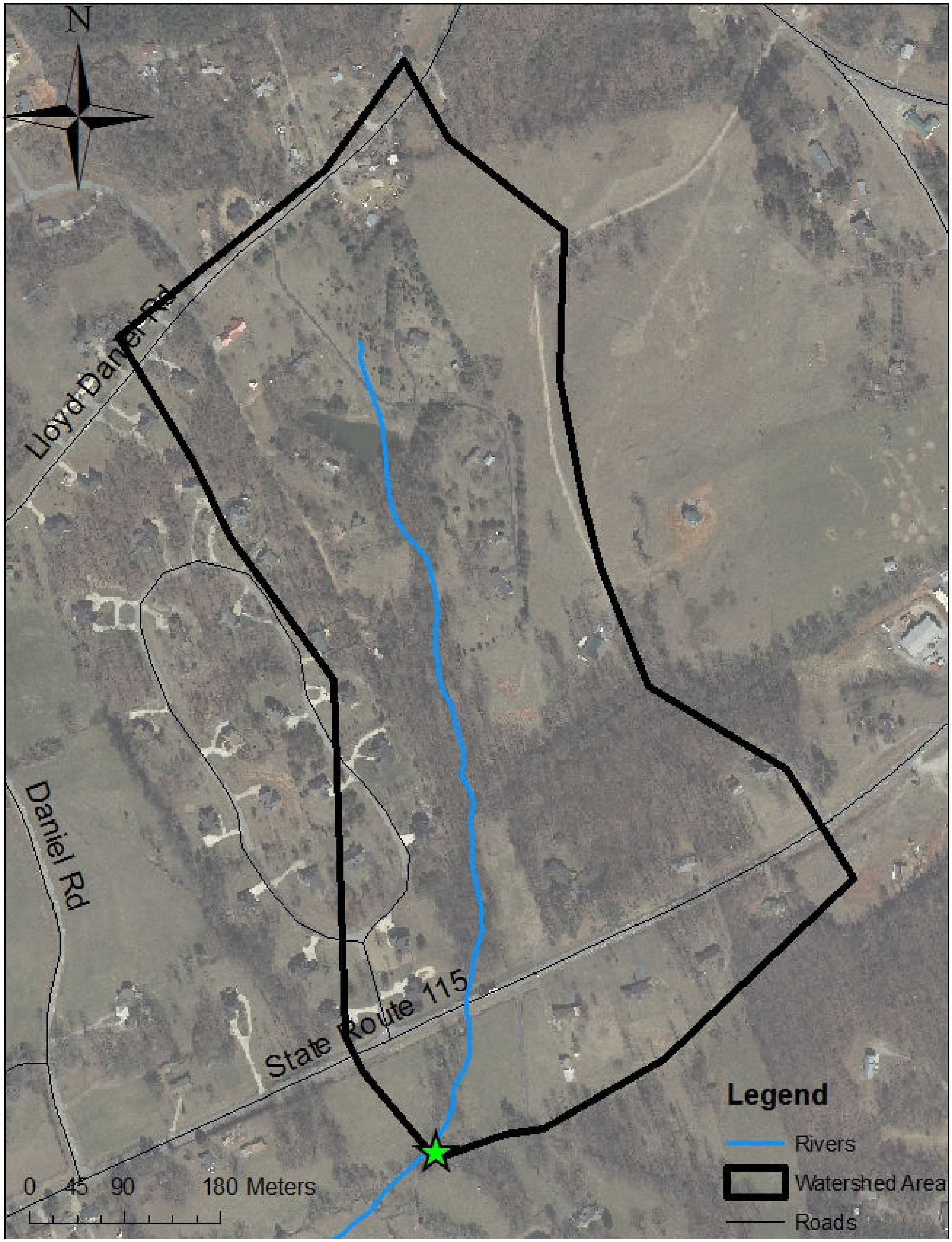

Figure 3.3 – Map with aerial photo, USGS rivers and watershed area

CHAPTER 4:

RESULTS

Sediment Analysis

As mentioned previously, a model was created to estimate SSC of the construction samples by filtering a representative group of samples. The model created from the lab data is shown in Figure 4.1. Included is the linear regression line and correlation value (R^2), all of which was created using Microsoft Excel©. The log vs. log graph was chosen because it portrayed the best correlation between SSC and turbidity. The samples with a known SSC (from lab work) were recorded as the actual SSC while the remaining samples were recorded as estimated values. Both actual and estimated values were used for calculations during the construction phase of the project.

The maximum, minimum, median, mean and standard deviation of SSC were found for each time period and location (Table 4.1). All values were greater during construction for both upstream and downstream locations. All downstream values were larger than the upstream values corresponding to the same time period. The average difference in SSC between time periods shows a large difference between pre-construction and during construction, especially at the downstream sampling location. The main reasoning for not comparing the data using t-test analysis is because of the large standard deviations, specifically during construction. Box plots created for time periods and sampling locations are shown in Figure 4.2. These plots also show the large variation in the downstream samples especially during construction.

A time series (Figure 4.3) of the SSC data shows how SSC changed throughout the project along with the calculated water discharge. During most sampling events, the downstream sampling point yielded a higher SSC than the upstream portion, showing that the stream is a source of sediment not a sediment sink. During construction differences between upstream and downstream (Figure 4.4) were elevated once the rock cross-vane installation finished. After that point in time most all construction activities were contained within the two sampling locations while equipment was on site.

There was no strong correlation shown between SSC and water discharge (Figures 4.5 and 4.6). Construction activities coupled with consistent flows and a small number of storm samples combined to a weak correlation between SSC and water discharge which would usually be expected to be positively correlated. Construction activities had the greatest impact causing large variations in SSC at similar discharge levels.

Due to the large variances the data was normalized by taking the difference between the log of the downstream SSC and log of the upstream SSC. A time series of the normalized SSC for each sampling event, used for the non-parametric analysis is shown in Figure 4.7. For the Wilcoxon test, the normalized construction data was compared to the median of the normalized pre-construction data (median = 0.536). The result of the test was that the medians were not equal (p = 0.000, α=0.05). These results show that the construction activities added a significant amount of excess sediment to the stream reach.

The last step in the sediment analysis was to determine if there was a difference in the bedload transport between the two time periods. The time series (Figure 4.8) of the bedload transport shows changes during the project along with the water discharge. Results from the statistical analysis of bedload transport are shown in Table 4.2. It was found that the bedload transport during construction actually decreased but the data showed no significant difference (p = 0.698, α=0.05).

Phosphorus Analysis

Of the 40 pre-construction and 36 construction samples sent to the lab only 3 and 9 samples respectively had a detectable concentration of TP, even at the ppb level. The samples with non-detectable TP were given a 0.01 ppb concentration for the data analysis steps. Box plots made for the different time periods and locations is shown in Figure 4.9. The downstream location during construction is the only point that shows noticeable variation. This is mainly because there were more samples that had detectable levels of TP for this location and time period than in the other location and time periods. The time series of TP and water discharge during the project (Figure 4.10) shows how the TP concentration changed during the project.

The maximum, minimum, median, mean and standard deviation of TP concentrations were found for each time period and location (Table 4.3). Throughout the whole project the downstream location had the highest mean TP concentration. The downstream sampling point, during construction, had the highest TP concentration max, mean and standard deviation. Due to the low number of non-detects, only descriptive statistics were used to describe TP.

Analysis of bedload TP concentration was also conducted and the results are shown in Table 4.2. Although there was no significant difference in the bedload transport during construction, there was a significant increase (p = 0.002, α=0.05) in the TP concentration of the bedload material moving through the stream.

In-situ Analysis

In-situ measurements were taken during all phases of the project. Tables 4.4 and 4.5 show the statistical results for these measurements. There were no significant changes in pH upstream (p = 0.084, α=0.05) or downstream (p = 0.139, α=0.05) during construction. Conductivity also showed no changes upstream (p = 0.097, α=0.05) or downstream (p = 0.138, α=0.05). DO measurements did show significant differences during construction both upstream (p = 0.003, α=0.05) and downstream (p = 0.013, α=0.05). Changes recorded in pH, DO and Conductivity are believed to be more directly related to the construction activity. Temperature showed a significant difference both upstream (p = 0.00o, α=0.05) and downstream (p = 0.000, α=0.05) but these changes were expected due to seasonal changes. Since pre-construction data did not contain measurements from all four seasons, it is not clear how much of the change in individual in-situ measurements was caused by the construction activities or seasonal variation.

Cross-Sectional Analysis

One of the main objectives of the restoration was to reconnect the channel to an active floodplain. This required excavation of the banks and a construction of a new channel. This excavation also changed the cross-section profile and area of the channel throughout the reach. Profile views of the surveyed cross-sections are shown in Figures 4.11, 4.12 and 4.13 comparing the cross-section at these give points before and after the construction of the restoration. The profiles of cross-sections 1 (Figure 4.11) and 2

(Figure 4.12) show the construction of the new floodplain allowing water room to spread out and dissipate energy during storm flows whereas it could not before construction. Due to land and monetary constraints there were few changes to the downstream cross-section as mentioned previously in the restoration description. All of the elevations shown on the graphs are elevations relative to the total station elevation that was set to an arbitrary 30.48 m (100 ft).

Cross-sectional areas (Table 4.6) were found for each cross-section before and after construction as well as at bankfull and top of bank for each respective cross-section. The cross-sectional areas increased for both cross-sections 1 and 2. This increase is mainly due to the excavation of the banks creating a new floodplain. The third cross-section remained fairly constant throughout the project due to minimal construction work around the downstream site. The major differences seen in the cross-sectional areas are at the top of bank, not bankfull areas.

Pebble Count Analysis

A "percent finer than graph" (Figure 4.14) was created using the pebble count results from both time periods. Before the restoration project the mean diameter (d_{50}) of the pebble count was fine 2 (7 mm) gravel while the survey at the end of the project resulted in a d_{50} of very coarse (1.5 mm) sand. The 80^{th} percentile diameter (d_{80}) decreased from coarse 2 (27mm) before construction to coarse 1 (19mm) after construction was complete. These results (see Table 4.7) show an overall decrease in the intermediate diameter of sediment between the time periods along with percent fines.

Tables

Table 4.1 – Statistical data for SSC by time period and location with values in mg/L (ppm)

Time Period & Location	Max	Min	Median	Mean	Standard Deviation
Before Upstream	22.03	0.5	2.95	5.05	5.84
Before Downstream	220.8	1.38	11.11	36.07	62.36
During Upstream	735.83	0.61	5.27	22.18	100.26
During Downstream	4369.08	2.17	144.48	445.1	796.67

Table 4.2 – Average, Standard Deviation and ANOVA p-value for Bedload Transport & TP concentration

Description	Avg Before	St. Dev Before	Avg During	St. Dev During	p value
Bedload Transport (g/s)	0.066	0.084	0.054	0.069	0.698
Bedload TP concentration (mg/L)	967	255	3415	2656	0.002

Table 4.3 – Statistical data for TP concentration by time period and location with values in μg/L (ppb)

Time Period & Location	Max	Min	Median	Mean	Standard Deviation
Before Upstream	10.00	0.01	0.01	0.84	2.88
Before Downstream	38.00	0.01	0.01	3.18	10.97
During Upstream	71.00	0.01	0.01	5.05	16.05
During Downstream	105.00	0.01	0.01	13.19	26.11

Table 4.4 – Average, Standard Deviation and ANOVA p-value for in-situ up stream measurements

Description	Avg Before	St. Dev Before	Avg During	St. Dev During	p value
pH	6.074	0.194	6.216	0.124	0.084
DO (mg/L)	10.233	0.96	11.5	0.511	0.003
Temp (C)	14.062	3.001	19.6	0.461	0.000
Conductivity (mS/cm)	0.058	0.004	0.062	0.004	0.097

Table 4.5 – Average, Standard Deviation and ANOVA p-value for in-situ up stream measurements

Description	Avg Before	St. Dev Before	Avg During	St. Dev During	p value
pH	5.974	0.232	6.106	0.169	0.139
DO (mg/L)	10.196	0.534	11.142	1.067	0.013
Temp (C)	14.135	3.084	21.042	1.437	0.000
Conductivity (mS/cm)	0.059	0.004	0.064	0.009	0.138

Table 4.6 – Cross Sectional Areas (m^2) before and after construction

	Before		After	
Cross-Section	Bankfull	Top of Bank	Bankfull	Top of Bank
1	1.16	6.97	1.82	8.92
2	0.79	9.29	0.85	10.68
3	1.07	7.48	1.14	7.46

Table 4.7 – Results from pre and post pebble counts

	Pre-Construction	Post Construction
D50 (mm)	7	1.5
D80 (mm)	27	19
% Fines (< 2mm)	40	50

Figures

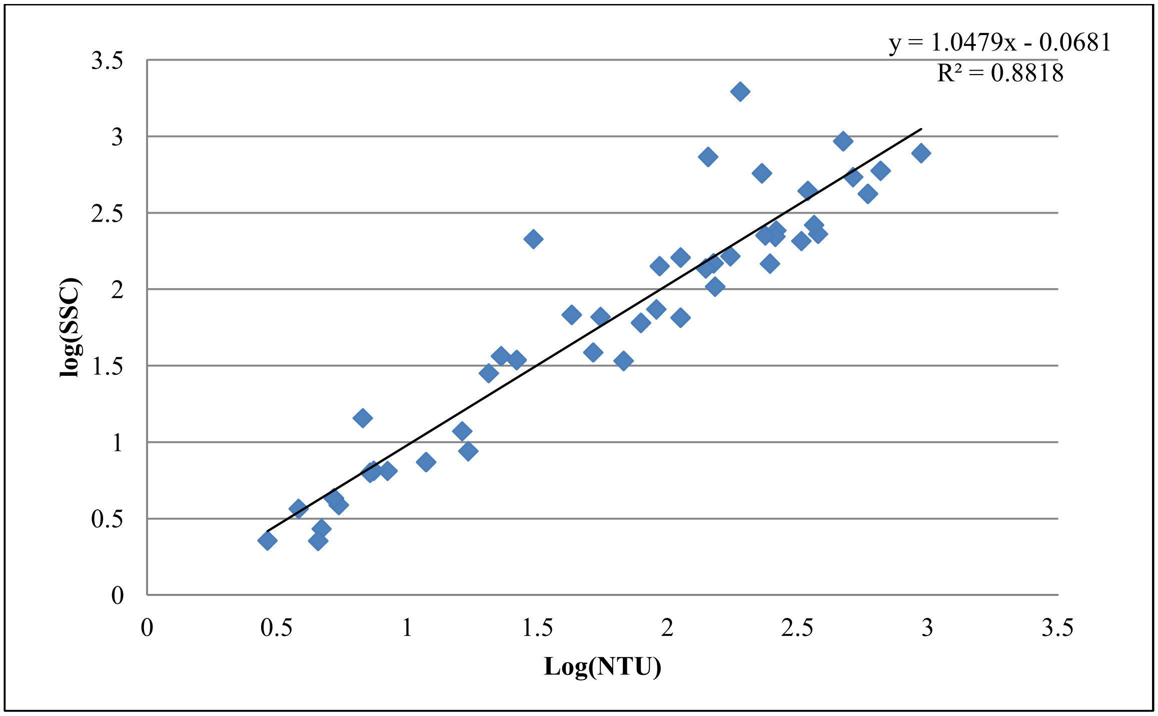

Figure 4.1: Model used to estimate SSC using field turbidity measurements

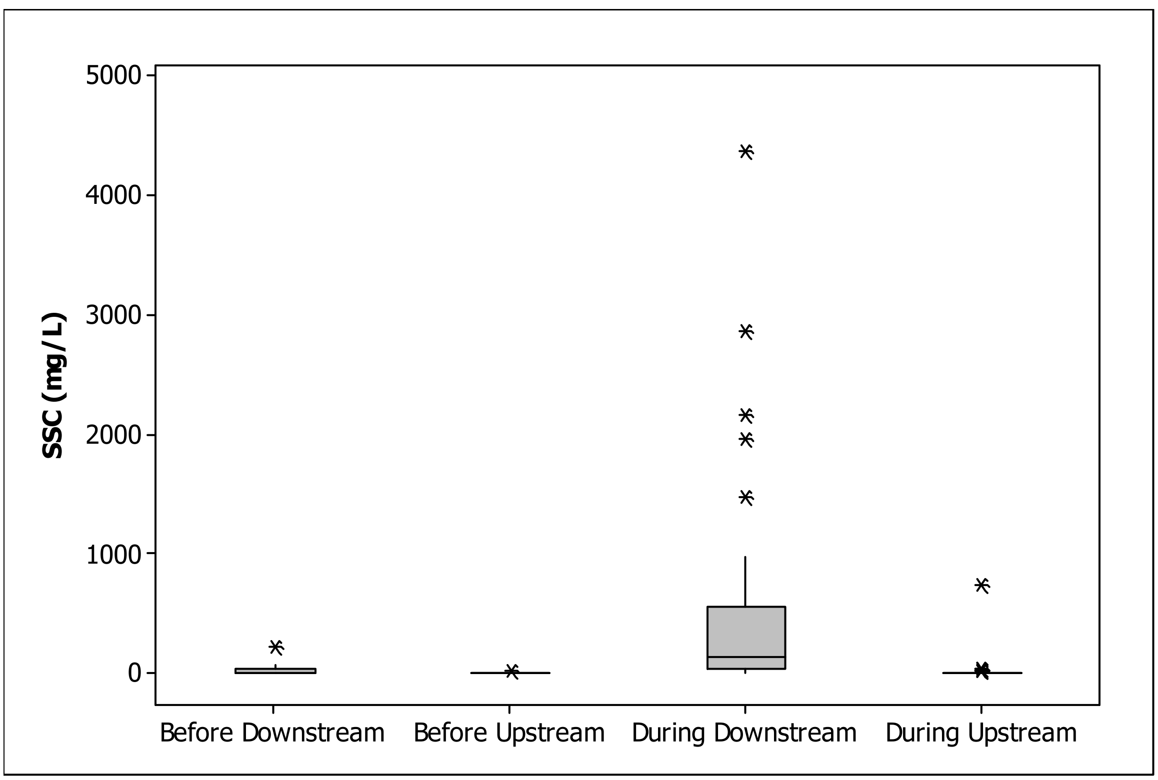

Figure 4.2 – Box plots of SSC for different time periods and sampling locations

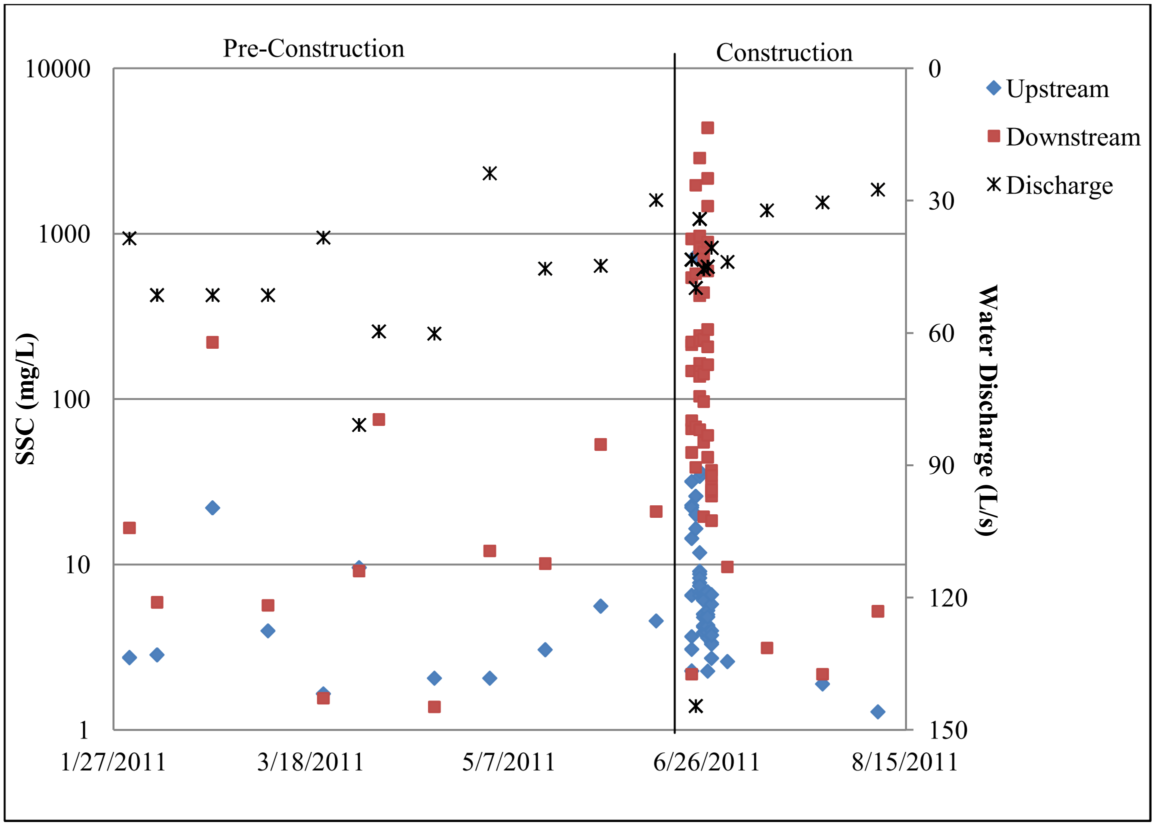

Figure 4.3 – Time series of SSC and water discharge during project

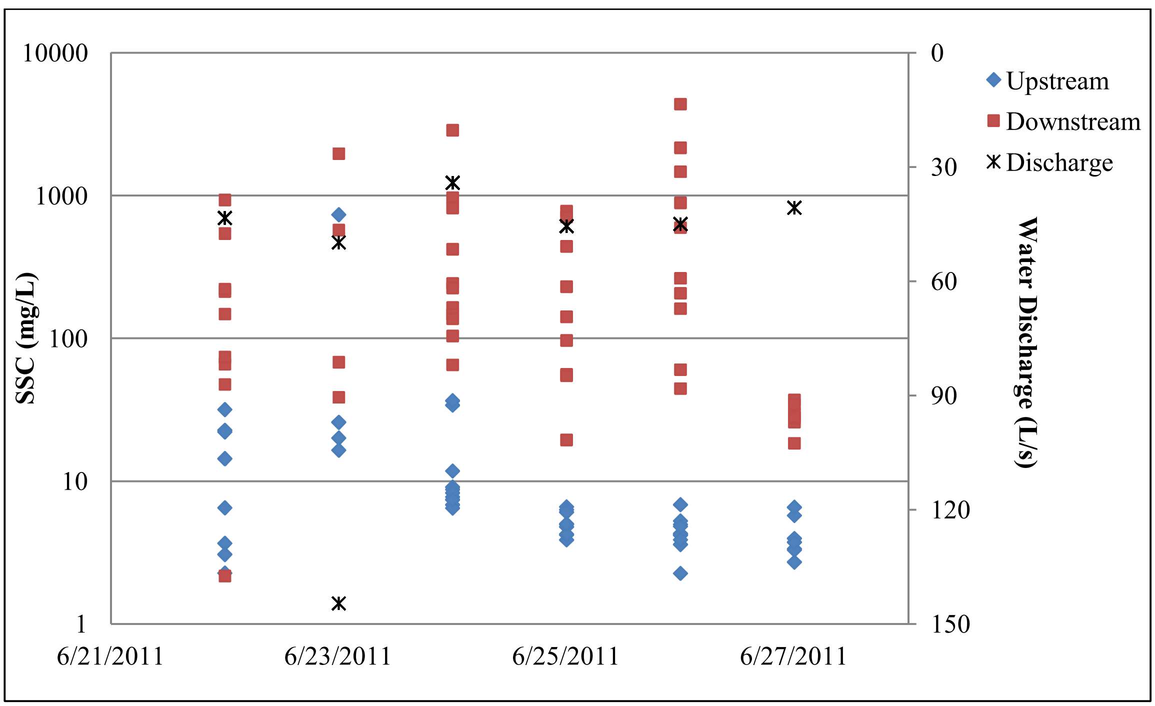

Figure 4.4 – Time series of SSC and water discharge while equipment was on site

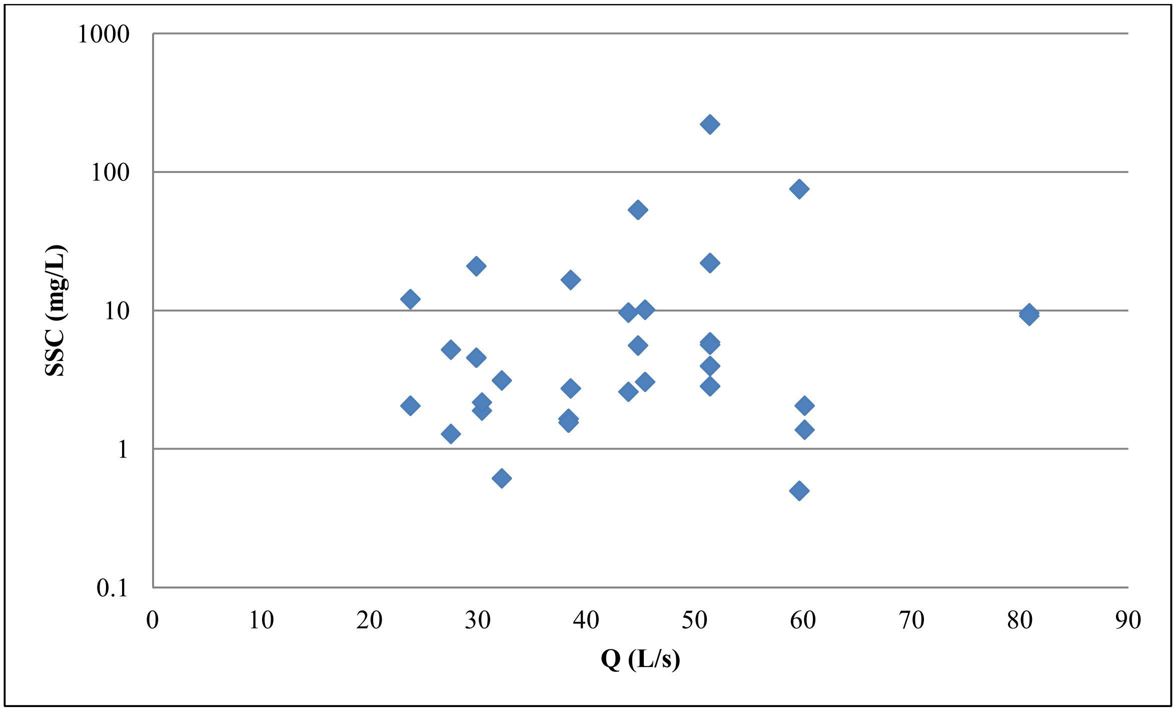

Figure 4.5 –SSC vs. Water Discharge excluding when equipment was on site

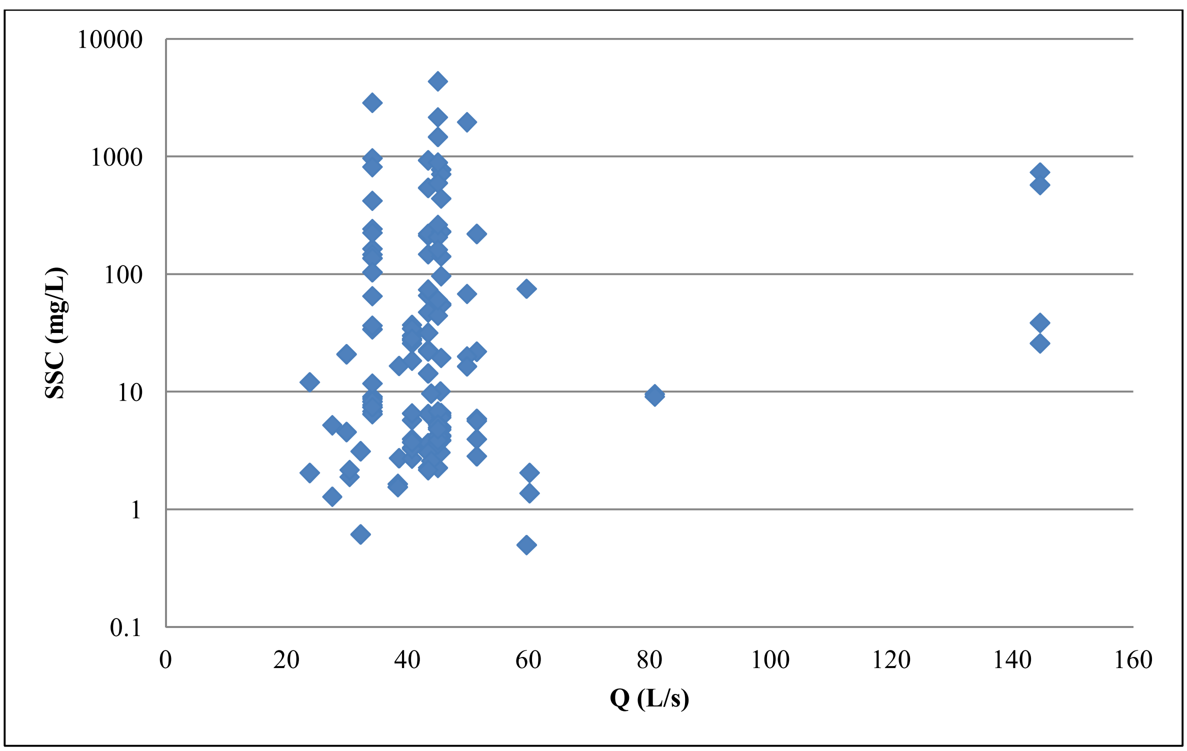

Figure 4.6 –SSC vs. Water Discharge including when equipment was on site

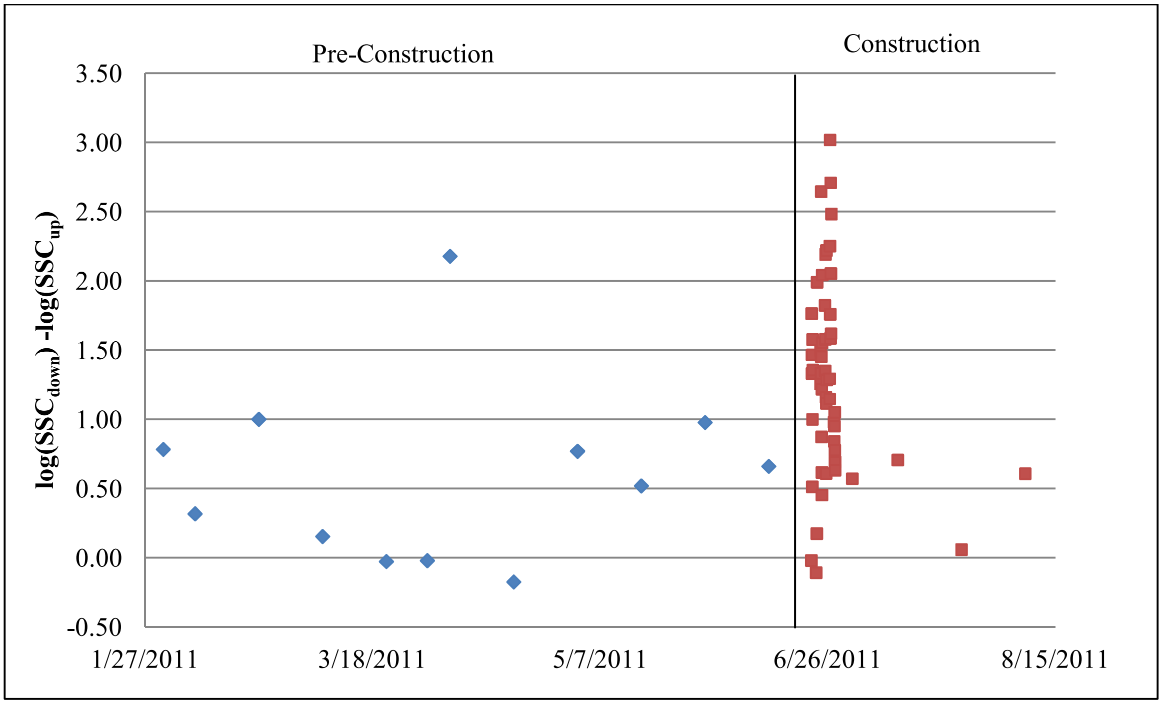

Figure 4.7 – Time series of normalized SSC used for Wilcoxon test

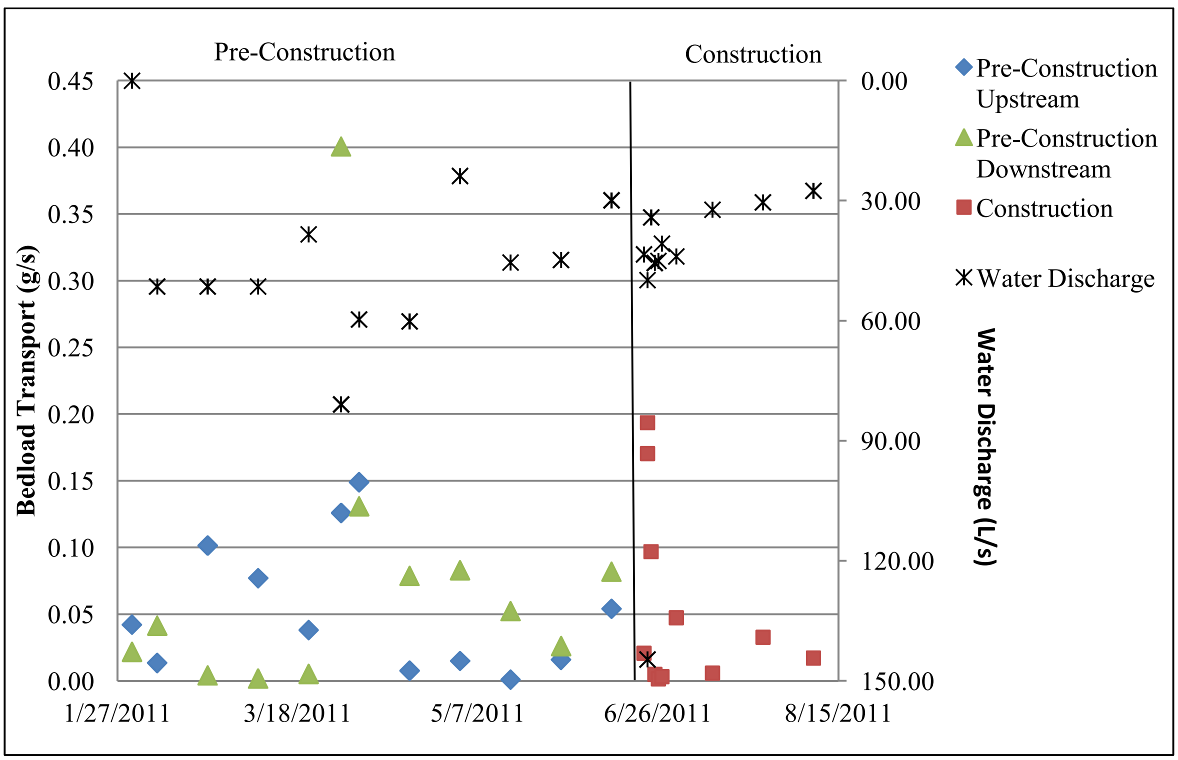

Figure 4.8 – Time series of bedload transport rate and water discharge during project

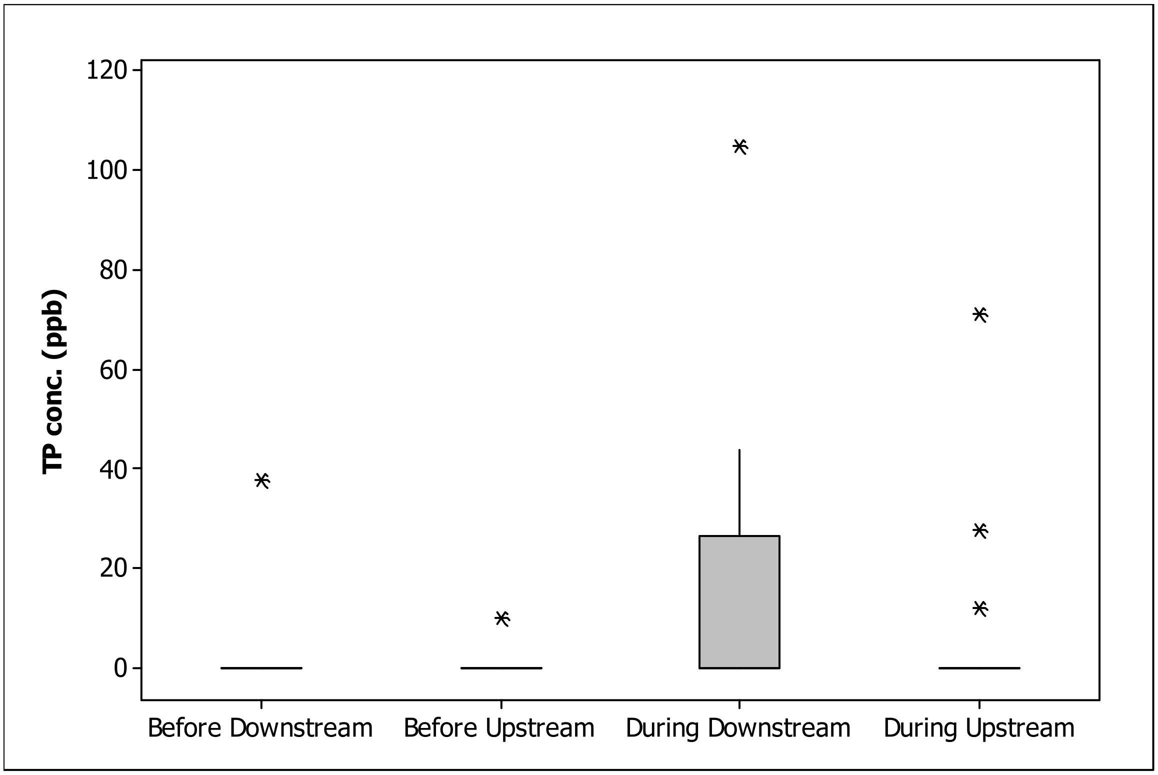

Figure 4.9 – Box plots of TP for different time periods and sampling locations

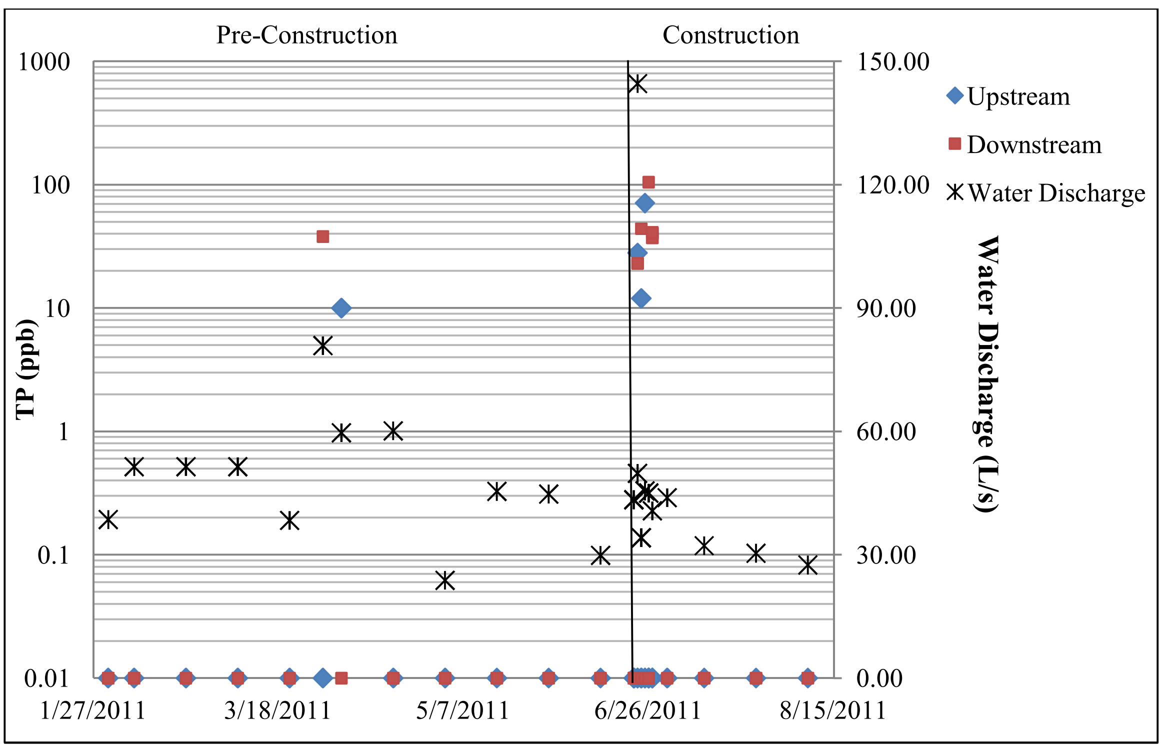

Figure 4.10 – Time series of TP concentration and water discharge during project

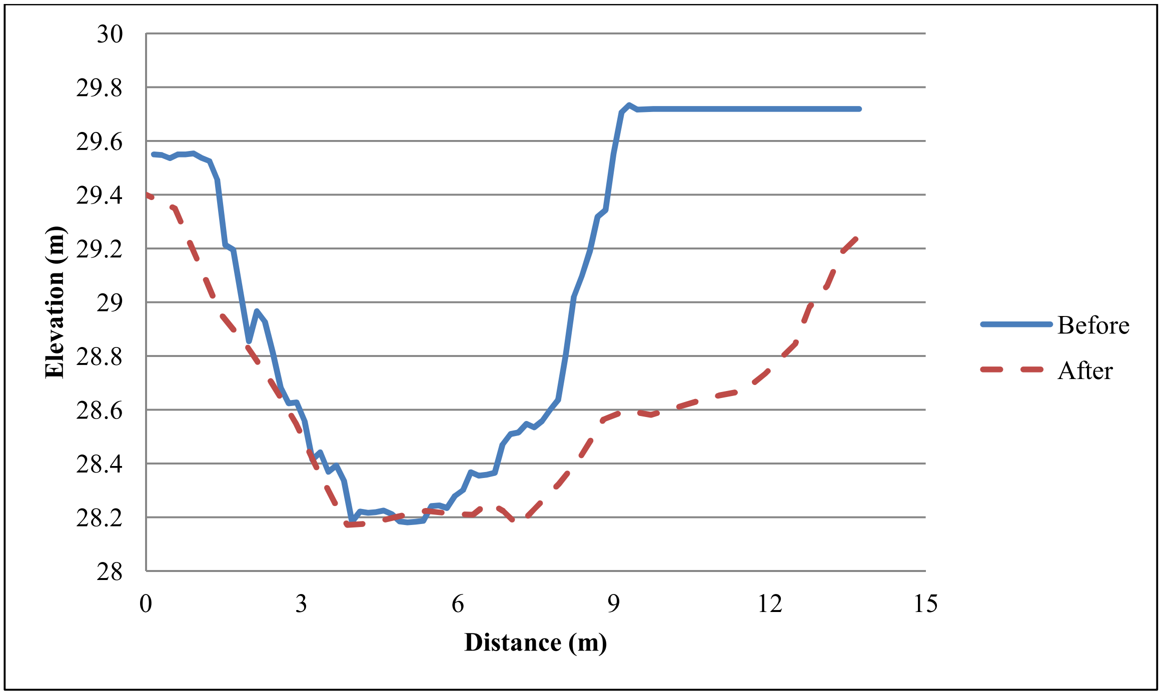

Figure 4.11 – Cross Section 1 (Upstream) profile view before and after

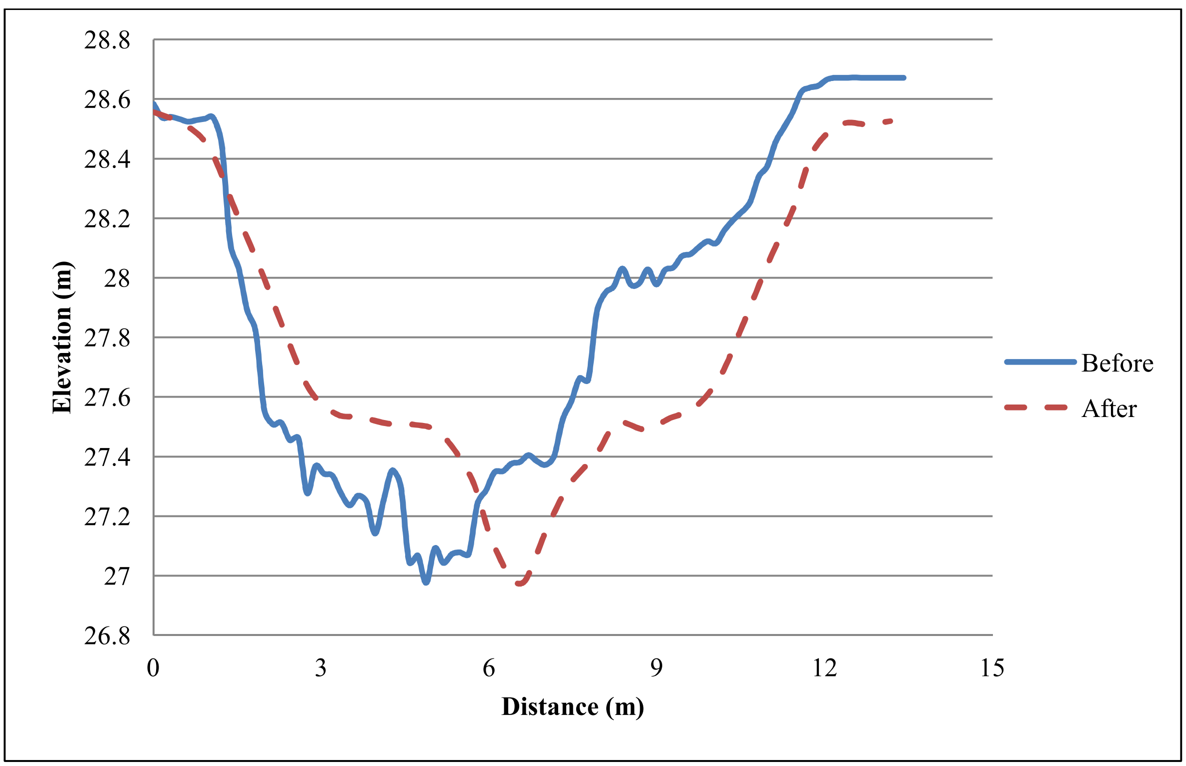

Figure 4.12 – Cross Section 2 (Middle point of reach) profile view before and after

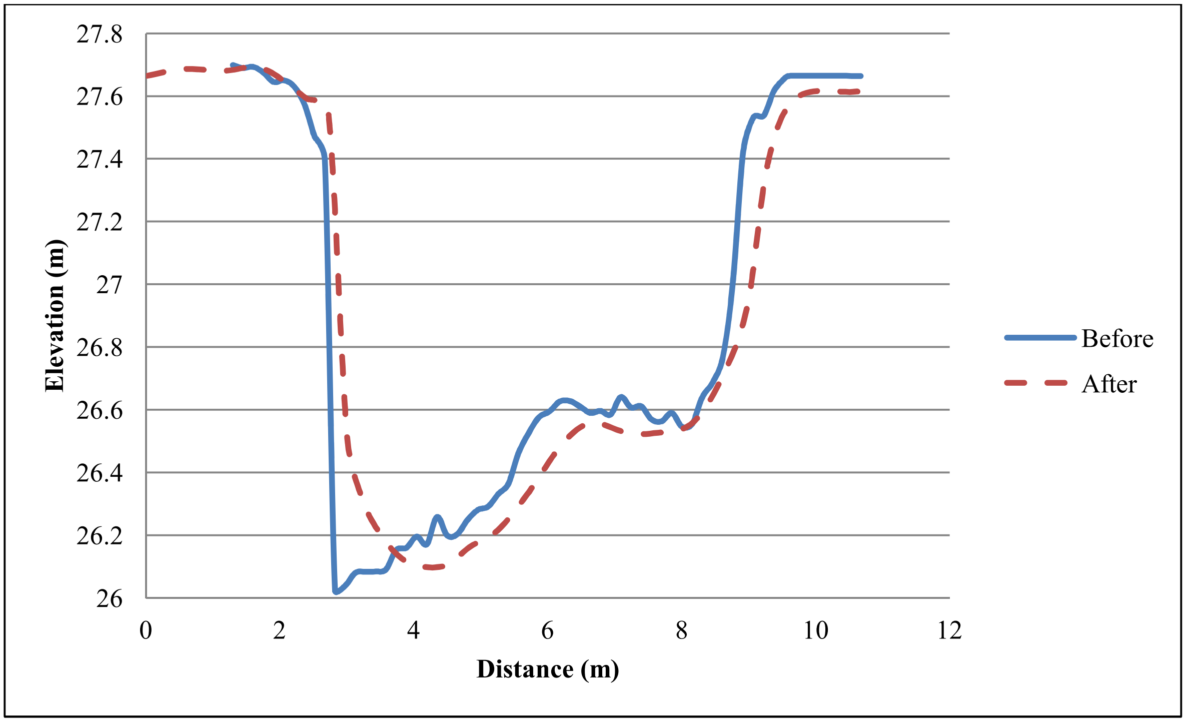

Figure 4.13 – Cross Section 3 (Downstream) profile view before and after

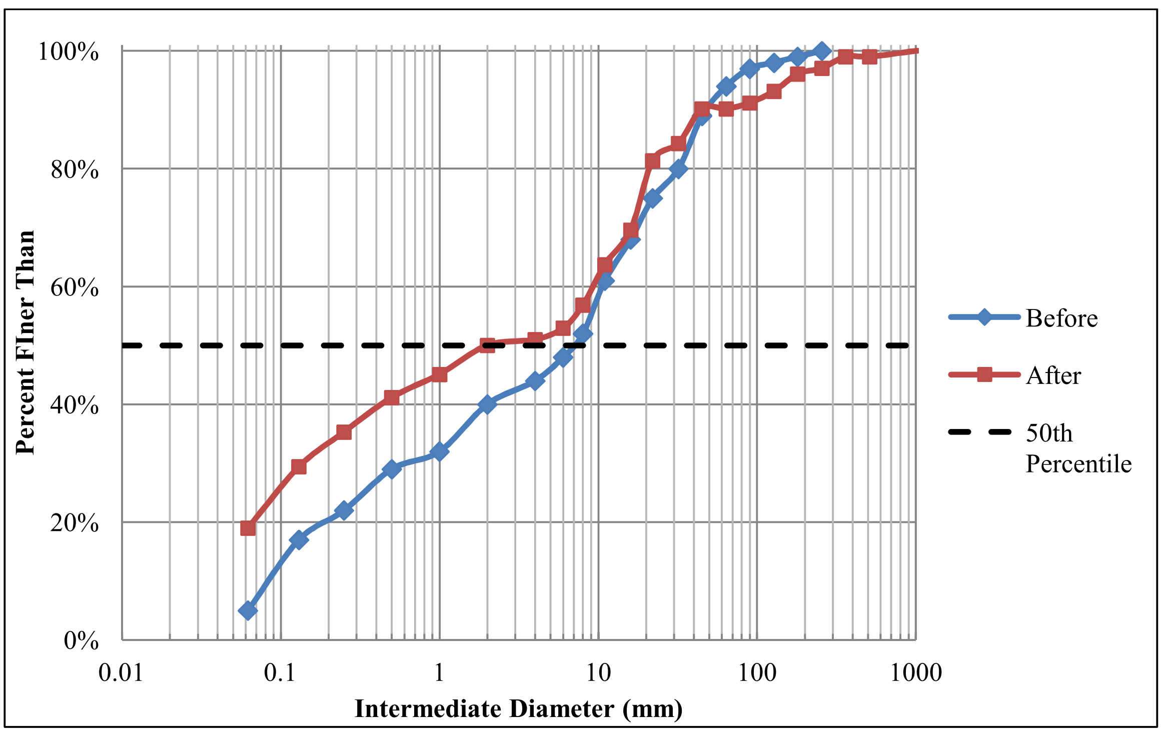

Figure 4.14 – Results from Before and After Pebble Count

CHAPTER 5:

DISCUSSION

Sediment

The results from this study show a large increase in SSC throughout the construction of a stream restoration project, particularly at the downstream sampling point in the studied stream reach. The high variances during construction led to the use of a non-parametric, Wilcoxon test where the difference in SSC between the time periods was found to be significant. These results agree with the initial hypothesis that the SSC would increase during construction.

During construction SSC samples ranged from 1-4400 mg/L. There were 9 sampling events that exceeded 1000 NTU (the threshold for the turbidimeter used) however these levels were not sustained for very long time periods. Throughout the project there were only 2 times where the 1000+ NTU events were found during back to back sampling events. When equipment stopped working in the active channel, the SSC downstream quickly drops back towards the lower levels of SSC within the hour between sampling events. Most days during construction this pattern was seen when the equipment operators took lunch breaks. The SSC of samples before the lunch hour were usually an order of magnitude higher than the after lunch samples. This quick response of the stream to migrate towards pre-existing SSC levels caused a high variability in the results.

The second factor heavily influencing the results was the use of the pump-around system during construction. The project was permitted to work “in the wet” but the contractor and foreman chose to use the pump-around system to reduce the amount of sediment flowing downstream and to make the construction run more smoothly. The pump-around system is a popular option where it can be used because the equipment operators do not have to struggle with water flowing in the area where they are working. For this restoration project, the pump-around system was installed to divert flow from the pool in the upstream section of the stream, around the area the equipment was working in and then released the flow between the equipment and the downstream sampling point. The system reduced the amount of water flowing through the construction area and reduced the amount of loose sediment that could be picked up by the stream flow and moved downstream.

If the pump-around system had not been used, more water would have been allowed to flow through the construction area. This could have decreased the SSC if the same amount of sediment was moved through the stream because of the increase in flow. The more likely occurrence would have been that this increased flow would have increased the sediment lost during construction and the results would have been similar if not elevated.

Other construction factors also factored into the results found in this study. The design of the restoration called for multiple pools to be created. These pools create areas of sediment deposition because they cause dissipation in the energy the stream has to move sediment. The creation of these pools limited the amount of sediment that could move downstream once they were constructed. The riffle sections that were built also had rock from the old stream channel and brought on-site placed into the channel. This rock covered the loose sediment in the newly constructed channel bed and reduced the amount of sediment moved downstream.

The erosion control practices that the contractor used during this restoration project impacted the amount of loose sediment that could enter the stream and be carried downstream. Coconut fiber matting was used on the newly created stream banks. The matting was installed at the toe of the new channel slope and covered most of the new floodplain as well. With this matting in place the amount of loose sediment that could be carried downstream when water was allowed to flow downstream was greatly reduced.

The bedload transport decreased during construction. This is likely due to the low flows while construction was occurring. Decreased flow, creation of pools, and inclusion of structures contributed to a reduction of stream power in the reach. This lower stream power reduced the energy available in the stream to move sediment; therefore, the bedload transport rate dropped.

Phosphorus

As previously mentioned the pastures surrounding the study reach had historically been fertilized using poultry litter and soil test results yielded “very high” scores on the index used for soil test phosphorus. The TP results show that the stream is picking up phosphorus from the upstream to downstream locations and had an increased TP concentration during construction. Although the differences were not tested for significance due to the low number of detects, the averages upstream (pre = 0.840×10^{-3} mg/L, post = 0.005 mg/L) and downstream (pre = 0.003 mg/L, post = 0.013 mg/L) do resemble those found in previous studies (i.e.: Romeis, 2008) in a forested watershed in

North Georgia. Although the studied reach was surrounded by pasture land the majority of the upper watershed is forested, particularly in the immediate riparian zone around the head of the stream. It should be reiterated that only a very small number of samples sent for TP analysis had detectable limits of TP. The majority of detectable TP was seen during construction.

The bedload transporting through the system showed a significantly higher TP concentration during construction than the bedload prior to construction. This could mean that the earthwork during the restoration caused some of the historically high phosphorus sediment to be placed into the channel and transported downstream. Due to the extensive excavation on-site it is difficult to prove whether or not this is what occurred.

In-situ

There were significant increases in DO and Temperature measurements but no significant differences were found in pH and Conductivity upstream and downstream during the project. Construction was found to elevate all of these readings from pre-existing conditions but it is not known if construction was the only factor causing these increases. The majority of the samples taken prior to construction were taken during the winter and spring months while construction occurred during the summer. There were several trees around the site removed that would decrease the amount of shade around the stream which would raise the water temperature. Sustained temperature increases could be seen until the riparian trees have had time to develop a canopy of the stream. Temperature changes could also be due to the ambient outdoor temperatures which exceed 32 Celsius during most of the construction period.

The limiting factor on analysis of all of these variables is the fact that there is no historical data from this stream reach that could be used to relate the measurements seen during construction to the pre-existing conditions during the same summer time period. If data was available from before the construction during the same season then there could be more validity placed on the results for the in-situ measurements.

Cross-Sectional

The cross-sectional analysis was performed to show the differences in the channel before and after construction in an attempt to better quantify the changes in the channel during the project. The increased cross-sectional area of the new channel and the newly cut floodplain will allow for the water to be better controlled during high storm flows and reduce the bank erosion and sediment loss in the restored reach. The bankfull cross-sectional areas were similar to the pre-existing conditions and this is by design. The newly constructed channel was designed to match the existing channel bankfull area, so the cross-sectional areas were expected to be close to the original. The main differences that the design imposed were on the top of bank cross-sectional areas which include the new floodplain.

A riparian grass mix was planted on the disturbed areas to aid in bank stability and to reduce erosion. There is a tree planting date set for December 13, 2011 that will include planting live stakes and potted trees. These trees will be the long term solution to bank stability, provide shade for fish and macroinvertabrates in the stream and will provide leafy material and organic matter to the stream. The vegetation plan implemented on this project was designed so that the cross-sections will not change substantially creating stability of the channel for the long term.

Pebble Count

There was an increase in fine sediment found in the stream at the conclusion of the project. The creation of pools created multiple sinks for this fine material within the stream channel, where before the stream had pushed much of the fine material through the system. The project was completed during a low flow period affecting how much water was available to transport the fines out of the system as well. With the use of old bed material and material brought on site, it is believed that average sediment particle size will return close to the fine gravel that was seen in the pre-construction survey. Klein et al. (2007), found a significant decrease in fine sediment one year after completion of restoration.

Limitations and Improvements

The major limiting factor on this project was the time frame in which the project took place. Due to the time consuming process of gaining access rights to the project site sampling was not able to begin until January, 2011. At a minimum a sampling period of at least one year before construction would have given the background information needed to draw better conclusions about the changes during construction. A one year sampling period would have allowed for background data during the time that the construction took place versus having just 6 months worth of data prior. These confounding issues with small sampling sizes and short time periods for sampling are discussed by in Ernst et al. (2010).

Ecological improvement was not the concentration for this project, but for further projects and long term analysis vegetative cover, shade, ambient temperature and a pre-construction fish survey would help complete the project from both an ecological and fluvial standpoint. Thus far the restoration seems to be having a positive effect on the surrounding ecosystem. No noticeable erosion has occurred to the constructed area. The creation of pools and use of brush toes have led to an increase in fish species and sizes being seen in the stream. A fish shocking survey (results in Table A.1) conducted after completion found 459 fish specimens from 6 different species in the stream reach. It is expected that once base flow levels are elevated other species will be allowed to move into the reach and colonize. A biological assessment is planned for spring 2012 in order to look at changes post-restoration. In order to monitor long term changes in the restoration reach it has been recommended that at least monthly sampling occur at the site following protocols outlined in this publication. No sampling plan has been designed or additional sampling occurred at the time of this publication.

One last topic that should be mention is the feasibility of the restoration in different situations. It was mentioned previously that the project was funded using EPA 319, matched funds from the landowner and SRWA and a donated restoration design. This allowed this project to be completed at low cost to the landowner while also giving the Habersham County and SRWA authorities a demonstration site. If this project were to be privately funded by a landowner the estimated costs would be $40,000 for construction and $8000 for design. At a cost of almost $50,000 a private landowner may look at more economical options to correct stream issues like livestock exclusion and invasive removal to improve riparian buffers and increase bank stability. This option is a very feasible, economical and common practice in Habersham County on other farms. This type of passive restoration also follows the fourth phase of stream restoration proposed by Rosgen (2006). This phase of restoration states that if the area around the stream can be managed such that the stream can repair itself then this should be the preferred solution to the problem (Rosgen, 2006). Allowing the stream to repair itself can lead to issues however. In this case it would be expected the stream would keep eroding its' banks until a floodplain was created. This would mean that more sediment would be transported downstream and could potentially cause issues downstream.

Restoring a stream, using methods similar to those used in the construction of this restoration project, shortcut the sediment removal process by manually removing sediment instead of letting it occur naturally. In watersheds containing catchments already impaired by sediment this could be an advantage to this method. In other cases the financial burden of removing this sediment could exceed the benefit of decreasing the amount of sediment to be transported downstream. Each project site has its' own unique set of impairments and constraints therefore all options should be considered and the best solution chosen for the given stream site.

CHAPTER 6:

CONCLUSIONS

In this experiment manual grab samples were used to observe changes in SSC and TP concentrations in a stream during construction of a NCD stream restoration project. Samples were taken for six months prior to construction to examine base levels of SSC and TP and the data from the pre-construction period was used as a baseline to compare changes during construction. A pump-around system was used during construction to divert the majority of the flow around the active construction area. This erosion control measure is thought to have heavily affected the results of this project. Due to the high variation in SSC and TP during the project, the results were normalized and statistical analysis was performed using a non-parametric Wilcoxon test on the medians of the normalized results.

The results showed that the construction activity caused a significant increase in SSC in the stream, proving the initial hypothesis of the project. The highest SSC levels during the project were recorded while equipment was on-site and were not sustained for long periods of time. The first sampling event that occurred after the equipment was moved off-site showed that the stream had returned to pre-construction SSC levels. This quick response by the stream reach shows that even though there was an increase in suspended sediment moving downstream the negative effects of this increase are not sustained for long periods of time.

The large amount of non-detectable TP concentrations during the project led to inconclusive data on changes in TP. Despite the high background levels of phosphorus in the pasture surrounding the stream these levels didn't correlate to the TP levels in the water samples. The only significant phosphorus change seen in the project was the increased TP concentration of the bedload material moving through the stream during construction.

The results from this study shed light on some of the in-stream effects of construction of a NCD restoration project on a first order stream. Although there was a significant increase in SSC during construction the excess levels were not sustained and a landowner downstream would not be expected to see any sustained water quality issues related to sediment. Downstream landowners would also not expect to see elevated TP levels in their streams while construction is occurring. These results show that when the correct preventative measures are taken during construction of a restoration project, minimal impacts will be seen downstream. The construction methods for this project match the fourth proposed criteria by Palmer et al. (2005) for successful river restoration, that construction activities should not cause long term harm. This experiment took place on a site where specific erosion control measures were used. To fully understand changes that occur during construction and how effective these erosion control measures are, an experiment where none of these controls or where differing control measures were used would be needed.

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APPENDICES

Appendix A:

Table A.1: Results from fish shocking survey post restoration

Common Name	Species	Number	Mass Wt. (g)	% Tot. #	% Tot. wt
Central Stoneroller	Campostoma anomalum	116	781	25.27	23.24
Creek Chub	Semotilus atromaculatus	253	1935	55.12	57.57
Yellowfin Shiner	Notropis lutipinnis	68	162	14.81	4.82
Bluegill	Lepomis macrochirus	6	159	1.31	4.73
Green Sunfish	Lepomis cyanellus	3	189	0.65	5.62
Bluehead Chub	Nocomis leptocephalus	13	135	2.83	4.02

Table A.2: Results from soil sample test on background conditions in pasture

					Mehlich 1 mg/kg (ppm)					
Lab	**Sample**	**LBC [1] (ppm $CaCO_3$/ pH)**	**pH $_{CaCl2}$**	**Equiv. water pH**	**Ca**	**K**	**Mg**	**Mn**	**P**	**Zn**
538	West Pasture	610	5.33	5.93	1511	267.1	217.3	13.54	256.6	28.02
539	East Pasture	506	4.97	5.57	825	185.4	134.9	11.17	117.6	13.05
540	Existing Banks	504	4.51	5.11	196	68.5	41.7	11.15	10.5	2.56
541	Existing Bed	332	4.56	5.16	133	43.5	28.5	34.64	14.7	3.29
542	New Banks	414	5.05	5.65	336	185.4	83.3	28.66	39.9	4.42
543	New Bed	159	4.65	5.25	83	42.9	22.7	8.54	5.8	1.30

Table A.3: Soil test index results for background conditions in pasture

	Mehlich 1 (soil test index kg/ha)					
Sample Location	**Ca**	**K**	**Mg**	**Mn**	**P**	**Zn**
West Pasture	554.91	98.02	79.85	4.96	94.17	10.28
East Pasture	303.06	68.10	49.56	4.04	43.14	4.77
Existing Banks	71.77	25.15	15.24	4.04	3.85	0.92
Existing Bed	48.64	15.97	10.46	12.67	5.32	1.28
New Banks	123.54	68.10	30.65	10.46	14.68	1.65
New Bed	30.47	15.79	8.26	3.12	2.20	0.55

Table A.3: Results from pebble counts

	Size Range (mm)	Class	Before Total #	Before Percentage	After Total #	After Percentage
Silt/Clay	<.062	S/C	5	5%	19	19%
Very Fine	.062 - .13	Sand	12	12%	11	11%
Fine	.13 - .25		5	5%	6	6%
Medium	.25 - .50		7	7%	6	6%
Coarse	.50 - 1.0		3	3%	4	4%
Very Coarse	1.0 - 2		8	8%	5	5%
Very Fine	2 - 4	Gravels	4	4%	1	1%
Fine 1	4 - 6		4	4%	2	2%
Fine 2	6 - 8		4	4%	4	4%
Medium 1	8 - 11		9	9%	7	7%
Medium 2	11 - 16		7	7%	6	6%
Coarse 1	16 - 22		7	7%	12	12%
Coarse 2	22 - 32		5	5%	3	3%
Very Coarse 1	32 - 45		9	9%	6	6%
Very Coarse 2	45 - 64		5	5%	0	0%
Small 1	64 - 90	Cobble	3	3%	1	1%
Small 2	90 - 128		1	1%	2	2%
Large 1	128 - 180		1	1%	3	3%
Large 2	180 - 256		1	1%	1	1%
Small 1	256 - 362	Boulder	0	0%	2	2%
Small 2	362 - 512		0	0%	0	0%
Medium	512 - 1024		0	0%	1	1%
Large	1024 - 2048		0	0%	0	0%
Very Large	2048 - 4096		0	0%	0	0%
		Total Count:	100	100%	102	102%

Appendix B: Results from Wilcoxon and ANOVA tests

Wilcoxon Signed Rank Test: lod(d) - lod(u) (SSC)

```
Test of median = 0.5909 versus median not = 0.5909

                     N for   Wilcoxon         Estimated
                  N   Test  Statistic      P     Median
lod(d) - lod(u)  53     53     1330.0  0.000      1.285
```

One-way ANOVA: Bedload Transport Rate (g/s) versus Construction

```
Source        DF       SS       MS     F      P
Construction   1  0.00097  0.00097  0.15  0.698
Error         33  0.20958  0.00635
Total         34  0.21056

S = 0.07969   R-Sq = 0.46%   R-Sq(adj) = 0.00%


                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level   N     Mean    StDev  --------+---------+---------+---------+-
No     24  0.06556  0.08385             (------------*------------)
Yes    11  0.05421  0.06919  (------------------*------------------)
                             --------+---------+---------+---------+-
                                 0.025     0.050     0.075     0.100

Pooled StDev = 0.07969
```

One-way ANOVA: Bedload P conc (ppm) versus Construction

```
Source        DF         SS        MS      F      P
Construction   1   36898873  36898873  11.89  0.002
Error         23   71387894   3103821
Total         24  108286767

S = 1762   R-Sq = 34.08%   R-Sq(adj) = 31.21%


                        Individual 95% CIs For Mean Based on
                        Pooled StDev
Level   N  Mean  StDev  +---------+---------+---------+---------
NO     14   967    255  (-------*-------)
YES    11  3415   2656                     (--------*---------)
                        +---------+---------+---------+---------
                        0      1200      2400      3600

Pooled StDev = 1762
```

One-way ANOVA: pH versus Construction Upstream

```
Source        DF      SS      MS     F      P
Construction   1  0.0969  0.0969  3.36  0.084
Error         18  0.5199  0.0289
Total         19  0.6168

S = 0.1699   R-Sq = 15.71%   R-Sq(adj) = 11.03%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ---+---------+---------+---------+------
No     12  6.0742  0.1936  (---------*----------)
Yes     8  6.2163  0.1240             (------------*-----------)
                           ---+---------+---------+---------+------
                            6.00      6.10      6.20      6.30

Pooled StDev = 0.1699
```

One-way ANOVA: DO (mg/L) versus Construction Upstream

```
Source        DF      SS     MS      F      P
Construction   1   7.711  7.711  11.59  0.003
Error         18  11.972  0.665
Total         19  19.684

S = 0.8156   R-Sq = 39.18%   R-Sq(adj) = 35.80%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean  StDev  --------+---------+---------+---------+-
No     12  10.233  0.960  (--------*-------)
Yes     8  11.500  0.511                    (---------*---------)
                          --------+---------+---------+---------+-
                              10.20     10.80     11.40     12.00

Pooled StDev = 0.816
```

One-way ANOVA: Temp (C) versus Construction Upstream

```
Source        DF      SS      MS      F      P
Construction   1  147.23  147.23  26.36  0.000
Error         18  100.53    5.59
Total         19  247.76

S = 2.363   R-Sq = 59.42%   R-Sq(adj) = 57.17%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean  StDev  ---------+---------+---------+---------+
No     12  14.062  3.001  (----*-----)
Yes     8  19.600  0.461                    (------*------)
                          ---------+---------+---------+---------+
                               15.0      17.5      20.0      22.5

Pooled StDev = 2.363
```

One-way ANOVA: Cond (mS/cm) versus Construction Upstream

```
Source        DF         SS         MS     F      P
Construction   1  0.0000494  0.0000494  3.06  0.097
Error         18  0.0002908  0.0000162
Total         19  0.0003402

S = 0.004019   R-Sq = 14.52%   R-Sq(adj) = 9.77%


                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level   N      Mean     StDev  ------+---------+---------+---------+---
No     12  0.058417  0.004078  (---------*--------)
Yes     8  0.061625  0.003926            (----------*-----------)
                               ------+---------+---------+---------+---
                                   0.0575    0.0600    0.0625    0.0650

Pooled StDev = 0.004019
```

One-way ANOVA: pH versus Construction Downstream

```
Source        DF      SS      MS     F      P
Construction   1  0.0989  0.0989  2.36  0.139
Error         21  0.8802  0.0419
Total         22  0.9791

S = 0.2047   R-Sq = 10.10%   R-Sq(adj) = 5.82%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  -----+---------+---------+---------+----
No     12  5.9742  0.2322  (-----------*------------)
Yes    11  6.1055  0.1694              (------------*-----------)
                           -----+---------+---------+---------+----
                              5.90      6.00      6.10      6.20

Pooled StDev = 0.2047
```

One-way ANOVA: DO (mg/L) versus Construction Downstream

```
Source        DF      SS     MS     F      P
Construction   1   5.136  5.136  7.43  0.013
Error         21  14.507  0.691
Total         22  19.643

S = 0.8312   R-Sq = 26.15%   R-Sq(adj) = 22.63%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean  StDev  ------+---------+---------+---------+---
No     12  10.196  0.534  (---------*---------)
Yes    11  11.142  1.067                  (----------*---------)
                          ------+---------+---------+---------+---
                             10.00     10.50     11.00     11.50

Pooled StDev = 0.831
```

One-way ANOVA: Temp (C) versus Construction Downstream

```
Source        DF      SS      MS      F      P
Construction   1  273.78  273.78  45.90  0.000
Error         21  125.25    5.96
Total         22  399.03

S = 2.442   R-Sq = 68.61%   R-Sq(adj) = 67.12%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean  StDev  ---------+---------+---------+---------+
No     12  14.135  3.084  (-----*----)
Yes    11  21.042  1.437                             (-----*-----)
                          ---------+---------+---------+---------+
                                15.0      17.5      20.0      22.5

Pooled StDev = 2.442
```

One-way ANOVA: Cond (mS/cm) versus Construction Downstream

```
Source        DF          SS          MS     F      P
Construction   1  0.0001230  0.0001230  2.37  0.138
Error         21  0.0010876  0.0000518
Total         22  0.0012106

S = 0.007197   R-Sq = 10.16%   R-Sq(adj) = 5.88%


                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level   N      Mean     StDev  ----+---------+---------+---------+-----
No     12  0.058917  0.004252  (------------*------------)
Yes    11  0.063545  0.009427               (-------------*-----------)
                               ----+---------+---------+---------+-----
                                 0.0560    0.0595    0.0630    0.0665

Pooled StDev = 0.007197
```