Riparian Corridor Master Plan

RCMP

December 2006

Campus Planning Services, Clemson University

List of Figures

Acknowledgements

Many dedicated people have contributed to the planning process and formation of this document, The Clemson University Riparian Corridor Master Plan (RCMP) provides a framework for preserving and restoring environmental quality on campus. The effort was coordinated by Gerald Vander Mey, head of Campus Planning Services, who guided the planning process, hosted input sessions, compiled goals and objectives and created graphics with assistance from Barry Anderson and Pete Knudsen. Rockie English provided conceptual guidance and informed the ecological component of this document with assistance from his watershed management and stream restoration graduate classes. Cal Sawyer formulated recommendations and with assistance from John Hayes, Cal compiled the modified curve number approach.

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Executive Summary

The Clemson University Riparian Corridor Master Plan (RCMP) committee formed in the fall of 2004 to address water quality and open space constraints and opportunities on campus. The RCMP seeks to create a healthy, safe, attractive, and sustainable environment within the riparian corridors of the campus. The RCMP outlines strategies that are informed by watershed assessment and on-going monitoring to meet goals and objectives. Clemson University has partnered with many federal, state and local entities to initiate a successful watershed master planning process that characterizes existing conditions and identifies instream and onsite opportunities to improve water quality.

The RCMP employs a dynamic management approach that focuses on planning, education, funding, and demonstration to fulfill its mission. This project builds on the Clemson Campus Master Plan and is funded and managed by the Campus Planning Services Department. The Clemson Environmental Committee and stakeholders represent the myriad of campus land uses.

As with many other areas, conventional agricultural practices, non-point source stormwater impacts, point source impacts, channel modification and other land-disturbing activities resulting from development have degraded the stream channels and adjacent riparian corridors. Some campus stream reaches are perturbed and have poor biological function. Channel instability has caused unnatural bank erosion that has undermined tree roots causing trees to fall and streambanks to fail. Channel instability threatens utilities and negatively impacts public health, safety, and welfare.

Corrective actions across the campus watershed will eventually enable the streams to return to highly functioning biological areas consistent with RCMP goals. Several different integrated management practices (IMP's) such as green roofs (living roofs), water harvesting and reuse, permeable parking, rain gardens (bioretention), turf reinforced swales, stormwater wetlands, and stream and associated riparian buffer restoration could be implemented on campus to improve water quality and approach predevelopment hydrological conditions. Many opportunities exist on campus to improve and preserve riparian areas further fulfilling the education mission of Clemson University.

1. Introduction

1.1. Overview

Impairments to the Hunnicutt Creek watershed stem primarily from past land management practices that have perturbed the environment. Conventional design of stormwater practices that accounted for larger and more intense precipitation events in the interest of flood control did not take biological process and habitat into account. The resultant hardening of the watershed and stream channels has negatively impacted stream and floodplain function, thereby severely limiting biological integrity. Previous land management techniques that include straightening stream channels, point source pollution impacts, clearing of vegetation and introduction of aggressive exotic species have also compromised biological integrity. Clemson University has an opportunity to reverse these trends, improve water quality, enhance stream and floodplain function, and improve biological integrity in an aesthetically pleasing manner. Incorporating low impact development techniques to reduce pollutant loading and peak flow and to stabilize base flow will augment stream restoration efforts. Chemical and biological monitoring can be used to document the preservation and restoration efforts.

Stream reaches are heavily impacted by stormwater and require a combination of mitigation and restoration in order to address reduced stream function. Until recently, standard practices include conveying runoff away from developed areas into an underground culverted drainage network. The cumulative impact of these decisions is evident in the heavily eroding and incised channels on campus that are forced to handle higher peak flows and volumes of stormwater. The base flow, or low flow during drier periods, is reduced and negatively impacts stream function.

This plan provides recommendations to improve the biological function of the riparian corridors within the cultural context of the university community.

1.2. Principles

Clemson University has established guiding principles for the Riparian Corridor Master Plan (RCMP). These include the following:

- The corridors are to be a healthy, safe and stable series of environments that will support the functional needs of research and teaching, as well as the service needs of the university.
- The corridors are to be a series of environments that provide for the best plant and animal communities native to the region.
- The corridors are dedicated green spaces that are a critical part of the community infrastructure equal to the roadways, utilities, or buildings on campus.

- The watersheds contributing runoff to Hunnicutt Creek must adequately respond to the needs of the riparian corridors.

1.3. Focus Areas

The RCMP employs a dynamic management approach that focuses on planning, education, funding, and demonstration to fulfill this mission:

Focus on Planning: Focus on process, the acquisition and understanding of good information, building consensus, and decision-making.

- Organize & Conduct Stakeholders Meetings
- Conduct Analysis using student and Committee help
- Develop alternative approaches/plans
- Select most appropriate solutions and refine into final plan.

Focus on Education: Involve students in watershed issues, analysis, BMPs, planning process, and science.

- Utilize students in collection of data.
- Involve the Students for Environmental Awareness.
- Employ graduate student to take substantial role in the overall process.

Focus on Funding: Identify likely funding sources for the Integrated Management Practices (IMPs) and other initiatives within the project and apply for funding.

- Make contact with EPA, SCDHEC, and other agencies.
- Approach University sources for matching funds.

Focus on Demonstration: Build interest and credibility.

- Identify logical priority areas for demonstration of best management practices through planning process.
- Design and implement best management practices.

1.4. Goals and Objectives

A series of stakeholder meetings held in April 2005 led to the identification of many short and long term goals. Throughout the course of these meetings several specific strategies and action items were also identified that will lead to the overall success of this plan. The action items are listed in the Recommendations Section.

Goal 1: Maintain the natural quality/processes of Clemson University and its riparian corridors by restoring, preserving, and protecting its natural systems.

- Objective: Restore degraded riparian corridors.
- Objective: Inventory and assess existing conditions throughout the watershed and specifically within the riparian corridors.
- Objective: Establish riparian corridors as dedicated green spaces that are a critical part of the community at least equal to the roadways, utilities, or buildings on campus. Riparian corridors must be preserved to protect the plant and animal communities native to the region, along with water quality, and bank and stream stability.
- Objective: Apply design techniques and integrated management practices to mimic pre-development hydrology and restore the campus hydrology to a stable state.

Goal 2: Showcase the streams and riparian corridors on university property to increase their values as educational and recreational resources and to maximize their abilities to meet the research, teaching, and service needs of the university.

- Objective: Heighten awareness for watershed restoration and protection.
- Objective: Investigate and protect any places or items of historic cultural value on campus, specifically within the riparian corridors.
- Objective: Provide opportunities for community education and recreation while maintaining safe user access within the riparian corridors without endangering the health or functions of those corridors.
- Objective: Attain regional and national recognition for efforts to protect and restore riparian corridors.

Goal 3: Reduce the destructive impacts affecting riparian corridors created through the design, development, and construction of university facilities. Use new development as an opportunity to improve both water quality and water quantity.

- Objective: Reduce on and off site erosion, pollution from construction and other land disturbance activities.
- Objective: Reinforce building standards and practices to minimize the impacts of construction on the watershed and riparian corridors.
- Objective: Utilize low impact development (LID) techniques on future projects.
- Objective: Implement water quantity controls.
- Objective: Implement Integrated Management Practices.
- Objective: Coordinate efforts with the City of Clemson to mitigate impacts on campus.

Goal 4: Reduce the negative impacts on the watershed and riparian corridors that are a product of daily operations or special activities occurring on campus. Seek opportunities to renovate the built environment and revise standard practices to lessen those impacts.

- Objective: Reduce stormwater runoff from university parking lots that rapidly deliver pollutants, sediment, and heavy flow into the riparian corridors.
- Objective: Reduce the amount of pollutants reaching campus watercourses as a result of detrimental practices or inferior design of the built environment.

Goal 5: Centralize authority for stormwater issues and establish an operational mechanism for funding and oversight.

- Objective: Examine the (long-term and short-term) economic and ecological costs of best management practices as compared to the costs of conventional practices used in addressing university waterways.
- Objective: Weigh the environmental and economic impacts that are created by continued substandard funding of stormwater management against the cost of establishing stormwater as a funded utility.
- Objective: Identify funding opportunities to finance stormwater management.
- Objective: Explore funding options beyond those offered by Clemson University in order to finance demonstration projects, research efforts, and educational endeavors within the university watershed and riparian corridors.

2. Watershed Description

2.1. Context

The foundation of this document is the idea that interconnected parts form an ecosystem. The ecosystem is connected “by flows of energy and materials” (Lyle, 1999. p 17). As John T Lyle points out, “We need to recognize that every ecosystem is a part-or subsystem- of a larger system and that it in turn includes a number of smaller systems” (Lyle, 1999. p 17). Varying scales can illustrate cultural, social and natural connections.

2.2. Inventory

2.2.1. Location

According to the Ecoregions of North Carolina and South Carolina Map, Clemson University is contained within the “Southern Outer Piedmont” and is located within the Tugaloo/Seneca River basin (HUC: 03060101) in Pickens County, South Carolina. The campus is approximately 2.72 square miles. The image below shows the watersheds, campus location and campus map depicting the watershed boundary. For the most part, campus and watershed boundaries overlap. The watershed drains the campus into the extant Seneca River Beds through Hunnicutt Creek and several other tributaries into the Corps of Engineers pump station which is pumped into Lake Hartwell. It is unusual that one entity controls the majority of a watershed.

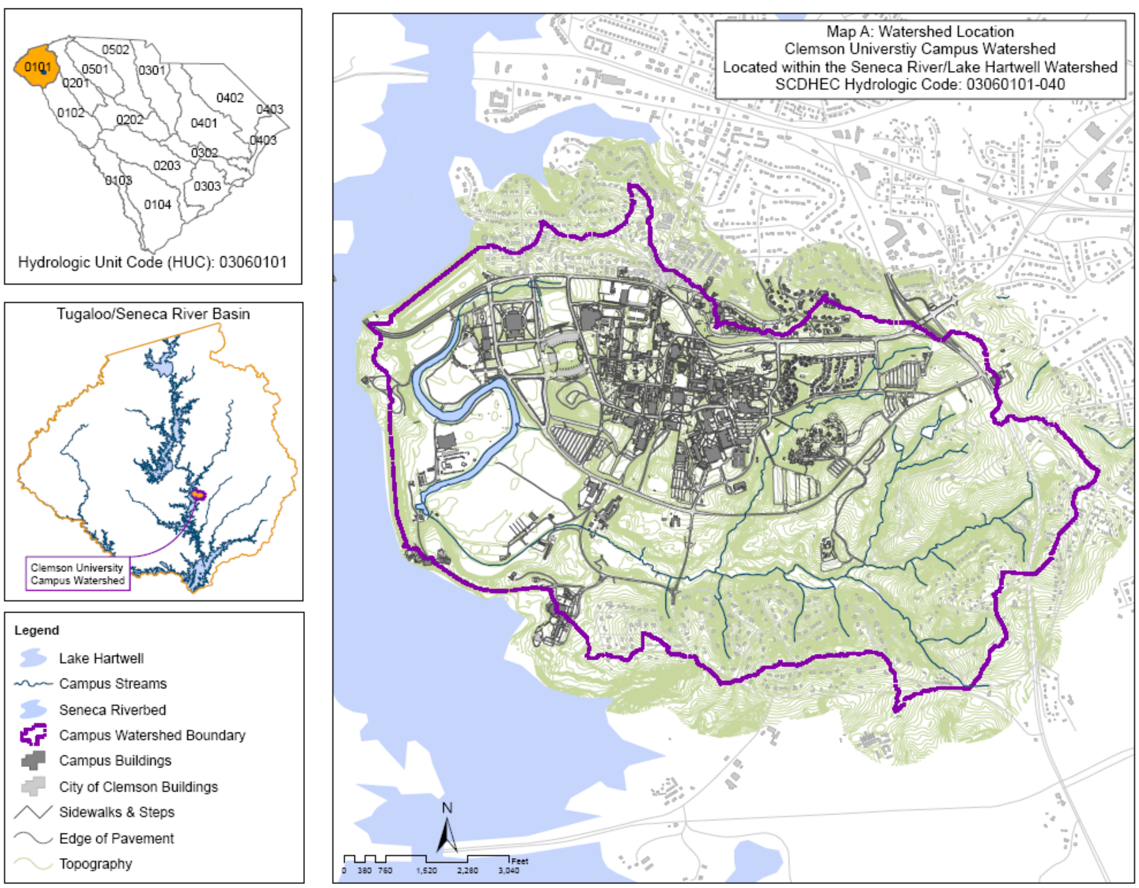

Figure 1: Vicinity Map

2.2.2. Existing Conditions

The Clemson University Master Plan contains baseline mapping of slope, elevation, aspect, hydrology and soils.

2.2.2.1. Slope, Aspect and Elevation

The slopes are generally rolling in the upland areas and flat on the extant floodplain, or the area referred to as the bottoms that also serve as flood storage for large storm events or pump failure. Several steep slopes exist on campus where the stream reaches have down cut, incised, heavily eroded and scoured the existing stream channel. Although the main drainage pattern is westerly, all aspects are present on campus because of the terrain. The elevation on campus ranges from 612 to 868 feet above sea level.

2.2.2.2. Hydrology

Several intermittent channels and perennial surface water features exist on campus. Stream reaches and some subwatersheds have been delineated from existing contour data. The drainage system drains westerly to the Corps of Engineers Pump Station that discharges to Lake Hartwell which is contained in the Tugaloo/Seneca River basin (HUC: 03060101) and drains to the Atlantic Ocean through regulated reservoirs.

Rainfall data was analyzed and 90% of the storms are below 1.2 inches of precipitation (Hayes, 2005).

2.2.2.3. Soils

Based on the Soil Conservation Service general soil map of Pickens County, the soils in the study area are of the Cecil-Madison-Pacolet association. These soils are well-drained, strongly sloping to steeply sloping, have dominantly clay subsoil, are moderately deep or weathered rock and occur on uplands. According to the Ecoregions of North Carolina and South Carolina Map, “gneiss, schist, and granite are typical rock types, covered with deep saprolite and mostly red, clayey subsoils. Kanhapludults are common soils, such as the Cecil, Appling, and Madison series (Griffin et al, 2002). The underlying geology suggests that erosion can be significant because there is little bedrock near the surface that can provide grade control. Additionally, for these soils stormwater runoff rates may be quite high.

2.2.2.4. Land Use and Cover

Many different land uses are present on campus which represents similar challenges faced by other urban and suburban watersheds and therefore serve as excellent demonstration sites for the land grant institution. Campus includes many residences, academic and administrative buildings and associated vehicular and pedestrian circulation systems. Less intensive land uses lie to the south such as athletic fields, dedicated green space, golf course and the agricultural fields. These uses release untreated stormwater that has perturbed stream reaches on campus.

2.2.2.5. Vegetation

Although campus lands have been impacted by many former agricultural uses, several different plant communities are present in the natural areas on campus.

Though these areas are mostly comprised of mixed hardwood upland forest there are remnants of a dynamic floodplain forest in the uncultivated area of "The Bottoms." Invasive exotic plant species have threatened many natural areas by altering plant community composition and limiting regeneration.

2.2.2.6. Invasive Species

Understory vegetation throughout the majority of Clemson's existing riparian corridors is dominated by invasive exotic species listed the in Appendices. These species were introduced for ornamental horticulture, wildlife habitat and forage, and erosion control. Invasive species out-compete native species and interfere with natural forest regeneration.

Figure 2: Aggressive exotic (Privet) displacing understory.

2.3. Analysis

2.3.1. Impervious Cover

Impervious cover ratio is the amount of surface area that does not infiltrate as a proportion of the total subject area, assuming the remaining area infiltrates. A forested area has higher infiltration rate whereas conventional development generally does not promote infiltration. Impervious cover percentages have a strong correlation to aquatic integrity; the more impervious cover, the poorer the aquatic community. The subwatersheds on campus range widely. For example, the catchment draining to the Strom Thurmond Center is significantly higher than the forested catchments found in the South Carolina Botanical Gardens. The impervious cover rates in some areas of the Botanical Gardens are only several percent, while the emergency services area and adjacent watershed is about 25%. Typical urban impervious cover rates for 1/4 and 1/8 acre subdivision are 38% and 65%, respectively (WIN TR-55 Small Watershed Hydrology Model).

Impervious cover ratings have been tied to water quality and species diversity. Tom Schuler at the Center for Watershed Protection and others have documented that as little as three to five percent impervious cover can cause stream reaches to become perturbed and unstable.

2.3.1.1. Emergency Services Area

An example of the contrast between two different areas on campus is illustrated below. The Emergency Management Services area has an impervious cover of approximately twenty five percent. The catchment area above the Strom Thurmond Institute has an impervious cover that is much greater and more closely resembles an urban setting.

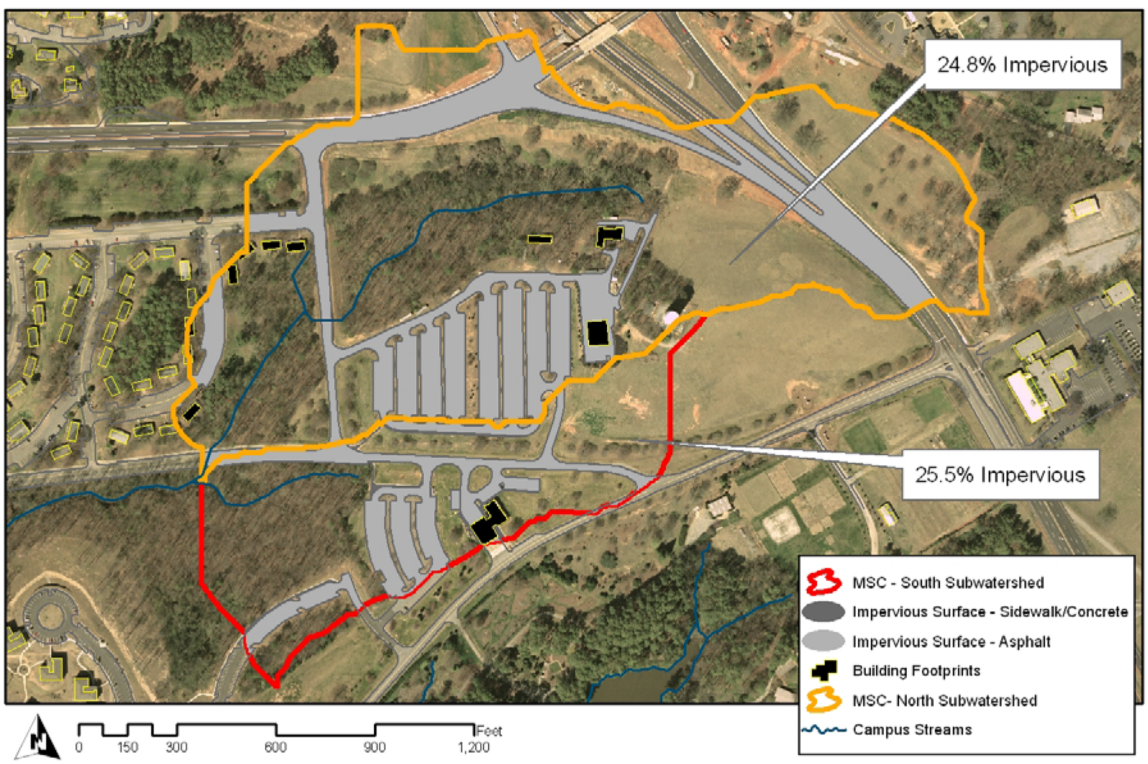

Figure 3: Emergency services catchment depicted in red and orange.

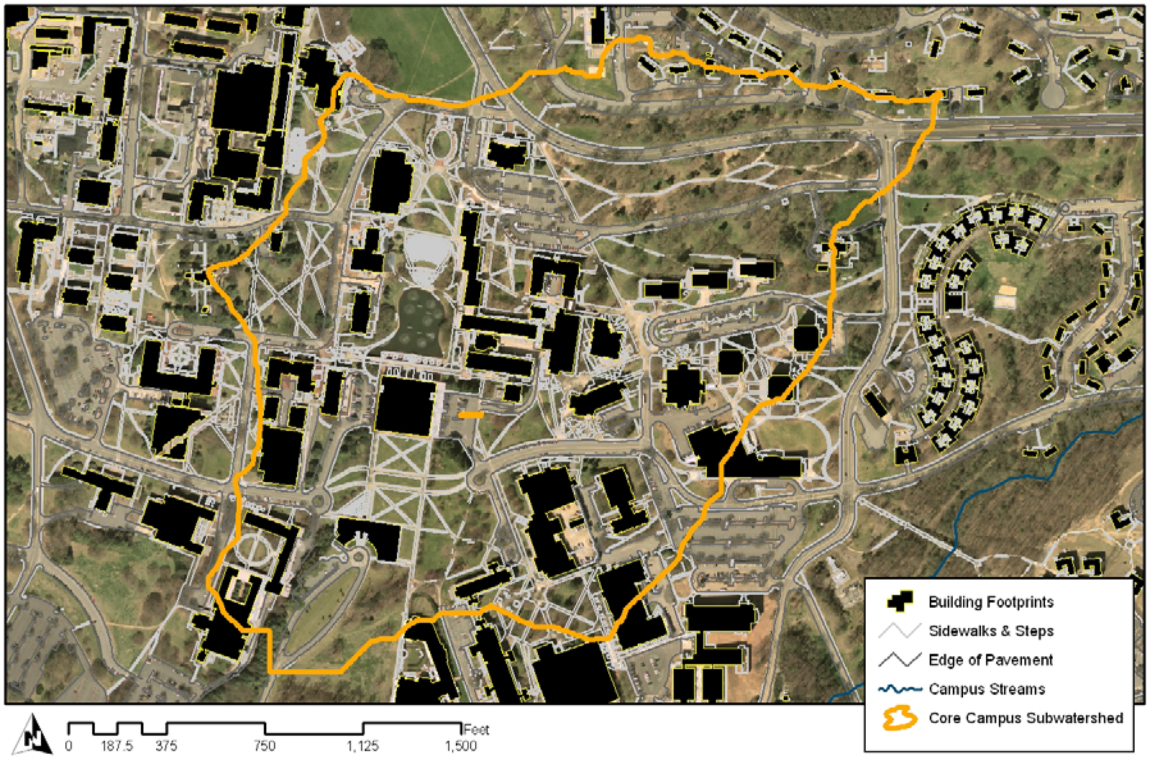

Figure 4: Strom Thurmond catchment depicted in orange.

Several long term benthic monitoring sites have been established at the respective catchment outlets; however the extant coal pile and removal activities in the summer of 2005 in the Emergency Services Catchment have confounded some of the results.

2.3.2. Stormwater

Impervious areas and hydrologic regime modification contribute runoff that has destabilized many of the stream channels throughout campus. Channels have been impacted because of the peak discharge of uncontrolled runoff. Stormwater will continue to threaten aquatic resources and impede efforts to reverse degradation unless it is addressed.

Figure 5: Eroded channel from uncontrolled stormwater

2.3.3. Intermittent and Perennial Channels

Stream channels convey runoff from precipitation and groundwater. Several types of channels exist. Channels that are only wet after a storm are considered intermittent, and channels that convey water all the time are considered perennial. Landscape modifications alter the flow patterns, can destabilize stream channels and reduce habitat function. More information about stream function can be found in the Stream Function section found in Appendix 1.

2.3.3.1. Permanent Cross Sections

Several permanent cross sections were installed on stream reaches in 2005. These sections are monitored for physical change. Using natural channel design classification, all but one of the stream reaches does not have access to their floodplain and are therefore incised. Incised streams cannot dissipate water and energy onto the floodplain. The resulting shear stress excessively erodes the channel and streambank. The following figures are cross sections and photographs that show instability.

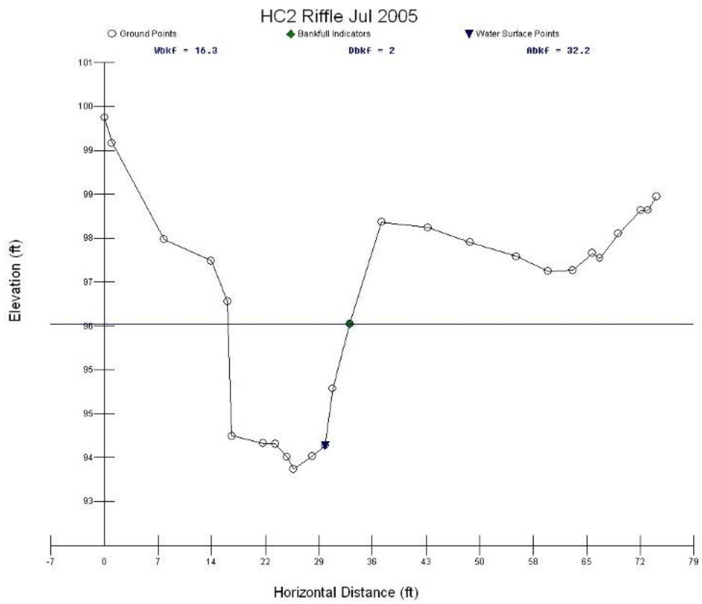

Figure 6: Stream cross section illustrating floodplain access at bankfull*.

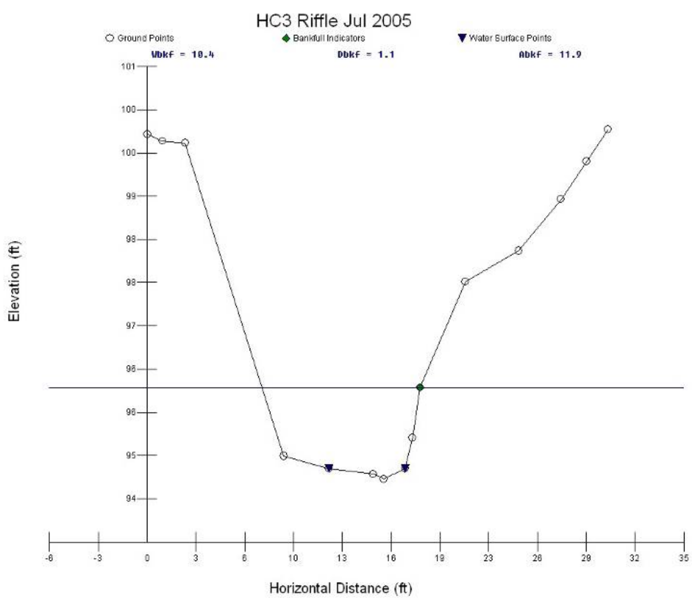

Figure 7: Stream cross section illustrating lack of floodplain access at bankfull*.

*Bankfull elevation is the incipient point of flooding in stable stream systems.

Figure 8: Incised channel without floodplain access

3. Campus Master Plan

3.1. Planning

The RCMP is intended to supplement the Campus Master Plan. The Campus Master Plan guides development, circulation, and infrastructure. It also directs preservation of forested and open space. Although not specifically mentioned, the riparian corridors are the armature of forested areas on campus and are integral to the open spaces that provide aesthetic enrichment to the campus experience. The mention of stormwater and its infrastructure are limited to discussions regarding relocation or extension.

3.2. Previous Pertinent Studies

Several studies have addressed water quantity and quality concerns on campus. Previous studies have included campus wide peak flow engineering studies, chemical and biological monitoring, and a watershed assessment that prioritized stream reaches for restoration and cited stormwater management as a critical concern.

3.2.1. Infrastructure modeled against Design Storm

An engineering study confirmed existing infrastructure can pass the specified storm event.

3.2.2. Storm Drain Outfall Inventory

The Clemson University Department of Environmental Health and Safety surveys the entire outfall system annually while the outfalls on campus that have dry weather flow are surveyed quarterly. Many outfalls direct discharge directly into the channel as shown below. Clemson University Facilities is provided a report of the findings of these surveys. This report provides a prescription of what needs to be improved or replaced and alerts Facilities of locations where severe erosion has occurred.

Figure 9: Stormwater outfall. Photo credit: Jeremy Pike.

3.2.3. Illicit Discharge and Detection

A multi-year effort to identify illicit discharges and connections is underway. If any illicit discharge or detections are found, corrective action would include redirecting the discharges to the appropriate system. Thus far, Clemson University Environmental Health and Safety has identified and terminated or changed the practices of several departments on campus that had been dumping chlorine, lab waste, and sometimes even sewage into the storm water system. Biological indicators show that conditions have improved as a result of these actions.

4. Opportunities

The mission of South Carolina's water quality protection agency (SCDHEC, Bureau of Water) "is to ensure that all water resources of South Carolina are of a quality suitable for use by all citizens and that all surface waters are of a quality suitable to support and maintain aquatic flora and fauna". Despite tremendous improvements in point source pollution we still have poor water quality throughout most of our state. In fact, South Carolina NPS water pollutants are responsible for the degradation of at least 43% of our streams and rivers (SCDHEC 1999). There is a need for continued efforts toward cleaning up our waterways.

4.1. Intervention

Restoring natural systems requires a plan to implement project goals. Actions such as design, planning, implementation and management are collectively referred to as an intervention, which includes the act of modifying the existing landscape and environment. Generally, ecological restoration goals seek to mimic an established stable system that is often referred to as a reference system. Success criteria differ in areas where the natural system is compromised because of impacts and changes to the watershed that prevent returning the area to a natural system. A goal for these areas includes striving for a restoration trajectory that may eventually approach the reference system. In some areas, only rehabilitation or stabilization may be feasible and success is measured by moving away from the degraded system (Palmer, 2005).

Monitoring is an important component for any intervention that seeks to stabilize, rehabilitate, restore, or preserve an area. Conducting periodic physical, biotic, and abiotic monitoring will help determine if the intervention is succeeding based on project goals. Monitoring data will inform adaptive management strategies used to reach the predefined project goals.

4.1.1. Conservation

Although limited, some monitoring data has suggested that several areas on campus are relatively healthy biological systems probably due in part to the fact that they are forested and have little impervious areas. These areas are mostly second growth forest that has succeeded from abandoned agriculture into hardwood forest. Although legacy impacts are evident across the landscape and present in the stream channels, these areas have good to high ratings for their benthic communities. Even a small change in land use will perturb these areas unless the existing hydrology is maintained. More research is needed in these areas as they may be able to serve as reference reaches in the future to guide further restoration efforts and to inform the restoration trajectory. Conservation implies active management. These areas include portions of the South Carolina Botanical Garden and a small forested area in the old Seneca River Floodplain known as “the bottoms.”

4.1.2. Restoration

Most areas on campus have been heavily modified during recent history. Likely originally composed of forests, the areas were then converted for agriculture and eventually developed with buildings, sidewalks, roads and other impervious areas. Pursuing restoration in these areas requires retrofitting or redesigning areas to mimic or approach predevelopment hydrology function through Low Impact Development techniques.

4.1.3. Rehabilitation

Rehabilitating the area is the next best solution if restoration is not achievable. Rehabilitation seeks to repair biological function.

4.1.4. Stabilization

Some areas of campus are heavily degraded. Until changes occur in the catchments above these areas, these areas should be stabilized to prevent further degradation or impacts to utilities.

4.2. University Commitment to Sustainability

Clemson University has established policies that will yield more sustainable development. In 2003, Clemson University President James F. Barker, a fellow of the American Institute of Architects, led the university's commitment to pursue nothing less than LEED silver certification for all major university capital improvement projects. The LEED certification system is a national building rating designed to accelerate the development and implementation of so-called "green" (environmentally appropriate) building practices. It is a program of the U.S. Green Building Council, a coalition of building industry leaders that works to promote buildings that maximize both economic and environmental performance. Water supply and management issues, especially landscape irrigation and storm water reuse, are dependent on project location. The placement choice of new construction often has the most direct impact to watershed issues, particularly to storm water runoff. Clemson University is committed to employing LEED principles during the site selection phase of all new construction. In the green-building process, LEED also requires that a plan be designed to control erosion and reduce negative impacts on water and air quality. These plans must be site specific and must prevent the following:

- Loss of soil during construction by storm water runoff and/or wind erosion (includes protecting the topsoil by stockpiling it for reuse).
- Sedimentation of storm sewer or receiving streams.
- Pollution of the air with dust and particulate matter.

It should be recognized that these policies have already made an impact on University properties. Earlier this year, Clemson University's Advanced Materials Research Laboratory became the first publicly funded facility in South Carolina to receive LEED certification from the U.S. Green Building Council. The renovation of Clemson's Fraternity Quad was completed in the summer of 2006 added another seven buildings that were constructed to LEED Silver certification standards. Beyond these major construction projects and renovations, Clemson University has committed to employing sustainable design practices for minor construction projects and when developing new or renovated landscapes and infrastructure.

To further demonstrate the University's dedication to promoting sustainability, Clemson University along with the University of South Carolina and the Medical University of South Carolina developed a partnership known as the South Carolina Sustainable Universities Initiative. In 1998, the presidents of the three schools signed a pledge to cooperate in leading the way toward a more sustainable future through teaching, research, community service and facilities management. Thirteen 4-year and technical schools throughout the state have since joined this partnership.

4.3. *Low Impact Development*

Implementation of a Riparian Corridor Master Plan to address preservation and restoration of the riparian corridors on campus includes the implementation of Low Impact Development. Integrated Management Practices (IMP's) like stormwater wetlands, bioretention and turf reinforced swales are proposed for future campus development. The stormwater wetlands treat stormwater runoff, which often carries pollutants. Regulating the peak flow and reducing pollutant loads will generally improve the water quality.

4.3.1. Modified Curve Number Reduction

Impervious surfaces at Clemson such as roads, parking lots, and rooftops reduce infiltration, filtration and groundwater recharge. This disruption of the hydrologic cycle can lower water tables, impact surface and sub-surface flows to existing water bodies, and increase the frequency and severity of flooding. In particular, higher flow velocities also increase the potential for detachment, transport and deposition of sediment, which is the leading cause of stream impairment on campus.

Storm water management efforts have historically followed the design storm concept. A typical design criteria requires that the post-development peak discharge for a 2- and 10-year frequency storm event be equal to or less than the same storm under pre-development conditions. Usually this involves incorporating best management practices like detention basins at the "end of the pipe."

In order to move away from this "end of the pipe" approach, a new paradigm is being utilized on progressive campuses throughout the United States (University of North Carolina, University of Michigan, University of Maryland, University of Florida and Purdue University). In order to address the hydrologic and hydraulic challenges of stormwater, the concept of Low Impact Development (LID) provides a series of procedures and practices to favorably modify the magnitude, frequency and duration of high stormwater flows. Projects utilizing low impact development design attempt to mimic the pre-development temporary storage (detention) and infiltration (retention) functions of the site. Such a functional landscape would emulate these conditions through runoff volume control and peak runoff rate control, flow frequency and duration control, and finally water quality control.

The intent and practice of low impact development could be achieved utilizing the following components of hydrologic analysis and design:

1. *Curve Number* – the curve number (CN) method for estimating runoff potential from storm rainfall is well established in hydrologic engineering

and subsequent analysis of environmental impacts. Curve numbers range from 30-98; with smaller numbers indicating less runoff volume and the highest figures corresponding to nearly total impervious cover.

$$CN = \frac{1000}{10+5P+10Q_a-10\sqrt{Q_a^2+1.25Q_aP}}$$

where: P = rainfall, in inches
Q_a = runoff volume, in inches

The major factors that determine CN are soils, land cover type, hydrologic condition, and antecedent moisture condition. The goal would be to lower the post-development CN by minimizing changes to post-development hydrology. Examples include lowering the overall amount of impervious area, minimizing site disturbance and distributing practices such as infiltration swales, vegetated filter strips, disconnected impervious areas, bioretention, and revegetation throughout the site.

2. *Time of Concentration*- post-development time of concentration (T_c) should be maintained close to that of pre-development T_c. This element is critical because LID is based on distributed best management practices. Lengthening the T_c can be achieved by such LID practices as maintaining pre-development flow path length, increasing surface roughness, detaining flows, flattening grades in impacted areas, disconnecting impervious areas and connecting pervious/vegetated areas. Project engineers will be forced to utilize an iterative process to analyze many different combinations of available practices.
3. *Detention* – detention is temporary storage designed to release excess runoff at a controlled rate. Aside from typical practices like ponds and basins, utilize LID practices like swales with check dams, diversion structures and constricting pipes.
4. *Retention* – provide retention storage for volume and peak control equal to or exceeding the predevelopment condition. As the retention storage volume of a site is increased, there is a corresponding decrease in peak runoff rate and volume. Retention would also encourage groundwater recharge utilizing such practices as infiltration swales, vegetated filter strips and bioretention.

Guidance for low impact development strategies and methods to mimic predevelopment hydrology for new construction and retrofits can be found in the following documents:
Low-Impact Development Design Strategies. Prince Georges County, MD (EPA 841-B-00-003) (January 2000).
Low-Impact Development Hydrologic Analysis. Prince Georges County, MD (EPA 841-B-00-002) (January 2000)

4.3.2. Integrated Management Practices

Integrated Management Practices are generally structural practices that capture and slowly release treated stormwater runoff. Using these devices in series will aid in the maximum pollutant reduction.

Generally, stormwater wetlands primarily treat water quality and secondarily control water quantity. Water quality is improved when pollutants are removed through settling or converted in an anaerobic setting. The stormwater wetland generally captures the first flush, which is the runoff during the beginning of the storm that has washed across the surfaces in the watershed and has likely picked up pollutants. The volume of the first flush is different depending on the local storm frequency, intensity, and duration. So, if the majority of small storms are captured and slowly released before the next storm event occurs, the stormwater wetland will reduce pollutants from being discharged offsite and encourage greater habitat for an increased biodiversity of organisms. The pollutant removal efficiency of wetlands is the best among BMPs as it allows particles to adsorb to plants or to settle to the ground. Many pollutants are bound to sediment, so if the sediment is captured, so are the pollutants. For stormwater wetlands to function properly, a large amount of surface area is required because the plants require a shallow, wet environment to flourish. Plants, and the bacteria hosted on plants roots, are beneficial to treating nutrients. Many of the plants are very attractive because they flower, have fall color, winter interest, or interesting fruit. Using indigenous plants creates habitat for other species and contributes to biodiversity. In some cases, stormwater wetlands reduce mosquito populations (Hunt, Apperson, 2005).

Figure 10: Townsend Memorial Garden (Stormwater Wetland at Brevard College).

Bioretention cells, or rain gardens, are small basins that receive and treat certain pollutants in stormwater runoff. The cells are dug several feet deep then backfilled with an underdrained gravel layer that is under a high infiltration media mix that supports plant species that tolerate mesic and xeric conditions. These attractive areas, which also help treat stormwater, can be used in a variety of site conditions. A design case study is enclosed in Appendices.

Figure 11: Rain Garden treating runoff at Asheville Buncombe Technical College.

A variation on rain gardens, or bioretention areas, is a rain pocket. It is constructed as a depression that is inline with the flow path and provides detention. Using several of these in combination can provide detention.

Figure 12: Rain Pocket at Operations Center at The North Carolina Arboretum

Turf reinforced matted swales are swales, or ditches, that are reinforced with a matting that can withstand higher velocities when vegetation is established underneath and grows through the matting. These TRM swales can be used in lieu of rip-rap channels which provide an aesthetically pleasing alternative.

Figure 13: Turf Reinforced Swale conveying runoff.

Permeable paving is a paving surface designed to allow runoff to pass through the top layer and then be detained in a gravel envelope below that is designed to carry certain structural loads. Permeable paving allows some pollutants to be sequestered and provide infiltration or detention during smaller storm events.

Figure 14: Permeable Paving for Bus Parking.

Green, or living, roofs can assist with rooftop runoff detention and reduce thermal impacts as well as provide other benefits. However, nutrients that runoff may need to be treated prior to infiltration or release into surface waters.

Figure 15: Green Roof in British Columbia.

Stream restoration using natural channel design techniques improves water quality and aquatic habitat. Many campus stream reaches are unstable and rapidly eroding and have poor habitat. Using indigenous materials and vegetation to create a stable dimension, pattern and profile will reduce erosion and improve aquatic habitat and water quality.

Figure 16: Stream restoration on Clemson University property.

Integrating the practices described in this section is the framework for creating a Low Impact Development landscape. Different IMP's have unique pollutant removal efficiencies and peak runoff controls. If used in series, these IMP's will demonstrate water quality improvement. Several retrofit opportunities are available on campus to demonstrate LID.

4.3.3. Riparian Corridor Vegetation

Buffers perform many environmentally, economically and socially significant functions. They maintain and improve water quality by protecting water resources from nonpoint pollutants such as sediment, nutrients and pesticides from both urban and agricultural activities. Buffers shade streams and regulate fluctuations in water temperatures.

Vegetated riparian buffers provide many environmental benefits for water quality, wildlife habitat, terrestrial and aquatic ecosystem health, and stream stability. They also provide a tranquil setting for recreation, observation, and educational opportunities. A riparian buffer is vegetated land adjacent to a stream or water body. The vegetation benefits water quality and habitat by helping to regulate temperature, add organic matter (leaves and twigs), assist in pollution reduction and provide wildlife habitat. The most stable and effective riparian buffers include a combination of native trees, shrubs, grasses and herbs that form a plant community adjacent to a stream or water body. As surface water flows over the land, it likely carries sediment, nutrients, pesticides and fecal coliform bacteria into streams. Pollutants can affect an aquatic ecosystem in a number of ways. Excess nutrients (nitrogen and phosphorus) can cause algal blooms, fecal coliform bacteria can be an indicator of waste-borne disease and pesticides can kill or sicken fish and aquatic invertebrates. Buffer vegetation slows and filters runoff water above ground causing sediment to settle out and be deposited and treated in the buffer. However, if runoff water doesn't spread over a buffer, it cuts channels and flows directly to the stream rendering the buffer ineffective for reducing sediment and sediment-attached pollutants.

Water also percolates through soil into the shallow ground water, which in many locations moves toward streams. Subsurface water often carries nitrate-nitrogen and sometimes pesticides. Nitrate that moves in the shallow ground water is diluted in the riparian area. Plants also use it, but more importantly, it is changed to nitrogen gas through denitrification.

Several factors such as hydrology, topography, geology, land use and management can influence buffer width. Generally, wider buffers are better for water quality and wildlife. Forested, native stream side forests, buffers, with widths of 100m (300ft) [sic 328 feet] and greater offer significant benefits for wildlife and biodiversity. Minimum buffer widths of thirty feet offer short term benefits. Buffers are most effective if they are continuous and forested (Wenger, 1999).

Buffers work best when they contain a diverse mixture of plants, since different plants have different rooting structures and accompanying function. A combination of fibrous and tap roots aid in soil structure and removing or converting nutrients to less harmful states of concentration.

If a wide forested buffer is not practical, as in many urban settings, a two-part buffer may be considered. It contains a primary buffer consisting of a forested strip next to the stream or water resource, and a secondary working buffer between the non-forest land use and the forested buffer. This buffer can consist of grasses, shrubs or additional forest, and would be available for haying, select logging or taking cuttings for horticultural production and other uses that do not disturb the soil. A wide variety of native trees, shrubs, and perennial species offer advantages for wildlife, water quality, and aesthetics.

4.4. Recommendations

The recommendations of the RCMP seek to improve the function of the streams and provide opportunities for research and recreation. The streams and associated riparian corridor, or stream side forests, cannot be successfully altered until stormwater from the watershed is controlled in a manner that mimics predevelopment hydrology. A holistic approach is required to reduce stormwater quantity and improve water quality on campus.

Extreme variability in stormwater runoff volume and peak discharge has severely limited physical and biological integrity of streams located within the campus of Clemson University. For decades engineers have designed stormwater conveyance systems that quickly and efficiently direct runoff from roads, parking lots and buildings and into the nearest surface water bodies. While these conventional practices have unquestionably minimized flooding on campus, their implementation also serves as the fundamental cause of numerous unintended consequences. Increases in runoff volume and peak discharge negatively impact natural channel stability by altering stream dimension, pattern and profile. When a stream channel is unstable, its ability to support diverse populations of fish and benthic macro-invertebrates is compromised. Because there is no dynamic equilibrium currently established within the boundaries of Clemson University's campus, aquatic resources can only generously be described as measurably degraded.

Ecological restoration of the streams is needed to reverse the degraded channel impacts, restore habitat and eventually return the streams to highly functioning biological areas consistent with RCMP goals. However, the watershed, or drainage area, needs to be addressed prior to restoring the stream systems because this drainage area supplies water, nutrients, and pollution to the stream system. Many opportunities exist on campus to improve and preserve riparian areas, implement stream restoration practices, treat stormwater runoff to improve water quality and reduce peak flows that are detrimental to stream function. Nestled together, these components form a Low Impact Development Strategy. Several different integrated management practices (IMP's) such as green roofs (living roofs), water harvesting and reuse, permeable parking, bioretention areas, turf reinforced swales, stormwater wetlands, stream restoration and associated riparian buffer installation could be implemented and demonstrated on campus, further fulfilling the education mission of Clemson University, South Carolina's land grant institution.

4.4.1. General

1. Establish process to engage university faculty and students in exploring opportunities for advancement of interdisciplinary curricula, research, and public service.
2. Convene a Campus Stormwater Summit. Invite key stormwater managers from other universities to discuss how the challenges of stormwater are addressed by their institutions. Try to uncover which standards, practices and procedures work best within the context of development in a university campus environment. The summit would highlight and reinforce Clemson's commitment to effectively addressing stormwater issues proactively.
3. Develop and implement a Stormwater Management Plan (SMP) encompassing all properties owned or operated by Clemson University. Among other elements, the SMP would institute design and construction standards related to stormwater for all new projects or major campus retrofits. Such standards would provide information on measures to mitigate stormwater impacts (quantity and quality) during construction and those resulting from development. Enforced at other academic institutions throughout the United States, these standards would allow full reconciliation with Clemson University's plan to obtain LEED certification for all future projects.
4. Institute an Office of Stormwater Management housed by an individual responsible for all aspects of stormwater management on Clemson University land holdings, including project review, permitting, construction, site inspection, and maintenance of all practices. This office would be considered equally along with other existing utility systems – water, heating, cooling, electrical and telecommunications.
5. Create a Stormwater Review Committee. The committee would be charged with reviewing Clemson University development projects as they relate to stormwater. They might be brought in during two parts of the process; that which addresses initial project design and subsequently during design review. The committee could stand alone or be a sub-committee under the existing Environmental Committee. The committee would be composed of engineers, hydrologists, biologists and landscape architects and utilize point system similar to UNC (and LEED) to score projects.

4.4.2. Goals and Objectives with Strategies

There are over fifty RCMP Stakeholders who were involved in the identification of goals and objectives. Many university departments, organizations and governmental agencies were represented in this group that includes the student government, faculty & staff senates, the City of Clemson, the South Carolina Department of Transportation, South Carolina Department of Health and Environment Control, and the US Army Corps of Engineers. The University's departments were represented and provided critical insight into the development and implementation strategy.

Goals and corresponding objectives are enumerated below.

Goal 1: Maintain the natural quality (processes) of Clemson University and its riparian corridors by restoring, preserving, and protecting its natural systems.

- Objective: Inventory and assess existing conditions throughout the watershed and specifically within the riparian corridors.
    - Strategy: Study to locate sources of creek impairment due to point source and non-point source pollution.
    - Strategy: Inventory and monitor the physical, chemical and biological parameters for surface and groundwater.
        - Action Item: Inventory, geocode and document pollution sources.
        - Action Item: Establish monitoring schedule to evaluate instream water quality for chemical composition and assess macroinvertebrate populations and correlate to stream health through pollution tolerance studies.

- Objective: Establish riparian corridors as dedicated green spaces that are a critical part of the campus (paramount) (at least) equal to the roadways, utilities, or buildings on campus. Riparian corridors must be preserved to protect the plant and animal communities native to our region, along with water quality, and bank and stream stability.
    - Strategy: Establish boundaries (buffers/zones) around riparian corridors to minimize non-point pollution, prevent erosion and flooding, preserve wildlife habitats, and protect recreational opportunities.
        - Action Item: Literature review and conduct analysis of existing conditions to determine effective widths of buffer zones.
        - Action Item: Provide mapping of geographically accurate corners/control points to provide references of boundary locations.
    - Strategy: Establish designated wildlife corridors.
    - Strategy: Install or preserve features that promote a thriving wildlife habitat for yet to be chosen indicator species.
        - Action Item: Identify specific wildlife corridors to be maintained as dedicated open spaces.
        - Action Item: Construct perches in standing water

bodies to promote habitat.
    - Action Item: Leave standing snags in stream corridors where it is safe to promote habitat.
    - Action Item: Leave fallen woody debris on ground (carbon sequestration)
    - Action Item: Promote large woody debris in channel

- Objective: Restore degraded riparian corridors.
  - Strategy: Eliminate invasive, exotic plant species.
    - Action Item: Coordinate control of invasive plant species (particularly Chinese Privet) in targeted areas with minimum impact on streambank stability.
    - Action Item: Investigate methodologies to minimize or preclude invasive species during native plant community revegetation.
  - Strategy: Restore native plant habitat and animal species.
    - Action Item: Identify vegetative restoration opportunities that support a diverse plant species which in turn promotes biodiversity.
    - Action Item: Identify species to be targeted when recreating wildlife habitats.
  - Strategy: Stabilize identified distressed stream banks.
    - Action Item: Analyze stream banks using bank hazard erosion index and bank bins.
    - Action Item: Create floodplains and utilize natural channel design techniques to restore stable stream pattern, profile and dimension.
  - Strategy: Employ stream restoration techniques…

- Objective: Apply design techniques and integrated management practices to mimic predevelopment hydrology and restore the campus hydrology to a stable state.
  - Strategy: Minimize runoff from all new buildings, parking lots, etc.
    - Action Item: Apply LEED standards to all new buildings
    - Action Item: Incorporate Low Impact Design/Development strategies into design guidelines to mimic predevelopment hydrology.
  - Strategy: Increase quantity and quality of university green spaces.
    - Action Item: Create 1% of new net green space over the next 10 years through replacement of surface parking lots, siting of new buildings, etc…
    - Action Item: Plant trees along roadways without compromising sight distances or other safety issues.

Goal 2: Showcase the streams and riparian corridors on university property to increase their multiple cultural and natural values as educational and recreational resources and to maximize their abilities to meet the research, teaching, and service needs of the university.

- Objective: Heighten awareness for watershed restoration and protection.
    - Strategy: Insure involvement of stakeholders throughout the planning process through regular communication.
    - Strategy: Educate the public as to what watersheds and riparian corridors are, what issues surround them, what values they hold, and why they need to be protected.
        - Action Item: Communicate to the public through publications, websites, lectures, etc..
- Objective: Provide opportunities for community education and recreation while maintaining safe access to riparian corridors without endangering the health or functions of those corridors.
    - Strategy: On site interpretation of watersheds, riparian areas, stormwater, management practices, conservation, and restoration.
    - Strategy: Identify opportunities to improve public access and circulation along riparian corridors.
        - Establish trails and overlooks along riparian corridors.
    - Strategy: Improve opportunities for passive recreation that are both safe and have minimal impacts on these sensitive areas.
    - Strategy: Identify existing resources or opportunities to explore and experiment with the riparian corridors and watershed in order to further educate the Clemson community.
        - Action Item: Utilize designated portion of the Calhoun Field Laboratory for demonstration of working landscape, stream restoration, or creation of riparian nursery.
        - Action Item: Use the Newman Road project as an opportunity to explore design alternatives that address the needs of the riparian corridor.
        - Action Item: Create nature trail between Botanical Gardens and Madren Center.
        - Action Item: Feature the Seneca Riverbed…
        - Action Item: “Lake to Lake” corridors…

- Objective: Investigate and protect any places or items of historic cultural value on campus, specifically within the riparian corridors.
    - Strategy: Literature and archeological survey of riparian corridors on university property to identify sites or relics of archaeological significance.
    - Strategy: Interpret identified cultural resource sites to

provide educational opportunities for the community.
    - Strategy: Establish policies or guidelines to protect sites of historic value.

- Objective: Attain regional and national recognition for efforts to protect and restore riparian corridors.
    - Strategy: Identify opportunities for recognition through ASLA, SCUP, APA, etc.
    - Strategy: Seek Audubon Certification for The Walker Course.
        - Action Item: Install stormwater wetlands…(Area near #2 tee is a preferred location)
        - Action Item: Redirect sheet flow to hole #4 retention area instead of towards creek.
        - Action Item: Limit sediment infiltration into pond on hole #9.
        - Action Item: Install dams at #6 tee to create wetland areas for overflow and infiltration.

Goal 3: Eliminate the destructive (impacts) qualities affecting riparian corridors created through the design, development, and construction of university facilities. Use new development as an opportunity to improve both water quality and water quantity.

- Objective: Reduce off site erosion and pollution from construction and other land disturbance activities.
    - Strategy: Reduce negative impacts of sedimentation
        - Action Item: Promote/require higher standards for screening of sediments around construction activities.
        - Action Item: Promote the newly adopted policy which is to protect trees (and their driplines) on construction sites.
        - Action Item: Insure continuation of street-sweeping to collect pollutants and minimize flood hazard
- Objective: Implement water quantity controls
- Objective: Utilize low impact development (LID) techniques on future projects.
    - Strategy: Mimic predevelopment hydrology, i.e. climax hardwood forests.
- Objective: Implement Integrated Management Practices
    - Strategy: Install practices to capture 1.2” of rain, or 90% of the rain events volume, to treat first flush.
        - Action Item: Implement as standard for design projects.
    - Strategy: Bypass larger storms and treat those to the minimum standards (10 year/25year).
    - Strategy: Voluntarily implement NEPA Phase 2 regulations

(above goal plus 85% annual TSS reduction?)

- Action Item: Monitor pollutants and hydrology after installation of BMPs.

- Objective: Coordinate efforts with City of Clemson to mitigate their impacts on campus.
- Objective: Reinforce building standards and practices to minimize the impacts of construction on the watershed and riparian corridors.
  - Strategy: Use the current revision of the Construction Services Green Book as an opportunity to strengthen and improve existing specifications.

Goal 4: Reduce the negative impacts on the watershed and riparian corridors that are a product of daily operations and special activities occurring on campus and seek opportunities to renovate the built environment and revise standard practices to lessen those impacts.

- Objective: Reduce stormwater runoff from parking lots on university property that rapidly delivers pollutants, sediment, and heavy flow into the riparian corridors.
  - Strategy: Re-evaluate parking strategies, facilities, and policies on campus.
    - Action Item: Remove impervious surface parking lots from the core campus and convert these areas into green space.
    - Action Item: Install car-pool parking at desirable locations.
    - Action Item: Streamline transit system to reduce parking requirements by up to 15%.
    - Action Item: Develop park-and-ride lots.
    - Action Item: Explore the use of pervious materials for surface parking lots.
    - Action Item: Apply sustainable building policies to any impervious area including new parking lot or parking structure.
    - Action Item: Prohibit game-day parking under trees located on unpaved lots to limit compaction of soils and damage to root systems.
    - Action Item: Explore the concept of “Green” parking structures when planning new facilities.
    - Action Item: Renovate Botanical Garden parking lot.
    - Action Item: Renovate Discovery Center parking lot.
    - Action Item: Evaluate game-day and special event parking policies.

- Objective: Reduce the amount of pollutants reaching campus watercourses as a result of bad practices or poor design of the built environment.
  - Strategy: Reduce opportunities for pollutants to enter stormwater system by revising policies, establishing control systems, and improving facilities for those departments regularly using harmful chemicals.
    - Action Item: Insure proper wash-down facilities are available and used properly for any service using fertilizers, pesticides, herbicides, fungicides, etc.
    - Action Item: Incorporate water reuse for above goal
    - Action Item: Institute integrated pest management strategies that reduce the usage of chemicals that are harmful to riparian habitats.
    - Action Item: Minimize herbicide usage near storm basins to reduce erosion at these locations.
  - Strategy: Illicit Discharge and Detection. Renovate substandard structures and utilities that may be responsible for the point source pollutants into the stormwater system.
    - Action Item: Illicit Detection performed by reviewing EHS dye tests to identify campus building/facilities whose pollutants are immediately directed into the stormwater system and retrofit identified systems
    - Action Item: Investigate suspicious materials in the McMillan Road area.
    - Action Item: Renovate identified/older buildings dumping pollutants directly into system.
    - Action Item: Apply LEED standards to all building renovations.
    - Action Item: Investigate leachate from coal pile and propose restoration strategy

Goal 5: Centralize authority for stormwater issues and establish an operational mechanism for funding and oversight.

- Objective: Weigh the environmental and economic impacts imposed upon the university that are created by continued substandard funding of stormwater management versus the cost of establishing stormwater as a funded utility.
- Objective: Identify funding opportunities to finance stormwater management.
  - Strategy: Consider adoption of fee structure to be tied to activities directly associated with stormwater issues such as parking.
  - Strategy: Enforce construction specifications and charge for liquidated damages or by levying fines for contractors not meeting those standards.

- Objective: Examine the (long-term and short-term) economic and ecological costs of best management practices as compared to the costs of present standard practices used in addressing university waterways.
- Objective: Explore funding options beyond those offered by Clemson University in order to finance demonstration projects, research efforts, and educational endeavors within the university watershed and riparian corridors.

4.4.3. Eminent Campus Development

Several areas on campus are in planning stages for retrofit or redevelopment. Eminent projects include the Academic Success Center, IT building, and Life Sciences buildings. The Municipal Services Complex and High Ground Precinct are also slated for redevelopment.

4.4.3.1. Municipal Services Complex

An alternative analysis for the Municipal Services Complex has been prepared and is included in the appendix. The alternatives compare conventional and low impact development approaches.

4.4.3.2. Hunnicutt Creek Headwaters

On Clemson's campus, the subwatershed that includes the C1 parking lot and Recycling Center is the headwaters of Hunnicutt Creek, and thus a top priority for restoration. This area contains a mixture of forested areas, parking lots, roads, and turf. The impervious surfaces negatively impact water quality by increasing storm flow and decreasing base flow water levels, and transporting contaminants and sediments with increased runoff.

A dense, healthy riparian buffer is needed to help manage the increased stresses on stream stability and health. Currently, the wooded area surrounding the headwaters consists of a mixture of native trees and shrubs, but with a dominating population of exotic invasive species (e.g. kudzu, privet, rose, etc.).

To restore the functions of this riparian buffer, invasive species should be controlled and/or eliminated (see following section). Also, in conjunction with a bank reconstruction and restoration project to decrease channel incision and restore floodplain connection, a variety of native trees, shrubs, grasses, and herbaceous perennials based on site characteristics (soil, slope, aspect, hydrology, sun/shade) should be planted within the wooded area to control erosion, manage stormwater runoff, provide nutrient and/or contaminant uptake, and provide food, shelter, and habitat for wildlife.

These functions will ultimately serve to enhance water quality, bank stability, and biotic integrity. As a primary priority project, the riparian restoration may easily be designed to provide aesthetic appeal throughout the year with various plant species and elements of design. Also, the site's high public visibility makes it a prime candidate for a demonstration project and provides multiple interdisciplinary research opportunities. Interpretive signage and recreational pedestrian pathways integrated into the site will allow students, faculty, and the public to observe, learn, and appreciate Clemson's goal to improve its riparian corridors.

4.4.3.3. Lightsey Bridge

One of the most visible stream restoration opportunities includes the reach under the pedestrian bridge that spans a valley where an extant meandering stream has been channelized to relieve erosion from the valley slope and bridge pier. This area lends itself well to stream restoration and the installation of a stormwater wetland. The stream restoration would include natural materials and attractive native vegetation that would improve aquatic and terrestrial habitat. The use of instream structures will redirect water into self maintaining pools and riffles that reduces shear stress on the banks, decreasing erosion. The following conceptual plan illustrates instream structures, pools, and constructed riffles.

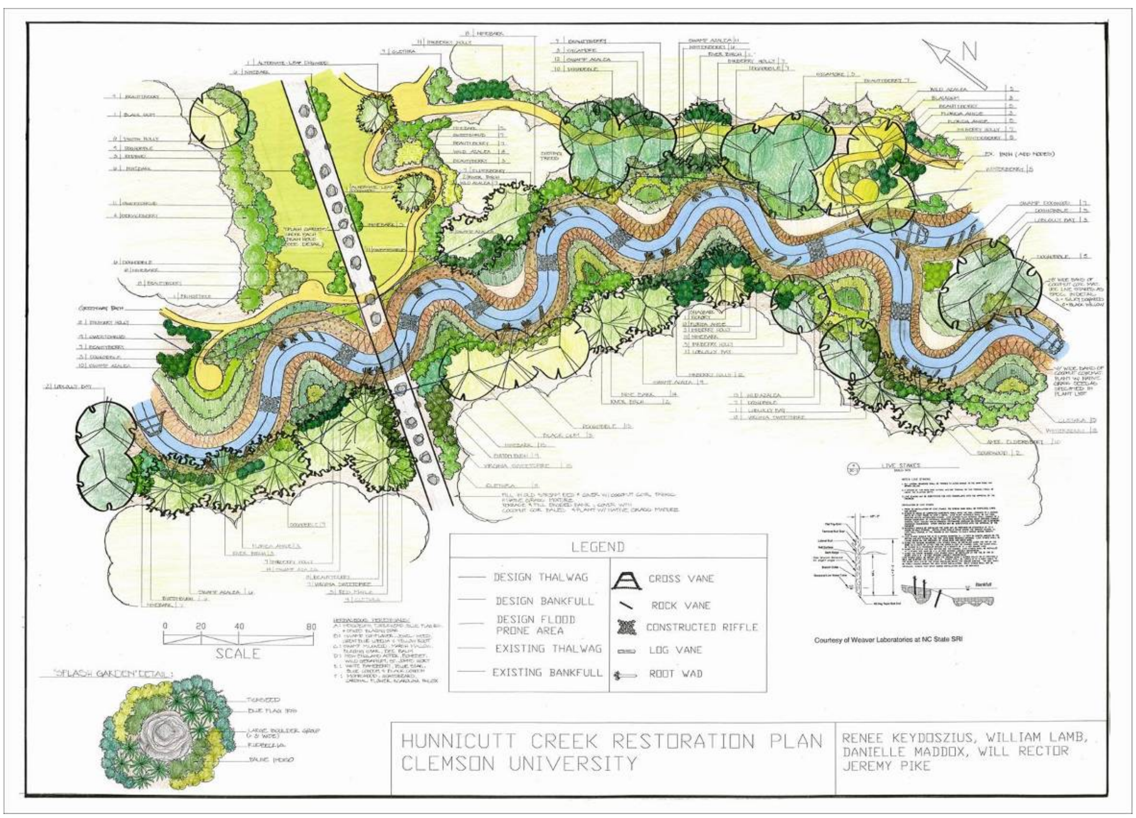

Figure 17: Stream restoration opportunity under pedestrian bridge (Keydoszius et al).

The stormwater wetland could treat the first flush, or the first portion of the runoff that most likely has the majority of the pollutants. Pollutants like nutrients, heavy metals, and sediment are treated or drop out of the water column when they are directed to a shallow pool that supports attractive emergent aquatic wetland species. The bridge affords opportunities to view the BMP's from above to observe implementation. Interpretive signage, tours and classes could benefit from an on campus educational opportunity to improve water quality.

Several other places on campus just upstream of this area would support a bioretention basin or rain garden. The rain garden is constructed like a basin that is underlain with a perforated pipe, gravel and a sandy loam soil mix that has a high infiltration rate. Stormwater collects briefly on the surface and infiltrates through the media. Some pollutants are sequestered in the media during infiltration.

4.4.3.4. The Walker Course

Many stream stabilization and restoration opportunities along the golf course. Several stream reaches are unstable and contributing significant sediment.

4.5. University Curricula

Utilize existing curricula on campus and involve students, staff and faculty in preservation and restoration activities. These projects could be developed and tracked through The Creative Inquiry program.

4.6. Extension and Engagement

The size and scale of this watershed will provide an excellent opportunity to demonstrate measurable results of the low impact development practices to the university community.

Workshops could be planned to address different target audiences such as environmental design professionals, natural resource managers, consultants, planners, elected and appointed officials and agency representatives, extension educators, local watershed action groups, and the media.

Additional information sessions would also be held for campus faculty whose curriculum could be enhanced by involvement in project results. Just some of the Departments on campus interested in the results include Civil Engineering, Forestry and Natural Resources, Agricultural and Biological Engineering, Environmental Engineering, School of Art, Architecture and Humanities, and the Horticulture Department.

5. Appendix 1: Stream Function (courtesy of North Carolina State University; Rivercourse 1 Fact Sheet)

Primer on Stream and Floodplain Function, reproduced with permission from North Carolina State University (from River Course Fact Sheet 1. AG-590-1).

Streams and rivers are integral parts of the landscape that carry water and sediment from high elevations to downstream lakes, estuaries, and oceans. The land area draining to a stream or river is defined as its watershed. When rain falls in a watershed, it runs off the land surface, infiltrates into the soil, or evaporates. As surface runoff moves downhill, it concentrates in low areas and forms small stream channels that combine and form larger streams or river that eventually drain to the oceans. The size and flow of a stream are directly related to its watershed area.

Other factors which affect channel size and stream flow are land use, soil types, topography, and climate. The morphology, or size and shape, of the channel reflect all of these factors. While streams and rivers vary greatly in size, shape, slope, and bed materials, all streams share common characteristics, like pools, riffles, steps, point bars, meanders, floodplains, and terraces. Bed material in the stream bed consists of mixtures of bedrock, boulders, cobble, gravel, sand, or silt/clay. All of these characteristics are related to the interactions among climate, geology, topography, vegetation and land use of the watershed.

In addition to transporting water and sediment, natural streams also provide the habitat for many aquatic organisms including fish, amphibians, insects, mollusks, and plants. Trees and shrubs along the banks provide a food source and regulate water temperatures. Channel features like pools, riffles, steps, and undercut banks provide diversity of habitat, oxygenation, and cover.

Natural Channel Stability
A naturally stable stream channel maintains its dimension, pattern, and profile over time so that the stream does not degrade or aggrade. Stable streams migrate across the landscape slowly over long periods of time while maintaining their form and function. Naturally stable streams must be able to transport the water and sediment load supplied by the watershed. Instability occurs when scouring causes the channel to incise (degrade) or excessive deposition causes the channel bed to rise (aggrade). A change in sediment or stream slope (channelization) causes rapid physical adjustments in the stream channel.

Channel Dimension
The dimension of a stream is its cross-sectional area. Stream width is a function of discharge (occurrence and magnitude), sediment transport (size and type), and the stream bed and bank materials. North Carolina has a humid subtropical climate with an abundance of vegetation and rainfall throughout the year.

Vegetation along the streambanks provides resistance to erosion so our streams are often narrower than streams in more arid regions. The mean depth of a stream varies greatly from reach to reach depending on channel slope and riffle/pool or step/pool spacing.

Stream Pattern

Stream pattern describes the “plan view” of a channel as seen from above. Streams are rarely straight on floodplains, they tend to form a sinuous alignment. The sinuosity of a stream is defined as the channel length following the deepest point in the channel (the thalweg) divided by the valley length. A meander increases resistance and reduces channel gradient relative to a straight reach. The meander geometry and spacing of riffles and pools adjust so that the stream performs minimal work. Stream pattern is qualitatively described as straight, meandering, or braided. Braided channels are less sinuous than meandering streams and possess three or more channels. Quantitatively, stream pattern can be defined through the following measurements shown in Figure 4: meander wave-length, radius of curvature, amplitude, and belt width.

Stream Profile

The profile of a stream refers to its longitudinal slope. At the watershed scale, channel slope generally decreases in the downstream direction. The size of the bed material also decreases in the downstream direction. Channel slope is inversely related to sinuosity. This means that steep streams have low sinuosities and flat streams have high sinuosities. The profile of the streambed can be irregular because of variations in bed material size and shape, riffle/pool spacing, and other variables. The water surface profile mimics the bed profile at low flows.

Channel Features

Natural streams have sequences of riffles and pools or steps and pools that maintain channel slope and stability. The riffle is a bed feature with gravel or larger size particles. The water depth is relatively shallow and the slope is steeper than the average slope of the channel. At low flows, water moves faster over riffles, which provides oxygen to the stream. Riffles are found entering and exiting meanders and control the streambed elevation. Pools are located on the outside bends of meanders between riffles. The pool has a flat slope and is much deeper than the average depth. At low flows, pools are depositional features and riffles are scour features. At high flows, however, the pool scours and bed material deposits on the riffle. This occurs because a force, called shear stress, applied to the streambed increases with depth and slope. Slope and depth increase rapidly over the pools during large storms, increasing shear stress and causing scour. The inside of the meander bend is a depositional feature called a point bar, which also helps maintain channel form. Step/pool sequences are found in high gradient streams. Steps are vertical drops often formed by large boulders, bedrock knickpoints, downed trees, etc. Deep pools are found at the bottom of each step. The step provides grade control and the pool dissipates energy. The spacing of step pools gets closer as the channel slope increases.

Conclusions

A stream and its floodplain comprise a dynamic environment where the flood-plain, channel, and bedforms evolve through natural processes that erode, transport, sort, and deposit alluvial materials. The result is a dynamic equilibrium, where the stream maintains its dimension pattern and profile over time, neither degrading nor aggrading. Land use changes in the watershed and channelization can upset this balance. A new equilibrium may eventually result, but not before large adjustments in channel form, such as extreme bank erosion or incision. By understanding and applying natural stream processes to stream restoration projects, a self-sustaining stream can be designed and implemented that maximizes stream and biological potential.

Appendix 2: Rain Garden Design Example (NCCES)

The information below was compiled by Jon Calabria and Jason Zink for a bioretention basin at an elementary school and a similar process would be used to design bioretention on the Clemson University Campus. **U**sed with permission.

Site Suitability

Overall, the site appears to be conducive for rain garden placement. Of concern is the potentially high slope of the terrain at the site, as well as the potential safety concern of a rain garden adjacent to an elementary school. These issues, and others, are discussed below.

Terrain: A review of the existing site plan shows a relatively large area at the outfall of two pipes presumably draining the school roofs. Specifically, a grassy area at least 100 feet square exists. Existing slope in this area is approximately 2-3 feet of fall for every 30 horizontal feet. The area, location, and existing vegetation appear to be conducive to rain garden placement. The slope appears to be relatively steep, and will be evaluated as a part of the design process.

Existing Vegetation: Several existing trees and the vegetated wood line should be preserved and respected during construction. Tree barrier fencing installed at the drip line should be considered.

Education Opportunities: Once the project is build and the site stabilized, the construction access could be easily converted into an interpretive are with signage detailing the project design, installation and benefits. Including students and faculty in the implementation will encourage ownership and a great case study.

Water Table: The seasonally high water table is greater than five feet below ground surface. It is recommended that the water table not be within two feet of the bottom of the constructed rain garden. This allows for at least a three foot rain garden depth, which is certainly within acceptable constraints.

Surface Hydrology: Site surface hydrology appears to be ideal. The approximately 18,000 square feet of school roofs are drained underground by two pipes, with outfalls at the top of the potential rain garden. The culverts could be shortened if needed.

Soil Type: Site soil types are from the Hiwassee soil series. Soil information is given in the problem statement. In general, the top six inches of soil appears to have hydraulic conductivity suitable for a rain garden. Beneath six inches, soil is clay, clay loam, or loam with a hydraulic conductivity below two inches per hour. As a result, the rain garden will likely require excavation and placement of imported soil. While this will affect cost, it is typical of Piedmont North Carolina sites.

Maintenance/Access: Maintenance will be a crucial part of the overall effectiveness of the rain garden. As part of a school campus, site maintenance should be available. Additionally, as part of a school campus, access for educational purposes is excellent. Access for construction equipment also appears to be acceptable.

Landscape Ordinances: Unknown for this property. It is assumed that no such ordinances exist, however the project will be contained to the grassed area.

Safety / Liability: Safety will be of concern during the construction and operation of the rain garden. The school should be aware of their potential for increased liability. Potential site hazards (e.g., outlet structure, ponding water) will be minimized during the design process. It should be noted that rain gardens are generally the safest of all constructed stormwater BMPs, due to the infrequent and short-lived ponding of water. The construction access could be off of the exit lane of the school.

Design Summary

The design of the bioretention area at the site consists of the following general steps, which are detailed in the subsequent section.

1. Determine watershed size and characteristic
2. Determine volume of runoff to catch
3. Determine size of bioretention area
4. Set bio-retention area depth and soil type
5. Size underdrain and gravel envelope
6. Assign an overflow device
7. Choose vegetation and a planting plan
8. Estimate final costs

Design Procedure and Results

Determine watershed size and characteristic: The watershed is known to be approximately 18,000 square feet and nearly 100% impervious (i.e., roof). Approximately one-quarter of the roof is at a pitch, while the remainder is flat. Although a flat roof can provide storage of runoff, it is it conservative to assume that the roof provides no storage (beyond that inherent in the curve number for impervious surface). Thus, a curve number of 98 is appropriate for this watershed. Soil characteristics are known and were described above.

Determine volume of runoff to catch: Given the goal of improving water quality, the first flush rainfall depth, or one inch, is chosen as the design storm. Using a curve number of 98 and a precipitation depth (P) of 1.0 inches, the runoff can be calculated as $(P - 0.2\ S)^2 \div (P + 0.8\ S)$, where $S=(1000\div CN) - 10$. The resulting runoff depth is 0.80 inches. (***Note:*** Even though the entire watershed is impervious, the calculated runoff depth is less than the rainfall depth due to evaporation and pool storage.) The total volume of runoff is equal to (0.80 inches) * (18,000 square feet), or 14,400 square foot inches. Thus, the total volume of runoff to treat is equivalent to 1,200 cubic feet.

Determine size of bioretention area: The storage volume of the bioretention area will be 1,200 cubic feet. An initial ponding depth of 9 inches is typical of those assigned to bioretention areas, and will be used here. Thus, the required surface area is (1,200 cubic feet) / (9 inches), or 1,600 square feet. A review of the site plan indicates that a rain garden this size can be accommodated.

Set bio-retention area depth and soil type: The onsite soil from 0-6 inches is a high-permeability loam, which would likely be acceptable for use in a rain garden. Below six inches, soil is clay, loam, and clay loam of moderate permeability. These soils should not be used in the rain garden. Thus, soil will be excavated from the site to the design depth and subsequently backfilled (after the placement of underdrain and gravel envelope) with the recommended mix of 85-90% sand, 8-12% silt and clay, and 3-7% organic matter. This soil mix should not be imported from an agricultural site, and should be tested for nutrient concentrations prior to use. Specifically, the P-index for the imported soil should be between 10 and 25. Imported soil should have a permeability of 1-2 inches per hour. While the native soil from 0-6 inches could theoretically be used in the rain garden, it is recommended that it is not, due to the importance of having homogeneous soil of known composition throughout the depth.

The design depth is based on the project goals and on the type of vegetation required. With the exception of nitrogen removal, water quality benefits generally occur in the top 18 inches of the rain garden. However, aesthetics are important to the elementary school, so plantings of trees and shrubs will be recommended. Trees and shrubs require at least 30-36 inches of rain garden depth. Thus, media depth of the rain garden is set to 36 inches. This depth is greater than two feet above the maximum water table depth.

The water drawdown rate can be calculated using Darcy's equation, $Q = (2.3 * 10^{-5}) * K * A * \Delta H/\Delta L$, where K is the hydraulic conductivity of the soil, A is the surface area, ΔH represents the driving head of the water, and ΔL represents the fill media depth. K is assumed to be 1 inch per hour, which represents the minimum allowed hydraulic conductivity of the soil; A is 1,600 square feet, and $\Delta H/\Delta L$ is set to equal 1 for simplicity. Assuming an initial 9 inch ponded depth of water, the time required to draw water down to two feet below the surface is found in the following manner:

- Find drawdown rate using Darcy's equation: $Q = (2.3*10^{-5})*1*1600*1 = 0.0368$ cfs
- Determine ponded volume to drawdown: V = 1,600 sq ft * 0.75 ft = 1,200 cubic feet
- Find time required to drawdown ponded volume: T = 1,200 cubic feet / 0.0368 cfs = 33,000 sec = 9 hours
- Find volume of water in top two feet of soil (assume soil porosity, n, = 0.45): V = 0.45* 2 feet * 1,600 square feet = 1,440 cubic feet
- Find time required to drawdown saturated volume: T = 1,440 cubic feet / 0.0368 cfs = 39,000 sec = 11 hours
- Find total time for drawdown of ponded water to 2 feet below surface: T = 9 hrs + 11 hrs = 20 hrs (***Note:*** This assumes that the surface drawdown and subsurface drawdown occur in discrete time steps. In reality, both will take place simultaneously, resulting in a drawdown time less than 20 hours.)

Size underdrain and gravel envelope: A rearranged version of Manning's equation, $N*D = 16 *(Q*n/s^{0.5})^{3/8}$, can be used to determine the required size of the underdrain piping. A safety factor of 10 is applies to the known flow rate. Thus, Q=0.368 cfs for use in underdrain sizing. Let Manning's n=0.015, a representative value for corrugated plastic pipes. Assume an internal slope of 0.5% (***Note:*** The site may allow for a larger slope. 0.5% would be the minimum acceptable slope.) Therefore, $N*D = 16*(0.368*0.015/0.005^{0.5})^{3/8}$, or N*D = 6.2. Therefore, one 6 inch pipe would be marginally acceptable. However, given the potential for pipe clogging, two 6 inch corrugated plastic pipes should be installed. A cleanout should be installed for each pipe. Additionally, an 8 inch gravel envelope (2 inches above the pipes) should be used.

Assign an overflow device: The rain garden is designed to accommodate the first flush rainfall with, generally, a maximum ponding depth of 9 inches. While bioretention areas are generally not designed to mitigate the peak flow of larger rainfall events, the runoff will need to be routed through the bioretention area. In this case, a square overflow box, modeled as a weir, is recommended to carry flows up to the 10-year, 24-hour design storm peak flow. Due to safety and logistical concerns, it is desired that the water not exceed an elevation of 2 inches above the crest of the overflow device. Given this, the overflow device is sized in the following manner:

- Find peak flow using Rational Equation, Q=CIA: C is set at 1.0, signifying an impervious watershed; I is set to the 10-year, 24-hour rainfall intensity for Asheville, or 5.70 inches per hour (***Note:*** The site is located between Asheville and Charlotte. The Asheville rainfall intensity is larger than that for Charlotte, so it is used.); A is equal to 0.42 acres. Thus, Q=2.4 cfs.
- Find weir length using weir equation, $Q= C_W*L*H^{1.5}$: The weir coefficient is set at 3.0; H is set to 2 inches, or 0.17 feet. Thus, L can be calculated to be 11.4 feet.
- Choose overflow device: Assuming a square overflow device, each side should be 3 feet in length, in order to meet the necessary weir length of 11.4 feet. The crest of the weir should be set at a height of 9 inches above the surface of the bioretention area. Safety devices and screens (to prevent floating mulch from entering the overflow device) should be considered. Land surrounding the bioretention area should be graded such that a standing water depth of 11 inches above the bioretention area land surface (equivalent to the 10 year storm) will not damage property.

Choose vegetation and a planting plan: The rain garden has been designed to accommodate plants sized up to trees and shrubs. Vegetation should be able to tolerate short periods of inundation, as well as periods of drought. A professional should be consulted to determine plant selection and spacing. Potential rain garden plants (adapted from Prince George's County Bioretention Plant List, accessed 3/8/05) are listed below.

Scientific name	**Common Name**	**Scientific name**	**Common Name**
Andropogon glomeratus	Broomsedge	*Calycanthus floridus*	Sweet Shrub
Carex lupulina	Hop Sedge	*Chionanthus virginicus*	White Fringetree
Chasmanthium latifolium	River Oats	*Diervilla sessilifolia*	Bush-honeysuckle
Eleocharis acicularis	Slender Spikerush	*Euonymus americana*	Hearts-a-bursting
Eleocharis palustris	Creeping Spikerush	*Ilex verticillata*	Winterberry
Eleocharis quadrangulata	Square Stem Spikerush	*Itea virginica*	Virginia Sweetspire
Elymus hystrix	Bottlebrush Grass	*Lindera benzoin*	Spicebush
Elymus virginicus	Virginia Rye	*Physocarpus opulifolius*	Ninebark
Panicum virgatum	Switchgrass	*Viburnum cassinoides*	Northern Wild Raisin
Asclepias incarnata	Swamp Milkweed	*Viburnum prunifolium*	Blackhaw
Aster novae-angliae	New England Aster	*Aronia arbutifolia*	Red Chokeberry
Bidens aristosa	Bur-marigold	*Asimina triloba*	Pawpaw
Bidens polylepis	Bur-marigold	*Cornus amomum*	Silky Dogwood
Chelone lyonii	Pink turtlehead	*Hypericum densiflorum*	Bushy St. John's-wort
Eupatorium fistulosum	Joe-pye-weed	*Spiraea tomentosa*	Hardhack
Eupatorium perfoliatum	Boneset	*Parthenocissus*	Virginia Creeper

		quinquefolia
Helenium autumnale	Sneezeweed	
Iris virginica	Virginia iris	
Leersia oryzoides	Rice Cutgrass	
Lobelia cardinalis	Cardinal Flower	
Mimulus ringens	Monkey-flower	
Osmunda regalis	Royal Fern	
Rudbeckia laciniata	Cutleaf Coneflower	
Vernonia noveboracensis	New York Ironweed	
Xanthoriza simplicissima	Yellowroot	

Appendix 3: Examination of Design Alternatives for the Proposed Clemson University Municipal Services Complex

Prepared by Cal Sawyer and Katie Sciera, used in part with permission.

A new development paradigm is being implemented in certain areas throughout the United States. To address the hydrologic and hydraulic challenges of stormwater, the concept of Low Impact Development (LID) provides a series of procedures and practices to favorably modify the magnitude, frequency and duration of high stormwater flows. Projects utilizing low impact development design attempt to mimic the pre-development temporary storage (detention) and infiltration (retention) functions of the site. LID techniques are based on the premise that stormwater management should not be seen as stormwater disposal (Prince Georges County, 1999). Instead of managing and treating stormwater in large, costly practices located at the bottom of drainage areas, LID addresses stormwater through small, cost-effective landscape features, called Integrated Management Practices (IMPs), located at the site level. These practices also help to maintain the ecological integrity of a system.

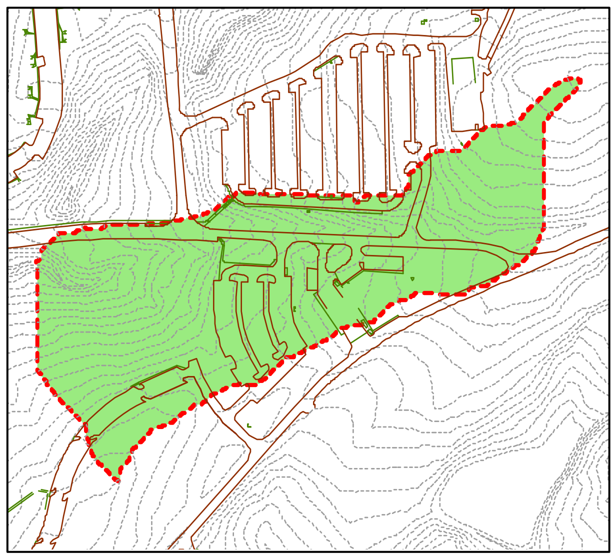

Figure 1 – MSC Subwatershed

Site Characteristics:
The sub-basin (Figure 1) to be modeled is contained within the Hunnicutt Creek watershed on the campus of Clemson University. The Office of Campus Planning has initiated conceptual planning to expand the Municipal Services Building and to extend Newman Road across the upper portions of the Lightsey Branch watershed, which will likely further alter the hydrology of the immediately adjacent creek channel.

The site is 15.4 acres and comprised of the well-drained, moderately sloped clays of the Cecil-Madison-Pacolet association. Current land use in the watershed consists primarily of the Clemson University Emergency Services facilities. Transportation uses bound the watershed to the north by the P-1 parking lot and to the east and south by Perimeter Road. Open and recreational uses include forest in moderate condition, landscaped turf areas which serve as the headwaters of the Lightsey Branch of Hunnicutt Creek.

1.0 Scenario Comparison and Basic Hydrologic Information

To evaluate the hydrologic changes over time, four scenarios were modeled. Scenario I was intended to assess pre-anthropogenic influences when the land was still forested and uninfluenced by hydromodification. Scenario II estimates hydrologic response to the region's historical cotton farming period. Current land cover was evaluated as Scenario III. Finally, Scenario IV evaluates the proposed Municipal Services Complex; a multi-purpose facility which will house fire, police and campus court services. As part of Section 2.0 of this report, low impact development design will be evaluated.

Table 1.1 Hydrologic Evaluation Summary

Area = 15.4 acres			2-yr, 24-hr event (P = 4.7")		10-yr, 24-hr event (P = 6.3")	
Scenario	CN	tc (hr)	Qcn (acre-ft)	Qp (cfs)	Qcn (acre-ft)	Qp (cfs)
I Forested	55	0.283	0.27	12.20	0.36	28.5
II Cotton	78	0.196	0.59	50.55	0.67	78.46
III Current	73	0.117	0.52	46.72	0.60	76.72
IV Proposed	72	0.117	0.50	44.80	0.59	74.38

TR-55 (SCS, 1984) was used to model hydrology and produced hydrographs. Scenarios I and II were strictly single land uses. Scenarios III and IV were calculated using 24 and 20 percent imperviousness, respectively. Overland flow was assumed to be the maximum of 99 feet and the remaining flow distance of 1632 feet was shallow concentrated flow for all scenarios, except LID. Rainfall data was specific for Pickens County, SC. Hydrologic parameters were calculated for 2-year and 10-year storms, in accordance with SCDHEC land use development regulations. Two year and 10-year storms were 4.7 inches and 6.3 inches of rainfall, respectively.

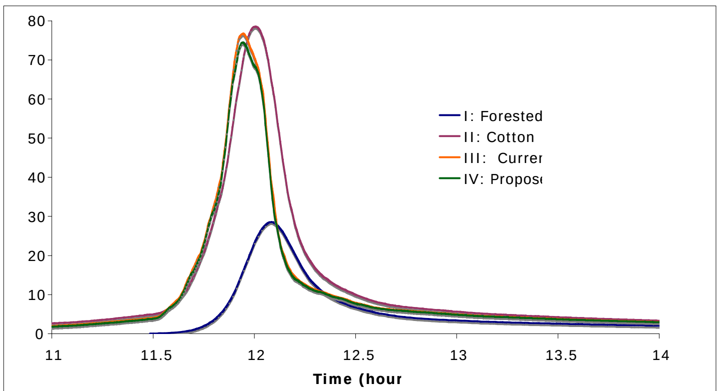

Figure 1.2 10-Year Storm Hydro

As forested land cover decreased and imperviousness increased, time of concentration (tc) decreased because water flow was not slowed or intercepted by vegetation, therefore, runoff volumes (Qcn), and peak discharges (Qp) for both design storm events increased (Table 1.1, Figures 1.1 and 1.2).

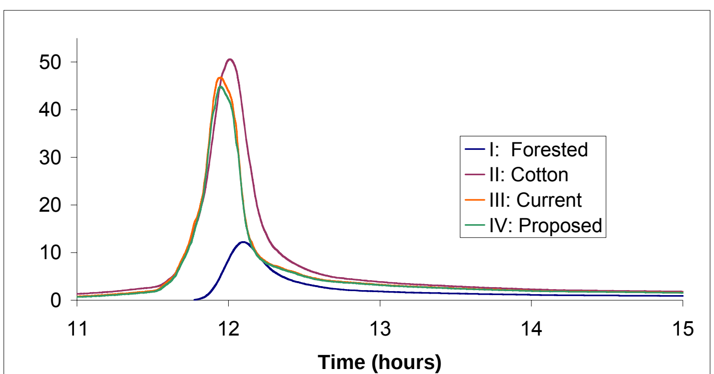

Figure 1.1 2-year Storm Hydrographs.

With land clearing and subsequent development, peak flows occurred earlier and were more intense. This increase in “flashy flow” can result in detrimental changes to stream morphology, and increased flooding. As volumes and discharge increase, contaminant loading should rise proportionally. Sections 2.0 and 3.0 of this report will evaluate how to remedy the changes in discharge and decreases in time of concentration using low impact development (LID) techniques and what impact there is on contaminant loading and risks to ecosystem health.

Stormwater management efforts have historically followed the design storm concept. A typical design criterion requires that the post-development peak discharge for a 2- and 10-year frequency storm event be equal to or less than the same storm under pre-development conditions. Usually such designs involve incorporating best management practices like detention basins at the “end of the pipe.”

In order to move away from this “end of the pipe” approach, a new paradigm is being utilized. Low Impact Development (LID) provides a series of procedures and practices to favorably modify the magnitude, frequency and duration of high stormwater flows. Projects utilizing low impact development design attempt to mimic the pre-development temporary storage (detention) and infiltration (retention) functions of the site.

The intent and practice of low impact development are achieved utilizing several components of traditional hydrologic analysis and design; simply applied in a different fashion:

Curve Number – the curve number (CN) method for estimating runoff potential from storm rainfall is well established in hydrologic engineering and subsequent analysis of environmental impacts. Major factors that determine CN are soils, land cover type, hydrologic condition, and antecedent moisture condition (Haan et al, 1994). The goal is to lower the post-development CN by minimizing changes to pre-development hydrology. Examples include lowering the overall amount of impervious area, minimizing site disturbance and distributing practices such as infiltration swales, vegetated filter strips, disconnected impervious areas, bioretention, and revegetation throughout the site.

Time of Concentration- post-development time of concentration (tc) should be maintained close to that of pre-development tc. This design element is critical because LID is based on distributed best management practices. Lengthening the tc can be achieved by such LID practices as maintaining pre-development flow path length, increasing surface roughness, detaining flows, flattening grades in impacted areas, disconnecting impervious areas and connecting pervious and vegetated areas. Project engineers are forced to utilize an iterative process to analyze many different combinations of available practices (Prince Georges County, 1997).

Detention – detention serves as temporary storage designed to release excess runoff at a controlled rate. Aside from typical practices like ponds and basins, LID utilizes practices like engineered swales with check dams, diversion structures and pipe constriction.

Retention – provide retention storage for volume and peak control equal to or exceeding the pre-development condition. As the retention storage volume of a site is increased, there is a corresponding decrease in peak runoff rate and volume. Retention would also encourage groundwater recharge, utilizing such practices as infiltration swales, vegetated filter strips and bioretention.

2.1 – LID Hydrologic Analysis – Process and Computational Procedure
Prior to developing any structural stormwater practices on site, significant reductions in stormwater quantity and quality impacts can be made through enhancements to site design. The Prince Georges County LID Manual (1997) contains thirteen (13) design techniques which can be utilized on undeveloped sites as they go though the process of development. However, the MSC watershed is already largely developed, and since there will have to be extensive grading and site disturbance prior to being redeveloped, these techniques were not considered. Many communities require that a checklist of these techniques be submitted with erosion and sediment control plans when seeking National Pollutant Discharge Elimination System permit coverage.

Before proceeding, the LID runoff curve number (CNLID) is determined. Using GIS polygon estimation, percentages are estimated for each land cover. LID analyzes the site CN in discrete units, unlike conventional composite CN determination. Equation 2.1

$$CN_C = CN_p + \left(\frac{P_{imp}}{100}\right) \text{x} \, (98 - CN_p) \, \text{x} \, (1\text{-}0.5R) CN_p$$

Where:

CN_c = composite CN

CN_p = composite pervious CN

P_{imp} = percent of impervious site area

R = ratio of unconnected impervious area to total impervious area

Equation 2.1

yields a CNLID of 66, which will be used during the duration of analysis. Further, LID requires that the post-development tc be returned to that of the pre-development. A variety of techniques is offered to the engineer for use to achieve the desired goal. WinTR-55 allowed for the input of extended flow lengths and increasing the surface roughness, which allowed a relatively easy return to pre-development time of concentration (.302 or about 18 minutes.

The next step is to determine the design storm. Again, because LID seeks to emulate the pre-development hydrology, the idea is to retain the same amount of rainfall within the development site as that retained by a forest in good condition, and then slowly release it. Pre-development CN is 55, for a forest in good condition and HSG B (Haan et al., 1994). Equation 2.2 is used to determine the amount of rainfall, P, needed to initiate runoff and then multiplied by a factor of safety equal to 1.5. The result is P = 2.4 inches. The model calls for the greater number between that calculated using Equation 2.2 and that of the 1-year, 24-hour storm event. WinTR-55 gives a value of 3.7 inches for the southern part of Pickens County, SC, so use P = 3.7 inches.

$$P = 0.2 \, \text{x} \left(\frac{1000}{CN_c} - 10\right) \text{x} \, 1.5$$

Equation 2.2

Estimating the required storage to handle runoff volume, or ∀R is the next value to address. Chart Series A plots volume as a function pre-development conditions and post-development CN. The storage area expressed is not for use in water quality computations, but is for runoff volume only. Using the physical characteristics of the site, a ∀R = 0.54 inches is determined. Further, if 9 inches is used as the design depth of IMPs, then a total of .92 acres will be required for distributed integrated management practices. Because some evapotranspiration is accounted for (not to exceed 10%), a final surface area of .83 acres will be required to address retention.

Proceeding further, the next determination to be made involves the volume to meet water quality requirements, ∀Q. Equation 2.3 is employed to compute the volume, which is a function of the first flush value of 0.5 inches and an impervious area equal to 4.4 acres (28%) of the site at 9 inches depth. ∀Q is determined to be 0.14 inches. Since ∀R > ∀Q, that volume is used.

$$\forall_Q = \frac{(\text{Site Area x \% IC})\text{ x 0.5"}}{\text{Site Area}}$$

Equation 2.3

Interestingly, perhaps the least challenging figure to determine is the volume of storage needed to maintain pre-development peak runoff rate using 100% retention, ∀R100. Chart Series B plots various rainfall amounts and storage volume as a function of peak discharge. If the times of concentration for pre- and post- are equal, the peak runoff rate is independent of tc for retention and detention practices (Prince Georges County, 1997). Chart B4 yields a ∀R100 = 0.60 inches. Since ∀R < ∀R100, there will be additional hybrid storage required to maintain pre-development Qp. Using Chart Series C, a volume is obtained for the volume of storage needed to maintain pre-development Qp using 100% detention, ∀D100. This value is determined to be .38 inches, and again reflects a comparison of the pre- and –post-development curve numbers.

Following closely on the heels of the least difficult value to obtain, is one of the more problematic. To handle this addition detention storage, we compute the ratio of retention to total storage, x. Equation 2.4 gives this ratio, which is then plugged into Equation 2.5 to obtain the additional amount of site area, above that already set aside for volume control.

$$x = \frac{50}{\forall_{R100} - \forall_{D100}} \times \left(-\forall_{D100} + \sqrt{\forall_{D100}^2 + 4}\{\forall_{\text{R100}} - \forall_{D100}\} \times \forall_R\right)$$

Equation 2.4

$$H = \forall_R \times (100 \div x)$$

Equation 2.5

The ratio is determined to be 93, which is then utilized to obtain the Hybrid Storage, H (H = 0.58 inches). Since the difference between ∀R (0.54 inches) and H is so small, only 0.04" of detention are required to be added. Total area for IMPs distributed across the site is equal to 15.4 ac X 0.58"/9.0", or .99 acres, so we'll use 1.0 acre. This is equivalent to 6.4% of the entire watershed. 1.0 acres is equal to 43, 560 ft2.

2.2 – Distribution of Storage Across Site

Distributing the IMPs evenly throughout the site is important in maintaining the longer time of concentration. Table 2.0 and Figure 2.1 show the watershed area and potential placement of various IMPs. Those practices chosen include bioretention, engineered swales, green roofs and level spreaders. Because cost is considered, I did not use underground storage, as was originally intended. A discussion with a colleague at NC State University illuminated the fact that green roofs used in concert with underground storage may not be the best use of either.

Table 2.1 BMP Distribution by Area

IMP Type	Designation	Location	Surface Area (ft^2)
Engineered Swale	ES1	NE of McMillan Road	2000
Bioretention	BR1	N of Visitors Parking Lot	1000
Bioretention	BR2	Staff Parking Lot	500
Green Roof	GR1	Police-Court Services	16,000
Green Roof	GR2	Fire Services	19,000
Engineered Swale	ES2	S of P-1 Parking Lot	2500
Bioretention	BR3	NW of Fire Services Driveway	1000
Level Spreader with Infiltration Trench	LS1	Forested Area W of Newman Road Extension	2000
		Total	44,000
		Required	43,560

Figure 2 – Rendered Site Plan with proposed IMP's superimposed on existing topography.

3.0 IDEAL: Contaminant Loadings and Ecological Effects

The Integrated Design and Evaluation Assessment of Loadings (IDEAL) Model was developed to assess the impact of Best Management Practices (BMPs) on water quality. These Best Management Practices include sediment ponds and vegetative filter strips (VFS). The spreadsheet-based model uses regional data to predict contaminant loadings for nitrogen, phosphorus, sediment, and bacteria (Hayes et al. 2003). The analysis for this project used IDEAL to model contaminant loadings based on changes in curve number (CN) and time of concentration (tc) because the developed scenarios lacked the traditional sediment pond or VFS.

For the purposes of this case study, all soil was entered as a Cecil sandy loam. This was the dominant soil for the sub-watershed, only a small portion was Pacolet fine sandy loam. The tc was calculated using WinTR-55 model. The rainfall data in WinTR-55 was county specific for Pickens County, whereas IDEAL used rainfall data for GSP airport in Greenville County. Loading estimates should still be fairly accurate, however, because the output data from IDEAL that will be used for comparison will look at trends and the average storm for the area.

Table 3.1. Numerical Water Quality Standards

	Value	Reference Range	Source
Nitrogen, total (TN)	0.69 mg/L	0.7-1.0 mg/L	a
Phosphorus, total (TP)	0.003656 mg/L	0.00225-0.01 mg/L	a
Bacteria, as fecal coliform	200 per mL	n/a	b
Total Suspended Solids	n/a	n/a	

a USEPA. 2000. Ambient Water Quality Criteria Recommendations: Rivers and Streams in Nutrient Ecoregion IX. USEPA Office of Water. EPA 822-B-00-019. December.
b USEPA 2003. Bacterial Water Quality Standards for Recreational Waters (Freshwater and Marine Waters) Status Report. USEPA Office of Water. EPA-823-R-03-008. June.

It was assumed that in Scenarios I (forested) and II (cotton) that there was 1% impervious surface. This assumption was necessary to calculate nitrogen (N) and phosphorus (P) export from the watershed. It was impractical to have no loading of nutrients in to the stream from the watershed since some nutrient export occurs in all systems, regardless of land use. Scenario II (cotton) was entered to assume a best-case scenario of cotton planted year round, and no exposed ground during the year. For scenarios III and IV, it was assumed that the impervious areas were not connected to drainage systems.

Nutrient loadings are of interest because of the potential for human health and ecological effects. The U.S. Environmental Protection Agency established ambient water quality criteria for total nitrogen (TN) to be 0.69 mg/L for South Carolina. This number is based upon a 25th percentile reference condition that is ecoregion specific. Ecoregions are areas of general similarity in ecosystems, type, quality, and quantity of environmental resources (USEPA 2006). The reference range for ecoregion IX, which includes Clemson, SC, is 0.7-1.0 mg/L (Table 1; USEPA 2000). Total phosphorus (TP) limits are derived in the same manner as nitrogen. The ambient water quality criterion for total phosphorus is 0.003656 mg/L with a reference range of 0.00225-0.01 mg/L (Table 1).

Loadings of nutrients are calculated by IDEAL using event mean concentrations (EMCs) that were defined based upon databases for Greenville, SC and other similar areas. However, these calculations do not account for percent imperviousness, therefore, are only an estimate of the true runoff concentrations. IDEAL uses Equation 3.1 to compute nutrient loadings:

$$Y_N = N_{EMC} * Q * A * Const \qquad \text{Equation 3.1}$$

Where:

N_{EMC} is the event mean concentration for nitrogen (or phosphorus or bacteria)

Q is the runoff volume

A is the watershed area

Const is a constant based on units.

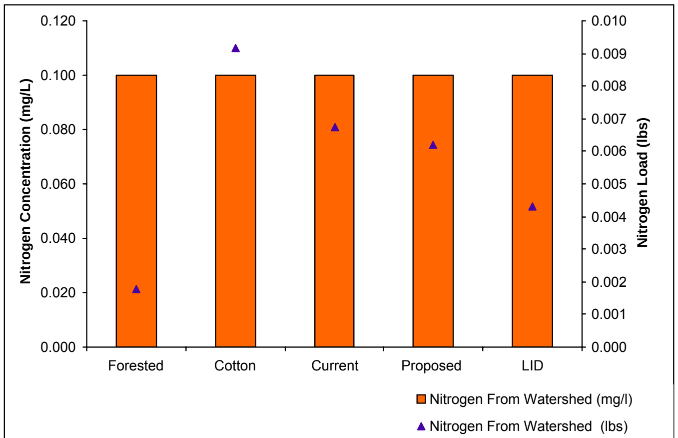

Figure 3.1 Average Storm Nitrogen Export from Watershed

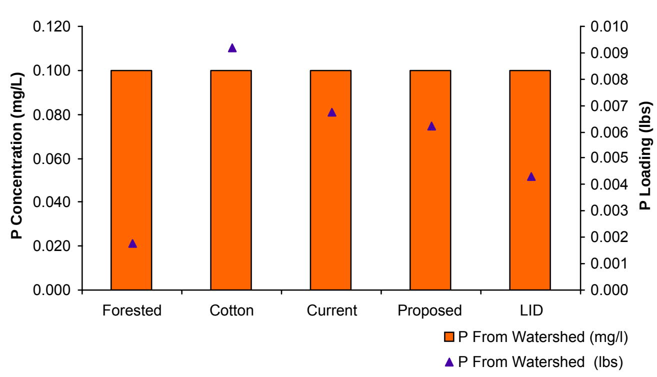

Figure 3.2. Average Storm Phosphorus Export from Watershed

Because this calculation uses EMCs, the concentration of nutrients in the runoff is the same in all scenarios, despite changes in runoff volume. These are shown in Figure 3.1. However, it is important to note, that all calculated nitrogen export concentrations are below the regulated value of 0.69 mg/L. Phosphorus export concentrations are shown in Figure 3.2. The concentrations are all well above the standard of 0.0037 mg/L. The model does not account for land use practices such as fertilizer application on landscaping, which could have a profound effect on nutrient loading. The trend in total nitrogen loading does demonstrate the changes in land use, where nitrogen export is the lowest when runoff volumes are controlled. Forested and LID scenarios exhibited the lowest curve number and runoff volumes (see Section 1.0) and have the lowest nutrient loading. The LID techniques reduce the loadings from the proposed Municipal Services Center (MSC) by 33% for both nitrogen and phosphorus.

It is important to keep nutrient loadings close to background (pre-development). Excessive nitrogen in water can lead to human health risks. The most famous human health risk from high nitrogen is “Blue Baby Syndrome” or methemoglobinemia. The nitrogen causes oxygen deprivation and brain damage in babies. There are also ecological risks to excessive nitrogen and phosphorus. The nutrients fertilize algae in lakes, which results in algae blooms. Algae blooms can in turn cause low dissolved oxygen and fish kills. According to the USEPA, nutrients were the second leading cause of impairments reported by states in their 1998 lists of impaired waters (USEPA 2000).

A way to maintain background (pre-development) bacterial loadings is also important. Bacteria are regulated based upon fecal coliform, enterococci, or total coliform. These measurements indicate the potential for harmful bacteria to be present and the regulations on bacteria are intended to prevent disease. Coliform bacteria are most common in urban and agricultural watersheds because they are the result of human and animal waste and leaky sewers (USEPA 2003), however, these bacteria are also naturally occurring. South Carolina regulates secondary contact fecal coliform at <200 bacteria per mL of water (USEPA 2003). Secondary contact is recreational contact with water. The drinking water standard is more protective.

The bacterial loadings from IDEAL are calculated using the same EMC approach as nutrients. Therefore, it is most useful to look at the overall loadings of bacteria into the stream. The trend in bacterial loading is similar to that of the nutrients (Figure 3.3). The natural forest exports the lowest number of bacteria, cotton being the highest, which could be due to exposed, disturbed soils. However, as runoff volumes are controlled with developed land, the bacterial loadings are reduced. Bacterial loadings are reduced by 30% when LID techniques are integrated into the proposed changes to the MSC. With more LID techniques employed, we could expect that bacterial loadings would be further reduced.

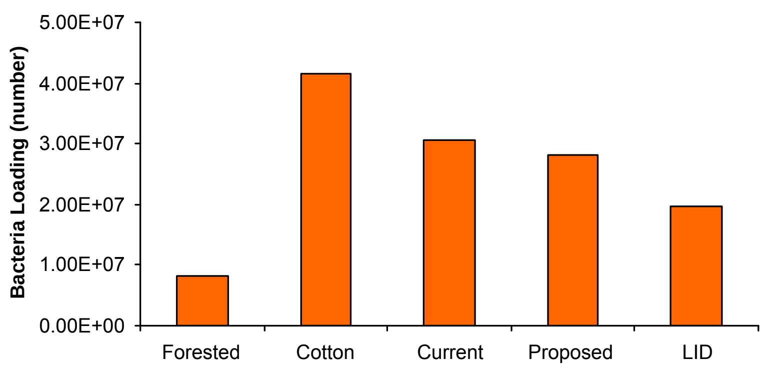

Figure 3.3 Bacteria Loading From Watershed.

The IDEAL model also calculates sediment loading. Sediment yield from pervious areas is calculated using the Modified Universal Soil Loss Equation (MUSLE):

Yp=95(Qqp)0.55(K)a(LS)a(CP)a Equation 3.2

Where:
Yp=pervious sediment yield
Q=runoff volume
qp=peak discharge
K=Soil Erodibility Factor
LS=Steepness Factor

CP=Cover Protection and Conservation Practice factors

The eroded particle size distribution for the soils is calculated using the CREAMS equation. The sediment yield from impervious areas is based on EMCs using the same formula as the nutrient loadings.

Total suspended solids are not regulated based upon a numerical standard. In 2003, the USEPA began developing criteria, but it is difficult to establish such criteria as a national standard when some sediment loading is natural, and depends on soil type and ecoregion (USEPA 2003b). South Carolina regulates suspended sediment during construction. Developers much capture 80% of sediment from a site and that is a difficult value to enforce.

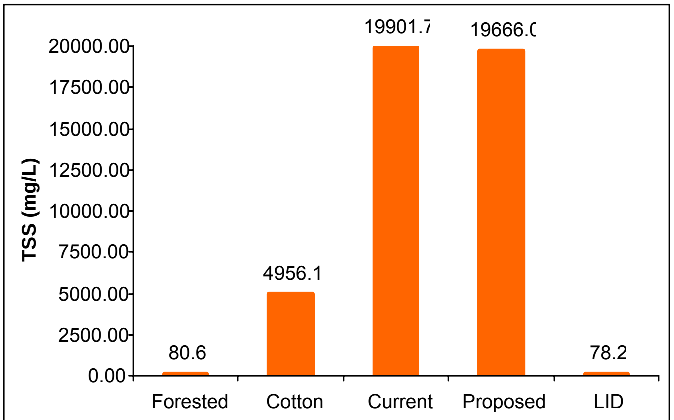

Figure 3.4 Average Storm Total Suspended Solids L

IDEAL calculated sediment loading concentrations (in mg/L) for all development scenarios. Because of drastic increases in flow from impervious surfaces, the current and proposed MSC scenarios had the highest sediment loading. However, by implementing some LID practices, total suspended sediment concentrations for the average storm could be reduced by 99%.

It is important to control total suspended sediment concentrations because of detrimental ecological effects. USEPA reported that 40% of assessed river miles in the U.S. were impaired due to sediment stress (2000b). Sediment stress causes physical and physiological effects on organisms. Total suspended sediments (TSS) fill in streambeds where insects live and fish lay eggs, which also lowers the oxygen in stream bed sediments, further affecting habitat. TSS affects water clarify and the general health of organisms because TSS can irritate fish gills, clog digestive systems, and reduce organism growth and reproduction (Capper, 2006, unpublished data). TSS can also carry chemical pollution into waters. Nutrients from fertilizer applications can be associated with sediment as well as heavy metals, hydrocarbons, and other organic compounds such as pesticides. All of these chemical contaminants can have a detrimental effect on a system's ecology and human health (Table 3.2).

Table 3.2 Sources of Pollution.		
	Pollutant	Source
Sedimentation	Particulates (TSS)	Pavement wear, vehicles, the atmosphere, maintenance activities
Nutrients	Nitrogen & Phosphorus	Atmosphere & Fertilizer Application
Heavy Metals	Lead	Leaded gasoline from auto exhausts and tire wear
	Zinc	Tire wear, motor oil, and grease
	Iron	Auto body rust, highway structures, engine parts
	Copper	Metal plating, bearings, engine parts, brake liner wear, fungicides & insecticides
	Cadmium	Tire wear, insecticide application
	Chromium	Metal plating, engine parts, brake linings
	Nickel	Diesel fuel & gasoline, oils, brake lining wear, asphalt paving
	Manganese	Engine parts
Hydrocarbons	Petroleum	Spills, leaks, antifreeze, hydraulic fluids, asphalt surface leachate
Other	Organic Compounds	Pesticides
	Bacteria	Leaky sewers, pets

Adapted from USEPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters

By examining nutrient, bacteria, and sediment loadings using a model such as IDEAL, development scenarios can be evaluated more quantitatively for their effects on human health and the environment. BMPs and LID techniques can be implemented to reduce the overall loadings and the risk of land use changes to the ecosystem. However, the limitations of the IDEAL model must be recognized. IDEAL does not model for all contaminants. Some systems may be particularly sensitive to contaminants, such as heavy metal loads from nearby roads, which are not modeled by IDEAL. Additionally, IDEAL does not account for surface applications of chemicals, like fertilizers and pesticides, which can increase some of the calculated loadings. IDEAL must be used with caution when trying to predict the potential ecological health of a system after land use change.

Summary and Conclusions

When forested land cover is reduced and land is developed, a multitude of natural ecosystem variables are thrown out of balance. The increase in imperviousness results in higher peak flows, higher contaminant loadings, and shorter time of concentrations. The higher peak flows and shorter time of concentrations can increase the risk of flooding and scour the stream channel resulting in decreased habitat and aesthetics. Additionally, the increased flows result in higher nutrient, bacteria, and sediment loading into the stream system. It can be assumed that other contaminants can be associated with sediment. The increase in these loadings results in detrimental ecological and human health effects. By implementing low impact development (LID) or by incorporating some of the LID principles, the risks of flooding, risks to human health and the environment can be reduced.

References

Haan, CT, BJ Barfield, and JC Hayes. 1994. Design Hydrology and Sedimentology for Small Catchments. Academic Press. San Diego, CA.

Hayes, JC, B. Barfield, K.F. Holbrook, J. Gillespie, J. Fersner, and B. Bates. 2003. A Model for Assessing the Impact of BMPs on Water Quality. Stormwater September/October 2003, Forester Communications, Inc.

Prince Georges County, Maryland. 1999. Low Impact Development Hydrologic Analysis. Department of Environmental Resources. Prince Georges County, MD.

Prince Georges County, Maryland. 1997. Low Impact Development Design Manual. Department of Environmental Resources. Prince Georges County, MD.

SCS. 1986. Urban Hydrology for Small Watersheds. Technical Release 55. US Department of Agriculture, Soil Conservation Service Engineering Division, Washington, DC.

USEPA. 2000. Ambient Water Quality Criteria Recommendations: Rivers and Streams in Nutrient Ecoregion IX. USEPA Office of Water. EPA 822-B-00-019. December 2000.

USEPA. 2000b. The Quality of Our Nations Waters. A Summary of the National Water Quality Inventory: 1998 Report to Congress. Office of Water, Washington DC. EPA-841-S-00-001.

USEPA. 2003. Bacterial Water Quality Standards for Recreational Waters (Freshwater and Marine Waters) Status Report. USEPA Office of Water. EPA-823-R-03-008. June 2003.

USEPA. 2003b. The Biological Effects of Suspended and Bedded Sediment (SABS) in Aquatic Systems: A Review. Internal Report. Office of Research and Development, Narragansett, RI. August 20, 2003.

USEPA. 2006. “Western Ecology Division, Corvallis, OR.” http://www.epa.gov/wed/pages/ecoregions/ecoregions.htm. Accessed 24 Apr 2006.

6. Appendix 4: Restoration Trajectory Species List

The 43 species listed below have been sampled in the Clemson area of South Carolina. (Page, Burr 1991). The odds of all species listed occurring in Honeycutt Creek are slim, but any combination could theoretically have existed there at one time. Since the area has not been sampled by Clemson University in recent history, and the fact that land use involving the Seneca River and neighboring tributaries has drastically altered the system, it is impossible to know exactly what species inhabited Honeycutt creek in the past. Large river species such as shad, herring, or gar may have even used the stream at some point when it was a true tributary of the Seneca River.

Possible Fish Assemblages of Hunnicutt Creek, Clemson, SC

Genus:	Species:	Common Name:	Habitat:
Ameiurus	natalis	Yellow Bullhead	Backwaters, sluggish flow over sand.
Ameiurus	catus	White Catfish	Sluggish, mud bottomed pools.
Ameiurus	brunneus	Snail Bullhead	Fast flowing rocky riffles and runs.
Ameiurus	nebulosus	Brown Bullhead	Sluggish, sandy pools.
Campostoma	anomalum	Central Stoneroller	Headwaters, rocky runs and pools.
Carpiodes	cyprinus	Quillback	Throughout stream.
Catostomus	commersoni	White Sucker	Rocky pools and riffles.
Clinostomus	funduloides	Rosyside Dace	Headwaters, rocky runs and pools.
Cottus	bairdi	Mottled Sculpin	Headwaters, rubble/gravel riffles.
Cyprinella	pyrrhomelas	Fieryblack Shiner	Rocky runs and pools.
Cyprinella	nivea	Whitefin Shiner	Sand/Gravel runs and riffles.
Esox	americanus	Redfin Pickerel	Backwaters, vegetated pools.
Etheostoma	olmstedi	Tessellated Darter	Sandy/Muddy pools.
Etheostoma	zonale	Banded Darter	Rocky riffles.
Etheostoma	inscriptum	Turquoise Darter	Rocky riffles.
Etheostoma	flabellare	Fantail Darter	Rocky riffles.
Gambusia	affinis	Mosquitofish	Brackish, standing backwater.
Hybognathus	regius	E. Silvery Minnow	Backwater pools.
Hybopsis	rubifrons	Rosyface Chub	Sand/Gravel pools and runs.
Hypentelium	nigricans	Northern Hog Sucker	Rocky riffles and runs.
Ictalurus	punctatus	Channel Catfish	Deep pools and runs, sandy or rocky.
Lepomis	gulosus	Warmouth	Quiet backwater mud/sand pools.
Lepomis	cyanellus	Green Sunfish	Backwater pools, sluggish waters.
Lepomis	macrochirus	Bluegill	Vegetated pools, sandy/muddy substrate.
Lepomis	microlophus	Redear Sunfish	Vegetated pools, sandy/muddy substrate.
Lepomis	auritus	Redbreast Sunfish	Rocky and Sandy pools.
Lepomis	gibbosus	Pumpkinseed	Quiet, vegetated pools.
Micropterus	salmoides	Largemouth Bass	Backwater pools w/ mud/sand substrate.
Minytrema	melanops	Spotted Sucker	Long deep pools over clay, sand, rocks.
Moxostoma	macrolepidotum	Shorthead Redhorse	Rocky riffles, runs, and pools.
Moxostoma	anisurum	Silver Redhorse	Mud, rock pools and runs.
Moxostoma	rupiscartes	Striped Jumprock	Sandy to rocky riffles and runs.
Nocomis	micropogon	River Chub	Headwaters, rocky runs and pools.
Nocomis	leptocephalus	Bluehead Chub	Headwaters, rocky/sandy runs and pools.
Notemigonus	crysoleucas	Golden Shiner	Backwaters, vegetated pools.
Notropis	scepticus	Sandbar Shiner	Flowing, sand bottomed pools, near riffles.
Notropis	lutipinnis	Yellowfin Shiner	Clear, rocky pools.
Notropis	hudsonius	Spottail Shiner	Sand/Gravel pools and runs.
Noturus	insignis	Margined Madtom	Fast flowing rocky riffles and runs.
Noturus	leptacanthus	Speckled Madtom	Gravel/Sand runs and riffles.
Perca	flavescens	Yellow Perch	Clear water pools near vegetation.
Rhinichthys	atratulus	Blacknose Dace	Headwaters, rocky runs and pools.
Semotilus	atromaculatus	Creek Chub	Headwaters, rocky/sandy runs and pools.

6.1.1. Vegetation

Suggested Riparian Corridor Tree Species for Clemson University

(from Hairston-Strang, 2005)

Wet Sites (Hydric)

Common Name	Scientific Name
Black walnut	*Juglans nigra*
Green ash	*Fraxinus pennsylvanica*
Swamp white Oak	*Quercus bicolor*
Sycamore	*Platanus occidentalis*
Red maple	*Acer rubrum*
River birch	*Betula nigra*
Silver maple	*Acer saccharinum*
Cottonwood	*Populus deltoides*
Pin oak	*Quercus palustris*
Willow oak	*Quercus phellos*
Black willow	*Salix nigra*
Servicberry	*Amelanchier canadensis*
Blackgum	*Nyssa sylvatica*

Moderate Sites (Mesic)

Common Name	Scientific Name
White Oak	*Quercus alba*
Green ash	*Fraxinus pennsylvanica*
Eastern White Pine	*Pinus strobus*
Sycamore	*Platanus occidentalis*
White ash	*Fraxinus americana*
River birch	*Betula nigra*
Cottonwood	*Populus detoides*
Pin oak	*Quercus palustris*
Willow oak	*Quercus phellos*
Northern red oak	*Quercus rubra*
Serviceberry	*Amelanchier canadensis*
Blackgum	*Nyssa sylvatica*
Yellow-poplar	*Liriodendron tulipifera*
American plum	*Prunus americana*
Crabapple	*Malus coronaria*

Dogwood	*Cornus florida*
Fringetree	*Chionanthus virginica*

Dry Sites (Xeric)

Common Name	Scientific Name
Dogwood	*Cornus florida*
Green ash	*Fraxinus pennsylvanica*
Eastern white pine	*Pinus strobus*
Chestnut oak	*Quercus primus*
Northern red oak	*Quercus rubra*
Post oak	*Quercus stellata*
Black oak	*Quercus velutina*
Sassafras	*Sassafras albidum*
American plum	*Prunus americana*
Persimmon	*Diospyros virginiana*
Eastern red cedar	*Juniperus virginiana*
Fringetree	*Chionanthus virginicus*
Pitch pine	*Pinus rigida*
Virginia pine	*Pinus virginiana*

7. Appendix 5: Biological Appendix

7.1. Biological

Evaluation of the macroinvertebrates community structure is a critical component in the biotic evaluation of water quality. Because stream water is continuously moving, physical and chemical measurements made at any given point in time may not indicate previous pollutants that have moved down-stream of the sample site. Because stream macroinvertebrates have less mobility than fish and exhibit a relatively long life span, they may serve as natural, continuous monitors of water quality being sensitive to long-term, low-level stress as well as pulsed, highly concentrated discharges of water pollutants. These characteristics have allowed environmental monitoring agencies to use macroinvertebrate community structure as a mechanism to evaluate disruption of biotic integrity caused by all forms of aquatic pollutants (EPA, 1999). Unfortunately, little research has been done on the range of responses a macroinvertebrate community may show to natural stressors like floods, droughts and landforms (Watzin and McIntosh 1999). Macroinvertebrate community analysis alone cannot determine the type of pollutant entering the stream ecosystem. Other types of analytical procedures must be coupled with macroinvertebrate community analysis to make cause and effect statements.

7.1.1. Fecal Coliform

The occurrence of pathogenic organisms in water-bodies has long been recognized and associated with water-borne diseases (Hunter et al. 1960). Fecal coliform bacteria are used by SC DHEC as indicators for pathogenic water pollution. It is bacteria found in the waste of all warm-blooded animals. The presence of coliforms in the water column indicates the presence of mammal waste, which may contain disease-causing organisms.

In the Hunnicutt Creek Watershed on the Clemson University campus, fecal coliform bacteria enter the watershed via direct methods such as wildlife, including ducks and geese, and assumed illicit discharges from pipes. Human impacts may be prevalent during home football games, when the campus is inundated with tens of thousands of people and insufficient restrooms. Indirect methods of fecal coliform contamination in this watershed include runoff over impervious surfaces during storm events collecting wildlife and human waste, storm water drains discharging into the creek, and sanitary sewer lines leaking or breaking, and either discharging or leaching into the creek.

There are currently seven water quality monitoring stations and three storm event monitoring stations on Hunnicutt Creek being monitored by the Clemson University Stream Laboratory. Hunnicutt Creek is classified as Freshwaters (FW) which makes it suitable for primary and secondary contact recreation and as a source for drinking water supply after conventional treatment in accordance with the requirements of the South Carolina Department of Health and Environmental

Control (SCDHEC). These waters are suitable for fishing, and the survival and propagation of a balanced indigenous aquatic community of fauna and flora. Hunnicuttt Creek coliform data collected in the past year indicate possible coliform excursions in the water column above the EPA approved SCDHEC standard of "Not to exceed a geometric mean of 200/100 ml, based on five consecutive samples during any 30 day period; nor shall more than 10% of the total samples during a any 30 day period exceed 400/100 ml" (SCDHEC 2004).
Table 1. Hunnicuttt Creek fecal coliform bacteria concentrations in the water column at base flow, 2005.

Station	Date	Location	Fecal Coliform (per 100ml)
HC 1	6/9/05	most downstream	4067
HC 1	7/23/05	" "	24,400
HC 1	10/31/05	" "	300
HC 2	6/9/05	just above HC 1	3567
HC 2	7/23/05		4000
HC 2	10/31/05		300
HC 3	6/9/05	northeast branch above HC 2	14,533
HC 3	7/23/05	Botanical Gardens	4100
HC 3	10/31/05		100
HC 4	6/9/05	middle east branch above HC 2	4800
HC 4	7/23/05	Botanical Gardens	6700
HC 4	10/31/05		600
HC 5	6/9/05	northwest branch, b/w HC 1 & 2,	5367
HC 5	7/23/05	at Perimeter Rd.	10,700
HC 5	10/31/05		200
HC 6	6/9/05	northwest branch above	4567
HC 6	7/23/05	McMillan Rd.	10,200
HC 6	10/31/05		<100
HC 7	6/9/05	northwest branch below	5167
HC 7	7/23/05	McMillan Rd.	4700
HC 7	10/31/05		800

7.1.2. Biotic Integrity

In-stream habitat types have been shown too directly and indirectly influence the distribution of macroinvertebrates and community assemblages (Statzner et al. 1988). As a result, in-stream habitat evaluations will always be coupled with macroinvertebrate community analysis (EPA, 1999). However, in-stream habitat is controlled primarily by the local climate, watershed geology, stream grade and land-use practices of the watershed (Allen, 1995). Of these, land-uses have been altered most by man. Land-use changes often alter stream discharge regime and sediment load. Discharge and sediment deposition will alter in-stream habitat types and the availability of habitat types largely determines the macroinvertebrate community structure (Raven et al. 1998, Roth et al.1996, McQuaid and Norfleet, 1999).

Although the riparian zone is located out of the stream channel, it greatly contributes to the macroinvertebrate community structure. Macroinvertebrate communities of heavily forested watersheds rely primarily on food resources developed outside (allochthanous) the stream ecosystem (McDowell and Fisher 1976). Allochtanous inputs come primarily in the form of leaf material contributed by plants growing in the riparian zone. Loss of streamside vegetation decreases allocthanous inputs as well as increasing sunlight on the streambed that may result in excessive aquatic plant growth and higher stream temperatures all of which impact macroinvertebrate community structure and function. Well-developed riparian zones help provide stable stream banks and protect soils from erosion.

Sediments mobilized from unstable, unvegetated stream banks and stream-side areas are deposited on the stream bottoms and may bury macroinvertebrates and cause a reduction in bottom (benthic) habitat by filling in of interstitial areas (Waters, 1995). Riparian zone development not only reduces sediment loading but has also been shown to mitigate and eliminate many other NPS aquatic pollutants such as nitrogen, phosphorus, and pathogenic microorganisms including fecal coliform bacteria (Gilliam, et al., 1997).

7.1.3. Urbanization Impacts on Fish

In the early 1990s, aquatic scientists introduced the concept of surrounding land use affecting fish communities. Fish exhibit well-defined zones of adaptation to habitat conditions and have different habitat requirements at different life stages and different seasons. Natural stressors, such as winter temperatures and great fluctuations in stream flow, affect the survival of fish if suitable refugia are not available. Anthropogenic changes in land use, more times than not, eliminates the refugia by either destruction or deposition of sediments or changes in nutrient inputs. For example, clearcutting a forest to stream edge, not only reduces the nutrient input based on leaf material, but also eliminates coarse woody debris necessary for fish cover for reproduction and refugia. Drained wetlands and stream channelization are also responsible for destruction of fish spawning habitat. Upstream impacts influence downstream fish communities.
Studies from other bioregions indicate that as urbanization increases species diversity, especially of sensitive species, declines. Some studies indicate that degradation of the biota starts with as little as 8% urbanization (impervious surface) of a watershed and irreparable damage starts at 25% urbanization.

The index of biotic integrity (IBI) is one means fisheries biologists use to assess the diversity of fish assemblages. IBI is a multimetric biological assessment based on taxa richness, species composition, and tolerance vs intolerance of species to disturbance or perturbations that reflects responses of biological systems to human actions. IBI tends to be high (good) in association with wetland and forest landuse and low (bad) with agriculture and urbanization. This is due to increased stormwater flows and sedimentation. The effects of urban land use are greater on streams with steep slopes. The higher the percentage of urban land use the stronger the negative association with IBI scores.

In stream segments, IBI of fish directly correlate with habitat quality (velocities, structure, substrate embeddedness, cover, and bank stability). Measures of landuse and riparian vegetation at larger spatial scales are superior predictors of stream ecological integrity than are more local measures, though protection of stream margins (riparian habitats) locally is insufficient to offset human induced changes to entire watersheds. Studies suggest narrow riparian buffers may be of little use in urban areas, however, wetlands, whether natural or constructed, are recommended as better buffers than narrow riparian habitats.

When riparian-site (smallest scale) was compared to riparian-reach (intermediate scale), the metrics of fish cover, large woody debris and undercut banks showed a strong positive association with forest. Overall, catchment-wide land use patterns are more strongly related to biological integrity than riparian land use patterns.

Nonindigenous and exotic fish species are also indicators of changes in water quality and/or habitat quality associated with human and/or natural disturbances. The stream is a continuous hierarchical and heterogeneous habitat containing longitudinal and lateral mosaics. By focusing on the heterogeneous nature of stream habitat at intermediate spatial and temporal scales, the role of fish movement links habitat patches together through time. As in terrestrial landscape ecology, multiple scales are important, since humans cause impacts at multiple scales. Maintaining habitat integrity is a more cost-effective use of limited resources for community level conservation.

8. References and Cited Literature

Allan, JD. 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annual Review of Ecology, Evolution and Systematics* 35:257-284.

Allen, J.D. 1995. Stream Ecology: Structure and Function of Running Waters, Chapman Hall. 399pp.

Barbour, M.T., J. Gerritsen, B. D. Snyder, J. B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Addition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water, Washington, D.C.

Casagrande, David G. The Human Component of Urban Wetland Restoration. *Bulletin 100*. Yale School of Forestry and Environmental Studies.

Doll, B.A. et al, 2003. *Stream Restoration: A Natural Channel Design Handbook*. North Carolina State University.

Eaton, Marcia Muelder. 2001. *Merit, Aesthetic and Ethical*. New York: Oxford University Press.

Ecoregions of North Carolina and South Carolina, (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:1,500,000).

Fausch, KD, CE Torgersen, CV Baxter and HW Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. *BioScience* 52(6):483-498.

Federal Interagency Stream Restoration Working Group (FISRWG). 1998. Stream Corridor Restoration: Principles, processes, and Practices. PB98-158348LUW.

Feruguson, Bruce K. 1998. *Introduction to Stormwater: Concept, Purpose, Design*. New York: John Wiley & Sons, Inc.

Gilliam, J.W., D.L. Osmond, and R.O. Evans. 1997. Selected Agricultural Best Management Practices to Control Nitrogen in the Neuse River Basin. North Carolina Agricultural Research Service Technical Bulletin 311, North Carolina State University, Raleigh, NC 53 pp.

Goetz, S.J, R.K Wright, A.J. Smith, E. Zinecker, and E. Schaub. 2003. IKONOS imagery for resource management: Tree cover, impervious surfaces, and riparian buffer analyses in the mid-Atlantic region. Remote Sensing of the Environment 88(2003): 195-208.

Griffith, G.E., Omernik, J.M., Comstock, J.A., Schafale, M.P., McNab, W.H., Lenat, D.R., MacPherson, T.F., Glover, J.B., and Shelburne, V.B., 2002,

Hairston-Strang, Anne. 2005. Riparian Forest Buffer Design and Maintenance. Maryland Department of Natural Resources Forest Service.

Harman, W. A., and G. D. Jennings. 1999. Natural Stream Processes. River Course Fact Sheet 1. AG-590-1. NC CES, Raleigh, NC.

Harman, W. A., and G. D. Jennings. 1999. Application of the Rosgen Stream Classification System to North Carolina. River Course Fact Sheet 2. AG-590-2. NC CES, Raleigh, NC.

Hauer, F.R., Lambert, G.A.. 1996. Methods In Stream Ecology. Academic Press Inc. San Diego, CA.

Hertgaard, M. 1999. *Earth Odyssey: Around the World in Search of Our Environmental Future*. New York: Broadway Books.

Herzog, Thomas R. et al, 2000 Cultural and Developmental comparisons of Landscape Perceptions and Preferences. *Environment and Behavior* 32:323-346.

Hunter, G.W. III, Fry, W.W., and J.C. Swartzwelder. 1960. A Manual of Tropical Medicine. W.B. Saunders Co., Philadelphia-London 3rd ed. 892p.

Interagency Committee on Water Resources, Subcommittee on Sedimentation. 1961. The single-stage sampler for suspended sediment. Report No. 13. US Government Printing Office. 105pp.

Kaiser, Florian G. and Shimoda, Todd A., 1999, Responsibility as a Predictor of Ecological Behaviour. *Journal of Environmental Psychology* 19: 243-253.

Karr et al., 2000. The Nature Conservancy and the International Network of Natural Heritage programs and Conservation Data Centers.

Karr JR and EW Chu. 1999. Restoring Life in Running Waters. Island Press, Washington DC.

Karr, JR and EW Chu. 2000. Sustaining living rivers. Hydrobiologia 422/423:1-14.

Knighton, David. 1984. Fluvial Forms and Processes. Rutledge, Chapman and Hall, Inc. New York, NY.

Leopold, Luna B. 1994. A View of the River. Harvard University Press. Cambridge, MA.

Leopold, Luna B., Wolman, Gordan M., and John P. Miller. 1992. Fluvial Processes in Geomorphology. Dover Publications, Inc. Mineola, NY.

Lothian, Andrew 1999. Landscape and the philosophy of aesthetics: is landscape quality inherent in the landscape or in the eye of the beholder? *Landscape and Urban Planning* 44:177-198.

Low-Impact Development Design Strategies. Prince Georges County, MD (EPA 841-B-00-003) (January 2000).

Low-Impact Development Hydrologic Analysis. Prince Georges County, MD (EPA 841-B-00-002) (January 2000)

Malakoff, David 2004. The River Doctor. *Science* 305:937-939.

Matilsky, Barbara 1992. *Fragile Ecologies: Contemporary Artists' Interpretations and Solutions*. New York: Rizzoli International Publications.

McDowell, W. H. and S.G. Fisher. 1976. Autumnal processing of dissolved organic matter in a small woodland stream ecosystem. Ecology, 57, 561-569.

McQuaid, B.F. and L. Norfleet. 1999. Journal of Soil and Water Conservation, 54, 657-665.

Miller, James H. 2004. Nonnative Invasive Plants of Southern Forests: A Field Guide for Identification and Control. USDA Forest Service.

Mozingo, Louise A., 1997. The Aesthetics of Ecological Design: Seeing Science as Culture. *Landscape Journal* 16:46-59.

Ogunseitan, Oladele, 2005. Topophilia and the Quality of Life. *Environmental Health Perspectives* 113:143-148.

Osmond, D.L., Gilliam, J.W. and Evans, R.O., 2002. *Riparian Buffers and Controlled Drainage to Reduce Agricultural Nonpoint Source Pollution*. North Carolina Agricultural Research Service Technical Bulletin 318, North Carolina State University, Raleigh, NC.

Page, L.M., Burr, B.M. 1991. A Field Guide to Freshwater Fishes. Peterson Field Guides. Houghton Mifflin Company, New York, NY.

Phankuch, D.J. 1975. Stream Reach Inventory and Channel Stability evaluation. USDA Forest Service, R1-75-002. Government Printing Office #696-260/200, Washington, DC. 26 pp.

Raven, P.J., N.T.H. Holemes, F.H. Dawson, P.J.A. Fox, M. Everard, I. R. Fozzard, and K. J. Rowen. 1998. River Habitat Quality: The Physical character of rivers and streams in the UK and Isle of Man. Environmental Agency. ISBN1 873760 42 9. Brisol, England.

Rosenthal, Ann, 2003. Teaching Systems Thinking and Practice through environmental art. *Ethics and the Environment* 8:154-168.

Rosgen, D.L. 1993. Applied Fluvial Geomorphology, Training Manual, Wildland Hydrology. Pagosa Springs, Colorado. 450 pp

Rosgen, D.L. 1996. Applied River Morphology. Wildland Hydrology. Pagosa Springs, Colorado. 378 pp.

Roth, N.E., J.D. Allen, and D.L. Erikson. 1996. Landscape influences on stream biotic integrity assessed at multiple scales. Landscape Ecology 11:141-156.

Roth, NE, JD Allen, and DL Erickson. 1996. Landscape influences on stream biotic integrity assessed at multiple spatial scales. *Landscape Ecology* 11:141-156.

Schlosser, IJ. 1995. Critical landscape attributes that influence fish populations dynamics in headwater streams. *Hydrobiologia* 303:71-81.

Schlosser. IJ. 1991. Stream fish ecology: a landscape perspective. *BioScience* 41(10):704-712.

Schueler, Thomas R., 1995. *Site Planning for Urban Stream Protection*. Washington: Metropolitan Washington Council of Governement.

Simon, Andrew, 1989. A Model of Channel Response in Disturbed Alluvial Channels. *Earth Surface Processes and Landforms* 14:11-26.

Snyder, CD, JA Young, R Villella and DP Lemarié. 2003. Influences of upland and riparian land use patterns on stream biotic integrity. *Landscape Ecology* 18:647-664.

South Carolina Department of Health and Environmental Control, Bureau of Water 1999. South Carolina Nonpoint Source Management Program 1999 Update. SCDHEC, Columbia, SC 174 pp.

South Carolina Department of Health and Environmental Control. 2004. South Carolina Regulation 61-68. Water Regulations and Standards. Bureau of Water. Columbia, SC. 60pp.

Special Issue, 1998. Eco-Relevatory Design: Nature Constructed, Nature Revealed. *Landscape Journal*. Special Edition.

Statzner, B., J.A Gore and V.H. Resh.1988. Hydraulic stream ecology: observed patterns and potential applications. Journal of the North American Benthological Society, 7. 307-60.

Thorne, Colin R., Hey, Richard D., and Malcolm D. Newson (Editors). 1997. Applied Fluvial Geomorphology for River Engineering and Management. John Wiley and Sons. New York, NY.

United States Environmental Protection Agency. Office of Water. 1997. Monitoring Guidance for Determining Effectiveness of Nonpoint Source Controls. EPA 841-B-96-004.

Wang, L, J Lyons, P Kanehl and R Gatti. 1997. Influences of watershed land use on habitat quality and biotic integrity in Wisconsin streams. Fisheries 22:6-12.

Waters, T. F. 1995. Sediment in Streams. American Fisheries Society Monograph 7. American Fisheries Society. Bethesda, Maryland. 251 pp.

Watzin, M.C. and A.W. McIntosh. 1999. Aquatic ecosystems in agricultural landscapes: A review of ecological indicators and achievable ecological outcomes. Journal of Soil and Water Society. 54, 636-644

Wenger, Seth. 1999. A Review Of The Scientific Literature On Riparian Buffer Width, Extent And Vegetation. Office of Public Service & Outreach, Institute of Ecology, University of Georgia

Wolman, M.G. 1954. A Method of Sampling Coarse River-Bed Material. Transactions of the American Geophysical Union. 35 (6) 951-956.