USING GREEN INFRASTRUCTURE TO SUPPORT WATER-BASED

RECREATION IN LAKE HERRICK

by

CHRISTOPHER LANE MORPHIS

(Under the Direction of Jon Calabria)

ABSTRACT

Lake Herrick was constructed on the University of Georgia's south campus in 1982 with facilities for swimming and boating. Following a period of declining water quality, the lake was closed and is now under-utilized. This research provides an understanding of the water quality problems and details how green infrastructure landscape design interventions can improve water quality. The ultimate goal is to enhance the lake's water quality and ecological health to reverse impairments and reinstate water-based recreation. An inventory and analysis of current and historical watershed conditions was conducted. Projective design was used to explore the feasibility of implementing a series of stormwater control measures (SCMs) throughout Lake Herrick's watershed. A total of 29 individual SCMs were proposed and illustrated with details including placement location, footprint, and total projected cost. The recommendations for lake management treatments provide insight and guidance for management and restoration planning at Lake Herrick.

INDEX WORDS: Watershed Management, Water Quality, Limnology, Hydrology, Green Infrastructure, Stormwater Control Measures

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by

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DEDICATION

This thesis is dedicated to Lake Allyn M. Herrick in the hope that its waters will one day be clean and filled with healthy and happy plants, animals, swimmers, and boaters.

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CHAPTER 1

INTRODUCTION

Stormwater runoff from urban development causes substantial pollution in surface waters. Investigation of water quality impairment at a lake on the University of Georgia's campus has revealed that the problems are characteristic of conditions in the watershed, rather than the lake itself. An important first step in improving the lake's water quality is to strengthen stormwater control measures in the lake's watershed. By facilitating such improvements, the University of Georgia will invest in the protection of natural resources on campus. The impetus to do so is found in the University's own commitment to environmental stewardship as stated in its Campus Master Plan, its Strategic Plan, and in the federal mandate of the Clean Water Act, which regulates pollutant discharges into the surface waters of the United States. This document is intended to provide context for understanding Lake Herrick's impairments and suggests possible courses of action for addressing those problems at their source using green infrastructure.

Problematic

Lake Allyn M. Herrick is a 15 acre lake adjacent to the University of Georgia's intramural field and Oconee Forest complex south of College Station Road. It was constructed in 1982 for purposes of recreation, research, and teaching. When the lake first opened, it featured a beach with a designated swimming area, a boathouse with canoes and sailboats available for student use, and a management plan that encouraged and provided for fishing. Additionally, the 45 acre tract of woods to the south of the lake, known as Oconee Forest, was established as a park complete with hiking trails, picnic areas, and a campground. The area immediately became a popular recreational amenity for the University of Georgia community and the surrounding residential neighborhoods. It has been the site of a mountain bike race and an annual triathlon, although both of those activities, along with boating and recreational swimming in the lake, were discontinued in 2002. However, Lake Herrick and the Oconee Forest area are still used by many classes for field studies in forestry, ecology, biology, and other biological sciences. The trails around the lake remain popular for walking, running, and biking; a ropes course and off-leash dog park are both well-used amenities. Additionally, the intramural field complex adjacent to the lake and Oconee Forest Park is very popular.

Despite the 45 acres of forest directly adjacent to the lake, Herrick's 325-acre watershed is primarily urban in character. Roughly 65 percent of its area is urban and residential development. The watershed and surrounding land have been subject to increasingly intensive use and development since the creation of the lake. Water quality has declined over time, as indicated by compounding management issues. Specific problems that have affected or currently affect the lake include invasion by aquatic weeds and waterfowl, cyanobacteria blooms, and difficulties related to establishing and maintaining a desirable fish population. Sedimentation is problematic and water quality tests have revealed high levels of contamination by fecal coliform bacteria and nutrients. A ban on swimming and boating was implemented in 2002, reflecting the growing severity of the lake's problems. Since then, Herrick has remained closed to water-based recreation and persists in an underutilized state.

Many of Lake Herrick's various problems are symptomatic of biological and chemical imbalances within the lake, but their underlying cause can be attributed to the accumulation of material inputs to the water body from throughout the lake's watershed. A watershed is "the land from which rain and surface water drain towards a central collector such as a stream, river, or lake" (Holdren et al. 2001, 165). Sediment, organic matter, and nutrient loading is a natural process inherent to all lakes and is referred to as eutrophication. The rate at which the process occurs is variable and depends on watershed conditions related to underlying geology, soil fertility, vegetative cover, runoff patterns, and land use. Many lakes, especially in the Southeast, are eutrophic simply due to background watershed characteristics. However, it is well-documented that human activities like construction, agriculture, and forestry tend to accelerate eutrophication. (Holdren et al. 2001, 2-4; Schueler and Simpson 2001, 748; Cooke et al. 2005, 14-15)

The most pervasive transport mechanism for the pollutants that cause accelerated sedimentation and eutrophication rates is termed nonpoint source pollution. It occurs when substances, including both those that occur naturally within a landscape and those that are human in origin, are conveyed into surface waters by stormwater runoff. It is diffuse in nature and has no centralized source. It is thus the opposite of point source pollution, which is pollution from a specific point of origin, such as discharges from a factory, a sewage treatment facility, or a marina. Nonpoint source inputs to surface waters are generated by all types of land disturbing activities. Broad categories of impactful land uses include agriculture, silviculture, resource extraction, waste disposal, construction, and residential, commercial, and industrial development. Some specific nonpoint source inputs include sedimentation from land-disturbing activities, general stormwater runoff from developed areas, illicit discharge or improper storage and disposal of harmful materials. The pollutants released and the severity of their effects on surface waters tends to vary depending on the types of land use in the watershed and the pollution control measures and management strategies employed (Georgia Department of Natural Resources 2000, 1).

The passage of the Clean Water Act in 1972, with its mandatory controls for pollutant inputs into waterways, has led to significant mitigation of point source impacts. Nonpoint source pollutants, however, have proven to be more difficult to regulate and are implicated as major contributors to the continued impairment of Georgia's waterways (Cooke et al. 2005, 11; Georgia Department of Natural Resources 2000, 35). In a study conducted from 1981 to 1983, 21 streams throughout the state were monitored to characterize the nonpoint source impacts from Georgia's most typical land uses: urban, agricultural, and silvicultural. The results indicated that urban runoff is the most severe contributor of nonpoint source impacts, and the leading cause of stream impairment in Georgia (Georgia Department of Natural Resources 2000, 61). Typical pollutants found in urban runoff include fecal coliform bacteria, metals, sediment, and nutrients (Georgia Department of Natural Resources 2000, 8).

A study conducted by the United States Environmental Protection Agency in 1986 revealed half of all lakes in the US to be eutrophic or hyper-eutrophic. This is a subjective designation that indicates that the water body has high rates of nutrient inputs and is undergoing the natural process of nutrient loading at an accelerated or undesirable rate. The condition was more prevalent amongst urban lakes, with 80% categorized as eutrophic. This is primarily because urban watersheds tend to contribute higher phosphorous loads than watersheds dominated by other land uses. Phosphorous loading is mainly driven by stormwater runoff, and is often a result of excessive fertilizer application. Other sources, many distinctly urban, include sewer overflows, municipal wastewater discharges, and septic malfunctions. (Schueler and Simpson 2001, 747-748) Phosphorous is the limiting nutrient for the growth of algae and aquatic macrophytes (weeds), which are two of the most prevalent sources of lake problems. Phosphorous levels are therefore a common focus of lake management activities. A great number of techniques have been devised for manipulating them, such as aluminum and copper sulfate treatments.

Urban watersheds also contribute high sediment loads. Sediment loading is one of the most prevalent problems affecting lakes in the United States, after nutrients and metals. It is considered the primary source of water quality impairment in 1/4 of impaired lakes, and it has been cited as Lake Herrick's single most significant water quality problem (Williams 1997). Sediment is an aggregation of particles of various materials. It is composed mainly of minerals and organic matter from soil, but many other substances may be mixed in or chemically bound to the particles. Urban lakes often have nutrients, metals, bacteria, pesticides, and polycyclic aromatic hydrocarbons (PAHs) associated with their sediments (Schueler and Simpson 2001, 749). Sediment makes the water more turbid, blocking light penetration. It negatively affects fish habitat, disrupting spawning and feeding, and can also cause water to smell and taste unpleasant. (Holdren et al. 2001, 161) Sedimentation is often associated with construction (Schueler and Simpson 2001, 749), as was the case when the UGA Bus Center was constructed on Riverbend Road in the mid-90's, causing a spike in sediment transport into Lake Herrick (Williams 1997). As with phosphorous, stormwater runoff is the predominant vector for sediment transport into surface waters. Sediment is also released directly into waterways via stream channel erosion, the result of increased peak water velocities and volumes associated with unmitigated impervious development (Brown and Caldwell 2007, 6).

Water quality monitoring has indicated that bacteria, nutrients, and sediment exceed established recommended limits and are primary parameters of concern at Lake Herrick. Thus, the lake is affected by all of the parameters commonly associated with urban nonpoint source pollution, and experience has shown these pollutants to be detrimental to the University of Georgia's recreational goals. Lake Herrick is just one among thousands of nonpoint-source impacted urban lakes in the United States. The biological and chemical processes that affect its condition have been widely studied and understood, and lake management techniques continue to evolve and reach new levels of sophistication. However, there is no panacea for addressing the complexities of urban nonpoint source pollution. Instead, a host of treatments exists to target various elements of both the symptoms and the underlying problems. The best solution for any individual lake must respond to the unique characteristics of the water body, its watershed, and the goals and capabilities of its managers.

Research Question

This document addresses the question: Can comprehensive watershed management techniques be applied to address Lake Herrick's pollution problems so that its former water-based recreational functions can be restored? This question reflects the notion that the watershed is the most logical unit for management. Water quality is influenced by the land cover and uses that runoff must pass through before it enters surface water. The watershed contributes both the water that feeds the lake, as well as the pollutants that impact it. The problems that affect Lake Herrick, then, are symptomatic of inputs of external origin; they are a result of conditions and processes within the lake's watershed (Holdren et al. 2001, 129, 165). Therefore, the solutions explored by this thesis focus primarily on the lake in the context of its watershed, and explore how watershed-scale interventions can influence the lake's water quality and reduce impairment.

Purpose

The purpose of this research is to gain an understanding of the problems that impact Lake Herrick's water quality and how landscape design interventions can reduce impairment. The ultimate goal is to generate information that can be applied to enhance Lake Herrick's water quality and ecological health so that it may be restored as a recreational amenity. This document is intended to provide guidance for stakeholders in understanding the current state of the lake and to suggest possibilities for reducing pollutant inputs. Central to this is the exploration of potential locations for green infrastructure interventions using projective design. New knowledge created by this process includes an account of the history of the Lake Herrick watershed, synthesis of water quality data, and a watershed analysis with an emphasis on ideal locations for SCM placement.

Goals

Effective watershed management requires first setting the desired function of the water body, and then defining specific measures for how to achieve that function (Holdren et al. 2001, 5). This section is divided into two parts: the first defines an overarching functional objective; this provides a framework for the second part, which defines the scope of the management activities explored in this thesis.

Long Term Functional Priorities for Lake Herrick

Maintaining a lake with clean water is an obvious goal. However, this requires resources – possibly substantial amounts of effort and money. Other, less resource-intensive courses of action may therefore be preferable.

The first alternative is inaction - do nothing at all. If no steps are taken to manipulate the lake's condition, it will probably continue to exist in a relatively benign state for many years. The lake will be subject to the persistent natural processes of sedimentation and eutrophication. It will fill with sediment over the course of decades, losing volume and depth and undergoing a succession of vegetation (Holdren et al. 2001, 4). Wetland conditions will extend throughout the cove near the bridge, and then throughout the body of the entire lake. Algae and rooted aquatic plants would dominate the growing expanses of shallow water, followed by a succession of common wetland plants. Accumulated biomass will eventually support woody vegetation (Lanier 2014). Such a course of inaction would ensure that the lake would remain unusable for purposes of water-based recreation. However, it would continue to be a natural aesthetic feature. The successional wetland ecosystem would provide habitat value for a variety of species, and academic and research opportunities for the University. If the process were well documented, it would provide a unique case study in the effects of natural processes on a man-made impoundment.

Another option is to remove the dam and allow the lake to revert to a stream. It is important to remember that Lake Herrick is not a natural ecosystem. It is a structure that was created by people relatively recently. Impounded lakes differ in fundamental ways from natural lakes, and their physical characteristics make them more susceptible to impairment. Perhaps of greatest consequence are their much larger watersheds, which contribute correspondingly large pollutant loads. (Schueler and Simpson 2001, 747) As a man-made environment, Lake Herrick is subject to maintenance requirements if it is to be expected to uphold specifically desired characteristics. Restoration of the creek that originally flowed through the landscape would allow for the reestablishment of self-maintaining natural processes. This relieves the University of Georgia of some maintenance burden, as it takes more effort to maintain an artificial system than a natural one. Another benefit of this approach would be the addition of 15 acres of restored natural area to the Oconee Forest Park, including wetlands. The creek would be a novel ecosystem within the park, and a positive contributor of habitat to a variety of plant and animal species.

This course of action is not without its drawbacks. It creates the potential for concentrated flow of sediment into the North Oconee River as the lake drains and the stream begins to cut down through accumulated sediment and carve a new channel. The wisest course of action to avoid overloading the North Oconee with sediment inputs would be to manage the process. Designing and constructing a new channel with appropriate fluvial geomorphologic dimensions, as well as stabilizing the former lake bed with vegetation, are both measures that would help prevent mass wasting of sediment.

Should it be determined that the most preferable course of action is to maintain Lake Herrick to use it for a specific purpose, then the next step is to define that purpose. The Environmental Protection Agency requires states to assign designated use classifications to their surface waters and adopt water quality standards that correspond with those uses. Designations include public water supply, protection and propagation of fish, shellfish, and wildlife, recreation, agriculture and industry, navigation, or other (USEPA 2014a). The North Oconee River is designated as a drinking water supply. In order to be considered compliant with their designated use, water bodies must meet criteria for certain water quality parameters – bacteria, dissolved oxygen, pH, and temperature – that are established by the state (State of Georgia 1974).

As a minor tributary to the North Oconee River, Lake Herrick does not have a designated use of its own. However, it is required to comply with and maintain downstream standards. As an urban water body that contributes water to a drinking water supply, Lake Herrick has the impetus of upholding “extensive watershed practices to protect public health” (Schueler and Simpson, 2001, 749). Monitoring has revealed that Lake Herrick is occasionally in violation of water quality standards for bacteria, nutrients, metals, and pH.

For the purpose of hypothetical exploration, this thesis is written with the presumption that obtaining water quality that supports contact recreation - swimming and boating - is the desired goal for Lake Herrick. The UGA Recreational Sports Department has expressed the wish to restore facilities for both activities, which have been popular amongst Lake Herrick users in the past. Fishing was popular as well, but could not be sustained for long. The high number of fishermen relative to the small size of the lake put heavy pressure on the fish populations. Population structures exhibited undesirable changes despite extensive nutrient subsidies and other chemical applications. It was costly to stock the lake with fish and apply fertilizer regularly, and the chemicals contributed towards the eutrophic conditions that drive algal blooms (Williams and Cook 1987, Shipman 1989, Smith et al. 1997).

Managing Lakes and Reservoirs defines a lake problem as "a limitation on the desired uses by a particular set of users" (2001, 5). Desired uses often conflict, and some are more practical than others.

The appropriateness of a particular use depends on the natural characteristics of the lake and its watershed. If the lake must be changed extensively from its natural state to meet a conflicting use, then it raises the question of whether it is worth the effort, time, and cost. (Holdren et al. 2001, 5) Managing a lake for fishing often entails boosting fish productivity by adding nitrogen and phosphorous-containing fertilizers, which is at odds with the goal of reducing nutrient loading for improved swimming and boating (Holdren et al. 2001, 34). The two objectives may be mutually exclusive depending on the amount of chemical inputs and the lake's capacity for absorbing them. Determining whether fishing is a feasible use for Lake Herrick alongside swimming and boating is beyond the scope of this thesis.

Ultimately, reducing bacteria and nutrient loading is beneficial to the purposes of maintaining drinking water supplies, facilities for contact recreation, and fishing. Minimizing pollutant inputs to the lake will also contribute towards the mitigation of urban nonpoint source pollution in the North Oconee River, helping it to meet its designated use as a water supply. This thesis is ultimately concerned with how design interventions can affect pollutant loading, regardless of the ultimate management goal.

Selecting Measures for Achieving Desired Function

It is necessary to define the measures that will be employed to address the specific problems and conditions that impede the realization of Lake Herrick's desired function. There are numerous well-established lake management techniques for managing problems related to excessive algae and sediment, the two primary impairments to meeting Lake Herrick's recreational use goals. Sediment treatments also affect bacteria levels, to the extent that sediment is acting as a vector for bacteria loading. Relevant methods include nutrient diversion, phosphorous inactivation, dilution or flushing, hypolimnetic withdrawal, artificial circulation, food-web manipulations, aluminum or copper sulfate treatment, herbicide treatment, sediment removal (dredging), aeration, and protection from urban runoff. (Cooke et al. 2005, 73-75; Schueler and Simpson 2001, 749)

All of these techniques except for protection from urban runoff are in-lake treatments that rely primarily on manipulating the water body's internal physical and chemical conditions to achieve desired characteristics. When applied targeting specific water quality variables, such treatments provide quick results with generally attainable up-front costs. In-lake treatments can be valuable elements of a long-term management strategy and are often the only cost-feasible way to manage eutrophication symptoms. However, these methods are costly in both the short and long term as they must be applied repeatedly and indefinitely. The effects of in-lake interventions are limited in that they only address the symptoms of pollution rather than the underlying cause (Schueler and Simpson 2001, 750). Lake Herrick's problems are caused by nonpoint source inputs of external origin as a result of urban watershed conditions and processes.

Although watershed-scale holistic solutions are often more difficult to implement, they are the best way to manage eutrophication (Schueler and Simpson 2001, 750). Effective long-term management must go beyond manipulating conditions within the aquatic environment and address problems at their source. Because many of Lake Herrick's problems stem from the undesirable effects of high eutrophication rates, management activities should focus on controlling the rate at which eutrophying inputs are added. (Holdren et al. 2001, 2, 129) By reducing the flow of pollutant inputs into the lake, watershed management strategies can reduce the burden on in-lake interventions by reducing the amount of work that they must perform, the amount of resources that must be devoted to them over time, and their long-term costs.

Lakes continually recycle materials, so nutrients and other contaminants tend to persistently affect conditions long after loading has been reduced. The appropriate role of in-lake treatments is to address this effect in a supplementary capacity to watershed-scale management; they can be used to increase the rate of uptake of the eutrophic substances that are already present in the lake. (Cooke et al. 2005, 14)

The management solutions proposed by this thesis will focus on mitigating nonpoint source pollutant inputs from throughout the watershed. Of particular interest is an emerging body of techniques collectively termed "green infrastructure." Green infrastructure is a term with multiple definitions and contexts, but this thesis will focus on its role in stormwater management. It refers to a host of systems that are employed to lessen the hydrologic changes and nonpoint source pollutants that development patterns impose on the landscape. This thesis will use projective design to explore the implementation of a type of green infrastructure strategies known as structural stormwater control measures (SCM). Specific SCM structures applied to the Lake Herrick watershed include water harvesting systems, porous paving, bioretention areas, and a stormwater wetland. Collectively, these are intended to contribute towards improved water quality, enhanced ecosystem function, and slowed runoff velocities in the Lake Herrick watershed. Stormwater control measures are widely endorsed and are being utilized for stormwater management purposes with increasing frequency (Bertule, et al. 2014, 9). As this thesis will demonstrate, they pose a likely means for the rehabilitation of our university resource.

Significance

Lake Herrick is the aesthetic centerpiece of South Campus' Oconee Forest and intramural field complex, and it has great potential ecological and recreational value. A diverse array of stakeholders in various departments throughout the University of Georgia have expressed interest in restoring the lake, and a multidisciplinary coalition is already hard at work on efforts to improve the quality of all surface waters on campus, including Lake Herrick. Leaders in the Recreational Sports department have expressed interest in re-opening Lake Herrick for swimming and boating, and the health and proper management of Oconee Forest and Lake Herrick have always been an imperative of the Warnell School of Forestry. The widespread desire to reinstate the lake's former uses has momentous possibility, if only its problems can be understood and synthesized into a plan of action.

Most of Lake Herrick's 325-acre watershed lies on UGA's property. This includes the majority of the intramural fields, a portion of the family housing complex, part of the campus transit bus depot, and all of Oconee Forest Park. The watershed also contains a residential neighborhood, some apartments, city streets, and a stretch of Highway 10. The University's predominant presence in the area, combined with its vested interest in the quality of the lake as a recreational and educational amenity of its own creation, are favorable social circumstances for efficient and comprehensive SCM-driven water quality improvement.

Although pollutant loads in Lake Herrick are becoming increasingly elevated over time, they are not so far out of hand as to be un-manageable. Water quality goals of reducing pollution to levels acceptable for swimming and boating are realistically obtainable; Lake Herrick's waters could conceivably be suitable for swimming soon after structural SCM implementation. The tangible recreational benefits brought about by successful restoration of the Lake Herrick watershed could catalyze similar efforts with other, more highly-impacted campus watersheds.

Efforts at regulating and remediating surface water contamination by point source pollutants have had widespread success in the decades since the passage of the Clean Water Act. As a result, municipalities are increasingly shifting their attention and resources towards the more complicated task of controlling nonpoint source problems (Georgia Department of Natural Resources 2000, 7). The U.S. Environmental Protection Agency regards urban runoff as one of the greatest sources of impairment in the nation's waterways. The United States population continues to grow and urbanize, and higher urban densities are projected for the future. This elevates the necessity of developing and implementing new strategies to counter further adverse water quality impacts (Garrison and Hobbs 2011, 8). Environmental policy advocates agree; the United Nations Environmental Programme, for example, calls for "improved decision making and appropriate assessment" of possibilities for water infrastructure that incorporates "social and environmental dimensions" in addition to more traditional water quality and quantity management objectives (Bertule et al. 2014, 9).

Green infrastructure plans are being developed and implemented for incorporation in municipal systems of numerous major cities. Cities on the forefront of GI practices include Chicago, Kansas City (MO), Milwaukee, Nashville, NYC, Philadelphia, Pittsburgh, Portland, Seatle, Syracuse, Toronto, and Washington DC (Garrison and Hobbs 2011, 6). Some low-level implementation is common to most regions of the country. In fact, some SCMs are already in use at UGA. Current practices installed on campus include green roofs, bioretention, water harvesting systems, and porous paving.

The emergence of green infrastructure is underpinned by a growing societal understanding about the value that natural systems can provide to society. Green infrastructure solutions are becoming more widely recognized as multi-functional technologies that are able to fulfill wider dimensions of social, economic, and environmental value. Such benefits are often intangible or otherwise difficult to quantify. However, valuation methods are becoming increasingly adept at modelling and accounting for the total social, economic, and environmental co-benefits, or "triple bottom line," that accompany the stormwater management services for which green infrastructure is primarily implemented. (Garrison and Hobbs 2011, 15) Potential co-benefits include: "food production, raw materials, medicinal resources, carbon sequestration and storage, pollination, habitat, maintenance of genetic diversity, recreation, tourism, aesthetic and cultural value, spiritual experiences," (Bertule et al. 2014, 19) air cooling and cleaning, reduction of asthma and other illnesses, reduction of cooling costs, and local green job creation. Green infrastructure implementation also avoids manufacturing costs associated with gray infrastructure such as concrete manufacturing and associated air pollution and carbon emissions. (Garrison and Hobbs 2011, 15)

The characteristic multi-functionality of green infrastructure is apparent in the potential benefits that could be derived from the implementation of SCM facilities on UGA's campus. In addition to directly improving water quality, they can also serve as demonstration projects for education and outreach to promote water quality protection practices amongst the campus community and general public. Efforts have been made with some of UGA's existing SCMs to harness their educational value, but most of them are not highly publicized or outfitted with interpretive information. SCM implementation in the Lake Herrick watershed constitutes a particularly apt educational opportunity for a diverse variety of people. Because the watershed's two major water bodies are at the center of UGA's recreational sports and nature park complex, they are highly visible and thus provide ample opportunity to showcase structural SCMs for demonstration, education, and research. Every stage of SCM installation, monitoring and maintenance is an opportunity to educate stakeholders through class instruction, research, workshops, field days, and general press. Target audiences in the Athens-Clarke County community include grade school students, practitioners involved with the design and construction of stormwater infrastructure, and residential landowners in the upper portion of the watershed. University students would benefit from classroom opportunities to learn about SCM function firsthand. Researchers interested in more in-depth involvement would be able to monitor SCM performance and develop cost-benefit analyses, thereby contributing to the growing body of research surrounding this nascent technology.

Monitoring is a particularly important component of projects that utilize SCMs for water treatment because there is currently only a small body of peer-reviewed literature that addresses the efficacy of these methods. Such technology is relatively new compared to conventional, mechanized water treatment methods, and an expanded knowledge base is necessary to improve modelling tools for more accurate projections of water quality improvement (Bertule et al. 2014, 66-67). The University of Georgia is home to a strong culture of high quality scientific research, and is thus suited to take full advantage of the opportunity to monitor the function of SCM facilities. Publication of research findings will contribute to the development and enhancement of green infrastructure technology.

Thesis Structure

Chapter Two of this thesis explores the natural processes affecting the lake. This provides context for interpreting the significance of water quality monitoring results and understanding the desirable chemical and biotic structure for maintaining water quality goals. Chapter Three is an inventory and analysis of Lake Herrick that documents the historical development and current conditions of the lake and its watershed. This includes an inventory of all relevant historic documentation related to the construction and management of the lake, a compilation and synthesis of water quality data and descriptions of management problems, a visual assessment of existing physical conditions, and identification of information that does not currently exist but would be useful for future study. Chapter Four is an overview of relevant structural stormwater control measures. Chapter Five focuses on applying green infrastructure to Lake Herrick through a projective design that places SCMs within Lake Herrick's watershed. The thesis concludes with Chapter Six, which provides a synopsis of the recommended course of action for meeting water quality goals at Lake Herrick.

CHAPTER 2

LIMNOLOGY

Lakes are ecosystems characterized by complex chemical, physical, and biological interactions. A thorough understanding of ecosystem structure and behavior is critical for those endeavoring to manage a body of water. Structural and functional characteristics differ from lake to lake, affected by the water body's physical form and the unique influences of local environmental conditions. This chapter provides an overview of basic limnology, with specific focus on the context of Lake Herrick: a relatively small, shallow, man-made water body in the Georgia piedmont. The chapter begins with a discussion of the differences between natural lakes and man-made impoundments. This is followed by exploration of the influence that regional geography and watershed conditions can have on a water body. Next is a review of the anatomy of lakes and reservoirs, and then a section on the physical, chemical, biological, and energetic processes and functions that may occur. This includes external flows of energy and materials into the water body and processes that influence the internal cycling and interactions of those materials and energy. Next is a profile of the common biotic assemblages found in lakes. The chapter ends with an overview of the water quality parameters that have been monitored in Lake Herrick, and how they relate to the lake ecosystem.

Lakes versus Reservoirs

Lake Herrick is more accurately described as an impoundment or reservoir. That is, "a lake created by artificially damming a stream or river." (Holdren et al. 2001, 1) Nearly all lakes in Georgia are man-made; the only natural lakes common in the southeast are the coastal plain and karst lakes in Florida. (Cooke et al. 2005, 24) Reservoirs are physically, chemically, and biologically similar to natural lakes, but differ in their age, morphology, location within the drainage basin, and hydrology. (Holdren et al.

2001, 23; Cooke et al. 2005, 24) The average reservoir is deeper, has more surface area, and cycles water faster than natural lakes. Because they are flooded river valleys reservoirs are often long and narrow, in contrast with the generally rounder perimeter that is characteristic of lakes. Natural lakes are more likely to have multiple small streams and wetlands that flow into them. Reservoirs, in contrast, are commonly supplied by one primary stream and have the characteristics of a river near the inflow point. (Cooke et al. 2005, 24) This is not the case with Lake Herrick, however, which is fed by two perennial streams. Reservoirs also include an engineered discharge mechanism. (Holdren et al. 2001, 23-24) This enables water levels to change much faster in a reservoir than in a lake as a result of management decisions, with ramifications for the survival of shoreline plant communities. (Cooke et al. 2005, 25)

Reservoirs tend to have watersheds that are "an order of magnitude greater" in size than those of natural lakes (Cooke et al. 2005, 24) because they are constructed for purposes of water supply and flood storage. Reservoirs' position in-line with streams also contributes to pronounced nutrient and sediment loading because stream channels undergo a natural constant erosive process. Reservoirs are thus subject to higher inflows of water, sediment, and nutrients than natural lakes and are more likely to develop problems with sediment and nutrient loading. (Cooke et al. 2005, 23; Holdren et al. 2001, 4, 24)

Throughout this chapter the word "lake" will be used interchangeably to describe both lakes and reservoirs.

Regional and Watershed Characteristics

The ecosystem of a water body includes and is influenced by its watershed in many ways. Watershed size is a particularly influential characteristic. A watershed is considered to be large if its area is seven to ten times greater than the water body's surface area. Water bodies with large watersheds tend to be more easily disturbed by human activity than those with small watersheds, they receive more runoff, more sediment and nutrient loading, and water cycles through the water body faster. They also respond faster to management interventions. (Holdren et al. 2001, 9, 18-19)

The topography surrounding the lake is also important. Steeper slopes cause greater volumes of runoff at higher-velocities, which leads to heightened erosion and thus higher rates of sediment and nutrient loading. Geology and soil types also affect sediment and nutrient loading. Mineral inputs can affect water chemistry and clarity. More erosion can be expected from loose soils with intermediate particle sizes. Small soil particle sizes cause higher rates of runoff due to their low infiltrative capacities. Runoff and the erosion and transport of particles and other materials are also influenced by land cover. Bare ground is highly susceptible to erosion because it has no protection from the force of rain drops. Conversely, dense vegetative cover prevents erosion and increases infiltration. Impermeable surfaces increase runoff volumes because the water that strikes them does not infiltrate into the soil. Human inputs into the landscape, such as fertilizer, pesticides, septic leachate, and road salts, are often conveyed into water bodies via runoff. (Holdren et al. 2001, 19-20)

The hydrologic effects of impermeable surface coupled with anthropogenic chemical and material inputs mean that landscapes that are dominated by intensive human use (primarily urban and agricultural areas) have significant influence on the watersheds within them. Lake managers are increasingly conscious of the unique characteristics of urban watersheds. Urban land use is a better indicator of consistent properties than trophic state, geomorphic origin, or any other ways in which limnologists have traditionally classified lakes. Urban development has a distinct and pervasive impact on lake quality. Urban lakes commonly share the following qualities: they tend to be small, with surface areas less than ten square miles. They are shallow, with average depths of less than 20 feet. They have large watersheds relative to the surface area of the water body, often with ratios greater than 10:1. This reflects the man-made origin of most urban lakes. Their watersheds "contain at least five percent impervious cover." They are usually managed for at least one purpose, including but not limited to water supply, recreation, or flood control. (Schueler and Simpson 2001, 747)

Urban watersheds produce high concentrations of pollutants, particularly pathogens, nutrients, turbidity, and chemicals. These inputs make it difficult for lakes to serve the drinking water supply purpose that is often a primary function. Urban watersheds contribute more sediment than other types of land uses, stemming from stormwater runoff, construction, and stream channel erosion. As a result, urban lakes tend to be more turbid than lakes in less developed environments. The sediment characteristics of urban lakes are often consistent; they contain nutrients, metals (especially zinc), and polycyclic aromatic hydrocarbons (PAHs). PAHs are linked to vehicle traffic. (Schueler and Simpson 2001, 748-749)

Many lake characteristics are influenced by the general geography of the water body. Relevant variables that can differ with physical location include "climate, mineral availability (soils and geology), vegetation, and physiography." The *ecoregion* is a common unit of categorization that has been developed to reflect the influence of "ecosystem regional patterns of nutrient concentrations, biotic assemblages, and lake trophic state." The United States contains 75 unique ecoregions. While properties of those specific ecoregions tend to be variable, they are more similar to each other than they are to separate ecoregions. Ecoregional classification helps in establishing what conditions are common, supported by nature, and attainable through reasonable levels of management. Goals that conflict with ecoregional characteristics can only be achieved through extraordinary expenditure. Thus, the classification system helps to inform whether expectations are realistic. (Cooke et al. 2005, 34-36)

For example, natural fertility is a factor that varies geographically. There is a possibility that an impoundment was never infertile to begin with, and natural processes may be working with exceptional force to fill it in with sediment and nutrients. Particularly concentrated management would be necessary to maintain the goal of excluding algae and sedimentation. In such a case of naturally high fertility, fishing may be a more appropriate use than swimming. (Holdren et al. 2001, 219)

Athens is in the Southern Outer Piedmont ecoregion, which is characterized by low-relief rolling hills underlain by fine-textured, mostly clayey soils over Precambrian and Paleozoic metamorphic and igneous rocks. The dominant vegetative biotic assemblage is loblolly-shortleaf pine, with some oak-hickory and oak-pine forests as well. The ecoregion’s northern boundary is roughly 45 miles north of Athens, and it extends about a hundred miles south of Athens to the Fall Line where it transitions to the Coastal Plain. (Georgia Department of Natural Resources 2001)

Lake and Reservoir Anatomy

Lakes and reservoirs have several distinct parts, each with different physical and ecological characteristics. They are ringed by the *marginal zone*. This area may also be referred to as the *riparian zone*, which is a term that applies to the shoreline of both lakes and streams. It is an ecotone, or ecological edge, where the terrestrial and aquatic environments meet. The marginal zone is not defined by distinct limits, but rather a gradient from land to water dictated by topography in relation to the waterline. Its extents may shift following changes in water level. (Holdren et al. 2001, 10; Cooke et al. 2005, 131) It encompasses several characteristic gradient-aligned vegetative communities: the submerged, emergent, semi-terrestrial, and terrestrial. Marginal zones have notably "high species diversity, very high biomass and productivity, high retention of materials, and periods of significant export of dissolved and particulate organic material that subsidize aquatic food webs." When inhabited by healthy plant communities, the marginal zone buffers shoreline sediments against erosive forces and reduces the pollutant concentrations and overall volume of both surface and sub-surface runoff. It thus has an important influence on water quality. Potential causes of marginal zone degradation that may apply to Lake Herrick or its tributaries include increased stream discharge and velocity, increased impervious area, and detrimental impacts associated with lawns. (Cooke et al. 2005, 131) Marginal zone rehabilitation, particularly for purposes of retaining runoff-borne pollutants, is applicable to certain areas of Lake Herrick's shoreline and tributary streams. It also could be an effective strategy for controlling erosion and improving the aesthetic quality of Parvo Pond’s western edge.

The aquatic portion of a water body can be divided into two general areas: the *photic zone* and the *aphotic zone*. The photic zone encompasses all water which is close enough to the surface that there is enough light for photosynthesis. Its depth depends on water transparency and can change seasonally due to the presence of algae and suspended solids. Within the photic zone is the *littoral zone*, which is characterized by shallow water, beginning at the shoreline in the marginal zone and extending to the depth at which light no longer penetrates to the bottom. It tends to be biologically diverse as its sediments support rooted plant growth. Both the sediments and the plant communities that grow in them provide habitat for a variety of flora and fauna. Also included in the photic zone is the *pelagic zone*, characterized by open water extending from the surface to the depth where light no longer penetrates. This depth varies depending on turbidity levels. A relatively shallow water body like Lake Herrick will be dominated by the photic zone; a large proportion of the lake can support plant growth. Those lightless depths beneath the photic zone are the aphotic zone, where no photosynthesis takes place. Within the aphotic zone are the *profundal zone*, which is beneath the pelagic zone, and the *benthic zone*, which consists of the lake's bottom sediments. (Holdren et al. 2001, 10, 22, 31)

Reservoirs often have several other zones which reflect their positions in the flow path of streams. The area extending from where a tributary stream flows into a reservoir is known as the *riverine zone*, and is characterized by high levels of mixing and flow. The *transition zone* is where flow velocity slows and sedimentation and clarity increase. The *plunge point* occurs when the inflowing water reaches a place where it is colder than the water at the surface of the reservoir and sinks to a level of equal density. If the current created by this plunge flow is strong enough, inflowing loads may not mix uniformly throughout the water body. This results in complex mixing effects that are inconsistent with standard models. Stream inflows often tend to be high in nutrients, but if their water is conveyed directly to the reservoir outlet with minimal mixing, those nutrients may not be dispersed throughout the water body to a high degree. The *lacustrine zone* of a reservoir is the deepest area near the dam that is most similar to the open water of a natural lake. It is characterized by high levels of internal nutrient recycling. The thermal properties of a reservoir are also influenced in at least a minor way by the design of the dam's water release mechanism. When the dam outflow draws water from the deeper parts of the lake, heat is stored. When shallow water is released, heat is discharged. (Cooke et al. 2005, 25)

Lakes also have divisions that reflect their thermal properties. *Stratification* is the process by which water becomes separated into distinct layers based on temperature variations at different depths. It affects the movement of nutrients throughout the water column and drives various ecological processes. Its functional implications will be addressed in more detail later in this chapter. The *epilimnion* is the warm surface water in a stratified lake. This zone is uniformly mixed by wind energy. The *hypolimnion* is cool, unmixed water at the bottom of the lake. The *metalimnion* is a zone of transition where the temperature is not uniform. Instead, there is a gradient between the high temperature of the epilimnion and the low temperature of the hypolimnion. The metalimnion is characterized specifically as an area where the temperature changes more than one degree Celsius for every meter of depth. The *thermocline* is the depth in the metalimnion with the highest rate of temperature change. (Holdren et al. 2001, 25)

The morphometry, or physical dimensions, of a water body has implications for its water quality and productivity. *Surface area* is a general measure of a lake's size. Its *volume* has bearing on the dilution of inflowing materials and the time that it takes for water to circulate through the lake. *Fetch* is the longest distance that wind blows over the surface of the lake. This affects water and sediment mixing, with implications for turbidity and nutrient dispersal. The *shoreline length* is the perimeter. This tends to be longer in reservoirs than in natural lakes (Schueler and Simpson 2001, 748). Water bodies with long shorelines relative to their surface area are more heavily influenced by inputs from their marginal zones, which may contribute large quantities of organic matter to the rest of the lake. The *maximum depth* is the lake's deepest point. This affects stratification and the proportion of the lake that is habitable to algae. In shallower lakes, algae can spread throughout most of the volume because light penetrates through a large portion of the water body. In deeper lakes, much of the volume may not receive enough light for algal growth. (Holdren et al. 2001, 21-23)

Dividing a lake's volume by its surface area gives the *mean depth*. Lakes are considered to be shallow if their mean depth is less than three meters. (Holdren et al. 2001, 151) Lake Herrick almost certainly falls into this category, as its maximum depth in 1999 was recorded at just 5.5 meters (Krauss et al. 1999) and it is probably much shallower for the most part.

Shallow lakes are more common than deep ones and their physical characteristics make them more likely to be eutrophic. Light is able to penetrate a large proportion of the lake, enabling extensive photosynthesis. There is also a higher sediment to water contact ratio, which stimulates nutrient recycling processes. (Cooke et al. 2005, 33; Holdren et al. 2001, 151) The impact of nutrient release from bottom sediments is more widespread in shallow lakes. In deeper lakes, stratification acts as a buffer against the spread of benthic sediments throughout the water column, but shallow lakes are more likely to lack distinct thermal layers most of the time. Interactions between shallow lake sediments and the water column are also more affected by bioturbation (disturbance by fauna), wind disturbance, gas bubbles, high pH from photosynthesis, and low dissolved oxygen. As a result of these characteristics, reductions in external nutrient loads have less of an effect in shallow lakes because internal nutrient interactions between the benthic and pelagic zones are more influential. In such cases, sediment treatments may be necessary as supplementary in-lake management activities for effective rehabilitation. (Cooke et al. 2005, 33)

Shallow lakes commonly exist in one of two states: the first condition is characterized by high nutrient concentrations, high turbidity, and high algae. Biotic assemblages may include planktivorous and benthivorous fish (carp and shad), herbivorous birds (Canada geese), and low numbers of phytoplankton grazers (large bodied zooplankton). These circumstances lead to "high internal [phosphorous] loading, turbid water, and little chance for extensive establishment of native submersed plants." The second condition is one of clear water, extensive macrophyte growth, and low nutrient concentrations. The biota is dominated by algae grazers (zooplankton) and piscivorous fish and birds (bass and herons). (Cooke et al. 2005, 33)

Shallow lakes are responsive to biomanipulation. "Adding grass carp at densities sufficient to eliminate macrophytes, for example, is almost certain to switch a clear lake to a turbid, algae-dominated one." (Cooke et al. 2005, 34) This statement is striking because it summarizes exactly what happened at one time during Lake Herrick's history. When a population of Brazilian *elodia* became established throughout the lake, it had the effect of turning the historically turbid water very clear. The plant was regarded as an undesirable weed and grass carp were introduced to graze it away. As the *elodia* population declined, the lake reverted to its turbid, algal-abundant state. (Williams 2013) It is possible that achieving Lake Herrick's management goals will require a making a decision as to which nuisance is more tolerable: macrophytes or algae. Most shallow urban lakes are dominated by one of the two. Once established, exotic weeds tend to be more persistent than algae because they draw their nutrients from bottom sediments, thriving on past inputs rather than current ones. (Cooke et al. 2005, 33; Schueler and Simpson 2001, 748)

Processes and Functions

Material Inputs

It is difficult to accurately compare different lakes, even in the same region, because variation in characteristics such as "depth, water source, erodibility of watershed soils, comparative watershed size, and local land use" all result in different function. (Holdren et al. 2001, 5) Other contributing physical, chemical, and biological factors include: "Rainfall cycles, watershed characteristics, lake basin shape and depth, lake water, [and] bottom sediments." The biological and chemical processes in waterbodies are influenced by both the internal contents and external inputs of water, soil, dissolved material, and particulates. Materials enter via aquatic tributaries, groundwater, overland flow, precipitation, and deposition of gas and particles from the atmosphere. (Holdren et al. 2001, 9, 13)

Groundwater may or may not contribute substantial volume and nutrients. Groundwater flows can be difficult to quantify, but it is possible to determine their contribution by measuring "the elevation of the groundwater table relative to the elevation of the lake surface." Relevant elevations can be determined by digging wells at various locations near the lake and measuring the height of the water within them, as well as the lake's surface. Where the water table is higher than the lake surface, the groundwater is moving towards the lake. Where the water table is lower, the lake is exporting water. The water table can be affected by slopes, soil type, bedrock type and depth, and the presence of permeable nearshore sediments. (Holdren et al. 2001, 112)

Particulates include soil and organic matter. Erosion of particulates into water is often heightened by human activities, and can be elevated after large storm events. Particulates can impair transparency and thus inhibit algal growth by blocking light. However, they also commonly carry nutrients that stimulate algal growth. They tend to have negative effects on fish and insect habitat and biology;

excessive sediment can smother spawning sites, irritate gills, and make it harder to locate prey by impairing visibility. (Holdren et al. 2001, 13)

Dissolved material that can potentially be conveyed into water bodies includes: minerals from bedrock (depending on the source and solubility of local bedrock), metals from bedrock (iron and aluminum are common) or of anthropogenic origin (more commonly zinc and lead), chemicals of all sorts, phosphorous and nitrogen, and oxygen. Oxygen supports biota and is necessary for various chemical reactions. (Holdren et al. 2001, 16) It enters water bodies through atmospheric mixing and as a byproduct of algal and macrophyte photosynthesis. The limit of oxygen saturation in water varies with temperature; cold water can hold more oxygen than warm water. High rates of photosynthesis during algal blooms can result in supersaturation, where a quantity of water is forced to dissolve more oxygen than it would normally be able to contain. Atmospheric diffusion of oxygen into water is slow. If rates of organic consumption reactions, such as bacterial decomposition of organic material, are particularly high or widespread, then oxygen may be depleted faster than it is replenished. Extremely low levels of dissolved oxygen is a condition referred to as anoxia, and it results in odors, fish-kills, and heightened release of certain nutrients from sediments. (Holdren et al. 2001, 18)

One other type of dissolved or particulate material that commonly enters urban lakes and streams is chemical pesticides. Pesticides are widespread in urban runoff. Low levels of chlorpyrifos and diazinon are particularly common. They are often present in a few parts per billion, and are usually "well below the threshold for acute toxicity for most aquatic and terrestrial organisms." The biological significance of the low-level presence of these chemicals is not clear. There has not been much research into the possibility of chronic non-lethal toxic impairment, but it has been shown that low concentrations of some common weed-killers will inhibit algal photosynthesis and damage aquatic plants. Unfortunately, pesticides are difficult to monitor. The techniques for doing so are complex and expensive, and there is a large diversity of chemical compounds. Certain chemicals are more toxic than others, and some highly toxic chemicals remain in widespread use. Even chemicals that have been banned for many years are still frequently detected in waterways. This probably reflects slow transport via groundwater or erosion of contaminated soils. It is clear that pesticides that are applied to the landscape do end up in streams all over the country. (Schueler and Holland 2000, 247-253)

Energy Inputs

Energy inputs to a lake ecosystem come from both sun and wind. Both contribute to mixing and nutrient cycling processes, but only sunlight is converted to biotic energy. Much of the light that reaches a lake is reflected. Some is absorbed by inert suspended material, and some is utilized by algae and plants for photosynthesis. Plant photosynthesis creates molecular oxygen, water, and sugar compounds (biomass). Biomass growth from photosynthesis is referred to as primary production – a process that is limited to the photic zone. Primary production is linked to the growth and sustenance of benthic organisms, such as insect larvae, crayfish, and clams, through sedimentation. The settling of organic matter particles, such as dead primary producers, on the lake bottom, is sometimes called "plankton rain" because it is constant and profuse. This benefits small benthic organisms that feed on the organic sediment and then become food for predators like fish and turtles. Bacteria and fungi also feed on sedimentary organic matter, decomposing it to inorganic compounds, carbon dioxide, and water in a process called oxidation. (Holdren et al. 2001, 31, 37)

Functional Processes that Influence Material and Energy Cycling

Hydraulic residence time is the average amount of time that water spends in a lake, from the time it enters to the time it flows out. It can also be thought of as the amount of time needed for the volume of inflow to equal the volume of the lake. It is a function of the rates of both inflow and outflow. For example, if the volume that enters a lake in a year is equal to the total volume of the lake, then the hydraulic residence time is a year. Its value can change based on seasonal variations in inflow and rate at which water is released. (Holdren et al. 2001, 13-14) Hydraulic residence time has a strong influence on ecology, and lakes and reservoirs with similar residence times often have similar ecosystem characteristics, even in the absence of similar morphology or watershed characteristics. (Cooke et al. 2005, 25)

The longer the hydraulic residence time, the more significant are the water quality effects of interactions between bottom sediments and the water column. (Holdren et al. 2001, 150) For shorter values, hydraulic residence time can be a more important limiting factor than nutrients for determining algal abundance. (Cooke et al. 2005, 25) In lakes with high flows and low volumes, which consequently have low residence times of ten days or less, algal cells are flushed out of the water body before they have enough time to grow. Algae is able to remain longer in lakes with intermediate residence times; as the residence time grows, nutrients, rather than time, become the limiting factor for algal growth. (Holdren et al. 2001, 15) This phenomenon offers no natural algal regulation for southeastern water bodies, where peak inflow occurs in the winter and early spring – times of algal dormancy. (Cooke et al. 2005, 25) However, it does enable treatment strategies that involve flushing algae out of reservoirs through rapid drawdown.

Stratification and Mixing

Thermal circulation is the most influential functional process that occurs in a lake. Water bodies undergo cycles of separation into thermal layers, or stratification, followed by mixing. Stratification is caused by "wind mixing, solar input, and by large differences in water density between cold and warm waters." (Cooke et al. 2005, 26) The temperature of water affects its density. As surface water absorbs atmospheric heat and sunlight, it becomes warmer and thus lighter than the cooler, denser water at the bottom. Eventually, two zones of different uniform densities form. These are the epilimnion and the hyplimnion. The difference in their densities becomes great enough that the metalimnion, which is the temperature gradient between them, buffers the two zones, preventing wind energy from mixing them. (Holdren et al. 2001, 25)

In the fall, the epilimnion cools and the difference in temperature between the epilimnion and hypolimnion shrinks. This causes more mixing at lower depths until finally the entire lake becomes homogenous. This process is *overturn*. It often drives algal blooms, as deep, nutrient laden waters are released from the hypolimnion and spread throughout the rest of the lake. (Cooke et al. 2005, 26; Holdren et al. 2001, 27)

In a *dimictic* lake, which stratifies once in the summer and once in the winter, overturn occurs in the fall and spring. This is a common condition in most deeper lakes with average depths of over five to seven meters. However, stratification depth may be deeper or a deep lake might not stratify at all if wind fetch is high, or there are no wind buffers near the shoreline. This is because strong winds are able to overpower the metalimnetic buffer, causing mixing that prevents the formation of thermally stratified layers. Many lakes in the south are *monomictic*, which means that it is never cold enough for winter stratification to occur because their surfaces do not freeze, so there is only one period of mixing per year. In this case, the fall through spring is one long period of circulation. Conversely, many lakes with mean depths less than ten feet are *polymictic*, which means that they circulate frequently and only stratify during periods of minimal wind. Since they are not very deep, there is often not a pronounced thermocline and bottom temperatures are similar to surface temperatures. Polymictic lakes may stratify once or twice, or many times, often just briefly for a few days during hot weather. They tend to be shallow and are much more common than monomictic and dimictic lakes because shallow lakes are plentiful and geographically widespread. A common condition for reservoirs is to have different sections, one of which is stratified and others that are not. Shallow bays near tributaries may be well-mixed because of kinetic forces from tributary input while the deeper section near the dam exhibits more traditional stratification. (Cooke et al. 2005, 26; Holdren et al. 2001, 27-29)

The hypolimnion receives constant inputs of oxygen through atmospheric mixing. Circulation within the lake causes oxygen to be distributed throughout the water column. Following stratification and formation of the metalimnion, oxygen supply to the hypolimnion becomes cut off because there is no more atmospheric gas exchange and there is no light for oxygen production via algal photosynthesis. Oxidation, caused by bacterial and fungal metabolism, decomposes organic matter at the bottom of the lake, depleting dissolved oxygen reserves and causing the hypolimnion to become anoxic. This condition has detrimental implications for fish, which need dissolved oxygen and cannot inhabit an anoxic hypolimnion. They also have difficulty inhabiting the epilimnion in the summertime because it is too warm. Other bottom-dwelling organisms, like crustaceans and macroinvertebrates, are also negatively affected. Unlike fish, they do not have the option of trying to survive closer to the surface. Hypolimnetic anoxia also promotes the release of nutrients, ammonia, iron, manganese, hydrogen sulfide, and methane from bottom sediments. During destratification events when layers mix, these substances become distributed throughout the water column. The nutrients (nitrogen and phosphorous) drive algal growth, which in turn leads to more organic decomposition and perpetuates the cycle of anoxia. Alternately, the deprivation of oxygen to benthic habitat may cause a temporary halt in decomposition and accumulation of organic sediments, as decomposer and detritivore metabolism cannot keep up with photosynthetic production. Because of its implications for productivity and fish habitat, hypolimnetic anoxia is an important factor in lake management and rehabilitation. (Holdren et al. 2001, 29, 37-38) Hypolimnetic anoxia has been observed in Lake Herrick's profundal zone on at least one occasion (Krauss et al. 1999, 6), and is likely a common occurrence but there is currently no regular monitoring taking place that would be able to detect it.

Internal Nutrient Loading

"Internal loading" of nutrients refers to the release and bioavailability of nitrogen and phosphorous from sources within a water body. Internal loading processes can be substantial nutrient contributors, especially if the lake is eutrophic. Bottom sediments are the most important internal source. Only a portion of nutrient inputs to a lake leave in outflow. Some phosphorous and nitrogen always accumulates in sediments. Sediments then release phosphorous during periods of epilimnetic anoxia or when they are disturbed. Bioturbation, or disturbance of bottom sediments by fish and insects, can have a significant role in nutrient release. Carp in particular "release [phosphorous] at rates similar to external loading" through their feeding activities, as they graze among bottom sediments. (Cooke et al. 2005, 31; Holdren et al. 2001, 151) Recreational swimming and wading could also result in bioturbation, and recreational management planning should anticipate the potential impact of human users. Other sources of internal nutrient loading include transport within the water column by algae, release from shoreline sediments due to wave disturbance, macrophyte decomposition, and release from sediments caused by changes in pH or dissolved oxygen. (Holdren et al. 2001, 146)

The amount of sediment in contact with the epilimnion is an important factor in internal loading. "Epilimnetic sediments are warm, leading to increased microbial decomposition rates and to nutrient release." Lakes with steep sides have less epilimnetic contact and are thus less prone to extensive nutrient release from sediments. (Cooke et al. 2005, 30)

Eutrophication

Eutrophication is "the loading of inorganic and organic dissolved and particulate matter to lakes and reservoirs at rates sufficient to increase the potential for high biological production, decrease basin volume, and deplete DO." This definition extends beyond mere nutrient loading to address a wider range of materials and processes. Silt loading, for example, contributes to eutrophic conditions because it makes the lake shallower, exposing sediments to warmth and photic conditions, thus facilitating macrophyte and algal growth. Decay of macrophytes and algae contributes to decreased dissolved oxygen levels, leading to the release of nutrients from bottom sediments. (Cooke et al. 2005, 31)

Oligotrophic conditions, in contrast, are characterized by high dissolved oxygen levels in deep water, high average depth with steep sides, clear water, diverse phytoplankton assemblages, and low algal biomass. Low rates of nutrient loading or large water volumes combined with short residence times lead to low nutrient concentrations and minimal primary productivity. The desirability of particular trophic conditions is relative to the goals of a lake's users. In the case of sports fishery management, high biological productivity is desirable. (Cooke et al. 2005, 33)

Symptoms of eutrophy include low dissolved oxygen or anoxic conditions in the deepest areas of a water body, as well as green or brown colored water. Exotic macrophyte growth is not symptomatic of eutrophy. (Cooke et al. 2005, 33) Water quality parameters may indicate eutrophic conditions, but it is important to consider that seasonal fluctuation is common for phosphorous, transparency, and chlorophyll concentrations, and other parameters, so monitoring data should be analyzed over a number of years. Climate fluctuations also contribute to changes in water quality. For example, runoff and subsequent external nutrient loading is increased by wet weather. This effect is especially pronounced in the summer, when storms can lead to algae blooms. (Holdren et al. 2001, 156-157)

Biota

Lakes have three biotic zones: the *wetland-littoral* zone, the open water *pelagic* zone, and the *benthic* or *profundal* zone. These zones are highly interactive with each other. (Cooke et al. 2005, 28)

The wetland-littoral is productive and functions as habitat for fish reproduction and waterfowl. It is dominated by macrophytes, which are "rooted emergent, floating, and submersed vascular plants" (Cooke et al. 2005, 29) that are large enough to be seen by the naked eye. There are many different forms of macrophytes, ranging from submerged plants (pondweeds), to rooted plants with floating leaves (such as lilies), and free-floating plants (like duckweed or hyacinth). The density of macrophyte communities can change seasonally. Plants tend to be particularly dense in eutrophic lakes. Most draw their nutrients from bottom sediments. They are different from algae, but may have masses of algae attached to them in floating mats. Although they are often perceived as pests, they are not necessarily weeds and eradication efforts may be short-sighted and overlook their ecosystem functions. They are important for stabilizing shallow sediments and preventing erosion, resuspension, and nutrient release from boat and wave action. The potential impact of boat wakes is not an issue at Lake Herrick, but wind has led to a fungal bloom on at least one occasion ("Lake Allyn M. Herrick History." n.d., 2). Macrophytes also facilitate biodiversity and ecosystem complexity by providing shelter and spawning grounds for fish, as well as habitat for waterfowl and macroinvertebrates like insects and snails. Some macrophyte species are visually pleasing, such as water lilies and pickerelweed. As with terrestrial plants, aggressive exotics are undesirable. The general lake management goal with regards to macrophytes should be to promote stable and diverse populations. (Cooke et al. 2005, 29-30; Holdren et al. 2001, 35, 122)

The wetland-littoral zone is also a source of detritus, defined as "non-living dissolved and particulate organic matter." Detritus provides consistent nutrients for microbial flora and plankton. It is an important base element of the lake food web. It can also enter lakes as a watershed input; many lakes that are heterotrophic (have more respiration than photosynthesis) are subsidized by terrestrial detritus inputs. Organic matter, whether originating as littoral detritus or an external input, is assimilated as energy and contributes to biomass production. (Cooke et al. 2005, 30-32)

The pelagic zone contains macro- and microplankton, and the fish and invertebrates that eat them. "Plankton" encompasses algae (including nuisance algae), "bacteria, fungi, protozoa, and filter-feeding crustaceans like *Bosmina* and *Daphnia*." Energy sources are sunlight and detritus input. In nutrient rich water bodies, the pelagic community is usually "dominated by one or a few species of highly adapted algae and bacteria, particularly nuisance blue-green algae (cyanobacteria)." Crustaceans feed on and regulate detritus, bacteria, and algae and are food for fish and insects. (Cooke et al. 2005, 30)

Algae, along with aquatic macrophytes, comprise the base of the aquatic food chain. They derive their energy from photosynthesis and are prey for zooplankton and some fish. Phytoplankton are floating algae. They can be found suspended throughout the water column, not just on the surface. They have no means of moving themselves, which makes them *planktonic*. Other types of algae inhabit substrates - these are *periphyton*. *Dinoflagellates* are free-swimming algae that use dual flagella for propulsion. Their blooms are associated with overabundant organic material and can cause "red tides." Diatoms have silicate cell walls and are dominant in the spring and early summer. Various other algal classes are grouped by color: green, blue-green, and golden. Green algae occur in nitrogen-driven blooms. They are a primary food source for zooplankton. (Holdren et al. 2001, 31)

Blue-green algae are also referred to as *cyanobacteria*, and are commonly regarded as nuisances. They were the first photosynthetic organisms to evolve. They are more properly referred to as *cyanobacteria,* and are like bacteria in that they do not have individual cells. They have the following defenses and competitive advantages over other algae: they can fix nitrogen (absorb atmospheric nitrogen), regulate their bouyancy via selective gas exchange, form colonial aggregations to become too big for zooplankton predation, produce neurotoxins and liver toxins (which can be an issue for the health of livestock and other mammals), and they have a mucus layer that acts as a protective coating against zooplankton. (Holdren et al. 2001, 31-32)

Different algal species can affect a lake in different ways. Blue-green algae are a common aesthetic nuisance because they float on the surface, leave a "paint-like film" on the shoreline, and cause the water to taste and smell unpleasant. Other algal species, like *Synura* (red), can change the color of the water. (Holdren et al. 2001, 121)

Phytoplankton populations exhibit general patterns toward seasonal succession. Biomass is low in early spring, and diatoms and golden algae dominate. Biomass grows and green algae become more abundant than diatoms in early summer. Blue-green algae dominate in mid-summer. Late season blooms spurred by nutrient release following fall mixing results in ephemeral growth of diatoms, cyanobacteria, and dinoflagellates. Examination of water color during an algal bloom can help to identify the primary groups present. (Holdren et al. 2001, 31, 36)

Algal populations are regulated by "water temperature, light, nutrients, hydraulic residence time," and predation. Phosphorous is the most common limiting factor. Water quality parameters, such as the ratio of nitrogen to phosphorous, can affect the relative abundance of algal species. For example, because blue-green algae are able to fix nitrogen, they are not limited by low-nitrogen conditions. (Holdren et al. 2001, 32-33, 119-120)

Long-term control of algal biomass is one of the most common lake management goals. It entails reducing nutrients in the water column by a significant degree. Phosphorous is usually of primary concern. Atmospheric deposition of phosphorous is not a significant factor, unlike carbon and nitrogen, so it can be regulated comprehensively by managing external and in-lake sources. It is critical to reduce external loading, but this is often not sufficient on its own because of internal recycling. (Cooke et al. 2005, 30)

Zooplankton are microscopic animals that feed on algae. They are herbivores, and many are filter feeders. Some are raptorial and may prey on other zooplankton in addition to algae. They are important prey organisms for juvenile planktivorous fish species, including many species of popular game fish. Some adult fish, such as crappie and perch, consume zooplankton as well. Thus, they serve a critical trophic function of transferring the primary production energy of algae up the food chain. Because they regulate algal populations, they can have a positive effect on water quality even in spite of moderate to high nutrient levels. (Holdren et al. 2001, 34)

Zooplankton are an important parameter for biomanipulation, which is the practice of using predator-prey relationships to influence environmental variables. Particular species, large *Daphnia* for example, are notably effective at regulating algae. Smaller zooplankton species have less of an effect on algal populations because they consume less. However, *Daphnia* are also heavily targeted by fish. Their presence or absence is informative as to whether fish predation is a significant factor. If *Daphnia* are being eaten by fish, their population will decline or persist at a low level, but they will have large numbers of eggs because they have abundant food. (Holdren et al. 2001, 124)

Food Webs, Energy Flow, and Nutrient Cycling

Algal and macrophyte production is the base of most lakes' organic food web. An exception is in rapidly flushed reservoirs that receive substantial organic inputs. Primary production biomass of algae and macrophytes is consumed by zooplankton, snails, and minnows. Zooplankton, in turn, are eaten by planktivores. This includes insects, fish, and some other zooplankton species. These in turn are consumed by piscivorous fish and birds. Because of energy loss during trophic transfer, the proportion of biomass at each trophic level differs by a factor of 10 to 20. All trophic levels contribute to the nourishment of detritivores, bacteria, and fungi. Recycled organic matter, processed by detritivores, then goes to renewed plant and algae production. (Holdren et al. 2001, 38-40) Keystone species are particularly influential links in the food web. Piscivorous fish, for example, regulate planktivorous fish, which regulate zooplankton, which regulate algae. Without a sufficient population of piscivorous fish, such as bass or pike, planktivorous fish eat all the zooplankton which frees algae from its predatory constraint. Interactions that could impact piscivorous fish populations include overfishing and poor habitat. Because of their sportfishing value, efforts are often made to boost piscivorous fish populations. This commonly takes the form of supplemental nutrient inputs for more overall lake productivity. However, research indicates that lakes become eutrophic before they reach their maximum sport fish biomass capacity. Therefore, water clarity is often sacrificed for good fishing. (Holdren et al. 2001, 40-41) A reasonable management goal might be to maintain a healthy piscivorous fish population for the purpose of algal regulation rather than sportfishing. This would likely reduce the need for supplemental nutrient inputs and the eutrophying effects that accompany them. Unfortunately, this outlook puts fishing in conflict with trophic balance. There seems to be a clear trade-off between clear water and good fishing.

Water Quality Parameters

There are many biological, chemical, and physical variables associated with lakes and streams that can be measured to provide quantitative data on the state of the lake environment. Below is a discussion of the water quality parameters that have been measured at Lake Herrick. Specific monitoring results are discussed in Chapter 3.

Stream Flow (stage)

Stage data provides information on the hydraulic impacts to a stream caused by storm events – the degree to which the flow rate changes during a storm. Stream flow is a product of velocity and volume. Velocity is a strong determinant of a stream's habitat value, influencing which organisms can live in the water. Volume has implications for water quality; a stream with higher flow has more capacity to dilute and absorb pollutants. Stage also determines the amount of sediment that is conveyed downstream versus settling on the bottom. Fast-moving streams tend to be better aerated and have higher levels of dissolved oxygen. (Brown and Caldwell 2007, 5-6) Stage measurements are relevant to Lake Herrick when applied to its tributary and outflow streams.

Total Suspended Solids (TSS)

Total suspended solids is a measure of mineral and organic matter in the water column. High levels of sediment can be indicative of erosion and can increase the size of flood zones, accelerate bank erosion, and alter aquatic habitat. When sediment accumulates in streams and water bodies, it covers and fills in coarse material and woody debris which function as habitat and spawning areas for fish and macroinvertebrate species. It also serves as a vector for transport of many pollutants, such as nutrients, metals, pesticides, and bacteria. TSS is a gauge of overall biological health; elevated sediment during wet weather indicates erosion in the watershed, which corresponds with decreased biological quality of a water body. (Brown and Caldwell 2007, 6; Brown and Caldwell 2011, 2.15)

Urban land use, with its associated high levels of impervious surface, drives particular patterns of detrimental sedimentation. Impervious development has the hydrologic effect of lowering stream baseflows and causing elevated stream volume and velocity during storms. Impacted streams often do not have enough current to suspend or transport sediment during baseflow conditions. Sediment builds up in stream channels gradually until periodic high-flow events sweep the accumulated material downstream. The power of high velocity, particle-laden flows is more erosive than typical baseflow carrying more natural sediment loads. The result is compounded sedimentation via stream channel scouring and erosion. Channels that are thus impacted become more geomorphically unstable over time, forming gullies that erode easily during wet weather events. (Brown and Caldwell 2011, 2.15-2.16)

Increases in sediment have the ability to negatively affect many of the other monitoring parameters. Heightened sediment influx results in continued loss of depth along with more inputs of bacteria, nutrients, metals, and organic matter. Decomposition of that organic matter drives down dissolved oxygen levels, resulting in the release of even more nutrients and metals from their chemical bonds. As larger areas of the lake bottom become exposed to warm sunlight, macrophyte and algal growth increases and in turn, so does organic matter production and decomposition. These changes are likely to be reflected by decreases in pH.

Bacteria: Fecal Coliform and Escherichia coli

Fecal coliform is the current state standard metric for health risk associated with bacteria contamination. Coliform bacteria of the family Enterobacteriaceae reside in the digestive systems of humans and warm-blooded animals. Most Enterobacteriaceae species are not pathogenic, but they are accompanied by less abundant pathogenic organisms that are more difficult to monitor directly because of their small numbers. They do not occur naturally in waterways, and their presence thus indicates contamination by human or animal waste. (Brown and Caldwell 2013, 2.7)

E.coli is a common bacterium that is associated with fecal coliform. Like fecal coliform, it is a non-pathogenic indicator for pathogenic organisms that inhabit mammalian digestive systems. Exposure to harmful bacteria can cause digestive and muscular distress, is particularly dangerous to children and the elderly, and can even be fatal. In the future, E. coli will most likely replace fecal coliform as the standard metric for bacteria because elevated amounts of fecal coliform have been found even in areas with minimal anthropogenic impact. The State government is seeking an alternative indicator specifically for human waste and the potential for human illness. The two are closely related, and their levels in Lake Herrick have displayed similar trends throughout the entire monitoring period (Brown and Caldwell 2013, 2.7–2.8).

The State of Georgia classifies the North Oconee River as a drinking water supply and has established the following regulations for its fecal coliform content: "For the months of May through October, when water contact recreation activities are expected to occur, fecal coliform is not to exceed a geometric mean of 200 per 100 ml based on at least four samples collected from a given sampling site over a 30-day period at intervals not less than 24 hours. Should water quality and sanitary studies show fecal coliform levels from nonhuman sources exceed 200/100 mL (geometric mean) occasionally, then the allowable geometric mean fecal coliform shall not exceed 300 per 100 ml in lakes and reservoirs and 500 per 100 ml in free flowing freshwater streams. For the months of November through April, fecal coliform not to exceed a geometric mean of 1,000 per 100 mL based on at least four samples collected from a given sampling site over a 30-day period at intervals not less than 24 hours and not to exceed a maximum of 4,000 per 100 mL for any sample" (State of Georgia 1974).

Dissolved Oxygen

Fish and other animals depend on oxygen dissolved in the water column to live. Air and water temperature, stream flow, aeration, atmospheric pressure, sediment levels, respiration, photosynthesis, and decomposition are all processes and parameters that affect dissolved oxygen levels. Dissolved oxygen in turn affects the solubility of certain metals and nutrients, decomposition rates, and habitat quality. Anthropogenic impacts such as leaking sewer lines and inputs of residential yard waste can increase decomposition rates, leading to reduced levels of dissolved oxygen. In environments where decomposition and other factors reduce the availability of dissolved oxygen, there is increased pressure on aquatic organisms. Anoxic conditions are a reflection of lake health; they are a fundamental detriment to fish and macroinvertebrate habitat. When dissolved oxygen levels are low, fish kills can occur. Oxygen depletion can be a result of natural causes, but can also be caused by improper lake management practices. For example, treating an algal bloom with herbicide can cause rapid algal die-off. The resulting decomposition and depletion of dissolved oxygen levels can result in a fish kill. (Brown and Caldwell 2007, 7-8; Holdren et al. 2001, 118)

In the summer, shallow lakes often mix periodically (while deeper lakes remain stratified in the summer but mix in the fall). In lakes of this sort, DO should be measured at the same time and with the same methods as temperature. Such periodic mixing creates cycles of stagnant periods, in which the lake becomes deprived of DO at the bottom. Anoxic bottom sediments release previously-bound phosphorus. Mixing then redistributes phosphorous from the bottom throughout the lake. The exposure of phosphorous to oxygen creates favorable conditions for algal blooms. (Holdren et al. 2001, 18, 118)

The State of Georgia has established regulations that specify minimum dissolved oxygen levels for state waterways. At least 5.0 mg/L is the mandated average concentration, or 4.0 mg/L for waters that support warm water fish species. (State of Georgia 1974)

Temperature

Water temperature can vary with climate, season, elevation, groundwater inflow, vegetation, and sun exposure. In heavily urbanized environments, temperature may be affected by increased exposure to solar radiation due to decreased canopy cover. Decreased base flow stemming from increased impervious cover can also result in higher temperatures; groundwater-fed base flow tends to have a stable temperature that buffers against variations in ambient air temperature. (Brown and Caldwell 2013, 2.4-2.5)

pH

pH measurements in aquatic systems tend to range from 6.0 to 9.0 due to reactions with the atmosphere. Waters with large amounts of decaying vegetation, as might be expected of Parvo Pond and Lake Herrick, tend to have elevated amounts of humic acid that results in decreased pH levels. Acids can also be introduced to aquatic systems via pollutants such as oxides of sulphur and nitrogen, which react with atmospheric water and precipitate as acid rain. (Brown and Caldwell 2007, 27)

When algae bloom, their growth removes carbon dioxide, a weak acid, from the water. This results in increased pH. At pH levels above 9.5, the rate of phosphorus release from sediment increases to equal or above that of anoxic conditions. This is conceivably a positive feedback mechanism for algal growth. (Holdren et al. 2001, 119)

Conductivity

Conductivity is a measure of the water's ability to conduct an electric current, and can provide insight into the levels of minerals and ionic constituents in the water column. It is a general measurement of water purity and, although it is not directly linked to biological health, it can indicate changes in water quality. For example, a sudden increase in stream conductivity could indicate a new source of dissolved ions, particularly metals but also possibly minerals of geologic origin, in the water. Conductivity does not specifically measure which ions or minerals are present, and it is not influenced by materials that do not ionize in water, such as oil. Conductivity can be influenced by regional geology; streams with granitic geological conditions generally do not have naturally high levels of conductivity because granite does not contain minerals that readily dissolve in water. Typical values for conductivity in the Georgia Piedmont range from 0.070 to 0.150 mS/cm. (Brown and Caldwell 2007, 29)

Turbidity

Turbidity is a measure of water clarity; it is influenced by suspended matter in the water column and is thus an indicator of sediment load and potentially the presence of visible pollutants in a stream. Increases in turbidity may indicate heightened erosion from stream banks, construction, or other sources. Turbidity is a similar metric to Total Suspended Solids, and can affect the chemical, biological, and physical conditions in much the same way as TSS. Turbidity is measured in Nephelometric Turbidity Units (NTUs). (Brown and Caldwell 2007, 31)

The state of Georgia's policy on turbidity is that "[a]ll waters shall be free from turbidity which results in a substantial visual contrast in a water body due to a man-made activity. The upstream appearance of a body of water shall be as observed at a point immediately upstream of a turbidity-causing manmade activity. That upstream appearance shall be compared to a point which is located sufficiently downstream from the activity so as to provide an appropriate mixing zone. For land disturbing activities, proper design, installation, and maintenance of best management practices and compliance with issued permits shall constitute compliance with Paragraph 391-3-6-.03(5)(d)." No definite numbers have been established to serve as guidelines, although the State regulates construction activity, prohibiting downstream increases in turbidity above 25 NTUs compared to levels upstream of the receiving waters. (State of Georgia 1974)

Volatile Organic Compounds (VOCs)

The EPA has established guidelines to limit the volatile organic compounds allowed in surface water. VOCs are often flushed into streams during rainfall events and originate from automobiles or other commercial, residential, or industrial sources. (Brown and Caldwell 2007, 33)

Oil and Grease

Grease is typically introduced to water bodies through sanitary sewer line leaks, which add household waste in addition to sewer waste. Grease can also indicate improper waste management by food industry sources. Oil inputs generally come from non-point source runoff from roads and parking lots. This is most common in areas with dense transportation infrastructure. Oil can also come from improper handling of waste at automobile maintenance and service centers. (Brown and Caldwell 2009, 3.20)

Total Phosphorous

In natural systems, phosphorous is typically a limiting nutrient that does not occur in abundance. Anthropogenic sources of phosphorous are abundant. Inputs from agricultural, domestic, and industrial waste (such as fertilizer, detergents, and wastewater or sewage) and stormwater runoff are common sources of elevated phosphorous in aquatic systems. Fertilizer runoff from lawns and landscaped areas is also common. Most soils in the Georgia Piedmont have the property of immobilizing phosphorous, as it binds readily with clay particles. Thus, phosphorous typically does not enter streams via runoff unless carried with eroded sediment from fertilized areas or when fertilizer is applied directly to the water. When submerged in particularly low dissolved oxygen conditions, phosphorous is released from its chemical bonds with clay, allowing it to mix into the water column. (Brown and Caldwell 2011, 3.39; Holdren et al. 2001, 33)

Elevated phosphorous levels during wet sampling events are generally attributable to stormwater runoff that carries inputs of dog waste, sewage, and fertilizer from landscaped areas. During dry weather, typical sources of elevated phosphorous are most often related to leaky sewer pipes or septic systems (Brown and Caldwell 2011, 3.39). Phosphorous is also an important atmospheric input. It originates from both agricultural and urban (industrial) sources. (Holdren et al. 2001, 17) The EPA's guideline for acceptable levels of phosphorous is 0.0365 mg/L, and the Environmental Protection Division (EPD) considers levels above 0.5 mg/L to be high. (Brown and Caldwell 2011, 2.19-2.20)

Total Nitrogen

Total Nitrogen (TN) is a measure of dissolved inorganic and organic nitrogen, as well as particulate forms. Inorganic nitrogen primarily includes nitrate (NO_3), nitrite (NO_2), and ammonium (NH_4+). Nitrogen is an essential nutrient for aquatic plants and algae, but it is typically not a limiting constituent. Nitrogen that is bound to organic matter cannot be used by plants or algae. Nitrite reacts readily to organic constituents and is therefore not found in abundance. Ammonium and nitrate are the first- and second-most preferred sources of nitrogen for most aquatic organisms. Nitrate is the more common form of nitrogen in high oxygen environments, and ammonium is more plentiful when oxygen is low. Common organic nitrogen sources in aquatic systems include leaves and vegetation, urine, fecal matter, garbage disposal waste, and ammonia-based household cleaners. Ammonia and nitrite can be toxic to fish, but nitrite often reacts with oxygen and converts to nitrate. Ammonium and nitrate are commonly found in commercial fertilizers which can be present in streams via runoff from lawns and landscaped areas. The EPA's guideline for acceptable levels of nitrogen is 0.69 mg/L. (Brown and Caldwell 2007, 35; Holdren et al. 2001, 18)

Metals

Metals from municipal or industrial sources can reach streams via stormwater runoff and are readily absorbed by organic matter and sediment particles. They can be released and become harmful to aquatic life under low or high pH conditions. (Brown and Caldwell 2007, 37) The State of Georgia specifies two classifications for elevated metal concentrations in waterways: acute and chronic. "The acute limitation may not be exceeded in a 1-day, 10-year minimum flow (1Q10), or higher stream flow, while the chronic limitation applies to the 7-day, 10-year minimum flow (7Q10), or higher stream flow." (State of Georgia 1974)

Conclusion

From this overview of lake ecology, a desirable condition for Lake Herrick can be conceptualized. The lake exhibits many of the typical characteristics of a man-made impoundment, which unfortunately enhance its susceptibility to eutrophying pollution. The most consequential problematic input is phosphorous, the most prevalent vector for which is probably sediment. It is apparent that the most effective way to control nutrient loading is by minimizing the influx of sediment from throughout the watershed. This means that erosion control measures are of primary importance.

Reducing the influx of sediment is not sufficient on its own, as internal nutrient loading will continue. Measures must also be taken to reduce the nutrients available in bottom sediments. Dredging is the most commonly utilized method for doing so. If Lake Herrick is re-shaped through dredging, it is worthwhile to consider the role that steep sides can play in reducing epilimnetic contact and thus nutrient release from sediments. It is also important to limit the potential for bioturbation. Establishment of littoral vegetation and other measures taken to protect benthic sediments from disturbance by swimmers and benthivorous fish will help to keep existing nutrients inert.

For recreational purposes, a clear-water, macrophyte-based assemblage is preferable to a turbid, algae-dominated state. Aside from nutrient concentrations, the biotic assemblage is the most influential factor regarding these conditions. Fortunately, as a shallow lake, Lake Herrick is susceptible to biomanipulation. This should not be overlooked as a powerful and relatively low-cost tool to achieve management goals. An understanding of limnology rooted in the basic concepts described in this chapter is a fundamental requirement for any lake manager seeking to employ biomanipulation techniques.

The most desirable biota include algae grazers (zooplankton) and piscivorous fish and birds (bass and herons). Cultivating these inhabitants entails managing against conditions and actors that tend to suppress them; pesticide and other chemical runoff from turf ground cover in the watershed may limit zooplankton growth, as do disproportionately high numbers of planktivorous fish. Management of the fish population is a viable strategy. Should piscivorous fish populations be established, it is critical that they not be exposed to excessive pressure from sport fishing; this is a real concern in a densely populated area.

One other factor that is critical to maintaining the functional integrity of a healthy lake is dissolved oxygen. Measures to ensure sufficient aeration will help to minimize the effects of hypolimnetic anoxia and contribute to desirable ecosystem processes.

Before any plans can be made to influence Lake Herrick's physical or biological properties, it is essential to have a thorough understanding of the lake's current condition. The following chapter contains detailed documentation of Lake Herrick's history and present state.

CHAPTER 3

INVENTORY AND ANALYSIS

This chapter contains an inventory of Lake Herrick's current and historical conditions. It begins with an account of the history of the lake's establishment and the series of management problems that led to the ban on swimming and boating in 2001. Next is a review of all available water quality monitoring data prior to 2004, followed by the presentation and analysis of a series of aerial photos that demonstrate the evolution of the lake's watershed since 1938. The remainder of the chapter addresses the lake and its watershed's current conditions. This begins with a review of all known documentation (and limitations thereof) regarding the water cycle, the findings of the MS4 monitoring program that began in 2004 and continues to produce regular water quality monitoring reports, and a section that puts Lake Herrick's water quality into regional context by comparing it to other urban lakes in the Georgia Piedmont. The inventory and analysis proceeds to document the conditions of the overall watershed, addressing the following categories: land use, on-campus areas of interest, general description of the off-campus watershed, aquatic vegetation, fish, wildlife, sensitive ecological areas, shore development and natural beauty, lake users, and policy and regulations. The chapter concludes with a summary of the problems that affect the lake and prevent the desired recreational uses.

The following account of the history of Lake Herrick and the subsequent analysis of historic monitoring data and the MS4 monitoring program were originally written by the author and submitted as part of a memo for the Spring 2014 ECOL 8710 Environmental Practicum class. The author's original text has been reproduced here with minor revisions. The memo was co-authored by six other students. Some of their contributions are referenced throughout this thesis and cited as Morphis et al., 2014.

History of the Lake Herrick Watershed

Establishment and Historic Management Problems

<u>Before Lake Herrick</u>

In 1925, a nursery was founded on the land that would eventually be flooded with water to create Lake Herrick. The ownership of the nursery is unclear, but organizations related to the University of Georgia were active in the area during this time period. In 1926, the Forestry Club built a 12' by 30' cabin out of pine logs; all that remains of this structure is its chimney, which sits in a clearing on high ground to the South of the lake and still sees occasional use. In 1931, UGA's School of Forest Resources officially acquired the land. The following year, the Board of Regents added 150 acres on the south end of the parcel, acquired from Denmark Farm, and the land was renamed Oconee-Denmark Forest. Both the forest and the nursery were used for research (Cook 1987, 1).

In the 1930's during the Great Depression, a Civilian Conservation Corps "side camp" was located on the land near the nursery. During this time, the area provided informal housing for UGA students, who occupied the Forestry Club cabin, the CCC building, the nursery building, and several shacks in the woods (Cook 1987, 1).

A fire tower was built on the high point to the south of the Forestry Club house in 1953. This area, referred to as Fire Tower Hill, is adjacent to the current location of the Athens Perimeter. Sometime in the 1950's, a spring-fed pond was created to the south of Lake Herrick's current location (Krauss et al. 1999, 3). By the late 1950's, the Forestry Club house had fallen into a state of disrepair and was demolished. A picnic shelter was erected in its place and remained for about twenty years; it was dismantled in 1980. In the early 1960's the Board of Regents swapped a portion of Oconee-Denmark Forest (mostly from the original Denmark Farm tract) for the land that is now the University Golf Course. The nursery was relocated to Whitehall Forest in 1968 (Cook 1987, 2-3). Following the relocation of the nursery, the land where Lake Herrick would eventually be constructed was kept mostly clear of trees and may have been used as pasture in association with the nearby horse barn.

In 1975, the Georgia Department of Transportation (DoT) built Highway 10 - the bypass that forms a perimeter loop around Athens. This resulted in the removal of the fire tower and the fragmentation of Oconee-Denmark Forest (Cook 1987, 3). During construction, the DoT installed two 30-inch diameter culvert pipes to convey water under the bypass into the Lake Herrick watershed (Williams 1997). The bypass runs along a high point that was the boundary for Lake Herrick's watershed. Thus, the culverts represent an interbasin transfer (Williams 2013). At this time, the forest was frequently utilized as an outdoor laboratory for teaching field methods in forest engineering classes. It was also popular with botany and dendrology instructors, who were attracted by its rich flora. Recreational hiking was not uncommon and people used the forest roads for running. Horseback riding was perhaps the most popular recreational activity, but by the early 1980's, the horse pastures that had existed in the area were being converted to lake bottom and the intramural fields. Motorcycles were noted as a nuisance, having run a trail up the area's steepest slope which was richest in wildflowers. The source document is not clear about the location of this slope, but it may have been referring to the still-operational powerline corridor. (Cook 1987, 3)

Lake Herrick and Oconee Forest Park: 1982 to 2005

Oconee Forest Park was established in 1982 as a 117-acre tract (the remainder of UGA's Oconee-Denmark Forest property) that was owned by the College of Agriculture but utilized extensively by the School of Forest Resources. That April, Dan Williams officially became the Oconee Forest Park's first employee. Through the School of Forest resources, he occupied the position of park manager until his retirement in 2014. The official boundary of Oconee Forest Park was divided into two pieces by Highway 10. The 45-acre western tract still exists in its entirety. The Oconee Forest Park Revised Master Plan for Development, drafted by former forestry professor Walter Cook (1987, 3-4), describes the area as bounded by Lake Herrick to the north, by a horse barn located on the "eastern slope of the area north of the park," by the Southern Railway to the west, by the Athens Perimeter Highway to the east, and by an open, triangular patch of land with a pond to the south. This land and pond, now recognized as part of the park, was originally used by the Physical Plant's Grounds Maintenance Unit for compost and landscape plant storage. Irrigation trucks were filled with water from the pond for watering landscape plants on campus. At the time that the park was established, Physical Plant was phasing out their use of the property (which was only accessible through Oconee Forest) pending its conversion to park land. The eastern tract, originally a narrow strip of about 40 acres (the source document does not account for the additional 32 acres in the 117 that it initially attributes to the forest park – presumably Lake Herrick counts for 15) was bordered by Riverbend East subdivision and the North Oconee River. A committee appointed by UGA's President Henry Stanford had recommended that the west bank of the North Oconee River corridor be included as part of the North Oconee River Greenway, but the tract remained undeveloped and there were no specific plans for its development as part of the park, probably because access was cut off by the loop (Cook 1987, 4-7).

The School of Forest Resources' stated goal for the park was to "preserve the remaining pieces of the Oconee-Denmark Forest in a more-or-less natural condition, and provide a forest environment, and facilities for enjoying it, to the campus community" (Cook 1987, 7). A description of the forest at this time noted that the vegetation throughout was composed of mixed pine trees and hardwoods of various sizes. The north and northwest slope had particularly large hardwoods and some "old woods pine." Also noted is the "excellent stand of large white oak" near the base of the northwest slope. Wildflowers and flowering understory trees such as dogwood, redbud, buckeye, serviceberry, and azalea were all common, especially on the north slope. (Cook 1987, 3-4)

The park's designers envisioned "a quiet place to get free from the tensions and pressures caused by academic requirements and the social abnormalities of living in non-family groups." As such, they specified the following objectives in the Oconee Forest Park Master Plan:

1. "To preserve the Park's natural character and influence."
2. "To provide for the enjoyment of activities appropriate to its natural environment."
3. "To allow use by students and faculty for practice, demonstration, teaching, and research." (Cook 1987, 7)

In June of 1982, construction of the dam for Lake Herrick was finished (Stevens 1982). Aerial photos indicate that the land that was flooded to create the lake was mostly clear of trees as early as 1938, with the exception of a narrow vegetated buffer along the stream that runs through the site. During construction, those remaining trees were removed and the lake bed was thoroughly cleared of stumps. Before the dam was closed, the lake bed was treated with 32 tons (1.5 tons/acre) of lime. Both tributary streams and the small pond in Oconee Forest Park were treated with Rotenone to eliminate undesirable "trash" fish. The reservoir was dedicated the following month. It had a surface area of 15 acres, a volume of about 150 acre feet, a maximum depth of 24 feet near the dam, and an average depth of about 9 feet ("Lake Allyn M. Herrick History." n.d., 1). Two fishing piers were built in short order, along with a road over the dam to provide access to them. The service road that runs south from the tennis courts to Parvo Pond[1], parallel to the railroad tracks, was constructed in September of that year (Cook 1987, 4). In October, the lake was stocked with 800 bream (*Lepomis macrochirus*), 800 red-ear sunfish (*Lepomis mircolophus*), and 800 channel catfish. 800 large-mouth bass were introduced the following May ("Lake Allyn M. Herrick History." n.d., 1). The bream and red-ear sunfish are closely related species, and no distinction is made between them in subsequent management documents.

In 1984, the School of Forest Resources constructed a boathouse to store ten canoes (which were purchased by the Recreational Sports Department sometime before 1987; Rec Sports continued to store them in the boathouse) and six small sailboats. The structure also included workspace and tool storage. During the winter of 1984 and '85, the instructor of a Forest Recreation class gave students the choice of writing a term paper or building trails. Consequently, students built over a mile of trails. The original purpose of these trials was to provide an outlet for "cerebral recreation and quiet contemplation." The park planners' vision was further explained as "an opportunity for a low-key, unhurried, tranquil, and

[1] Parvo Pond is a colloquial name for the small pond within Oconee Forest Park that feeds into Lake Herrick via a tributary stream. The date of the pond's construction is not clear, but it existed before Oconee Forest Park was established. When referenced in documents from the 1980's, the pond is referred to by its location rather than a proper name. Sometime in the last thirty years, the water body picked up its informal and pejorative nickname which refers to canine parvovirus - a highly contagious disease that is spread between dogs via contact with their feces.

enjoyable encounter with an attractive, natural environment." The trails quickly became very popular, and mainly for a previously unanticipated activity: jogging. Park managers realized that much of the park's popularity was due to the opportunities for active recreation created by the trails, rather than the inherent naturalness of the forest. This point may have caused a slight shift in park administrators' vision for the area, but it did not conflict with the overall mission of preserving the forest environment for the enjoyment of the University community. (Cook 1987, 4-5, 8)

One problem that was beginning to become evident at this point was the issue of sanitation, as the park did not have restroom facilities. Plans were drawn for a 16'x24' restroom to be located near the picnic area. However, construction was put on hold pending the provision of electricity and a water source. Various plans that were considered to supply the park with water included running a line across (either above or under) the lake or to build a well with a storage tank. The plan was to provide electricity and water to the existing boathouse and picnic area structures, as well as the proposed restroom (and a drinking fountain in front of it), shelterhouse, multi-purpose facility, and manager's residence. Park administrators postponed the construction of new structures and trails and stopped actively promoting visitation to the park, recognizing that current use was already at or above capacity until proper restrooms could be built (Cook 1987, 11-12). Electricity and water were extended to the boathouse and picnic pavillion in 1994. Restrooms were built at the intramural fields and across the footbridge near the tennis courts. The proposed multi-purpose facility and manager's residence have not been built.

Between mid-summer 1983 and winter of 1985, a serious erosion problem developed. Physical Plant attempted to grade the service road in the 1300 foot long powerline corridor that parallels the bypass in Oconee Forest Park. This quickly resulted in the formation of a deep gully, and the eroded soil washed into Lake Herrick. Over a couple of months, about 5000 cubic feet of sediment formed a delta that was estimated to be 50 feet long, 20 feet wide, and 5 feet deep. By fall of 1984, the erosion had begun to slow down as it worked its way into deeper, firmer soil. That winter Physical Plant attempted to re-grade the road, resulting in the depletion of the remaining ground cover vegetation and the renewal of the erosion, which had by then progressed to critical levels. The School of Forest Resources developed and implemented a plan to halt the erosion by constructing a series of box culverts and covering the slope with a layer of straw mulch, pending grass seeding in the spring. (Cook 1985)

Having allowed nearly two years for the stocked fish populations to grow, the lake was opened for fishing in March 1985. Established limits were 5 bass per person per day, 5 catfish per person per day, and 50 bream per person per day. The minimum size for bass was 14 inches, and there was no minimum size for catfish or bream. Soon thereafter, in May, an annual fertilization regimen was implemented; park staff applied liquid fertilizer (10-30-0 formula) at one gallon per surface acre during the growing season. During this first season, samples derived from electro-fishing indicated a growing population with a balanced ratio of bass to bream. ("Lake Allyn M. Herrick History." n.d., 2)

In 1985, following a year of fishing, samples indicated smaller fish sizes overall and increasing bream relative to bass. Filamentous algae were also detected in the lake in 1985 and 1986; park management determined that the appropriate treatment was to apply copper sulfate crystals to the lake – 200 pounds the first year and 35 pounds the next. ("Lake Allyn M. Herrick History." n.d., 2)

By 1986, it was apparent that chemical treatment of the intramural fields, described in one document as fertilization and liming but probably not limited to just those two treatment methods, could be suppressing the growth of phytoplankton in the lake. Phytoplankton are essential to the lake's ecology because they are the base of the food chain for the lake's fish populations. The stated management objective at this time with regards to fishing was to "provide better fishing without impeding swimming," so a healthy phytoplankton population would be essential to accomplish this. A consultant who was commissioned to provide management recommendations advised applying more lime to the lake over the winter at a rate of ½ ton per acre, as well as to apply liquid fertilizer (10-30-0 at a rate of one gallon/acre) every 2-3 weeks while the water temperature was above 65 degrees Fahrenheit. Although the recommended frequency of application was notably high, the treatment was anticipated to provide phytoplankton with enough nutrients to overcome suppression by herbicide inputs and produce an 18" bloom that would block out light and kill submerged algae (which had apparently not been sufficiently suppressed by the tons of copper sulfate crystals that were dumped into the lake previously).

Theoretically, this would be most effective in the deeper parts of the lake; algae are more difficult to suppress in shallow water. This fertilizer treatment would be followed up with copper sulfate spot treatments in areas that continued to exhibit algae problems. The extent to which this advice was implemented is not clear – a handwritten note on the document expresses concern about the expense of a second lime application. In any case, the consultant noted that the fish population was on a desirable trajectory and predicted that good fishing would be attainable if high-phosphorous fertilizer applications continued (Hancock 1986).

In July 1986, the water turned a chalky green and gave off a putrid, rotting odor. White, slimy strands were observed floating in the water. Cooperative Extension Service fisheries experts George Lewis and Ronnie Gilbert explained that high winds were causing organic matter to be stirred up from the bottom of the lake, resulting in a fungal bloom. The water cleared on its own after a week. 1986 also marks the beginning of annual fecal coliform testing performed by UGA's Environmental Safety Service ("Lake Allyn M. Herrick History." n.d., 2). There is no indication of how many years these tests were conducted for. In the nearly three decades since those tests were initiated, the Environmental Safety Service (now known as the Environmental Safety Division) has moved offices, experienced significant staff turnover, and even changed their organizational goals and the services that they offer. Any records of the tests have been lost and the people who had been in charge of administering the testing are no longer available for contact (Favaloro 2014).

Also in 1986, efforts to encourage Canada geese to nest at the lake were successful. Of two pairs received in July 1986, one pair had nested and reared three young during their first season at the lake. The flock had grown to seven geese and could fly, but instead chose to remain and make Lake Herrick their permanent home. In the summer of 1987, a flock of about twenty geese flew in and took up residence. The birds preferred to rest around the beach. Initially they were a popular attraction with the swimmers, who fed and watched them, but their feces quickly degraded the sand at the beach to the point of being disgusting and unsanitary (Williams and Cook 1987).

Recreational Sports Director Jane Russell complained that the beach was losing significant revenue, so a plan was implemented to discourage the geese from using the beach. Droppings were manually removed, signs were posted prohibiting feeding the geese, and the lifeguards were trained to fire a gun loaded with harmless "screamer bullets" to scare the geese away. A wildlife damage control expert who was consulted suggested building a new, separate habitat area for the geese to divert them from the beach. The area would be located to the west of the beach between the two inlet bays – 20 tons of sand would be spread over an area large enough to accommodate the bird population (Williams and Cook 1987).

The habitat area was built and, predictably, the geese used that area *and* the beach. Over the next two decades, flocks of 20-40 geese congregated on the beach at Lake Herrick on a regular basis (Williams and Cook 1987) and were attributed to at least three separate beach closures due to excess fecal coliform pollution ("Lake Allyn M. Herrick History." n.d., 3). They are part of a local population that lives in Athens year round and moves between several local locations (Williams and Cook 1987).

Historically, Oconee-Denmark Forest (and Oconee Forest Park, in its early years) was a popular location for horseback riding; the nearby horse barn had provided easy access to the forest. By the time the Oconee Forest Park Revised Master Plan for Development was published in 1987, most of the barn's former pasture land was under water and management had banned horses on park trails. Recreational riding was confined to a single riding ring which, along with the barn, would soon be cleared and replaced by sports fields. Around this time, mountain bikes were noted as a "menace" on the trails. The Revised Master Plan for Development cites the need for "sustained and determined efforts" to rid the park of bikes, like the ones that were taken to drive out the horses. Currently, bikers still ride some of the trails throughout the park but access to many trails is restricted by signage and gates. However, measures to restrict bike access are sometimes thwarted; a gate on the trail that parallels the stream between Lake Herrick and Parvo Pond has been dismantled, and bikers have been observed riding on the prohibited stretch of trail. Unauthorized swimming from the fishing piers has also been a problem (Cook 1987, 9). There has most likely been a sharp reduction in the number of swimming violations in the years since the swimming ban was implemented, as public perception of the cleanliness of the water has changed. However, there are still instances of people swimming off of the piers (Anecdote from anonymous student), probably out of ignorance due to the lack of posted rules and water quality information.

Research activities were notably limited during the first years of the park, but were still predicted to be the most valuable future use. No specific reason was given as to why research would be more valuable than recreation or teaching. The park was experiencing extensive educational use by classes, labs, recreation interns and practicums. Day camps and interpretive programs for children and adults had also been offered. This was expected to be more frequent when running water and bathrooms became available (Cook 1987, 10-11).

Other plans for expansion that were noted in the Revised Master Plan for Development include the footbridge that crosses the cove on the south end of the lake and a few additional trails, which have subsequently been built. A couple of facilities that were planned for construction have not been built. These include a manager's residence, for a full-time, live in manager, and a multi-purpose facility. The multi-purpose facility would include space for group picnics (which had proved to be a surprisingly popular activity), day camping for kids, departmental meetings, and informal parties. The space was to be accompanied by an amphitheater that would have electricity for showing movies and presentations. Both facilities were planned to be located in the southeast corner of the park, the manager's residence tucked away just north of the multi-purpose facility (Cook 1987, 15-17).

By 1987, the fish population in the lake was much smaller that it had been three years earlier when fishing was originally allowed. Heavy fishing pressure was resulting in a significant depletion of bass and bluegill. Channel catfish were being depleted as well; their population may have been dwindling because they generally do not reproduce well in stocked ponds. It was becoming apparent that, due to the heavy fishing pressure, it would be impossible to maintain good fishing with self-sustaining fish populations alone. The park manager began to subsidize Lake Herrick's fish population by introducing 2000 young catfish every year for about five years (Williams and Cook 1987).

In summer 1989, park management commissioned fishing management recommendations from two individuals. The advice was solicited with the objective of providing better fishing in light of the problem of too few, skinny bass and an overabundance of small bream. The first consultant interpreted the water quality as “very good” and not in need of change. Populations of bream and bass were both reproducing, but analysis of electrofishing and seine data indicated that the bream were stunted and smaller than they should have been. Very few were growing into the intermediate (3-5 inch) size range, and almost none got any larger than five inches. The report notes that the 2000 four-inch catfish that were introduced annually were probably competing with the bream and bass for food. Fertilization, although it would help the fish grow larger, was not recommended because it would be quickly diluted by water flowing in from tributaries and it would turn the water green (presumably from blooms of algae or phytoplankton), which would be repulsive to swimmers. Ultimately, the consultant recommended decreasing the daily limit on bass from five to two and increasing the limit on bream from 50 to 100. He stated the need for posters to help people distinguish between different kinds of fish (Yoder 1989).

The second consultant noted that the lake was “extremely” overcrowded with bream. The ratio of total weight of forage species (catfish and bream) to carnivorous species (largemouth bass) was balanced. However, the total weight of harvestable fish to total weight of fish overall was undesirable, at only 13 percent (versus the more desirable 40-85 percent). The author noted that the best way to correct the ratios would be to drain the pond and start over, which she acknowledged to be impractical. Her recommendation was similar to the first: take advantage of fishing pressure by stopping all bass fishing and encouraging unlimited bream harvest. This would be supplemented by seining a fifteen-foot perimeter around the pond and removing all bream and mosquito fish (a non-game fish species that apparently had established a population in the lake at some point). The consultant recommended continued fertilization, but liming would not be necessary as the lake already received sufficient inputs via runoff from the intramural fields. It was noted that there was no algae problem, but copper sulfate could be used in the event of one. A handwritten note indicated that management found this plan preferable to the first one. (Shipman 1989)

A report published a decade after these fishing management plans were produced mentions that Lake Herrick was limed, stocked, and fertilized from 1982 to 1989. Fertilization and liming were discontinued in 1989 and stocking stopped the following year (with the exception of channel catfish, which were stocked until 1992) (Krauss et al. 1999).

A 1989 memo drafted by UGA law students outlines several avenues by which pollutants were known to enter Lake Herrick. The first is runoff from the intramural fields; the University's grounds crew sprays fertilizer, herbicide, insecticides, and fungicides on the "upper bank" of the fields, but rarely on the lower bank that is closer to the lake. A separate maintenance crew under the direction of the School of Forest Resources used Roundup to control vegetation around the Parvo Pond, some of which probably also entered the lake. One feeder stream was noted as conveying water from a pond on the far side of the bypass and probably received runoff from the bypass. The other feeder stream, which flows through the residential neighborhood on the other side of East Campus Road, conveys runoff of unknown quality. The student authors recommended regular monitoring of the lake and its feeder streams, and suggested that detailed records should be maintained and the information made available to the general public. They also noted that an estimated 5-6,000 people "use the lake annually," although they do not specify the activities that constitute said "use," nor do they provide a source for this information (Dance and Pulliam 1989). A 1989 survey indicated that Oconee Forest Park receives over 50,000 individual visits per year, in addition to extensive group recreation and teaching use (Williams 1997).

Also in 1989, the aquatic plant Brazilian *elodia* became established in Lake Herrick. The plant was likely introduced by somebody dumping the contents of their aquarium; *elodia* is a common aquarium plant because it filters water very effectively. This property had the notable effect of turning the lake's historically murky water quite clear (Williams 2013). The plant quickly spread throughout the lake, forming thick mats on the bottom to a depth of about twelve feet. This made fishing difficult, was advantageous to bream (which were already over-abundant), and was a problematic safety and aesthetic concern during the 1995 Recreational Sports Triathlon. The impediment to the triathlon seems to have been the last straw; in March 1996, 125 fingerling grass carp were added to the lake. The previous winter had brought "die-back" conditions, so the carp nearly eradicated the *elodia* within six months ("1996 Addendum." n.d.). The carp had haploid genetics and were thus unable to establish a breeding population in the lake. They are also herbivorous and thus cannot be caught by rod or reel – an essential trait for survival under heavy fishing pressure. A small amount of *elodia* continues to grow in the water and around Lake Herrick's banks, but it has not rebounded to anywhere near the overgrown conditions that proved to be so problematic (Williams 2013).

In the mid-'90's, UGA built the Bus Center on Riverbend Road. Construction resulted in notably high sediment inputs into the Lake Herrick watershed through the 30-inch pipes that run under Highway 10. The Campus Planning Department was notified of the erosion problem and made efforts to impound the stormwater and detain and release it more slowly. This anecdote speaks to a process that has been ongoing since the lake was built: erosion and sedimentation. Years of erosion have caused sediment to come to rest in and above Parvo Pond, in the stream between the pond and the lake, in the upper reaches of the cove where the stream enters the lake, and across the lake bottom itself. Each big storm re-entrains the sediment, washing it further downstream. Over the twelve year period from 1985 to 1997, the maximum lake depth below the footbridge decreased by six inches (Williams 1997). The maximum depth near the dam was eight meters when the lake was created. Measurements taken in 1999 showed it to be no deeper than 5.5 meters (Krauss et al. 1999). This change of nearly 100 inches in 17 years indicates a much higher rate of sedimentation at the dam than that observed in the cove near the footbridge.

There are three primary sources by which stormwater and sediment enters the lake via Oconee Forest Park (this description does not include inputs from other parts of the watershed - the intramural fields or East Campus Road and the area to the west of it). Normal runoff from within the park does not generate significant sediment input because the area is mostly forested. Roads are kept surfaced with gravel and lined with road dips and culverts for drainage. These maintenance practices are adequate for normal water and sediment quantities. Trails are reinforced with water diversion bars, gravel, and wood chips on an as-needed basis. Strong winter storms can occasionally overwhelm park drainage systems, causing erosion and sedimentation, so regular spring maintenance is conducted to address winter impacts (Williams 1997).

Most sediment in Lake Herrick comes from water diverted into the lake and its tributaries from outside the forest park. There are four main sources – two of them are the aforementioned culvert pipes that convey water (and probably other undesirable runoff) from the Bus Center. Another is the culvert pipe that conveys water from the Family Housing apartment complex on Roger's Road. The fourth source of sedimentation has its origins within the Oconee Forest Park: the degradation of trails by excessive numbers of mountain bikes, and visitors with pets who often and consistently do not heed leash rules. Yearly maintenance to remediate these impacts is significant in terms of time and money (Williams 1997).

In 1997, after more than a decade of fishing, a well-balanced and large bass population remained elusive. Managing for higher quality fish in the face of heavy fishing pressure was still problematic; students produced another management plan. Bass and bream were specified as the two desirable sport fishing species; stocking of channel catfish had been discontinued five years previously. Both desirable fish populations were reproducing, but there were very few intermediate sized bream because of competition with crappie and heavy predation pressure from largemouth bass, crappie, and gar. The bass were not reaching their desired plumpness either, primarily because they did not have a sufficient food base (bream) on account of competition from crappie and gar (Smith et al. 1997). It is not clear why crappie were not regarded as desirable for recreational fishing, as they are generally popular amongst anglers. Their origin in Lake Herrick is undocumented – perhaps they were introduced in the previous five years as a substitute for the discontinued channel catfish. The gar are also of mysterious origin. This plan was the first mention of their presence in the lake. They were not likely to have been introduced intentionally by the lake manager, but they have been known to travel from rivers through sewers and culverts to reach lakes and ponds (Wikipedia 2014).

The students noted that fertilization was not being conducted regularly. They recommended a fertilization program to increase the lake's productivity, as fertilization would result in phytoplankton blooms, which would shade out weedy aquatic vegetation and provide food for fish. They caution that, once initiated, fertilization must be done on a regular basis. Irregular fertilization can result in oxygen depletion and cause a fish kill. They observed that aquatic vegetation was present in the lake and noted that it could cause problems in the future if left unmanaged. They concluded with the recommendation that, since increased fishing is not the objective, management activities should focus on regulating fishermen rather than the fish population. This could be accomplished with more signs about rules for size and catch limits (Smith et al. 1997).

In July 2002, following a solicitation by Oconee Forest Park management to investigate an odd change in color, UGA hydrology professor Dr. Todd Rasmussen reported that the lake water was a "brownish olive color." He speculated that it probably had to do with urban stormwater entering the lake from recent storms, primarily via the western tributary. A heavy dose of urban stormwater could contain pesticides, herbicides, sediments, pathogens, metals, nutrients, and other assorted pollutants. He suggested that, without further input, the lake would return to its regular color soon (Rasmussen 2002). This manifestation of pollution in the water at Lake Herrick spurred conversation. One correspondence between UGA staff members in the Environmental Safety Division and the Recreational Sports Department attributed declining water quality to urban runoff and domestic and wild animal populations. The author, Environmental Safety Division employee Renee Perro, suggested water quality testing, previously limited to fecal coliform tests during the swim season, should be more frequent and comprehensive. Conditions had become degraded to the point that testing under the guidance of a hydrologist or other specialist would probably be necessary to judge the suitability of the lake for swimming (Perro 2002).

Two weeks after the initial email about Lake Herrick's strange coloration, the water had not returned to its normal color. Instead, a "suspended substance" was observed to be clouding the water. Biology professor Marshall Darley stated that he had taken a plankton sample from the footbridge five to six weeks previously and observed an abnormally high number of cyanobacterial colonies. He thought that they belonged to the genera Microcystis, which is known to produce toxins. Whatever it was, it had been appearing in samples for at least a year, but never as abundantly as he had observed it in June. He made reference to a book that states that that 50-70 percent of cyanobacterial blooms are toxic, and it would be unwise for any animal to consume water that appears to be affected by such a bloom (Darley and Williams 2002).

Dr. Darley returned to the lake and took a sample with a net. A single sweep near the surface clogged the net, which had never happened previously. He was almost completely certain that the mysterious substance was a cyanobacterium (blue-green algae), and believed it to be of the genus Microsystis, which commonly forms blooms. The genus is known to be toxic to animals that consume water in which they are present. The best known toxins produced by cyanobacteria are hepatotoxins and neurotoxins, which do not cause problems unless ingested. Additionally, "lipopolysaccharide endotoxins produced by some Microcystis strains have been implicated in cases of fever and inflammation in humans who have bathed or showered in water that contains cyanobacterial blooms" (Darley and Williams 2002). Dr. Darley suggested that swimming and wading would not be advisable, but limited hand contact is probably safe. He had personally exposed his bare hands to the lake water for over thirty minutes while conducting tests and experienced no adverse effects. He suggested that it would still be safe to hold canoeing classes, but it would be prudent to have some clean water available to wash hands when engaged in activities that could result in contact with the water. He also mentioned that the resident turtles, fish, and ducks did not seem to be affected, which was a positive sign. (Darley and Williams 2002)

By late August, roughly a month after the cyanobacterial bloom had peaked, the Microcystis was subsiding. However, this episode marked the beginning of an annual cycle. A 2005 correspondence confirms that nutrient concentrations in the lake, especially phosphorus, were consistently causing blue/green algae blooms each growing season. This was exacerbated by hot and "calm" weather, and dry spells followed by sudden heavy rain that carried with it proportionally heavy pollutant runoff inputs. (Williams 2005)

Also in 2005, Warnell School of Forestry employees made an effort to improve conditions at Parvo Pond. The pond had been subject to overuse at the off-leash dog area, and was a possible source of contamination. It used to overflow frequently and spill over the forest road into the lake. An eroded gully, formed by these overflow events, is still visible. The plan was to rehabilitate the pond, although it is not clear what this was to specifically entail. The dam was breached but had to be patched immediately due to regulatory issues. No rehabilitation work was completed, and the pond has been left alone since then. It is smaller than it used to be, drawn down from its original two acres out of concern for the stability of the dam. Heavy winter rains often result in the pond's outlet pipe getting clogged, so it must be unclogged manually each year (Williams 2013). The pond is also surrounded by silt fencing – this may have been installed in conjunction with plans for rehabilitation activities and simply never removed. It was most likely placed intentionally either as a long-term preventative measure against sediment input to the pond, or to keep dogs out of the water.

The beach at Lake Herrick was closed and swimming prohibited, either in 2002 or 2005. Official documentation of this event has proved elusive, but it can be inferred that the decision to close the beach was influenced by the growing variety and severity of water quality issues. Sailing, canoeing, and kayaking classes were discontinued and recreational boating prohibited as well, out of concern for the possibility of somebody accidentally falling into the lake. Since 2005, written documentation of management activities, observations, and problems is lacking.

Aerial Photos: 1938-2013

The following series of aerial photos shows the changing landscape of the Lake Herrick watershed over the course of 75 years from 1938 to 2013. A red line demarcating the watershed boundary has been superimposed over each photo, including a boundary line that delineates the Parvo Pond subcachment (the smaller, southern-most portion of the watershed).

Figure 1: 1938 aerial photo of the Lake Herrick watershed. The watershed and most of the surrounding landscape is used for agriculture, with the exception of Oconee-Denmark forest.

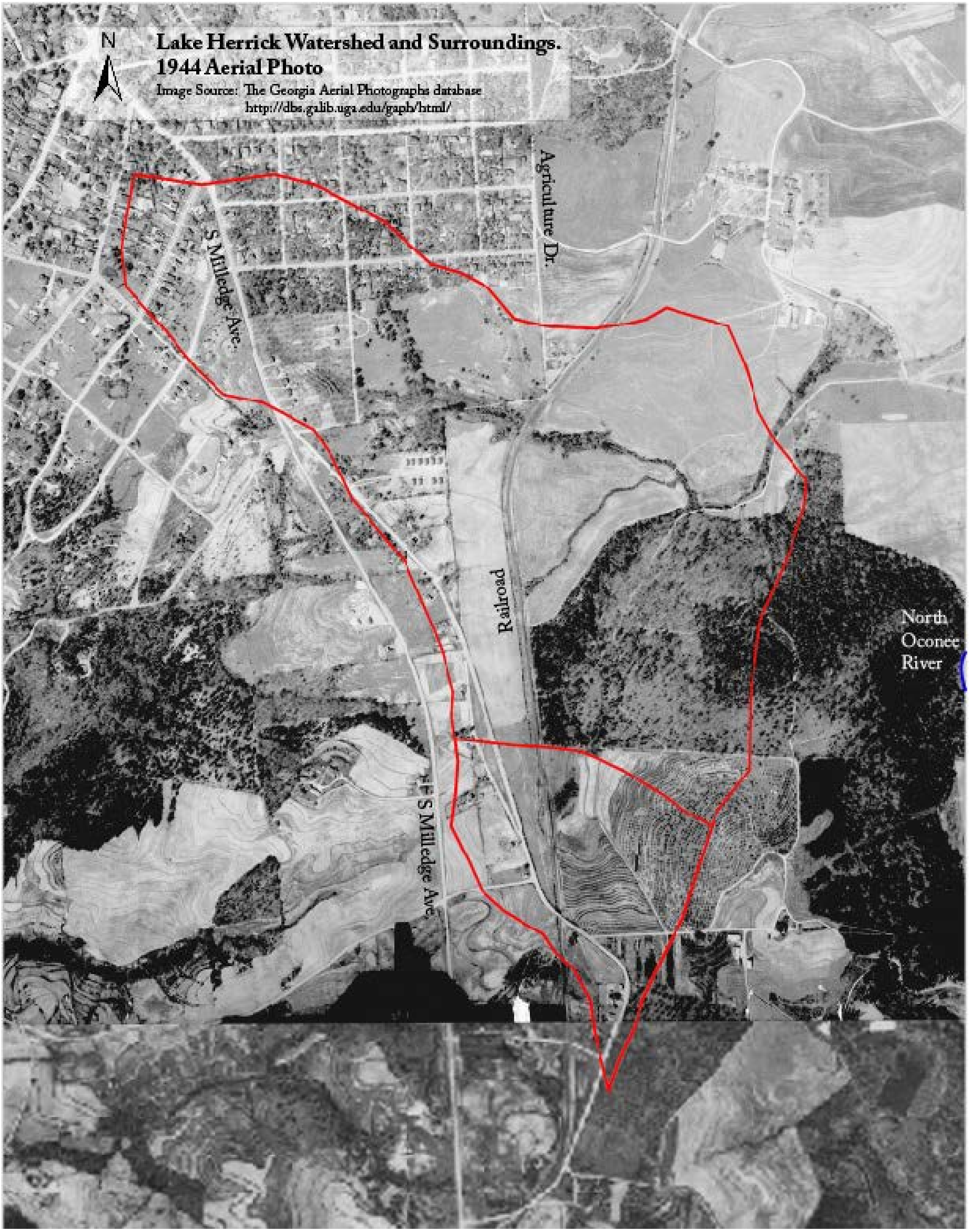


Figure 2: 1944 aerial photo of the Lake Herrick watershed. A set of buildings has been constructed just inside the western watershed boundary, but otherwise the landscape remains largely unchanged from 1938. Sparse foliage in Oconee-Denmark forest is probably indicative of a winter-time photo rather than deforestation.

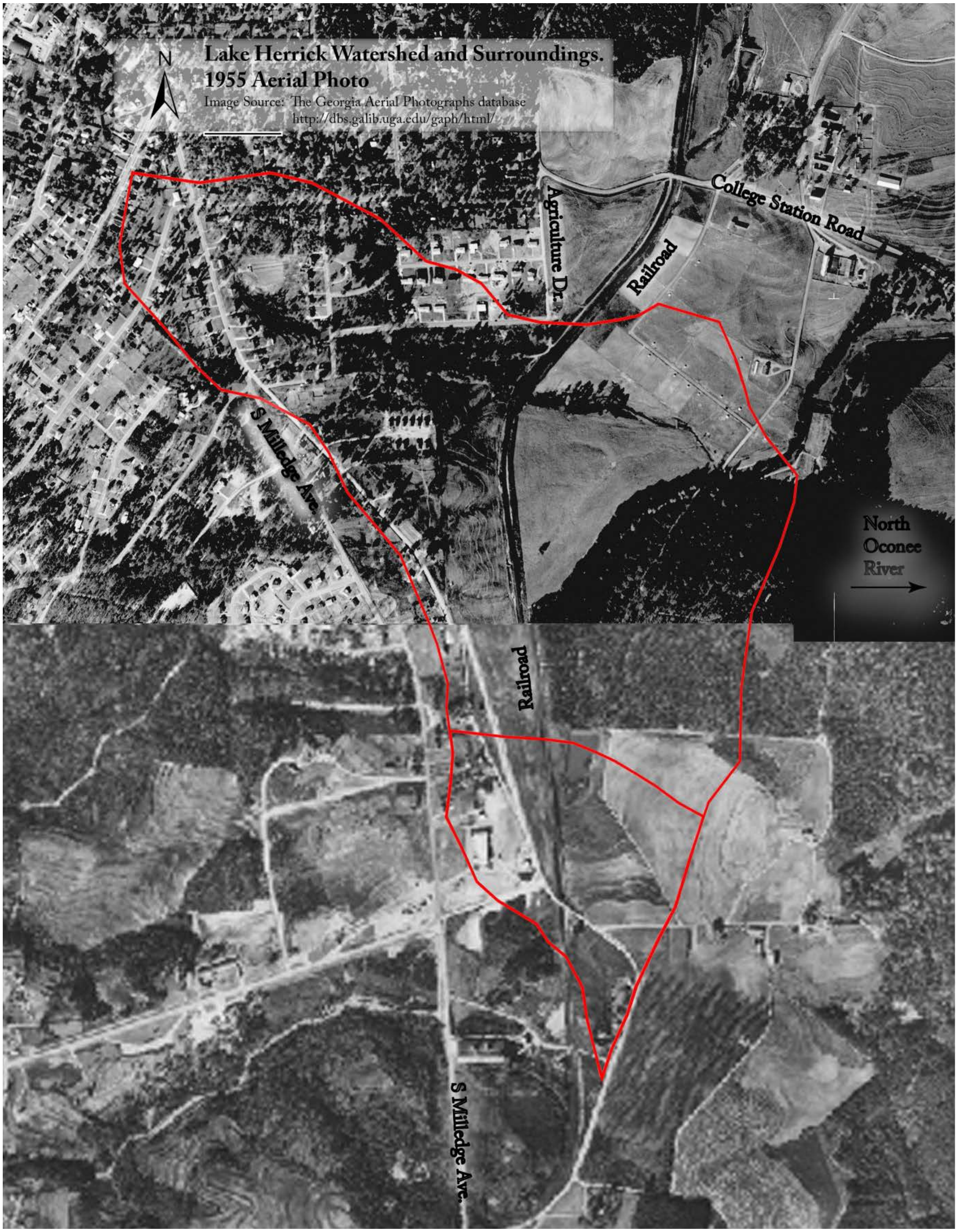


Figure 3: 1955 aerial photo of the Lake Herrick watershed. New development has popped up in the northwestern portion of the watershed. Parvo Pond has been built, as has a large building along the western boundary of its subcachment.

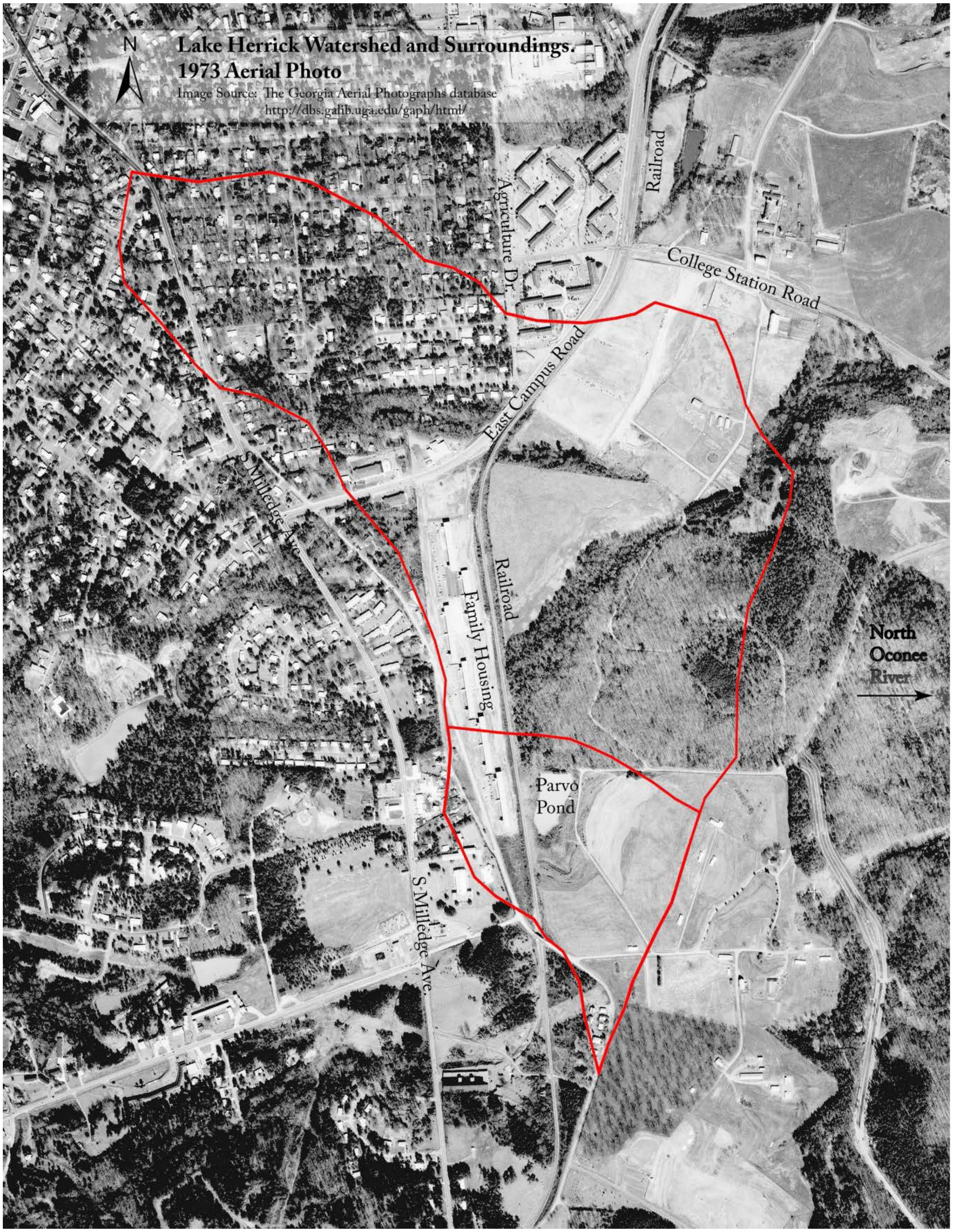


Figure 4: 1973 aerial photo of the Lake Herrick watershed. The Family Housing complex is now present, and the neighborhood in the northwest portion of the watershed has reached its current-day extent and density.

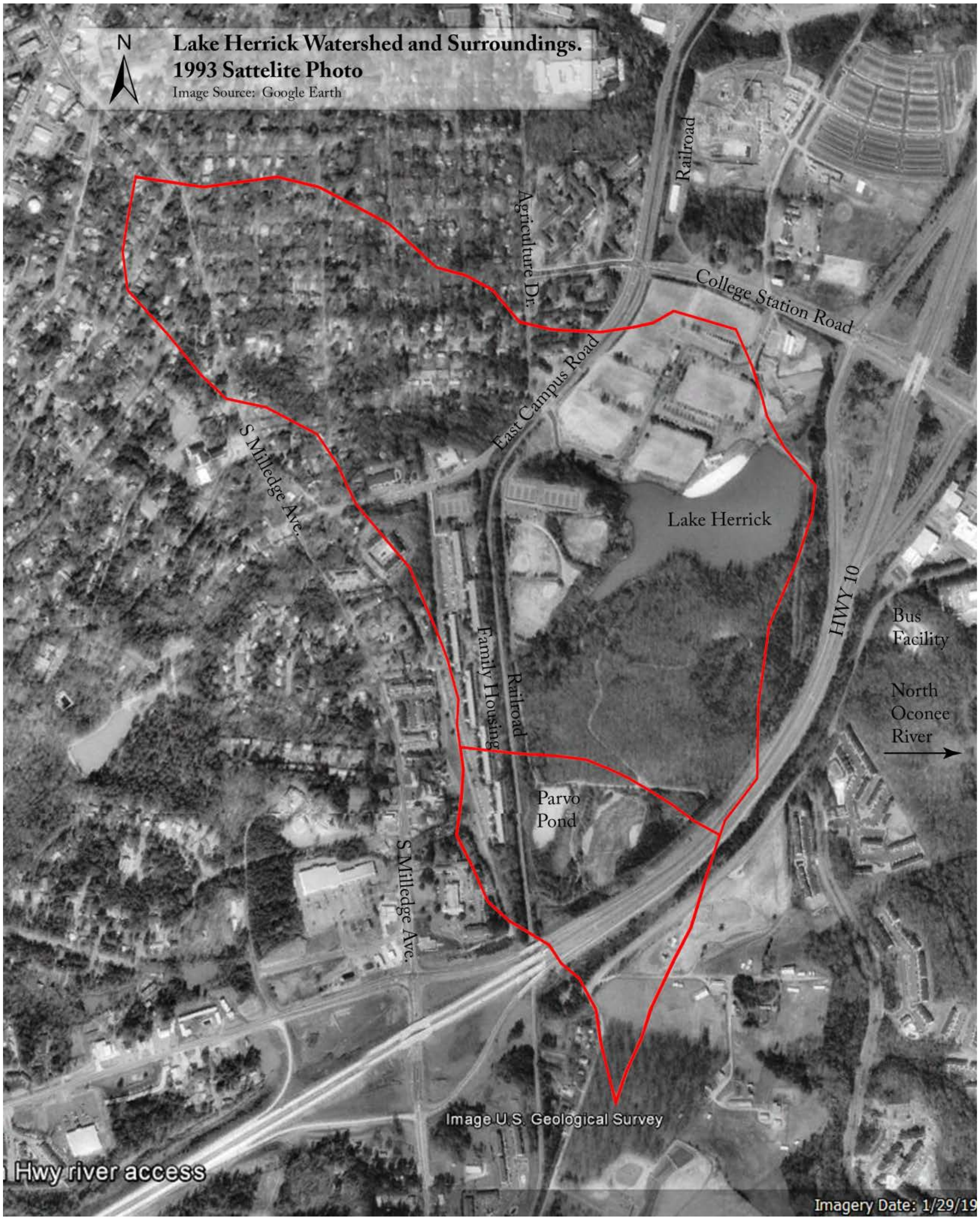


Figure 5: 1993 satellite photo of the Lake Herrick watershed. Lake Herrick, the intramural fields, baseball fields, tennis courts, Oconee Forest Park, and Hwy 10 are all established. The UGA Campus Transit facility is under construction. Parvo Pond is a different color than Lake Herrick; heightened sediment inputs from the construction may have contributed to this, but the pond is also perpetually turbid due to input from a natural spring.

Figure 6: 2013 satellite photo of the Lake Herrick watershed. The watershed is as we know it today. Parvo Pond has lost substantial surface area since 1993. This is due to a combination of sediment infill and intentional drawdown out of concern for the stability of the dam (Williams 2013).

Water Quality Data from various sources: 1986-1999

Water quality data prior to 2006 is sporadic. Samples are rarely replicated consistently, so what little information exists is patched together from different sources using different methods. A 1986 report recorded the lake's pH at 8.5-9 and the dissolved oxygen (DO) at 9.5 milligrams per liter (mg/L) (Williams 1997). A separate document reports a 1986 dissolved oxygen sampling value of 4 mg/L (Hancock 1986). In 1988, samples analyzed by the UGA Cooperative Extension Service detected trace amounts of herbicide, but they were below levels that could be accurately measured. The samples were taken at various locations in a single day. However, a handwritten note at the top of the report indicates that the same results were given for 13 additional samples (Bush 1988). In 1989, a document reported the average pH and DO values from 2 sampling events (separated by a week) as 7.5 and 9.7, respectively (Yoder 1989). In 1997, the pH was recorded as 6.0 and DO as 9.2 in a single, unreplicated sampling event (Smith et al. 1997).

In 1999, 4 students in a graduate level forestry class reviewed water quality conditions at Lake Herrick under the direction of Dr. Todd Rasmussen. In the report, the students surveyed Lake Herrick, Parvo Pond, and the 2 tributary streams at 15 different sampling locations. Samples were taken weekly for 6 weeks.

	Bridge	**Forest Stream**	**Urban Stream**	**Lake Outlet**	**Urban Cove**	**Dam**
DO (mg/L)	6.47	6.14	5.95	6.27	7.32	5.18
Conductivity (unknown units)	43.17	49.67	90.78	53.29	44.50	46.53
pH	6.77	6.29	6.27	6.27	6.75	6.55
Turbidity	11.88	20.31	28.76	8.25	13.23	13.8

Table 1 displays the mean values for select parameters sampled at 6 different monitoring points.

The authors acknowledged concern about bacteria levels, but reported that testing did not show fecal coliform concentrations above 200 colony forming units (cfu) per 100 mL. The highest concentrations of bacteria were found in Parvo Pond and at a monitoring point in the tributary stream adjacent to the tennis courts. (Krauss et al. 1999)

A series of measurements was taken near the lake's surface between September 2, 2001 and January 5, 2002. Measurements of alkalinity, CO2, NO3, NH4, PO4, Secchi depth, and various types of plankton were all recorded. However, the document provides no information regarding sampling location, method, author, or other contextual details ("Lake Herrick Data from Sept. 2 to Nov. 11, 2001." n.d.).

	Sept 2, 2001	**Sept 23, 2001**	**Oct 13, 2001**	**Nov 9, 2001**	**Jan 5, 2002**
DO	8.3	8.5	9.6	7.8	9.6
pH	6.3	6.7	7.7	6.7	6.6

Table 2 displays the results of DO and pH samples taken at an unspecified sampling location at Lake Herrick between September 2001 and January 2002 ("Lake Herrick Data from Sept. 2 to Nov. 11, 2001." n.d.).

Local Context: UGA Campus Watersheds

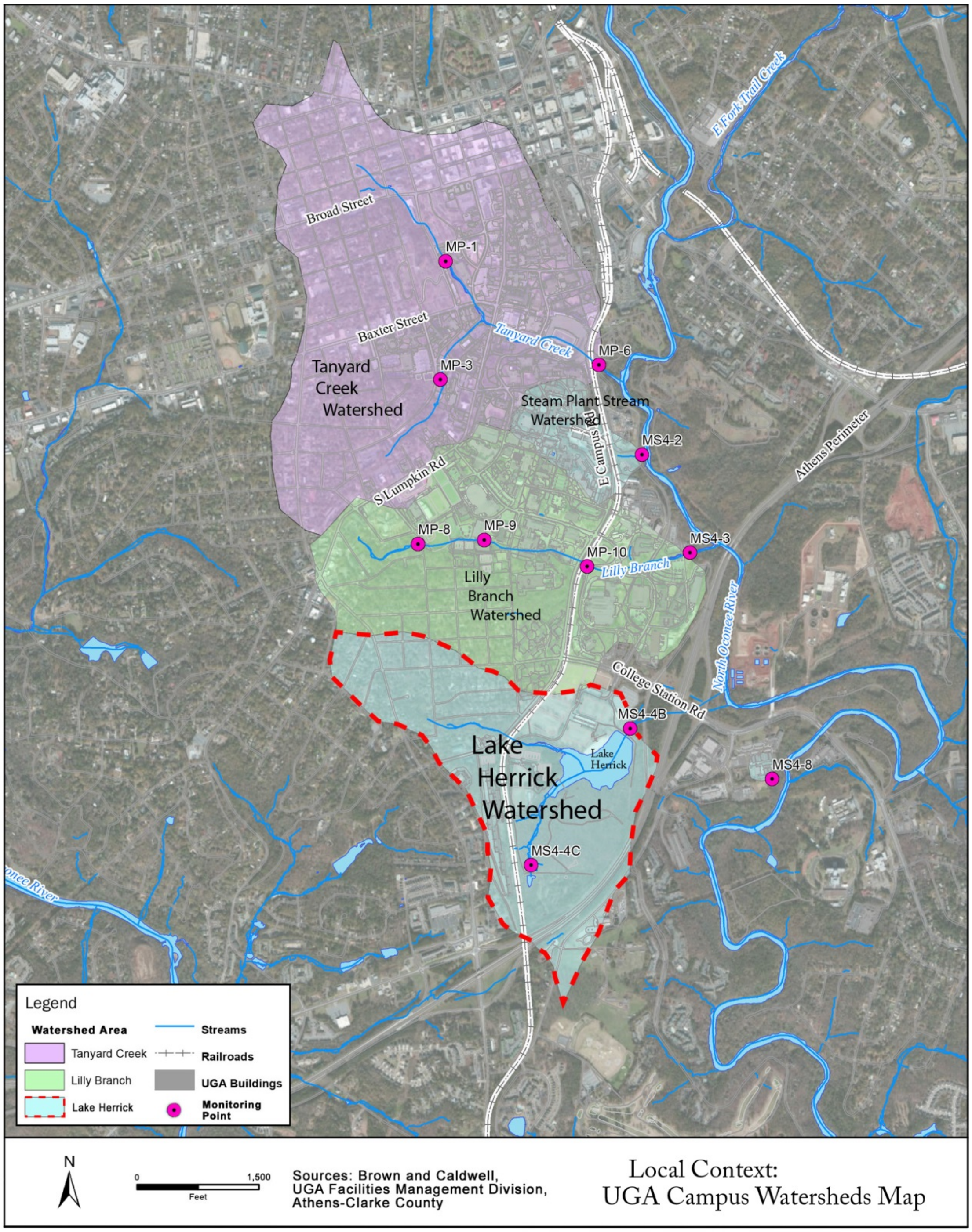


Figure 7: Local Context Map

Figure 8: Map of the Lake Herrick watershed

Inventory of Current Conditions

Water Cycle

The student report "Water Quality in Lake Herrick and its Tributaries" included analysis of temperature measurements taken at one meter depth intervals down to a depth of five meters. The results indicate that Lake Herrick was thermally stratified from early September 1999, when monitoring began, through late October. The lake mixed at the end of October, leading to an algal bloom in early November. Although these results are based on limited data, they do indicate that Lake Herrick is subject to at least some degree of thermal stratification. The effects of stratification may become less pronounced as the lake continues to lose depth due to sediment accumulation; the report indicated that, although Lake Herrick originally had a maximum depth of eight meters, it was only 5.5 meters deep at the time that the study was conducted. (Krauss, et al. 1999)

A more long-term and comprehensive monitoring program would be useful towards understanding the extents and effects of stratification in Lake Herrick. Crucial information to obtain includes rates of water flow into and out of the lake and changes in lake level. This is essential for determining the amount of nutrients a lake can assimilate each year without problems, also known as the Total Maximum Daily Load (TMDL). Other important processes that could be better understood with more comprehensive data include seasonal turnover, mixing, and stratification.

Water Quality

<u>The MS4 Monitoring Program: 2004-present</u>

In 2003, the University of Georgia contracted environmental consulting firm Brown and Caldwell (B+C) to conduct a series of water quality tests on the streams that run through campus. Between November 10, 2003 and September 7, 2004, the firm conducted 8 sampling events at nine locations. The purpose of the testing was to evaluate stormwater discharge and generate baseline information in anticipation of receiving a National Pollutant Discharge Elimination System permit. In 2006, B+C resumed water quality monitoring on a regular basis to continue to identify and evaluate water quality issues in stormwater discharged from UGA property. The program has continued and is currently ongoing. B+C conducts a total of eight sampling events each year; four during dry conditions, and four during wet weather events to gauge the differences between stormwater runoff and base-flow conditions. Sampling locations were established at strategically located stormwater outfalls on UGA campus. Two locations are associated with Lake Herrick. MS4-4b is located at the outflow of the lake, and MS4-4a was located along a tributary to the lake, just downstream of the outflow to Parvo Pond. In October 2007, MS4-4a was discontinued as a sampling location when it became filled in with a beaver dam wetland. It was replaced by MS4-4c, located closer to the Parvo Pond outlet.

B+C samples for stream flow, total suspended solids (TSS), fecal coliform, E.coli, volatile organic compounds (VOCs), total phosphorus, total nitrogen, metals (As, Cu, Pb, and Zn), oil & grease, mercury, pH, dissolved oxygen, temperature, and conductivity (Brown and Caldwell 2007, 1). Refer to Appendix A for a series of tables and charts that display average values from each annual monitoring period for select parameters.

Stream Flow (stage):

The 2007 monitoring report found a general pattern amongst all sampling locations of elevated stream flows during spring storm events but no significant difference between dry and wet weather stream flows in the fall (Brown and Caldwell 2007, 16). The 2009 monitoring report indicated that stage at MS4-4b had relatively high variation between wet and dry events, while MS4-4c stayed more consistent (Brown and Caldwell 2009, 3.7-3.9), and the 2010 monitoring report found no significant difference between wet and dry sampling for either location (Brown and Caldwell 2010, 3.9). The 2011 report indicated higher average flows at MS4-4b than MS4-4c (Brown and Caldwell 2011, 3.16-3.17), but at MS4-4b those fell to lower average dry event stages during the 2012/2013 sampling period (Brown and Caldwell 2013, 3.6).

Total Suspended Solids (TSS):

In 2006 TSS levels for MS4-4b, as well as most of the other MS4 sampling locations, were all relatively low. Levels at MS4-4a were nearly double that of many of the other locations, and average measurements for wet weather sampling were four times higher than dry weather sampling. This is indicative of elevated sediment flows from Parvo Pond, especially during storm events. (Brown and Caldwell 2007, 18-19) Sampling in 2007 and 2008 detected relatively unchanged TSS levels for wet events, but a two- to threefold increase for dry events (Brown and Caldwell 2009, 3.2-3.3). Sampling in 2009 and 2010 revealed the same general pattern, with MS4-4c exhibiting about twice the levels of suspended sediment as MS4-4b. The relationship between wet and dry averages for MS4-4b was roughly the opposite of that which was detected in sampling from 2007/2008; readings were elevated during wet events and had fallen during dry events (Brown and Caldwell 2010, 3.2-3.3). At a glance, these fluctuations are probably within the bounds of natural variation. Statistical analysis could provide more insight into the nature of the data. These patterns, of higher TSS during wet events and dry events and higher TSS at MS4-4c than b, hold true for sampling in 2010 and 2011 as well (Brown and Caldwell 2011, 3.18-3.19). During the 2012/2013 sampling period, TSS levels had increased at MS4-4c (Brown and Caldwell 2013, 3.6). They remained elevated during both dry and wet weather sampling during the 2014 monitoring period. (Brown and Caldwell 2014, 3.7)

Pathogens - Fecal Coliform and Escherichia coli:

During the 2006 monitoring period, MS4-4a had a dry event fecal coliform average of 101.43 CFU/mL and a wet average of 268.33 CFU/mL. MS4-4b had a wet average of 36.67 CFU/mL and a dry average of 268.33 CFU/mL that was elevated by a single exceptionally high reading of 1,500 CFU/mL. The rest of the MS4-4b sampling results were in the <20-60 CFU/mL range. For both fecal coliform and E. coli, MS4-4a results were generally three to ten times higher than MS4-4b readings (Brown and Caldwell 2009, 3.5-3.7).

During sampling events in 2007 and 2008, average fecal coliform values for dry weather monitoring were about ten times lower than for wet weather events. Both wet and dry measurements at MS4-4c averaged 5 to 10 times higher than MS4-4b (Brown and Caldwell 2009, 3.5-3.7). Results from 2009 and 2010 were similar to the 2007/2008 monitoring. MS4-4c values were still generally elevated above the State's criteria, but they were lower than they had been during the previous period and there was less of a difference between wet and dry events. MS4-4b values generally fell within the range of the State's criteria, with only one exception in September 2009 (Brown and Caldwell 2010, 3.5-3.7). B+C reports that during the 2010/2011 monitoring period, fecal coliform averages remained steady and generally unchanged from the previous period at MS4-4b but increased significantly at MS4-4c. Wet weather results had fallen from 2007/2008 but dry weather results remained comparable. MS4-4c levels were lower than 2009 and 2010 sampling during dry weather but were twice as high during wet weather. During the 2012/2013 monitoring period, MS4-4b had no elevated bacteria concentrations but MS4-4c exceeded standards for 5 out of 7 sampling events. Wet event concentrations at MS4-4c were much higher than historical events; dry event concentration was slightly higher. E.coli levels remained consistent with this pattern (Brown and Caldwell 2013, 3.8-3.10). Monitoring in 2014 indicated higher bacteria levels during wet sampling events, consistent with prior monitoring. Concentrations again exceeded State criteria during multiple sampling events at MS4-4c, but only three times, compared to five during the previous monitoring period. No elevated samples were detected at MS4-4b. B+C concludes that bacteria is generally elevated at MS4-4c, but not at MS4-4b. (Brown and Caldwell 2014, 3.9, 4.2)

Dissolved Oxygen:

Measurements for MS4-4a and b were both generally well over the established limit of 5.0 mg/L, but during the wet and dry sampling events in November 2006, the DO measurements for both locations averaged 2.4 mg/L. These low readings do not correlate with low flows (DO is often higher when stream flows are elevated during wet events) and may instead be related to the decomposition of organic materials, which uses oxygen as part of the chemical process (Brown and Caldwell 2007, 7-8). The 2009

Monitoring Report revealed DO levels consistently within the range of 6-11 mg/L – well within compliance of the State's regulations (Brown and Caldwell 2009, 3.10).

The 2010 monitoring report cites DO as a constituent of concern for MS4-4c; 4 out of 7 samples fell below the State's criteria for the parameter (Brown and Caldwell 2010, 3.10-3.12). Likewise with the 2011 monitoring report, which cites 3 additional dates in 2010 and 2011 where the parameter fell below the State's criteria. This happened once at MS4-4b as well, although Lake Herrick outlet conditions usually tend to be consistently well-oxygenated (Brown and Caldwell 2011, 3.2). During the 2012/2013 sampling period, DO was never recorded below the State's criteria (Brown and Caldwell 2013, 3.2). Low oxygen levels can be attributed to the slow-moving nature of the stream that connects Parvo Pond and Lake Herrick, as well as the presence of high amounts of iron reducing bacteria. Further suppressing streamflow was the recently constructed beaver dam that was present just downstream of the sampling location (Brown and Caldwell 2011, 3.2).

Temperature:

Temperature has been consistent at MS4-4 a, b, and c for all monitoring events. It corresponds to seasonal change and ambient air temperature and is not deemed a concern (Brown and Caldwell 2013, 3.2).

pH:

The average pH for both MS4-4a and b for all sampling events in 2006 was very close to 7 (Brown and Caldwell 2007, 27-28). During 2 separate measuring events in October and December, pH for both MS4-4b and c exceeded the State's criteria of 6 to 8.5. Their values of 9.24 and 10.00 at MS 4-4b and 9.14 and 11.00 at MS4-4c respectively, are briefly noted in the Brown and Caldwell 2009 monitoring report and explained simply as an anomaly. A return to more normal pH values close to 7 for 5 sampling dates in 2008 support this explanation (Brown and Caldwell 2009, 3.13-3.14). The 2010 monitoring report reveals 3 out of 7 pH readings at MS4-4c to be slightly below the State's criteria of 6.

Two of these readings were taken during wet events and 1 during a dry sampling event. pH at MS4-4b was consistently within the range of 6-7 (Brown and Caldwell 2010, 3.15-3.16). Sampling in 2010 and 2011 revealed a single event in which pH at MS4-4b was below the State's criteria. However, low pH readings were found at all sampling locations on this particular day and could be attributed to malfunctioning equipment. Four out of 8 sampling events for this period at MS4-4c were below the State's criteria (Brown and Caldwell 2011, 3.7-3.8). All pH measurements were within the State's criteria for the 2012/2013 sampling period (Brown and Caldwell 2013, 3.3-3.4). Wet and dry averages at MS4-4c were reportedly "lower than the ideal pH for natural waters" during the 2014 sampling period. (Brown and Caldwell 2014, 3.4) B+C notes pH as a constituent of concern for both MS4-4b and c, and suggests several sources that could be influencing the water's pH: acid rain, decomposing organic matter, or runoff from coal burning or other polluting facilities (Brown and Caldwell 2011, 3.7).

Conductivity:

There was no difference in average conductivity for wet and dry sampling at either location, and values generally fell within the expected range with the exception of a single elevated reading at MS4-4a during a dry monitoring event in August 2006 (Brown and Caldwell 2007, 29-30). Between 2008 and 2011, numerous conductivity readings at the Lake Herrick monitoring locations dropped slightly below the typical regional range of 0.070 to 0.150 mS/cm (Brown and Caldwell 2009, 3.15-3.16; Brown and Caldwell 2010, 3.17-3.18; Brown and Caldwell 2011, 3.10-3.11). However, lower than normal values are not as much a cause for concern as are elevated values. Conductivity readings at MS4-4b and c were slightly higher than historical averages during the 2012/2013 monitoring period, but lower than historical averages during the 2014 monitoring period. (Brown and Caldwell 2013, 3.5; Brown and Caldwell 2014, 3.5) Continual increases could indicate a trend of ionic constituents of concern in the watershed.

Turbidity:

In 2006, MS4-4a had a dry average of 27.9 NTU and a wet average of 51.8 NTU. MS4-4b had a dry average of 7.6 NTU and a wet average of 56.6 NTU. Turbidity values increased during wet events, and tend to be higher at MS4-4a for dry events but higher at MS4-4b for wet events (Brown and Caldwell 2007, 31-32). Monitoring events in 2007 and 2008 indicated a wet average of 21.44 and a dry average of 10.02 for MS4-4c and a wet average of 633.31 and a dry average of 10.86 for MS4-4b. This significant increase in MS4-4b's wet average can be attributed to a single elevated reading of 1875 NTU during a sampling event on March 4, 2008. Monitoring in 2009 and 2010 revealed values that were generally consistent with prior data, although the dry average at MS4-4c jumped to 84.30 NTU (Brown and Caldwell 2009, 3.17-3.18). Monitoring in 2010 and 2011 revealed values at MS4-4c to be generally somewhat higher than at MS4-4b. During one wet event, MS4-4c's turbidity jumped to 1,000 NTU. Values were typically lower, ranging between 6.55 and 43.2. (Brown and Caldwell 2011, 3.13-3.14) Averages during the 2012/2013 monitoring period were consistent with historical measurements; notably, turbidity tends to be elevated during dry conditions. (Brown and Caldwell 2013, 3.6) Measurements taken during the 2014 monitoring period indicated elevated values during both dry and wet monitoring at MS4-4c, consistent with historical results. (Brown and Caldwell 2014, 3.6).

Volatile Organic Compounds (VOCs):

VOCs were sampled 4 times in 2006 – 2 wet and 2 dry – and were not detected in any of the samples (Brown and Caldwell 2007, 33). Four sampling events were repeated between 2007 and 2008, 2009 and 2010, and 2010 and 2011 with the same result (Brown and Caldwell 2009, 3.20; Brown and Caldwell 2010, 3.21-3.22; Brown and Caldwell 2011, 3.34-3.35).

Oil and Grease:

Three MS4 monitoring locations are occasionally sampled for oil and grease because they receive runoff from automobile maintenance facilities (Brown and Caldwell 2009, 3.20). The MS4-4 locations are not included, but perhaps they should be tested for inputs from the UGA bus facility.

Total Phosphorous:

In 2006, MS4-4a and b were the only two MS4 sampling locations that were below or near the EPA guideline of 0.0365 mg/L – the other six locations on campus that were tested had elevated phosphorous (Brown and Caldwell 2007, 33-34). Sampling from 2007, 2008, 2009, and 2010 detected somewhat higher levels of phosphorus, with nearly all samples at concentrations higher than the EPA guideline. However, all samples were still well below the EPD's 0.5 limit (Brown and Caldwell 2009, 3.21-3.22; Brown and Caldwell 2010, 3.24-3.25). In September of 2011, phosphorous measurements at MS4-4b reached an all-time high of 0.242. Subsequent measurements throughout 2011 were lower, falling near, and often slightly above, the EPA guideline. A single monitoring event in 2011 detected phosphorous at MS4-4c at 1.2 mg/L. Although the other measurements during this period were substantially lower, this raised the dry sampling average above the average for the previous two years. The corresponding level for Lake Herrick during this event was below the method detection limit of 0.0050 mg/L (Brown and Caldwell 2011, 3.38-3.39). During the 2012/2013 monitoring period, total phosphorous levels exceeded the EPD's limit during one dry MS4-4c sampling event and one wet MS4-4b event. Dry weather values for both sampling points were overall lower than historical values (Brown and Caldwell 2013, 3.12-3.13). Both the wet and dry weather means were slightly higher than the historical average at MS4-4c during the 2014 monitoring period. MS4-4b and c both have slightly higher wet weather averages than dry weather averages, which suggests loading via runoff. (Brown and Caldwell 2014, 3-12)

Total Nitrogen:

All values of TN sampled in 2006, with the exception of a single sampling event at MS4-4a, exceeded the EPA's suggested value of 0.69 mg/L (Brown and Caldwell 2007, 35-36). In many cases they were at least double that value. Between 2007 and 2011, values for MS4-4b and c remained similarly elevated (Brown and Caldwell 2009, 3.24-3.25; Brown and Caldwell 2010, 3.26-3.27; Brown and Caldwell 2011, 3.40-3.41). Nitrogen concentrations at both sampling points rose even higher above historical means during the 2012/2013 sampling period. A TN reading of 8.6 mg/L was recorded during one MS4-4c dry weather event. The 2013 Brown and Caldwell report suggests that animal waste is a likely source of nitrogen during baseflow events. The increase during wet events is more likely to be linked to the abundance of landscaped area where fertilizers are used (Brown and Caldwell 2013, 3.13-3.14). During the 2014 monitoring period, wet and dry values for both MS4-4b and c were slightly lower than historical averages. The wet mean at MS4-4b is lower than the State's maximum criteria, but the wet mean at MS4-4c is higher. (Brown and Caldwell 2014, 3.13)

Metals:

From 2006 to 2008, arsenic, copper, lead, and zinc (all of which can be harmful in high concentrations) were sampled during eight events – half wet and half dry. Arsenic was not detected in significant quantities. MS4-4a and b were the only two sampling locations in which copper was not detected above the State's acute or chronic maximum allowable criteria. Likewise, the sampling locations associated with Lake Herrick were the only two in which excessive amounts of lead and zinc were never detected (Brown and Caldwell 2007, 37-39; Brown and Caldwell 2009, 3.26-3.29). One MS4-4b sample in 2009, and one in 2013 exceeded the State's chronic criteria for lead, but was still below the acute value. Lead is regarded as a constituent of concern for all MS4 monitoring locations, and exceeded state criteria at both MS4-4b and c in 2014. A MS4-4c sample in 2010 exceeded both acute and chronic criteria for zinc. Results from all other samples were below both acute and chronic State maximum allowable limits

(Brown and Caldwell 2010, 3.27-3.32; Brown and Caldwell 2014, 4.3). Copper at MS4-4b exceeded the state's criteria during a sampling event in 2013 (Brown and Caldwell 2013, 3.16).

Water Quality Monitoring Summary and Analysis:

The high variability observed in stage relationships between MS4-4b and c and between wet and dry sampling events for both locations may indicate that there are not enough samples to identify a definite pattern. The 2010 Brown and Caldwell report identifies bacteria as a main parameter of concern; during that monitoring period, Lake Herrick's outflow only had one elevated bacteria sample but half of the samples from the Parvo Pond outflow exceeded bacterial standards (Brown and Caldwell 2010, 3.5-3.7). Over the course of the MS4 monitoring program bacteria levels have exhibited a slight downward trend in Lake Herrick and rarely exceed the State's criteria. In Parvo Pond, however, bacteria are elevated and levels are increasing.

pH has become a constituent of concern in recent years, especially at Parvo Pond, dipping below acceptable limits in 2009, 2010, and 2011. This indicates high levels of organic decomposition, which may be driving dissolved oxygen depletion. Based on data from the MS4 monitoring program and sporadic measurements from previous years, dissolved oxygen levels have fluctuated from year-to-year. It occasionally drops below acceptable limits, most notably during the 2009/2010 monitoring period. Parvo Pond consistently has lower dissolved oxygen levels than Lake Herrick.

Average turbidity levels have remained fairly constant in Lake Herrick over time, excluding a significantly heightened average during the 2007/2008 monitoring period. Average turbidity in Parvo Pond has increased greatly over the course of the MS4 monitoring program. TSS has followed a similar trajectory. It tends to be higher at Parvo Pond than at Lake Herrick. No clear pattern has been established of the relationship between TSS levels and wet and dry weather, perhaps indicating the need for more frequent sampling. Parvo Pond and its corresponding tributary stream is a clear vector for elevated quantities of sediment flowing into Lake Herrick.

Nitrogen and phosphorous have also both been on the rise in recent years; the 2010 B+C report identifies both nutrient types as main parameters of concern, and in 2011 and 2012 each parameter had one particularly elevated reading at Parvo Pond during dry events in September. This suggests that nutrient concentrations are being driven by internal loading, rather than runoff, as warm weather stimulates stratification, anoxia, and nutrient release from bottom sediments. However, an elevated phosphorous sample taken from the Lake Herrick outflow during a wet sampling event in January 2013 demonstrates that external loading is also a factor. Overall, there is no clear association with elevated nutrient levels for either wet or dry sampling events. Average increases in both parameters at Parvo Pond are mirrored by less severe increases at Lake Herrick, perhaps influenced by inputs from the pond.

Metals have generally not been present in notable amounts, although excessive levels of copper, lead, and zinc have been detected in recent years. Conductivity, temperature, and VOCs have remained fairly constant over time and are not constituents of concern.

Parvo Pond exhibits more undesirable levels of almost every parameter than Lake Herrick, and significant changes in numerous parameters indicate a relatively rapid decline in water quality since 2010. The pond conveys polluted water to Lake Herrick, the impact of which becomes diluted at least to some extent by the lake's larger volume. Improving the water quality of Parvo Pond will facilitate the rehabilitation of Lake Herrick. Despite its currently detrimental contributions, the pond does have the beneficial effect of acting as a buffer, protecting Lake Herrick from receiving more direct impacts in full force.

B+C noted that the earthen dam at the Parvo Pond outfall is leaking in places and the wooden supports for the outfall pipe had collapsed (Brown and Caldwell 2010, 4.6-4.8). The pond has no outlet structure, and flows discharge through two pipes, forming two separate streams below the dam. The streams have very little baseflow and support high levels of iron-reducing bacteria. They also noted the severely eroded state of the gullies that contribute water and sediment to Lake Herrick. The 2011 B+C report suggests that the water quality could be improved by installing an outlet control structure (Brown and Caldwell 2011, 4.4). In 2013, B+C noted a significant increase in bacterial concentration at this location and cited the nearby dog park as a likely contributor (Brown and Caldwell 2013, 4.4).

Regional Water Quality

Other lakes in the same ecoregion are likely to have similar problems. Comparing water quality to lakes in undisturbed watersheds can help determine whether problems are due to development practices or if they are natural and reversible via management strategy. One useful tool for doing so is the Trophic State Index. This quantifies phosphorous-based eutrophy as a coefficient. It is useful for comparing the lake's state with other lakes in the area, and allows for the tracking of changes following management activities, restoration practices, and watershed modification. It works for lakes that are phosphorous-limited, but not as well for lakes that are nitrogen-limited, where a great amount of turbidity is due to erosion rather than biotic sources, or that are heavily plagued by macrophytes. The trophic state index was developed to predict the behavior of natural northern lakes, so its applicability to Lake Herrick is questionable but warrants further investigation. (Holdren et al. 2001, 153, 158)

In 2003, Ecos Environmental Design, Inc. and four partner organizations assessed the fisheries quality, dam integrity, and surrounding landscape conditions of 18 bodies of water. The study sites were all in DeKalb County, which encompasses the eastern half of Atlanta and extends east of the city. All of the lakes in the study are associated with parks and managed by the county Parks and Recreation Department. Because Atlanta and much of the area surrounding the city is characterized by urban land use, the assessed lakes can be expected to receive similar runoff inputs and use impacts as Lake Herrick. The study found that all lakes were in need of management programs to monitor water quality, maintain fisheries, and control macrophyte populations. Nearly all were in need of maintenance improvements for their dam spillway, and outlet structures. Most had shoreline areas that lacked native vegetation and required stabilization. Invasive plants and aquatic weeds were present in the water or surrounding areas of half the lakes. Common aquatic weeds included duckweed, water lettuce, spike rush, ludwigia, elodia, pithophora, fanwort, bladderwort, parrot’s feather, and najas. Erosion was a substantial issue for more than half of the lakes, occurring on land near the lake (often associated with impervious areas or heavy pedestrian traffic on natural surfaces), along tributary streams, and at the water's edge. Consequently, eight of the lakes had notable sediment buildup. Less commonly reported but occasionally observed were instances of pollutant inputs and runoff impacts. Only one instance of algae was reported. (ECOS Environmental, Inc., et al. 2003)

Testing generally indicated good water quality. However, each lake was only tested a single time; the study relies mostly on visual assessment techniques. Overall, the study focuses primarily on geotechnical maintenance details, like the dam and outlet structures. All of the lakes are evaluated for their suitability as fisheries, rather than contact-recreational function, reflecting different management goals than those of Lake Herrick. Although the study's focus does not exactly align with the issues relevant to Lake Herrick, some notable similarities do exist. Erosion and sedimentation is clearly a widespread problem, especially as related to recreational user impacts. Geotechnical instability is also more common than might be expected. There is no evidence of problems with Lake Herrick's dam, but Parvo Pond has been observed to have issues with its outlet structures and spillway. This puts it in good company with the DeKalb County lakes. The abundance of aquatic weeds is a testament to the notion that lakes are inevitably subject to infestation by either weeds or algae (Cooke, et al. 2005, 33).

Watershed

Land Use Analysis

Lake Herrick has a total watershed area of about 313 acres, with the low point defined as the lake's outlet. This can be divided into two sub-catchments: the roughly 54-acre Parvo Pond sub-catchment (66.4 acres, according to Brown and Caldwell 2011, 2.11), which flows into the roughly 259-acre Lake Herrick sub-catchment (248 acres, according to Brown and Caldwell 2011, 2.11). For the combined watershed, about 65% is general Urban/Residential land use. This includes UGA's sports fields and surrounding areas. 29% is Forest/Natural Areas, and 6% is Water/Wetlands. Roughly 44 acres

(14 percent of the watershed) is impervious surface. The University of Georgia owns 202 acres, or 65 percent, of the watershed. (UGA Grounds Department GIS data).

A watershed is considered to be large if its area is seven to ten times larger than the area of the lake's surface. Lake Herrick's total watershed area of 313 acres is 16.66 times larger than the total area of water/wetlands, so the watershed is unquestionably large relative to the size of the water body. This is not surprising, as man-made reservoirs typically do have large watersheds compared to natural lakes (Schueler and Simpson 2001, 747). Large watershed lakes tend to be more easily disturbed by human activity than small watershed lakes and are subject to more runoff, sediment, and nutrient loading, and shorter hydraulic residence time. However, they also respond faster to management interventions. (Holdren et al. 2001, 18-19)

The United States Department of Agriculture notes that ideal ground-cover conditions for a lake or pond watershed are established, stable, and permanent vegetation. The next best are agricultural lands with erosion control and soil conservation practices. There should be minimal erosion, so that the pond does not fill up with sediment. Erosion control and protection is an ongoing process. "Protection of the drainage area should be started as soon as you decide to build a pond." (US Department of Agriculture 1982, 11) Thus, it should be a first step in planning for the rehabilitation of an existing water body.

On-Campus Watershed

There are at least 38 culvert pipes associated with the University of Georgia's property in the Lake Herrick watershed (UGA Grounds Department GIS data). This does not include the sewer and street drainage system, or drainage infrastructure associated with Highway 10 or the residential neighborhood. "The storm sewer system along the streets in owned and maintained by Athens-Clarke County. The system within the campus is maintained by the University" (The University System of Georgia Board of Regents 1999, 112). The drainage infrastructure for the family housing complex was probably installed first, around the time that the complex was constructed prior to its 1973 opening (University Housing, n.d). It is possible that some of these may have been renovated in subsequent years in conjunction with maintenance on the buildings. Culverts associated with the intramural fields and the Bus Facility and Loop would have been installed later, between 1973 and 1993. The eventual need to repair or replace aging drainage infrastructure is an opportunity to augment existing sites with green infrastructure practices.

Certain culverts are particularly notable as probable sources of unmitigated contaminant transport. A report from 1989 describes herbicide, insecticide, fungicide, and occasional but irregular fertilizer applications to the intramural fields. Jane Russell, then-manager of the intramural fields, and Dr. Walter Cook from the School of Forestry both agreed that these treatments were a likely source of chemical inputs into the lake (Dance and Pulliam, 1989). This is supported by the assertion that "lawns connected to the lake via storm runoff… are major nutrient sources... [and] may be responsible for significant macrophyte and algae growth" (Cooke et al. 2005, 132).

There is also the possibility that the chemicals applied to the intramural fields, as well as lawns in the residential portions of the watershed, could suppress algal and phytoplankton communities. Pesticides are widespread in urban runoff. Low levels of chlorpyrifos and diazinon are particularly common. They are often present in a few parts per billion, and are usually "well below the threshold for acute toxicity for most aquatic and terrestrial organisms." However, there has not been much research into the possibility of chronic or non-lethal toxic impairment. It has been shown that low concentrations of some common weedkillers will inhibit algal photosynthesis and damage aquatic plants. Results are mixed as to the toxicity of pesticides and herbicides in runoff. Certain chemicals are more toxic than others, and some highly toxic chemicals are in widespread use. Even chemicals that have been banned for many years are still frequently detected in waterways. This probably indicates slow transport via groundwater or erosion of contaminated soils. It is clear that pesticides that are applied to lawns do end up in streams all over the country. The biological significance of the presence of these chemicals in low levels is not clear. Pesticides are difficult to monitor - the techniques are complex and expensive, and there is a diverse variety of chemical compounds. (Schueler and Holland 2000)

The current treatment regime for the intramural fields entails fertilization three times annually. NPK fertilizer is applied at a rate of one pound per thousand square feet. To prevent excessive runoff, the fertilizer releases slowly when triggered by specific temperature and moisture conditions. A pre-emergent herbicide is applied once in the spring and once in the fall, followed by spot treatments where needed. No fungicide or pesticide is used. (Orr 2015)

Three of the four intramural fields along East Campus road fall within Lake Herrick's watershed. Along with some road surface adjacent to the parking deck, they are drained by a culvert pipe that discharges into a swale that runs along the east side of the southern-most field. This swale terminates in a drain that conveys runoff under Lake Herrick Drive and discharges near the shoreline where the western tributary stream flows into the lake. Much of the surface of the swale is bare soil. This is possibly because there are a number of large trees that provide shade and prevent the growth of grass. There is denser grass coverage towards the bottom of the swale near the drain. Here, the grass is noticeably

Figure 9: Photo of the upper portion of the intramural fields swale. The swale is shaded and grass coverage is sparse.

Figure 10: Photo of the lower portion of the intramural fields swale. Sediment is visibly streaked across the grass.

stained with sediment from the upper reaches of the swale. This conveyance feature is a clear contributor of sediment to Lake Herrick. Piles of accumulated sediment are visible near the discharge point, along the streambed where the tributary stream flows into Lake Herrick.

Oconee Forest Park is the largest forested area on UGA's main campus. It is over 40 acres and contains mixed successional vegetation. Trees include oak, hickory, tulip poplar, beech and pine. Understory plants include dogwood, assorted native shrubs, an herbaceous layer, and a leaf litter floor.

(Cook 1987, 3-4) The School of Forestry has reportedly used Roundup to manage vegetation bordering Parvo Pond. It is not clear whether this is still a regular practice. There are no reported chemical treatments anywhere else in Oconee Forest Park. (Dance and Pulliam, 1989)

The park's recreational trails and roads are both probable sources of sediment input to Lake Herrick. One study conducted by students reports apparent sediment runoff from "road culverts in the park." (Krauss et al. 1999) However, a conflicting report comes from park manager Dan Williams, stating that the roads are properly maintained and repaired on an annual basis. The trails are regularly maintained as well, but it is clear that the trail system is subject to erosion due to heavy use, potentially exacerbated by mountain bikes. (Williams 1997; Ayers, Saint, and Gross 1998)

Another potential source of sedimentation, un-mentioned in management documents, is channel erosion in the stream that connects Parvo Pond and Lake Herrick. The stream appears to be gullied, with little streambank vegetation to stabilize the soil and no floodplain areas. The channel's morphology and biotic characteristics are unstable and thus susceptible to erosion during high flows. B+C has reported on the stream's gullied dimensions, low baseflow, and habitation by high levels of iron-reducing bacteria. (Brown and Caldwell 2011, 4.4)

Lake Herrick and Parvo Pond were subject to heavy sediment loads generated by the construction of the University's Bus Facility on Riverbend Road during the mid-1990's. It is likely that sediment loads from that site have subsided, as construction was completed around 20 years ago and the ground is now fully covered in vegetation and impervious surface. However, runoff from the facility still flows into Parvo Pond, following an overland path that includes some ditches that appear to have been carved out by erosion. Runoff from large storm events likely does still convey sediment into Parvo Pond,

Figure 11: Photo of a ditch that conveys runoff from the bus facility to Parvo Pond.

and it may carry metals, oils, or other compounds from the busses that use the facility.

There are two additional drainage ditches in the watershed that are deeply incised and likely contributing large amounts of sediment to the lake: one is at the outlet of an exceptionally long culvert pipe that drains the family housing parking lot. This discharges in the forest near the tennis courts, in close proximity to the wetland area. Here, the drainage ditch has become a deep gully, eroding to depths of over five feet. This process has undoubtedly contributed substantial sediment to Lake Herrick's inlet cove. Because the flow-path by which runoff is conveyed to this point is very long, there are opportunities for siting design interventions to mitigate the impact of erosive discharge.

Figure 12: Photo of the eroded gully where runoff from Family Housing discharges.

The second deeply incised drainage ditch, also of substantial erosion concern, runs alongside the Oconee Forest Park forest road. It conveys runoff from the road, as well as the northern-most culvert under Highway 10. Near the gate to the off-leash dog area, runoff enters a culvert that runs under the road and discharges into a patch of woods near the outlet of Parvo Pond. Here, a network of ditches conveys runoff a short distance into the tributary stream that connects Parvo Pond to Lake Herrick. Although the ditch that runs along the forest road may receive periodic maintenance, the ditches in the woods downstream of the culvert are apparently unmaintained.

Two potential sources of bacteria include the off-leash dog park adjacent to Parvo Pond in Oconee Forest Park, and a buried sewer line that runs along the north-western edge of Lake Herrick. The sewer line runs in close proximity to the edge of the lake, roughly parallel to the shoreline from the western side of the dam to where the western tributary stream crosses under Lake Herrick Drive. It terminates at the restroom building near the tennis courts. It is possible that leaks in this sewer line could leach bacterial contaminants into Lake Herrick. However, there is no indication that this is currently an issue.

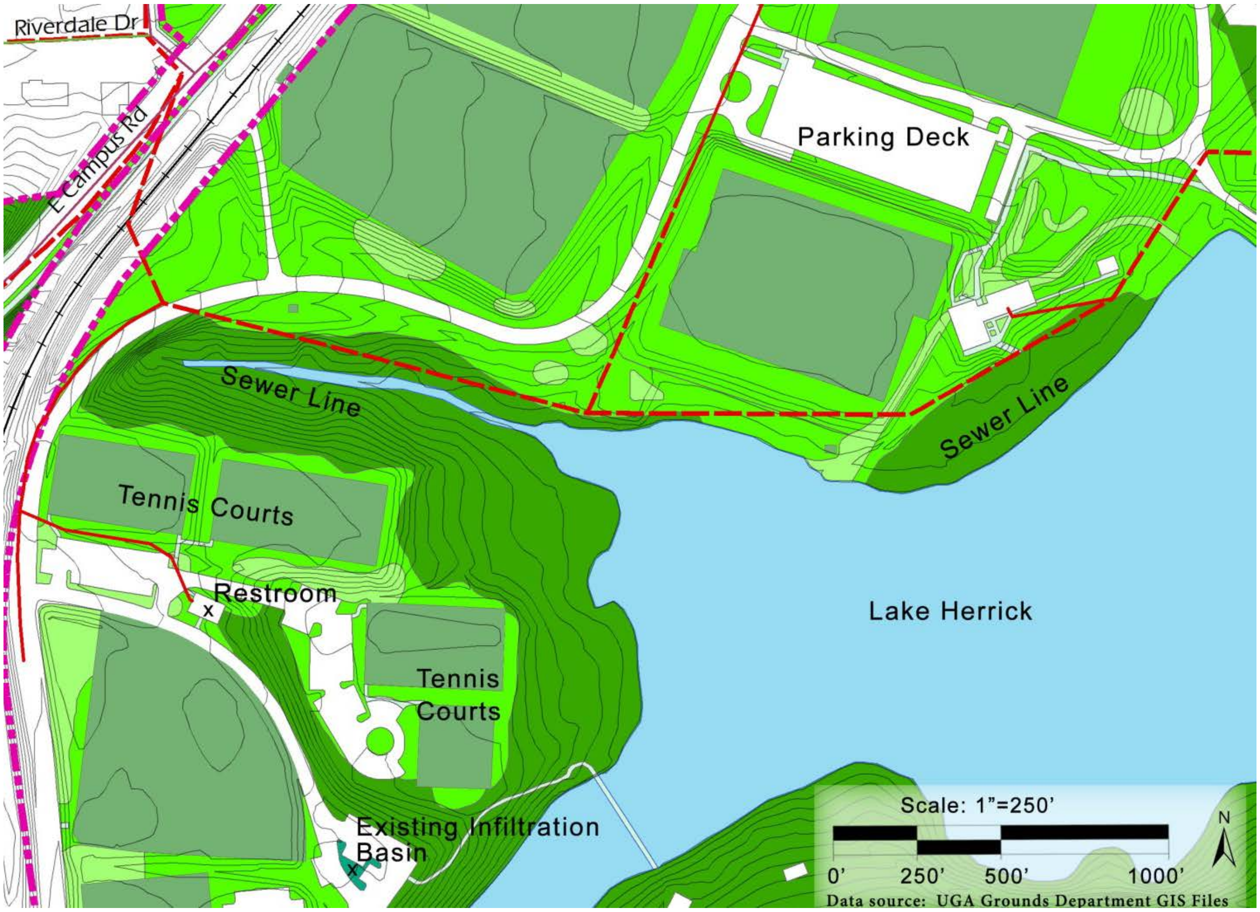


Figure 13: Map of the sewer line that runs close to the lakeshore.

A third possible source of pathogen contamination specific to Parvo Pond may be leaking sewage infrastructure at the Family Housing complex. Although overland runoff from the Family Housing development is conveyed to a point in the tributary stream to Lake Herrick and is not within Parvo Pond's stormwater catchment, groundwater flow from the landscape surrounding Family Housing probably does reach the pond. Subsurface flow of contaminants from poorly functioning sewer lines is then a potential mechanism for persistent pathogen input.

There is a small number of existing structural stormwater control measures within the Lake Herrick watershed. The two connected parking lots closest to the wooden bridge that spans Lake Herrick's southern bay both drain to rain gardens. The stalls in one of those parking lots are constructed with permeable pavement. That lot drains to a roughly 1,500 square-foot rain garden with an elevated outlet that facilitates some ponding and infiltration. Its exact dimensions are not clear because it is not recorded in the Grounds Department's GIS files. This area overflows through two culvert pipes to a second 1,438-square foot depressed island in the center of the lot closest to the tennis courts (see Figure 13). This island was designed as an infiltration basin by Beall Gonnsen & Company with input from University Architects and the Grounds Department. It was the first infiltration-based stormwater control measure on campus, constructed circa 2000 and renovated circa 2008. (Vick 2015) Currently, its inlet and outlet structures are oriented in a way that provides for little storage, and no infiltration. It apparently provides little stormwater management function beyond simple conveyance, limited uptake by plants, and a slightly extended time of concentration. The structure should be monitored to ensure that it is functioning properly. It could potentially be retrofitted for enhanced filtration and infiltration. (UGA Grounds Department GIS data)

Figure 14: Photo of a storm inlet near the tennis courts. This outlet structure in one of the existing rain gardens is not elevated, and thus allows for no ponding before the SCM overflows. Better function could be achieved if the structure's inlet elevation were raised.

Off-Campus Watershed

111 acres, or 35 percent of Lake Herrick's watershed is not owned by UGA. 99 acres (32 percent) consist of a medium-density residential neighborhood and surface streets. Surface streets and sidewalks are owned and maintained by Athens-Clarke County. Runoff from the streets and neighborhood enters Lake Herrick via its western tributary stream. This area likely contributes standard pollutant inputs associated with residential development, including nutrients, bacteria, and herbicides and pesticides. 11 acres (3 percent) of the watershed are part of Highway 10. Owned by the Georgia Department of Transportation, this is the southeastern boundary of Oconee Forest Park. Roughly 60 percent of this is in Parvo Pond's subcachment, and the other 40 percent is in Lake Herrick's subcachment. (UGA Grounds Department GIS data) Runoff from the loop drains through grass swales, although it is not clear whether these swales drain into the watersheds or whether they convey runoff beyond the northern watershed boundary. Runoff from this area is likely to be carrying metals, oil, and sediment associated with automobiles.

Aquatic Vegetation

Lake Herrick's littoral zone contains patches of aquatic vegetation, but many areas are bare. Macrophytes are abundant in the cove with the wooden pedestrian bridge, along the shoreline near the dam, and near the fishing piers. However, distribution appears to be sparse and could be more diverse. Although most species are apparently native, Brazilian *elodia* persists at low levels in the cove near the bridge and probably elsewhere. (Williams 2013) Other unidentified exotics that may be Eurasian milfoil or Parrot's Feather have also been observed. (Lanier 2015)

Aquatic vegetation provides habitat and refuge from predation for zooplankton, macroinvertebrates, and juvenile fish. It also stabilizes sediments from the effects of wind and waves. Despite their benefits, macrophytes are sometimes considered undesirable because they can limit recreational uses and be considered an aesthetic nuisance. Their proliferation often results from a combination of high nutrient levels, exotic invasions, and low water levels. Exotic macrophytes may also be of concern because their dense growth tendencies can make formerly viable fish habitat inaccessible and inhibit infusion of dissolved oxygen in the water column. Management goals should seek to maintain a diverse, native aquatic macrophyte population and limit the growth of invasive/exotic plants. (Holdren et al. 2001, 35; Lanier 2015)

Fish

The fish populations in Lake Herrick are currently unknown, but are likely to consist mostly of crappie and gar, with perhaps some largemouth bass and bream. These were the species present at the time of the last known fish survey, conducted in 1997. The degree to which Lake Herrick's fish population has been managed since then is unknown. (Smith et al. 1997).

Future surveys of the fish community should cover species, size distribution, and prey abundance for game fish. This information can help to determine whether desirable game species have been eliminated or otherwise ceased to persist in the lake, or if issues related to competition for food or habitat are affecting reproduction or growth and health. Notably, although benthivorous fish such as carp are commonly used to combat unwanted macrophyte growth, their presence can be detrimental to water quality because their feeding activity stirs up sediment. They expose bacteria and nutrients to the water column and reduce visibility. (Holdren et al. 2001, 126)

Wildlife

Oconee Forest Park is home to a variety of bird species, turtles, squirrels, a small population of red foxes, and probably other common species like rabbits, raccoons, frogs, snakes, salamanders. It may be frequented by deer, although the heavily used recreational trails that extend throughout its area and its isolation from other large tracts of forest diminish its habitat value for large mammals. The author has personally observed deer nearby in the forest at Horseshoe Bend off of College Station Road and in the neighborhood along Riverbend Parkway. However, Highway 10 is a barrier to their movement into the Oconee Forest Park.

Beavers have been active in the past, at one time damming the stream that connects Parvo Pond to Lake Herrick and contributing to the formation of the wetland which now exists just upstream of the lake. The beavers were eradicated as a nuisance. Another nuisance species that has proved to be more difficult to eradicate are Canada geese. A population of geese continues to frequent Lake Herrick, creating a maintenance problem at the swimming beach and contributing to bacteria and nutrient loading. No geese were observed at the lake during site visits in the winter of 2015. However, they are known to travel between local water bodies. The local flocks are not migratory, and instead inhabit Georgia year-round. (Williams 2013)

Geese are known to be “significant importers of nutrients to lakes," as they defecate material of external origin into the lake; a wild goose can defecate up to 92 times daily. Nutrient loading may be compounded by internal effects, as they convert "particulate [phosphorous] in the form of fish and macrophytes into soluble [phosphorous], or by enriching littoral sediments that later release [phosphorous] to the water column." The goose population is symptomatic of inadequate vegetation in the littoral zone around the lake. Geese are repelled by dense vegetation that can impair their movement and conceal predators. (Cooke et al. 2005, 132)

Figure 15: Photo of red fox in Oconee Forest Park. This is one species of mammal whose presence in Oconee Forest Park may come as a surprise. Foxes do thrive in suburban and even urban environments. Their presence at Lake Herrick has potential implications for the regulation of the resident Canada goose population; eggs are among the many types of food that foxes consume. (Casey 2013, 30-32) Photo courtesy of Krista Gridley, taken at Oconee Forest Park on March 31, 2014.

Sensitive Ecological Areas

The Lake Herrick watershed is not home to any endangered species of plant or animal, nor rare or endangered ecosystems. One ecological area of note, though, is the wetland which has been expanding, driven by sediment infill, in the cove where the Parvo Pond tributary stream flows into Lake Herrick. Any interventions that would affect the wetland will have to undergo heightened scrutiny for permitting and may be subject to prohibitive limitations. Should dredging in this area be identified as a desirable course of action, it will be prudent to act soon, before the wetland grows in size and significance.

Shore Development and Natural Beauty

Views across Lake Herrick toward Oconee Forest Park provide a pleasant natural scene in the midst of a heavily developed area. Views in the opposite direction, from Oconee Forest Park towards the intramural fields, have recently been impacted by the construction of a four-story parking deck located just behind the beach.

Figure 16: Photo of the view across Lake Herrick from the wooden bridge. Planting evergreen trees and other vegetation towards the left side of the new intramural fields parking deck would improve the view and make the structure less of a visually overwhelming element in the landscape.

Silt fencing extends all the way around Parvo Pond, and is an unsightly feature. Although it probably was never intended as a long-term strategy for mitigating sediment inputs to the water body, it has remained in place for many years. Alternative sediment control strategies should be implemented, as this structure detracts from the aesthetic quality of the landscape.

Figure 17: Photo of silt fencing around Parvo Pond.

Lake Users

Presumably, most of Lake Herrick's users are affiliated with the University of Georgia. However, the facilities surrounding Lake Herrick are accessible and may also be used by the general public.

A survey conducted in 2014 randomly sampled 77 University of Georgia students to gauge their perceptions about Lake Herrick. All four years of university class standing were roughly evenly represented. Most students did not use the intramural fields or Oconee Forest Park frequently, but 40 percent reported that they had been to Lake Herrick at least once before, often for a class activity. Another 40 percent reported that they had never heard of Lake Herrick. Many students expressed regret over the lake's impaired condition and a desire for restoration. 69 percent of students indicated that they would be interested in using the lake's facilities for outdoor social events, such as cookouts. 68 percent indicated a desire to go boating, 52 percent said that they would like to go swimming, 48 percent responded that they would like to play beach volleyball, and 44 percent said that they would be interested in fishing. (Morphis et al. 2014, 27-32)

Policy and Regulations

Various policies and laws apply to Lake Herrick at the University, State, and Federal levels. Specific regulations regarding stormwater are "delegated to the County by the State" (The University System of Georgia Board of Regents. 1999, 117).

The University of Georgia Master Plan, dated July 22, 1999, contains the following passage:

> *"The challenge for the next generation of campus designers is how to correct nearly four decades of campus architecture and landscape design that failed to understand the physical environment of the institution as connected to the pedagogical mission of the university. Critical to this is a return to an understanding of the land and the symbolic potential of landscape. At the close of the 20th century, we are becoming ever more aware of both the practical and moral imperative concerning sustainable design. Land and resources are ever more scarce in the modern university. Ironically, the university community finds itself back in the leadership game — what is a vision for a sustainable landscape of the future?" (The University System of Georgia Board of Regents. 1999, 12)*

The University's official policy towards promoting sustainable landscapes is one of environmental advocacy, detailed in the Institutional Mission and Strategic Plan: "The University has established environmental literacy and stewardship as an institutional priority... The University will expand its commitment to environmental programs and stewardship." (The University System of Georgia Board of Regents. 1999, 37-38)

The Master Plan also identifies storm water quality issues as "a serious concern" and acknowledges that, as "there is little or no detention of stormwater from the city of Athens or the University itself,… storm water flowing into the campus streams, lakes, and the Oconee River carries with it typical non-point source pollutants." (The University System of Georgia Board of Regents. 1999, 52-53) The document recognizes the poor state of rivers and streams on UGA's campus, contributing the following description of the problems: "Because the streams are often not visible, the polluted condition of the water is not noticed by many members of the University community. The high density of impervious surfaces on and surrounding the campus increase the frequency and amount of erosion and degradation of the campus rivers and streams." (The University System of Georgia Board of Regents. 1999, 53)

Unfortunately, at the time that the most recent Master Plan was published, the University had not taken substantial steps to incorporate stormwater planning. The only mention of stormwater infrastructure in the plan's section on the characteristics and future outlook of the University's various infrastructure systems is, "[t]he information provided for the stormwater infrastructure was very minimum [sic]. Due to insufficient data it was not possible to complete a map and offer additional information to the stormwater system." (The University System of Georgia Board of Regents. 1999, 284) The plan does acknowledge this oversight: "Presently the University does not have a compressive [sic] stormwater management plan, nor does it provide for individual or regional detention of stormwater. All future projects that increase stormwater runoff will be required by Athens/Clarke County to detain additional water in a stormwater management facility." (The University System of Georgia Board of Regents. 1999, 112)

The University of Georgia would be well-served in studying campus' existing stormwater infrastructure and developing a management plan to promote the construction and maintenance of effective facilities. Doing this would help UGA to protect its watersheds and natural resources, on which the Master Plan takes the following position: "Waterways are the natural resource in greatest need of protection. Like all places, the University of Georgia campus is part of a larger region that is dependent on local water supplies. Prevention of siltation and other forms of water pollution should be priority for the University. Restoration and protection of enough stream bank habitat to create successful corridors for wildlife should also be a primary focus of future development.

"As described in Sections III A 1.1e and III C 2.1, the woodlands on the campus are places that serve as research and recreation areas as well as wildlife habitat. These few remaining areas should be protected at all costs and restored whenever possible." (The University System of Georgia Board of Regents. 1999, 126)

The Master Plan proposes broad direction for natural resource protection with the specific policy that "[n]atural spaces such as Lake Herrick and the corridor adjacent to the Oconee River will be enhanced to provide recreational opportunities in the form of trails and to stabilize and prevent erosion and degradation." (The University System of Georgia Board of Regents. 1999, 275) However, unlike its commitment to many other categories of capital expenditures, UGA has not prioritized any natural area restoration and management projects in its capital improvement and phasing plan (The University System of Georgia Board of Regents. 1999, 315-326). Planning landscape maintenance with the same diligence that is given to improvements to campus buildings and parking facilities would be a substantial step towards meeting many of the University's strategic goals for development.

The University of Georgia's 2020 Strategic Plan outlines the University's overarching goals and priorities, and contains action items ("benchmarks"), for the promotion of those objectives. The management of water quality at Lake Herrick and all of the University's surface waters and their watersheds is extensively pertinent to many facets of UGA's mission. In particular, the measures proposed in this thesis are aligned with four of the seven specific Strategic Directions that the University seeks to fulfill. Those are: Strategic Direction III: Investing in Proven and Emerging Areas of Research Excellence, Strategic Direction IV: Serving the Citizens of the State of Georgia and Beyond, Strategic Direction VI: Improving and Maintaining Facilities and Infrastructure, and Strategic Direction VII: Improving Stewardship of Natural Resources and Advancing Campus Sustainability.

Research is a fundamental goal of the University of Georgia. UGA strives to uphold the responsibility of world-class universities to "improve the lives of their constituencies by addressing both immediate issues as well as 'grand challenge' problems" related to a host of categories including safe and sufficient water supply, education, global health, and environmental degradation. The solutions to such complex problems lie in shared responsibility and cooperation through "multi-disciplinary approaches and multi-level teams working and partnering within and beyond the University." ("The University of Georgia 2020 Strategic Plan" 2012, 14)

The design, construction, and evaluation of nascent stormwater management technologies is an opportunity for "[r]enovating outdated facilities and building new ones that will address growing student interest, expanding initiatives in engineering and public health, and changing needs of the research enterprise." ("The University of Georgia 2020 Strategic Plan" 2012, 25) It would also serve to "improve the quality of [UGA's] research faculty and infrastructure, encourage interdisciplinary and entrepreneurial activities, and foster global as well as local agendas." ("The University of Georgia 2020 Strategic Plan" 2012, 14) The challenges addressed in the management of Lake Herrick's watershed are akin to those of thousands of urban watersheds worldwide. The contribution of research and advancement of solutions to problems on our own campus, then, has implications of global import.

The implementation of a watershed management plan and corresponding SCM design, construction, and monitoring activities also constitutes an excellent opportunity for interdisciplinary research. The varied problems associated with this work necessitate the input of many different fields of expertise. The University of Georgia's College of Environment of Design, Odum School of Ecology, Warnell School of Forestry and Natural Resources, College of Engineering, Department of Biology, Department of Recreational Sports, Grounds Department, University Architects, and Office of Sustainability all have interest in various aspects of Lake Herrick's management and rehabilitation.

The Office of Sustainability in particular is a strong leader in the cause of campus watershed protection, with the stated goals of "[collaborating] with departments across campus – as well as colleagues across the state and region - to develop and promote sustainable operations…, [enhancing] on-campus research opportunities in the area [of] water resource conservation and improvement." and maintaining "collaborative efforts to restore natural systems." Of particular interest in this matter are projects that "provide examples to other organizations and communities on how to integrate sustainability into existing and new operations." (UGA Office of Sustainability 2010, 5-6)

The School of Ecology's River Basin Center is likewise closely aligned with the restoration goals of Lake Herrick, with its mission statement "[t]o pursue interdisciplinary research and analysis in the areas of water quality and quantity, aquatic biodiversity, and how land use practices impact aquatic resources." (UGA River Basin Center 2015)

Additionally, the Campus Watersheds Advisory Committee is the University's leading entity for coordinating matters regarding the management and rehabilitation of watersheds and surface waters on campus. The Committee consists of faculty and staff from the aforementioned UGA schools, departments, and offices, as well as student leaders and representatives from the Athens-Clarke County government.

The widespread support demonstrated by the University of Georgia community and administration both for efforts to restore Lake Herrick and the broader effort to manage all of the University's watersheds is of considerable interest with regards to the 2020 Strategic Plan's Strategic Direction III, Strategic Priority H: "Improve support for interdisciplinary research programs by establishing and investing in a few strategic "grand challenge" targets in order to nucleate research across the University…" ("The University of Georgia 2020 Strategic Plan" 2012, 16)

Strategic Direction IV, Strategic Priority B encourages "linking UGA research and innovation to real-world problems" and calls for outreach and support for applied research and actionable science to address "critical issues in Georgia including… the environment." ("The University of Georgia 2020 Strategic Plan" 2012, 19-20) SCM implementation accompanied by community outreach about watershed management practices has the potential to improve local water quality and encourage the widespread adoption of positive environmental practices, both in the local communities within UGA's campus watersheds and beyond. It provides the basis for a novel environmental education and interpretive demonstration project, and an opportunity to address UGA's Strategic Direction IV, Strategic Priority A: "Document educational and outreach programs that enhance the social, economic, and environmental well-being and health of individuals and communities." ("The University of Georgia 2020 Strategic Plan" 2012, 19) The opportunity for using SCM facilities at Lake Herrick as a teaching technique is also supported by a benchmark of Strategic Direction VII, Strategic Priority E: "to identify, develop, fund, and install interpretive signs for key campus sustainability efforts" with the specific goal of installing interpretive signs by 2020. ("The University of Georgia 2020 Strategic Plan" 2012, 28-29)

Strategic Direction VII states that "it is incumbent upon the University to provide leadership concerning unprecedented environmental challenges." ("The University of Georgia 2020 Strategic Plan" 2012, 27) The University of Georgia strives to "create opportunities for students, faculty, and staff to enhance the quality of life throughout their communities. A sustainable university acts as a living laboratory where sustainability is researched, taught, tested, and constantly refined. UGA must demonstrate and promote leadership in sustainable living and learning, contextualizing the local as part of the global in sustainability." ("The University of Georgia 2020 Strategic Plan" 2012, 27) The effectiveness with which we manage our University's natural resources has a direct bearing on the quality of life in and beyond Athens-Clarke County. Protecting the quality of our water supply comes with recreational, environmental, public health, and educational benefits. The management decisions pertaining to Lake Herrick are an opportunity for the University to strengthen its commitment to the stewardship of its natural resources and demonstrate leadership in the research, development, and implementation of watershed protection techniques.

The document expresses the University's intent to support such endeavors in clear terms: "Over the next decade, the University's campuses should be examples to others in reducing their environmental footprints to the greatest extent possible. This includes efforts to… carefully use and reuse scarce water resources [and] improve air and water quality... Second, in the effort to prepare students for effective leadership on campus and beyond, sustainability should be infused into formal and informal educational opportunities throughout the University. Campus buildings and landscapes should be incorporated as teaching opportunities, which through design and functional interpretation will reveal innovative practices with the potential to enlighten and inform students and citizens about sound approaches to sustainable living. Third, research generated by UGA faculty and students as well as advances from the global community will be used to… continue the search for… methods that will reduce human impacts on the environment. A priority for the University at large is to design and construct… landscapes that embody the latest in environmental advances." ("The University of Georgia 2020 Strategic Plan" 2012, 27)

Overall, the University of Georgia community is quite active in furthering the environmental goals detailed in the University's strategic plan. Natural resource protection, conservation, and enhancement initiatives abound amongst the categories of energy and climate, green building and historic preservation, recycling and waste reduction, alternative transportation, food service, university housing, green cleaning, purchasing and procurement, printing services, campus grounds, and water resources. UGA has demonstrated its commitment to sustainability and innovation in areas related to the goal water resource protection:

"The University has been aggressively implementing water-saving projects, resulting in overall water usage down 30% over the last three years. In 2007 and 2010, UGA won water conservation award due for the success of its Every Drop Counts campaign. Overall, UGA has 15 cisterns installed or under construction, totaling over 530,000 gallons of storage capacity for continuous reuse of harvested rain and condensate water. In addition, over 50 rain gardens and other stormwater quality features have been installed on the UGA campus to improve water quality… Sustainable and functional UGA campus landscapes provide beauty and culture, as well as education and ecological restoration. In the past 15 years, the University has removed over 1.5 million square feet of asphalt and added over 46 acres of campus greenspace. UGA has been reducing impervious paving and creating greenspace, utilizing native plants and trees, actively improving stormwater quality, using efficient irrigation strategies, and restoring wildlife habitats." (UGA Office of Sustainability 2010, 2-3)

Summary of Problems

Dan Williams has identified sedimentation as the most significant water quality problem in the lake. Sediment inputs primarily enter the lake from its two tributaries. The sediment carries bacteria and nutrients, causes the water to be "unacceptably cloudy," and is slowly filling the lake. One primary source of sedimentation is the area around Parvo Pond, which contains large amounts of highly erodible fill dirt. The pond itself is loaded with sediment. Historically it had more volume, but much of the south end of the pond has been filled with sediment that washed in through one of the 30-inch culverts under the loop and formed a delta. The culverts that bring runoff from the bypass and the UGA Transit Center contributed significant sediment loads both during and after the facility's construction. It is not clear whether that particular development still contributes excessive sediment. A high amount of sediment in overland flows is also noted, some of which can be attributed to trail erosion caused by mountain bikes. A considerable amount of unconsolidated sediment rests in Lake Herrick near the inlets of both streams and in its deepest area near the dam. Decreasing lake depth is a testament to this. The sediment brings in organic material, nutrients, and bacteria. When combined with hot dry weather and limited water circulation, this contributes to toxic blue-green algae blooms. (Williams 1997)

Conflicting management schemes have also been problematic. The School of Forestry wanted to manage the lake to provide good fishing, and the Recreational Sports Department wanted good swimming. Management for fishing entailed fertilizing the lake to stimulate diatomaceous algae and zooplankton (Krauss et al. 1999; Shipman 1989). Much of the excess nutrients from fertilization accumulated in the lake sediments; when they are stirred up, they stimulate algal and fungal blooms that interfere with swimming and potentially with fishing as well.

Summertime blooms of fungi and cyanobacteria of the genus *microcystis* have been a recurring problem and were apparently the final straw in the sequence of water quality problems that led to the closure of Lake Herrick's swimming and recreational boating facilities. The recurrence of these blooms was well documented in the summer of 2002 when they first became a substantial problem (Darley and Williams, 2002). It is not known whether they have continued to occur annually or to the same great extent as they did in 2002. However, visual observations in the winter of 2015 revealed higher algal abundance than would be expected for winter months (Lanier 2015). Nearly all of the blue/green algae blooms are concentrated in the two coves and the adjacent areas (*Summary of Lake Herrick's Problems based on Current Knowledge, n.d.*). Presumably this is because sunlight is able to penetrate all the way to the bottom of the shallow coves, and because those areas are filled with nutrient-laden sediments.

Managing Lakes and Reservoirs notes that algae often cause foul odors as they die and decay (Holdren et al. 2001, 218). It is not clear whether odor has been a problem at Lake Herrick aside from during the single documented fungal bloom in July 1986 ("Lake Allyn M. Herrick History." n.d., 2), or whether the algal blooms were toxic as was feared.

Bacterial contamination is also an issue; the lake receives bacterial inputs from overland runoff, the two tributary streams, and animals ("*Summary of Lake Herrick's Problems based on Current Knowledge.*" n.d.). Sanitation concerns related to the flock of geese that inhabits the beach caused a significant maintenance problem and ultimately contributed to the closure of Lake Herrick's swimming facilities (Williams and Cook 1987). Wildlife probably causes much of the bacterial contamination, but waste from dogs, especially near the off-leash dog park area adjacent to Parvo Pond, may also be a factor. The contribution of dog waste is supported by the observation that waterfowl activity appears to be concentrated in Lake Herrick, but monitoring results indicate much higher levels of bacteria in Parvo Pond than in the lake itself. The possibility of pathogen inputs from leaky sewage infrastructure associated with the Family Housing buildings should also be investigated. Although monitoring results usually show bacteria levels in the lake to be in compliance with Georgia Department of Natural Resources standards for open water swimming areas, concern about bacterial contamination is often expressed amongst members of the University community at large. The general public perception of the lake seems to overestimate the degree to which the water is contaminated.

One final problem is the heavy impact on the landscape by the huge numbers of people who utilize the Lake Herrick watershed for recreational purposes. Oconee Forest Park alone reportedly receives over 50,000 visitors annually. With these visitors come park rules violations, many of which have contributed to contaminant loading in Lake Herrick. People do not observe leash rules or clean up after their pets, possibly driving bacterial contamination. They take more fish than catch limits allow for, which caused difficulty in maintaining desirable fish populations. Extensive bike use, particularly on trails that are marked off-limits, has contributed to erosion and sedimentation. (Williams 1997) Notably, a wire gate meant to prevent mountain bikes from accessing the trail that runs parallel to the tributary stream has been dismantled, and bikers have been observed riding this off-limits section of trail. All of these violations are inevitable to some degree, but they may be reduced by more effective signage, enforcement, and site design.

CHAPTER 4

GREEN INFRASTRUCTURE

So far, this thesis has identified the problems that affect Lake Herrick primarily as reactions to pollutant inputs from throughout its watershed. This chapter explores the general mechanisms for the transport of those pollutants, and methods that have been developed to mitigate that transport. First is an explanation of the detrimental impacts that land disturbance imposes on natural hydrologic processes in the landscape. This leads to a review of the conventional stormwater infrastructure practices that accompany development, which simultaneously provide essential stormwater management to developed property while causing downstream environmental degradation. Next, an alternative set of technologies is introduced. Collectively known as green infrastructure, these practices have the capability to protect against such degradation. The chapter concludes with a review of specific green infrastructure strategies that could potentially be employed to manage stormwater runoff in the Lake Herrick watershed.

The Hydrologic Cycle and the Impacts of Development

When rainwater falls on undeveloped land, much of it is intercepted by vegetated canopy that dissipates the energy of the falling drops. As water comes into contact with the ground, it does so in a diffuse manner. About 50 percent of it infiltrates into the soil. Root systems support infiltration both by increasing the porosity, and thus storage capacity, of the soil, and through direct vegetative uptake of water. The storage capacity of individual plants can be quite large; a mature deciduous tree can soak up between 500 and 700 gallons of water each year, and some mature evergreens are able to absorb as much as 4000 gallons per year. About 40 percent of the water that is intercepted by vegetation eventually evapotranspires back into the atmosphere. This happens through either the metabolic process of the plant as it uses the water in photosynthesis, or by evaporation off the leaves in the case of water that was intercepted by the canopy and never made it to the ground in the first place (Garrison and Hobbs 2011, 7).

The water that infiltrates into the soil without being taken up by plants becomes groundwater. It replenishes deep aquifers or travels laterally to feed surface waters by emerging through seeps and springs. Water that flows from the subterranean water table into surface waters is termed "baseflow." This is in contrast to overland flow: storm runoff that is neither evapotranspired nor infiltrated, but instead runs over the surface of the landscape and feeds directly into surface water drainages. In natural systems where vegetative cover is abundant and development is absent, overland flow makes up only a small portion of rainfall – 10 percent or less (Garrison and Hobbs 2011, 7).

Wherever land is developed with roads, sidewalks, buildings, and other structures, the removal of vegetative cover and replacement by impervious surfaces alters the natural hydrologic properties of that land. Water cannot infiltrate through impervious surfaces, so their presence in the landscape reduces infiltration and evapotranspiration and increases volumes of overland flow. The resulting runoff tends to overflow from these surfaces at high velocities because they lack the structural roughness to delay the rate of runoff such as a natural vegetative canopy provides (Garrison and Hobbs 2011, 7).

Permeable soils adjacent to developed land usually do not have the infiltrative capacity to intercept the elevated quantities of runoff and counter hydrologic alterations. Depending on the natural characteristics of the soil, they are likely to already be saturated with the stormwater that falls on them directly. The water that flows from impervious surfaces generally does so with enough volume and velocity that it will erode soil, carrying it along rather than seeping into it. Adjacent soil might also be compromised by compaction – a process by which soil is tamped down, reducing the pore space between its particles and reducing its infiltrative capacity. The volume of water that the soil can hold, along with the rate at which water can travel through the soil, may be reduced if the ground is subject to heavy foot traffic or was ever driven on by vehicles during clearing, grading, or construction activities.

Gray Infrastructure

For this reason, development is accompanied by the installation of storm infrastructure to drain excess runoff in a manner that protects property from flooding and erosion. Networks of drains, gutters, pipes, tunnels, basins, mechanical devices and culverts are conventionally built with a focus on transporting runoff and used municipal water downstream and away from impervious surfaces. Other components of grey infrastructure systems include sanitary storm, combined sewers, stormwater inlets, pumping stations, wastewater metering chambers, and other water treatment and control devices. These are constructed for the purposes of conveying and treating greywater, wastewater, stormwater, and sewage. (Philadelphia Water Department 2015)

This sort of stormwater infrastructure is firmly grounded in engineering convention, having been implemented widely for over a century. Complex networks of water infrastructure are now constructed with sophisticated and precise construction standards. Such systems typically perform their intended water conveyance functions very well. However, provisions for protecting water quality and hydrologic integrity are less standard, and usually overlooked in conventional stormwater system design. The systems are employed with the narrow focus of a single management problem: site drainage. Consequently, other runoff-related impacts, particularly pollution and flooding, are shifted off site and heightened downstream.

Widespread development and the conventional stormwater management techniques that accompany it have had profound impacts on natural hydrologic systems, with negative effects on both the quality and quantity of water supplies. Research indicates that areas of impervious cover in a watershed between 25 and 60 percent lead to severe hydrologic changes and alteration of stream flow regimes. Areas of impervious land cover of over 60 percent are sufficient to suppress groundwater infiltration to the point where stream base flow is completely eliminated. Under such conditions, formerly perennial streams are reduced to floodwater drainages. (Garrison and Hobbs 2011, 7)

Modern storm infrastructure replaces the natural spatially diffuse and temporally gradual flow of stormwater through a watershed with rapid and channelized conveyance. Storm surges are deployed from culverts in concentrated bursts, flooding stream channels with powerful erosive force. This often results in ecosystem degradation and declines in water quality and supply. When channel erosion disconnects rivers from their floodplains, for example, the riparian system is no longer able to function. Important ecosystem services such as "flood control, ground water recharge, pollution control, and supply regulation" are impaired or lost (Bertule et al. 2014, 9).

In addition to its detrimental effects on ecological and hydrologic systems, municipal stormwater is laden with pollutants that are swept off of pavement, rooftops, and lawns. For example, when fertilizer is applied to the intramural fields, rainwater may wash some of that fertilizer from the fields and carry it through the existing system of culverts into the lake. There, it contributes to the elevated nutrient levels found in the water body, driving algae blooms. Such pathways for nonpoint source pollutant transport are ubiquitous among conventional stormwater management infrastructure systems, or "grey infrastructure."

The prevailing idea is that, although undesirable substances are entering waterways, they will eventually be diluted to harmless levels. In practice, however, such conveyance systems are significant vectors for surface water pollution, with effects that are apparent for many miles downstream. The US Environmental Protection Agency regards urban runoff as one of the most significant sources of waterway impairment; although only 3 percent of land in the United States is urban, stormwater runoff from that land is responsible for 13-35 percent of all miles of impaired waterways (Garrison and Hobbs 2011, 7).

Lake Herrick is no exception to the deleterious effects of urban runoff; its problems with excessive sedimentation, nutrient inputs, and pathogens are all characteristic of lakes in urban watersheds. The overwhelming abundance of algae stems from eutrophication - a common condition in urban lakes. 80 percent of lakes with urban watersheds are eutrophic, owing to the elevated amounts of phosphorous that run off from developed areas (Schueler and Simpson 2001, 748). Notably, stormwater runoff is the most common cause of beach closings; polluted runoff was attributed to a 36 percent of all closings due to a known source in 2010 (Garrison and Hobbs 2011, 9). Stormwater pollutant inputs, along with the persistence of undesirable wildlife, played a primary role in the 2002 closure of Lake Herrick's beach.

Green Infrastructure

Managing Stormwater Quantity and Quality

Green infrastructure represents an alternative strategy for managing stormwater that addresses some of the problems created by more conventional techniques. Rather than conveying stormwater directly into stream channels, green infrastructure systems prioritize directing runoff through a series of treatment structures to filter out pollutants and slow the release of water (Schuessler 2011, 11). Green infrastructure restores some of the hydrologic conditions lost to development by mimicking the function of natural systems. It promotes a more natural regime of hydraulic transport by shifting the balance to increase infiltration and evaporation and reduce overland flow (Garrison and Hobbs 2011, 13).

Specific green infrastructure techniques vary by scale. Measures can be specific to a small site, such as a backyard rain garden, or employed regionally, such as a management strategy that encompasses the headwaters of a large watershed. Common regional scale practices include the restoration, protection, or management of woodlands, riparian buffers, & wildlife habitat to maintain natural processes. Large-scale green infrastructure practices are particularly important for protecting headwaters and groundwater recharge areas. They commonly provide a host of ecosystem services and are not necessarily implemented specifically for their stormwater management benefits. Neighborhood and site-scale green infrastructure focuses on strategies like tree planting, wetland restoration, open space maintenance, and the construction and maintenance of structural stormwater control measures (SCMs). Common SCM techniques include porous pavement, green roofs, parks, roadside plantings, and rain barrels. SCMs are not limited to constructed objects, though. Just as important are expanses of impervious surface that are never built. Measures to reduce impervious area, such as narrow, curbless streets bordered by drainage swales, are useful techniques (Garrison and Hobbs 2011, 13). Each type of SCM has its own unique strengths for removing different types of pollutants or promoting water retention, infiltration, or evaporation. Thus, the specific structures employed in a project depend on the management goals that have been set. Objectives for SCM implementation vary by site, but focus generally falls on managing either water quality or quantity (Schuessler 2011, 102).

The two basic objectives of managing stormwater quantity are to reduce the overall volume and the velocity at which it travels. The mechanisms for volume reduction remain unchanged from the original functions of the hydrologic cycle: infiltration and evaporation. Slowing the velocity is actually a third means of reducing volume, as it increases the efficacy of the infiltrative and evaporative processes (Schuessler 2011, 88). Green infrastructure installations reduce runoff velocity by routing flow over rough surfaces, as in the case of grassed swales, and by pooling runoff into depressions. Often, water catchment structures are outfitted with specially engineered soil media that promotes infiltration. Water treated by these facilities percolates through the soil, recharging groundwater supplies or seeping gradually and steadily into surface water as stream baseflow (Garrison and Hobbs 2011, 14). An individual SCM unit will typically be limited in its infiltrative capacity relative to the large runoff volumes generated by extensive impervious surfaces. With widespread implementation, however, green infrastructure has the potential to increase the rates and volumes of aquifer recharge, thereby increasing clean water supplies. Resiliency during droughts would also be enhanced through sustained release of water from soil and groundwater (Bertule et al. 2014, 43).

In the case of Lake Herrick, goals will be oriented more towards controlling the quality of runoff inputs into the lake, rather than the quantity. Specific water quality objectives include the removal of Lake Herrick's primary pollutants of concern: sediment, nutrients, and bacteria. The mechanisms of water quality regulation fall into four general categories: erosion control, temperature control, biological control, and purification (Bertule et al. 2014, 15).

Erosion Control

Sediment is the most widespread pollutant in North America, and it comes laden with contaminants like nutrients, chemicals, and bacteria. Effective erosion control can improve aquatic habitat, avert the spread of contaminants, and prevent the need for expensive dredging operations. Erosion control measures reduce sediment loads by stabilizing slopes, banks, and shorelines. Because erosion is a natural process, SCMs mimic natural erosion controls. There are many materials that can be used to stabilize drainage elements, but green infrastructure solutions emphasize the use of plant roots to retain soil rather than utilizing static engineering techniques like stone or concrete. (Garrison and Hobbs 2011, 14; Holdren, et al. 2001, 189) In cases where the erosion of perennial stream channels and intermittent drainage pathways is caused by compromised geomorphic structure, erosion control may require more intensive interventions that go beyond stabilizing reinforcement. In these situations, full-scale channel reconstruction may be the most effective long-term solution.

Erosion control measures also work by taking steps to dissipate the velocity and volume of stormwater flows. Stormwater quantity reduction can play an important role as a control measure because lower volumes translate to lower rates of erosion. SCM designs that reduce erosion by reducing stormwater volume and velocity constitute a form of biomimicry; they are inspired by the natural flowpath of water as it travels through undisturbed watersheds. For example, the mulch layer in a rain garden mimics the functional effect of a forest canopy by dissipating rainfall energy before it makes contact with the soil. Of course, a multi-story vegetative canopy is ideal for dissipating rainfall energy - much better than just one layer of cover. Effective SCMs establish and maintain vegetative cover. Other ground-layer barriers, such as rough terrain and large debris like stones and logs continue to slow runoff. Trees and vegetation uptake water through their roots, aiding in infiltration. Water is stored in the soil and slowly discharges from groundwater into streams. (Garrison and Hobbs 2011, 14; Holdren, et al. 2001, 189)

Although excessive sediment can impair water quality and ecosystem health, some suspended sediment is natural in aquatic systems. Natural sediment loads can be influenced by regional soils, geology, and other inherent ecosystem characteristics. Certain ecosystems, such as estuaries and coastal wetlands, depend on sediment inputs for nutrients. Removing suspended sediment can also increase light penetration, which influences species composition in the water column, potentially in a detrimental way (Bertule et al. 2014, 15). Efforts to reduce sediment loading in surface waters should consider the extent to which sedimentation is occurring as a natural process.

Temperature Control

Water temperature control is relevant to waterways that are subject to thermal inputs from factories or power plants, or that are overexposed to sunlight due to the absence of a vegetated buffer and overhead canopy. Overland runoff from impervious areas also tends to be warmer than flows from vegetated areas. Excessively high water temperatures can impact aquatic habitat and impair the ability of aquatic ecosystems to purify water. In stratified lakes, increased summer temperatures can cause anoxia, which heightens phosphorous release from sediments and causes algal blooms. Too much sunlight can also cause in-stream primary productivity to become elevated, resulting in altered invertebrate species composition. Green infrastructure in the form of vegetative buffers and urban tree plantings can reduce temperatures and sun exposure by shading waterways. (Bertule et al. 2014, 15)

Biological Control

The biological control offered by green infrastructure is a holistic benefit. It refers specifically to the regulation of invasive species and disease by promoting healthy balance in ecosystems. (Bertule et al. 2014, 15)

Purification

Water purification refers to the direct removal of a variety of pollutants. This is done by retaining runoff and the sediment and pollutants that it contains (Bertule et al. 2014, 15). Different types of SCMs employ different mechanisms for doing so. Mechanisms can be biological or chemical, and their appropriateness for managing any particular substance depends on its specific physical and chemical properties. Of primary importance, for example, is whether the pollutant is particulate or dissolved. Removal mechanisms include "sedimentation, precipitation, filtration, adsorption, biodegradation, and photodegradation" (Schuessler 2011, 102). General cleaning occurs as water moves through soil and vegetation, and when it remains still long enough for sediment to settle (Schuessler 2011, 11). As water travels through soil, it is purified by processes of aerobic decomposition by microbes and chemical precipitation as pollutants become adsorbed to soil particles. Physical filtration also helps to remove particulates and sediment. (Fairfax County 2005)

Monitoring has demonstrated a range of results for any given SCM. Performance can vary depending on characteristics related to design, watershed conditions, and runoff quality. Although the practice of SCM implementation continues to be refined, there is little doubt as to the effectiveness of the underlying principles on which their function is based. In a study that tested the capacity of soil infiltration to purify runoff, researchers characterized the water quality of polluted highway runoff after six different storms. The runoff had been toxic to macroinvertebrate and fish species in a local stream, killing most populations and impairing the ability of the survivors to reproduce. The study demonstrated that acute mortality and sublethal reproductive toxicity were both substantially reduced by filtering the polluted runoff through soil infiltration media. (McIntyre et al. 2014)

Combining Green and Gray Infrastructures

Green and gray infrastructures have distinct functional differences in the way that they direct the flow of water from developed areas and into waterways, and in the way that they treat wastewater. However, investigations of the potential feasibility and value of green infrastructure tend to be in accord that the two approaches are not mutually exclusive, but rather are best used in conjunction (The Nature Conservancy 2013, 7; Bertule et al. 2014, 7). One study identifies two primary areas of opportunity for green infrastructure applications: First, when aging industrial infrastructure needs to be replaced and functionality could be enhanced by integrating green infrastructure solutions. Second, when areas are environmentally stressed and would benefit from improved land use and enhanced biodiversity (The Nature Conservancy 2013, 7).

The need for replacement of aging industrial infrastructure is significant; the estimated cost of water infrastructure repairs in the next 20 years, nationwide, is $300 billion. In addition to repair, many existing sewage treatment, drinking water conveyance, and stormwater conveyance systems need to be updated to reflect changes in capacity. Urban populations are growing and densifying, and storm volumes are increasing as a result of climate change (Garrison and Hobbs 2011, 8). This presents an opportunity to retrofit existing gray systems with appropriately sited green infrastructure elements for improved efficiency. (Bertule et al. 2014, 7)

Grey infrastructure solutions are appealing because they offer immediate and visible impacts. Once constructed, they instantly function at full capacity. A water treatment facility can filter thousands of gallons of water per day from the moment that it is brought online. A network of storm drains is able to protect developed areas and maintain passible streets and sidewalks by conveying water quickly and efficiently out of sight, even during a heavy downpour. Newly constructed green infrastructure systems, on the other hand, often exhibit the lackluster combination of high implementation costs and low initial function (Bertule et al. 2014, 67). It can take time (years, even) for green infrastructure interventions to mature to the point where they are able to provide service at full design capacity (The Nature Conservancy 2013, 5). The capability of an SCM to infiltrate stormwater increases as its root systems expand; the pollutant removal properties of stormwater wetlands also depend on well-established vegetation (Schuessler 2011, 102). Within a few years of establishment, green infrastructure systems' function generally improves and they are able to perform with minimal maintenance. Their operational costs tend to be low as they do not need constant supervision and often only require intermittent monitoring and feedback. Fluctuations in commodity prices, such as oil, gas, and electricity, do not affect the costs of green infrastructure operation. Ultimately, their value tends to appreciate over time as they function passively and become more interconnected with their surroundings. (The Nature Conservancy 2013, 7; Bertule et al. 2014, 5)

Part of the appeal of green infrastructure lies in its competitive affordability. They tend to have similar cost requirements to grey infrastructure systems throughout the entirety of their life spans. Regular costs are associated with their construction, operation, maintenance, and repair. When it inevitably comes time to replace aging infrastructure, green infrastructure retrofits are often cheaper than repairing or re-building the conventional design. For example, since 2003 the city of Portland, Oregon has been installing green streets, which incorporate narrower street widths, landscaping, permeable pavement, bioretention, and swales. This approach has proved to be more cost-effective in many cases than installing new storm lines. The comparison of implementation costs does not even take into account the additional benefits that green streets and parking retrofits provide: traffic calming, better pedestrian infrastructure, and aesthetic appeal. (Garrison and Hobbs 2011, 20)

The Philadelphia Water Department compared various approaches for reducing combined sewer overflows. They found that, over a 45 year period, it would accrue more dollar value in benefits than it invests by implementing a primarily green infrastructure-based strategy. They concluded that the same degree of reduction through a conventional gray approach would cost billions more and would not include any added benefits beyond water quality. (Garrison and Hobbs 2011, 22)

A review conducted by the US Environmental Protection Agency in 2007 reported that "in the vast majority of cases... [green infrastructure] practices save money for developers, property owners, and communities while protecting and restoring water quality." The results indicated that implementation costs alone were lower than they would have been for conventional development. Additional savings were accrued indirectly by avoiding environmental impact costs. A 2011 study by the American Society of Landscape Architects found that green infrastructure "reduced or did not influence costs 75 percent of the time" (Garrison and Hobbs 2011, 19).

When it comes to municipal stormwater management and treatment, the cost effectiveness of green and grey infrastructure solutions is a matter of scale and treatment volume. Whereas green infrastructure performs best as a collection of dispersed, small-capacity site interventions, they are often impractical at larger scales; they function using low energy passive treatment mechanisms and therefore require large physical footprints (The Nature Conservancy 2013, 5). Conversely, grey treatment methods are most cost effective when treating large quantities of water; conventional water treatment plants are built with the capacity to handle tens of thousands of gallons of water per day. Stormwater wetlands are a sensible alternative to conventional treatment plants when employed to treat runoff from small catchments, but they may be more expensive than mechanical treatment at larger scales because of the need for large areas of land (Bertule et al. 2014, 28).

Green infrastructure is well suited to be employed in conjunction with or in a supporting role to existing gray systems. The net effect of widespread green infrastructure retrofits is alleviated strain on downstream grey infrastructure practices. Mechanical purification using water treatment plants is the conventional solution for treating polluted water. Green infrastructure can supplement or serve as an alternative to conventional water purification by pre-treating contaminated water. Where existing water treatment infrastructure may be overwhelmed by excessively large volumes of pollutant-laden water, green infrastructure can slow down and reduce contaminant transport through bioretention and infiltration (Bertule et al. 2014, 16). Stormwater capture, reuse, and infiltration measures ultimately reduce the volume and severity of contamination needed to be processed by large treatment facilities. The corresponding reduction in electricity use could result in decreased electricity consumption, and thus greenhouse gas emission (Garrison and Hobbs 2011, 17).

Criteria for Effective Implementation

Green infrastructure installations can be designed to restore degraded hydrologic function in developed areas by optimizing the rates at which stormwater runoff evaporates into the atmosphere and infiltrates into the soil. In doing so, they can provide water cleansing, effective sequestration of nonpoint source pollutants, and a host of other benefits. This is accomplished most effectively with widespread implementation of small scale structures (Bertule et al. 2014, 28). The closer a structural SCM is to the source of runoff, the better it will work. SCMs are most effective when they treat small drainage areas of less than an acre; this is most analogous to the hydrologic form and function of the natural landscape. Large-scale treatment structures that collect runoff over large areas are more prone to erosion and their capacity can more easily be exceeded in large storm events (Schuessler 2011, 102).

Size is an important consideration when designing SCMs. If a structure is too small and its capacity is regularly exceeded, its infiltrative or purifying function can be impeded and problems related to erosion and pollutant export are likely to arise. A common sizing goal is to design SCMs to capture and infiltrate runoff volume up to the 90th percentile storm event. In Georgia, this is 1.5 inches. For the sake of cost effectiveness in designing SCMs primarily for the purpose of removing nonpoint source pollutants, the first flush volume is another common benchmark. This is the rainfall volume that is responsible for collecting and conveying most of the nonpoint source pollutant load that has accumulated on the ground. This is 1.2 inches in Georgia. This is a smaller volume than the 90th percentile storm event, so SCMs designed to this standard are limited in their infiltrative capacity and the mitigation of runoff volume is reduced. However, any rainfall in excess of the first flush volume is expected to be relatively free of pollutants. No matter their design volume, SCMs must incorporate a pathway for overflow during larger storm events (Schuessler 2011, 48, 80, 102).

SCMs also have limited capacities for pollutant inputs. This is another important design consideration. For example, when using a wetland to assimilate pollutants, if the load exceeds the capacity of the structure then its function could decline. Excess pollutants may flow out of the system, and with severe deterioration the structure could cease to provide filtration services at all. If green infrastructure is to be function properly, its limits and maintenance needs must be accounted for (Bertule 2014, 13).

Limitations and Challenges

Clearly, the efficacy of green infrastructure is subject to a host of complexities and limitations. Although they appear to hold promise for enhanced management of development impacts, green infrastructure techniques are not silver bullets. When implemented improperly, they bear more resemblance to the double-edged sword. For example, increased infiltration and groundwater recharge can potentially raise the water table and cause basement flooding in nearby buildings (Bertule et al. 2014, 43). It is important to be aware of the possibility for lateral water movement through porous fill material when locating infiltration-based SCM facilities, such as rain gardens and infiltration basins, near buildings and other structures. A general rule of thumb is to site SCM facilities that utilize infiltration no less than ten feet from buildings. (Schuessler 2011, 45)

While the capacity for green infrastructure to recharge groundwater supplies is largely beneficial, it is important to consider the potential for groundwater contamination. Permeable pavements, for example, are not suitable to areas where road salts or heavy metals might infiltrate into the soil. Fuel stations and other sites where hazardous materials are handled, such as the UGA Campus Transit Facility in Lake Herrick's watershed, should not utilize permeable pavement (Bertule et al. 2014, 42).

Green infrastructure solutions are always site specific and will be most effective when they are implemented with sensitivity to local environmental conditions. Their design must account for site characteristics including soil types, compaction and fill, depth of bedrock and water table, and the location of subsurface utilities and other man-made structures (Schuessler 2011, 102). One disadvantage that major industrial corporations foresee in implementing green infrastructure solutions is the need for customization in order to respond to location-specific environmental conditions. Although a degree of technical standardization is possible, SCM design must respond to the inherent variability of ecological factors. SCM solutions tend toward higher degrees of biological complexity than does the predominant industrial engineering-based paradigm. So far, the engineering community has little expertise in designing ecosystems (The Nature Conservancy 2013, 8). While this characteristic may yield increased costs for those who seek to install SCMs, landscape architects can take note of the opportunity to play a crucial role in addressing this challenge.

Green infrastructure encompasses a variety of pioneering techniques, and in many cases evidence of their practicality is supported by only a small body of empirical research and underlain by theory that signifies a fundamental departure from established stormwater management conventions. Challenges to widespread implementation include a general lack of awareness by decision makers, funding and regulation policies that do not acknowledge the potential role and value of green infrastructure, and lack of sufficient cost-benefit analysis. Cost-benefit analysis is a complex endeavor that incorporates numerous methods of calculation spanning various disciplines, such as economics, ecology, and engineering. There are various modelling tools to establish quantifiable environmental changes from green infrastructure investments, similar to predictions that can be made for gray infrastructure. Those tools are limited by the accuracy of the science and of the assumptions that they are based on. One area of modelling that is still limited is the ability to accurately predict the marginal benefits ("co-benefits") of green infrastructure investment, other than water quantity and quality. Many of the benefits that are often attributed to green infrastructure, like improved recreational opportunity, are difficult to quantify. There is also very little historical cost-benefit data to inform economic analysis. This is in contrast to the plethora of corresponding historical performance data for gray infrastructure. (Bertule 2014, 56, 67)

Furthermore, the long-term efficacy of green infrastructure projects is difficult to predict because they depend on complex interlinked environmental factors. Variables that could degrade SCM function include temperature and rainfall fluctuations, general climate change, extreme weather, or disease (The Nature Conservancy 2013, 8; Bertule 2014, 66). However, gray infrastructure is also susceptible to external factors of its own, such as power loss, mechanical failure, and price fluctuations (The Nature Conservancy 2013, 6). The result is that there is higher perceived risk and more overall scrutiny and uncertainty about the feasibility and value of green infrastructure projects. However, technologies for gathering data and modeling results are advancing rapidly (Bertule 2014, 67).

Types of Green Infrastructure

Specific SCMs that are applicable for watershed-scale stormwater treatment include a variety of structures, some of which are meant to be interlinked and some of which can stand alone. Most lists are not comprehensive, but commonly include many of the following: downspout disconnection, rainwater harvesting, rain gardens, planter boxes, bioswales, permeable pavements, green roofs, tree planting (US EPA 2014b), constructed and stormwater wetlands, infiltration basins, detention basins, sediment forebays, sand filters (Schuessler 2011, Bertule 2014), and combined level spreader and vegetative filter strip systems (NCDENR 2010). This chapter is not comprehensive in its coverage of SCMs. Instead, it focuses on the structures that have the most potential for use in the Lake Herrick watershed. The following is an overview of those SCMs.

Bioswales

A bioswale is a linear depression for directing runoff flows. They also provide a secondary role in filtering pollutants. Filtration by soil percolation helps to remove sediment and pollutants via physical, chemical, and biological processes in the soil. This process can remove copper, zinc, and lead by more than 90 percent, phosphorous by up to 80 percent, and nitrogen by about 60 percent. (Bertule 2014, 39)

Channels can be vegetated, mulched, or xeriscaped. Vegetated swales incorporate moisture-tolerant plants and have the additional quality of sequestering carbon and removing pollutants from air. Grasses are often particularly appropriate. They should be placed where they can manage runoff from specific swaths of impervious area such as parking lots, roads, or plazas. They are not necessarily well suited for dense urban spaces because they require large areas of permeable surface. Their linear form makes them particularly appropriate for siting along roads and highways. (Bertule 2014, 39-40)

One common variation on the bioswale is the enhanced swale, which utilizes a series of check dams to divide the structure into dry or wet cells. This is a response to the notion that swales are most effective at infiltration and silt and pollutant removal when designed to maximize the residence time of rainwater. Check dams increase residence times by disrupting the flow of water and forming micropools. The areas of pooling behind check dams are often outfitted with engineered soils to enhance infiltration rates. (Atlanta Regional Commission et al. 2001, 3.1-3)

Bioswales often, but not always, terminate in a rain garden. Rain gardens and bioswales both provide retention, infiltration, and pollutant treatment. They have similar flood control and groundwater recharge benefits. (Bertule 2014, 39)

Rain Gardens (Bioretention)

Rain gardens, also referred to as "bioretention," are vegetated depressions in the landscape that are designed to infiltrate and filter runoff (Bertule 2014, 39). They are generally shallow, with four to eight inches of holding capacity, and their design should spread water evenly throughout the garden and avoid concentrating flows to any location. Rain gardens are often designed to capture and infiltrate the pollutant laden first flush (Schuessler 2011, 48-61). In these cases, they usually have an underdrain that allows the structure to release excess volume (Bertule 2014, 39). They are supposed to drain completely within 24 to 48 hours (Schuessler 2011, 48). They must be built to withstand exposure to rainfall, runoff, and high nutrient concentrations, particularly nitrogen and phosphorous. They clean runoff, can reduce the stress on gray infrastructure by slowing the rate and reducing the volume of runoff (Bertule 2014, 39), and they can be aesthetically attractive landscape elements.

Plants that develop deep root systems are effective at aiding in soil infiltration. Deep roots contribute to infiltration rates, which become faster as root systems mature. Monitoring of multiple infiltration basins in Kansas City, Missouri found *Spartina pectinata* (prairie cordgrass) and *Sporobolus heterolepsis* (prairie dropseed) to be the best performing plants. The cordgrass was best suited for the wet zone and the dropseed grew best around the edges. In less than two years, the two species had reached 30-inch root establishment depth. Ideal species for the southeast are likely to be different than those used in the Kansas City study; in general, the US EPA recommends using turf. Plants should be specified according to the site's soil and water conditions, which will vary. It is important to consider moisture zones, aesthetics, weed control, and microclimate creation. (Schuessler 2011, 45; US Environmental Protection Agency 2014h)

The rain gardens in the Kansas City case study were long and narrow, and served a conveyance function in addition to standard retention and treatment. Rain gardens and bioswales are closely related in their functional characteristics. Both perform general pollutant filtration and infiltrate some runoff. The two differ in that conveyance is the primary function of bioswales. (Schuessler 2011, 48-60)

Monitoring showed that the rain gardens absorbed contaminants from rooftop runoff. Contaminant load was low, with Total Nitrogen equal to 2.5 parts per million, Total Phosphorous equal to 0.2 parts per million, and Total Suspended Solids at 40.3 mg/L. The rain gardens absorbed 56 percent of Total Nitrogen and 50 percent of Total Phosphorous. The rain gardens’ area was 11.3 percent of the rooftop area that they were catching. This was an adequate ratio for pollutant removal, but the authors believed that the rain gardens possibly could have handled greater loads. Their pollutant removal ability was limited because they were undersized; "additional ponding within the raingardens would have improved [their] performance." (Schuessler 2011, 98) The structures only had capacity for a 1/3-inch rain event, whereas the standard goal for Kansas City is the 1.37-inch “water quality rain event.” The rain gardens also exported "fairly low levels" of Chloride (Cl), Sulfur (S), and TSS. The authors hypothesize that this was also due to their undersized design. Even if space is limited and BMPs cannot be installed at the ideal size, smaller BMPs can still be beneficial. However, their design must address the fact that undersized BMPs are particularly susceptible to erosion. (Schuessler 2011, 49, 61)

The rain gardens in this study were designed to distribute in-flowing runoff through level spreaders for a total of 11 entry points. The mouths of the inlet pipes were masked with stones that reduced erosion by dissipating energy. The spreading of water over a large area also maximized infiltration. Runoff was recorded as taking about an hour and a half to infiltrate through the rain gardens when they were dry. Thus, the rain garden increases the time of concentration by functioning as a form of detention. This time was reduced by 50-70% when the rain garden was already wet or saturated. Rain gardens should be designed to dry out between rain events. They are not wetlands, and the plant selection must reflect this. (Schuessler 2011, 88)

The Kansas City rain gardens had simple maintenance requirements. They were not prone to weed establishment, and post-construction erosion control measures were successful. A problem did develop with mulch clogging the outlet grate during large rain events. The authors noted that performance could be improved by adding rock check dams to keep the mulch away from the drain.

Infiltration Basins

Infiltration basins retain stormwater and infiltrate it, usually over a period of two or three days. They are typically designed off-line, so that a certain volume of water enters the basin while excess volumes bypass the system. However, they may also be built in-line and incorporate an underdrain to allow excess volume to pass through and then exit the structure. Because they have no underdrain, infiltration basins can be designed to infiltrate greater volumes of water. The volume that they are constructed to accommodate includes the subsurface storage capacity provided by engineered soils. Ideally, overflow only occurs during large storm events and the basin infiltrates the majority of water that enters it. Stormwater filters through roots and soil and, in addition to substantially reducing stormwater volumes, removes sediment, metals, nutrients, bacteria, and organic matter ("oxygen-demanding substances"). Infiltration basins can reduce the necessary treatment capacity and cost of downstream SCMs. (Schuessler 2011, 22)

Infiltration basins are best suited for treating areas under ten acres. They should be located in flat, continuous areas with suitable soils for infiltration. The entire bottom of the basin must be flat so that water is distributed evenly and not concentrated in any one area. Soils are the most limiting factor in designing infiltration basins; they must be permeable enough to infiltrate runoff quickly, but not so quickly that treatment does not occur. Ideal infiltration rates are from 0.5 to 3 inches per hour. Another important consideration is the potential for groundwater contamination; infiltration basins should not be used to treat heavily polluted runoff, especially in important groundwater recharge areas. (US Environmental Protection Agency, 2014h)

Adequate pretreatment is essential for removing coarse particulate material that could clog the basin and reduce its infiltrative capacity. Grassed swales and vegetated filter strips are effective for this purpose. Careful attention should be given to any potential sources of erosion, as infiltration practices are particularly susceptible to clogging. An underdrain with a valve should be incorporated as a means of draining the basin in the event that it does become clogged. (US Environmental Protection Agency, 2014h)

Infiltration basins require careful maintenance. They have much higher rates of failure than other SCMs, especially when soils are not highly permeable. They should be closely monitored for signs of erosion or sub-optimal infiltration. The bottom should be aerated annually, and sediment should be removed and sod reapplied on a five-year basis. (US Environmental Protection Agency 2014h)

Downspout Disconnection

Downspout disconnection is the practice of rerouting rooftop downspouts to flow into water harvesting systems or permeable areas rather than directly into a storm sewer system (US EPA 2014b).

Rainwater Harvesting

Rainwater harvesting refers to systems that capture water as it flows off of the rooftops. It is often implemented in conjunction with downspout disconnection. Water is stored in rain barrels or larger-volume cisterns and can be used for greywater applications such as toilet flushing and irrigation. It is a useful strategy for mitigating both drought and flood impacts by extending water supplies in times of need and reducing the volume of runoff that is released into storm sewers and surface waters. (Bertule 2014, 6)

When stored rainwater is used to irrigate food crops in gardens, questions tend to arise about the cleanliness of rooftop runoff. Few studies have been done in the United States regarding rooftop runoff quality. It is likely that quality varies depending on materials and construction regulations. Rooftop runoff is cleaner than most stormwater runoff from other sources, but can still contain contaminants, especially "heavy metals, polycyclic aromatic hydrocarbons (PAHs), microbes, pathogens, and pesticides." (DeBusk, et al. 2009, 1) PAHs usually originate from traffic or industry, and can collect on rooftops as particulate matter. Pathogens can come from the fecal matter of insects, birds, and small mammals. Metals come from adsorption reactions of water on metal roofs. This is especially possible in the presence of acid rain. Zinc, copper, and aluminum are common. Some metals have been shown to be present in rainfall before making contact with rooftops. Zinc, however, has been demonstrably higher after contact with rooftops in at least one study. Most metal concentrations are likely to be filtered out of the water when they make soil contact. They bind with soil particles and organic matter, and thus do not accumulate in produce. Excessive soil concentration of metals can, however, cause phytotoxicity, or poisoning of plants. If soil tests indicate excessively high levels of zinc or any other metal, the plants should not be consumed. Other chemicals that can leach off of rooftops may have been applied for waterproofing on wooden or asphalt shingles. Herbicides are also sometimes applied to rooftop materials to prevent root penetration. (DeBusk, et al. 2009, 1-2)

Rainwater harvesting is suitable for residential use because of its ease of use and management. Water collected from rooftops is not fit for potable use without filtration and treatment. Ultraviolet treatment can remove bacteria. It should be utilized in combination with a filtration system. It is advisable to conduct regular soil tests if water harvested from rooftops is being applied for irrigation. Produce grown with rainwater should be washed thoroughly. (DeBusk, et al. 2009, 1-2)

Planter Boxes

Planter boxes are containers filled with soil and plants. Depending on their size they may be planted with herbaceous vegetation or even be large enough to support trees. They are commonly used in conjunction with downspout disconnection to provide a location for depositing rooftop runoff. Their compatibility with downspout disconnection and their compact dimensions make them ideal for placement in dense urban areas against buildings and along sidewalks. (Fairfax County 2005)

Planter boxes are effective for delaying the flow of runoff, reducing runoff volumes, and decreasing pollutant concentrations. Reductions in flow rate are achieved by nature of the additional time that it takes for water to drain through the soil and gravel layers in the planter. Planter boxes can also be designed to incorporate ponding for additional retention time, or include a gravel storage bed below the soil layers. Overall runoff volume is reduced as some water is taken up by plants and evapotranspirated. Planter boxes have been shown to have about the same pollutant removal effectiveness as bioretention facilities. Outflow can be linked to swales or pipe conveyance systems using underdrains. Planter boxes require periodic maintenance to ensure that plant root growth is adequate, the soil is draining properly, and the underdrain does not become clogged. (Fairfax County 2005)

Sediment Forebay

A sediment forebay is a detention trap that causes suspended sediment to drop out of runoff before the water proceeds downstream. Forebays are pools, typically at least three feet deep at the entry point and a foot deep at the outlet with a sloped bottom in between. These dimensions facilitate sediment settling and energy dissipation. They are typically used to provide pretreatment for stormwater wetlands, rain gardens, or sand filters, shielding them from infill by sediment. The forebay, rather than the downstream SCM, fills with silt over a five to ten year period. Regular clearing or dredging is necessary to remove accumulated sediment and litter and to keep downstream SCMs free of debris. For this reason, forebay placement should accommodate access by machinery. (Schuessler 2011, 65; Hunt and Doll 2000, 4; NCDENR 2007, 11)

Sand Filter

Sand filters remove sediment and particulate pollutants such as bacteria, nutrients, and metals. They do not affect dissolved substances. Sand filter designs are versatile and take up little space. They can be installed at the ground's surface, or enclosed in an underground basin. They are suitable for use in any type of soil. They can be placed on slopes of up to six percent, but must accommodate about five feet of elevation difference between their inflow and outflow. Their flexibility allows them to accommodate a variety of placement constraints and makes them well-suited for post-development retrofits. (Schuessler 2011, 65, 81; US Environmental Protection Agency 2014g)

Sand filters are limited in their treatment capacity and can only accommodate relatively small runoff volumes in comparison to higher-volume SCMs such as detention ponds. A surface-level sand filter should ideally treat no more than ten acres, and an underground sand filter is limited closer to two acres. Larger treatment areas are possible but make the facility more susceptible to clogging. Sand filters must be protected against high-velocity runoff, which can cause erosion. This is most commonly accomplished through a two-stage design in which water enters a settling chamber and then flows through a level spreader into a filter bed that may consist of sand or other types of media. Filtered water is conveyed out through an underdrain that consists of a perforated pipe set in a layer of gravel. The settling chamber removes coarse particles from the system, and should be designed to accommodate about 25 percent of the water quality volume. Flows in excess of the water quality volume should be routed around the filter using a flow splitter. (US Environmental Protection Agency 2014g)

Sand filters require more frequent maintenance than many other SCMs. Maintenance should occur annually and may include clearing the sediment chamber, weeding, and general inspection to ensure structural integrity, proper flow, and absence of erosion. Surface-level filters may not be considered aesthetically pleasing. However, they can be designed with a grass layer on top so that they blend better with their surroundings. (Schuessler 2011, 65; US Environmental Protection Agency 2014g)

Permeable Pavement

The impact of constructing impervious surfaces can sometimes be offset by using permeable types of pavement rather than traditional asphalt or concrete. Permeable paving reduces runoff volume by allowing at least some stormwater to filter through it. Specific types of permeable paving include "pervious concrete and asphalt, permeable interlocking concrete pavers (PICPs), concrete grid pavers, and plastic reinforced grass pavement." These materials are usually conglomerates of coarse particles, giving them high pore-space for water storage and infiltration. Beneath the surface are two underlying layers: one of fine sediment that acts as a filter, and a gravel conveyance and storage layer underneath. The gravel also provides structural support. Permeable pavement structures are built with traditional gray infrastructure materials, but they mimic the hydrologic function of soil. (Bertule 2014, 41)

Permeable pavement helps to regulate water supply and quality and aids in drought mitigation. It can potentially reduce storm runoff volumes by 70 to 90 percent. Pavement layers also filter pollutants. Tests have shown them to be effective in reducing 85 to 95 percent of Total Suspended Solids, 65 to 85 percent of Total Phosphorous, 80 to 85 percent of Total Nitrogen, 30 percent of nitrate, and up to 98 percent of metals. Pavers also dampen noise, absorb less heat than conventional concrete or asphalt, and facilitate evaporation that results in a cooling effect. (Bertule 2014, 6, 42)

Permeable pavement is not as durable as impervious concrete or asphalt. Thus, it is ideally utilized in areas with low traffic, such as "residential roads, parking lots, walkways, driveways, [and] patios." Permeable pavement may not be suitable for areas with heavily compacted or slow-draining soils. Heavy clay content can impede infiltration and impair SCM function. Pore clogging in the surface layer is also a matter of concern; permeable pavement must be vaccum-swept three or four times per year to clear debris that would otherwise degrade its infiltrative function. Permeable pavement is not suitable for surfaces that are susceptible to high concentrations of pollutants such as road salts, metals, or gasoline. Runoff-borne contaminants can infiltrate into the soil and even make their way into groundwater supplies. (Bertule et al. 2014, 42) Areas where this may be a concern would be better addressed with other stormwater structures that are intended more specifically for pollutant removal.

Green Roofs

Green roofs are among the most highly-publicized and widely-recognized stormwater SCMs. They are used to reduce stormwater runoff volume, insulate buildings and reduce urban heat proliferation, and enhance the durability of rooftops. In many instances, they may also reduce pollution by replacing conventional roof shingles, which can leach lead, zinc, pyrene, and chrysene. Green roofs can be intensive, with soil media deeper than six inches, or extensive, with soil media shallower than six inches. Extensive roofs are usually solely implemented for their environmental functions, while intensive roofs are typically designed to accommodate human interaction and aesthetic appreciation. Extensive green roofs are able to retain and evapotranspirate about 50 percent of all rainfall, thus reducing the burden on stormwater conveyance systems. (US Environmental Protection Agency 2014i)

Green roofs are particularly appropriate for densely developed urban areas because they capitalize on unutilized rooftop space and, unlike many other stormwater SCMs, they take up no additional space. Their applicability for retrofitting existing structures varies; the building’s capacity to support the added weight of the roof is a primary limiting factor. (US Environmental Protection Agency 2014i)

The effectiveness of green roofs has been studied widely, and their capacity for reducing peak runoff volumes is proven. Uncertainties still exist about their potential for exporting nutrients and other possible contaminants. (US Environmental Protection Agency 2014i)

Level Spreader

Level spreaders are not SCMs themselves, but rather are used to convert channelized flow to diffuse flow to prepare it for entry to a SCM without causing erosion. They are most often associated with vegetated filter strips and bioretention. A level spreader is a poured concrete curb, a minimum of ten feet long and a maximum of 100 feet long. Water pools behind it in a blind swale and then flows over the top uniformly along its length, like the edge of an infinity pool. The swale is "blind" because it is directionless. It is more precisely described as a shallow trough, no more than a foot deep, that is constructed of earth and coated with riprap or sod. It can also be made of concrete, which makes sediment removal maintenance easier. It runs the width of the level spreader. For best results, water should enter the blind swale at one end, flowing parallel to the level spreader, rather than perpendicular. This is because if it enters perpendicular, it is more likely to spill over the lip near the entry point. Parallel entry ensures that the entire swale will fill with water before it starts to spill over. The blind swale may also incorporate a forebay at its entrance, which should have a surface area of 0.2 percent of the drainage area. (NCDENR 2007, 2-13)

The curb, or pourover lip, should be three inches above the downslope ground surface, which is a three-foot wide area covered in a geotextile fabric and topped with a three to four inch layer of stone. The level spreader may be straight or curved outwards, but never concave because this would concentrate the outflow. Earthen or concrete berms at either end of the curb hem in the sides and keep water directed over the lip. The top should be at an even elevation all the way across, sited parallel to the natural contours of the terrain so that minimal grading is necessary. (NCDENR 2007, 2-13)

One important consideration for the blind swale is drainage. An underdrain should be used if the soil has a low infiltration rate (less than two inches per hour). This underdrain will drain into the bypass channel to prevent standing water in the swale from acting as mosquito breeding habitat. If the swale's infiltration rate is extremely slow, to the point where even underdrains do not function well, then the blind swale could potentially be designed as a linear wetland and not drain at all. (NCDENR 2007, 13)

Vegetated Filter Strip

Vegetated filter strips remove sediment, nutrients, metals, and organic material. They can delay runoff, but provide no assistance with volume capture aside from minimal infiltration during small storms. They do not have high enough pollutant removal rates to function as standalone SCMs, but they are most effective when incorporated into treatment trains. (NCDENR 2007, 1-14)

Specifically, vegetated filter strips are swaths of land that filter diffuse flow. They can be natural or engineered. Existing natural riparian buffers and forested areas may be used as filter strips as long as they do not contain any draws or channels. They are ideal for use along roads, given the need for sheet flow, but they can even be applied after flow has become channelized when used in conjunction with a level spreader. (NCDENR 2007, 14)

Vegetated filter strips should be a minimum of thirty feet wide. Their lengths are determined by the target discharge rate that they are designed to accommodate. They must have uniform lengthwise slope, with no cross-slope. The vegetated filter strip and its side slopes should have six inches or more of topsoil with amendments for fertility. Excess flow beyond the capacity of the VFS should be routed through a flow splitter and into an alternate drainage to a stream. The flow should not erode the drainage or the stream. Erosion concern can also be eliminated by bypassing excess flow into a pipe rather than a channel. In order to prevent erosion where bypassed water is deposited to a stream, the bypass channel should be angled rather than perpendicular to the stream, so as not to erode the opposite bank, and enter into a deep pool. (NCDENR 2007, 10)

Maintenance is necessary for perpetuating the vegetated filter strip's pollutant removal function, and to prevent the structure from becoming a pollutant source. For the first two years following its installation, the structure should be inspected for erosion and proper function following moderate to major storm events. After the first two years, the SCM should be inspected quarterly. If erosion is occurring, structural damage should be repaired immediately and the cause determined. The soil should be cored if compaction is evident. Regular maintenance for engineered filter strips also includes mowing and upkeep of grass. The forebay requires the most frequent maintenance; it should be kept free of leaves, sediment, and debris. The blind swale should be kept free of successional vegetation. (NCDENR 2007, 20)

Stormwater Wetlands

Wetlands often occur naturally adjacent to other surface water. However, at least half of all natural wetlands in North America have been destroyed to make room for agriculture and development in the past 200 years. Their disappearance represents the loss of a variety of functions, compounded by the influx of an array of pollutants introduced by development. Stormwater wetlands are an effective structural treatment for the pollution impacts that typically accompany development. (Hunt and Doll 2000, 1)

Engineers have identified the value of wetlands for water supply and quality regulation, biological control, and water temperature control, and have become adept at creating artificial wetlands that are specially designed to maximize desired characteristics of natural wetland ecosystems. Constructed wetlands can provide similar habitat benefits as natural wetlands for birds and fish species, and they often reduce runoff volumes by 5 to 10 percent via seepage and evaporation. This results in some degree of groundwater recharge. Wetlands are primarily constructed as biological wastewater treatment facilities for treating nutrient pollution. They are intended to supplement or substitute conventional treatment plants in treating domestic wastewater and sewage, industrial waste and sludge, and runoff from agricultural and livestock operations. (Bertule 2014, 6, 28) Wetlands are also built for the specific purpose of treating general urban runoff, in which case they are termed “stormwater wetlands.” Stormwater wetland functions include "improving water quality, improving flood control, enhancing wildlife habitat, and providing education and recreation." (Hunt and Doll 2000, 2) They enhance biodiversity to the greatest extent of any form of green infrastructure. (Bertule 2014, 25)

Stormwater wetlands are the most effective SCM for pollutant removal. This is because the variety of mechanisms that they use makes them versatile and well-rounded, rather than only targeting a single form of pollutant. They have the "best median removal rate for total suspended solids, nitrate-nitrogen, ammonia-nitrogen, total phosphorus, phosphate-phosphorus, and some metals." (Hunt and Doll 2000, 3) Wetlands have been demonstrated to remove up to 85 percent of Total Suspended Solids, 75 percent of Total Phosphorous, 55 percent of nitrogen, and 45 percent of organic carbon. (Bertule 2014, 29) The design of any specific wetland may vary depending on its targeted pollutants. Stormwater wetlands use a variety of mechanisms to remove pollutants - more than any other SCM. These "include sedimentation, filtration, adsorption, microbial activity (nitrification and denitrification), and plant uptake." (Hunt and Doll 2000, 2)

Wetlands remove pathogens by exposing them to sunlight as they rest in shallow water, or by exposing them to desiccation when they become trapped in areas that dry out between rain events. If pathogen removal is a major goal, wetlands should be designed to maximize the amount of area that dries between large storm events. (Hunt and Doll 2000, 3)

The process of sedimentation entails water moving slowly through a wetland, causing sediment, trash, and debris to drop out and settle on the bottom. Vegetation aids this process by slowing the water, which facilitates sedimentation, and by physically intercepting particles (filtration). These processes manage Total Suspended Solids, litter and debris, and phosphorous, bacteria, and pathogens attached to sediment particles. Adsorption occurs when dissolved metals and soluble phosphorous drop to the wetland floor and chemically react with soil particles. Their charges bond with charges in the soil. Adsorption is effective for pollutant removal, but it is a finite process. There are a limited number of charged particles in the soil on the wetland floor, and once they have all reacted with metals and phosphorous, the wetland has reached its adsorption capacity and this mechanism ceases to be effective for new inputs. (Hunt and Doll 2000, 2)

Microbial activity is a method by which wetlands break down a variety of organic substances and pathogens. The most prominent occurrences of this are the chemical processes of nitrification and denitrification, by which nitrogen inputs are removed. Wetland soils are saturated with water and thus are anaerobic. However, many wetland plants pump atmospheric oxygen down to their root zones, which creates aerobic areas in the soil. Nitrogen-containing pollutant inputs are often Organic Nitrogen. This decomposes naturally into ammonia, which becomes converted into Nitrate Nitrogen through the process of nitrification. Nitrification is catalyzed by nitrifying bacteria that inhabit aerobic environments. Nitrate then moves from the aerobic to anaerobic soil zones, where denitrification occurs. Bacteria that inhabit anaerobic zones convert nitrogen to gas that is diffused harmlessly in the atmosphere, which is composed of about 80 percent nitrogen. (Hunt and Doll 2000, 2; Bertule 2014, 25)

Nitrogen and phosphorous removal also occurs when wetland plants absorb the substances for their own growth. However, when the plants die these substances are released back into the environment. Thus, this is only a temporary form of removal unless the plants are harvested and disposed of elsewhere. It may also lead to the export of organic nitrogen, as organic matter is transported out of wetlands when plants die. They are usually flushed out by large storms. A flow splitter can be incorporated into the design to bypass large storms around or away from wetlands, thus reducing substance export. (Hunt and Doll 2000, 2-3)

Wetland design must ensure that the wetland is sized properly to handle anticipated flow volumes. Undersized wetlands tend not to perform well because they get flushed out more frequently. Large flows tend to pass through too quickly, without being fully treated. (Hunt and Doll 2000, 3; Schuessler 2011, 80) In addition to adequate sizing, wetland performance depends on "upstream site stabilization, erosion control, vegetation establishment, and maintenance" (Schuessler 2011, 78). Sediment inflows from construction, trail use, stream channel incision, or any other sources of erosion can compromise wetland function. For this reason, wetland design should incorporate a forebay. The standard in the mid-Atlantic is that the forebay's area should be ten percent of the entire wetland surface area. (Hunt and Doll 2000, 4; Bertule 2014, 28)

Constructed wetlands ideally have dense and diverse vegetative cover. (Bertule 2014, 28) In addition to its pollutant removal functions, vegetation makes wetlands less habitable to water fowl.

Ducks and geese, which can cause substantial bacteria loading, tend to avoid tall dense vegetation and narrow stretches of open water, because they "prefer open lines of sight to be able to observe potential predators" (Schuessler 2011, 77).

There are potential unintended consequences that can accompany stormwater wetland creation. They can foster a variety of unwanted species drawn to their characteristic nutrient-rich habitat. This includes exotic/invasive plants, snakes, waterfowl, and disease-bearing mosquitoes. (Bertule 2014, 30; Schuessler 2011, 65) Mosquitoes tend to be most problematic in monocultures. With a diversity of vegetation, wetlands can provide sufficient habitat for animals that regulate mosquito populations. Favorable animals include dragonflies, frogs, some birds, and some fish. Other potential limitations include the need to assess drowning risk in areas where small children will be present, and the need for large areas of flat land. The surface area requirement for a wetland is greater than or equal to that of any other SCM. (Hunt and Doll 2000, 11)

There is currently not enough data about wetland function. Existing monitoring data exhibits high variability. This could be due to differences in design effectiveness or unique watershed characteristics. It could also have to do with details of monitoring design, such as the time of year that monitoring is conducted or the temporal proximity of data collection to weather events. Typically, long-term monitoring provides more accurate and contextually sensible data than limited or short-term monitoring. Information regarding maintenance cost is also lacking. Theoretically, this should be about the same as "the cost of maintaining a pond." (Hunt and Doll 2000, 3, 11)

Wet Ponds

Wet ponds are ponds that contain a perennial pool of water. They are used primarily for detention and pollutant removal. Wet ponds provide flood control, detaining and slowly releasing water from above the permanent pool. They do not provide infiltration. Primary pollutant removal mechanisms are settling and biological uptake. Biological uptake is most commonly performed by algae, which absorb nutrients. They are effective in treating a wide range of pollutants, and can even be used to absorb highly polluted runoff, such as downstream of a gas station. Wet pond pollutant removal effectiveness varies between ponds, but they are recognized as some of the most effective SCMs for pollutant removal. Typical pollutant removal rates are around 67 percent of Total Suspended Solids, 48 percent of Total Phosphorous, 31 percent of Total Nitrogen, 24 percent of Nitrate Nitrogen, 24.73 percent of metals, and 65 percent of bacteria. (US Environmental Protection Agency 2014c)

Wet ponds are widely applicable in non-arid regions. They generally require a drainage area of at least 25 acres to maintain their pool. In dense urban areas, this can be a space limitation. They are built in a variety of shapes and sizes. There are five key features that they all share: pretreatment, treatment, conveyance, maintenance reduction, and landscaping. Pretreatment refers more specifically to a forebay to help settle out coarse sediments. This prevents infill of the pond, so the need for periodic dredging is reduced to this smaller pool. The forebay should be 10 percent the volume of the permanent pool. It should be cleaned every 5 to 7 years. (US Environmental Protection Agency 2014c)

Pollution treatment works better the longer water stays in a pond. Thus, the permanent pool volume should be maximized for optimal function. Techniques can be used to prolong flow paths and increase hydraulic residence time. For example, underwater berms extend the water's route through the pond. A length to width ratio of at least 1.5:1 is helpful for ensuring a long flow path from the entry to the dam. Linking multiple ponds into a "treatment train" also works well. If stratification is anticipated, a mixing mechanism such as a fountain can help to keep the entire water column oxygenated. This will prevent nutrient buildup and facilitates processes that improve the water quality. (US Environmental Protection Agency 2014c)

The main concern regarding conveyance is erosion potential of the receiving channel. The outfall should be stabilized to prevent erosion. (US Environmental Protection Agency 2014c)

To reduce the need for maintenance, and to ensure that maintenance is easier when it does take place, a trash rack should be installed over the inlet structure to prevent clogging. No orifice less than 3 inches in diameter should be used; small orifices clog more easily than larger ones. A forebay and drawdown pipe are both essential features for ease of maintenance access. A vegetated buffer around the pond helps to control erosion, remove pollutants, and enhance aesthetic value. (US Environmental Protection Agency 2014c)

Detention Basins

Detention basins manage water quantity by capturing stormwater and releasing it slowly to prevent erosion and flooding. They are one of the most effective structural SCMs for managing large rain events, but they have limited effect on water quality. (Schuessler 2011, 64, 84)

Tree Planting

The practice of tree planting can include the establishment and maintenance of an urban tree canopy, or reforestation, afforestation, and forest conservation efforts in more remote areas. Tree populations aid in erosion control and regulation of water supply and quality through soil stabilization and water retention. Eroded soils cannot store as much water and thus result in increased flood risk. Trees increase infiltration; forested areas store more water and release it slowly via evaporation. Afforestation may reduce overall runoff and groundwater recharge because more water is lost to evapotranspiration. Increased forest cover leads to a more constant supply of water but less total volume available at a given time. Extensive tree growth is particularly important in upper watersheds where they reduce downstream flooding risk caused by storms. When forest cover is located strategically within the watershed, it can prevent pollutants from entering water bodies and regulate sediment flow. Forests have a positive influence on water quality because they reduce the amount of sediment that enters adjacent water bodies and trap some water pollutants. Roots stabilize banks and shorelines, preventing erosion. (Bertule 2014, 20-21)

On a large scale, preservation and proper management of forests has been shown to provide effective water treatment at lower costs than treatment plants. One third of the top 100 largest cities in the world derive their drinking water from protected forests. Forests also have some of the greatest co-benefits provided by any type of green infrastructure, including pollination, air quality, climate cooling, biodiversity, and functioning as a carbon sink. They also create potential opportunities for income through agroforestry and ecotourism. (Bertule 2014, 20-21)

Land Conservation and Restoration

Forests, streams, wetlands, and other natural environments are green infrastructure by nature of the myriad ecosystem services that they provide. Conserving undeveloped natural areas, designing new green spaces, and restoring spaces that have been impacted by development can thus be regarded as green infrastructure maintenance. Wetlands restoration and conservation, for example, aids in water supply and quality regulation and flood moderation. Reconnecting incised streams with their floodplains by reconstructing their natural channel geometries is another common restoration activity that can reduce flood impacts and improve water quality. Incised streams often generate large amounts of sediment through erosion. Their floodplains are elevated high over steep channel walls, and are thus inaccessible for handling excess volume during high flows. Incised channels are geomorphically unstable and, without the recourse of a floodplain, are prone to scouring from the unnaturally high runoff volumes that accompany development. (Bertule 2014, 6, 20-23)

Treatment Trains

The practice of routing water through multiple SCMs in a sequence is referred to as a treatment train. This is advantageous because no single SCM is able to treat all forms of pollution, and pollutant loads and stormwater volumes can often exceed the treatment capacity of individual structures. Each component of a treatment train is designed to treat a different aspect of runoff or pollution. Systems of interlinked SCMs do not necessarily need to be long or complex; they can be as short as two subsequent SCMs. For example, a rain garden that intercepts water from one or more roof downspouts and conveys outflow to a detention basin. (Schuessler 2011, 84) Structural SCMs are also just one component of a treatment train. Others include site development strategies and management practices (Schuessler 2011, 64).

A more complex example of a treatment train for a site could entail vegetated swales with native plants intercepting runoff and conveying it into a series of rain gardens, followed by a sediment forebay and sand filter, and then a wetland that discharges into a lake. Such an arrangement would be effective for reducing runoff volumes and treating a variety of contaminants. The swales provide some initial infiltration to reduce the volume that must be treated. They are able to remove a large portion of the suspended solids and some nutrients and metals, but tend to export pathogens. The bioretention provides additional removal of metals and nutrients, and may infiltrate some water. The combined forebay and sand filter provide high rates of removal for suspended solids, nutrients, metals, and pathogens. This prepares water for entrance to the stormwater wetland, which provides the final stage of treatment. Wetlands are among the most effective SCMs for pollutant removal, especially of pathogens and nitrogen. The combined effect of these four SCMs yields high levels of nutrient, metal, bacteria, and suspended solid removal, some infiltration, and substantial delay of runoff. (Schuessler 2011, 50; US Environmental Protection Agency 2014d, e, f, & g)

When implementing a treatment train, care should be taken to minimize erosion from construction activities. Excessive erosion can severely inhibit system performance, so it is advisable to install SCMs from upstream to downstream. In the example given above, the wetland would be established last, after the preceding SCMs are stabilized and plants are established. Prior to establishment, the planned wetland area could be used as a temporary sediment pond. (Schuessler 2011, 80)

CHAPTER 5

PROJECTIVE DESIGN

In this chapter, 32 sites were identified as potential locations for SCM placement. Their catchments were delineated by manually tracing their contour lines in ArcMap. The catchments were characterized by land use and soil type, a composite curve number (CN) was assigned to each, and runoff volumes were modelled using HydroCAD for a 1.2-inch storm event. This is the "water quality" volume, or "the volume required to remove a significant percentage of the stormwater pollution load, defined… as an 80% removal of the average annual post-development total suspended solids (TSS) load. This is achieved by intercepting and treating a portion of the runoff from all storms and all the runoff from 85% of the storms that occur on average during the course of a year." (Atlanta Regional Commission et al., 2001, 2.1-47). SCM interventions are sized to treat this volume because "rainfall between 0.5 and 1.5 in. normally accounts for about 75 percent of all stormwater pollutants. So, capturing and treating runoff from these small storms is the key to addressing pollutant discharge." (Vick, et al. 2012. 92) Time of concentration (T_c) was calculated for each catchment using the Rational Method. Projected maximum discharge rates (CFS) and volumes were recorded for the 1.2" storm. Relevant catchment data is included in Appendix B. General specifications for many of the proposed interventions were generated, including estimates of treatment capacity, footprint, and cost. The models and designs presented here are general and based on coarse estimates for the purpose of evaluating feasibility, as is appropriate for a preliminary evaluation of this scope. More detailed design iterations will be necessary if SCM implementation is pursued for any of the proposed interventions.

In all, this plan explores the placement of 32 different structural SCMs on the University of Georgia's campus to treat runoff from the most densely developed impervious areas in Lake Herrick's watershed. Full implementation would result in SCM coverage of 80.72 acres, or 31 percent of the total watershed.

Figure 18: Map of proposed SCM placement in the Lake Herrick watershed.

Family Housing:

The six-building Family Housing complex on Rogers Road is the most densely-developed site within Lake Herrick's watershed. Opened in 1973 (University Housing, n.d.), its facilities are in need of continuous upkeep, presenting opportunities for stormwater retrofits. The complex is suitable for a SCM treatment train that would sequentially treat runoff from its various catchments and subcatchments. Management of runoff from this site should be regarded as crucial, as it undoubtedly has a substantial impact on Lake Herrick's water quality.

Stormwater pipes run along the south side of family housing building N and the north sides of buildings P,Q,R, and S. Each of these pipes connects a cluster of parking lot and courtyard drains to a main line buried behind the row of buildings, running roughly parallel to the buildings and railroad track. This storm line connects to a second culvert in the vicinity of the railroad tracks. The second culvert runs under the Redcoat Band Practice field and discharges into an extremely eroded gully in the woods near the Parvo Pond tributary inflow to Lake Herrick, just upstream of the wetland.

The outlet point of this particular conveyance system is of particular concern. The gully formation is extensive and is a clear source of substantial erosion and sediment input to Lake Herrick's already heavily sediment-entrained inlet cove. Priority should be given to measures that reduce the volume and velocity of stormwater flows through the final culvert. However, the entire system directs unmitigated contaminant-laden parking lot runoff into Lake Herrick. The most effective way to relieve pressure from erosive forces at the final culvert outlet is to treat stormwater close to its source. Implementation of SCMs should begin close to the parking lot and courtyard drain inlets and progress down towards the lake.

The proposed treatment train for the Rogers Road Family Housing catchment entails four to five steps of treatment. First, runoff from the building rooftops should be detained and filtered by re-routing the downspouts to flow into planter boxes and, in the case of Building Q, rain barrels. Parking lot runoff volumes should be reduced by replacing the parking stalls with permeable substrate. Water quality from the parking lots is of equal concern as volume, so the runoff that enters parking lot drains should be conveyed through a sand filter. For two of the ten parking lot catchments, bioretention appears to be more feasible than sand filters, and it should be implemented accordingly. For an additional layer of volume reduction and filtration, culverts should discharge into a level spreader and vegetated filter strip in the places where the storm drain networks that drain the buildings, parking lots, and surrounding up-slope areas converge. Excess volume from the filter strips discharges to a bioswale, which conveys runoff to the existing culvert underneath the railroad tracks. Finally, a detention basin should be constructed at the final outlet of the conveyance system, where runoff discharges into an incised gully near one of Lake Herrick's tributary streams. This structure would ideally be sized to accommodate somewhat larger storm volumes than the 1.2 inch water quality event. The receiving gully should be reconstructed with more stable channel dimensions to prevent further erosion. The combined effectiveness of all of these interventions should substantially reduce the volume and enhance the quality of stormwater runoff from the Rogers Road Family Housing complex.

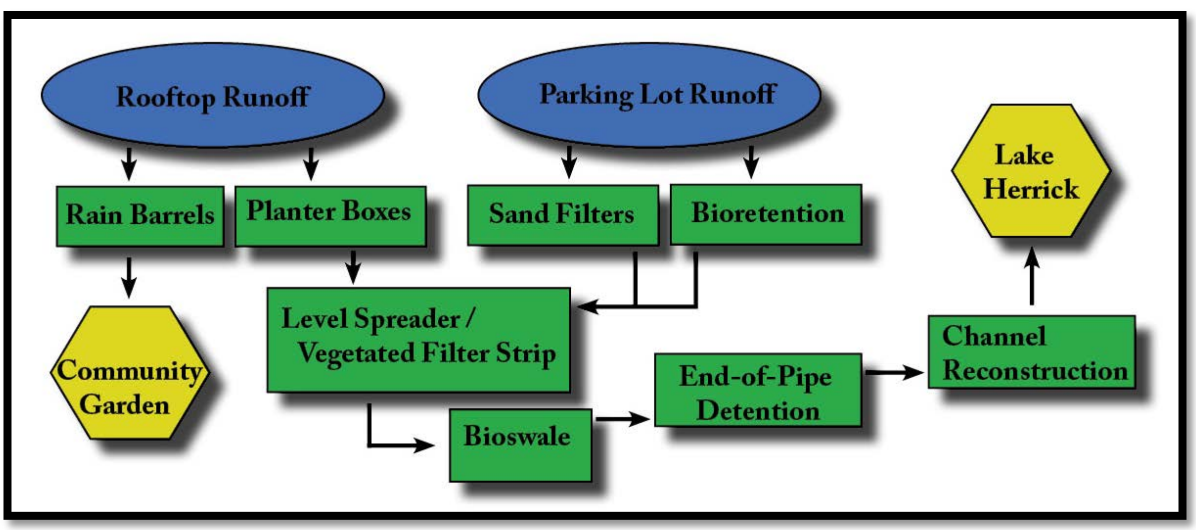


Figure 19: Flowchart of the proposed Family Housing treatment train.

Rooftop Water Harvesting and Downspout Disconnection

The family housing building rooftops drain through gutters that run directly to the ground. On the side of the buildings facing the parking lot, water runs a short distance through a small courtyard space into a drop inlet where it joins runoff from the parking lot. On the side of the building that faces the train tracks and Oconee Forest Park, water flows from the gutters across the ground towards the railroad right of way. No major erosion has developed here, although small furrows can be observed in the ground near some of the downspouts. Patches of clay soil are exposed throughout the yard downslope of the buildings, and small deposits of sediment are present across some of the paved paths that run through the area. Other than paths and areas maintained for a functional purpose (garden, playground, pavilion), the predominant ground cover is grass and large amounts of pine straw from the clumps of mature pine trees. It is likely that flow from the rooftop downspouts does drive substantial transport of organic matter and sediment.

Dispersing flows from the family housing rooftop downspouts would check the low-level erosive transport. Additionally, water from the rooftop can potentially be reused for both functional and aesthetic benefits. A cistern or several rain barrels should be installed to capture water near the garden area (behind Building Q) and provide irrigation at the Family Housing

Figure 20 (left): Map of proposed Family Housing planter box and rain barrel locations.

community garden. At each downspout that is not being utilized for rainwater harvesting, planter boxes would serve to detain the remainder of the runoff and filter any contaminants that might flow off the roof. The planter boxes should be planted with attractive, low maintenance, native vegetation to uptake rainwater and contribute to a pleasant environment. Planter boxes could potentially even serve as additional space to grow edible plants.

Each building rooftop is divided into eight individual downspout catchments. Each catchment should be fitted with an appropriately sized planter box or rainwater harvesting vessel. Planter boxes should be sized based on monthly rainfall volumes. The monthly rainwater supply from each of these catchments is equal to the monthly rainfall times the catchment area (Vick et al. 2012, 94). In Athens, the mean monthly rainfall between 1944 and 2012 ranged from a high of 5.05 inches in March to a low of 3.18 inches in October. The mean annual rainfall was 48.03, which divides to roughly 4 inches per month. (The Southeast Regional Climate Center 2015) This volume, times the individual downspout catchment area of 1055 square feet for building Q, gives a monthly rainwater supply of 348.15 cubic feet for each of the catchments associated with rainwater harvesting. Four individual rain barrels or a single large cistern should be sized accordingly, with a flow splitter provided to divert volumes in excess of those projected.

Planter boxes, placed below each of the remaining 44 downspouts, do not need to be sized to accommodate monthly rainfall volumes. Instead, they should have the capacity to temporarily contain the volume of a predetermined storm event as the water filters through the planting media. Like the rainwater harvesting system, excess flows should be diverted using a flow splitter. Because of their location directly adjacent to the buildings, water should not be allowed to infiltrate further into the ground once it has been discharged from the planter boxes. This could cause basement flooding or instability in the building foundations. Instead, water should continue along its current flowpath, whether overland or into storm drains.

Catchment	Building	Rooftop Area (SF)	Individual Downspout Catchment Areas (SF)
A	M	14,917	1243
B	N	l3,520	1126
C	P	12,588	1049
D+E	Q	12,660	1055
F	R	12,345	1028
G	S	12,417	1034

Table 3 displays measurements of the rooftop areas of the Family Housing buildings.

Permeable Parking Stalls

The 10 catchments that drain the parking lots in the Roger's Road family housing complex have a combined impervious surface area of 193,220 square feet. 57,215 square feet, or about 30 percent of the total impervious area, is associated with parking stalls and may be suitable for replacement with permeable pavement. Unfortunately, all of this area is underlain by poorly-drained PgC3 and CZb3 soils (HSG C). The infiltration rate of these soils should be determined; porous pavement requires a soil infiltration rate of 0.5 inches per hour in order to be effective (Vick et al., 2012, 118). If infiltration rates are too slow, it could be a serious impediment to installation of permeable pavement, possibly necessitating excavation of existing soil and replacement with more permeable media. If so, the associated costs are likely to be prohibitive.

Catchment	Total Impervious Area (SF)	Parking Stall Area (SF)	Ratio of Parking Stalls to Total Impervious
H	28,144	8,400	.298
I	26,519	4,920	.186
J	7,632	2,220	.291
K	13,204	6,369	.482
L	25,995	3,185	.123
M	7,527	3,450	.458
N	20,330	7,894	.388
O	17,676	5,925	.335
P	19,039	6,423	.337
Q	27,184	8,429	.310
All	**193,220**	**57,215**	**.296**

Table 4 displays measurements of the impervious portions of the catchments that drain the Family Housing parking lots, and the areas that could potentially be converted to permeable surface.

Parking Lot Sand Filters

The family housing parking lots and their associated catchments have a collective area of 5.12 acres, about 86 percent of which is impervious. The parking lots drain through 26 individual drop and curb drains to a storm line network. There are 14 additional drains from the family housing building courtyards that connect to the parking lot storm lines.

The northern-most parking lot catchment at the Rogers Road Family Housing complex, Catchment O, is not linked to the same conveyance system as the rest of the Family Housing complex. Instead, runoff enters a culvert through seven interlinked drains. The culvert outlet conveys it to a drainage ditch, through which it travels for roughly 500 feet before entering the west tributary creek.

The culvert network could be outfitted with off-line sand filters to remove contaminants from runoff as it leaves the parking lot. This area is particularly suitable for sand filter placement because each of its catchments is highly impervious. Underground sand filters would be ideal, because they could be installed underneath the existing parking lot and linked to the storm drain system without taking any additional space, so long as provisions are made for maintenance access. The family housing parking lots

Figure 21 (left): Map of proposed Family Housing sand filter locations.

are particularly suitable for sand filter implementation because, on average, they sit twelve feet higher than the area that they drain to. This means that a sand filter installed just below grade underneath or adjacent to one of these lots would have the necessary amount of elevation drop (at least five to eight feet), or head, which it requires to function. (US Environmental Protection Agency, 2014g)

Underground sand filters are best suited to treat catchments of two acres or less. The current drainage network in the Family Housing parking area contains nine individual catchments, eight of which are suitable to be outfitted with their own sand filter. (US Environmental Protection Agency, 2014g)

Sand filters are most commonly designed to filter the water quality volume while bypassing larger flows. The design volume is important for determining the sand filter's capacity; the pretreatment sedimentation chamber should be at least 25 percent of the water quality volume, with a length-to-width ratio should be at least 2:1. The sand filter should be equipped with an orifice or weir to pass the water quality volume while diverting all excess flows. Inside the chambers, medium sand would be employed as the filtering media. After percolating through the sand, water exits the filtration chamber through a perforated pipe underdrain. Treated runoff re-joins bypassed overflows and continues through the existing storm drain network. (Atlanta Regional Council et al. 2001, 3.2-63; US Environmental Protection Agency, 2014g)

The eight catchments of interest for sand filter application range in area from 0.25 to 1.14 acres, 56 to 86 percent impervious surface, and 0.010 to 0.047 acre feet of runoff projected for the water quality storm event. For the sake of generating a rough estimate of design specifications for sand filters to treat these catchments, averages are taken for the relevant catchment characteristics. A sand filter is designed based on those averages. Although individual sand filters must be designed to respond to the specific properties of their own catchments, this average sand filter serves as a generalized model to evaluate the feasibility of implementation in the Family Housing parking lot catchments.

Initial approximations of the required sand filter dimensions were calculated using the procedures specified on pages 3.2-68-70 of the Georgia Stormwater Management Manual Volume 2 (Technical Handbook). A step-by-step account of the sizing process is included in Appendix D. The results of a

Catchment	Area (acres)	% Impervious	CN	Number of Storm Drains	1.2” Storm Projected Runoff Volume (ac.ft.)	Peak rate of discharge for 1.2” Storm (Q_{wq}) (CFS)
H	1.14	56.75	88	7	0.036	0.76
I	1.00	60.83	89	3	0.035	0.74
K	0.43	70.06	90	2	0.016	0.35
M	0.25	68.31	90	1	0.010	0.21
N	0.57	82.32	98	2	0.047	0.92
O	0.57	70.94	92	3	0.026	0.57
P	0.51	86.22	95	3	0.031	0.67
Q	0.77	81.56	94	3	0.043	0.92
Average	**0.75**	**82.43**	**92**	**3.4**	--	--

Table 5 displays measurements and calculations detailing the proposed sand filter catchments.

single iteration of calculations indicate buried chambers with total footprints of 226 square feet and total volumes of 892.5 cubic feet. The total lengths would be around 30 feet, and the structures would range from 6 to 8 feet in width. Further design iterations would yield more precise dimensions and likely indicate the need to position the floor of the chambers at depths greater than the six feet estimated here.

Sand filter implementation costs vary widely by region. Underground sand filters installed in Washington D.C. cost roughly $14,000 per acre of impervious area treated. (US Environmental Protection Agency, 2014g) Given that the average 0.75 acre Family Housing parking lot catchment is 82.42 percent impervious, this works out to 0.62 acres of impervious area per catchment. Thus, each sand filter would cost roughly $8,654 to install, for a total cost in the area of $70,000 to treat all eight proposed catchments. Surface sand filters are often cheaper and have been more widely implemented than below-ground sand filters. This may make them a better option, space permitting.

Given their high cost relative to the real estate value of the Rogers Road Family Housing development, installation of sand filters may not be economically justifiable. Bioretention could be a viable alternative. The following section explores the possibility of implementing bioretention facilities in two of the Family Housing parking lot catchments.

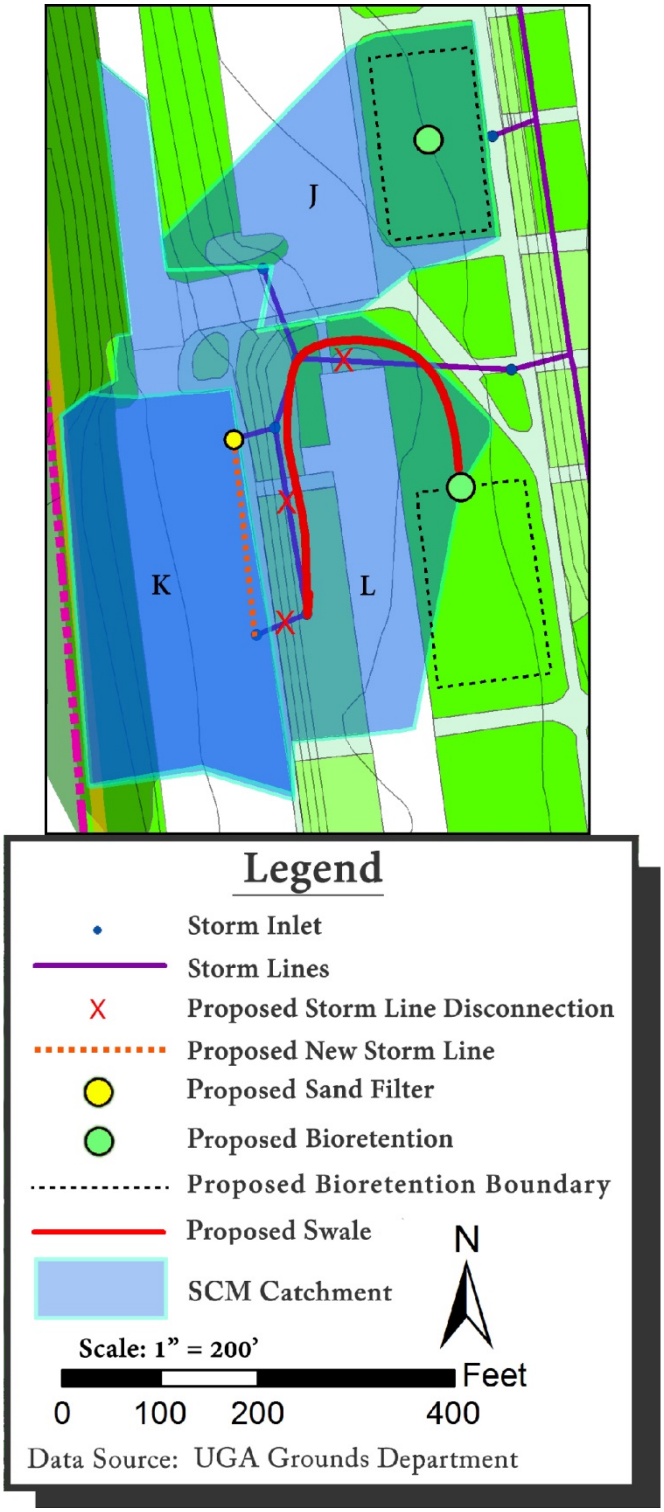


Figure 22: Map of proposed Family Housing bioretention locations.

Parking Lot Bioretention

The drainages for Buildings N and the north half of P (Catchments J and L, respectively) are difficult to apply sand filters to because of their topography and the arrangement of their existing storm drain systems. There is no grade change immediately adjacent to the parking lot next to Building N, which limits sand filter placement opportunities. Both drainages are connected to a storm line network that connects to those of the more southern parking lot catchments at the very end of the proposed bioswale, just before the runoff is piped under the railroad tracks. Because runoff from Catchments J and L would bypass the proposed bioswale and thus have very little opportunity for infiltration, bioretention is proposed for these catchments instead of sand filtration. However, a sand filter layer may be incorporated into the bioretention area designs. This would enhance the facilities' ability to filter runoff and improve their overall function. (Atlanta Regional Council et al. 2001, 3.2-47)

Bioretention can be accomplished with two facilities, one in the open area next to the Building N parking lot, and the other behind

Building P. Runoff from the parking lot and front of Building P would be conveyed to the other end of the building using a shallow grass channel.

Bioretention is optimal for areas of 0.5 to 2 acres, and should be about 5 percent of the contributing impervious area. (Atlanta Regional Council et al. 2001, 3.2-47) Catchment J is 0.37 acres and Catchment L is 1.22 acres, with 7,632 and 25,995 square feet of impervious area, respectively. Thus, 381 square feet are needed to treat Catchment J, and 1,300 square feet for Catchment L. Both proposed bioretention areas have more than adequate space available to meet these requirements.

This rule-of-thumb treatment area-based sizing method can be double-checked using the following volume-based sizing method: To size bioretention facilities, first determine the desired treatment water volume. In this case, it is the water quality volume. The storage and treatment volume is divided by the desired depth to determine the area. Here, a maximum depth of 12 inches is assumed. (Vick et al. 2012, 93) For the 1.2 inch storm event, catchment J produces 0.009 acre feet of runoff and catchment L produces 0.038 acre feet of runoff. Because an acre-foot is the surface area at which a given volume is distributed at a depth of a foot, the necessary footprint for the bioretention facilities with a foot of depth is simply equivalent to those runoff volumes. Thus, 0.009 acre feet or 392 square feet are needed to treat Catchment J, and 0.038 acre feet or 1,655 square feet for Catchment L. The numbers generated by both of the sizing methodologies are very similar, so both are presumed accurate for providing a rough estimate of dimensional requirements.

On-line designs are not advised for areas surpassing 0.5 acres, so the Catchment L bioretention facility must incorporate an overflow bypass mechanism. This can be accomplished by using a flow splitter. (Atlanta Regional Council et al. 2001, 3.2-48)

A five-foot difference is required between the inflow and outflow elevations. Although the proposed areas are relatively flat, outflow could be directed through a permeable pipe buried under the bioretention facility. Thus, the required amount of head can be met with subterranean drainage pipes that re-connect to the existing buried drainage infrastructure. (Atlanta Regional Council et al. 2001, 3.2-47)

The construction, design, and permitting cost of bioretention can be estimated using the equation $C=7.30V^{0.99}$. V is equal to the volume in cubic feet of water treated by the facility. (US Environmental Protection Agency 2014f) Thus, two bioretention facilities designed to treat the water quality volumes from Catchments J (392 ft^3) and L (1655 ft^3) would cost around $2695 and $11,218, respectively. These estimates are for the area within the footprint of the bioretention facility itself. They do not take into account the grass channels and other pretreatment and conveyance modifications (such as replacing storm drains with overland pathways) that would need to be implemented to ensure that runoff flows to the facilities in the desired manner.

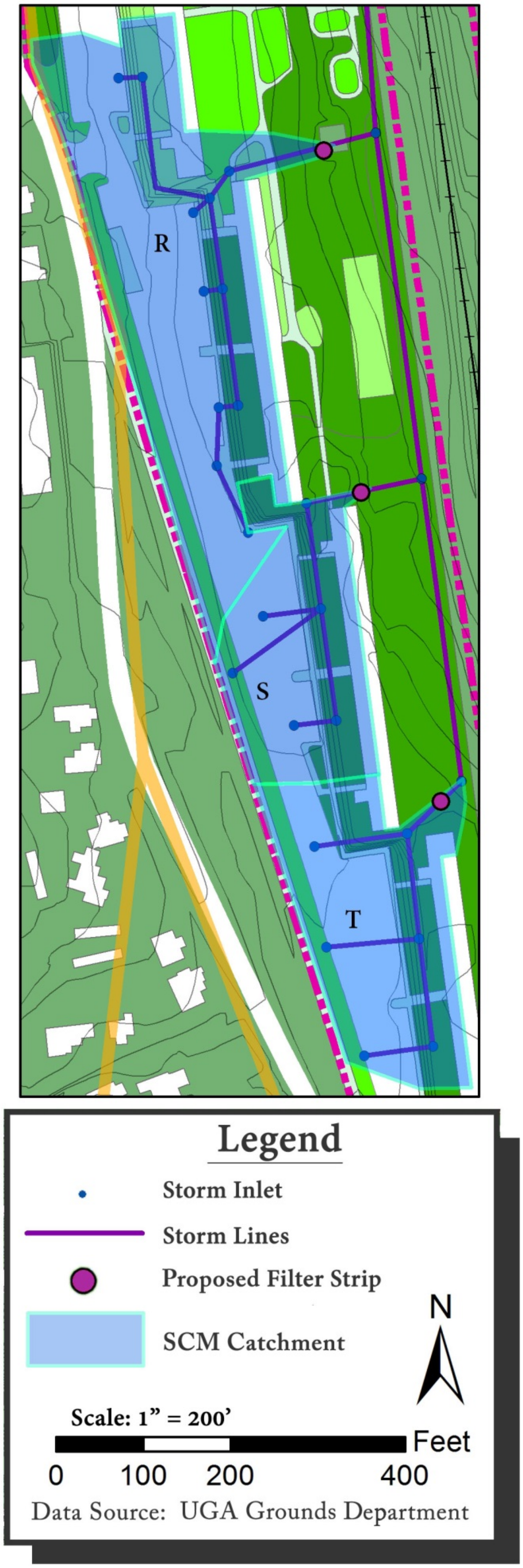
Catchment	Area (Acres)	% Impervious	1.2" Storm Projected Runoff Volume (ac.ft.)	Bioretention Facility Size (SF)	Projected Cost
J	0.37	47.44	0.009	381	$2695
L	1.22	48.96	0.038	1,300	$11,218

Table 6 displays measurements and calculations detailing the proposed bioretention facilities and their catchments.

Level Spreaders and Vegetated Filter Strips

The culverts that run along the north sides of buildings Q, R, and S should be disconnected from the main line and instead discharge to individual level spreader-filter strip (LS-VFS) systems. The three catchments feeding into the proposed LS-VFS systems encompass the five southern-most parking lot sand filter catchments, as well as the courtyard and half the rooftop drainages of Buildings Q, R, S, and half of Building P.

The proposed filter strips should be graded with slopes between 2 and 6 percent. The existing slopes in the proposed areas where the existing stormwater culvert system would discharge into the LS-VFS system are all within this range. This is ideal, as it minimizes the need for grading. In order to minimize erosion and flow channelization, both the top and toe of the slope should be flat. The vegetated



filter strips are not suitable for pedestrian traffic. Implementation must consider circulation, and establish routes around the SCMs where necessary. (Atlanta Regional Commission et al., 2001. 3.3-4-5)

The LS-VFS should receive a certain amount of flow, which varies depending on the type of vegetative cover used. Excess flows should be bypassed. Maximum flows for various VFS types are as follows: 2 CFS for wooded or riparian buffers, 5 CFS for herbaceous cover, and 10 CFS for engineered, grass-covered filter strips. (NCDENR 2007a, 9) Projections using HydroCAD show that any of these filter types would be adequate for treating the entire 1.2-inch water quality volume. However, the 2 CFS maximum flow is exceeded in catchment R by the 1.5-inch storm event. A 25-year storm would produce flows of up to 18.24 CFS. All three proposed vegetated filter strips will require flow splitters guiding excess flows into bypass channels or overflow spillways.

The depth of flow over a filter strip is a function of its width. It takes six feet of width to spread one cubic foot to a height of two inches. So if the level spreader is sized to distribute flows of up to 10 CFS, for

Figure 23 (left): Map of proposed Family Housing level spreader/vegetated filter strip locations example, then the width required to keep that flow under the maximum allowable depth of two inches is 60 feet. However, 10 CFS is the highest permissible velocity for high-performance engineered filter strips. Because of the shaded conditions in the VFS placement areas, it is likely to be difficult to maintain a dense grass cover, and flows as high as 10 CFS may cause erosion. Therefore, it would be prudent to limit flows to 5 CFS or less and consider cultivating perennial woody vegetation rather than grass cover on the filter strip.

The requisite widths to treat the 1.2-inch water quality storm event are roughly 8 feet for Catchment R and 4 feet for Catchments S and T. If it is desirable to implement higher capacity filter strips that could treat flows of up to 5 CFS, then widths of 30 feet would be necessary. 5 CFS exceeds the maximum projected discharge rate for the 1-year storm event for Catchments S and T, but is below the maximum projected discharge rate for Catchment R. Ideally the filter strips will be 25 feet long, although 15 feet is an acceptable minimum length (NCDENR 2007a, 14).

Very little cost data on filter strips is available because of regional variability. One very rough estimate, derived by extrapolating the costs of seed and sod, puts filter strip construction at anywhere from $13,000 to $30,000 per acre. This does not include grading, design, or maintenance. Maintenance costs about $350 per acre per year. (US Environmental Protection Agency, 2014j)

Catchment	**Area (Acres)**	**% Impervious**	**# of Sand Filters within Catchment**	**1.2” Storm Projected Runoff Volume (ac.ft.)**	**1.2” Storm Projected Max Discharge Rate (CFS)***	**Existing slope at proposed VFS inlet point (%)**
R	2.45	58.21	3	0.077	1.35	2.6
S	1.06	61.58	1	0.037	0.65	3.5
T	1.55	47.65	1	0.039	0.67	2.6

Table 7 displays measurements and calculations of the proposed filter strip’s catchments.
**The maximum discharge rate would be reduced by the implementation of proposed sand filters within the LS-VFS catchment.*

Catchment	Width (feet)(sized for 2” max. allowable depth of flow)	Length (feet)	Area (sqft)
R	8.1 (1.2” wq storm event)	15 (minimum)	121.5
R	8.1 (1.2” wq storm event)	25 (ideal)	202.5
S	3.9 (1.2” wq storm event)	15 (minimum)	58.5
S	3.9 (1.2” wq storm event)	25 (ideal)	97.5
T	4.0 (1.2” wq storm event)	15 (minimum)	60
T	4.0 (1.2” wq storm event)	25 (ideal)	100
R,S,T	30 (5 CFS storm event)	25 (ideal)	750

Table 8 explores some of the various possible dimensions for vegetated filter strip design.

Bioswale

The main storm line that runs behind the Family Housing buildings should be replaced by an open channel that would provide additional filtration, infiltration, and lower conveyance velocities. Overflow that bypasses the filter strips and any additional runoff can be collected in a bioswale and conveyed to the current main line culvert outlet point. By this point, at least the water quality volume of runoff from the impervious surfaces associated with the Family Housing complex has been treated by SCMs including planter boxes, sand filters, and vegetated filter strips. This series of treatments should have already substantially reduced pollutant loads, so this conveyance feature could take the form of a simple grass channel. Grass channels are bare-bones swales that provide some filtration and infiltration. In addition to their low-level pollutant removal and volume reduction capabilities, grass channels also delay the flow of runoff, protecting downstream channels by increasing residence time. They must be designed carefully to provide low flow rates. The most important design considerations are “channel capacity and minimization of erosion.” (Atlanta Regional Commission et al., 2001. 3.3-11)

The Georgia Stormwater Manual recommends designing such channels in a way that their conveyance velocity does “not exceed 1.0 foot per second during the peak discharge associated with the water quality design rainfall event, and the total length of a grass channel should provide at least 5 minutes of residence time.” (Atlanta Regional Commission et al., 2001. 3.3-11) These specifications should not be difficult to achieve, given that the proposed swale is long and has a mild gradient. From beginning to end, the structure would be 975 feet long and have an elevation change of 17 feet, for an average gradient of 1.75 percent. This gradient is not distributed evenly along the length of the swale, however. It is most pronounced near the high point of the swale and becomes shallower as the swale loses elevation.

A potential sticking point with the installation of grassed channels or enhanced swales is that both SCMs have a maximum recommended drainage area of 5 acres. The total area of Catchment U, which drains the proposed swale, is 12.86 acres. The catchment has 47.45 percent impervious area, so occasionally high runoff volumes are inevitable. Open channels are required to be sized to safely convey the full volume of a 25-year storm event, which becomes difficult with larger drainages. HydroCAD calculations indicate that a 25-year storm would generate 5.22 acre feet of runoff in Catchment U. However, it is possible to design open channels so that a primary channel, which conveys the entire volume of most storms, is embedded within a secondary channel that can transport overflows if needed. (Vick, et al. 2012, 130) The

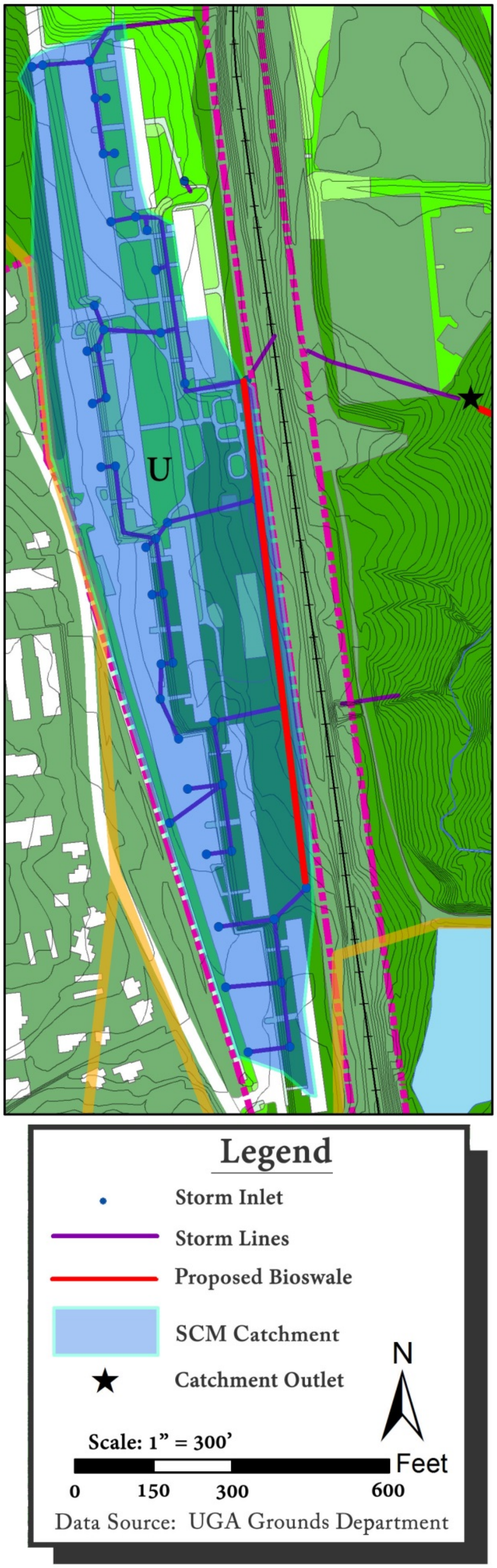


Figure 24 (left): Map of proposed Family Housing bioswale location implementation of the proposed SCMs higher in the catchment would also alleviate pressure on the swale by reducing the total volume that runs through it as well as distributing that volume over a longer period of time.

If better performance in pollutant removal, volume reduction, and flow rate attenuation is desired, as well as bolstered reinforcement against erosion, the swale might be enhanced with check dams at various points along its length. These would be useful both in the steeper upper reaches, where they would reduce flow velocities, as well as the lower reaches where they would quell the force of high volumes and provide additional opportunity for infiltration. Check dams in the lower reaches could be accompanied by shallow basins with engineered soil for micropool-driven infiltration. Immediately after the swale is constructed and seeded, permanent matting should be laid along the ground for structural reinforcement against erosion. Vegetation would grow through the matting, providing further stability. (Vick et al., 2012, 130-132) These measures will be most pertinent if the majority of proposed upstream SCMs are not employed, or even if they are implemented and additional treatment is still desired.

Catchment	**Area (Acres)**	**% Impervious**	**CN**	**1.2" Storm Projected Runoff Volume (ac.ft.)**	**25-Year Storm Projected Runoff Volume (ac.ft.)**
U	12.86	47.45	85	0.294	5.22

Table 9 displays measurements and calculations regarding the proposed bioswale catchment.

End of Pipe

Measures to treat runoff from the Family Housing complex should culminate with maintenance at the end of the runoff's flowpath in the forest near the Redcoat Band practice field. The culvert outlet should be renovated and the gullied channel that leads to the tributary stream should be repaired and stabilized. Reinforcement of the channel with riprap or some other substrate would dampen erosive forces, but a more extensive overhaul in which the channel is re-shaped to more stable morphologic dimensions would be the most effective long-term solution. Such extensive work is bound to be more expensive than simple channel armoring, but it could be warranted if it is desirable to minimize the runoff pathway's detrimental effects on Lake Herrick over a decades-long time span.

Particular attention should be given to the connection between the culvert outlet and the channel. The outflow point should be stabilized in a way that also reduces the velocity and dissipates the force of the outflow. This could be accomplished by constructing a reinforced drop-pool cascade in the initial steep portion of the channel, or with a basin or pool designed to retain effluent and release it slowly through a weir.

The pipe's catchment is roughly the same as Catchment U which flows to the bioswale in the previous section. The anticipated runoff characteristics are the same, minus any changes in volume or concentration on account of the swale.

Tennis Courts, Fields, and Surface Lots

The tennis courts, baseball and Redcoat Band practice fields, bathroom, and connecting parking lots constitute a high concentration of impervious, runoff-generating surfaces in close proximity to the water body. Runoff from this area and discharge piped from the Family Housing parking lot flow into the lake, wetland, and both tributary stream channels. Some measures have been taken here to protect the channels and Lake Herrick's shoreline from the impact of impervious cover. A forested buffer, ranging in width from 85 to 150 feet, separates the developed areas from the lake. A few development-related features do encroach on the buffer: an elevated boardwalk and three culvert outlets. The newest construction in this area, a parking lot next to the band practice field, incorporates gravel parking stalls. Runoff from the lot flows into a rain garden, and overflow is culverted to a second rain garden before being discharged through one more culvert into the forest.

Notably elevated pathogen levels were detected in the wetland area of the perennial stream during sampling in 1999 conducted by Dr. Rasmussen's hydrology class. Only one sample was taken and monitoring has not been conducted in the same place since then. The pathogen concentrations recorded at that sampling point could be attributed to either runoff from the tennis court and parking lot area, discharge from the family housing culvert, contamination from Parvo Pond's outflow, inputs from the forest, or even bacteria proliferation in the channel itself, as has been noted just below Parvo Pond's outflow (Brown and Caldwell 2011, 4.4). The sewer pipe that runs along a portion of Lake Herrick's shoreline is another possible source of pathogen contamination to this area. The closest that the sewer line comes to the wetland portion of the perennial stream is at its terminus at the restroom building near the tennis courts, so contaminants would need to travel about a hundred yards via subsurface flow to reach the point where they were detected. The highly permeable soils in this area make this a possible scenario. In any case, it is unclear whether such large concentrations of pathogens occur here with chronic frequency or whether that sample was a rare outlier. Further monitoring is necessary to determine the persistence and severity of contamination.

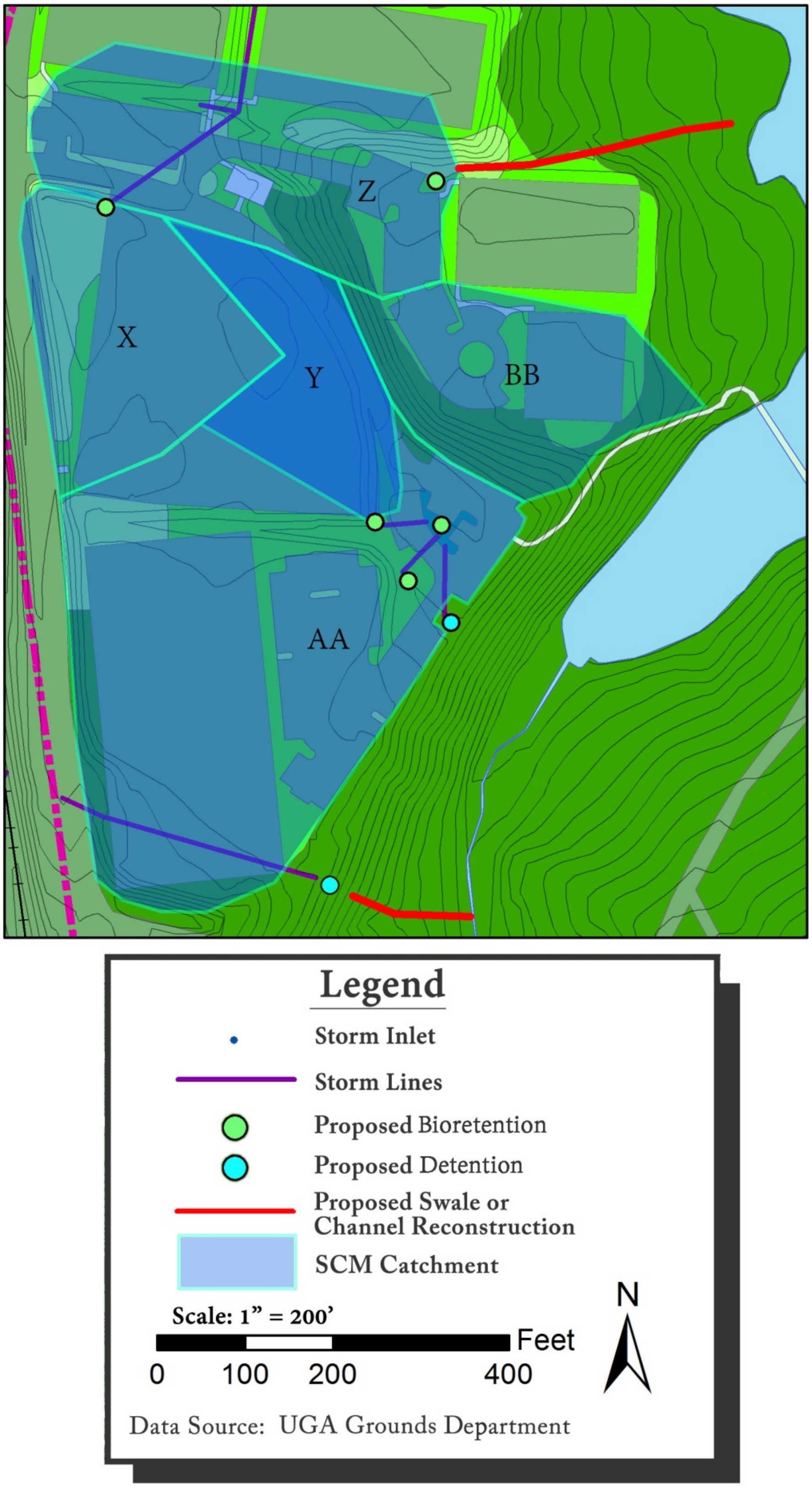


Figure 25: Map of proposed tennis court, field, and surface lot SCM locations.

Catchment X – Field and Pine Grove

Runoff from Catchment X, which is primarily landscaped area and a portion of a sports field, funnels into a culvert where it is conveyed to Lake Herrick's western tributary stream channel, just upstream of where the stream enters the lake. The catchment has no impervious surface, overwhelmingly well-drained CYb2 soils (hydrologic group A), and a curve number of 39. Catchment X thus produces no runoff at all up to the 1-year storm event.

This area is very low priority with regards to stormwater management, although it is important to evaluate and mitigate potential fertilizer impacts. There are also some functional considerations associated with the existing drainage infrastructure that should be addressed: The area just before the culvert inlet is a low-lying grove of mature pines that tends to store water. An inspection of the area in the winter of 2015 revealed that the culvert inlet was blocked with large amounts of organic debris. Although water probably does flow through the inlet when it accumulates in excess, the culvert functions much like an underdrain and the majority of water is more likely to infiltrate in the pine grove. The drainage therefore functions much like a retention or infiltration-based system, which is preferable to rapid conveyance. However, the culvert system was designed for unimpeded drainage. It is possible that excessive ponding could put stress on the mature pine trees that are growing in the landscaped depression. Should problems arise from the currently impeded drainage, this area should be re-evaluated for the possibility of enhancing its bioretention capabilities.

Catchment	**Area (Acres)**	**% Impervious**	**CN**	**1.2" Storm Projected Runoff Volume (ac.ft.)**
X	1.48	47.44	39	0.009

Table 10 displays measurements and calculations regarding Catchment X.

Tennis Court Parking Lots

Parking Stall Overhaul

The impervious area in Catchments Z and BB is dominated by driveways and parking. Between the two catchments, a total of 18,400 square feet of parking stall area, or roughly 25 percent of their combined impervious surfaces, is suitable for renovation with permeable pavement.

Of the 50,100 square feet of impervious surface in Catchment Z, 13,100 square feet, or roughly 26 percent, is parking stalls. The majority (36,878 square feet, or 73.60 percent) of the catchment's impervious surface lies on well-drained CYb2 soil (hydrologic group A). 12,440 square feet, or about 25 percent of the total impervious area, lies on slightly less well-drained CbA soil (hydrologic group B). Only 783 square feet, or 1.5 percent, lies on PgC3 soil (hydrologic group C) that may not provide adequate infiltration for permeable pavement. An upturned underdrain could potentially be utilized to provide drainage for volumes that exceed a predetermined infiltration or storage volume.

Of the 24,941 square feet of impervious surface in Catchment BB, 5,300 square feet, or roughly 21 percent, is parking stalls that could be renovated with permeable pavement. 16,993 square feet, or X percent of the catchment's impervious surface lies on well-drained CYc2 soil (hydrologic group A). 6,712 square feet, or about X percent of the total impervious area, lies on slightly less well-drained CbA soil (hydrologic group B).

Of these two catchments, Z should be prioritized over BB for permeable pavement retrofits because it has twice the impervious area, and the erosive effects on its drainage pathway are visually apparent whereas runoff from the parking lot and tennis court in Catchment BB appears to be adequately drained by the existing swale. Catchment BB should be monitored for erosion and action taken accordingly. Runoff from Catchment Z can be further mitigated via the following SCM intervention:

Bioretention and Enhanced Swale at Corner Outflow

Concentrated runoff from the Catchment Z parking lots drains to a corner of one of the parking lots, adjacent to a tennis court. Currently, this spot is the beginning of an apparently naturally-formed shallow swale that conveys the water through the forested buffer to Lake Herrick. Some erosion is apparent, and the flow path is reinforced with a series of stone check dams. There is a small notch in the shoreline where the swale meets the lake, indicating possible shoreline retreat as a result of erosion. It would be advantageous to treat runoff with bioretention before any excess volume is conveyed to the lake. A bioretention facility can be constructed with the specifications given in Table 11. The sizing and cost estimate methods are the same as those used for the proposed Family Housing parking lot bioretention facilities.

Catchment	**Area (Acres)**	**% Impervious**	**1.2" Storm Projected Runoff Volume (ac.ft.)**	**Bioretention Facility Size (SF)**	**Projected Cost**
Z	2.11	54.51	0.013	566	$3878

Table 11 displays measurements for Catchment Z and projected dimensions and cost for the proposed bioretention.

The existing swale should be enhanced for better conveyance of flows that bypass or exit the bioretention facility. Its current flow path, from the parking lot to the lake, is 388 feet. It drops 13 feet in elevation over this length, for an average gradient of 3.35 percent. This grade is fairly even over the entire length of the swale, although it does become slightly steeper towards the middle. The swale's channel currently consists of exposed soil and organic debris, with wild vegetation growing in and around it at random. Ideally, dense herbaceous vegetation should be established. It is likely that shaded conditions will make this difficult, as the swale is in a forested area. At the very least, reinforcement with matting would help to protect the soil from erosion. Adjustments to the existing check dams and the ground behind them could help to encourage more effective micropool infiltration. This would be a particularly beneficial strategy for this location, given the highly permeable soils.

Overhaul of Existing Rain Gardens

Catchments Y (a sub-catchment of AA) and AA are already equipped with structures that were originally designed to function as bioretention facilities (See pages 89 and 90 for more details on these). In a unique arrangement, runoff from the fields, driveways, and parking areas of Catchments Y and AA flow into two landscaped depressions equipped with drop inlets. The outflow from these inlets is conveyed through culverts into a depressed parking lot island, which discharges through a third inlet into the forested buffer adjacent to the Lake Herrick wetland.

Of these three bioretention areas, only one appears to function properly. The southern-most facility, which receives runoff from the Redcoat Band practice field and the southern-most parking lot, has the outward appearance of a proper bioretention facility. It apparently infiltrates most of the stormwater that flows into it, and its slightly raised inlet (elevated roughly six inches) accommodates overflow volumes. Its effectiveness is no doubt augmented by the permeable gravel parking stalls in the parking lot that drains to it.

The landscaped depression and drop inlet that receives runoff from Catchment Y is well-positioned to function as a bioretention facility, but the drop inlet is not elevated and thus the area does not retain any volume. If the inlet structure were raised slightly, the area would then retain and infiltrate the majority of the water that flowed into it.

Both of these drainages, as well as a roughly 14,000 square-foot expanse of parking lot, overflow into the central landscaped depression. This is another advantageously-located potential bioretention facility, but its problem is the same as that of the Catchment Y outlet; the culvert inlet that drains it is not elevated over the two culvert outlets that convey water to it.

Notably, the parking lot and its island are situated on well-drained CYc2 and PfD2 (both Hydrologic group A) soils. It is therefore feasible to retrofit roughly 4,540 square feet of parking stall area with permeable pavements, thus further reducing the necessary infiltrative capacity of the central bioretention area.

The Catchment Y outlet and the parking lot island are both opportune for conversion to enhanced stormwater management function by way of simple culvert adjustments. Their catchments are largely permeable and are underlain by well-drained soils. Modelling indicates that the 1.2 inch storm would not generate any runoff at all, so these facilities can easily be optimized to accommodate runoff in excess of the water-quality volume.

Like the culvert outlet at the end of the Family Housing runoff pathway, the final culvert outlet of Catchment AA is in need of interventions to minimize its impact on the surrounding forest. It has not yet eroded a massive gulley through the forest like the Family Housing outlet has, but it was presumably built more recently. With its current configuration, deterioration of the flow path from the culvert outlet into the Lake Herrick wetland is inevitable. Retention and energy-dissipating strategies similar to those proposed for the Family Housing culvert outlet should be evaluated and implemented.

As the closest expanses of impervious development to the edge of Lake Herrick, this group of catchments has great potential environmental impact. The University seems to have recognized this in its newest construction; the southern-most parking lot is most recent development in this area, and it has been equipped with notable stormwater control measures. The hydrologic impact of the remaining impervious surface is in the unique position to be mitigated very effectively with minimal additional investment.

Catchment	**Area (Acres)**	**% Impervious**	**1.2" Storm Projected Runoff Volume (ac.ft.)**	**1-Year Storm Projected Runoff Volume (ac.ft.)**	**Bioretention Facility Size to Retain 1-Year Storm (SF)**	**Projected Cost**
Y	1.48	12.55	0	0.009	392	$2695
AA	5.22	24.82	0	0.209	9104	$60,668

Table 12 displays measurements and calculations regarding the proposed bioretention facilities and their catchments. The projected costs are for facilities sized to retain the 1-year storm, because modelling indicates that no runoff is generated by the water quality storm event. It is probable that optimal treatment could be achieved with smaller facilities, at less cost.

The Parvo Pond Sub-Catchments

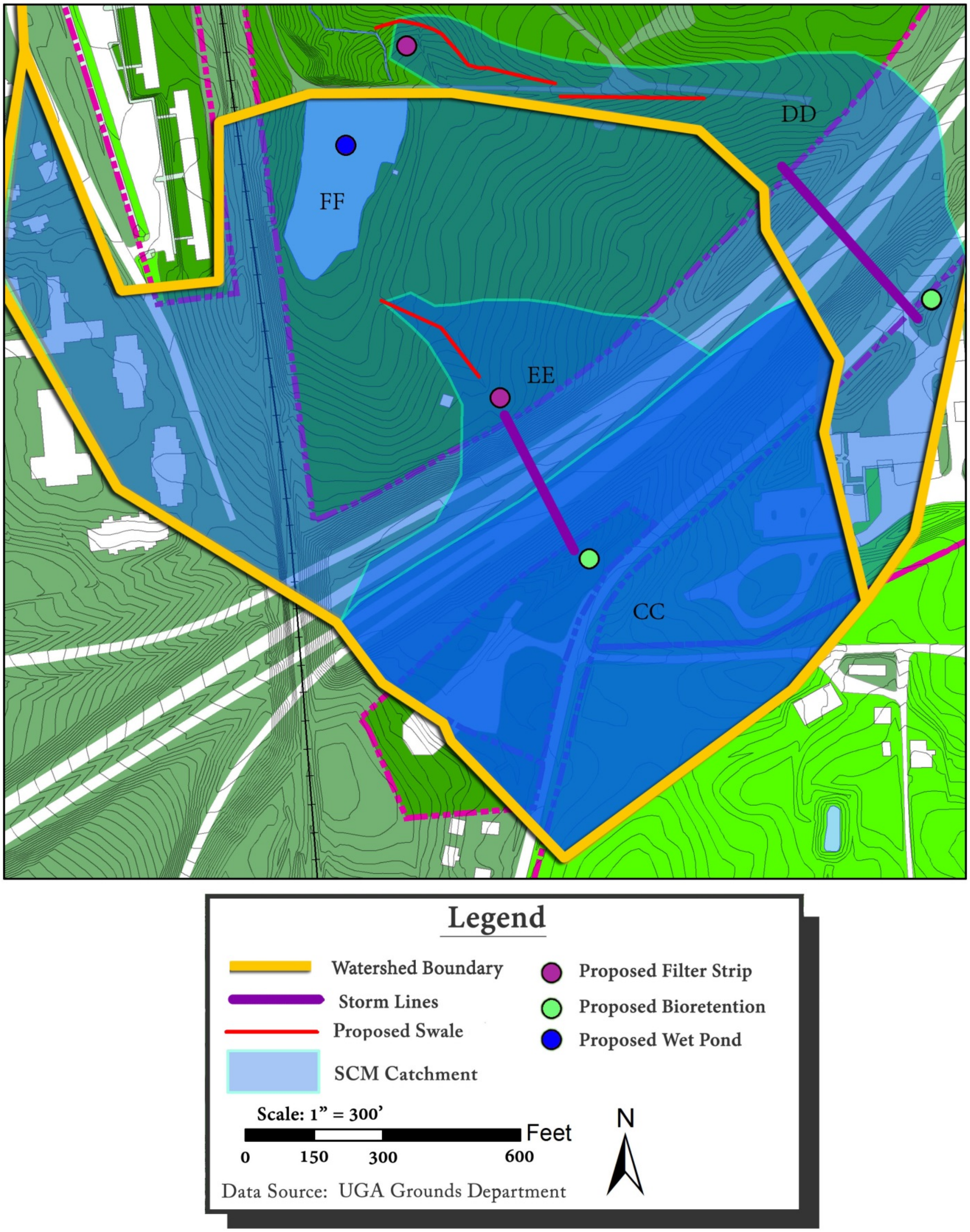


Figure 26: Map of proposed Parvo Pond, Oconee Forest Park, and bus facility SCM locations.

Flow Path between Bus Facility and Parvo Pond

Bioretention at Highway 10 Culvert Inlet

Bioretention would be an effective first step in slowing and treating pollutant-laden runoff from the UGA bus facility on Riverbend Road. A bioretention area prior to the inlet of the southernmost culvert beneath the loop would capture runoff from the largest portion of the bus facility. The area near the inlet has sufficient open space and an advantageous location because no diversion or other modification of the runoff flowpath would be necessary. However, if the facility were located here, it would need to be able to accommodate runoff from a catchment that, at 16.56 acres, is substantially larger than the 5 acre maximum recommended for bioretention. Despite its size, it is realistic to suppose that a single bioretention facility could realistically treat the runoff from Catchment CC because the total impervious area is only 4.74 acres. The catchment could also be divided further into smaller subcatchments with on-site SCM treatment at the bus facility.

Bioretention facility size: 0.05*(16.56*.2867) = .2374 acres = 10,341 ft^2

Projected cost: $C = 7.30V^{0.99} = 7.30(0.007*43560)^{0.99} = 7.30(304.92)^{0.99}$ = \$2102.

Catchment	Area (Acres)	% Impervious	1.2” Storm Projected Runoff Volume (ac.ft.)	Bioretention Facility Size (SF)	Projected Cost
CC	16.56	28.67	0.007	10,341	$2102

Table 13 displays measurements and calculations regarding the proposed bioretention facility and its catchment.

Level Spreader – Vegetated Filter Strip at Highway 10 Culvert Outlet

A level spreader and vegetated filter strip would be a useful way to diffuse and treat flows as they discharge from the outlet of the southernmost culvert under Highway 10. The culvert outlet is a part of Catchment CC, which is 16.56 acres and 28.67 percent impervious. The outlet is located on a hill with wild vegetative growth – mostly shrubs with few mature trees. The surrounding area has a slope of roughly 7 percent, but the land becomes flatter near the base of the hill. This would perhaps be the most appropriate point to locate the SCM.

Projections generated by HydroCAD indicate a peak flow rate of 0.01 CFS for Catchment CC. This means that natural wooded vegetative growth (2 CFS maximum peak flow) would be a sufficient cover type for treating the 1.2-inch water quality volume. This is advantageous because it substantially reduces the need for maintenance. Because the water quality volume and maximum rate of flow are both very small, SCM implementation would be optimized by designing the structure to treat a larger storm event. A 2 inch rainfall produces a maximum flow rate of 1.76 CFS. This could be distributed at a depth of two inches over a width of 10.56 feet. At an ideal 25 foot length, the filter strip would need to be 264 square feet to treat a 2 inch rainfall. Notably, peak rates of flow would be lowered by the implementation of the proposed bioretention at the culvert inlet described in the preceding section.

Vegetated Swale from Vegetated Filter Strip to Parvo Pond

It would be beneficial to address the drainage ditch that conveys water from the outlet of the southernmost culvert beneath the loop to Parvo Pond. In its current state, the ditch exports sediment and holds pools of stagnant water. The conveyance could be converted from a pollutant source to pollutant sink by turning it into a vegetated swale. The current flow path is 440 feet in length, with a 28 foot change in elevation over a roughly even gradient (7 percent). The first 300 feet consist of the aforementioned drainage ditch, and the final 140 feet consist of a culvert under a swath of turf that discharges into Parvo Pond. The greatest pollutant removal function could be achieved by converting the entire flow path to a swale; at the very least, the portion which is currently an incised ditch should be renovated.

The catchment has a drainage area of 9.13 acres, 24.64 percent of which is impervious, and contains seven different soil types ranging from hydrologic group A to D. The soil directly beneath the drainage ditch of interest is about half PgC3 soil (Hydrologic group C) and half PfD2 (Hydrologic group A), so moderate infiltration could be achieved. Given the relatively steep slope, check dams would be useful to slow runoff and create micropools for infiltration.

Parvo Pond Wetland

A stormwater wetland at the south end of Parvo Pond could provide treatment for nearly all of the runoff that enters the pond and protect the water body from detrimental inputs. Of particular concern with Parvo Pond are high levels of bacteria. The source of bacterial contamination is not certain, but the presence of a popular off-leash dog park adjacent to the pond suggests that pet waste could be could be the culprit. A swale built parallel to the east shore of the pond could intercept inputs of dog waste and other runoff-borne pollutants and convey it into the wetland for pretreatment before it enters Parvo Pond.

Because there is available space in excess of the 1.2-inch storm capacity, an analysis was conducted to determine the optimal wetland size. The anticipated volumes of various storms were charted against the necessary surface area for a wetland with an average depth of 9 inches to handle those volumes (Figure 26). The variables relate as an exponential curve. The point of inflection on this curve represents the optimal treatment volume short of having to accommodate for exponential increases in required capacity. Thus it was determined that a 1.6-inch rainfall is the most practical treatment volume. Coincidentally, 1.62 inches is the 95^{th} percentile rain event for Athens. This volume is greater than or equal to 95 percent of the precipitation of all 24 hour storms in the region. Like the water quality storm event, it is a common benchmark for designing stormwater management facilities. A wetland with the capacity to handle that volume requires 9,467 square feet of surface area with an average depth of 9 inches. Its construction is projected to cost around $50,000. Figure 27 shows the size and topographic requirements of such a system.

The model wetland portrayed in this chapter is designed with a long, meandering flow path for optimal retention time, and thus functional performance. Its 185-foot length and 50-foot width surpasses the ideal 3:1 length-to-width ratio. This is better than falling short of the ideal ratio, because too much width relative to length could compromise function by causing the flow path to short circuit. (NCDENR 2007b, 2) However, it is not clear whether the 3.7:1 ratio portrayed here would result in functional enhancement beyond the recommended 3:1 ratio. It is possible that slightly increasing the width relative to the length so that the dimensions correspond more precisely with the ideal ratio would improve function by making the flow path more sinuous, thereby exposing more water to the shallow water areas where the majority of filtration occurs.

The necessary 3:1 maximum side slope gradient is accommodated. An elevation difference of 8 inches between the water's surface in the wetland and in Parvo Pond allows for a cascading discharge zone to increase the outflowing dissolved oxygen. (NCDENR 2007b, 2-4) The wetland should only capture stormwater, and its placement should avoid the flowpath of the natural spring that feeds Parvo Pond. Alternately, because year-round hydration of the wetland is critical, it could possibly be designed in-line with the natural spring, which would then help provide critical volume to the wetland in dry times. It is unclear whether the spring is beneath the pond's surface, or located on land somewhere near the southern edge of the water body. Future design iterations should reflect the spring's location in relation to the wetland.

Rainfall Depth (in.)	Design Storm	Runoff Volume (ac.ft.)	Surface Area (sq.ft.)(9"avg depth)	Probable Construction Cost (dollars)
1.2	First Flush	0.0040	232	1,161
1.5	--	0.1030	5,982	29,911
1.6	--	0.1630	9,467	47,335
1.75	--	0.2750	15,972	79,860
2	--	0.5180	30,085	150,427
3.2	1-Year	2.4570	142,703	713,512
5.7	10-Year	9.0170	523,707	2,618,536
6.6	25-Year	11.8660	689,177	3,445,886

Table 14 displays calculations regarding the required dimensions for a stormwater wetland to treat various design volumes.

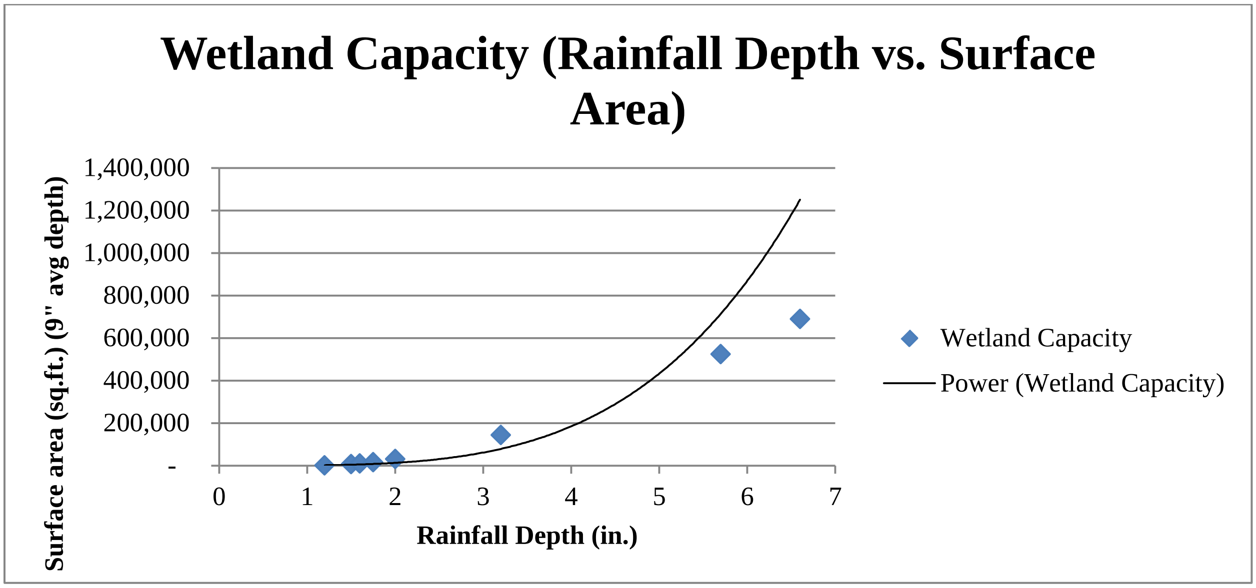


Figure 27: Wetland Capacity Optimization Chart estimates wetland capacity by plotting rainfall depth against surface area. The SCM size is optimized at the point of inflection on the power curve, which is where the curve begins to increase on the Y axis at a greater rate than the X axis.

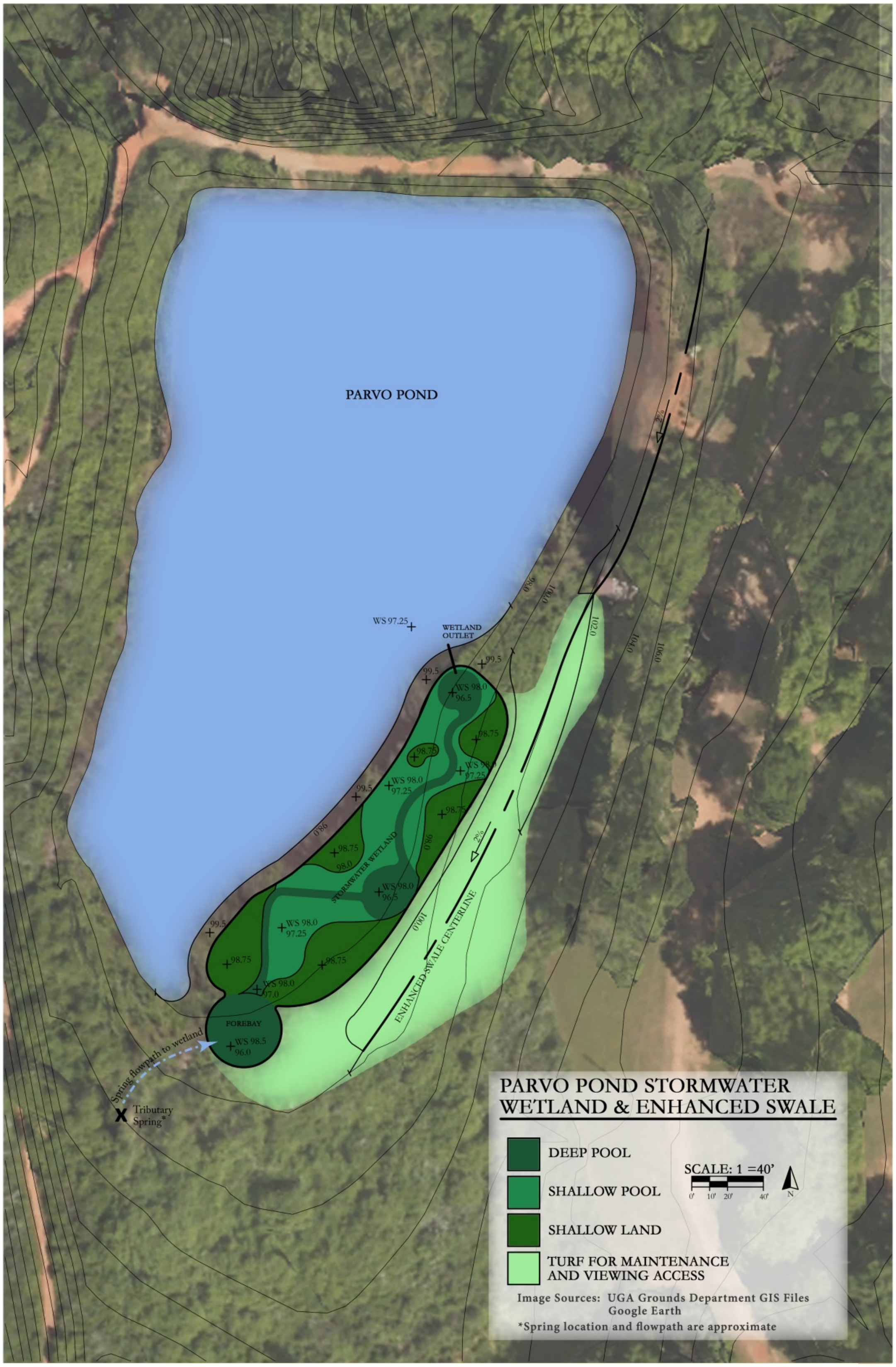


Figure 28: Plan of the proposed stormwater wetland at Parvo Pond

In-Line Wetland:

There is another scenario regarding stormwater wetland placement that might warrant further investigation: rather than creating an off-line wetland to treat runoff from a portion of Parvo Pond's catchment, perhaps the existing wetland at the lowest reach of the stream connection between Parvo Pond and Lake Herrick could be modified with stormwater wetland enhancements. This wetland would treat a much larger area than the one described above – about 137 acres, versus 53. Its placement would make more sense though, as it would treat runoff from the densely impervious catchments of Family Housing and the tennis courts area, while still encompassing the desired Parvo Pond catchment.

The idea of modifying an existing wetland to enhance desired storm water treatment functions, especially in this case where it would be in-line with a perennial stream rather than off-line as is conventional for stormwater wetlands, raises many questions. An in-depth investigation is beyond the scope of this thesis, but does present intriguing possibilities.

Parvo Pond Overhaul

Water samples taken at Lake Herrick's outlet indicate that fecal coliform levels are usually in compliance with the standards set by the State of Georgia for recreational water quality, but are occasionally elevated. Samples taken at the outlet of Parvo Pond frequently indicate much higher bacterial concentrations, which presumably become diluted when mixed with the more voluminous waters of Lake Herrick. Pollution control measures will need to address bacteria to ensure that concentrations do not rise any further in Lake Herrick.

The government's water quality standards for recreational designations deal solely with bacteria and do not encompass nutrients. However, algal blooms have been a substantial problem in the past, resulting in beach closures and the cancellation of boating classes. The proliferation of algae is driven by eutrophic conditions. Thus, nutrients are a parameter with substantial influence regarding the recreational goals for the lake. Pollution control measures will need to target nutrient inputs. It is likely that this, and reductions in other loading by other contaminants, can be accomplished at least partially through rehabilitation of Parvo Pond. The 1.5 acre water body is well-situated to be remodeled as a wet detention area that could intercept, detain, and treat a portion of the polluted runoff that enters Lake Herrick.

Parvo Pond was built sometime between 1944 and 1951, as indicated by aerial photos. It was originally used for irrigation when UGA operated a plant nursery in its vicinity. Over time, sediment loading has caused it to shrink in size. Roughly 20 years ago, it served as a sediment basin during construction of the UGA Bus Facility. It also appears to have received sediment inputs from general runoff. Currently, silt fencing surrounds the pond as a practically permanent fixture. Parvo Pond exhibits strong signs of pollution, as evidenced by not-so-ideal water quality parameter values.

The ideal conditions for a pond drainage area are established and stable vegetated cover. The next best are agricultural lands with erosion control and soil conservation practices. Regardless of the watershed's land use, erosion should be minimized so that pond does not fill up with sediment. Erosion control and protection is an ongoing process. "Protection of the drainage area should be started as soon as you decide to build a pond." (US Department of Agriculture 1982, 11) Thus, it should be a first step in planning for the rehabilitation of an existing pond. The land surrounding the pond should be stabilized with plants; much of the adjacent ground is currently bare and is likely contributing to its continued degradation. This includes the off-leash dog park, where grass cover is very patchy, and the trail that runs along the west side of the pond, where the ground cover consists of exposed but compacted clay soil. Also of particular importance is stabilization of the major runoff pathways that flow into the pond – particularly those detailed in the preceding sections of this chapter.

In planning for a major rehabilitation of Parvo Pond, the size and volume of the water body should be considered. A proper wet pond, optimized for treatment of runoff, has a permanent pool equal to the water quality volume of its catchment. This allows water from each storm to enter the pond and undergo gravitational settling and biological uptake of contaminants until it is displaced by the next storm event. (Atlanta Regional Commission et al, 2001, 3.2-4) The capacity of a pond can be estimated by calculating the pond-full surface area at established normal pond-full water elevation (SA). Multiply SA by 0.4 times the maxiumum water depth in feet at the dam. (US Department of Agriculture 1982, 12) If

Parvo Pond is 1.5 acres and has an estimated average depth of 2.5 feet, then it has 3.75 acre-feet of storage volume. If Lake Herrick is 15 acres and has a maximum depth of 18 feet (5.5 meters), then it has an approximate capacity of 108 acre-feet. When applying this method to Lake Herrick, it is important to recognize that it generates rough estimates which, while sufficient for ponds, do not account for the greater topographic complexity of a larger lake.

As a general rule of thumb, Athens-Clarke County lies in a geographic region in which 2 acres of drainage area sustains about an acre-foot of storage in a pond. This is in contrast to more arid climates, such as those of many western states where 60 to 120 acres of land are needed to fill an acre-foot. (US Department of Agriculture 1982, 10) Thus, Parvo Pond requires 7.5 acres of drainage to sustain its volume. Parvo Pond has a catchment of 45.5 acres, which should be more than adequate for a constant supply of water. Lake Herrick, in contrast, has a 284-acre watershed. It has a surface area of 15 acres, an estimated average depth of 8 feet, and thus 120 acre-feet of storage volume. Going by the 2 acre of drainage area per acre-foot of storage rule, Lake Herrick requires 240 acres to sustain its volume. Thus, the lake is fairly adequately sized for its watershed. Notably, these are coarse estimates based on large-scale geography. Local watershed conditions are sure to contribute. These numbers could be refined by applying a more regionally or site-specific tool to calculate runoff.

However, Parvo Pond is not only fed by runoff. Much, and probably most, of its volume comes from a spring. Although traditional wet pond SCM function might be ideal for Parvo Pond, its spring-fed nature cannot be overlooked; the pond has a continuous flow of water feeding into it. For this reason, displacement of permanent storage can be expected to occur constantly, so the pond will have a shorter hydraulic residence time than a conventional wet pond. This may reduce the treatment performance of the pond. Two possible courses of action with regards to re-sizing Parvo Pond would be to either accept the reduced hydraulic residence time and treatment performance and size the pond to the water quality volume anyways, or to make the pond larger to accommodate the additional volume of the perennial spring.

It is likely that dredging and re-shaping of the pond's basin will be necessary to ensure proper function. It is important to ensure that the water body has appropriate depth relative to its surface area; large expanses of shallow water are not recommended because they increase evaporation and facilitate the spread of weeds. (US Department of Agriculture 1982, 9) Waste material from construction of an excavated pond can be distributed throughout the surrounding landscape. Dredged sediments might be suitable for this as well, as long as they are not toxic. In this case, material should be shaped and graded with natural contours, rather than piled. It should not obscure existing horizon lines, and it should be vegetated to stabilize it and help it blend in to the landscape. (US Department of Agriculture 1982, 60) Smooth, flowing shorelines are aesthetically preferable. Topographic variety can be enhanced with the addition of constructed peninsulas or islands. (US Department of Agriculture 1982, 26) This could be a viable way of utilizing some sediment from dredging.

Rehabilitation of the marginal zone and shoreline vegetation would be a worthwhile strategy for controlling erosion and improving the aesthetic quality of Parvo Pond, particularly along its western edge. The pond's surroundings and the way in which views are utilized can influence its apparent size. Shoreline vegetation can be designed to add visual interest and habitat value. If closely surrounded by trees, the pond will appear smaller than it would if it had more open area around it. Irregular clearings around the pond, rather than a straight vegetated edge, are most natural in appearance. (US Department of Agriculture 1982, 54) The most desirable views are where "the major sight line crosses the longest dimension of water surface." (US Department of Agriculture 1982, 12) This helps to distract attention from engineered structures, such as the dam, pipe inlet, and spillway. In the case of Parvo Pond, the longest sight line and potentially best view is on top of the dam. This means that pipe inlet and spillway structures will be closer at hand, but potentially able to be masked with strategically-placed shoreline vegetation. (US Department of Agriculture 1982, 12)

Maintenance of Parvo Pond's dam, outlet, and spillway structures will be a necessary component of rehabilitation. In recent surveys of the pond, Brown and Caldwell reported on various issues of concern with regards to these engineered structures. "[T]he earthen dam at the Parvo Pond outfall is leaking in places and the wooden supports for the outfall pipe ha[ve] collapsed" (Brown and Caldwell 2010, 4.6-4.8), and the pond outlet is in poor shape, which likely facilitates the growth of iron-reducing bacteria in the stream channel that it flows into. (Brown and Caldwell 2011, 4.4) In a separate interpretation of the observed rust-colored substance that coats the channel just below the pond's outflow, Jim Lanier hypothesized that the outflowing water comes from the bottom of the Pond, where it is anoxic. As it comes into contact with the air, iron becomes oxidized and precipitates. (Lanier 2015) Thus, the substance may be chemical rather than biological in origin. If so, it is possible that the water quality of the outflow could be improved by aeration or by re-engineering the outlet structure to discharge from the top of the water column.

Notably, the samples that reflect Parvo Pond's water quality were taken just downstream of the pond's outfall. They are thus a direct reflection of the water that is entering Lake Herrick. It is possible that some parameters may be even higher in certain areas of the pond itself. The outlet structure could be renovated to shield Lake Herrick from even higher loads of bacteria, dissolved oxygen, and sediment by selectively releasing water from the top of the water column, where levels of dissolved oxygen and suspended solids are likely to be more favorable.

The pond should have a small pipe as a principal spillway, which is sized to drain the water level down to normal stage following precipitation up to the 10-year storm event. (US Department of Agriculture 1982, 27) Commonly used structures include hooded or canopy inlets, which extend straight through the dam at a slight downward angle. They are cheaper than drop inlets because they do not require a riser (US Department of Agriculture 1982, 39). They require substantial stage in order to generate enough pressure to run through the pipe at full capacity. This could be regarded as an impairment to drainage and thus a functional problem, but it would have the positive effect of slowing the discharge rate (which can be done with pipe sizing anyway), and thus increasing retention time. Drop inlet risers are another common type of outlet device. Their intakes are oriented straight up vertically so that normal stage is set at the elevation of the opening. Water flows in, drops vertically, and then the pipe turns and proceeds more horizontally under the dam. The openings of drop inlets can be enlarged by adding a bell-shaped extension to the end of the pipe, increasing their intake capacity. (US Department of Agriculture 1982, 26) This structure is ideally equipped with a trash rack. (US Department of Agriculture 1982, 37) The principal spillway may connect to a pipe that runs through the dam at the bottom elevation of the pond. This pipe can be equipped with a valve or gate (and trash guard) to open it and drain the pond fully from the bottom. (US Department of Agriculture 1982, 36-37) A drainpipe is a desirable feature for facilitating maintenance and management for fish production. (US Department of Agriculture 1982, 43)

Any object that extends all the way through an embankment should be equipped with a gravel and sand filter. The filter, along with a drainage diaphragm, is a mechanism for intercepting seepage that travels along the outside of the pipe, potentially compromising the dam's integrity. Alternatively, an anti-seep collar can be used. This is a barrier – a metal plate that extends perpendicular to the pipe and deflects seepage outward. (US Department of Agriculture 1982, 41) Erosion on or seepage through the dam should be dealt with immediately. The dam should be mowed frequently to prevent the growth of woody plants that would compromise its structural integrity. (US Department of Agriculture 1982, 68)

The principal spillway is assisted by an auxiliary spillway, which is earthen and acts as an overflow structure in the event of higher volume storms. (US Department of Agriculture 1982, 26) This protects the dam from potential damage caused by overtopping. (US Department of Agriculture 1982, 27) The dimensions of the spillway are engineered to the standards required to pass a 25 year storm event. Spillways for larger dams, such as that at Lake Herrick, are recommended to be designed for the 50 year storm frequency. (US Department of Agriculture 1982, 19) Earthen spillways can be protected against erosion by establishing plant cover – perennial grasses. (US Department of Agriculture 1982, 32) Parvo Pond is in need of auxiliary spillway maintenance. A gullied channel can be observed where past overflow events have caused destructive erosion for lack of a properly designed spillway.

Adequate maintenance is critical for ensuring that a pond can meet its intended purpose throughout its life. Parvo Pond is in need of maintenance, regardless of its influence on Lake Herrick. Given its location next to a dog park, it should not be a viral hazard for dogs. It should be restored as an aesthetic feature worthy of the admiration of Oconee Forest Park's 50,000 annual visitors, ringed by native plants instead of silt fencing and renamed to reflect more positive connotations.

Stream Connection between Parvo Pond and Lake Herrick

Renovation of the pond's outlet would be an opportunity to address the poor state of the stream channel that connects Parvo Pond to Lake Herrick. B+C has reported that the stream is gullied (and thus prone to erosion), has low baseflow, and is inhabited by high levels of iron-reducing bacteria. (Brown and Caldwell 2011, 4.4) Serious consideration should be given to restoration work that would improve its geomorphic dimensions and flow regime for greater hydrologic function and stability.

Overland Drainage

Infrastructure enhancement is proposed to improve the drainage of Catchment DD, with particular focus on the gullies running through the forest in the lowest portion of the catchment. The catchment is 10.14 acres with 24.64 percent imperviousness (associated with Highway 10 and the bus facility in the upper part of the drainage) and drains to the stream channel just downstream of Parvo Pond. Specific measures to improve the quality of this drainage include constructing a proper spillway for Parvo Pond and renovating the catchment's incised central flow path with a bioswale or grass channel. This path consists of a roadside drainage ditch that runs along a portion of Oconee Forest Park road, flows into a culvert under the road, and discharges through a deep gulley through the forest and into the stream channel just below the Parvo Pond outlet.

The ditch that runs along the forest road near the ropes course and dog park is incised and exposes bare earth. It is a source of erosion and sediment conveyance; it would benefit from conversion to a swale that would filter and retain pollutants rather than export them. The proposed swale is roughly 300 feet long, located where the ditch runs parallel to forest road along its southern edge and terminating at the point where runoff is culverted under the road. More detailed site analysis would help to pinpoint the ideal starting location. For the purposes of coarse projected design, the swale's starting point is 20 feet higher than the culvert inlet. Thus the flow path has a grade of 6.6 percent. For most of its length the underlying soil is PgC3 (Hydrologic group C), so opportunities for infiltration are limited.

Upon discharge from the culvert under the forest road, water currently flows through a deeply incised drainage gully into the main stream channel. Further erosion and pollutant loading could be halted by renovating this part of the drainage pathway with a shallow swale as well. This proposed swale would be 475 feet long, and changes 26 feet in elevation (5.5 percent gradient) from top to bottom. The gradient is somewhat even, but does become steeper with proximity to the perennial stream channel. Check dams would slow flow rates, dissipate energy, and encourage infiltration and convert some overland flow to subsurface flow as it enters the channel. The soil underlying the drainage pathway on the North side of the forest road is well-drained PfD2 and CYc2 (Hydrologic group A), so high levels of infiltration are feasible.

Catchment DD is larger than the recommended 5 acres for bioswales, but HydroCAD indicates that it generates no runoff up to the 3.2-inch, 1-year storm event. The 25-year storm event generates 0.891 acre feet of water. Thus the swales would be subject to occasional high forces but would not undergo frequent stress. Shade is prevalent throughout the drainage pathway because it runs through a forested area. It is probably not feasible to establish dense herbaceous vegetation throughout most of the swale, so turf matting or other structural reinforcement would be necessary.

Catchment	**Area (Acres)**	**% Impervious**	**1.2" Storm Projected Runoff Volume (ac.ft.)**	**1-Year Storm Projected Runoff Volume (ac.ft.)**	**25-Year Storm Projected Runoff Volume (ac.ft.)**
DD	10.14	24.64	0	0.213	0.891

Table 15 displays measurements and calculations regarding Catchment DD.

Intramural Fields

Enhanced Swale to Bioretention

The 11.69-acre Catchment V, which drains three of the intramural fields, is 35 percent impervious. Its permeable areas have well-drained CYb2, CYc2 (Both Hydrologic group A) and Cba (Hydrologic group B) soils. As a result, the catchment generates little runoff relative to some of the others analyzed in this chapter. However, the pollutants from this catchment have a potentially detrimental impact on Lake Herrick. The drainage is a clear source of erosion, and the fields most likely contribute a variety of nutrients and chemicals that affect Lake Herrick's phytoplankton, algae, and macrophyte communities. The swale that wraps around the southeastern edge of the southern-most field in the catchment is in need of renovation. Currently, runoff erodes the bottom of the swale before entering a storm drain adjacent to the bend in the road. After a culvert conveys the runoff a short distance, stormwater is

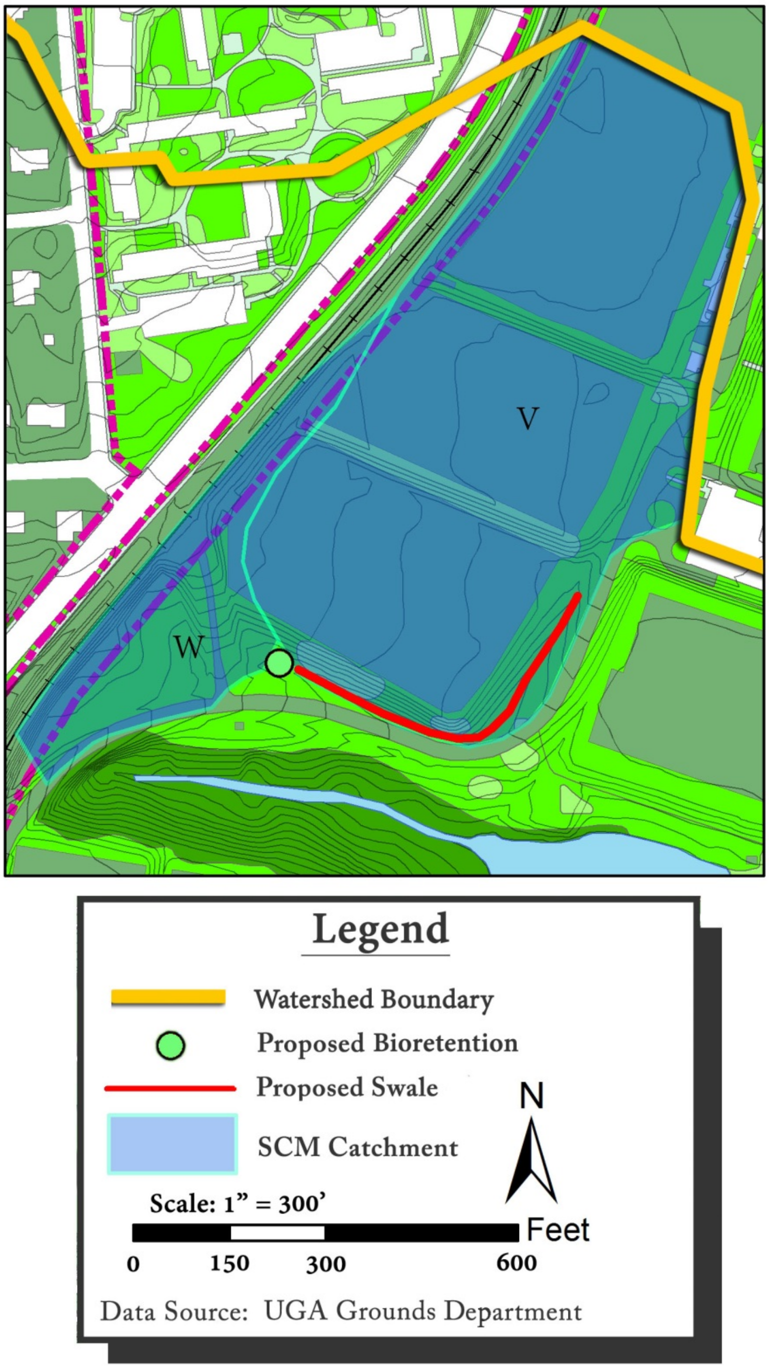


Figure 29: Map of proposed Intramural Field SCM locations.

discharged, flows through another short, incised ditch, and flows into Lake Herrick.

Fortunately, this problematic situation can be addressed with a simple, aesthetically attractive, and highly visible modification: The storm drain should be eliminated and the flow path re-routed to turn the corner and extend to a new bioretention facility in an existing landscaped depression.

Enhanced swale

The proposed swale has a length of about 540 feet and undergoes 12 feet of elevation change for an average gradient just over 2 percent. This gradient is fairly evenly distributed, although the topography does become flatter near the center of the proposed flow path where the existing storm drain is.

The upper portions of the swale, nearest to the culvert outlet that would be its beginning point, receive heavy shade from mature deciduous trees. This could prevent the establishment of dense vegetation, and is certainly contributing to the current problem of bare ground that erodes when exposed to runoff. Other forms of reinforcement, like synthetic matting, may be necessary for the first 150 feet or so of the swale. Like many of the afore-described swales in this chapter, micropool function created by check dams would be a useful feature. There is great potential for infiltration because the entire swale pathway and its proposed bioretention terminus (described below) are underlain by well-drained HSG A soils.

Bioretention

A bioretention area would be useful for filtering and infiltrating runoff at the end of the proposed swale. An existing landscaped area with dense grass and a few recently-planted oak trees is ideal for conversion to bioretention. The area sits in a depression and receives runoff from Catchment W, in addition to Catchment V. Calculations indicate that the currently available open space is at least three times larger than the area needed to contain and filter runoff from the 1-year storm event. It is feasible to size bioretention for this volume because the catchment's well-drained soils and abundant permeable space generate relatively low runoff volumes. Bioretention could be augmented with infiltration basin characteristics for substantial reductions in the volumes of direct runoff inputs to Lake Herrick. Any volume in excess of the proposed facility's capacity could overflow through an underdrain or elevated inlet.

Bioretention facility size: 0.05*(14.1*.0587) = 0.041 acres = 1785 ft^2

Projected cost: $C = 7.30V^{0.99} = 7.30(0.089*43560)^{0.99} = 7.30(304.92)^{0.99}$ = $2102.

Catchment	**Area (Acres)**	**% Impervious**	**1-Year Storm Projected Runoff Volume (ac.ft.)**	**Bioretention Facility Size (SF)**	**Projected Cost**
V+W	14.1	5.87	0.089	1785	$2012

Table 16 displays measurements and calculations regarding the proposed bioretention facility and its catchments.

Conclusion

It will be necessary to prioritize the implementation of the 32 SCMs proposed in this chapter, as some are more functionally effective or financially feasible than others. The general philosophy of SCM use emphasizes small, widespread measures close to the source of runoff rather than large structures optimized for end-of-pipe treatment of large catchments. It is also important to implement SCMs sequentially, beginning with the upper parts of a watershed and working downhill. This prevents sediment generated by construction from flowing into existing SCMs and impairing their function. These two criteria are convenient, because they indicate that the highest priority SCMs will also be the smallest and therefore the most affordable. However, it is crucial that their implementation be widespread; a single rain garden or sand filter will yield little to no noticeable water quality protection for Lake Herrick.

The Family Housing complex on Roger's Road is the densest impervious development in Lake Herrick's watershed, and a glance at the extent of the erosion at its outfall in the forest near the Redcoat Band practice field make clear the detrimental results of its current drainage pathway. From this standpoint, the first SCMs to be implemented should treat the family housing rooftop and parking lot catchments. Parking stall renovation and bioretention near the tennis courts are also economical interventions that treat relatively small catchments with high amounts of impervious area. B+C also recommends prioritizing stabilization of stormwater outfalls from this area. (Brown and Caldwell 2014, 4.6)

Another important criterion is visibility; SCMs that are highly visible to a large number of people should have priority because of their educational benefits. The proposed bioswale and bioretention next to the intramural fields are the two most visible SCMs detailed in this chapter. They are also relatively simple interventions that efficiently utilize available space. Likewise, the proposed rehabilitation of Parvo Pond would be highly visible and has the greatest potential aesthetic benefit. This is another intervention specifically recommended by B+C. (Brown and Caldwell 2014, 4.6)

Interventions of secondary priority include those that target larger catchments: the bioretention and level spreader associated with the Bus Facility drainage, the filter strips at the Family Housing complex, and most of the proposed swales fall into this category. Many of those swales entail renovating existing open channels. The Oconee Forest Park landscape is extensively gullied, a condition that contributes great amounts of sediment Lake Herrick. Measures to improve the condition of these incised drainage pathways would be of great benefit in addressing sediment transport, which is one of the most significant problems that the lake faces. The importance of such channel restoration is equal to that of the implementation of new SCMs.

CHAPTER 6

CONCLUSION

The primary objectives that must be accomplished to address Lake Herrick's management and contamination problems are removing and reducing further buildup of nutrients and sediments that contribute to the proliferation of pathogens and algae, removing the Canada geese, and developing a system to monitor the lake on an ongoing basis. (*Summary of Lake Herrick's Problems based on Current Knowledge, n.d.*) It is possible that large reductions in pathogen loads may not be necessary to achieve the recreational goals for Lake Herrick. Pathogen testing, although infrequent, indicates that bacteria levels in Lake Herrick are almost always suitable for contact recreation. The main concern then becomes keeping the geese off the beach for the sake of aesthetic quality, rather than disease risk, and managing algal blooms. The usual extent of summertime algal proliferation is currently unknown, but it may not be entirely prohibitive to swimming. At the very least, boating seems like a reasonable activity short of the very worst algal blooms.

Reducing Contaminant Inputs and Removing Existing Loads

The SCM design interventions detailed in Chapter Five should be effective towards long-term reductions in the rate of contaminant inputs associated with eutrophication, pathogen proliferation, and sediment infill. The structural SCM methods explored by this thesis are one of many potential tools and approaches that the University of Georgia could pursue in its management of the campus landscape. The task of managing a watershed gives rise to a complex array of options and decisions. Ultimately, the chosen course of action is governed by many factors. A growing body of research suggests that structural watershed management techniques are a viable and cost-effective method for long-term water quality protection. However, the use of SCMs and more general campus watershed planning and management efforts may be constrained by any number of financial, administrative, legal, political, institutional, and environmental factors. Some portions of the design interventions advocated in this document may prove less feasible or preferable in comparison to alternative courses of action. One certainty, though, is that

SCMs are a powerful tool with the potential to benefit the University community in a multitude of ways that goes beyond their basic stormwater management function.

There is no doubt that SCMs should play a role in the protection of campus watersheds, and they should be given strong consideration in planning efforts to the fullest extent that is ultimately deemed feasible and appropriate. Their implementation should be a top management priority for two reasons. First, they will reduce the recurring need for in-lake management interventions. Second, their construction is likely to contribute contaminant-laden sediment to the lake. Implementing watershed management techniques first and then treating the lake is preferable to treating the lake and then negating the progress made by that treatment with the effects of construction.

The functional advantages and cost-effectiveness of certain non-SCM watershed management techniques should not be overlooked. Constant attention must be given to the impact that the tens of thousands of annual visitors can have as they engage in the landscape surrounding the Lake. Management of user impacts is a continuous process that necessitates vigilance and adaptation. For example, effectively conveying and enforcing park rules should always be a top priority. Trails should be monitored and maintained, closed, or re-routed when problems arise. Bolstered enforcement of rules regarding trail use in Oconee Forest Park is a measure that would help to reduce sediment loading in the watershed's surface waters. Mountain bikes, which have been a "menace" on the trails for decades (Cook 1987, 9), are still prevalent and sometimes used in off-limits areas. Clearer signage and maintenance of gates would help to reduce infractions and the erosion that they cause. Currently, Oconee Forest Park is one of the only mountain bike trails near Athens. A holistic solution for preventing mountain bike impacts within the Lake Herrick watershed could be to partner with organizations like SORBA and the Athens Land Trust to provide adequate mountain bike facilities elsewhere nearby. Placing and maintaining dog waste bag and receptacle stations throughout Oconee Forest Park would reduce pathogen inputs to Parvo Pond and Lake Herrick. This would be especially beneficial at the dog park, where there is currently signage encouraging dog owners to dispose of their waste properly, but no amenities to provide assistance in doing so. The provision of such simple amenities would be a less expensive and probably equally effective alternative to the construction of an enhanced swale to protect the pond, as is explored in Chapter Five.

Once SCMs and other watershed management strategies have been constructed or enacted, in-lake management can commence. Dredging the areas of Lake Herrick and Parvo Pond that have been filled in with sediment is likely to be necessary for achieving any substantial change. In a shallow lake like Lake Herrick, reductions in external nutrient loads alone are not sufficient to affect the desired in-lake conditions because “internal nutrient interactions between the benthic and pelagic zones are more influential” relative to deeper lakes where larger volumes separate the benthos from the shallower portion of the water column (Cooke, et al. 2005, 33). Dredging will increase the overall depth of the water bodies, reducing the influence of the physical conditions that contribute to eutrophication and provide habitat for pathogens. It will also remove much of the accumulated nutrient load that cycles through the ecosystem and drives algal blooms. The extent to which sediment infill has occurred can be determined by comparing the current bottom contours with the contours that were used during the lake’s construction. The creation of depth profiles by physically measuring and recording sediment layers is another, more precise method for gauging the amount of infill that the lake has experienced. As a general rule of thumb, it will be useful to dredge shallow areas to a depth of at least four feet to deter weed growth and provide fish habitat. (ECOS Environmental, Inc., et al. 2003, 16.6; Holdren et al. 2001, 116)

When the flow of nutrients has been curtailed and existing sediment buildup removed, management focus can shift to rehabilitating the lake ecosystem. An ecosystem that supports certain desired environmental characteristics, especially those related to water clarity and suppression of algal populations, can better accommodate the University’s recreational goals.

Shallow lakes commonly exist in one of two general states: the first condition is characterized by high nutrient concentrations, high turbidity, and high algae. Biotic assemblages may include planktivorus and benthivorous fish such as carp and shad, herbivorous birds like Canada geese, and low numbers of phytoplankton grazers (large bodied zooplankton). These circumstances lead to "high internal [phosphorous] loading, turbid water, and little chance of extensive establishment of native submersed plants." Currently, Lake Herrick is characteristic of this first state. The second condition is one of clear water, extensive macrophyte growth (which stabilizes bottom sediments), and low nutrient concentrations. The biota is dominated by piscivorous fish and birds like bass and herons, and algae grazers such as zooplankton. (Cooke et al. 2005, 33) *Restoration and Management of Lakes and Reservoirs* notes that if a watershed is large relative to the lake surface and has erodible, nutrient rich soils, then algae or weeds are essentially impossible to avoid. Achieving Lake Herrick's management goals will require a making a decision as to which nuisance is more tolerable: macrophytes or algae. Most shallow urban lakes are dominated by one of the two. (Cooke et al. 2005, 33; Schueler and Simpson 2001, 748)

Clear, macrophyte-dominant, oligotrophic conditions are most compatible with the desired use for the lake. To the greatest extent possible, this should be the goal for both Parvo Pond and Lake Herrick.   In the case of Parvo Pond, the water body's spring-fed nature could be an irreconcilable impediment to achieving clear water; the natural spring apparently drives perpetually high turbidity. Regardless, the growth of healthy, diverse macrophyte communities should be encouraged for both the lake and the pond. This could be supported by long-term marginal zone rehabilitation and management activities at Parvo Pond, Lake Herrick, and the perennial streams in the watershed. Native shoreline plantings and weeding of undesirable invasive macrophytes would be useful for establishing preferable plant communities. The most desirable characteristics in planning and maintaining macrophyte populations are diversity and stability, and limited growth of invasive exotic plants. (Holdren, et al. 2001,35)

Shallow lakes are responsive to biomanipulation, which is the practice of using predator-prey relationships to influence environmental variables. It would be useful to apply biomanipulation principles to Lake Herrick by maintaining a healthy piscivorous fish population for the purpose of algal regulation. Boosting piscivorous fish populations and biomass in support of sportfishing is already a common lake management practice. However, this often entails the use of supplemental nutrient inputs that drive eutrophication. Rather than attempting to maximize the number and size of piscivorous fish, emphasis should be on supporting a moderate and balanced population for its regulatory effect on planktivorous fish. The impetus of protecting the lake's zooplankton population from excessive suppression, as opposed to maximizing the sport value of the fish, precludes the incentive for using chemical subsidies.

It is conventional practice to apply rotenone upon refilling a lake during or after draining and dredging. This kills all of the fish so that the lake can be restocked with the desired assemblage. The required amount, and thus price, of rotenone depends on the volume of water and the water temperature. Rotenone works best at higher temperatures. This practice might be implemented effectively after dredging at Lake Herrick and Parvo Pond in order to reset the fish populations and set them up for successful biomanipulation. (ECOS Environmental, Inc., et al. 2003, 7.5)

Additional in-lake interventions can be taken to improve the quality of the water bodies for both fish and humans. Recreational swimming and wading constitute a form of bioturbation, and management planning should anticipate the potential impact of human users. A geotextile cover over the bottom sediments near the beach, extending to depths of six feet or more, could help to prevent sediment disturbance and nutrient resuspension, as well as macrophyte establishment, in the swimming area. Shoreline fish habitat can be improved by providing cover. Fallen trees are especially effective for this purpose. (ECOS Environmental, Inc., et al. 2003, 2.5)

Aeration is another practice that would enhance the lake's water quality. By facilitating the spread of dissolved oxygen throughout the lake, aeration would improve fish habitat and promote the metabolic processing and breakdown of organic and chemical inputs by benthic microorganisms. This dampens the negative impacts of stratification- and algal bloom-driven anoxia. Other useful in-lake treatment methods, optimal for reducing nutrient loads, are floating wetlands and alum treatments. The establishment of any of these engineered systems would help to promote desirable lake chemistry at any stage of the restoration and management process, even prior to the implementation of SCMs.

Removing the Canada Geese

Lake Herrick's resident geese have proved to be a substantial management burden, and contributors of bacteria and nutrients to the lake. Their removal will constitute a step in the reduction of contaminant input and crucial progress towards the long-term maintenance of the beach. They have evaded previous efforts to drive them away with loud noises and divert them with alternative habitats. (Williams and Cook 1987) Planting dense vegetation along the lake's shoreline will help to make the area surrounding the lake less habitable to them, as geese prefer clear lines of sight in order to reduce their vulnerability to predators. Where it is desirable to maintain views for aesthetic enjoyment, shoreline buffer vegetation can be managed for visibility by planting low-growing shrubs and pruning them down to three feet or limbing up trees to six feet. (ECOS Environmental, Inc., et al. 203, 8.map) Goose-deterring shoreline plantings can be implemented as part of a broader effort towards rehabilitating Lake Herrick's marginal zone. The additional benefits associated with efforts to ensure the ecological integrity of the shoreline include better retention of runoff-borne pollutants, improved biotic habitat that will support overall food web health, and enhanced water quality as a result of stabilized shoreline sediments. (Cooke, et al. 2005, 133). This approach can be applied to all shoreline areas except for the dam, which must be kept clear of all woody vegetation, and the beach.

The beach has proved to be particularly attractive to the geese. Because this is a fenced-in space, it seems feasible to use a guard dog to monitor the beach and harass the geese when they approach. If Lake Herrick is made to be substantially less hospitable to the geese, they are likely to seek a new home. Another possibility would be to employ a more direct method: cook the geese and serve them at an invasive species roast, as the Warnell School of Forestry has organized on at least one occasion. Canada geese do have a reputation for being quite palatable.

Developing an Effective System to Monitor the Lake and SCMs

In the 2014 ECOL 8710 Environmental Practicum memo "Restoring Lake Herrick: Information for Improved Water Quality and Enhanced Recreational Value," Laura Keys reported on guidelines for the implementation of a sampling plan that would fulfill the State's requirements for bacterial monitoring for full-contact recreational use. This sampling plan represents the minimum monitoring required to support the water-based recreational goals established by this thesis. (Morphis et al. 2014, 34-38)

More rigorous analysis of existing monitoring data is needed to develop a strong theory regarding the nature of the pollution present in the Lake Herrick watershed. Average trends indicate that water quality is decreasing in both Lake Herrick and Parvo Pond. More frequent monitoring would provide a clearer picture of water quality trends over time by contextualizing the high variability that results when averages are skewed by single outlier values. It would also be helpful to monitor at various locations within the water bodies themselves, in addition to the existing outflow points and proposed bacteria sampling. This would enable the formation of a more complete picture of the interactions between chemical, biological, and physical processes within the water bodies, rather than just a snapshot of the downstream water quality once water has already exited the impoundments.

Monthly or bi-weekly temperature and dissolved oxygen measurements, taken at every meter in depth from the top of the water column to the bottom, would be useful for determining stratification patterns. This, in turn, can inform predictions of the lake's fundamental processes. Another useful management practice would be to sample plants once or twice during each growing season and record water depth, the height of plant growth, species composition, and density. A map can be created of the macrophyte community, showing distributions of the various species. Changes in environmentally sensitive species can indicate changes in the lake's condition. Zooplankton should also be sampled weekly or biweekly from fall to spring. This can be done by pulling a plankton net vertically from the bottom to the water surface. The most important information to gather is the dominant species and their average length. (Holdren et al. 2001, 117-122)

One of the benefits of constructing SCMs on UGA's campus is their potential to further the University's mission for research. There is a general need for long-term monitoring of SCM performance, publication of case studies, and further exploration, development, and enhancement of SCM technologies. There are already several ongoing green infrastructure projects on campus, such as the

Tanyard Creek vegetative buffer management activities organized by the College of Environment and Design's Cultural Landscape Lab. The Sustainability and Landscape Performance Lab, also a unit of the College of Environment and Design, exists as a conduit for research and observation of the functional performance of designed interventions in the landscape. Their established interest in documenting matters of landscape performance makes them a likely partner for monitoring and analysis of SCM function.

Implementation Power

Artificial lakes require continuous management. The act of building Lake Herrick three decades ago implied a commitment to providing the necessary upkeep. UGA has expended substantial resources in creating and maintaining the lake. In recent decades, however, the burden of maintenance has proved to be more demanding than most people may have anticipated. More intensive management is now necessary in order to ensure that the lake remains a usable amenity for the University community and a contributor of clean water for downstream communities. So far, the University has been slow to respond to the growing challenges. Lake Herrick has become mere scenery to be admired from a distance but never engaged physically. Although its condition has declined in recent years, the lake is still quite young relative to its potential useable lifespan. The University of Georgia does have a social and financial imperative to attentively and deliberately maintain their investment; to do otherwise would be to squander the resources that have already been invested, as well as the future potential of a valuable campus amenity.

The challenges of maintaining water quality in an urban landscape extend beyond wildlife nuisances, urban nonpoint source pollution, and the burdens that development imposes on natural hydrology. The planning, time, and material resources that must be devoted to the proper management of such a large and popular facility as the Lake Herrick-Oconee Forest Park-Intramural Fields complex is substantial. Therein lies a social aspect to Lake Herrick's problems; the environmental challenges will only be met effectively by a well-organized, clearly coordinated effort on the part of many people.

Collaboration amongst organizations throughout the University of Georgia and Athens will yield the beneficial input of abundant local perspectives, expertise, and resources. There are many organizations within the University of Georgia with interest in the quality of the lake. Relevant groups include the Warnell School of Forestry and Natural Resources, UGA College of Environment of Design, Odum School of Ecology, College of Engineering, Department of Biology, Department of Recreational Sports, Grounds Department, University Architects, River Basin Center, and Office of Sustainability. The Upper Oconee Watershed Network and the Georgia River Network are both local organizations that could yield useful partnerships. Stakeholder engagement with other property owners in the Lake Herrick watershed will also be important for ensuring effective management. The Georgia Department of Transportation, the Athens-Clarke County Water Department, and residents of the neighborhood adjacent to the lake are all of interest for establishing outreach partnerships.

The effectiveness with which these units work together is of great consequence regarding the implementation power to manage and protect Lake Herrick. The degree of coordination in planning and goal-setting will determine whether the Lake ultimately recovers its full recreational potential or remains underutilized. Whether it will continue to serve the University of Georgia community for decades to come will mirror the extent to which the community serves it.

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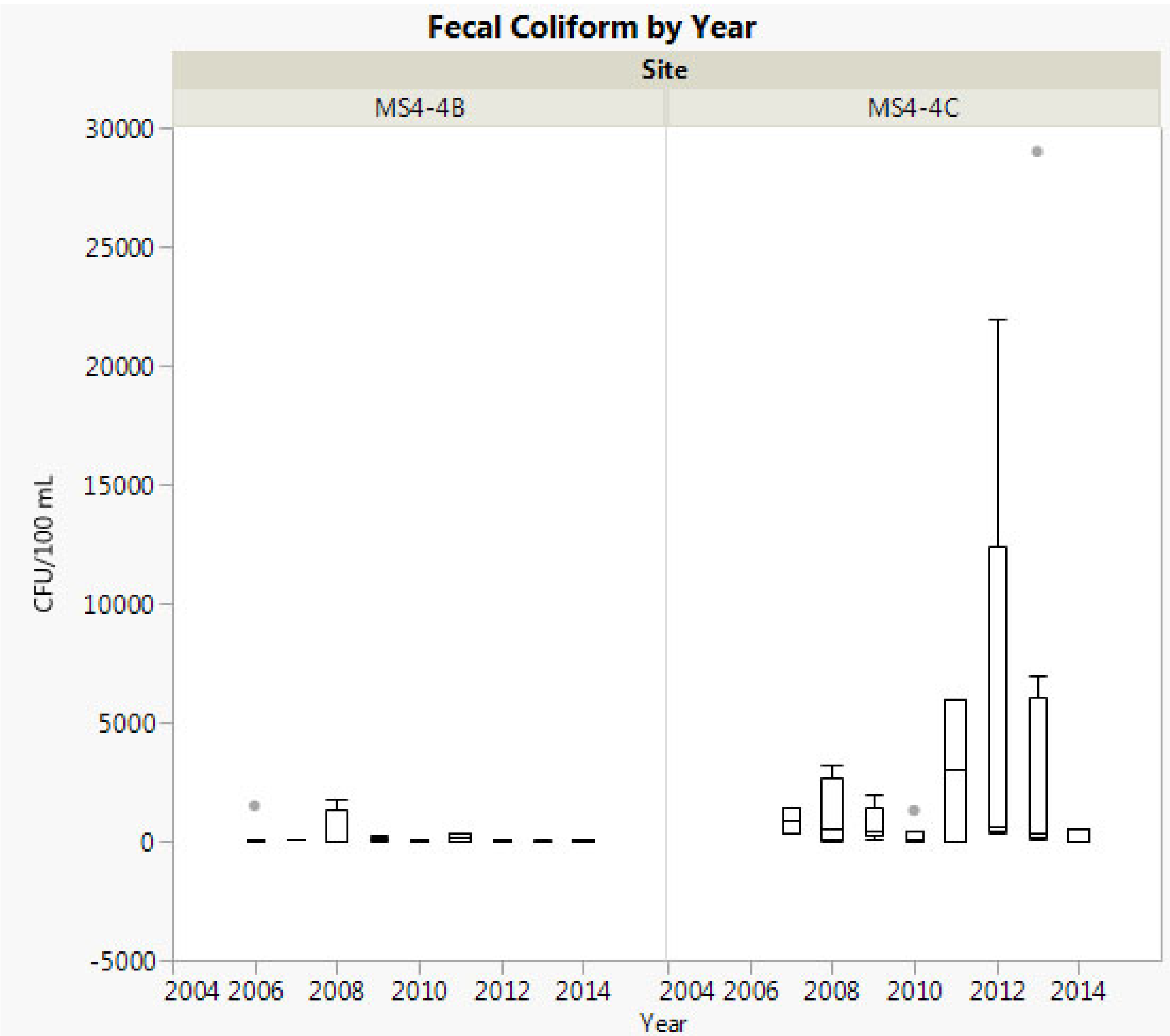
APPENDIX A

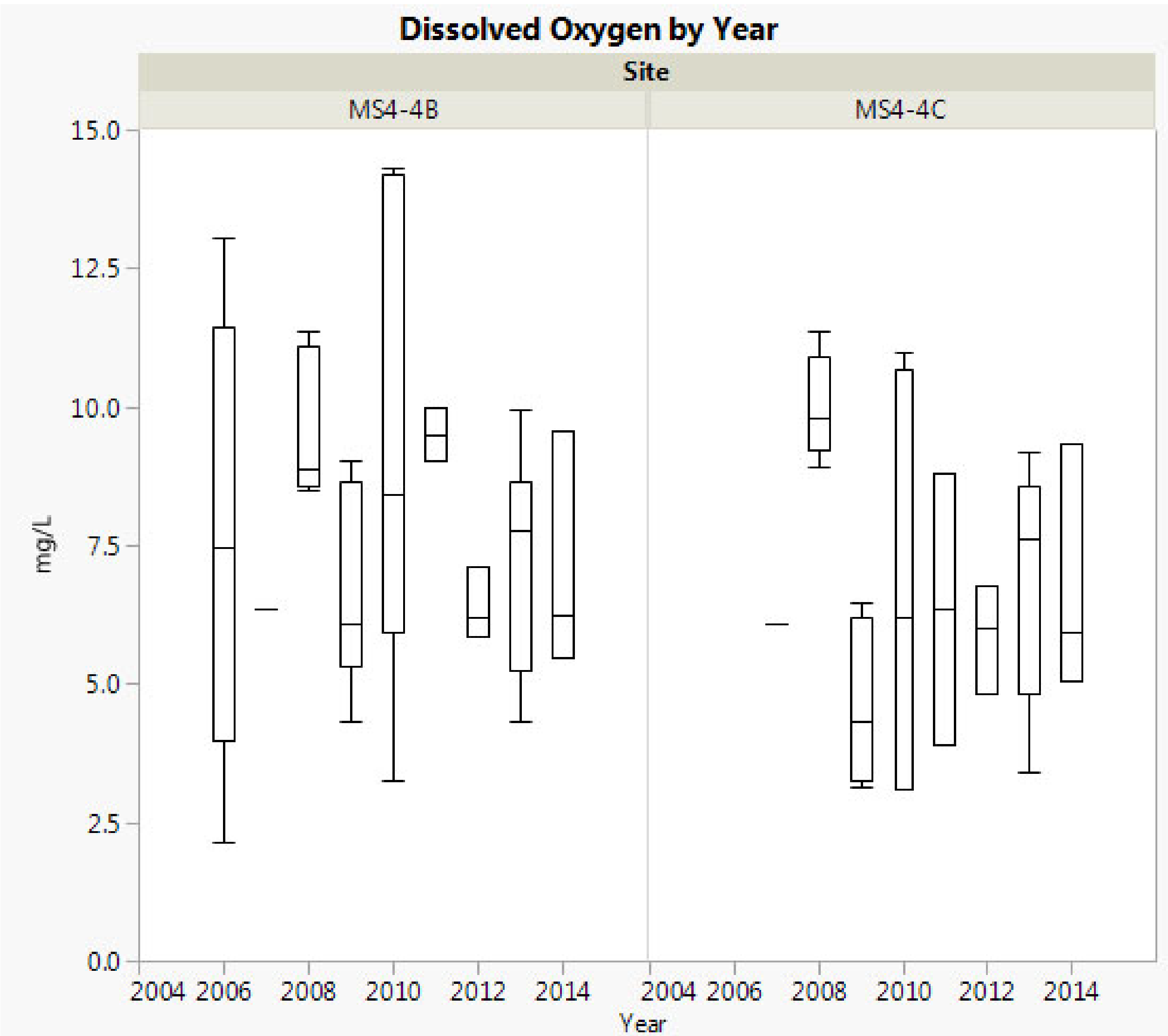
CHARTS AND TABLES OF SELECT WATER QUALITY MONITORING PARAMETERS

The following tables list average values for wet, dry and combined sampling events of select parameters during each monitoring period. Each accompanying chart displays values for all sampling events grouped by year. Data was taken downstream of the outflow points of Lake Herrick (MS4-4Bb) and Parvo Pond (MS4-4c). All data is from the 2007, 2009, 2010, 2011, 2013, and 2014 Brown and Caldwell monitoring reports.

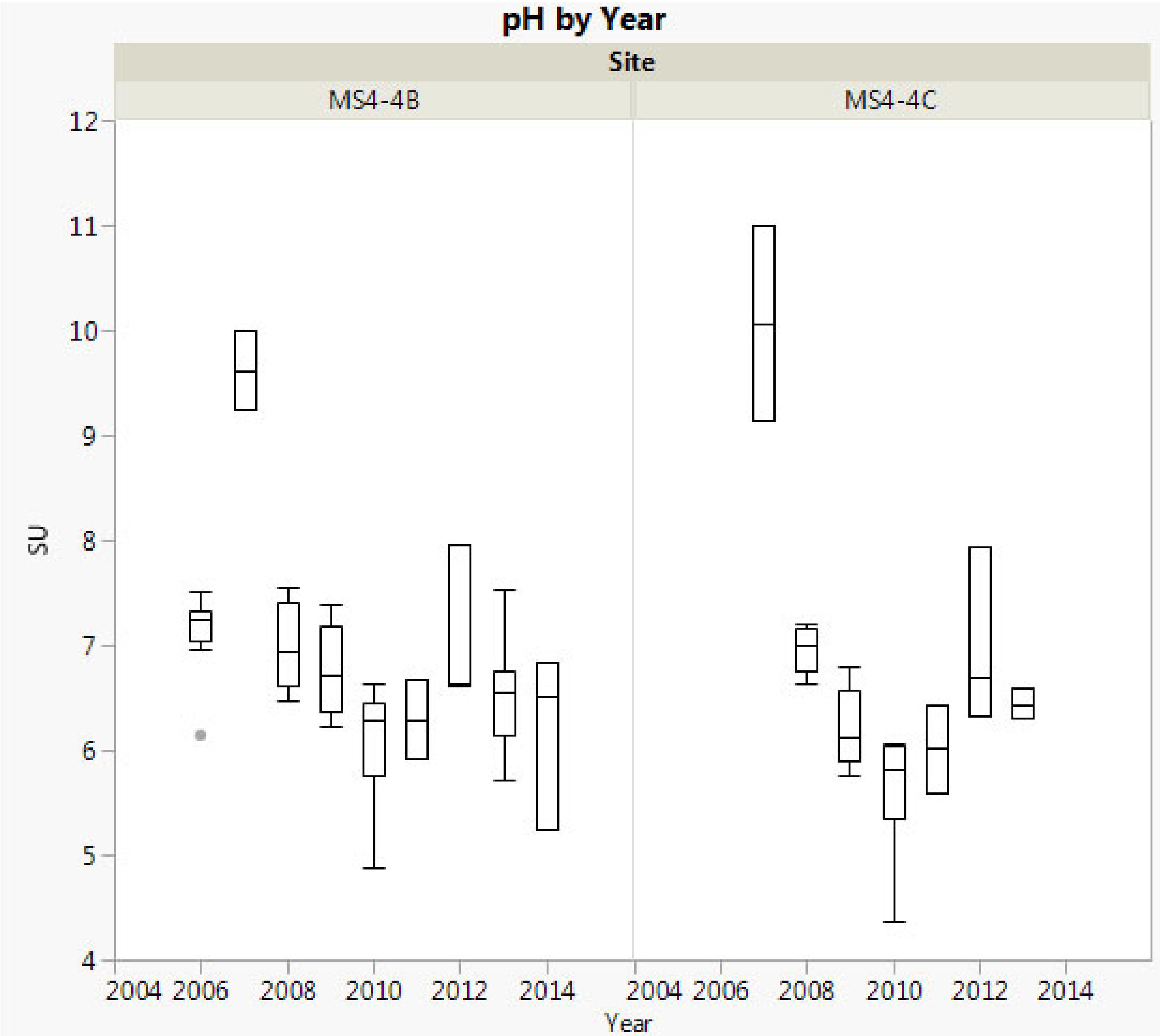
	Fecal coliform (CFU/100 mL)			
	Monitoring dates	Avg. (Wet)	Avg. (Dry)	Avg. (All)
MS4-4b	Feb 18, 2006 -Dec 13, 2006	36.67	268.33	195.55
	Oct 4, 2007 - Aug 13, 2008	630	18	280
	May 22, 2009 - Jan 21, 2010	143	53	98
	Sept 23, 2010 - Jun 23, 2011	151	32	92
	Sept 27, 2012 - May 22, 2013	55	21.6	31.10
MS4-4a	Feb 18, 2006 -Dec 13, 2006	600	101.43	278.89
MS4-4c	Oct 4, 2007 - Aug 13, 2008	2233	270	1111
	May 22, 2009 - Jan 21, 2010	565	618	591
	Sept 23, 2010 - Jun 23, 2011	1905	92	999
	Sept 27, 2012 - May 22, 2013	12650	829.4	4206.70



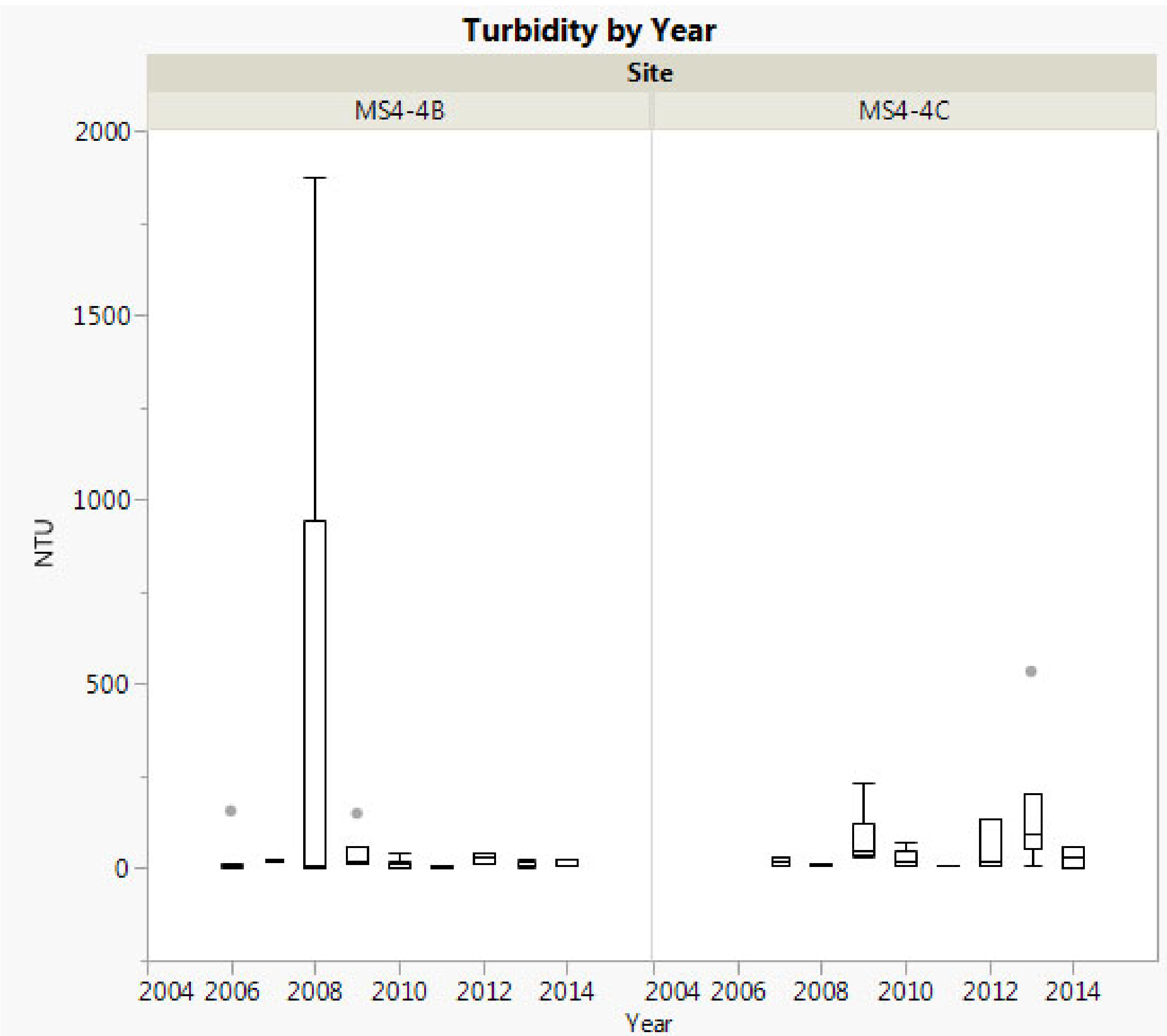
	Dissolved Oxygen (mg/L)			
	Monitoring dates	Avg. (Wet)	Avg. (Dry)	Avg. (All)
MS4-4b	Feb 18, 2006 -Dec 13, 2006	6.69	8.32	7.77
	Oct 4, 2007 - Aug 13, 2008	9.88	8.72	9.10
	May 22, 2009 - Jan 21, 2010	6.56	8.61	7.58
	Sept 23, 2010 - Jun 23, 2011	7.83	8.42	8.13
	Sept 27, 2012 - May 22, 2013	8.08	6.44	6.99
MS4-4a MS4-4c	Feb 18, 2006 -Dec 13, 2006	5.77	8.32	7.20
	Oct 4, 2007 - Aug 13, 2008	9.70	9.18	9.36
	May 22, 2009 - Jan 21, 2010	4.50	6.29	5.52
	Sept 23, 2010 - Jun 23, 2011	5.02	7.38	6.20
	Sept 27, 2012 - May 22, 2013	6.42	6.30	6.34



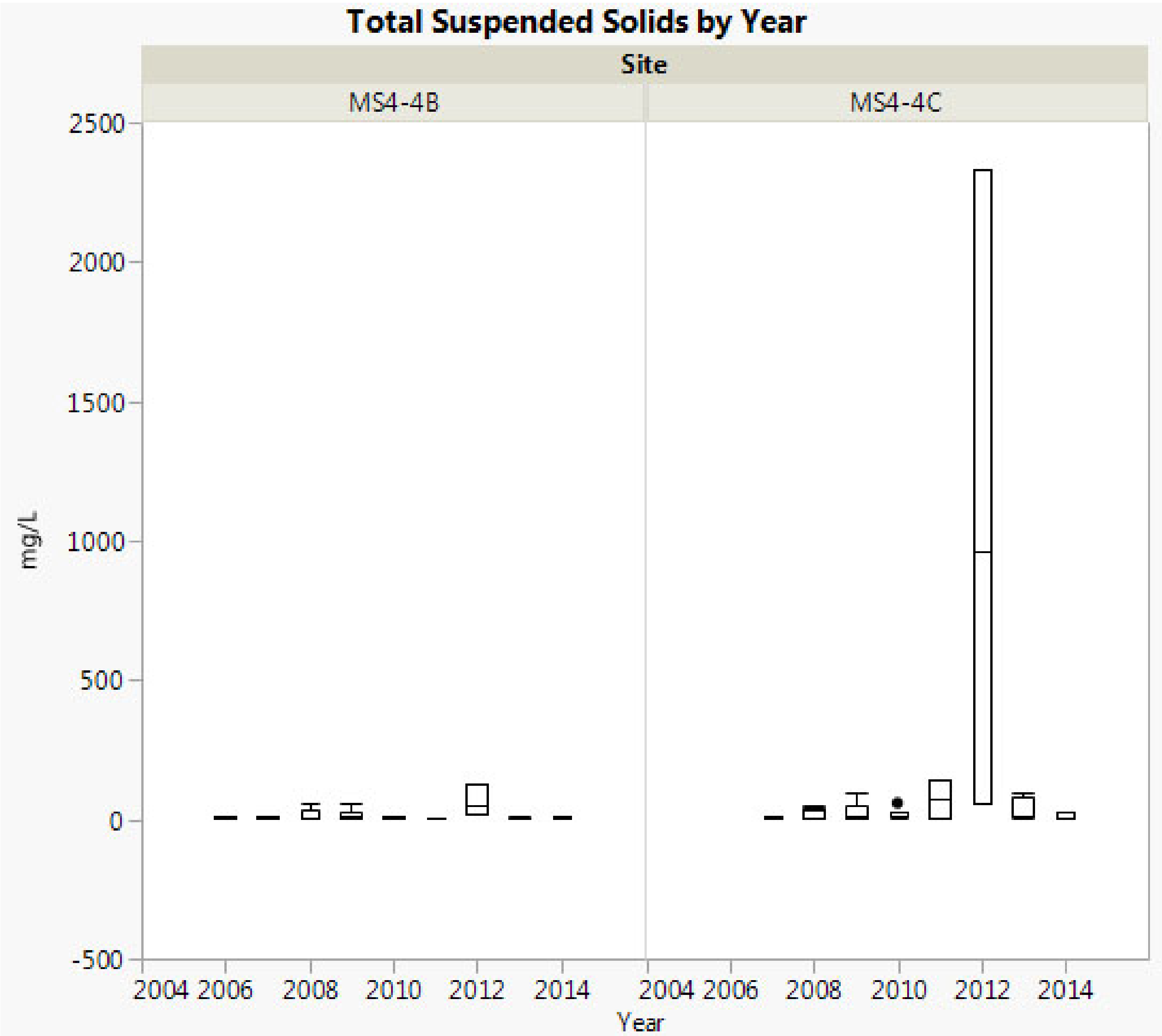
	pH (s.u.)			
	Monitoring dates	Avg. (Wet)	Avg. (Dry)	Avg. (All)
MS4-4b	Feb 18, 2006 -Dec 13, 2006	6.93	7.23	7.13
	Oct 4, 2007 - Aug 13, 2008	7.91	7.62	7.75
	May 22, 2009 - Jan 21, 2010	6.62	6.78	6.70
	Sept 23, 2010 - Jun 23, 2011	6.45	5.90	6.17
	Sept 27, 2012 - May 22, 2013	6.6	6.87	6.78
MS4-4a	Feb 18, 2006 -Dec 13, 2006	6.86	7.13	7.04
MS4-4c	Oct 4, 2007 - Aug 13, 2008	8.29	7.52	7.85
	May 22, 2009 - Jan 21, 2010	5.97	6.35	6.16
	Sept 23, 2010 - Jun 23, 2011	5.91	5.81	5.86
	Sept 27, 2012 - May 22, 2013	6.32	6.91	6.71



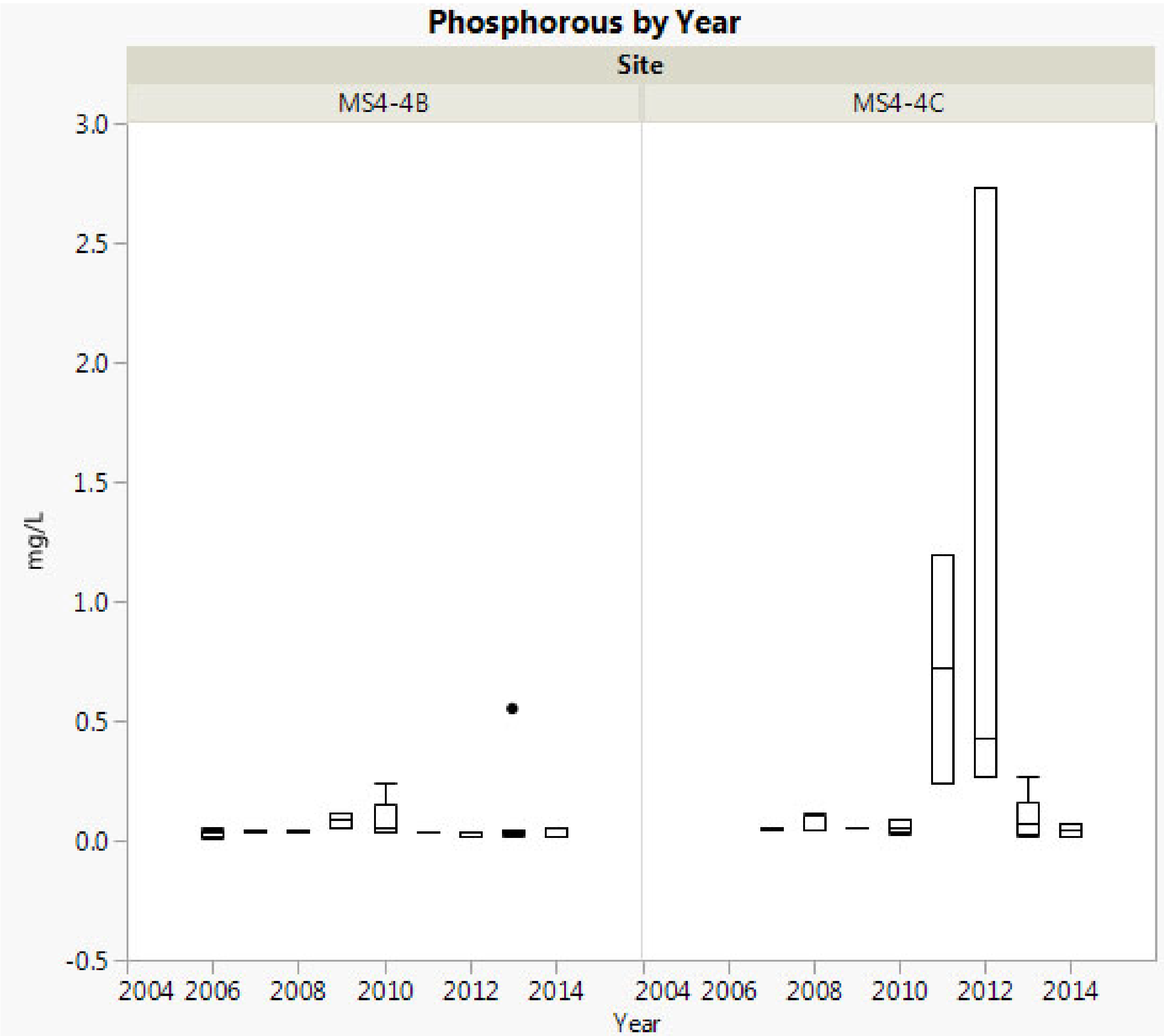
	Turbidity (NTU)			
	Monitoring dates	Avg. (Wet)	Avg. (Dry)	Avg. (All)
MS4-4b	Feb 18, 2006 -Dec 13, 2006	56.6	7.6	23.9
	Oct 4, 2007 - Aug 13, 2008	633.31	10.86	277.62
	May 22, 2009 - Jan 21, 2010	58.6	15.35	36.98
	Sept 23, 2010 - Jun 23, 2011	10.63	14.01	12.32
	Sept 27, 2012 - May 22, 2013	23.80	20.83	21.82
MS4-4a	Feb 18, 2006 -Dec 13, 2006	51.8	7.6	23.9
MS4-4c	Oct 4, 2007 - Aug 13, 2008	21.44	10.02	13.83
	May 22, 2009 - Jan 21, 2010	57.35	84.3	70.82
	Sept 23, 2010 - Jun 23, 2011	265.13	24.05	161.81
	Sept 27, 2012 - May 22, 2013	135.50	141.45	139.47



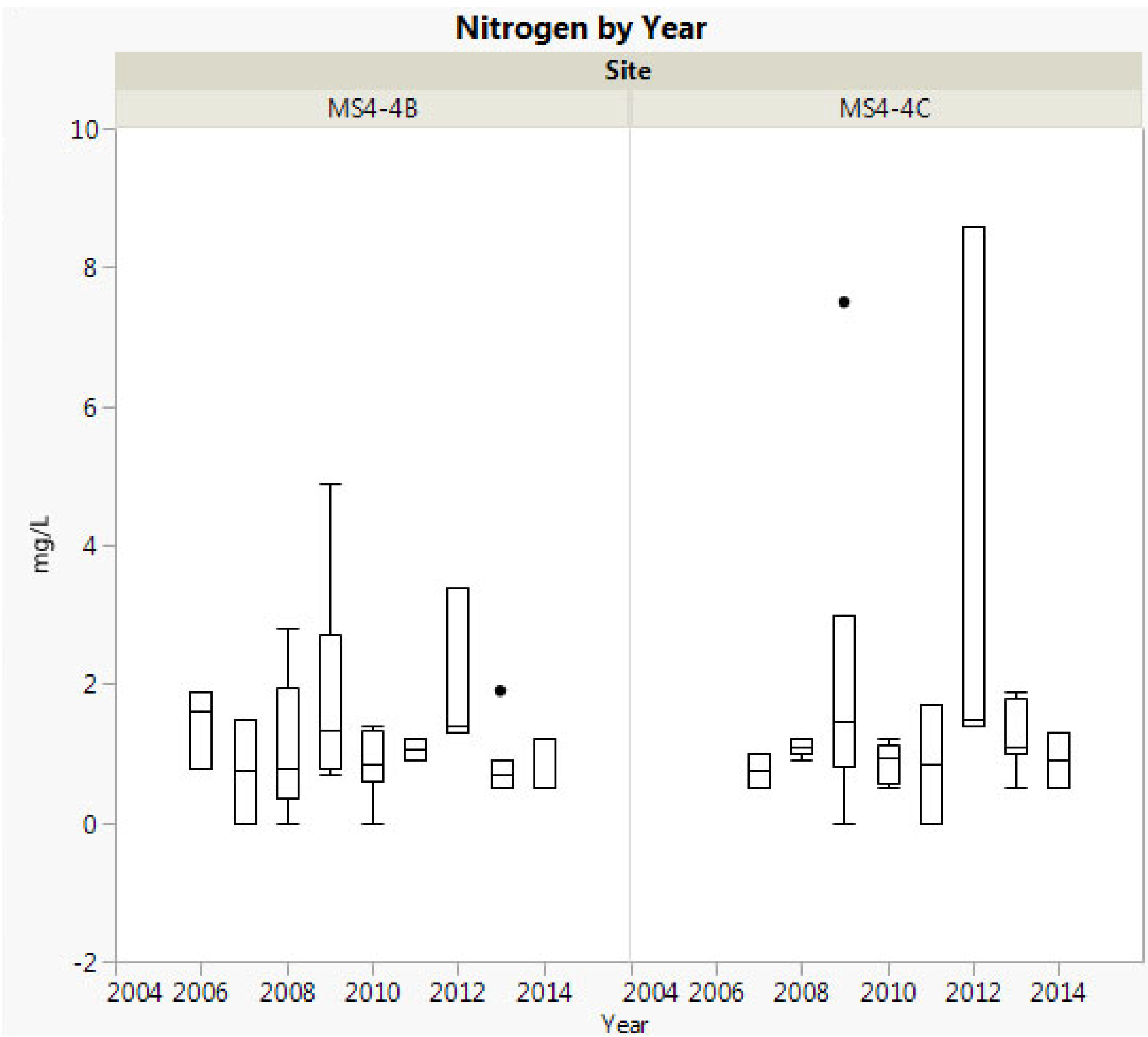
	Total Suspended Solids (mg/L)			
	Monitoring dates	Avg. (Wet)	Avg. (Dry)	Avg. (All)
MS4-4b	Feb 18, 2006 -Dec 13, 2006	7	8	7.6
	Oct 4, 2007 - Aug 13, 2008	5	23	15
	May 22, 2009 - Jan 21, 2010	24	11	17
	Sept 23, 2010 - Jun 23, 2011	7.4	3.1	5.3
	Sept 27, 2012 - May 22, 2013	13.00	47.6	36.07
MS4-4a	Feb 18, 2006 -Dec 13, 2006	32	8	18.7
MS4-4c	Oct 4, 2007 - Aug 13, 2008	32	14	21
	May 22, 2009 - Jan 21, 2010	31	33	32
	Sept 23, 2010 - Jun 23, 2011	44.4	11.1	27.8
	Sept 27, 2012 - May 22, 2013	77.80	837.3	584.13



	Total Phosphorous (mg/L)			
	Monitoring dates	Avg. (Wet)	Avg. (Dry)	Avg. (All)
MS4-4b	Feb 18, 2006 -Dec 13, 2006	0.025	0.041	0.034
	Oct 4, 2007 - Aug 13, 2008	0.036	0.040	0.038
	May 22, 2009 - Jan 21, 2010	0.074	0.043	0.058
	Sept 23, 2010 - Jun 23, 2011	0.040	0.076	0.058
	Sept 27, 2012 - May 22, 2013	0.294	0.04	0.12
MS4-4a	Feb 18, 2006 -Dec 13, 2006	0.051	0.041	0.033
MS4-4c	Oct 4, 2007 - Aug 13, 2008	0.073	0.057	0.064
	May 22, 2009 - Jan 21, 2010	0.065	0.037	0.051
	Sept 23, 2010 - Jun 23, 2011	0.094	0.331	0.213
	Sept 27, 2012 - May 22, 2013	0.212	0.865	0.65



	Total Nitrogen (mg/L)			
	Monitoring dates	Avg. (Wet)	Avg. (Dry)	Avg. (All)
MS4-4b	Feb 18, 2006 -Dec 13, 2006	1.2	1.6	1.4
	Oct 4, 2007 - Aug 13, 2008	0.4	1.5	1.1
	May 22, 2009 - Jan 21, 2010	2.4	0.9	1.7
	Sept 23, 2010 - Jun 23, 2011	1.2	1.0	1.1
	Sept 27, 2012 - May 22, 2013	1.65	1.53	1.57
MS4-4a	Feb 18, 2006 -Dec 13, 2006	1.1	1.2	1.2
MS4-4c	Oct 4, 2007 - Aug 13, 2008	1.1	1.0	1.0
	May 22, 2009 - Jan 21, 2010	2.9	1	2.1
	Sept 23, 2010 - Jun 23, 2011	1.2	0.9	1.1
	Sept 27, 2012 - May 22, 2013	1.65	3.28	2.74



APPENDIX B

SCM CATCHMENT FACT SHEET

Catchment	Area (AC)	% Impervious	CN	T_c (min.)	Design Storm	Design Storm Runoff Volume (AC.FT.)	Proposed SCM
A	0.34	100	98	5.00	1.2”	0.028	Downspout Disconnection
B	0.31	100	98	5.00	1.2”	0.025	Downspout Disconnection
C	0.29	100	98	5.00	1.2”	0.024	Downspout Disconnection
D	0.15	100	98	5.00	1.2”	0.012	Downspout Disconnection
E	0.15	100	98	5.00	1.2”	0.012	Downspout Disconnection
F	0.28	100	98	5.00	1.2”	0.023	Downspout Disconnection
G	0.29	100	98	5.00	1.2”	0.024	Downspout Disconnection
H	1.14	56.75	88	7.00	1.2”	0.036	Sand Filter
I	1.00	60.83	89	8.00	1.2”	0.035	Sand Filter
J	0.37	47.44	86	7.00	1.2”	0.009	Bioretention
K	0.43	70.06	90	5.00	1.2”	0.016	Sand Filter
L	1.22	48.96	88	5.00	1.2”	0.038	Bioretention
M	0.25	68.31	90	5.00	1.2”	0.010	Sand Filter
N	0.57	82.32	98	5.00	1.2”	0.047	Sand Filter
O	0.57	70.94	92	5.00	1.2”	0.026	Sand Filter
P	0.51	86.22	95	5.00	1.2”	0.031	Sand Filter
Q	0.77	81.56	94	5.00	1.2”	0.043	Sand Filter
R	2.45	58.21	88	8.36	1.2”	0.077	Filter Strip
S	1.06	61.58	89	5.36	1.2”	0.037	Filter Strip
T	1.55	47.65	86	5.36	1.2”	0.039	Filter Strip
U	12.86	47.45	85	7.78	1.2”	0.294	Bioswale
V	11.69	0.35	41	44.00	3.2”	0.007	Bioswale+Bioretenti on
W	2.41	32.60	60	19.00	3.2”	0.082	Bioretention
X	1.48	0	39	22.00	1.2”	0.009	Bioretention
Y	1.48	12.55	47	18.00	1.2”/3.2”	0/0.009	Bioretention
Z	2.11	54.51	75	12.19	1.2”	0.013	Bioretention+Biosw ale
AA	5.22	24.82	62	11.40	1.2”/3.2”	0/0.209	Bioretention
BB	1.41	40.62	60	16.15	--	--	None
CC	16.56	28.67	66	8.44	1.2”	0.007	Bioretention
DD	9.13	27.29	56	12.33	25-year	0.891	Bioretention+Swales
EE	21.16	26.39	67	19.18	1.2”	0.016	Filter Strip and Bioswale
FF	44.94	26.36	66	12.33	1.6”	0.163	Wetland + Wet Pond

APPENDIX C

SAND FILTER DESIGN METHODOLOGY

The first step in sizing a sand filter is to compute the peak rate of discharge for the water quality design storm (Q_{wq}). This was computed using HydroCAD using the average area and CN of the eight catchments, and a T_c of five minutes. WQv (water quality volume) is 0.035 acft, or 1,524 ft^3 and Q_{wq} is 0.75 cfs.

The equation $A_f = (WQ_v)(d_f)/[(k)(h_f + d_f)(t_f)]$ was used to find the filtration basin chamber's surface area. A_f is the surface area (ft^2) of the filter bed, d_f is the filter bed depth, k is the coefficient of permeability of filter media (3.5 ft/day for sand), h_f is the average height of water above the filter bed (ft), and t_f is the design filter bed drain time (days). Filter bed depth (d_f) is assumed to be 18 inches (a common standard). The average height of water above the filter bed (h_f) is assumed to be 3; this value can vary based on site but 3 corresponds to a filter bed buried 6 feet underground. The design filter bed drain time (t_f) is the 1.67 day (40 hour) recommended maximum.

Thus,

$A_f = (1524)*(1.5)/[(3.5)*(3+1.5)*1.67] = 2286/26.3 = 86.92\ ft^2$. The filtration basin chamber has a footprint of about 87 square feet and a depth of 18 inches, for a total volume of 130.5 ft^3.

The next step is to size the sedimentation chamber. This should have the capacity to store at least 50 percent of the WQ_v, or 762 ft^3 of water. It should have a length-to-width ratio of 2:1. The surface area is determined using the following equation: $A_s = -(Q_o/w)*Ln(1-E)$. Q_o is the rate of outflow, which is the same as the WQ_v over a 24 hour period. W is the particle settling velocity (ft/sec), which is 0.0004 feet per second for catchments with greater than 75 percent impervious surface. E is the trap efficiency, which is assumed to be 90 percent (0.9).

Thus,

A_s equals $(0.0081)(WQ_v)$ square feet for catchments with greater than 75 percent impervious surface. $A_s = (0.0081)(1524) = 12.3\ ft^2$. Because the sedimentation chamber should be able to store at least 762 ft^3 of water, it must be 61.95 feet deep.

Unfortunately, this dimension does not fit the available head nor is it a reasonable number. However, it is already established that the sedimentation chamber needs to contain at least 762 ft^3 of water, and the manual specifies that it must have a minimum depth of 2 feet. Furthermore, there is 6 feet of head above the filtration basin chamber, so the sedimentation chamber can have a depth of at least 5.5 feet. 762/5.5 = 138.54, so the sedimentation basin will have an assumed surface area (A_s) of 140 ft^2. A length of 17.5 feet and a width of 8 feet meets the minimum 2:1 length-to-width requirement.

The following calculations determine the storage volumes within the entire facility and the sedimentation chamber orifice size:

$V_{min} = 0.75*WQ_v = 0.75*1524 = 1143\ ft^3 = V_s + V_f + V_{f\text{-}temp}$

V_f is the water volume within the filter bed and pipe. It is equal to $A_f * d_f * n$. n is the porosity, and has a value of 0.4. A_f is 86.92 and d_f is 1.5, so $V_f = 86.92 * 1.5 * 0.4 = 52.15\ ft^3$.

V_w, the wet pool storage volume, $= A_s * h_s = 140 * 5.5 = 770\ ft^3$

V_{temp}, the temporary storage volume, $= V_{min} – (V_f + V_w) = 1143 – (52.15 + 770) = 320.85\ ft^3$

h_{temp},the temporary storage height, $= V_{temp}/(A_f + A_s) = 320.85/(86.92+140) = 1.41$ ft

h_{temp} should be greater than or equal to 2 * h_f, or greater than 6. Since this is not the case, h_f should be decreased and the dimensions re-calculated. Once the dimensions are refined to the point where they are functional, the inlets, pretreatment facilities, underdrain system, and outlet structures can be designed, followed by the overflow weirs.

APPENDIX D

STORMWATER WETLAND DESIGN METHODOLOGY

Watershed Modeling

1. Obtain GIS layers
    a. Most data from Grounds Department
    b. Soil data from NRCS Web Soil Survey
        i. Delineate Area of Interest (AOI)
        ii. Export spatial data to GIS
2. Characterize watershed land use for Lake Herrick Subwatershed, Parvo Pond Subwatershed, and total combined watershed.
    a. Insert aerial photo jpeg.
    b. Export GIS layers related to land cover (buildings, roads, sidewalks, etc.) and soil types as dwg.
    c. Align land cover vector lines over aerial photo using the outline of Lake Herrick as shape reference. Scale aerial imagery to match vector lines.
    d. Measure surface area of each land cover type within each soil zone. Record data in table (excel spreadsheet Watershed Land Use)
    e. Arrange land cover types by soil hydrologic group (A,B,C,D). Sum matching land uses within each soil hydrologic group to find total land cover areas by soil hydrologic group.
    f. Divide land cover areas by total subwatershed and watershed areas to find land cover proportions.
3. Input soil group and land cover proportions into HydroCAD (Settings -> Watershed) to determine weighted average CN.

a. Parvo Subwatershed has weighted CN of 64; 82.39% pervious area and 17.61% impervious area.

b. Herrick Subwatershed has weighted CN of 59; 79.11% pervious area and 20.89% impervious.

Wetland Sizing

4. Using HydroCAD, run hydrographs to project runoff volume for various rainfall events in the Parvo Subwatershed.
    a. Select Parvo Subwatershed node.
    b. Go to Settings dropdown menu, select Calculation, and select Rainfall tab.
    c. Create desired custom rainfall events: 1.2" (water quality/first flush), 1.5", 1.6", 1.75", 2", 3.2" (1-year)
        i. Input Depth (inches), input Name of rainfall event and save. Apply. Repeat for each desired depth.
    d. Find runoff volume (ac.ft.) for each rainfall event.
        i. Select each rainfall event using dropdown menu in top toolbar. Right click Parvo Watershed node and select Node Report. View runoff volume (in hydrograph tab). Record in Excel document Wetland Sizing for each rainfall event.
5. Convert runoff volume value from ac.ft. to surface area (sq.ft.) at 9" average depth.
    a. Value in ac.ft. is the acreage of the wetland if it contains the entire volume of runoff at 1 foot of depth.
        i. First, convert value to acreage at 9" depth; X(ac.ft)*12 (in/ft)/9in = Y ac.
        ii. Next convert to sq.ft.; Y(ac)*43560(sq.ft./ac) = Z sq.ft.
6. Plot a scatter chart with rainfall depths (x) and wetland surface areas (y). Apply a trendline as a power function to view the general relationship between the two variables. The variables relate as an exponential curve. Wetland function is optimized at the *point of inflection.*

a. This is where the curve begins to rise vertically along the Y axis at a greater rate than it travels horizontally along the x axis. Beyond this point, the size of the wetland must increase at an exponential rate to handle corresponding gains in runoff volume. To put it simply, this is the greatest “bang for buck” from a functional standpoint.

b. The chart shows the point of inflection to be somewhere above the 3.2” 1-year storm. This is an estimate, rather than a precise calculation.

c. There is a way to precisely determine the point of inflection using calculus. I did not do this, because we chose to determine the optimal size of the wetland based on cost (see point 7) rather than function; a wetland with capacity to treat the 1.6” storm event is roughly about what we can afford to pay for.

7. Estimate probable construction cost for each wetland size by multiplying the sq.ft. surface area by 5.

APPENDIX E

319 GRANT APPLICATION

The following document was submitted to the US Environmental Protection Agency through its 319 Grant program which provides funding in support of endeavors to manage nonpoint source pollution. The author of this thesis contributed content and edits to the grant application.

SECTION 319(h) FY2015 GRANT PROPOSAL

PROJECT COVER PAGE

Project Title: TMDL Implementation Plan for the 9-Element Watershed Management plan for the North Oconee Watershed; Tanyard Creek to Lake Herrick

Applicant: The University of Georgia (UGA)
Athens, GA 30602
Phone: (706) 542-5465

Primary Contact: Tyra Byers (Interim Contact, but year round administrator will be Contact if this grant is funded)
Sustainability Coordinator
River Basin Center and Office of Sustainability
1800 East Broad Street
University of Georgia
Athens, GA 30606
706.542.1301

Date of Pre-Application Meeting with GAEPD Staff: ____October 14, 2014____________

1. Is the project proposal implementing an existing watershed-based plan that addresses USEPA's Nine Elements of Watershed Planning?

   YES _x_ NO ___

   If YES, identify the title of the plan and provide a copy as an Attachment to the application:

   TITLE: _Nine Element Watershed Management Plan UGA Campus Streams (for the North Oconee River: Tanyard Creek to Lake Herrick Catchments)

2. Was the watershed-based plan developed using Section 106, 604(b) or 319(h) Grant funds?

   YES _X_ NO ___

3. List the page numbers and section headings/subheadings where each of the Nine Elements of Watershed Planning can be found in the attached watershed-based plan.

   1. Identification of sources contributing to nonpoint source (NPS) pollution to be controlled:
      Pages_110-18__ Section_III. Impairment Summary__
      Summary: Levels of fecal coliform, *E.Coli,* pH, nutrients (Total P and Total N), metals, and invasive species exceed mandated or recommended benchmarks. Bacterial contamination, identified as the principal problem facing campus watersheds, has been traced to four candidate sources: faulty sewage pipes, animal waste (dogs and geese), leaking dumpsters, and improper disposal of grease and food waste from food service businesses. Several explanations have been proposed for abnormally low pH levels, but identification is inconclusive thus far and warrants further investigation. Further monitoring and investigation is also needed to determine the sources and severity of nutrient contaminants, but it is likely that measures to reduce bacterial contamination will also be effective against excess nutrients. Varied and diffuse sources likewise contribute to the presence of metals, sediment and TSS, and invasive species throughout the watersheds of interest.

2. Estimated load reductions expected from recommended NPS management measures:
   Pages_N/A_ Section__N/A___________
   Summary: NPS

3. NPS management measures necessary to achieve established TMDLs or improvement:
   Pages_19-27_ Section_IV. Current & Proposed Management Measures__
   Summary: Strategies to reduce pollutant loads are as follows: 1. Implement best management practices that reduce stormwater flow and eliminate the targeted pollution sources; 2. Repair leaking sewer lines and stubs; 3. Restore targeted stream segments and effective riparian buffers; 4. Provide and facilitate ongoing education, outreach and community engagement on watershed stewardship and best practices to an audience that includes the UGA community, businesses, and residents within the watershed, and K-12 students; 5. Continue targeted water quality monitoring and stream walks to identify additional pollution sources and determine the effectiveness of management activities.

4. Funding sources needed and authorities relied upon to implement the plan:
   Pages__28_ Section_5. Develop More Informed Funding Strategy and Procure Funding____
   Summary: Match and external funding sources will be obtained by partnering with organizations whose goals are reflected in the Nine Element Plan. Potential partners within the University of Georgia include the Grounds Department, University Architects, Recreational Sports Department, Warnell School of Forestry, the Office of Sustainability, and the River Basin Center at the Odum School of Ecology. Local/municipal entities include the Athens-Clarke County Public Utilities Department, the Stormwater Management Program, and the Water Conservation Office. Other potential funding sources include grants, specifically the Clean Water Act 319 grant, the Five Star Restoration grant, UGA Campus Sustainability Grants (for student initiatives).

5. Education & outreach strategies to engage public participation in implementing the plan:
   Pages_29__ Section__5. Milestones/Schedule____
   Summary: The Outreach and Education table outlines a ten-year plan which details the actions to be taken, the parties responsible for those actions, and the projected costs. Action items are organized on an annual basis. Some examples include continued development of a watershed website, maintenance of an online database, and coordinating the administrative transfer of an existing environmental education campaign at a local elementary school and expanding to additional schools in the watershed. Also included is the continuation of the following: Athens Clarke-County illicit discharge hotline, general community education and outreach, and an extension program to promote water efficiency and the reduction of fertilizer and pesticide use.

6. Schedule or timeline for implementing the recommended NPS management measures:
   Pages_28-29/30-31_ Section__5. Milestones/Schedule_______________
   Summary: 10-year schedules have been developed for the initiation/installation, maintenance, and monitoring of BMPs to address the following: pollutant inputs stemming from dog waste and dumpster leaks, outreach and education, water quality monitoring, stormwater control measures, riparian buffer management and invasive species removal.

7. Interim, measurable milestones to determine progress of implementation:
   Pages_28-31_ Section_5D. Milestones/Schedule__
   Summary: Milestones to determine progress of implementation are listed following each 10-year schedule.

8. Criteria to determine success in water quality improvement or need to revise plan
   Pages_41__ Section__VI. Plan Review_______
   Summary: To determine whether loading reductions are being achieved over time and substantial progress is being made toward attaining water quality standards, the Campus Watersheds Advisory Committee will perform the following actions: 1. Compare milestone goals in fecal coliform, phosphorous, and nitrogen load reductions with actual sampling results. 2. Examine monitoring data to determine if any new water quality issues have arisen. 3. Review progress made with the BMPs and education/outreach steps identified in the plan. 4. Discuss the potential effect of implementing new BMPs and other strategies. 5. Discuss necessary adjustments and revisions needed in the targets listed in the plan.

9. Evaluation of effectiveness of implementation efforts measured against above criteria:
   Pages_28-31__ Section__5. Plan Review and Amend Monitoring Plan and Explore Modeling Options ___
   Summary: The Campus Watersheds Advisory Committee plans to review and revise the plan annually. The review will be scheduled by the UGA Office of Sustainability and the UGA River Basin Center and will be informed by results from ongoing water quality monitoring data.

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PROJECT DESCRIPTION

1. **Project Title:** TMDL Implementation Plan for the 9-Element Watershed Management plan for the North Oconee Watershed; Tanyard Creek to Lake Herrick

2. **Lead Organization:** University of Georgia (UGA)
Athens, GA 30602
(706) 542-5856

Primary Contact: Tyra Byers
Sustainability Coordinator
River Basin Center and Office of Sustainability
1800 East Broad Street
University of Georgia
Athens, GA 30606
706.542.1301

Project Start Date: 10/1/15
Project End Date: 10/1/18

Federal Amount: $381,038
Match Amount: $336,769
Total Project Amount: $717,807

3. **Project Goals:**

The goal of this project is to implement the Nine Element Watershed Management Plan for the North Oconee River; Tanyard Creek to Lake Herrick to ameliorate adverse impacts from impervious cover in the target watersheds, enhance ecosystem health, and promote watershed education, awareness, and behavior change to reduce inputs from nonpoint source pollution. Social benefits beyond water quality improvements include strengthened partnerships between UGA and the Athens-Clarke County community, enhanced aesthetic and recreational value, and increased educational opportunity for UGA students and the general public.

Specific objectives include constructing and evaluating the performance of stormwater control measures (SCMs) on UGA's campus to effect quantitative reductions in nonpoint source pollution and to serve as demonstration sites for educational outreach for UGA and the wider Athens-Clarke County (ACC) community. Educational programs will be developed and delivered regarding best management practices to address specific nonpoint sources identified in the nine element plan with audiences including UGA maintenance employees and area businesses and residents. The project will also foster implementation of SCMs on private property in the watersheds.

4. Project Background:

Over the past several years, project partners have developed a Nine Element Watershed Management Plan for the Oconee River from Tanyard Creek to Lilly Branch on the North Oconee River. The plan aims to improve the water quality of the four stream catchments which run through the University of Georgia's campus to the North Oconee River. Three of the catchments are highly developed and include portions of downtown Athens in addition to campus. The fourth contains a lake and a pond which are impacted by nonpoint source pollutant-laden stormwater runoff, despite the catchment's higher proportion of permeable land cover. Surface waters in all four catchments are impaired with fecal coliform and demonstrate other elevated parameters indicative of poor water quality. In addition, stream buffers are degraded and there is limited access to floodplains. Heavily impacted urban conveyances and their associated watersheds provide a unique challenge for watershed planning efforts due to their old infrastructure, piped sanitary networks, land use changes and constrained floodplains and buffers. While there is currently a general lack of awareness about these waters by all sectors of the public, the potential for using them as demonstration sites to promote a water stewardship ethic and adoption of best management practices is enormous; the streams and lake of interest occupy prominent locations: in downtown Athens, through the heart of campus (including adjacent to and under UGA's enormously popular Sanford Stadium), and central to a widely-used outdoor recreation complex within the Lake Herrick catchment.

UGA, Athens Clarke County, UGA Architects and Grounds, the Upper Oconee Watershed Network, the UGA Alumni Association, and faculty and students have all turned their attention to these catchments in recent years with activities including nonpoint source investigations, bioassessments, water quality monitoring, implementation of SCMs such as raingardens and vegetated roofs, detection of sewer leaks, invasive species removal, and educational programs.

This grant targets four sub-catchments of a North Oconee River watershed:

Lilly Branch

Lilly Branch is a tributary of the North Oconee River with a watershed that includes the Five Points neighborhood of Athens, Georgia and the eastern portion of the UGA Campus. Approximately two-thirds of the 1830-meter stream reach is encased in culverts. The longest stretch of day-lighted stream outlets on east campus adjacent to the Lamar Dodd School of Art, enters two culverts supporting roads and then flows into the North Oconee River.

Lilly Branch is an impaired urban stream with a long history of alteration beginning with intensive cotton farming over a century ago, and more recently, with watershed urbanization. Over forty percent of the 409-acre Lilly Branch watershed is impervious, with limited riparian zones. This urbanization generates high storm water flows that scour stream reaches of Lilly Branch and pollute the North Oconee with sediment. Water quality data indicates high levels of fecal coliform, excessive copper and zinc, and high nutrient loads. Remediation of hydrocarbon contamination from Leaking Underground Storage tanks is ongoing. Bioassessments for invertebrates show only the most pollution-tolerant organisms survive in Lilly Branch. In addition, the day-lighted section of the stream near the Lamar Dodd School of Art is heavily incised, disconnected from the flood-plain, and infested with invasive exotics.

Tanyard Creek

Tanyard Creek bisects the UGA campus and drains a 2.02-square kilometer watershed that is 74% impervious surface. Approximately 50% of the stream length is piped, including a segment beneath Sanford Stadium. It is listed on Georgia's 303(d) list for failure to meet its designated use of fishing as a result of fecal coliform levels. Macroinvertebrate sampling indicates very poor water quality. Turbidity ranges from 2 to 220 NTU and often exceeds USEPA-recommended levels of 25 NTU while conductivity also exceeds recommended levels. More detailed information is included in the Nine Element Plan that characterizes land use and monitoring data.

Physical Plant Drainage

The Physical Plant Drainage is entirely contained within the UGA campus. It is piped for most of its reach, daylighting a few hundred meters before entering the Oconee River. It includes several UGA buildings and parking lots and includes the steam plant and Facilities Management staging areas.

Lake Herrick

Lake Allyn M. Herrick is a 15-acre water body on the southern end of UGA's campus, located in the center of the Intramural Field and Oconee Forest Park complex. Its watershed encompasses 248 acres, including 66.4 acres which drain into the subwatershed of a tributary pond which carries the pejorative nickname "Parvo Pond." This reference to canine parvovirus, a highly contagious pathogen spread between dogs via fecal contact, is a testament to the pond's notoriously poor water quality. Land uses within the watershed include the entirety of UGA's intramural fields and Oconee Forest Park, an apartment-style graduate student housing complex, a stretch of State-owned highway, a campus transit facility (bus maintenance and storage), and a portion of a residential neighborhood. The lake was constructed in 1982 for purposes of recreation, research, and teaching. It originally featured a beach with a swimming area, a boathouse with canoes and sailboats available for student use, and a management plan that provided for fishing. However, swimming and boating were banned in 2002 following a period of declining water quality and various management problems. The lake managers also stopped stocking the water with fish. Since then, the lake has remained closed and persists in an underutilized state, although Lake Herrick and the Oconee Forest Park continue to be used by many classes for field studies in forestry, ecology, biology, and other biological sciences, and are popular for both organized and informal recreation.

Lake Herrick and Parvo Pond are affected by elevated levels of sediment, bacteria, and nutrients. Monitoring results frequently reveal pH and dissolved oxygen levels to be excessively low. Monitoring indicates that the water quality is steadily declining with regards to all of the aforementioned parameters of concern. Water quality conditions are consistently worse in Parvo Pond compared to Lake Herrick on all counts. Contaminant inputs are attributed to general nonpoint source pollution from urban stormwater runoff, erosion and sedimentation within the watershed, and bacteria inputs from both wildlife (Canada geese) and domestic pets (given the presence of a popular dog park adjacent to Parvo Pond).

This project will improve water quality, enhance ecosystem function, slow storm water flows and educate the public on watersheds, and water quality. It includes the installation and demonstration of a variety of SCMs in areas of the watershed where our modeling has determined them to be most efficacious. These will include water harvesting, porous paving, bioretention areas, and a stormwater wetland. The installation of these SCMs will directly result in decreased pollutant loading to Tanyard Creek, Lilly Branch, the physical plant drainage, and Lake Herrick.

We will use every stage of SCM installation, monitoring and maintenance as an opportunity to educate a variety of stakeholders through class instruction, research, workshops, field days, and general press. University students will benefit from classroom opportunities to learn about SCM function firsthand. Researchers will be able to monitor SCM performance and contribute to the growing body of research surrounding this promising technology. Target audiences in the Athens-Clarke County community include elementary school students, practitioners involved with the design and construction of stormwater infrastructure, and landowners in the headwaters of the watershed. The project will also create targeted education campaigns for other best management practices identified in the nine element plan that encourage behavior to protect water quality by residents, landowners, and UGA maintenance staff.

Grant deliverables

Project partners systematically assessed the sources of contamination and potential solutions and seek funding to address the following priorities:

- Implement and monitor SCM demonstration sites on campus and private land via ACC Stormwater Services to address impairment sources including fecal coliform bacteria, metals, nutrients and turbidity.
- Support staff, faculty, graduate assistants, and private contractors to design, install and monitor SCMs and other BMPs and to conduct targeted outreach and education activities.
- Complement outreach by facilitating installation of SCMs on private and commercial properties through the private landowners' incentive program partnership with Athens Clarke-County government.
- Conduct targeted education and outreach campaigns to address the following issues: leaking dumpsters, illicit discharges, contamination from pet waste, and installation and maintenance of rain gardens and barrels.

Implementation of structural stormwater control measures

UGA has committed to integrating Stormwater Control Measures (SCMs) into the Lake Herrick/Oconee Forest Park site plan to reduce pollutant loading and create habitat potential. The Lake Herrick watershed is a worthy candidate for efficient and successful SCM-driven water quality improvement that is highly visible. The majority of the catchment is controlled and managed by the University of Georgia. A portion of an existing water body (Parvo Pond) can be retrofitted with an enhanced swale and stormwater wetland to address fecal and other constituent loading. These SCMs would treat the first flush of the nonpoint source pollution runoff that enters Lake Herrick. Montoring and education programming are proposed to extend scientifically based information regarding the reduction of nonpoint source pollution.

Monitoring is a particularly important component of projects which utilize SCMs for water treatment because there is currently only a small body of peer-reviewed literature which addresses the efficacy of these methods. Such technology is relatively young compared to conventional, mechanized water treatment methods, and an expanded knowledge base is necessary to improve modelling tools for more accurate projections of water quality improvement. The University of Georgia is home to a strong culture of high quality scientific research, and is will thus be able to take full advantage of the opportunity to monitor the function of SCM facilities. Publication of research findings will contribute to the development and enhancement of green infrastructure technology.

On-campus SCM facilities will also serve as demonstration projects for education and outreach to promote practices amongst the general public which will likely lead to water quality improvements. Because the catchments two major water bodies are at the center of UGA's recreational sports and nature park complex, they are highly visible and thus provide ample opportunity to showcase structural SCMs for demonstration, education, and research. Although pollutant loads are increasingly elevated, they are not so far out of hand as to be un-manageable. Water quality goals – to reduce pollutants to levels acceptable for swimming and boating – are realistically obtainable; Lake Herrick's waters could conceivably be suitable for swimming within a few years of structural SCM implementation. The tangible recreational benefits brought about by successful restoration of the Lake Herrick watershed could catalyze similar efforts with other, more highly-impacted campus watersheds. Funding this grant proposal would ensure these projects are constructed and monitored.

Private Landowners' Incentive Program for SCM Installation

Much of the headwaters of the catchments are controlled by private residential and commercial owners. These areas were targeted in the Nine Element Watershed Management Plan for pollution reduction. Water harvesting, rain gardens and riparian buffers are most appropriate in these areas. Project partners Athens Clarke-County Stormwater Services would facilitate the incentive program for the use of rain barrels, cisterns and rain gardens on private property. Letters of support from these entities suggest that existing partnerships will be enhanced and beneficial changes to improve stormwater will occur if this proposal is funded.

Other suspected impairment sources include commercial waste management practices in the watersheds. Bacteria and runoff from uncovered dumpsters and improper discharge of waste, especially from food service establishments, may both be significant contributors of pollutants. This grant application seeks funding for UGA and partners to educate landowners about covering and plugging dumpsters to reduce contaminants that are likely reaching surface waters. Outreach campaigning will also target restaurant owners and employees to enhance their understanding of the impact that their waste disposal practices can have on local water quality.

Each of the nonpoint pollution sources listed above requires an increase in public awareness and ensuing behavior change to improve water quality and eventually delist the impaired surface waters. This grant would fund demonstration projects and accompanying education and outreach. If successful, the educational campaign can be modeled for other urban watersheds with similar nonpoint pollution sources.

Education and Outreach

Reducing nonpoint source pollution inputs will require targeted education campaigns aimed at businesses, land owners and the University of Georgia community; some of these will capitalize on our SCM projects as teaching tools. Direct and indirect educational outreach will be offered through workshops, field days and tours, and targeted education campaigns to foster behavior change. Specific programs will include workshops for professional design and construction practitioners, local landowners and business owners, elementary school children, and UGA employees. For example, UGA Grounds Department will host workshops for facilities staff to improve trash and recycling storage and materials storage practices on campus, resulting in reduced nonpoint source contamination. Funding for signage and web delivery is also requested in this grant application. Prominent signage at the Oconee Forest Park Stormwater Wetland will serve many students and visitors.

Future Directions

The Watershed Management Plan details the long-term goals of the effort to improve surface water quality in the four catchments. The document outlines milestones for success regarding the initiation of BMPs for managing pet waste, eliminating contamination from dumpster runoff, managing outreach and education programs, monitoring for water quality parameters, removing invasive species and managing riparian buffers, and installing structural SCMs.

5. Project Activities:

Project Activity #1: *Implement SCMs on UGA campus.*

Task 1: *Construct SCMs and educational interface for Science and/or Business Learning Center.*

- **Deliverables:** *Structural SCMs installed around new building(s) and at least one interactive dashboard installed in building common area.*
- **Measures of Success:** *Certificates of Completion for a minimum of two (2) BMP systems in accordance with NRCS specifications.*

Task 2: *Administer exotic/invasive vegetation removal and vegetated buffer management program.*

- **Deliverables:** *Report detailing project workdays and quantifiably measured results.*
- **Measures of Success:** *Restoration of native vegetation to targeted stream buffers in campus watersheds.*

Task 3: *Complete final stages of design development for Parvo Pond stormwater wetland and enhanced swale*

- **Deliverables:** *Project manual with construction documents, bid proposals and management, construction observation.*
- **Measures of Success:** *Ability to construct wetland to the specifications of documents produced.*

Task 4: *Construct Parvo Pond stormwater wetland and enhanced swale*

- **Deliverables:** *Structural SCMs installed at Parvo Pond site.*
- **Measures of Success:** *Certificate of Completion/Payment Request on BMP system in accordance with NRCS specifications.*

Task 5: *Monitor SCM performance and disseminate results.*

- **Deliverables:** *Acquisition of all equipment specified in budget. Samples collected and recorded for fecal coliform, some nutrients and metals at stormwater wetland; flow weighted composite samples capture at least four consecutive seasons with three storms each season to detect seasonal differences.*
- **Measures of Success:** *Water quality analyses conducted and changes in water quality as a result of stormwater control measures and activities documented.*

Findings presented at minimum of one professional conference and published in at least one peer-reviewed publication.

Project Activity #2: *Implement SCMs on Private Property*

Task 6: *Work with ACC to provide education and incentives to landowner on rain gardens, rain swales, and cisterns*

- **Deliverables:** *Development of an incentive program for landowners*
- **Measures of Success:** *Number of SCM's installed*

Task 7: *Install pet waste collection stations*

- **Deliverables:** *At least 3 pet waste collection stations installed.*
- **Measures of Success:** *Reduction in fecal coliform inputs to campus watershed subcatchments.*

Project Activity #3: *Education and outreach targeting the campus community*

Task 8: *Interpretive signage for stormwater wetland.*

- **Deliverables:** *Two signs fabricated and installed detailing function, design and construction of projects.*
- **Measures of Success:** *Installed two signs at stormwater wetland.*

Project Activity #4: *Education and outreach targeting Athens-Clarke County*

Task 9: *SCM design workshop*

- **Deliverables:** *Present workshop to design and engineering practitioners regarding an introduction to stormwater treatment and how to design a site with interconnected SCMs' to mimic predevelopment hydrologic water and nutrient flows.*
- **Measures of Success:** *Questionnaire (retrospective) to assess change in knowledge using Wilcoxon Rank Sum statistic for analyses.*

Task 10: *SCM construction workshop*

- **Deliverables:** *Present workshop detailing the implementation of SCM's to design and engineering professionals, contractors and maintenance personnel.*
- **Measures of Success:** *Questionnaire (retrospective) to assess change in knowledge using Wilcoxon Rank Sum statistic for analyses.*

Task 11: *SCM monitoring workshop*

- **Deliverables:** *Present workshop for design and engineering professionals, contractors and maintenance personnel, detailing the monitoring associated with either the construction or post occupancy evaluation of SCM's.*
- **Measures of Success:** *Questionnaire (retrospective) to assess change in knowledge using Wilcoxon Rank Sum statistic for analyses.*

Task 12: *Illicit Discharge education for businesses*

- **Deliverables:** *Data on what business owners know about illicit discharge and its enforcement, what would motivate them to change behavior, what the impediments are that cause them to discharge improperly.*
- **Measures of Success:** *Data collected from 70% of targeted businesses and development and implementation of pilot program to change behavior*

Task 13: *Education on water quality impacts from pet waste*

- **Deliverables:** *Brochure included with stormwater utility fee notice with information regarding water quality impacts of dog waste and instructions for proper disposal.*
- **Measures of Success:** *Brochures created and sent to residents.*

Task 14: *Elementary Education*

- **Deliverables:** *Work with Barrow Elementary school to further develop and implement watershed education program and expand the program to Chase St Elem and Clarke Middle School*
- **Measures of Success:** *Hours of programming delivered to elementary school students.*

Task 15: *UGA Employee Training Program*

- **Deliverables:** *Deliver a required training to appropriate UGA staff whose jobs impact water quality.*
- **Measures of Success:** *Relevant employees complete the training module.*

Project Activity #5: *Researching, reporting, and generating feedback*

Task 16: *Quarterly and final reports*

- **Deliverables:** *Quarterly and annual reports written and submitted.*
- **Measures of Success:** *Successful submittal of reports.*

Task 17: *Communications outreach*

- **Deliverables:** *Formative research and analysis of three key audiences: dog owners, business owners, and property owners. Development and pilot testing of communication messages, creation of a communication plan based on social marketing principles.*
- **Measures of Success:** *Specific, measurable objectives for increasing awareness and initiating behavior change will be developed based on formative research and will be part of the written plan*

Task 18: *Continue ongoing water quality monitoring activities throughout the campus watersheds.*

- **Deliverables:** *UGA Grounds Department will renew contract with Brown & Caldwell to conduct quarterly monitoring at established points throughout catchments.*
- **Measures of Success:** *2016 and 2017 campus watershed monitoring reports*

Task 19: *Update 9-Element Plan*

- **Deliverables:** *2015 plan will be updated with appendices to reflect progress of SCM implementation and expanded detail regarding future efforts.*

- **Measures of Success:** *Plan is updated.*

•

6. Roles and Responsibilities of Participating Organizations:

Organization Name	Specific Responsibilities
UGA River Basin Center (*Lead Organization*)	• Execute grant contract with GAEPD • Request payments from GAEPD on a quarterly basis • Pay funds to appropriate contractor(s) and vendor(s) and request reimbursements from GAEPD • Track the progress of project activities completed, grant funds expended, and match values provided in accordance with the drawdown & implementation schedule • Track all project activities in accordance with the implementation schedule • Complete and submit quarterly progress reports and invoices to GAEPD by January 15th, April 15th, July 15th, and October 15th of each project year • Complete & submit close-out report at conclusion of project • Coordinate educational programming
GAEPD	• Provide 60% of total project costs • Review and approve project deliverables • Participate in meetings, as appropriate • Review and assist as needed with 319(h) Grant protocols • Provide project oversight and contract management
UGA Office of Sustainability *(Project Coordination)*	• Work with RBC Staff on Quarterly and Annual Reports • Coordinate Faculty, Staff and Graduate Assistants • Maintain project database • Work with Environmental Practicum Students • Assist with workshops and employee education module.
UGA College of Environment and Design	• Assist with design, and project oversight for SCM implementation at Parvo Pond • Provide educational outreach including design of brochures, websites, and fiberglass embedded graphic outdoor signage; Setup and coordinate field tours and workshops • Assist ACC with cost share program • Install and maintain sampling stations and equipment, download and analyze data. • Travel to observe other demonstration projects and present findings at professional conferences. • Disseminate results in peer-reviewed scientific journals • Assist with educational outreach content; coordination and preparation of field tours and workshops. • Assist with preparation and submission of quarterly and final reports. • Coordinate Elementary Education Campaign
UGA Odum School of Ecology	• Oversee Environmental Practicum students • Participate in advisory committee • Assist with development and implementation of SCMs

	• Coordinate student and faculty involvement in the project • Assist with Elementary Education Campaign
UGA Environmental Practicum	• The Environmental Practicum, an interdisciplinary graduate-level course focusing on the integration of science and policy, will research pertinent issues and perform many of the public education and outreach activities. Students are co-taught by a team of faculty including the principal investigators.
UGA Office of University Architects	• Coordinate contractors for educational events and site access
UGA Physical Grounds Department	• Design and install campus SCM's • Coordinate contractors for educational events and site access
Athens-Clarke County Stormwater Department	• Illicit discharge education and outreach • Manage urban cost share program for SCMs.

7. Project Location:

a) **Project Area Description and Map:**

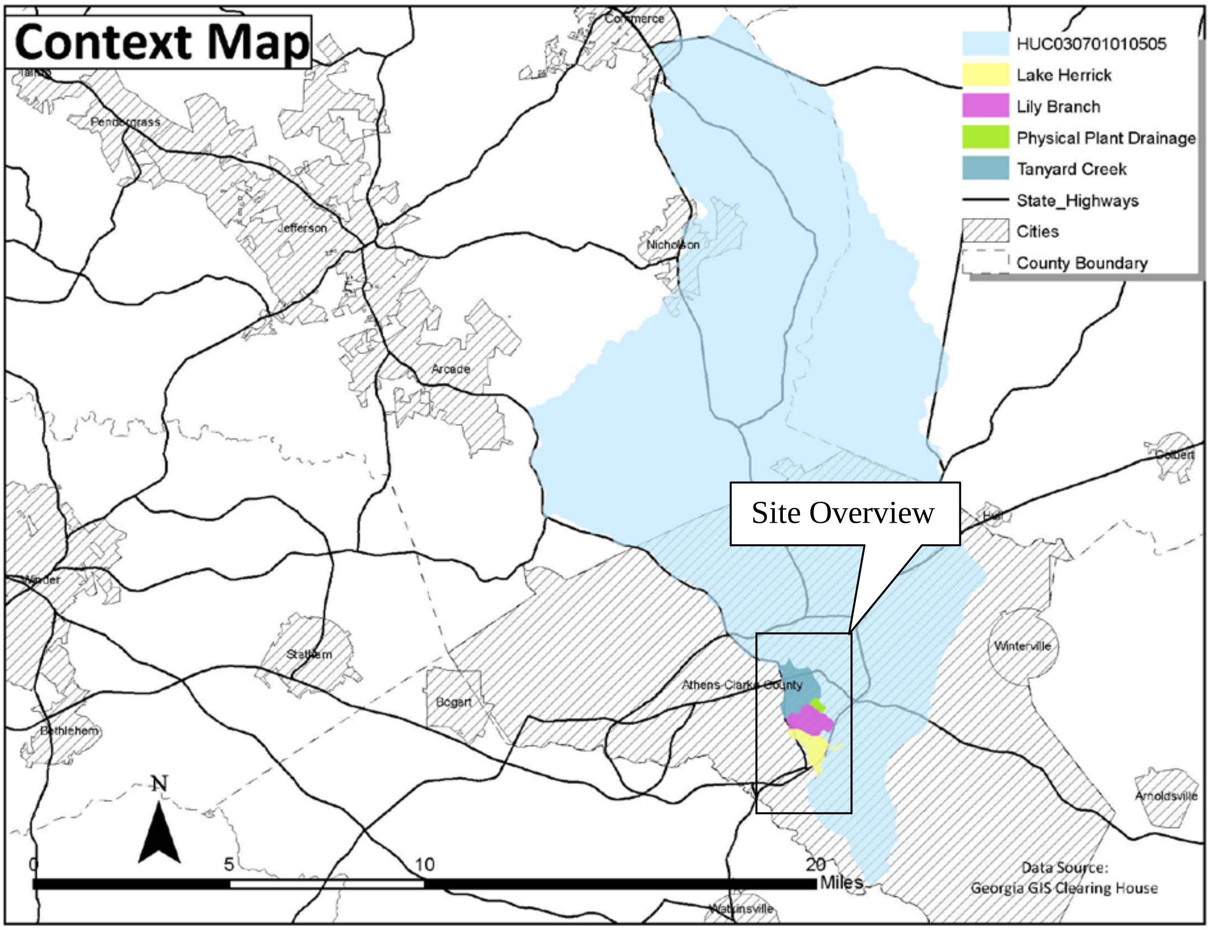

Figure 1: Site Context and Overview locates four catchments within HUC #: 030701010505.

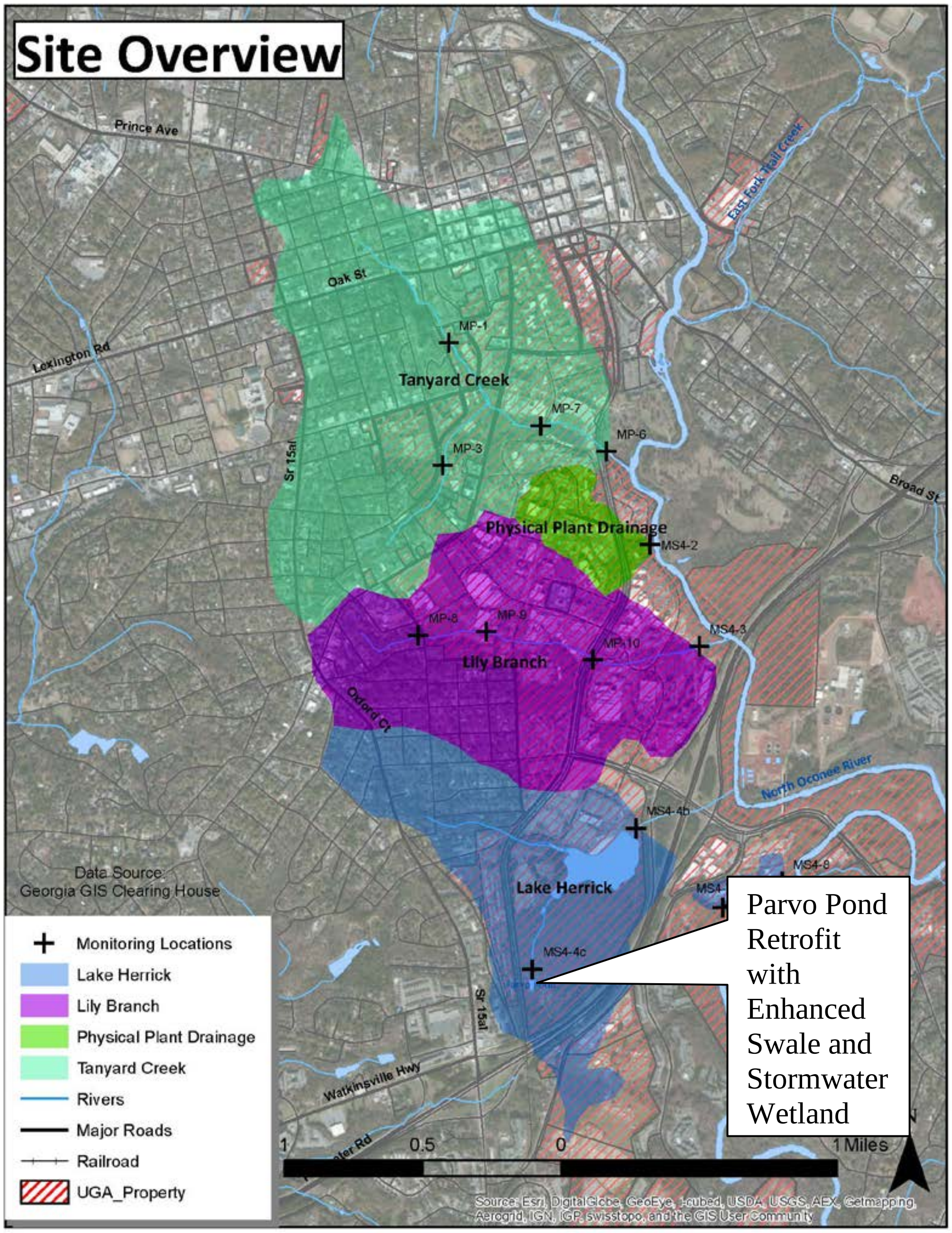

Figure 2: Site Overview illustrating four catchments. 319 Funds will be implemented primarily at the Parvo Pond Site as shown.

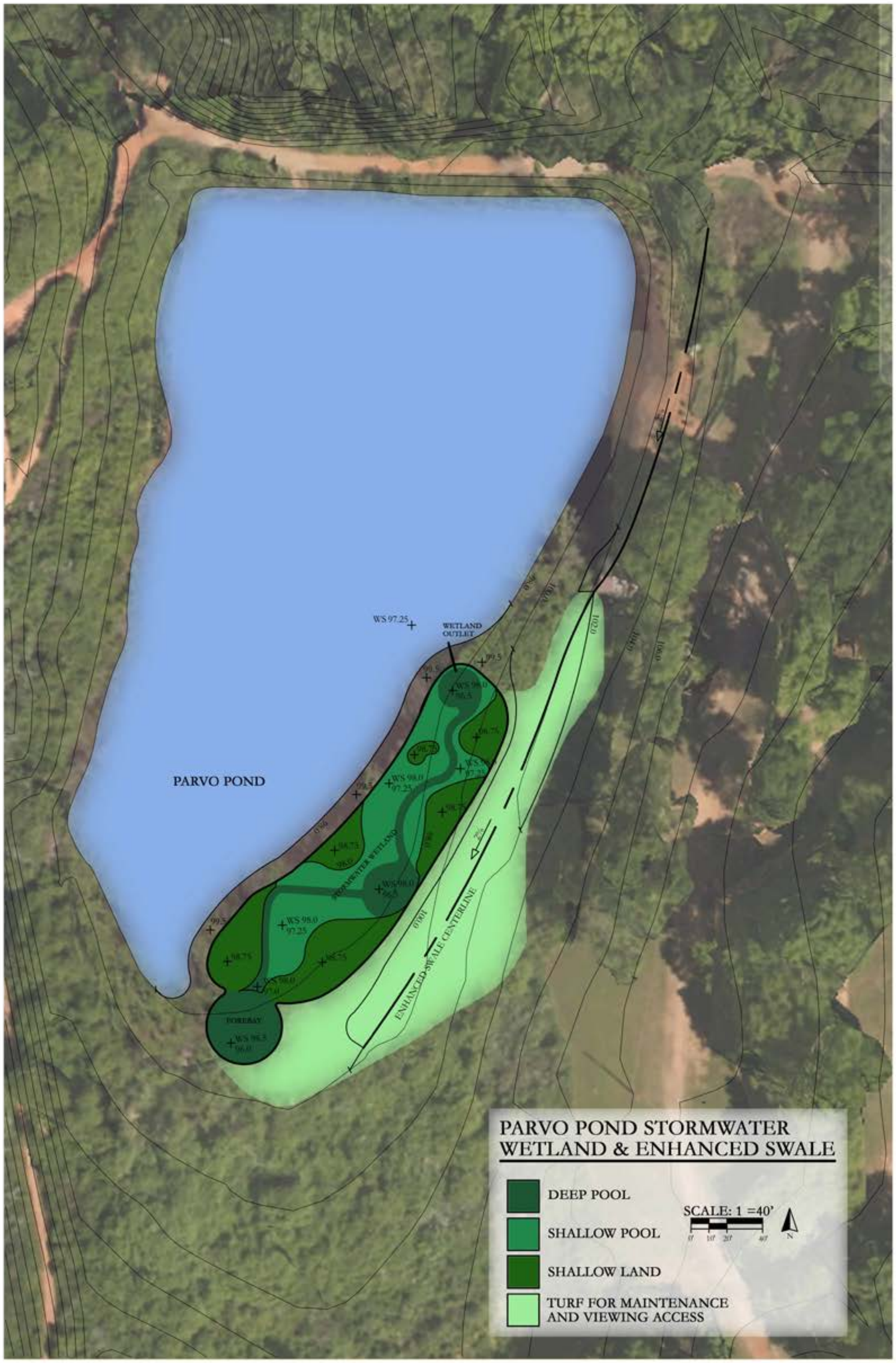

Figure 3: Conceptual Plan of Enhanced Swale and Stormwater Wetland

b) Watershed(s) or Project Area Size (Acres): 1,318.32 Acres total. This includes 1,070.32 acres for the combined Tanyard Creek, Lilly Branch, and Physical Plant catchments. The Lake Herrick catchment is 248 acres in its entirety; the Parvo Pond sub-catchment is 66.4 acres.

c) County or Counties: Athens-Clarke County

d) List the Following for the Watershed(s) or Project Area:

Stream Miles: __2.88___ Lake Acreage: __17.5___ Wetland Acreage: ________

e) Land Uses within the Watershed(s) or Project Area (Percentages):

	Tanyard Creek, Lilly Branch, & Physical Plant Drainage	*Lake Herrick*
Agricultural	2%	0%
Commercial Forestry	0%	0%
Urban/Residential	84%	65%
Mining/Extraction	0%	0%
Forest/Natural Areas	11%	29%
Water/Wetlands	3%	6%
TOTAL	100%	100%

*Land uses within the Lake Herrick Watershed are listed separately from the land uses associated with the Tanyard Creek, Lilly Branch, and Physical Plant Drainage watersheds because the two project areas are of significantly different character. The Lake Herrick watershed contains a much higher proportion of permeable surface, while the watersheds of the three streams are generally more impervious and urbanized.

Data Source & Date: Data for Tanyard Creek, Lilly Branch, and Physical Plant Drainage: Atlanta Regional Information System, UGA Office of University Architects GIS Database, American Planning Association; Data for Lake Herrick: UGA Grounds Division GIS Database and Bing Maps aerial photography, October 2013. ______________________

f) Hydrologic Unit Code(s), Watershed Name(s) and Priority Watershed(s):

HUC #: __030701010505___ Name: _Tributaries to North Oconee_ Priority: ____

8. Nonpoint Source Pollution Impairments and Healthy Waters:

a) Section 305(b)/303(d) List of Waters:

Water Body Segment Name (Segment Length (Miles) or Embayment Acreage)	County Location(s)	Criterion Violated or Water Quality Concern	Listing Status Category 4a, 5 or 1	Plan Exists to Implement TMDL or Address Water Quality Concern YES / NO
North Oconee River	Trail Creek to Oconee River, Clarke County	Fecal Coliform	4a	Yes

b) Secondary Pollutant(s):
Sediment, Total Nitrogen, Total Phosphorus, Copper, Zinc

c) Other Documented Nonpoint Source Impacts (Only Applicable to Project):

Segment Impacted: North Oconee River, Trail Creek to Oconee River, Clarke County

Pollutant(s) or Water Quality Threat(s): *Sediment, Total Nitrogen, Total Phosphorus, Copper, Zinc,elevated pH, and low Dissolved Oxygen*

Source(s) of Documentation: UGA Watershed Management Plan, Brown & Caldwell Tanyard Creek, Lilly Branch, and MS4 Locations Water Quality Report September 2013 (Appendix)

9. Monitoring:

X DRAFT QA/QC Water Quality Monitoring Plan Attached *(listed in Section 12.)*

☐ Project Will Not Include Water Quality Monitoring

10. Project Budget:

(See pages 24 - 27 of the FY2015 General Guidelines for Section 10 Instructions)
(Sign and date one-sentence Disclaimer provided at bottom of Project Budget)
(Supply Narrative related to Project Activities & Tasks to Justify Expenses and Match Value for Appropriate Item Class Category Entries)

Please double-check all budget calculations!

Item	Item class category	319 Grant funds 60% maximum	Nonfederal matching funds 40% minimum	Total
A	Staff Position 1 - 0.2 FTE ($15,000/year) for 3 years: description of duties: River Basin Center staff salary to coordinate Grant and associated projects; prepare and submit quarterly and final reports; coordinate educational programming; contract administration for construction and educational outreach projects; disseminate research-based information	$ 45,000		$ 45,000
A	Matching Research Salary: Administration		$ 12,000	$ 12,000
A	Staff Position 2 - .25 FTE ($19,250/year) for CED faculty summer salary over two years. CED faculty to assist graduate students. Description of duties: assist Staff Position with associated project management; assist staff person with preparation and submission of quarterly and final reports; direct and indirect educational outreach content for field tours and workshops; travel to observe other demostration projects and present findings at professional conferences.	$ 38,500		$ 38,500
A	Matching Research Salary: Planning and Conceptual Design Development for Parvo Pond stormwater wetland in Herrick catchment; data collection for assessment phases. Match letter included.		$ 16,750	$ 16,750

Item	Item class category	319 Grant funds 60% maximum	Nonfederal matching funds 40% minimum	Total
A	Staff Position 3 - .25 FTE ($14,000/year) for 1 CED graduate assistant for 2 years: description of duties: assist Staff Position with direct and indirect educational outreach including design of brochures, websites, fiberglass embedded graphic outdoor signage; setup and coordinate field tours and workshops; associated project management; assist staff person with preparation and submission of quarterly and final reports; assist ACC with cost share program	$ 28,000		$ 28,000
A	CED Assistantship		$ 6,000	$ 6,000
A	Staff Position 4 - .25 FTE ($17,500/year) for graduate assistant for 1 years: description of duties: install and maintain sampling stations and euiptment, download and analyze data; disseminate results in peer reviewwed scientific journals and assist Staff Position with direct and indirect educational outreach content; coordinate with CED assistantship; coordinate and prepare field tours and workshops; associated project management; assist staff person with preparation and submission of quarterly and final reports;	$ 17,500		$ 17,500
A	Staff Position 5 - 2 Interns over two years at OoS ($2,640/year) Intern Position at the Office of Sustainability	$ 10,560		$ 10,560
B	Fringe Benefits: Staff Position 1 (28%) for 3 years	$ 12,600		$ 12,600
B	Fringe Benefits: Staff Position 2 (28%) for 2 years	$ 10,780		$ 10,780
B	Fringe Benefits: Staff Position 3 (5%) for 2 years	$ 1,400		$ 1,400

Item	Item class category	319 Grant funds 60% maximum	Nonfederal matching funds 40% minimum	Total
B	Fringe Benefits: Staff Position 4 (5%) for 2 years	$ 875		$ 875
B	Fringe Benefits: Staff Position 5 (5%) for 2 years	$ 528		$ 528
C	Travel: PI, Co-PI, assistants, and staff travel to coordinate projects and disseminate results at professional meetings	$ 14,000		$ 14,000
D	Equipment: 2 ISCO samplers with glass and plastic bottles, tipping bucket rain gauge, bubblers to detect stage, flumes, Flowlink software and associated pump, withdrawl tubing, dessicant; Purpose/Use: Flow weighted sampling equiptment to determine any changes due to project enhancement activities primarily for use in Herrick catchment	$ 16,000		$ 16,000
E	Supplies: laptop computers, software; Purpose/Use: download data from monitoring equipment in the field, run flowlink software, educational outreach and dissemination of results	$ 7,380		$ 7,380
E	Supplies: 6 continuous water level and temperature sensors and associated hardware and software; Purpose/Use: record information to document any changes in water quality as a result of stormwater control measures and activities across four catchments (Tanyard, Lily, PPD, Herrick)	$ 8,700		$ 8,700
E	Supplies: Purchase at least one cistern and assosciated pumps for water harvesting and reuse (8K), dumpster covers and plugs (3K), Pet waste collection stations and refill bags (3K), workshop Supplies (4K); Purpose/Use: SCM implementation and dissemination of outreach information across four	$ 18,000		$ 18,000

Item	Item class category	319 Grant funds 60% maximum	Nonfederal matching funds 40% minimum	Total
	catchments (Tanyard, Lily, PPD, Herrick)			
F	Contractual: Design, permit, construction and administration of stormwater control measures and educational interface for both Science and/or Business Learning Centers		$ 5,000	$ 5,000
F	Contractual: Anderson Foundation and other nonfederal sources including inkind match for all watersheds to monitor and document conditions for impaired channels and aggressive exotic vegetation in Lilly and Herrick catchments.		$ 44,000	$ 44,000
F	Contractual: Ford Foundation to monitor and treat aggressive exotic vegetation in Lilly and Herrick catchments.		$ 12,500	$ 12,500
F	Contractual: Water Quality Lab analyses and dissemination of results. Analyses of fecal coliform, some nutrients and metals at stormwater weltand, flow weigthed composite pre and post samples to capture at least four consecutive seasons with four storms each season to detect seasonal effect. Up to 40 grab samples of SCM's will be analyzed as available. W1 Basic Water Test (pH, P, Cu, Zn), W4: Any single anion in W3--Phosphate (PO4), W8: Ammonium Nitrogen (NH4-N), W11: Conductivity, W17: Kjeldahl Nitrogen , W21: TSS, W27 A: Total Phosphorus, W32: Total Nitrate + Nitrite as N, W35: Fecal/E coli	$ 20,800		$ 20,800
F	Contractual: Fabricate Fiberglass Embedded Signage and associated supports	$ 4,500		$ 4,500

Item	Item class category	319 Grant funds 60% maximum	Nonfederal matching funds 40% minimum	Total
F	Contractual: Printing of Workshop Materials, Web design and hosting	$ 1,250		$ 1,250
F	Contractual: Consultants to assist with tasks including Graphic Design, review of publications and reporting	$ 1,250		$ 1,250
F	Contractual: Later phases of Design Development (including Specifications, Project manual with Construction Docs, Bid Proposals and management, Construction observation) of enhanced swale and Parvo Pond stormwater wetland in Herrick catchment	$ 18,500		$ 18,500
F	Contractual: Preconstruction Sediment and Erosion Control, Construction of flow splitter (if needed) enhanced swale, stormwater wetland with drawdown and culvert for enhanced swale and Parvo Pond stormwater wetland in the Herrick subcatchment.	$ 74,000		$ 74,000
F	Contractual: Contract with ACC stormwater services for incentive program to implement SCMs on private property across four catchments (Tanyard, Lily, PPD, Herrick)	$ 25,000		$ 25,000
F	Contractual: UGA Grounds Dept Quarterly Monitoring by Brown and Caldwell over two years across four catchments (Tanyard, Lily, PPD, Herrick) and includes likely construction of stormwater control measures, which may include vegetated roofs, water harvesting (rain barrels and cisterns), bioretention (rain pockets and rain gardens), stormwater wetlands, permeable parking and improving non point sources with implementation of pads, covers, and plugs on dumpsters, secondary		$ 50,000	$ 50,000

Item	Item class category	319 Grant funds 60% maximum	Nonfederal matching funds 40% minimum	Total
	containment and sand filters in one or more of the four catchments (Tanyard, Lily, PPD, Herrick). Match letter included.			
G	N/A			
H	N/A	$ -	$ -	$ -
	Total Direct Charges:			
I	(Sum of A-H)	$ 375,123	$ 146,250	
	Indirect Charges:	$ -	$ 187,562	
	Indirect on Match (fringe on salaries)		$ 14,375	
J	(0% Eligible for Reimbursement with Federal Dollars)			
	Total:			
K	(Sum of I and J)	$ 375,123	$ 333,812	$ 708,935

Below are supplemental tables that show subtotals for each budget item and match sources from nonfederal funds, but do not include waived indirect charges.

Budget Category Subtotals of Requested 319 Grant Funds	Amount
A	$ 139,560
B	$ 26,183
C	$ 14,000
D	$ 16,000
E	$ 34,080
F	$ 145,300
Grand Total	**$ 375,123**

Nonfederal Match Source (excluding waived indirects)	Amount
Nonfederal Match from UGA Office of University Architects	$ 5,000
Nonfederal Match from UGA Grounds Department	$ 50,000
Nonfederal Match from UGA Ecology	$ 68,500
Nonfederal Match from UGA CED	$ 22,750
Grand Total	**$ 146,250**

Disclaimer: Match contributions are from non-federal sources and do not overlap current or future projects funded by either 319(h) or other federal grants.

Signed: ______________________________ Title: ____________________ Date: ________

Organization: ____

Narrative Justification for Item Class Categories:

- **Personnel (A):** River Basin Center Staff - 0.3 FTE ($20,000/year) for 2 years; CED Faculty - .2 FTE ($14,000/year); CED Grad Assistant 1 - .25 FTE ($14,000/year); CED Grad Assistant 2 - .25 FTE ($24,000/year); OoS Interns - 2 Interns over two years at OoS ($2,640/year),

Narrative Justification (A): River Basin Center Staff salary to coordinate Grant and associated projects; prepare and submit quarterly and final reports; coordinate educational programming; contract administration for construction and educational outreach projects; disseminate research-based information. **CED Faculty** salary to assist River Basin Center Staff with associated project management; assist staff person with preparation and submission of quarterly and final reports; direct and indirect educational outreach content for field tours and workshops; travel to observe other demonstration projects and present findings at professional conferences. **CED Grad Assistant 1** to assist CED Faculty with direct and indirect educational outreach. **CED Grad Assistant 2** to install and maintain sampling stations and equipment, download and analyze data; disseminate results in peer reviewed scientific journals and assist CED Faculty with direct and indirect educational outreach content; coordinate with CED assistantship; coordinate and prepare field tours and workshops; associated project management; assist River Basin Center Staff with preparation and submission of quarterly and final reports. **OoS Intern 1** to assist with general project administration, coordination of workshops and educational programs. **OoS Intern 2** to assist with general project administration, coordination of workshops and educational programs.

- **Fringe Benefits (B):**
  - UGA Indirects waived 50% Maximum of Grant Request; $187,562 total.
  - River Basin Center Staff - 0.3 FTE - 28% fringe rate) for 2 years
  - CED Faculty - .25 FTE - (28% fringe rate) for 2 years

  - CED Grad Assistant 1 - .25 FTE - (5% fringe rate) for 2 years
  - CED Grad Assistant 2 - .25 FTE - (5% fringe rate) for 2 years
  - OoS Interns - (5% fringe rate) for 2 years.

- **Travel (C):** River Basin Center Staff, CED Faculty, and CED Grad Assistants travel to coordinate projects, transport samples, and disseminate results at professional meetings. Mileage charged at current federal rate.

  Narrative Justification (C): Travel corresponds to Project Activity #1 (Implement SCMs on UGA campus), Task 5 (Monitor SCM performance and disseminate results); research findings are to be presented at a minimum of one professional conference.

- **Equipment (D):**
  - Laptop computers and software correspond to Project Activity #1 (Implement SCMs on UGA campus), Task 5 (Monitor SCM performance and disseminate results); Computers will be used to record and analyze data and publish results in at least one peer-reviewed publication. Computers will also be used for administration of all tasks associated with Project Activity #4 (Education and outreach targeting Athens-Clarke County).
  - 6 continuous water level and temperature sensors and associated hardware and software correspond to Project Activity #1 (Implement SCMs on UGA campus), Task 5 (Monitor SCM performance and disseminate results); the equipment will be used to log environmental data for the purpose of documenting changes in water quality as a result of SCM implementation at Parvo Pond and other BMP-related activities across four catchments (Tanyard, Lily, PPD, Herrick).
  - 2 ISCO samplers with glass and plastic bottles, tipping bucket rain gauge, bubblers to detect stage, flumes, Flowlink software and associated pump, withdrawl tubing, and desiccant correspond to Project Activity #1 (Implement SCMs on UGA campus), Task 5 (Monitor SCM performance and disseminate results); the equipment will be used to log environmental data for the purpose of documenting changes in water quality as a result of SCM implementation at Parvo Pond.

  Narrative Justification (D): Equipment will be used to collect and analyze data, disseminate results

- **Supplies (E):**
  - For SCM implementation: At least one cistern and associated pumps for water harvesting and reuse ; Dumpster covers and plugs; Pet waste collection stations and refill bags
  - For dissemination of outreach information: Workshop Supplies

  Narrative Justification (E): All supplies are for the purpose of SCM implementation and dissemination of outreach information across four catchments (Tanyard, Lilly, PPD, Herrick).

- **Contractual (F):**
  - Design, permit, construction and administration of stormwater control measures and educational interface for both Science and/or Business Learning Centers
  - Preconstruction Sediment and Erosion Control, Construction of flow splitter (if needed) enhanced swale, stormwater wetland with drawdown and culvert for enhanced swale and Parvo Pond stormwater wetland in the Herrick subcatchment

UGA Grounds Dept construction of stormwater control measures, which may include vegetated roofs, water harvesting (rain barrels and cisterns), bioretention (rain pockets and rain gardens), stormwater wetlands, permeable parking and improving non-point sources with implementation of pads, covers, and plugs on dumpsters, secondary containment and sand filters in one or more of the four catchments (Tanyard, Lily, PPD, Herrick) non-Federal match)

- Ford Foundation and other nonfederal sources including inkind match for Tanyard and Lilly Branch Aggressive Exotic Management
- Water Quality Lab analyses and dissemination of results. Analyses of fecal coliform, some nutrients and metals at stormwater wetland, flow weighted composite samples to capture at least four consecutive seasons with three storms each season to detect seasonal differences. Grab samples of private SCM's will be analyzed as available.
- Fabricate Fiberglass Embedded Signage and associated supports
- Printing of Workshop Materials, Web design and hosting
- Consultants to assist with tasks including Graphic Design, review of publications and reporting
- Planning and Conceptual Design Development for Parvo Pond stormwater wetland in Herrick catchment; data collection for assessment phases Non-Federal match)
- Later phases of Design Development (including Specifications, Project manual with Construction Docs, Bid Proposals and management, Construction observation) of enhanced swale and Parvo Pond stormwater wetland in Herrick catchment
- Contract with ACC stormwater services for incentive program to implement SCMs on private property across four catchments (Tanyard, Lily, PPD, Herrick)
- UGA Grounds Dept Quarterly Monitoring by Brown and Caldwell over two years across four catchments (Tanyard, Lily, PPD, Herrick) non-Federal match)

Narrative Justification (F): UGA Office of Procurement will be responsible for bidding serviced in excess of threshold amounts. Projects will be bid.

- **Construction (G):**

- **Other (H):**
  Narrative Justification (H):

- **Indirect Charges (J):** Waived indirect costs will be applied in the category
  Narrative Justification (J): n/a

11. **Project Implementation & Drawdown Schedule:** Included file: :"ImplementationDrawdownSchedule_N_Oconee_UGA"

12. Project Attachment(s):

Appendix include support letters, Nine Element Plan, QAQC