EVERY SITE IS A WATERSHED:RETROFITTING A SUBDIVISION WITH LOW IMPACT DEVELOPMENT APPLICATIONS

by

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(Under the Direction of Alfie Vick)

ABSTRACT

Conventional stormwater conveyance systems have been primarily focused on removing excess runoff from urban and residential areas as quickly as possible. Conveyance practices have decreased the time of concentration of stormwater runoff, increased runoff volume and peak flow that together, create multifaceted problems on-site and downstream. Instead of rapid conveyance, scientific principles of ecosystem balance, including the concept of stormwater infiltration, are being emphasized as superior system management. This thesis will analyze and compare conventional conveyance strategies with on-site infiltration methods in an existing suburban residential subdivision in Athens-Clarke County, Georgia. Since the study site is post-developed, this research and design focus is on minimal site redesign to meet specific runoff limits that resemble the pre-developed landscape. The value in this research project will show that entire post-developed subdivisions can be revisited and corrected to meet pre-developed standards. With specific ecological design principles that imitate natural processes, conventional residential developments can be retrofitted to manage stormwater on site.

Index words: Peak flow, Base flow, Detention, Infiltration, Conveyance, Low impact development, Time of concentration, Runoff volume, Rainfall abstraction

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DEDICATION

To my wife Holly, and my parents Don and Dianne, thank you for all of your love and support. This academic accomplishment is the product of your belief in me and your unconditional dedication to helping me strive for success.

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Thank you Professor Alfie Vick, for your thoughtful guidance and contribution throughout this thesis. Being able to count on your patience and commitment made completion of this academic goal possible. Thank you to my reading committee, David Spooner, Pratt Cassity and Josh Koons for your time and expertise.

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"There can be no doubt that a society rooted in the soil is more stable than one rooted in pavements."

Aldo Leopold

"Water is the most critical resource issue of our lifetime and our children's lifetime. The health of our water is the principal measure of how we live on the land."

Luna Leopold

"Stormwater infiltration is not just a means of mitigating the hazardous aspects of storm water; it is a means of reclaiming water resources and rehabilitating urban watersheds."

Bruce Ferguson

"We will only know the worth of water when the well is dry."

Benjamin Franklin

CHAPTER ONE

THESIS CONSTRUCTION

Introduction

Stormwater design and management is only as good as the science and perspective behind it. Conventional stormwater conveyance and later detention systems have had a limited perspective on ideal goals of stormwater management. Conveyance systems were designed to remove nuisance runoff as quickly as possible to prevent major flooding. Later, detention systems were conceived to detain runoff and slow the peak flow rate. These systems effectively accomplished their design intent but caused an increase in total runoff volume, an increase in the duration of flow and a decrease in the time of concentration. Most residential communities in the United States utilize conventional stormwater management practices to remove runoff from their development site to a nearby stream or water body.

Over the last twenty years, a more progressive perspective called low impact development is leading the way in changing how we think about stormwater management. Low impact development (LID) concepts, as described in Prince George's County Stormwater Manual, were developed "specifically to address runoff issues associated with new residential, commercial and industrial suburban development" (Prince George's County 1999). This thesis will analyze and compare conventional conveyance detention systems with the promise of low impact development and how a new application, stormwater retrofit, can be used with an existing concept (LID) to produce increased opportunity for watershed protection and water quality.

Problem Statement

Water resource loss and degradation is a significant problem for urbanizing societies. As the population grows, more land is converted to impervious surfaces. Rooftops, roadways, and parking lots cover what used to be porous soils and forest that allowed rainwater to percolate into the soil. These urban, impervious surfaces deflect rainwater away from infiltration, soil moisture, recharge, subsurface storage and base flow (Ferguson 1994). Additionally, conventional stormwater management systems collect and concentrate runoff to generate increases in peak flow rate, runoff volume, and the duration of flow.

These outcomes overwhelm rivers and streams and destroy the quality of the watershed. Pollutant load is increased along with a rise in water temperature which is detrimental to many aquatic species. Aquifers are depleted due to the lack of groundwater recharge. Streams and rivers become impaired and both the quality and quantity of our water resources are put in jeopardy.

Conventional stormwater management is a dominant perspective and current practice that cannot solve the problems of water resource loss and watershed protection. Although low impact development offers a more ecologically sound way of thinking about stormwater management, LID is usually associated with new development. In the Prince George's Stormwater Manual, the authors state that their LID concepts "were originally formulated to address runoff issues associated with new development and the increasing development pressure in Prince George's County, Maryland (Prince George's County 1999). However, in the Environmental Protection Agency paper, *2008 Action Strategy for Green Infrastructure*, the EPA suggests that LID could also be considered for "retrofitting existing developments" (EPA 2008). Existing suburban developments also need to be considered and evaluated as to the potential to retrofit to meet low impact development goals of achieving a pre-development hydrologic profile. In this thesis, it is proposed that an existing subdivision development can be retrofitted to meet the pre-development hydrologic regime using low impact development principles.

Research Objectives

The purpose of this thesis is to compare and contrast conventional stormwater practices with recent green infrastructure concepts and the impact both perspectives bring to the science and design of stormwater management systems. Specifically, the operative thesis of this research will be that low impact development concepts targeted toward new development models would also be effective if applied to retrofitting existing neighborhoods. A quantitative analysis and comparison of different strategies of stormwater management will be conducted relative to their hydrologic and ecologic impact.

This thesis will focus on three specific goals:

1. To compare and contrast existing stormwater management practices.
2. To apply quantitative analysis of the study site to measure runoff profiles with conventional and LID practices.
3. To design a retrofit model utilizing LID concepts to achieve a pre-development hydrologic regime for the study site.

Methodology

For purposes of this thesis, the analysis of stormwater events and management will be concerned with the pre-development hydrologic regime which includes the "first flush" event and the one year, 24-hour storm. By targeting these two events, the objective of mimicking the pre-development profile of water quality and protection of stream bank and channel erosion can be achieved (Atlanta Regional Commission 2001). Managing the "first flush" (first 1.2 inches of rainfall which transports majority of pollutant load) of stormwater is important because the first flush from frequent small storms, in a one year period, transports approximately 80-85 percent of the pollutant load and can be effectively infiltrated, usually onsite.

The protection of stream bank and channel integrity is also necessary to maintain overall watershed quality and mimic the pre-development hydrologic profile. *The Georgia Stormwater Management Manual (GSMM)* specifies that runoff from a one year, 24-hour rainfall event would need to be managed to protect downstream channels from erosion and sediment deposits. The *Georgia Stormwater Management Manual* also defines statewide stormwater sizing criteria for stormwater control and mitigation in four areas:

- Water quality
- Channel Protection
- Overbank Flood Protection
- Extreme Flood Protection

The study site's current detention system while fulfilling certain flood protection goals does not meet the goals of the smaller storm event associated with water quality and channel protection. The retrofitting of an existing suburban subdivision to meet the demands of water quality and channel protection is intended to compliment the already established detention system.

As noted in the *Georgia Stormwater Management Manual* the suitability of structural stormwater controls for purposes of water quality treatment and channel protection is relative to stormwater sizing criteria. Table 1 illustrates the selection of stormwater management technology for purposes of retrofitting the existing subdivision development.

Table 1 *Georgia Stormwater Management Manual* Matrix for Suitability of Stormwater Controls to Meet Stormwater Sizing Criteria.

Structural Stormwater Control	Water Quality Volume (WQ_v)	Channel Protection (CP_v)	Overbank Flood Protection (Q_{p25})	Extreme Flood Protection (Q_f)
General Application				
Stormwater Ponds	✓	✓	✓	✓
Stormwater Wetlands	✓	✓	✓	✓
Bioretention Areas	✓	✪	●	●
Sand Filters	✓	✪	●	●
Infiltration Trenches	✓	✪	●	●
Enhanced Swales	✓	✪	✪	●
Limited Application				
Biofilters	○	●	●	●
Filtering Practices	✓	●	●	●
Wetland Systems	✓	●	●	●
Hydrodynamic Devices	○	●	●	●
Porous Surfaces	✓	✪	●	●
Chemical Treatment	✓	●	●	●
Proprietary Systems	*	*	*	*
Detention Controls	●	✓	✓	✓

✓ = Able to meet stormwater sizing criterion (for water quality, this control is presumed to meet the 80% TSS reduction goal when sized to treat the WQ_v and designed, constructed and maintained properly)

○ = Typically provides partial treatment of WQ_v. May be used in pretreatment and as part of a "treatment train"

✪ = Can be incorporated into the structural control in certain situations

● = Not typically able or used to meet stormwater sizing criterion

* = The application and performance of specific commercial devices and systems must be provided by the manufacturer and should be verified by independent third-party sources and data

The methodology employed in this thesis to determine runoff between pre-development and post-development of the study site will be the Urban Hydrology for Small Watersheds Model, commonly referred to as Technical Release-55 or TR-55. This hydrology model was developed by the USDA National Resource Conservation Service (NRCS), formerly the Soil Conservation Service. The TR-55 Model is used to estimate runoff volume as well as changes in time of concentration and peak flow. The program uses curve numbers that represent the amount of impervious surface, filtration properties of soil and land cover. Curve numbers range from 0-

98 with smaller numbers representing less runoff. The TR-55 Model was designed to analyze runoff patterns during a single 24-hour storm event observed within a given period. Data for the one year, 24-hour "design storm" is derived from the *Georgia Stormwater Management Manual* estimates of rainfall distribution for Athens, Georgia.

The calculated pre-development curve number for this site (undeveloped and forested) will be used in the SCS TR-55 runoff formula along with rainfall distribution to determine the pre-development runoff rate. The next step uses the same formula to calculate the post-development runoff rate for the site and determine the increase in runoff created by development. Once the increase in runoff volume has been established, a low impact development retrofit will be proposed throughout the existing subdivision to represent the level of infiltration and bioretention technology needed to improve the site's management of water quality and downstream channel protection.

Design Principles

In his 1773 travels through the Piedmont region William Bartram described a clear and pristine river in his journal that he observed on his trip through Georgia (Sanders 2001). That river was the Oconee River that runs through Athens, Georgia and is the receiving river body of the study site in this thesis project. The Oconee River is no longer the pristine waterway described by Bartram but is instead labeled an impaired river by the Environmental Protection Agency (EPA 2008). Due to urban and agricultural runoff controlled by conventional stormwater management practices, the many watersheds in the Oconee River Basin are contributing to watershed degradation. Low impact development offers promise in the management of stormwater for new developments, "from the ground up" but this thesis proposes that this same green infrastructure technology is the best and most appropriate strategy to retrofit existing subdivision developments along an impaired river such as the Oconee Watershed Basin. Low impact technology is best suited for this conceptual retrofit project because the technology is simple, runoff is maintained onsite, and there are many opportunities to infiltrate runoff throughout the study site.

The design principles that will provide guidance throughout this thesis are listed here but will be described in detail in Chapter Six.

1. Design with nature.
2. Treat every site as a watershed.
3. Look for more small opportunities.
4. Work as close to the source of runoff as possible.
5. Understand nature's geometry.
6. Minimize impervious surfaces.

These design principles are consistent with the understanding of how the water cycle works in a continuous closed loop system. Impacts made at one end of the loop will have consequences for other aspects of the water cycle. The more impervious surfaces created by land development will mean more runoff and typically less infiltration and groundwater recharge. Roadways will contribute to the pollutant load in streams and rivers if not cleansed through infiltration. The responsible choice in stormwater management cannot be made without an understanding of the water cycle and the cause and effect loop.

CHAPTER TWO

CAUSE AND EFFECT

The Hydrologic Cycle

The continuous movement of water above, on and below the earth's surface is called the hydrologic cycle. Precipitation in the form of snow or rainfall is a natural process which nourishes our planet and sustains life. For thousands of years nature has provided its own version of an effective and efficient stormwater management system. Following precipitation, water collects on trees and vegetation and eventually evaporates; more water filters into the ground and feeds vegetation and trees and is transpired back into the atmosphere; and additional water percolates deep into the soil and recharges the water table or underground water supply. The remaining water that is classified as surface runoff accumulates in rivers, streams, lakes and estuaries; and gradually continues on its natural path to the ocean.

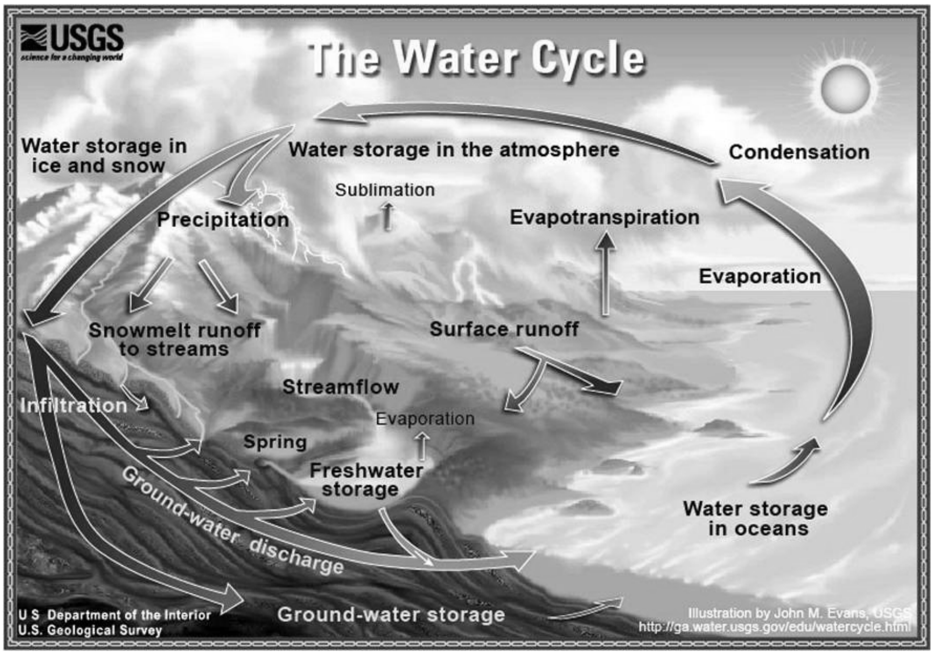


Figure 1 Water Cycle from USGS (Evans 2006).

In a pre-development environment, approximately forty percent (40%) of precipitation is transported to the atmosphere through evapo-transpiration and fifty percent (50%) typically percolates deep into the soil and recharges the water table. The remaining ten percent (10%) is surface runoff depicted in Figure 2 (NYSDEC 1992).

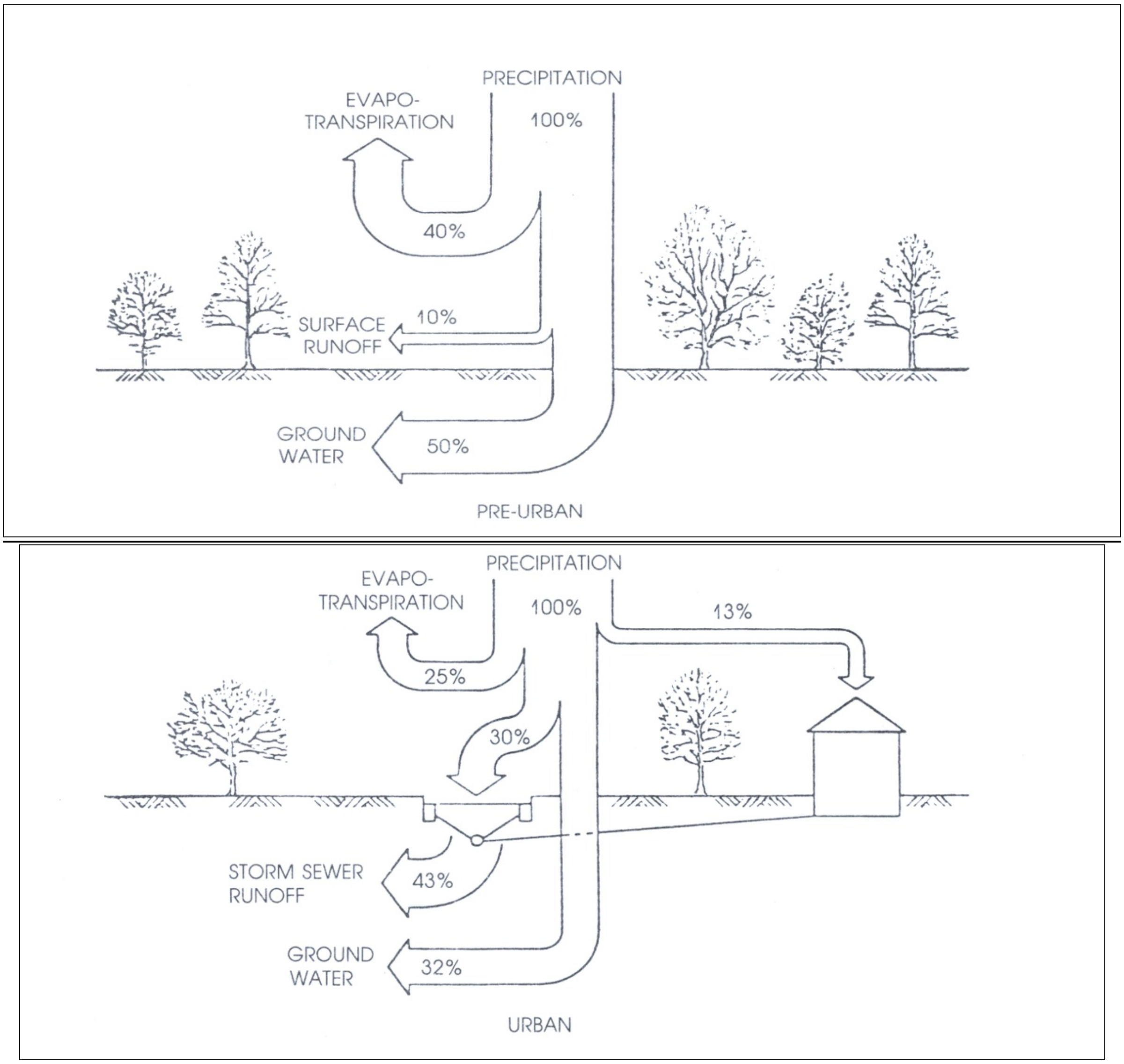
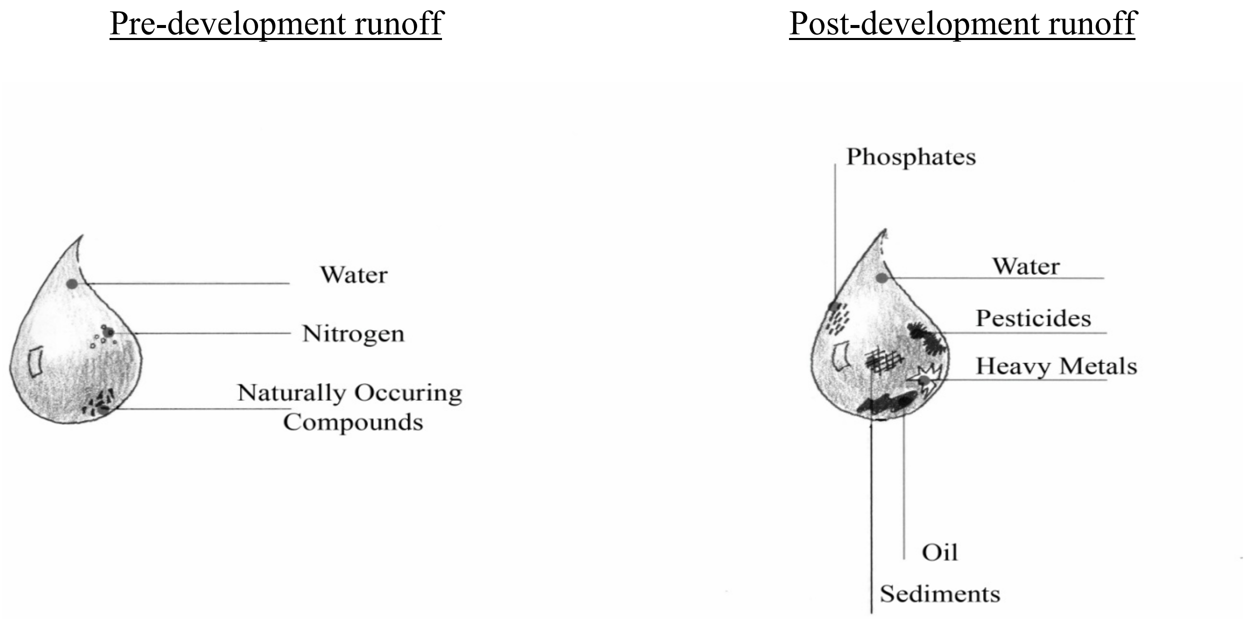


Figure 2 Hydrologic Changes Resulting from Urbanization (NYSDEC 1992).

In a post-developed or urbanized environment the hydrologic cycle is altered to produce twenty-five percent approximately (25%) evapo-transpiration and thirty-two percent (32%) ground water recharge. A significant increase, estimated at forty-three percent (43%), is channeled off as storm sewer runoff (NYSDEC 1992). Stormwater runoff is therefore exceedingly different in a post-development environment in two major ways (Richman 3):

1. The amount of runoff is increased in volume and rate flow
2. The physical characteristics of the runoff are changed (Figure 3)



Pre-development runoff

Post-development runoff

Figure 3 Comparison of stormwater runoff (Richman 1997).

Post-development runoff captures pollutants as it moves over impervious surfaces such as rooftops, driveways, streets, parking lots and concrete gutters. Additionally, conventional drainage systems incorporating conveyance and detention technology tend to increase storm flow volume and velocity which create surges downstream. These stream surges, carrying pollutants at increased velocity, contribute to bank erosion and endanger fish and other wildlife.

Landscape Types

To better understand stormwater dynamics in the hydrologic cycle, it is imperative that major types of landscape topography be considered. The hydrologic function of a given landscape is maintained at a general level by the landform… the topography and earth materials through which water passes (Ferguson 1994). Three major types of landscape topography (landform shapes and features) are reviewed here in the context of stormwater management. Natural topography (undisturbed land), agricultural topography and urban/suburban topography will be discussed in relation to how precipitation passes above, on and below these landscape surfaces.

In its natural landscape topography, the earth's soil surface is covered with a complex mix of mulch, roots, and pores that absorb rainwater. According to Leopold, approximately forty percent (40%) of precipitation transpirates and returns to the atmosphere while fifty percent (50%) percolates within the soil and recharges the water table. A small amount, roughly ten percent (10%) is considered as surface runoff into rivers, streams and lakes (NYSDEC 1992). In this pristine and undisturbed environment, the recharging of ground water helps to restore aquifers and clean water base flow in nearby rivers and streams. Additionally, aquatic and terrestrial systems typically thrive and the ecosystem as a whole gravitates toward balance.

Agricultural landscape typography contains vegetative cover during growing seasons and is typically left barren after harvesting is complete. According to Vellidis, runoff quantity varies significantly based on soil type, presence of vegetation, physical soil structure, field topography and the timing and intensity of the rainfall (2003). This type of landscape topography is more problematic than urban runoff, not because of runoff volume, but because of pesticide and bacterial contaminants transported to local streams, aquifers and lakes. Additionally, eroded soil contributes to sediment deposits in local waterways affecting water quality. Vellidis points to research that validates an average of seventeen (17) tons of soil is lost per acre per year from over 223 million acres of land used for agricultural purposes (2003).

Urban landscape topography is characterized largely by the sealing of the land surface with impervious pavements and rooftops creating a hydraulically new type of landform (Ferguson 1994). If the soil is sealed with impervious material as used in road systems, parking lots and rooftops, it is obvious that rainfall will flow downhill on top of those surfaces to the lowest possible point. In most urban landscapes this rainfall is viewed as nuisance runoff and is usually channeled away to a detention pond or stream. Consequently, the peak flow of the runoff, both volume and flow rate, causes flooding of streams and stream bank erosion. Additionally, rainwater heated by hot urban surfaces combined with a large pollutant load jeopardizes the health of ecosystems downstream. According to Leopold this urban landscape or what Ferguson refers to as "a hydraulically new type of landform" has less than thirty-two percent (32%) of precipitation available to recharge the water table while storm sewer runoff is increased to approximately forty-three percent (43%) (1968 and 1994). This percentage of runoff is substantially greater than the approximate ten percent (10%) of runoff in Leopold's description of the pre-developed landscape.

Conveyance and Detention Drainage Systems

Strategies for managing stormwater have been around as long as man has lived in permanent settlements. Early management efforts consisted primarily in diverting excess runoff away from settlements, towns and cities in an attempt to control flooding and prevent damage to life and property. Typical drainage systems were created to remove runoff with sewage disposal in a quick and efficient manner away from population centers. This was an important practice not just for aesthetic reasons but an essential step in the prevention of disease for the general public. Fredrick Law Olmsted, the noted father of landscape architecture, created what may have been the first modern conveyance system of stormwater management. In 1869, Olmsted designed a system of buried pipe for the City of Riverside, Illinois to quickly convey stormwater off the city streets into a nearby river. The streets of Riverside were typically covered with mud and horse manure that created both an unpleasant and unsanitary environment. In Ferguson and Debo's book, *On-Site Stormwater Management,* the authors conclude that Olmsted's design was exactly the right thing to do in 1869… it solved the problem of Olmsted's time.

Slowly another strategy to manage stormwater emerged during the 1950's to respond to the flooding downstream caused by "end of pipe" conveyance system technology. This strategy, known as "detention" was directed at building detention facilities and detention ponds to detain runoff and manage stormwater so not to exceed pre-development peak flow rates. It was thought at the time that by detaining excess runoff temporarily, and later, releasing the water gradually would reduce flooding caused by conveyance systems. The goal of conveyance and detention systems was still viewed as a way to primarily reduce or control flooding. Detention was effective in controlling peak flow rates of stormwater runoff but actually increased runoff volumes and extended the duration of rate flow (Prince George's County 1999). The evolution of thinking about stormwater management was still immersed in flood prevention. A more comprehensive understanding of stormwater management would gradually evolve that was concerned about water quality and the ecological impact caused by conveyance and detention technology.

During the 1960's through the 1980's, academic research and an increased awareness of the environment led to questions about water quality and the pollutant load carried by stormwater. Urbanization and residential developments with roadway systems created more impervious surfaces contributing to higher percentages of runoff and pollutants. Point source and nonpoint source pollution became the focus of research and subsequent federal intervention.

Point source pollution, defined as a single identifiable local source of pollution was easily recognizable as industrial and municipal wastewater discharges that was directly piped into local rivers and streams. Nonpoint source pollution was pollutants carried to water bodies from diffuse sources, such as oil and chemical contaminants, from urban centers and roadways and excess fertilizers, insecticides and livestock waste from agricultural land.

In 1961 the Federal Water Pollution Control Act was passed and in 1966 the Clean Water Restoration Act became law. These federal regulations set clean water standards for states and municipalities. In 1972 the Clean Water Act was amended to include stronger language and scope that made it unlawful to discharge runoff and pollutants into any stream or water body. In 1987 the Water Quality Act was passed with water quality guidelines and enforcement provisions delegated to the Environmental Protection Agency (EPA).

Gradually, with the advancement of research, science and technology coupled with new federal regulations, states and municipalities were required to devise and design better stormwater systems that had to address point source pollution. Nonpoint source pollution was more complicated and would take more time to address with added regulations and guidelines. However, progress was being made and the inertia of older strategies of conveyance and detention was being overcome.

During the 1970's and 1980's research and hydrology studies proved that conveyance and detention systems accelerated runoff volume, increased peak flow and decreased the time of concentration of rainwater. With spiraling population growth, urbanization and extensive suburban development, researchers and land use professionals were advocating for more responsible management of stormwater runoff. The dynamics of conveyance and detention that worked for certain drainage goals was now being considered detrimental to the more comprehensive goal of water quality and ecosystem management.

In the 1860's conveyance seemed appropriate and efficient; as was conveyance and detention in the 1960's…but the goals of stormwater management was evolving from flood prevention to an emphasis on water quality and better management of the environment. A better idea, soil infiltration, was seen as a way to mimic nature and correct the deficiencies inherent in conveyance and detention technology.

Infiltration Drainage Systems

Infiltration is defined by Dunne as the movement of water into the soil and stormwater infiltration is defined by Ferguson as the artificial forcing of urban runoff away from surface discharge and into the underlying soil (1978 and 1994). The process of infiltration begins at the source of the potential runoff and diverts the water into the soil rather than conveying the runoff away from the site. Soil characteristics, as well as vegetation, have an impact on how fast or slow the water percolates into the soil. As water moves deeper into the soil, the groundwater supply is replenished and gradually base flow of nearby streams is increased through higher groundwater levels. During periods of drought, it is especially important that there is a healthy supply of groundwater to help stabilize streams and rivers.

The benefits of site infiltration in an urban/suburban area are identified by Ferguson as promoting overall ecosystem health and balance (1994). Four positive impacts noted by Ferguson include:

1. the prevention of stormwater surges
2. the maintenance of subsurface recharge

3. the prevention of channel erosion
4. the improvement of water quality

A major problem in urban/suburban environments is that conventional stormwater conveyance and detention methods contribute to an increase in storm flow volume and velocity. Paved road systems, sidewalks and rooftops prevent the natural infiltration of precipitation and runoff is channeled quickly away from the site. In this scenario, both the volume and velocity of runoff are increased, and observed in the form of stormwater surge. By incorporating full and partial infiltration basins within the urban environment, all water diverted to the on-site basin is water that will not contribute to the peak surge of other drainage downstream. According to studies conducted by Ferguson, infiltration is capable of reducing volume and peak rate of storm flow at the point of discharge and consistently downstream, thereby reducing the probability of urban flooding (1994).

The maintenance of subsurface recharge and soil moisture is another benefit of infiltration technology. Since urban/suburban developments are known to quickly channel stormwater to an offsite and downstream location, there is a real lack of opportunity for sufficient absorption of water into the soil. The lack of subsurface recharge affects the groundwater supply and soil moisture and consequently, the urban ecosystem. By retaining a significant percent of potential runoff, urban and suburban trees and streams benefit from healthy soil moisture not otherwise consistently available. A balanced ecosystem is just as important for an urban/suburban setting as it is a rural environment.

On-site infiltration can also prevent excessive sediment deposits in local streams by preventing erosion. The increased velocity and peak flow from conveyance methods overwhelm local streams by eroding stream banks and adding further sedimentation in the channel downstream. When streams accumulate excessive sediment deposits, streambeds aggrade. Additionally, aquatic life tends to decline. Infiltration methods, by reducing volume and peak flow, can bring sediment discharge levels to within the parameters of the pre-developed condition of the landscape.

Non-point source pollution is a major contributing factor to the degradation of our streams and rivers. Pollutants on impervious surfaces are washed away and carried by runoff through drainage pipes to detention ponds and finally released to local streams and rivers. These pollutants directly affect the quality of the water supply and damage aquatic ecosystems. Ferguson concludes that infiltration is the best possible method to reduce pollutant load from streams, rivers and other water resources (1994). He states that infiltration exploits the physical, chemical and biological powers of the soil to trap, alternate and transform pollutants before they reach aquifers or streams. Infiltration systems are also ideal to manage “first flush” from small storms. A “first flush” event is considered to be the first 1.2” of rainfall which is expected to transport most of the pollutant load from stormwater runoff. In analyzing a storm hydrograph, the runoff volume associated with this rainfall amount is a small portion of the total storm discharge but contains a larger percentage of the pollutant load (Prince George’s County 1999). Infiltration systems will allow runoff to soak into the soil and cleanse pollutants through the soil filtration process. An emphasis on small frequent storms accomplishes two significant points. First, frequent small storms deliver a great deal of precipitation during the year and when infiltrated it keeps the groundwater recharged throughout the year. Second, the infiltration of frequent small storms consistently manages the “first flush” of pollutants being washed away from impervious surfaces into the soil for cleansing (Ferguson 1994).

Land use planners, landscape architects and civil engineers would gradually embrace and become advocates for an alternative strategy and method to manage stormwater that would include the science of infiltration hydrology. Land use professionals from Prince George's County, Maryland and the Bay Area of San Francisco laid the groundwork for a more comprehensive and natural system of stormwater management in 1990 that would be referred to as low impact development.

Low Impact Development

In the early 1990's, the Prince George's County, Maryland, Department of Environmental Resources devised a stormwater management plan labeled "Low Impact Development". This approach to managing stormwater recommended standards in planning and design for new developments to ensure that post-development hydrologic functions would mimic that of the pre-developed hydrology. This same concept of mimicking nature in stormwater management design was also being pioneered in San Francisco, California by the regional water resource group, the Bay Area Stormwater Management Agencies Association (BASMAA). In their manual, *Start at the Source*, BASMAA emphasizes that their agenda is to specifically reduce impervious land coverage, slow runoff and maximize every opportunity for infiltration of rainwater into the soil (Richman 1999). The National Association of Home Builders (NAHB) Research Center in 2003 defines LID as an approach to land development that uses various land planning design practices and technologies to simultaneously conserve and protect natural resource systems and reduce infrastructure cost (2003). Low Impact Development still allows land to be developed but suggest that a more cost-effective method exists that also helps mitigate potentially harmful environmental impacts. The Environmental Protection Agency in their *2008 Action Strategy for Green Infrastructure* paper links "LID" and "Green Infrastructure" by stating that green infrastructure generally refers to systems and practices that use or mimic natural processes to infiltrate, evapo-transpirate, or reuse stormwater runoff onsite where it is generated. The EPA further endorses low impact development by suggesting that LID works everywhere…new developments, redevelopment, retrofit to existing developments, and a wide range of land uses from ultra-urban to low density development (2008).

The goal of low impact development is radically different from conventional stormwater management philosophy and strategy. Conventional conveyance and detention strategies were built on the premise that stormwater is problematic; excess runoff had to be channeled offsite to prevent flooding and destruction. There was little thought given to the hydrology of the site and generally the consequences for the larger area watershed. Gradually scientific inquiry would show that conventional design and management of stormwater caused increases in volume, frequency and rate of discharge for runoff (Prince George's County 1999).

In contrast, the goal of low impact development is to protect the ecological integrity of the watershed by utilizing techniques and site-specific practices that mimic nature and seeks to achieve a pre-development hydrologic profile. LID's intent is to control runoff but also to have a positive impact on water quality, stream stability, base flows and habitat structure (Prince George's County 1999).

LID begins with the understanding that every site for development is different but emphasizes that basic site analysis and design concepts will apply to most all sites and contribute to stormwater control and better ecosystem management.

Five basic concepts developed by the Prince George's County, Maryland Department of Environmental Resources and independently, by the Bay Area Stormwater Management

Agencies Association are strikingly similar in their approach to managing stormwater by seeking to replicate pre-development hydrology regimes in post-developed sites. These five concepts are:

<u>Prince George's County</u>	<u>BASMAA</u>
1. Focus on the Hydrology of the Site	1. Every Site is a Watershed
2. Control at the Source	2. Start at the Source
3. Think Micro Management	3. Think Small
4. Use Simple Non-Structural Methods	4. Keep it Simple
5. Create a Multifunctional Landscape	5. Integrate the Solutions

Every site is a watershed. By focusing on the hydrology of the site and understanding that every site is a watershed drives land planners to first define the "development envelope" which prioritizes consideration of the natural hydrologic features of the site before anything else (Richman 1999). This process would include the identification of sensitive areas, existing drainage patterns and location of existing streams, slopes and soil types. This first step should guide the development to minimize disturbance to the natural hydrologic function of the area and within the content of the larger watershed.

Start at the source. Control at the source is the reverse philosophy of the older conveyance and detention methods of managing stormwater. In the LID approach stormwater is valued as a resource that contributes to ecosystem balance. Therefore, it is imperative to mitigate any hydrologic impacts of land use as close to the source of disturbance as possible.

Think small. Thinking small and thinking micromanagement involves planning for frequent small storms and planning for the small size of each watershed that is to be controlled. In the Bay Area of San Francisco, approximately eighty percent (80%) of the total annual rainfall is produced by the accumulated contribution of many small storms (Richman 1999). Micromanagement techniques, such as infiltration and depression storage can be implemented and distributed on small lots throughout a development. Each lot and common area would create opportunities for small contributions to the overall stormwater management plan.

Keep it simple. Stormwater drainage systems, historically, have been complex and mechanical with expensive infrastructure following the design of "end of pipe" solutions. LID, in keeping it simple, focuses on simple systems that typically use lower technology materials such as natural materials that can be integrated into the landscape. By using shallow basins, rain gardens, bioswales and infiltration trenches there are multiple and distributed opportunities to mimic the natural landscape and the natural hydrologic function of the site.

Integrate the solutions. LID uses many diverse opportunities within a site to allow development but sets expectations for smarter, ecocentric, and multifunctional infrastructure. Prince George's County, in their planning manual states … with LID, every urban landscape or infrastructure feature (roof, streets, parking, sidewalks, and green space) can be designed to be multifunctional, incorporating detention, retention, filtration, or runoff use (1999). These small solutions distributed throughout a development make a large impact on controlling stormwater at its source.

LID Strategies and Practices

As stated previously, the LID approach to managing stormwater refers to practices and systems that use or mimic natural processes to slow runoff and maximize every opportunity on site to capture and infiltrate runoff into the soil. Further, the goal of LID is to achieve the pre-development hydrologic profile. This approach is also flexible in that there is the recognition that each site is different and will require multiple and distributed strategies throughout a particular site. Also there is usually sufficient opportunity to plan for large storms as well as small frequent storms. Where more control becomes necessary, due to factors such as low permeable soil, conventional controls can supplement to meet the overall hydrologic control objectives (Prince George's County 1999).

The process of determining a particular low impact development strategy is described by Prince George's County in a progression of six steps (1999):

1. <u>Define the hydrologic control required to meet pre-development profile</u>.

   This would require site analysis to include the infiltration profile, discharge frequency and volume of discharge.

2. <u>Evaluate the site constraints.</u>

   Look at available space, drainage patterns, soil characteristics, and slopes existing in the site.

3. <u>Screen for best strategies</u>

   LID strategies have to be based on the site characteristics. In addition to constraints, hydrologic functions of the site have to be understood. A review of the hydrologic features should include runoff volume, peak discharge, runoff frequency, infiltration capacity, interception, and water quality.

4. <u>Evaluate likely strategies</u>

   The initial design should identify potential strategies with their hydrologic computations to judge if the hydrologic control objectives are met. If not, there will be a need to adjust the number and size of the strategies until the hydrologic objectives are met.

5. Select Optimal Strategies

Integrate mix of strategies that meet performance goals while considering design requirements such as space, site aesthetics and maintenance issues.

6. Design Conventional Controls if needed.

If the hydrologic controls cannot be met due to site constraints, such as low permeable soils, hard rock or pressure of high water table, there would be a need to supplement with conventional controls such as detention or retention.

LID strategies and practices are typically a mix of small lot-size configurations that are distributed over a site but integrated to manage the overall hydrologic control and quality objectives. Several states, including Maryland, California, Delaware, Iowa and Florida have made pioneering efforts in identifying and adapting these management practices. These practices may be labeled by different names but all share the common thread of keep it simple, think small, start at the source, every site is watershed and integrate the solutions. These practices include:

- Bioretention which consist of a landscaped depression with several components which contribute to infiltration into the soil and absorption and filtering with grasses and plant material. A bioretention basin can consist of a pretreatment filtering with grass channels, a surface water ponding area, a planting area, a soil zone, underdrain system and an over flow outlet structure (Prince George's County 1999).
- Dry wells consist of small pits filled with pea gravel or stone. Dry wells work best as infiltration devices placed close to buildings to collect roof top runoff.
- Filter strips are strips of thick growing vegetation planted to collect and filter runoff from impervious surfaces before reaching a receiving water body or bioretention structure.

- Vegetated buffers can be natural or planted but serve mainly to protect sensitive areas such as wetlands, woodlands or erodible soils. Vegetated buffers filter pollutants, provide some infiltration and tend to slow stormwater flows.
- Grass swales can be wet or dry but primarily function to direct runoff away from roadways. LID designed grass swales are planned to control volume, and additionally, infiltration.
- Rain barrels and cisterns are simple water storing devices that capture runoff from rooftops and stored for reuse at a later time.
- Infiltration trenches are excavated trenches that are filled with stone to form a subsurface basin. Stormwater is diverted to the trench for temporary storage and infiltration.
- Turf block consist of interlocking concrete grid filled with soil and grass that captures rainwater to infiltrate the soil and reduce the amount of runoff flow. Typical use would be driveways, street shoulders and overflow parking areas.
- In-street infiltration areas can be created by erecting porous landscape areas on the street side to reduce runoff and promote infiltration. Curb cuts along the infiltration areas allow smaller storm flows to infiltrate into the area, while larger flows are diverted to the stormwater system once the infiltration area fills (Wenk Associates, Inc).

Summary

Stormwater management has evolved slowly but significantly over the last century from basic conveyance and detention systems that were primarily concerned with flood prevention to a drainage system that included infiltration hydrology with an emphasis on maintaining the pre-development hydrologic regime of post-developed sites. Within the last twenty years a dynamic and promising approach called low impact development has brought a radical shift in thinking about stormwater. With low impact development methodology, major efforts are directed at focusing on the development site as a watershed and to protect the water quality, stream stability, base flows and habitat structures to achieve ecosystem balance. This line of thinking reverses the previous accepted practice of piping stormwater offsite to a practice that is based on the premise that stormwater is resource that needs to be utilized wisely.

CHAPTER THREE

SITE SELECTION AND DESCRIPTION

The study site selected for this thesis project lies within the Upper Oconee Watershed (Figure 4). The property is adjacent to the North Oconee River just upstream of the confluence of the Middle and North Oconee Rivers. The sites sub-watershed classification is Athens-Clarke County Middle Oconee River / Shoals and Cedar Creek Watersheds zone 5 and 6 (Figure 5). As of 2008, the United States Environmental Protection Agency's "Waterbody Report for the Oconee River" designates the river segment adjoining the subject site as impaired. The impaired status as recognized by the EPA identifies fecal coliform as the primary cause of impairment. The Agency's report also suggest the probable source of the river's impairment status is urban-related stormwater runoff. In addition to the EPA's assessment of the sub-watershed's physical status, the Upper Oconee Watershed Network (UOWN) has also provided a great amount of insight towards the watershed's overall health ranking. UOWN, an Athens, Georgia based non-profit volunteer organization was formed in 2000 and has since been a leader in advocating to improve water quality in the Upper Oconee River basin through community-based monitoring and education. UOWN's nine years of involvement in the Upper Oconee Watershed have focused on both seasonal and land-use trends on physical, chemical and biological water quality indicators.

Figure 4 Location of the Upper Oconee Watershed (UOWN).

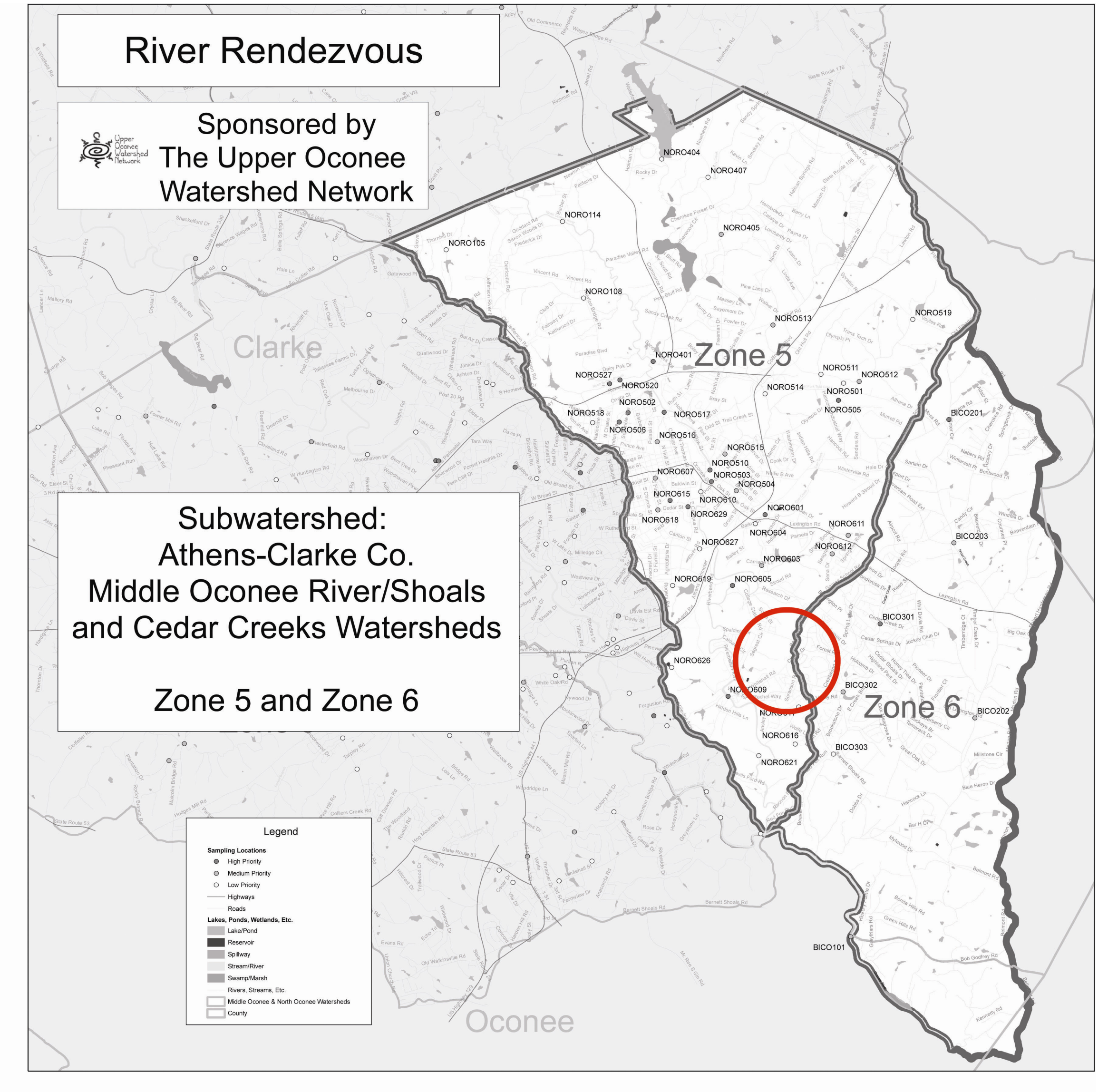


Figure 5 Map illustrating location of the sub-watershed of subject site (UOWN).

UOWN's monitoring efforts include the following seven parameters: precipitation, conductivity, turbidity, *Escherichia coli*, fecal coliforms, nitrate and phosphate. Within these parameters the group's data collection focuses on three types of land-use designations: urban, suburban and rural. Streams located within the urban classification are located in the urban core of Athens and are impacted by dense development, impervious surfaces, industrial areas and sewer lines. The suburban interface includes streams located outside the urban core and impacted by suburban-style development, industrial areas and sewer lines. Rural streams are located in the agriculturally zoned "Greenbelt" and are either relatively undisturbed by development or are impacted by agricultural uses. With regard to the subject site of this thesis, the site is located in a suburban environment and the land cover type is consistent with the characteristics defined in suburban areas of the regions watershed.

UOWN's findings indicate that numbers of fecal coliforms and *E. coli* are highest in suburban and urban stream types. Their study also shows that a variety of contaminants enter streams and rivers from surrounding impervious surfaces during storm flows. In addition to stormwater runoff, contaminants are found to enter streams and rivers from groundwater and point source discharges during low flow. These patterns are consistent with a post-development landscape designed with conveyance and detention stormwater management practices. Other findings of the UOWN's analysis indicate that turbidity and bacterial numbers were positively correlated with precipitation within 24 hours of the sampling event. Stormwater runoff from high flow events when compared to low flow events, can substantially increase sediment transport and bacteria levels in Upper Oconee River basin sites (Little et al. 2007). Problems associated with these reported findings suggest a new strategy and method of implementation is needed to restore balance to the Upper Oconee Watershed.

Athens-Clarke County's newly evolving strategy for stormwater management includes a public education campaign, a series of "lead by example" initiatives and a phased best management practices program that includes an implementation matrix in the following areas (Athens-Clarke County Stormwater):

- Public education
- Public involvement
- Elimination of unlawful discharges
- Controls on new construction
- Post-construction management of wet weather runoff
- Implementation of good housekeeping activities for municipal operations

Based on 2000 Census data, the EPA designated Athens-Clarke County as a National Pollutant Discharge Elimination System (NPDES) Phase II municipality requiring Athens to develop a stormwater management program addressing the above key areas. In keeping with federal requirements the ACC government imposed a stormwater utility fee to fund items planned for in the stormwater management implementation matrix.

A few of the successful projects that have been completed in Athens include the use of porous concrete at 120 W. Dougherty Street, porous pavement at the Athens Welcome Center, the daylighting of a stream at North Avenue, stormwater treatment train at Lumpkin Woods and Willow Street sand filter and CBD detention pond. These projects illustrate a shifting in the basic philosophy of stormwater management in Athens, Georgia.

The State of Georgia's stormwater management program is administered by the Georgia Environmental Protection Division (GAEPD). As demonstrated in Athens, the State of Georgia has also adopted a stormwater management philosophy that aims to "reduce both stormwater quality and quantity impacts, and protect downstream area and receiving waters" (Atlanta Regional Commission 2001). The State's stormwater requirements are "mirrored after the federal NPDES program" (Stormwater Authority, LLC). Prepared in 2001, The *Georgia Stormwater Management Manual* is a comprehensive stormwater policy guidebook divided into three volumes. Volume One is designed to provide guidance for local jurisdictions on the basic principles of effective urban stormwater management. This volume includes site and watershed level stormwater management. Volume Two is the more technically oriented volume providing guidance on the techniques and measures that can be implemented to meet a set of stormwater management minimum standards for new development and redevelopment. Volume Three includes a collection of pollution prevention practices for stormwater quality for use by local jurisdictions, businesses and industry and local citizens.

The recent direction of federal, state and local stormwater management policy is reflective of a growing awareness of the impacts of urbanization on the hydrologic landscape. In keeping with the shift in stormwater management policy, the thesis recognizes that a development site is a watershed within a watershed and can provide a site-by-site opportunity to improve more than just a single development's hydrologic performance. Rather, improved performance of an entire watershed is possible through collective implementation. The subject site of this thesis was selected because of its history as a natural landscape and the evolution of that landscape to a developed suburban environment. The sites topography, existing stormwater system and relationship to the Oconee River also qualify the property as a candidate for the kind of change that is needed to reverse the impacts of conveyance and detention technology. A successful design including the retrofitting of bioretention and infiltration technology could provide a more natural hydrologic function to both the subject site and the greater watershed. The following chapter will present a more complete analysis of the subject site's pre-development condition in order to demonstrate how the site manages runoff from the 1-year 24-hour storm event on a forested piedmont landscape.

CHAPTER FOUR

PRE-DEVELOPMENT STORMWATER ANALYSIS

Site Location

The study site for this stormwater management analysis was chosen primarily for its history as a forested landscape along the North Oconee River and the development of that landscape to a single-family suburban subdivision (Figure 6). The site's transition from a naturally functioning hydrologic landscape to a man altered and urbanized conveyance system presents the ideal scenario to analyze and compare conventional conveyance and detention strategies with low impact development methods.

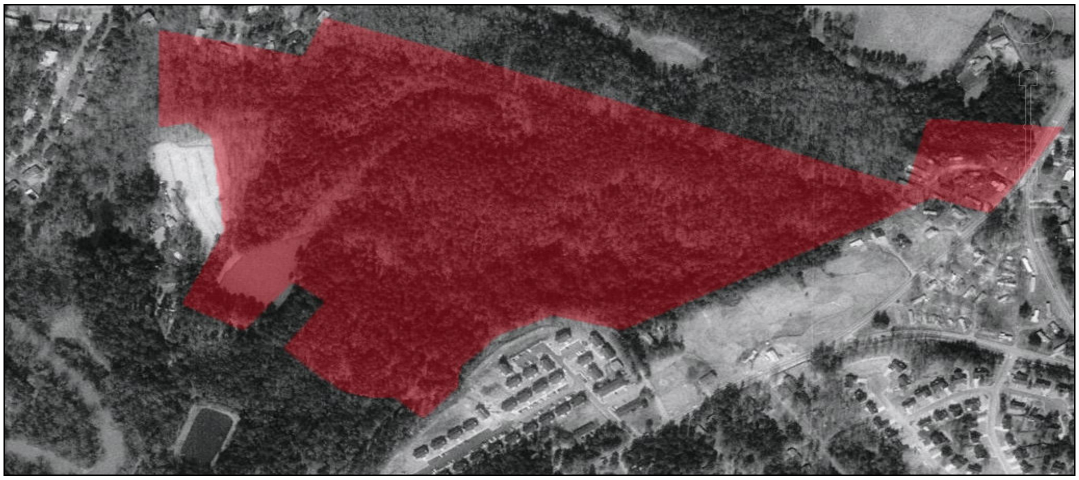


Figure 6 1980 Aerial Photo of Study Site as Typical Piedmont Forest (Google Earth).

The property is located in the southeast portion of Athens-Clarke County, Georgia (Figure 7). The site's 69 acres is bordered by the Oconee River floodplain and forest to the West, multi-family residential to the South and single family residential to the North and East. The site is accessible from the East on Barnett Shoals Road (Figure 8).

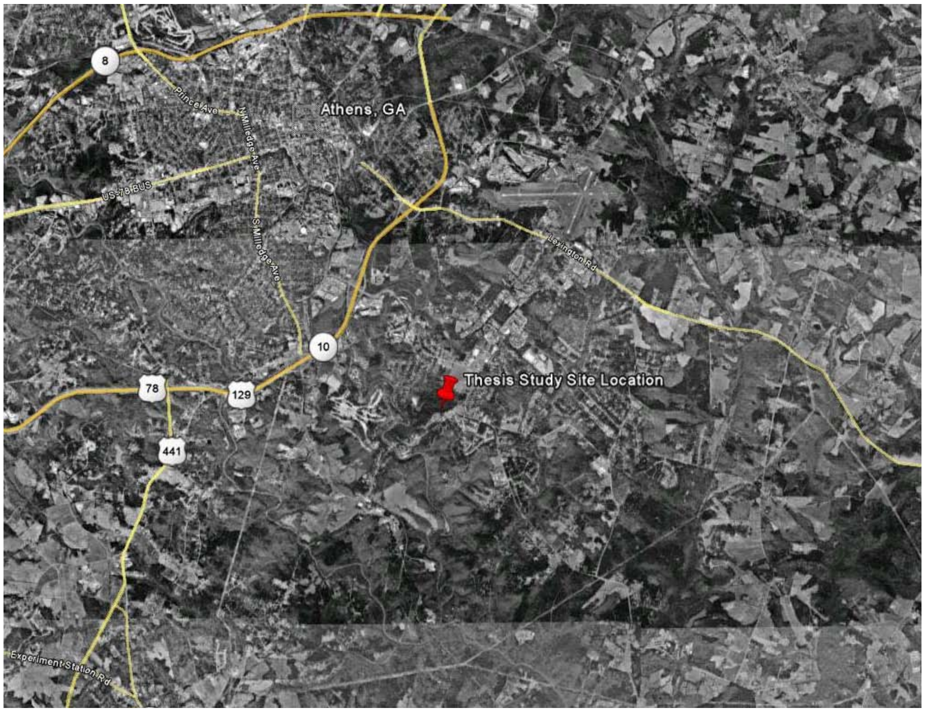


Figure 7 Vicinity Map of Study Site (Google Earth).

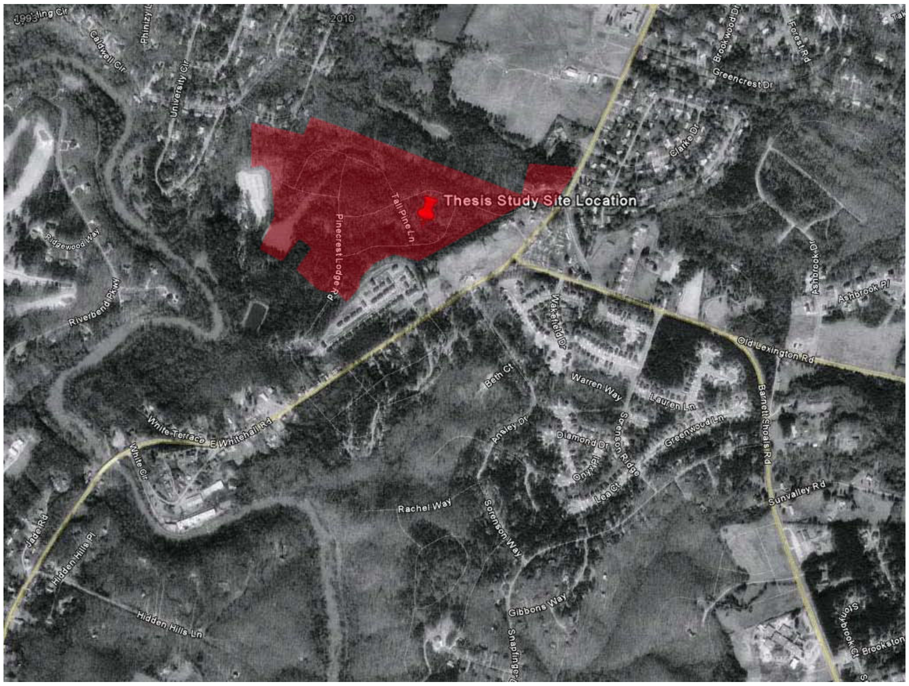


Figure 8 Location Map of Study Site (Google Earth).

Land Cover and Soil Description

Prior to development, the site was characterized as forested with moderate to steep slopes (Figure 9). Common of the topography in the Piedmont region, the study site's sloped terrain included a series of intermittent streams that drained to the floodplain of the Oconee River (Figure10).

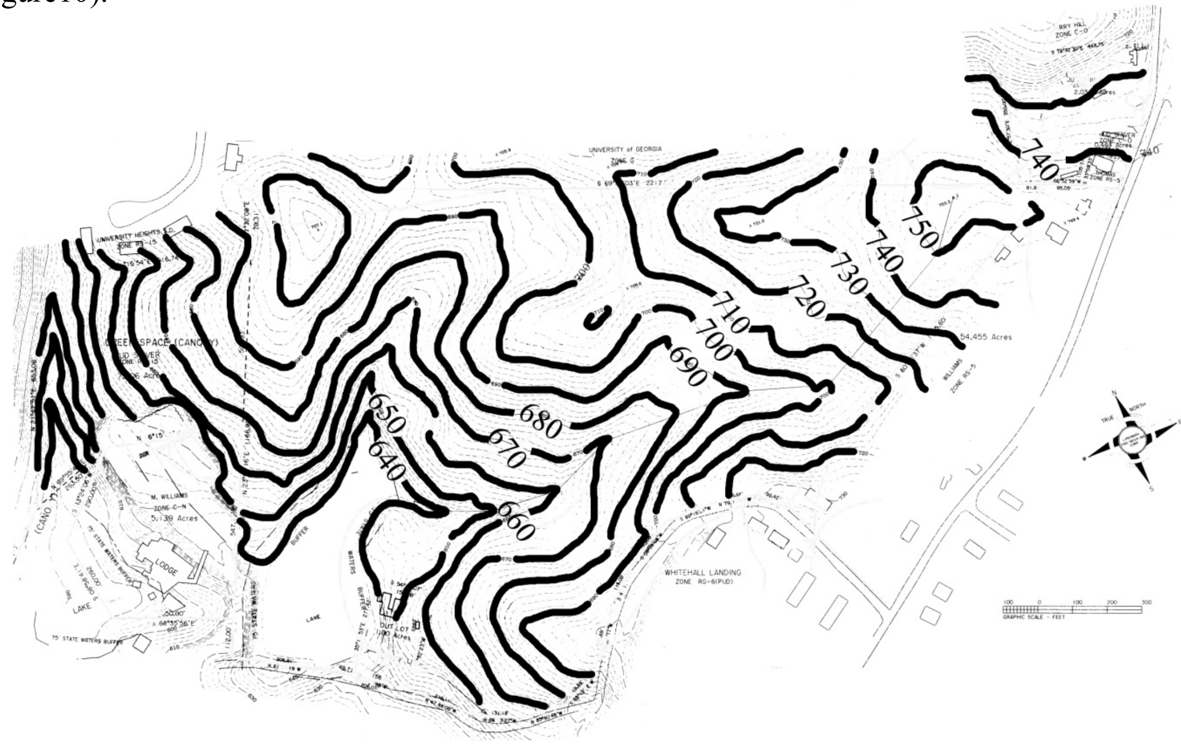


Figure 9 Pre-development topography of subject site (Landmark Engineering).

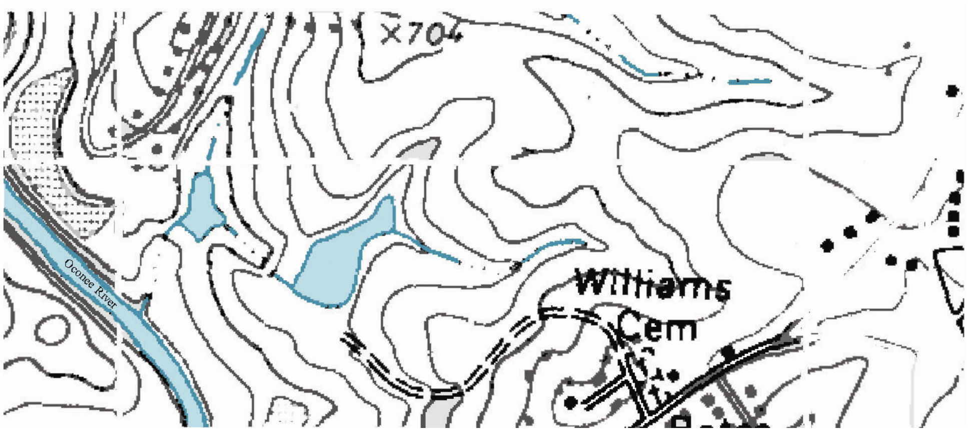


Figure 10 Pre-development hydrology of the subject site (Trails.com).

The site’s land cover consisted of a mixed pine-hardwood forest typical in the Georgia Piedmont region. Soils in this region of the Piedmont are often deep and on upland portions of this region range from gently sloping to steep. As noted in Figure 11, the site’s soils are divided into four different soil series: Cecil, Davidson, Madison and Pacolet.

The Cecil series consists of well-drained soils on uplands. These soils have formed mainly in material weathered from gneiss and granite but mixed in many places with quartzitic or basic material. The slopes range from 0 to 10 percent but most commonly are between 2 and 10 percent. The Cecil soils occupy the largest acreage of any soil type in Clarke and Oconee Counties (USDA 1968).

The Davidson series consists of well-drained soils on uplands. These soils have formed mainly in material weathered from diorite, hornblende, or gneiss, but partly in material weathered from mica schist. The slopes range from 2 to 25 percent but are most commonly between 4 and 15 percent. Bedrock is at a depth of 6 to 10 feet (USDA 1968).

The Madison series consists of deep, well-drained soils on uplands. These soils have formed in material weathered from quartz and mica schist, mixed in places with gneiss or basic material. The slopes range from 2 to 25 percent but are mainly between 10 and 25 percent. Bedrock is between 3 and 8 feet deep or more (USDA 1968).

The Pacolet series consists of well-drained, sloping soils of the uplands. These soils have formed in material weathered from gneiss, schist and granite. They occupy large areas throughout Clarke and Oconee Counties. The slopes range from 6 to 25 percent (USDA 1968).

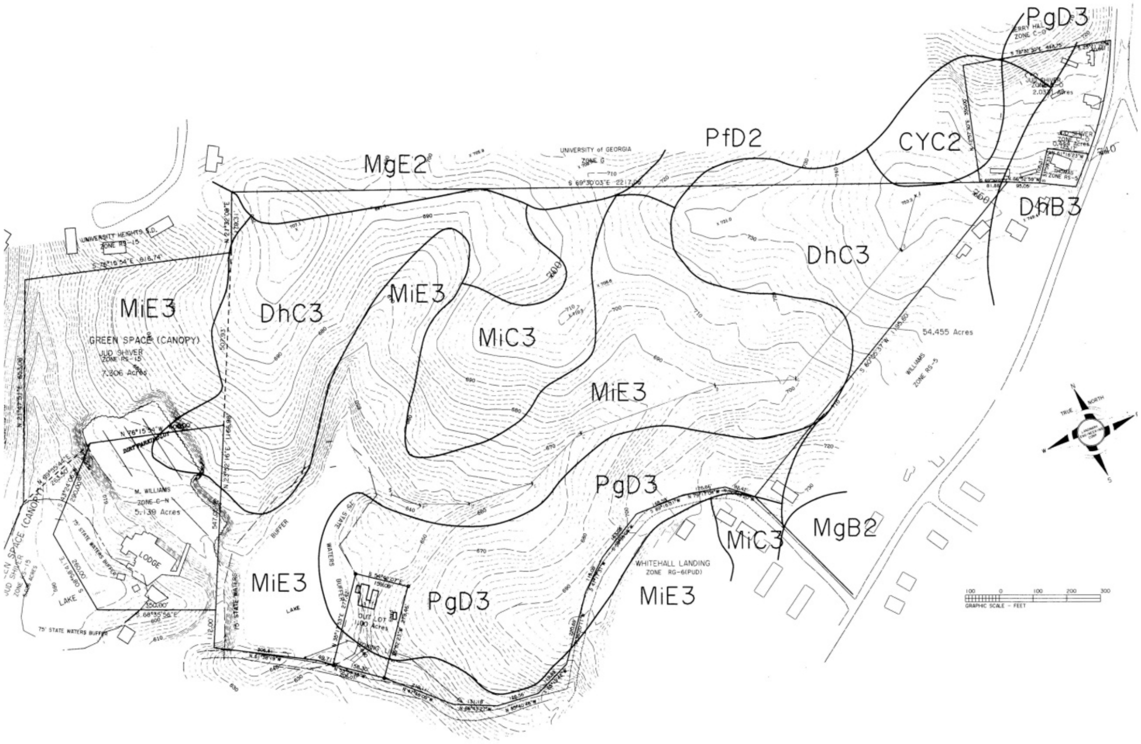


Figure 11 Soil Identification Map for Study Site (Landmark Engineering).

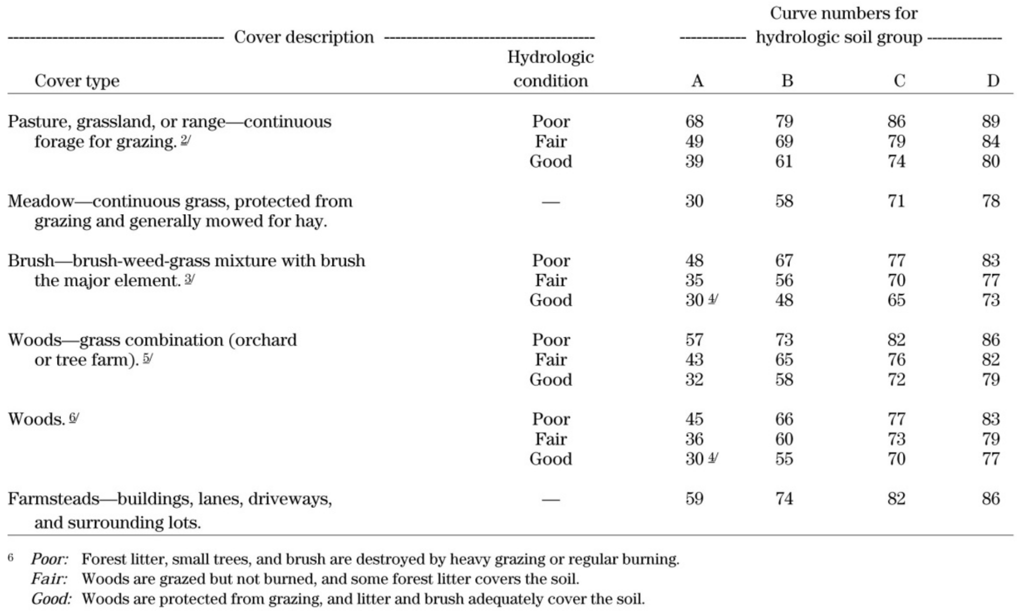
Based on the well-draining nature of the site's soil composition, infiltration is a realistic approach for managing stormwater throughout the property. Each of the four soil types is classified according to the U.S. Hydrologic Soil Group Classification as Group B soils. Soils are classified into hydrologic soil groups (HSG's) to indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting. The infiltration rate is the rate at which water enters the soil at the surface. HSG also indicates the rate at which water moves within the soil. The Soil Group B is defined as follows: Group B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (USDA 1986).

In summary, the 69-acre study site is composed of one hundred percent (100%) Group B soils. This soil classification (Group B) will be used in Chapters 4-6 as means of establishing curve numbers that will provide data for time of concentration and runoff rate for the pre-developed and developed site.

Pre-development Condition and Computation of Curve Number

Based on Technical Release 55, the pre-developed site was classified as having one hundred percent (100%) Soil Group B and Cover Type, Woods in Good Hydrologic Condition. The appropriate curve number applied to this study site in its pre-developed condition is 55.

Table 2 Runoff Curve Numbers For Other Agricultural Lands (USDA 1986).



Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. 2/	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. 3/	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 4/	48	65	73
Woods—grass combination (orchard or tree farm). 5/	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. 6/	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 4/	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

[6] *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Computation of Runoff

Following establishment of the site's curve number, runoff for the 1-year 24-hour storm event may be calculated using the SCS TR-55 formula:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

Where Q = runoff (inches)

= .31 inches

P = rainfall (inches)

= 3.4 inches (Atlanta Regional Commission 2001)

S = potential maximum retention after runoff begins (inches)

= (1000/CN) – 10

= 8.18 inches

The estimated runoff for the 1-year, 24-hour storm event on the study site is .31 inches.

The remaining two components that account for rainfall composition on the pre-developed site are initial abstraction (I_a) and rainfall retained on site ($S_{actural}$).

I_a = "All loses before runoff begins, including water retained in surface depressions water intercepted by vegetation, evaporation and infiltration" (USDA 1986).

= 0.2S

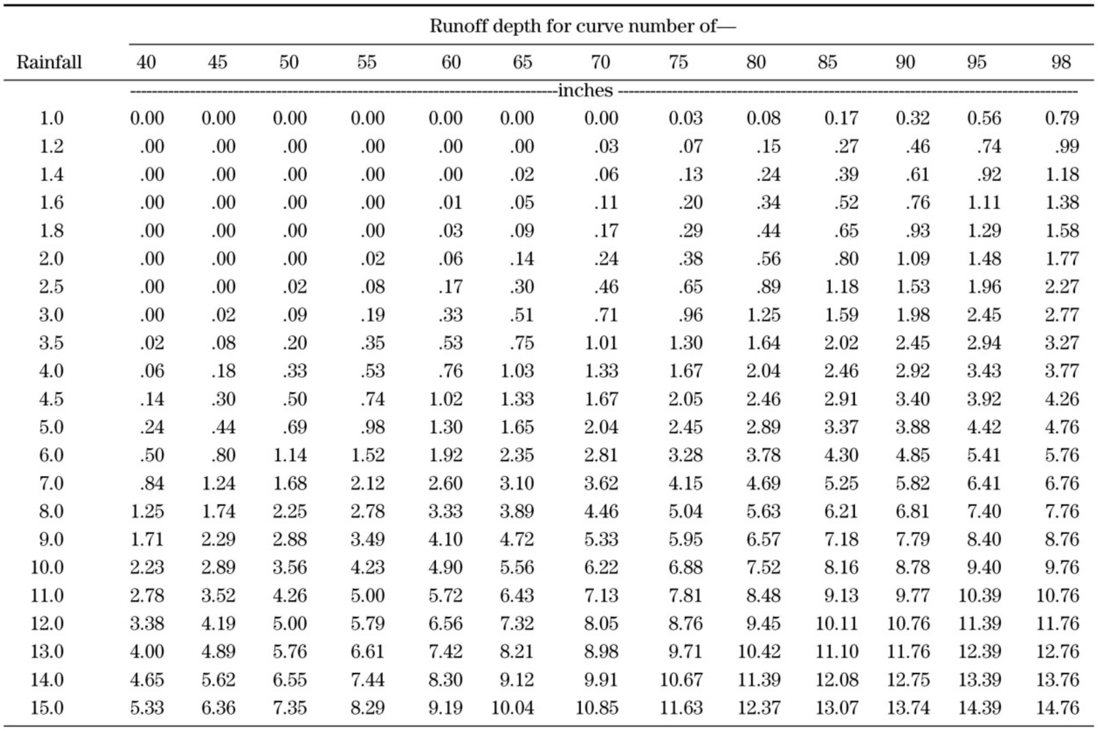
= 1.64 inches

S_{actual} = After runoff begins, rainfall retained on site through infiltration and evapo-transpiration (Vick 2006).

= P – I_a – Q

= 1.45 inches

Table 3 Runoff Depth for Selected Curve Numbers and Rainfall Amounts (USDA 1986).



	Runoff depth for curve number of—												
Rainfall	40	45	50	55	60	65	70	75	80	85	90	95	98
							inches						
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.15	.27	.46	.74	.99
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92	1.18
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11	1.38
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29	1.58
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48	1.77
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45	2.77
3.5	.02	.08	.20	.35	.53	.75	1.01	1.30	1.64	2.02	2.45	2.94	3.27
4.0	.06	.18	.33	.53	.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	.14	.30	.50	.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	.24	.44	.69	.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	.50	.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

Table 4 Pre-development Initial Abstraction, Runoff and Retention for the 1-year 24- hour storm event.

	Depth (inches)	Volume (cubic feet)	% Rainfall
Initial Abstraction (I_a)	1.64	415,891	48
Runoff (Q)	.31	78,613	9
Retention After Runoff (S_{actual})	1.45	367,708	43
Rainfall (P)	**3.4**	**862,212**	**100**

Computation of Time of Concentration

The next step in the series of stormwater computations is to calculate time of concentration. This information will be useful in the comparison of landscapes (pre-developed versus post-developed) to reflect the travel time of water from one location in the watershed to another. TR-55 defines Time of Concentration (Tc) as the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest within the watershed. Tc is computed by summing all of the travel times for consecutive components of the drainage conveyance system. This calculation was performed on the pre-development site by analyzing 1995 aerial photos and establishing obvious drainage patterns throughout the site. As noted in Figure 12, sheet flow, shallow concentrated flow and channel flow were established and measured for determining total time of concentration. TR-55 defines sheet flow as flow over plane surfaces, usually occurring in the headwaters of streams. With sheet flow, the friction value (Manning's n) is an effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges and rocks; and erosion and transportation of sediment. The roughness coefficient values (n values) are for very shallow flow depths of about .1 foot. See Table 5 below that references the roughness coefficients or Manning's n for sheet flow. As indicated in Manning's roughness coefficient table, the roughness coefficient used in the pre-development sheet flow computation is .4 (woods – light underbrush). The sheet flow for travel segment AB is calculated using:

$$T = \frac{.007(nL)^{.8}}{(P_2)^{.5}s^{.4}}$$

where:

T_t = travel time

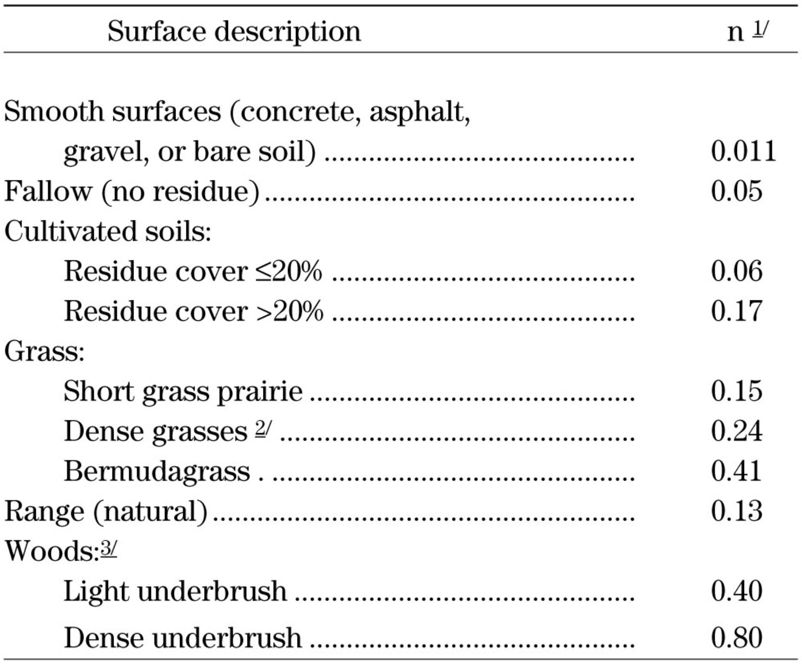
N = Manning's roughness coefficient

L = flow length (ft)

P_2 = 2-year, 24-hour rainfall (in)

S = slope of hydraulic grade line (ft/ft)

Table 5 Roughness coefficients (Manning's n) for sheet flow (USDA 1986).



Surface description	n [1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses [2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods:[3]	
Light underbrush	0.40
Dense underbrush	0.80

As sheet flow progresses through the natural drainage system, stormwater transitions to shallow concentrated flow which is depicted in Table 6 as segment BC. As noted on Table 6, travel segment BC spans 490 feet of the pre-developed site. Computation of this segment's travel time includes factors such as surface type, flow length, slope and average velocity.

$$T_t = \frac{L}{3600\ V}$$

where:

L = flow length (ft)

V = velocity (ft/sec)

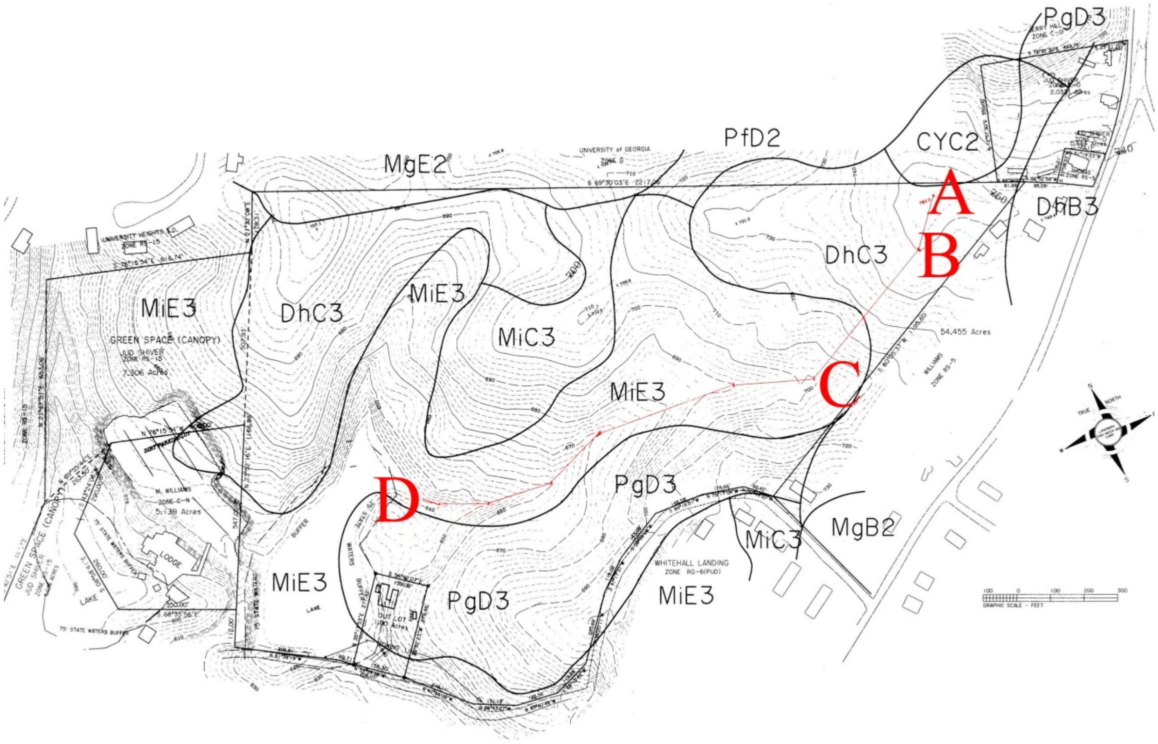
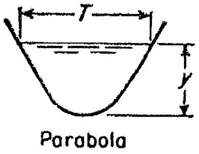


Figure 12 Travel time segments for pre-developed study site.

The final segment of the natural drainage system for the pre-developed site is segment CD, open channel flow. This segment spans 1,100 feet and can be referenced on Figure 12. Open channel flow was calculated using a series of computations from Chow's, "Open Channel Hydraulics." As Chow explains there are two types of open channels, natural and artificial. In the pre-development landscape, the natural open channel exists and most likely would be described as parabolic in form. Natural channel sections are irregular in form and vary from parabolic to trapezoidal in shape. Chow admits that the parabolic form is the best approximation of sections of small and medium sized natural open channels. Once the general shape of the channel has been identified, a cross sectional flow area may be determined:

Cross sectional flow area (ft^2) = $^2/_3$Ty



T = 6

y = 4

= 16

The next computation, solving for the wetted perimeter is defined by Chow as the length of the line of intersection of the channel wetted surface with a cross-sectional plane normal to the direction of flow.

Wetted perimeter (ft) = T + ($^8/_3$)(y^2/T)

= 13.1

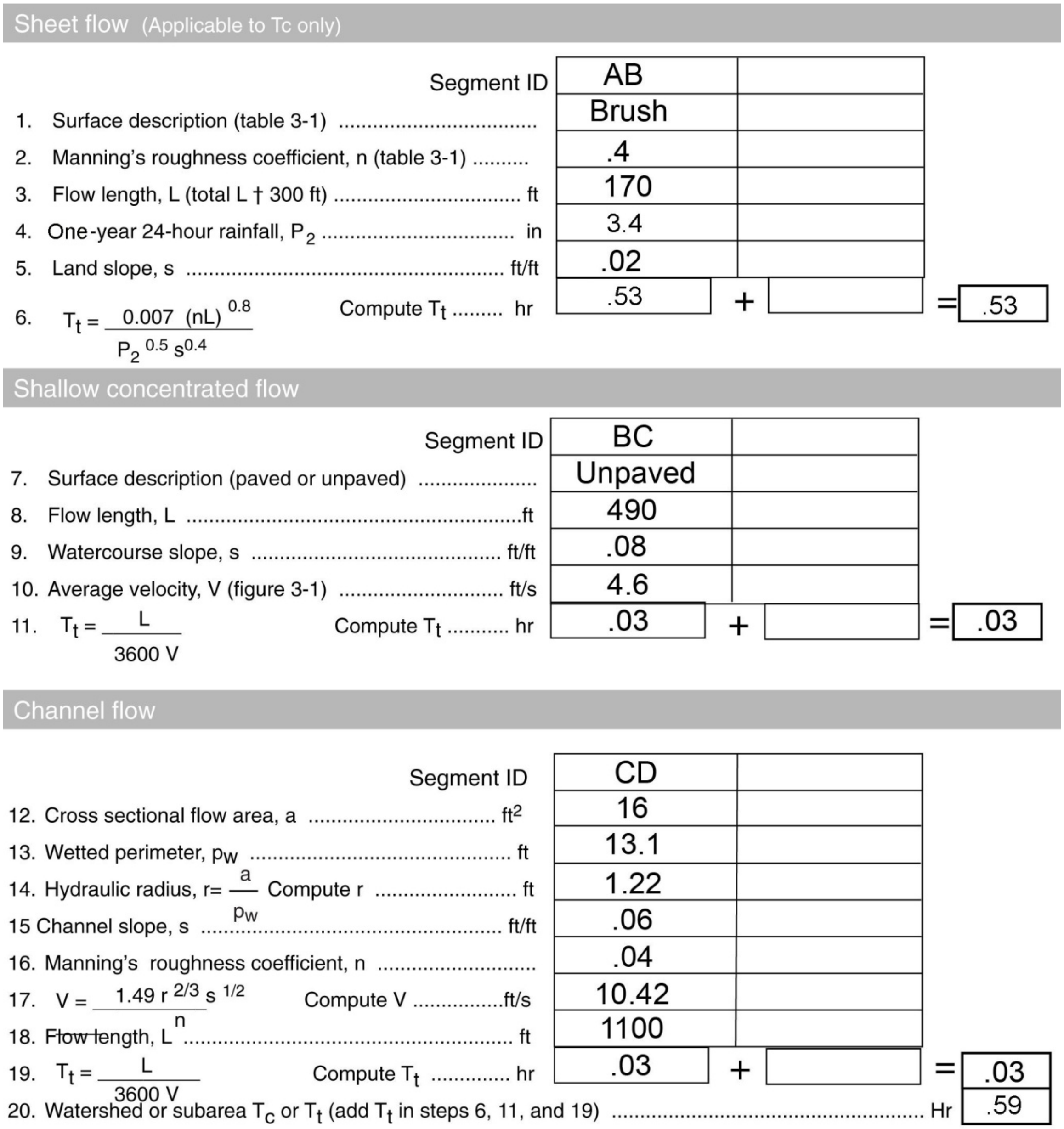
The hydraulic radius, the ratio of water area to its wetted perimeter is solved by:

Hydraulic radius (ft) = $\frac{2T^2y}{3T^2 + 8y^2}$

= 1.22

Table 6 summarizes each measurement in the process of establishing the Tc for the pre-developed site. This time of .59 hours will later be compared to the Tc of the developed site to establish how much infiltration will be required to meet the performance criteria of the proposed site retrofit.

Table 6 Time of Concentration Computation for Pre-developed site (USDA 1986).



Sheet flow (Applicable to Tc only)

Segment ID	AB			
1. Surface description (table 3-1)	Brush			
2. Manning's roughness coefficient, n (table 3-1)	.4			
3. Flow length, L (total L † 300 ft) ... ft	170			
4. One-year 24-hour rainfall, P_2 ... in	3.4			
5. Land slope, s ... ft/ft	.02			
6. $T_t = \frac{0.007\ (nL)^{0.8}}{P_2^{\ 0.5}\ s^{0.4}}$ Compute T_t ... hr	.53	+		= .53

Shallow concentrated flow

Segment ID	BC			
7. Surface description (paved or unpaved)	Unpaved			
8. Flow length, L ... ft	490			
9. Watercourse slope, s ... ft/ft	.08			
10. Average velocity, V (figure 3-1) ... ft/s	4.6			
11. $T_t = \frac{L}{3600\ V}$ Compute T_t ... hr	.03	+		= .03

Channel flow

Segment ID	CD			
12. Cross sectional flow area, a ... ft^2	16			
13. Wetted perimeter, p_w ... ft	13.1			
14. Hydraulic radius, $r = \frac{a}{p_w}$ Compute r ... ft	1.22			
15 Channel slope, s ... ft/ft	.06			
16. Manning's roughness coefficient, n	.04			
17. $V = \frac{1.49\ r^{2/3}\ s^{1/2}}{n}$ Compute V ... ft/s	10.42			
18. Flow length, L ... ft	1100			
19. $T_t = \frac{L}{3600\ V}$ Compute T_t ... hr	.03	+		= .03
20. Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19) ... Hr				.59

Results and Interpretation

Following computation of curve number, runoff and time of concentration for the pre-developed site, one is able to draw conclusions about hydrologic patterns present on the study site prior to development. Initial abstraction and retention after runoff account for 91% of a rainfall event. Only 9% of the rain event manages to escape the site and enter the nearby surface water systems. The site's ability to function as a natural hydrologic system provides for aquifer recharge, minimized erosion, decreased pollutant load into surface water systems and the sustained integrity of stream hydrology. Unlike natural systems, development of the study site with conveyance and detention techniques manages stormwater in a very different manner. In the following Chapter, Post-development Storm Water Analysis, computations will show an increase in runoff rate, runoff volume and a decrease in time of concentration.

CHAPTER FIVE

POST-DEVELOPMENT STORMWATER ANALYSIS

A snapshot of the developed site reveals a conventional curb and gutter stormwater conveyance system which pipes stormwater underground to a detention pond down slope of residential units. This sixty-nine acre study site has been significantly altered from a forested micro-watershed on the Oconee River to a residential subdivision consisting of 169 detached single-family residential units. The street system, driveways and rooftops are estimated to reconfigure the landscape to twenty-six percent (26%) impervious surface. A conventional stormwater gutter system and detention pond transports surface runoff directly to the Oconee River only a few hundred yards away. While this approach expediously manages the removal of stormwater away from the site, it is an approach that has neglected to maintain stormwater runoff at levels commensurate with the pre-developed condition of the landscape.

Figure 13 2004 Aerial Photo of Study Site as Post-developed (Google Earth).

Post-development Conditions and Computation of Curve Number

As demonstrated in the pre-development stormwater analysis, computation of curve number, runoff and time of concentration will provide an understanding of how stormwater is distributed throughout the post-developed site. Unlike the curve number calculation for the pre-developed site, the post-development curve number calculation will require multiple steps to account for a weighted curve number. While the pre-developed site's composition was "woods in good condition", the post-developed site's composition varies from impervious surfaces to "open space in fair condition". For purposes of this assessment the cover type "open space" applies to areas within the subject site designated as dedicated conservation easement and 50 - 75% grass cover. The "forest" designation applies to residual wooded areas within the subject site recognized as "woods in good condition". This variation in cover type demands a computation of curve number that is weighted by percentage of cover types so that the study site's composition is accurately represented. As shown in Table 7, the weighted curve number for the post-developed site is 75.

Table 7 Runoff curve number for post-developed study site.

Cover Description	**Land Area (Acres/Sq. Ft.)**	**Land Area (%)**	**Curve Number**	**Weighted Curve Number**
Impervious structures	5.85 / 254,826	8.38	98	8.21
Impervious streets	9.1 / 396,919	13.04	98	12.78
Impervious sidewalks	1.74 / 75,794	2.49	98	2.44
Impervious parking	1.3 / 57,064	1.88	98	1.84
Open Space	44.5/ 1,940,226	63.76	69	43.99
Forest	7.3 / 318,249	10.5	55	5.78
Total Weighted Curve Number				**75.04**

Post-development Environment

As illustrated in Figures 14 and 15, impervious and pervious cover is representative of a conventional suburban subdivision. The development is composed of single-family detached units on an average lot size of 7,027 square feet. Of the 169 single-family units, 118 are three bedroom and 51 are two bedroom.

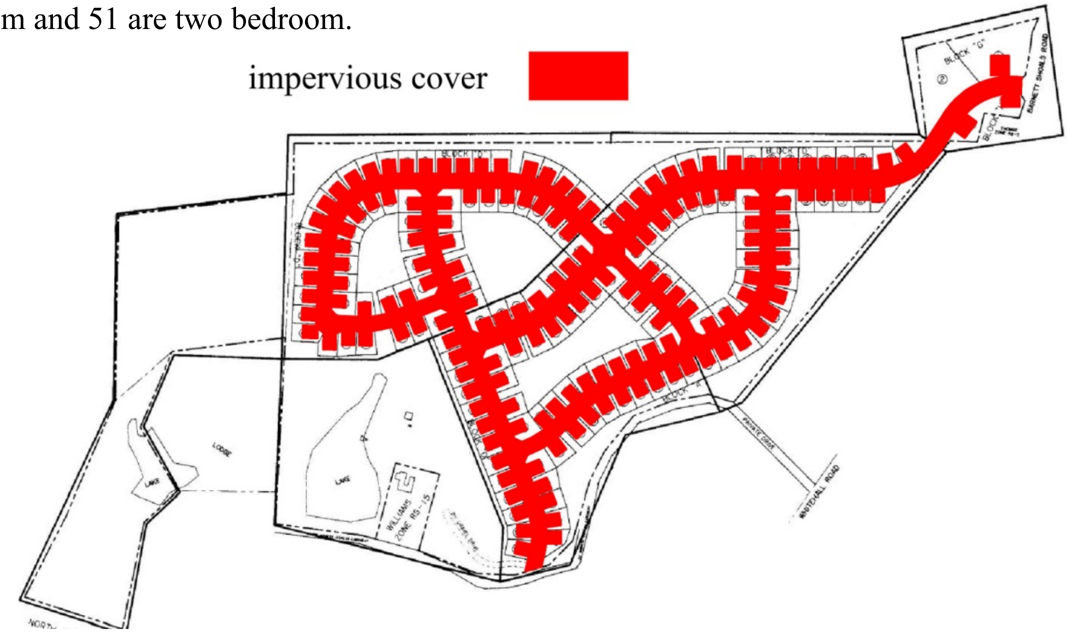


Figure 14 Site plan of impervious cover for post-developed site.

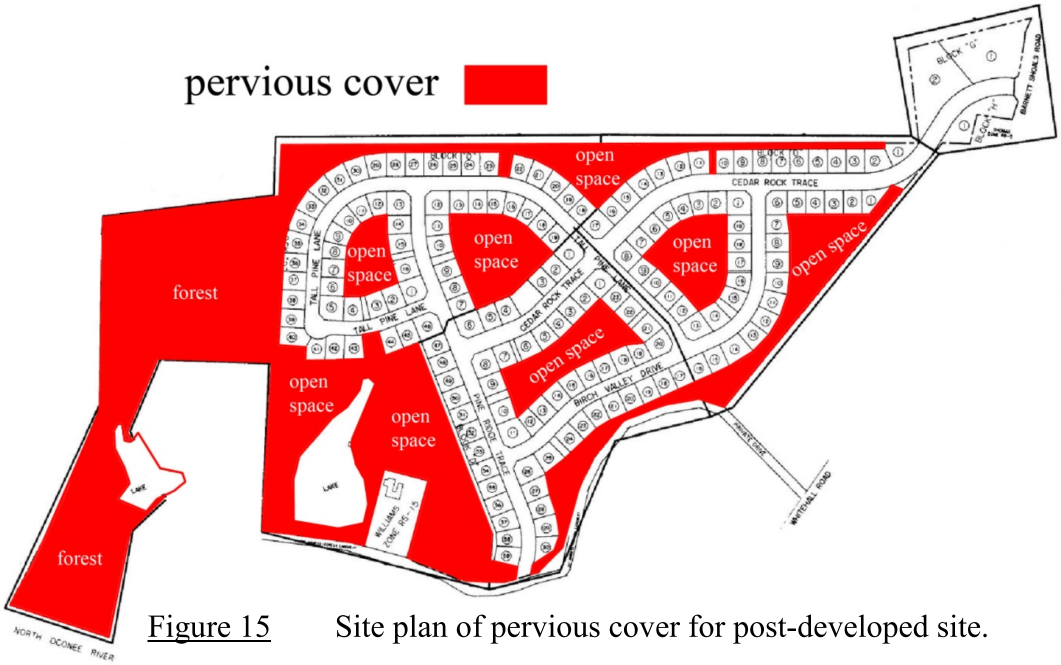


Figure 15 Site plan of pervious cover for post-developed site.

Table 8 Runoff Curve Numbers For Urban Areas (USDA 1986).

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

[1] Average runoff condition, and $I_a = 0.2S$.

[2] The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

[3] CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

[4] Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

[5] Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Computation of Runoff

A comparison between pre and post-development curve numbers indicates the effects of increasing the amount of impervious surface on a site and how that relates to stormwater runoff. The weighted curve number 75 will be used to calculate post-development runoff for the 1-year 24-hour storm event by using the equation:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

Where Q = runoff (inches)

= 1.23 inches

P = rainfall (inches)

= 3.4 inches (Atlanta Regional Commission 2001)

S = potential maximum retention after runoff begins (inches)

= (1000/CN) – 10

The estimated runoff for the 1-year, 24-hour storm event on the study site is 1.23 inches.

The remaining two components that account for rainfall composition on the pre-developed site are initial abstraction (I_a) and rainfall retained on site ($S_{actural}$).

I_a = "All loses before runoff begins, including water retained in surface depressions water intercepted by vegetation, evaporation and infiltration" (USDA 1986).

= 0.2S

S_{actual} = After runoff begins, rainfall retained on site through infiltration and evapo-transpiration (Vick 2006).

= $P – I_a – Q$

Table 9 Post-development Initial Abstraction, Runoff and Retention for the 1-year 24-hour storm event.

	Depth (inches)	Volume (cubic feet)	% Rainfall
Initial Abstraction (I_a)	.67	169,906	20
Runoff (Q)	1.23	311,918	36
Retention After Runoff (S_{actual})	1.5	380,388	44
Rainfall (P)	**3.4**	**862,212**	**100**

Computation of Time of Concentration

Following runoff computations, time of concentration calculations are necessary to depict travel time of stormwater runoff within the study site. Again, identifying the drainage system's path from the hydraulically most distant point in the watershed to the point of collection will allow us to compute the site's time of concentration. Figure 16 illustrates the travel segments and their course of conveyance throughout the developed site.

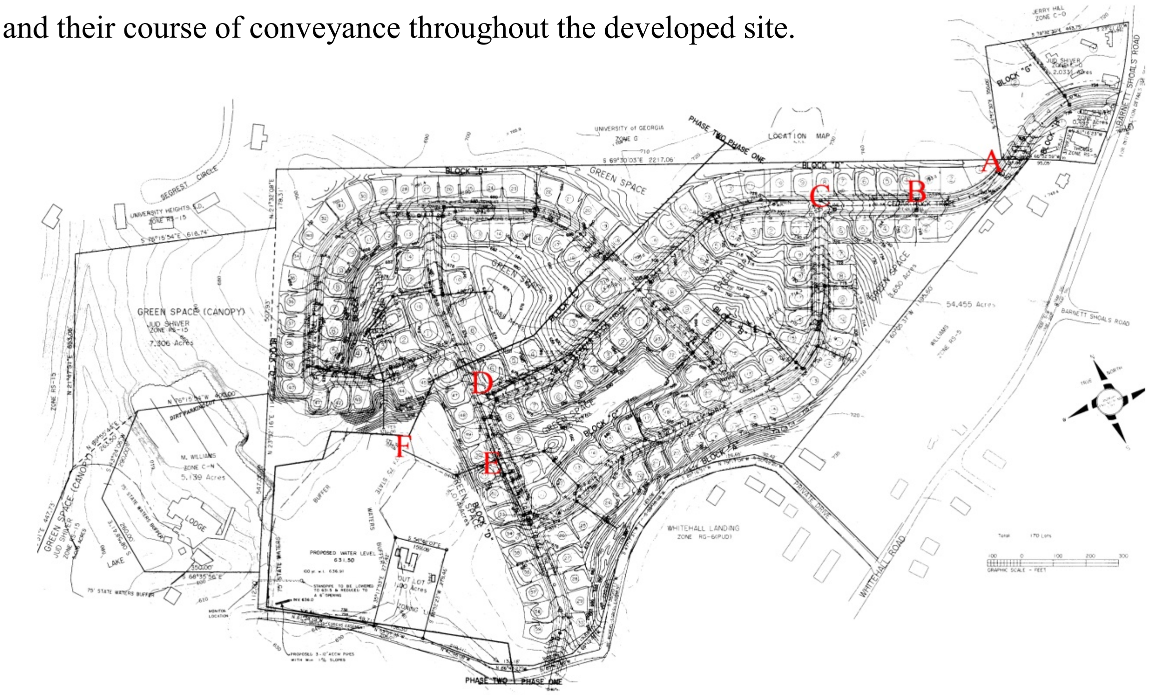


Figure 16 Travel time segments for post-developed study site.

Factors considered and measured in this conveyance process include: surface type, slope, velocity, flow length and flow area. These parameters calculated for sheet flow, shallow concentrated flow and channel flow provide us the travel time for stormwater runoff in this conveyance system. As described in Chapter 4, runoff moves through the developed site's conveyance system in these three forms. The first segment, AB spans 280 feet in the form of sheet flow (T_t = .047). The second segment, BC spans 300 feet in the form of shallow concentrated flow (T_t = .019). The final segment, CDEF travels 1,760 feet in the form of channel flow (T_t = .008). Computation of this travel time can be referenced below. Table 10 summarizes each measurement in the process of establishing the T_c for the post-developed site.

Table 10 Time of Concentration Computation for Post-developed site (USDA 1986).

Sheet flow (Applicable to Tc only)

Segment ID	AB		
1. Surface description (table 3-1)	pavement (asphalt)		
2. Manning's roughness coefficient, n (table 3-1)	.011		
3. Flow length, L (total L † 300 ft) .... ft	280'		
4. One-year 24-hour rainfall, P_2 .... in	3.4		
5. Land slope, s .... ft/ft	.014		
6. $T_t = \frac{0.007\ (nL)^{0.8}}{P_2^{\ 0.5}\ s^{0.4}}$ Compute T_t .... hr	.051	+	= .051

Shallow concentrated flow

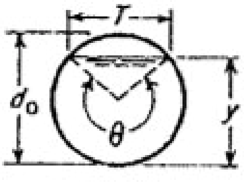
Segment ID	BC		
7. Surface description (paved or unpaved)	paved		
8. Flow length, L ....ft	300'		
9. Watercourse slope, s .... ft/ft	.05		
10. Average velocity, V (figure 3-1) .... ft/s	4.3		
11. $T_t = \frac{L}{3600\ V}$ Compute T_t .... hr	.019	+	= .019

Channel flow

Segment ID	CDEF		
12. Cross sectional flow area, a .... ft^2	3.53		
13. Wetted perimeter, p_w .... ft	4.71		
14. Hydraulic radius, $r = \frac{a}{p_w}$ Compute r .... ft	.75		
15 Channel slope, s .... ft/ft	.052		
16. Manning's roughness coefficient, n	.024		
17. $V = \frac{1.49\ r^{2/3}\ s^{1/2}}{n}$ Compute V ....ft/s	11.69		
18. ~~Flow~~ length, L .... ft	1,760'		
19. $T_t = \frac{L}{3600\ V}$ Compute T_t .... hr	.042	+	= .042
20. Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19) .... Hr			.112

The final segment of the natural drainage system for the post-developed site is segment CDEF, channel flow. This segment spans 1,760 feet and flows in a closed conduit to its source of collection. Channel flow was calculated using a series of computations from Chow's, "Open

Channel Hydraulics." Unlike the natural channel referenced in Chapter 4, the closed conduit in this post-developed environment is an artificial channel and performs differently in its conveyance of stormwater. The "circle" or "pipe" shape will be used to calculate the travel time of the channel flow for segment CDEF.



Circle

Cross sectional flow area (ft^2) = $^1/_8(\theta - \sin\theta)\, d_o^2$

= 3.53

The next computation, solving for the wetted perimeter is defined by Chow as the length of the line of intersection of the channel wetted surface with a cross-sectional plane normal to the direction of flow.

Wetted perimeter (ft) = $^1/_2\, \theta\, d_o$

= 4.71

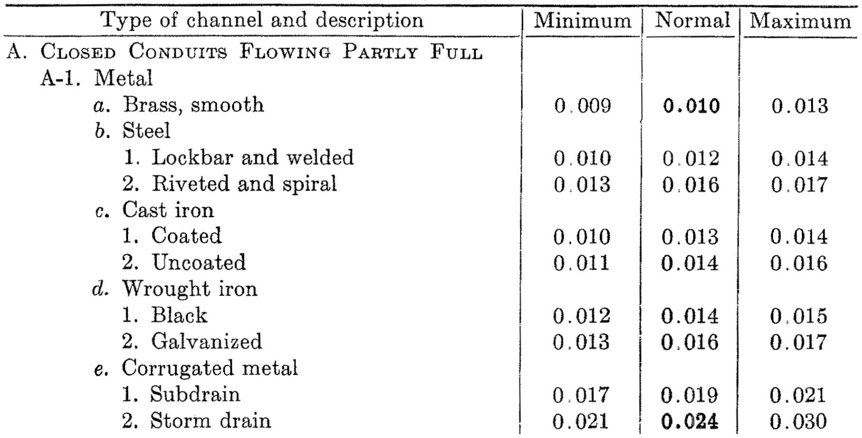
The hydraulic radius, the ratio of water area to its wetted perimeter is solved by:

Hydraulic radius (ft) = $^1/_4 \left(1 - \dfrac{\sin\theta}{\theta}\right) d_o$

= .75

The roughness coefficient (.024) used in determining the average velocity (V) in this channel flow calculation was referenced below in Table 11.

Table 11 Values of the Roughness Coefficient n (Chow 1959).



Type of channel and description	Minimum	Normal	Maximum
A. CLOSED CONDUITS FLOWING PARTLY FULL			
A-1. Metal			
a. Brass, smooth	0.009	**0.010**	0.013
b. Steel			
1. Lockbar and welded	0.010	0.012	0.014
2. Riveted and spiral	0.013	0.016	0.017
c. Cast iron			
1. Coated	0.010	**0.013**	0.014
2. Uncoated	0.011	**0.014**	0.016
d. Wrought iron			
1. Black	0.012	**0.014**	0.015
2. Galvanized	0.013	**0.016**	0.017
e. Corrugated metal			
1. Subdrain	0.017	**0.019**	0.021
2. Storm drain	0.021	**0.024**	0.030

Results and Interpretation

Time of concentration for the developed site is .11 hours. When compared to the pre-developed site, there was a decrease in time of concentration of .48 hours and an increase in runoff of .92 inches. This decrease in time of concentration and increase in runoff is due to the increase in impervious surface and the resulting increase in runoff velocity and volume as drainage is more quickly carried throughout the sites drainage system. A closer comparison of the pre and post-developed computations shows us that the 69.86-acre site (3,043,101.6 square feet) increased in runoff by 233,304.46 cubic feet (311,917.91 – 78,613.46) as a result of development.

Table 12 Summary of runoff for pre and post-development scenarios.

	Pre-development	Post-development
Runoff (Q) – inches 1-year storm event	.31	1.23
Runoff conversion to volume	(.31 / 12) x 3,043,101.6	(1.23 / 12) x 3,043,101.6
Runoff Volume – cubic feet	**78,613.46**	**311,917.91**

Development of the site increased runoff by 297% and decreased the sites total storage and infiltration by 30%. The design proposal introduced in the following chapter will use this information to retrofit the site with a system that functions more like the pre-developed landscape using LID technology.

CHAPTER SIX

POST-DEVELOPMENT RETROFIT

Design Principles

This chapter will propose that low impact development technology be used on site to meet runoff performance criteria similar to the pre-developed landscape. As stated in Chapter 1 of this thesis project, the design principles of this research are focused on minimal site redesign throughout the post-developed site. For a scheduled development, many of the design alternatives presented in this chapter could be incorporated before the site is completely developed. However, the value in this retrofit project will show that entire post-developed subdivisions can be revisited and corrected to meet pre-developed standards. These design principles previously introduced were basic guidelines for the shaping of this project's design concept.

Design Principle #1. Design with nature:

> The environment – land, sea, air and creatures – does change; and so the question arises, can the environment be changed intentionally to make it more fit, to make it more fitting for man and the other creatures of the world? Yes, but to do this one must know the environment, its creatures and their interactions – which is to say ecology. This is the essential precondition for planning – the formulation of choices related to goals and the means for their realization. (McHarg 1995)

By understanding the context and history of the environment for which we are planning, we are better suited to make design decisions that benefit the living systems that are directly and indirectly connected to the study site. Prior to development, the study sites composition was a moderately sloping piedmont forest. Within that forest were relationships and natural mechanisms for managing stormwater runoff. The infiltration techniques presented in this project's design solution are intended to imitate those relationships or "design with nature."

Design Principle #2. Treat every site as a watershed:

> Rain falls on every site. What happens to the rain depends on the sites place in the larger watershed, and on the smaller watersheds within the site. From where does water enter the site? To where does it go? Understanding that a site has a position in the larger context is essential to stormwater management. (Richman 1999)

The position of this 69-acre subdivision sits on a moderately sloping piece of land directly above the Oconee River. By treating the site as a micro-watershed and planning for on-site stormwater collection and infiltration, there will be a positive contribution to the overall hydrologic system.

Design Principle #3. Look for more small opportunities:

> For decades planners, engineers and builders have been trained to think big – to design systems that will handle peak flows from the biggest storms. Yet most pollutants and flow-induced impacts to streams are in the early rains and small storms. Designing systems to accommodate the big storm is still essential for protection of life and property, but small-scale techniques, applied consistently over an entire watershed, can have a big impact – both improving stormwater quality and reducing peak flows. (Richman 1999)

In an effort to deal with the one year, 24-hour storm event, the sites retrofit will incorporate small infiltration and bioretention areas throughout the site to collect stormwater from individual rooftops, driveways and abutting hard surfaces.

Design Principle #4. Work as close to the source of runoff as possible:

> What happens immediately after a drop of rain hits the ground? Rather than convey stormwater away for treatment at the end of a pipe, water quality is most easily and economically achieved if stormwater management starts at the point that water contacts the earth. (Richman 1999)

In an effort to collect stormwater runoff directly from the localized source, multiple LID technologies will be located throughout the subject property.

Design Principle #5. Understand nature's geometry:

> Nature's geometry is an important organizing principle for ecological design. It determines the context for design, whether at the scale of a root system or an entire watershed. (Van Der Ryn 1996)

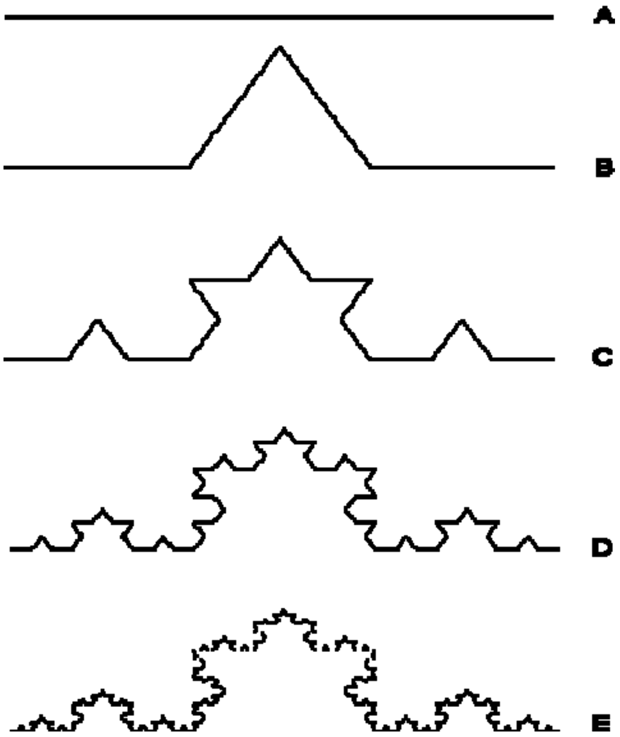


Figure 17   Illustration of fractal geometry that represents a progressively greater level of detail at smaller levels of scale (Van Der Ryn 1996).

The Koch curve demonstrates this concept well as illustrated in Figure 17. As we move from stage to stage in the construction of this curve we are able to see more and more detail and an even smaller level of scale. This principle when applied to the thesis project will allow the study site to benefit from nature's geometry; multiple LID technologies dispersed with high surface to volume ratios.

Design Principle #6. Minimize impervious surfaces

> Impervious areas directly connected to the storm drain system are the greatest contributor to nonpoint source pollution. Any impervious surface which drains into a catch basin, area drain, or other conveyance structure is a directly connected impervious area. As stormwater runoff flows across parking lots, roadways and other paved areas, the oils, sediments, metals and other pollutants are collected and concentrated. If this runoff is collected by a drainage structure and carried directly along impervious gutters or in sealed underground pipes, it has no opportunity for filtering by plant material or infiltration into the soil. It also increases in speed and volume, causing higher peak flows downstream, requiring larger capacity storm drain systems, increasing flood and erosion potential. (Richman 1999)

By converting small areas throughout the study site to infiltration and bioretention zones, the site will be less reliant on the existing stormwater conveyance system and better suited to manage stormwater more locally and at smaller scales.

The following design proposal will demonstrate how these design principles can be retrofitted into the site and utilized to meet runoff performance criteria of the pre-developed landscape through minimal site redesign. Minimal site redesign as applied to this thesis includes low impact development features that are small in size and are implemented with very little disturbance to the site. Features meeting this criterion will require no large scale grading and will not cause major changes to existing infrastructure.

Design Proposal

Within detached-single family, small lot subdivisions there are many opportunities for on-site stormwater management. Backyards, front yards and planter strips all provide adequate space for LID implementation. Upon close examination of the study sites infrastructure, capacity and orientation it becomes obvious that inefficiencies are present throughout the site. The sites development pattern is suburban in nature and density. Dispersed throughout the subdivision are spaces that are underutilized for their potential as stormwater collection areas. The design proposal of this thesis project is based on the conversion of many of the sites underutilized features to multiple types and sizes of LID implementations. Examples of the LID technologies will be demonstrated in two key forms: in-street infiltration areas and bioretention areas. The technologies presented in this retrofit proposal are not unlike many of the LID systems used today. The significance of this proposal demonstrates that these proven technologies are appropriate as retrofits on a larger scale, and that subdivisions designed with detention systems can be revisited and corrected to meet goals of both water quality and channel protection on site (Figure 18).

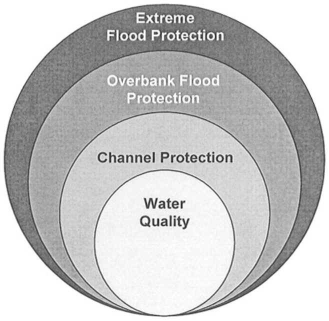


Figure 18 Unified stormwater sizing criteria of the *Georgia Stormwater Management Manual*.

In-street Infiltration

Planter strips are dispersed throughout the subject site and are proposed as target locations for in-street infiltration areas. Existing right-of-way widths range from 50 feet to 60 feet and pavement widths are consistently 23 feet throughout the subdivision. Conversion of planter strips to infiltration areas will not affect emergency access or travel lane widths as pavement width will remain at 23 feet. The design capacity of in-street infiltration areas dispersed throughout the study site is 29,400 cubic feet. This volume is satisfied within 120 on-street areas that each measure 7 feet x 35 feet and will be retrofitted to a depth of 12 inches (Figure 19). The infiltration areas in this design proposal are located and sized to capture stormwater from both the adjoining street and neighboring portions of sidewalk. In the event that stormwater accumulation exceeds that of a "first flush" storm event, an overflow mechanism will be incorporated into the system to allow for release back into the existing storm sewer system.

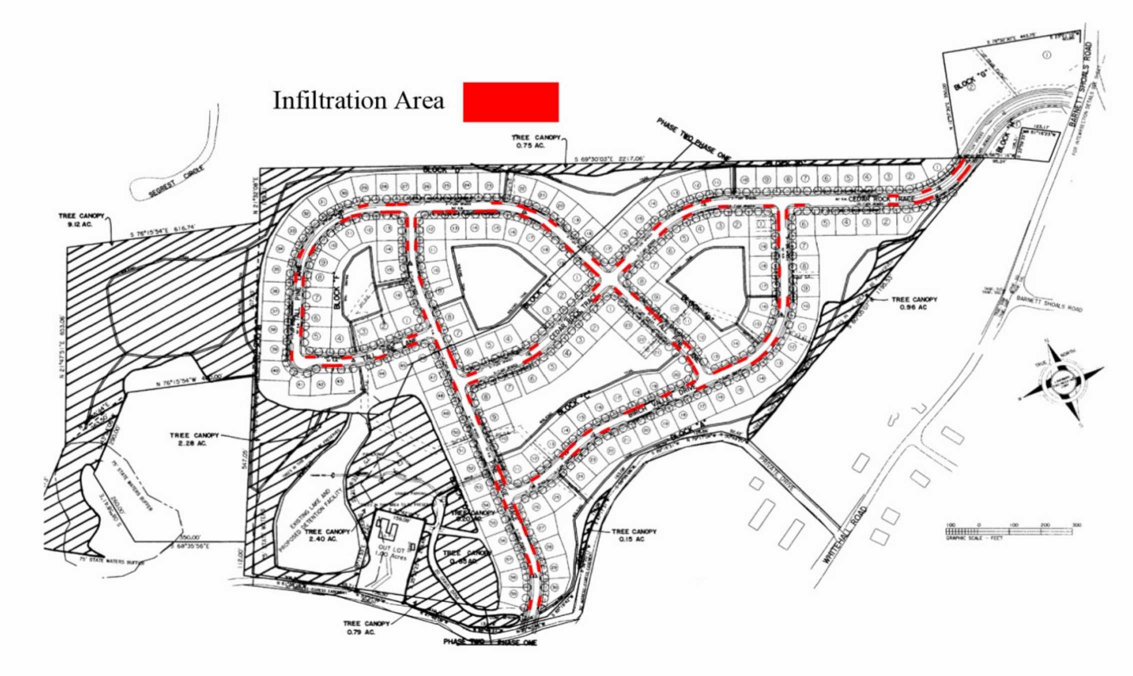


Figure 19 Site plan of infiltration area dispersal throughout subject site.

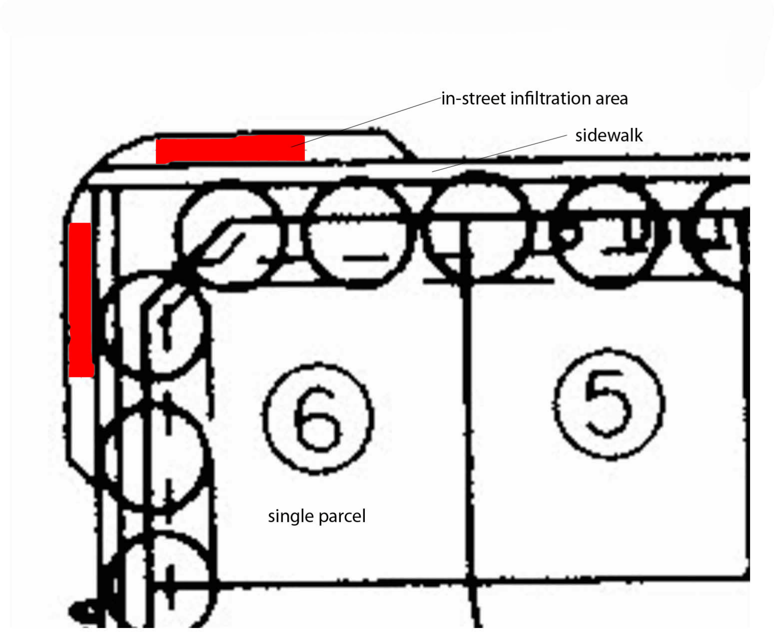


Figure 20   Illustration of typical infiltration area location within subject site.

Important features present within this stormwater collection system include:

1. Curb cut inlets which collect surface flows.
2. Sediment traps composed of a concrete inlet pad and pervious basin for trapping larger sediment.
3. Shallow slope (>3:1) with 12" depth.
4. Vegetation planted on side slopes.
5. Geotextile liner
6. Outlet / Overflow designed for larger storm events which convey larger volumes to existing stormwater sewer system.
7. Infiltration matrix

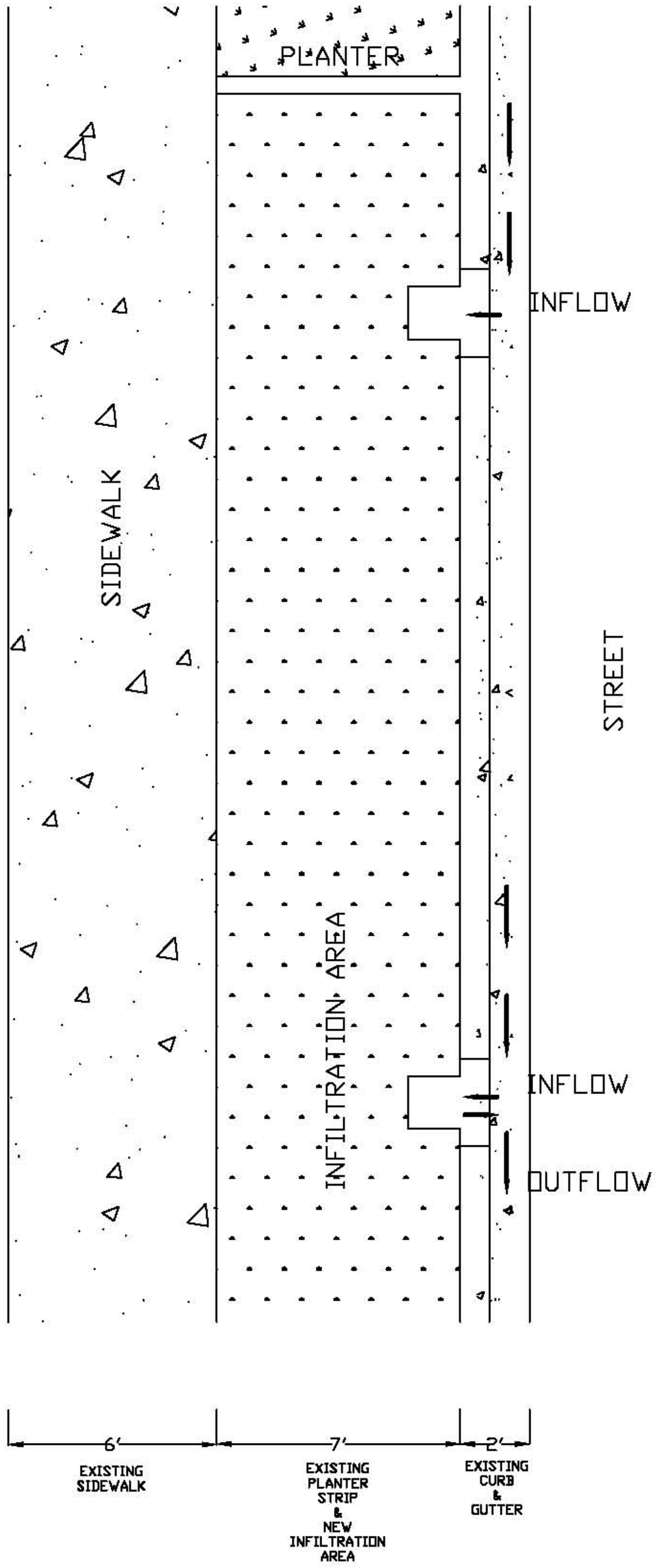


Figure 21 Plan of typical infiltration area within subject site.

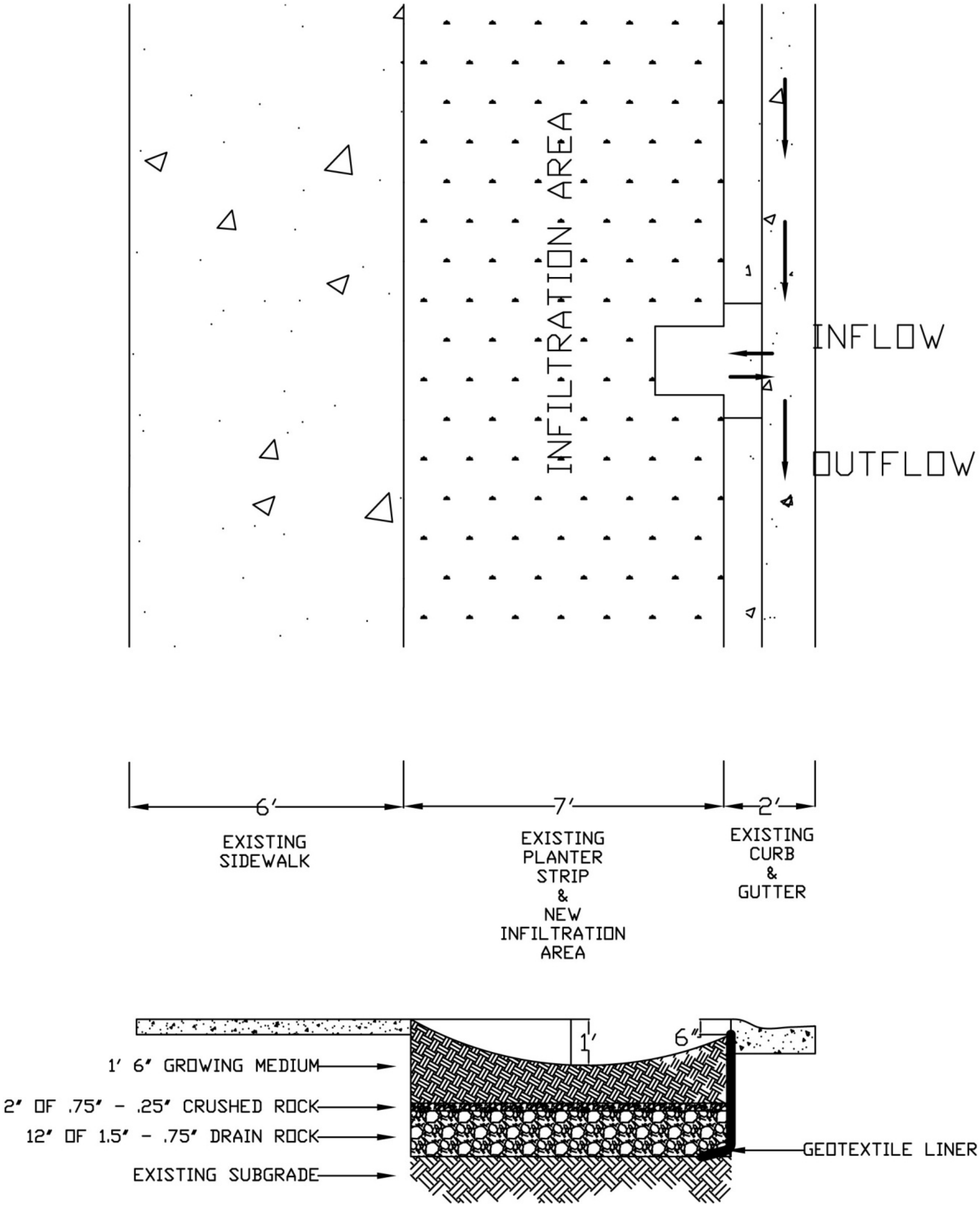


Figure 22 Section of typical infiltration area within subject site.

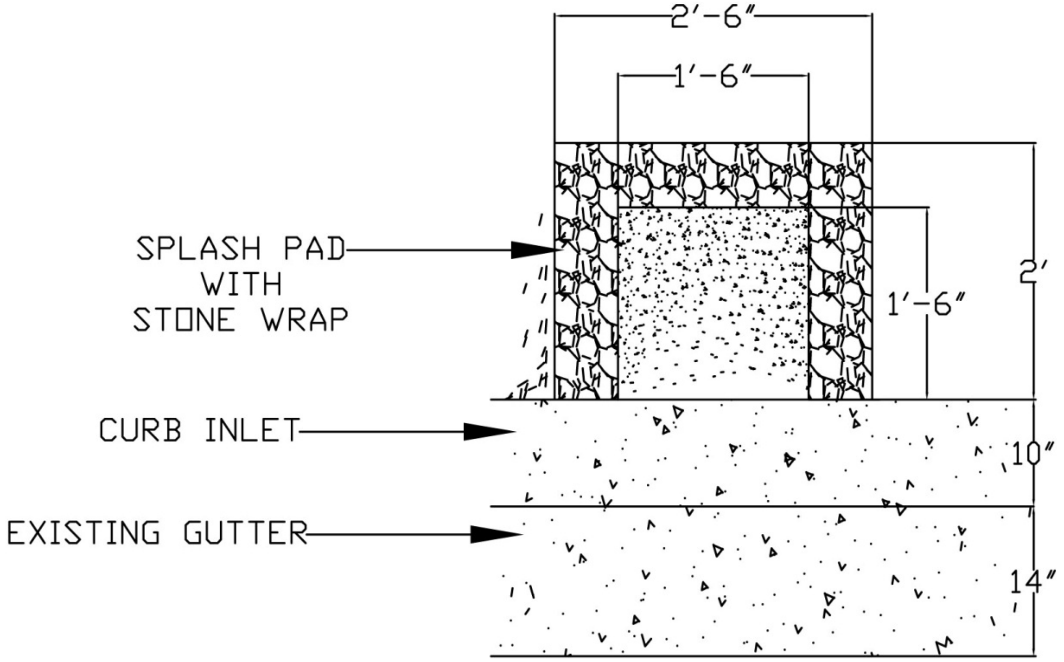


Figure 23 Plan of typical curb inlet within infiltration area.

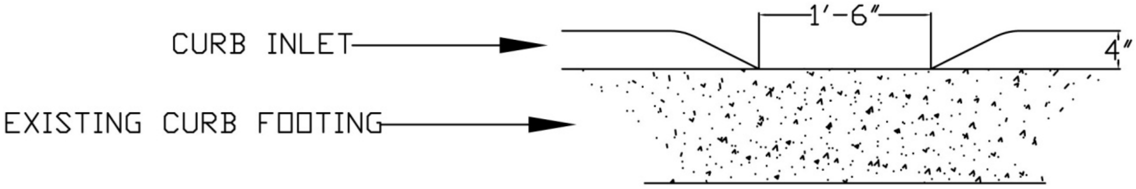


Figure 24 Section of typical curb inlet within infiltration area.

Filtration and trapping of sedimentation can best be accomplished within the infiltration areas by using the appropriate mulch and soil compositions. The bottom of the infiltration area will function best with long fiber shredded wood mulch that facilitates a greater level of perviousness and allows for easier maintenance during periodic removal of sediment. The infiltration matrix should be composed of the following soil mixture (Table 13) to maximize effectiveness in trapping pollutants and supporting vegetation that traps pollutants.

Table 13 Soil mixture for infiltration matrix within stormwater infiltration areas. (City of Portland, Oregon).

Sandy Loam Mix		
100% sandy loam as defined below		
Textural class / USDA Designation	Size in mm	Percent of Total Weight
Gravel	> 2 mm	Less than 5%
Sand	.05 – 2 mm	70 - 80%
Silt	.002 - .05 mm	15 - 20%
Clay	< .002 mm	Less than 5%

Maintenance of the system is based on the systems performance. A build-up of sedimentation may lead to a reduction in infiltration capacity. When performance of the system declines, removal of sedimentation is required so that the system can return to optimum infiltration capacity. Plant material suggested for this stormwater infiltration system will tolerate both wet and dry cycles and can be replaced as needed during sediment removal operations. The following list is an example of appropriate plant material for an in-street infiltration area.

Plant Material:

Greenhead Coneflower - *Rudbeckia laciniata*

Sedge – *Carex spp.*

Coneflower – *Echinacea purpurea*

Yarrow – *Achillea spp.*

Broomsedge. – *Andropogon virginicus*

The following photographs are taken of a neighborhood in Portland, Oregon. The installation of infiltration areas into an existing streetscape allows for improved on-site infiltration similar to those proposed in this thesis project. Not unlike the design proposal for this project, the photographs reflect the addition of smarter ecological design principles into an existing conventional stormwater conveyance system (City of Portland, Oregon).

Figure 25 In-street infiltration area retrofitted into existing neighborhood.

Figure 26 In-street infiltration detail retrofitted into existing neighborhood.

Bioretention

Because of parcel sizes and the orientation and location of homes within the development, bioretention areas are proposed in front, side and rear yards throughout the subject site. Following computation of the in-street infiltration area capacity (29,400 cubic feet), the retrofit proposal will require bioretention areas to accommodate 203,904 cubic feet (233,304 – 29,400) in order to adequately account for the post-development increase in stormwater runoff for the 1-year 24-hour storm event. This volume dispersed throughout the subject site translates to approximately 1,200 square feet of bioretention area per residential lot. Closer examination of this proposal indicates that this type of retrofit distribution is an unrealistic expectation for the subject site. Implementation of this type would require every parcel to dedicate a large percentage of each yard to bioretention area. With average lot sizes of approximately 7,000 square feet it is unlikely that all property owners would be willing to incorporate this proposal into their existing site. A more practical expectation is that a portion of property owners would be willing to participate in the retrofit proposal and that bioretention areas retrofitted into those parcels would range in size from 400 square feet to 550 square feet. The proposed site plan (Figure 27) illustrates a hypothetical schematic accounting for 60 bioretention areas of 550 square feet and 60 bioretention areas of 400 square feet. The total design capacity of bioretention areas in this proposal is 57,000 cubic feet. While this retrofit does not entirely fulfill the objectives of this thesis project, it does provide adequate capacity for managing runoff volumes associated with water quality or "first flush" while adhering to the goal of minimal site redesign. The water quality or "first flush" volume used in this schematic was calculated with the *Georgia Stormwater Management Manual* formula which yields "the treatment volume required to remove a significant percentage of the total pollution load inherent in stormwater runoff by intercepting and treating the 85th percentile storm event, which is equal to 1.2 inches" (2001).

$$WQ_v = \frac{1.2R_vA}{12}$$

Where WQ_v = water quality volume (acre-feet)

= 85,360 cubic feet

$R_v = .05 + .009\ (I)$ where I is percent impervious cover

= .284

A = site area in acres

= 69 acres

Further detail about the design of bioretention areas is provided in the following drawings.

Figure 27 Site plan of bioretention area dispersal throughout subject site.

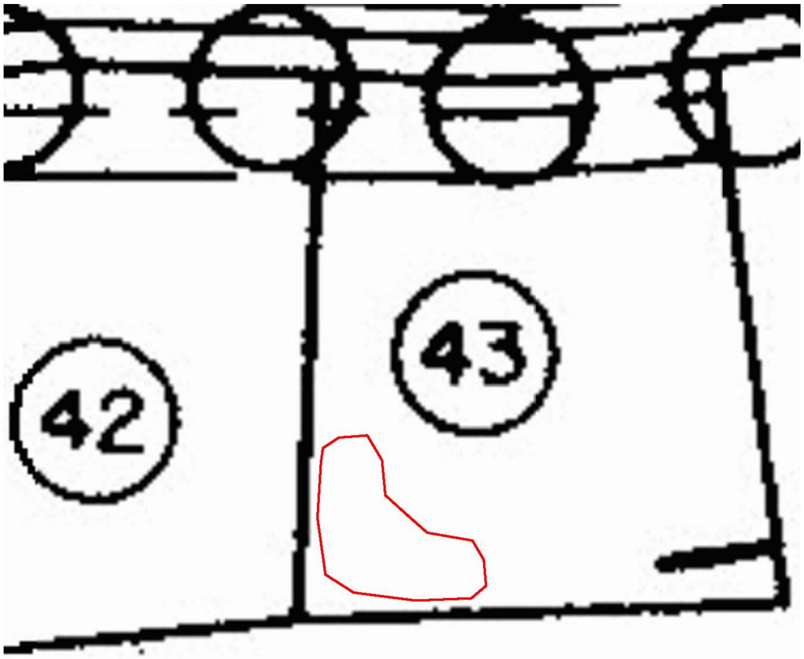


Figure 28 Illustration of typical bioretention area location within subject site

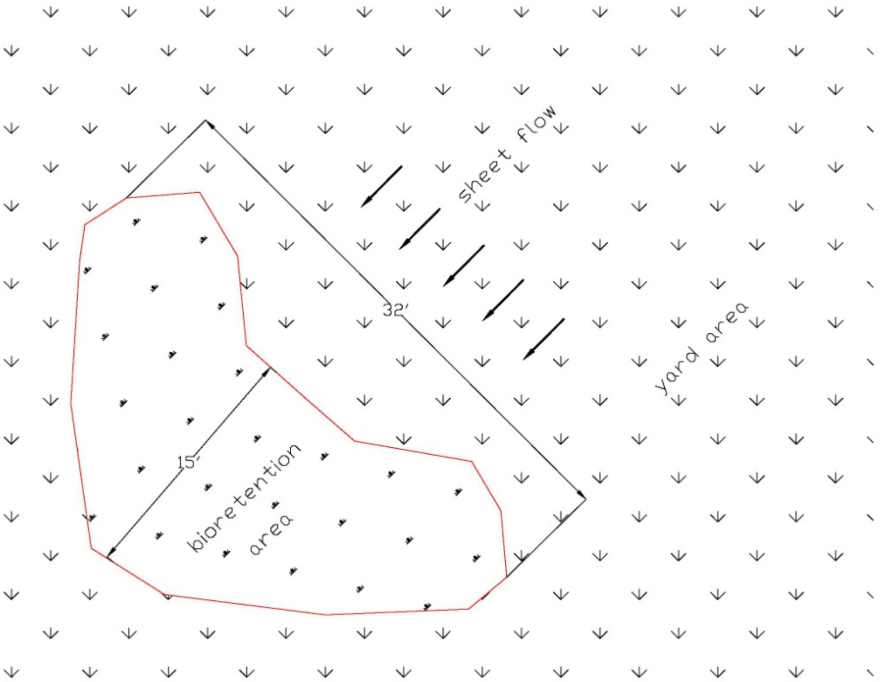


Figure 29 Plan of a typical bioretention area on subject site.

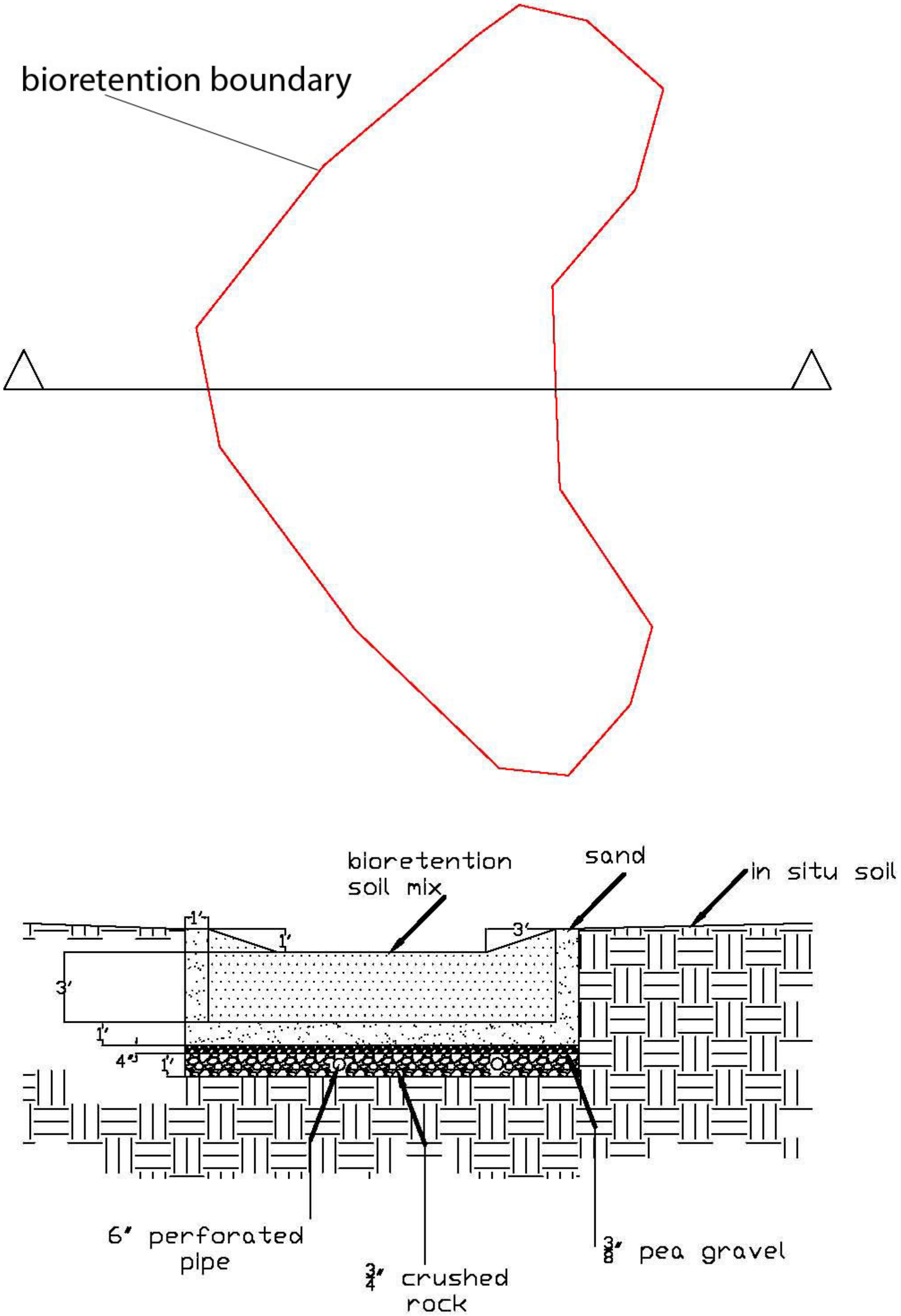


Figure 30 Section of typical bioretention area within subject site.

Figure 31 represents the typical placement of bioretention areas on residential lots and how they relate to other site features. Bioretention areas will function as infiltration type systems. They will have the appearance as attractive landscape depressions that range in size from 400-550 square feet. The size and shape of each bioretention area will vary from yard to yard but will function in the same manner, capturing runoff from each property more closely to the source.

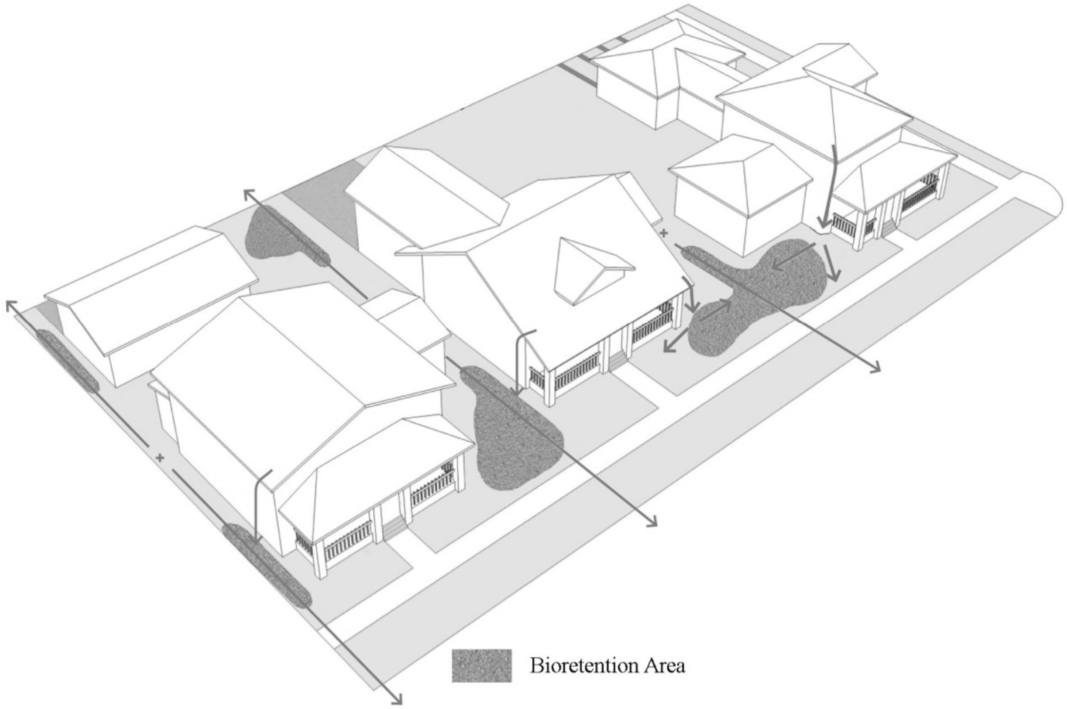


Figure 31 Representation of bioretention areas on each lot (Wenk Associates, Inc.).

Important features of each bioretention system include:

1. Sheet flow through turf grass leading to each area
2. Shallow slopes (3:1) with 12" depth
3. Ornamental grasses and shrubs that can tolerate both moderately wet and dry conditions
4. Outlet / Overflow designed for larger storm events which convey larger volumes to existing stormwater sewer systems
5. Infiltration matrix
6. Turf grass surrounding the perimeter of bioretention area.

Each bioretention area will be depressed to a maximum depth of one foot and a maximum side slope of 3:1. Runoff from surrounding surfaces will sheet flow into the bioretention facilities where they will be treated during infiltration, absorption and evapo-transpiration processes. Runoff in the form of sheet flow will allow for an even distribution of runoff entering each bioretention system and will minimize erosion potential. Plant selection and soil composition are important to the success of each area. The infiltration matrix should be composed of the following soil mixture (Table 14) to maximize effectiveness in trapping pollutants and supporting vegetation that traps pollutants. Based on this matrix, infiltration rates should exceed ½ inch per hour. Filtration and trapping of sedimentation can best be accomplished within the infiltration areas by using the appropriate mulch composition. The bottom of the infiltration area will function best with long fiber shredded wood mulch that facilitates a greater level of perviousness and allows for easier maintenance during periodic removal of sediment.

Table 14 Soil mixture for stormwater bioretention areas (City of Portland, Oregon).

<table>
<tr><td colspan="3">Sandy Loam Mix</td></tr>
<tr><td colspan="3">100% sandy loam as defined below</td></tr>
<tr><td>Textural class / USDA Designation</td><td>Size in mm</td><td>Percent of Total Weight</td></tr>
<tr><td>Gravel</td><td>> 2 mm</td><td>Less than 5%</td></tr>
<tr><td>Sand</td><td>.05 – 2 mm</td><td>70 - 80%</td></tr>
<tr><td>Silt</td><td>.002 - .05 mm</td><td>15 - 20%</td></tr>
<tr><td>Clay</td><td>< .002 mm</td><td>Less than 5%</td></tr>
</table>

Plant selection within each area should include both ornamental grasses and shrubs.

The following list is an example of appropriate plant material for a bioretention area.

Shrubs:

Bottlebrush Buckeye – *Aesculus parviflora*

American Beautyberry – *Callicarpa Americana*

Witch Hazel – *Hamemelis virginiana*

Wax Myrtle – *Myrica cerifera*

Inkberry – *Ilex glabra*

Fothergilla – *Fothergilla gardenii*

Groundcovers and Perennials:

Fountain Grasses – *Pennisetum spp.*

Sedge – *Carex spp.*

Coneflower – *Echinacea purpurea*

Daylily – *Hemerocallis spp.*

Maintenance of the system is based on the systems performance. A build-up of sedimentation may lead to a reduction in infiltration capacity. When performance of the system declines, removal of sedimentation is required so that the system can return to optimum infiltration capacity.

Discussion of Retrofit Inadequacy

In order to meet the broader objective of accommodating the 1-year 24-hour storm event (channel protection), the retrofit proposal would require an additional 146,904 cubic feet of storage volume. This volume could be accommodated in underground storage facilities or in other site features such as retention ponds. Unfortunately, with a focus on minimal site redesign, the expense and disturbance to the subject site caused by implementation of these features would be in contradiction to the project's goals and would therefore be considered a "failure" of the design. For a closer study of the incorporation of retention ponds into the projects retrofit, the following drawings illustrate the extent of development required to provide the outstanding 146,904 cubic feet of volume to accommodate the 1-year 24-hour storm event. It should be noted however, that the areas designated as retention ponds are currently recorded as conservation easements and are therefore not eligible for grading activities.

Figure 32 illustrates the location of these hypothetical retention areas on the subject site. As recognized by the *Georgia Stormwater Management Manual*, the use of retention basins is suitable for minimum drainage areas of 25 acres. These systems are rated to handle stormwater runoff for purposes of water quality and channel protection. Hydrologic group B soils are appropriate for these systems and will allow for storage and infiltration of stormwater over an extended period of time. The appearance of these areas will be depressions that include a forebay, weir and lower pond within the subdivision common space.

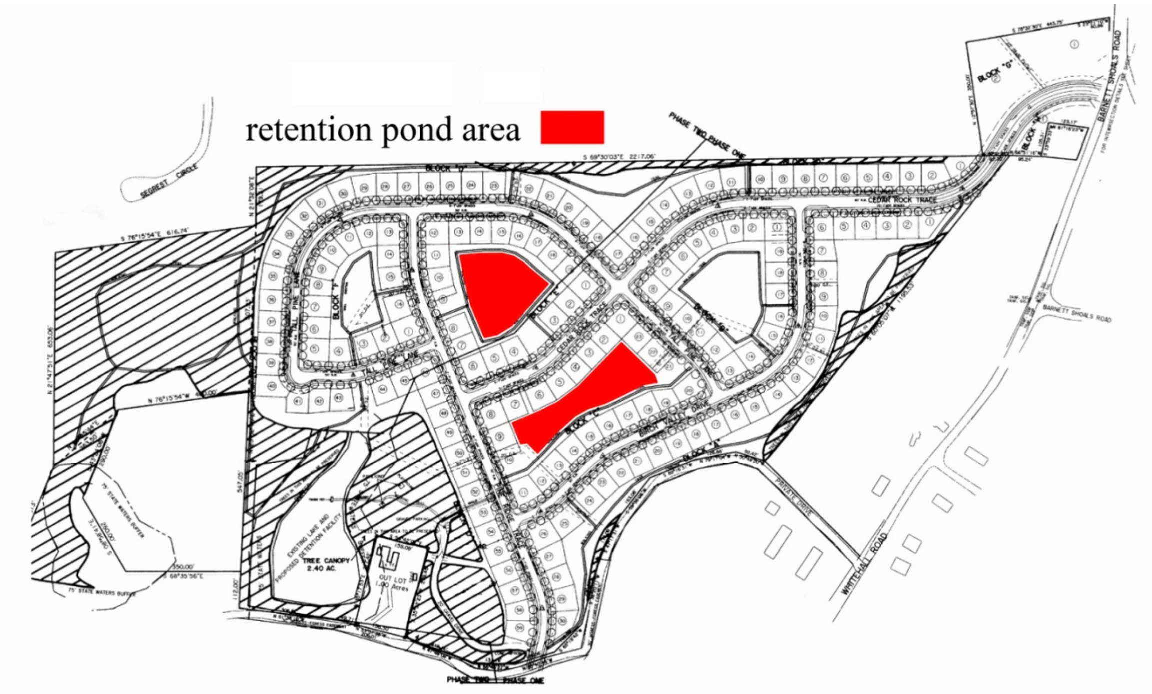


Figure 32 Site plan of retention pond locations on subject site.

Design of these areas will target the 1-year 24-hour storm event, while larger storm events will be directed from the retention areas to the existing conveyance system. The overall volume accommodated within the retention facilities is 167,708 cubic feet, greater than the 146,904 cubic feet needed.

Water quality treatment within each retention pond is implemented through a small pond feature called a forebay where a gravitational settling process allows contaminants to settle before stormwater moves to the lower retention pond depression (Figure 34). The following figures represent the features of the retention ponds and details associated with implementation and function.

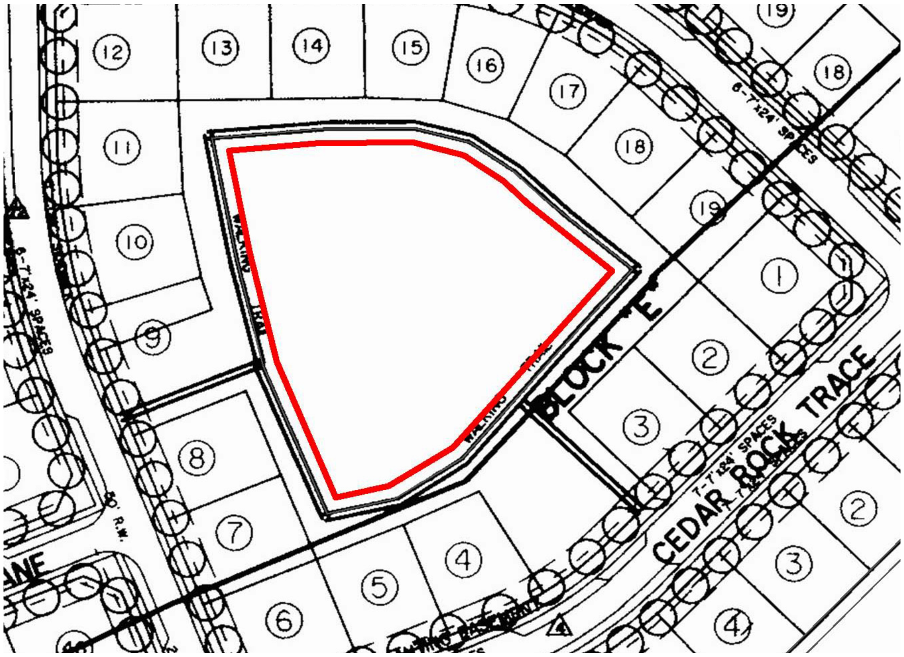


Figure 33 Illustration of a retention pond location on subject site.

Summary

Low impact development technology is proposed throughout the study site to improve the manner in which stormwater is treated and managed using multiple infiltration opportunities. A total of 86,400 cubic feet of stormwater runoff will be successfully managed through in-street infiltration and bioretention areas to accommodate the water quality volume associated with the "first flush" storm event. Because of design limitations noted in the retrofit proposal, 146,904 cubic feet of stormwater runoff associated with the larger 1-year 24-hour event will not be infiltrated on site. In an effort to mimic the pre-development landscape in the management of stormwater runoff for purposes of water quality and channel protection, introduction of features like retention ponds and underground storage facilities are determined not to fit with key goals of minimal site redesign and infiltrating on site. "Infiltration is most feasible when planned at the earliest stages of site layout. When site planning is at its best, provisions for infiltration merge with those of buildings, pavements, road and path alignments, grading and vegetation. Where infiltration cannot feasibly capture enough of the storm volume to control downstream peaks to the required degree, it can still be used to treat low flows for water quality" (Ferguson 1994).

The resulting benefits of this partially successful retrofit will decrease stormwater runoff velocity and volume and increase time of concentration thereby restoring the landscape to a more natural hydrologic system. Even though water quality within the watershed can be improved, pre-planning for adequate bioretention would be necessary to ensure channel protection benefit and achieving a pre-development hydrologic profile.

CHAPTER SEVEN

CONCLUSION

Summary Statement

This thesis has demonstrated that a developed subdivision utilizing traditional drainage methods performs poorly when evaluated with the goal of mimicking pre-development hydrology. Unlike conveyance and detention methods, many LID practices are superior in meeting pre-development performance criteria for stormwater runoff. However, through minimal site redesign, the retrofit proposal of this thesis only partially meets the objectives of restoring the site to a pre-development hydrologic profile. Initial abstraction within the pre-developed landscape accounts for 415,891 cubic feet of stormwater before runoff. Initial abstraction for the post-developed landscape accounts for 169,906 cubic feet of stormwater before runoff. An increase in impervious surface and a decrease in cover type capable of absorption and transpiration is responsible for this shift in initial abstraction. The retrofit of multiple infiltration and bioretention areas throughout the post-developed environment provides an additional 86,400 cubic feet of storage capacity that will account for a portion of the developed site's initial abstraction deficiency. Although not an equal substitution for the pre-developed site, the retrofit proposal does improve the sites performance. The water quality volume of stormwater associated with the "first flush" event is accommodated in the retrofit proposal. This success is a display of the retrofit mimicking a portion of the site's natural hydrology. The remaining stormwater volume unaccounted for in the retrofit proposal and required for channel protection (1-year 24-hour storm event) is 146,904 cubic feet. The additional volume of stormwater associated with the 1-year storm event for a development of this size (69 acres) is difficult and costly to infiltrate on site once the site has been fully developed. Consideration of LID technology in the planning stages prior to development is critical for successful on-site infiltration for developments of this size. During the planning stages of this thesis, many LID concepts were explored and considered as potential introductions into the developed site. A combination of policy barriers and site specific obstacles reduced the number of viable retrofit options on this particular subject site. As with the subject site chosen for this thesis, every site comes with its own barriers and obstacles that are difficult to work around once established. The surest way to eliminate these barriers and obstacles is to consider LID implementation at the beginning of a development and to promote policy that works in favor of LID technology.

Final Thoughts

The primary goal of successful stormwater management should be to imitate the natural hydrology of the pre-developed site. Stormwater management objectives should therefore be multifaceted and utilize design principles that are congruent with sound ecological planning. Morton and colleagues point to six major objectives that should be considered in planning for ecological stormwater management (NYSDEC 1992):

1. Prevent increases in volume and flow
2. Minimize erosion and degradation of streams
3. Prevent decreases in groundwater recharge
4. Maintain integrity of stream hydrology
5. Reduce pollutant load in stormwater runoff
6. Secure benefits such as open space protection, recreational opportunities and enhanced landscaping.

Although these objectives seem reasonable and prudent, one may argue that a disconnect exists between knowledge and practice; what we know and what we do. State and local land use codes sometimes prohibit the use of many ecological principles in favor of traditional and efficient engineering systems of stormwater removal. Additionally, many ecological methods are viewed as increasing the cost of developing a site; therefore, both economic and political barriers exert influence over scientific principles. As with the environmental movement and increased awareness of global warming, it has taken many years to arrive at the present time where citizens are beginning to understand how destructive practices affect the earth and its ecosystems. Likewise with stormwater management, decision makers need to continue efforts toward promoting knowledge (ecology) over short-sighted solutions so that best management practices are achieved.

Additionally work needs to focus on professional and lay education, incentives for developers and homeowners and updating and revising land use codes as applied to stormwater management. All approaches should be pursued simultaneously; survey courses for stormwater management in engineering and planning schools and seminars for concerned citizens and members of planning commissions. Incentives for developers such as certain fee waivers and fast track review of plans could dilute resistance while reduced stormwater fees for homeowners could be offered for utilizing rain barrels and rain gardens. Finally, city and county codes need to be updated to embrace and promote ecological principles as best management practices. As an example of moving in this direction, the State of Washington recently made the decision to make LID mandatory. The 2008 ruling overturned language for the NPDES Phase I Permit that previously encouraged LID to language that requires LID on new developments (Locklear 2009). This action is the first of its kind requiring LID implementation through the NPDES program.

Implementation of this decision is a movement toward best management practices in stormwater management and should continue until practice embraces state of the art knowledge and technology.

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