PAVING THE WAY TO BETTER STORMWATER MANAGEMENT: WATER QUALITY, POROUS PAVEMENT, AND PUBLIC POLICY

by

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(Under the Direction of C. Ronald Carroll)

ABSTRACT

Urbanization is a pervasive threat to stream ecosystems. I examined the effects of urbanization on watershed hydrology and explored ways in which to reduce those negative impacts. The Etowah River basin (Georgia, USA) showed evidence of hydrologic alteration due to urbanization even at low levels (3-15%) of urban land use. Peak flows have increased and pollutant concentrations have increased significantly over time. Because the increase in stormwater runoff is causing measurable effects in Georgia streams, I tested the viability of using porous pavements for stormwater management on the fine-grained soils of the Piedmont. Monitoring of a full-scale grassy porous pavement parking lot demonstrated a 93% reduction in the volume of runoff and a significant decrease in turbidity of runoff for the porous lot vs. a nearby asphalt lot. A field experiment further supported these findings; concrete porous pavers were also effective in reducing the volume of runoff as well as nutrient and total suspended solids loads when compared to concrete controls. Porous pavements are an effective stormwater management practice for small storm events (< 2.64 cm). However, the use of porous pavements and other innovative stormwater management techniques are often prohibited or discouraged by local government regulations. Evaluation of zoning and subdivision regulations across the

Etowah River Basin identified areas that require revision in order to implement low impact development techniques. Working with an interdisciplinary group of researchers, I developed management tools, site design guidelines and a model stormwater management ordinance, that encouraged the use of source controls for stormwater. This was a drastic departure from the traditional collection and conveyance approach common in the Etowah River basin. The management tools are intended to reduce the degradation caused by impervious surfaces by preserving or mimicking natural watershed hydrology.

INDEX WORDS: Stormwater management, porous pavements, hydrologic alteration, low impact development

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INTRODUCTION AND LITERATURE REVIEW

The human population is projected to reach a population size of 8.9 billion by 2050 (United Nations 2003). This increasing population will continue to place a tremendous burden on the Earth's ecosystems. Historically, ecological research has focused on pristine or 'natural' areas and the influence of humans was often excluded (Palmer et al. 2004). However, pristine ecosystems are rapidly disappearing as more of the landscape is being converted for human uses (Vitousek et al. 1997). By 2007 over half of the human population will live in urban areas, the first time in history that more humans have lived in urban vs. rural areas (United Nations 2004). Because we cannot preserve all ecosystems, an important question for ecologists to address is what options exist when conservation of intact habitats is not possible (Palmer et al. 2004). Recently, Palmer et al. (2004) recommended an ecological research agenda that focuses on maintaining ecosystem services through ecological restoration and design. In areas where preservation of undisturbed ecosystems is not feasible, it may be possible nevertheless to incorporate ecosystem functions in the human environment (Palmer et al. 2004). In particular, there is a need for ecological design solutions for problems relating to urbanization, the degradation of freshwater ecosystems, and exchange of materials between ecosystems (Palmer et al. 2004). My dissertation addressed urbanization and its continued threat to aquatic ecosystems. My doctoral research examined how to maintain, or at least mimic certain features of, natural watershed hydrology in urbanized areas.

The Stormwater Problem

Urbanization is a pervasive threat to aquatic ecosystems. In urbanized areas, the increase in impervious surfaces causes significant changes in the quantity and quality of water delivered to streams (Brabec et al. 2002). Increases in impervious surface cover have been the focus of many studies examining how land use change affects aquatic ecosystems (Klein 1979, Arnold and Gibbons 1996; Booth and Jackson 1997). Impacts on streams are detectable at 8-12% total impervious surface cover of watersheds; although a recent study in Alaska shows impacts at levels as low as 4-5% impervious surface cover (Ourso and Frenzel 2003). Impacts on streams are considered unavoidable above 25% impervious surface cover (Schueler 1994; Booth and Jackson 1997).

As land use is converted from natural to urban uses, the movement of water through the environment is changed. Altered hydrology is one of the primary means by which urbanization affects stream ecosystems. In urban areas, peak flows are commonly greater than those in non-urbanized areas for all except the largest flood events (Booth 1991; Rose and Peters 2001). Impervious surfaces deliver a higher volume of water to streams via surface runoff (Arnold and Gibbons 1996; Dunne and Leopold 1978; Booth and Jackson 1997; Paul and Meyer 2001; Booth et al. 2002). The alteration in hydrology is one of the most serious threats to aquatic ecosystems because flow is a major determinant of physical habitat in streams, aquatic species have evolved life history traits in response to the natural flow regime, connectivity of aquatic habitats is essential for population viability, and altered flow regimes facilitate successful invasion by exotic species (Bunn and Arthington 2002).

Significant changes in channel morphology occur at 10-20% impervious surface area (Bledsoe and Watson 2001). Channel form is determined by sediment and water supply (Dunne and Leopold 1979) therefore increasing the frequency and magnitude of storm events has a large effect on stream channel geomorphology (Wolman and Miller 1960). As development of a watershed begins, sediment yields increase due to construction activities (Arnold et al. 1982). However, over time sediment yields decrease in areas covered by impervious surfaces (Arnold et al. 1982). The change in sediment and water supply result in increased channel erosion (Wolman and Schick 1967). Consequently, streams in urban areas commonly become enlarged (Arnold et al. 1982), incised (Doyle et al. 2001), or both (Hammer 1972).

Along with changes in hydrology and channel morphology, declines in the quality of stormwater runoff accompany urbanization (Brabec et al. 2002). Commonly observed changes in water chemistry of urban streams are increases in oxygen demand, conductivity, suspended solids, nutrients, hydrocarbons, and metals (Paul and Meyer 2001). Metals such as lead, zinc, chromium, copper, manganese, nickel, cadmium, mercury are common constituents of urban runoff (Marselek et al. 1999; Legret and Pogatto 1999). These chemical changes, combined with the alterations in hydrology and channel morphology, are major stressors for aquatic organisms. As a consequence, the abundance and richness of macroinvertebrates and fish are lower in urban streams (Klein 1979; Crawford and Lenat 1989; Horner et al. 1996; May et al. 1997).

Nonpoint source pollution is the leading cause of impairment for streams in the United States (EPA 2003). In Georgia, 98% of streams listed as partially or fully impaired identify stormwater runoff as the cause of degradation (EPD 2002). As awareness of the impacts of nonpoint source pollution increased, measures to control stormwater runoff were developed. Historically, stormwater control focused on sanitation and flood prevention (Reese 2001). However, as the stormwater problem grew, new approaches appeared that focused on protecting water quality and aquatic ecosystems (Reese 2001). These changes in management approaches were largely prompted by federal requirements to reduce pollution from stormwater runoff.

Federal and State Stormwater Management Requirements

The major federal provisions that mandate stormwater control are the Clean Water Act (CWA) and, indirectly, the Coastal Zone Management Act (CZMA). Nonpoint source pollution is most effectively and efficiently controlled through the management of land uses. Traditionally, land use control is under the jurisdiction of state and local governments. Recent amendments to the CZMA and CWA, however, include provisions to address nonpoint source pollution and stormwater more specifically.

The CZMA amendments in 1990 required states to develop programs to control nonpoint source pollution in coastal waters (Ferrey 1997). Both the United States Environmental Protection Agency (EPA) and National Oceanic and Atmospheric Administration (NOAA) must approve the state programs. States are required to identify land uses that contribute to the impairment of coastal waters. The CZMA is limited to coastal states, and in Georgia only 12 coastal counties within the state fall under its requirements. In contrast, the CWA provides for more comprehensive nonpoint source controls and directly addresses management of stormwater.

The CWA amendments of 1987 were the first to directly address the problem of stormwater. Section 405 of the CWA amendments is the cornerstone of stormwater regulation and establishes a phased approach to stormwater management. This approach essentially treats stormwater as a point source, with each stormwater outfall requiring a National Pollutant Discharge Elimination System (NPDES) permit. In 1990, EPA promulgated rules for implementing Phase I of the stormwater program (EPA 1990). Phase I required stormwater

NPDES permits for industrial facilities, construction sites over five acres, and municipal separate storm sewer systems which served a population of 100,000 or more. Phase I permits are similar to traditional NPDES permits in that they have numerical effluent limits for pollutant discharges and require monitoring.

EPA published the Phase II rules of the stormwater program in 1995 and these requirements went into effect March 2003 (EPA 1995). Phase II expands the federal stormwater program to include construction sites larger than one acre and small municipal separate storm sewer systems (serving populations of 10,000-100,000). Rather than stringent effluent limits and monitoring requirements, the Phase II program relies on the use of Best Management Practices (BMPs) to meet the requirements of the program. The six minimum requirements of the Phase II program are:

- Public Education and Outreach
- Public Involvement and Participation
- Illicit Discharge Detection and Elimination
- Construction Site Runoff Control
- Post-construction Runoff Control
- Pollution Prevention and Good Housekeeping

The Phase II rule does not specify which BMPs must be used to meet these requirements. The rule was drafted to allow individual communities to develop stormwater management plans tailored to their specific needs. Under the rule, EPA and the states are required to develop guidance on which BMPs are available for each of the six requirements. EPA has prepared a menu of BMPs and has posted this information on its stormwater website.

In Georgia, stormwater programs are delegated by EPA to the Georgia Environmental Protection Division (EPD 2002b). EPD uses a general permit for stormwater activities, including Phase II permits (EPD 2002b). General permits include requirements that apply to all permittees rather tailoring requirements to individual permittees. Phase II permittees, which include municipal separate storm sewer systems, submit a Notice of Intent (NOI) to be included under the General Permit. The NOI must show that permittees have developed a stormwater management plan that meets the federal stormwater requirements. EPD refers permittees to the Georgia Stormwater Management Manual (ARC 2003) for choosing and designing stormwater BMPs and encourages MS4s to consider their management plans 'flexible and constantly evolving.' All Phase II communities must develop and implement a stormwater management plan by December 2006.

Structural Best Management Practices

Many BMPs exist for controlling urban stormwater runoff. These BMPs may be organized into two major groups, nonstructural and structural BMPs. Examples of nonstructural BMPs include low impact development, better site design, good housekeeping measures, maintenance programs, hazardous material disposal, illicit discharge detection and elimination, and education and outreach programs. Structural BMPs, which are the most common means to control stormwater runoff, include but are not limited to detention and retention systems, constructed wetlands, infiltration practices and filtering practices. Following are brief descriptions of these common structural BMPs.

Detention and Retention Practices

Detention systems are the most widely applied stormwater control practices because they satisy the peak runoff reduction requirements in local regulations and are cost effective (Schueler 1987). Detention systems retain stormwater runoff following a storm event and slowly release flows to the drainage network. There are several types of detention ponds; the variations are based on whether the pond has a permanent pool of water (wet vs. dry ponds), and how long the water is detained (detention vs. extended detention). Retention ponds, also known as wet ponds, have a permanent pool of water and are generally used in larger (>200 acres) residential and commercial developments. The basic design of detention ponds is similar; however, the size, shape, and depth depend on the specific site and flows to be controlled. Detention ponds remove pollutants through gravitational settling (Whipple and Hunter 1981). Retention ponds are more effective at removing pollutants than dry ponds given the longer residence time, and thus settling time, of water in the pond (Field et al. 1993). Pollution removal efficiency can be increased by increasing the volume of the pond and the detention time (Comings et al. 2000).

Although detention/retention systems provide control of peak discharge rates, they do not actually reduce the volume of stormwater runoff produced. As an analogy, consider the traffic created in metropolitan Atlanta if several major events were to let out at rush hour. The traffic jam would last for hours. Because of this, many events are scheduled at different times to avoid this peak in traffic. Detention systems effectively do the same thing; detention delays the release of stormwater so that all the runoff does not reach the stream at the same time in order to avoid flooding. It does not, however, change the total volume of runoff produced. Detention provides moderate pollutant removal efficiencies for sediment, phosphorus, and nitrogen. On average, dry ponds remove 47% total suspended solids concentrations, 19% total phosphorus concentrations and 25% total nitrogen concentrations (Winer 2000). Retention ponds have higher removal efficiencies, removing 80% total suspended solids concentrations, 51% total phosphorus concentrations and 43% total nitrogen concentrations (Winer 2000).

Many communities are moving away from complete reliance on detention because it does not address the underlying cause of many stormwater impacts, namely the increasing volume of runoff as development proceeds. There are several reasons why detention fails including sizing problems, lack of volume control, and lack of ongoing maintenance (Schueler 1987). In fact, most detention ponds are not sized correctly using the most common methods for designing ponds (Booth and Jackson 1997; Horner et al. 2002). Studies show that detention ponds are not able to mitigate the negative effects of development on stream ecosystems (Maxted and Shaver 1996; Booth and Jackson 1997; Horner et al. 2002) The same amount of hydrologic and geomorphologic alteration and habitat destruction are found in watersheds using detention as those without. Because there are serious concerns about the effectiveness of detention it should not be solely relied upon to prevent stormwater impacts.

In a highly urban environment, the options for stormwater control may be limited (Schueler 1987). In these areas, streams are probably already degraded and are possibly past the point of recovery. Because it is unlikely that restoration of these streams will occur without restoring the natural hydrology, in-stream detention in these areas may be necessary in order to protect downstream reaches. Although not recommended for most areas, regional instream detention can be a valid option for an urban retrofit where land choices for BMP placement are limited.

Constructed Wetlands

Constructed or stormwater wetlands move a step beyond detention by incorporating biological components into design (Schueler 1987). The premise behind constructed wetlands is to mimic the benefits provided by natural wetlands. These benefits include filtration of pollutants, flood control, and wildlife habitat (Schueler 1987). The function of stormwater wetlands is to slow the flow of stormwater and filter pollutants. They are designed in much the same way as detention ponds but with the addition of wetland plant species and a focus on the use of biological processes to treat stormwater. Many of the pollutants are filtered by these added biological components; wetland plants trap particles and promote settling, giving microbial organisms a chance to process pollutants (Center for Watershed Protection 1995). Like detention ponds, there are a variety of designs for constructed wetlands, from shallow marshes to extended detention wetlands. There is wide public acceptance of wetlands and they are considered 'natural' amenities in many communities (Schueler 1987). Wetlands are actually safer than detention ponds; a lower number of drownings occur in wetlands when compared to detention because wetlands are generally incorporated into a development rather than tucked away and fenced off from the community so the community is more aware of them, wetlands have gentler slopes than detention ponds, and wetlands are generally more shallow than wet ponds (Schueler 1987). However, constructed wetlands are not as commonly used as detention because of the higher costs associated with construction (EPA 1999).

The benefits of constructed wetlands include improvement in downstream water quality, enhancement of vegetation and wildlife, and flood attenuation (EPA 1999). Constructed wetlands have approximately 20% higher pollutant removal capabilities than detention ponds, with shallow marsh and extended detention wetlands generally more effective than other constructed wetland types (Winer 2000). The effectiveness of the wetland may vary with season, with highest removal efficiencies during the growing season (Center for Watershed Protection 1995). Constructed wetlands provide peak storm flow control like detention systems, thus providing control of the design storm. However, constructed wetlands can also cause negative impacts up and downstream as well as within the wetland (EPA 1999). Limits to effectiveness include difficulty in establishing wetland plants and contamination of ground water and wildlife. If wetland systems are built in a stream there are more potential negative impacts such as upstream habitat destruction, habitat fragmentation, invasion of exotic invasive species, and increased downstream temperatures (EPA 1999).

Filtering Practices

Filtering practices include sand filters, organic filters, and biofilters. Because these practices are expensive and often difficult to install and maintain, they are not commonly used (EPA 1999). However, filtering practices are very effective at removing pollutants from runoff (Winer 2000). Sand filters can achieve high removal rates for sediment (58-87% removal) and metals (25-80%; Winer 2000) . Filtering practices are intended primarily for water quality improvement; they provide little volume or peak runoff control and generally do not restore or mimic natural hydrology (EPA 1999).

One type of biofilter is a simple strip of grass or other vegetation used to treat stormwater runoff (Schueler 1987). Filter strips are inexpensive to construct and maintain. They should be designed to receive only overland sheet flow and all precautions should be used to prevent channels from forming in the filter strip. In order to function effectively, filter strips must have a level-spreading device, be densely vegetated, be graded to a uniform and low slope, and be at least as long as the contributing runoff area. Filter strips do not provide for peak or volume control of stormwater runoff. They are, however, effective for removing particulate pollutants; forested filter strips have higher removal capabilities than grassed filters (Schueler 1987).

Bioretention was developed in Prince George's County, Maryland, and has been used as a stormwater BMP since 1992 (Prince George's County 1993). Bioretention uses vegetation, soil, and sand to remove pollutants from stormwater runoff. A typical bioretention area consists of a grass filter strip, sand bed, ponding area, organic layer, soil, and plants. Bioretention may rely on infiltration or act as a biofilter. Bioretention areas that are designed as biofilters have an underdrain that discharges filtered runoff downstream after it passes through the bioretention area. Bioretention areas have high pollutant removal efficiencies, ranging from 49% for total nitrogen to 97% removal for copper. A bioretention area constructed in a parking lot in Maryland reduced pollutant loads of metals 43-79% and nutrients 67-87% (EPA 2000).

Filter practices are designed to handle runoff from small areas only so their use is limited. This is particularly true for structural filtering practices that require maintenance in order to function effectively. EPA (1999) states that the filter media may clog and need to be replaced every 3-5 years. Less maintenance is required for biofilters; however, biofilters are not maintenance-free as once believed. Filtering devices can be very useful in combination with other BMPs that require pretreatment of runoff (Schueler 1987; EPA 1999; Prince George's County 1999). Grass filter strips are well suited for pretreatment of runoff for infiltration devices. Bioretention areas are ideal for use in median strips, parking lot islands, and swales (EPA 1999). Filter practices are not appropriate for locations with high water tables, steep slopes, unstable soils, or high sediment loads.

Open Channel Practices

Open channel practices include swales, ditches, and grass channels (Schueler 1987, EPA 1999). Grassed swales are common in low-density residential areas and along highways as an alternative to curb and gutter (Schueler 1987; Center for Watershed Protection 1998). Open channel systems can be modified to include check dams to provide stormwater management of small storm events but open channel systems have a limited capacity to handle runoff from large storms and most are used in conjunction with other BMPs (Schueler 1987). Open channel practices control peak flow by slowing the flow of runoff and allowing a small portion of the runoff to infiltrate into the underlying soil (Schueler 1987). These practices have limited pollutant removal capabilities because the runoff is only in contact with the swale for a short period of time. Moderate to high removal rates of particulate pollutants (31-93%) have been reported for grassed swales (Kercher et al. 1983; Winer 2000). Swales and open channel systems are generally limited to areas with low flows and slopes (Schueler 1987). Routine maintenance is required; however, this generally is inexpensive (EPA 1999).

Infiltration Practices

The goal of infiltration practices is to percolate runoff into the soil. Several types of infiltration practices exist. The most common are infiltration trenches, porous pavement, and bio-infiltration practices. These practices use a base of well-sorted gravel under the structure that stores runoff until it can percolate into the soil (EPA 1999). Because infiltration practices specifically set out to infiltrate stormwater, the risk of ground water contamination is a concern. Ground water contamination problems associated with infiltration practices in urban areas are due to the high pollutant load of urban runoff. Pollutants of particular interest are those that are highly mobile, occur in high concentrations, and have a high soluble fraction. These characteristics allow the pollutant to move through the soil to the water table in concentrations high enough to violate drinking water standards (Pitt et al. 1996).

The major pollutants of concern for contaminating ground water from the use of infiltration practices are nutrients, metals, toxins, and pathogens (Pitt et al. 1996). The most common metals found in urban runoff are zinc, copper, lead, and cadmium. These are toxic in high concentrations and do not break down in the soil (Pitt et al. 1996). Other commonly found toxins are polycyclic aromatic hydrocarbons (PAH) and pesticides. Pathogens, bacteria, and viruses can also percolate through soil to contaminate ground water (Pitt et al. 1996).

The risk of ground water contamination from infiltration practices is relatively low Subsurface pollutant concentrations are one or more orders of magnitude below typical values for urban runoff. A model of the movement of metals through porous pavement demonstrated that the greatest depth a metal traveled below the pavement was only 30 cm (Legret et al. 1999). Higher concentrations of metals in soils are found in areas paved with asphalt than in areas where porous pavements were used (Rushton 2001). In many studies, pollutants are trapped in the upper layers of the porous pavement (Legret et al. 1999; Legret and Collandini 1999; Rushton 2001). At one infiltration basin site, no soil contamination was found after four years of operation (Barbosa and Hvitved-Jacobsen 1999).

Although the risk of ground water contamination may be low, it is still possible. Ground water contamination is rare in residential areas but a potential threat in commercial and industrial sites (Pitt et al. 1996). There are several ways to reduce the risk of contaminating ground water when using infiltration practices (EPA 1999). First, different sub-bases have varying adsorptive properties (Sansalone 1999). The major means of pollutant removal for infiltration practices is physically trapping particles within the sub-base or soil. Selecting materials with a high adsorptive ability can increase the pollutant-trapping ability of infiltration ponds (Sansalone 1999). Pretreatment may also be necessary if the infiltration device will receive runoff from an area with high pollutant loads, such as a heavily used parking lot (Schueler 1987; EPA 1999). Pretreatment measures include filtration practices, such as grassed swales, that trap pollutants before they reach the infiltration device. Also, source reduction of pollutants can reduce the risk of ground water contamination.

Infiltration practices are one of the most promising BMPs and have several advantages over other BMPs (Schueler 1987; EPA 1999). Unlike detention facilities they can reduce stormwater volume as well as peak discharges (Schueler 1987). This means that infiltration practices may restore pre-development hydrological conditions. There is little information available on the efficacy of infiltration BMPs. However, infiltration practices that have been studied have the highest pollutant removal rates of any stormwater BMP (Winer 2000). Infiltration practices remove 95% total suspended solids, 70% total phosphorus and 51% total nitrogen from stormwater (Winer 2000).

There is a growing body of research on one particular infiltration BMP – porous pavements. Along with mitigating the negative effects of storm flows, porous pavements allow for ground water recharge and maintenance of stream base flows (Schueler 1987). Porous pavements are very effective at removing pollutants such as metals, suspended solids, and nutrients from stormwater runoff (Winer 2000). Other benefits include durability, noise reduction, and a safer driving surface (Wayson 1998). Also, land is not sacrificed for stormwater control; porous pavement sites function as parking areas while providing on-site stormwater management.

Porous pavements are not commonly used in the United States because they are viewed as difficult to install and maintain. The disadvantages include (1) possible contamination of ground water, (2) lack of expertise of engineers and contractors for installation, (3) potential to clog if not maintained, (4) high failure rates, (5) inability to treat fuel or toxins that are commonly on parking lots and roadways, (6) some codes prohibit installation, and (7) anaerobic conditions may develop under the pavement and impede decomposition. They are more expensive than traditional paving materials, and have limited applicability (Schueler 1987; EPA 1999). EPA (1999) recommends that porous pavements be used only in areas that receive light use, that are relatively flat or $<5\%$ slope, that have deep permeable soils located away from drinking water sources, and that there is a 4 foot clearance beneath the pavement to bedrock or the water table.

The high failure rates that have been reported for porous pavements are largely due to improper installation and lack of maintenance, rather than a failure of the pavement itself. In Maryland, porous parking lots studied over a four-year period had a failure rate of 85% (Lindsey et al. 1992). None of the lots had the proper sediment control measures at the beginning of the study, however, and very few were maintained properly. Pavements that were installed and maintained properly function effectively for decades. In Sweden, porous pavements have been effective over 30 years or more of use (Backstrom 2000).

One of the most compelling reasons for using porous pavements is effectiveness at removing pollutants. Pollutant removal efficiencies for metals, nutrients, and solids are 80-95% (Rushton 2001; Legret et al. 1995). Porous pavements and other infiltration devices are more effective than other BMPs, such as detention facilities, in removing pollutants from stormwater (Winer 2000). Reluctance to use infiltration practices is apparently due to inexperience with the materials. Need for maintenance, which consists of power washing and vacuum sweeping, can be viewed not as a failure of the porous pavement but as evidence of their effectiveness. These infiltration devices must be unclogged regularly because they are more effective at trapping pollutants than other BMPs. With proper maintenance, porous pavements can be as long-lived as conventional pavements (Schueler 1987).

A New Approach to Stormwater Management

No one BMP is going to fix the stormwater problem. Detention ponds are currently the most commonly used stormwater BMP; however, studies have shown that detention alone is not enough to protect stream ecosystems (Maxted and Shaver 1996; Booth and Jackson 1997; Horner et al. 2002). Infiltration practices have the highest pollutant removal capabilities of all stormwater BMPs (Winer 2000) but they can be expensive, are susceptible to clogging if not maintained, and may not be appropriate for treating runoff from large areas or areas receiving highly contaminated runoff (EPA 1999). Using a combination of BMP types rather than sole reliance on one type of BMP can best achieve stormwater requirements. For example, both infiltration and detention practices could be used on a site. By using porous pavement in parking lots, the volume of runoff generated is reduced and therefore the size of the detention pond needed to meet regulations can be reduced.

Low Impact Development (LID) goes beyond simply using a combination of BMPs to achieve compliance with stormwater regulations. LID seeks to preserve the natural hydrology of a development site through the use of site planning and distributed on-site stormwater controls (Prince George's County 1999). This approach has many benefits, including lower pollutant loads, reduced soil erosion, reduced development costs, increased property values, and increased local property tax revenues (Center for Watershed Protection 1999). Although developers and local governments may be willing to try LID techniques, many cannot under existing zoning and development codes (Center for Watershed Protection 1998). Encouraging this holistic approach to stormwater management will require revision of existing regulations as well as evidence that it truly provides ecological and economic benefits.

My dissertation addresses the question of *how* to develop while still maintaining the hydrologic functions of a watershed. Chapter 1 examines the impacts of urbanization in the Etowah River basin, located near Atlanta, Georgia. My objective was to identify changes in hydrology and chemical pollutant concentrations that are related to increasing urbanization in the basin. After characterizing the problem of urbanization, particularly urban runoff, I examined the use of a best management practice, porous pavement, which has the potential to reduce stormwater impacts. In Chapters 2 and 3, I explore whether porous pavements are an effective stormwater best management practice on clay soils, which are common in the Piedmont. The experiments described in these two chapters sought to determine if porous pavements can reduce the volume of runoff, nutrient loads, and sediment loads on fine-grained soils when compared to impervious surfaces. Finally, working with an interdisciplinary team of researchers, I reviewed existing stormwater and development regulations in order to identify where improvements could be made to provide more protection for aquatic resources. Chapter 4 describes this review as well as the development of new stormwater and development regulations for the Etowah River basin. My goal in revising and developing these policies was to change current development and stormwater management practices so that the predevelopment hydrology of a site is mimicked or preserved.

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CHAPTER 1

LONG-TERM HYDROLOGIC AND WATER QUALITY TRENDS IN THE UPPER ETOWAH RIVER BASIN, GEORGIA USA[1]

[1]Dreelin, E. A., L. A. Fowler and C. R. Carroll. To be submitted to *Water Research*.

Abstract

The upper Etowah River basin (Georgia, USA) is a hotspot of aquatic biodiversity and is under increasing development pressure from rapid human population growth and the consequent conversion of land to urban uses. Our objective was to examine existing monitoring data in order to identify trends in hydrologic and water quality parameters in the Upper Etowah River basin. We analyzed long-term data for two USGS gauges, Canton and Dawsonville, in the Upper Etowah River basin. We predicted that peak discharges, flood frequencies, annual runoff coefficients, and solute concentrations would increase over time in areas experiencing increasing levels of urbanization. We found no discernable trends in annual precipitation, peak flow, mean annual discharge, or annual runoff coefficients at Canton, the larger downstream gauge. The discharge of the 2-year flood has increased 3% at Canton. Conductivity and concentrations of nitrate + nitrite have increased significantly over time at both gauges. These trends were detectable at low levels of urbanization (3-15% urban land use). We recommend stormwater management strategies that focus on source control, those which reduce the volume of stormwater runoff produced, in order to reduce impacts on aquatic species.

Introduction

Urbanization is an ever-increasing threat to stream ecosystems (Paul and Meyer 2001). In urbanized areas, the increase in impervious surfaces causes significant changes in the quantity and quality of water delivered to streams (Brabec et al. 2002). Increases in impervious surface cover have been the focus of many studies examining the impacts of land use change (Klein 1979, Arnold and Gibbons 1996; Booth and Jackson 1997). These studies find impacts on streams at 8-12% total impervious surface cover of watersheds; although a recent study in Alaska shows impacts at levels as low as 4-5% impervious surface cover (Ourso and Frenzel 2003). Above 25% impervious surface cover, impacts on streams are considered unavoidable (Scheuler 1997; Booth and Jackson 1997).

Altered hydrology is one of the primary means by which urbanization affects stream ecosystems. Peak flows in urban areas are commonly greater than those in non-urbanized areas for all except the largest flood events (Booth 1991; Rose and Peters 2001). In urbanized areas, impervious surfaces deliver a higher volume of water to streams via surface runoff (Arnold and Gibbons 1996; Dunne and Leopold 1978; Booth and Jackson 1997; Paul and Meyer 2001; Booth et al. 2002). The alteration in hydrology is one of the most serious threats to aquatic ecosystems because flow is a major determinant of physical habitat in streams, aquatic species have evolved life history traits in response to the natural flow regime, connectivity of aquatic habitats is essential for population viability, and altered flow regimes facilitate successful invasion by exotic species (Bunn and Arthington 2002).

Significant changes in channel morphology occur at 10-20% impervious surface area (Bledsoe and Watson 2001). Channel form is determined by sediment and water supply (Dunne and Leopold 1979). Increasing the frequency and magnitude of storm events has a large effect on stream channel geomorphology (Wolman and Miller 1960). During construction, sediment yields increase, however, over time sediment yields decrease in areas covered by impervious surfaces (Arnold et al. 1982). The change in sediment and water supply result in increased channel erosion (Wolman and Schick 1967). Consequently, streams in urban areas commonly become enlarged (Arnold et al. 1982), incised (Doyle et al. 2001), or both (Hammer 1972). Channel stability indices provide an indication of how stream channels respond over time; channels considered unstable are likely to experience rapid changes in geomorphology (Doyle et al. 2001). Based on empirical hydrologic observations of urban and forested watersheds, Booth and Jackson (1997) developed a channel stability index for urban streams. The transition from stable stream channels to unstable channels occurs when the 10-year forested or pre-development discharge equals the 2-year post-development discharge. However, a classification of stable following this criterion does not mean that the stream has not been affected by urbanization (Booth et al. 2002).

Along with changes in hydrology and channel morphology, declines in the quality of stormwater runoff accompany urbanization (Brabec et al. 2002). Commonly observed changes in water chemistry of urban streams are increases in oxygen demand, conductivity, suspended solids, nutrients, hydrocarbons, and metals (Paul and Meyer 2001). Metals such as lead, zinc, chromium, copper, manganese, nickel, cadmium, mercury are common constituents of urban runoff (Marselek et al. 1999; Legret and Pogatto 1999). These chemical changes, combined with the alterations in hydrology and channel morphology, are major stressors for aquatic organisms. As a consequence, the abundance and richness of macroinvertebrates and fish are lower in urban streams (Klein 1979; Crawford and Lenat 1989; Horner et al. 1996; May et al. 1997).

North America north of Mexico has the richest freshwater fish fauna in the world (Page and Burr 1991). Of the approximately 800 fish species found in North America, 349 are located in the Southern Appalachians (Burkhead et al. 1997). The southeastern aquatic fauna are also one of the most endangered, 20% of the fish species are imperiled (Burkhead et al. 1997). The Coosa River system, which includes the Etowah River, has more recent extirpations and extinctions of aquatic organisms than other systems in the region (Burkhead et al. 1997).

In order to reduce the risk of further extinctions, there is a need to understand how human alteration of the landscape is affecting aquatic habitats. Our objective was to examine long-term monitoring data in order to identify trends in hydrologic and water quality parameters in the Upper Etowah River basin. We predicted that peak discharges, flood frequencies, annual runoff coefficients, and solute concentrations would increase over time in areas experiencing increasing levels of urbanization.

Study Site

The Etowah River drains an area of 4823km^2 and is located north of Atlanta, Georgia (Fig. 1.1). The Etowah River basin is a hotspot of aquatic species diversity; there are 76 extant fish species, four of which are locally endemic (Burkhead et al. 1997). Currently ten fish species are imperiled, seven are state protected and three are federally endangered. Many of the remaining populations are located in the upstream portions of the basin in Cherokee, Dawson, Lumpkin, and Pickens Counties.

The Etowah River basin contains some of the fastest-growing counties in Georgia and the United States; Forsyth County was recently named the fourth fastest-growing county in the nation (US Census Bureau 2003). Prior to 1960, human population growth was relatively stable, after 1960 however, population growth in the Upper Etowah counties rapidly increased (Fig. 1.2). Most of this growth has occurred in communities closest to Atlanta; however, growth in the upstream counties where many of the remaining populations of imperiled species are found is projected to increase. For example, Cherokee County is expected to experience a growth rate of 23% between 2000 and 2010 (Cherokee County, 2000).

Data Sources and Methods

Land use data were obtained from the Georgia Land Use Trends Project (NARSAL 2004). Land use data for each county were available for 1974, 1985, 1992, and 1998. The area of land in each land use class and percent change in land use class for each date were calculated for the counties in the study area. Because there were only four data points for land use data, we considered time as a surrogate for land use change in our analysis of hydrologic and water quality trends.

We compiled flow and water quality data from a variety of sources across the Etowah River basin (Dreelin et al. 2003); however, the only available long-term data were from USGS gauges located on the mainstem of the Etowah River. For this analysis we used data from two gauges, Canton and Dawsonville, in the headwaters of the Etowah River upstream of Lake Allatoona, a regional reservoir (Fig. 1.1). The Dawsonville gauge (02389000) is located in Dawson County and drains an area of 277 km^2. The Canton gauge (02392000) is located downstream of Dawsonville in Cherokee County and drains 1588 km^2, which includes the Dawsonville drainage. Hydrologic and water quality data for both gauges were downloaded from the USGS website (http://nwis.waterdata.usgs.gov). Precipitation records were available for both Canton and Dawsonville gages, these data were downloaded from the National Climate Data Center website (www.ncdc.noaa.gov).

Based on the changes in population size, we divided the record into pre-development (prior to 1960) and post-development (after 1960) time periods. We chose 1960 as the demarcation between pre- and post-development periods because human population size began to increase exponentially after 1960 (Fig. 1.2). We calculated flood frequencies and discharges for the Canton gage for both time periods using the annual peak discharge record and Gumble method (Dunne and Leopold 1978). Changes in flow were not examined at Dawsonville because of the shorter period of record. The channel stability index was calculated by dividing the post-development 2-year flood discharge by the pre-development 10-year flood discharge (Booth and Jackson 1997). The 2-year and 10-year discharges are flood events that have a recurrence interval of two and ten years, respectively. Channels are considered unstable if the stability index is greater than one. Annual runoff coefficients were calculated for each year of record based on the average annual streamflow and annual precipitation. Simple linear regression was used to identify any trends in total annual precipitation, mean annual discharge, peak discharge, and runoff coefficients over time.

For the water quality analysis, we chose parameters that had a period of record of at least 20 years. These were specific conductance, nitrate-nitrite, and total phosphorus at both the Dawsonville and Canton gages. Only samples collected in the winter months (December–February) were used in the analysis to reduce the affect of seasonal changes in solute concentrations. Stepwise multiple regression was used to examine trends in the water quality parameters. Explanatory variables entered into the model were date, streamflow, daily and weekly precipitation, and turbidity. All statistical analyses were performed in SAS JMP 5.1.

Results

As the human population size grew in the Upper Etowah basin, land use was converted from forestry and agricultural uses to urban and suburban land uses (Table 1.1). The basin is still largely forested (52-85%) although urban use has increased since 1974. Most of the urbanization was characterized by low-intensity uses such as single family houses, schools, and recreational areas. From 1974 to 1998, there was a 126-682% increase in the area of land in the low intensity urban land class. During the same time period, there was a 5-32% decrease in the area of land used for agriculture. The area of forested land increased over time because increases in mixed woodlands offset losses in deciduous forests and evergreen forests. Cherokee County experienced the largest increase in urban land uses and as a result we expected to observe increases in the hydrologic and water quality parameters over time at Canton.

There were no significant trends in precipitation, peak discharge, mean annual discharge or runoff coefficients over time at Canton (Fig. 1.3). The discharge of the 2-year flood has increased from the pre-1960 to post-1960 period at Canton (Table 1.2). The discharge of the 2-year flood has increased 3% at Canton. The channel stability index for Canton (0.47) was within the range for stable channels (<1; Table 1.3).

All three water quality parameters showed significant increasing trends at Canton (Table 1.3; Fig. 1.5). Date and stream flow were the best predictors for specific conductance (r^2=0.72) and nitrate + nitrite (r^2=0.48) whereas stream flow alone was the best predictor for total phosphorus (r^2=0.37). Only specific conductance and nitrate + nitrite showed significant positive trends over time at Dawsonville; there was no discernable trend in phosphorus (Table 1.3; Fig. 1.6). Date was the best predictor of specific conductance (r^2=0.57) and nitrate + nitrite (r^2=0.47) at Dawsonville. Although we only show regression results for winter data, data for the other seasons follow these same trends.

Discussion

Although increases in peak discharge are commonly observed in urban watersheds (Dunne and Leopold 1978), peak discharges for the Canton gauge did not show a significant increasing trend over time. By comparison, peak discharges in Peachtree Creek, an urban stream in the metro-Atlanta area, were 30-100% higher than other non-urban streams in northeast Georgia (Rose and Peters 2003). Increases in discharge of at least 250% have been observed in urban watersheds (Espey et al. 1965). An increase in impervious surface area of 3% to 33% in the Accotink Creek watershed (Virginia, USA) resulted in significant increases in mean daily discharge over a time (Jennings and Jarnagin 2002). However, Interlandi and Crocket (2003), who also used long-term USGS gauge data, found no significant trend in mean annual discharge for the Schuykill River (Pennsylvania, USA). Although urban land uses in the Etowah River basin have increased over the period of record, current levels are still low (3-15%). As a result, we may not be able to detect changes due to urbanization, particularly at larger scales. Roy et al. (unpubl. data) found that small subwatersheds (8-20km^2) in the Etowah River basin in areas with high impervious surface area had higher, more frequent stormflows. These changes in flow are important management considerations because alterations of stream flow result in significant changes in aquatic habitat (Poff and Allen 1995).

Although we did not find large increases in peak and mean annual discharge, we did observe changes in flood frequency and runoff coefficients. The discharge of the 2-year flood has increased only 3% for Canton. Basins in Puget Sound that had significant increases in urbanization also had significant increases in flood frequency (Moscrip and Montgomery 1997). The pre-urban 10-year recurrence interval discharge corresponded to the 1-4 year recurrence interval events in the post-urban record. In essence, the flood that generally occurred every 10 years occurred every 1-4 years in urban areas. Sullivan et al. (2004) observed a 20% increase in the 25-year flow due to highly connected impervious surfaces and drainage network. As urbanization and the construction of impervious surfaces increase, water is delivered more efficiently to streams via storm sewer systems. This is reflected in the increase in annual runoff coefficients, the ratio of discharge to precipitation, over time. Rose and Peters (2003) found that the runoff coefficient for urbanized Peachtree Creek were not significantly different than other less-urbanized streams in the Georgia Piedmont. However, a regression of rainfall and runoff showed that less precipitation was required to generate runoff in Peachtree Creek. The runoff coefficient can be more effective than peak discharge alone for identifying changes in flow due to urbanization (Beighly and Moglen 2002).

The change in flood frequency and annual runoff coefficient are of critical importance to preserving aquatic organisms because changes in flow correspond to changes in habitat. Human alteration of the natural flow regime alters natural hydrologic variation and disturbance which alters habitat dynamics, thus creating new conditions which native organisms may not be able to survive (Poff et al. 1997). Canton falls within the range of stable channels (post-development 2-yr discharge < pre-development 10-year discharge) although the 2-year flood is approaching the 10-year predevelopment discharge. Changes in flood frequency of small floods (1-2.3 recurrence interval) are important because the bankfull discharge is commonly the channel-shaping flow. Thus, the change in flow regime relates to a change in channel morphology and instream habitat for aquatic organisms.

We found a strong relationship between conductivity, date, and flow. Interlandi and Crockett (2003) also found significant relationships between conductivity, total annual precipitation, discharge, and time for the Schuykill River (Pennsylvania, USA). Increases in ion concentrations in urban areas are so common that it has been suggested that conductivity be used as an indicator of the impact of urbanization (Wang and Lin 1997; Herlihy et al. 1998). This strong relationship between urbanization and conductivity has also been observed in the Etowah basin (Roy et al. 2003). The consistently strong negative relationship between conductivity and biotic indices suggest that increased conductivity may lead to biotic impairment (Roy et al. 2003).

An increase in nutrient concentrations is common in urban streams (Paul and Meyer 2001). We observed significant increases in nitrate + nitrite at both Canton and Dawsonville. Wernick et al. (1998) also found elevated concentrations of nitrate in urban streams. We expected to see an increase in phosphorus over time as well because phosphorus concentrations in Lake Allatoona, a downstream reservoir, are elevated and approximately 70% of the phosphorus load comes from the Etowah River (A. L. Burrus Institute, 1998). However, we only found a weak relationship between flow and phosphorus at Canton and no detectable trend at Dawsonville. The relationship between flow and phosphorus at Canton suggests that phosphorus is entering the stream via stormwater runoff because concentrations are higher as flows increase. For both nitrate + nitrite and phosphorus, much of the variation in nutrient concentrations remains unexplained. The low r^2 values are likely due to the small sample size of the Dawsonville dataset and because we only considered a few explanatory variables. Also, current levels of urbanization are low (3-15% urban land use) and a large percentage of the watershed is still forested (52-84%). In forests, microbial and plant processes immobilize or remove nutrients (Blood et al. 1989; Qualls et al. 1991; Hart et al. 1994).

The impact of land use change at large catchment scales commonly has been considered a relatively minor influence on flood response as a result of compensating effects of more complex storage and release mechanisms (Fohrer et al. 2001). Larger basins contain a mosaic of land uses which may mask the effects of urbanization, at least at low levels of imperviousness. The influence of urbanization, particularly impervious surfaces, is even more apparent in small watersheds studied by Roy et al. (unpubl. data) where a strong negative relationship was found between hydrologic alteration due to high impervious surface area and the richness and abundance of the fish assemblage.

Although we did not observe trends in flow variable, we did observe significant trends in the water quality data. Our date + flow model explained 72% of the variation in conductivity for Canton (Table 1.3). Trends were weaker or not detectable at Dawsonville. Discharge and year of sample were also the best predictors of water quality for the Schuykill River in Pennsylvania USA (Interlandi and Crockett 2003). As opposed to instream habitat structure, which is determined mainly by local conditions, nutrient supply is influenced by regional conditions including land use (Allan et al. 1997).

Effective conservation of stream fishes requires research questions and management strategies to be addressed at scales that match life histories of the species of interest (Fausch et al. 2002). Our study considered with Roy et al. (unpubl. data) allows for preliminary inferences about the effects of urbanization on hydrology at different scales using a multi-scale nested approach (see Fausch et al. 2002). At the larger scale, the Canton drainage (1588 km^2), hydrologic alteration was not detectable although there were slight changes in flood frequency. At the smaller scale (8-20km^2), alteration of the hydrologic regime is apparent and mechanistic links between flow alteration and fish communities can be examined (Roy et al. unpubl. data). Changes in hydrology at small scales can be related to negative impacts on fish communities. Based on observations of altered storm flows in subwatersheds with high (>20%) impervious cover, we recommend developing management strategies which focus on on-site source control of stormwater.

Innovative stormwater management can reduce the volume of runoff and pollutant loads entering waterways. Improved site planning and Low Impact Development techniques treat stormwater problems at the source rather than relying on conveyance and detention (Center for Watershed Protection 1998; Prince George's County 1999). The main goals of this approach are to use hydrology as a framework for site design, use simple on-site controls for stormwater management, and to minimize construction of impervious surfaces. This approach has been shown to have many benefits, including lower pollutant loads, reduced soil erosion, reduced development costs, increased property values, and increased local property tax revenues (Center for Watershed Protection 1999). Reducing impervious surfaces and clustering development not only provides reduced stormwater impacts, but significant cost savings aw well (Burchell and Mukherji 2003) and improved public health (Gaffield et al. 2003). We recommend incorporating these innovative stormwater management techniques into local government land use and development policies. This is especially critical now, as levels of urbanization are low and sensitive species are still present. Given that future growth scenarios show an increasing population size in the basin and growth under the current stormwater practices generally leads to negative impacts on aquatic biota, limiting the amount of imperviousness and mimicking the natural flow regime is critical for protecting aquatic species.

Conclusions

The Upper Etowah River basin has experienced rapid growth since 1960. Along with a drastic increase in human population size, land use has been converted from agricultural and forested uses to urban and suburban uses. In the same time period, flood frequencies have increased at Canton and concentrations of nutrients and conductivity have increased at both Canton and Dawsonville. Relationships between water quality parameters, flow and date were stronger at Canton, the larger drainage. In order to reduce the effects of hydrologic alteration on imperiled aquatic species we recommend management strategies that focus on reducing the proportion of rainfall that becomes surface runoff.

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Table 1.1. Percent of land in each land use class for the Upper Etowah counties for 1974 and 1998.

	1974 Percent Land Use					1998 Percent Land Use				
	Cherokee	Dawson	Forsyth	Lumpkin	Pickens	Cherokee	Dawson	Forsyth	Lumpkin	Pickens
Total Urban	3.6	2.31	3.18	1.64	1.68	15.41	4.26	15.32	3.53	6.59
Clearcut	4.36	2.25	2.95	0.89	2.18	5.69	9.54	3.19	2.50	5.04
Total Forest	75.24	86.17	58.48	89.55	83.98	66.16	76.93	52.13	85.46	78.78
Agriculture	13.91	7.66	26.25	7.61	11.8	9.53	7.24	19.45	8.22	8.94

Table 1.2. Flood discharges and channel stability index for the Canton and Dawsonville gauges. The record for each gauge was divided into pre- and post-development periods at 1960, when human population size in the basin started to increase rapidly.

	PRE-DEVELOPMENT		POST-DEVELOPMENT		
Gauge	2-yr Flood (cfs)	10-yr Flood (cfs)	2-yr Flood (cfs)	10-yr Flood (cfs)	Channel Stability Index
Canton	10930	23710	11223	30540	0.47
Dawsonville	2757	4275	3663	5713	1.33

Table 1.3. Results of stepwise multiple regression for the water quality parameters at Canton and Dawsonville. Explanatory variables entered into the model were date, streamflow, daily precipitation, weekly precipitation, and turbidity. Only the best models are shown.

Station	Response Variable	Model	R^2	P
Canton	Conductivity	Date + Flow	0.72	<0.0001
	Nitrate + nitrite	Date + Flow	0.48	<0.0001
	Phosphorus	Flow	0.37	<0.0001
Dawsonville	Conductivity	Date	0.57	<0.001
	Nitrate + nitrite	Date	0.47	<0.01
	Phosphorus	---	---	---

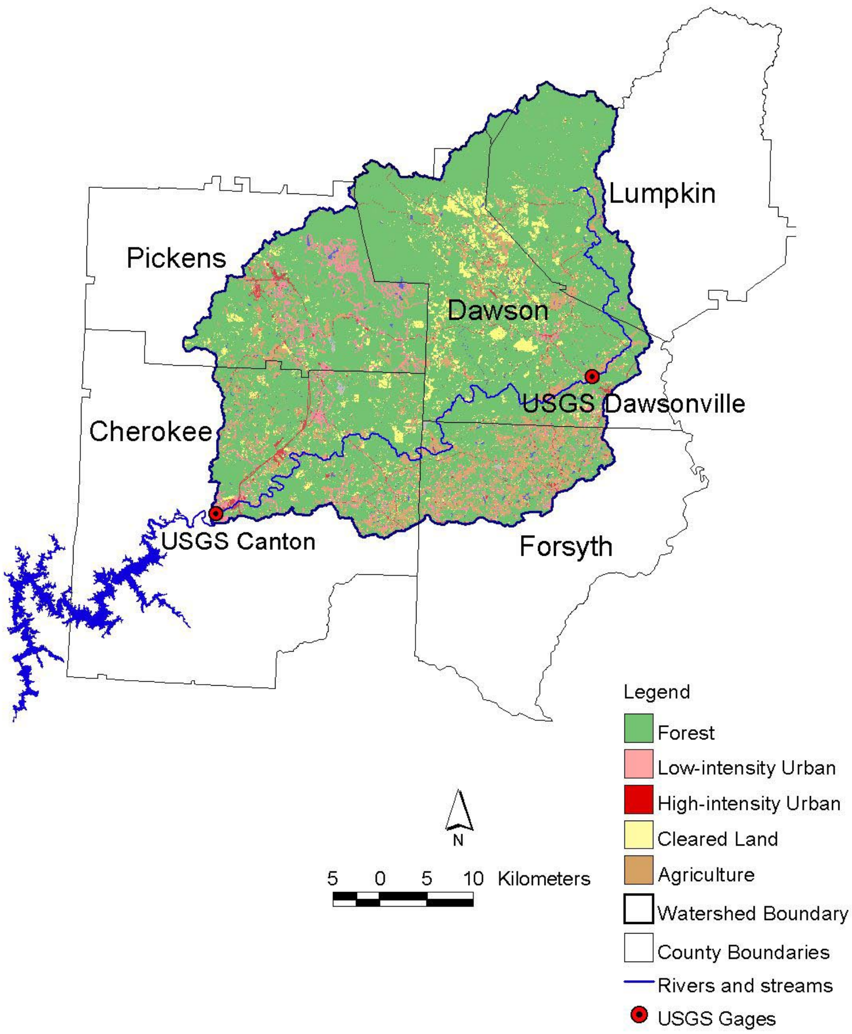

Figure. 1.1. Map of the Upper Etowah River basin showing the location of the two USGS gauges and current (1998) land use.

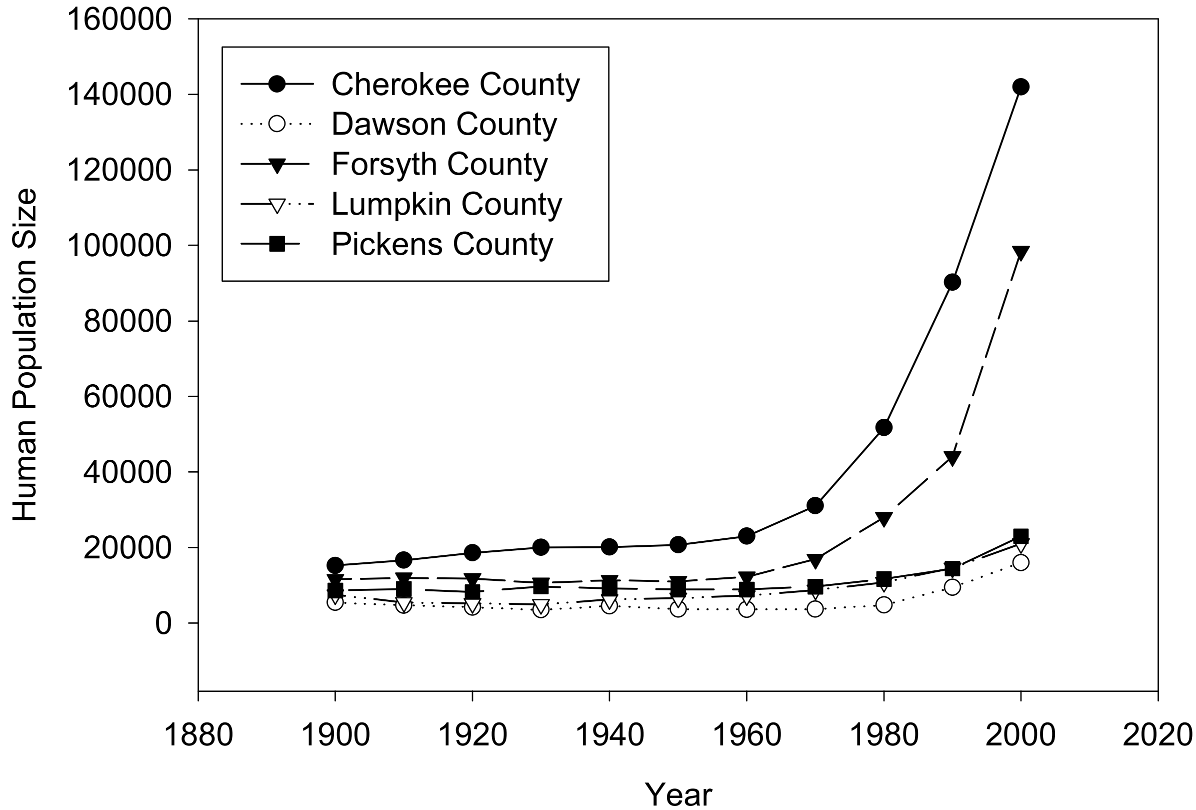

Figure 1.2. Human population growth in the counties of the Upper Etowah River basin rapidly increased after 1960 (US Census Bureau 2003).

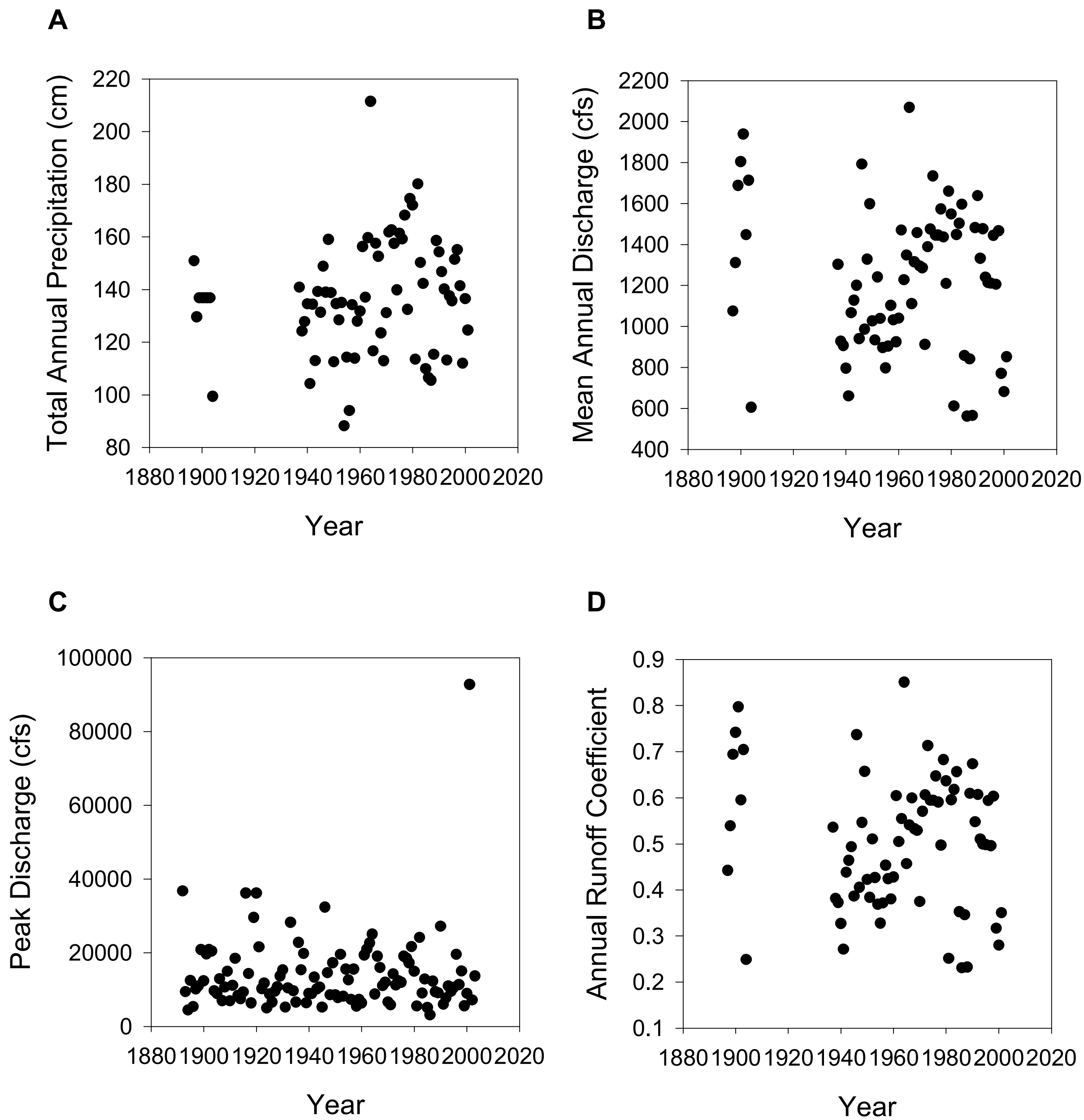

Figure 1.3. No significant trends in (A) total annual precipitation, (B) mean annual discharge, (C) peak discharge, or (D) annual runoff coefficients were observed at Canton.

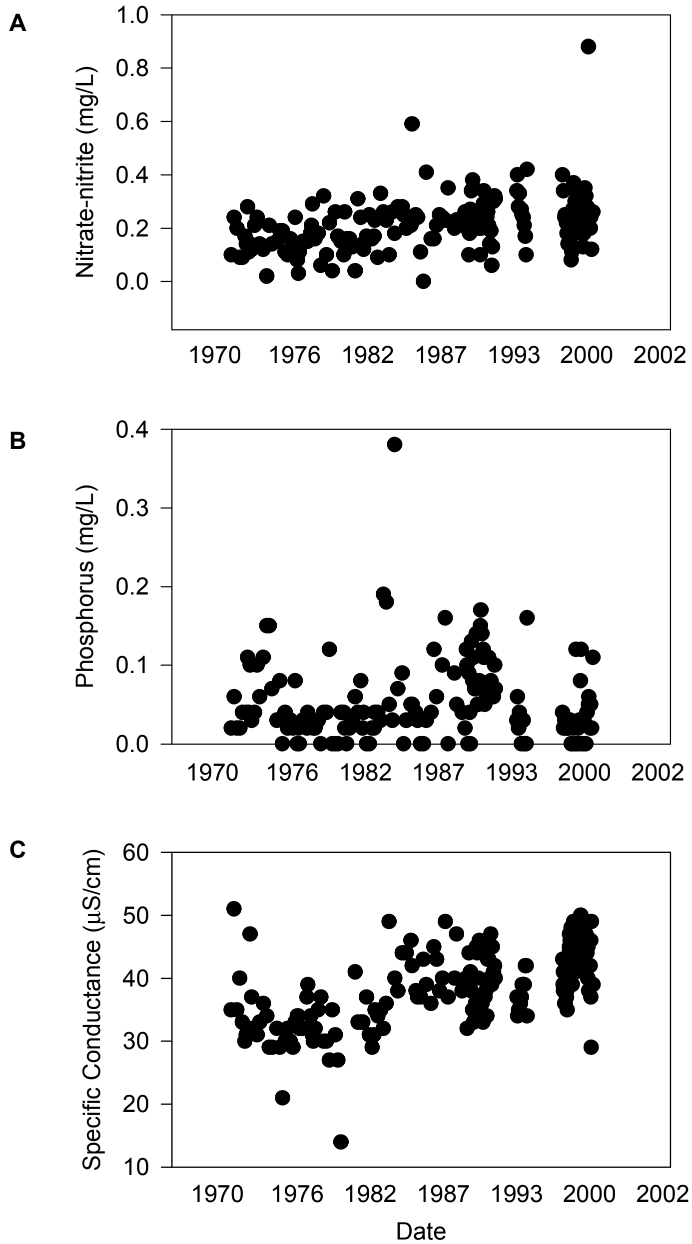

Figure 1.4. Nitrate + nitrite concentrations (A), total phosphorus concentrations (B), and conductivity (C) have significantly increased over time at Canton (see Table 1.3 for multiple regression results for winter samples).

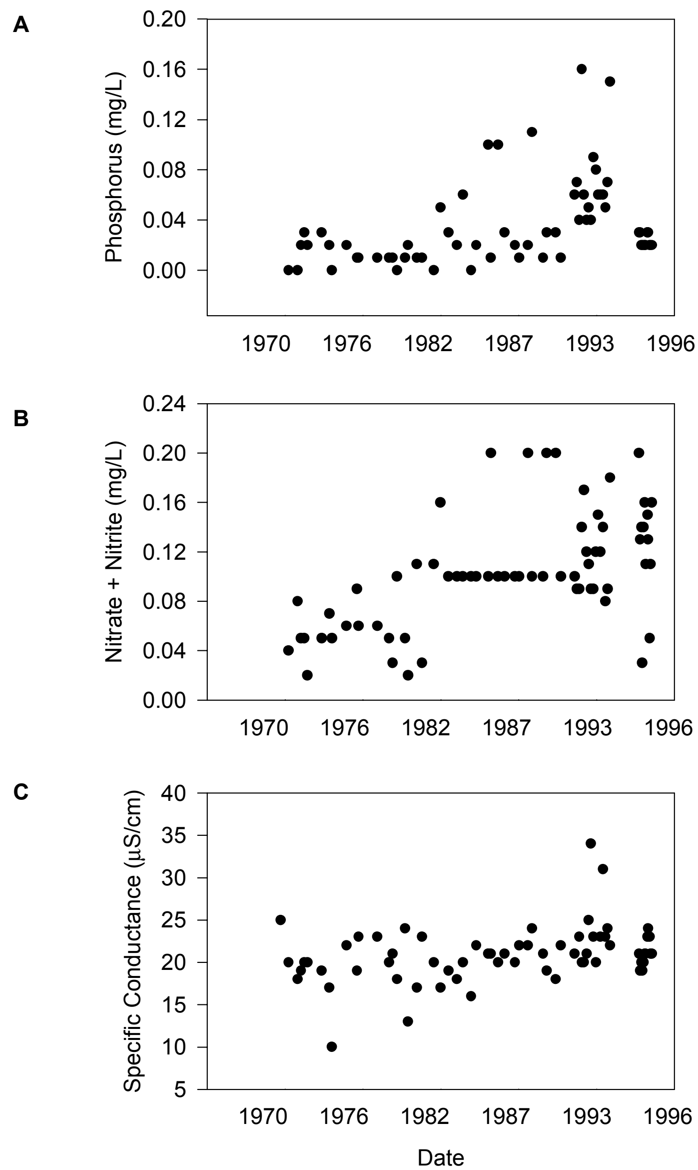

Figure 1.5. Nitrate + nitrite concentrations (A) and conductivity (C) have significantly increased at Dawsonville. We found no significant trends in phosphorus concentrations (B) at Dawsonville (see Table 1.3 for multiple regression results for winter samples).

CHAPTER 2

A TEST OF POROUS PAVING EFFICACY ON CLAY SOILS DURING NATURAL STORM EVENTS[1]

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[1]Dreelin, E. A., L. A. Fowler, and C. R. Carroll. To be submitted to *Journal of the American Water Resources Association.*

Abstract

Porous pavements allow precipitation to infiltrate through the pavement to the soil, reducing the volume of stormwater runoff produced at a site. However, porous pavements are not widely used on fine-grained soils due to concerns about their performance. Our objective was to investigate the efficacy of porous pavements in controlling stormwater runoff on fine-grained clay soils of the Georgia Piedmont. We compared the performance of an asphalt parking lot and a porous pavement parking lot in Athens, Georgia during 10 storm events. The porous lot produced 93% less runoff than the asphalt lot. The total volume of runoff at the porous lot was significantly less than the asphalt lot ($t=2.96$, $p=0.009$). Turbidity was significantly greater at the asphalt lot ($t=6.18$, $p<0.001$) whereas conductivity was significantly higher at the porous lot ($t=2.31$, $p=0.03$). Most metal and nutrient concentrations were below detection limits at both lots during seven of the 10 storm events. During those storms in which we could detect pollutants, calcium, zinc, silica, and total phosphorus concentrations were higher at the asphalt lot whereas total nitrogen concentrations were higher at the porous lot. Our results suggest porous pavements are a viable option for controlling small storms or the first flush from large storms on clay soils.

Introduction

Nonpoint source pollution is the leading cause of impairment for streams in the United States (EPA 2002a), particularly in urban settings where the proliferation of impervious surfaces has greatly increased the magnitude of polluted stormwater runoff (Arnold and Gibbons 1996). Impervious surfaces significantly alter the natural hydrologic cycle by preventing infiltration of runoff and conveying precipitation rapidly into stream channels, which in turn increases the volume and peak rate of runoff associated with storm events (Dunne and Leopold 1978). Stream channel morphology quickly responds to these changes in hydrology, re-shaping natural streams into eroded, and incised conveyances (Arnold et al. 1982; Bledsoe and Watson 2001). The loss of natural stream channel structure due to altered hydrology has been broadly implicated in the degradation of urban aquatic habitats (see Chapter 1). Impervious surfaces also serve as a vector for delivering pollutants directly to streams. When storm flow bypasses the natural filtering process water undergoes when it flows through soils, we lose access to a critical ecosystem service (Palmer et al. 2004). Thus, it is not surprising that indicators of biotic integrity are generally low in watersheds with 10% or more impervious cover (Klein 1979; Arnold and Gibbons 1996; Booth and Jackson 1997).

Historically, efforts to mitigate the effects of stormwater on aquatic ecosystems have focused on the use of best management practices (BMPs). A variety of BMPs have been developed to control stormwater, ranging from large structural devices such as detention ponds to simple good housekeeping measures. Unfortunately, many of these techniques are designed solely to avoid flooding, and therefore rarely incorporate features that promote infiltration. More recently, the use of porous pavements has emerged as an alternative technology for on-site stormwater control. Porous pavements allow precipitation to infiltrate through the pavement and into the soil, preserving much of the natural hydrology. Porous pavement has several advantages over other stormwater BMPs. Unlike detention/retention facilities, porous pavement can reduce total stormwater volume as well as peak discharges (Schueler 1987). In addition to mitigating the negative effects of storm flows, porous pavements also allow for ground water recharge and maintenance of instream base flow (Schueler 1987; EPA 1999). Other benefits include durability, noise reduction, and increased safety for vehicular traffic due to reduced spray generation on driving surfaces (Schueler 1987; Wayson 1998; EPA 1999). Also, valuable land is not sacrificed to a single use; porous pavement sites are functional parking areas that also provide on-site stormwater control.

Because they are viewed as difficult to install and maintain, particularly on clay soils, porous pavements are not commonly used in Georgia (EPA 1999, Georgia Stormwater Management Manual (ARC 2003). The perceived disadvantages of porous pavement include: 1) high failure rates from clogging with fine sediments; 2) possible contamination of ground water from parking lot residues; and, 3) high cost of installation and maintenance. Further, the U.S. EPA (1999) recommends that porous pavements be used only on soils with low clay content (<30%), in areas that receive light traffic, that have relatively flat slope (<5%), that have deep permeable soils located away from drinking water sources, and that there is at least a 4-foot clearance between the pavement and bedrock or the water table. When municipalities and developers are presented with these challenges and limitations, porous pavements are perceived as less cost-effective. However, recent experimental evidence has demonstrated that under many conditions porous pavements are actually more effective than traditional BMPs, and in the long term, less expensive (Schueler 1987; Winer 2000).

Perhaps the most compelling reason for using porous pavements and other infiltration devices is their effectiveness at removing pollutants. When urban runoff passes through porous pavements, removal efficiencies for metals, nutrients, and solids are typically 80-95% (Schueler 1987; Pratt et al. 1995; Legret et al. 1999; Legret and Colandini 1999; Rushton 2001). Traditional BMPs, such as detention facilities, are far less efficient in removing pollutants from stormwater (3-80% removal, Winer 2000). When properly maintained (i.e., washed and vacuumed), porous pavements can provide pollutant removal services over the long-term

(Lindsey et al. 1992, Brattebo and Booth 2000). The cost of maintaining porous pavements should therefore not be viewed as additional to the cost of traditional paving technologies. Rather, it should be compared to the cost of treating stormwater (or alternatively, trading off the cost of point source treatment) when evaluating the cost-effectiveness of its application.

Although previous studies of porous pavements have demonstrated their effectiveness on sandy soils, it remains unclear whether porous pavements will prove useful in areas where native soils are fine grained and infiltration rates are low (Booth and Leavitt 1999). Our objective was to determine whether porous pavement is a viable BMP for controlling stormwater runoff on the clay soils of the Georgia Piedmont. Here, we directly compare runoff volumes and pollutant loads generated from a porous lot constructed in Athens, Georgia vs. a traditional asphalt lot of similar configuration and age.

Methods

We simultaneously monitored a Grassy Paver™ porous parking lot and a traditional asphalt parking lot constructed during the winter of 2002-2003 in Athens, Georgia. The soils in this area are primarily Cecil-Madison-Pacolet associations, which are well-drained soils with clayey subsoils formed from weathered gneiss and schist. Infiltration rates of these soils range from 4.8-16.7 cm/hr (ARC 2003). These soils can have high clay content; the Bt horizon of Cecil soils may be as much as 35-60% clay (ARC 2003). The lots were located in Athens-Clarke County (South East Clarke Park), and were approximately 366 m apart. The park contains athletic fields, nature trails, public restrooms, concession stands, and playgrounds. During the study period the porous lot principally served the nature trails whereas the asphalt lot was an overflow area for the athletic fields. Because construction of the park facilities was not complete during sampling, both lots were low-use parking facilities. We never observed more than two vehicles in either lot during storm events. However, use of the lots was likely greater during good weather, and should increase as more of the amenities of the park become available.

The porous pavement consisted of a plastic matrix filled with soil and planted with grass over a base of open-graded gravel. The matrix and gravel allowed water to filter through the pavement to the underlying soil. Because of concerns about low infiltration rates, an underdrain system was installed that consisted of a series of perforated drainage pipes under the gravel base. The porous and asphalt parking lots were similar in age, size, slope, and use (Table 2.1). Surface runoff at both lots drained to a single curb cut at the down-slope end of the parking lot.

We monitored 10 storm events from March – June in 2003, using EPA standard protocols for monitoring urban stormwater BMPs (EPA 2002b). We collected a 40 mL grab sample of stormwater runoff at the curb cuts every 20 minutes during the first three hours of a storm event. We also recorded depth and width of flow (cm) in the curb cuts to calculate the volume of runoff generated by each lot. Precipitation (cm) was measured with a tipping-bucket rain gage located at the asphalt lot. We assumed precipitation amounts were the same at both lots given their close proximity. Conductivity (µS/cm) was measured with a QuiKcheK™ Model 116 Conductivity-1 Pocket Meter immediately following collection of the grab sample. The water samples were then stored on ice or in a refrigerator until chemical analyses could be performed. The turbidity (NTU) of each grab sample was measured in the lab with an Orbeco-Hellige Model 966 turbidimeter prior to making two 20-mL flow-weighted composites for nutrient and metals analysis. The composite was formed by combining aliquots from each grab sample (Constant time- volume proportional to flow; EPA 2002b). The amount of each aliquot removed from a grab sample and added to the composite was proportional to the flow calculated at the time the grab sample was collected. The University of Georgia (UGA) Agricultural and Environmental Services Lab analyzed each composite sample following EPA standard methods (EPA 1983) for aluminum, calcium, cadmium, chromium, copper, iron, potassium, magnesium, manganese, sodium, nickel, phosphorus, silica, and zinc. The UGA Institute of Ecology Chemical Analysis Lab analyzed the samples for total nitrogen (mg/L) and nitrates + nitrites (mg/L) using a persulfate digest prior to automated colorimetry following standard methods (EPA 1983). We calculated the event mean concentration for detectable pollutants based on data from all 10 storm events (EPA 2002). We calculated the total flow for a lot using a modified Manning's equation (Dunne and Leopold 1978).

We investigated differences in the mean volume of runoff generated and pollutant loads at the porous pavement lot and the asphalt parking lot using paired student's t-tests performed with SAS Version 8 (SAS Institute). We also examined the relationship between volume of precipitation and volume of runoff at both lots using simple linear regression. All P values cited in the text are for two-tailed tests.

Results

Between 1998 and 2003 Georgia experienced moderate to severe drought conditions, which affected the number of storms we were able to sample. Also, most of the storm events we monitored were small and were preceded by dry conditions. The 10 storm events we monitored ranged between 0.02-1.85 cm of rainfall (Table 2.2). Although these storms are small, storms in this range constitute the majority of storm events experienced in Athens, Georgia even during non-drought years (NCDC 2004).

The porous paver lot generated 93% less runoff than the asphalt lot (mean ± SE; porous, 1.36 ± 0.46 m^3, asphalt, 19.93 ± 6.25 m^3; paired t-test, $t_9 = 2.96$; P = 0.009; Fig. 2.1). In fact, runoff was so low at the porous lot that no runoff was generated during three of the storms (0.02, 0.03, and 0.15 cm). Only once, during the largest storm event (1.85 cm), did we observe water flowing out of the underdrain from the porous lot. Overall, the slope of the regression between depth of runoff and precipitation for the porous lot was weaker (P= 0.02, r^2=0.55, Fig. 2.1B) than that of the asphalt lot (P<0.0001, r^2=0.55, Fig. 2.1A). The slope of the asphalt regression was significantly different from that of the porous lot for storms greater than 0.25 cm of total rainfall. The timing of runoff was also markedly different between lots. Runoff from the asphalt lot was flashy, quickly rising after the onset of precipitation and peaking after only 0.5 cm of rainfall regardless of the size of the storm (Fig. 2.2). Runoff from the porous lot was more subdued, only gradually increasing with time, and never exhibiting a peaked hydrograph.

The conductivity of runoff from the porous lot was approximately twice that from the asphalt lot (mean ± SE; porous, 98.75 ± 8.81 μS/cm; asphalt, 42.8 ± 5.44 μS/cm; t_9=6.18, P < 0.001), whereas turbidity was higher at the asphalt lot (porous, 22.74 ± 3.82; asphalt, 97.65 ± 118.57; t_9 = 2.31, p = 0.03). Consistent with the hydrograph findings, turbidity and conductivity levels exhibited a clear 'first flush' effect in runoff from the asphalt lot (Fig. 2.3). Samples collected early in a storm event had higher concentrations than those taken later during the storm (Fig. 2.3). Conductivity gradually increased during storm events at the porous lot, whereas turbidity generally decreased over the course of a storm.

For seven of ten sampled storms, metal and nutrient concentrations were below the detection limit of 0.005 mg/L at both lots. We never detected cadmium, chromium or copper at either parking lot during any storm events. For the three storms that we were able to detect pollutants, event mean concentrations of calcium, zinc, silica, and total phosphorus were 17-80% higher at the asphalt lot, but total nitrogen concentrations were 43 % higher at the porous lot (Table 2.3).

Discussion

During natural storms of <2 cm total precipitation the grassy porous pavement lot effectively reduced the amount of stormwater runoff despite being sited on clay-rich Piedmont soils. The volume of runoff at the porous lot averaged 93% less than that of the similar-sized asphalt lot. In fact, only the largest storm events produced any measurable runoff from the porous lot. Given that we did not observe water flowing through the underdrain for nine of ten storms, it appears the bulk of the precipitation successfully infiltrated into the clayey soils after passing through the porous pavement. The reduction in runoff we observed was greater than that reported for sandy soils, where porous pavements reduce the volume of runoff 40-45% compared to conventional parking lots (Rushton 2001). However, the strength of our results was likely affected by the small storm events typical of the study period, and the drought conditions preceding our collections. In general, porous pavements can store 55% of the 1-hour 0.15 cm storm if initially dry and 30% if initially wet (Andersen et al. 1999). Porous pavements are commonly designed to handle smaller storms, or the first flush of a large storm event, rather than treating/retaining the total volume of water as required by stormwater regulations (Schueler 1987). Our findings suggest porous pavements could be used effectively on clay soils for the control of runoff from small storm events, and the retention of the 'first flush' during larger storms.

Total precipitation was a weaker predictor of runoff for the porous lot. Porous pavements have a large water storage capacity due to the void space in the gravel base. Our porous lot was designed with a 25 cm gravel base that will effectively retain 7-8 cm of precipitation from a single storm. This storage capacity likely contributed to the effective control of small storms and significantly reduced the runoff response to rainfall. In contrast, precipitation explained the majority of the variation in runoff (88%) from the asphalt. Flow from the asphalt lot was very responsive to precipitation. Every storm event we monitored produced runoff at the asphalt lot, with flow peaking after 0.5 cm of precipitation regardless of storm size. Precipitation becomes runoff on impervious parking lots when total rainfall exceeds the depression storage capacity of the lot, which occurred at 0.5 cm for our asphalt lot. Not surprisingly, runoff from the asphalt lot was flashy, and storm hydrographs exhibited the highly peaked response curve commonly observed in urban streams with armored channels. At the porous lot, the response to storm events was more similar to pre-development conditions (i.e., natural land surfaces), where there is a significant lag between the onset of precipitation and stormwater runoff (Dunne and Leopold 1978).

Because we could not separate runoff generated by the concrete sidewalk and curb-and-gutter rim surrounding the porous lot from the actual pavement, our calculations of runoff volume from the porous lot likely represent overestimates. Runoff typically began after approximately 0.1 cm of rainfall; however, this early runoff was clearly coming from the concrete surfaces. Although this did not prevent us from detecting differences between the lots, it implies a potentially significant impediment to effectively implementing innovative stormwater management technologies. Local zoning codes often require that all parking lots, even those constructed of porous materials, have curb and gutter structures to drain surface runoff from the lot. These codes are often artifacts of past management paradigms which emphasized collection and conveyance of stormwater (Reese 2001). To maximize the effectiveness of porous paving, overflow and backup structures should be included to supplement the design of porous pavement sites in areas where large storms are frequent. The overall strategy should be to reduce or completely eliminate imperviousness and drainage connections wherever possible.

The conductivity of runoff samples from the porous lot was double that of the asphalt lot, and typically increased over the course of a storm. The high conductivity was probably due to ions leaching from the newly constructed pavement, particularly the gravel base. Similar results were obtained by Pagatto et al. (2000), who observed an 8% difference in the conductivity of runoff from a porous asphalt site vs. traditional asphalt. Although not measured in the present study, the conductivity of infiltrate from porous sites can also be greater than surface runoff from asphalt (Brattebo and Booth 2003). However, Pratt et al. (1995) observed a reduction in the conductivity of runoff from a porous lot over a 6-month period as ions were washed from the pavement. They concluded the decline was due to removal of surface material from the stones used in the base of the porous pavements. We may expect a similar decline as our lot ages, although such speculation will require future monitoring efforts to confirm.

The mean turbidity of runoff samples from the porous lot was significantly less than that of the asphalt lot. This result was not surprising as porous pavements are extremely effective at removing particles from stormwater (Schueler 1987; Winer 2001). Recent studies report a 75-81% reduction in suspended solid concentrations for runoff from porous pavements when compared to impervious surfaces (Pagatto et al. 2000; Rushton 2001). Although porous pavements can effectively filter particles from runoff, the accumulation of sediments will eventually clog the pavement and reduce its effectiveness (Schueler 1987). Sediment accumulation was responsible for the eventual failure of 69% of the porous parking lots surveyed by Lindsey et al. (1992). Care should be taken to design and site porous pavement lots such that sediments in runoff from surrounding areas do not quickly overwhelm the capacity of the pavement.

Turbidity and conductivity were highest in the 'first flush' runoff from the asphalt lot. Due to antecedent drought conditions, there were generally days to weeks with little or no rainfall prior to the storm events during the study period. Pollutants typically build-up during the dry days preceding storm events (Vaze and Chiew 2002), and are subsequently washed off in a single concentrated pulse. In most applications, the first flush volume can be effectively stored in the 15 cm gravel base already required for conventional impervious pavements (Schueler 1987). However, use of an impervious pavement prevents this option. Porous pavements, which are particularly effective during small storms or early in larger events, can possibly be used to treat the first flush.

Chemical pollutant concentrations were below detection limits during most storms for both lots. The low pollutant loads we observed were likely due to the limited use these new parking lots had received. Both lots were commonly empty or had few parked vehicles; however, use of the lots is likely to increase greatly as the county park they serve reaches completion. When pollutants were detected, concentrations of calcium, zinc, silica and total phosphorus were higher at the asphalt lot, whereas total nitrogen was higher at the porous lot. Similarly, Legret and Colandini (1999) reported significantly lower concentrations of lead, cadmium, and zinc for porous sites vs. stormwater drained from impervious pavements. Porous pavements retain 80-90% of lead (Balades et al. 1995) and reduce total metal loads at least 75% when compared to traditional asphalt parking lots (Rushton 2001). Our finding that the porous lot was less effective in reducing nitrogen concentrations was also in agreement with the study by Rushton (2001). We expect pollutant loading will increase once the county park is completed, and with heightened use during summer months.

Although we did not detect many significant differences in pollutant concentrations from the lots, we expected generally lower concentrations at the porous lot. Because the porous lot generates less surface runoff, pollutants should pass through the gravel reservoir and infiltrate into the soil. Although infiltration is a significant source of protection for surface water, it is also a potential source of contamination for ground water resources. However, recent evidence suggests this should not preclude the use of porous pavements. Most metals (lead, zinc, and copper) do not infiltrate deeper than 30-35 cm (13.78 in) below the pavement (Legret et al. 1999). Even cadmium, the most mobile of the metals, never reached a depth of greater than 70 cm (27.56 in) in a study by Legret et al. (1999). These values are well above the 1.2 m water table horizon recommended for porous pavement installations (EPA 1999). Additional studies in Florida corroborate the low risk of ground water contamination when using porous pavements (Rushton 2001).

During the course of the study the grassy pavement exhibited significant wear. As stormwater control, the lot functioned effectively. However, even the apparently low level of use was sufficient to visibly erode the porous pavement. In a similar grassy pavement application, Brattebo and Booth (2003) noted that grass growth was spotty and locally sparse after five years of use. The porous lot we monitored received at least two automobile trips per day (a county vehicle unlocking the park gate), although it should be noted we did not monitor lot use during good weather. Even with apparently light use, much of the grass died in the travel lane, exposing the plastic grid and underlying soil. The rapid erosion was probably due to a combination of improper installation and use exceeding the capabilities of the pavement. For this type of pavement, it is recommended that grass be planted in the open cells of the plastic matrix (Ferguson, pers. comm.). In the Athens installation however, the matrix was covered with soil and sod was laid over the entire area. When cars drove onto the lot, the roots of the grass were probably crushed against the plastic matrix rather than being protected by it. It is therefore critical that the design and choice of porous pavements consider the traffic load the pavement will receive. For example, properly installed grassy porous pavement could be limited to use in the parking stalls, with a more durable porous pavement in the travel lanes. Completely grassy lots should be limited to use in overflow areas that receive either seasonal or occasional use associated with special events.

Overall, our findings clearly demonstrate that porous pavements can function effectively to reduce runoff during typical storm events when sited on clay soils. However, the relatively small storms that dominated our study period preclude any conclusions as to their ability to control runoff from large storm events. It is likely that during large or intense storms, the differences we observed between runoff volume at the asphalt and porous lot would decrease as the storage capacity of the gravel base is exceeded. In Florida, porous pavements were more effective in controlling small storms and less effective during storms with high rainfall intensity and saturated soils (Rushton 2001). Porous pavements could be used effectively in combination with other stormwater BMPs (e.g., constructed wetlands) to control peak runoff associated with large but infrequent storms.

Conclusions

Hydrologic alteration due to urbanization has a negative impact on aquatic systems (Chapter 1). Many studies have shown that with increased impervious surface cover in a watershed, biotic integrity of aquatic ecosystems decline. Thus, management measures that reduce the amount of impervious cover or disconnection of impervious areas are often recommended to improve the health of urban and suburban streams. Porous pavements can be one means through which the impervious surface area of a development site can be reduced. Our results suggest that porous pavements can be used on Piedmont soils as long as the surface type is designed to withstand the traffic load. Although clay-rich soils of the Georgia Piedmont have relatively slow infiltration rates, this does not preclude the use of infiltration BMPs. Careful planning and design is required to ensure the pavement will function properly and maintenance is required.

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Table 2.1. Characteristics of the porous and asphalt parking lots monitored in this study.

Lot	Area (m^2)	Parking Spaces	Longitudinal Slope	Cross Slope	Construction Completed
Grassy Pave	187	35	0.02	0.002	November 2002
Asphalt	64	25	0.003	0.02	November 2002

Table 2.2. Summary of the storm events monitored at the porous pavement and asphalt parking lots in Athens, Georgia.

Storm Date	Precipitation Depth (cm)	Runoff Depth (cm)		Runoff Coefficient	
		Asphalt	Porous	Asphalt	Porous
26 Feb 2003	0.22	0.20	0.02	0.87	0.09
1 Mar 2003	0.15	0.11	0	0.72	0
6 Mar 2003	0.15	0.09	0.01	0.59	0.09
14 Mar 2003	0.03	0.02	0	0.78	0
15 Mar 2003	0.88	0.60	0.16	0.67	0.18
17 Mar 2003	0.93	0.33	0.20	0.35	0.22
19 Mar 2003	0.03	0.01	0.006	0.39	0.26
26 Mar 2003	1.85	1.74	0.13	0.93	0.07
5 Apr 2003	0.38	0.21	0.01	0.55	0.02

Table 2.3. Event mean concentrations of detectable stormwater pollutants for the porous and asphalt parking lots in Athens, Georgia. Pollutants were only detectable during four storm events.

Lot	Calcium (mg/L)	Zinc (mg/L)	Silicon (mg/L)	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)
Grassy Paver	6.91	0.01	1.36	0.41	5.17
Asphalt	8.29	0.05	2.72	0.46	2.96

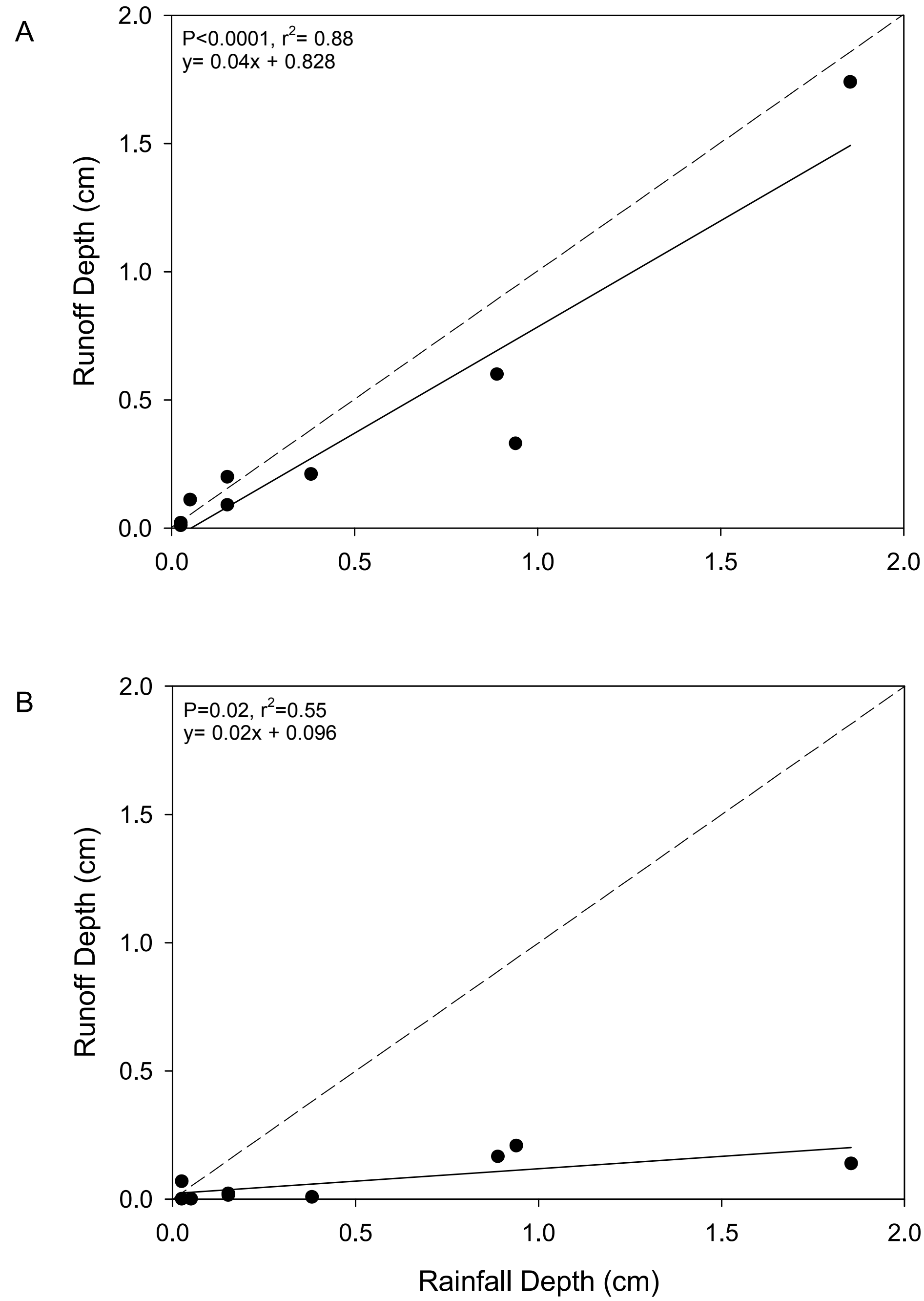

Figure 2.1. The asphalt lot (A) produced significantly more surface runoff than the porous lot (B) in Athens, Georgia. The dashed line represents a 1:1 ratio between runoff and rainfall depth.

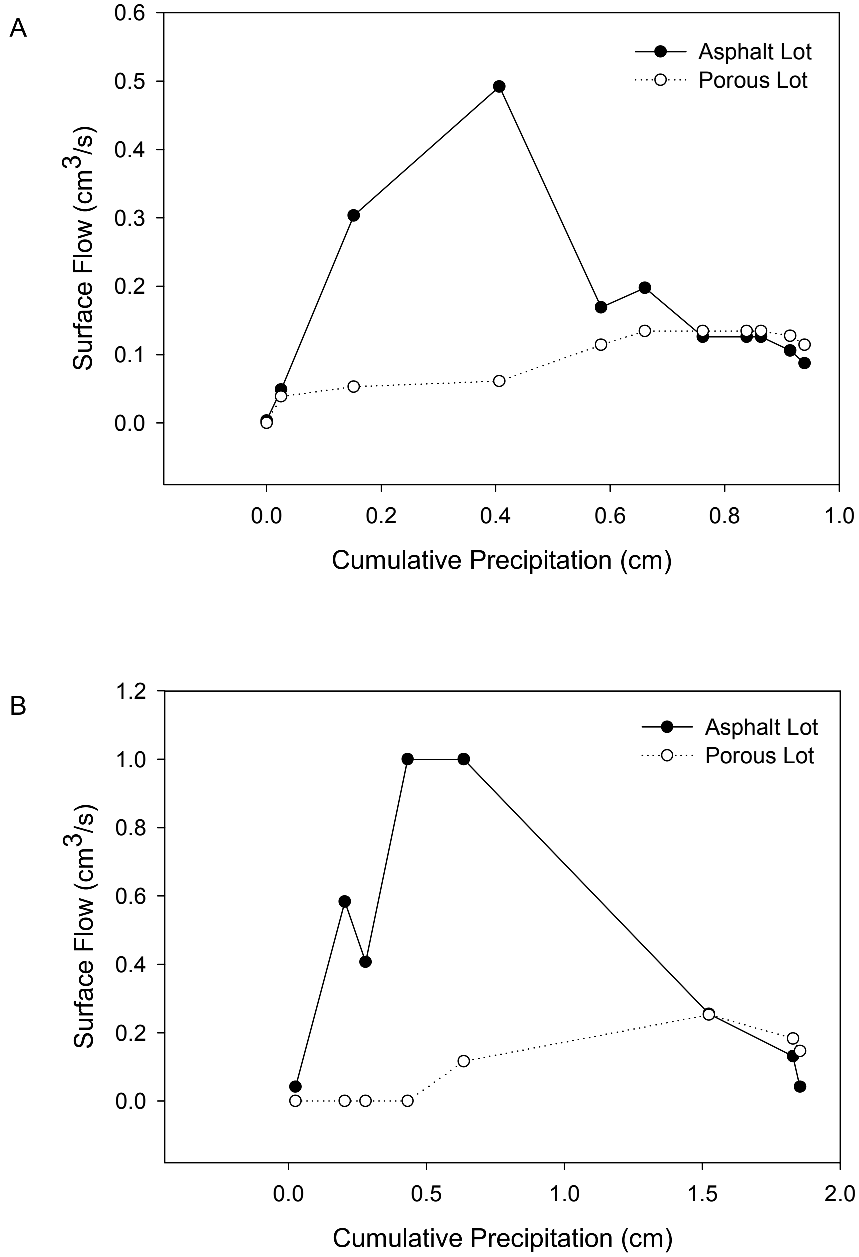

Figure 2.2. Surface flow during a small storm event (A) and large storm event (B) at the two study lots.

A

B

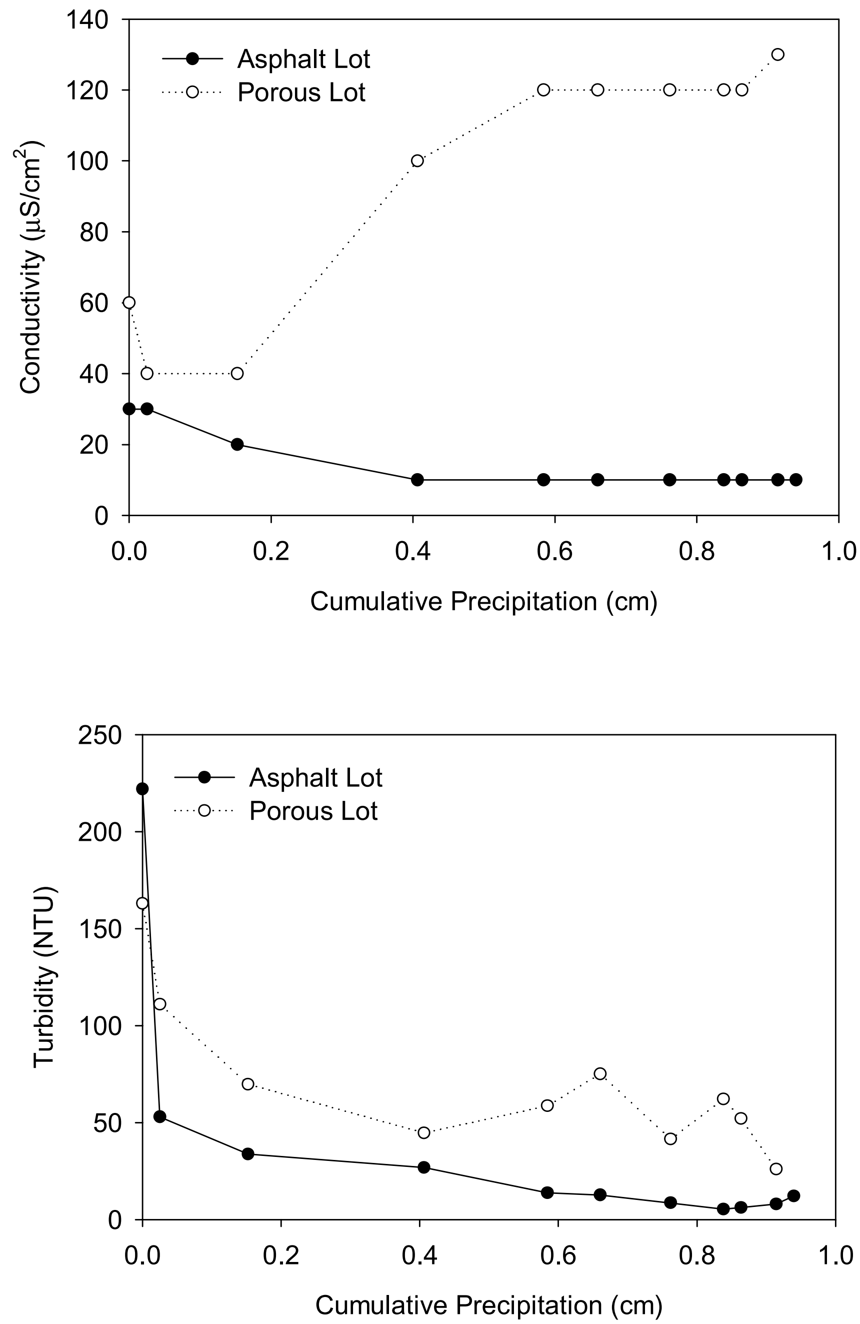

Figure 2.3. Conductivity and turbidity at the two study lots over the course of one storm.

CHAPTER 3

POROUS PAVERS REDUCE NUTRIENT AND SEDIMENT LOADS IN STORMWATER RUNOFF ON CLAY SOILS[1]

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[1]Dreelin, E. A., L. A. Fowler, and C. R. Carroll. To be submitted to *Journal of the American Water Resources Association.*

Abstract

Porous pavements are one option for on-site management of stormwater runoff. However, it is unclear if they will function effectively on clay soils, particularly for storm events larger than ~2 cm. Our objectives were to test if porous pavements are effective on clay soils and if there is a measurable change in performance with increased storage capacity of the base. We constructed 48 0.25m^2 experimental plots, 36 concrete porous pavers and 12 concrete control plots. Three base types for the porous pavement were constructed: 15.24 cm (6 in) of gravel, 25.4 cm (10 in) of gravel, and 15.24 cm (6 in) of gravel over 5.08 cm (2 in) of sand. Nutrients and sediment were added to the plots to evaluate how well porous plots reduce the pollutant load of surface runoff. We simulated a 1.4 cm and 2.64 cm storm event and collected surface runoff from the plots. Surface runoff at the porous plots was 99% less than that of the concrete plots. Nutrient concentrations did not differ among the plots for the 1.4 cm storm event but were 85-99% higher for concrete plots during the 2.64 cm simulated storm. Total phosphorus, total nitrogen, and total suspended solids loads were significantly higher for the concrete plots than porous plots for large storm events. Porous pavers on clay soils effectively reduced the volume of surface runoff, nutrient loads, and sediment loads for small (<2.64 cm) simulated storm events.

Introduction

The proliferation of impervious surfaces is principally responsible for the degradation of urban aquatic ecosystems (Brabec et al. 2002). Impervious surfaces alter watershed hydrology by increasing the frequency and magnitude of peak flows (Dunne and Leopold 1978; Roy et al. unpubl. data). Stream channels quickly respond to these changes in hydrology, resulting in the unstable, eroded and bed-armored channels typical of urbanized landscapes (Bledsoe and Watson 2001). Not surprisingly, the quality of aquatic habitats in urban areas also quickly degrades (Booth 1991). When total impervious surface cover reaches 8-20% of the watershed (Schueler 1994; Karr and Chu 2000), the diversity of aquatic insects (Roy et al. 2003, Benke et al. 1981; Crawford and Lenat 1989; Jones and Clark 1987) and fishes (Crawford and Lenat. 1989; Roy et al. unpubl. data) decline precipitously. As overall imperviousness rises above 25%, strong impacts on aquatic systems are unavoidable and possibly beyond restoration (Karr and Chu 2000). Until recently, the land use planning process has generally ignored the ecological consequences of urban development (Arnold and Gibbons 1996). However, as we become increasingly aware of the benefits of retaining natural landscape features in urban settings (i.e., ecosystem services), we must seek ways to sustain those critical natural functions that are either too costly, or technologically impossible, to reproduce.

Current stormwater management techniques rely heavily on conveyance and detention approaches that often fail to protect aquatic resources from degradation (Booth et al. 2000). In fact, measures of biotic integrity show no improvement in watersheds employing conventional stormwater BMPs versus those without any stormwater controls (Jones et al. 1996; Maxted and Shaver 1996). Recognizing this failure has led to a recent evolution in stormwater management paradigms (Reese 2001). Instead of focusing solely on sanitation and flood, more holistic approaches to stormwater management, such as low impact development (LID), seek to minimize hydrologic alterations that result from increases in imperviousness (Prince George's County 1999). LID and similar techniques to manage growth have the potential to reduce impacts on aquatic systems as well as save money. A recent comparison of traditional development strategies in the U.S. vs. a managed growth approach resulted in less demand for water and sewer infrastructure and a projected savings of $12.6 billion (6.6%) in development costs (Burchell and Mukherri 2003). Significant cost savings are also realized at the site level. For example, build-out comparisons of distributed source controls for stormwater runoff show construction savings between 12-20% when LID site planning techniques are used (Center for Watershed 2000).

A central goal of the LID stormwater management paradigm is to preserve as much as possible the valuable ecosystem services that a natural hydrologic regime provides. Ecosystem services, such as flood protection by wetlands and crop pollination by insects, are services provided by natural systems that directly benefit humans (Palmer et al. 2004). These services can be preserved by protecting intact ecosystems, the approach traditionally advocated by many ecologists, or by engineering built environments to incorporate or maintain ecosystem services in areas where habitats cannot be preserved (Palmer et al. 2004). In particular, there is a need for ecological design solutions for problems relating to urbanization and the degradation of freshwater ecosystems. Following this approach, design solutions that maintain or mimic pre-development hydrology and the ecosystem services provided by intact soils (e.g., infiltrating precipitation, removing pollutants and recharging ground water resources) must be developed and tested.

Porous pavements are one management technique that can be used effectively to reduce the impacts of stormwater runoff. Porous pavements allow precipitation to infiltrate through the surface and into the soil. The result is a reduction in the volume of surface runoff generated during storm events of 30-93% when compared to impervious pavements (Chapter 2; Rushton 2001; Pratt et al. 1995). By reducing runoff, pollutant loading from sites with porous pavements is also significantly reduced (Brattebo and Booth 2003; Rushton 2001; Schueler 1987).

Although porous pavements have many potential benefits, they are more costly than traditional pavements (Schueler 1987), and are perceived to have limited application in Georgia. For example, porous pavements are currently not recommended for soils with clay contents greater than 30% (EPA 1999). However, recent experimental evidence has demonstrated they can function effectively on clay soils when used to capture small storm events and the first flush of larger storms (Chapter 2).

Several design options exist for porous pavements depending on their intended use (Schueler 1987). Full exfiltration systems are designed with a large gravel or stone base to ensure that 100% of the design storm infiltrates the pavement or evaporates. Partial exfiltration systems have smaller bases that include an underground drainage system. Runoff from small storms fully infiltrate, whereas heavy flows associated with large storms pass through the pavement and into more traditional detention/retention facilities, or directly into local waterbodies. Alternatively, water quality systems are designed to retain and treat the first flush from storms, commonly defined as the first half-inch of runoff. These systems have a smaller gravel base equipped with an underdrain system that discharges to other stormwater BMPs. Hence, there is considerable flexibility in the design of the porous pavement systems depending on their intended use, site conditions, and cost.

Our goal was to examine the efficacy of porous pavements sited on clay-rich soils during simulated storm events larger than those previously monitored in Georgia. Because of the low infiltration rates of Piedmont soils, we also wanted to determine if enlarging the gravel base of the pavement would significantly improve its ability to reduce runoff and remove pollutants (nutrients, sediment). We hypothesized that porous pavements would effectively control the 1.4 cm (0.7 cm/hr) and 2.64 cm (1.32 cm/hr) storm events (vs. a traditional impervious surface), and that increasing the depth of the base, and consequently the storage volume, would improve performance.

Methods

Study Site and Experimental Apparatus

In August 2003, we constructed a mosaic of 48 0.25m^2 experimental porous paver plots at the University of Georgia Horseshoe Bend Experimental Area in Athens, Georgia. Horseshoe bend is a 14-ha facility comprised of old fields, successional forests, and agroecosystem plots. It has deep clay soils with infiltration properties typical of newly exposed Piedmont soils in northern Georgia. Prior to construction of the plots, we cleared all surface vegetation and the first several centimeters of soil from a fallow agricultural field. We chose an open field to ensure full exposure to natural precipitation during the pre-experimental period

Each experimental plot was 0.5 m square and varied in depth, surface pavement, and base material according to the treatment. To test whether porous pavers function effectively on clay soils, and whether modifications to the base material would increase stormwater infiltration on clay soils, we constructed 12 replicates each of four combinations of surface pavement and base as follows (Fig. 3.1):

Porous Pavement 1: EcoStone®, a commercially available porous concrete paver, overlaying 5.08 cm (2 in) of pea gravel and 15.24 cm (6 in) of #57 gravel (1-1.5" diameter). Referred to as **6G** in the text.

Porous Pavement 2: EcoStone® pavers over 5.08 cm (2 in) of pea gravel, 15.24 cm (6 in) of #57 gravel, and 5.08 cm (2 in) of sand. Referred to as **6G+S** in the text.

Porous Pavement 3: EcoStone® pavers over 5.08 cm (2 in) of pea gravel and 25.4 cm (10 in) of #57 gravel. Referred to as **10G** in the text.

Impervious Control: A patch of newly poured concrete over 5.08 cm (2 in) of pea gravel and 15.24 cm (6 in) of #57 gravel. Referred to as **concrete** in the text.

Each plot was dug by hand in a 4 × 12 grid arrangement with 0.5m separating the plots (Fig. 3.2). We lined each experimental plot with a 12-mil plastic liner to prevent lateral infiltration of water during the trials. We placed a vertical piece of 1.27 cm (0.5 in) diameter PVC pipe in a corner of the hole prior to filling with the base material. The PVC pipe was perforated around the lower four cm and served as a monitoring well for infiltrated stormwater. We then added the base material and constructed the pavement in accordance with regular parking lot construction practices, with one exception. Because each plot was small and essentially comprised of unreinforced edge, we did not mechanically compact the plots. After the base and pavers/concrete were installed, we used silicone caulk to seal the plastic liner to the sides of the pavement to ensure surface water did not drain down the sides (Fig. 3.3). We ran a piece of 0.32 cm (0.125 in) standard aquarium tubing through the liner and into a nalgene sample bottle to collect surface runoff samples. We simulated storms using a simple garden sprinkler. Prior to the start of experiments, we conducted a preliminary series of trials with the sprinkler and a tipping bucket rain gauge to ensure simulated storm events were repeatable and delivered the same amount of precipitation to all experimental plots.

Experimental Design and Data Analysis

Our three porous pavement treatments represent a range of current and proposed parking lot construction practices. A 5.08-cm (2 in) layer of pea gravel was used in all treatments as a bedding layer for the pavement. The 15.24 cm (6 in) gravel base (6G, concrete control) is the current practice for conventional impervious pavements. We added 5.08 cm (2 in) of sand to this standard application (6G+S) to test whether a small amount of sand could compensate for the low infiltration rates of Piedmont soils. Finally, the 25.4-cm (10 in) gravel base (10G) is currently recommended by Athens-Clarke County for standard construction of porous pavement parking lots. Experiments were conducted approximately 8 months after plot construction (22 March – 19 May 2004). During the period between construction and testing, the plots were fully exposed to natural storm events to 'season' the plots and preclude any artifacts associated with recent construction (e.g., high conductivity, Chapter 2).

Because porous pavements are commonly used to control small storm events, or the first flush of large events (ARC 2003), we chose to simulate relatively small, high frequency storms. For each of the trials described below we simulated two storm events, small (1.4 cm; 0.7 cm/hr) and large (2.64 cm; 1.32 cm/hr), which represent the one-month and three-month 2-hour storm events for Athens, Georgia (ARC 2003). For each simulated storm, the sprinkler was placed in the center of the plots with the rain gauge 2m from the sprinkler. All trials were preceded by 36 hours of dry conditions. Our simulated storm events were larger than the natural storms we previously monitored at a nearby grassy porous pavement parking lot installation during the spring of 2003 (Chapter 2). However, that monitoring took place at the end of a severe drought period that significantly reduced the frequency and magnitude of natural storms.

Experiment 1 - Runoff Trials. To test whether porous pavers significantly reduced stormwater runoff vs. traditional impervious pavement, we measured total surface runoff from two test storms (one small, one large) for each pavement treatment (four treatments, N=12 for each). We directly compared the runoff amounts between treatments with separate one-way ANOVAs and post-hoc Tukey-Kramer multiple comparison tests for small and large storms. We predicted: 1) that total runoff would be significantly less on all porous pavements vs. the impervious control; 2) adding sand to the standard 15.24-cm (6 in) gravel base would improve infiltration of surface runoff (runoff from 6G+S < 6G); and, 3) increasing the depth of gravel would reduce total surface runoff (runoff from 10G < 6G).

Experiment 2 - Nutrient Trials. To test whether porous pavers significantly reduce nutrient concentrations in stormwater runoff, and total nutrient loading, we measured the volume and the concentration of total nitrogen (mg/L) and total phosphorus (mg/L) in runoff from small and large simulated storms. Prior to simulation of the storm event, we added dry aliquots of 15-30-15 MiracleGro™ All Purpose Plant Fertilizer to each of the plots at one of three concentrations (hereafter referred to as low, medium, and high). The treatment levels represent the manufacturer's recommended concentration (56.6 mg/L total phosphorus, 24.68 mg/L total nitrogen), twice the recommended concentration (161.9 mg/L total phosphorus, 89.38 mg/L total nitrogen), and half the recommended concentration (11.68 mg/L total phosphorus, 9.12 mg/L total nitrogen). We chose to use commercially available fertilizer to mimic the most likely source of nutrients in parking lots (i.e., fertilizer washing from lawns and landscaped areas). Plots from each of the four pavements were randomly assigned to a nutrient treatment level, resulting in four replicates per fertilizer concentration/pavement combination. All of the runoff from each plot was collected, stored on ice, and transported to the UGA Institute of Ecology

Chemical Analysis Lab for total phosphorus and total nitrogen. Total phosphorus was measured by digesting the samples with ascorbic acid followed by automated colorimetry (EPA 1983). Total nitrogen was measured using a persulfate digest followed by automated colorimetry (Qualls 1989). The nutrient loading (mg) from each plot was calculated as concentration (mg/L) multiplied by total runoff (L).

We investigated differences in nutrient concentrations and total loadings among the treatments (pavement, fertilizer quantity) with separate two-way ANOVAs for small and large storms. Significant main effects were followed up with one-way ANOVAs and post-hoc Tukey-Kramer multiple comparison tests to identify significant differences in mean concentrations and loadings. We predicted: 1) that nutrient concentrations and loadings would be significantly less on all porous pavements vs. the impervious control; 2) adding sand to the standard 15.24 cm (6 in) gravel base would improve nutrient retention (concentrations in runoff and total loading from 6G+S < 6G); and, 3) increasing the depth of gravel would improve nutrient retention (concentrations in runoff and total loading from 10G < 6G). We also compared among porous paver base configurations to determine the most effective combination for removing nutrients from runoff.

Experiment 3 - Sediment Trials. To test whether porous pavers significantly reduce sediment in stormwater runoff, we measured volume, turbidity (NTU), and total suspended solids (mg/L, TSS) in runoff from small and large simulated storms. Prior to simulation of the storm event, we added dry aliquots of locally collected sediment to each of the plots at one of three concentrations (hereafter referred to as low, medium, an high). Sediment was collected several meters from the experimental plots. We based the low treatment level (0.1 g) on the TSS load typically observed in runoff from roads (Wu et al. 1998). The medium (1 g) and high (10 g) treatment levels represent one and two order increases in magnitude. We chose these levels to represent the higher sediment loads associated with a range of local construction activity. Plots from each of the four pavements were randomly assigned to a sediment treatment level, resulting in four replicates per sediment load/pavement combination. All of the runoff from each plot was collected and transported to the UGA Institute of Ecology for subsequent analysis. We measured turbidity directly from the samples with a Brand bench turbidimeter. A 20mL subsample was then freeze-dried and TSS was calculated as difference between the initial bottle weight and the post-freeze drying weight divided by the sample volume. Sediment loading from a plot was calculated as TSS (mg/L) multiplied by the total volume of runoff (L).

We investigated differences in turbidity and TSS among the treatments (pavement, sediment quantity) with separate two-way ANOVAs for small and large storms. As before, significant main effects were followed up with one-way ANOVAs and post-hoc Tukey-Kramer multiple comparison tests to identify significant differences in mean turbidity and TSS, and total sediment. We predicted: 1) that both measures of sediment concentration and total sediment loading would be significantly less on all porous pavements vs. the impervious control; 2) adding sand to the standard 15.24 cm (6 in) gravel base would improve sediment retention (turbidity and TSS in runoff and total sediment loading 6G+S < 6G); and, 3) increasing the depth of gravel would improve sediment retention (turbidity and TSS in runoff and total sediment loading from 10G < 6G). We also compared among porous paver base configurations to determine the most effective combination for removing sediments from runoff. All statistical analyses were performed with SAS JMP version 5.1.

We originally intended to test the total volume and concentrations of nutrients/sediment from both surface runoff and infiltrate. However, the porous pavements were so efficient at infiltrating precipitation, we were generally unable to obtain infiltrate samples from the monitoring wells. Therefore, all results described below refer to values derived from surface runoff only. Further, we only present one-way ANOVAs for significant pavement main effects. We included three fertilizer treatments in order to test the relative ability of the porous pavement base configurations to remove nutrients. The lack of infiltrate precluded this test, and we omit description of any differences in treatment means in the interest of brevity.

Results

Runoff Trials. The volume of surface runoff was significantly greater for the concrete controls vs. each of the porous paver plots for both small (one-way ANOVA, $F=35.71$, $P<0.0001$) and large ($F=82.29$, $P<0.0001$) simulated storms (Fig. 3.4). Post-hoc Tukey-Kramer tests failed to detect any significant differences at the $P<0.05$ level among all pairs of porous paver treatments. Runoff from the porous paver plots was generally minimal, averaging 0.002-0.02% of that from the impervious surface (mean ± SE; small storm, concrete, 723.9 ± 133.0 ml; all porous combined, 0.13 ± 0.07 ml; large storm, concrete, 981.2 ± 111.6 ml; all porous combined, 0.26 ± 0.13 ml). Thus, porous pavers effectively reduced surface runoff for the design storms (prediction 1 supported), but there were no observable differences in performance due to base design (predictions 2 and 3 not supported).

Nutrient Trials. Two-way ANOVA detected significant effects of fertilizer treatment and pavement type on total phosphorus concentrations during large simulated storms (fertilizer main effect, $F=8.55$, $P=0.002$; pavement main effect, $F=26.9$, $P<0.0001$), whereas total nitrogen was only affected by pavement type ($F=14.5$, $P<0.0001$). A posteriori tests revealed significant differences in phosphorus concentrations from the pavement types at the high (one-way

ANOVA, F=22.8, P=0.0003; Tukey-Kramer, concrete > 6G = 6G+S = 10G) and medium (one-way ANOVA, F=6.8, P=0.01; Tukey-Kramer, concrete > 6G+S > 6G = 10G) fertilizer treatment levels (Fig. 3.5A). Total nitrogen concentrations were significantly different among pavement types at the medium fertilizer treatment (F=14.7, P=0.002; Tukey-Kramer, concrete > 6G = 6G+S = 10G) and marginally insignificant at the high fertilizer treatment (F=3.82, P=0.058; Tukey-Kramer, concrete > 6G = 6G+S = 10G, Fig. 3.5C).

As above, pavement type also significantly affected total phosphorus (two-way ANOVA, F=13.5, P<0.0001) and total nitrogen (F=23.4, P<0.0001) loading, whereas the fertilizer main effect was only significant for total phosphorus loading (F=4.63, P=0.02). The main effect of pavement on phosphorus and nitrogen loading was significant for all three fertilizer applications (one-way ANOVA: phosphorus, high fertilizer F=7.2, P=0.005, medium fertilizer F=13.3, P=0.0004, low fertilizer F=6.43, P=0.008; nitrogen, high fertilizer F=8.31, P=0.003, medium fertilizer F=63.5, P<0.0001, low fertilizer F=6.38, P=0.008). In all cases loadings from the concrete control were significantly different from all porous pavements, and there were no significant differences among porous pavements (Tukey-Kramer, concrete > 6G = 6G+S = 10G, P<0.05, Fig. 3.5B&D).

There were no significant main effects of fertilizer treatment or pavement type on nutrient concentrations during small storms (two-way ANOVA, all P>0.2, Fig. 3.6A&C). However, both phosphorus (two-way ANOVA, F=3.25, P=0.03) and nitrogen (F=6.00, P=0.002) loading were affected by pavement type (Fig.3.6B&D). Total phosphorus and nitrogen loading differences were only significant at the medium fertilizer treatment (one-way ANOVA, phosphorus, F=7.87, P=0.004; nitrogen, F=13.16, P=0.0004). In both cases, the loading from concrete was greater than any porous pavement, and there were no effects of base type on loading from porous treatments (Tukey-Kramer, concrete > 6G = 6G+S = 10G, P<0.05).

Sediment Trials. For large storms, two-way ANOVA revealed significant main effects of pavement type and sediment treatment on turbidity (pavement, F=10.09, P=0.002; sediment, F=5.14, P=0.04), total suspended solids (pavement, F=4385.3, P<0.0001; sediment, F=24.89, P=0.0002), and sediment loading (pavement, F=14.41, P<0.0001; sediment, F=31.67, P<0.0001) in surface runoff (Fig. 3.7). Significant differences in turbidity occurred at the medium sediment treatment level (one-way ANOVA, F=7.57, P=0.04) where the mean turbidity in runoff from the concrete control was greater than any porous pavement (Tukey-Kramer, concrete > 6G = 6G+S = 10G, P<0.05). For total suspended solids, significant differences were detected at the low (one-way ANOVA, F=8.37, P=0.02) and medium (F=2067.12, P<0.0001) sediment treatments. Unlike the previous findings for nutrient concentration, mean TSS concentrations were highest from the 6G pavement at the medium sediment treatment (Tukey-Kramer, 6G > concrete = 6G+S = 10G). However, at low sediment TSS was significantly higher in runoff from the concrete control (Tukey-Kramer, concrete > 6G = 6G+S = 10G, P<0.05). Significant differences in sediment loading arose in the high (one-way ANOVA, F=27.20, P<0.0001) and medium (F=14.18, P=0.0003) sediment treatments where loading from the concrete control was significantly higher than all porous pavement configurations (Tukey-Kramer, concrete > 6G = 6G+S = 10G, P<0.05).

For small storms, significant main effects of pavement type and sediment treatment were detected for turbidity (two-way ANOVA, pavement, F=4.87, P=0.046; sediment, F=17.38, P=0.002) and total sediment loading (pavement, F=24.02, P<0.0001; sediment, F=4.31, P=0.02) from surface runoff (Fig. 3.8). Only pavement type was significant in the full model for total suspended solids (F=6.65, P=0.01). Turbidity was significantly higher in runoff from the concrete control vs. all porous pavements (Tukey-Kramer, concrete > 6G = 6G+S = 10G, $P<0.05$) at the high sediment treatment (one-way ANOVA, $F=14.26$, $P=0.007$), and marginally insignificant at the medium sediment treatment ($F=6.51$, $P=0.055$). The TSS results mirrored those of large storms, with significant differences only at the medium sediment treatment (one-way ANOVA, $F=71.44$, $P=0.003$), and higher mean concentration in runoff from the 6G porous pavement (Tukey-Kramer, 6G > control = 6G+S = 10G). Significant differences in total sediment loads occurred during all three sediment treatments (one-way ANOVA, high sediment, $F=12.17$, $P=0.0006$; medium sediment, $F=7.80$, $P=0.004$; low sediment, $F=7.64$, $P=0.004$). In all comparisons, sediment loading from the concrete controls was greater than that of any porous pavement treatment (Tukey-Kramer, concrete > 6G = 6G+S = 10G, $P<0.05$).

Discussion

Porous pavers effectively controlled runoff during the one-month (0.70 cm/hr) and three-month (1.32 cm/hr) storm events when sited on clay soils. Regardless of base configuration, all porous plots produced < 1% of the surface runoff from the concrete control plots. In fact, the porous plots infiltrated stormwater so effectively we were unable to collect samples of the infiltrate from the monitoring wells. These findings are in keeping with our previously reported observations from a nearby full-scale grassy porous parking lot (Chapter 2), where only a single monitored storm (1.85 cm) produced any flow from an under-gravel drainage system. Although the total precipitation from our large storm (2.64 cm) should have resulted in the accumulation of water in the monitoring well, it is likely our decision not to mechanically compact the underlying substrate increased infiltration into the soil. This may also have contributed to the lack of significant differences among the three porous pavement configurations in total surface runoff from the one-month and three-month simulated storms. It appears the addition of a layer of sand or extra gravel did not result in any immediately apparent increases in performance for stormwater control, although long-term benefits may accrue. For example, the increased base layer could result in a lower failure rate from clogging, or at least increase the interval between required maintenance activities. Overall, we observed a greater reduction in runoff (vs. an impervious surface) than previously reported for porous pavement applications (Andersen et al. 1999). For porous pavements sited on sandy soils, Rushton (2001) reported a 40-45% reduction in stormwater runoff volume. It is somewhat surprising that fine clay sediments would drain stormwater as efficiently as sand, although our plots did not receive any vehicle traffic or other activity normally associated with parking lots. Thus, our current findings, coupled with those of a previous study (Chapter 2), are best accepted as a 'proof of concept' finding that demonstrates the potential efficacy of porous pavements to control runoff from small storm events when sited on clay soils.

The porous pavers were also effective at reducing the concentration of nutrients in surface runoff. We observed an average of 99% less total phosphorus and 85% less total nitrogen in surface runoff samples from porous plots treated with fertilizer when compared to concrete controls. These differences were more apparent during the high storm events, and for the high and medium nutrient treatments, suggesting that pollutant reduction efficiency may vary with storm intensity and concentration of the influent. When pollutant concentrations are low, and close to the 'irreducible level' (i.e., beyond the treatment capabilities of the best management practice), no actual pollutant removal may occur (Schueler 1996). With one exception, there were no meaningful differences in the nutrient concentrations in runoff from the three porous paver configurations (the 6G+S had higher phosphorus during the large storm, medium fertilizer trial). Conventional stormwater BMPs (e.g., detention ponds) typically exhibit low to moderate (15-60%) removal efficiencies for phosphorus and nitrogen. Removal efficiencies for porous pavements are generally higher, averaging 65% for total phosphorus and 83% for total nitrogen (Winer 2000). We observed nitrogen reductions greater that those reported from a porous asphalt highway (30-68%, Pagotto et al. 2000), although the large differences in use between the studies make such direct comparisons problematic.

Total nutrient loads from the porous plots were also significantly less than those from the concrete controls. The difference in nutrient loads was clearly a function of the greatly reduced volume of surface runoff coming from the porous plots. There were also no significant differences in nutrient loading from each of the porous paver configurations. Although the 6G+S treatment had higher phosphorus concentrations than the 6G and 10G bases, when volume of runoff was included the difference became unimportant. Our findings are consistent with a study of porous and impervious parking lots from Florida, where pollutant loads in surface runoff from porous pavements were quite low even though nutrient concentrations were not less than those from the impervious surface (Rushton 2001). Pollutant removal by porous pavements occurs in the gravel base via direct filtering of particles (Pratt et al. 1995), adsorption (Sansalone 1999), and microbial activity (Schueler 1987). Although we were unable to generate measurable infiltrate, such functions will be an important feature of the porous pavement configurations we tested. Overall, it appears porous pavers do not always reduce surface runoff pollutant concentration, but consistently reduce pollutant loads by retaining much of stormwater runoff generated at a site.

Porous pavements were also very effective at mitigating the effect of adding sediment to the plots immediately before a storm. The turbidity of surface runoff averaged 87-91% less from porous lots, although effects were only evident at the medium and high treatment levels. The failure to detect differences for small additions of sediment may have been associated with naturally occurring sediment on or in the porous pavers. In our study of a full-scale grassy porous pavement installation that experienced 'natural' sediment deposition, turbidity was also greatly reduced vs. a traditional impervious pavement parking lot (Chapter 2). As with nutrients, the benefits of porous pavements were more apparent when we examined total suspended solid loads vs. concentrations. Although recent studies report a 75-81% reduction in suspended solid concentrations for runoff from porous pavements when compared to impervious surfaces (Pagotto et al. 2000; Rushton 2001), our only significant result was a higher TSS concentration for the 6G porous pavement (vs. all others) at the medium treatment level. Variation in TSS concentrations was high among treatments, possibly due to variations in pre-existing sediment loads on the study site. However, when total runoff volume is accounted for, total sediment loads from concrete controls were significantly higher than all porous plots for all but one treatment combination (large storm , low sediment). Overall, our findings are consistent with previous studies (Pagotto et al. 2000; Rushton 2001). Total sediment loads are significantly reduced at sites using porous pavements vs. impervious pavements.

Because porous pavements filter particles, there is the potential for these particles to fill voids in the gravel base and decrease the ability of the pavement to infiltrate water (Schueler 1987). In fact, clogging due to sediment accumulation was responsible for the eventual failure of 69% of the porous parking lots surveyed by Lindsey et al. (1992). It is therefore not surprising that potential clogging by fine sediments has been a considerable impediment to the implementation of porous pavements in regions with clay-rich soils. Although we observed sediment particles remaining on the surface of the experimental plots (both porous and concrete) after the sediment trials, we did not observe any clogging of the porous plots. The intensity of precipitation and runoff influence the types of particles removed from pavements during storm events (Vaze and Chiew 2002). Rainfall may disintegrate and/or dissolve particles, with larger storm events removing more of the surface pollutant load (fixed and free) (Vaze and Chiew 2002). Small storm events usually wash very little of the surface pollutants from pavements, and the remainder may actually adhere to the pavement and become part of the 'fixed' pollutant fraction. Thus, our simulated storm events likely did not have the intensity to completely wash sediment from the plots. Although we did not observe clogging even with the direct addition of sediment to the experimental plots, we do not yet know how well these plots and other porous pavement installations will perform over time. Monitoring of the existing porous facilities will be required to determine how well they maintain infiltration capabilities with increasing use and age.

Our general failure to detect significant differences among the porous pavement base types we tested should not be interpreted too deeply. Although not statistically different, the gravel plus sand base did generate less runoff than the gravel bases during storm trials. The addition of a layer of sand rather than additional gravel may yet prove a viable option for increasing the depth of the base. However, as we mentioned above, we anticipate the benefits of increasing the storage volume in a porous paver application would derive from reduced pollutant loads in the infiltrate. Clearly, our ability to test this hypothesis was compromised by our choice of storm size. Further study is needed to examine whether sand/gravel combinations will remain effective over time, or if there is potential for clogging from sand particles migrating into the gravel base.

In Georgia, porous pavements are recommended for the control of small storm events (ARC 2003; Chapter 2). However, if the goal is to control the volume of surface runoff during small storm events, current design standards may require too deep a gravel base (10 inches). The design of the base depth will be determined by several factors related to use and treatment goals (e.g., site conditions, traffic load, design specifications for pavement type, water quality vs. runoff control). Local regulations should permit flexibility in design rather than applying a rigid standard. Our results demonstrate that for the simulated storms, four inches of additional gravel (currently required by Athens-Clarke County) did not improve hydrologic performance of the pavement, at least with respect to surface runoff volume. For small storms, the additional cost of the added gravel does not translate to a realized short-term benefit in performance of the porous pavement. Attempts to minimize the cost of porous pavements, and other innovative stormwater techniques, will likely lead to quicker acceptance by the development community. However, the benefits and limitations of each design alternative must be carefully communicated to managers and developers.

Porous pavement, as demonstrated here and in Chapter 2, is an effective infiltration best management practice for controlling small (<2.64 cm) storms on clay soils. In Georgia, watersheds with high imperviousness experience storm flows that are more frequent and of higher magnitude than watersheds with low imperviousness (Rose and Peters 2001; Roy et al. unpubl. data). In these altered systems, the diversity and abundance of the biotic community is reduced (Roy et al. unpubl. data). Progressive stormwater management techniques that employ infiltration are currently being recommended to protect valuable native fish communities (Roy et al. unpubl. data; Chapter 1). Preserving the hydrologic functions of a watershed is a fundamental principle of LID (Prince George's County 1999). It is a drastic departure from reliance on pipe and pond systems that essentially treat precipitation as waste. As ecologists continue to demonstrate the mechanistic links between impervious surfaces and negative effects on ecosystems, we must refine our approach to protect valuable ecosystem functions. Porous pavements, used in conjunction with LID strategies, have the potential to preserve a vital ecosystem service in developed areas by minimizing the hydrologic alterations caused by impervious surfaces.

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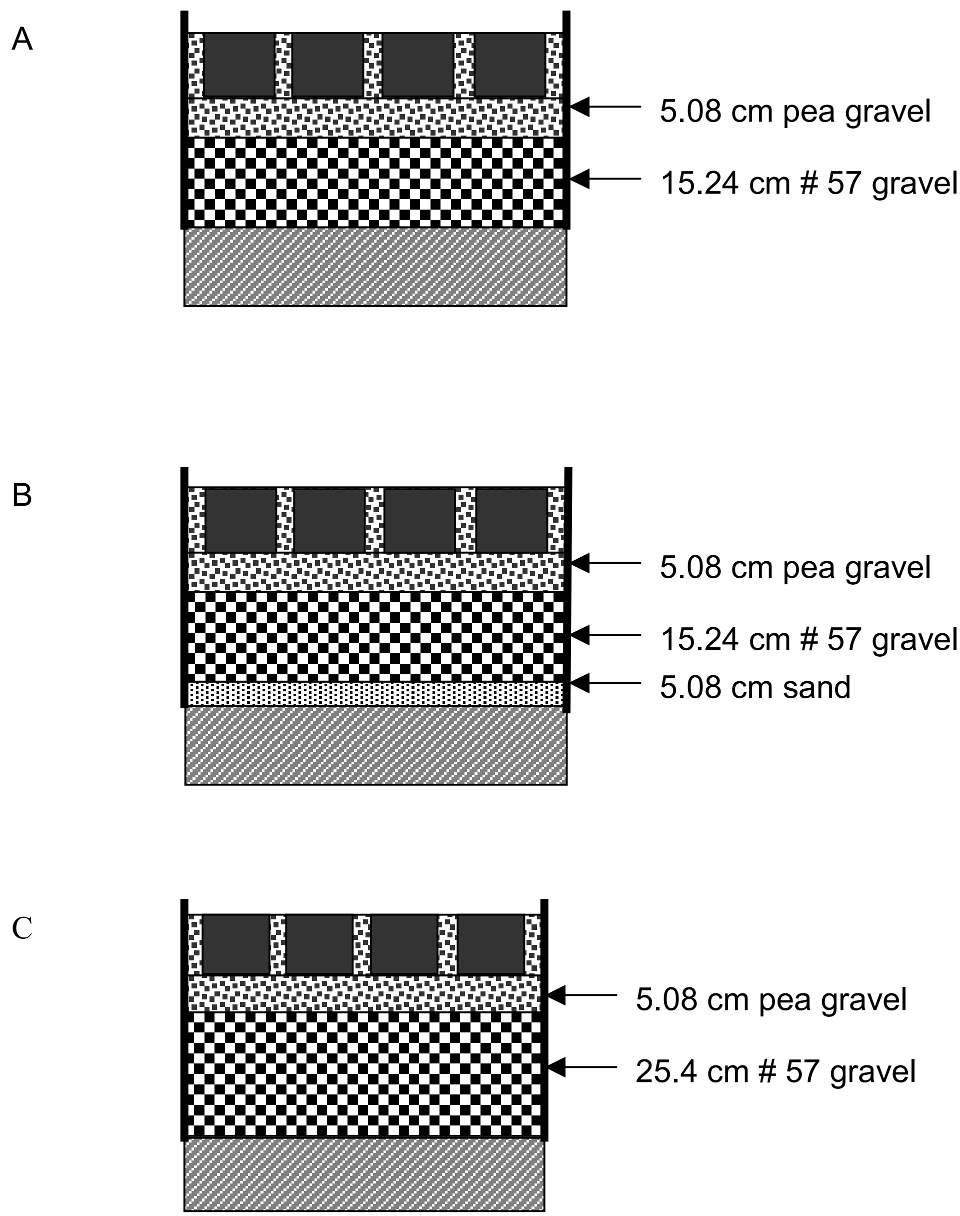

Figure 3.1. Schematic diagram of cross sections through porous pavement base types (A) 15.24 (6 in) of gravel, 6 G, (B) 15.24 cm (6 in) of gravel of a 5.08-cm layer of sand 6G+S, and (C) 25.4 cm (10 in) of gravel, 10 G.

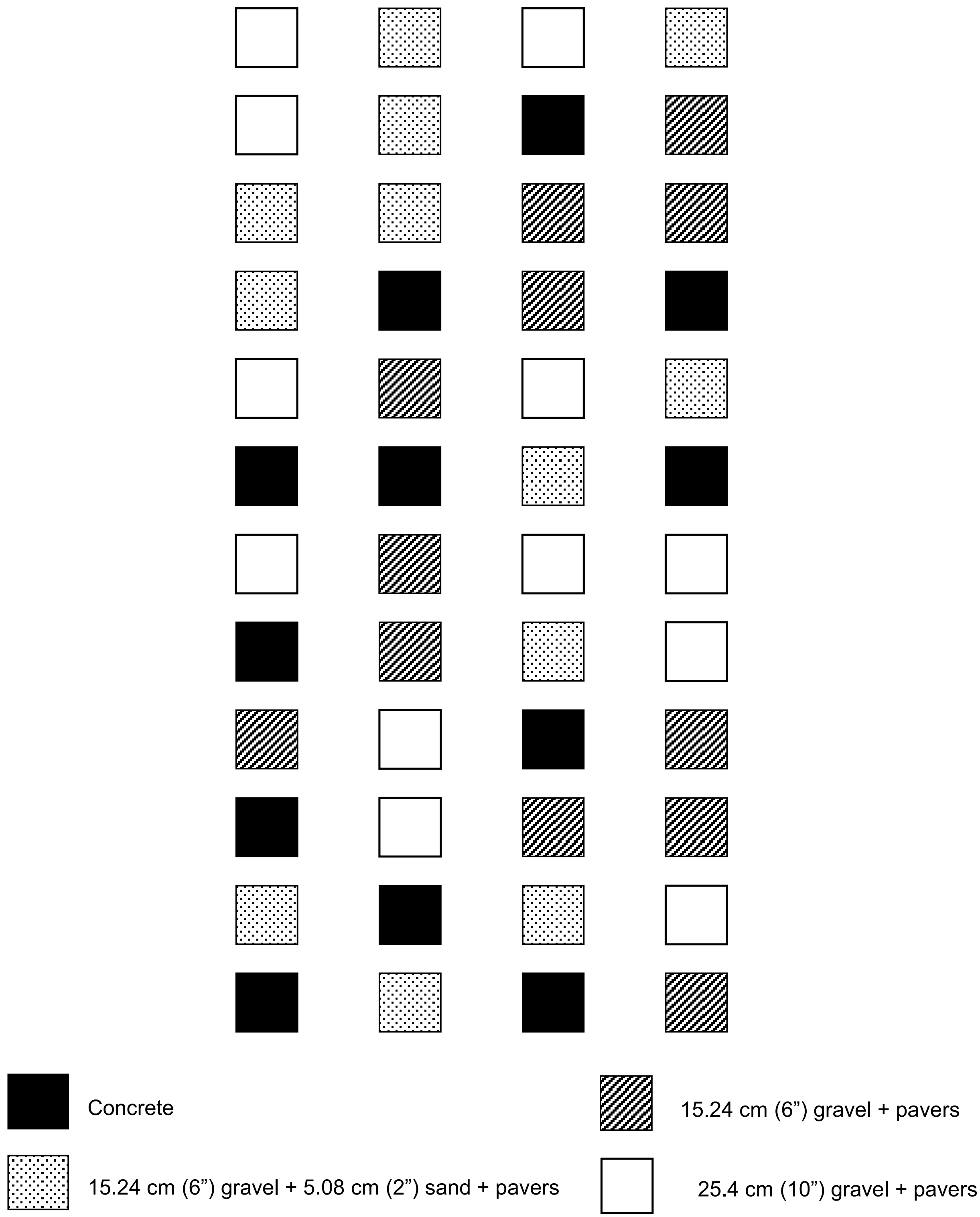

Figure 3.2. Schematic diagram of experimental plots showing configuration of base types.

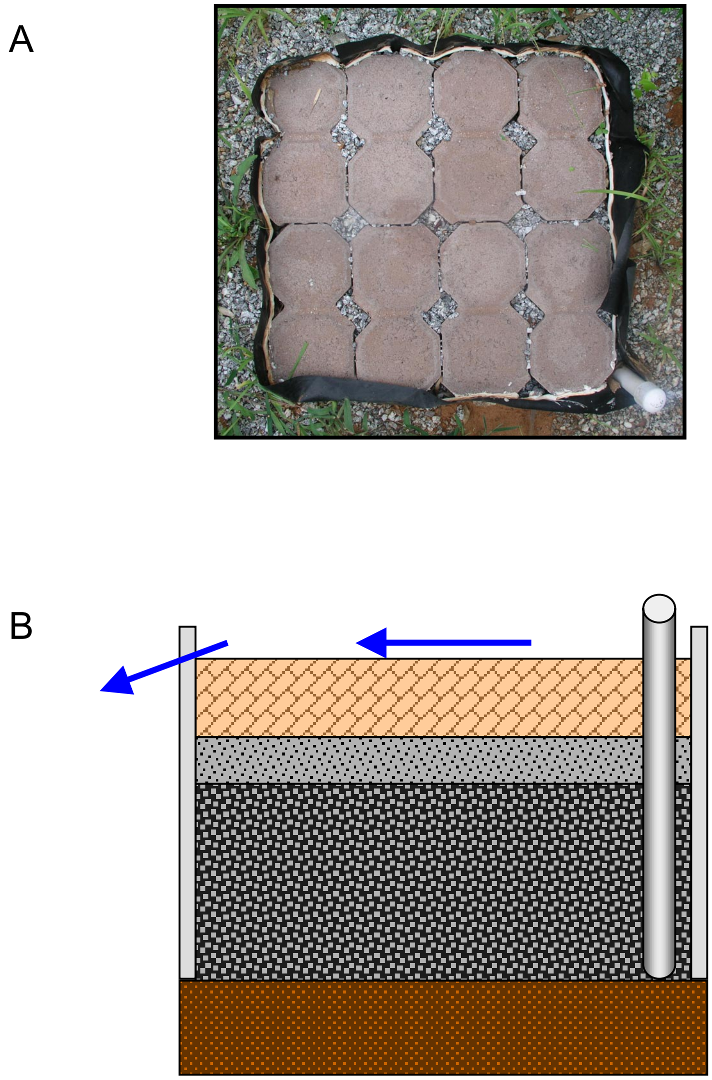

Figure 3.3. (A) Photo of porous experimental plot and (B) schematic of how surfance runoff was collected from all experimental plots.

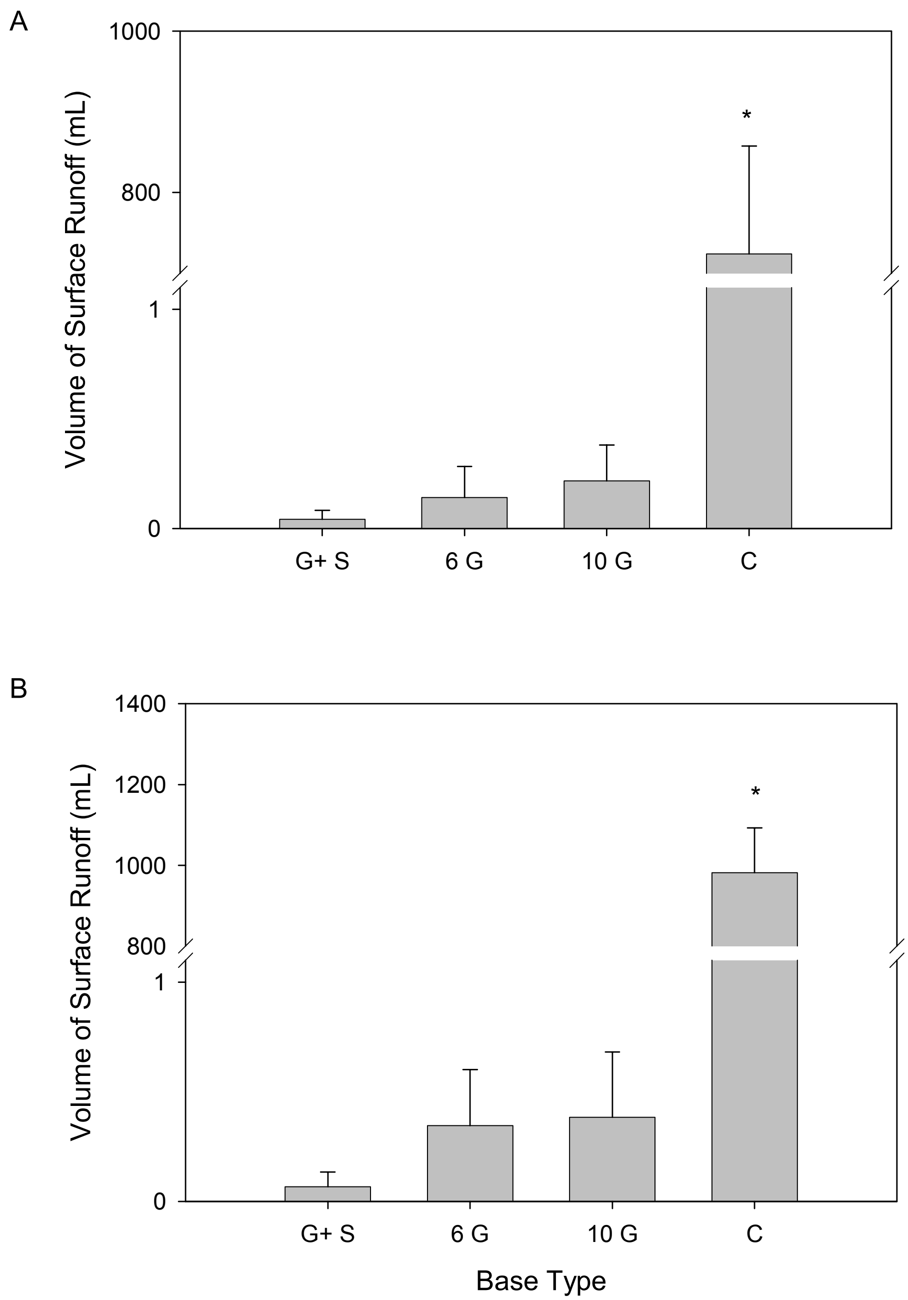

Figure 3.4. The volume of surface runoff from concrete control plots is significantly greater than that of porous plots during (A) 1.4 cm and (B) 2.64 cm simulated storm. No significant differences were found among base types of porous plots.

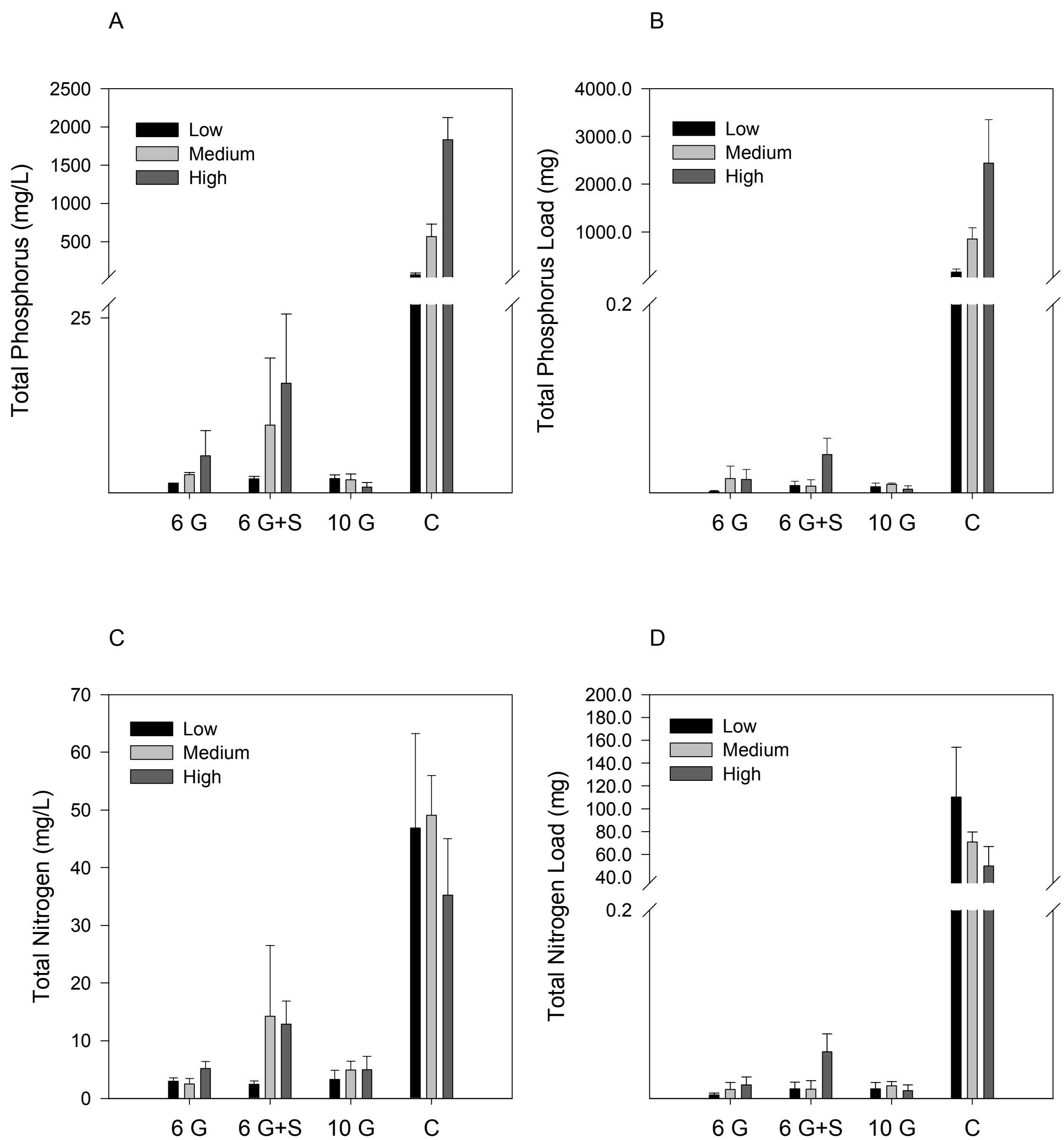

Figure 3.5. Nutrient concentrations and loads were higher for the concrete plots vs. porous plots for all base types during the 2.64 cm simulated storm event.

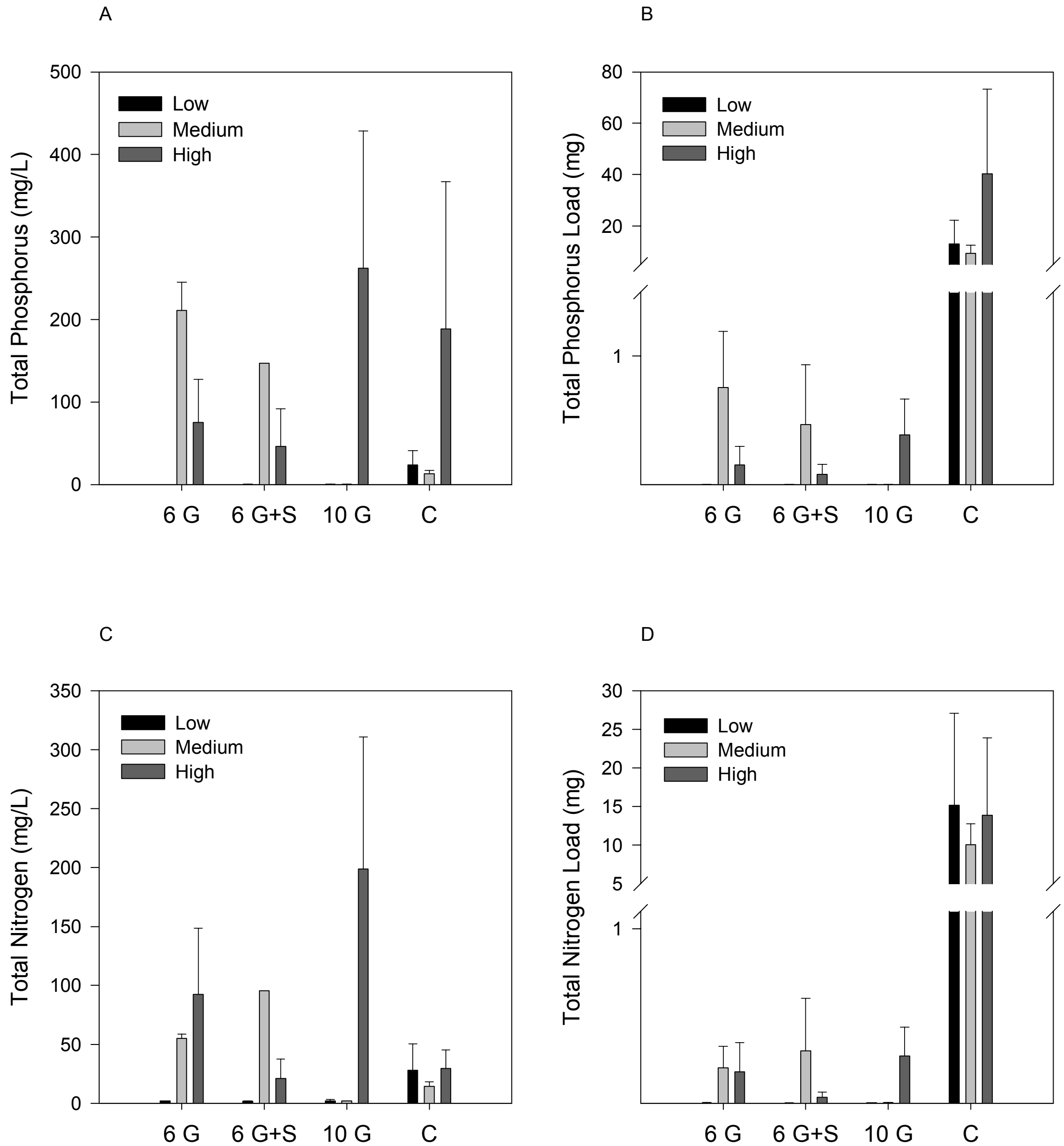

Figure 3.6. No significant treatment effects on nutrient concentrations were observed during the smaller 1.4 cm storm but nutrient loads from the concrete (C) plots were significantly greater than the porous plots. No differences between porous base types were found.

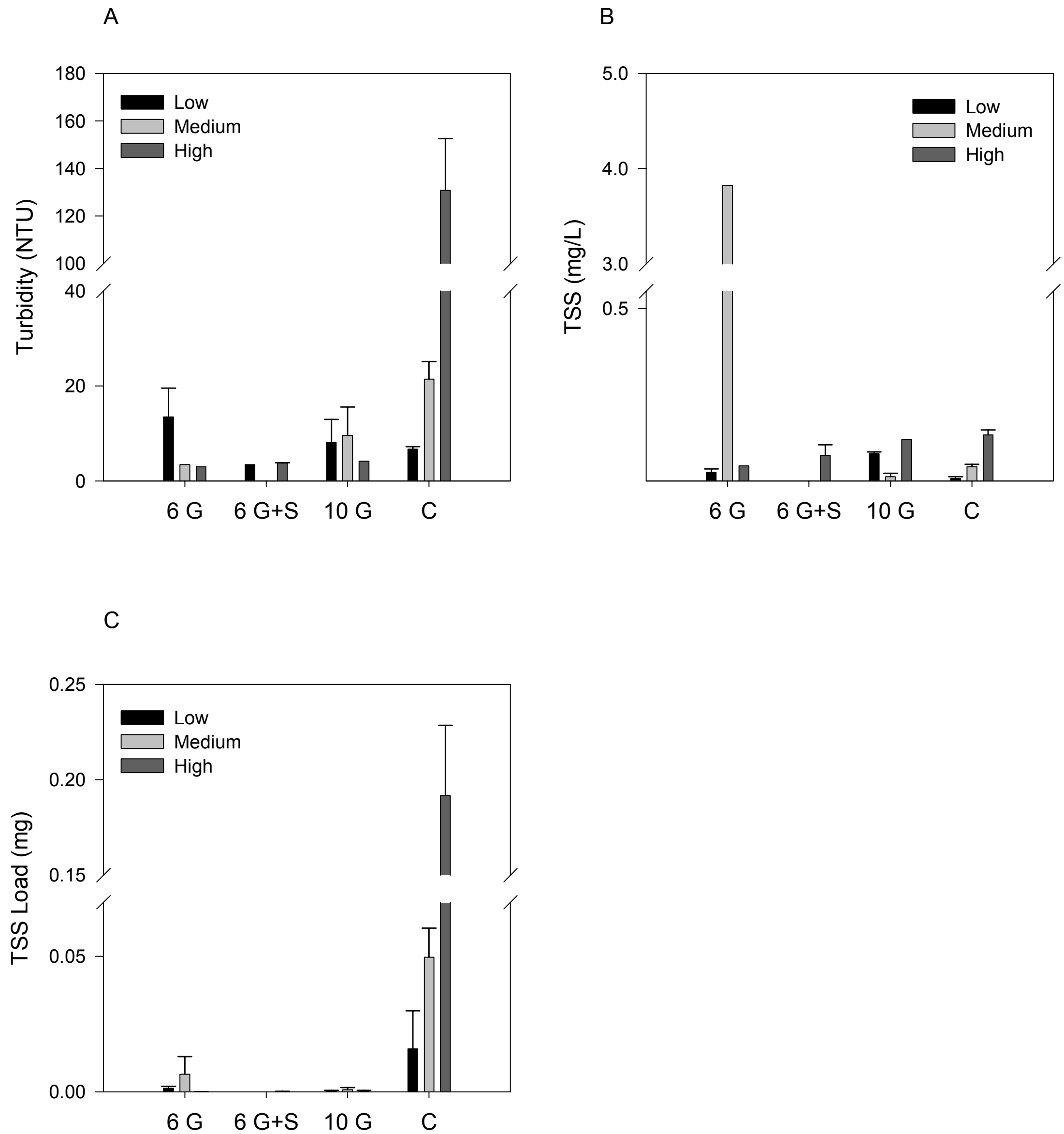

Figure 3.7. Results of the sediment trials for the 2.64 cm storm. Turbidity (A) was significantly greater for concrete plots than all porous plots, TSS (B) was significantly higher for the sand and gravel (6 G+S) base type. For all treatment levels TSS loads (C) were significantly higher for the concrete controls than all porous plots.

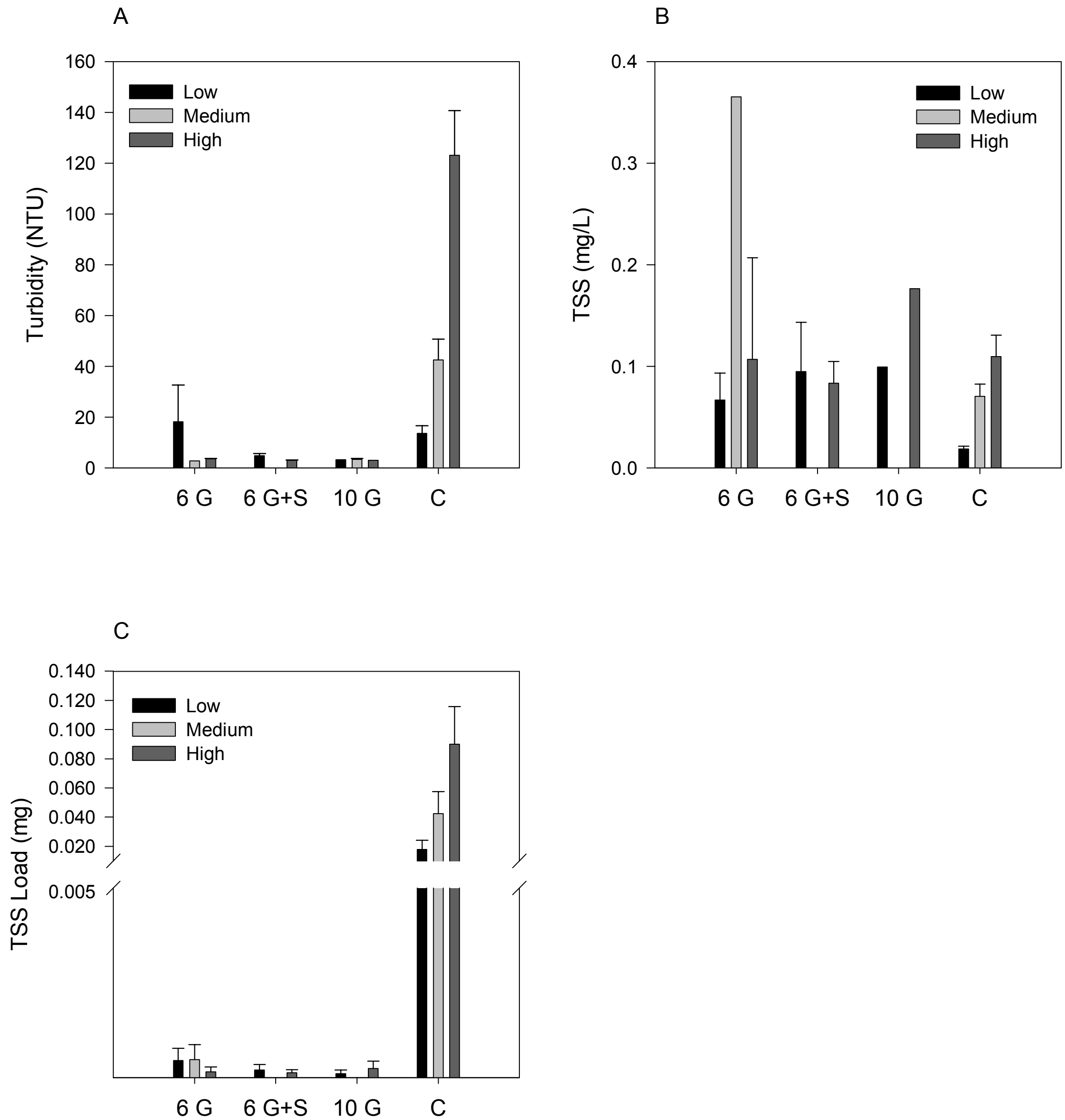

Figure 3.8. For the 1.4 cm simulated storm turbidity (A) was significantly greater at concrete vs. porous plots, TSS concentrations (B) were higher for the gravel+sand (6 G+S) porous plots. TSS loads (C) were significantly higher for the concrete plots than all porous plots at all treatment levels.

CHAPTER 4

IMPROVING STORMWATER MANAGEMENT TO PROTECT IMPERILED SPECIES: A CASE STUDY IN THE ETOWAH RIVER BASIN (GEORGIA, USA)[1]

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[1]Dreelin, E. A., J. R. Reed, L. A. Fowler and C. R. Carroll. To be submitted to *Journal of the American Planning Association.*

Abstract

Traditionally, stormwater management has focused on conveying runoff away from private property as quickly as possible to prevent flooding. Many studies have shown the negative impacts to receiving water bodies associated with this type of stormwater management and with increases in impervious surface area. These impacts include changes in hydrology, geomorphology, increased pollutant loads and loss of sensitive species. Working with local jurisdictions, we developed site design guidelines for residential, commercial and industrial development, and a model stormwater management ordinance for the Etowah River watershed (Georgia, USA). We examined zoning, subdivision and stormwater regulations in the Etowah River basin as part of a larger project to develop a Habitat Conservation Plan for imperiled fish species. The site design guidelines and model ordinance use a source control approach to stormwater management which differs from methods commonly used in North Georgia and Metro Atlanta. The goals of these techniques are to reduce impervious surface area while preserving the natural hydrology of a site as much as possible, thereby reducing the negative impacts on aquatic ecosystems. The guidelines and ordinance are based on research into the effects of urbanization on imperiled species in the Etowah River basin and low impact development policies from across the nation.

Introduction

As we develop the landscape and convert land from forested to urban uses, we alter the way water moves through the environment. This alteration in watershed hydrology, driven by increased runoff volumes from impervious surfaces, induces a cascade of physical and biological changes that result in degraded aquatic habitats. Impervious surfaces cause an increase in the volume of surface runoff that results in more frequent and substantially larger storm flows (Dunne and Leopold 1979). Due to altered hydrology stream channels become unstable, erode, and ultimately become enlarged (Arnold et al. 1982) and incised (Bledsoe and Watson 2001). Aquatic habitat, which is largely a function of hydrology and channel morphology (Bunn and Arthington 2002), declines in both diversity and quality (Booth 1991). As a result of environmental stressors associated with urbanization, the richness of aquatic insects and fishes declines (Klein 1979; Crawford and Lenat 1989; Horner et al. 1996; May et al. 1997).

Planning efforts to reduce the impacts of urbanization have largely centered on land preservation techniques. Many regions of the US have sought to protect aquatic resources by regulating development on a landscape scale (Godschalk 2000). Many local governments have adopted riparian buffer ordinances, which restrict or prohibit construction within a specified distance of a stream, and several states have adopted programs that encourage smart growth as means of combating urbanization and sprawl. Under the current smart growth approach, designated watersheds are sacrificed to urban development in order to preserve open spaces which typically have low levels of imperviousness (Jackson 2002). Stormwater mitigation techniques in these areas are used to reduce the prevalence of water-borne disease vectors and improve water quality (Jackson 2002) and protect property from flooding. Because of the recognition of impervious surfaces as a primary driver of the deleterious effects of urbanization (Arnold and Gibbons 1996), impervious surface limits have also been suggested (Center for Watershed Protection 2003a).

However, because we lack information regarding the causal mechanisms of changes observed in areas with high imperviousness, our management strategies may not actually address the cause of the problem. For example, urbanization was identified as a threat to an endangered stream crustacean in Australia (Walsh et al. 2004). As a result, management efforts were taken to reduce access to preserves where the species was found, improve the sewer system, and control sediment loads off roads (Walsh 2004). However, the distribution of the threatened species was better explained by connection of the drainage system than other elements of urbanized areas such as the prevalence of septic systems or roads (Walsh et al. 2004). Stormwater runoff, rather than just total impervious surface area, was identified as the most likely factor threatening the species (Walsh et al. 2004; Walsh 2004). Therefore, management strategies must not only consider where development occurs in a landscape but also *how* it occurs.

Low Impact Development (LID) has emerged as a highly effective approach to managing stormwater (EPA and LIDC 2000). LID site planning and similar approaches such as Better Site Design (Center for Watershed Protection 1998) focus on source control for stormwater rather than conveyance and detention (Prince George's County 1999). The main goals of this approach are to use hydrology as a framework for site design, use on-site controls for stormwater management, and minimize impervious surfaces to ultimately create a multifunctional landscape. This approach has been shown to have many benefits, including lower pollutant loads, reduced soil erosion, reduced development costs, increased property values, and increased local property tax revenues (Center for Watershed Protection 1999). Reducing impervious surfaces and clustering growth not only reduces stormwater impacts, but also provide significant cost savings (Burchell and Mukherji 2003), and protects public health (Gaffield et al. 2003). The health benefits include decreasing exposure to waterborne diseases, promoting a more mobile lifestyle, and improving air quality (Gaffield et al. 2003; Buzbee 2003).

The Etowah River basin provides a useful model for studying the effects of urbanization and land use policy. The Etowah is located near Atlanta, Georgia in one of the fastest growing regions of the country (US Census Bureau 2003). A gradient of urbanization exists across the basin; upstream jurisdictions in the headwaters are rural and urban land use increases downstream (Chapter 1). Land use policy also varies across the basin with the rural jurisdictions having far fewer restrictions concerning development practices than the more populous jurisdictions closer to Atlanta. Also, regional scientific research is available that can inform policy decisions.

The Etowah River basin is part of the Mobile River drainage, one of the most diverse aquatic ecosystems on the planet (Burkhead et al. 1999) and is home to 10 imperiled fish species. Because it is such a unique system, minimizing the impacts of development is a particular concern. Urban streams in the Etowah have finer bed particles, which favor cosmopolitan fish species rather than natives (Walters et al. 2003). Aquatic insect communities are also less diverse and composed of tolerant species in urbanized areas of the basin (Roy et al. 2003). Increased frequency, magnitude and volume of storm flows have been found in areas with high impervious surface cover (Roy et al. unpubl. data). Streams with increased storm flows have fewer sensitive fish species and fewer endemic fish species (i.e., those fish found only in the region). Based on these findings, researchers recommended improving stormwater management, especially by increasing infiltration, as an essential step toward protecting imperiled fish species.

Although developers and local governments may be willing to try LID techniques to reduce stormwater impacts, many cannot under existing zoning and development codes (Center for Watershed Protection 1998). We sought to examine county and city codes to identify barriers to implementing LID techniques in the Etowah River basin, Georgia USA. Our objectives were to identify areas for improvement and recommend changes to the local governments on incorporating our findings into local land use regulations.

Methods

The Etowah River basin, a highly diverse ecosystem, is located northeast of Atlanta, Georgia and includes 11 counties (Figure 4.1). Because of the Etowah basin's proximity to Atlanta, it is under tremendous development pressure. There are currently 10 imperiled fish species in the basin, seven state threatened and three federally endangered, including four endemic species. Fifteen species of fish have already been extirpated from the system (Burkhead et al. 1997). Counties within the basin are consistently listed as the fastest growing counties in the US (US Census Bureau 2003). Because of this rapid growth, many streams within the basin are impaired and urban runoff is the leading cause of impairment (GaEPD 2002).

In 2000, an interdisciplinary group from the University of Georgia (advisory committee) formed to develop a regional Habitat Conservation Plan (HCP) under the Endangered Species Act for the imperiled fish species in the basin. The HCP will include a series of guidelines and ordinances designed to protect aquatic systems from the impacts of human developments informed by ecological research performed by members of the advisory committee. These management tools address a variety of stressors to imperiled species such as stormwater runoff, erosion and sedimentation, stream crossings and habitat fragmentation. Signatories to the HCP will be required to adopt the recommendations of the plan in order to receive incidental take permits from US Fish and Wildlife Service. Nine of the 11 counties, those which have extant populations of imperiled species, and the major cities within these counties are participating in development of the HCP. These permits allow takings of individual endangered fish provided the species as a whole is protected in accordance with the HCP.

Hydrologic alteration was identified as one of the key stressors to imperiled species (Roy et al. unpubl. data; Chapter 1). Consequently, improved stormwater management, particularly methods to disconnect and reduce impervious surfaces, was identified as an essential component of the HCP. We reviewed the existing development codes of the nine counties and five largest cities in the basin using the Center for Watershed Protection Codes and Ordinances worksheet (Center for Watershed Protection 2003b, Appendix A). We then prepared draft site design guidelines and a model post-development stormwater management ordinance. The draft site design guidelines were based on model development principles generated by a national site design roundtable (Center for Watershed Protection 1998) and national LID guidelines (Prince George's County 2000). The draft stormwater management ordinance was based on the Metropolitan North Georgia Water Planning District's (hereafter referred to as District) post-development stormwater management ordinance.

The District developed a model post-development stormwater ordinance because many of its member governments must comply with federal Phase II stormwater regulations that require post-development stormwater management (District 2003). Members of the HCP that are also subject to the District's requirements include the counties of Bartow, Cherokee, Cobb, Forsyth, Fulton and Paulding and cities lying within those counties. If any of these member governments fail to implement the plans developed by the District, they will be ineligible for state grants or loans for water supply and conservation projects. Therefore, the District ordinance was used as a model for the HCP ordinance to ensure that those governments would comply with District requirements. The District model ordinance provides minimum measures for post-development stormwater management; however, the model has several weaknesses. Language for definitions, permit review fees, performance bonds, maintenance and inspection agreements is absent or unclear.

In March 2004, a Stormwater and Better Site Design Technical Committee was convened to address post-development stormwater issues for the Etowah HCP. The committee was composed of technical staff from local governments (i.e., planners and engineers) and developers, homebuilders, engineers and architects in the Etowah watershed. A series of meetings was held to critically evaluate the draft documents. The documents were revised based on input from the committee members. The committee also recommended developing a site design checklist in addition to the documents being reviewed. We created a checklist based on a point system developed by the Corps of Engineers (2003) and with feedback from the committee members.

Results

We encountered a wide variety of development codes across the basin. As expected, the downstream counties had more comprehensive development regulations and most have adopted stormwater ordinances. However, development codes in the more rural jurisdictions did not address many of the development criteria we were evaluating (e.g., parking ratios, cul-de-sac dimensions, lot geometry). In fact, Lumpkin County is in the process of adopting its first zoning ordinance.

The Technical Committee developed 18 site design guidelines that focused on reducing or disconnecting impervious surfaces (Table 4.1, Appendix B). We identified sections of the local zoning and subdivision codes that required revisions or additions to allow the site design guidelines to be implemented. For example, setback distances and parking space requirements exceeded those recommended by the guidelines (Center for Watershed Protection 1998, 1999; Figure 4.2). For many of the site design guidelines, we recommend setting minimum and maximum requirements which would establish a range of effective practices within which site planners could operate.

Because the design guidelines were intended to be flexible in their application depending on local conditions, no requirements for specific BMPs were included. Instead, we developed a site design checklist that awards points for utilizing the site design guidelines and LID principles (Appendix C). Individuals who apply for stormwater permits under the model ordinance would have to complete the checklist and submit it to the local government at a consultation meeting required by the model stormwater ordinance. A minimum number of points, based on which BMPs and LID site planning measures are included in the proposed design, would be required to obtain a stormwater permit. The committee recommended a sliding scale for the number of points required for plan approval. Under this system sensitive areas, such as those with known populations of imperiled species or potential for restoration, would require more points for approval than projects in other areas. The sliding scale would represent a prioritization of watersheds for protection based on continuing scientific research in the basin and input from local governments.

We also revised the District ordinance to ensure a higher level of protection from the detrimental effects of stormwater (Table 4.2, Appendix D). Many of the current stormwater ordinance requirements in the downstream counties of the basin focus on controlling flooding and peak runoff rate whereas several of the upstream counties have not adopted any post-development stormwater management ordinances to date. As with the District ordinance, our model ordinance established performance standards for flood control, water quality, and stream channel protection. However, the model ordinance we developed focuses on source control of stormwater rather than conveyance and detention. Because research in the basin shows the status quo is not preventing hydrologic alteration due to development (Chapter 1, Roy et al. unpubl. data), we chose to depart from the traditional pipe and pond approach. In order to encourage the use of infiltration techniques, a credit system was developed whereby the use of LID techniques can reduce the storage volume required under the ordinance. The District ordinance also includes the use of these credits; however, we have revised the credit system so that a greater reduction in storage volume is achieved by using infiltration technologies. Another major change in the ordinance was the addition of a Sensitive Areas section which requires infiltration of the first 1.2” of rainfall in designated areas. Sensitive Areas would be designated by the local jurisdiction based on recommendations from scientists conducting research on the fish populations.

Discussion

The goal of the site design guidelines was to reduce the volume of runoff generated by developed areas in order to protect imperiled aquatic species. Our approach emphasized the use of LID principles and site planning techniques designed to conserve natural areas and the hydrologic function of a site (Center for Watershed Protection 1998, 1999, 2000; Prince George’s County 1999). Implementing some of these guidelines will require revising development regulations in many of the government jurisdictions within the Etowah River watershed. Many of the site design guidelines focus on reducing the amount of impervious areas constructed and infiltrating stormwater runoff as closely to the source as possible.

We encountered wide variation in the regulations governing lot geometry for residential areas. Shorter setback and frontage distances reduce the amount of impervious surface area of individual lots or parcels (Stone 2004). In a study of the influence of zoning and subdivision codes on the extent and distribution of impervious surfaces in Wisconsin, a 1-m increase in lot frontage related to a $6.85m^2$ increase in the total impervious surface area of a parcel (Stone 2004). Similar relationships were found with front setback distances and street width. Also, moderate to high-density development had less impervious surface than low-density development per bedroom (Stone 2004). Therefore, the most effective approach to decreasing impervious surface cover is to decrease the size and dimension requirements of single-family parcels.

A major portion of the impervious surface budget is composed of roads, parking lots, and driveways (Center for Watershed Protection 1998). We found that parking lot requirements were one area that city planners, engineers and local developers readily agreed needed revisions. Most of the parking space requirements in the basin were based on Institute of Transportation Engineers (1987) recommendations rather than actual parking demand in the area. Studies examining actual use in comparison to parking space supply find that there is an oversupply of parking spaces (Willson 1995). The parking ratio requirement for shopping centers could be lowered from 5 parking spaces per 1000 ft^2 gross floor area to 3 spaces without any negative effects on most businesses (Albanese and Matlack 1998). Also, almost all jurisdictions specify that impervious surfaces be used to pave parking lots, driveways, and sidewalks; porous pavements are not allowed. Porous pavements are a viable option for stormwater control even on Piedmont soils provided they are designed properly (Chapter 1 and 2). Porous pavements are well suited for use in overflow areas in parking lots (Center for Watershed Protection 1998). We also found that landscaping requirements for parking lots discouraged use of on-site stormwater controls. Many local governments require planting strips to be surrounded by curb and gutter and have an irrigation system. However, these areas have the potential to be used for infiltration of runoff (Prince George's County 1999).

One of the more contentious issues in developing the site design guidelines was that of controlling runoff from roads. Road runoff has a high pollutant load, commonly higher than other forms of impervious surfaces (Bannerman et al. 1993). Runoff from roads carry pollutants such sediment, metals (Davis et al. 2001), and polyaromatic hydrocarbons (Smith et al. 2000). In order to mitigate the potential impacts of road runoff in the Etowah basin we recommended decreasing the width and length of roads as well as identifying innovative measures to manage runoff such as alternatives to traditional curb and gutter conveyances. National studies have shown that road widths can be reduced to 18 feet and still allow for safe passage of emergency and service vehicles (Center for Watershed Protection 1998). We proposed establishing a road width narrower than current regulations (18 vs. 20-26 feet), but this was not politically feasible in the Etowah. Rather than setting one road width requirement, we next recommended that a range of road widths be allowed. In order to encourage narrow streets, the site planning checklist awards more points for narrower roads. We also recommended using techniques to manage road runoff as close to the source as possible rather than using curb and gutter to convey stormwater, and the resulting impacts, downstream. For example, grassed swales have been used effectively to control stormwater from roads. Swales remove on average 81% of suspended solids (Winer 2000). Other alternatives, particularly innovative combinations of BMPs such as bioretention and interconnected swales, were also encouraged. Seattle's Street Edge Alternative program demonstrates how reduced street widths in conjunction with swales, infiltration trenches, and bioretention techniques reduce runoff volume as well as create an attractive streetscape (City of Seattle 2004).

The approach to stormwater management has evolved from purely focusing on the engineering of efficient conveyance systems to prevent flooding to a more holistic approach seeking to minimize alteration of the pre-disturbance hydrology and preserving valuable ecosystem resources (Reese 2001). The goal of our revised model post-development stormwater management ordinance is to minimize hydrologic alteration through encouraging the use of source controls. Because research in the Etowah River basin has shown that sensitive species are less abundant in areas with high impervious surfaces (Roy et al. unpubl. data), we have emphasized disconnecting impervious surfaces and required infiltration for sensitive areas. Disconnection of impervious surfaces directs runoff to permeable areas rather than becoming part of the stormwater treatment stream.

Maintenance of BMPs is a major concern particularly in LID projects which use distributed stormwater management systems. Maintenance of BMPs is essential for effective stormwater management (Lindsey et al. 1992). EPA (2004) also stresses the need for ongoing maintenance and provides sample language for maintenance agreements. The most common approach, which we have incorporated, is to require a maintenance agreement that explicitly states the party responsible for maintenance and outlines a minimum maintenance schedule. Public education will be essential as the HCP is implemented so that homeowners understand the need for maintaining BMPs on their property.

Because LID techniques can reduce the impacts of stormwater on receiving water bodies, we expect this approach to be protective of imperiled species. A recent study demonstrated that 50 New Urbanism developments that employed similar techniques to those we recommended were more effective than conventional developments at achieving watershed protection (Berke et al. 2003). New Urbanism developments are high-density developments with mixed land uses where the design focus is the pedestrian rather than the automobile. New Urbanism developments in infill areas (those in existing developments) had a greater amount of impervious sidewalks and were less likely to restrict construction in sensitive areas such as riparian buffers and wetlands (Berke et al. 2003). This was due to the emphasis on creating a pedestrian-friendly development rather than protecting ecosystem services. Case studies of a variety of LID projects, ranging from green roofs to entire LID subdivisions, demonstrate that LID techniques are effective at reducing runoff volume and pollutant loads, are economical, and have growing public acceptance (NRDC 2001).

Resistance to the site design guidelines and ordinance was greatest at the local government level. Developers were generally more willing to implement LID techniques because LID was viewed as cost effective. They also supported revising the zoning and subdivision codes to allow more flexibility for site design requirements. In particular, they appreciated knowing what elements the plan review staff would be looking for in advance rather than being faced with having to change the site design well into the permit process. Lloyd et al. (2002) also found that gaining local governmental approval for an LID project one of the most challenging parts of the project. Raising awareness of LID techniques, frequent communication, and compromise were essential for success of the project (Lloyd et al. 2002).

The local government representatives on our technical committee were city and county planners, engineers and architects. Their major concerns were the effectiveness of LID techniques, how these site design guidelines affect plan review, and ongoing maintenance costs of stormwater BMPs. Lloyd et al. (2002) found similar concerns at this level of government.

The Steering Committee of the HCP, made up of city council members, county commissioners and local government staff, were willing to accept these guidelines and model ordinance given support from their staff and the developers in the area. It was critical to have the local government and development community at the table when developing the guidelines and ordinance. Ultimately, success in implementing multi-jurisdictional management plans may be more dependent on regional politics than the technical aspects of the plan (Jones and Gordon 2000). By including the local governments in the policy development, we hoped to produce 'buy-in' for the recommendations of the HCP resulting in broad adoption by the local jurisdictions.

The HCP recommendations are currently under review by the local jurisdictions and will likely be voted on during Autumn 2004. As the plan moves from developing recommendations to adopting policy, technical staff from the University of Georgia will be available to local governments to provide assistance in reviewing and revising existing codes. Ecologists will continue to monitor and study fish populations in order to monitor the status of the populations and further understand causes of their decline. The HCP includes long-term monitoring as part of the adaptive management plan to ensure the policies are truly protective of imperiled species. In addition, we have the opportunity to evaluate the effectiveness of different stormwater management techniques in paired watershed studies.

Conclusions

As part of a larger effort to protect imperiled fish species in the Etowah River basin, we sought to improve local development and stormwater regulations to decrease the hydrologic impacts of human development. Existing zoning, subdivision, and stormwater codes often prohibited the use of LID techniques to reduce stormwater runoff. We developed site design guidelines and a post-development stormwater management ordinance that encourage on-site control of stormwater runoff. We also worked with government staff and developers to incorporate local needs and concerns in the recommended policies. Existing codes will require revisions to redefine the limits within which site planners design developments and to allow implementation of LID strategies. In addition to setting the regulatory framework, we developed a site design checklist as a tool for implementing the new requirements. Thus, plan review staff and developers will have the same means for evaluating site designs. We expect these improvements in stormwater management to be more protective of aquatic ecosystems than the status quo. However, monitoring will be required to evaluate the effectiveness of these policies in protecting imperiled species in the Etowah River basin.

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Table 4.1. Site design guidelines developed by the Stormwater and Better Site Design technical committee for the Etowah River Habitat Conservation Plan. Guidelines were based on national development principles (Center for Watershed Protection 1998, 1999).

SITE DESIGN GUIDELINES
Design residential streets for the minimum required pavement width needed to support travel lanes, on-street parking, and emergency vehicle access. Encourage alternatives for managing runoff from roads such as bioretention areas, infiltration trenches, and swales.
Wherever possible, residential street right-of-way widths should reflect the minimum required to accommodate the street, sidewalk, and road runoff BMPs.
Minimize the use of cul-de-sacs and incorporate means to reduce their imperviousness in areas where they are used.
Use vegetated open channels to convey and treat stormwater runoff where site conditions are appropriate.
Review existing parking ratios based on actual parking demand. Required ratios should be enforced as a maximum rather than a minimum.
Revise parking codes to lower parking requirements where public transportation is available or shared parking arrangements are used.
Reduce the imperviousness of parking lots by providing compact car spaces, minimizing stall dimensions, and using porous materials where appropriate.
Provide stormwater treatment for parking lot runoff using bioretention areas, filter strips, and other BMPs that can be integrated into required landscaped areas and traffic islands.
Eliminate minimum lot sizes and express requirements in number of houses per unit area.
Encourage open space or cluster development by simplifying the permitting process and allowing more flexible site design regulations for these types of developments.
Set minimum and maximum setback and frontage distances to reduce parcel imperviousness.
Allow more flexibility in the design standards for sidewalks. Encourage the use of alternative walkways that promote community connectivity and reduce total impervious surface area.
Encourage alternative driveway surfaces and designs that reduce imperviousness.
In areas with open space, clearly state how open space will be managed and by whom.

SITE DESIGN GUIDELINES

Disconnect rooftop runoff from the storm sewer system. Direct rooftop runoff to pervious areas.

Do not discharge untreated stormwater into local streams, lakes, wetlands, or sensitive areas.

Table 4.2. Comparison of the Metropolitan North Georgia Water Planning District (District) model post-development stormwater management ordinance and the model ordinance developed for the Etowah Regional HCP.

SECTION	DISTRICT ORDINANCE	HCP ORDINANCE
Applicability		Adds redevelopment that adds and additional 1000 ft^2 of impervious cover
Definitions		Revised definition of Better Site Design; adds examples to definition of 'hot spot'; adds Stormwater BMP and water quality storm definitions
Concept Plan and Consultation Meeting		Adds HCP Site Design Checklist to stormwater concept plan requirements
Performance Bonds	Left up to discretion of local jurisdiction	Requires bond no less than the total cost of stormwater management system; bond released after final inspection
Application Review Fee	Fee based on structure established by local jurisdiction	Adds that all monetary contributions will be credited to local budgetary category to support plan review, administration and management of permitting process, and inspection and maintenance of projects subject to ordinance
Performance Criteria-Water Quality	All stormwater runoff adequately treated before discharge	Stormwater practices must treat first 1.2" rainfall of all storms and remove 80% of post-development total suspended solids
Performance Criteria-Stream channel protection	Requires preservation/restoration of buffer, erosion prevention measures, and 24-hr detention of 1-yr, 24-hr storm	Can reduce or waive detention requirement through the use of infiltration practices
Sensitive Areas	Not in ordinance	Sensitive areas defined by jurisdictions based on needs of imperiled species; Requires infiltration of 1.2"

SECTION	DISTRICT ORDINANCE	HCP ORDINANCE
		rainfall for all storms, no net increase in total suspended solids loads, and no net increase in runoff rates and channel erosion
Ongoing Inspection and Maintenance	Inspection and maintenance required	Explicitly states owners are responsible for maintenance; maintenance schedule required as part of stormwater management plan; includes details of inspection reports and minimum requirements for inspection schedule

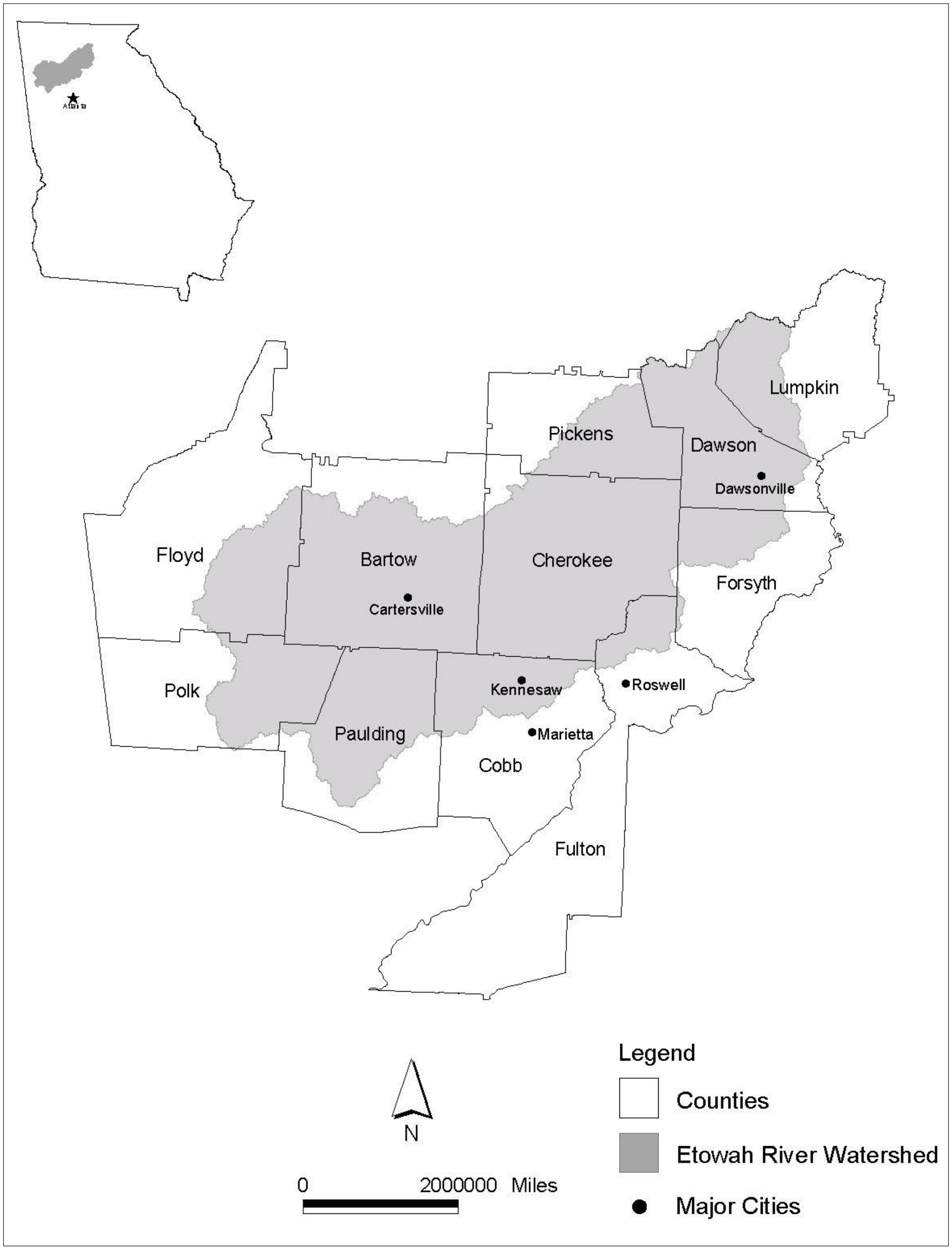

Figure 4.1. Map of the Etowah River basin showing county and watershed boundaries.

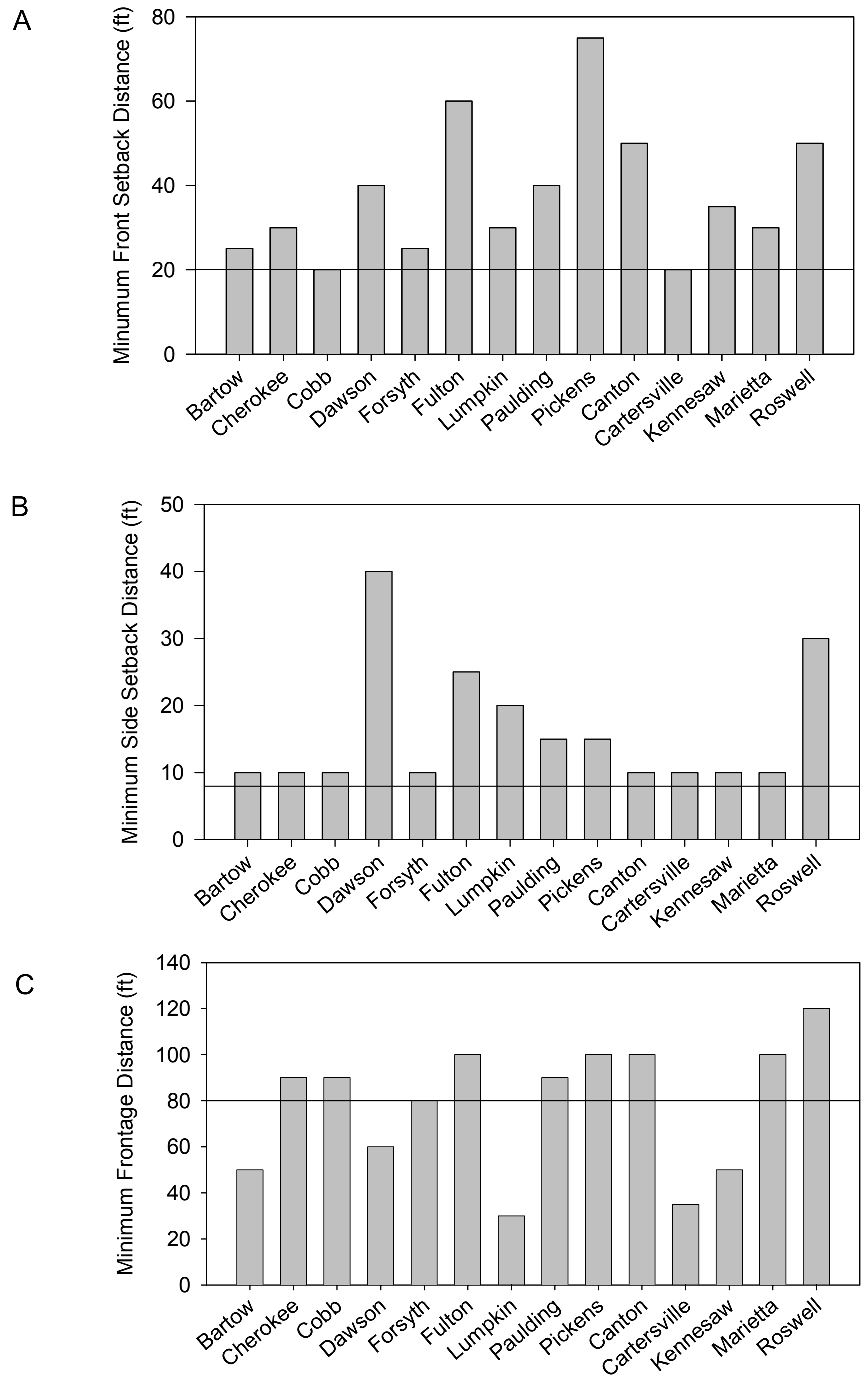

Figure 4.2. Example of how current requirements compare with recommendations for (A) front setbacks, (B) side setbacks, and (C) frontage distances for single-family residential zones in the Etowah basin jurisdictions. The line shows the recommended limit based on Better Site Design principles (Center for Watershed Protection 1998).

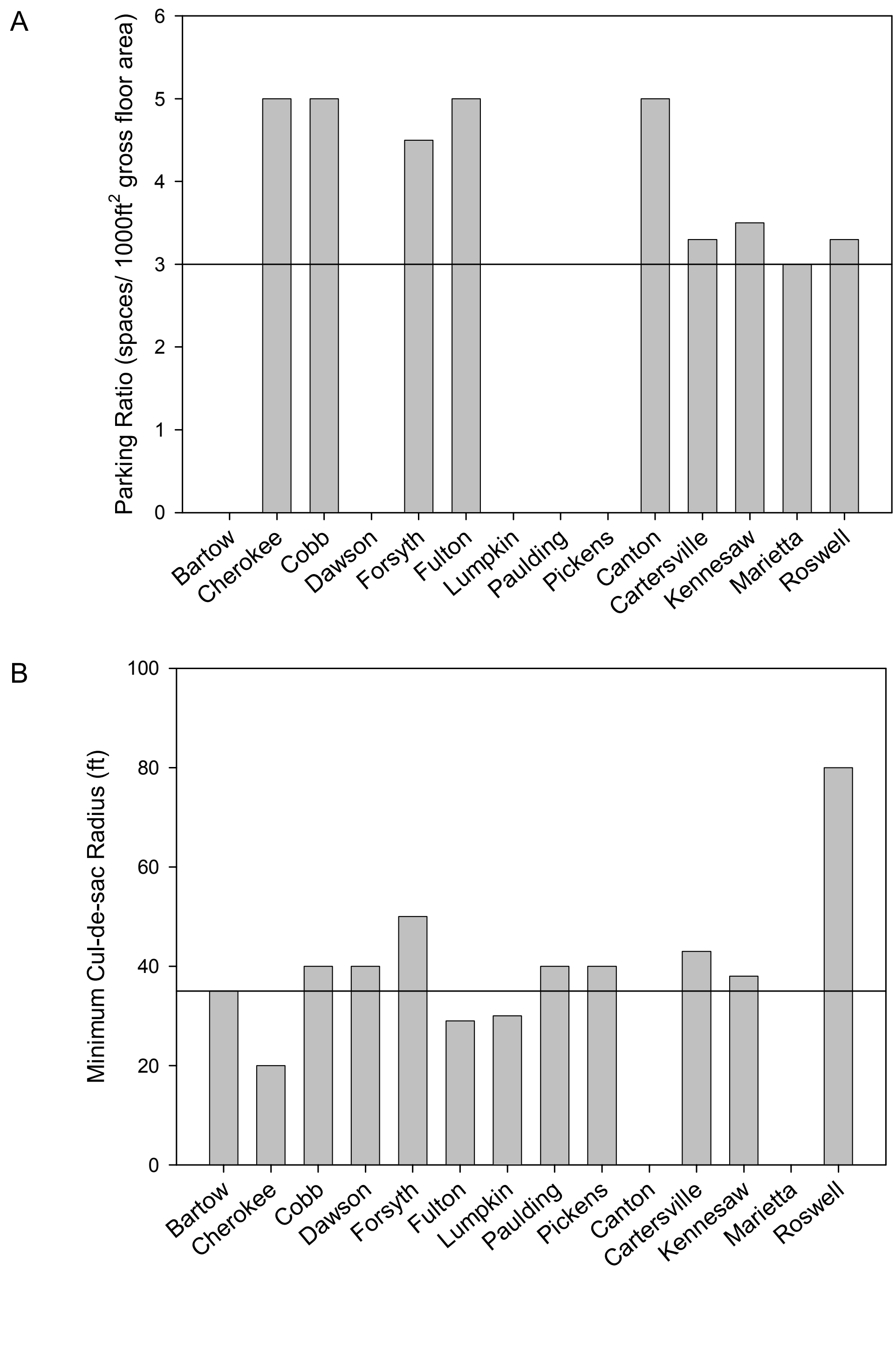

Figure 4.3. Current regulations for (A) parking ratios and (B) cul-de-sac radius are above the site design guidelines (reference line) in many jurisdictions.

CONCLUSION

Traditional land use planning has not addressed the ecological context of the watershed (Arnold and Gibbons 1996). Consequently, the common patterns of growth result in the degradation of stream ecosystems. However, new approaches to development incorporate ecological functions in planning and site design (Prince George's County 1999). My goal was to examine the consequences of urbanization and research means to mitigate them. I specifically addressed three questions (1) does long-term data for the Etowah River show changes due to increasing urbanization, (2) can porous pavements be used effectively on clay soils to reduce the impacts of impervious surfaces and (3) how can low impact development techniques be encouraged through public policy. The overall goal was to directly use science to create effective management tools that reduce hydrologic alteration due to urbanization.

The Upper Etowah River basin has experienced rapid growth since 1960 and consequently land use has been converted from agricultural and forested uses to urban and suburban uses. In the same time period, flood frequencies have increased. The hydrologic response is more pronounced in the smaller drainage basin where we observed a 33% increase in discharge for the 2-year flood event. Recurrence intervals and runoff coefficients were more responsive to small changes in the percent of urban use than were peak or mean annual discharge. Pollutant concentrations have also increased over time; this was more apparent at the larger watershed scale. In order to reduce the effects of hydrologic alteration on imperiled aquatic species we recommend management strategies that focus on reducing the proportion of rainfall that becomes surface runoff.

Progressive stormwater management techniques that employ infiltration are currently being recommended to protect valuable native fish communities in northeastern Georgia (Roy et al. unpubl. data; Chapter 1). Porous pavements can be one means through which the impervious surface area of a development site can be reduced. Porous pavement, as demonstrated in Chapters 2 and 3, is an effective infiltration best management practice for controlling small (<2.64 cm) storms on clay soils. Although clay-rich soils of the Georgia Piedmont have relatively slow infiltration rates, this does not preclude the use of infiltration BMPs.

Preserving the hydrologic functions of a watershed is a fundamental principle of LID (Prince George's County 1999). It is a drastic departure from reliance on pipe and pond systems that essentially treat precipitation as waste. As ecologists continue to demonstrate the mechanistic links between impervious surfaces and negative effects on ecosystems, we must refine our approach to protect valuable ecosystem functions. Porous pavements, used in conjunction with LID strategies, have the potential to preserve a vital ecosystem service in developed areas by minimizing the hydrologic alterations caused by impervious surfaces.

However, current zoning, subdivision, and stormwater codes often prohibited the use of LID technique. I evaluated local government regulations and developed site design guidelines and a post-development stormwater management ordinance that encourage on-site control of stormwater runoff. Existing codes will require revisions to redefine the limits within which site planners design developments and to allow implementation of LID strategies. It is expected that these improvements in stormwater management will be more protective of aquatic ecosystems than the status quo. However, monitoring will be required to evaluate the effectiveness of these policies in protecting imperiled species in the Etowah River basin over time.

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APPENDIX A

CODE AND ORDINANCE REVIEW

	Feature	Model Guideline	Counties									Cities				
			Lumpkin	Bartow	Cherokee	Forsyth	Fulton	Cobb	Paulding	Pickens	Dawson	Canton	Cartersville	Kennesaw	Marietta	Roswell
1. Street Width																
	a. What is the maximum pavement width (back of curb to back of curb) allowed for streets in low density residential developments ?	20 ft for no on-street paking, 24 with parking on one side; 26 for parking on both sides	20	20	18	24	22	15-24	24	24	20	20	22	24	24	29
	b. At higher densities are parking lanes allowed to also serve as traffic lanes (i.e., queuing streets)?	Yes	no											no	no	
2. Street Length																
	a. Do street standards promote the most efficient street layouts that reduce overall street length?	Yes	No	no	no	no	yes	no	no	no	no	no	no	no	no	
3. Narrow Right of Way																
	a. What is the minimum right-of-way (ROW) width for a residential street?	< 45 ft	60	60	60	50-80	40	50-100	50	20-24	24	50	60	50	50	50
	b. Does the code allow utilities to be placed under the paved section of the ROW?	Yes	yes	no	yes					yes			yes (generally in row)	yes	yes*	Yes
4. Cul-de-sacs																
	a. What is the minimum radius allowed for cul-de-sacs?	< 35 ft	30	35	20	50	29	40	40	40	20		43 paved; 60 ROW	38 paved; 50 ROW	80	
	b. Can a landscaped island be created within the cul-de-sac?	Yes	yes		yes		yes		yes							

			Counties									Cities				
	Feature	**Model Guideline**	**Lumpkin**	**Bartow**	**Cherokee**	**Forsyth**	**Fulton**	**Cobb**	**Paulding**	**Pickens**	**Dawson**	**Canton**	**Cartersville**	**Kennesaw**	**Marietta**	**Roswell**
	c. Are alternative turn arounds such as "hammerheads" allowed on short streets in low density residential developments?	Yes	no		no		no		yes	yes	yes			No		
5. Vegetated open channels																
	a. Are curb and gutters required for most residential street sections?	No	yes	yes	yes	no	no	yes	no		yes	yes	Yes	yes	yes	Yes
	b. Are there established design criteria for swales that can provide stormwater quality treatment (i.e., dry swales, biofilters, or grass swales)?	Yes	yes	yes	yes		yes	yes	yes	yes	yes	yes*	no	no*	no	Yes
6. Parking ratios																
	a. What is the minimum parking ratio for a professional office building (per 1000 ft2 of gross floor area)?	3			3.5	4	3	3				4	3.3	3.5	3	3.3 (4 max)
	b. What is the minimum required parking ratio for shopping centers (per 1,000 ft2 gross floor area)?	3-3.5			5	4.5	5	5				5	3	5	3.5-4	3.6 (4.4 max)
	c. What is the minimum required parking ratio for single family homes (per home)?	2	2	2	2	2	2	2				2	2	2	2	2 (4 max)
	d. Are the parking requirements set as maximum or median (rather than minimum) requirements?	Yes	no	no	no	no	no	no	no	no	no	no	no	no	no	Yes
7. Parking Codes																
	a. Is the use of shared parking arrangements allowed?	Yes			yes	no	yes	yes	yes	yes	no	no	yes	yes	yes	Yes
	b. Are model shared parking agreements provided?	Yes			no	no	no	no	no	no	no	no	no	no	no	No

			Counties									Cities				
	Feature	**Model Guideline**	**Lumpkin**	**Bartow**	**Cherokee**	**Forsyth**	**Fulton**	**Cobb**	**Paulding**	**Pickens**	**Dawson**	**Canton**	**Cartersville**	**Kennesaw**	**Marietta**	**Roswell**
	c. Are parking ratios reduced if shared parking arrangements are in place?	Yes										no	no	no (except churches)	only churches	Yes
	d. If mass transit is provided nearby, is the parking ratio reduced?	Yes										no in regs; yes in policy	no	no	yes	Yes
8. Parking Lots																
	a. What is the minimum stall width for a standard parking space?	9 ft		8.5	8.5	9		9				9	9	8.5	9	9
	b. What is the minimum stall length for a standard parking space?	18 ft		18	19	18						20	18	19	20	20
	c. Are at least 30% of the spaces at larger commercial parking lots required to have smaller dimensions for compact cars?	Yes										no		no	no (25%)	No
	d. Can pervious materials be used for spillover parking areas?	Yes			yes	yes	no	yes			no	no	no	no	no	Yes
9. Structured Parking																
	a. Are there any incentives to developers to provide parking within garages rather than surface parking lots?	Yes		no	no	no	no	yes	no	no	no	no		no	yes (density bonus)	No
10. Parking lot runoff																
	a. Is a minimum percentage of a parking lot required to be landscaped?	Yes	yes	no	no	yes	no	no	no	no	no	yes	no	yes	yes	Yes
	b. Is the use of bioretention islands and other stormwater practices within landscaped areas or setbacks allowed?	Yes	no	no	yes	yes	yes	no	no	no	no		yes	yes		

			Counties									Cities				
	Feature	Model Guideline	Lumpkin	Bartow	Cherokee	Forsyth	Fulton	Cobb	Paulding	Pickens	Dawson	Canton	Cartersville	Kennesaw	Marietta	Roswell
11. Open space design																
	a. Are open space or cluster development designs allowed in the community?	Yes	yes	yes	yes	yes		yes	yes	yes	yes	yes	yes	yes	yes	Yes
	b. Is land conservation or impervious cover reduction a major goal or objective of the open space design ordinance?	Yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	Yes
	c. Are the submittal or review requirements for open space design greater than those for conventional development?	No	yes	no	no	yes		no	no	no	no	yes	yes	no	yes	No
	d. Is open space or cluster design a by-right form of development?	Yes	yes	yes	no	no		no	no	no	no	no				Yes
	e. Are flexible site design criteria available for developers that utilize open space or cluster design options (e.g, setbacks, road widths, lot sizes)	Yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	Yes
12. Setbacks and frontages																
	a. Are irregular lot shapes (e.g., pie-shaped, flag lots) allowed in the community?	Yes	yes	yes	no	yes	yes	yes	yes	yes	yes	no	no	no	no	yes
	b. What is the minimum requirement for front setbacks for a one half (½) acre residential lot?	20 ft	30	25	30	25	60	20	40	75	40	50	20	35-40	30	50
	c. What is the minimum requirement for rear setbacks for a one half (½) acre residential lot?	25 ft or less	20	25	30	25	50	25	40	15	40	35	20	35	30	40
	d. What is the minimum requirement for side setbacks for a one half (½) acre residential lot?	8 ft	20	10	10	10	25	10	15	15	40	10	10	10	10	30

			Counties									Cities				
	Feature	Model Guideline	Lumpkin	Bartow	Cherokee	Forsyth	Fulton	Cobb	Paulding	Pickens	Dawson	Canton	Cartersville	Kennesaw	Marietta	Roswell
	e. What is the minimum frontage distance for a one half (½) acre residential lot?	80 ft or less	30	50	90	80	100	90	90	100	60	100	35	50	100	120
13. Sidewalks																
	a. What is the minimum sidewalk width allowed in the community?	4 ft or less	none	4	4	none	none	none		none		4	4	4		4
	b. Are sidewalks always required on both sides of residential streets?	No	no	no	no	no	no	yes	no	no	no	no	no	no		No
	c. Are sidewalks generally sloped so they drain to the front yard rather than the street?	Yes	no		no	no		no		no	no		no	no		
	d. Can alternate pedestrian networks be substituted for sidewalks (e.g., trails through common areas)?	Yes	yes	no	yes	no		no				no				
14. Driveways																
	a. What is the minimum driveway width specified in the community?	</= 18 ft	none		none	none					10	20	12	12	24?	
	b. Can pervious materials be used for single family home driveways (e.g., grass, gravel, porous pavers, etc)?	Yes	yes		yes			no					yes	no	no	
	c. Can a "two track" design be used at single family driveways?	Yes	no		no											
15. Open space management																
	a. Does the community have enforceable requirements to establish associations that can effectively manage open space?	Yes	no	no	yes	no	no	no	no	no	no		yes	yes		Yes

			Counties									Cities				
	Feature	Model Guideline	Lumpkin	Bartow	Cherokee	Forsyth	Fulton	Cobb	Paulding	Pickens	Dawson	Canton	Cartersville	Kennesaw	Marietta	Roswell
	b. Are open space areas required to be consolidated into larger units?	Yes	no	no	no	yes	no	no	no	no	no		no	no	no	No
	c. Does a minimum percentage of open space have to be managed in a natural condition?	Yes	yes	yes	no	no	no	no	no	no	no		no	no	no	No
	d. Are allowable and unallowable uses for open space in residential developments defined?	Yes	no	yes	yes	yes	no	yes	yes	no	no		yes	yes	no	No
	e. Can open space be managed by a third party using land trusts or conservation easements?	Yes	yes	yes				yes					yes	yes		Yes
16. Rooftop runoff																
	a. Can rooftop runoff be discharged to yard areas?	Yes											yes	yes	yes	
	b. Do current grading or drainage requirements allow for temporary ponding of stormwater on front yards or rooftops?	Yes												no		No
17. Tree preservation																
	a. If forests or specimen trees are present at residential development sites, does some of the stand have to be preserved?	Yes			No	No (encouraged)		No				yes	no	no	no	Yes
	b. Are the limits of disturbance shown on construction plans adequate for preventing clearing of natural vegetative cover during construction?	Yes			Yes	Yes		Yes				yes	yes	yes	yes	Yes
18. Land conservation incentives																

			Counties									Cities				
	Feature	**Model Guideline**	**Lumpkin**	**Bartow**	**Cherokee**	**Forsyth**	**Fulton**	**Cobb**	**Paulding**	**Pickens**	**Dawson**	**Canton**	**Cartersville**	**Kennesaw**	**Marietta**	**Roswell**
	a. Are there any incentives to developers or landowners to conserve non-regulated land (open space design, density bonuses, stormwater credits or lower property tax rates)?	Yes	no	no			no	yes	yes	yes	no	no	no	no	yes	Yes
	b. Is flexibility to meet regulatory or conservation restrictions (density compensation, buffer averaging, transferable development rights, off-site mitigation) offered to developers?	Yes	no	no	yes			yes	yes	yes	no	no	no	no	no	Yes
19. Stormwater outfalls																
	a. Is stormwater required to be treated for quality before it is discharged?	Yes	no	no	no	No	no	yes	no			no	no	no	no	Yes
	b. Are there effective design criteria for stormwater best management practices (BMPs)?	Yes	no	yes	yes	No	no	yes	yes	yes	yes	yes*	yes*	no	no*	Yes
	c. Can stormwater be directly discharged into a jurisdictional wetland without pretreatment?	No	yes	yes	yes	No	no	no		no		yes	yes	yes		No
	d. Does a floodplain management ordinance that restricts or prohibits development within the 100 year floodplain exist?	Yes	yes	yes	yes	Yes	no	no	no	yes	no	no	no	no		No

* not in code but provided by state law or manual

APPENDIX B

SITE DESIGN GUIDELINES

Site Design Guidelines

The goal of these site design guidelines is to reduce the volume of runoff generated by developed areas in order to protect imperiled aquatic species. This approach emphasizes the use of Better Site Design principles that utilize site planning techniques to conserve natural areas and the hydrologic function of a site (Center for Watershed Protection 1998, 1999). Implementing some of these guidelines may require revising development regulations in some of the government jurisdictions within the Etowah River watershed. The site design guidelines have been incorporated into the Code and Ordinance Worksheet (Appendix A), which can be used to identify which codes need to be revised. Many of the site design guidelines focus on reducing the amount of impervious areas constructed and infiltrating stormwater runoff as closely to the source as possible. The following guidelines are not strict requirements for every site; their application should be based on local conditions. Design specifications for many of the techniques discussed below are included in the Georgia Stormwater Management Manual (Atlanta Regional Commission, 2001). Specific recommendations and examples of how to implement the guideline follow each principle.

Design residential streets for the minimum required pavement width needed to support travel lanes, on-street parking, and emergency, maintenance, and service vehicle access. These widths should be based on traffic volume and desired speed.

- Set a maximum pavement width for residential streets:
    - 24 ft (back of curb to back of curb) for road with parking on one side of street
    - 26 ft for road with parking on both sides of street
    - 20 ft for roads with no on-street parking

Develop alternatives for managing runoff from roads that encourage treatment of stormwater runoff as close to the source as possible.

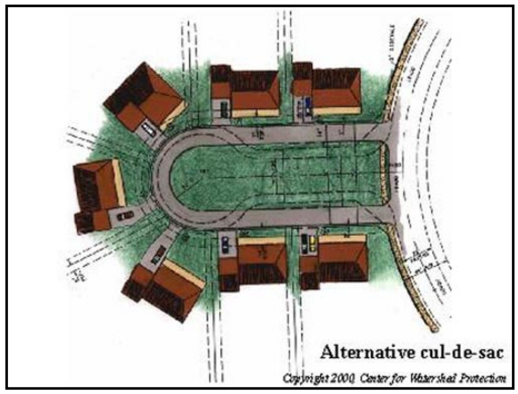
- Use roll top curbs that allow sheet flow into adjacent swales or infiltration areas. This option includes the use of bioinfiltration areas, infiltration trenches, interconnected swales, and detention swales.
  - Allow planting strip designs that use amended soil that promotes both plant health and stormwater infiltration.
  - Design so that runoff filters through soil and moves down-gradient along the length of the strip or swale.

  - An overflow pipe can be incorporated into design
  - Allow designs with or without curb & gutter
  - Rock and vegetated systems should be used where velocities may be too high for standard vegetation practices.
- Use permeable pavements for low traffic areas (on-street parking, sidewalks).
- Use tree pits as infiltration areas.

Wherever possible, residential street right-of-way (ROW) widths should reflect the minimum required to accommodate utilities, the travel-way, sidewalk, and vegetated open channels.

- The required ROW width should be related to the methods chosen to manage stormwater runoff (wider for streets using swales or bioretention, narrower for streets using curb & gutter).

Minimize the number of residential street cul-de-sacs and incorporate landscaped areas to reduce their imperviousness. The radius of the cul-de-sacs should be the minimum required to accommodate emergency and maintenance vehicles. Alternative turnarounds should be considered.



- Recommend 35 ft or the minimum required for emergency vehicles turning radius on cul-de-sacs.
- Allow alternatives to cul-de-sacs such as hammerheads and loop roads.
- Allow vegetated islands in the center of cul-de-sacs that can be used to infiltrate runoff.

Where density, topography, solids, and slope permit, vegetated open channels should be used in the street ROW to convey and treat stormwater runoff.

- Do not require curb & gutter on all roads; allow open section roads.
- Zoning should not restrict use of open section roads. If land use changes, staff should be allowed to revisit the road section.

- Restrict use on steep slopes.
- Design to prevent erodible velocities for the ten-year storm event.

The required parking ratio governing a particular land use of activity shall be enforced as a median of national standards in order to curb excess parking space construction. Existing parking ratios should be reviewed for compliance taking into account local and national experience to see if lower ratios are warranted and feasible.

- Review and update existing ratios based on actual demand.

Parking Ratio	**Model Recommendation**	**Current Requirements**
Professional office building	3 spaces/1000ft^2	3-4 spaces/1000ft^2
Shopping Center	3-3.5 spaces/1000ft^2	3.5-5 spaces/1000ft^2
Are requirements a maximum?	Yes	No

- Required parking ratios should be changed from a minimum to a maximum requirement.
- Developers should be allowed to "ghost in" additional spaces. In the future, if demand requires it, the owner should be able to increase the size of the parking lot without going through the entire planning approval process. In these cases, stormwater management should be designed for the maximum possible impervious surface area.

Parking codes should be revised to lower parking requirements where mass transit is available or enforceable shared parking arrangements are made.

- Incorporate language encouraging and permitting shared parking into ordinances.
- Examine options to allow for shared parking when a new development adjoins an existing development.
- Provide model shared parking agreements.

Reduce the overall imperviousness of parking lots by providing compact car spaces, minimizing stall dimensions, incorporating efficient parking lanes, and using pervious materials in the spillover areas where possible.

- Set maximum parking stall dimension requirements
- Incorporation of compact car spaces should be allowed and encouraged. Compact car spaces should be allowed as a certain percentage of the total parking spaces, at the discretion of the developer and Planning staff.

- Wheel stops should be placed at the end of parking stalls only.
- Permit use of pervious materials in overflow areas if the site is appropriate. Site conditions will be reviewed by the Planning staff at the time of submittal.
- Provide incentives for structured parking.

Wherever possible, provide stormwater treatment for parking lot runoff using bioretention areas, filter strips, and/or other practices that can be integrated into required landscaping areas and traffic islands.

- Encourage infiltration practices in local stormwater and parking lot landscaping regulations.
- Require a minimum percentage of parking lot area to be landscaped
- Eliminate irrigation and curb & gutter requirements for landscaped islands used as bio-infiltration areas.

Eliminate minimum lot sizes and express requirements in number of houses per unit area.

Advocate open space development incorporating smaller lot sizes to minimize total impervious area, reduce total construction costs, conserve natural areas, provide community recreational space, and promote watershed protection.

- Make cluster development by-right; do not require additional plan review and public hearings.
- Allow reduced lot size for detached housing on public water and sewer, with the condition that the applicant must demonstrate a workable design that does not increase yield allowed by zoning.
- Relax permit fee requirements for cluster submittals.
- Consider providing incentives to encourage clustering.

Relax side yard setbacks and allow narrower frontages to reduce total road length in the community and overall site imperviousness. Relax front setback requirements to minimize driveway lengths and reduce overall lot imperviousness.

- Consider setting maximum and minimum setbacks and frontages. The setbacks should be related to the methods chosen to treat street runoff (larger for streets using swales or bioretention, narrower for streets using curb & gutter).

Setbacks & Frontages*	Model Recommendation	Current Requirements
Front setback	20 ft	20-75 feet
Side setback	8 ft	10-40 feet
Rear setback	25 ft or less	15-50 feet
Minimum frontage	80 ft or less	30-120 feet

* These are minimum requirements for ½ acre residential lots.

- Minimum side yard setbacks should be based on the fire code. This will provide maximum design flexibility without sacrificing safety and emergency access.
- Lot frontage requirements can be waived on private streets so long as there is a Homeowners Association agreement in place.

Promote more flexible design standards for residential subdivision sidewalks. Where practical, consider locating sidewalks on only one side of the street and providing common walkways linking pedestrian areas.

- Sidewalks can be allowed on only one side of the road (for both open and closed section streets) at the discretion of the Planning Commission and in consideration of density and traffic volume issues.
- Where a suitable alternative path system exists, sidewalks would not be required.
- Provide incentives for developments that promote connectivity.
- Sidewalks may be constructed of pervious materials, provided they meet ADA requirements.
- Sidewalks should not be required around the entire perimeter of a cul-de-sac.

Reduce overall lot imperviousness by promoting alternative driveway surfaces and shared driveways that connect two or more homes together.

- Promote the use of permeable pavements and two-track designs.

Clearly specify how community open space will be managed and designate a sustainable legal entity responsible for managing both natural and recreational open space.

- Explicitly define allowable and unallowable uses of open space

- Require establishment of legal entities that can effectively manage open space.
- Ensure that the initial setup of Home Owners Associations (HOA), or other legal entity, is adequate to cover the proposed and required operation and maintenance issues associated with open space management. Adequate HOA documents should contain provisions for annual assessments, reserve fund for capital improvements, lists of improvements/common areas to be maintained, and provisions for collecting and enforcing assessments.

Direct rooftop runoff to pervious areas such as yards, open channels, or vegetated areas and avoid routing rooftop runoff to the roadway and the stormwater conveyance system.

- Disconnection of rooftop runoff must ensure no basement seepage or impacts to septic systems or wells.
- The disconnection should drain continuously through a vegetated channel, swale, or filter strip to the property line or BMP.
- Downspouts should be at least 10 feet away from the nearest impervious surface.

Stormwater should not be discharged untreated into streams, jurisdictional wetlands, sole-source aquifers, or sensitive areas.

- Encourage on-site infiltration of stormwater by strengthening stormwater ordinances.
- Encourage the ‘treatment train’ approach to stormwater management that uses a series of distributed techniques rather than large structural controls.

APPENDIX C

SITE DESIGN CHECKLIST

SITE DESIGN GUIDELINE CHECKLIST

Prior to developing any structural stormwater practices on a site, significant reductions in the impacts of stormwater and runoff, and increases in water quality from water flowing off-site, can be made through enhancements in site design. The checklist below can be used to minimize stormwater impacts and return site hydrology to a more natural pre-development system. Please indicate the practices that you are applying to your development, and note the extent to which each model development principle is being implemented.

Stormwater Management and Site Design

Parking areas, roadways, and driveways are the greatest contributors of impervious surfaces. Impervious areas alter site hydrology and directly impact water quality. Examples of these areas include streets, parking lots, rooftops and other paved or compacted surfaces that do not allow water to infiltrate into the ground.

The following methods can be used to reduce the total runoff volume from impervious surfaces.

Plans will receive the following credit points per line item:

20% - 50% = 1 pt.

51% - 80% = 5 pts.

81% - 100% = 10 pts.

1.0 Residential Streets

Design residential streets for the minimum required pavement width necessary to safely accommodate vehicular traffic. (On curbed streets widths should be measured from back of curb to back of curb. On non-curbed streets, widths should be measured edge to edge of pavement).

1.1 20 ft for roads without on-street parking

Percentage of roads in compliance with these specifications:

___20%-50% (1pt)

___51%-80% (5pt)

___81%-100% (10pt)

1.2 24 ft for road with parking on one side of street

Percentage of roads in compliance with these specifications:

___20%-50% (1pt)

___51%-80% (5pt)

___81%-100% (10pt)

1.3 26 ft for road with parking on both sides of street

Percentage of roads in compliance with these specifications:

___20%-50% (1pt)

___51%-80% (5pt)

___81%-100% (10pt)

If road widths are not in compliance, provide justification:

____

____

____

2.0 Systems for Stormwater Management

Develop alternatives to traditional stormwater management.

Traditional stormwater management is the practice of moving water off site as quickly as possible to a centralized facility, such as a pond or a local tributary. Model development principles strive to allow infiltration of water to occur as close as possible to the original area of rainfall. By engineering terrain, vegetation, and soil features to perform this function, costly conveyance systems can be avoided, and the landscape can retain more of its natural hydrological function.

The development plan should include use of best management practices for stormwater. (Construction and engineering details are located in the Georgia Stormwater Manual, Vol. 2, located online at: www.georgiastormwater.com)

Best management practices for stormwater include but are not limited to the following: bioretention areas, vegetated swales, interconnected swales, porous pavements, infiltration trenches, directing rooftop runoff to vegetated swales. (Maximum centerline slope for vegetated swales is 4%).

Percentage of stormwater from a 2 year storm event which will be infiltrated on site: (Show calculations. Calculation work sheets are provided in the Georgia Stormwater Manual, Vol. 2)

___20%-50% (1pt)

___51%-80% (5pt)

___81%-100% (10pt)

If alternatives to traditional stormwater management were not used, please include justification for not implementing:

____

____

____

____

3.0 Use no curb, roll top curbs, mountable curbs to allow sheet flow of stormwater into swales or infiltration areas.

Percentage of total street length using no curb, roll top curbs, mountable curbs:

___20%-50% (1pt)

___51%-80% (5pt)

___81%-100% (10pt)

(percentages indicated should be a cumulative calculation of all sides of all streets in plan).

If curb and gutter is used, provide justification:

____

____

____

____

4.0 In residential areas, avoid the use of cul-de-sacs as much as possible.

If cul-de-sacs are included in plan, please provide justification for choosing cul-de-sacs over an interconnected network of streets. A network of interconnected streets generally results in an overall decrease in impervious surface on site (depending on topography):

____

____

____

____

4.1 If cul-de-sacs are used, central landscaped areas should be incorporated.

Percentage of cul-de-sacs which include central landscaped areas:

___20%-50% (1pt)

___51%-80% (5pt)

___81%-100% (10pt)

4.2 If cul-de-sacs are used, the radius should reflect the minimum required turning radius for emergency and maintenance equipment which is 35ft. On curbed cul-de-sacs this should be measured from back of curb to back of curb. On non-curb streets, this should be measured from width of pavement edge to center.

Percentage of cul-de-sacs with turning radii no greater than 35ft:

___20%-50% (1pt)

___51%-80% (5pt)

___81%-100% (10pt)

5.0 Build shared parking on site.

Parking Ratio	**Model Recommendation**	**Current Requirements**
Professional office building	< 3 spaces/1000ft^2	3-4 spaces/1000ft^2
Shopping Center	3-3.5 spaces/1000ft^2	3.5-5 spaces/1000ft^2

Developers will be permitted to "ghost in" additional spaces. If future demand requires, the owner can increase the size of the parking lot without undertaking an entire planning approval process. If ghosting in additional spaces is anticipated, stormwater management should be designed for the maximum possible impervious surface area.

Percentage of parking spaces designated for use by more than one business (% shared parking).

___20%-50% (1pt)

___51%-80% (5pt)

___81%-100% (10pt)

5.1 Percentage of total parking area designated for compact car use:

___20%-50% (1pt)

___51%-80% (5pt)

___81%-100% (10pt)

6.0 Build with reduced setbacks on one or more sides of residential homes.

Recommended setbacks:

Setbacks & Frontages	**Recommended setbacks & frontage**	**Current Requirements***
Front setback	20 ft or less	20-75 feet
Side setback	8 ft or less	10-40 feet
Rear setback	25 ft or less	15-50 feet
Minimum frontage	80 ft or less	30-120 feet

* These are minimum requirements for ½ acre residential lots.

Percentage of houses meeting the recommended setback and frontage specifications:

___20%-50% (1pt)

___51%-80% (5pt)

___81%-100% (10pt)

7.0 Utilize cluster development techniques to preserve site in a natural state.

Percentage of site remaining undisturbed (not cleared or graded) by construction activities:

___20%-50% (1pt)

___51%-80% (5pt)

___81%-100% (10pt)

Total # of points ________ out of 110

Much of the material for this checklist is excerpted from the Prince George's County, Md., 1999 *Low Impact Development Design Strategies: An Integrated Design Approach*. Largo, Maryland. All planned low impact development techniques should conform to the designs of those presented in this manual. Descriptions of the above and other site design techniques can be found in the low impact development references listed in aforementioned manual or in the Georgia Stormwater Manual.

APPENDIX D

MODEL POST DEVELOPMENT STORMWATER ORDINANCE

MODEL POST-DEVELOPMENT STORMWATER MANAGEMENT ORDINANCE

Introduction

It is hereby determined that:

(1) Land development projects and other land use conversions, and their associated changes to land cover, permanently alter the hydrologic response of local watersheds and increase stormwater runoff rates and volumes, which in turn increase flooding, stream channel erosion, and sediment transport and deposition;

(2) Land development projects and other land use conversions also contribute to increased nonpoint source pollution and degradation of receiving waters;

(3) The impacts of post-development stormwater runoff quantity and quality can adversely affect public safety, public and private property, drinking water supplies, recreation, aquatic habitats, fish and other aquatic life, property values and other uses of lands and waters;

(4) These adverse impacts can be controlled and minimized through the regulation of stormwater runoff quantity and quality from new development and redevelopment, by the use of both structural and nonstructural measures;

(5) Localities in the State of Georgia are required to comply with a number of both State and Federal laws, regulations and permits which require a locality to address the impacts of post-development stormwater runoff quality and nonpoint source pollution;

Therefore, the (*local jurisdiction*) has established this set of stormwater management policies to provide reasonable guidance for the regulation of post-development stormwater runoff for the purpose of protecting local water resources from degradation. It has determined that it is in the public interest to regulate post-development stormwater runoff discharges in order to control and minimize increases in stormwater runoff rates and volumes, post-construction soil erosion and sedimentation, stream channel erosion, and nonpoint source pollution associated with post-development stormwater runoff.

Section 1. General Provisions

1.1. Purpose and Intent

The purpose of this ordinance is to protect, maintain and enhance the public health, safety, environment and general welfare by establishing minimum requirements and procedures to control the adverse effects of increased post-development stormwater runoff and nonpoint source pollution associated with new development and redevelopment. It has been determined that proper management of post-development stormwater runoff will minimize damage to public and private property and infrastructure, safeguard the public health, safety, environment and general welfare of the public, and protect water and aquatic resources. This ordinance seeks to meet that purpose through the following objectives:

(1) Establish decision-making processes surrounding land development activities that protect the integrity of the watershed and preserve the health of water resources;

(2) Require that new development and redevelopment maintain the pre-development hydrologic response in their post-development state as nearly as practicable in order to reduce flooding, streambank erosion, nonpoint source pollution and

increases in stream temperature, and maintain the integrity of stream channels and aquatic habitats;

(3) Establish minimum post-development stormwater management standards and design criteria for the regulation and control of stormwater runoff quantity and quality;

(4) Establish design and application criteria for the construction and use of structural stormwater control facilities that can be used to meet the minimum post-development stormwater management standards;

(5) Encourage the use of nonstructural stormwater management and stormwater better site design practices, such as reducing impervious cover and the preservation of greenspace and other natural areas, to the maximum extent practicable. Coordinate site design plans, which include greenspace, with the county's greenspace protection plan;

(6) Establish provisions for the long-term responsibility for and maintenance of structural stormwater control facilities and nonstructural stormwater management practices to ensure that they continue to function as designed, are maintained, and pose no threat to public safety; and,

(7) Establish administrative procedures for the submission, review, approval and disapproval of stormwater management plans, and for the inspection of approved active projects, and long-term follow up.

1.2. Applicability

(1) This ordinance shall be applicable to all land development, including, but not limited to, site plan applications, subdivision applications, and grading applications, unless exempt pursuant to Subsection 2 below. These standards apply to any new development or redevelopment site that meets one or more of the following criteria:

a. New development that involves the creation of 5,000 square feet or more of impervious cover, or that involves other land development activities of 1 acre or more;

b. Redevelopment that includes the creation, addition or replacement of 5,000 square feet or more of impervious cover, or that involves other land development activity of one (1) acre or more;

c. Redevelopment that adds an additional area of impervious cover equal or greater than 1000 square feet;

d. Any new development or redevelopment, regardless of size, that is defined by the (*administrator*) to be a hotspot land use; or,

e. Land development activities that are smaller than the minimum applicability criteria set forth in items A and B above if such activities are part of a larger common plan of development, even though multiple, separate and distinct land development activities may take place at different times on different schedules.

(2) The following activities are exempt from this ordinance:

a. Individual single-family or duplex residential lots that are not part of a subdivision or phased development project;

b. Additions or modifications to existing single-family or duplex residential structures;

c. Agricultural or silvicultural land management activities within areas zoned for these activities; and,

d. Repairs to any stormwater management facility or practice deemed necessary by the (*administrator*).

1.3. Designation of Ordinance Administrator

The (*title of administrator*) or (*designee*) is hereby appointed to administer and implement the provisions of this ordinance.

1.4. Compatibility with Other Regulations

This ordinance is not intended to modify or repeal any other ordinance, rule, regulation or other provision of law. The requirements of this ordinance are in addition to the requirements of any other ordinance, rule, regulation or other provision of law, and where any provision of this ordinance imposes restrictions different from those imposed by any other ordinance, rule, regulation or other provision of law, whichever provision is more restrictive or imposes higher protective standards for human health or the environment shall control.

1.5. Severability

If the provisions of any section, subsection, paragraph, subdivision or clause of this ordinance shall be adjudged invalid by a court of competent jurisdiction, such judgment shall not affect or invalidate the remainder of any section, subsection, paragraph, subdivision or clause of this ordinance.

1.6. Stormwater Management Manual

The (*local jurisdiction*) will utilize the policy, criteria and information including technical specifications and standards in the latest edition of the Georgia Stormwater Management Manual and any relevant local addenda for the proper implementation of the requirements of this ordinance. The manual may be updated and expanded periodically, based on improvements in science, engineering, monitoring and local maintenance experience.

Section 2. Definitions

"Applicant" means a person submitting a post-development stormwater management application and plan for approval.

"Better Site Design" means site design approaches and techniques that can reduce a site's impact on the watershed and can provide for nonstructural stormwater management. Better site design includes conserving and protecting natural areas and greenspace, reducing impervious cover, and using natural features for stormwater management.

"Channel" means a natural or artificial watercourse with a definite bed and banks that conducts continuously or periodically flowing water.

"Conservation Easement" means an agreement between a land owner and the (*local jurisdiction*) or other government agency or land trust that permanently protects open space or greenspace on the owner's land by limiting the amount and type of development that can take place, but continues to leave the remainder of the fee interest in private ownership.

"Detention" means the temporary storage of stormwater runoff in a stormwater management facility for the purpose of controlling the peak discharge.

"Detention Facility" means a detention basin or structure designed for the detention of stormwater runoff and gradual release of stored water at controlled rates.

"Developer" means a person who undertakes land development activities.

"Development" means a land development or land development project.

"Drainage Easement" means an easement appurtenant or attached to a tract or parcel of land allowing the owner of adjacent tracts or other persons to discharge stormwater runoff onto the tract or parcel of land subject to the drainage easement.

"Erosion and Sedimentation Control Plan" means a plan that is designed to minimize the accelerated erosion and sediment runoff at a site during land disturbance activities.

"Extended Detention" means the detention of stormwater runoff for an extended period, typically 24 hours or greater.

"Extreme Flood Protection" means measures taken to prevent adverse impacts from large low-frequency storm events with a return frequency of 100 years or more.

"Flooding" means a volume of surface water that is too great to be confined within the banks or walls of a conveyance or stream channel and that overflows onto adjacent lands.

"Greenspace" or "Open Space" means permanently protected areas of the site that are preserved in a natural state.

“Hotspot” means an area where the use of the land has the potential to generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater. Hotspots include, but are not limited to, fueling stations and golf courses.

“Hydrologic Soil Group (HSG)” means a Natural Resource Conservation Service classification system in which soils are categorized into four runoff potential groups. The groups range from group A soils, with high permeability and little runoff produced, to group D soils, which have low permeability rates and produce much more runoff.

“Impervious Cover” means a surface composed of any material that greatly impedes or prevents the natural infiltration of water into soil. Impervious surfaces include, but are not limited to, rooftops, buildings, streets and roads, except those designed specifically to allow infiltration.

“Industrial Stormwater Permit” means a National Pollutant Discharge Elimination System (NPDES) permit issued to an industry or group of industries which regulates the pollutant levels associated with industrial stormwater discharges or specifies on-site pollution control strategies.

“Infiltration” means the process of percolating stormwater runoff into the subsoil.

“Jurisdictional Wetland" means an area that is inundated or saturated by surface water or ground water at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions, commonly known as hydrophytic vegetation.

“Land Development” means any land change, including, but not limited to, clearing, digging, grubbing, stripping, removal of vegetation, dredging, grading, excavating, transporting and filling of land, construction, paving, and any other installation of impervious cover.

“Land Development Activities” means those actions or activities which comprise, facilitate or result in land development.

“Land Development Project” means a discrete land development undertaking.

“Inspection and Maintenance Agreement" means a written agreement providing for the long-term inspection and maintenance of stormwater management facilities and practices on a site or with respect to a land development project, which when properly recorded in the deed records constitutes a restriction on the title to a site or other land involved in a land development project.

“New Development” means a land development activity on a previously undeveloped site.

“Nonpoint Source Pollution” means a form of water pollution that does not originate from a discrete point such as a sewage treatment plant or industrial discharge, but involves the transport of pollutants such as sediment, fertilizers, pesticides, heavy metals, oil, grease, bacteria, organic materials and other contaminants from land to surface water and ground water via mechanisms such as precipitation, stormwater runoff, and leaching. Nonpoint source pollution is a by-product of land use practices such as agricultural, silvicultural, mining, construction, subsurface disposal and urban runoff sources.

“Nonstructural Stormwater Management Practice” or “Nonstructural Practice” means any natural or planted vegetation or other nonstructural component of the stormwater management plan that provides for or enhances stormwater quantity and/or quality control or other stormwater management benefits, and includes, but is not limited to, riparian buffers, open and greenspace areas, overland flow filtration areas, natural depressions, and vegetated channels.

“Off-Site Facility” means a stormwater management facility located outside the boundaries of the site.

“On-Site Facility” means a stormwater management facility located within the boundaries of the site.

"Overbank Flood Protection" means measures taken to prevent an increase in the frequency and magnitude of out-of-bank flooding (i.e. flow events that exceed the capacity of the channel and enter the floodplain), and that are intended to protect downstream properties from flooding for the 2-year through 25-year frequency storm events.

"Owner" means the legal or beneficial owner of a site, including but not limited to, a mortgagee or vendee in possession, receiver, executor, trustee, lessee or other person, firm or corporation in control of the site.

"Permit" means the permit issued by the (*local jurisdiction*) to the applicant which is required for undertaking any land development activity.

"Person" means, except to the extent exempted from this ordinance, any individual, partnership, firm, association, joint venture, public or private corporation, trust, estate, commission, board, public or private institution, utility, cooperative, city, county or other political subdivision of the State, any interstate body or any other legal entity.

"Post-development" refers to the time period, or the conditions that may reasonably be expected or anticipated to exist, after completion of the land development activity on a site as the context may require.

"Pre-development" refers to the time period, or the conditions that exist, on a site prior to the commencement of a land development project and at the time that plans for the land development of a site are approved by the plan approving authority. Where phased development or plan approval occurs (preliminary grading, roads and utilities, etc.), the existing conditions at the time prior to the first item being approved or permitted shall establish pre-development conditions.

"Project" means a land development project.

“Redevelopment” means a land development project on a previously developed site, but excludes ordinary maintenance activities, remodeling of existing buildings, resurfacing of paved areas, and exterior changes or improvements which do not materially increase or concentrate stormwater runoff, or cause additional nonpoint source pollution.

“Regional Stormwater Management Facility” or “Regional Facility” means stormwater management facilities designed to control stormwater runoff from multiple properties, where the owners or developers of the individual properties may assist in the financing of the facility, and the requirement for on-site controls is either eliminated or reduced.

“Runoff” means stormwater runoff.

“Site” means the parcel of land being developed, or the portion thereof on which the land development project is located.

“Stormwater Best Management Practice (BMP)” means structural and nonstructural practices that control stormwater runoff and provide for or enhance stormwater quantity and/or quality control or other stormwater management benefits.

“Stormwater Management” means the collection, conveyance, storage, treatment and disposal of stormwater runoff in a manner intended to prevent increased flood damage, streambank channel erosion, habitat degradation and water quality degradation, and to enhance and promote the public health, safety and general welfare.

“Stormwater Management Facility” means any infrastructure that controls or conveys stormwater runoff.

“Stormwater Management Measure” means any stormwater management facility or nonstructural stormwater practice.

"Stormwater Management Plan" means a document describing how existing runoff characteristics will be affected by a land development project and containing measures for complying with the provisions of this ordinance.

"Stormwater Management System" means the entire set of structural and nonstructural stormwater management facilities and practices that are used to capture, convey and control the quantity and quality of the stormwater runoff from a site.

"Stormwater Retrofit" means a stormwater management practice designed for a currently developed site that previously had either no stormwater management practice in place or a practice inadequate to meet the stormwater management requirements of the site.

"Stormwater Runoff" means the flow of surface water resulting from precipitation.

"Structural Stormwater Control" means a structural stormwater management facility or device that controls stormwater runoff and changes the characteristics of that runoff including, but not limited to, the quantity and quality, the period of release or the velocity of flow of such runoff.

"Subdivision" means the division of a tract or parcel of land resulting in one or more new lots or building sites for the purpose, whether immediately or in the future, of sale, other transfer of ownership or land development, and includes divisions of land resulting from or made in connection with the layout or development of a new street or roadway or a change in an existing street or roadway.

"Water Quality Storm" means a storm event that produces 1.2 inches of rainfall in 24 hours over the study site.

Section 3. Permit Procedures and Requirements

3.1. Permit Application Requirements

No owner or developer shall perform any land development activities without first meeting the requirements of this ordinance prior to commencing the proposed activity.

Unless specifically exempted by this ordinance, any owner or developer proposing a land development activity shall submit to the (*local jurisdiction*) a permit application on a form provided by the (*local jurisdiction*) for that purpose.

Unless otherwise exempted by this ordinance, the following items shall accompany a permit application in order to be considered:

(1) Stormwater concept plan and consultation meeting certification in accordance with Section 3.2;

(2) Stormwater management plan in accordance with Section 3.3;

(3) Inspection and maintenance agreement in accordance with Section 3.4, if applicable;

(4) Performance bond in accordance with Section 3.5; and,

(5) Permit application and plan review fees in accordance with Section 3.6.

3.2. Stormwater Concept Plan and Consultation Meeting

Before any stormwater management permit application is submitted, it is recommended that the landowner or developer meet with the (*local jurisdiction*) for a consultation meeting on a preliminary concept plan for the post-development stormwater management system to be utilized in the proposed land development project. This consultation meeting shall take place at the time of the preliminary plan of subdivision or other early step in the development process. The purpose of this meeting is to discuss the post-development stormwater management measures necessary for the proposed project, as well as to discuss and assess constraints, opportunities and potential ideas for stormwater management designs before the formal site design engineering is commenced.

To accomplish this goal the following information shall be included in the concept plan which shall be submitted in advance of the meeting:

A. Existing Conditions / Proposed Site Plans

Existing conditions and proposed site layout sketch plans, which illustrate at a minimum: existing and proposed topography; perennial and intermittent streams; mapping of predominant soils from soil surveys (when available); boundaries of existing predominant vegetation and proposed limits of clearing and grading; and location of existing and proposed roads, buildings, parking areas, existing easements, and other impervious surfaces.

B. Natural Resources Inventory

A written or graphic inventory of the natural resources at the site and surrounding area as it exists prior to the commencement of the project. This description should include a discussion of soil conditions, forest cover, topography, wetlands, and other native vegetative areas on the site, as well as the location and boundaries of other natural feature protection and conservation areas such as wetlands, lakes, ponds, floodplains, stream buffers and other setbacks (e.g., drinking water well setbacks, septic setbacks, etc.).

Particular attention should be paid to environmentally sensitive features that provide particular opportunities or constraints for development.

C. Stormwater Management System Concept Plan

A written or graphic concept plan of the proposed post-development stormwater management system including: preliminary selection and location of proposed structural stormwater controls; a completed Site Design Checklist for Developers; location of existing and proposed conveyance systems such as grass channels, swales, and storm drains; flow paths; location of floodplain/floodway limits; relationship of site to upstream and downstream properties and drainages; and preliminary location of proposed stream channel modifications, such as bridge or culvert crossings.

Local watershed plans, the (*local jurisdiction*) greenspace projection plan (if applicable), and any relevant resource protection plans will be consulted in the discussion of the concept plan. If necessary, a follow-up meeting may be held to verify the post-development stormwater management measures necessary for the proposed project before formal design commences.

3.3. Stormwater Management Plan Requirements

The stormwater management plan shall detail how post-development stormwater runoff will be controlled or managed and how the proposed project will meet the requirements of this ordinance, including the performance criteria set forth in Section 4 below.

This plan shall be in accordance with the criteria established in this section and must be submitted with the stamp and signature of a Professional Engineer (PE) licensed in the state of Georgia, who must verify that the design of all stormwater management facilities and practices meet the submittal requirements outlined in the submittal checklist(s) found in the Georgia Stormwater Management Manual.

The stormwater management plan must ensure that the requirements and criteria in this ordinance are being complied with and that opportunities are being taken to minimize adverse post-development stormwater runoff impacts from the development. The plan shall consist of maps, narrative, and supporting design calculations (hydrologic and hydraulic) for the proposed stormwater management system. The plan shall include all of the information required in the Stormwater Management Site Plan checklist found in the Georgia Stormwater Management Manual. This includes:

A. Common address and legal description of site

B. Vicinity Map

C. Existing Conditions Hydrologic Analysis

The existing condition hydrologic analysis for stormwater runoff rates, volumes, and velocities, which shall include: a topographic map of existing site conditions with the drainage basin boundaries indicated; acreage, soil types and land cover of areas for each sub-basin affected by the project; all perennial and intermittent streams and other surface water features; all existing stormwater conveyances and structural control facilities; direction of flow and exits from the site; analysis of runoff provided by off-site areas upstream of the project site; and methodologies, assumptions, site parameters and supporting design calculations used in analyzing the existing conditions site hydrology. For redevelopment sites, predevelopment conditions shall be modeled using the established guidelines for the portion of the site undergoing land development activities.

D. Post-Development Hydrologic Analysis

The post-development hydrologic analysis for stormwater runoff rates, volumes, and velocities, which shall include: a topographic map of developed site conditions with the post-development drainage basin boundaries indicated; total area of post-development impervious surfaces and other land cover areas for each sub-basin affected by the project; calculations for determining the runoff volumes that need to be addressed for each sub-basin for the development project to meet the post-development stormwater management performance criteria in Section 4; location and boundaries of proposed natural feature protection and conservation areas; documentation and calculations for any applicable site design credits that are being utilized; methodologies, assumptions, site parameters and supporting design calculations used in analyzing the existing conditions site hydrology. If the land development activity on a redevelopment site constitutes more than 50 percent of the site area for the entire site, then the performance criteria in Section 4 must be met for the stormwater runoff from the entire site.

E. Stormwater Management System

The description, scaled drawings and design calculations for the proposed post-development stormwater management system, which shall include: A map and/or drawing or sketch of the stormwater management facilities, including the location of nonstructural site design features and the placement of existing and proposed structural stormwater controls, including design water surface elevations, storage volumes available from zero to maximum head, location of inlet and outlets, location of bypass and discharge systems, and all orifice/restrictor sizes; a narrative describing how the selected structural stormwater controls will be appropriate and effective; cross-section and profile drawings and design details for each of the structural stormwater controls in the system, including supporting calculations to show that the facility is designed according to the applicable design criteria; a hydrologic and hydraulic analysis of the stormwater management system for all applicable design storms (including stage-storage or outlet rating curves, and inflow and outflow hydrographs); documentation and supporting calculations to show that the stormwater management system adequately meets the post-development stormwater management performance criteria in Section 4; drawings, design calculations, elevations and hydraulic grade lines for all existing and proposed stormwater conveyance elements including stormwater drains, pipes, culverts, catch basins, channels, swales and areas of overland flow; and where applicable, a narrative describing how the stormwater management system corresponds with any watershed protection plans and/or local greenspace protection plan.

F. Post-Development Downstream Analysis

A downstream peak flow analysis which includes the assumptions, results and supporting calculations to show safe passage of post-development design flows downstream. The analysis of downstream conditions in the report shall address each and every point or area along the project site's boundaries at which runoff will exit the property. The analysis shall focus on the portion of the drainage channel or watercourse immediately downstream from the project. This area shall extend downstream from the project to a point in the drainage basin where the project area is 10 percent of the total basin area. In calculating runoff volumes and discharge rates, consideration may need to be given to any planned future upstream land use changes. The analysis shall be in accordance with the Georgia Stormwater Management Manual.

G. Construction-Phase Erosion and Sedimentation Control Plan

An erosion and sedimentation control plan in accordance with the Georgia Erosion and Sedimentation Control Act or NPDES Permit for Construction Activities. The plan shall also include information on the sequence/phasing of construction and temporary stabilization measures and temporary structures that will be converted into permanent stormwater controls.

H. Landscaping and Greenspace Plan

A detailed landscaping and vegetation plan describing the woody and herbaceous vegetation that will be used within and adjacent to stormwater management facilities and practices. The landscaping plan must also include: the arrangement of planted areas, natural and greenspace areas and other landscaped features on the site plan; information necessary to construct the landscaping elements shown on the plan drawings; descriptions and standards for the methods, materials and vegetation that are to be used in the construction; density of plantings; descriptions of the stabilization and management techniques used to establish vegetation; and a description of who will be responsible for ongoing maintenance of vegetation for the stormwater management facility and what practices will be employed to ensure that adequate vegetative cover is preserved.

I. Operations and Maintenance Plan

Detailed description of ongoing operations and maintenance procedures for stormwater management facilities and practices to ensure their continued function as designed and constructed or preserved. These plans will identify the parts or components of a stormwater management facility or practice that need to be regularly or periodically inspected and maintained, and the equipment and skills or training necessary. The plan shall include an inspection and maintenance schedule, maintenance tasks, responsible parties for maintenance, funding, and access and safety issues. Provisions for the periodic review and evaluation of the effectiveness of the maintenance program and the need for revisions or additional maintenance procedures shall be included in the plan.

J. Maintenance Access Easements

The applicant must ensure access from public right-of-way to stormwater management facilities and practices requiring regular maintenance at the site for the purpose of inspection and repair by securing all the maintenance access easements needed on a permanent basis. Such access shall be sufficient for all necessary equipment for maintenance activities. Upon final inspection and approval, a plat or document indicating that such easements exist shall be recorded and shall remain in effect even with the transfer of title of the property.

K. Inspection and Maintenance Agreements

Unless an on-site stormwater management facility or practice is dedicated to and accepted by the (*local jurisdiction*) as provided in Section 3.4 below, the applicant must execute an easement and an inspection and maintenance agreement binding on all subsequent owners of land served by an on-site stormwater management facility or practice in accordance Section 3.4.

L. Evidence of Acquisition of Applicable Local and Non-local Permits

The applicant shall certify and provide documentation to the (*local jurisdiction*) that all other applicable environmental permits have been acquired for the site prior to approval of the stormwater management plan.

3.4. Stormwater Management Inspection and Maintenance Agreements

Prior to the issuance of any permit for a land development activity requiring a stormwater management facility or practice hereunder, the applicant or owner of the site must, unless an on-site stormwater management facility or practice is dedicated to and accepted by the (*local jurisdiction*), execute an inspection and maintenance agreement, and/or a conservation easement, if applicable, that shall be binding on all subsequent owners of the site.

The inspection and maintenance agreement, if applicable, must be approved by the (*local jurisdiction*) prior to plan approval, and recorded in the deed records upon final plat approval.

The inspection and maintenance agreement shall identify by name or official title the person(s) responsible for carrying out the inspection and maintenance. Responsibility for the operation and maintenance of the stormwater management facility or practice, unless assumed by a governmental agency, shall remain with the property owner and shall pass to any successor owner. If portions of the land are sold or otherwise transferred, legally binding arrangements shall be made to pass the inspection and maintenance responsibility to the appropriate successors in title. These arrangements shall designate for each portion of the site, the person to be permanently responsible for its inspection and maintenance.

As part of the inspection and maintenance agreement, a schedule shall be developed for when and how often routine inspection and maintenance will occur to ensure proper function of the stormwater management facility or practice. The agreement shall also include plans for annual inspections to ensure proper performance of the facility between scheduled maintenance and shall also include remedies for the default thereof.

In addition to enforcing the terms of the inspection and maintenance agreement, the (*local jurisdiction*) may also enforce all of the provisions for ongoing inspection and maintenance in Section 7 of this ordinance.

The (*local jurisdiction*), in lieu of an inspection and maintenance agreement, may accept dedication of any existing or future stormwater management facility for maintenance, provided such facility meets all the requirements of this ordinance and includes adequate and perpetual access and sufficient area, by easement or otherwise, for inspection and regular maintenance.

3.5. Performance Bonds

The (*local jurisdiction*) shall require from the developer a surety or cash bond, irrevocable letter of credit, or other means of security acceptable to the (*local jurisdiction*) prior to the issuance of any building and/or grading permit for the construction of a development requiring a stormwater management system. The amount of the security shall not be less than the total estimated construction cost of the stormwater management system. The bond required in this section shall include provisions relative to forfeiture for failure to complete work specified in the approved stormwater management plan, compliance with all of the provisions of this ordinance, other applicable laws and regulations, and any time limitations. The bond shall not be fully released without a final inspection of the completed work by the (*local jurisdiction*), submission of “as-built” plans, a signed maintenance agreement, and a certification of completion by the (*local jurisdiction*) that the stormwater management system complies with the approved plan and provisions of this ordinance. A procedure may be used to release parts of the bond held by the (*local jurisdiction*) after various stages of construction have been completed and accepted by the (*local jurisdiction*). The procedures used for partially releasing performance bonds must be specified by the local authority in writing prior to the approval of a stormwater management plan.

<u>3.6. Application Procedure</u>

(1) Applications for land development permits shall be filed with the (*local jurisdiction*).

(2) Permit applications shall include the items set forth in Section 3.1 above (two copies of the stormwater management plan and the inspection maintenance agreement, if applicable, shall be included).

(3) The (*local jurisdiction*) shall inform the applicant whether the application, stormwater management plan and inspection and maintenance agreement are approved or disapproved.

(4) If the permit application, stormwater management plan or inspection and maintenance agreement are disapproved, the (*local jurisdiction*) shall notify the applicant of such fact in writing. The applicant may then revise any item not meeting the requirements hereof and resubmit the same, in which event subparagraph 3 above and this subparagraph shall apply to such re-submittal.

(5) Upon a finding by the (*local jurisdiction*) that the permit application, stormwater management plan and inspection and maintenance agreement, if applicable, meet the

requirements of this ordinance, the (*local jurisdiction*) may issue a permit for the land development project, provided all other legal requirements for the issuance of such permit have been met.

(6) Notwithstanding the issuance of the permit, in conducting the land development project, the applicant or other responsible person shall be subject to the following requirements:

a. The applicant shall comply with all applicable requirements of the approved plan and this ordinance and shall certify that all land clearing, construction, land development and drainage will be done according to the approved plan;

b. The land development project shall be conducted only within the area specified in the approved plan;

c. The (*local jurisdiction*) shall be allowed to conduct periodic inspections of the project;

d. No changes may be made to an approved plan without review and written approval by the (*local jurisdiction*); and,

e. Upon completion of the project, the applicant or other responsible person shall submit the engineer's report and certificate and as-built plans required by Section 6.2.

3.7. Application Review Fees

A non-refundable permit fee will be collected at the time the stormwater management plan is submitted. All of the monetary contributions shall be credited to a local budgetary category to support local plan review, administration and management of the permitting process, and inspection of all projects subject to this ordinance. The (*local jurisdiction*) shall develop a fee schedule based on the area of land disturbed by the project and may amend the fee schedule from time to time.

3.8 Modifications for Off-Site Facilities

The stormwater management plan for each land development project shall provide for stormwater management measures located on the site of the project, unless provisions are made to manage stormwater by an off-site or regional facility. The off-site or regional facility must be located on property legally dedicated for the purpose, must be designed and adequately sized to provide a level of stormwater quantity and quality control that is equal to or greater than that which would be afforded by on-site practices and there must be a legally-obligated entity responsible for long-term operation and maintenance of the off-site or regional stormwater facility. In addition, on-site measures shall be implemented, where necessary, to protect upstream and downstream properties and drainage channels from the site to the off-site facility.

A stormwater management plan must be submitted to the (*local jurisdiction*) which shows the adequacy of the off-site or regional facility.

To be eligible for a modification, the applicant must demonstrate to the satisfaction of the (*local jurisdiction*) that the use of an off-site or regional facility will not result in the following impacts to upstream or downstream areas:

(1) Increased threat of flood damage to public health, life, and property;

(2) Deterioration of existing culverts, bridges, dams, and other structures;

(3) Accelerated streambank or streambed erosion or siltation;

(4) Degradation of in-stream biological functions or habitat; or

(5) Water quality impairment in violation of State water quality standards, and/or violation of any state or federal regulations.

Section 4. Post-Development Stormwater Management Performance Criteria

All site designs shall establish stormwater management practices to control the peak flow rates of stormwater discharge associated with specified design storms and reduce the volume of stormwater runoff generated. These practices should seek to use pervious areas for stormwater treatment and to infiltrate stormwater runoff from driveways, sidewalks, rooftops, parking lots, and landscaped areas to the maximum extent practical to provide treatment for both water quality and quantity.

The following performance criteria shall be applicable to all stormwater management plans, unless otherwise provided for in this ordinance:

4.1. Water Quality

All stormwater runoff generated from a site shall be adequately treated before discharge. Stormwater practices must treat the first 1.2 inches of runoff from all storms and remove 80% of the post-development total suspended solid load from treated runoff. It will be presumed that a stormwater management system complies with this requirement if:

(1) It is sized to treat the prescribed water quality treatment volume from the site, as defined in the Georgia Stormwater Management Manual; and,

(2) Appropriate structural stormwater controls or nonstructural practices are selected, designed, constructed or preserved, and maintained according to the specific criteria in the Georgia Stormwater Management Manual; and,

(3) Runoff from hotspot land uses and activities identified by the (*local jurisdiction*) are adequately treated and addressed through the use of appropriate structural stormwater controls, nonstructural practices and pollution prevention practices.

4.2. Stream Channel Protection

Protection of stream channels from bank and bed erosion and degradation shall be provided by using all of the following three approaches:

(1) Preservation, restoration and/or reforestation (with native vegetation) of any stream buffers protected through other regulations; and,

(2) Erosion prevention measures such as energy dissipation and velocity control; and,

(3) 24-hour extended detention storage of the 1-year, 24-hour return frequency storm event. This requirement may be reduced or waived through the use of other structural and nonstructural measures that allow for infiltration of runoff. The storage volume may be reduced by the volume that is infiltrated.

4.3. Overbank Flooding Protection

Downstream overbank flood and property protection shall be provided by controlling (attenuating) the post-development peak discharge rate to the pre-development rate for the 25-year, 24-hour return frequency storm event. If control of the 1-year, 24-hour storm under Section 4.2 is exempted, then peak discharge rate attenuation of the 2-year through the 25-year return frequency storm event must be provided.

4.4. Extreme Flooding Protection

Extreme flood and public safety protection shall be provided by controlling and safely conveying the 100-year, 24 hour return frequency storm event such that flooding is not exacerbated.

4.5. Structural Stormwater Controls

All structural stormwater management facilities shall be selected and designed using the appropriate criteria from the Georgia Stormwater Management Manual. All structural stormwater controls must be designed appropriately to meet their intended function. For other structural stormwater controls not included in the Georgia Stormwater Management Manual, or for which pollutant removal rates have not been provided, the effectiveness and pollutant removal of the structural control must be documented through prior studies, literature reviews, or other means and receive approval from the (*local jurisdiction*) before being included in the design of a stormwater management system. In addition, if hydrologic or topographic conditions, or land use activities warrant greater control than that provided by the minimum control requirements, the (*local jurisdiction*) may impose additional requirements deemed necessary to protect upstream and downstream properties and aquatic resources from damage due to increased volume, frequency, and rate of stormwater runoff or increased nonpoint source pollution loads created on the site in question.

Applicants shall consult the Georgia Stormwater Management Manual for guidance on the factors that determine site design feasibility when selecting and locating a structural stormwater control.

4.6. Stormwater Credits for Nonstructural Measures

The use of Better Site Design and nonstructural stormwater management measures is encouraged to minimize reliance on structural stormwater management measures. The use of one or more site design measures by the applicant may allow for a reduction in the water quality treatment volume required under Section 4.1 and the stream channel protection volume required under Section 4.2.3. The applicant may, if approved by the (*local jurisdiction*), take credit for the use of stormwater better site design practices and reduce the water quality and channel protection volume requirements. For each potential credit, there is a minimum set of criteria and requirements which identify the conditions or circumstances under which the credit may be applied. The site design practices that qualify for this credit and the criteria and procedures for applying and calculating the credits are included in the Georgia Stormwater Management Manual.

4.7. Drainage System Guidelines

Stormwater conveyance facilities, which may include but are not limited to culverts, stormwater drainage pipes, catch basins, drop inlets, junction boxes, headwalls, gutter, swales, channels, ditches, and energy dissipaters shall be provided when necessary for the protection of public right-of-way and private properties adjoining project sites and/or public right-of-ways. Stormwater conveyance facilities that are designed to carry runoff from more that one parcel, existing or proposed, shall meet the following requirements:

(1) Methods to calculate stormwater flows shall be in accordance with the Georgia Stormwater Management Manual;

(2) All culverts, pipe systems and open channel flow systems shall be sized in accordance with the stormwater management plan using the methods included in the Georgia Stormwater Management Manual; and,

(3) Design and construction of stormwater conveyance facilities shall be in accordance with the criteria and specifications found in the Georgia Stormwater Management Manual.

Section 5. Sensitive Areas

5.1. Sensitive Areas

The (*local jurisdiction*) may define Sensitive Areas where more protective stormwater regulations are required to ensure the preservation of imperiled aquatic organisms. In these areas, where site conditions permit, stormwater runoff shall be managed by onsite infiltration in preference to other stormwater BMPs that discharge runoff into waterbodies. This stormwater management practice provides greater protection for aquatic organisms and surface water quality, and also augments stream baseflows, reduces of flash storm flows and prevents of stream bank erosion.

5.2. Post-development Stormwater Management Performance Criteria for Sensitive Areas

(1) No net increase in sediment loads. Stormwater control systems shall be designed to reduce to the maximum extent possible the total suspended solids from stormwater runoff from storm events with magnitudes as high as the water quality storm and to retain, as

closely as possible, the pre-development hydrologic response of the site and the watershed.

(2) No net increase in stormwater runoff rates and stream channel erosion. Stormwater control systems shall be designed so that, to the maximum extent possible, the post-development stormwater runoff rates from the site and at any point in the watershed between the site are no greater than pre-development rates, in order to retain as closely as possible the pre-development hydrologic response of the watershed.

(3) No net increase in stormwater runoff volumes. Wherever suitable infiltration, soil permeability, and favorable geologic conditions exist, stormwater control systems shall be designed so that stormwater runoff from impervious surfaces is infiltrated into the soil for the first 1.2 inches of rainfall.

5.3. Procedures for Measuring Compliance with No Net Increase Goals

(1) Hydrologic/hydraulic analyses shall be prepared and submitted demonstrating that the post-development stormwater runoff rates and volumes do not exceed the standards set forth in this ordinance for the water quality storm and the 2-, 10-, 25-, and 100-year storms.

a. The hydrologic and hydraulic analyses shall generally conform with methods developed by the Natural Resources Conservation Service and published in National Engineering Handbook, Section 4 - Hydrology, Technical Release No. 55 and Technical Release No. 20.

b. Standards and procedures for developing hydrographs and calculating peak rates of runoff shall be as shown in the Georgia Stormwater Management Manual.

c. Rainfall - Frequency relationships shall be as shown in Technical Paper No. 40, "Rainfall Frequency Atlas of the United States" published by the U.S. Weather Bureau.

(2) For infiltration facilities proposed to meet the no net increase goals of this ordinance, the results of a subsurface investigation and soil tests demonstrating the suitability of the area's soils and ground water table for infiltration and treatment of runoff shall be provided.

(3) In preparing the required analysis it shall be acceptable to utilize the average removal efficiency statistics provided in the Georgia Stormwater Management Manual.

(4) It will be presumed that a stormwater management system complies with these requirements if appropriate stormwater BMPs are selected, designed, constructed, preserved and maintained according to the specific criteria in the Georgia Stormwater Management Manual.

5.4. Water Quality Control and Infiltration Measures

In most instances, the water quality control and infiltration performance requirements of this section will be satisfied by multiple structures or devices. Furthermore, most structures or devices will achieve both a water quality control and infiltration benefit. Compliance with the no net increase provisions of this section will be based on a project-wide summation of runoff characteristics. The applicant shall show how the collection of structures or devices incorporated in the stormwater management plan will jointly satisfy the performance requirements of this ordinance.

In order to meet the no net increase provisions of this ordinance with regard to stormwater runoff volumes and sediment loadings, stormwater management facilities shall provide for the control of stormwater runoff in accordance with the following basic principles:

(1) Infiltration should be implemented which will retain and infiltrate the first 1.2 inches of rainfall.

(2) Runoff shall be managed at the source whenever possible.

(3) Water quality and infiltration device treatment trains shall be designed that utilize the natural qualities of the landscape.

(4) Detention/retention basins are generally not suitable as infiltration facilities.

Utilizing the above design principles, a stormwater management plan shall be designed for the project area, utilizing the stormwater control "Best Management Practices" (BMPs) presented in the Georgia Stormwater Management Manual.

In estimating the removal efficiencies of the water quality control measures proposed, it shall be acceptable to utilize the average removal efficiency statistics provided in the Georgia Stormwater Management Manual.

5.5 Variance from Strict Compliance

If the natural or existing physical characteristics of the project site preclude achievement of any of the above no net increase goals, the (*local jurisdiction*) may grant a variance from strict compliance with the specific no net increase provisions the achievement of which are precluded, provided that the applicant demonstrates to the satisfaction of the municipal engineer that the adjacent waterways will not be impacted by the:

(1) Increased threat of flood damage to public health, life, and property;

(2) Deterioration of existing culverts, bridges, dams, and other structures;

(3) Accelerated streambank or streambed erosion or siltation;

(4) Degradation of in-stream biological functions or habitat; or

(5) Water quality impairment in violation of State water quality standards, and/or violation of any state or federal regulations.

Where partial compliance with a specific no net increase provision is possible, the (*local jurisdiction*) engineer will direct the applicant to satisfy a reduced-performance criterion. At a minimum, the reduced-performance criterion must meet the provisions of Section 4 of this ordinance. Those no net provisions that are not precluded by the site's physical characteristics shall be met.

Section 6. Construction Inspections of Post-Development Stormwater Management System

6.1. Inspections to Ensure Plan Compliance During Construction

Periodic inspections of the stormwater management system construction shall be conducted by the staff of the (*local jurisdiction*) or conducted and certified by a professional engineer who has been approved by the (*local jurisdiction*). Construction inspections shall utilize the approved stormwater management plan for establishing compliance.

All inspections shall be documented with written reports that contain the following information:

(1) The date and location of the inspection;

(2) Whether construction is in compliance with the approved stormwater management plan;

(3) Variations from the approved construction specifications; and,

(4) Any other variations or violations of the conditions of the approved stormwater management plan.

If any violations are found, the applicant shall be notified in writing of the nature of the violation and the required corrective actions.

6.2. Final Inspection and As Built Plans

Upon completion of a project, and before a certificate of occupancy shall be granted, the applicant is responsible for certifying that the completed project is in accordance with the approved stormwater management plan. All applicants are required to submit actual "as built" plans for any stormwater management facilities or practices after final construction is completed. The plan must show the final design specifications for all stormwater management facilities and practices and must be certified by a Professional Engineer. A final inspection by the (*local jurisdiction*) is required before the release of any performance securities can occur.

Section 7. Ongoing Inspection and Maintenance of Stormwater Facilities and Practices

7.1. Maintenance Responsibility

Stormwater management facilities and practices included in a stormwater management plan which are subject to an inspection and maintenance agreement must undergo ongoing inspections to document maintenance and repair needs and ensure compliance with the requirements of the agreement, the plan and this ordinance.

The owner of the property on which work has been done pursuant to this Ordinance for private stormwater management facilities, or any other person or agent in control of such property, shall maintain in good condition and promptly repair and restore all grade surfaces, walls, drains, dams and structures, vegetation, erosion and sedimentation controls, and other protective devices. Such repairs or restoration and maintenance shall be in accordance with approved plans.

A maintenance schedule shall be developed for the life of all stormwater management facilities and shall state the maintenance to be completed, the time period for completion, and who shall perform the maintenance. This maintenance agreement shall be included in the approved stormwater management plan.

7.2 Maintenance Inspections

A stormwater management facility or practice shall be inspected on a periodic basis by the responsible person in accordance with the approved inspection and maintenance agreement. In the event that the stormwater management facility has not been maintained and/or becomes a danger to public safety or public health, the (*local jurisdiction*) shall notify the person responsible for carrying out the maintenance plan by registered or certified mail to the person specified in the inspection and maintenance agreement. The notice shall specify the measures needed to comply with the agreement and the plan and shall specify the time within which such measures shall be completed. If the responsible person fails or refuses to meet the requirements of the inspection and maintenance agreement, the (*local jurisdiction*), may correct the violation as provided in Subsection 8.2 hereof.

The (*local jurisdiction*) shall ensure that preventative maintenance is performed by inspecting all stormwater management systems. Inspection shall occur during the first year of operation and at least once every three years thereafter. In addition, a maintenance agreement between the owner and (*local jurisdiction*) shall be executed for privately-owned stormwater management systems as described in 3.4 of this section.

Inspection reports shall be submitted to and maintained by the (*local jurisdiction*) for all stormwater management systems. Inspection reports for stormwater management systems shall include:

(1) The date of inspection

(2) Name of inspector

(3) The condition of:

 (a) Vegetation or filter media

 (b) Fences or other safety devices

 (c) Spillways, valves, or other control structures

 (d) Embankments, slopes, and safety benches

 (e) Reservoir or treatment areas

 (f) Inlet and outlet channels and structures

 (g) Underground drainage

 (h) Sediment and debris accumulation in storage and forebay areas

 (i) Any nonstructural practices

 (j) Any other item that could affect the proper function of the stormwater management system

(4) Description of the need for maintenance

After notification is provided to the owner of any deficiencies discovered from an inspection of a stormwater management system, the owner shall have 30 days or other time frame mutually agreed to between the (*local jurisdiction*) and the owner to correct the deficiencies. The (*local jurisdiction*) shall then conduct a subsequent inspection to ensure completion of repairs.

If repairs are not undertaken or are not found to be done properly, then enforcement procedures following 8.2 of this section shall be followed by the (*local jurisdiction*).

7.3. Right-of-Entry for Inspection

The terms of the inspection and maintenance agreement shall provide for the (*local jurisdiction*) to enter the property at reasonable times and in a reasonable manner for the purpose of inspection. This includes the right to enter a property when it has a reasonable basis to believe that a violation of this ordinance is occurring or has occurred and to enter when necessary for abatement of a public nuisance or correction of a violation of this ordinance.

7.4. Records of Maintenance Activities

Parties responsible for the operation and maintenance of a stormwater management facility shall provide records of all maintenance and repairs to the (*local jurisdiction*)**.**

7.5. Failure to Maintain

If a responsible person fails or refuses to meet the requirements of the inspection and maintenance agreement, the (*local jurisdiction*), after thirty (30) days written notice (except, that in the event the violation constitutes an immediate danger to public health or public safety, 24 hours notice shall be sufficient), may correct a violation of the design standards or maintenance requirements by performing the necessary work to place the facility or practice in proper working condition. The (*local jurisdiction*) may assess the owner(s) of the facility for the cost of repair work which shall be a lien on the property, and may be placed on the ad valorum tax bill for such property and collected in the ordinary manner for such taxes.

Section 8. Violations, Enforcement and Penalties

Any action or inaction which violates the provisions of this ordinance or the requirements of an approved stormwater management plan or permit, may be subject to the enforcement actions outlined in this Section. Any such action or inaction which is continuous with respect to time is deemed to be a public nuisance and may be abated by injunctive or other equitable relief. The imposition of any of the penalties described below shall not prevent such equitable relief.

8.1. Notice of Violation

If the (*local jurisdiction*) determines that an applicant or other responsible person has failed to comply with the terms and conditions of a permit, an approved stormwater management plan or the provisions of this ordinance, it shall issue a written notice of violation to such applicant or other responsible person. Where a person is engaged in activity covered by this ordinance without having first secured a permit therefore, the notice of violation shall be served on the owner or the responsible person in charge of the activity being conducted on the site. The notice of violation shall contain:

(1) The name and address of the owner or the applicant or the responsible person;

(2) The address or other description of the site upon which the violation is occurring;

(3) A statement specifying the nature of the violation;

(4) A description of the remedial measures necessary to bring the action or inaction into compliance with the permit, the stormwater management plan or this ordinance and the date for the completion of such remedial action;

(5) A statement of the penalty or penalties that may be assessed against the person to whom the notice of violation is directed; and,

(6) A statement that the determination of violation may be appealed to the (*local jurisdiction*) by filing a written notice of appeal within thirty (30) days after the notice of violation (except, that in the event the violation constitutes an immediate danger to public health or public safety, 24 hours notice shall be sufficient).

8.2 Penalties

In the event the remedial measures described in the notice of violation have not been completed by the date set forth for such completion in the notice of violation, any one or more of the following actions or penalties may be taken or assessed against the person to whom the notice of violation was directed. Before taking any of the following actions or imposing any of the following penalties, the (*local jurisdiction*) shall first notify the applicant or other responsible person in writing of its intended action, and shall provide a reasonable opportunity, of not less than ten days (except, that in the event the violation constitutes an immediate danger to public health or public safety, 24 hours notice shall be sufficient) to cure such violation. In the event the applicant or other responsible person fails to cure such violation after such notice and cure period, the (*local jurisdiction*) may take any one or more of the following actions or impose any one or more of the following penalties.

(1) Stop Work Order -The (*local jurisdiction*) may issue a stop work order which shall be served on the applicant or other responsible person. The stop work order shall remain in effect until the applicant or other responsible person has taken the remedial measures set forth in the notice of violation or has otherwise cured the violation or violations described therein, provided the stop work order may be withdrawn or modified to enable the applicant or other responsible person to take the necessary remedial measures to cure such violation or violations.

(2) Withhold Certificate of Occupancy - The (*local jurisdiction*) may refuse to issue a certificate of occupancy for the building or other improvements constructed or being constructed on the site until the applicant or other responsible person has taken the remedial measures set forth in the notice of violation or has otherwise cured the violations described therein.

(3) Suspension, Revocation or Modification of Permit - The (*local jurisdiction*) may suspend, revoke or modify the permit authorizing the land development project. A suspended, revoked or modified permit may be reinstated after the applicant or other responsible person has taken the remedial measures set forth in the notice of violation or has otherwise cured the violations described therein, provided such permit may be reinstated [upon such conditions as the (*local jurisdiction*) may deem necessary] to enable the applicant or other responsible person to take the necessary remedial measures to cure such violations.

(4) Civil Penalties **-** In the event the applicant or other responsible person fails to take the remedial measures set forth in the notice of violation or otherwise fails to cure the violations described therein within ten days, or such greater period as the (*local jurisdiction*) shall deem appropriate (except, that in the event the violation constitutes an immediate danger to public health or public safety, 24 hours notice shall be sufficient) after the (*local jurisdiction*) has taken one or more of the actions described above, the (*local jurisdiction*) may impose a penalty not to exceed $1,000 (depending on the severity of the violation) for each day the violation remains unremedied after receipt of the notice of violation.

(5) Criminal Penalties **-** For intentional and flagrant violations of this ordinance, the (*local jurisdiction*) may issue a citation to the applicant or other responsible person, requiring such person to appear in (*appropriate municipal, magistrate or recorders*) court to answer charges for such violation. Upon conviction, such person shall be punished by a fine not to exceed $1,000 or imprisonment for 60 days or both. Each act of violation and each day upon which any violation shall occur shall constitute a separate offense.